

Stream bank soil and phosphorus losses within grazed pasture stream reaches in the Rathbun  
Watershed in southern Iowa

by

Mustafa Tufekcioglu

A dissertation submitted to the graduate faculty  
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

Major: Forestry (Forest Biology – Wood Science)

Program of Study Committee:

Thomas M. Isenhardt, Major Professor

James R. Russell

Jesse A. Randall

John L. Kovar

Richard C. Schultz

Iowa State University

Ames, Iowa

2010

Copyright © Mustafa Tufekcioglu, 2010. All rights reserved.

## TABLE OF CONTENTS

## CHAPTER 1. GENERAL INTRODUCTION

Introduction.....	1
Stream bank erosion.....	4
Objectives of the study.....	4
Description of the physiographic region and treatments.....	5
Thesis organization.....	6
References.....	6

CHAPTER 2. STREAM BANK EROSION AS A SOURCE OF SEDIMENT  
AND PHOSPHORUS IN GRAZED PASTURES OF THE RATHBUN  
WATERSHED IN SOUTHERN IOWA

Abstract.....	11
Introduction.....	11
Materials and Methods .....	15
Study sites and treatments.....	15
Identifying stream bank eroding areas.....	16
Installation of stream bank erosion pins .....	17
Soil bulk density sampling from stream banks and riparian areas.....	18
Soil-P sampling and estimation of soil and total P loss from stream banks.....	19
Rainfall data .....	20
Data analysis .....	20
Results and Discussion.....	20
Lengths and areas of severe and severely eroding stream banks.....	20
Stream bank and riparian area soil bulk densities.....	22

Relationship between bank erosion and independent variables .....	23
Erosion rate and soil loss based on Strahler stream order classification ....	27
Total soil-P concentrations and losses of soil and soil-P from stream bank	28
Summary and Conclusions .....	29
References.....	30
 <b>CHAPTER 3. STREAM STAGE AND STREAM BANK EROSION IN GRAZED PASTURE REACHES IN THE RATHBUN WATERSHED IN SOUTHERN IOWA</b>	
Abstract.....	46
Introduction.....	47
Materials and Methods.....	49
Study sites and treatments.....	49
Stream bank erosion pins.....	50
Stream stage data.....	51
Data analysis.....	52
Result and Discussion.....	53
Stream bank erosion rates.....	53
Stream stage data.....	54
Conclusion.....	57
References.....	57
 <b>CHAPTER 4. STREAM MORPHOLOGY, RIPARIAN LAND-USE AND STREAM BANK EROSION WITHIN GRAZED PASTURES IN THE RATHBUN WATERSHED IN SOUTHERN IOWA: A CATCHMENT-WIDE PERSPECTIVE</b>	
Abstract.....	75
Introduction.....	76

Material and Methods.....	78
Study sites and treatments.....	78
Scope of the work.....	79
Stream bank soil particles size analysis.....	80
Stream bed slope and sinuosity.....	80
Land-use determination within 50 m strips on either side of the stream.....	81
Catchment size, total stream lengths and stream order classification.....	81
Stream bank erosion rates.....	81
Data analysis.....	81
Results and Discussion.....	82
Stream bank soil particle size.....	82
Stream bed slope and sinuosity.....	83
Catchment stream length and size.....	84
Impacts of land-use within 50 m strips on either side of the stream.....	85
Conclusions.....	86
References.....	87
CHAPTER 5. GENERAL CONCLUSIONS.....	101
References.....	103
Acknowledgments.....	103

## CHAPTER 1

### GENERAL INTRODUCTION

#### Introduction

Increased sediment load can negatively impact local stream integrity and increase downstream flux of attached nutrients (IDNR, 1997). Phosphorus (P) moves to surface waters predominantly attached to sediment as particulate P (Sharpley et al. 1987) and has been identified as a limiting nutrient for eutrophication of many lakes and streams (Correll, 1998). Increased P concentration in streams often promotes algal blooms and excess growth of other aquatic nuisance plants. Aerobic decomposition of the enhanced organic matter production may lead to hypoxic conditions and reduce stream integrity (Carpenter et al. 1998).

Along with overland flow and bed sediment re-suspension, stream bank erosion is an important pathway of non-point source pollutants into surface waters and has been found to account for 40-70% (Laubel et al. 2003), 50% (Schilling and Wolter, 2000), 23-56% (Thoma et al. 2005), 46-76% (Nagle et al. 2007), 25% (Simon, 2008) and more than 50% (Laubel et al. 1999) of a catchment's suspended sediment export. In addition to sediment, total-P contribution to channels from stream bank erosion has been shown to vary from 56 % (Roseboom, 1987), 15-40 % (Laubel et al. 2003), to 7-10 % (Sekely et al. 2002). The large range of estimated sediment and P loads to streams from bank erosion is likely because of the large number of variables involved in the process and the unique relationships among them. Such variables include over-hanging banks, bank angle, bank vegetation cover, estimated stream power (Laubal, 2003), and channel width, depth, and slope (Odgaard, 1987).

Riparian land-uses such as grazing and row-crop production have been shown to impact rates of stream bank erosion (Striffler, 1964; Zaimes and Schultz, 2002). In the Midwest, less than 10% of land-use is perennial vegetation, with more than 70% within row crops or pastures (Burkart, 1994). In Iowa, intensive agricultural land-use as row-crop and pasture compromise more than 90% of the land-uses and has been shown to increase overland flow which can increase the volume of water in stream channels and result in channel incision and widening and an extensive growth of gully networks (Zaimes et al. 2004). Moreover, previous research in Iowa by Downing and Kopaska (2001) concluded that a watershed with a higher proportion of land in pasture may contribute more P to streams than a watershed with a higher proportion of land in row-crops. However, the pathways of this input were not identified in this work. A recent study by Alexander et al. (2008) estimated that 37 percent of the P contributed to streams and lakes in the Mississippi River Basin comes from manure on pastures and range land. Grazing can decrease water infiltration and change species composition through increased soil compaction and surface erosion, processes that contribute to changes in stream morphology and ultimately watershed hydrology (Agouridis et al. 2005). It has also been shown that unlimited access of cattle can reduce local stream integrity (Line et al. 2000; Sherer et al. 1988; Hagedorn et al. 1999; Collins and Rutherford, 2003). The magnitude of the impact of riparian grazing is related to the grazing management system. Research findings by Zaimes et al. (2008b) and Magner et al. (2008) indicated that using rotational or intensive/short rotational grazing practices instead of continuous grazing could reduce the amount of sediment and P load to streams.

Gburek and Sharpley (1997) suggested that to control P export from a watershed resulting from grazing, areas that have potentially high soil P levels and surface runoff

should be targeted for conservation practices. These areas have been identified as generally within 60 m of the stream (Gburek et al. 2000) or under trees where shade is provided for livestock (Mathews et al. 1993). On an areal basis, these critical source areas (CSAs) have been shown to account for only about 10% of the pasture area but about 90% of available P export (Pionke et al. 1997). Zaines et al. (2009) also found that loafing areas had high total-P concentrations compared to other areas of the riparian pastures indicated that these areas could be significant source of total-P to surface water.

Several other studies have assessed the relationship between riparian grazing management and water quality. In one study to determine the contribution of cattle access points to fecal bacteria in streams, Hagedorn et al. (1999) measured a 94% reduction in fecal coliform populations after an off-stream water supply and stream-side fencing were installed. In a similar study conducted by Sherer et al. (1988) to determine the impact of livestock on fecal coliform levels in stream sediment, it was found that animal access points to the stream were potentially major contributors of bacteria to the stream sediments. With respect to sediment and nutrients, Line et al. (2000) observed a reduction in total suspended sediment and total-P of 82% and 76%, respectively, after the installation of stream-side fencing. Agourids et al. (2005) observed that using an off-stream water source and fence to exclude cattle from riparian areas did not significantly change stream cross-sectional areas, but did reduce the impact of cattle on localized areas that contributed sediment and manure to the stream channel. Several authors have emphasized the opportunity costs for landowners in implementing alternate riparian grazing practices. For example, Dougherty et al. (2004) concluded that, although reducing the P export from CSA's with proper management strategies would have profound effects on stream water quality and aquatic life, the

adaptation and implementation of these new management practices may not be accepted by landowners because of possible reduction in arable land-use. So when recommending riparian conservation practices, it is essential to consider the effects of such CSAs on farm profitability.

### **Stream bank erosion**

Stream bank erosion is generally considered to be controlled by three major processes (Lawler, 1992a). The first is mass bank failure, a geotechnical process that occurs when large blocks of bank fall into the stream because the bank angle is too steep and the bank exceeds its critical stable height. The second process is fluid entrainment, a fluvial process that is related to the action of flowing water on the stream bank. During a high discharge event there is an increase in water velocity and an increase in shear stress along the entire wetted perimeter that dislodges soil from the bank (Lawler, 1992a). The third process is subaerial preparation, a physical process that includes desiccation of soil materials by freeze-thaw cycles that expand and contract pore spaces in the soil, loosening the adjacent soil particles and causing them to slough off into the stream (Lawler, 1992a). The dominant erosion process within a stream system depends on the location of the eroding bank (downstream, mid-, and upstream) and the drainage area above the point of failure. Mass failure processes are dominant in the downstream portion of large river systems, fluvial processes in the midstream or mid-sized drainage basins, and physical processes in the upstream or the small drainage basin (Lawler, 1995).

### **Objectives of the study**

The goal of this research was to assess stream bank soil and P losses within grazed pasture stream reaches in the Rathbun Watershed in southern Iowa. Three studies were



conducted. The objective of the first study was to assess the effects of different livestock stocking intensities in riparian pastures on sediment and P loads from stream bank erosion. The null hypothesis of this study was that there were no differences in sediment and P contributed to streams from the banks of grazed riparian pastures under different stocking rates.

The objective of the second study was to assess the relationship between stage (flow depth) and stream bank erosion rates from grazed pasture stream reaches under different stocking densities and within different stream orders. The null hypothesis was that there was no relationship between stream stages and bank erosion rates.

The objective of the third study was to relate the impact of riparian land-use and stream morphologic characteristics (bank soil texture, stream bed slope and sinuosity) at the field and catchment scales with stream bank erosion from grazed riparian pasture stream reaches. The null hypothesis was that catchment land-uses and stream morphologic characteristics did not affect stream bank soil loss along the stream reaches of grazed riparian pastures.

### **Descriptions of the physiographic region and treatments**

This study was conducted on thirteen cooperating beef cow-calf farms along stream reaches in the Rathbun Lake watershed in southern Iowa. The Southern Iowa Drift Plain is dominated by many stepped erosion surfaces and integrated drainage networks consisting of rills, gullies, creeks, and rivers created by long geologic weathering processes (Prior, 1991). In this region stream bank erosion takes place in glacial materials deposited about half million years ago. 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). The riparian grazing treatments in the study were classified by stocking rates that ranged from 0 to 28 cow-days  $\text{m}^{-1}$  yr. Additional details regarding study site and treatments are provided within the chapters describing the study.

### **Thesis organization**

The dissertation consists of five chapters. Chapter one is a general introduction to sediment and P contributions to surface water from pasture land-use and describes the importance of stream bank erosion as one of the major sources of sediment and P into streams. The second chapter (first manuscript) is entitled “Stream bank erosion as a source of sediment and P in grazed pastures of the Rathbun watershed in southern Iowa” and will be submitted to the Journal of Soil and Water Conservation. Chapter 3 is entitled “Stream stage and stream bank erosion in grazed pasture reaches in the Rathbun watershed in southern Iowa” and will be submitted to the Journal of Environmental Quality or Journal of Hydrology. Chapter 4 is entitled “Stream morphology, riparian land-use and stream bank erosion within grazed pastures in the Rathbun watershed in southern Iowa: A catchment-wide perspective” and will be submitted to the Journal of Agriculture, Ecosystems and Environment. The chapter four is followed by a general conclusion chapter (chapter 5).

### **References**

- Agouridis, C. T., D. R. Edwards, S. R. Workman, J. R. Bicudo, B. K. Koostra, E. S. Vanzant, and J. L. Taraba. 2005. Stream bank erosion associated with grazing practices in the humid region. Transactions of the American Society of Agricultural Engineers 48 (1):181-190.
- Alexander, R. B., Smith, R. A., Schwarz, G. E., Boyer, E. W., Nolan, J. V. and Brakebill, J. W. 2008. Differences in phosphorus and nitrogen delivery to the Gulf of Mexico from the Mississippi River Basin. Environ. Sci. Tech. 42:822-830.

- Braster, M., T. Jacobson, and V. Sitzmann. 2001. Assessment and Management Strategies for the Rathbun Lake Watershed.  
[www.rlwa.org/Documents/Rathbun%20Lake%20Watershed%20Assessment.pdf](http://www.rlwa.org/Documents/Rathbun%20Lake%20Watershed%20Assessment.pdf)
- Burkhart, M. R., S. L. Oberlin, M. J. Hewitt, and J. Pickles. 1994. A framework for regional agro-ecosystems characterization using the National Resources Inventory. *Journal of Environmental Quality* 23:866-874.
- Carpenter, S. R., Caraco, N. F., Correll, D. L., Howarth, R. W., Sharpley, A. N. and V.H. Smith. 1998. Nonpoint pollution of surface waters with phosphorus and nitrogen. *Ecological Application* 8:559–568.
- Collins, R., and K. Rutherford. 2003. Modeling bacterial water quality in streams draining pastoral land. *National Institute of Water and Atmospheric Research* 38:700-712.
- Correll., D. L. 1998. The role of phosphorus in the eutrophication of receiving waters: A review. *Journal of Environmental Quality* 27:261-266.
- Dougherty, W. J., N. K. Fleming, J. W. Cox, and D. J. Chittleborough. 2004. Phosphorus transfer in surface runoff from intensive pasture systems at various scales: A review. *Journal of Environmental Quality* 33:1973-1988.
- Downing, J. A. and Kopaska, J. 2001. Diagnostic study of Rock Creek Lake and its watershed: Recommendations for remediation. Iowa Department of Natural Resources. Des Moines, IA.
- Gburek, W. J., A. N. Sharpley, A. L. Heathwaite, and G. J. Foldor. 2000. Phosphorus management at the watershed scale: a modification of the phosphorus index. *Journal of Environmental Quality* 29:130-144.
- Gburek, W. J., and A. N. Sharpley. 1997. Delineating sources of phosphorus export from agricultural watersheds. An American Society of Agricultural Engineers Meeting Presentation. Paper no: 972206.
- Hagedorn, H., S. L. Robinson, J. R. Filtz, S. M. Grubbs, T. A. Angier, and R. B. Reneau, JR. 1999. Determining source of fecal pollution in a rural Virginia watershed with

- antibiotic resistance patterns in fecal streptococci. *American Society for Microbiology*. 65(12):5522-5531.
- 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.
- Laubel, A., B. Kronvang, A. B. Hald and C. Jensen. 2003. Hydromorphological and biological factors influencing sediment and phosphorus loss via bank erosion in small lowland rural streams in Denmark. *Wiley Interscience. Hydrological Processes* 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. 1992a. Process dominance in bank erosion. p. 117-142. *In* P.A. Caling et al. (ed.) *Lowland floodplain rivers: geomorphological perspectives*. A British Geomorphological Research Group Symposia Series, John Wiley, Chichester, United Kingdom.
- Lawler, D.M. 1995. The impact of scale on the processes of channel-side sediment supply: A conceptual model. p. 175-184. *In* International Association of Hydrological Sciences (ed.) *Effects of scale on interpretation and management of sediment and water quality*. Proceedings of a symposium in Boulder CO. International Association of Hydrological Sciences Publication No. 226.
- Line, D. E., W. A. Harman, G. D. Jennings, E. J. Thompson, and D. L. Osmond. 2000. Nonpoint-source pollutant load reductions associated with livestock exclusion. *Journal Environmental Quality* 29:1882-1890.
- Magner, J.A., B. Vondrack and K.N. Brooks. 2008. Grazed riparian management and stream channel response in Southeastern Minnesota (USA) streams. *Environmental Management*. 42:377-390.

- Mathews, B. W., L. E. Sollenberger, V. D. Nair, and C. R. Staples. 1993. Impact of grazing management on soil nitrogen, phosphorus, potassium, and sulfur distribution. *Journal of Environmental Quality* 23:1006-1013.
- Nagle, G. N., T. J. Fahey, J. C. Ritchie and P. B. Woodbury. 2007. Variations in sediment sources and yields in the Finger Lakes and Catskills regions of New York. *Hydrological Processes* 21, 828-838.
- Odgaard, A. J. 1987. Streambank erosion along two rivers in Iowa. *Water Resource Research* 23:1225-1236.
- Pionke, H. B., W. J. Gburek, A. N. Sharpley, and J. A. Zollweg. 1997. Hydrologic and chemical controls on phosphorus loss from catchments. In H. Tunney, ed., *Phosphorus Loss to Water from Agriculture*. CAB International Press, Cambridge, England 225–242.
- Prior, J. C. 1991. *Landforms of Iowa*. Iowa Department of Natural Resources University of Iowa Press, Iowa City, Iowa.
- Roseboom, D. P. 1987. Case studies of stream and river restoration. In: Korab, H. *Management of the Illinois River system, the 1990's and beyond: Proceedings of a Governor's conference on April 1-3, 1987 at Peoria, Illinois for citizens, organizations, industry, and government representatives and resources management professionals*. Water Resources Center, University of Illinois. Urbana, Illinois 184-194.
- Schilling, K.E. and C.F. Wolter, 2000. Applications of GPS and GIS to Map Channel Features in Walnut Creek, Iowa. *Journal of American Water Resources Association* 36(6):1423-1434.
- Sekely, A. C., D. J. Mulla, and D.W. Bauer. 2002. Streambank slumping and its contribution to the phosphorus and suspended sediment loads of the Blue Earth River, Minnesota. *Journal of Soil and Water Conservation* 57:243-250.

- Sharpley, A. N., S. J. Smith and J. W. Naney. 1987. Environmental impact of agricultural nitrogen and phosphorus use. *Journal of Agricultural and Food Chemistry*. 35: 812-817.
- Sherer, B. M., J. R. Miner, J. A. Moore, and J. C. Buckhouse. 1988. Resuspending organisms from a rangeland stream bottom. *American Society of Agricultural Engineers* 31(4):1217-1222.
- Simon, A. 2008. Fine-sediment loadings to Lake Tahoe. *Journal of the American Water Resources Association* 44(3), 618-639.
- 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
- Thoma, D. P., S. C. Gupta, M. E. Bauer and C. E. Kirchoff. 2005. Airborne laser scanning for riverbank erosion assessment. *Remote Sensing of Environment* 95, 493-501.
- Zaimes, G. N. 2004. Riparian land-use practice impacts on soil and sediment characteristics, and on stream and gully bank erosion soil and phosphorus losses with an emphasis in grazing practices. Dissertation (Ph.D.). Iowa State University, Ames, IA.
- 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, and T. M. Isenhardt. 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., R.C. Schultz, and T.M. Isenhardt. 2008b. Streambank soil and phosphorus losses under different riparian land-uses in Iowa. *Journal of the American Water Resources Association*. 44(4):935-947.
- Zaimes, G. N., R. C. Schultz, and M. Tufekcioglu. 2009. Gully and stream bank erosion in three pastures with different management in southeast Iowa. *Journal of Iowa Academy of Science*. 116: 1-8.

## CHAPTER 2

**STREAM BANK EROSION AS A SOURCE OF SEDIMENT AND PHOSPHORUS IN GRAZED PASTURES OF THE RATHBUN WATERSHED IN SOUTHERN IOWA****Abstract**

Livestock grazing of riparian zones can have a major impact on stream banks if improperly managed. The goals of this study were to determine the sediment and phosphorus losses from stream bank soils under varying cattle stocking rates and identify other factors that impact stream bank erosion in the Southern Iowa Drift Plain. The study was conducted on thirteen cooperating beef cow-calf farms within the Rathbun Lake watershed in South Central Iowa. Stream bank erosion rates over three years were estimated by using the erosion pin method. Eroded stream bank lengths and area, soil bulk density and stream bank soil-P concentrations were measured to calculate soil and total soil-P lost via stream bank erosion. Results revealed that the length of severely eroded stream banks and compaction of the riparian area were positively related to an increase in number of livestock grazing on the pasture stream reaches. While there was no direct relationship between bank erosion and stocking rate, the erosion rates from two sites enrolled within the Conservation Reserve Program (CRP) were significantly lower than those from all grazed pasture sites especially when seasonal effect, specifically winter/spring, was considered. This result suggests that use of riparian areas as pasture has major negative impacts on water quality and channel integrity through increased sediment and phosphorus from bank erosion, and that impact could be reduced through management of livestock grazing within these riparian areas.

**Introduction**

Sediment is a naturally occurring component of aquatic ecosystems, and the transport and deposition of sediment are natural processes within fluvial systems. However, sediment imbalance, specifically excess sediment, is a significant concern for water quality and aquatic life. Sediment and sedimentation have been recognized as a leading cause of water body impairment nationally (US EPA 2003) and have been identified by U.S. Environmental Protection Agency (EPA) as a priority area for improving the quality of the Nation's waters. In most cases, phosphorus (P) moves to surface waters attached to sediment as particulate P (Sharpley et al. 1987) and has been identified as a major limiting nutrient for eutrophication of many lakes and streams (Correll, 1998). Increased P concentration in streams often promotes toxic algal blooms and excess growth of other aquatic nuisance plants. Aerobic decomposition of the enhanced organic matter production may lead to hypoxic conditions and reduces stream integrity (Carpenter et al. 1998).

Along with overland flow and bed sediment re-suspension, bank erosion is one of the important pathways of non-point source pollutants transport into surface waters and accounts for 40-70% (Laubel et al. 2003), 50% (Schilling and Wolter, 2000), 23-56% (Thoma et al. 2005), 46-76% (Nagle et al. 2007), 25% (Simon, 2008) and more than 50% (Laubel et al. 1999) of a catchment's suspended sediment export. In addition to sediment, total-P contribution to channels from stream bank erosion was estimated to vary from 56 % (Roseboom, 1987), 15-40 % (Laubel et al. 2003), to 7-10 % (Sekely et al. 2002). The large range of estimated sediment and P loads to streams from bank erosion is likely because of the large number of variables involved in the process and the unique relationships among them. Such variables include over-hanging banks, bank angle, bank vegetation cover, estimated stream power (Laubal, 2003), and channel width, depth, and slope (Odgaard, 1987).



While stream bank erosion is a natural, continuous process of healthy meandering streams, it is often accelerated by human activities (Henderson, 1986). Pasture grazing and row-crop production are the two main agricultural practices in the Midwest responsible for this acceleration. Moreover, previous research in Iowa by Downing and Kopaska (2001) concluded that a watershed with a higher proportion of land as pasture may contribute more P to streams than a watershed with a higher proportion of land in row-crop use, but pathways of this input were not identified in this work. A recent study by Alexander et al. (2008) reported that 37 percent of the P contributed to streams and lakes comes from manure on adjacent pasture and range land. There are, however, considerable differences between various grazing practices. Research findings by Zaimes et al. (2008b) and Magner et al. (2008) indicated that using rotational or intensive/short rotational grazing practices instead of continuous grazing could reduce the amount of sediment and P load to streams. Another study by Haan et al. (2006) suggested that reduction in sediment and P loss via surface runoff from grazed pastures can be achieved with the grazing management practices that maintain adequate forage cover to protect the soil surface from direct raindrop impacts. Additionally, the study also found that areas of high slope and late spring grazing did increase the sediment and P loss via surface runoff.

This study was conducted within the Rathbun Lake Watershed in South Central Iowa. Rathbun Lake is the primary water source for 70,000 residents in southern Iowa and northern Missouri. In addition to providing drinking water, this 4,500 hectare lake provides recreation opportunities for one million visitors annually, and flood control for downstream land. Thirteen water bodies in the Rathbun Lake watershed, including Rathbun Lake, have been listed as impaired on the 2008 Iowa Department of Natural Resources 303d listing of

impaired waters (IDNR, 2008). The Rathbun Land and Water Alliance identified 23,887 hectares in 15 sub-watersheds of the Rathbun Lake watershed as priority land that produces nearly 73% of all sediment and P delivered annually to Rathbun Lake from the watershed (Braster et al. 2001). Soil erosion from stream banks has been identified as an important source of sediment and associated P delivery to Rathbun Lake, potentially accounting for 26% of the total estimated sediment delivery from the watershed (Isenhardt and Sitzmann, 2001). One potential contributing factor to this erosion is livestock grazing on riparian pastures which comprise 38% of the watershed. There are 468 livestock grazing and feeding operations in the Rathbun Lake watershed, of which 90% are beef cattle operations. Of these operations, 350 rely on grazing with little or no confinement. Thus, the identification and implementation of cost-effective grazing management and conservation practices that limit deterioration of riparian zones could have profound effects on the water quality of Rathbun Lake.

The objective of this study was to quantify sediment and P losses from stream bank soils in grazed riparian pastures under different stocking rates, ranging from 0 to 28 cow-days  $\text{m}^{-1}$  stream length, and to identify any possible relationships among stream bank erosion variables including erosion rates from severely eroded banks, livestock grazing stocking rates on the pastures, amount of precipitation received on a given site, length and area of severely eroded banks along the stream reaches, soil bulk density from severely eroded banks and riparian areas, and the stream order (Strahler, 1957) of the stream reach in question. The null hypothesis was that there were no differences in sediment and P contributed to streams under different stocking rates and also no relationship between bank erosion and stream bank descriptive variables.

## Materials and Methods

### Study sites and treatments

Thirteen cooperating beef cow-calf farms along sub-stream reaches of the Rathbun Lake watershed located in the Southern Iowa Drift Plain were chosen to conduct the study (Fig. 1 & 2). Site selection was based on the three major requirements: (1) landowner permission to access a site during the three-year of study period; (2) landowner willingness to keep a detailed grazing record to allow accurate stocking rate calculation; and (3). all pasture stream reaches include a stream with perennial flow.

The Southern Iowa Drift Plain is dominated by many stepped erosion surfaces leading to the presence of rills, gullies, creeks, in integrated drainage networks, and rivers created by the long geologic weathering processes (Prior, 1991). In this region, stream bank erosion takes place in glacial materials deposited about a half million 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 to poorly drained. The 143, 323 hectare Rathbun Watershed consists of 38% pasture and hayland, 30% crop land, 12% CRP, 13% woodland and 7% urban/road/water (Braster et al. 2001).

