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Prepared in cooperation with the University of Wisconsin-Platteville Pioneer Farm Program

Collection Methods, Data Compilation, and Lessons Learned from a Study of Stream Geomorphology Associated with Riparian Cattle Grazing along the Fever River, University of Wisconsin-Platteville Pioneer Agricultural Stewardship Farm, Wisconsin, 2004–11

Open-File Report 2016–1179

U.S. Department of the Interior
U.S. Geological Survey

Cover. A herd of red Angus cattle prefer to cross the Fever River at a constructed crossing to reach ungrazed areas of a rotational paddock. The crossings help to reduce erosion and trampling along the banks and bed of the river through the rest of the pastured areas. Photograph by Marie Peppler, U.S. Geological Survey.

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RYAN K. ZINKE, Secretary

U.S. Geological Survey
William H. Werkheiser, Deputy Director
exercising the authority of the Director

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Contents

Figures

Tables

Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
acre	0.004047	square kilometer (km^2)
square foot (ft^2)	0.09290	square meter (m^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
cubic foot (ft^3)	28,316	cubic centimeter (cm^3)
cubic foot (ft^3)	28.32	cubic decimeter (dm^3)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
	Mass	
pound, avoirdupois (lb)	0.4536	kilogram (kg)
	Density	
pound per cubic foot (lb/ft^3)	16.02	kilogram per cubic meter (kg/m^3)
pound per cubic foot (lb/ft^3)	0.01602	gram per cubic centimeter (g/cm^3)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as

$$°F=(1.8\times°C)+32.$$

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as

$$°C=(°F–32)/1.8.$$

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
	Density	
gram per cubic centimeter (g/cm^3)	62.4220	pound per cubic foot (lb/ft^3)

Datum

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Altitude, as used in this report, refers to distance above the vertical datum.

Collection Methods, Data Compilation, and Lessons Learned from a Study of Stream Geomorphology Associated with Riparian Cattle Grazing along the Fever River, University of Wisconsin Platteville Pioneer Agricultural Stewardship Farm, Wisconsin, 2004–11

By Marie C. Peppler and Faith A. Fitzpatrick

Abstract

Stream geomorphic characteristics were monitored along a 0.8-mile reach of the Fever River in the Driftless Area of southwestern Wisconsin from 2004 to 2011 where cattle grazed in paddocks along the riverbank at the University of Wisconsin-Platteville's Pioneer Farm. The study reach encompassed seven paddocks that covered a total of 30 acres on both sides of the river. Monitoring data included channel cross-section surveys, eroding bank measurements and photograph points, erosion-pin measurements, longitudinal profile surveys, measurements of the volume of soft sediment in the channel, and repeated time-lapse photographs. Characteristics were summarized into subreaches by use of a geographic information system. From 2004 to 2007, baseline monitoring was done to identify geomorphic conditions prior to evaluating the effects of management alternatives for riparian grazing. Subsequent to the full-scale baseline monitoring, additional data were collected from 2007 to 2011. Samples of eroding bank and in-channel soft sediment were collected and analyzed for dry bulk density in 2008 for use in a sediment budget. One of the pastures was excluded from cattle grazing in the fall of 2007; in 2009 channel cross sections, longitudinal profiles, erosion-pin measurements, photographs, and a soft sediment survey were again collected along the full 0.8-mile reach for a comparison to baseline monitoring data. Channel cross sections were surveyed a final time in 2011. Lessons learned from bank monitoring with erosion pins were most numerous and included the need for consistent tracking of each pin and whether there was deposition or erosion, timing of measurements and bank conditions during measurements (frozen, postflood), and awareness of pins loosening in place. Repeated freezing and thawing of banks and consequential mass wasting and jointing enhance fluvial erosion. Monitoring equipment in the paddocks was kept flush to the ground or located high on posts to avoid injuring the cattle.

Introduction

Bank erosion is a natural process that occurs in meandering streams (Leopold and others, 1964); however, in the Midwestern United States, historical and present agricultural activities in uplands, riparian areas, and channels have increased erosion (Waters, 1995; Lyons and others, 2000; Simon and Rinaldi, 2000; Knox, 2001). Reducing streambank erosion is important because sediment carried by streams has adverse environmental effects. For example, sediment carried by streams is a major source of phosphorus (Waters, 1995). Waters with phosphorus levels above the State water-quality standard make up 61 percent of the proposed waters to be newly listed as impaired in Wisconsin (Wisconsin Department of Natural Resources, 2015). Continuous cattle grazing in riparian areas may increase local erosion processes in a meandering stream, because cattle may remove or trample the bank vegetation, which in turn affects channel morphology, water chemistry, and fish and aquatic-insect habitat (Kauffman and Krueger, 1984; Fitch and Adams, 1998). However, studies of livestock exclusion from riparian corridors have shown mixed results in reducing bank erosion and improving water quality and habitat (Trimble, 1994; Sarr, 2002; Kauffman and others, 2004). Some studies have shown reduced bank erosion after row-cropped or continuously grazed riparian areas are converted to managed grazing land (Lyons and others, 2000; Sovell and others, 2000; Zaimes and others, 2004).

There are many different methods for managing livestock-grazing activities. Rotational grazing or stocking is defined as the practice of allowing livestock to graze in two or more paddocks of a larger pasture with periods between grazing periods when a pasture is unused or at "rest" (Forage and Grazing Terminology Committee, 1991). The nonsystematic rotation of stock with the goal of achieving a specific management objective is defined as "deferred grazing." At the University of Wisconsin (UW)-Platteville Pioneer Farm (Pioneer Farm), rotational-deferred grazing was adopted to meet the goal of returning pastures to environmental conditions appropriate for grazing by moving the herd on the basis of shade, forage needs, and pasture conditions. The length of the grazing period generally is shorter than the rest period. In situations where cattle spend a limited time in an area and a longer rest time is allowed for vegetation recovery, negative effects on the streambank are thought to be reduced (Kauffman and Kruger, 1984).

In May 2002, seven rotational-deferred paddocks were established in a riparian pasture along a 0.8-mile (mi) reach, or section, of the Fever River at the Pioneer Farm in southwestern Wisconsin (fig. 1). From 1996 to 2002, this pasture was used for rotational grazing in five paddocks. In 2002, the fences were changed to create seven paddocks. Four cattle crossings were installed by the end of winter 2003. In 2001, the U.S. Geological Survey (USGS) began monitoring runoff, solids, nutrients, bacteria, and selected pesticides from various upland fields with a variety of best management practices along the study reach as well as upstream and downstream along the Fever River (Stuntebeck and others, 2011) (fig. 1).

In June 2004, the USGS, in cooperation with the Pioneer Farm, began monitoring bank and channel changes along the Fever River (fig. 2). Cattle were grazed in the rotational-deferred paddocks generally from April through November, with a rest period during the winter months. The Fever River is laterally migrating through the pasture; eroding and slumping banks were common and were thought to be developing at an increased rate because of trampling by cattle. The UW-Platteville was interested in long-term monitoring of bank erosion along the reach through the pasture to determine if vegetation and banks would stabilize as a result of the rotational-deferred practices and constructed cattle crossings.

The major goals of this study were to monitor bank erosion, channel shape, location, and stream-substrate characteristics from 2004 through 2011 associated with riparian rotational-deferred grazing. This pastured reach was monitored specifically from 2004 to 2007 to establish baseline conditions before application of new management techniques. There was no control reach along the Fever River with standard grazing practices during the baseline monitoring; however, Paddock 7 was left fallow after the 2007 grazing period. A subset of measurements were made in 2009 and 2011 to document the effects of excluding cattle from Paddock 7 along with tracking continued geomorphic changes along the Fever River in the grazed paddocks.

Study Area and Hydrologic Context

At Pioneer Farm, the Fever River, also known downstream as the Galena River, drains 2.94 square miles of the Driftless Area of southwest Wisconsin. Land cover in the watershed is 90 percent agriculture, 5 percent grassland, 3 percent forest, and 1 percent barren and water (Reese and others, 2002). The farm is a partnership of the Wisconsin Agricultural Stewardship Initiative and the UW-Platteville. The goals of the farm are to develop and evaluate best management practices while keeping farm operations profitable to protect and enhance natural resources.

Streamgages were installed by the USGS on the Fever River upstream in Paddock 7 (USGS ID 05414849) and immediately downstream of the pastured area (USGS ID 05414850) (fig. 1). Real-time continuous data were collected at the upstream gage from October 2005 to September 2007 and at the downstream gage from August 2002 to September 2008. Long-term flow statistics were determined by using data from the streamflow record at the downstream gage (USGS ID 05414850 because it has a longer period of record than the upstream gage. Long-term annual median flow was approximately 1.2 cubic feet per second (ft^3/s). Bankfull flow (probability of about 0.667) was about 50–60 ft^3/s, based on field evidence of water levels after runoff events matched to recorded stage at the USGS streamgage. No large floods happened during the 2004–7 baseline monitoring period (fig. 2); flood magnitudes were generally less than the 2-year (yr) recurrence interval as determined through comparison with records from the Fever River at Pioneer Farm (USGS ID 05414850) and the Galena River at Buncombe, Wis. (discontinued gage USGS ID 05415000). The summer of 2005 was particularly dry with only a few small runoff events. One notable runoff event with a peak flow of 105 ft^3/s in February–March 2005 was caused by rain over frozen ground. Four of the five other floods with flows greater than 50 ft^3/s during the baseline monitoring period resulted from spring or summer rainstorms. Data from the Galena River at Buncombe gage indicated that the largest flood recorded during 2002–7 had a 0.50 exceedance probability (2-yr recurrence interval).

Between 2007 and 2009, during the rest period for the paddock exclusion study, conditions were much wetter than the prior baseline monitoring period. The summer of 2008 was particularly wet, with baseflows great than 7 ft^3/s, multiple events with flows greater than the peak observed during the baseline monitoring, and a peak flow of over 300 ft^3/s. No flow data are available after September 2008, but based on nearby gages, baseflow at Pioneer Farm was likely elevated during the 2009 assessment of bank conditions.

