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RIPARIAN LAND USES AND PRECIPITATION INFLUENCES ON STREAM BANK EROSION IN CENTRAL IOWA[1]

George N. Zaimes, Richard C. Schultz, and Thomas M. Isenhart[2]

ABSTRACT: Human alterations to the Iowa landscape, such as elimination of native vegetation for row crop agriculture and grazing, channelization of streams, and tile and ditch drainage, have led to deeply incised channels with accelerated streambank erosion. The magnitude of streambank erosion and soil loss were compared along Bear Creek in central Iowa. The subreaches are bordered by differing land uses, including reestablished riparian forest buffers, row crop fields, and continuously grazed riparian pastures. Erosion pins were measured from June 1998 to July 2002 to estimate the magnitude of streambank erosion. Total streambank soil loss was estimated by using magnitude of bank erosion, soil bulk density, and severely eroded bank area. Significant seasonal and yearly differences in magnitude of bank erosion and total soil loss were partially attributed to differences in precipitation and associated discharges. Riparian forest buffers had significantly lower magnitude of streambank erosion and total soil loss than the other two riparian land uses. Establishment of riparian forest buffers along all of the nonbuffered subreaches would have reduced streambank soil loss by an estimated 77 to 97 percent, significantly decreasing sediment in the stream, a major water quality problem in Iowa.
(KEY TERMS: riparian land uses; riparian forest buffer; streambank erosion; precipitation; stream restoration.)

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INTRODUCTION

Streambank erosion can contribute 30 to 60 percent (Wilkin and Hebel, 1982; Lawler *et al.,* 1999; Amiri-Tokaldany *et al.,* 2003) to as much 80 percent (Simon *et al.,* 1996) of the sediment load in incised streams. In Iowa, streambank erosion contributions have been reported between 25 and 50 percent of the sediment load (Hamlett *et al.,* 1983; Odgaard, 1987; Schilling and Wolter, 2000). As sediment is the greatest water quality problem in the United States (U.S.) (Simon and Darby, 1999), reduction of streambank erosion is a priority for reducing total sediment load in streams. Riparian forest buffers provide a management tool that helps reduce streambank erosion in agriculturally dominated watersheds (Schultz *et al.,* 2000).

Bank erosion is a natural function of streams and cannot be eliminated entirely (Henderson, 1986). However, in Iowa and other agriculturally dominated states, streams are deeply incised as a result of accelerated streambank erosion caused by human alterations. In Iowa, in a period of 150 years, 99.9 percent of prairies were plowed, 95 percent of wetlands were drained, and 70 percent of forests were cleared (Whitney, 1994). Most of this land has been converted to row crop agriculture and continuously grazed cool season grass pastures (Burkhart *et al.,* 1994). The end result is that Iowa's landscape has been changed more by agriculture than that of any other state in the U.S. (Dinsmore, 1994).

Channelization efforts that began in the late 1800s in Iowa have decreased the original stream length of larger streams (> 129 km^2 drainage area) by 45 percent (Bulkley, 1975). At the same time, wetland drainage with tiles improved soil moisture conditions for growing crops (Menzel, 1983). Agriculture tiling efforts, along with digging of agricultural ditches, have increased the total length, drainage density, and channel frequency of intermittent streams by more than 50 percent in most Iowa headwater watersheds

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(Andersen, 2000). The increased length of headwater streams has led to accelerated streambank erosion, contributing to soil loss.

These human alterations have decreased both the water storage capacity of the landscape and the time it takes for water to reach streams, resulting in an increase in the total amount of water in channels. Higher annual and peak discharges have increased stream scouring potential and sediment transport capacity, leading to extensive channel incision (Menzel, 1983; Schumm, 1999). The natural responses to anthropogenic modifications are predicted by the Channel Evolution Model (Schumm *et al.,* 1984). In response to human alterations, the dynamic equilibrium of the stream channel (Stage I, stable) can be lost because channels begin to deepen (Stage II, incision) and then widen with high rates of bank erosion (Stage III, widening). Streambank widening rates in Stage III can vary several orders of magnitude from 1.5 m/yr to more than 100 m/yr (Simon *et al.,* 1999). Eventually the channel becomes wide enough that sediment sloughed off the banks is not carried away from the bank toe, and plants become reestablished (Stage IV, stabilizing). With time the channel may again reach a new dynamic equilibrium (Stage V, stable).

Controlling streambank erosion is an expensive task that takes considerable time and effort, especially in heavily disturbed watersheds. Control is difficult because so many interacting factors influence bank erosion. These factors include watershed and riparian vegetation cover and land use, topography, bank material, river morphology, weather cycles (especially precipitation patterns), watershed area, and channel stage (Hooke, 1980; Hagerty *et al.,* 1981; Schumm *et al.,* 1984; Geyer *et al.,* 2002). Of major interest are riparian land use and precipitation patterns. Riparian land use has a direct impact on the vegetation cover and the type and amount of disturbance on the streambanks. Large daily precipitation events can influence stream discharge in low-order streams (Junk *et al.,* 1989). Years with lower than average precipitation can provide a deceiving picture that banks are stabilizing.

A relatively inexpensive method for increasing streambank stability is the establishment of riparian forest buffers. This method generally takes longer to stabilize streambanks than traditional hard and/or soft streambank engineering methods such as rip-rap, live fascines, and brush mattresses (USDA-NRCS, 1996) or instream methods such as grade control structures.

One of the stated functions of riparian forest buffers is stabilizing streambanks (USDA-NRCS, 1997), but empirical data are scarce on the extent and magnitude to which forest buffers stabilize streambanks. The objectives of this study were: to quantify the differences in streambank erosion for channels adjacent to riparian forest buffers, row crop fields, and pastures in the riparian area; and to investigate the influence of precipitation, a surrogate for high discharge, on streambank erosion.

Streambank erosion along a subreach with reestablished riparian forest buffers was compared to subreaches with row crop fields adjacent to streams and continuously grazed riparian pastures where livestock had full access to the stream. The null hypothesis was that different riparian land uses and precipitation amounts would not impact streambank erosion. For this study, precipitation was the best available variable for correlating discharge with bank erosion because of the lack of stream discharge data and the proximity of a weather station to one of the subreaches. The flashiness of most second-order streams in Iowa allows good correlation between precipitation and stream discharge. This paper reports the results of approximately three years of new data plus one year of previously published data (Zaimes *et al.,* 2004).

STUDY REACH

An 11 km reach of Bear Creek was selected because it has been designated as a National Restoration Demonstration Watershed by the interagency team implementing the Clean Water Action Plan (1999) and as the Bear Creek Riparian Buffer National Research and Demonstration Area by the U.S. Department of Agriculture (USDA, 1998). This study complements the extensive research on a variety of subjects conducted along this reach over the past decade. The 11 km study reach is classified as a second-order stream and lies on the most recently glaciated landform of Iowa (12,000 to 14,000 years), the Des Moines Lobe, in Story and Hamilton Counties in central Iowa (latitude 42°11´N, longitude 93°30´W). The area is flat with a poorly integrated natural drainage system that consists of incised stream channels, dredged ditches, and field drainage tiles. The riparian zones of the study reach consist of one subreach of reestablished riparian forest buffers, two subreaches of row crop fields, and two subreaches of continuously grazed riparian pastures (Figure 1).

