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HIGH STAGE EVENTS AND STREAM BANK EROSION ON SMALL GRAZED PASTURE STREAM REACHES IN THE RATHBUN LAKE WATERSHED, SOUTHERN IOWA, USA

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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 frequency of high-stage events over short periods of time (forming flash hydrographs). The objective of this study was to assess the relationship between the number of high stream stages and corresponding 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 bank erosion rates were correlated with the different stream stages data to assess their impact on stream bank erosion. Based on the different model assumptions, there were generally strong linear relationships between high stage and bank erosion. Approximately 75% of the variability in stream bank erosion rates was directly linked to the number of high stages/erosive stream flow depths. Conservation practices that reduce these erosion 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.

Keywords: streambank erosion, stage-erosion relationship, grazing pasture system, agricultural small order streams.

INTRODUCTION

Alteration in the hydrologic cycle of an agricultural watershed is influenced by the change in land-use affecting the percent of cover in row-crop or grazed pasture. The changes in land use 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 (peak) flow, and less evapotranspiration as a result of reduced soil-water storage and/or 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 steady-state conditions develop (Menzel, 1983).

Another important factor affecting the function of the hydrological cycle is change in the precipitation amount and such characteristics as intensity, frequency and duration. 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), but with precipitation patterns possibly changing to short torrential downpours in contrast to longer, more gentle rain. 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 suggested 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). Raymond et al. (2008) and Schilling et al. (2010) suggested that land-use change and management practices are more important than the changes due to climate in explaining increased stream flow in the Mississippi River.

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 (Burkhart et al., 1994; Whitney, 1994). Most of the wetlands were converted to agricultural land through use of artificial subsurface drainage. Along with these changes, streams were also channelized to provide drainage outlets and 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, reductions in soil-water storage have resulted in an increase and acceleration of peak discharge leading to flashy hydrographs during storm events (Bormann et al., 1999). Knox (2001) concluded that agricultural land use, along with artificial subsurface drainage and channelization, has increased peak discharges from high-frequency floods to such an extent that comparing modern process rates with those prior to human disturbance is 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 in a number of studies (Fitzpatrick, 2001; Karwan et al., 2001; Straub, 2004; Wallbrink and Olley, 2004).

Stream bank erosion accounts for a significant portion of the total soil contributions to receiving water bodies. Studies by Laubel et al. (1999, 2003) and Schilling and Wolter (2000) 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 et al. (2004) reported that gully and stream bank erosion contributed 48% of the total sediment load to an estuary. Ranges of total-phosphorus (P) contribution to channels from stream bank erosion have been variously documented as 7–10% (Sekely et al., 2002), 15–40% (Laubel et al., 2003) and 56% (Roseboom, 1987). A review by Fox et al. (2016) reported that stream bank and gully erosion accounted for 6 and 93% of total P and 7 and 92% of the suspended sediment load within a channel, respectively.

Our companion studies, conducted in the same pasture stream reaches as this study, concluded that intensive grazing management of these pastures had significant impacts on riparian land uses that increased the bank soil bulk density, eroded stream bank length (Tufekcioglu et al., 2012) and manure covered ground, and decreased forage sward heights (Bare et al., 2012). However, these two studies found no immediate relationship between pasture stocking rate and stream bank erosion and further suggested that bank erosion mainly driven by the stream hydro-geomorphologic characteristics should be identified in both field and catchment scales. The objective of this study is to assess the mathematical relationship between the number of high stage events classified into a four different "sections" and the responding seasonal bank erosion amounts in six reaches of low order channels within the Rathbun Lake Watershed in southern Iowa.

MATERIALS AND METHODS

Study sites and treatments

Six cooperating beef cow-calf farms along stream reaches of the Rathbun Lake Watershed in southern Iowa USA 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 (Prior, 1991). The major riparian soil association in the Rathbun watershed is the Olmitz-Vesser-Cola Association (USDA Soil Survey, 1971). Such soils are loam, silt loam and silty clay loam. Soils in this complex are poorly to moderately drained. Land-use within the 143,323 ha of the Rathbun watershed consisted of 38% pasture and hay land, 30% crop land, 12% Conservation Reserve Program, 13% woodland and 7% urban/road/open water (Braster et al., 2001).