Description of Paddocks, Constructed Crossings, and Cattle

The seven paddocks included a total of 30 acres and 4,347 feet (ft) of stream length (table 1). The average paddock area was 4.3 acres. Three areas nearby and adjacent to the river but outside of the paddocks served as exclosures (ungrazed control areas): a small area between paddocks 1 and 2, a larger area between Paddock 1 and College Farm Road, and a small area around a USGS streamgage in Paddock 3 (fig. 1). A lane along the west side of the paddocks provided cattle access from the barn to each paddock. Small springs and seeps were numerous in the pastures and along the banks within each paddock. The pastures had medium forage quality,

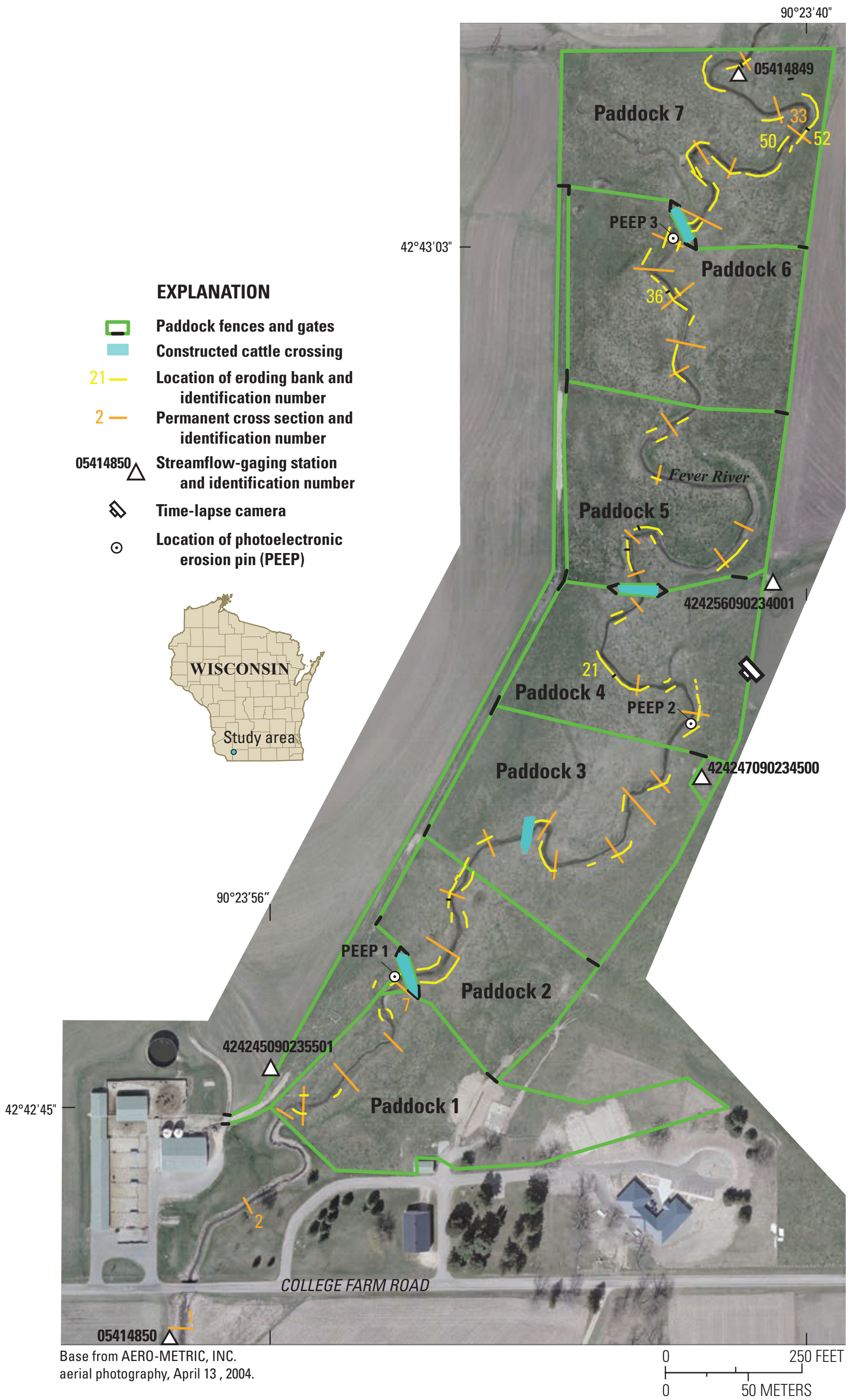

Figure 1. Location of the University of Wisconsin-Platteville Pioneer Agricultural Stewardship Farm rotational grazing paddocks for beef cattle and U.S. Geological Survey geomorphic monitoring sites.

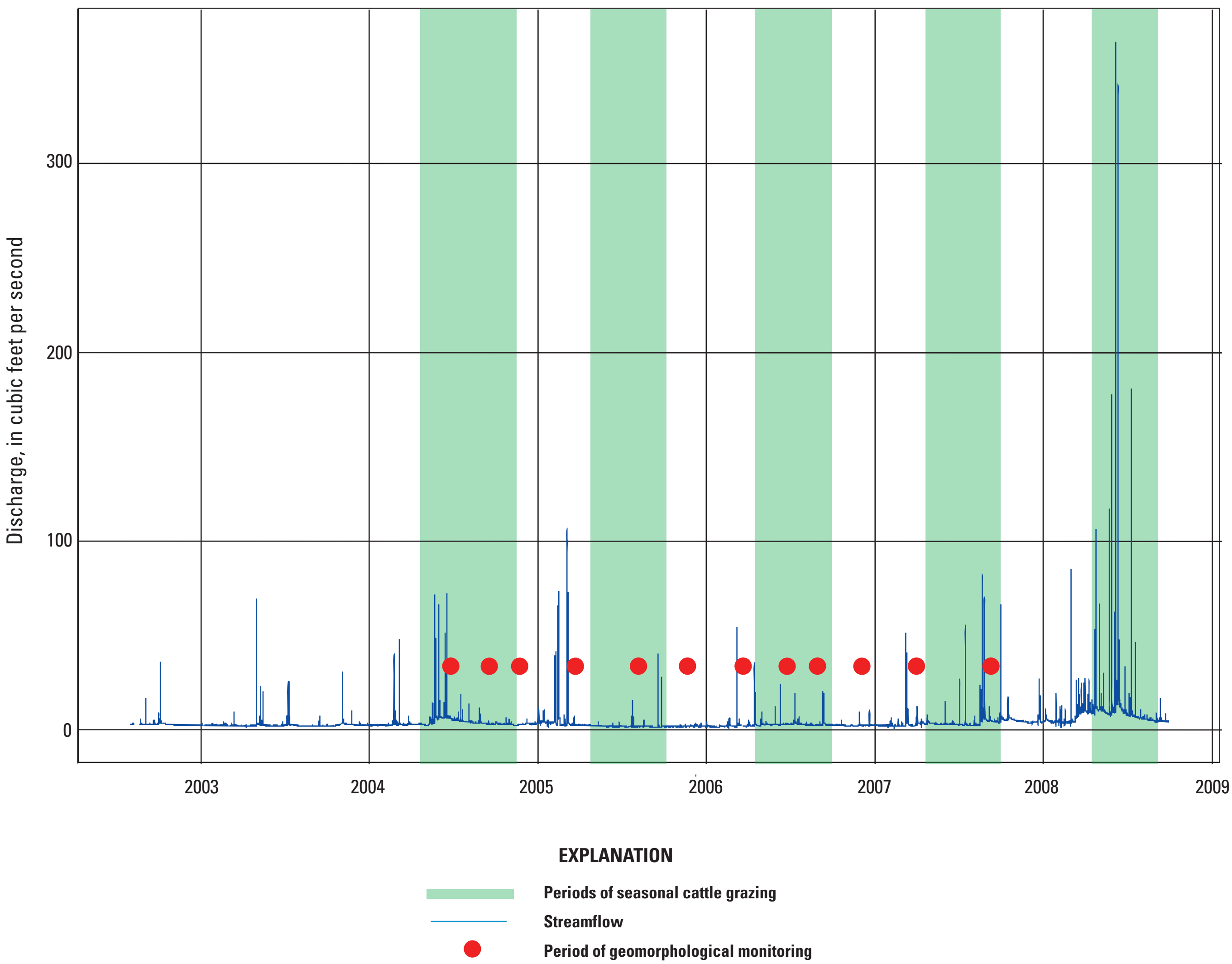

Figure 2. Seasonal cattle grazing (green bars) relative to geomorphology monitoring dates (red dots) and streamflow along the Fever River at Pioneer Farm (2002–8). Hydrograph data are from the U.S. Geological Survey streamgage on the Fever River (USGS ID 05414850).

Table 1. Pasture characteristics and monitoring information for rotational-deferred paddocks at the University of Wisconsin-Platteville Pioneer Agricultural Stewardship Farm, Wisconsin.

[NA, not applicable; Px, Photoelectronic erosion pin identification number]

Section	Area of paddock, in acres	Percentage of total bank length monitored	Number of cross sections	Number of eroding banks/ banks with erosion pins	Number of erosion pins
Paddock 1	5.0	16.3	4	7/0	0
Paddock 2	2.9	57.5	2	10/0	0
Paddock 3	4.8	23.5	6	12/1	1
Paddock 4	3.8	31.3	3	13/2	13, P2
Paddock 5	4.2	17.8	6	10/1	3
Paddock 6	4.5	33.5	5	10/1	3, P3
Paddock 7	4.7	46.5	6	21/6	33
Outside paddocks	NA	NA	[1]3	1/1	6, P1
Total	29.9	26.7	35	84/12	59

[1]Cross sections 1, 2, and 7 are outside of the paddocks.

and small parts of Paddocks 1, 2, 3, and 4 were mechanically harvested or were occasionally skipped in the grazing sequence to allow the grass to grow longer for harvest. Portions of Paddocks 5 and 6 had wetland areas and were grazed more frequently after periods of dry weather. Paddocks 1 and 7 had the only shade trees in the study area and, consequently, were grazed more heavily during hot weather.

Four stream crossings for the cattle were constructed in the winter and spring of 2003. A variety of construction materials were used, including gravel and rock, webbing, and recycled tires filled with gravel. The crossings were compared for cattle use, channel- and bank-stability effects, cost, and to test the durability of different construction materials. As the cattle were rotated through the paddocks, gates and fencing at three crossings could be switched so that the cattle had access to a crossing from each paddock. One crossing in Paddock 3 was in the middle of the paddock and not fenced and gated like the others. Streambanks were not fenced off in any of the paddocks, so cattle could freely access and cross the streams.