The 20 m wide riparian forest buffer (Figure 1) consists of three vegetation zones parallel to the stream (Isenhart *et al.,* 1998; Schultz *et al.,* 2000). The first zone (10 m wide), nearest the stream, is composed of trees that stabilize the streambank and provide long

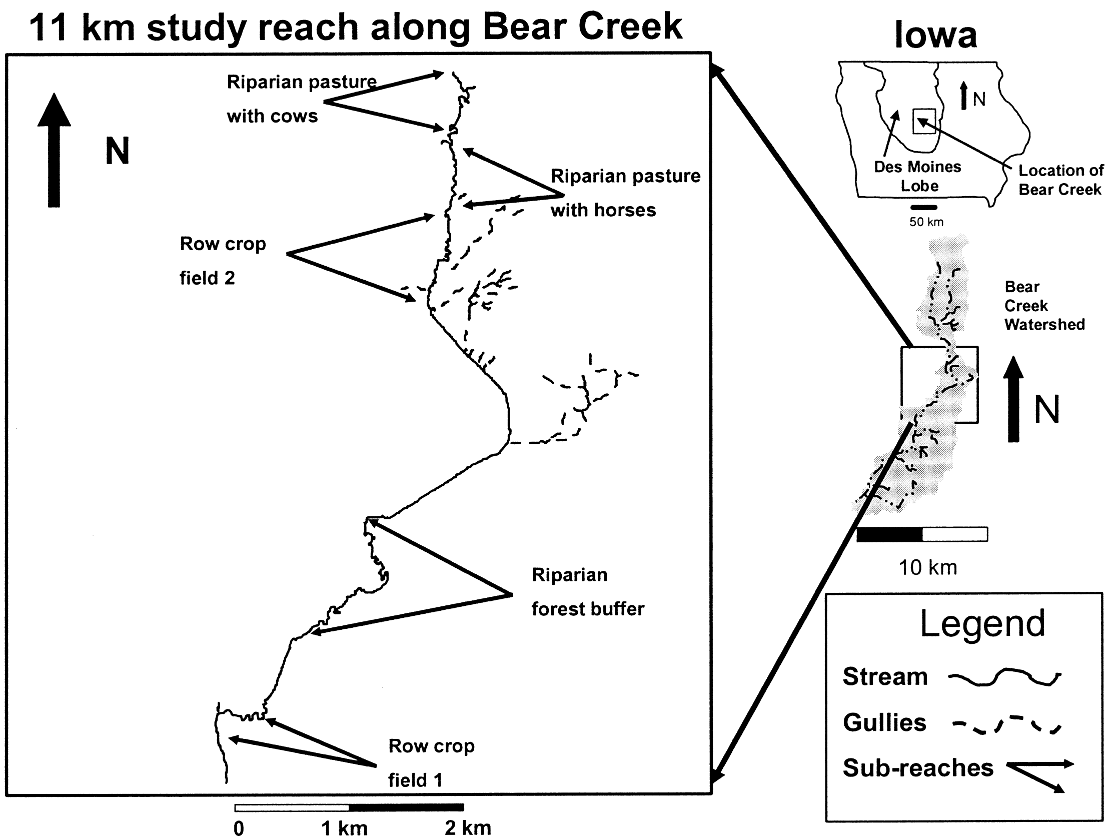


Figure 1. A Map of the Bear Creek Watershed in Story and Hamilton Counties in Central Iowa (latitude 42°11´N, longitude 93°30´W) Showing the Location of the Three Riparian Land Uses and Their Subreaches.

term nutrient storage. The second zone (3.6 m wide) includes shrubs that increase habitat diversity, reduce floodwater velocities, and trap flood debris. The third zone (6.4 m wide) consists of warm season grasses and forbs that trap sediment, nutrients, and agricultural chemicals in overland flow. Riparian forest buffers established in 1990 and 1994 were used as one subreach because of the minimal difference in age, structure, and development of the plant communities.

Corn (*Zea mays* L.) and soybeans (*Glycine max* (L.) Merr.) were grown in alternating years on the row crop fields adjacent to the stream (Figure 1), and both subreaches had a narrow strip (< 4 m) of grasses and annual weeds along the streambank. The two row crop field subreaches were 6.8 km apart. A riparian forest buffer was planted in 2000 in the riparian area of row crop field Subreach 1. This subreach was still considered a row crop field because the very young age of the buffer made the authors assume it would have minimal impact on stabilizing the streambanks.

Riparian pastures (Figure 1) consisting of cool season grasses – primarily Kentucky bluegrass (*Poa pratensis* L.) – were continuously grazed from the beginning of May to the end of October, a practice typical of this part of Iowa. Pastures were confined to the riparian zone and back slope of the narrow stream valley, allowing livestock access to the whole pasture and stream channel during the entire grazing season. The riparian pasture had two adjacent subreaches; one of the pastures had cattle with a much higher number of animal units (kg/ha) than the other, which had horses.

The dominant soil series for the study reach were Spillville (fine loamy, mixed, mesic Cumulic Haplaquolls) and Coland (fine loamy, mixed, mesic Cumulic Hapludolls) (DeWitt, 1984). Both soils are alluvial, moderately permeable, on 0 to 2 percent slopes, and overall similar (DeWitt, 1984). Particle analysis for soil samples taken at 30 cm intervals on 13 different streambank faces across all three riparian uses classified their texture as clay loam or sandy clay loam (Zaimes *et al.,* 2004). There were no major tributaries within the study reach and only several classic gullies (Figure 1). As a result, channel dimensions (depth and width) and discharge remained relatively constant throughout the study reach. Finally, based on the Channel Evolution Model (Schumm *et al.,* 1984), all the riparian land use subreaches were in Stage III (widening).

METHODS

Rainfall Data

Rainfall data were recorded from June 1998 until July 2002 using a tipping bucket gauge located within the riparian area of the study reach. Daily and yearly rainfall data from the local weather station were correlated to streambank erosion. Monthly and yearly precipitation amounts for the study period were compared to the monthly and yearly means from a 51-year precipitation dataset from a weather station near Ames, Iowa, about 20 km south of the study reach (Climate Station: No. IA0200, Ames-8-WSW; climate record: 1951-2003 from Iowa State University Department of Agriculture, 2004) to determine whether they were outside the range of normal variability.

Streambank Erosion Pins

The erosion pin method was used to measure the magnitude (mm) of streambank erosion (Wolman, 1959). Erosion pins were preferred over other methods that measure the magnitude of erosion because erosion pins have much higher resolution (Lawler, 1993). In addition to measuring magnitude, three other variables were used to compare streambank erosion between the riparian land uses. These variables were severely eroded bank lengths (percent) and areas (m^2/km) and soil loss per unit length of streambank (tonnes/km).

Erosion pins were 762 mm long, 6.4 mm in diameter, made of steel, and inserted perpendicularly into the bank face. This length was chosen because the authors had witnessed past bank erosion of up to 500 mm per event. Hooke (1979) recommends that at least one-third of the pin remain buried in the streambank face to reduce the risk of loss during a major erosion event. Pins also should not exceed 800 mm in length because at that length they can increase bank stability by reinforcing the soil, particularly increasing cantilever stability (Hooke, 1979). The 6.4 mm diameter was small enough to cause minimum disturbance to the streambank but large enough not to bend in high discharge events (Lawler, 1993). Horizontal and vertical distances between the pins in the plots were 1 m and 0.3 m, respectively. Vertical distances were smaller because streambank erosion is more variable vertically than horizontally (Lawler, 1993). Networks of erosion pins with similar vertical and horizontal distances did not influence streambank erosion processes (Hooke, 1979; Lawler 1993).