The riparian grazing treatments for this study were classified by stocking rates ranging from 0 to 28 cow-days  $\text{m}^{-1}$  yr and by stream order category including 1<sup>st</sup>, 2<sup>nd</sup> and 3<sup>rd</sup> stream orders (Strahler, 1957; Table 1). Cow-days per meter (m) of stream length per year was calculated as the product of number of cows and the number of days they were grazed on the pasture over a year divided by the grazed pasture stream length on one side of the stream channel;

*Cow-days stream length = Cow-days (number of cows x days stocked) / stream length*

However, because of differences in animal's metabolic size (NRC, 1996), the equation used for the "cow-days" calculation was modified as;

*Cow-days = (Number of cows x 1 x days stocked) + (Number of heifers x 0.86 x days stocked) + (Number of bulls x 1.20 x days stocked)*

During the three years of the study, detailed information regarding number of cows, heifers and bulls and their grazing days for each pasture management was compiled in record books kept by the cooperating producers.

Two of the thirteen farms were selected because their stream reaches were enrolled with the Conservation Reserve Program (CRP) utilizing the cool-season grass filter practice (CP 21), by fencing the livestock out of the riparian area immediately adjacent to the stream. These two sites were used as the controls in the study. The stream reaches of CRP sites were located along 1<sup>st</sup> order streams (Strahler, 1957; Table 1). There were six other grazed pastures located along 1<sup>st</sup>, three along 2<sup>nd</sup> and two along 3<sup>rd</sup> order streams. The dominant grass types on these continuously grazed pastures were tall fescue (*Festuca arundinacea*), reed canarygrass (*Phalaris arundinacea*), bluegrass (*Poa pratensis*), orchardgrass (*Dactylis glomerata*), smooth brome grass (*Bromus inermis*), birdsfoot trefoil (*Lotus corniculatus*), clover (*Trifolium*), sedges (*Cyperaceae*), broadleaf weeds, and shrubs. On these pastures, cattle had full access to the streams and entire pasture throughout the grazing period, which was year-round continuous stocking. Additionally, almost all the stream reaches have scattered trees near the stream banks.

### **Identifying stream bank eroding areas**

In November 2006, lengths and heights of severe and very severely eroded stream banks along 13 riparian pasture stream reaches in the Rathbun watershed were surveyed using Global Positioning System (GPS) hand-held units and analyzed using a Geographic Information System (GIS) program (Arc View 9, ESRI INC. Redlands, California). Severely eroding banks were defined as bare with slumps, vegetative overhang and/or exposed tree roots while very severely eroding banks were defined as bare with massive slumps or washouts, severe vegetative overhang and many exposed tree roots (USDA-NRCS, 1998). Severe and very severely eroded stream banks along the stream reaches were identified by visual observation and recorded using GPS handheld units. The lengths of eroded stream bank segments were determined by walking along the top of the eroded banks with GPS hand-held units. Eroded bank heights were measured manually with height poles at 2 or 3 different bank locations depending on the length and height variations of the eroded segment. The height data were manually entered into the GPS unit. Color infrared digital orthophotos collected in 2002 were used in the GIS program, and starting and end points of eroded bank segments were connected to determine eroded bank length. Bank length was multiplied by the average eroded bank height to calculate eroded bank area for each eroded segment. To get total eroded bank area from a given pasture reach, all eroded areas of each pasture reach were summed. The total eroded stream length for each pasture reach was divided by the total stream bank length of the reach to calculate the percent of eroded bank length per pasture stream reach.

### **Installation of stream bank erosion pins**

The pin method was used to quantify the rate of stream bank erosion (Wolman, 1959). This method was chosen because it is 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). A random subset of eroded bank lengths equating to fifteen percent of the total eroded bank length in each pasture stream reach was chosen for erosion pin installment. A total of 1340 total pins were installed in the study. The number of pin plots per pasture stream reach ranged from four to nine depending on the lengths of the randomly selected eroding segments. Within each plot, erosion pins were installed within two rows directly above one another and had columns ranged from three to seventeen depending on eroded segment length for each individual plot. Pin plots consisted of two rows located at  $1/3$  and  $2/3$  of the stream bank height (Fig. 3). When the bank height was less than one meter, only one pin row was installed at  $1/2$  the bank height. Steel pins were 6.4 mm in diameter and 762 mm long because erosion rates of up to 500 mm per erosion event had been observed by previous researchers (Zaimes et al. 2006). Pins were installed in November 2006. Exposed pin lengths were measured during the winter/spring, summer and fall seasons of 2007, 2008 and 2009. For each measurement period, the previous measurement of 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 of pins that were completely lost during an erosion event (Zaimes et al. 2006). Calculated erosion rates were regressed on the measured independent variables of stocking rate, eroded stream bank length and area, bank soil bulk density, and rainfall to assess their impact on stream bank erosion.

#### **Soil bulk density sampling from stream banks and riparian areas**

The soil core method (3 cm in diameter and 10 cm in depth) was utilized to determine stream bank and riparian area soil bulk densities (Naeth et al. 1990). For eroded bank

segments, where pin plots were located, soil bulk density sample collection was based on horization of stream bank soils. Two soil cores from the mid-point of each horizon were collected for the laboratory analysis. Since each horizon from the eroded bank surface had different widths, width-weighted averages were used to calculate mean soil bulk density for the mean bank height for the plot. These values were also used to calculate total bank soil loss. Additionally, two surface soil cores (3 by 10 cm) from the riparian areas, 8 m away perpendicular to the middle column of each pin plot, were collected to determine the impact of cattle stocking rates on soil compaction of the riparian areas, regardless of whether the sampling location was vegetated or trafficked by the cattle. In the laboratory, soil bulk density samples were weighed after drying for 1 day at 105 °C (Blake and Hartge, 1986).

#### **Soil P sampling and estimation of soil and total-P losses from stream banks**

Soil samples collected for bulk density were analyzed for soil total-P concentration. Samples used for P analysis were first air-dried and then sieved through a 2 mm screen. Soil-P determination was based on soil digestion in aqua regia (Crosland et al. 1995), followed by a colorimetric evaluation of the digested sample for P (Murphy and Riley, 1962).

Total stream bank soil loss for each stream reach was estimated by using total stream bank eroding area multiplied by the product of the mean stream bank erosion rate and the mean soil bulk density from all eroded bank sections in a pasture reach.

To estimate total-P loss from stream banks, the total soil loss from the reach was multiplied by the mean P concentration of the given reach. Stream bank soil and total-P loss per kilometer length of stream bank were estimated by dividing the total stream bank soil loss for each pasture reach by its stream bank length (m) and multiplying by 1000 (m) to allow comparisons between the treatments whose reaches were each of different lengths.

**Rainfall data**

Daily precipitation data were collected from six weather stations that were evenly distributed around research sites within the Rathbun watershed during the three-year study period. However, during the course of the study (Nov 2006 to Nov 2007), several of the weather stations malfunctioned because of lightning strikes. For those times when no data were collected, weather data were obtained from the “Chariton Station” of National Oceanic and Atmospheric Administration (NOAA). Rainfall data were grouped according to the measurement periods (seasons) of bank erosion measurement including winter/spring (last week of November through first week of May), summer (first week of May first week of August) and fall (first week of August through last week of November).

**Data analysis**

The impacts of cattle stocking rate and amount of precipitation on stream bank erosion were examined using the mixed models procedure within the Statistical Analysis Systems (SAS Institute, 2003). Multiple regression models including stocking rate, precipitation, eroded bank length, stream bank soil bulk density, year, and season, as the independent variables, were used to explain the variability in the dependent variable, stream bank erosion. Site was also included in the model, as a random effect, to account for correlation between repeated measurements on the sites. Significance level was considered as  $p < 0.1$ , since bank erosion is influenced many spatial, temporal, climatic and anthropogenic impacts.

**Results and Discussion****Lengths and areas of severe and severely eroding stream banks**



Thirteen to 36% of the total stream lengths of the 13 study reaches were severely or very severely eroded, representing eroded stream bank areas that ranged from 428 to 1121 m<sup>2</sup> km<sup>-1</sup> (Table 1). Livestock stocking rates were significantly correlated to eroded stream bank lengths ( $p=0.09$ ; Fig. 4), but not to the eroded stream bank areas most likely due to having study sites along streams of three different stream orders, which contributed to greater variability in average bank height. This result suggests that stream morphologic characteristics such as taller banks and hydrology play a crucial role in increasing eroded stream bank area as stream order increases (Table 1). Similar results are reported in a study by Lyons et al. (2000), who reported a significantly higher percent of eroded banks in continuously grazed pastures with stocking rates ranged from 0.5-5.9 ha<sup>-1</sup> animal units than in intensive rotationally grazed pastures with stocking rate ranging from 0.8-1.8 ha<sup>-1</sup> animal units over a six month grazing period. Grazing of livestock on riparian areas could weaken soil structure by increasing soil compaction and surface runoff and reducing vegetative cover that provides surface roughness against water erosion (Tufekcioglu, 2006). In this work, it was observed that the physical and/or mechanical impact of livestock on stream bank erosion was mainly related to the steepness of the stream bank. Cattle grazing, drinking, and stream crossing activity along the stream reaches were preferably concentrated on the gently inclined banks, under trees, and/or access points in localized areas, and increased the susceptibility of these banks to further erosion by high stream flow, similar to findings from other studies (Trimble, 1994; Agouridis et al. 2005; Evans et al. 2006). Field observation also suggested that livestock have difficulty accessing vertical banks so have little impact on the erosion of those banks. On these banks, the eroded bank area and erosion rates are mainly influenced by stream morphologic and hydrologic characteristics, which could explain the

insignificant relationship found between stocking rates and erosion rates in this study. In other words, erosion rates recorded herein, in most cases, were mainly the result of stream morphologic and hydrologic conditions rather than the physical/mechanical impact of cattle trampling or grazing on the banks. However, this also suggests cattle grazing and trampling did increase the total percentage of eroded bank lengths for each individual stream reach, and that such a response variable provides a better indicator of grazing impacts on riparian areas compared to bank erosion measurements using erosion pins. This is similar to findings of a study by Zaimes et al. (2008b).

Differences in length and area of eroded stream banks were also not significantly different between CRP and grazed pastures. However, this insignificance in the eroded length could be partially related to the low number of CRP replicate reaches (2) investigated in this study and/or the fact that stream hydrology had greater influence on these banks than did livestock grazing.

### **Stream bank and riparian area soil bulk densities**

One of the important ways to document soil compaction by livestock is to measure surface soil bulk density. No significant correlations were observed between livestock stocking rates and stream bank soil bulk densities which ranged from 1.18 to 1.59 g cm<sup>-3</sup> (Table 1). Livestock trampling impacts on the top of the banks probably had little effect on total bulk density over the average depths of the banks. However, there was a positive significant correlation between riparian soil bulk density, which ranged from 1.26 to 1.67 g cm<sup>-3</sup>, and stocking rates which ranged from 0 to 28 cow-days m<sup>-1</sup> stream length ( $p=0.09$ ; Fig. 5). Similar relationships between stocking rate and soil bulk density were found by other grazed pasture studies (Dormaar et al. 1998; Donkor et al. 2001).

The increase in surface soil bulk density by livestock leads to soil compaction and a change in soil structure, particularly a reduction in macropore size ( $>1000\text{-}\mu\text{m}$  diam.), which, in turn, reduces water infiltration and percolation into lower soil horizons. This effect has the potential to increase surface runoff and decrease water-holding capacity. The greater runoff can result in greater transport of sediment and nutrient load, especially P, to stream ecosystems. Such impacts were observed in a study by Kumar et al. (2010), who reported greater macroporosity in soils under a perennial-buffer ( $0.02\text{ m}^3\text{ m}^{-3}$ ) than under a rotationally grazed ( $0.005\text{ m}^3\text{ m}^{-3}$ ) or continuously grazed pasture ( $0.004\text{ m}^3\text{ m}^{-3}$ ). Similarly, Dormaar et al. (1998) concluded that heavy grazing ( $2.4\text{ AUM ha}^{-1}$ ) and very heavy grazing ( $4.8\text{ AUM ha}^{-1}$ ) treatments resulted in a reduction in water-holding capacity of the pasture soil compared to light grazing ( $1.2\text{ AUM ha}^{-1}$ ). A study by Mwendera and Saleem (1997) also reported significantly higher amounts of surface runoff and soil loss from heavy ( $3.0\text{ AUM ha}^{-1}$ ) and very heavily grazed pastures ( $4.2\text{ AUM ha}^{-1}$ ) than lightly grazed ( $0.6\text{ AUM ha}^{-1}$ ) and moderately grazed pastures ( $1.8\text{ AUM ha}^{-1}$ ). Another study by Nguyen et al. (1998) found that cattle grazing significantly increased surface runoff with greater suspended solids, total nitrogen and total P from plots during rainfall simulations.

During warm sunny days, cattle tend to spend more time in shade and/or near or in available sources of water. Long, narrow riparian pastures tend to concentrate livestock along the banks with greater concentrations under trees growing along the banks (Bear, 2010). As a result, these areas are subject to greater compaction than larger non-riparian pastures.

### **Relationship between bank erosion and independent variables**

Stepwise multi-linear regression analysis in this three-year study revealed no explanation for the stream bank erosion rates by the independent variables stocking rate, amounts of precipitation, eroded bank length and area, and stream bank soil bulk density. Stream bank erosion is an evolving complex process that likely involves too many interactions of factors across multiple scales. Such interacting factors include: riparian land use type and its intensity, bank soil properties, stream stage characteristics mainly governed by rainfall frequency, intensity, duration and timing, and morphologic features of the stream channels such as stream bank and bed slopes and sinuosity.

Significant differences in erosion rates were observed among years and among seasons, and between treatment-season interactions. Second ( $p = 0.03$ ) and third year ( $p = 0.02$ ) bank erosion rates were significantly higher than those in the first year (Fig. 6). Higher erosion rates in the second and third years were mainly the result of high rates observed in the winter/spring period of these two years (Fig. 6). Average winter/spring erosion rates were significantly higher than rates in the summer ( $p < 0.0001$ ) and fall ( $p < 0.0001$ ; Fig. 7), similar to findings of other studies (Prosser et al. 2000; Zaimes et al. 2006; Evans et al. 2006; Simon et al. 2006). The differences in erosion rates between CRP and grazed pasture sites were not significant. However, when the seasonal effect was included in the mixed model, the seasonal erosion rates appeared to be influenced by riparian land-use management. Especially for the winter/spring seasons, when most of the erosion took place, average bank erosion rates from CRP sites (10 cm) were significantly ( $p = 0.0128$ ) lower than those from the grazed pastures (18 cm; Table 1). This difference suggests that vegetated riparian areas without livestock contribute less eroded soil to a stream because of increased bank stability and soil strength resulting from mechanical reinforcement of the soil and hydrological effects

such as dewatering of bank soil (Simon and Collison, 2002). Moreover, there has been a growing debate whether woody riparian vegetation with a greater quantity of large diameter perennial roots provides better bank stabilization (Harmel et al. 1999; Wynn et al. 2004; Wynn and Mostaghimi, 2006) than grass cover with a fibrous root system (Lyons et al. 2000). However, recent research by Knight et al. (2010) does suggest that addition of a grassed zone along a riparian forest buffer would reduce sediment loss due to ephemeral gullies and thus increase stream water quality because the fibrous roots and dense grass overstory provide a stable frictional surface which slows surface runoff and reduces erosion. Another study by De Baets et al. (2008) concluded that grass vegetation increased soil strength in the topsoil (0-10 cm) whereas shrubs provided greater strength at lower depths (0-50 cm).

Total and annual precipitation amounts varied during the three years of this study. Annual precipitation in the third year (107 cm) was significantly lower than in the second year 123 cm ( $p = 0.01$ ) and in the first year 120 cm ( $p = 0.01$ ; Fig. 8). However, when looking at seasons, the only significant difference in average precipitation was found between fall (37 cm) and summer (41 cm;  $p = 0.02$ ; Fig. 9). Average precipitation for winter/spring was 38 cm.

Over the three years of this study, average erosion rates ( $24 \text{ cm yr}^{-1}$ ; Table 1) on the eleven grazed pastures was higher than the average erosion rates ( $4.5 \text{ cm yr}^{-1}$ ) of a similar three-year erosion study on seven grazed pastures that was conducted on the same landform (Southern Iowa Drift Plain) approximately 80 kilometers east of the Rathbun watershed from 2002 to 2004 (Zaimes et al. 2008b). When comparing the fifteen-year precipitation data prior to our three year study period, it is clear that the three-year study period during which this

study was conducted had higher average annual rainfall and more intense rainfall events (Fig. 10). The increase in precipitation in recent wet years was likely one of the main reasons for the greater bank erosion and soil loss recorded from the thirteen farms in the Rathbun watershed. Although higher erosion rates from these pasture banks can be directly related to an increase in total precipitation in recent years, the increase in erosion rates is also related to the frequency, timing, intensity and duration of the rainfall events that were not measured in the present study. These features could be important to explain spatial and temporal patterns in bank erosion due to their effects on stream power during individual runoff events and can help researchers to distinguish or isolate the other effects on bank erosion that comes from the land-use itself.

There was a significant positive relationship in the first year between erosion rate and precipitation ( $p < 0.0001$ ; Fig. 11). In contrast, during the second and third year of the study there was a negative significant relationship between erosion rate and precipitation ( $p < 0.0001$ ; Fig. 11). The result can be related to the higher precipitation rates during the summer of 2008 and fall of 2009 (Fig. 8). The fall ( $p = 0.009$ ) and summer erosion rates ( $p = 0.004$ ) from all three-years were positively correlated with total fall and summer precipitation amounts. In contrast, winter/spring erosion rates among years had a significantly negative relationship with total annual precipitation amount ( $p < 0.0001$ ; Fig. 6 & 8). Although winter/spring seasons of the second and third year had lower precipitation amounts compared to first year, the erosion rates from these two years were higher than those during the winter/spring seasons of the first year (Fig. 10). This suggests that, regardless of the quantity, the impact of precipitation amount on bank erosion during the winter/spring was relatively higher compared to the summer and fall seasons. This observation may be due to higher

moisture content of banks, induced by soil freeze/thaw cycles and increasing rainfall frequency, which coincide with increases in stream discharge and stage. A study by Simon et al. (2000) found that major bank failures took place during prolonged wet periods rather than peak storm events due to an increase in soil unit weight and a decrease in matric suction in which the binding capacity of the soil particles was reduced.

One of the challenges in trying to relate bank erosion responses to precipitation is the lack of precipitation data within the specific watersheds in which we were working. We had to use rainfall data from six established weather stations that were some distance from the specific pasture sites. We also did not have stage or discharge data for any of the streams that could be directly correlated to precipitation in the specific watersheds. Also, we had pasture sites on different stream orders (1<sup>st</sup>, 2<sup>nd</sup> and 3<sup>rd</sup>) which mean that these streams probably had different equilibrium states (slope and sinuosity) and responded differently to discharge and sediment inputs. In other words, their bank soil resistance to same amount of precipitation and/or discharge would be different which, in turn, would result in different bank erosion rates.

### **Erosion rate and soil loss based on Strahler stream order classification**

Third order stream reaches had significantly higher stream bank erosion rates than both second ( $p = 0.0129$ ) and first order ( $p = 0.0184$ ) streams (Fig. 12). This difference probably is result of the fact that higher stream power can exert a greater amount of stress on stream banks during high flow events. Additionally, these banks are more likely to collapse in response to gravity when saturated by high flows because saturation increases soil bulk unit (specific) weight (Simon et al. 2000). In terms of soil loss, third order stream reaches

had significantly ( $p= 0.001$ ) higher stream bank soil loss than first order stream reaches (Fig. 12).

### **Total Soil-P concentrations and losses of soil and total soil-P from stream banks**

Stream bank soil total-P concentrations ranged from 246 to 349 mg kg<sup>-1</sup> (Table 1) were lower than the range (360-555 mg kg<sup>-1</sup>) observed from Southern Iowa Drift Plain by Zaimes et al. (2008a). Differences in soil and soil total-P losses from stream banks between CRP and grazed pastures were not significant. Stream bank soil losses in the two CRP sites were 58 and 85 tonne km<sup>-1</sup>yr<sup>-1</sup> and in the grazed pastures were ranged from 111 to 664 tonne km<sup>-1</sup>yr<sup>-1</sup> (Table 1). Similar to the trend in soil, total-P losses ranged from 20 and 21 kg km<sup>-1</sup>yr<sup>-1</sup> in CRP sites and from 33 to 183 kg km<sup>-1</sup>yr<sup>-1</sup> in grazed sites. Zaimes et al. (2008b) recorded stream bank soil losses of 197-264, 94- 266, and 124-153 tonne km<sup>-1</sup>yr<sup>-1</sup>, from continuous, rotational and intensive rotationally grazed pastures in Iowa, respectively, and 6-61 tonne km<sup>-1</sup>yr<sup>-1</sup> from other pastures where cattle were fenced out of streams. The greater range of soil and P loss in our study can again be partially attributed to the increase in precipitation amount in recent years and, specifically, its greater effect on increasing bank erosion in third order streams (Table 1). The range of soil loss from stream bank erosion (10-663 tonne km<sup>-1</sup> yr<sup>-1</sup>) in Vermont is similar to the range recorded in this study (DeWolfe et al. 2004).

Since stocking rates were not correlated to bank erosion rates, there was also no relationship between stocking rates and both soil and soil total-P losses from the pasture reach. However, in a surface runoff study on the critical stream bank source areas of livestock access points and loafing areas, Tufekcioglu (2006) noted that use of low stocking rates had the potential to reduce total-P losses compared to higher stocking rates, but this



relationship may not be sufficient to mitigate the impact of livestock on riparian source areas and stream water quality. Similarly, a study by Haan et al. (2010) on cattle distribution suggested that percent of time cattle spend in the stream or adjacent riparian areas can be reduced with a rotational stocking system utilizing lower stocking rates to maintain adequate forage cover.

### **Summary and Conclusions**

Stocking rates of grazing livestock significantly affect riparian areas and adjacent stream banks. The increase in eroded bank length and soil bulk density in the riparian areas was significantly related to an increase in stocking rates. This relationship suggests that some of the proximate causative factors related to nutrient and soil losses from stream banks and riparian areas of grazed pastures can be directly related to the cattle stocking rates. Stream bank erosion rates were less from CRP stream reaches than from grazed pasture sites during the winter/spring measurement period. This difference suggests that riparian areas without grazing livestock produce smaller amounts of sediment and its attached P from bank erosion and possibly from surface runoff. Study findings imply that nutrient losses from stream banks and riparian areas could be reduced by improved riparian pasture management. Additionally, data showed that under the condition of prolonged wet years, third order stream channels produced greater amounts of sediment than first and second order channels. This difference suggest that stream size and morphology, and the timing and intensity of precipitation, are important causative factors driving sediment flux, and may mask the impacts of improved riparian pasture management.

## References

- Agouridis, C. T., D. R. Edwards, S. R. Workman, J. R. Bicudo, B. K. Koostra, E. S. Vanzant, and J. L. Taraba. 2005. Stream bank erosion associated with grazing practices in the humid region. *Transactions of the American Society of Agricultural Engineers* 48 (1):181-190.
- Alexander, R. B., Smith, R. A., Schwarz, G. E., Boyer, E. W., Nolan, J. V. and Brakebill, J. W. 2008. Differences in phosphorus and nitrogen delivery to the Gulf of Mexico from the Mississippi River Basin. *Environ. Sci. Tech.* 42:822-830.
- Bear, D. A. 2010. Pasture management effects on nonpoint source pollution of Midwestern watersheds. MS Thesis. Iowa State University.
- Blake, G. R., and K. H. Hartge. 1986. Bulk Density. In: Clute A. Ed. *Methods of soil analysis: Part 1. Physical and mineralogical methods*. 2<sup>nd</sup> ed. Madison, Wisconsin: American Society of Agronomy and Soil Science Society of America 363-375.
- Braster, M., T. Jacobson, and V. Sitzmann. 2001. *Assessment and Management Strategies for the Rathbun Lake Watershed*.  
[www.rlwa.org/Documents/Rathbun%20Lake%20Watershed%20Assessment.pdf](http://www.rlwa.org/Documents/Rathbun%20Lake%20Watershed%20Assessment.pdf)
- Carpenter, S. R., Caraco, N. F., Correll, D. L., Howarth, R. W., Sharpley, A. N. and V.H. Smith. 1998. Nonpoint pollution of surface waters with phosphorus and nitrogen. *Ecological Application* 8:559–568.
- Correll., D. L. 1998. The role of phosphorus in the eutrophication of receiving waters: A review. *Journal of Environmental Quality* 27:261-266.
- Crosland, A.R., F.J. Zhao, S.P. McGrath, and P.W. Lane. 1995. Comparison of *aqua regia* digestion with sodium carbonate fusion for the determination of total phosphorus in soils by inductively coupled plasma atomic emission spectroscopy ICP). *Commun. Soil Sci. Plant Anal.* 26:1357-1368.

- Daniel, T.C., A. N. Sharpley, D. R. Edwards, R. Wedepohl, and J. L. Lemunyon. 1994. Minimizing surface water eutrophication from agriculture by phosphorus management. *Journal of Soil and Water Conservation* 49(2, supplemental):30-38.
- De Baets, S., J. Poesen, B. Reubens, K. Wemans, J. De Baerdemaeker and B. Muys. 2008. Root tensile strength and root distribution of typical Mediterranean plant species and their contribution to soil shear strength. *Plant Soil* 305, 207-226.
- DeWolfe, M. N., W. C. Hession, and M. C. Watzin. 2004. Sediment and phosphorus loads from streambank erosion in Vermont, USA. pp. 1-10. In: G. Sehlke, D.F. Hayes, and D.K. Stevens (eds.), *Critical Transitions in Water and Environmental Resources Management*, American Society of Civil Engineers, Reston, VA.
- Donkor, N. T., J. V. Gedir, R. J. Hudson, E. W. Bork, D. S. Chanasyk and M. A. Naeth. 2002. Impacts of grazing systems on soil compaction and pasture production in Alberta. *Canadian Journal of Soil Science* 82, 1-8.
- Dormaar, J. F. and W. D. Willms. 1998. Effect of forty-four years of grazing on fescue grassland soils. *Journal of Range Management* 51 (1), 122-126.
- Downing, J. A. and Kopaska, J. 2001. Diagnostic study of Rock Creek Lake and its watershed: Recommendations for remediation. Iowa Department of Natural Resources. Des Moines, IA.
- Evans, D. J., C. E. Gibson and R. S. Rossell. 2006. Sediment loads and sources in heavily modified Irish catchments: A move towards informed management strategies. *Geomorphology* 79, 93-113.
- Haan, M.M., J.R. Russell, J.D. Davis, and D.G. Morrical. 2010. Grazing management and microclimate effects on cattle distribution relative to a cool-season pasture stream. *Rangeland Ecology Management*. 63(5): 572-580
- Haan, M.M., J.R. Russell, W.J. Powers, J.L. Kovar, and J.L. Benning. 2006. Grazing management effects on sediment and phosphorus in surface runoff. *Rangeland Ecology Management*. 59: 607-615.