Herd size averaged about 35 cows and heifers, 20 calves, and 1 bull from 2004 to 2011. From April 20 to November 15, 2004, the pastures supported a mixed herd of Red and Black Angus and Hereford-Angus crossbred cattle consisting of 37 cows and heifers, 23 calves, and 1 bull. The age of the herd ranged from yearling to 10 years with an average age of 4 years. Age is important to note because cattle are known to have habitual grazing patterns, and most of these animals were reared in the pasture prior to the crossing and fence installation. As the animals were rotated among paddocks, their habits changed, and the effects on the banks of cattle movement may have been affected by an increased use of the constructed crossings by the herd. Each year, from September to November, the number of cattle in the pasture decreased as the calves were weaned and sold.

The nonsystematic herd rotations generally included about 4 days of grazing and 17 days of rest from April through November, starting in 2002. The timing of the rotations was based on forage quality and condition, the nutrition needs of the cattle, shade, and weather (Alicia Prill-Adams, UW-Platteville Farm, oral commun., 2004). During the 2004 grazing period, the time cattle spent in each paddock typically lasted 2–5 days, and the cattle were in each paddock from four to seven times. Average rest periods—when the cattle were absent from a paddock—ranged from 7 to 20 days. The fences were reconfigured in 2007 to five total paddocks. In addition, areas were added to Paddock 1 in 2007 along the southeastern area (not shown on map), giving the cattle more area to graze farther from the stream. Less detailed cattle use data are available for 2005–11.

The cattle crossings were in place and in good condition throughout the baseline monitoring period from 2004 to 2007, when cattle used the constructed crossings but also crossed the channel at various other locations in each paddock. During this time they also used the stream as a water source and a place to cool off. A supplemental gravity feeder for the calves was placed in the lane near Paddocks 4 and 5 along with the mineral feeder for the cows and calves. Monitoring daily cattle use of each paddock were not recorded at any time during the monitoring period, resulting in a level of unquantifiable uncertainty to the study.

Following the 2007 grazing season, Paddock 7 was excluded from grazing and left permanently fallow to improve riparian bird and wildlife habitat, and the crossing was permanently included in Paddock 6. Aside from the trees, the land in Paddock 7 was considered to be relatively low grazing quality due to a groundwater tributary and steep banks. The exclusion of Paddock 7 from the study provided an opportunity to study how eroding banks either recover or continue to erode once cattle pressure is removed. The bedrock channel bottom of the stream through this paddock eliminated any possibility of incision and its effect on bank erosion.

Purpose and Scope

The purpose of this report is to present the techniques for measuring changes in stream geomorphology and the data collected in association with a study of changes in bank and channel erosion and deposition associated with riparian cattle grazing at Pioneer Farm, Wisconsin, from 2004 through 2011. Field data included in this report are channel cross-section surveys, bank erosion measurements and photograph points, erosion-pin measurements, longitudinal profile surveys, measurements of the volume of soft sediment in the channel, and repeat, time-lapse photographs. The organization and content of the geomorphic data included in the appendixes is also described. Finally, the report describes some lessons learned in regards to monitoring streambank erosion using bank erosion pins, while keeping cattle safety in mind.

Geomorphic Monitoring Methods

The channel and banks of the Fever River in the seven paddocks were monitored using a variety of methods: channel cross-section surveys, quantitative measurements and photographs of eroding banks, erosion pins, longitudinal profile surveys, measurements of in-channel soft sediment volume, and time-lapse photography (Peppler and Fitzpatrick, 2005; table 2). These methods were combined to present a complete picture of geomorphic changes that can take place in pastures similar to those in the study area.

Channel Cross-Section Surveys

Thirty-five channel cross sections (fig. 1, table 1) were established to measure channel movement, incision or aggradation, and bank failures using the methods of Harrelson and others (1994). Three cross sections (numbers 1, 2, and 7) are outside of the paddocks. Cross-sections 1 and 2 are downstream of the paddocks; cross section 7 is within the paddock

Table 2. Timeline of data collection and field activities on the Fever River at Pioneer Farm.

[Blue indicates the type of monitoring that was done during a month. An em dash indicates that monitoring was not done during a month. PEEP, photoelectronic erosion pin. No data were collected in 2010 (blank cells in table)]

Activity	2004												2005												2006											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Baseline monitoring data collection	—	—	—	—	—																															
Streamgage operation (downstream)																																				
Streamgage operation (upstream)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—															
Cross-section survey	—	—	—	—	—		—	—		—		—	—	—		—		—		—	—	—	—		—	—		—	—		—	—		—	—	
Bank measurements	—	—	—	—	—		—	—	—	—	—		—	—	—	—	—	—	—		—	—		—	—	—	—	—	—	—		—	—	—	—	—
Bank photos	—	—	—	—	—		—	—		—	—		—	—		—	—			—	—	—		—	—	—		—	—		—	—		—	—	
Erosion pin check	—	—	—	—	—		—	—		—	—		—	—		—	—			—	—	—		—	—	—		—	—		—			—	—	
PEEP 1 recording	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—					—	—	—	—	—
Photo electronic erosion pin (PEEP) 2 recording	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—											—	—	—	—	—
Photo electronic erosion pin (PEEP) 3 recording	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—											—	—	—	—	—
Photo electronic erosion pin (PEEP) check	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—				—	—	—				—		—		—	—	—
Longitudinal Profile focused survey	—	—	—	—	—		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
Soft sediment and substrate mapping	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—				
Bulk density sample collection	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Time-lapse photos	—	—	—	—	—	—	—				—		—							—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

Table 2. Timeline of data collection and field activities on the Fever River at Pioneer Farm.—Continued

[Blue indicates the type of monitoring that was done during a month. An em dash indicates that monitoring was not done during a month. PEEP, photoelectronic erosion pin. No data were collected in 2010 (blank cells in table)]

Activity	2007												2008												2009											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Baseline monitoring data collection									—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Streamgage operation (downstream)																						—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Streamgage operation (upstream)										—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Cross-section survey	—	—	—		—	—	—		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		—	—	—	—
Bank measurements		—	—	—	—	—		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
Bank photos	—	—	—		—	—	—		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Erosion pin check	—	—	—		—	—	—		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
PEEP 1 recording	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Photo electronic erosion pin (PEEP) 2 recording	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Photo electronic erosion pin (PEEP) 3 recording	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Photo electronic erosion pin (PEEP) check	—		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Longitudinal Profile focused survey	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Soft sediment and substrate mapping	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		—	—	—	—
Bulk density sample collection	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Time-lapse photos	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

Table 2. Timeline of data collection and field activities on the Fever River at Pioneer Farm.—Continued

[Blue indicates the type of monitoring that was done during a month. An em dash indicates that monitoring was not done during a month. PEEP, photoelectronic erosion pin. No data were collected in 2010 (blank cells in table)]

Activity	2010			2011											
				Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Baseline monitoring data collection				—	—	—	—	—	—	—	—	—	—	—	—
Streamgage operation (downstream)				—	—	—	—	—	—	—	—	—	—	—	—
Streamgage operation (upstream)				—	—	—	—	—	—	—	—	—	—	—	—
Cross-section survey				—	—	—	—	—	—	—		—	—	—	—
Bank measurements				—	—	—	—	—	—	—	—	—	—	—	—
Bank photos				—	—	—	—	—	—	—		—	—	—	—
Erosion pin check				—	—	—	—	—	—	—	—	—	—	—	—
PEEP 1 recording				—	—	—	—	—	—	—	—	—	—	—	—
Photo electronic erosion pin (PEEP) 2 recording				—	—	—	—	—	—	—	—	—	—	—	—
Photo electronic erosion pin (PEEP) 3 recording				—	—	—	—	—	—	—	—	—	—	—	—
Photo electronic erosion pin (PEEP) check				—	—	—	—	—	—	—	—	—	—	—	—
Longitudinal Profile focused survey				—	—	—	—	—	—	—	—	—	—	—	—
Soft sediment and substrate mapping				—	—	—	—	—	—	—	—	—	—	—	—
Bulk density sample collection				—	—	—	—	—	—	—	—	—	—	—	—
Time-lapse photos				—	—	—	—	—	—	—	—	—	—	—	—

area, but it was made inaccessible to cattle by the use of fencing surrounding that area (fig. 1). All cross sections were established perpendicular to the estimated bankfull channel and extended into the flood plain. They were spaced somewhat evenly throughout the length of the river in an effort to obtain channel conditions representative of meander bends and straight stretches. Cross-section endpoints were marked using steel reinforcement bars (rebar) with numbered plates welded to the top. These bars were pounded flush to the ground surface to prevent cattle injury. Cross-sectional surveys were done by use of an electronic theodolite (Harrelson and others, 1994; Fitzpatrick and others, 2004). Subsequent surveys were referenced to the same coordinate system by initially setting up the theodolite over a known base point and backsighting to a known benchmark. Each cross section was surveyed along 12 to 30 points to detect small changes in bank and channel elevations.

Northing and easting coordinates were transformed into linear distances along each cross section using the following equation:

$$d_t = \sqrt{\left(x_e - x_s\right)^2 + \left(y_e - y_s\right)^2} d_t = \sqrt{\left(x_e - x_s\right)^2 + \left(y_e - y_s\right)^2} \qquad (1)$$

where

- d_t is the distance along a cross section from the cross-section endpoint,
- x_e is the easting coordinate of the cross-section endpoint,
- x_s is the southing coordinate of the survey point,
- y_e is the northing coordinate of the cross-section endpoint, and
- y_s is the northing coordinate of the survey point.

This transformation allowed subsequent surveys to be overlain for display of cross-sectional changes and for calculation of sediment volumes and fluxes.

Figure 3 shows an example of the effects at cross-section 33 of the development of a cattle crossing across the Fever River channel from June through November 2004. The irregular surface on the right bank upstream of bank 50 in the November 2004 survey represents the effects of numerous newly developed stream crossing paths by individual cattle.

Channel cross sections were surveyed approximately every 2 months from spring to fall, roughly coinciding with the cattle-grazing schedule and runoff events such as the spring melt (Harrelson and others, 1994). Fifteen cross-section surveys were completed between June 2004 and August 2011 (table 2).