Erosion pin network plots were only placed on severely eroded streambanks. Severely eroded banks included banks that were bare with slumps, vegetative overhang, and/or exposed tree roots or were bare with massive slumps or washouts, severe vegetative overhang, and many exposed tree roots (USDA-NRCS, 1998). These banks were selected because they are the main source of sediment in channels compared to more vegetated moderately and slightly eroding bank sites. Beeson and Doyle (1995) found that bank erosion in nonvegetated stream bends can be 30 times greater than in vegetated bends.

The number of pin network plots placed in each riparian land use was based on its total bank length and number of severely eroded bank sites. Erosion pin plots were randomly selected. All the severely eroded banks were identified and recorded on a recent aerial photograph (scale 1:24,000) so they could be relocated at a later date. Within each subreach, each severely eroded bank was assigned a number, with 1 as the farthest downstream eroding bank in the subreach. A random number generator was used to select locations for the pin network plots from the total number of severely eroded banks in each subreach. The dimensions of the erosion pin plots varied from 5 to 12 m in length and 1.5 to 2.2 m in height, depending on the dimensions of the severely eroded banks.

The riparian forest buffer had six plots (159 total pins); the row crop fields had a total of eight plots (279 total pins); and the pastures had a total of eight plots (343 total pins). Compared to other studies that have used pin networks, this study had a much larger number of erosion pins (781), with more frequent measurements (monthly or bimonthly, except during the winter months) over approximately a four-year period, resulting in a large number of individual observations of erosion measurements (> 22,000) (Lawler, 1993).

Pins were initially installed with approximately 50 mm exposed. The lengths of the exposed portions of the pins were measured approximately every month from June 1998 to June 2000 and bimonthly from June 2000 to July 2002 except during winter months. During the winter, most pin plots were typically not easily accessible and/or were covered with snow and ice. A much milder winter in 2001 enabled measurement of the pins in January.

The magnitude of streambank erosion was estimated by subtracting each measurement on the erosion pin from the previous measurement. Positive differences indicated erosion, while negative differences indicated deposition. Although many researchers have not reported negative erosion in the past, Couper *et al.* (2002) recommend its use because it can affect the total magnitude of erosion. In this study the negative readings were considered deposition and were used to determine how much sediment was leaving the streambank and actually reaching the stream water to be carried away as suspended sediment. It has been recommended (Hooke, 1979; Lawler, 1993) that when a pin is completely lost, a length of two-thirds of the original pin length should be used to represent the magnitude of bank erosion. Two-thirds of 762 mm, the erosion pin length, is 502 mm. But numerous pins in this study were observed to remain in the bank with more than 600 mm of the pins exposed. As a result, 600 mm of soil loss was assumed when a pin was completely lost in this study. The magnitude of bank erosion for an erosion pin plot was the average of all the pins in the plot. For each measuring period, the erosion of all the pin plots in a riparian land use was averaged to estimate the magnitude of erosion for that riparian land use.

This paper presents the combined results of pin data collected from June 1999 to July 2002 and the previously published data collected from June 1998 to June 1999 (Zaimes *et al.,* 2004). Data were separated into four periods, each approximately one year in length: Period 1 was from June 6, 1998, to June 6, 1999; Period 2 was from June 7, 1999, to June 9, 2000; Period 3 was from June 10, 2000, to July 7, 2001; and Period 4 was from July 8, 2001, to July 23, 2002. The magnitude of bank erosion for each period was the sum of the magnitudes of bank erosion for every time the pins were measured in that period.

Severely Eroded Bank Length and Height Survey

A streambank survey was conducted in the summer of 2002. In this survey the length and height (at intervals of 2 m in length) were measured for every severely eroded bank in each riparian land use subreach. As mentioned earlier, only the severely eroded banks were included because they are the main source of bank derived sediment. The height of the eroding portion of the streambank was estimated with a scaled height pole (accuracy of 1 cm). The percentage of total severely eroding bank length for each subreach was calculated by dividing the total length of its severely eroding banks by its total bank length (USDA-NRCS, 1998). Eroding streambank areas were calculated as the product of the average height (the mean from measurements at 2 m length intervals) and total length of each severely eroded bank within a subreach. The total bank eroding area for each subreach was determined as the sum of all its severely eroding bank areas. The area of severely eroded bank per unit length (m^2/km) for each subreach was estimated by dividing its total bank eroding area by its total bank length. A similar streambank survey was conducted in summer 1998 for the same subreaches (Zaimes *et al.,* 2004), allowing a comparison of severely eroded bank lengths and areas between 1998 and 2002.

Total Streambank Soil Loss

Total streambank soil loss (metric tons or tonnes) was estimated by using magnitude of streambank erosion, soil bulk density, and total severely eroded bank area for each subreach. Total soil loss was estimated for each of the four periods of erosion pin data. Bank surveys were conducted only in 1998 and 2002, so the severely eroded areas estimated from the 1998 survey were used for Periods 1 and 2, and the eroding areas from the 2002 survey were used for Periods 3 and 4. Bulk density values were estimated only once during the study, in 1999, by collecting soil samples at 30 cm intervals from the top to the bottom of a bank face (Zaimes *et al.,* 2004). For the entire study reach, a total of 13 bank faces were sampled across all three riparian uses. The streambank soil loss per unit length of streambank (tonnes/km) was estimated by dividing the total streambank soil loss for each subreach by its total streambank length.

Data Analysis

The general linear model (GLM) in Statistical Analysis System (SAS), an analysis of variance general purpose procedure (SAS Institute, 1996), was used to compare the mean magnitudes of streambank erosion because the dataset was unbalanced. The dataset was unbalanced because it had different numbers of subreaches and plots for each of the riparian land uses. To compare the magnitude of streambank erosion among the riparian land uses and the subreaches, the lsmeans pdiff function of GLM in SAS was used. The p-values from the lsmeans pdiff were adjusted for multiplicity of tests with Tukey's method. Comparisons of magnitudes of streambank erosion among riparian land uses were made for each period, for the sum of the last three periods, and for the sum of all four periods of the study. Analysis of variance in SAS was used to compare the magnitude of bank erosion of all 22 plots for the four periods. Finally, to determine if any of the months during the research period had precipitation outside the range of normal variability, z scores were estimated in SAS. The monthly and annual precipitation amounts were compared to the monthly and annual means calculated from a 51-year precipitation dataset from a weather station near Ames, Iowa. Monthly and annual precipitation amounts were considered outside the range of normal variability if their z scores were three times greater than the standard deviation.

RESULTS

Precipitation and Magnitude of Streambank Erosion

Magnitudes of streambank erosion greater than 20 mm were measured primarily in spring and early summer (Figure 2). These periods were typically characterized by many medium (20-40 mm) and/or one or two large (> 40 mm) closely spaced daily precipitation events that resulted in high discharge (Figure 2a, 2d). This was not true with repeated medium and large daily precipitation events in the fall of Period 3 (Figure 2d). High magnitudes of bank erosion also occurred with low (< 20 mm) daily precipitation events (Figure 2c), indicating that other factors are also important in generating substantial bank erosion.

Statistically, the magnitude of bank erosion for Period 1 was significantly greater than the mean of Periods 2, 3, or 4 for all three riparian land uses combined ($p = 0.0006$), row crop fields ($p = 0.026$), pastures ($p = 0.0159$), and riparian forest buffer ($p = 0.0943$). Period 1 had above average yearly precipitation (992 mm) and twice the average for the months in which major bank erosion was measured (302 and 192 mm, in June 1998 and April 1999, respectively) (Figure 2a), compared to the 51-year averages (833 mm, 128 mm, and 88 mm yearly, June and April, respectively). Three periods – 2, 3, and 4 – had annual precipitation amounts below the 51-year average, with 459 mm, 807 mm, and 622 mm, respectively. None of the months or years during the study period were outside the range of normal variability (z scores) when compared to the means calculated from the 51-year precipitation record.