- Haigh, M. J. 1977. The use of erosion pins in the study of slope evolution. British Geomorphologic Research Group, Technical Bulletin 18:31-49.
- Harmel, R. D., C. T. Haan and R. Dutnell. 1999. Bank erosion and riparian vegetation influences: Upper Illinois River, Oklahoma. American Society of Agricultural Engineers 42 (5), 1321-1329.
- Henderson J. E. 1986. Environmental designs for stream bank protection projects. Water Resource Bulletin 22:549-558.
- House, W. A., T. D. Jickells, A. C. Edwards, K. E. Praska, and F. H. Denison. 1998. Reactions of phosphorus with sediments in fresh and marine waters. Soil Use and Management 14:139-146.
- Iowa Department of Natural Resources. 2008. 303d List of Impaired Waters. <http://www.igsb.uiowa.edu/wqm/WQA/303d/2008/303dSC.htm>.
- Isenhardt, T. and V. Sitzman. 2001. Assessment of the Ecological Integrity of Stream Corridors in the Rathbun Lake Watershed Using the Stream Visual Assessment Protocol. Appendix E. IN: Assessment and Management Strategies for the Rathbun Lake Watershed. Braster, M., T. Jacobson, and V. Sitzmann (ed). [www.rlwa.org/Documents/Rathbun%20Lake%20Watershed%20Assessment.pdf](http://www.rlwa.org/Documents/Rathbun%20Lake%20Watershed%20Assessment.pdf).
- Knight, K. W., R. C. Schultz, C. M. Mabry and T. M. Isenhardt. 2010. Ability of remnant riparian forests, with and without grass filters, to buffer concentrated surface runoff. Journal of the American Water Resources Association 46 (2), 311-322.
- Kumar, S., S. H. Anderson and R. P. Udawatta. 2010. Agroforestry and grass buffer influences on macropores measured by computed tomography under grazed pasture system. Soil & Water Management & Conservation 74 (1), 203-212.
- Laubel, A., B. Kronvang, A. B. Hald and C. Jensen. 2003. Hydromorphological and biological factors influencing sediment and phosphorus loss via bank erosion in small lowland rural streams in Denmark. Wiley Interscience. Hydrological Processes 17:3443-3463.

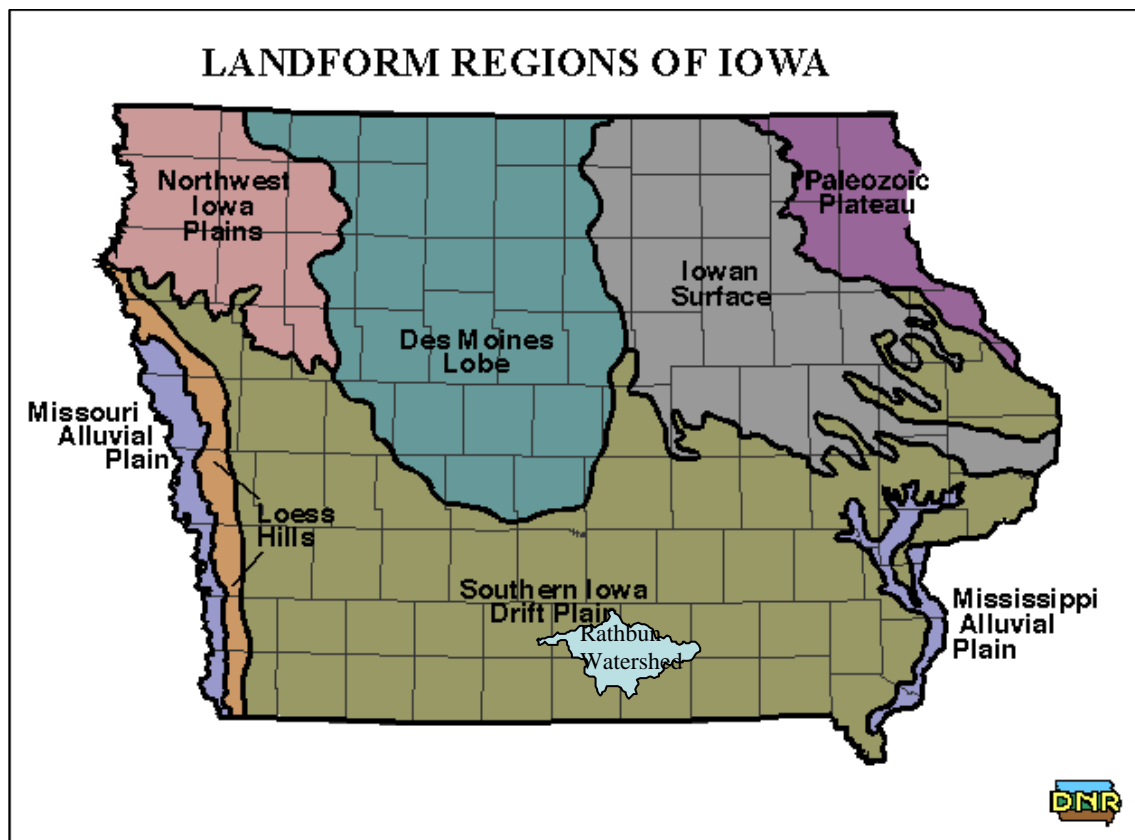
- Laubel, A., L. M. Svenden, B. Kronvang, and S. E. Larsen. 1999. Bank erosion in a Danish lowland stream system. *Hydrobiologia* 410:279-285.
- Lawler, D. M. 1993b. Needle ice processes and sediment mobilization on river banks: The River Ilston, West Glamorgan, UK. *Journal of Hydrology* 150:81-114.
- Lyons, J., B. M. Weigel, L. K. Paine and D. J. Undersander. 2000. Influence of intensive rotational grazing on bank erosion, fish habitat quality, and fish communities in Southwestern Wisconsin Trout streams. *Journal of Soil and Water Conservation* 55 (3), 271-276.
- Lyons, J., S. W. Trimble and L. K. Paine. 2000. Grass versus trees: managing riparian areas to benefit streams of Central North America. *Journal of the American Water Resources Association* 36 (4), 919-930.
- Magner, J.A., B. Vondrack and K.N. Brooks. 2008. Grazed riparian management and stream channel response in Southeastern Minnesota (USA) streams. *Environmental Management*. 42:377-390.
- Murphy, J and J.R. Riley. 1962. A modified single solution method for the determination of phosphate in natural waters. *Anal. Chim. Acta*. 27:31-36.
- Mwendera, E. J. and M. A. Mohamed Saleem. 1997. Infiltration rates, surface runoff, and soil loss as influenced by grazing pressure in the Ethiopian highlands. *Soil Use and Management* 13, 29-35.
- Naeth M. A., D. J. Pluth, D. S. Chanasyk, A. W. Bailey. 1990. Soil compacting impacts on grazing in mixed prairie and fescue grassland ecosystems of Alberta. *Canadian Journal of Soil Science* 70:157-167.
- Nagle, G. N., T. J. Fahey, J. C. Ritchie and P. B. Woodbury. 2007. Variations in sediment sources and yields in the Finger Lakes and Catskills regions of New York. *Hydrological Processes* 21, 828-838.
- Nguyen, M. L., G. W. Sheath, C. M. Smith and A. B. Cooper. 1998. Impact of cattle treading on hill land; Soil physical properties and contaminant runoff. *New Zealand Journal of Agricultural Research* 41, 279-290.

- NRC, 1996. Nutrient Requirements of Beef Cattle. 7<sup>th</sup> ed. Natl. Acad. Press, Washington, DC.
- Odgaard, A. J. 1987. Streambank erosion along two rivers in Iowa. *Water Resource Research* 23:1225-1236.
- Prior, J. C. 1991. Landforms of Iowa. Iowa Department of Natural Resources University of Iowa Press, Iowa City, Iowa.
- Prosser, I. P., A. O. Hughes and I. D. Rutherford. 2000. Bank erosion of an incised upland channel by subaerial processes; Tasmania, Australia. *Earth Surface Processes Landforms* 25 (10), 1085-1101.
- Rathbun Land & Water Alliance. 2010. Centerville, IA. Accessed on February 2010. <http://www.rlwa.org/Documents/Rathbun%20Lake%20Brochure.pdf>
- Roseboom, D. P. 1987. Case studies of stream and river restoration. In: Korab, H. Management of the Illinois River system, the 1990's and beyond: Proceedings of a Governor's conference on April 1-3, 1987 at Peoria, Illinois for citizens, organizations, industry, and government representatives and resources management professionals. Water Resources Center, University of Illinois. Urbana, Illinois 184-194.
- SAS (Statistical Analysis System) Institute. 2003. SAS Release 9.1 ed. SAS Inst., Cary, North Carolina.
- Schilling, K.E. and C.F. Wolter, 2000. Applications of GPS and GIS to Map Channel Features in Walnut Creek, Iowa. *Journal of American Water Resources Association* 36(6):1423-1434.
- Sekely, A. C., D. J. Mulla and D.W. Bauer. 2002. Streambank slumping and its contribution to the phosphorus and suspended sediment loads of the Blue Earth River, Minnesota. *Journal of Soil and Water Conservation* 57:243-250.
- Sharpley, A. N., S. J. Smith and J. W. Naney. 1987. Environmental impact of agricultural nitrogen and phosphorus use. *Journal of Agricultural and Food Chemistry*. 35: 812-817.

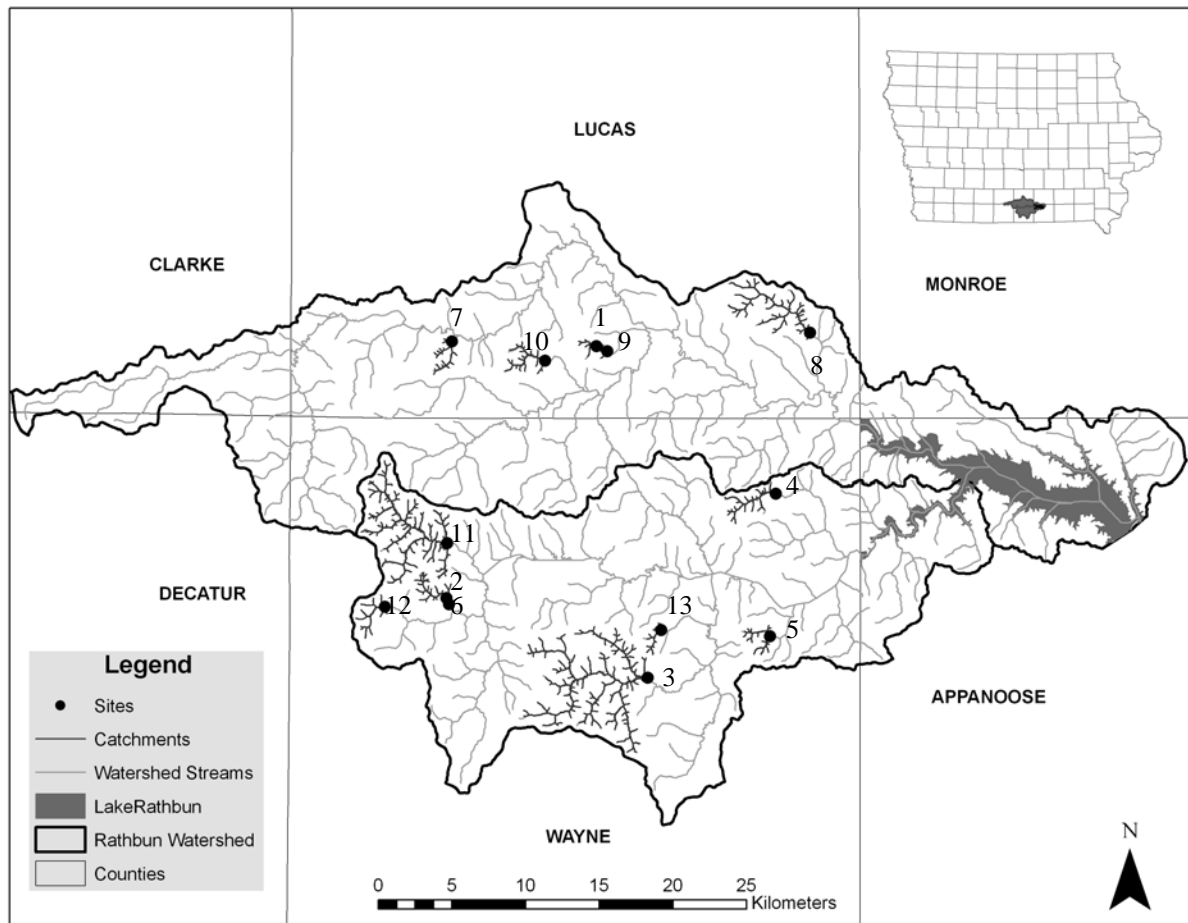
- Simon A, Curini A, Darby SE, Langendoen EJ (2000) Bank and near-bank processes in an incised channel. *Geomorphology* 35:193-217.
- Simon, A and Collison, A.J.C. (2002) Quantifying the Mechanical and Hydrologic Effects of Riparian Vegetation on Streambank Stability. *Earth Surface Process and Landforms*. 27:527-546.
- Simon, A. 2008. Fine-sediment loadings to Lake Tahoe. *Journal of the American Water Resources Association* 44(3), 618-639.
- Simon, A., N. Pollen and E. Langendoen. 2006. Influence of two woody riparian species on critical conditions for streambank stability: Upper Truckee River, California. *Journal of the American Water Resources Association* 42(1), 99-113.
- Strahler AN (1957) Quantitative analysis of watershed geomorphology. *Am Geophysical Union Trans* 38:913-920
- Thoma, D. P., S. C. Gupta, M. E. Bauer and C. E. Kirchoff. 2005. Airborne laser scanning for riverbank erosion assessment. *Remote Sensing of Environment* 95, 493-501.
- Trimble, S. W. 1994. Erosional effects of cattle on streambanks in Tennessee, U.S.A. *Earth Surface Processes and Landforms* 19, 451-464.
- Tufekcioglu, M. 2006. Riparian land-use impacts on stream bank soil and phosphorus losses from grazed pastures. M.S. Thesis. Iowa State University.
- U.S. Environmental Protection Agency. 2003. Strategy for water quality standards and criteria: Setting priorities to strengthen the foundation for protecting and restoring the nation's waters. EPA-823-R-03-010.
- United State Department of Agriculture. Soil Conservation Service. Soil Survey. Wayne County, Iowa. 1971.
- United States Department of Agriculture-Natural Resource Conservation Service. 1998. Erosion and Sediment Delivery. Field Office Technical Guide Notice Number. IA-198. United States Department of Agriculture and Natural Resource Conservation Service, Des Moines, Iowa 13.

- Wolman, M. G. 1959. Factors influencing erosion of a cohesive river bank. *American Journal of Science* 257: 204-216.
- Wynn, T. and S. Mostaghimi. 2006. The effects of vegetation and soil type on streambank erosion, Southwestern Virginia, USA. *Journal of the American Water Resources Association* 42 (1), 69-82.
- Wynn, T. M., S. Mostaghimi, J. Burger, A. Harpold, M. Henderson and L-A. Henry. 2004. Variation in root density along stream banks. *Journal of Environmental Quality* 33 (6), 2030-2039.
- Zaimes, G. N. 2004. Riparian land-use practice impacts on soil and sediment characteristics, and on stream and gully bank erosion soil and phosphorus losses with an emphasis in grazing practices. Dissertation (Ph.D.). Iowa State University, Ames, IA.
- Zaimes, G.N., R.C. Schultz, and T.M. Isenhardt. 2006. Riparian land uses and precipitation influences on stream bank erosion in central Iowa. *Journal of the American Water Resources Association*. 42(1): 83-97.
- Zaimes, G.N., R.C. Schultz, and T.M. Isenhardt. 2008a. Total phosphorus concentrations and compaction in riparian areas under different riparian land-uses of Iowa. *Agriculture, Ecosystems and Environment*. 127: 22-30.
- Zaimes, G.N., R.C. Schultz, and T.M. Isenhardt. 2008b. Streambank soil and phosphorus losses under different riparian land-uses in Iowa. *Journal of the American Water Resources Association*. 44(4):935-947.

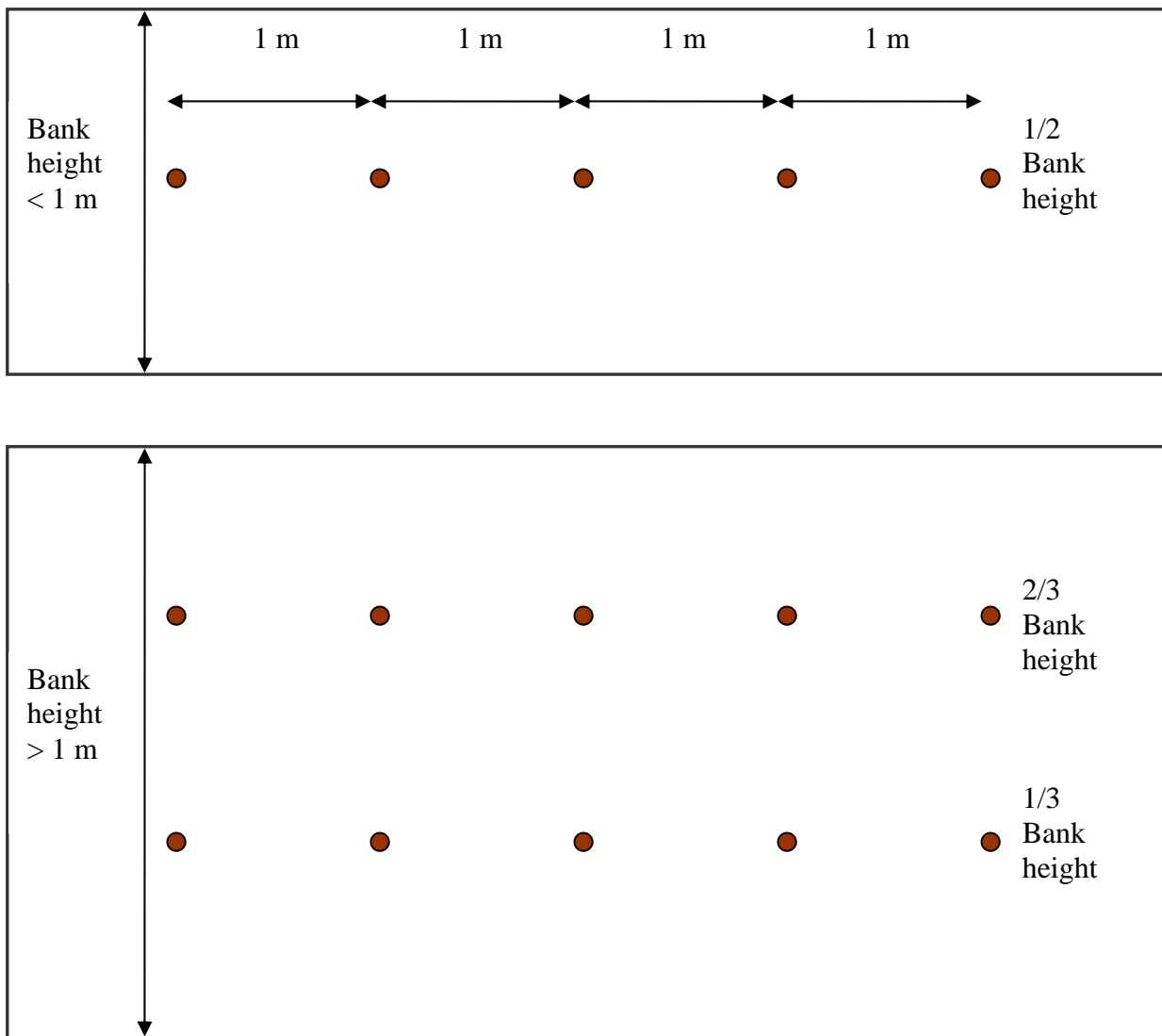




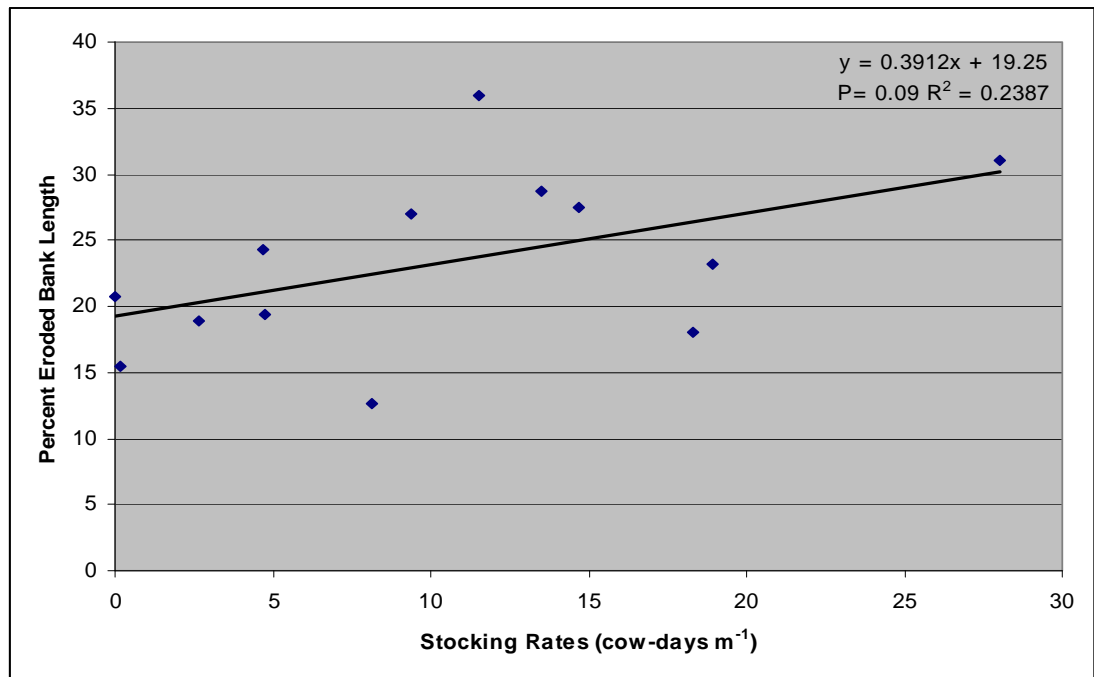
**Figure 1:** Location of the Rathbun watershed within the Southern Iowa Drift Plain land form region.



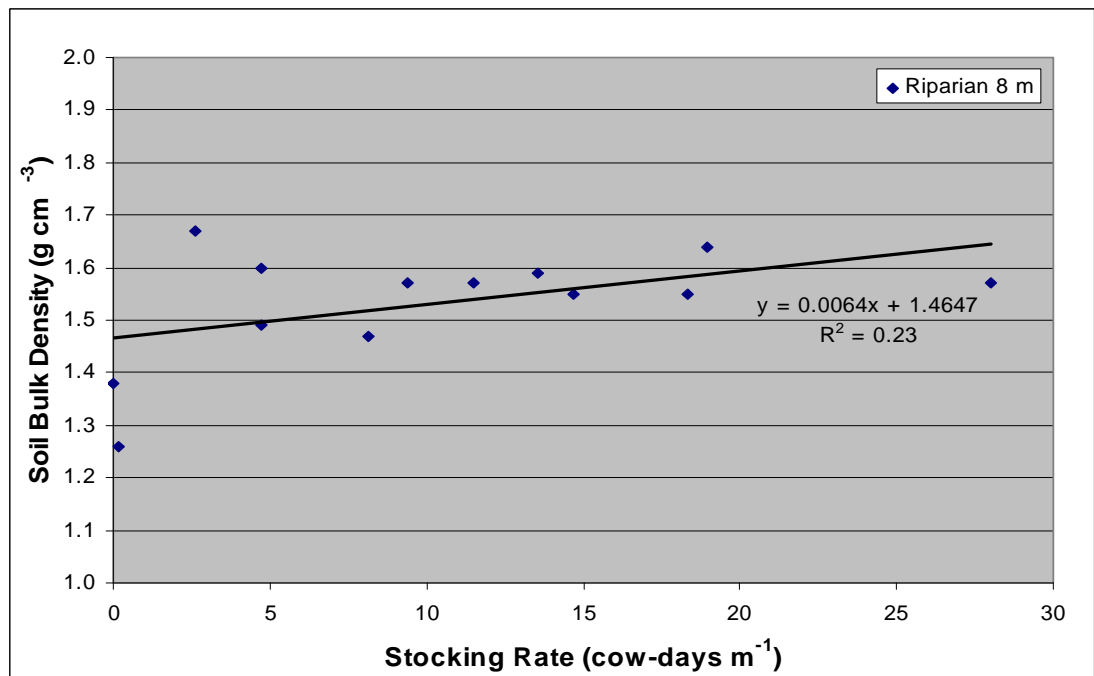
**Figure 2:** Location of thirteen study sites and their channel system within Rathbun Lake watershed in Southern Iowa. Numbers represent pasture identification based on the stocking rates from smallest to largest.



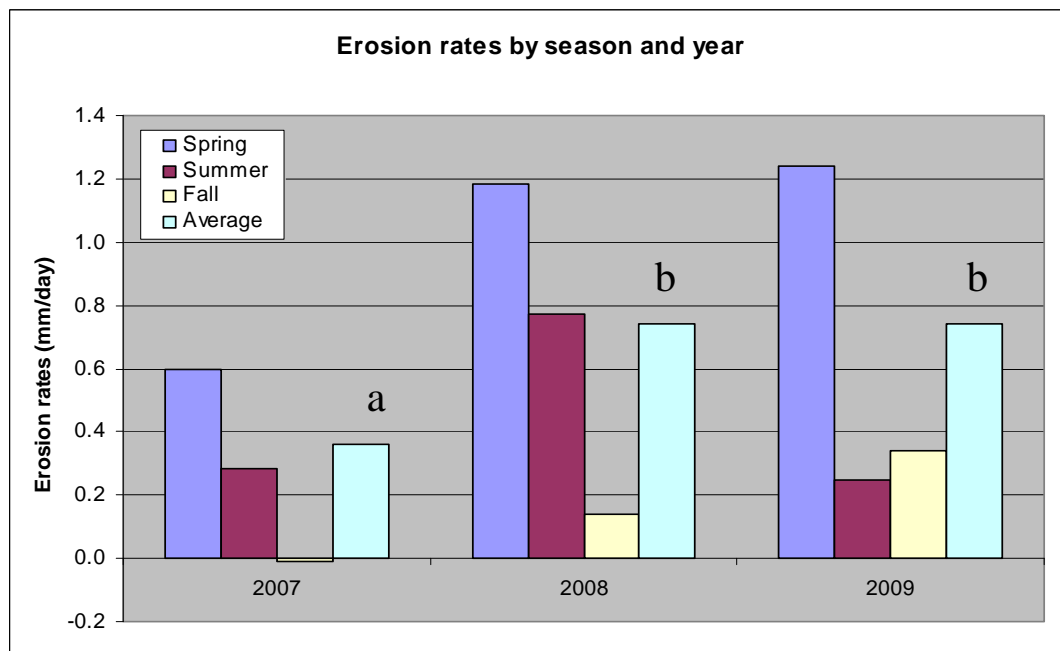
**Figure 3:** Schematic of steel pin placement and spacing on eroding stream banks.