Eroding Bank Measurements and Photograph Points

Of the approximately 8,700 linear ft of banks along the Fever River though the pasture, 2,677 ft are eroding. Baseline monitoring included measuring 84 areas where the banks were eroding, and they were distributed along every paddock (table 1; fig. 4). Additional portions of the banks are eroding, but cover less than 1 contiguous square foot. At each of the 84 eroding bank areas, the length, width, and depth of the eroding area were measured; the connectivity with the stream and the causes of erosion were noted, the eroding area was drawn or sketched on special field information sheets (fig. 5); and the area was photographed. Sketches and measurements of the eroding banks included the locations of cross sections and erosion pins. Possible causes for erosion were interpreted while USGS staff were in the field and included hydraulic or freeze-thaw forces acting against the base or toe of a bank, mass wasting along upper banks on the outside of bends where the stream intersects a terrace, cattle trampling (entering or exiting the stream or walking along the bank), and cattle scratching on the bank (fig. 6), or a combination of these causes.

Photograph points were established across the channel from the 84 eroding bank areas. Photographs were taken periodically throughout the study, showing different times of the year, vegetation states and water levels (table 2). The final set of photographs was taken in 2011. Photographs of bank 36 show the development of slumping caused by cattle trampling along the top edge of the bank, and slumping was especially noticeable in the winter months (fig. 7). The photographs illustrate how the height of the vegetation along the bank (related to the length of the rest period) may affect interpretations of bank stability.

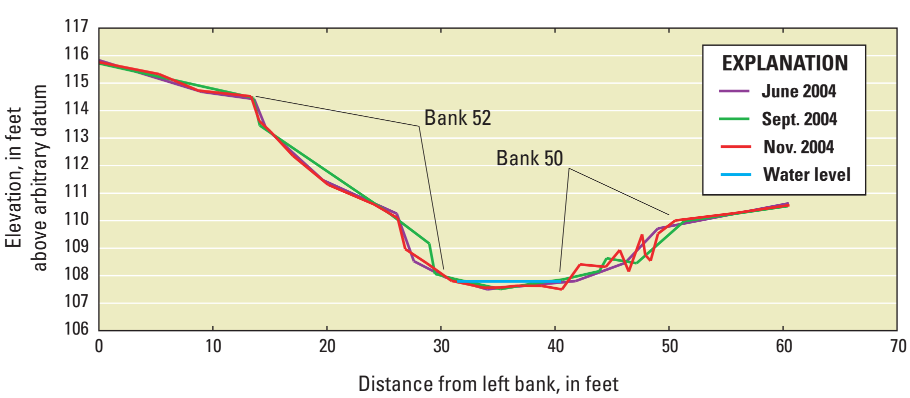

Figure 3. Changes in cross section 33 in Paddock 7 from June through November 2004.

EXPLANATION

- Pasture and paddock fence locations in 2007
- Cross-section location and identification number
- Eroding bank location and identification number

Reach ID	Description of reach slope and soft sediment storage	Reach percent slope
A	Soft sediment accumulation and shallow water around gravelly crossing	0.21
B	Steep bed slope but low water surface and bankfull slope, little to no soft sediment storage	0.43
C	Steep area with some soft sediment storage above and in the crossings	0.25
D	Three crossings and scratching areas, very steep, minimum soft sediment storage	0.59
E	Major natural grade control, bedrock (crossing just upstream)	1.20
F	Lower portion of low gradient upstream of major instream bedrock outcrop	0.25
G	Upper portion of low gradient, upstream of major instream bedrock outcrop	0.17
H	Steep, shallow, little soft sediment storage	0.45
I	Low slope, soft sediment storage, bedrock at base of reach	0.20
J	Steeper reach than the middle reaches, soft sediment storage	0.40
K	Slope break and instream bedrock outcrop	0.74
L	Deep narrow channel with lots of soft sediment storage	0.15

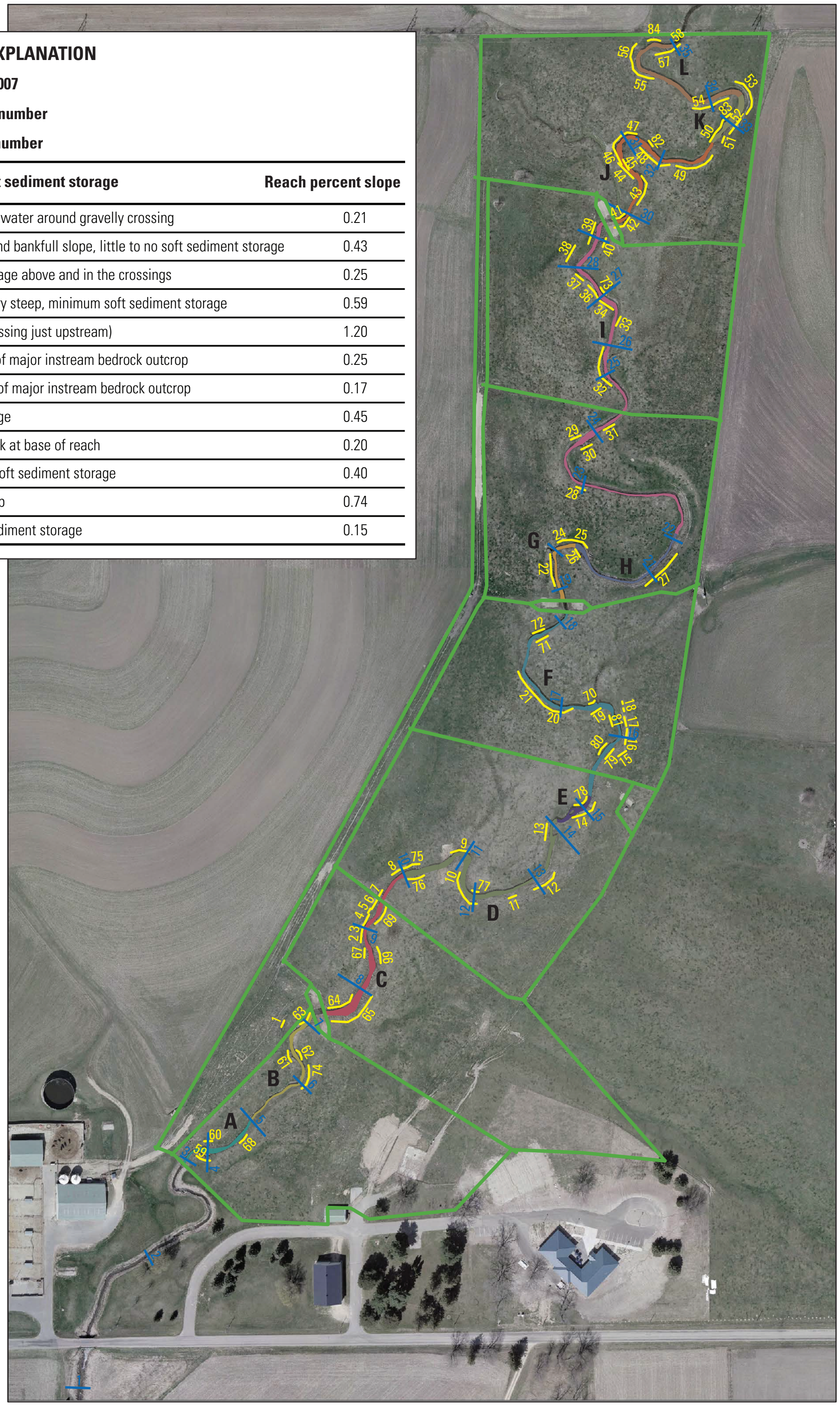

Figure 4. Areas of eroding bank, soft sediment reaches, and major stream characteristics in 2007.

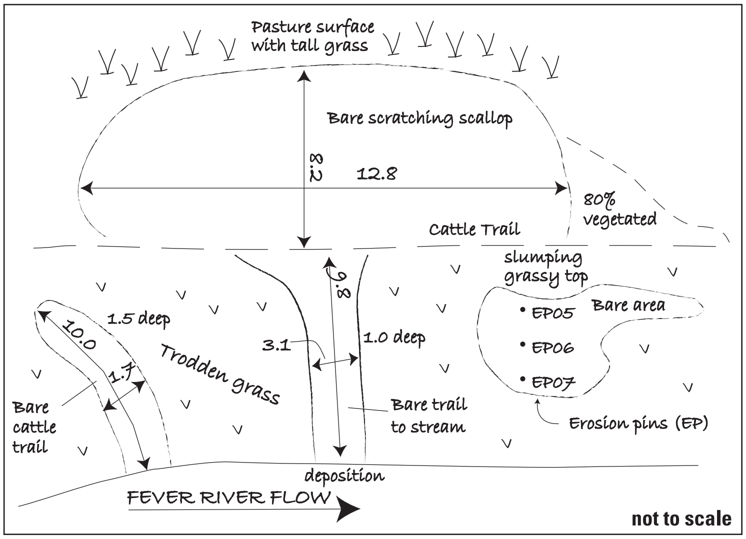

Figure 5. Example sketch of bank measurements and features.

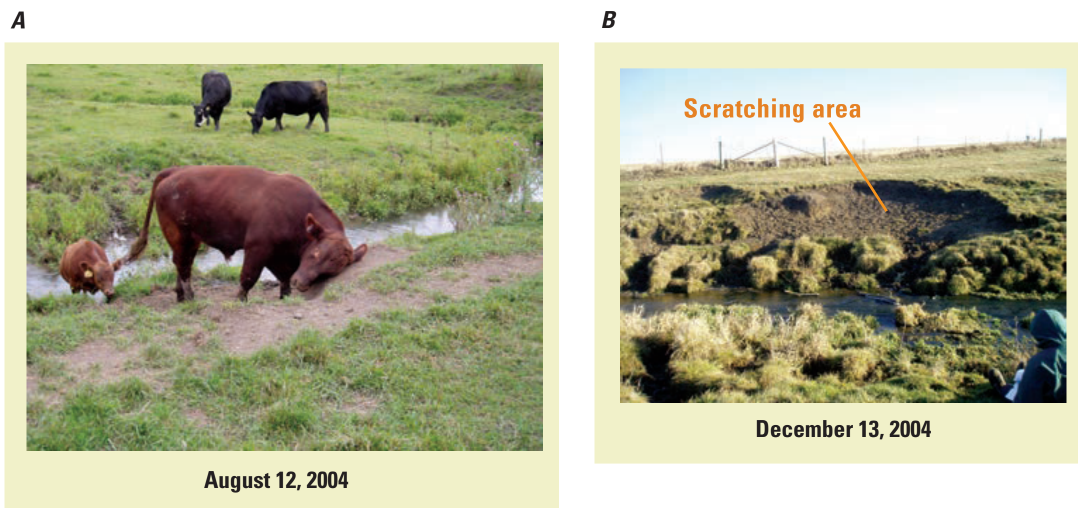

Figure 6. *A*, Cattle scratching themselves against bank 52 in Paddock 7 in August 2004, and *B*, the area where cattle scratched themselves against the bank in December 2004.