Riparian Land Uses and Magnitude of Streambank Erosion

In Period 1, magnitude of streambank erosion in the riparian forest buffer was significantly less than magnitudes in the row crop fields ($p = 0.0253$) and pastures ($p = 0.0826$) (Figure 3). In Period 2, magnitude of erosion in the riparian forest buffer was only significantly less than that in the row crop fields ($p = 0.0721$) (Figure 3). There were no statistically significant differences for Periods 3 and 4 in magnitudes of erosion among the three riparian land uses. Magnitude of erosion for the entire period (Periods 1 through 4) was significantly less in the riparian forest buffer than in the row crop fields ($p = 0.0242$) and pastures ($p = 0.0465$) (Figure 3). Magnitude of erosion for the entire study period increased in the following order: riparian forest buffer (198 mm), continuously grazed pastures (594 mm), and row crop fields (643 mm). Finally, the magnitude of erosion in the pasture with cattle was significantly higher than that in the pasture with horses for the entire study period ($p = 0.0694$) and in Period 3 ($p = 0.0636$). The magnitudes of erosion were 278 and 903 mm for Period 3 and the entire period, respectively, for the pasture with cattle and 52 and 284 mm for Period 3 and the entire study period, respectively, for the pasture with horses.

Riparian Land Uses and Severely Eroded Bank Lengths and Areas

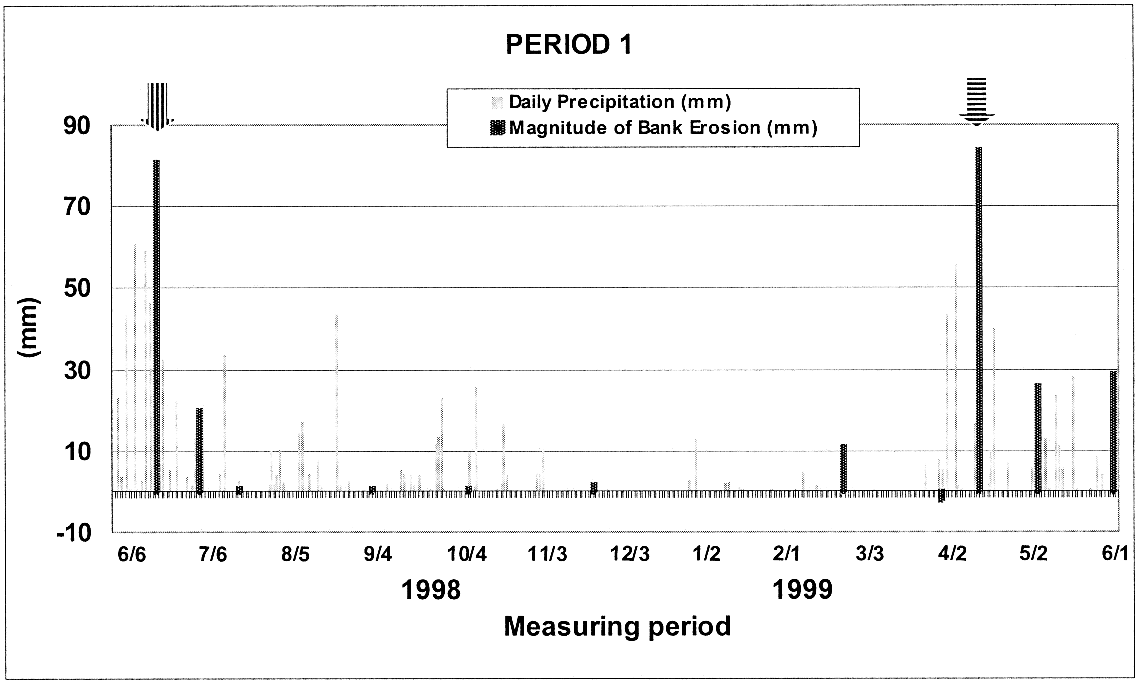
The riparian forest buffer had significantly less severely eroded bank length and area than the row crop fields and pastures in both 1998 and 2002 (Figures 4 and 5). Lengths and areas of severely eroded banks decreased or remained similar for almost all riparian land uses between the 1998 survey and the 2002 survey (Figures 4 and 5). Eroding lengths and areas in the riparian forest buffer decreased by 48 and 60 percent, respectively. Those decreases were much greater than for the combined row crop fields, 11 and 20 percent, respectively, and the combined pastures, 2 and 2 percent, respectively.

Eroding lengths and/or areas of the two row crop fields and two pasture subreaches were not always consistent. In 1998 row crop field subreach 1 had larger bank eroding areas than row crop field Subreach 2, but this was reversed in 2002 (Figure 5). The eroding areas were reduced by 41 percent for row crop field Subreach 1 but only by 7 percent in row crop field Subreach 2 during that period. The pasture subreach with horses had lower eroding lengths and areas than the pasture subreach with cattle (Figure 4 and 5). The pasture subreach with cattle was the only riparian land use to show an increase in severely eroded bank lengths and areas between 1998 and 2002.

Riparian Land Uses and Soil Loss

Soil loss per unit of bank length was always least for the riparian forest buffer (Figure 6). In Period 1 the row crop fields and pastures soil losses were similar. In Period 2 the row crop fields had the highest soil loss per unit of bank length, while in Periods 3 and 4

(a)



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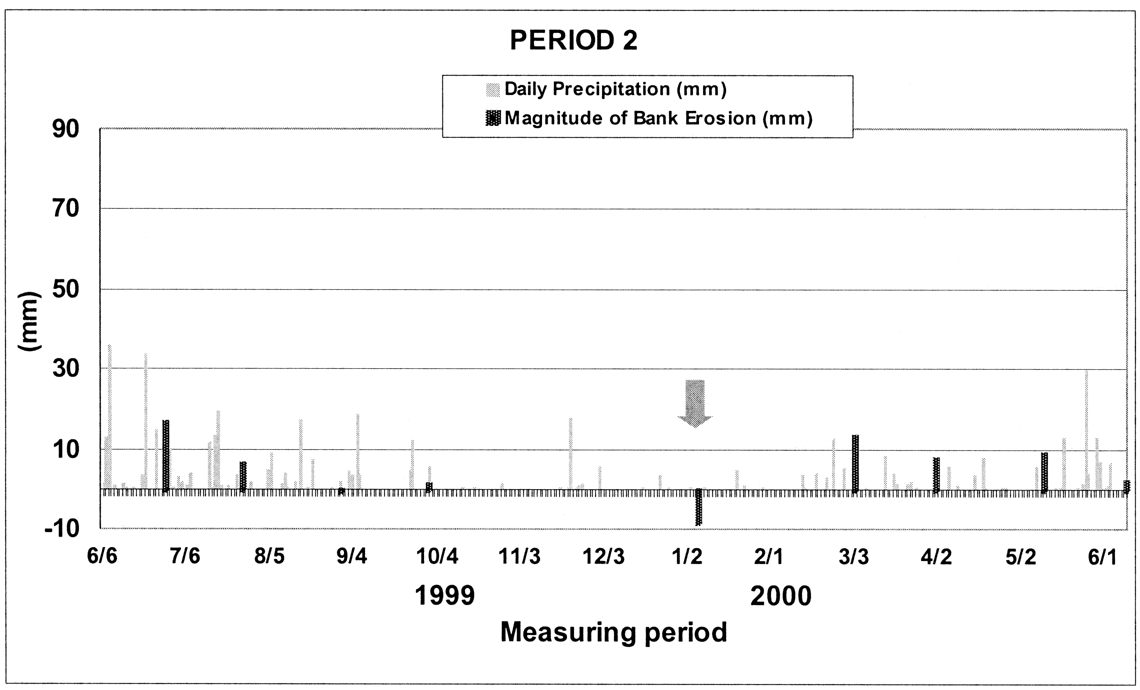