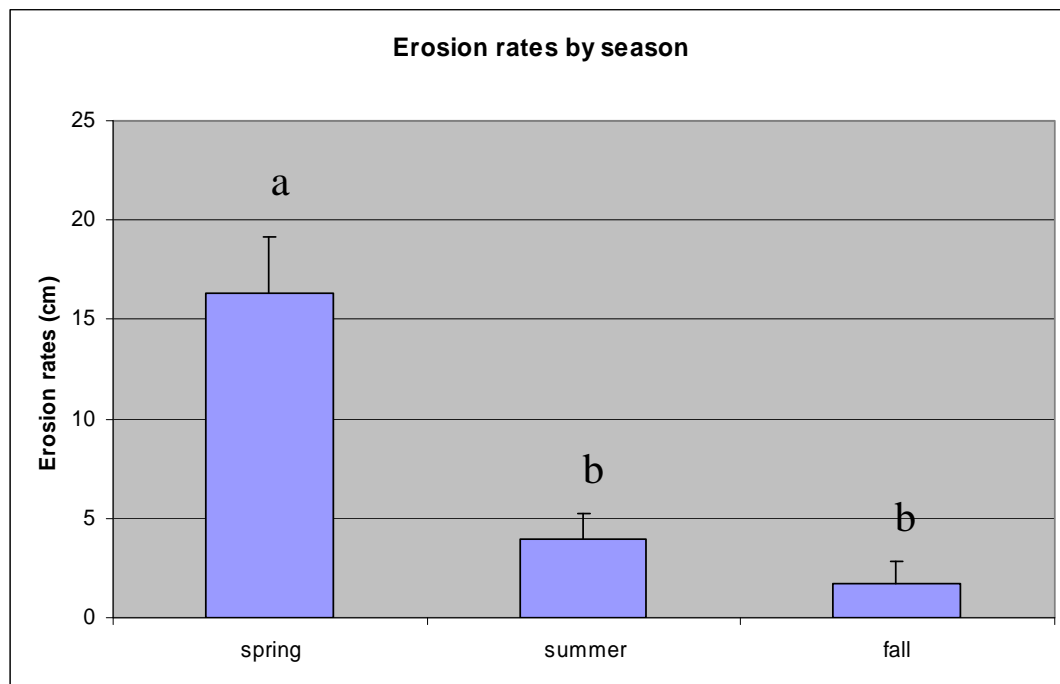
**Figure 4:** Relationship between stocking rates and percent eroded bank length of the total treatment reach length (includes both banks).



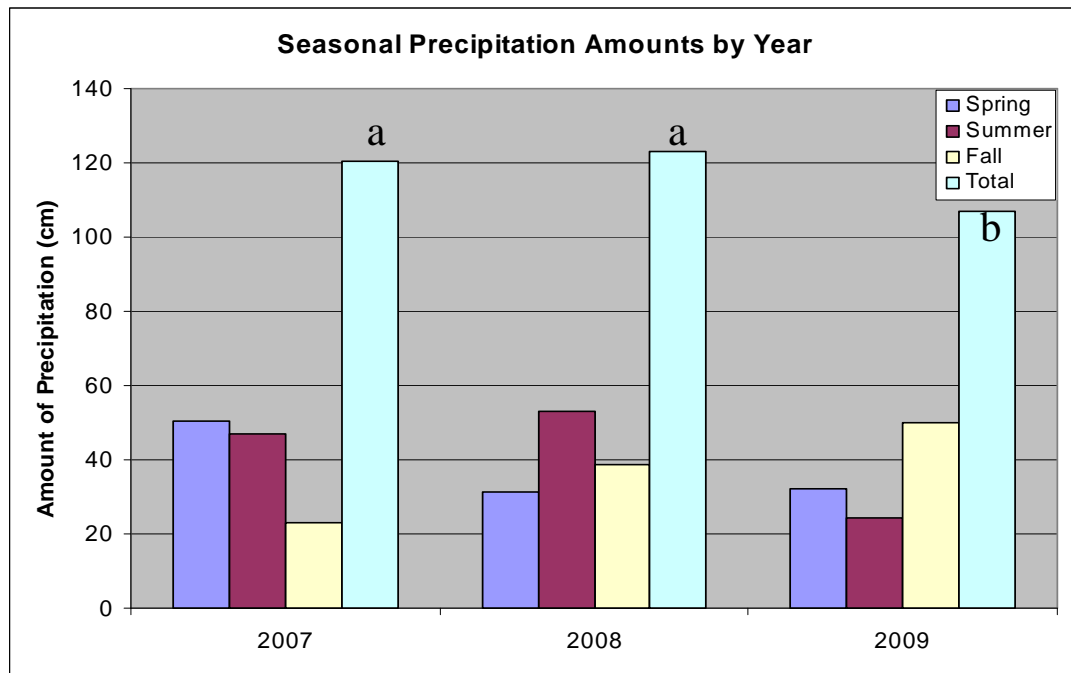
**Figure 5:** Relationship between cattle stocking rate and soil bulk density from riparian areas (8 m away from eroded bank).



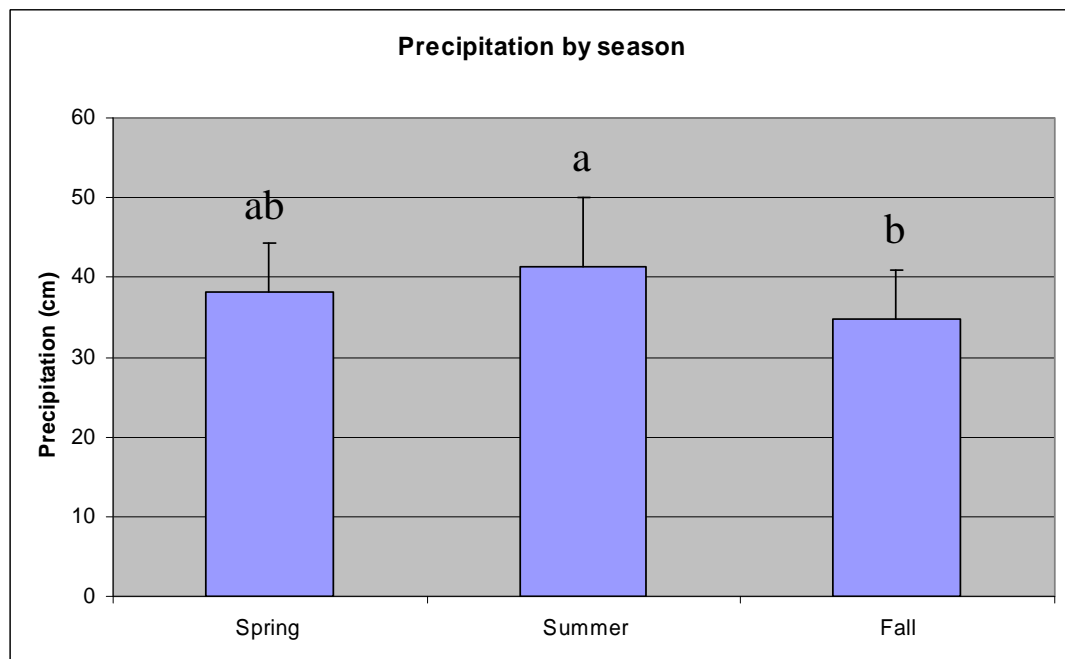
**Figure 6:** Erosion rates by years and seasons averaged over all stocking treatments.



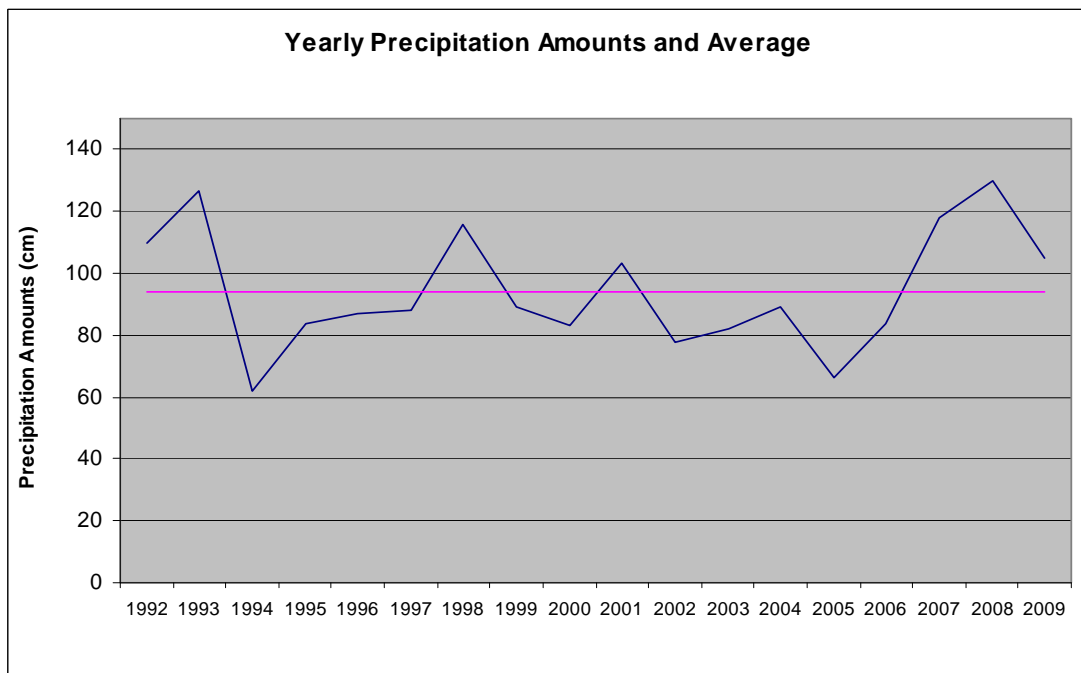
**Figure 7:** Average erosion rates by seasons averaged over all stocking treatments.



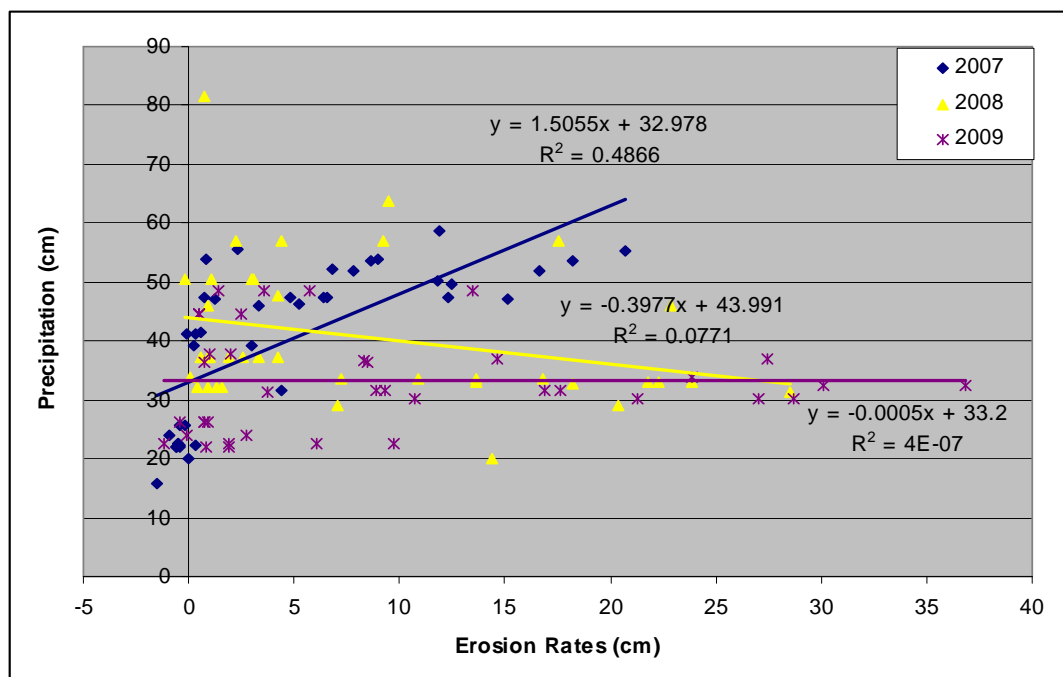
**Figure 8:** Differences in precipitation by years and seasons averaged over all stocking treatments.



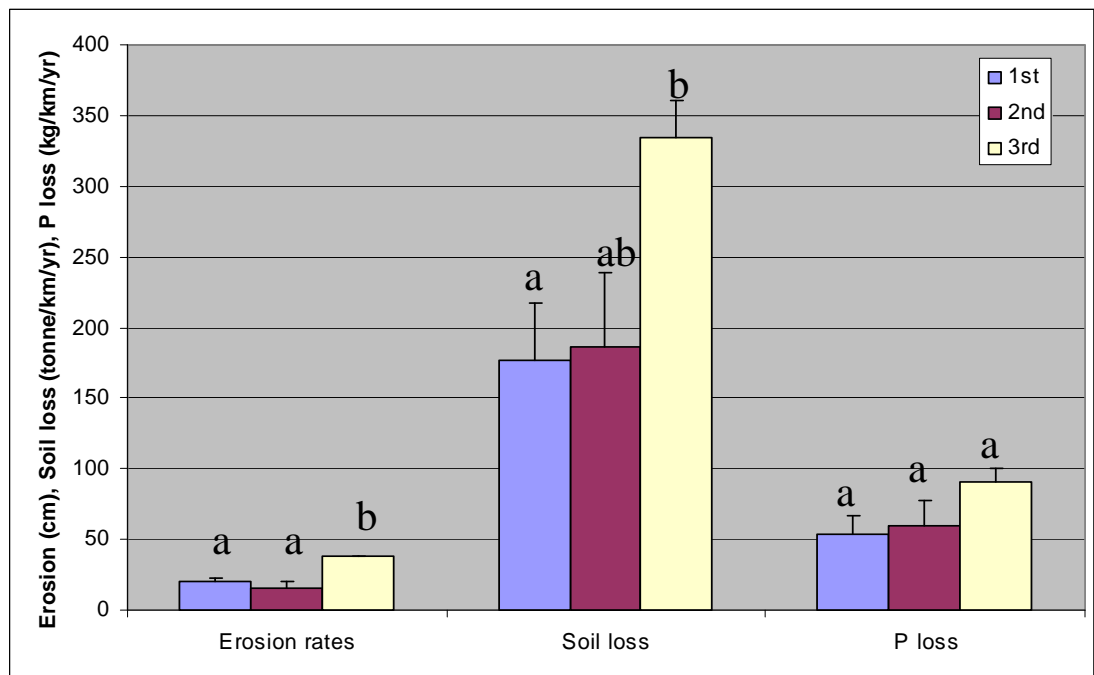
**Figure 9:** Differences in average precipitation by seasons averaged over all stocking treatments.



**Figure 10:** Yearly precipitation amounts from 1992 to 2009 compared to the average precipitation at Chariton, Iowa (straight line; 94 cm yr<sup>-1</sup>) from NOAA weather records.



**Figure 11:** Relationship between erosion rates averaged over all stocking rates and total annual precipitation for the years 2007-2009.



**Figure 12:** Differences in erosion rates, soil loss and total-P losses among 1<sup>st</sup>, 2<sup>nd</sup>, and 3<sup>rd</sup> stream category



**Table 1.** Soil and total-P losses from severe and very severely eroded stream banks under different stocking rates and stream orders in the Rathbun watershed of southern Iowa.

Farm ID		Stocking rate	Stream order	Erosion rate	Bulk density	Eroded area	Soil loss	P concentration	P loss
		cow-days/m/yr	by Strahler	cm/yr	g/cm <sup>3</sup>	m <sup>2</sup> /km	tonne/km/yr	mg/kg	kg/km/yr
Site 1	(CRP)	0	1 <sup>st</sup>	9	1.38	477	58	349	20
Site 2	(CRP)	0	1 <sup>st</sup>	15	1.18	465	85	246	21
Site 3	(grazing)	3	3 <sup>rd</sup>	38	1.58	1095	664	276	183
Site 4	(grazing)	5	2 <sup>nd</sup>	25	1.48	775	285	329	94
Site 5	(grazing)	5	1 <sup>st</sup>	26	1.44	645	245	281	69
Site 6	(grazing)	8	1 <sup>st</sup>	34	1.35	428	196	279	55
Site 7	(grazing)	9	1 <sup>st</sup>	17	1.48	605	150	305	46
Site 8	(grazing)	12	2 <sup>nd</sup>	9	1.55	1121	164	322	53
Site 9	(grazing)	14	1 <sup>st</sup>	10	1.47	756	116	300	35
Site 10	(grazing)	15	2 <sup>nd</sup>	13	1.32	654	111	293	33
Site 11	(grazing)	18	3 <sup>rd</sup>	38	1.53	1061	612	269	165
Site 12	(grazing)	19	1 <sup>st</sup>	23	1.37	480	151	337	51
Site 13	(grazing)	28	1 <sup>st</sup>	25	1.59	1029	416	327	136
Average CRP/spring				10			56		16
Average CRP/summer				1			6		2
Average CRP/fall				1			8		2
Average grazing/spring				18			208		62
Average grazing/summer				4			54		16
Average grazing/fall				2			21		6
Total average (CRP)				12	1.28	471	72	298	21
Total average (grazing)				24	1.46	786	283	302	84

## CHAPTER 3

**STREAM STAGE AND STREAM BANK EROSION IN GRAZED PASTURE  
STREAM REACHES IN THE RATHBUN WATERSHED IN SOUTHERN IOWA****Abstract**

Stream bank erosion in agricultural landscapes is a major pathway for non-point source sediment and phosphorus loading of receiving waters. Previous studies have shown direct and indirect effects of land use on stream bank erosion, and identified high erosion rates within riparian pastures. One potential impact of agricultural land-use on stream bank erosion is the alteration of stream stage characteristics, including an increase in the frequency of high stage events over short periods of time (flash hydrograph formation). The objective of this study was to assess the relationship between the numbers of high stream stage events, as they directly reflect higher erosive streamflow, and contribute to stream bank soil erosion. The study was conducted in six grazed pasture stream reaches within the Rathbun Lake watershed, a reservoir on the Chariton River located within the Southern Iowa Drift Plain. 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 (number of times of occupancy of each stage by high stream flow depth) with the remaining 25% possibly due to stream bank soil antecedent moistures prior to a discharge event, and differences in the duration of the high stream stages.

## Introduction

Alteration in the hydrologic cycle of an agricultural watershed (surface runoff, soil-water holding capacity and infiltration) is primarily driven by the change in land-use affecting the percent of cover in row-crop or grazed pasture, and the change in precipitation intensity, frequency, duration and amount. These changes eventually affect the pathways of water flow between and/or within the aquatic and terrestrial ecosystems. These changes may result in increased surface runoff, reduced water infiltration (Schultz et al. 2004) and increased stream and base flow, and less evapotranspiration as a result of reduced soil-water storage and seasonal plant cover (Schilling et al. 2009). As channels experience increased numbers of erosive peak flows, channel morphology is modified through incision and widening before new equilibrium conditions can develop (Menzel 1983).

In the Mississippi River basin, trends suggest an increase in stream flow associated with an increase in precipitation (Lins and Slack, 1999; Kalra et al. 2008). Similarly, studies by Guo et al. (2008) and, Tomer and Schilling (2009) suggest that climate change is the main driving force behind increases in discharge. However, other studies suggest that increases in stream flow cannot be completely explained by an increase in precipitation (Gebert and Krug, 1996; Schilling and Libra, 2003; Zhang and Schilling, 2006). Studies by Raymond et al. (2008) and Schilling et al. (2010) suggested that land-use change and management practices are more important than the changes imposed by the climate in explaining the increased stream flow in the Mississippi River. While it can be argued that land-use changes provide the greatest influence on changes in streamflow characteristics and stream morphology, Carleton et al. (2008) points out that alteration in climate and weather patterns is under the influence of changes in land cover and land use.

In the last 150 years, 99% of Iowa's tall grass prairie and 95% of its wetlands have been converted to row crop and grazed pasture agriculture (Whitney, 1994; Burkhart et al. 1994). Most of the wetlands have been converted to agricultural land through the use of artificial subsurface drainage. Along with these changes, streams were also channelized to provide drainage outlets and to increase arable land area for agricultural production. Such changes have been documented to increase stream gradient and channel incision (Hupp, 1992) and stream discharge, increase sediment and nutrient losses (Knox, 2001; Schilling 2004), and reduce stream sediment storage (Kroes and Hupp, 2010). Additionally, a reduction in soil-water storage has resulted in an increase and acceleration of peak discharge leading to flashy hydrographs during storm events (Bormann et al. 1999). Another study by Knox (2001) concluded that agricultural land use, along with the artificial subsurface drainage and channelization, has increased the peak discharges from high-frequency floods to such an extent that makes comparison of modern process rates with those prior to human disturbance a formidable challenge. 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).

Stream bank erosion accounts for a significant portion of the total soil and phosphorus (P) losses to receiving water bodies. Studies by Laubel et al. (1999; 2003), and Schilling and Wolter (2000) have reported that bank erosion can contribute significant amounts of suspended sediment to fluvial systems, accounting for at least half of a watershed's annual suspended sediment export. Bartley (2004) reported that gully and stream bank erosion contributed 48% of the total sediment load to an estuary. Ranges of total-P

contribution to channels from stream bank erosion have been documented from 56 % (Roseboom, 1987), 15-40 % (Laubel et al. 2003), to 7-10 % (Sekely et al. 2002).

The objective of the study was to assess the relationship between stream bank erosion rates during summer and fall seasons and peak 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.

## **Materials and Methods**

### **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 (Fig. 1). 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  $m^{-1}yr$  (Table 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 were classified as first –order streams (Strahler,

1957; Table 1) and the other two sites were located on second and third order streams, respectively.

The dominant grass types on these continuously grazed pastures were tall fescue (*Festuca arundinacea*), reed canarygrass (*Phalaris arundinacea*), bluegrass (*Poa pratensis*), orchardgrass (*Dactylis glomerata*), smooth brome grass (*Bromus inermis*), birdsfoot trefoil (*Lotus corniculatus*), clover (*Trifolium*), sedges (*Cyperaceae*), broadleaf weeds, and shrubs. On these pastures cattle had full access to the entire pasture including the streams throughout the year-round grazing period. Almost all the stream reaches had some trees scattered near the stream banks.

### **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. Additional detail regarding eroded stream bank surveying and pin plot installation is provided in chapter 2 of this dissertation. 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 (Fig. 2). 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 60 cm 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. 3). While there was some lag in water table depth to stream stage, the high hydraulic conductivity of the alluvial soils and close proximity of the wells to the stream bank allowed for adequate stream stage gauging to assess the relationship between stream stage, wetting of the stream bank profile, and bank erosion. These locations also reduced the risk of losing the wells and transducers during large storm events. 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.

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. 3). 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. Larsen et al. (2006) 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 (numbers of time) 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. Such results highlight the complexity of the interactions between riparian land use, hydrology, and stream bank erosion. Because this study lacked ungrazed controls, it was not possible to isolate the role of grazing of any stocking level on stream bank erosion. Chapter 2 of this dissertation describes a companion study relating stream bank erosion and stocking rates that includes sites used in this study as well as ungrazed controls.

### **Stream bank erosion rates**

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 (Fig. 4). While the differences in erosion rates between the winter/spring and both summer and fall seasons were large, the trends of erosion rates were similar between winter/spring and summer, and between winter/spring and fall (Fig. 5). These relationship suggest that the erosion-causing factors across all six sites are similar, but their magnitudes of impact are different among the seasons due to changes in bank soil-water content and stream flow characteristics (or stage), variables which are potentially affected by grazing management.

These results also suggest that the relationship between bank erosion and stream stage for the summer and fall seasons should be similar to the relationships for the winter/spring seasons, for which data were not available.

### **Stream stage data**

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 ( $p = 0.09$ ;  $R^2 = 0.73$ ), flooding 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 24 and the corresponding erosion rate was 1 cm (Table 2). There was a highly correlated relationship between total stream stage occupancies and erosion rates across the seasons (Fig. 6a & 6b). In site 2, total high stream stage occupancy was 63 and the corresponding erosion rate was 3 cm (Table 2). This relationship between total stream stage occupancy and erosion rates was also highly correlated too (Fig. 7a & 7b). Site 3 had the highest number of total stages of all sites (101), which was highly correlated to the observed erosion rate (4 cm; Table 2, Fig. 8a & 8b). 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 (Table 2, Fig. 9a & 9b). 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 (Table 2). Site 5 (Fig. 10a & 10b) had lower correlation between total stream stage and erosion rates than site 6 (Fig. 11a & 11b). 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 sites in the influence of stream morphologic characteristics such as stream bed and bank slope and height, sinuosity and stream order. 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 location. When looking at different sites from different watersheds, there were changes in stream morphologic characteristics, 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.

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: 2008b). 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 et 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. 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 and resulting 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**

- Bartley, R., J. Olley, and A. Henderson. 2004. A sediment budget for the Herbert River catchment, North Queensland, Australia. *International Association of Hydrological Sciences* 288:147-154.
- Bormann, H., B. Dieckruger, 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.

- Burkart, M. R., S. L. Oberle, M. J. Hewitt, and J. Pickus. 1994. A frame work for regional agroecosystems characterization using the national resource inventory. *Journal of Environmental Quality* 23: 866-874.
- Braster, M., T. Jacobson, and V. Sitzmann. 2001. Assessment and Management Strategies for the Rathbun Lake Watershed.  
[www.rlwa.org/Documents/Rathbun%20Lake%20Watershed%20Assessment.pdf](http://www.rlwa.org/Documents/Rathbun%20Lake%20Watershed%20Assessment.pdf).
- Carleton, A. M., D. J. Travis, J. O. Adegoke, D. L. Arnold and S. Curran. 2008. Synoptic circulation and land surface influences on convection in the Midwest U.S. “Corn Belt” during the summer of 1999 and 2000. Part II: Role of vegetation boundaries. *J. Climate* 21, 3617-3641.
- 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.
- Gebert, W. A. and W. R. Krug. 1996. Streamflow trends in Wisconsin’s driftless area. *Water Resource Bulletin* 32 (4): 733-744.
- Guo, H., Q. Hu and T. Jiang. 2008. Annual and seasonal streamflow responses to climate and land cover changes in the Poyang Lake basin, China. *Journal of Hydrology* 355, 106-122.
- Haigh, M. J. 1977. The use of erosion pins in the study of slope evolution. *British Geomorphologic Research Group, Technical Bulletin* 18:31-49.
- Hupp, C. R. 1992. Riparian vegetation recovery patterns following stream channelization: A geomorphic perspective. *Ecology* 73: 1209-1226.
- 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>. Access on 04/25/2010.
- Kalra, A., T. C. Piechota, R. Davies and G. A. Tootle. 2008. Changes in U.S. streamflow and Western U.S. snowpack. *Journal of Hydrologic Engineering* 13 (3), 156-163.