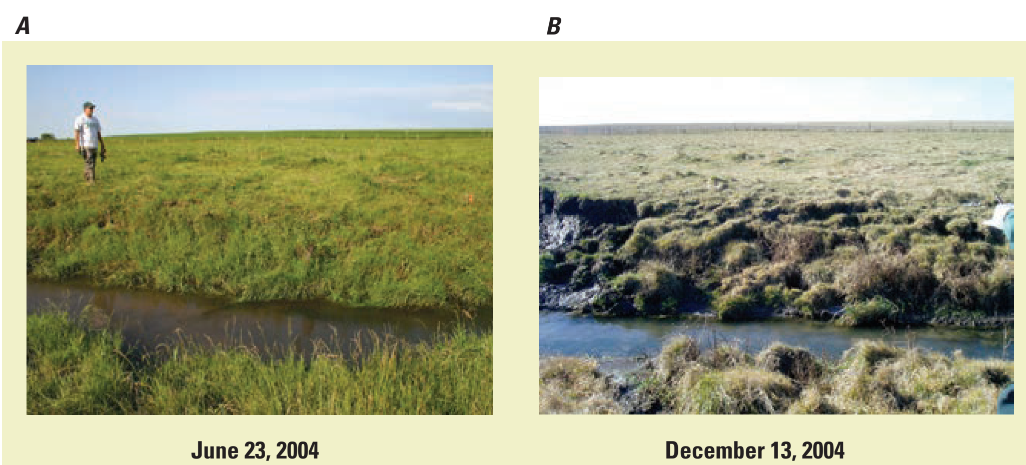

Figure 7. Development of bank slumps from cattle trampling, bank 36, Paddock 6 in 2004, *A*, in June, and *B*, in December. (Photo *A* by Randy Mentz)

Eroding-terrace cuts are often enhanced by repeated cattle scratching. A bare spot may be formed initially by hydraulic erosion, which can lead to mass wasting at the outsides of bends or at areas of cow trampling. The bare area can then be expanded by cattle scratching. The areas used for scratching are typically scallop shaped and are formed by repeated head movement and hoof scraping (fig. 7*A*). Most, but not all, scratching areas have a direct hydraulic effect on the channel, because cattle paths connect the scratching areas to the stream at a non-constructed cattle crossing (fig. 7*B*). Eroding areas enhanced by scratching were recorded in the bank-measurement notes.

Erosion Pin Measurements

Erosion pins are a precise way to measure the linear distance that a bank has retreated or advanced over a period of time. In the summer of 2004, 59 steel erosion pins were installed in 12 eroding banks in the Pioneer Farm riparian pastures (table 1). The pins are not completely embedded in the banks when set; the length of exposed pin was measured multiple times per year through August 2007 (table 2). For consistency, the upstream side of the pin was measured.

Each pin was 2 ft long with a diameter of 0.25 inch. The pins were set in vertical arrays of two or three pins inserted parallel to the water surface; most of the pins were pounded into the bank face leaving 0.2 ft exposed. In selected locations along the lower areas of banks, the pins were left further out to avoid having them buried by sediment deposition, if possible. The original design had included installation of 150 pins; yet only 59 were installed because only a limited number of locations were available where pins would not potentially injure cattle. In addition, pins were installed only in locations where the bank erosion appeared to be caused exclusively by fluvial processes. All of the pins were placed in areas that were generally vertical and outside of areas with any cattle traffic. The number of pins in each array was determined by the height of the bank and the bank profile. Relatively high and vertical eroding banks had three pin arrays. If a bank had only lower or undercut eroding sections then either two pin arrays or possibly a single pin was used. Most of the pins were in banks composed of loose silty sediment topped with a root zone that easily eroded. Of the 59 erosion pins installed, 47 were lost as of August 2007. Half the losses were caused by direct cattle trampling and the other half were buried by block failures or loose bank sediment.

The array of three erosion pins was designed to facilitate the monitoring of mass wasting at the top of the banks, short-term deposition at the water level, and overall erosion as the bank recedes. The typical failure mechanism for the banks was rotational block failure (fig. 8, bank 21). After the block failure at bank 21 that occurred between June 24, 2004, and September 17, 2004, the top erosion pin (EP–19) was dislodged and found in the stream in the remaining clump of slumped vegetation and roots. Depending on the amount of rotation and bank angle, sometimes the failed block would be found covering the bottom erosion pin.

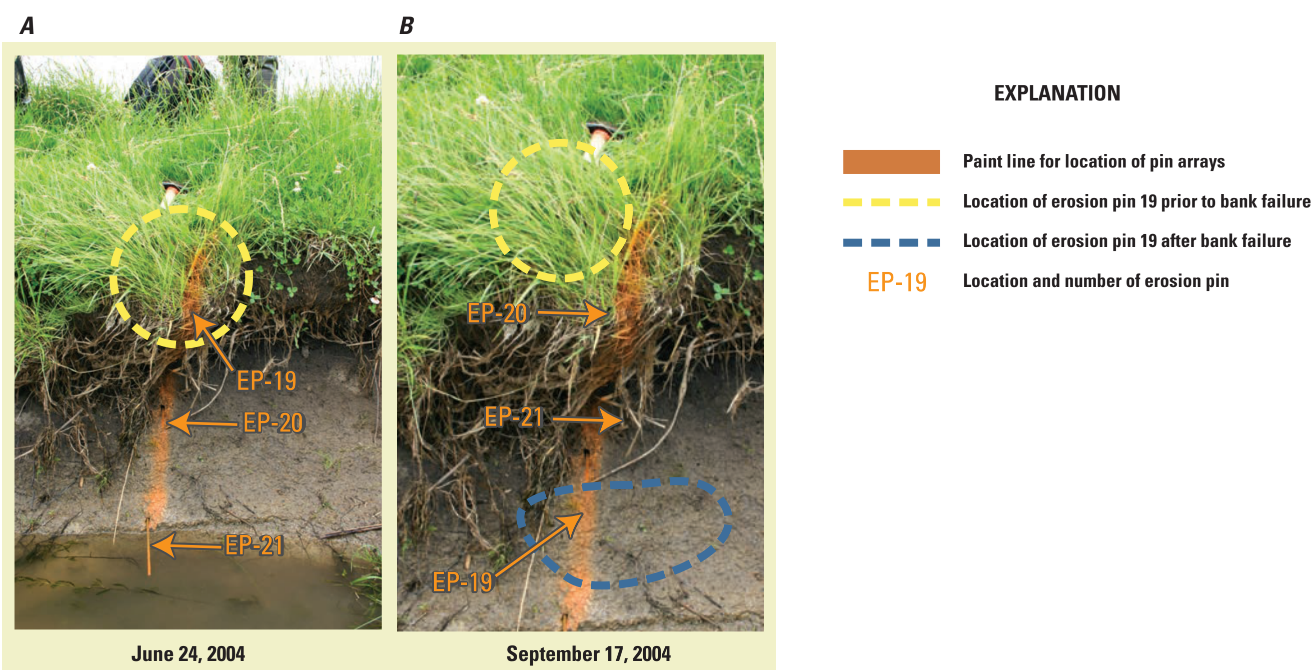

Figure 8. Erosion pins at bank 21, Paddock 4 during a recorded bank failure in 2004, *A*, in June, and *B*, in September.

Photoelectronic erosion pins (PEEPs) are arrays of photovoltaic cells that are enclosed in a clear plastic tube and set in an eroding bank to develop a time-series for bank erosion measurements. Three sites with eroding banks and conditions favorable for establishing small cattle exclosures with portable electric fencing equipment to protect the PEEPs from cattle damage were selected (fig. 1). The PEEPs were installed on September 12, 2005, by coring a small horizontal hole perpendicular to the bank face and intersecting it with a vertical hole about 4 ft away from the bank top. The PEEP was threaded through the horizontal hole and then linked through the vertical hole to a solar panel and datalogger mounted on a post above the height that cattle were able to reach within the fenced area (Peppler and Fitzpatrick, 2005). The datalogger recorded the voltages for the front, back, and center array of photovoltaic cells in 15-minute intervals.

The three PEEPs were calibrated a few days after installation on a day with full sun. The voltages for the front, back, and center arrays were recorded with known lengths of the plastic tube and related number of photovoltaic cells exposed. These voltages were used to develop a curve that was used to convert the voltages to lengths of plastic tube exposed to sunlight. Nearby arrays of the steel erosion pins were helpful in calibration and interpretation. The PEEPs were in operation for about 1 year, from the summer of 2006 through summer of 2007.

Longitudinal Profile Surveys

Longitudinal profiles of the Fever River, from south of College Farm Road to the northern edge of Paddock 7, were surveyed in 2004 and 2006 (table 2). The thalweg of the channel and the water surface were measured at various points along the length of the river, and the data were plotted to determine average water-surface slope. Additional data collected during the longitudinal profile surveys included depth of in-channel soft sediment, location and bed elevations of constructed and natural cattle crossings, locations of spring seeps, and bedrock outcropping on the stream bottom.