Riparian grazing treatments were classified by stocking rates ranging within 3–19 cow-days m^{-1} yr^{-1}. Cow-days per stream length were calculated as the product of the number of cows and number of days they were on the pasture divided by stream length. From the six sites, stream reaches for four (sites 2–5) were classified as first-order streams (Strahler, 1957; Fig. 1 and Table 1). Site 1 was second order and site 6 was third order. Additionally, all of these stream reaches were in the widening stage (stage III) of the channel evaluation model (Schumm et al., 1984). Other pasture stream reach (site) characteristics including pasture size, bank height, stocking rates, stream reach bed slope, stream bed sinuosity, catchment size and total erosion rate are presented in Table 1.

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

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

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

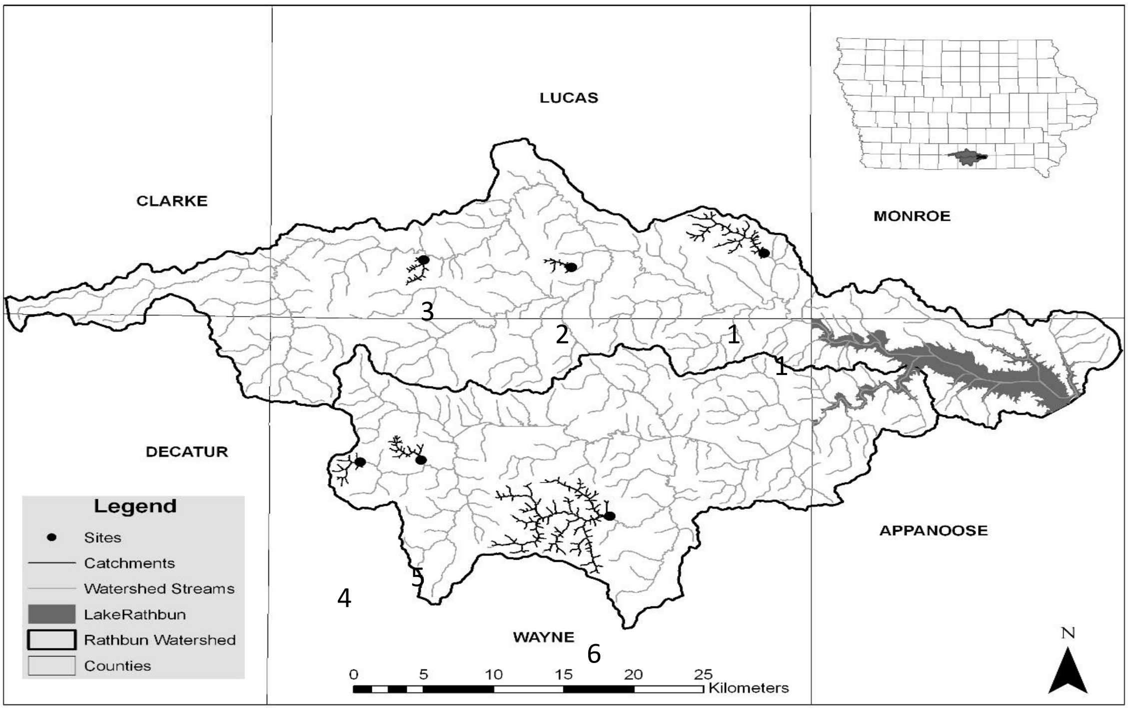

Figura 1. Stream stage (transducer) locations/sites and catchments stream system within the Rathbun Watershed in southern Iowa. Numbers correspond to site identification (ID). Site 1 is located on a second order stream, site 6 is on a third order stream and sites 2–5 are on first-order streams (Strahler, 1957).