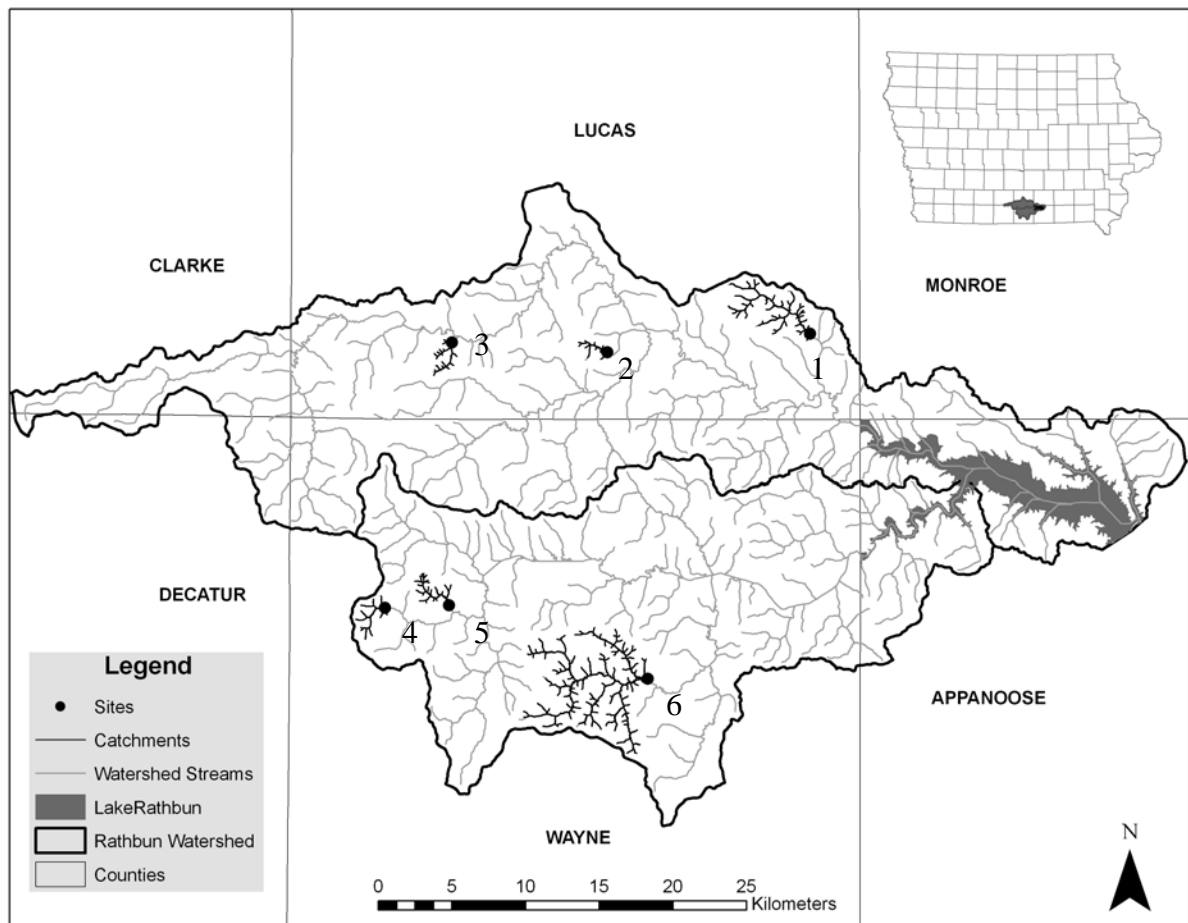
- Karwan, D. L., J. D. Allan, and K. M. Bergen. 2001. Changing near-stream land use and river channel morphology in the Venezuelan andes. *Journal of the American Water Resources Association* 37 (6) 1579-1587.
- Knox, J. C. 2001. Agricultural influences on landscape sensitivity in the Upper Mississippi River Valley. *Catena* 42, 193-224.
- Kroes, D. E. and C. R. Hupp. 2010. The effect of channelization on floodplain sediment deposition and subsidence along the Pocomoke river, Maryland. *Journal of the American Water Resources Association*. 1-14. DOI: 10.1111/j.1752-1688.2010.00440.x
- Larsen, E. W., A. K. Fremier and S. E. Greco. 2006a. Cumulative effective stream power and bank erosion on the Sacramento River, California, USA. *Journal of the American Water Resources Association* 42 (4): 1077-1097.
- Laubel, A., B. Kronvang, A. B. Hald and C. Jensen. 2003. Hydromorphological and biological factors influencing sediment and phosphorus loss via bank erosion in small lowland rural streams in Denmark. *Wiley Interscience. Hydrological Processes* 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, Surface Processes and Landforms* 18 (9): 777-821.
- Lins, H. F., and J. R. Slack. 1999. Streamflow trends in the United States, *Geophysical Research Letters* 26 (2) 227-230.
- Menzel, B. W. 1983. Agricultural management practices and the integrity of instream biological habitat. 305-329. In: Schaller F.W. and Bailey G.W. (eds), *Agricultural Management and Water Quality*. Iowa State University Press, Ames, Iowa.
- Nanson, G. C. and E. J. Hickin. 1986. A statistical analysis of bank erosion and channel migration in Western Canada. *Geological Society of American Bulletin* 97: 497-504.

- Novotny, E. V. and H. G. Stefan. 2007. Stream flow in Minnesota: Indicator of climate change. *Journal of Hydrology* 334, 319-333.
- Prior, J. C. 1991. Landforms of Iowa. Iowa Department of Natural Resources University of Iowa Press, Iowa City, Iowa.
- Raymond, P. A., N-H. Oh, R. E. Turner and W. Broussard. 2008. Anthropogenically enhanced fluxes of water and carbon from the Mississippi River. *Nature* 451, doi:10.1038/nature06505.
- Roseboom, D. P. 1987. Case studies of stream and river restoration. In: Korab, H. Management of the Illinois River system, the 1990's and beyond: Proceedings of a Governor's conference on April 1-3, 1987 at Peoria, Illinois for citizens, organizations, industry, and government representatives and resources management professionals. Water Resources Center, University of Illinois. Urbana, Illinois 184-194.
- SAS (Statistical Analysis System) Institute. 2003. SAS Release 9.1 ed. SAS Inst., Cary, North Carolina.
- Schilling, K. E., M. K. Jha, Y-K. Zhang, P. W. Gassman and C. F. Wolter. 2009. Impact of land use and land cover change on the water balance of a large agricultural watershed: Historical effects and future directions. *Water Resources Research* 45 (7): 1-12.
- Schilling, K. E and C. F. Wolter. 2000. Applications of GPS and GIS to map channel features in Walnut Creek, Iowa. *Journal of American Water Resources Association* 36:1423-1434
- Schilling, K. E. 2004. Relation of baseflow to row crop intensity in Iowa. *Agricultural Ecosystem Environment* 105, 433-438.
- Schilling, K. E., K-S. Chan, H. Liu and Y-K. Zhang. 2010. Quantifying the effect of land use land cover change on increasing discharge in the Upper Mississippi River. *Journal of Hydrology*, doi: 10.1016/j.jhydrol.2010.04.019.
- Schilling, K.E., and R.D. Libra. 2003. Increased baseflow in Iowa over the second half of the 20th century. *J. American Water Resources Association* 39:851–860.

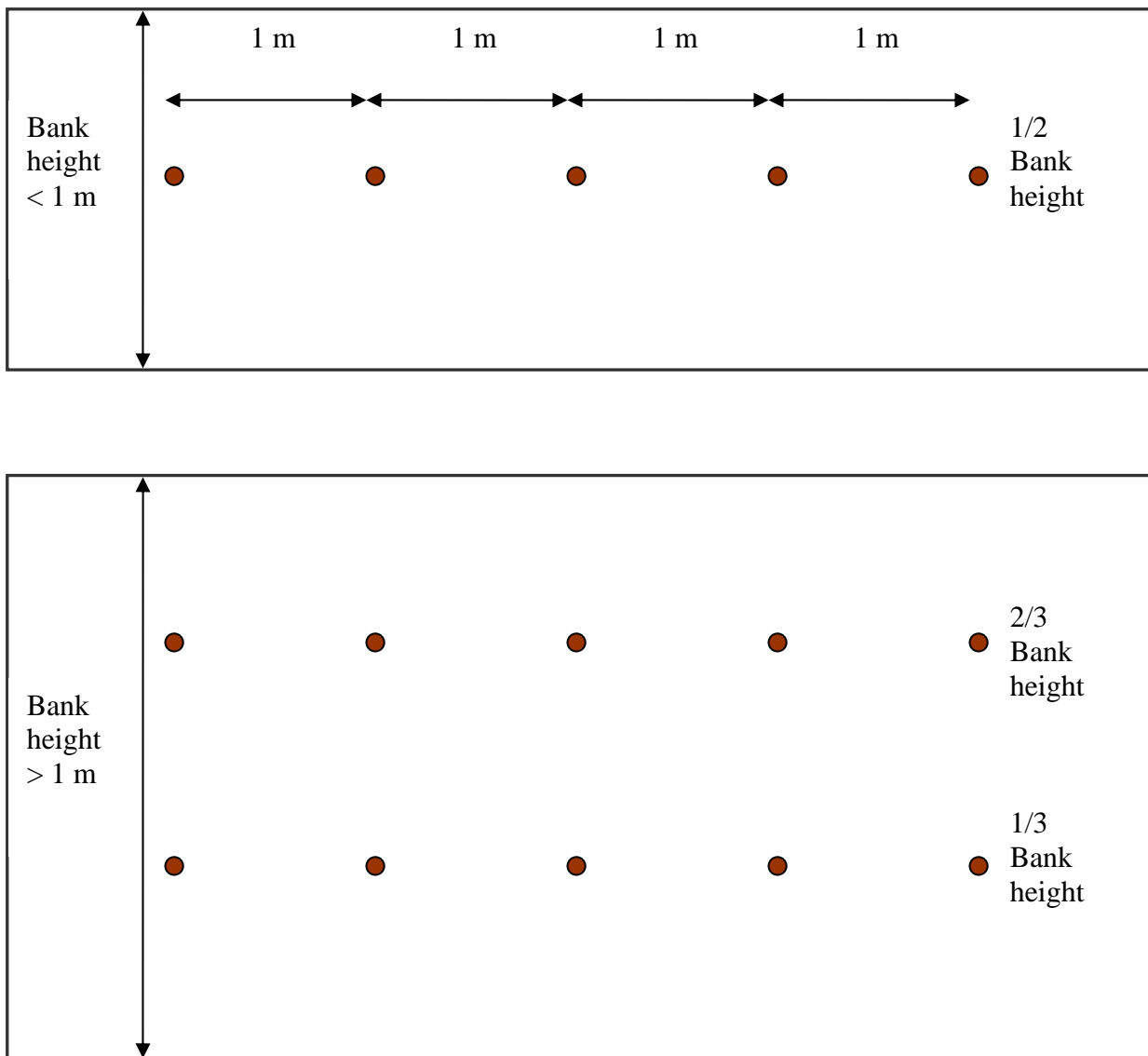


- Schultz, R. C., T. M. Isenhardt, W. W. Simpkins, and J. P. Colleti. 2004. Riparian forest buffers in agroecosystems- lessons learned from the Bear Creek Watershed, central Iowa, USA. *Agroforestry Systems* 61: 35-50.
- Schultz, R. C., T. M. Isenhardt, J. P. Colletti, W. W. Simpkins, R. P. Udawatta, and 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.
- Sekely, A. C., D. J. Mulla, and D.W. Bauer. 2002. Streambank slumping and its contribution to the phosphorus and suspended sediment loads of the Blue Earth River, Minnesota. *Journal of Soil and Water Conservation* 57:243-250.
- Simon, A and Collison, A.J.C. 2002. Quantifying the Mechanical and Hydrologic Effects of Riparian Vegetation on Streambank Stability. *Earth Surface Process and Landforms* 27:527-546.
- Strahler A. N. 1957. Quantitative analysis of watershed geomorphology. *Am Geophysical Union Trans* 38:913-920.
- Straub, T. D. 2004. St. Louis metro east region sediment and geomorphic study. *Proceedings of the 2004 World Water and Environmental Resources Congress: Critical Transitions in Water and Environmental Resources Management* p 4463-4474.
- Tomer, M. D. and K. E. Schilling. 2009. A simple approach to distinguish land-use and climate-change effects on watershed hydrology. *Journal of Hydrology* 376, 24-33.
- United State Department of Agriculture. Soil Conservation Service. Soil Survey. Wayne County, Iowa 1971.
- Wallbrink, P and Jon Olley. 2004. Sources of fine grained sediment in incised and un-incised channels, Jugiong Creek, NSW, Australia. *International Association of Hydrological Sciences* 288, 165-169.
- Whitney, G. G., 1994. *From coastal wilderness to fruited plain*. Cambridge University Press, Cambridge, United Kingdom.

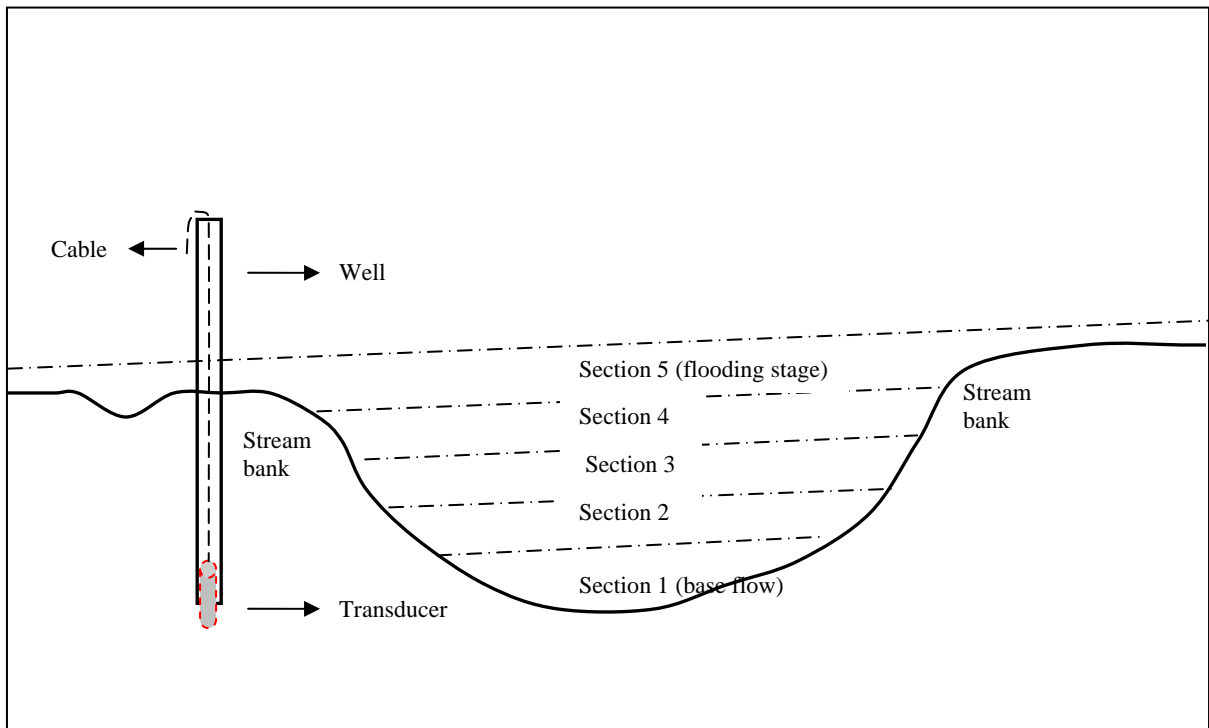
- Wolman, M. G. 1959. Factors influencing erosion of a cohesive river bank. *American Journal of Science* 257: 204-216.
- Zaimes, G. N., R. C. Schultz and T. M. Isenhardt. 2006. Riparian land-uses and precipitation influences on stream bank erosion in central Iowa. *Journal of American Water Resources Association* 42: 83-97.
- Zaimes, G. N., R. C. Schultz, and T. M. Isenhardt. 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., R. C. Schultz, and T. M. Isenhardt. 2008b. Stream bank soil and phosphorus losses under different riparian land-uses in Iowa. *Journal of the American Water Resources Association*. 44 (4): 935-947.
- Zhang, Y. K. and K. E. Schilling. 2006. Increasing streamflow and baseflow in Mississippi River since the 1940s: Effect of land use change. *Journal of Hydrology* 324, 412-422.



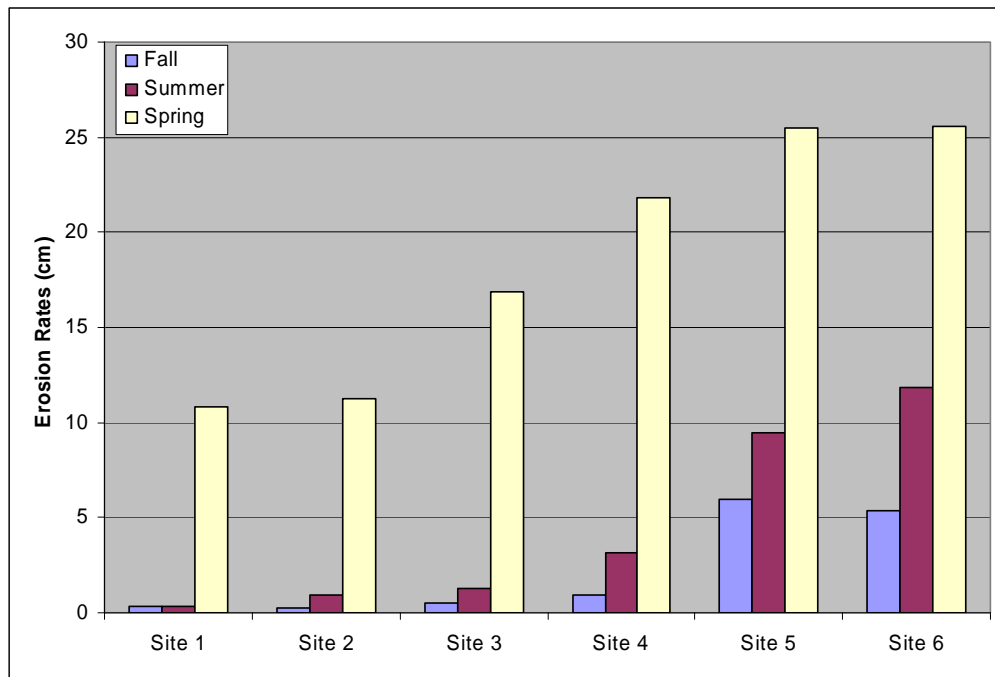
**Figure 1.** Stream stage (transducer) locations/sites and catchments stream lengths within the Rathbun Watershed in Southern Iowa. Numbers correspond to site identification (Id). Site 1 is located on the second order stream. Site 6 is in third order stream and all the other sites (2, 3, 4 and 5) are in first order stream category (Strahler, 1957).



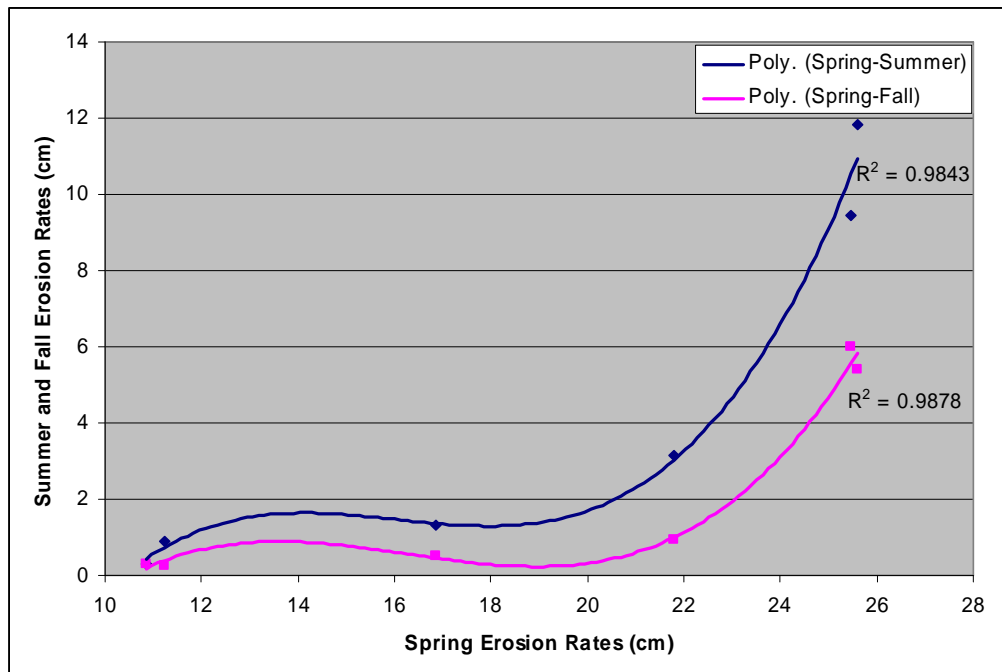
**Figure 2.** Schematic of steel pin placement and spacing on eroding stream banks.



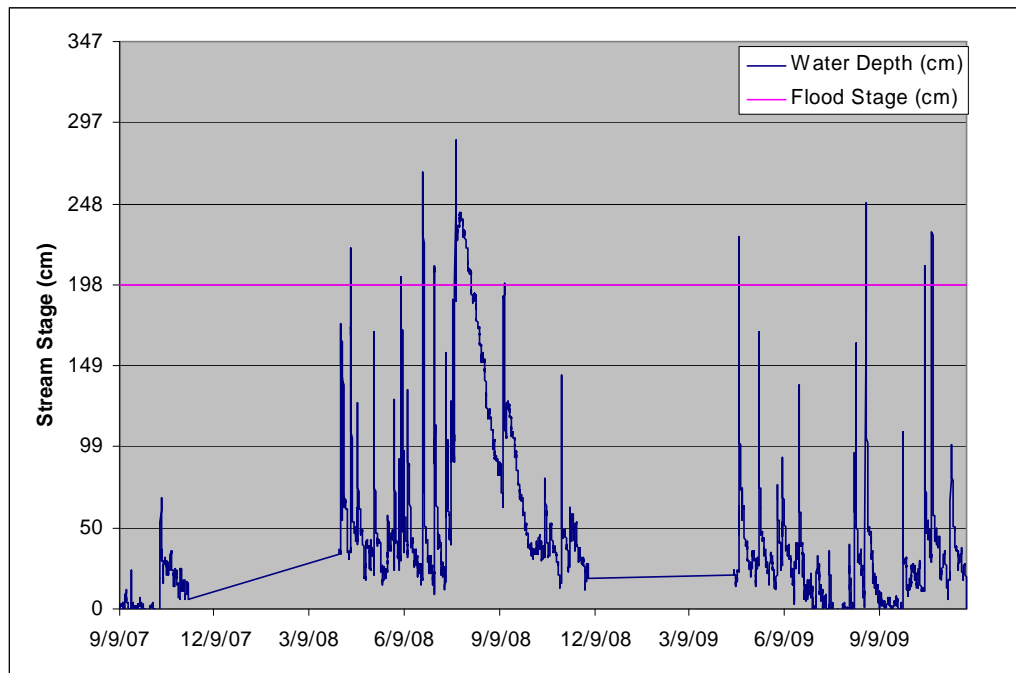
**Figure 3.** Location of the transducer on stream bank and five different preset stream stage sections and their predicted erosion response values (section 1= 0, section 2= 1, section 3 = 1, section 4= 1 and section 5= 1). The assigned/predicted erosion values for each section were based on the assumption 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.



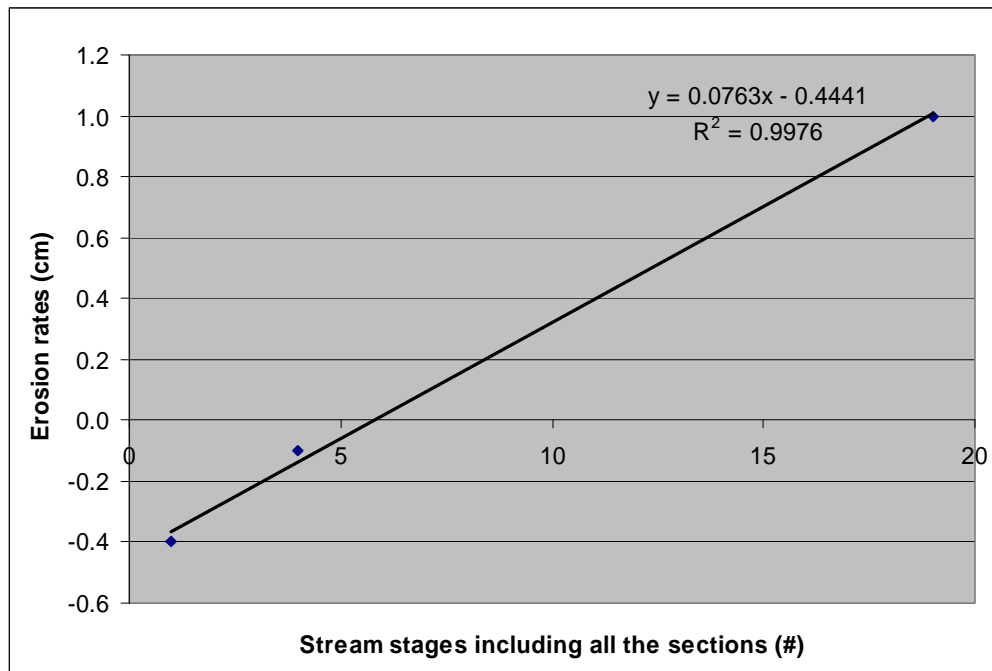
**Figure 4.** Seasonal differences in average stream bank erosion from six different sites during the period of fall 2007 – fall 2009.



