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Riparian land-use impacts on bank erosion and deposition of an incised stream in north-central Iowa, USA

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ABSTRACT

Stream bank erosion and deposition are complex phenomena because of the many factors that influence them. These factors can be spatial such as bank aspect, height and slope or temporal such as seasonal and yearly precipitation and streamflow events. Riparian land-use also has a major influence. This study investigated for two years, spatial and temporal patterns and dominant geomorphologic processes of stream bank erosion and deposition along a 10 km reach of Bear Creek in north-central Iowa, USA. The channel sub-reaches used were adjacent to a riparian forest buffer, a perennial grass filter and a continuously grazed pasture. Two plots were placed in each sub-reach; one on a north-facing outside bank (north-bank) and the other on a south-facing outside bank (south-bank). Each plot had two photo-electronic erosion pins (PEEPs) placed at 1/3 of the bank height (bottom-bank) and the other at 2/3 of the bank height (top-bank). PEEP daily measurements were compared to daily precipitation and streamflow. The continuously grazed pasture banks had the highest erosion rates. The grass area banks had approximately equal rates of erosion and deposition. The riparian forest buffer banks had high erosion rates during the second year. In the continuously grazed pasture, fluvial entrainment was the dominant erosion process, although minor mass failures also caused erosion. In the riparian forest buffer most erosion was recorded after moderate streamflows removed the bank soil loosened by freeze–thaw cycling. This occurred in late winter/early spring, when trees provide primarily mechanical but not hydraulic reinforcement to stream banks and on the lower part of the banks that have less extensive root networks. Overall, stream bank erosion and deposition in each sub-reach occurred during different time periods and under different processes and conditions. This indicates the need for continuous erosion and deposition measurements along with continuous soil moisture, soil temperature and streamflow measurements to fully comprehend these erosion phenomena.

1. Introduction

Accelerated and extensive stream bank erosion can have detrimental effects on aquatic and terrestrial ecosystems. An understanding of stream bank erosion is necessary to efficiently and effectively manage streams, rivers and their riparian areas. Many studies of stream bank erosion have been conducted during the last decades (Bull, 1997; Couper and Maddock, 2001; Lawler, 1993, 2005; Pollen, 2007; Pollen-Bankhead and Simon, 2010; Wynn et al., 2008) but, many facets of stream bank erosion processes are still not well understood, because of their high temporal and spatial complexity (Langendoen et al., 2009; Lawler, 2005; Wynn et al., 2008).

The agricultural land-use changes for the last 200 years in the Midwestern United States have had a greater impact on fluvial geomorphology than any natural disturbance in the last 10,000 years (Knox, 2006). Most of the natural vegetation of the region has been converted into annual row-crops and cool-season grass pastures (Burkhart et al., 1994). Row-crop agriculture and continuous grazing decrease biodiversity and overall vegetation cover, lower surface roughness and rates of evapotranspiration (Hoffman and Ries, 1991), and reduce soil porosity which decreases water infiltration (Bharati et al., 2002; Marquez et al., 1999). These alterations increase surface runoff, total annual and peak streamflows, stream scouring potential and sediment transport capacity (National Research Council, 2002). Since the beginning of the twentieth century it is estimated that surface runoff and peak streamflows in Iowa agricultural watersheds have increased by 2–3 times and 10–50 times, respectively (Piest et al., 1977).

Stream channelization or straightening has been practiced extensively in the region to make fields more rectangular and easier to farm. This practice increases channel incision by increasing the stream

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gradient by up to an order of magnitude and reducing its roughness (Simon and Rinaldi, 2000). Artificial drainage efforts including the installation of subsurface tile drainage and surface drainage ditches have increased the total length, drainage density and channel frequency of intermittent streams by more than 50% in most Iowa headwater watersheds (Andersen, 2000).

All the aforementioned land cover and stream channel changes have led to hydrologic disequilibrium conditions of streams and caused incision. Incised channels have undergone or are undergoing excessive channel erosion which causes many environmental, human and economic problems (Erskine, 1999). Stable channels that develop disequilibrium conditions move through five phases before they re-establish equilibrium: I) stable, II) incising (degradation), III) widening, IV) aggrading and V) quasi-equilibrium (Schumm et al., 1984).

Most of Iowa streams are in the widening (III) or aggrading (IV) phases (Hadish, 1994). Both phases are associated with accelerated and excessive stream bank erosion that is exacerbated by current riparian land-uses (Schumm et al., 1984). The lack of perennial plant cover and its associated root mass along many stream banks of row-crop fields, further increases susceptibility to stream bank erosion (Pollen-Bankhead and Simon, 2010; Wynn and Mostaghimi, 2006). In riparian areas used as pastures the direct effect of livestock trampling and treading results in the mechanical breakdown and erosion of stream banks (Trimble, 1994). The indirect effects are the results of cattle tendencies to remove the protective vegetation on the top of the banks (Trimble and Mendel, 1995). Odgaard (1987) and Schilling and Wolter (2000) estimated that 45–50% of the sediment in several Iowa streams originated from bank erosion while Wilson et al. (2008) reported an even higher percentage of 80%. The establishment of undisturbed perennial riparian vegetation with high root mass development increases the flow resistance on most fluvial surfaces including stream banks (Schultz et al., 2004).