The dominant grass species 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. Thus, stream reaches and their stage characteristics were impacted by the hydrological change due to land use impact.

Almost all studied stream reaches (total bank length range of 612–2276 m) had some trees (5–10) scattered near stream banks. The major soil textural unit in the bank soils of the six sites was silt loam. Further description and details of pasture sites and bank variables are found in companion studies (Bear et al., 2012; Tufekcioglu et al., 2012).

Stream bank erosion pins

The erosion pin method was used to quantify sediment loss from bank erosion (Wolman, 1959). This method 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). After surveying the total length of severely and very severely eroded stream banks, 15% of these bank lengths in each pasture were randomly selected for installation of erosion pins (Tufekcioglu et al., 2012). There were 4–9 pin plots depending on the total length of eroded stream banks per pasture. Erosion pin plots had two rows of 6–34 pins, 1 m apart, at 1/3 and 2/3 of the stream bank height, resulting in 3–17 columns with pins directly above one another, depending on eroded length. When 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). Pins were installed in November 2006. Exposed pin lengths (cm) were measured during the winter/early spring (last week of November to first week of May), summer (first week of May to first week of August) and fall (first week of August to last week of November) 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. However, when the difference was negative, the pin measurement represented deposition. An erosion rate of 600 mm was assumed in the case where pins were lost during an erosion event since, in previous measurement, they were usually set for (approximately) 160 mm. Seasonal erosion amounts were correlated with stream stages to assess the relationship between stream bank erosion and stage.

Stream stage data

Water table depth in the near riparian zone at each of six reaches was recorded within monitoring wells installed approximately 0.5 m from the stream bank edge (Fig. 2).

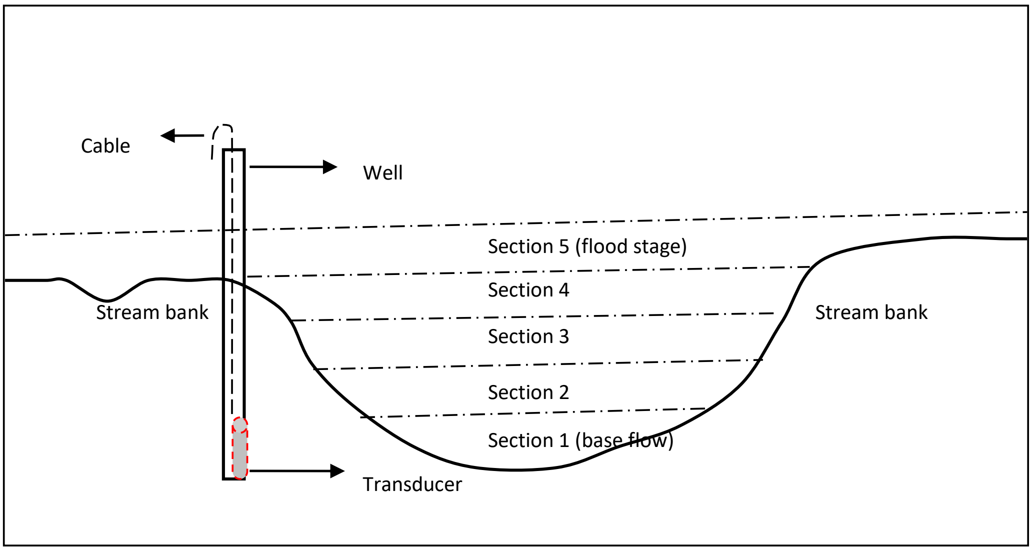

Figura 2. Location of the transducer on the stream bank and five different preset stream stage sections and their cumulatively predicted erosion response values (section 1 = 0, section 2 = 1, section 3 = 2, section 4 = 3 and section 5 = 4). The assigned/predicted erosion values for each section were based on the assumption that there was a linear relationship between stream bank erosion rate and stage.

