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Regional Sediment Management Program

Evaluation of Cedar Tree Revetments for Bank Stabilization at the Locust Creek Conservation Area, Missouri

Quantifying Bank Erosion Volumes from Preproject to Postfailure

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Abstract

The US Army Corps of Engineers Regional Sediment Management (RSM) program funded research to assess the longevity and effectiveness of cedar tree revetments for sediment reduction. Between 1988 and 1997, the Missouri Department of Conservation (MDC) constructed multiple cedar tree revetments, plantings, and a grade-control structure at an experimental stream management area on Locust Creek within the Locust Creek Conservation Area (LCCA). For the first few years, MDC also replaced missing trees as needed. MDC monitored these sites with photographs and cross sections until 2004.

This study evaluated bank stability on Locust Creek from 1970 to 2019 using aerial imagery, lidar, ground surveys, and a December 2019 site visit to estimate the areal change in streambanks and the volume of sediment eroded over the years. Based on their dates of construction, the project compared preproject, with-project, and postfailure conditions at each site. The project included cedar tree revetments, other hardwood revetments, plantings, and a grade-control structure. This research found a 50% to 64% reduction in erosion for approximately 14 years.

As of December 2019, all tree revetments had failed, and banks were bare and steep. The grade-control structure remained intact and continued to stabilize bed and banks immediately upstream.

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Preface

This study was conducted for the Regional Sediment Management (RSM) program under project, “Longevity and Effectiveness of Nature-based Bank Protection for Reducing Sediment Loading to Rivers,” funding account U4381265; AMSCO 008303.

The work was performed jointly by the River Engineering and Restoration Section of the Kansas City District and the River and Estuarine Engineering Branch of the Flood and Storm Protection Division, US Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory (ERDC-CHL). At the time of publication, Mr. David P. May was branch chief, Dr. Cary Talbot was division chief, and Dr. Julie Rosati was the technical director for Flood and Coastal Risk Management. The deputy director of ERDC-CHL was Mr. Keith Flowers, and the director was Dr. Ty V. Wamsley.

The commander of ERDC was COL Christian Patterson, and the director was Dr. David W. Pittman.

1 Introduction

The Kansas City District of the US Army Corps of Engineers (USACE) recently submitted the *Grand River Ecosystem Restoration Feasibility Study* (USACE 2020) to Congress. The final selected plan was to achieve upstream sediment reduction via an estimated 300 bank-stabilization projects. Because the purpose of this bank stabilization is to reduce sediment loads rather than to protect infrastructure, the Kansas City District wanted to explore low-cost methods, rather than traditional rock stabilization, to reduce erosion. This report documents the effectiveness of low-cost cedar tree revetments, installed between 1988 and 1997 at the Locust Creek Conservation Area (LCCA), for reducing bank erosion.

1.1 Background: Cedar tree revetments

Cedar tree revetments are a low-cost bioengineering technique in which longitudinally placed cedar trees are used to protect the toe of an eroding streambank (Figures 1 and 2). The cedar trees are secured with anchors driven into the soil substrate to lock the revetment in place. Once anchored in place, the cedar trees reduce near-bank shear stress and velocity to the previously eroding bank. The fern-like branches increase channel roughness on the lower bank toe and induce sediment deposition. If sediment can be captured, new vegetation will establish and further stabilize the toe, providing a stable lower bank for the mid and upper banks to revegetate.

Cedar tree revetments also provide woody habitat and cover for aquatic organisms (Gough 1991; McClure 1991). The habitat can be especially important in streams lacking natural supplies of woody debris.

Figure 1. Planview of cedar tree revetment. (Image modified from NRCS 1996.)