In-Channel Soft Sediment Depth and Volume

The thickness and extent of in-channel soft sediment deposits in the study reach were measured in 2006 and 2009 by continuously walking the channel and measuring soft sediment depths at the midpoint of the channel. While walking the channel, personnel kept field notes on a large map, which was used for dividing the reach into areas of similar soft sediment thickness. The first survey (fall 2006) was impromptu, and measurements were semiquantitative, depending on whether or not the stream could be waded. For example, conditions such as “water, thigh deep; sediment ankle deep; gravel bed” were recorded, and these notes were later translated into “water, 2.1 ft deep plus or minus 0.2 ft; sediment, 0.7 ft thick plus or minus 0.3 ft.” Sediment thickness was relatively easy to measure, because a hard bottom of gravel or cobble could be felt underneath the high-water content, muck-like soft sediment. For the summer 2009 survey, a thin meter stick was used to measure water and sediment depths; all other methods were the same as those used during the 2006 survey.

Geographic Information System Analyses of Reach Characteristics

Banklines of the Fever River along the study reach were delineated by use of a geographic information system (GIS) to analyze and process a 2003 high-resolution aerial ortho-photograph taken and processed by Aero-Metric, Inc. for Pioneer Farm. The banklines were used to divide the Fever River study reach into sections having similar geomorphic features.

The field notes and soft sediment thicknesses collected were used with a GIS to divide the reach into subareas of similar water and soft sediment depths and bed substrate. The boundaries marked on a map in the field were digitized into 98 subareas for 2006 and 94 subareas for 2009. The average soft sediment depth was then applied to each subarea to estimate soft sediment volume.

Combining the similar areas of soft sediment volumes, channel characteristics, and stream slope yielded 12 unique reaches (fig. 4). Slopes were measured using the detailed longitudinal profile for the water surface and ranged from 0.15 to 1.2 percent.

Sediment Bulk Density

Samples of representative sediment from 5 eroding banks and 11 areas of in-channel soft sediment deposition were collected in 2008 for dry bulk-density analyses. These data were used for volume-weight conversions of sediment from eroding banks and in-channel soft sediment. Eroding banks sampled ranged from organic-rich floodplain, vertical-accretion deposits affected by cattle trampling to clayey bedrock residuum without evidence of disturbance by cattle.

Collection of sediment samples from eroding banks followed procedures usually employed for collecting a relatively intact specimen of fine-grained material suitable for laboratory geotechnical tests (American Society for Testing and Materials, 2000). A short, thin-walled metal tube, 5 centimeters long with an inner diameter of 4.8 centimeters, was gently pushed into the vertical face of the eroding bank. The tube was dug out of the bank face and scraped clean of clinging sediment on the outside of the cylinder. The open ends of the cylinder were scraped with a sharp knife so that the undisturbed bank sample was even with the edges of the cylinder. The sample was carefully removed and dried at 105 degrees Celsius at the USGS Wisconsin Water Science Center for approximately 48 hours and (or) until the dry weight remained consistent after three measurements. To calculate dry bulk density, the mass of the dried sediment was divided by the total volume of the cylinder (solid plus air and moisture volume).

In-channel soft sediment samples were all collected from shallow water areas with slow-moving currents. The same metal tube used for the bank samples was pushed by hand vertically through the soft fine-grained sediment until the surface of the sediment was even with the top edge of the tube. The sampling was done from downstream to upstream to keep the shallow water clear enough to check visually the sediment-water interface and to make sure only undisturbed sediment was collected. Samples were collected from the margins and center of the channel. Macrophytes were common and areas of established streambed with thick roots were avoided. The samples were extracted by inserting a metal trowel under the tube and carefully bringing the tube out of the water and depositing the liquefied sample into a glass jar. Laboratory drying was similar to that done for the bank samples, and dry bulk density was estimated by dividing the mass of the dry sediment by the cylinder volume of the wet sediment (in grams per centimeter or pounds per cubic foot).

Time-Lapse Photographs

A time-lapse camera was installed in August 2004, and Paddocks 1–4 were photographed every 8–24 hours to show pasture conditions and forage length relative to the rotation cycles of cattle grazing. A Kodak DC290 time-lapse camera was setup in Paddock 4 on a pole about 8 ft above the paddock and facing southwest toward the Fever River and College Farm Road. The camera operated from August 6, 2004, to October 20, 2004, with photographs taken twice a day at 8:00 a.m. and 4:00 p.m. The camera was operated once a day at 12:00 p.m. from December 20, 2004, to December 29, 2004, before it was deconstructed for the winter. The camera began operation in February 11, 2005, for daily photos taken at 12:00 p.m. until it was removed on July 24, 2005.

Miscellaneous Photographs and Field Notes

In addition to the field notes regularly taken on bank and channel conditions during the monitoring surveys, miscellaneous photographs and notes were taken of bank, channel, and substrate conditions, recent flooding, and conditions of the rebar at cross-section endpoints during every field visit to the farm. In addition, photographs of vegetation conditions (instream, bank, and pasture) along with cattle crossings, cattle behavior, fence conditions, and aquatic biota including fish, wildlife, and insects were collected. Group field tours and USGS gaging-station operations were also photographed. At the conclusion of the monitoring, field notes were checked for completeness and scanned into electronic documents.

Geomorphic Data Descriptions and Uses

The following sections contain descriptions of data files for all the data that were collected as part of the geomorphology study from 2004 to 2011. The data in appendixes 1–9 include channel cross-section surveys, eroding bank measurements and photograph points, erosion pin measurements, longitudinal profile surveys, in-channel soft sediment volume estimates, GIS analyses of reach characteristics, bulk density analyses of bank and in-channel soft sediment samples, time-lapse photographs, and miscellaneous photographs and field notes.

Channel Cross-Section Surveys

Channel cross-section data include one folder of scanned field notes, one location map, and three Microsoft® Excel spreadsheets with channel cross-section survey data (appendix 1). Scanned field notes are organized by field visit. The map “CompleteSurveying Field Map.bmp” is included to show the locations of the cross sections, survey benchmarks (red points), and cross-section endpoints (purple points) along the study reach.

The spreadsheets with cross-section data are grouped by transect number: transects 1–9, 10–24, and 25–35 (appendix 1). Cross-section data were collected 15 times from June 2004 through August 2011. The terms “cross section” and “transect” are used interchangeably throughout the field notes and digital files and are considered to have the same meaning. Within each spreadsheet, there are worksheets for abbreviations and labels, cross-section survey data and graphs (for example “6-28-04” and “T1”). For all cross-sections, 0.0 is at the left rebar location. In August 2007, the left rebar on T30 was moved 5 ft further away from the stream to avoid a developing cattle trail interfering with the location. The last three surveys for T30 start at –5 ft relative to the previous surveys. A worksheet entitled “Abbreviations and labels” contains information on abbreviations and labels used on the worksheets and their descriptions.

The cross-section plots include a mix of elevations from the top of the soft sediment and hard channel bottom. Data point labels identify cross sections that have a measured soft sediment depth. In some of the surveys conducted in December, the Fever River was frozen and the channel was not surveyed at all cross sections. For some cross-section plots during winter surveys, unusual-looking straight lines for water surfaces should be checked to confirm the presence of ice over the channel. On rare occasions surveys needed vertical shifts to correct for changes in benchmarks or other circumstances at the time of the survey; however, the raw data and calculations for these corrections have been archived separately and are not published with this report.

Eroding Bank Measurements and Photograph Points

Data files for eroding bank measurements and photograph points are organized into four folders in appendix 2: bank measurement field sheets, bank photographs, bank survey field maps, and field notes. Scans of bank measurement field sheets are organized into one file for each of the banks visited during the study, although some of the field sheets contain more than one bank. The files are named “PF_BankXX.pdf,” where XX is the bank number. Summary measurements and comments were compiled into Microsoft® Excel spreadsheets labeled “Bank Data Sheet.xls” and “BankLength.xls.”

Bank photographs are sorted into folders by paddock number. Within the folders, there are a few subfolders with photographs organized by bank number for those banks that had a particularly large collection of photographs. Other bank photographs with fewer repeat photographs are listed separately. All photographs are labeled with the same naming convention: “BX Y MMDDYYYY.jpg,” where X is the bank number, Y is the photograph number, the date is expressed by “MM” for the month, “DD” for the day, and “YY” for the year. Photograph number 1 is always taken from the designated photograph point. Photographs numbered with 2 or higher are of other angles or other detailed features of the bank area. For example:

- B1 1 083107–bank 1, photograph point 1, August 31, 2007
- B1 1 03142006–bank 1, photograph point 1, March 14, 2006
- B1 2 083107–bank 1, photograph point 2, August 31, 2007

Files in the bank survey field maps folder are scans of maps with field notes recorded directly on them. These are organized and labeled by field trip date with the naming convention of MM_YYYY or MM_DD_YYYY.

The field notes folder contains scans of field notes that describe the order that the bank photographs were taken. These notes also contain additional information about pasture or cattle conditions, and interpretations about causes of erosion.

Erosion Pin Measurements

Data for erosion pin measurements are in appendix 3 and are organized into three folders containing erosion pin photographs, field notes, and PEEP photographs, as well as individual Microsoft® Excel spreadsheets of PEEP data and calibration curves. In addition, a summary spreadsheet “EP Data Sheet.xls” contains a compilation of all the field notes and maps.

Erosion pin photographs are named “EP XX-XX Y MMDDYYYY.jpg” where EP stands for Erosion Pin, photograph XX is the number of the erosion pin or pins; Y may be the photograph number, if applicable, and the date. Field notes include comments on the photographs taken and other bank conditions or cattle trampling in the area. PEEP photographs are organized into folder by trip and named “BX PEEPY Z MMDDYYYY.jpg,” where X is the bank number, Y is the PEEP number, and Z is the photograph number followed by the date. Occasionally, the bank number is left off of the photograph name.

The Microsoft® Excel spreadsheets of PEEP data are organized by PEEP number have multiple worksheets for raw data and excerpted noon data. A moving average and graph of the data points collected at noon each day are also included. A separate spreadsheet named “PEEP calibration curves.xls” contains all of the calibration data and correction curve calculations.

Longitudinal Profile Surveys

Data for longitudinal profile surveys are in appendix 4 and organized into two files. Longitudinal profile data for water surface, thalweg, and bankfull altitudes and resulting plots from June 2004 and December 2006 are compiled in separate worksheets in the Microsoft® Excel file “PlattevilleSurveyLongitudinalProfile020807.xls.” Additional data points are included that were collected along the channel and banks between cross sections. Both years of data are plotted in the “Graph2004-6” tab along with cattle crossings (constructed and natural), possible springs, and bedrock. Reach slope calculations are in the “AddlDataSlope” worksheet. The worksheet “TranFixedDistance” contains the distance along the longitudinal profile established for each transect, made consistent among survey years for multiple year comparisons. A worksheet entitled “Abbreviations and labels” contains information on abbreviations and labels used on the worksheets and their descriptions.