Sites were selected as having near-average stream bank height for a given stream reach with uniform stream cross-sections. Although 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 gauging of stream stage 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 concerns, transducers were removed from wells during winter (December–March). Therefore, no stream stage data were recorded during winter; only summer and fall bank erosion data were correlated with stream stage data.
The total cross-sectional area of the stream was divided into four equal stage "sections" with respect to its total vertical bank height and defined as "section 1" (base flow), "section 2", "section 3", "section 4" and "section 5" (flood stage/upper threshold; Fig. 2). Stream stage data were classified according to the high flow depth match with the corresponding sections (number of times of occupancy of a section by the high stream flow depth) and the recorded section events were correlated with seasonal erosion rates in each site to determine if there was a relationship between bank erosion and stage within both "given section" and for "all sections' total". Because section 1 was the base flow condition (a lower flow threshold) where there was minimal erosive flow and/or no bank erosion, it was not included in the correlation analysis. A study by Larsen et al. (2006a) also removed lower stream discharge from the cumulative effective stream power, which improved the statistical relationship between bank erosion and stream power. In our study, sections 2–5 had an erosion response (index) value of 1, 2, 3 and 4, respectively, based on the assumption of a linear relationship between stage and bank erosion (Fig. 2). A linear correlation between erosion and stream power was observed and further suggested testing the mathematical relationship of Larsen et al. (2006a).
Assessing the relationship between erosion and discharge or stage among the sites with different stream orders/system and land characteristics is a challenging issue. Namely, same amount of discharge in two different stream systems can have different responses in terms of bank retreat. This is not just because of area differences in the wetted parameters of the stream cross-section but the erodibility of the bank soil and its vegetative cover. Thus, herein, the six reaches were not only evaluated for the response of site-specific conditions but also for cumulative effects of causative erosion factors by examining the correlation between bank erosion rates and the frequency of four different preset stream stages (sections) from all sites. Using the "section" approach to examine the relationship between bank erosion and stage is important to illustrate the impacts of major flow events (numerically) by the stage (section) differences proportional to the given total bank heights of each individual stream reach from all sites.

Data analysis

The relationship between stream stage and stream bank erosion was examined using the mixed procedure within the Statistical Analysis Systems (SAS Institute, 2003). Change in stream stage (occupancy of the sections by stream flow in numbers of times) was used as an independent variable to explain 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 because bank erosion is affected by many spatial, temporal, climatic and anthropogenic factors. To assess the fit of our model to data, we considered the correlation between the model predictions and observed responses. This statistic has a similar interpretation to that of R^2 in linear models.

RESULTS

We found a strong relationship between stream bank erosion and the frequency of high stage events in six reaches of low-order stream channels. In terms of land use effects as a grazed pasture, although we did not find a relationship between cattle stocking rate (Lu d m^{-1}: livestock unit day per stream length) and stream bank erosion rate, there was a significant relationship between stocking rates and both eroding stream bank length and riparian soil bulk density. Details regarding this relationship were presented in the companion study conducted on the same grazed pasture sites (Tufekcioglu et al., 2012). Such results highlight the complexity of interactions between riparian land use, stream hydrology and ultimately stream bank erosion.

Stream bank erosion occurs under the sets of physical complex processes and is further affected by spatial and temporal scale differences (Zaimes et al., 2006). A number of variables can influence stream bank erosion rate including channel depth, slope and width (Odgaard, 1987) as well as bank vegetation, bank angle and stream power (Laubel, 2003). This study identified numbers of site characteristics, including pasture size, bank height, stream bed slope and sinuosity, and catchment size (Table 1), that may have different impacts on the measured bank erosion rates. However, herein the mathematical relationship was only assessed between bank erosion amount and high stage events per season as the main controlling factor of bank erosion across the six different pasture sites with and without pooled data.