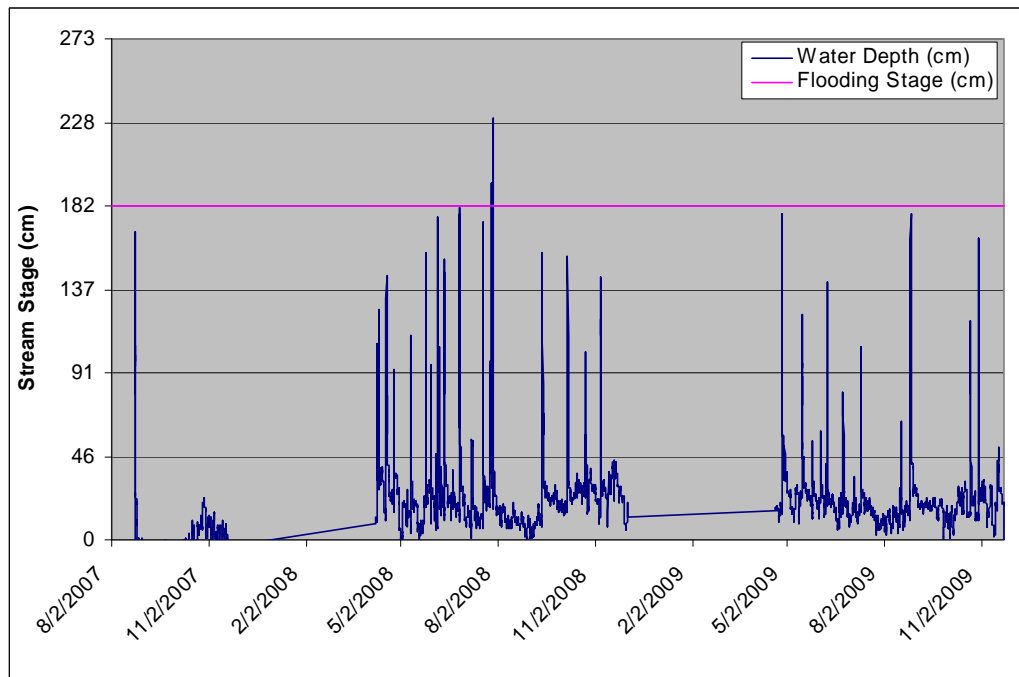
**Figure 5.** Relationship between erosion rates of spring and summer, and between spring and fall.



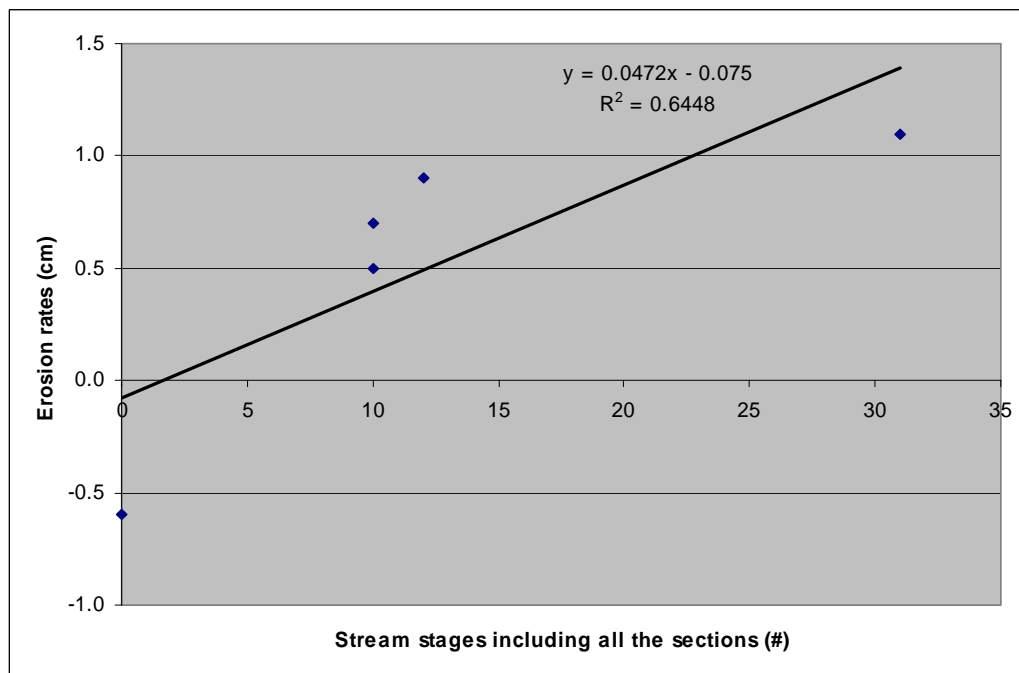
**Figure 6a.** Total stream stage by event based that were occupied from August 9, 2007 to November 24, 2009 and 5 different stage sections, including section 1 (0 to 50 cm), section 2 (51 to 99 cm), section 3 (100 to 149 cm), section 4 (150 to 198 cm) and section 5 (199 to 248 cm) from study site 1. Note; parallel stage lines in section 1 shows the winter time range when there was no transducer in the wells. Stream stage values were represented in Table 2.



**Figure 6b.** Relationship between total stream stage (occupancy of section 2 through section 5 in number of times) and erosion rates across seasons (summers and falls) from study site 1.

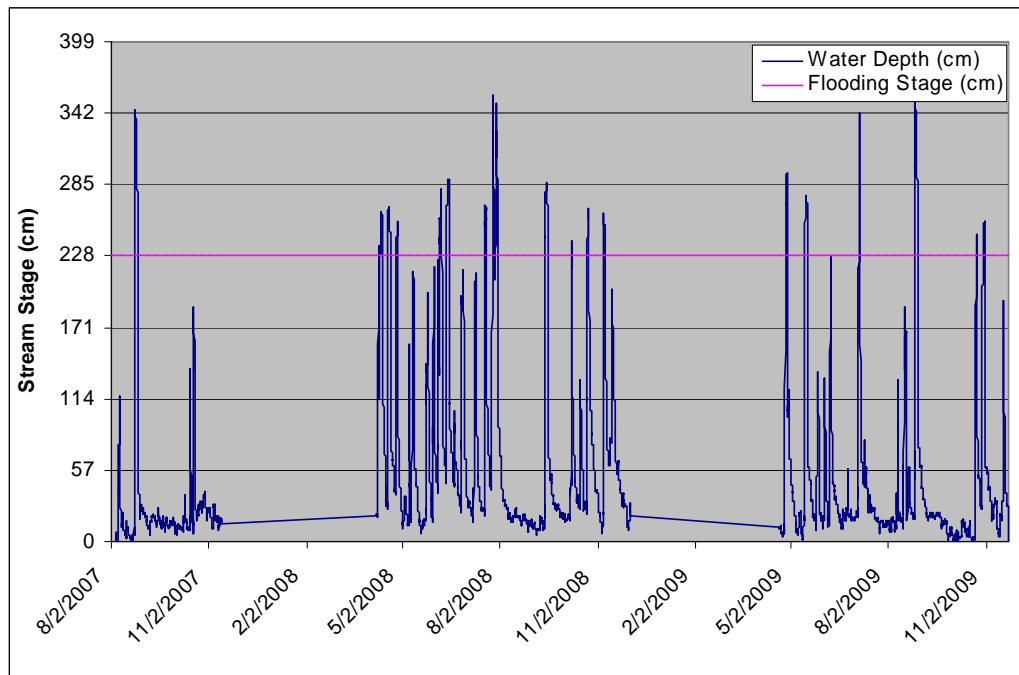


**Figure 7a.** Total stream stage by event based that were occupied from August 2, 2007 to November 2, 2009 and 5 different stage sections, including section 1 (0 to 46 cm), section 2 (47 to 91 cm), section 3 (92 to 137 cm), section 4 (138 to 182 cm) and section 5 (183 to 228 cm) from study site 2.

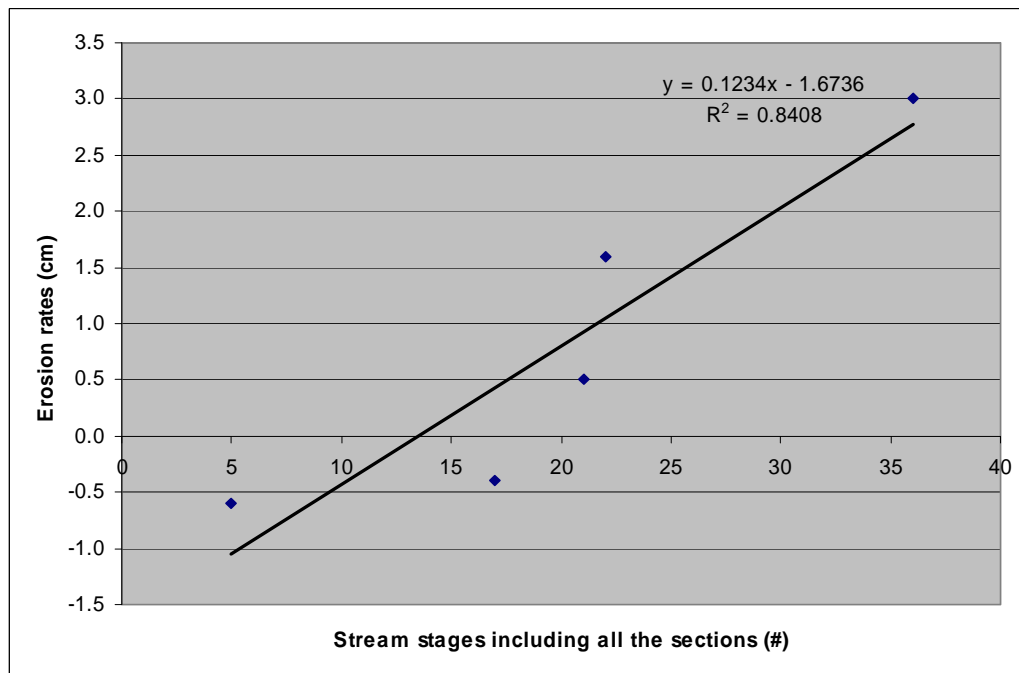


**Figure 7b.** Relationship between total stream stage (occupancy of section 2 through section 5 in numbers of time) and responded erosion rates across seasons (summers and falls) from study site 2.

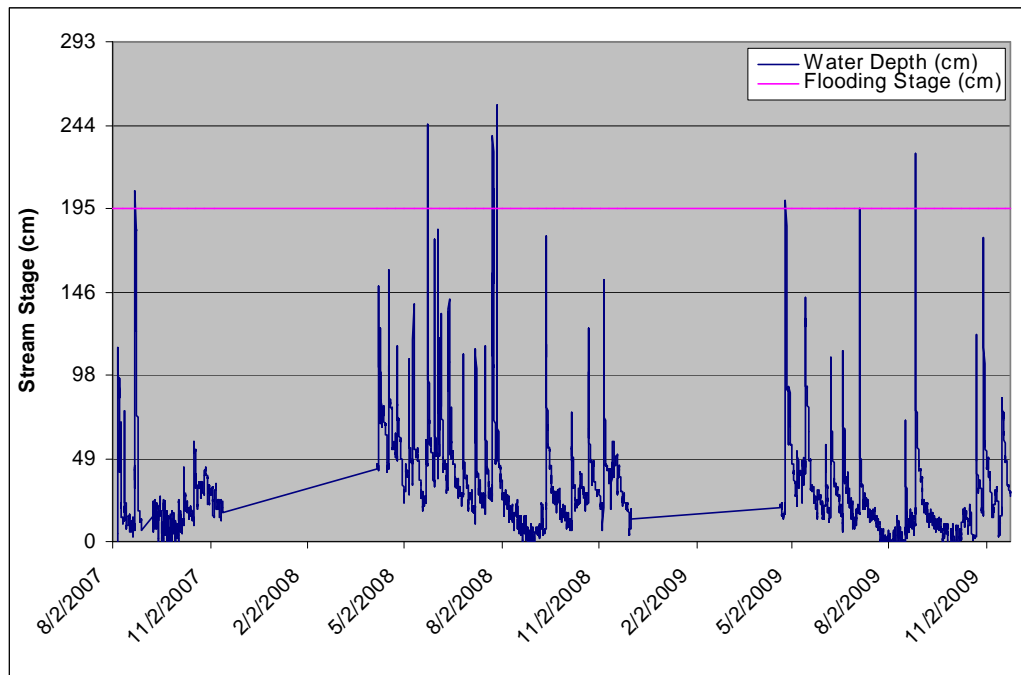




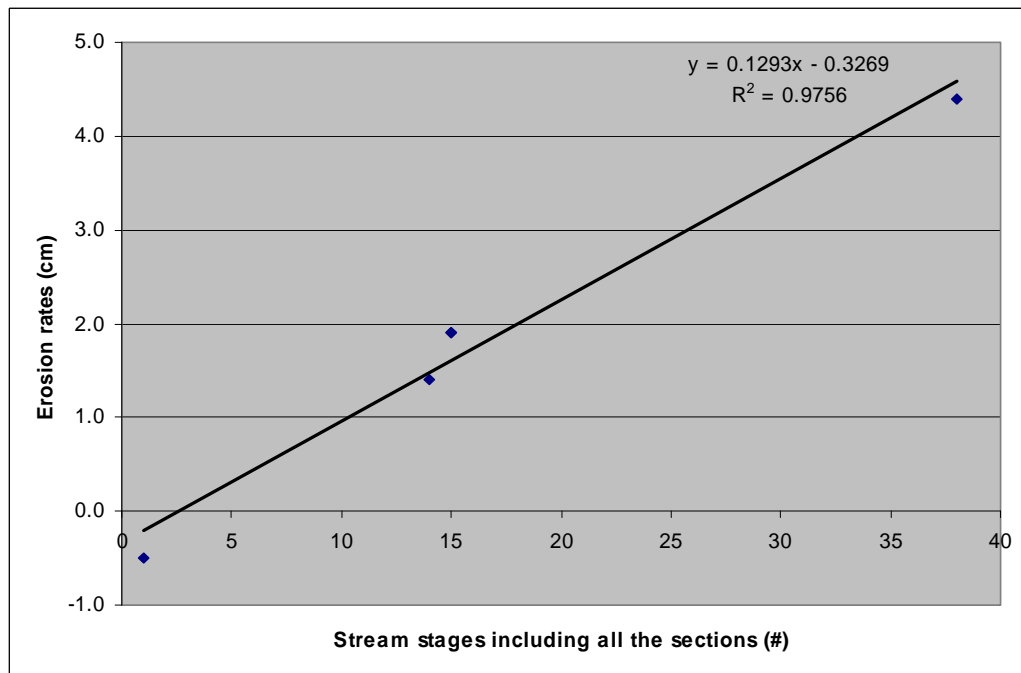
**Figure 8a.** Total stream stage by event based that were occupied from August 2, 2007 to November 2, 2009 and 5 different stage sections, including section 1 (0 to 57 cm), section 2 (58 to 114 cm), section 3 (115 to 171 cm), section 4 (172 to 228 cm) and section 5 (229 to 285 cm) from study site 3.



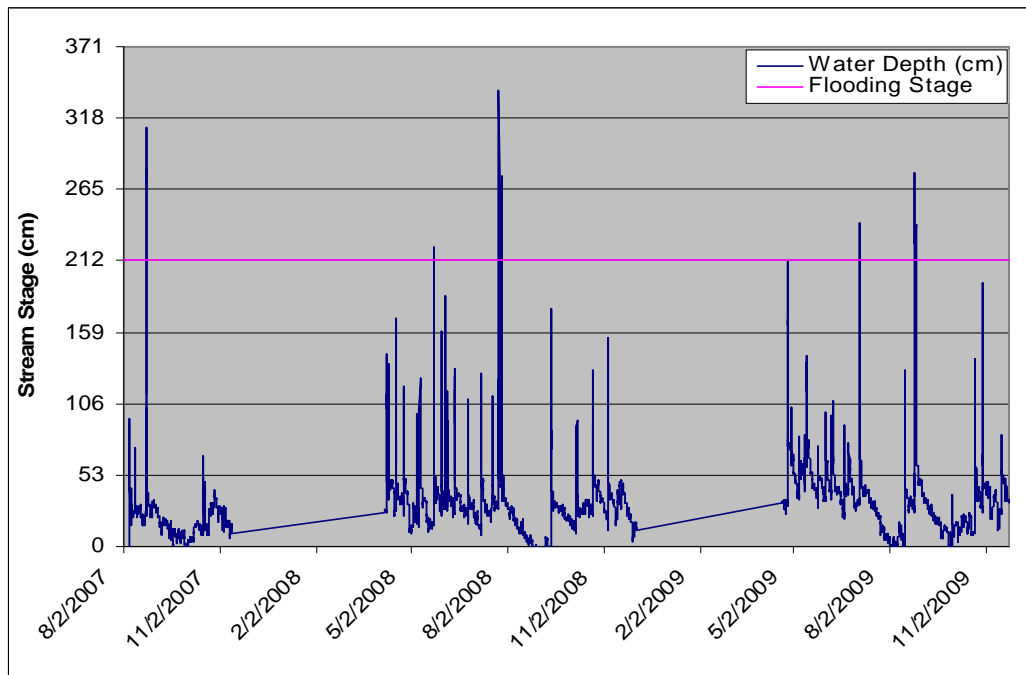
**Figure 8b.** Relationship between total stream stage (occupancy of section 2 through section 5 in number of times) and responded erosion rates across seasons (summers and falls) from study site 3.



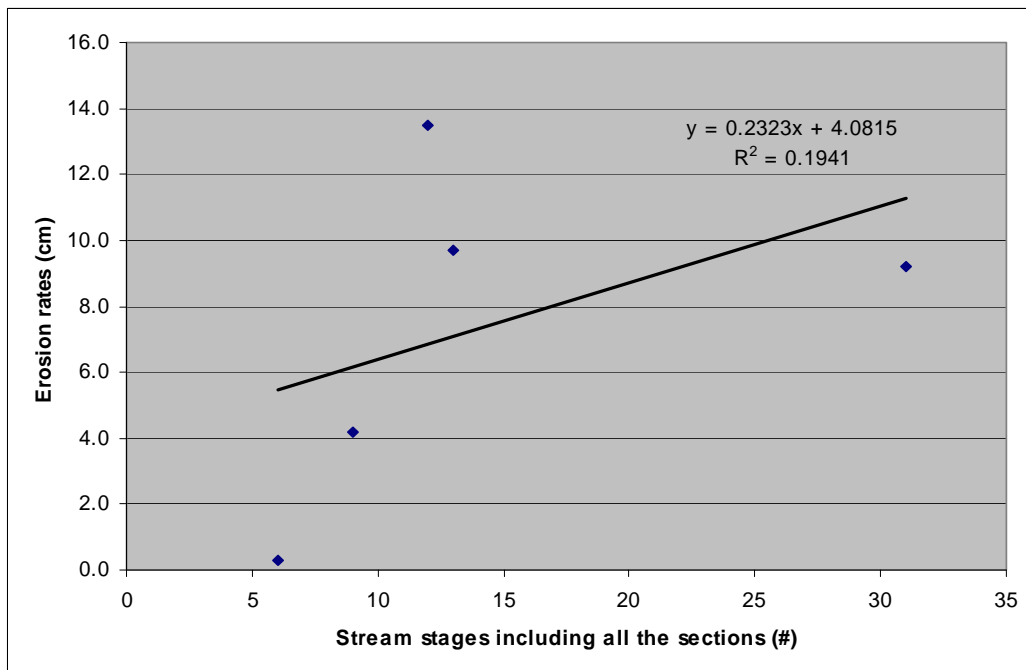
**Figure 9a.** Total stream stage by event based that were occupied from August 2, 2007 to November 2, 2009 and 5 different stage sections, including section 1 (0 to 49 cm), section 2 (50 to 98 cm), section 3 (99 to 146 cm), section 4 (147 to 195 cm) and section 5 (196 to 244 cm) from study site 4.



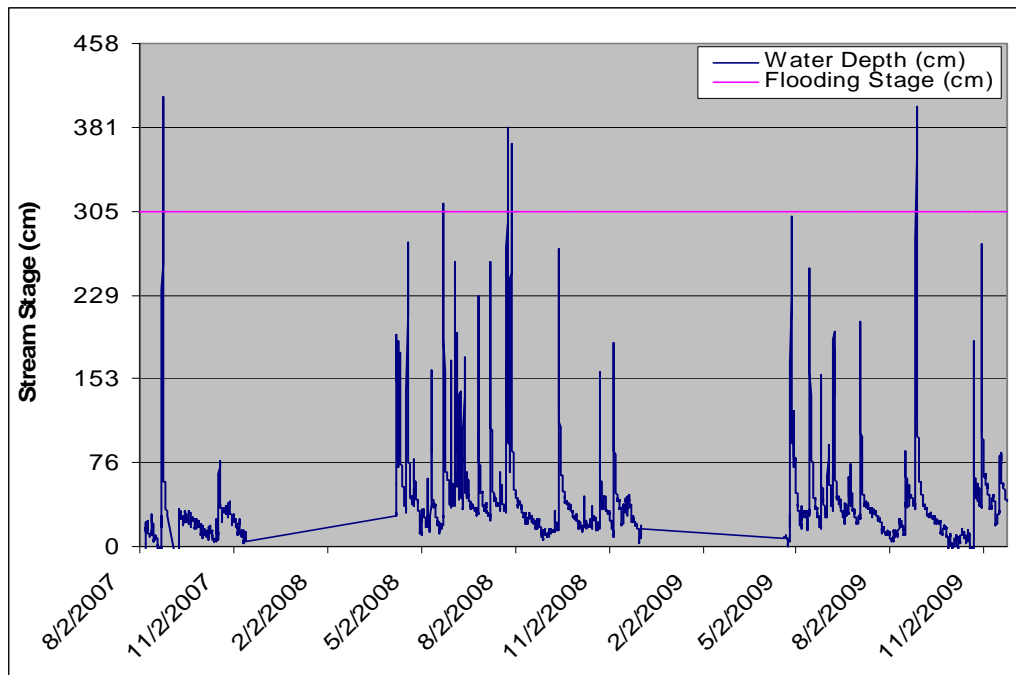
**Figure 9b.** Relationship between total stream stage (occupancy of section 2 through section 5 in number of times) and responded erosion rates across seasons (summers and falls) from study site 4.



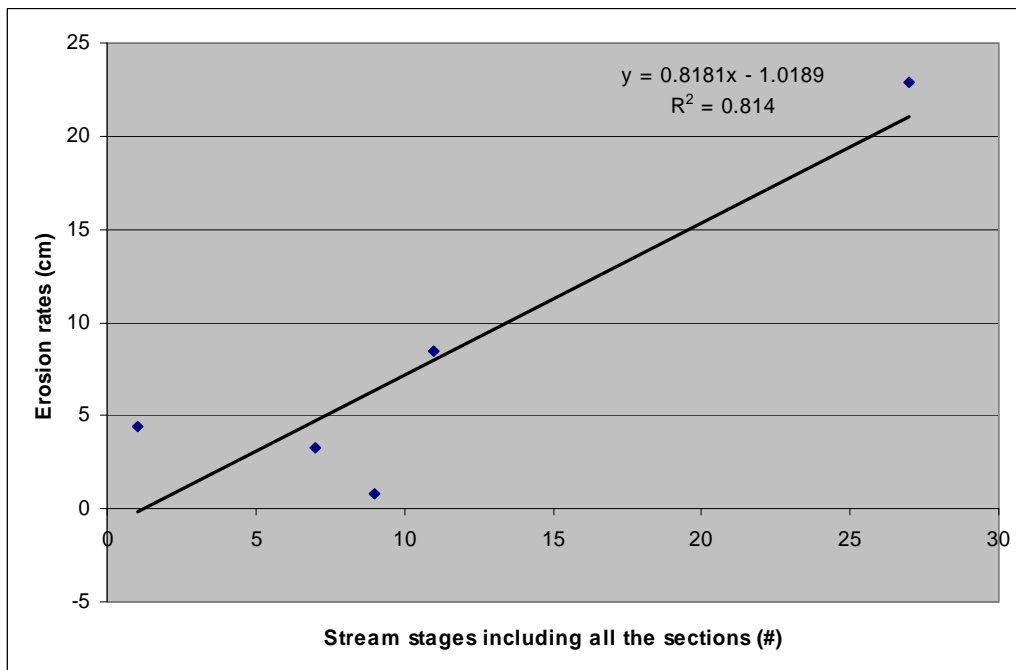
**Figure 10a.** Total stream stage by event based that were occupied from August 2, 2007 to November 2, 2009 and 5 different stage sections, including section 1 (0 to 53 cm), section 2 (54 to 106 cm), section 3 (107 to 159 cm), section 4 (160 to 212 cm) and section 5 (213 to 265 cm) from study site 5.



**Figure 10b.** Relationship between total stream stage (occupancy of section 2 through section 5 in numbers of time) and responded erosion rates across seasons (summers and falls) from study site 5.



**Figure 11a.** Total stream stage by event based that were occupied from August 2, 2007 to November 2, 2009 and 5 different stage sections, including section 1 (0 to 76 cm), section 2 (77 to 153 cm), section 3 (154 to 229 cm), section 4 (230 to 305 cm) and section 5 (306 to 381 cm) from study site 6.



**Figure 11b.** Relationship between total stream stage (occupancy of section 2 through section 5 in number of times) and responded erosion rates across seasons (summers and falls) from study site 6.

**Table 1.** Studied pasture stream reach (site) characteristics including stream length, stocking rates, stream reach bed slope, stream bed sinuosity, pasture size and total erosion rates.

Site Id	Stream length (m)	Stocking rates (Cow-days/m yr)	Stream bed slope (%)	Stream sinuosity	Pasture size (ha)	Total erosion rates (cm)
Site 1	1138	12	0.4	1.5	55	1
Site 2	1120	14	0.8	1.4	29	3
Site 3	1040	9	0.6	2.0	107	4
Site 4	890	19	1.6	1.1	25	9
Site 5	306	8	1.6	1.3	3	37
Site 6	922	3	1.5	1.2	29	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.

**Table 2.** Event based numbers of time stage (section) occupancy by seasons of the year 2007, 2008 and 2009, and erosion rates by seasons and seasonal total.