A separate Microsoft® Excel spreadsheet, “Crossing Elevation Comparisons.xls,” contains a subset of data that were used to track elevation changes in the four cattle crossings from 2004 to 2009.

In-Channel Soft Sediment Depth and Volume

In-channel soft sediment depth and volume data for the 2006 and 2009 surveys are organized into multiple file types in appendix 5. A field map (08_11_2009.tif) for the 2009 measurements shows the reach with handwritten field notes. Abbreviations on the map are explained in a worksheet “Abbreviations” in the Microsoft® Excel spreadsheet “SedVolumeCalculations.xls.” In the same spreadsheet, reach descriptions and methods for determining the reach boundaries are listed in the “Reach Information” and “Methods” worksheets. The 2006 and 2009 data are in the worksheet “Sediment Volume Calculations.” A few photographs were included in a folder “August 2009 soft sed survey.”

Geographic Information System Analyses of Reach Characteristics

The geospatial data were organized into a GIS with a base map of an ortho-photograph collected in 2003 by Aero-Metric for the Pioneer Farm (appendix 6). Shapefiles are in the folder “PioneerFarmGISPublishShapefiles.” Other files include “Pioneer Farm Package.mpk” for ease of plotting data. The following shape files are included:

- Banks.shp—locations of eroding bank locations,
- Fall06attr.shp—stream reaches and data associated with the fall 2006 soft sediment volume estimate,
- photopoints.shp—locations of photograph points for eroding bank locations,
- platte_paddocks1.shp—boundaries of rotational-grazing Paddocks 1–7 at the start of the study in 2004,
- StrCenterArc.shp—edited stream centerline,
- Summer09attr1.shp—stream reaches associated with the August 2009 soft sediment volume estimate,
- Transects.shp—locations of the surveyed cross-sections or transects, and
- XYmapdata.shp—total station data that includes the occupied points, reference marks, and benchmarks and cross-section endpoints referenced to an arbitrary coordinate system.

In addition to the GIS files, a metadata file that contains abbreviations and explanations for codes used in the GIS shapefiles is provided. An example screen capture of GIS data is in “CaptureofPioneerFarmGISMapFile.JPG.”

Sediment Bulk Density

The results from laboratory analyses of bulk density of selected eroding streambanks and in-channel soft sediment deposits are in appendix 7. Files include the scanned field notes from the sampling “2008 07 22 – sampling – pioneerfarm.pdf” and laboratory results “bulk density lab data.xls.” A folder named “Bulk Density Sampling Photographs 072308” contains photographs taken in the field during the sediment sampling. The bulk density results, “bulk density lab data.xls,” include all weight measurements and calculations for bank and soft sediment densities. Photographs are included in the folder and captions or information about the subjects of the photographs are in the associated field notes.

Time-Lapse Photographs

Appendix 8 includes the series of photographs from the time-lapse camera. The file structure was dictated by the camera, but each photograph is named sequentially and was time and date stamped to ensure the photographs remain in order. Also included are scanned field notes from camera field checks and photographs of the time-lapse camera setup.

Miscellaneous Photographs and Field Notes

Appendix 9 contains a mix of photographs and miscellaneous notes that did not fit specifically in any of the other appendixes. There are three folders of photographs:

- Cattle photographs—197 total pictures in 8 folders that are organized by cattle behavior or field trip date. Because the focus of the study was to document how the cattle interact with the streambanks, there are a number of behavior photographs.
- Matching Sets of Photographs—22 photographs of before-and-after series of interest. There are six bank sets and one erosion pin set.
- Misc Photographs—466 files in 26 folders that are organized by topic. Photographs include flora and fauna, flood documentation, channel crossing documentation, equipment and other subjects.

A variety of field notes was collected over the course of the study for almost all data types. The field notes are filed in multiple appendixes along with the appropriate data type for ease of data interpretation. Because more than one type of data was collected on some field trips, such as bank measurements and erosion pin measurements, a duplicate set of all field note files are in appendix 9 in the folder “Field Notes.” The file naming structure is “YYYY MM DD – TRIPTYPE – pioneerfarm.pdf,” where the date of the trip is followed by a brief description of the data collected on the trip. Scanned field notes from the first reconnaissance trip to the farm are in “2004 06 21 - reconforbank - pioneerfarm.pdf.”

Lessons Learned

Monitoring bank erosion and channel changes associated with riparian cattle grazing required flexibility in traditional sampling methods that kept the safety of the cattle and the field staff in mind at all times. A compilation of lessons learned, mainly from monitoring bank erosion, is intended to assist in the next study of this kind.

Erosion Pins

The measurements of bank erosion and movement by use of the erosion pins are understood to have limitations. A major limitation is that the time resolution is dependent on the frequency and timing of the pin measurements. Following the March 5–7, 2005, flood and subsequent pin measurements, a few additional issues became apparent that must be taken into consideration when calculating bank erosion volumes and rates. These issues include pin influence on erosion processes, measurement of block failures, pin stability and movement, and sediment deposition along base of banks.

There are two ways that the erosion pins can actually protect against erosion. First, undercutting can be retarded by the erosion pin in an area of high water velocity where the pin is at a critical depth for erosion from flood flow, even with pin diameters as small as 0.25 inch. One example of this is from streambank 63, where the bank eroded around the bottom third pin (EP06) in an array that was submerged during the March flood, as would be expected from fluvial-related toe erosion. Simultaneously, the pin at the top of the same array (EP04), above the high water mark, had little erosion and few recorded block failures. The center pin (EP05) was located at the point between erosion below and no erosion above. Observations of the bank just upstream of the pin array indicated that the bank eroded above the level of the center pin—that is, there was more erosion, higher up on the bank just upstream. As the water eroded the bank from upstream and from underneath, it came to the length of the pin in the bank all at once. The pin reinforced the bank material above it and protected the top portion of the bank from block failure. For this study, a convention was thus established to always measure along the upstream side of the pin. As a result, the measurement of erosion on the center pin was greater than at the top and bottom pins, because the center pin was measured on the upstream—rather than the downstream—protected side of the pin. Another example at EP05 resulted in an upstream measurement of 1.73 ft and a downstream measurement along the pin of 0.65 ft. A photograph from April 8, 2005, shows exactly how this looks when soil collapses and erodes away only on the upstream side of the pin (fig. 9). This may be an extreme case, but on a smaller event scale or when measurements taken over a longer period of time, this measurement error could be missed if care is not given to record measurements consistently on the same side of a pin. Therefore, the placement of each pin and the flow events around the time of the pin measurements should be considered during the interpretation of each erosion pin measurement. Lower pins are more likely than upper pins to catch cycles of erosion and deposition over time scales of 6 months or less as blocks of eroded banks tend not to be carried away by flows all at once. Conversely, upper pins are more likely to be part of significant block failure and be removed over a short time period.

In some instances, erosion pins may prevent block failures. The erosion pins in the upper portions of the array, or the pins placed singly, as in bank 48 with EP44 and EP45, were placed to measure the block-type failures of chunks of bank that fall off the upper grassy portions of the bank. In the Fever River, undercutting is most obvious just beneath the base of the root zone, and it causes the upper sections of the banks to topple into the channel in large blocks held together by grass roots. Even a small diameter horizontal erosion pin has the potential to keep the block from breaking loose entirely from the rest of the bank. An erosion pin can actually support a block in place at the base, perhaps stalling or preventing failure entirely (fig. 10).

Pin movement is a third problem, especially after flood events. For example, EP40, found in bank 44, was found loose in its hole during a measurement following flood conditions. It was assumed to have been pulled (or plucked) out of the bank by flowing water. Originally, the end of the pin was installed approximately in line with the other two pins in the array. After the flood, EP40 was protruding noticeably further than EP38 and EP39. When touched, EP40 was loose and could easily be pushed back to a point that was roughly even with the ends of EP38 and EP39. It was suspected that EP40 had moved back and forth over time in its original hole (fig. 11). When EP40 was pulled to see if it was secure, suction sometimes held it in place. The measured distance from the top of the vegetation was unchanged and no other evidence of odd effects from the flood were visible where erosion pin plucking took place. Similar movement was seen in bank 50, EP59, where the cohesive tendencies of the fine-grained bank material allowed the hole from the pin to be maintained.

Pin plucking could be prevented or slowed if the erosion pins were significantly longer and extended into the bank to the point where the flow would not have the strength to pull them out. Another solution would be to reduce the diameter of the pin to only a few millimeters to reduce friction caused by streamflow, so that the flow could not "grab" onto them in the same way. The problem with thinner pins, however, is that the flow and debris in the water would probably bend them over, thus further disrupting the measurement. Thicker pins or pins with a rougher surface that could hold onto the bank material better than the pins that were used, such as half-inch rebar, may not be prone to being pulled out, but instead may contribute to bank stability.