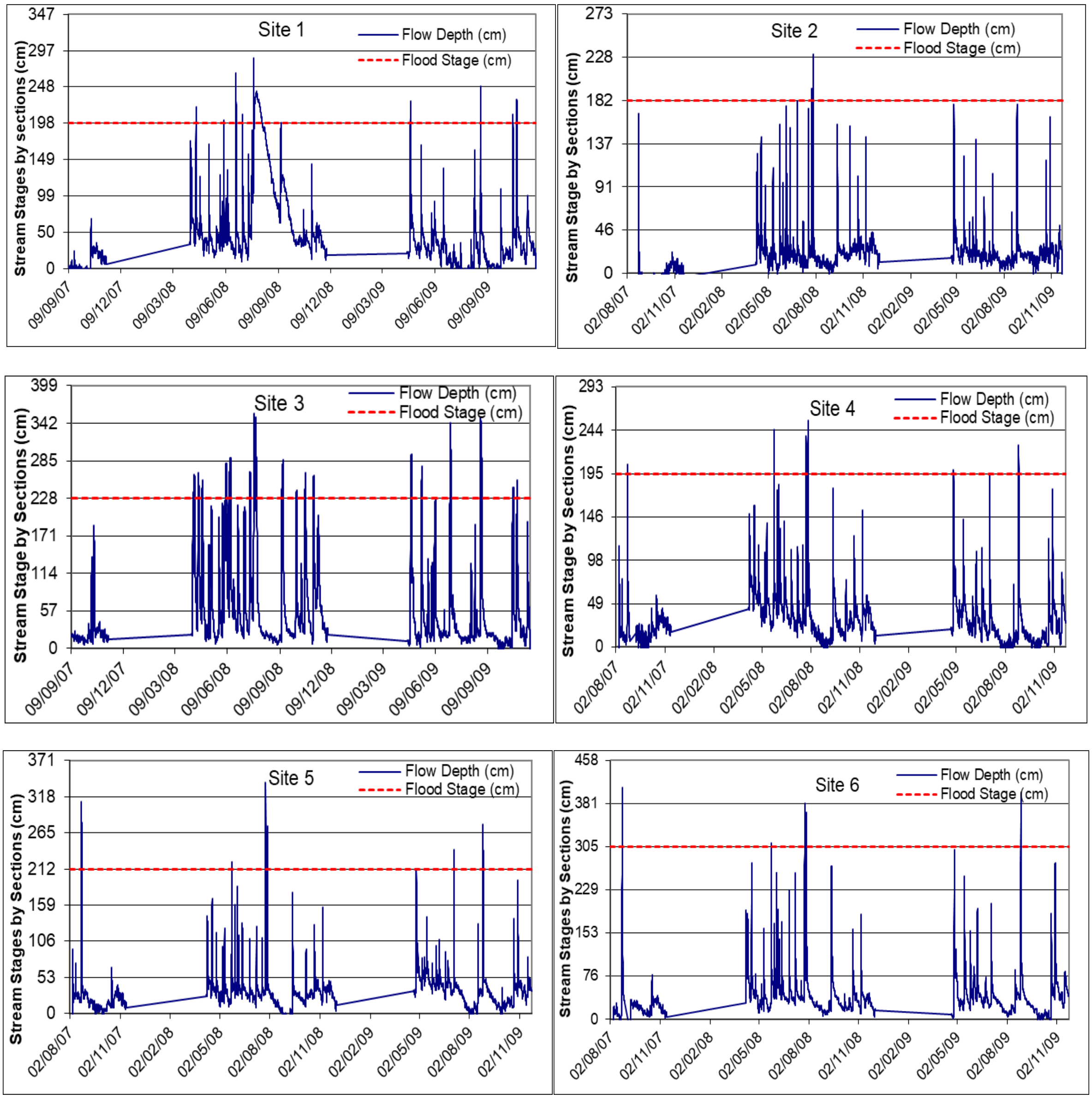

Figure 3. All stream stage events that were occupied from August/September 2007 to November 2009 from the six study sites (sites 1– 6). Stream stages further classified as “sections” including sections 1–5. Each study site had different vertical section heights based on the total bank height of the given site. For instance, in site 1 the section heights were ranged for sections 1–5 as 0–50, 51–99, 100–149, 150–198 and 199–248 cm, respectively. Note: parallel stage lines in section 1 show the winter time range when there was no transducer in the wells to measure the stage. Stream stage values by each section and sections’ totals are presented in Table 2.