Site Id	Stage section's depth ranges (cm) & Erosions (cm)	Fall 2007	Summer 2008	Fall 2008	Summer 2009	Fall 2009	All the seasons (Total)
Site 1	Section 2 (51-99)	1	12	9	3	7	11
Site 1	Section 3 (100-149)	0	12	4	1	5	6
Site 1	Section 4 (150-198)	0	8	3	0	4	4
Site 1	Section 5 (199-248)	0	5	0	0	3	3
Site 1	Section's total	1	37	16	4	19	24
Site 1	Erosion	-0.4	missing	missing	-0.1	1.0	1
Site 2	Section 2 (47-91)	0	12	5	6	5	28
Site 2	Section 3 (92-137)	0	10	4	3	3	20
Site 2	Section 4 (138-182)	0	7	3	1	2	13
Site 2	Section 5 (183-228)	0	2	0	0	0	2
Site 2	Section's total	0	31	12	10	10	63
Site 2	Erosion	-0.6	1.1	0.9	0.7	0.5	3
Site 3	Section 2 (58-114)	2	11	6	7	7	33
Site 3	Section 3 (115-171)	2	10	6	5	6	29
Site 3	Section 4 (172-228)	1	10	5	3	5	24
Site 3	Section 5 (229-285)	0	5	5	2	3	15
Site 3	Section's total	5	36	22	17	21	101
Site 3	Erosion	-0.6	3.0	1.6	-0.4	0.5	4
Site 4	Section 2 (50-98)	1	18	9	9	8	45
Site 4	Section 3 (99-146)	0	12	4	4	3	23
Site 4	Section 4 (147-195)	0	5	2	1	2	10
Site 4	Section 5 (196-244)	0	3	0	1	1	5
Site 4	Section's total	1	38	15	15	14	83
Site 4	Erosion	-0.5	4.4	1.9	1.9	1.4	9
Site 5	Section 2 (54-106)	3	14	5	8	5	35
Site 5	Section 3 (107-159)	1	11	3	3	4	22
Site 5	Section 4 (160-212)	1	4	1	1	2	9
Site 5	Section 5 (213-265)	1	2	0	1	1	5
Site 5	Section's total	6	31	9	13	12	71
Site 5	Erosion	0.3	9.2	4.2	9.7	13.5	37
Site 6	Section 2 (77-153)	1	10	3	5	5	24
Site 6	Section 3 (154-229)	0	9	3	3	3	18
Site 6	Section 4 (230-305)	0	5	1	1	2	9
Site 6	Section 5 (306-381)	0	3	0	0	1	4
Site 6	Section's total	1	27	7	9	11	55
Site 6	Erosion	4.4	22.9	3.3	0.8	8.5	40

Note: Missing erosion values are due to flooding events during summer and fall 2008. Also, numbers that are inside the parenthesis represent the stage section depth range from the stream beds.

## **CHAPTER 4**

### **STREAM MORPHOLOGY, RIPARIAN LAND-USE AND STREAM BANK EROSION WITHIN GRAZED PASTURES IN THE RATHBUN WATERSHED IN SOUTHERN IOWA: A CATCHMENT-WIDE PERSPECTIVE**

#### **Abstract**

Factors influencing stream bank erosion at the field scale include watershed land-use, stream morphology, and riparian management practices such as cropping and grazing. This study assesses the relationship of riparian land-use, stream morphologic characteristics (bank soil texture, stream bed slope and sinuosity), and catchment scale variables to stream bank erosion within grazed riparian pastures in the Southern Iowa Drift Plain. Thirteen cooperating beef cow-calf farms and their catchments in the Rathbun Lake watershed in South Central Iowa were chosen to conduct this study. Stream bank erosion rates were determined during three years using the erosion pin method. Results suggest that the integration of stream morphologic characteristics and riparian land-uses at both the field and catchment scale are necessary to explain the current level of stream bank erosion and possibly for predicting a time-line for the channel to reach channel equilibrium according to the “channel evolution model”. Larger catchment size or catchments with more total channel length were found to experience more bank erosion due to greater magnitude of discharge and taller saturated banks associated with larger and more incised channels. A significant positive relationship between percent sand in the bank soil and bank erosion rates infers that bank soils with less cohesiveness are more erodible. Catchment-scale assessments of the thirteen watersheds showed that within the 50 m corridor on both sides of the stream, 46 to

61 % of riparian area was devoted to agricultural use and only 6 to 11 % was in ungrazed perennial vegetation, much of it enrolled in the Conservation Reserve Program. Overall, intensive agricultural use of riparian areas in such extent of time and scale could be directly and/or indirectly related to excessive amounts of stream bank soil loss to stream and lake leading to their impairment and reduction of ecological services.

### **Introduction**

A river's ability to erode and transport materials has been shown to be "a balance between driving and resisting forces (Ritter et al. 2002). Driving force is directly related to the potential energy produced by the flow/discharge characteristics of a given stream cross-section. The driving force in Iowa streams has increased as a result of an increase in precipitation and the impact on surface runoff resulting from the conversion of 99% of Iowa's tall grass prairie and 95% of its wetlands to row crop and grazed pasture agriculture (Whitney, 1994; Burkart et al. 1994). In addition, some streams were also channelized to increase arable land area for more agricultural production (Guthrie, 2000). The resulting higher stream gradients and discharge has increased channel incision (Hupp, 1992) and the ability of streams to carry larger loads of sediment and nutrients throughout many parts of the Mississippi basin (Anderson 2000; Knox, 2001; Schilling 2004). Since stream discharge and gradient are proportional to sediment load and particle size (Lane, 1955), an increase in discharge and/or slope (driving force) must be balanced with an increase in sediment yield and/or sediment size (resisting forces). In other words, any increase in discharge characteristics of an unstable stream channel must be followed with a morphological adjustment to dissipate the increased hydro-energy to create a new "state of equilibrium". The morphological adjustment first starts with incision followed by widening and then



aggradation, finally re-creating bank heights that are less than the critical height for instability and failure (Simon and Klimetz, 2008). Over the long term, the change in the cross-sectional profile initiated by channel incision translates into a change in the longitudinal view as continued adjustments in the channel advance into the upper watershed (Simon and Rinaldi, 2006). Stream sinuosity is increased through meandering at the lower gradient downstream end of the channel network to reduce flow velocity in an effort to establish an equilibrium state from the modified upstream portion of the channel system. Such adjustments could take many decades to complete (Yan et al., 2010).

The impact of local riparian land-use factors such as grazing intensity on stream bank erosion and/or cross-sectional channel modification has not been well established. This is partially due to the many interacting factors such as bank soil properties (cohesion of the channel bank soil or major textural unit), stream flow characteristics, and channel morphology (stream bed slope and sinuosity), all of which can play crucial roles in the adjustment of bank physiography (Simon and Rinaldi, 2006). However, some studies have concluded that riparian cattle grazing can initiate the first step towards greater eroded bank area and consequent destabilization (Trimble, 1994; Evans et al. 2006; Magner et al. 2008), and that grazing can be considered as a geomorphic agent (Trimble, 1994). Indeed, a three-year study by Zaimes et al. (2008b) recorded greater stream bank erosion rates from grazed pastures (continuous, rotational, and intensive rotational) than from riparian forest buffers and grass filters.

In a riparian grazing system, the improvement in stream water quality will most likely be achieved with a set of integrated best management practices (BMPs) that are linked with stream geomorphic and hydrologic characteristics (Agouridis et al. 2005). Additional

resistance to stream flow can be introduced with a continuous cover of ground vegetation on the stream banks. This riparian vegetation can increase bank stability and soil strength by mechanical reinforcement of the soil as a result of soil-root binding and from the hydrological effects of soil moisture extraction by transpiration, which leads to a reduction in soil pore-water pressure (Simon and Collison, 2002). While herbaceous vegetation can effectively reduce the erosive effect of overland flow, woody vegetation has been observed to be more effective in reducing high stream bank erosion rates (Harmel et al. 1999; Geyer et al. 2000; Zaimes et al. 2004, 2006) and in promoting channel stabilization (Dosskey et al. 2010). A recent study by Knight et al. (2010) suggests that the addition of a grass zone to the outside of a riparian forest buffer would reduce sediment loss resulting from ephemeral gullies and increase stream water quality. Another study by De Baets et al. (2008) concluded that grass vegetation increased soil strength in the topsoil (0-10 cm) whereas shrubs increased soil strength in the subsoil (0-50 cm). Other BMPs, such as timing of cattle grazing, non-riparian shade, alternative water sources, and livestock exclusion with fencing, have been shown to effectively increase stream bank stabilization (McInnis and McIver, 2009; Ranganath et al. 2009) and stream water integrity (Williamson et al. 1996; Line et al. 2000; Byers et al. 2005; Miller et al. 2010).

The purpose of this study was to assess the effect of riparian land use and stream morphologic characteristics including stream bank soil particle size, and stream bed slope and sinuosity at the field and catchment scale, on stream bank erosion measured in grazed riparian stream reaches.

## **Materials and Methods**

### **Study sites and treatments**

Thirteen cooperating beef cow-calf farms along stream reaches in the Rathbun Lake watershed located on the Southern Iowa Drift Plain were chosen to conduct the study (Fig. 1). The Southern Iowa Drift Plain is dominated by many rills, gullies, creeks, stepped erosion surfaces, integrated drainage networks, 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. Land use in the 143,323 ha Rathbun Watershed consists of 38% pasture and hayland, 30% crop land, 12% CRP, 13% woodland and 7% urban/road/water (Braster et al. 2001). Riparian grazing treatments on the thirteen farms were classified by stocking rates that ranged from 0 to 28 cow-days  $m^{-1}$  yr. More detailed results regarding stocking rates, and pasture characterization and its effect on bank erosion were provided in the first chapter of this dissertation. In this chapter, we will specifically focus on the effect of riparian land use and land cover (LULC) and stream morphologic features at both the field and catchment scales, on stream bank erosion.

### **Scope of the work**

Studies have shown that well-justified decisions regarding stream water quality and morphology can only be made if multi-scale processes (plot, field, and watershed) are accounted for in an integrated way. In this study it was decided to monitor a number of soil and stream morphologic characteristics at the treatment pasture sites (stations) where erosion pins were installed and measured. These characteristics were stream bank soil texture, stream bed slope and sinuosity. Since stream bank erosion is directly related to stream hydrology, any factor that contributes to a change in stream stage should also be monitored in order to document a change in stream bank erosion. As a result we also measured stream characteristics at the catchment scale, which can contribute to an overall change in stream

stage at the treatment pasture sites. These characteristics at the catchment scale (whole channel system) included current land-use management of riparian areas within a 50 m strip on either side of the stream reaches, stream bed slope, sinuosity, and catchment stream length.

### **Stream bank soil particle size analysis**

Stream bank soil was sampled using the soil core method (3 cm in diameter and 10 cm in depth; Naeth et al. 1990). Soil samples for texture analysis were collected from eroded bank segments of the pasture stream reaches, where erosion pin plots were located. Soil sample collection was based on horizonation of stream bank soils. Two soil cores from the mid point of each horizon were collected for laboratory analysis. Since each soil horizon from the eroded bank surface had different heights, height-weighted averages were used to calculate mean texture for the mean bank height for the plot. Soil particle sizes were determined by the pipet method, which relies on a solution of sodium hexametaphosphate to disperse soil aggregates into individual textural units (Gee and Bauder, 1986).

### **Stream bed slope and sinuosity**

Slope and sinuosity measurements were calculated at two different scales using Geographic Information System (GIS) Arc Map 9.2 tools. One set of measurements was calculated at the grazed pasture stream reach (station) scale where the erosion pin plots were located. The other set included measurements at the catchment scale of stream reaches located above each of the treatment pastures. Stream bed slope values were calculated as the difference in elevations (rise) between the lowest and highest point of stream reach divided by the horizontal stream length (run) of a given stream reach. Sinuosity was estimated by first digitizing the total meandered length of a given stream reach at one meter resolution

from 2002 Color Infrared digital orthophotos and then dividing that value by the straight line valley length of the reach.

#### **Land-use determination within 50 m strips on either side of the stream**

Land-use was determined using color-infrared 2002 orthophotos (NRCS, 2002) for the catchments above each of the grazed pasture sites (stations) where the pin plots were located. Similarly, land-use and land cover was determined within a 50 m strip along both sides of the stream using GIS Arc Map 9.2 tools. Land-use categories were classified as agricultural (grazed grassland, alfalfa, winter wheat, corn, and soybean), unmanaged (ungrazed grassland and deciduous forest), Conservation Reserve Program (CRP), and other (open water, roads, wetlands and residential areas) by stream order category (Fig. 2).

#### **Catchments size, total stream lengths and stream order classification**

Catchment sizes and total stream lengths above each grazing pasture treatment were delineated and measured on a 2002 digital orthophotos using GIS (Arc Map 9.2) software. Stream order was manually assigned to each catchment reach using the Strahler (1957) classification system. Estimates of land use area within the 50 m strips along both sides of the streams were also described by stream order category (Fig. 2; Table 3).

#### **Stream bank erosion rates**

The erosion pin method was utilized to measure stream bank erosion rates (Wolman, 1959). Additional details regarding the erosion pin method and its use are provided in chapter two of this dissertation.

#### **Data analysis**

Relationships among bank soil texture, stream bed slope and sinuosity, and catchment land-use management on stream bank erosion were examined using the mixed procedure in

the Statistical Analysis Systems (SAS Institute, 2003). A multiple regression model including stream bank soil texture, stream bed slope and sinuosity, and land-use category (%) were used to explain the variability in the dependent variable, stream bank erosion rate. The acceptable significance level was considered as  $p < 0.1$  since bank erosion is influenced by many spatial, temporal, climatic and anthropogenic impacts.

### **Result and Discussion**

Stream bank erosion is a complex process driven by many interacting factors including bank soil properties (texture and structure), stream morphology (longitudinal slope and sinuosity of the stream bed), and riparian land-use and its direct and indirect effects on stream hydrology and bank stability. In a degraded stream system, these factors are dynamic and adjust until a “state of equilibrium” is reached within the stream network. Once equilibrium has been reached, stream bed and bank degradation is minimized because the stream channel has adjusted to transport all of the sediment supplied to it with the available discharge. This dynamic process of channel modification is described by the channel evolution model (Simon and Klimetz 2008).

In this three-year study, stepwise multi linear regression analysis revealed no significant interaction among stream bank erosion rates, stream bank soil texture, stream bed slope and sinuosity, and catchment land-use category (%). However, there were some positive relationships between stream bank erosion rates, and both bank soil sand particles (%) and catchment stream lengths.

#### **Stream bank soil particle size**

The dominant stream bank textural unit of the thirteen sites was “silt loam” (Table 1). In this study, there was a significant relationship ( $p = 0.04$ ) between stream bank erosion rates

and percent of sand in the bank soil (Fig. 3). Cohesiveness of a soil decreases with a higher percent of sand particles, which increases its potential for detachment by stream flow at a lower shear stress (Wynn and Mostaghimi, 2006). Evans et al. (2006) also found higher bank erosion rates with sandier bank materials. The percent of sand significantly ( $p = 0.03$ ) increased with soil samples collected further down from the top of the stream bank (Fig. 4). This may partially explain the higher erosion rates recorded from taller third order stream banks (Table 2). However, higher percent of sand particle in the lower soil horizon was possibly due to deposition.

### **Stream bed slope and sinuosity**

Stream morphologic characteristics of the pasture reaches were compared to those of the catchment to see if there was any interaction between them that could shed light on stream bank erosion in the pasture reaches. Although there were no significant interactions for a given stream order, from the data we can extrapolate/speculate that pasture stream reaches that were more sinuous and had lower stream bed slopes (site 3, 5, and 11) were most likely to yield smaller erosion rates (Table 2). However, in the case of site 5 and 11, this was possibly due to location of the stream reaches in the stream network. Site 5 was located just above the confluence with a third order reach and site 11 was just above the confluence with Rathbun Lake, so these two sites did not experience as much stream bed incision and bank erosion as the other sites because of frequent water high water events from the higher order water bodies. Lower stream bank erosion rates were also recorded from site 1 and site 6, likely the result of both sites having well-established perennial vegetation through enrollment in the CRP. Additional information regarding the impact of CRP management on bank erosion from these two sites was provided in the second chapter of this dissertation, which

basically indicated that during the winter/spring season stream bank erosion rates from CRP sites were significantly lower than from the grazed pasture sites. Grazing pasture site 7 experienced higher erosion rates than other first order streams, possibly because this site was located just below the CRP site 6 (Fig. 1) where sediment input to stream water was lower. This may have increased the erosion rate from site 7 in order to maintain the equilibrium between stream power and sediment load ( $Q_w \cdot S \sim Q_s \cdot D_{50}$ ), as suggested by Lane's (1955) channel equilibrium model. In other words, if there is no sediment input with increased discharge passing through the vegetated banks of the CRP stream reach, stream banks and bed of the unvegetated stream reaches of grazed pasture below the CRP site may erode more to increase suspended sediment concentration in the discharge (Zaimes et al. 2004).

#### **Catchment stream length and size**

There was a significant relationship ( $p= 0.0309$ ) between erosion rates and catchment size (Fig. 5). An even stronger relationship was found ( $p= 0.0173$ ) between erosion rates and catchment stream lengths (Fig. 5). The larger catchment size or longer stream length translate into higher discharge and stream power, which exerts greater stress on stream banks during high flow events. This implies that when assessing stream bank erosion at the field scale, it is important to account for the complexity of the stream channel network introduced by scale differences. Additionally, the gravitational force increases with bank saturation on the taller banks of higher order streams which increases the soil bulk unit weight (Simon et al. 2000), triggering bank failure and slumping. In the case of incised stream reaches with taller banks (mainly second and third order stream), bank stabilization should include trees along stream banks in addition to shrub and grass cover towards the field edge, whereas stream reaches



with shorter bank (first order and ephemeral channels) could be stabilized with only grass and shrub cover (Zaimes et al. 2004).

### **Impacts of land use within 50 m strips on either side of the stream**

Riparian land-use at the catchment scale within the 50 m corridor on both sides of the stream was found to consist of 46 to 61% agricultural use (row-crop and grazing), 6 to 11 % in CRP (grass filter,) with the rest mainly unmanaged (Table 3). The small amount of riparian area within conservation buffers (maximum of 11%) illustrates a significant opportunity for implementation of management to reduce surface runoff and bank erosion (Lyons et al. 2000). However, because variation in stream power (Larsen et al. 2006a) and/or stage (Tufekcioglu, 2010) is highly correlated to bank erosion rate, the impact of riparian management alone on bank erosion would not be enough to explain differences in erosion rates from these thirteen sites. The connectivity of the stream ecosystem at the larger scale is not only important for aquatic ecosystem integrity (Johnson and Covich, 1997; Ranganath et al. 2009) and water quality (Allan et al. 1997), but is also important for the stream morphologic and hydrologic modification that occurs further away from the place of perturbation. Richards et al. (1996) found that stream morphological characteristics were strongly related to catchment conditions. This relation could be one of the major reasons that the erosion rates in this study did not correlate with pasture grazing intensities (cattle stocking rates). In this case, when evaluating the effect of stocking rates on the change of bank morphology at the field scale, selection of bank erosion as the sole response variable may not be an appropriate choice (Lucas et al. 2009) since it is not only under the influence of adjacent land-use, but also the complex nature of stream biogeochemical and hydrologic interactions in the longitudinal dimension (Gove et al. 2001).

Since riparian areas are considered to be the critical source areas for sediment and nutrient contributions to the stream, their protection is very important for stream water quality and aquatic integrity. However, conversion from agricultural to conservation land-use represents opportunity costs to landowners. The magnitude of such costs can be assessed using a hypothetical situation where the total stream lengths on either side of the stream were buffered with perennial vegetation within 50 m. Under this scenario, an average of 2.1 % of the total watershed would be required to buffer the streams (Table 4). Without a consideration of farm profitability, I believe that the ultimate solution to the stream water impairment problem at the large scale and long term lies in the dedication of this 2 % percent of overall land-use for the recovery of riparian corridor function and stream habitat integrity.

### **Conclusions**

Multi linear regression analysis showed no significant interaction between the independent variables stream bank soil particle size, stream bed slope and sinuosity, and percent of riparian land-use, with stream bank erosion rate as the response variable. This may be due to the complexity of the interactions between stream morphology and hydrology at both the field and catchment scales, and insufficiency in the duration (3 years) of the study. However, significant relationships between percent of bank sand particles and bank erosion rates revealed that bank soils with less cohesiveness are more likely to erode due to reduced binding capacity of the soil against erosive flow. The stream morphology (stream bed slope and sinuosity), and riparian land-use data suggest that integration of the stream morphologic characteristics and land-uses both at the field and catchment scale is necessary for the explanation of bank erosion rates and ultimately for the identification of the current stage of channel evolution. Larger catchments or stream channels were found to be related to higher

bank erosion rates than smaller catchments, possibly due to the high potential stream discharge and taller saturated banks, which increase the gravitational force in the soil column resulting in soil strength failure and collapse. At the catchment scale, riparian vegetation cover assessment showed that within the 50 m corridor on both sides of the stream, 46 to 61 % of riparian area was devoted to agricultural crop use and grazing and only 6 to 11 % was in CRP with the rest mainly in “unmanaged use”. These data and previous studies allow the speculation that, in the long term and at the catchment scale, high percentage of agricultural land-use in riparian areas can be either directly and/or indirectly related to alteration of stream hydrologic regimes. In order to reach equilibrium state condition, where energy input to the stream channel is balanced with the minimal channel boundary resistance, such land-use changes will result in changes in stream bank erosion and channel morphology.

### **References**

- Agouridis, C. T., D. R. Edwards, S. R. Workman, J. R. Bicudo, B. K. Koostra, E. S. Vanzant, and J. L. Taraba. 2005. Stream bank erosion associated with grazing practices in the humid region. *Transactions of the American Society of Agricultural Engineers* 48 (1):181-190.
- Allan, J. D., D. L. Erickson, and J. Fay. 1997. The influence of catchment land use on stream integrity across multiply spatial scales. *Freshwater Biology* 37: 149-161.
- Anderson, K. L. 2000. Historical alterations of surface hydrology in Iowa’s small agricultural watersheds. MS thesis. Iowa State University, Ames, Iowa.
- Braster, M., T. Jacobson, and V. Sitzmann. 2001. Assessment and Management Strategies for the Rathbun Lake Watershed.  
[www.rlwa.org/Documents/Rathbun%20Lake%20Watershed%20Assessment.pdf](http://www.rlwa.org/Documents/Rathbun%20Lake%20Watershed%20Assessment.pdf)

- Burkart, M. R., S. L. Oberle, M. J. Hewitt, and J. Pickus. 1994. A frame work for regional agroecosystems characterization using the national resource inventory. *Journal of Environmental Quality* 23: 866-874.
- Byers, H. L., M. L. Cabrera, M. K. Matthews, D. H. Franklin, J. G. Andrea, D. E. Radcliffe, M. A. McCann, H. A. Kuykendall, C. S. Hoveland, and V. H. Calvert II. 2005. Phosphorus, sediment, and *Escherichia coli* loads in unfenced streams of the Georgia Piedmont, USA. *Journal of Environmental Quality* 34: 2293-2300.
- De Baets, S., J. Poesen, B. Reubens, K. Wemans, J. De Baerdemaeker and B. Muys. 2008. Root tensile strength and root distribution of typical Mediterranean plant species and their contribution to soil shear strength. *Plant Soil* 305, 207-226.
- Dosskey, M. G., P. Vidon, N. P. Guwick, C. J. Allan, T. P. Duval, and R. Lowrance. 2010. The role of riparian vegetation in protecting and improving chemical water quality in streams. *Journal of the American Water Resources Association*. 46(2): 261-277.
- Evans, D. J., C. E. Gibson and R. S. Rossell. 2006. Sediment loads and sources in heavily modified Irish catchments: A move towards informed management strategies. *Geomorphology* 79, 93-113.
- Gee, G. W and J. W. Bauder. 1986 . Particle-size analysis. *In* Method of soil analysis: Part 1-Physical and mineralogical methods. 2<sup>nd</sup> ed. A. Klute ed. Soil Science Society of America Book Series: 5. Madison, WI. 383-411.
- Geyer, W. A., T. Neppl, K. Brooks, and J. Carlisle. 2000. Woody vegetation protects streambank stability during the 1993 flood in Central Kansas. *Journal of Soil and Water Conservation* 55(4): 483-486.
- Gove, N. E., R. T. Edwards, and L. L. Conquest. 2001. Effects of scale on land use and water quality relationships: A longitudinal basin-wide perspective. *Journal of the American Water Resources Association* 37(6): 1721-1734.
- Guthrie, W. K., 2000. Drainage, drainage, drainage: Creating natural disasters in Southeastern Nebraska. *Great Plains Quart* 20(4), 297-310.

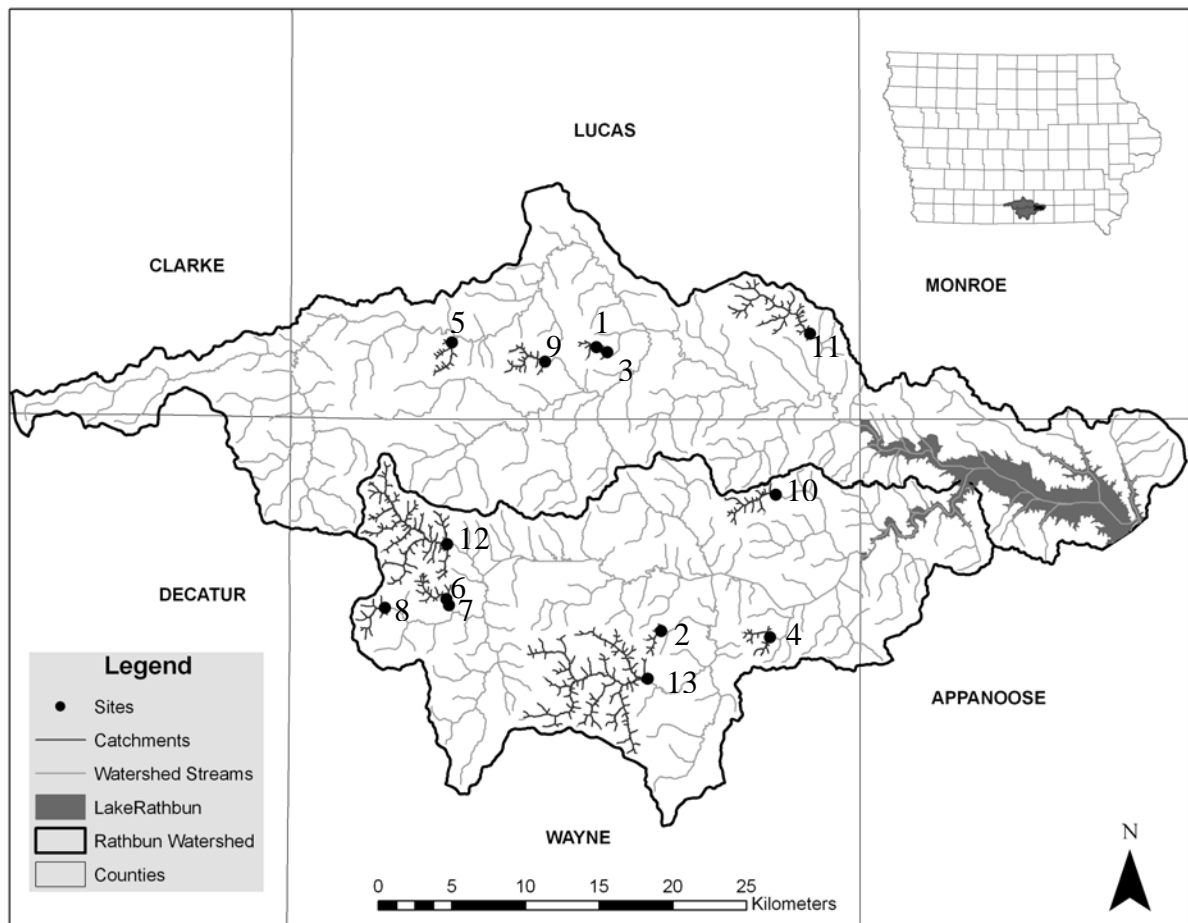
- Harmel, R. D., C. T. Haan and R. Dutnell. 1999. Bank erosion and riparian vegetation influences: Upper Illinois River, Oklahoma. *American Society of Agricultural Engineers* 42 (5), 1321-1329.
- Hupp, C. R. 1992. Riparian vegetation recovery patterns following stream channelization: A geomorphic perspective. *Ecology* 73, 1209-1226.
- Johnson, S. L., and A. P. Covich. 1997. Scales of observation of riparian forest and distributions of suspended detritus in a prairie river. *Freshwater Biology* 37: 163-175.
- Knight, K. W., R. C. Schultz, C. M. Mabry and T. M. Isenhardt. 2010. Ability of remnant riparian forests, with and without grass filters, to buffer concentrated surface runoff. *Journal of the American Water Resources Association* 46 (2), 311-322.
- Knox, J. C., 2001. Agricultural influences on landscape sensitivity in the Upper Mississippi River Valley. *Catena* 42, 193-224.
- Lane, E. W., 1955. Design of stable channels. *Transactions of the American Society of Civil Engineers* 120, 1234-1260.
- Larsen, E. W., A. K. Fremier and S. E. Greco. 2006a. Cumulative effective stream power and bank erosion on the Sacramento River, California, USA. *Journal of the American Water Resources Association* 42 (4): 1077-1097.
- Line, D. E., W. A. Harman, G. D. Jennings, E. J. Thompson, and D. L. Osmond. 2000. Nonpoint-source pollutant load reductions associated with livestock exclusion. *Journal Environmental Quality* 29:1882-1890.
- Lucas, R. W., T. T. Baker, M. K. Wood, C. D. Allison, and D. M. VanLeeuwen. 2009. Streambank morphology and cattle grazing in two montane riparian areas in western New Mexico. *Journal of Soil and Water Conservation* 64(3): 183-189.
- Lyons, J., B. M. Weigel, L. K. Paine and D. J. Undersander. 2000. Influence of intensive rotational grazing on bank erosion, fish habitat quality, and fish communities in Southwestern Wisconsin Trout streams. *Journal of Soil and Water Conservation* 55 (3), 271-276.