The fourth problem was the deposition of soil on an erosion pin before pin could be measured. Soil deposition is probably a known assumption for erosion pin measurements, but this study provided excellent opportunities to measure the erosion and the subsequent deposition. In bank 49, EP54 was situated above a shelf on the lower bank that was most likely a very old block failure (fig. 12). During the March 2005 flood, straw, grass, and sticks were thrown up onto the shelf and were lodged under the pin. Snow then fell around the pin and debris and on the surface below. Differential melting, due to the warmth of the pin heating slightly from being in the sun, caused the snow and a section of bank above the pin to melt, and then the loose soil fell. The bank above the pin crumbled away as it thawed, the soil clumps fell on the pin, and the debris and snow held up the clumps (fig. 11). When the ruler was slid along the upstream and underside of the pin all the way to the frozen bank behind it, the measurement was 1.35 ft of exposed pin; most likely from the March flood activity. When the ruler was moved to the top of the pin under the loose soil, supported by the debris and snow below, 0.85 ft of

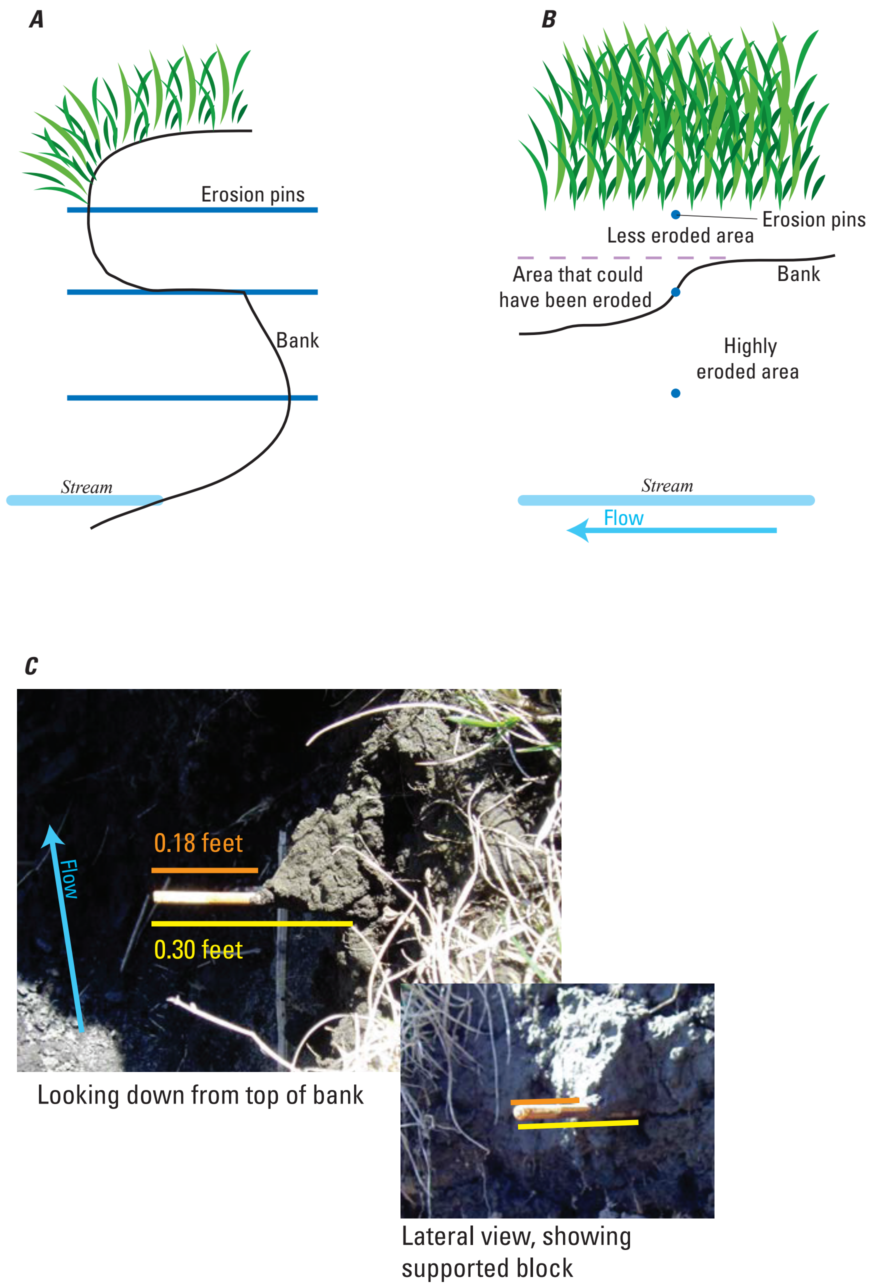

Figure 9. Erosion pins providing bank protection *A*, in cross section, *B*, from instream, and photographs of *C*, erosion pin 19 with measurements on April 8, 2005.

exposed pin was measured. Depending on when the pin measurement is made, in relation to freeze-thaw events, the net measurement will likely be somewhere between the combined erosion and deposition over the spring melt.

In summary, erosion pin data need careful individual analyses for interpretation of bank erosion processes. Each type of measurement and bank situation will result in different readings. Additionally, the convention chosen for the repeat measurements (for example, always the upstream side of the pin) must be used consistently. Careful documentation of each pin placement, the reason why it was placed there (measure erosion, deposition or net erosion), and the exact conditions at the time of each measurement (frozen, postflood, etc.) are crucial to interpreting the data correctly. If this level of detail is neglected, the interpretation of the data can be completely erroneous and can paint a false picture of erosion and deposition episodes in the monitoring area.

Effects of Freeze-Thaw Processes on Bank Erosion

In this study, the causes of eroding banks were categorized by the physical processes of fluvial erosion (direct removal of bank sediment by flowing water), cattle, or a combination of both. During cold months, repeated freezing and thawing of bare soil and sediment in eroding banks enhanced mass wasting. Surface moisture in the banks would freeze and

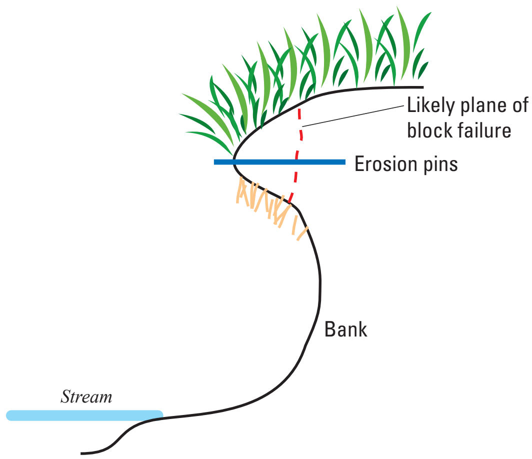

Figure 10. An erosion pin supporting the nose of an undercut bank and slowing or preventing a block failure.

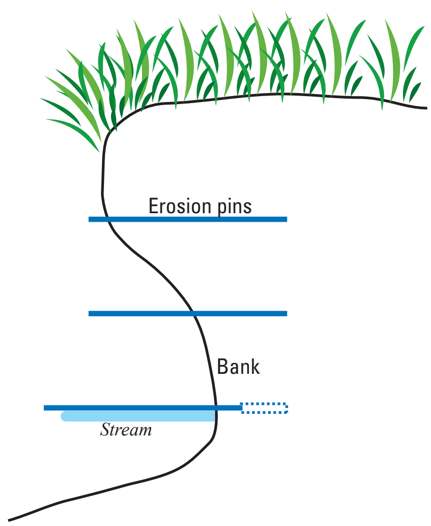

Figure 11. The plucking of an erosion pin out of its hole by flowing water, without completely removing it.

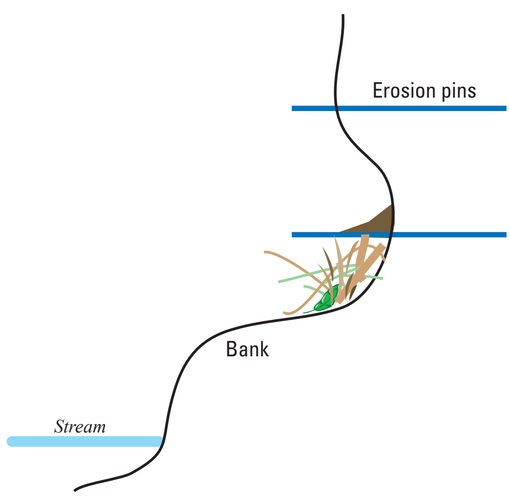

Figure 12. Flood debris supporting an erosion pin covered with loose soil clumps that could be measured and interpreted incorrectly.

expand, thus causing jointing and sloughing. Sediment would build up at the base of banks and then be easily carried away by the next high flow.

Geomorphic Monitoring with a Focus on Cattle Safety

The close presence of a herd of beef cattle to the monitoring sites meant that anything placed in the paddocks related to geomorphic monitoring had to be safe for both the cattle and the equipment. For cross-section endpoints, no metal pin flags, flagging, or bare rebar could be used. Metal plates with the cross-section number were welded to rebar and installed flush with the ground surface. This required that a metal detector be used to find the cross-section endpoints, especially during the summer or during rest periods between grazing when the vegetation was thickest. Permanent benchmarks were located outside the paddocks. Occasionally, hollow plastic posts were used, similar to what was used to string the electric fence.

Erosion pins were also another possible safety issue to the cattle, whether the pins were in the bank or had fallen out into the stream, where cattle might lean or step on them. The number of erosion pins placed in eroding banks was minimized, and the pins were placed only in banks that had limited use by cattle.

Equipment was located outside of the paddocks when possible. The time-lapse camera was placed on a high post along the edge of a paddock, out of reach of the cattle. The data recorders for the PEEPs were also located on sufficiently high posts.

Summary

Stream geomorphic data were collected by the U.S. Geological Survey along a 0.8-mile reach of the Fever River in the Driftless Area of southwestern Wisconsin from 2004 to 2011 to characterize baseline bank and channel conditions associated with paddock-based riparian cattle grazing at the University of Wisconsin-Platteville’s Pioneer Farm. The intensive monitoring from 2004 to 2007 identified geomorphic conditions prior to evaluating the effects of alternative types of riparian grazing management. Monitoring data included channel cross-section surveys, eroding bank measurements and photograph points, erosion-pin measurements, longitudinal profile surveys, measurements of in-channel soft sediment volume, and repeat, time-lapse photographs. Characteristics were summarized into subreaches by use of a geographic information system. Samples of eroding bank and in-channel soft sediment samples were collected and analyzed for dry bulk density in 2008 for use in sediment budgets. Data from channel cross-section surveys and measurements of bank erosion collected in 2007 and 2009 are useful for describing differences in geomorphic conditions between grazed paddocks and excluded Paddock 7. These data will be used by Pioneer Farm researchers in future studies and experiments to document changes in bank and channel erosion and deposition related to riparian grazing practices.

Lessons learned from bank monitoring with erosion pins were most numerous and included the need for consistent tracking of each pin and whether there was deposition or erosion, timing of measurements and bank conditions during measurements (frozen, postflood), and awareness of pins loosening in place. Repeated freezing and thawing of banks and consequential mass wasting and jointing enhance fluvial erosion. Monitoring equipment in the paddocks was kept flush to the ground or located high on posts to avoid injuring the cattle.

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Appendixes

The appendixes are available online at https://doi.org/10.3133/ofr20161179.

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