Stream bank erosion and stream stage

The stability of the stream bank soil is controlled by two main anthropogenic factors. First is adjacent land use such as row-crop, grazed pasture, grass filter and/or forest buffer. It has been well documented that riparian areas with perennial vegetation cover and without livestock and machinery impacts have lower rates of stream bank erosion (Laubel et al., 1999, 2003; Zaimes et al., 2004, 2008). Mixed stands of riparian woody and grass species increase bank stability and soil strength by mechanically reinforcing soil (soil–root binding) and dewatering bank soil through increased evapotranspiration (Simon and Collison, 2002). Second is the change in stream flow characteristics (particularly number of high flow peaks/stages and differences in flow duration) in response to long-term changes in amount and pattern of precipitation and land use/cover at the watershed scale.

Studies have reported that bank failures are mostly governed by peak intensities of flow (Julian and Torres, 2006; Luppi et al., 2009); however, this interaction needs further investigation under varying temporal and spatial scales. Indeed, Larsen et al. (2006a) found that cumulative effective stream power was significantly correlated with bank erosion ($R^2 > 0.70$). Similarly, in our study stream bank erosion and stream stage were strongly correlated. There was a significant relationship between the frequency of high stream stage events and bank erosion for each vertical stream bank "section" from all sites; section 2 ($p = 0.04$; $R^2 = 0.74$), section 3 ($p = 0.03$; $R^2 = 0.75$), section 4 ($p = 0.09$; $R^2 = 0.73$), flood section 5 ($p = 0.1$; $R^2 = 0.73$) and for all sections' total for sections 2–5 ($p = 0.03$; $R^2 = 0.75$). The correlations indicated that the number of high flow events passing through sections 2 and 3 were mainly responsible for the observed bank erosion rates for all sites. However, the higher p-values for sections 4 and 5 suggested a weaker relationship between bank erosion and frequency of higher stream stages. A study by Larsen et al. (2006a) revealed a tendency for higher discharge to exert proportionally less impact on bank erosion and further implied a nonlinear relationship between bank erosion and higher discharge.

In this study, since the cumulative stage event (sections 2–5) values represent "all sections' total" from the cross-sectional area of the streams, they were used to examine the following relationships between stream stage and erosion amount from each individual study site. For site 1, the total number of high stream stage occupancy (flow) events from all seasons and sections was 77 and the corresponding total erosion amount was 0.5 cm (Table 2). There was a strong positive linear relationship ($R^2 = 0.99$) between total stream stage occupancies/flow events and erosion across the seasons (Fig. 3 and 4). At site 2, the total number of high stream stage occupancies was 63 and the corresponding total erosion amount was 3 cm (Table 2). The total stream stage occupancy and erosion for site 2 were also strongly related ($R^2 = 0.75$). However, prediction of the erosion value by the observed higher stage events (20–30) fell below a linear fit, suggesting a nonlinear relationship and was best predicted with a polynomial model ($R^2 = 0.93$; Figs 3 and 4). Site 3 had the highest numbers of total stages of all sites (101; Table 2) that were strongly correlated ($R^2 = 0.84$) with the measured seasonal erosion values (total erosion: 4 cm; Figs 3 and 4). At site 4, the total high stream stage occupancy was 83 and the corresponding total erosion amount was 9 cm (Table 2), with a strong positive linear relationship ($R^2 = 0.97$) between the two (Fig. 3 and 4). At sites 5 and 6, total high stream stage occupancy was 71 and 55, respectively, with corresponding erosion amounts of 37 and 40 cm, which were higher than all other sites (Table 2).

Table 2. Event-based high stage (sections 2–5 and sections' total) numbers by seasons of 2007–2009 and the corresponding erosion amounts by season and seasonal total.