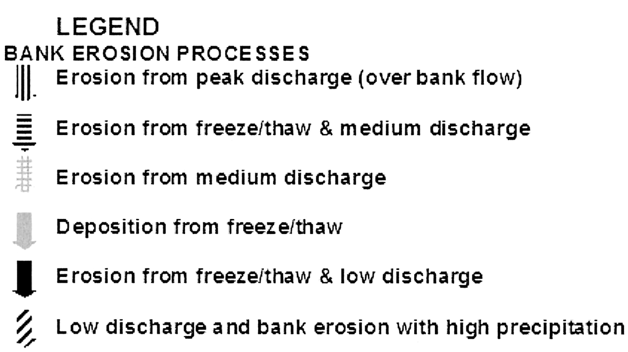
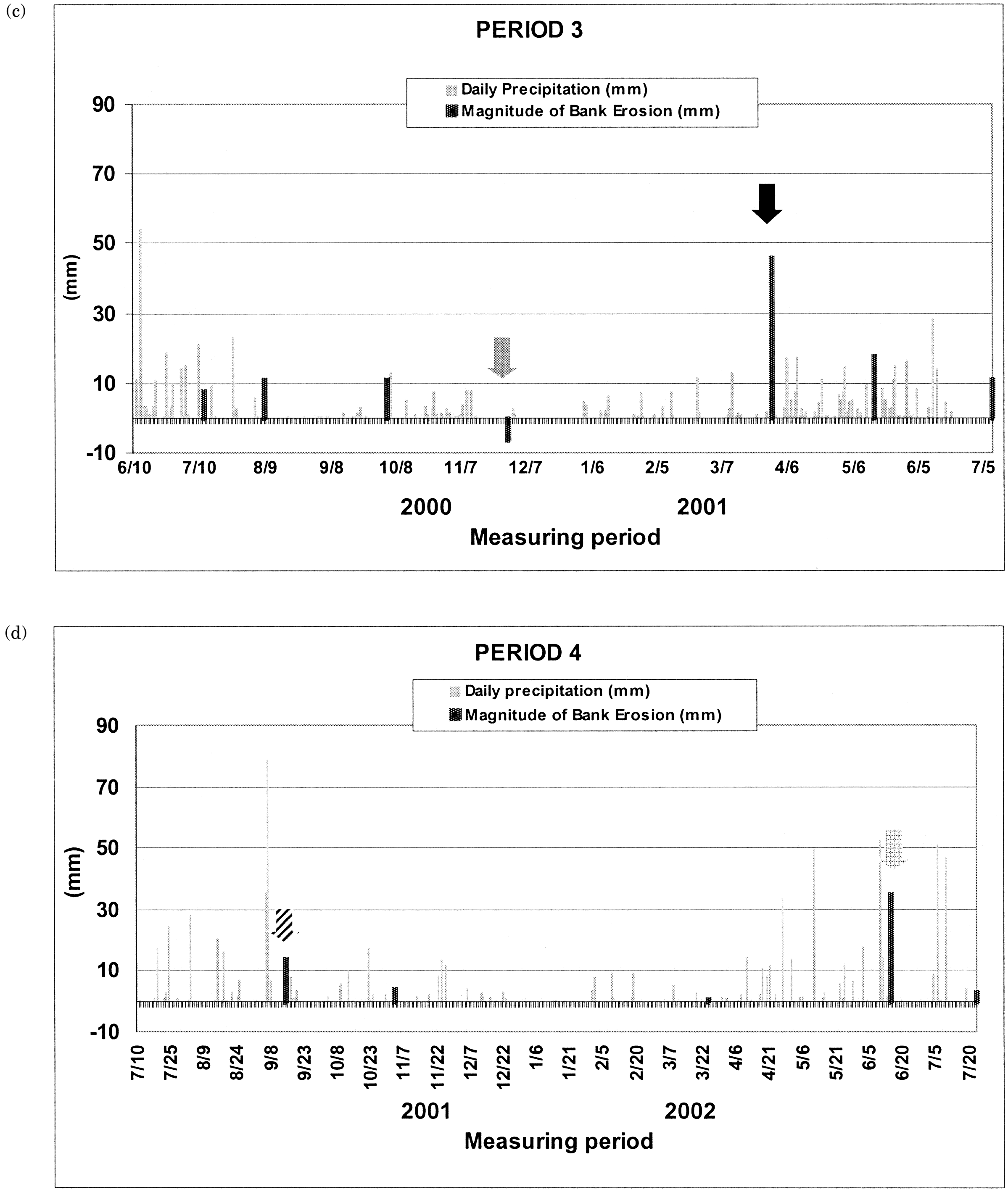


Figure 2. Daily Precipitation (mm) From a Recording Tipping Bucket Station in the Study Reach and Mean Magnitude of Streambank Erosion (mm) from 22 Plots Along Bear Creek in Central Iowa: (a) Period 1, June 6, 1998, to June 6, 1999; (b) Period 2, June 7, 1999, to June 9, 2000; (c) Period 3, June 10, 2000, to July 7, 2001; (d) Period 4, July 8, 2001, to July 23, 2002.



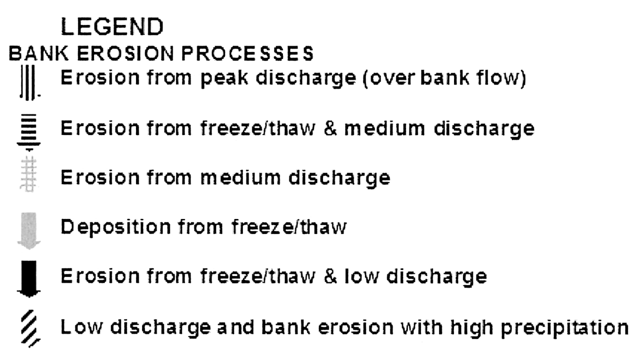


Figure 2 (cont'd). Daily Precipitation (mm) From a Recording Tipping Bucket Station in the Study Reach and Mean Magnitude of Streambank Erosion (mm) from 22 Plots Along Bear Creek in Central Iowa: (a) Period 1, June 6, 1998, to June 6, 1999; (b) Period 2, June 7, 1999, to June 9, 2000; (c) Period 3, June 10, 2000, to July 7, 2001; (d) Period 4, July 8, 2001, to July 23, 2002.

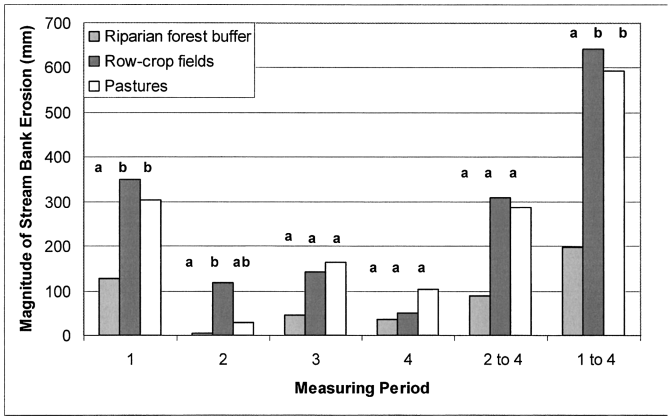


Figure 3. The Magnitude of Streambank Erosion for the Three Riparian Land Uses Along Bear Creek in Central Iowa. The letters indicate significant differences in riparian land uses in each period. Differences were considered significant when p values were less than 0.1000. Periods as in Figure 2.