- Magner, J.A., B. Vondrack and K.N. Brooks. 2008. Grazed riparian management and stream channel response in Southeastern Minnesota (USA) streams. *Environmental Management*. 42:377-390.
- McInnis, M. L., and J. D. McIver. 2009. Timing of cattle grazing alters impacts on stream banks in an Oregon mountain watershed. *Journal of Soil and Water Conservation* 64(6): 394-399.
- Miller, J., D. Chanasyk, T. Curtis, T. Entz, W. Willms. 2010. Influence of streambank fencing with a cattle crossing on riparian health and water quality of the Lower Little River in Southern Alberta, Canada. *Agricultural Water Management* 99(2): 247-258.
- Naeth M. A., D. J. Pluth, D. S. Chanasyk, A. W. Bailey. 1990. Soil compacting impacts on grazing in mixed prairie and fescue grassland ecosystems of Alberta. *Canadian Journal of Soil Science* 70:157-167.
- NRCS. 2002. <http://www.igsb.uiowa.edu/nrgislibx/newsletters/2004-06%20gis%20newsletter%20vol%20ii.pdf>
- Prior, J. C. 1991. Landforms of Iowa. Iowa Department of Natural Resources University of Iowa Press, Iowa City, Iowa.
- Ranganath, S. C., W. C. Hession, and T. M. Wynn. Livestock exclusion influences on riparian vegetation, channel morphology, and benthic macroinvertebrate assemblages. *Journal of Soil and Water Conservation* 64(1): 33-41.
- Richards, C., L. B. Johnson, and G. E. Host. 1996. Landscape-scale influences on stream habitats and biota. *Canadian Journal of Fisheries and Aquatic Sciences* 53(1): 295-311.
- Ritter, D. F., R. C. Kochel, and J. R. Miller. 2002. Process geomorphology, 4<sup>th</sup> ed. Book. Page 190.
- SAS (Statistical Analysis System) Institute. 2003. SAS Release 9.1 ed. SAS Inst., Cary, North Carolina.

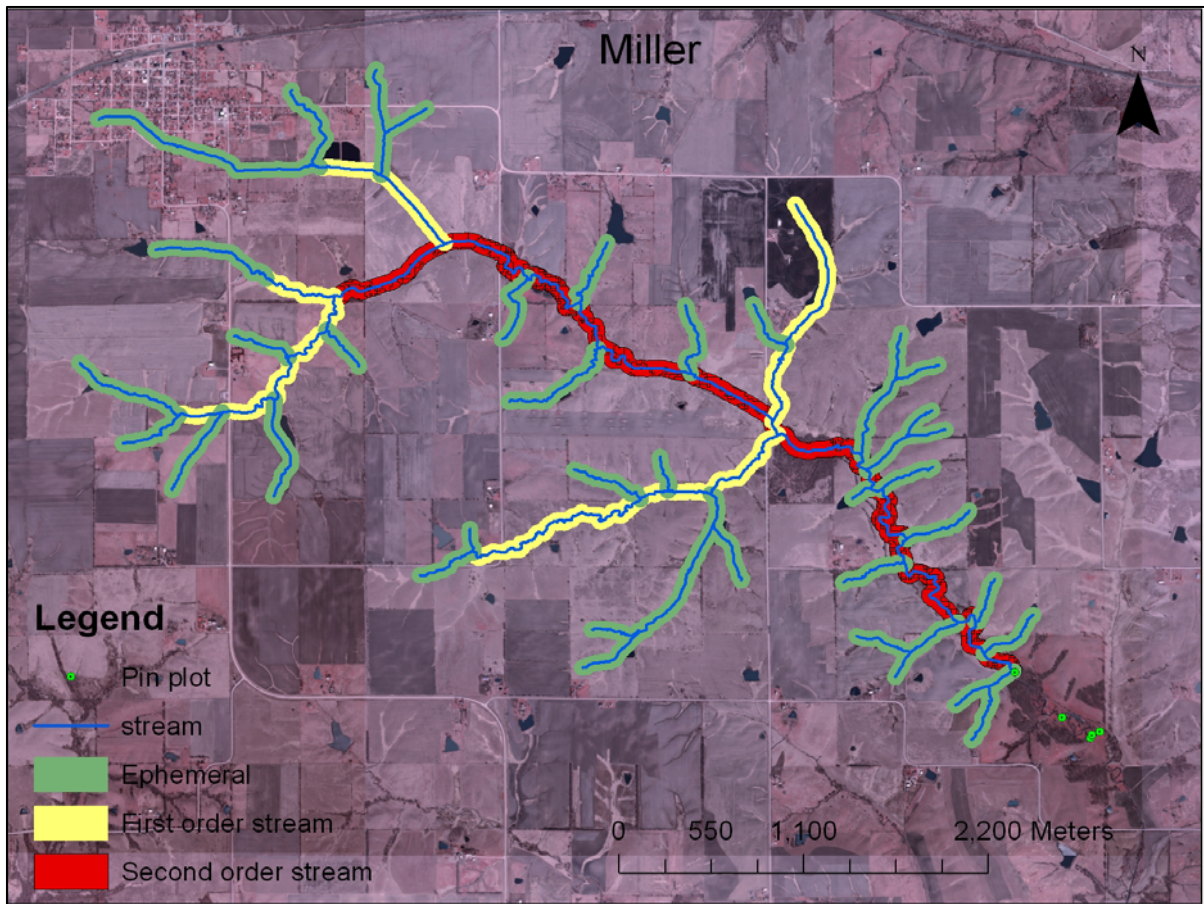
- Schilling, K. E., 2004. Relation of baseflow to row crop intensity in Iowa. *Agricultural Ecosystem Environment* 105, 433-438.
- Sharpley, A. N., W. J. Gburek, G. Folmar, and H. B. Pionke. 1999. Sources of phosphorus exported from an agricultural watershed in Pennsylvania. *Agricultural Watershed Management* 41:77-89.
- Simon A, Curini A, Darby SE, Langendoen EJ (2000) Bank and near-bank processes in an incised channel. *Geomorphology* 35:193-217.
- Simon, A and Collison, A.J.C. (2002) Quantifying the Mechanical and Hydrologic Effects of Riparian Vegetation on Streambank Stability. *Earth Surface Process and Landforms*. 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.
- Simon, A. and M. Rinaldi. 2006. Disturbance, stream incision, and channel evolution: The roles of excess transport capacity and boundary materials in controlling channel response. *Geomorphology* 79, 361-383.
- Strahler AN (1957) Quantitative analysis of watershed geomorphology. *Am Geophysical Union Trans* 38:913-920
- Trimble, S. W., 1994. Erosional effects of cattle on streambanks in Tennessee, U.S.A. *Earth Surface Processes and Landforms* 19, 451-464.
- Tufekcioglu, M., 2010. Stream bank soil and phosphorus losses in response to the alteration of the hydrologic and morphologic characteristics of the grazed pastures stream reaches in south central Iowa. Ph.D. Dissertation. Iowa State University, Ames, IA.
- Whitney, G. G., 1994. From coastal wilderness to fruited plain. Cambridge University Press, Cambridge, United Kingdom.

- Williamson, R. B., C. M. Smith, and A. B. Cooper. 1996. Watershed riparian management and its benefits to a eutrophic lake. *Journal of Water Resources Planning and Management* 122(1): 24-32.
- Wolman, M. G., 1959. Factors influencing erosion of a cohesive river bank. *American Journal of Science* 257: 204-216.
- Wynn, T. and S. Mostaghimi. 2006. The effects of vegetation and soil type on streambank erosion, Southwestern Virginia, USA. *Journal of the American Water Resources Association* 42 (1), 69-82.
- Yan, B., M. D. Tomer, and D. E. James. 2010. Historical channel movement and sediment accretion along the South Fork of the Iowa River. *Journal of Soil and Water Conservation* 65(1), 1-8.
- Zaimes, G. N., R. C. Schultz, and T. M. Isenhardt. 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., R.C. Schultz, and T.M. Isenhardt. 2006. Riparian land uses and precipitation influences on stream bank erosion in central Iowa. *Journal of the American Water Resources Association*. 42(1): 83-97.
- Zaimes, G.N., R.C. Schultz, and T.M. Isenhardt. 2008b. Streambank soil and phosphorus losses under different riparian land-uses in Iowa. *Journal of the American Water Resources Association*. 44(4):935-947.

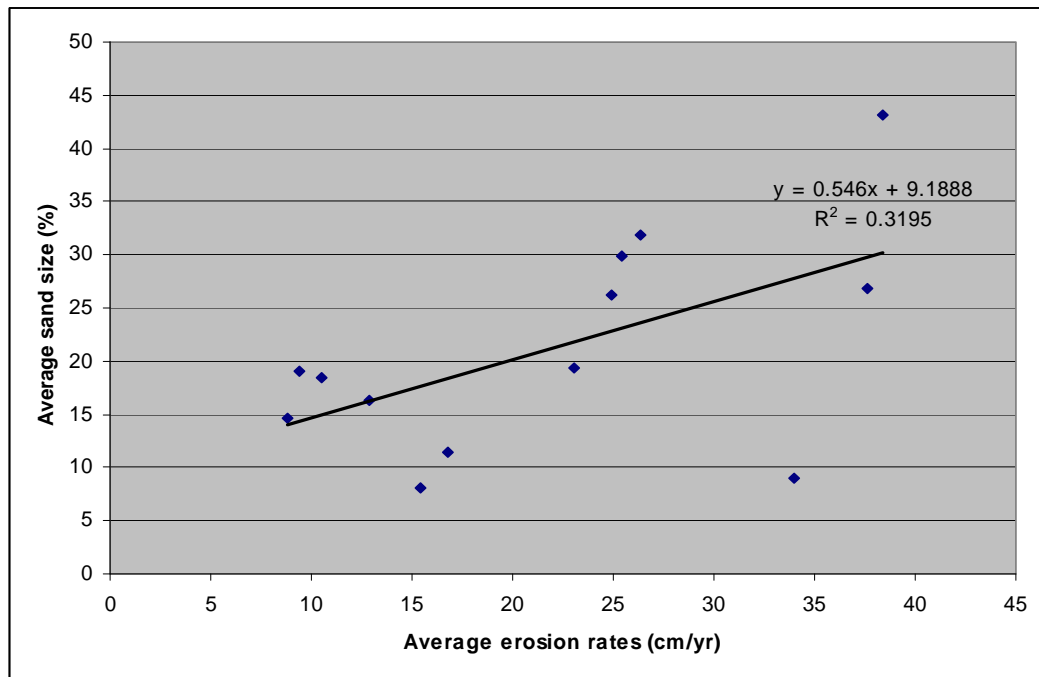




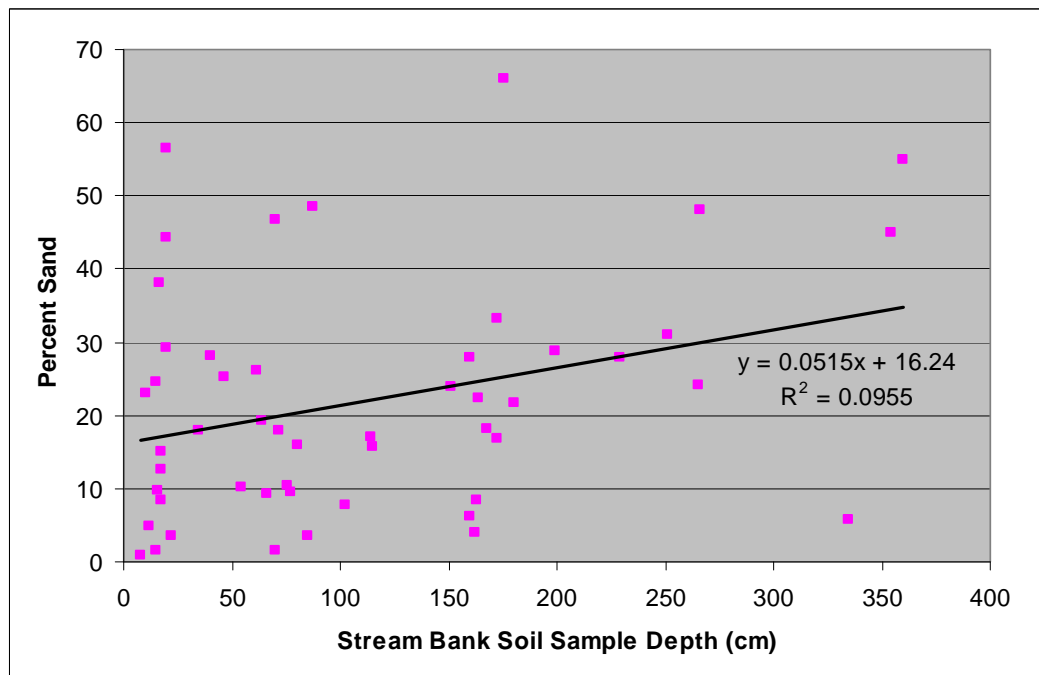
**Figure 1:** Location of thirteen study sites and their catchments within Rathbun Lake watershed in South Central Iowa. Numbers represent pasture Id based on the catchment sizes from smallest to largest. Note: site 6 and 1 are under CRP management and all other sites were in grazing management.



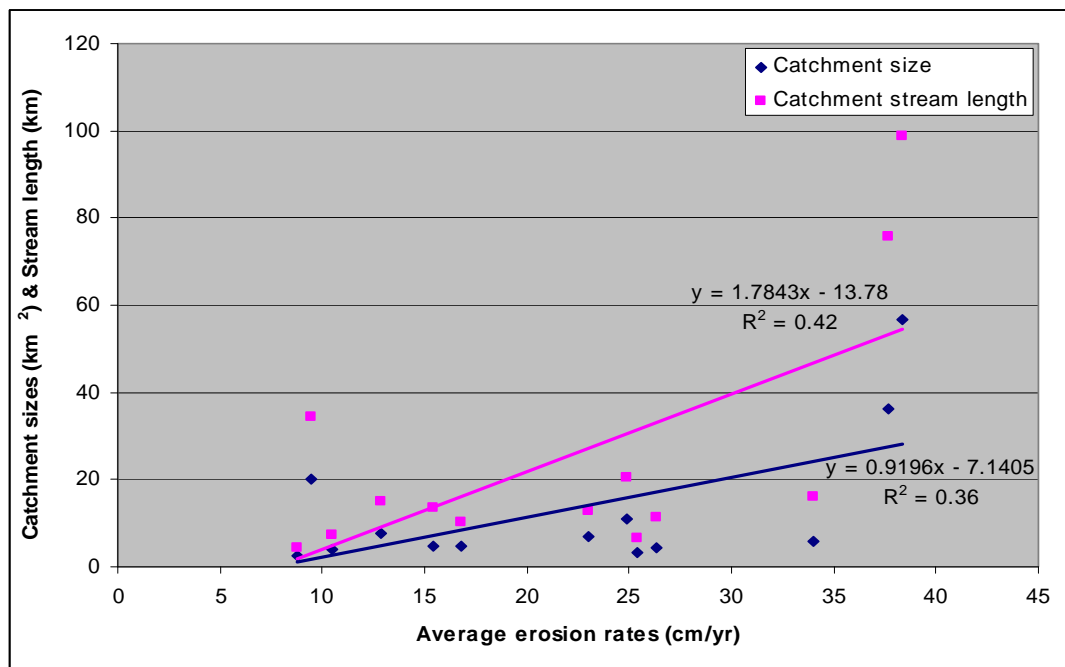
**Figure 2:** Catchment stream lengths of the pasture site/Id 11 and its 50 m buffered areas based on the stream order category.



**Figure 3.** Relationship between erosion rates and percent sand particle size



**Figure 4.** Relationship between percent sand particles and height of stream bank at which sample was collected. Note: Only stream banks taller than 150 cm are include.



**Figure 5:** Relationship between stream bank erosion and both catchment size and catchment stream length.

**Table 1.** Percent particle sizes and their textural units from stream bank soils of the thirteen stream reaches.

Site Id	Land-use	Sand (%)	Silt (%)	Clay (%)	Soil textural units
1	CRP	15	58	28	silt clay loam
2	Grazed	30	50	20	loam
3	Grazed	18	60	22	silt loam
4	Grazed	32	50	18	silt loam
5	Grazed	11	65	24	silt loam
6	CRP	8	65	27	silt loam
7	Grazed	9	66	25	silt loam
8	Grazed	19	60	21	silt loam
9	Grazed	16	62	21	silt loam
10	Grazed	26	54	19	silt loam
11	Grazed	19	60	21	silt loam
12	Grazed	27	56	18	silt loam
13	Grazed	43	38	19	loam

**Table 2.** Stream morphologic characteristics in both field and catchment scales and total erosion rates from pasture fields.

Site Id	Stream bed slope	Stream sinuosity	Stream order	Erosion rates (cm, year)
1	1.7(2.1)	1.1(1.1)	I	8.6
2	2.0(1.8)	1.2(1.4)	I	25.3
3	0.8(1.7)	1.4(1.2)	I	10.3
4	1.3(2.0)	1.6(1.4)	I	26.3
5	0.6(1.6)	2.0(1.2)	I	16.6
6	2.0 (1.3)	1.5(1.3)	I	15.3
7	1.6(1.4)	1.3(1.3)	I	34.0
8	1.6(0.7)	1.1(1.2)	I	23.0
9	0.8 (0.8)	1.4(1.4)	II	13.0
10	0.7(0.8)	1.4(1.3)	II	25.0
11	0.4(0.6)	1.5(1.3)	II	9.3
12	0.3(0.3)	1.1(1.4)	III	37.6
13	1.5(0.3)	1.2(1.4)	III	38.3

Note; numbers inside the parenthesis represent the given stream feature at the catchment scale. Stream order category is based on Strahler (1957).

**Table 3.** Land-use types within 50 m on either side of the streams by stream order in studied catchments of the Rathbun watershed.

Stream order	Agriculture (%)	Unmanaged use (%)	CRP (%)	Other (%)
Ephemeral	61	25	11	3
1 <sup>st</sup>	64	26	7	3
2 <sup>nd</sup>	52	39	6	3
3 <sup>rd</sup>	46	47	7	0

Use in agriculture: grazed grassland, alfalfa, winter wheat, lush grass, corn, soybean.

Unmanaged use: ungrazed grassland, deciduous forest.

CRP: conservation reserve program.

Other: open water, roads, wetlands, industrial and residential areas  
([ftp://ftp.igsb.uiowa.edu/gis\\_library](ftp://ftp.igsb.uiowa.edu/gis_library))

**Table 4.** The percent of total catchment area devoted to riparian buffers if 6 m wide buffers were established along ephemeral channel and 18 m wide buffers were established along all other perennial channels that were designated as “agriculture” land use in this study. Note: The buffer widths of 6 m and (12+6) m are the minimum grass filter and forest buffer widths with the grass width of 6 m, respectively, recommended by NRCS.

Site Id	Buffered riparian area (km <sup>2</sup> )	Catchment size (km <sup>2</sup> )	Buffered catchment area (%)
1	0.02	2.5	0.9
2	0.08	3.2	2.7
3	0.07	3.9	1.9
4	0.10	4.4	2.2
5	0.08	4.7	1.6
6	0.14	4.8	3.0
7	0.16	5.8	2.8
8	0.12	7.1	1.7
9	0.14	7.6	1.9
10	0.16	10.9	1.5
11	0.36	20.1	1.8
12	0.82	36.3	2.2
13	1.24	56.6	2.2
Average			2.1



## CHAPTER 5

### GENERAL CONCLUSIONS

Row-crop cultivation and riparian pasture grazing are two agricultural practices widely recognized as potential sources of phosphorus (P) and sediment to surface waters if not carefully managed. An assessment of the magnitude of sediment and P contribution from such sources, along with the development of cost-effective management practices, is essential for maintaining sustainable agricultural practices and stream ecological integrity. Stream bank erosion within agricultural landscapes is a major pathway for non-point source sediment and P loading to receiving waters. Previous studies have shown direct and indirect effects of land use on stream bank erosion, and identified high bank erosion rates from riparian pastures. Other studies have shown significant variation in sediment and nutrient loading to streams among different riparian grazing practices. The overarching goal of this research was to assess stream bank soil and P losses within grazed pasture stream reaches in the Rathbun Watershed in southern Iowa. Specific objectives of this study were to: 1) compare the effects of varying livestock stocking rates on sediment and P losses from stream bank erosion; 2) assess the relationship between the number of high stream discharge events on stream bank soil erosion rates, and 3) evaluate the impacts of current riparian land-uses and stream morphologic characteristics (bank soil texture, stream bed slope and sinuosity) at the field and catchment scale on stream bank erosion.

In the first study, the length of severely eroded stream banks and soil compaction of the riparian area were found to be significantly related to the higher riparian stocking rates. While there was no significant correlation between bank erosion rates and stocking rates, the

erosion rates from the sites under CRP management were significantly lower than those from grazed pasture sites, particularly during the winter/spring season. This suggests that use of riparian areas for grazing can impact channel characteristics and water quality by increasing sediment and P loads from bank erosion, and that riparian grazing management practices should include a consideration of the impacts of grazing on stream bank erosion and stream integrity.

The second study found that approximately 75% of the variability in stream bank erosion can be directly correlated to the frequency of high stream discharge events, and the remaining 25% is probably due to differences in percent bank soil antecedent moistures and frequency and number of freeze-thaw events prior to the high stream discharge events. The results suggest that hydrologic regime is a major driving force for stream bank erosion in the studied pastures and that hydrology is not only influenced by adjacent land use but the catchment characteristics above the pasture sites. It can be inferred from these results that stream bank soil loss can be reduced by implementing riparian and watershed practices that increase soil water-holding capacity and reduce surface runoff and high stream flow.

In the third study, an evaluation of stream morphologic characteristics and land-use both at the field and catchment scale was found to be necessary to explain current stream bank erosion rates. Larger catchment size or catchments with more stream length were found to have greater bank soil loss than did smaller catchment size, likely due to the potential of the high energy of stream discharge and taller saturated banks in higher order channels. These factors increase the gravitational force in the soil column resulting soil strength failure and collapse. A significant relationship between percent of bank soil sand particles and bank erosion rates revealed that bank soils with less cohesiveness are more likely to erode due to

the reduced binding capacity of the soil against erosive flows. Catchment-scale assessments in the study watersheds showed that within the 50 m corridor on both sides of the stream, 46 to 61% of the riparian area was devoted to agricultural crop and pasture use and only 6 to 11% was in CRP with the rest mainly in unmanaged use.

Overall, intensive agricultural use of the riparian areas throughout these catchments can be directly and/or indirectly related to excessive amounts of sediment and nutrient load to the streams and their impairment for providing ecological services. Such impacts on riparian areas and surface water quality can likely be reduced with well-defined pasture management practices (off-stream water sources, nutrient supplement placement away from the stream, stable crossing points, rotational grazing with lower stocking rates, timing of the grazing) and conservation buffer practices, that consider pasture characteristics such as pasture shape and size and shading by trees along the stream banks (Haan et al. 2006, 2010; Bear, 2010).

### **References**

- Bear, D. A. 2010. Pasture management effects on nonpoint source pollution of Midwestern watersheds. MS Thesis. Iowa State University.
- Haan, M.M., J.R. Russell, J.D. Davis, and D.G. Morrical. 2010. Grazing management and microclimate effects on cattle distribution relative to a cool-season pasture stream. *Rangeland Ecology Management*. 63(5): 572-580
- Haan, M.M., J.R. Russell, W.J. Powers, J.L. Kovar, and J.L. Benning. 2006. Grazing management effects on sediment and P in surface runoff. *Rangeland Ecology Management*. 59: 607-615.

### **Acknowledgments**

This research has been funded by the USDA Cooperative State Research, Education, and Extension service. For their generous help in the field and laboratory we would like to

thank the following staff and students: E. Kilburg, S. Mulder, T. Harms, W. Phillips, F. Boyer, D. Bear, M. Haan, S. Nellesen, N. Hongthanat, N. Ohde, K. Knight, T. Hanson, L. A. Long, J. Lancial, Z. DeYoung, A. Wendt, K. Kult, J. Palmer, G. Johnsen, L. Barney, B. Ott, C. Conant and R. Burch. We also would like to thank the landowners for allowing us to use their farms as research sites. Without their great cooperation this project would not have been possible.

Finally, for their great help and support throughout my graduate study here in ISU, I thank my committee members and advisors, Tom Isenhardt and Dick Schultz. It has been a wonderful journey working with you!