Site ID	Stage sections' depth ranges (cm) & erosion (cm)	Fall 2007	Summer 2008	Fall 2008	Summer 2009	Fall 2009	All seasons
Site 1	Section 2 (51–99)	1	12	9	3	7	32
Site 1	Section 3 (100–149)	0	12	4	1	5	22
Site 1	Section 4 (150–198)	0	8	3	0	4	15
Site 1	Section 5 (199–248)	0	5	0	0	3	8
Site 1	Sections' total	1	37	16	4	19	77
Site 1	Erosion	−0.4	missing	missing	−0.1	1.0	0.5
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	Sections' total	0	31	12	10	10	63
Site 2	Erosion	0	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	Sections' 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	Sections' 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	Sections' 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	Sections' 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. Numbers inside parentheses represent the stage section depth range from the stream beds.

In contrast to other sites, the relationship between erosion and high stage from site 5 was not linear ($R^2 = 0.19$). Further, logarithmic regression was employed to model the relationship between erosion and high stage occupancies from site 5 and resulted in $R^2 = 0.38$. However, the best prediction of erosion values from site 5 was for a polynomial model ($R^2 = 0.85$; Figs 3 and 4), as for site 2. Finally, at site 6, bank erosion and stage were (strongly) linearly related ($R^2 = 0.81$; Figs 3 and 4).

Examining the regressions for all sites (pooled data) showed that approximately 75% of the variability in bank erosion was directly explained by the change in total high stream stages which, in turn, reflected or accounted for the effects of site characteristics (e.g. stream bed and bank slope, bank height and sinuosity) on bank erosion. We suggest that the remaining 25% was probably due to the moisture content of bank soil prior to each rainfall and the differences in duration of the flow stages that were not investigated. Bank soil moisture prior to each rainfall event (Casagli et al., 1999) and duration of high stage events were also stated as important controlling agents for bank erosion rates by Larsen et al. (2006a). In general, an increase in the number of total high stream stage events (high stage occupancy) translates to an increase in bank erosion; however, the extent of this relationship is unique to each site's characteristics as described in this study. Study sites from different watersheds differed in some stream morphologic characteristics (Table 1) even though they were on the same stream order class, which in fact would affect the energy dynamics of the stream and its power to erode. For instance, the magnitude of erosion amounts in response to similar total high stream stage events was greater for sites 4–6 (9, 37 and 40 cm respectively; Table 2), whereas the sinuosity of streams was lower and the streambed slopes were higher, indicating possible increase in erosiveness of stream flow (Table 1). Further, we suggest that although the relationships between stream stage and bank erosion were similar (mostly positive linear pattern) among the studied sites, the magnitude of bank erosion in each site was determined/affected by specific characteristics unique to each site (e.g., bank height, bank soil erodibility and stream bed slope and sinuosity) with respect to number of high stage events.