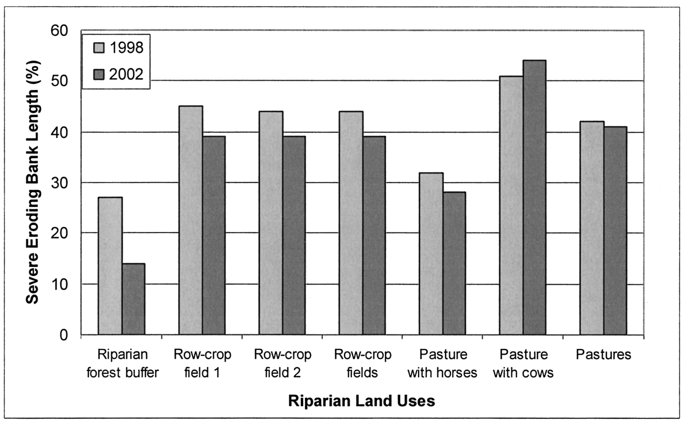


Figure 4. Severely Eroded Bank Lengths for the Three Riparian Land Uses and Their Subreaches Along Bear Creek in Central Iowa, Based on Streambank Erosion Surveys Taken in 1998 and 2002.

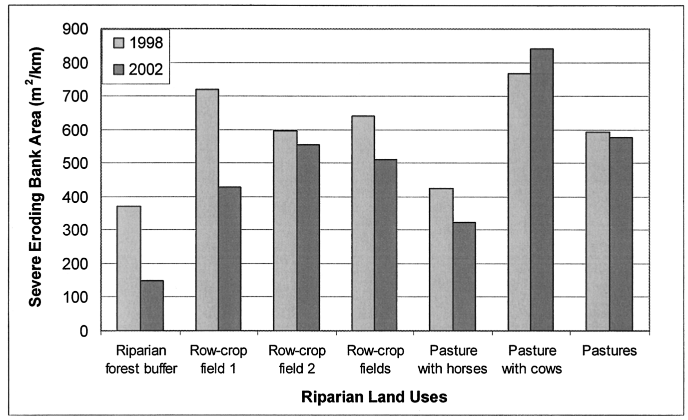


Figure 5. Severely Eroded Bank Areas for the Three Riparian Land Uses and Their Subreaches Along Bear Creek in Central Iowa, Based on the Streambank Erosion Surveys Taken in 1998 and 2002.

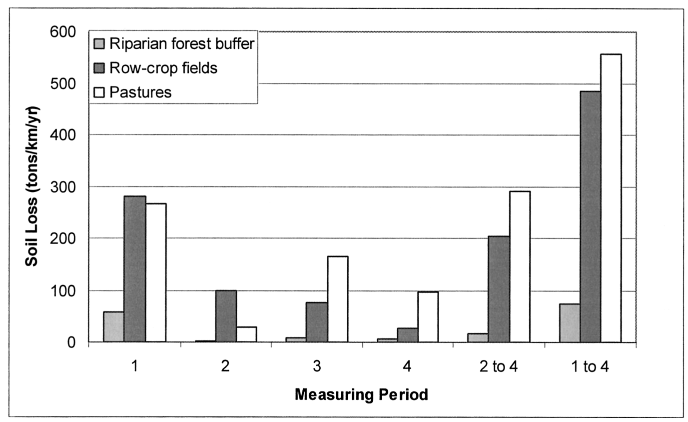


Figure 6. Soil Losses Per Unit Lengths for the Three Riparian Land Uses Along Bear Creek in Central Iowa. Periods as in Figure 2.

the pastures had the highest soil loss (Figure 6). Over the entire period, soil loss per unit of bank length for the three riparian land uses increased in the following order: riparian forest buffer, 75 tonnes/km; row crop fields, 484 tonnes/km; and pastures, 557 tonnes/km. Finally, Period 1 had the highest soil loss per unit of bank length for all riparian land uses. Both the riparian forest buffer and the row crop fields had higher soil losses in this period than in the other three periods combined (Figure 6).

Applying the soil loss per unit length to the total bank length in each subreach, the total 7.5 km of study reach contributed 2,652 tonnes soil from bank erosion in Period 1; 554 tonnes in Period 2; 1,086 tonnes in Period 3; and 582 tonnes in Period 4; the total was 4,873 tonnes over the entire period (Table 1).

DISCUSSION

The magnitude of streambank erosion was episodic with seasonal and yearly variation (Hagerty *et al.*, 1981). Not all large increases in bank erosion were coincident with high precipitation and high flow events, suggesting that other factors influenced bank erosion (Figure 2). This was particularly evident in September of Period 4 (Figure 2d), when many medium and high daily precipitation events occurred but

TABLE 1. Total Streambank Soil Losses in the Three Riparian Land Uses and Their Subreaches Along Bear Creek in Central Iowa.

Riparian Land Use	Bulk Density[1] (g•m/L)	Stream Bank Length[2] (km)	Total Soil Loss Period 1[3] (tonnes)	Period 2[3] (tonnes)	Period 3[4] (tonnes)	Period 4[4] (tonnes)	Period 2 to 4 (tonnes)	Period 1 to 4 (tonnes)
Riparian Forest Buffer	1.24 (0.04)	6.4	370	12	53	38	103	513
Row Crop Fields 1	1.34 (0.05)	1.4	598	173	172	60	404	1,314
Row Crop Fields 2	1.33 (0.03)	2.8	570	242	146	53	441	1,166
Row Crop Fields 1 and 2	1.33 (0.03)	4.2	1,198	415	318	113	845	2,599
Riparian Pasture (horses)	1.34 (0.03)	2.2	231	3	50	45	98	331
Riparian Pasture (cattle)	1.33 (0.05)	2.1	924	124	665	380	1,170	2,179
Riparian Pastures (both)	1.33 (0.03)	4.3	1,155	127	715	425	1,268	2,510
Totals		14.9	2,693	554	1,086	576	2,216	5,622

Notes: Measuring periods were grouped as: Period 1, June 6, 1998, to June 6, 1999; Period 2, June 7, 1999, to June 9, 2000; Period 3, June 10, 2000, to July 7, 2001; Period 4, July 8, 2001, to July 23, 2002.
[1]From Zaimes *et al.* (2004); standard errors in parentheses.
[2]Includes the bank lengths of each side of the stream channel.
[3]Estimated by multiplying specific period mean magnitude of streambank erosion, mean bulk density, severely eroded bank area per unit length 1998.
[4]Estimated by multiplying specific periods mean streambank erosion magnitude, mean bulk density, severely eroded bank area per unit length 2002.

failed to produce significant magnitudes of bank erosion. In contrast, medium and high daily precipitation events did increase the magnitudes of bank erosion during spring and early summer (Figure 2a, 2d).