Three major natural stream bank erosion processes have been identified (Couper and Maddock, 2001; Lawler et al., 1997; Wynn and Mostaghimi, 2006): i) fluvial entrainment, ii) mass wasting or failure and iii) subaerial preparation or processes. Fluvial entrainment is the direct removal of soil particles or aggregates from the stream bed or bank by streamflow (Table 1). When the height and angle of the bank have increased to the point that the gravitational forces exceed the shear strength of the bank material, mass wasting or failure can occur (Table 1). Finally, subaerial preparation is a physical process that reduces soil strength by weakening and loosening of the bank material by climatic factors (Table 1). In most studies, subaerial processes dominate upstream reaches (headwater streams), fluvial entrainment midstream reaches and mass failure downstream reaches (larger rivers) (Couper and Maddock, 2001; Henshaw et al., 2012).

While many studies in the Midwestern United States have investigated the impact of riparian land-use on stream bank erosion rates (Lyons et al., 2000; Sekely et al., 2002; Zaimes et al., 2004, 2006, 2008) there has not been the same emphasis on identifying the timing of stream bank erosion or deposition and which processes cause them. Understanding the processes that drive stream bank erosion is essential for selecting the most appropriate measures to enhance stream bank stability (Simon and Collison, 2002).

The focus of this study was to identify when stream bank erosion and deposition actually occur and the erosion processes that dominate under different riparian land-uses. To achieve this, the following were investigated on three sub-reaches adjacent to different riparian land-uses (riparian forest, grass filter and continuous pasture): i) temporal changes;—when stream bank erosion or deposition events occur; (ii) spatial changes;—the impacts of bank aspect (north and south-facing) and position (top and bottom part of the bank) on erosion and deposition; and (iii) stream bank erosion processes;—which processes are dominant in these types of streams.

2. Methods

2.1. Study area

The research was conducted along a 10 km, second order reach of Bear Creek in north-central Iowa, USA (coordinates of the most southern point of the reach are 42°18′82″ N, 93° 49′ 52″ W- and of the most northern point are 42°23′82″ N, 93° 47′ 63″ W) (Fig. 1). Bear Creek has been designated as a National Restoration Demonstration Watershed by the interagency team implementing the Clean Water Action Plan (1999) because of the extensive stream corridor research conducted over the last 24 years (Berges et al., 2010; Bharati et al., 2002; Lee et al., 2003; Marquez et al., 1999; Schultz et al., 2004; Simpkins et al., 2002; Tufekcioglu et al., 2003; Zaimes et al., 2004, 2006). The study reach is typical of streams in the relatively flat, intensive row-cropping landscape of the Midwestern United States. Channels are deeply incised and experience accelerated stream bank erosion (phase III widening) due to anthropogenic disturbance associated with intensive row-crop agriculture (e.g. land-uses changes, channelization and artificial drainage) (Hadish, 1994). The watershed area of the study reach is 52 km^2 from the most southern point of the 10 km reach. The majority of the watershed is in row-crop agriculture with occasional pastures (typically in the riparian area), homesteads and small pockets of forest. Row-crop fields, pastures and well-established conservation practices (riparian forest buffers and grass areas) are adjacent to the stream in the study reach.

The study reach has an average of 17.3 days/year with snowfall of at least 0.25 cm with most occurring in January (4.4 days) (NOAA, n.d.). The stream channel is covered with snow for many days and experiences frequent freeze–thaw cycling. The average precipitation is 91.0 cm/year, with June being the wettest month (12.6 cm) (NOAA, n.d.). The average annual high temperature is 14 °C while the average low is 4 °C (NOAA, n.d.). July is the hottest month with an average high of 29 °C and an average low of 16 °C and January is the coldest month with an average high of −1 °C and an average low of −11 °C (NOAA, n.d.). The average annual relative humidity is 69% for the region and ranges from 80% in the morning to 56% in the afternoon (NOAA, n.d.).

Table 1
The three major natural stream bank erosion processes and their major characteristics (Couper and Maddock, 2001; Lawler et al., 1997; Simon et al., 2000; Wynn and Mostaghimi, 2006).

Name	Process	Characteristic conditions	Types
Fluvial entrainment	Hydraulic	Occurs during the rising limb of a storm flow hydrograph	a) Lateral erosion b) Basal scour c) Undercutting
Mass wasting or failure	Geotechnical	Common along deeply incised channels. Occurs during the recessional limb of a storm flow hydrograph	a) Slab failures, b) Rotational slips c) Pop-out failures
Subaerial preparation or processes	Preparatory	Rain splash, freeze–thaw cycling during fall, winter and spring, desiccation associated with wetting and drying cycles during summer	a) Creep erosion b) Loosened material on the bank removed by subsequent streamflow