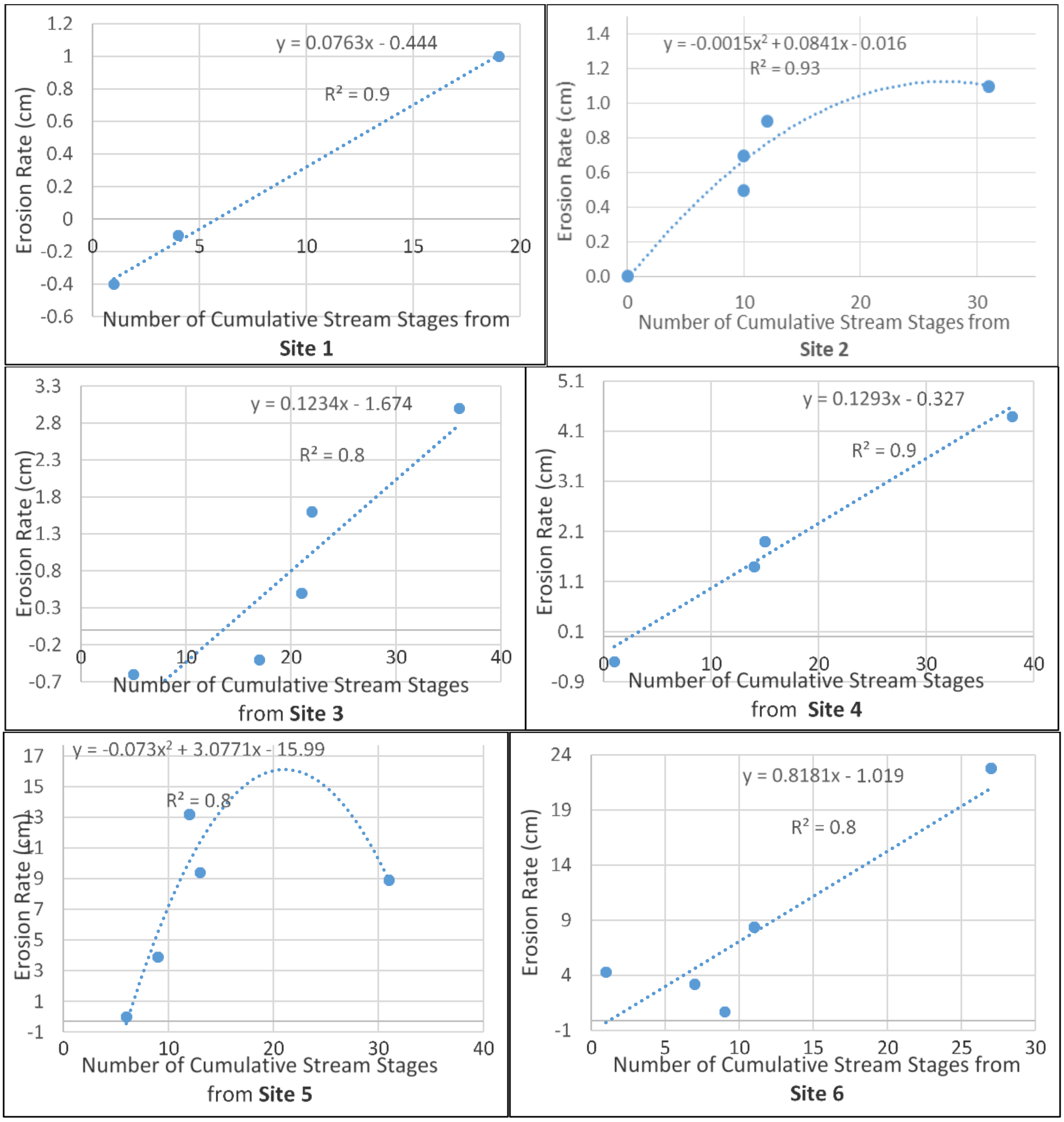

Figure 4. Relationship between cumulative stream stages (in number of times of occupancy of section 2 through section 5) and corresponding erosion rates across seasons (summers and falls) from the six sites (site 1-6).

In this study, change in stream hydrology or stream stage variation (number of high stage events) in response to precipitation and/or current management practices was the major factor affecting bank erosion amount. The recorded high stage numbers 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 stages. 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 correlation among the high erosive stream flow or stage and bank erosion could further assist in predicting changes in channel migration pattern, slope and sinuosity and perhaps also the time line to reach 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.

CONCLUSIONS

The study results suggested that stream bank erosion across grazing pasture sites was highly correlated (R^2 = 0.75) with the frequency of high stream stage events, but that the magnitude of erosion rate among the stream reaches differed because of differences in stream morphologic characteristics, including stream order, and stream bed slope and sinuosity. In conclusion, effective/erosive stream flows (mainly measured by stream stage of stream bank sections 2 and 3), with greater number of events per year, were most likely to increase stream bank erosion and result in more soil loss from each site. This information is valuable for the prediction of stream bank erosion in regard to the number of high stage events proportional to the total bank height. The remaining variability (~25%) was likely due to stream bank soil antecedent moisture prior to a discharge event, and differences in the duration of the high flow depth as it contributes to bank soil saturation.

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