The density of vegetation cover is the main difference between spring or early summer and fall in this area of Iowa. Row crop fields dominate this area with little or no vegetation cover on most of the watershed in early spring because the fields are fallow. After the annual row crops are planted later in spring, plants still have low water use, the fields have low infiltration rates, and much of the precipitation ends in overland and drainage tile flow that causes peak or medium discharges. Peak discharge events can cause substantial magnitudes of bank erosion, through shear stress of the water on the banks (fluid entrainment) (Lawler *et al.,* 1999) or during the recessional limb of hydrographs because of rapid drawdown of the water table in the banks (Simon *et al.,* 1999). An out-of-bank flood discharge event (authors' personal observations) was the main cause of erosion in June (1998) of Period 1 (Figure 2a). Medium discharge events, similar to the June event of Period 4, can also cause streambank erosion with the same mechanisms as peak discharges, but the magnitude of erosion is typically smaller (Figure 2d). In contrast, in September of Period 4, higher precipitation events did not produce a significant magnitude of bank erosion because during early fall the row crops (primarily) and other vegetation were mature and transpiring significant amounts of water that decreased antecedent soil moisture, increasing available storage for soil moisture, and thereby decreasing overland flow and peak discharges (Figure 2d). Specifically, the 15-minute precipitation intensity and daily precipitation for September of Period 4 were higher than those in June (1998) of Period 1 that produced an out-of-bank flood discharge event.

Another mechanism that can influence the magnitude of bank erosion is freeze and thaw (Lawler *et al.,* 1999). Freeze and thaw loosens the soil on the bank face, and the loosened soil creeps or falls from the upper part of the bank to the lower because of gravity or flows with melting snow and ice. In Period 2 (Figure 2b), pins were measured in January because the winter was much milder than usual and the pin plots were accessible and not covered with snow or ice. At that time all 22 plots had net soil deposition, even though the pins on the upper parts of the bank of most plots had erosion. Similarly, most plots experienced net deposition in late November of Period 3 when daytime and nighttime air temperatures alternated between above freezing and below freezing values (Figure 2c). While deposition can result from different phenomena (Couper *et al.,* 2002), the main processes occurring in this study were likely freezing and thawing because of the nature of the soil materials in the deposit and the timing of the deposition events. In January of Period 2 and November of Period 3, the plots had net deposition because loosened soil from freeze and thaw had not been moved yet because of low baseflow. In contrast, in March of Period 3, soil loosened on streambanks from freeze and thaw was removed by small discharge events (authors' personal observations) (Figure 2c). Finally, medium discharges after freeze and thaw, as in April of Period 1, resulted in a magnitude of bank erosion comparable to that caused by out-of-bank floods (peak discharge), as in June (1998) of Period 1 (Figure 2a) (Zaimes *et al.,* 2004).

Bank erosion magnitudes were greatest in Period 1 relative to the other three periods. The severely eroded bank lengths and areas of the streambank survey of 1998 were also greater compared to the survey of 2002 except in the pasture with cattle. The higher magnitude of these two variables led to higher soil loss in Period 1 compared to the other three periods. There were two reasons for the decrease in streambank erosion for all three riparian land uses following Period 1. The first was below average rainfall for Periods 2, 3, and 4. Precipitation was enough to support increased vegetation growth on the banks but not enough to produce high peak discharge events. The other reason was that a significant portion of the riparian area in this watershed was planted in some conservation practice (grass filter or riparian forest buffer), which also may have decreased overland flow and led to smaller peak discharge events (Lee *et al.,* 2000).

The streambank erosion rates (mm/yr) and trends among riparian land uses of this study fall into the range of rates found in many other reported studies, even though many of them were conducted in very different environments and in other countries (Table 2). In general, the rates measured in this study correlated well with those reported for watersheds with drainage areas of up to 97 km^2. Locally, the Four Mile Creek watershed in Iowa had similar erosion rates and drainage area (Hamlett *et al.,* 1983) as found in this study. However, in this study, the bank erosion rates were also similar to ones found in watersheds of similar size to other states in the U.S., Australia, Canada, United Kingdom, and Luxemburg. The 1959 study at Watts Beck, Maryland, USA (Wolman, 1959), conducted along a grazed riparian pasture reach and the 1980 study at Four Mile Creek, Iowa, USA (Hamlett *et al.,* 1983), along row crop fields both had higher erosion rates than those found in the 1986 study at Kirkston, Scotland (Stott *et al.,* 1986), and the 1987 study at Schrondweilerbaach, Luxemburg (Duijsings, 1987), where the study areas had forested riparian zones (Table 2). Similar responses were found in this study, in which the pastures and row crop fields likewise had higher erosion rates than the riparian forest buffers. All of these studies suggest that riparian forest buffers can be effective in reducing streambank erosion elsewhere in the U.S. and around the world.

The riparian forest buffer had the lowest values for all four bank erosion variables (magnitude, severely eroded bank lengths, severely eroded bank areas, and soil loss) compared to the row crop fields and pastures. When streambanks become covered with perennial vegetation, their roughness coefficient should increase, which in turn should decrease stream water velocity and stream power along the bank. Trees, especially willows (*Salix* spp.) and silver maple (*Acer saccharinum* L.), protect streambanks because of their high stem density and deep and fibrous rooting habits that provide support to soil to resist fluid entrainment (Shields *et al.,* 1995; Abernethy and Rutherfurd, 2000). The increase in shear resistance of streambanks from trees depends on the rooting depth of the trees and streambank height (Simon and Darby *et al.,* 1999). If roots cover only part of the streambank face (where banks are very tall), then bank shear strength will not increase for the entire bank face, leaving the uncovered parts susceptible to undercutting and streambank erosion. In contrast to trees, annual row crops have very shallow annual roots that are present for only part of the year. Heavy stocking rates in continuously grazed pastures also reduce the number and length of roots on perennial pasture grasses that anchor the soil, while heavy trampling along and on the streambank increases streambank instability (Belsky *et al.,* 1999).

The impact of riparian forest buffers was also evident in the two row crop field subreaches. The severely eroded bank length for both row crop fields decreased 5 to 6 percent (Figure 4) from 1998 to 2002, but the severely eroded bank area of row crop field Subreach 1 decreased much more substantially (41 percent) compared to row crop field Subreach 2 (7 percent) (Figure 5). The difference between the row crop fields was the establishment of a riparian forest

TABLE 2. Comparison of Streambank Erosion Rates Along Bear Creek in Central Iowa With Published Streambank Erosion Rates for Drainage Areas of Similar Size (0 to100 km^2) or in the State of Iowa.

Reference	River/Location	Drainage Area (km^2)	Erosion Rate (m/yr)	Method
This Study				
Riparian Forest	Bear Creek, Iowa, USA	52	0.004 to 0.142	Erosion Pins
Row Crops			0.050 to 0.387	
Pastures			0.029 to 0.295	
Allen (1895)	Des Moines, Iowa, USA	~13,000	> 6.0	Historical References, Planimetric Survey
Dryer and Davis (1911)	Normal Branch, Indiana, USA	2.6	0.9 to1.8	Planimetric Survey
Wolman and Leopold (1957)	Watts Beck, Maryland, USA	9.6	0.075	Repeated Cross Profiling
Wolman (1959)	Watts Beck, Maryland, USA	9.6	0.5	Planimetric Survey, Repeated Cross Profiling, Erosion Pins
Leopold *et al.* (1964)	Watts Beck, Maryland, USA	9.6	0.5	Erosion Pins
Twidale (1964)	R. Torrens, Australia	77.8	0.58	Erosion Pins
Leopold *et al.* (1966)	Slopewash Tributary, New Mexico, USA	0.1	0.006	Erosion Pins
Bluck (1971)	R. Endrick, Scotland, UK	97.7	0.5	Historical References
Handy (1972)	Des Moines, Iowa, USA	~10,000	3 to 19.0	Historical References
Hill (1973)	Crawfordsburn Rivul., North Ireland, UK	3.0	0 to 0.5	Erosion Pins
Hill (1973)	Clady Rivulet, N. Ireland, UK	2.0	0 to 0.064	Erosion Pins
Leopold (1973)	Watts Beck, Maryland, USA	9.6	0.5	Planimetric Survey, Repeated Cross Profiling
Imeson and Jungerius (1974)	Birbaach, Luxemburg	1.6	0.008	Erosion Pins
Lewin *et al.* (1974)	Maesanant, Wales, UK	0.5	0.03	Planimetric Survey, Erosion Pins
Piest and Bowie (1974)	Pigeon Roost, Mississippi, USA	4.0-303.0	0.02-0.5	Repeated Cross Profiling
Hughes (1977)	Cound, England, UK	100.0	0.64	Planimetric Survey, Repeated Cross Profiling
Lawler and Bull (1977)	Pennard Pill, Wales, UK	30.0	1.25	Planimetric Survey
McGreal and Gardiner (1977)	Lagan, N. Ireland, UK	85.0	0.08 to 0.14	Erosion Pins
Lawler (1978)	Ilston, Wales, UK	6.4	0.05	Erosion Pins
Hooke (1979)	Various, England, UK	9.6 to 620.0	0.08 to 1.18	Repeated Cross Profiling
Hooke (1980)	Various, England, UK	9.6 to 620.0	0.08 to 1.18	Repeated Cross Profiling, Erosion Pins
Hamlett *et al.* (1983)	Four Mile Creek, Iowa, USA	55.5	0.39	Repeated Cross Profiling
Gardiner (1983)	Lagan, North Ireland, UK	85.0	0.08 to 0.14	Erosion Pins
Murgatroyd and Ternan (1983)	Narrator, England, UK	4.8	< 0.03	Erosion Pins
Nanson and Hean (1985)	Illawarra, Australia	1.6 to 37.8	0 to 32.7	Repeated Cross Profiling
Duysings (1986)	Schrondweilerbaach, Luxemburg	0.6	0.02 to 0.035	Repeated Cross Profiling, Erosion Pins
Stott *et al.* (1986)	Kirkston G., Scotland, UK	< 7.7	0.016 to 0.076	Repeated Cross Profiling Erosion Pins
Bray (1987)	N. Nashwaaksis, Canada	26.9	0 to 2	Planimetric Survey, Repeated Cross Profiling
Duijsings (1987)	Schrondweilerbaach, Luxemburg	0.6	0.02 to 0.035	Repeated Cross Profiling, Erosion Pins
Lawler (1987)	Ilston, Wales, UK	6.7	0.067	Erosion Pins
Odgaard (1987)	Des Moines, Iowa, USA	5,700.0	8	Historical References
Odgaard (1987)	East Nishnabotna, Iowa, USA	2,500.0	7.6 to 8	Historical References
Leeks *et al.* (1988)	Trannon, Wales, UK	72.0	0.03 to 0.96	Historical References, Repeated Cross Profiling

buffer in spring of Period 2 along the row crop field Subreach 1. Even though newly planted perennial plants in the buffer provided only minimal cover, cultivation and harvest disturbances associated with row crop culture were eliminated, minimizing disturbances along the streambanks of row crop Field 1 compared to the row crop Field 2.

The impact of different management of similar riparian land uses is evident in the two pasture subreaches. The pasture with cattle had consistently higher magnitudes of bank erosion than those for the pasture with horses for the entire study period (sum of all four periods) and for Period 3. The pasture with cattle was also the only subreach to show an increase in eroding stream length (3 percent) and eroding area (10 percent) from 1998 to 2002. The reasons for the increase in severely eroded bank lengths and areas was probably correlated to the increase in cattle stocking rates in 1999 through 2001 compared to 1998 and less available water in the channel during these drier years that led cattle to enter the stream in more places. In contrast, the horse pasture showed a decrease in eroding length (4 percent) and an even larger decrease in eroding area (24 percent). The main management difference was that the pasture with cattle had 3 to 3.5 times more animal units (kg/ha) than the pasture with horses, depending on the year. In addition, cattle tend to spend more time in and close to streams than other livestock (Platts, 1981). The stocking rate for the cattle pasture was particularly high, 2.3 to 3.1 cow/calf pairs per hectare. For Kentucky bluegrass (*Poa pratensis* L.) pastures in Iowa, the recommended stocking rates are 0.5 to 1.3 cow/calf pairs per hectare (Barnhart *et al.,* 1998).

SUMMARY AND CONCLUSIONS

Riparian vegetation and land use are an integral part of streambank erosion, but high precipitation levels and associated high discharges can also influence the erosion process. Differences in the magnitude of bank erosion, severely eroded bank lengths and areas, and soil losses throughout this study are partially attributable to differences in precipitation that were associated with the occurrence of substantial discharge events. Other processes such freeze and thaw events and season, which impacted the density of the vegetation cover of the watershed, were also implicated. The variation in soil losses from streambank erosion over the entire study period also suggest that a dataset of many years is needed to get a good estimate of bank erosion contributions to stream sediment load. One-year datasets can be misleading in estimating the long term contributions of bank erosion to stream sediment loads.

To estimate the potential impact of riparian forest buffers on the overall sediment load derived from streambank erosion along the study reach of Bear Creek, it was assumed that all nonbuffered subreaches had reestablished riparian forest buffers of at least four years of age. The assumption also was made that the magnitude of streambank erosion and the severely eroded bank areas of these recently buffered subreaches would have been equal or similar to those of the actual riparian forest buffer monitored in this study (Figures 3 and 5). Since bank surveys were only conducted in 1998 and 2002, the riparian forest severely eroded bank areas from the 1998 survey were used to estimate reductions for Periods 1 and 2 and from the 2002 survey for Periods 3 and 4. Based on these assumptions, the soil losses from the nonbuffered subreaches would decrease by 1,752 tonnes for Period 1 (77 percent reduction), by 525 tonnes for Period 2 (97 percent reduction), by 957 tonnes for Period 3 (93 percent reduction), and by 476 tonnes for Period 4 (88 percent reduction), a total of 3,709 tonnes or an 84 percent reduction for the entire study period had they all had a well established riparian forest buffer. However, if stream power was not reduced along with the increased bank protection, the channel would erode sediment from other subreaches to maintain the equilibrium suggested by Lane's (1955) channel equilibrium model. If the subreaches were not in Stage III (widening) of the evolution model (Schumm *et al.,* 1984), responses might have been different as well.

The presence, density, and type of riparian and streambank vegetation influence streambank erosion (Beeson and Doyle, 1995). As the percentages increase of row crop fields and overstocked continuously grazed land in riparian zones, streams deepen and widen because of increased overland flow and less vegetation cover on the banks (Hamlett *et al.,* 1983; Geyer *et al.,* 2002). In these incised channels, riparian forest buffers can help increase streambank stability because of deeper and denser rooting habits than those of crop or grass plants and at a lower cost than most streambank bioengineering methods. Lee *et al.* (2000) found that riparian forest buffers can reduce sediment from overland flow from row crop fields up to 90 percent. Narrow corridors of riparian forest buffers provide an excellent riparian alternative land use to row crop fields and continuously overgrazed pastures to reduce the greatest nonpoint source pollution problem along Midwestern streams – sediment from streambank erosion and overland flow.

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