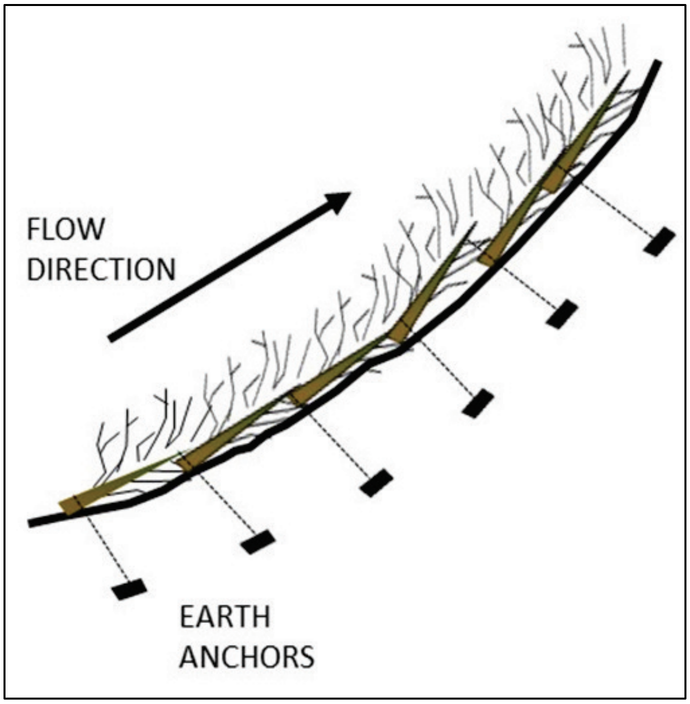
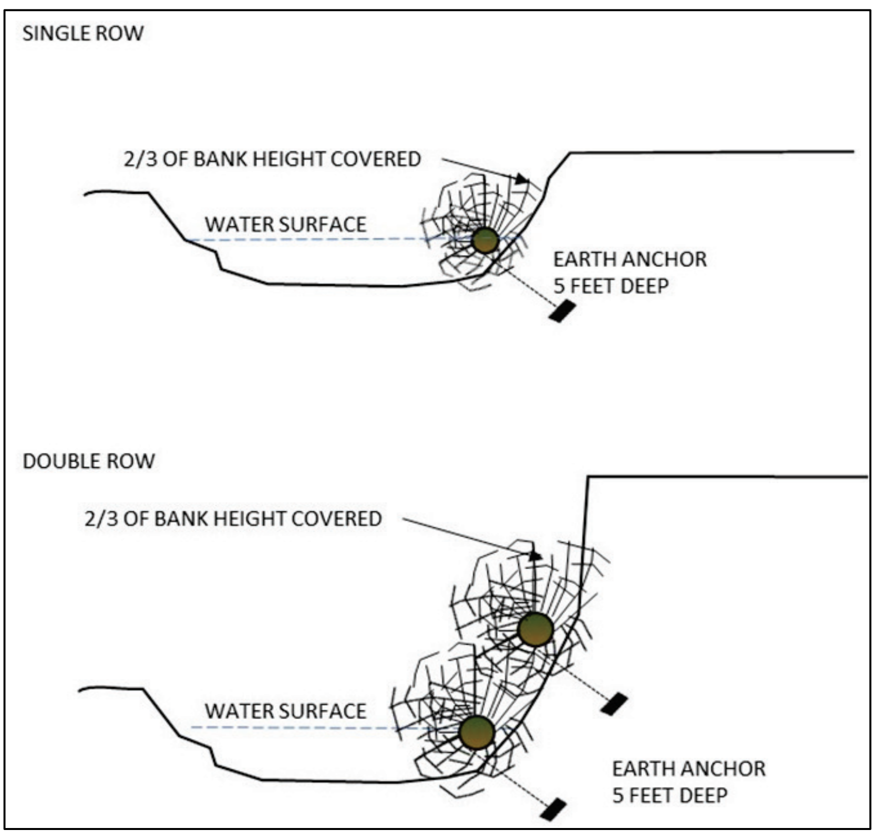


Figure 2. Illustration of single-row and double-row cedar tree revetments. (Image modified from Fantz et al. 1993.)



1.2 Objectives

The Kansas City District is conducting ongoing watershed studies that require supplementary information on potential low-cost bank stabilization methods. Therefore, the focus of this report is investigating cedar tree revetments. Do cedar tree revetment projects reduce bank erosion as well as traditional rock placement for stabilization? Are they durable and lower in cost than rock revetments? The objectives of this report are to assess and document the effectiveness of low-cost cedar tree revetments and to determine if they are a viable alternative to traditional rock revetments. A secondary objective is to determine if cedar tree revetments provide lasting reduction of bank erosion.

1.3 Site descriptions

Locust Creek is a fifth order sand-bed stream and a tributary of the Grand River, which flows into the Missouri River. In 1987, the Missouri Department of Conservation (MDC) created the Experimental Stream Management Area on Locust Creek to develop and test stream management techniques. Between 1988 and 1997, MDC constructed multiple streambank stabilization projects on Locust Creek, within the LCCA (Figure 3).

This reach of Locust Creek became unstable in 1970, after a meander cutoff shortened the stream and increased stream energy through the reach. The channel has kept an actively meandering pattern since that time. As a consequence of the meander cutoff, channel bed degradation was also occurring, and a loose rock riffle grade-control structure was constructed at the downstream end of the bank stabilization reaches. This structure and the bank stabilization measures were combined to form a system approach (i.e., bed and bank) to stream stabilization for the LCCA.

Four cedar tree and three hardwood revetment projects were built between 1989 and 1997 (Table 1). Several of the sites included additional stabilization measures, such as bank sloping and revegetation.

Figure 3. Site map of Locust Creek streambank stabilization projects. (Image modified from MDC n.d.)

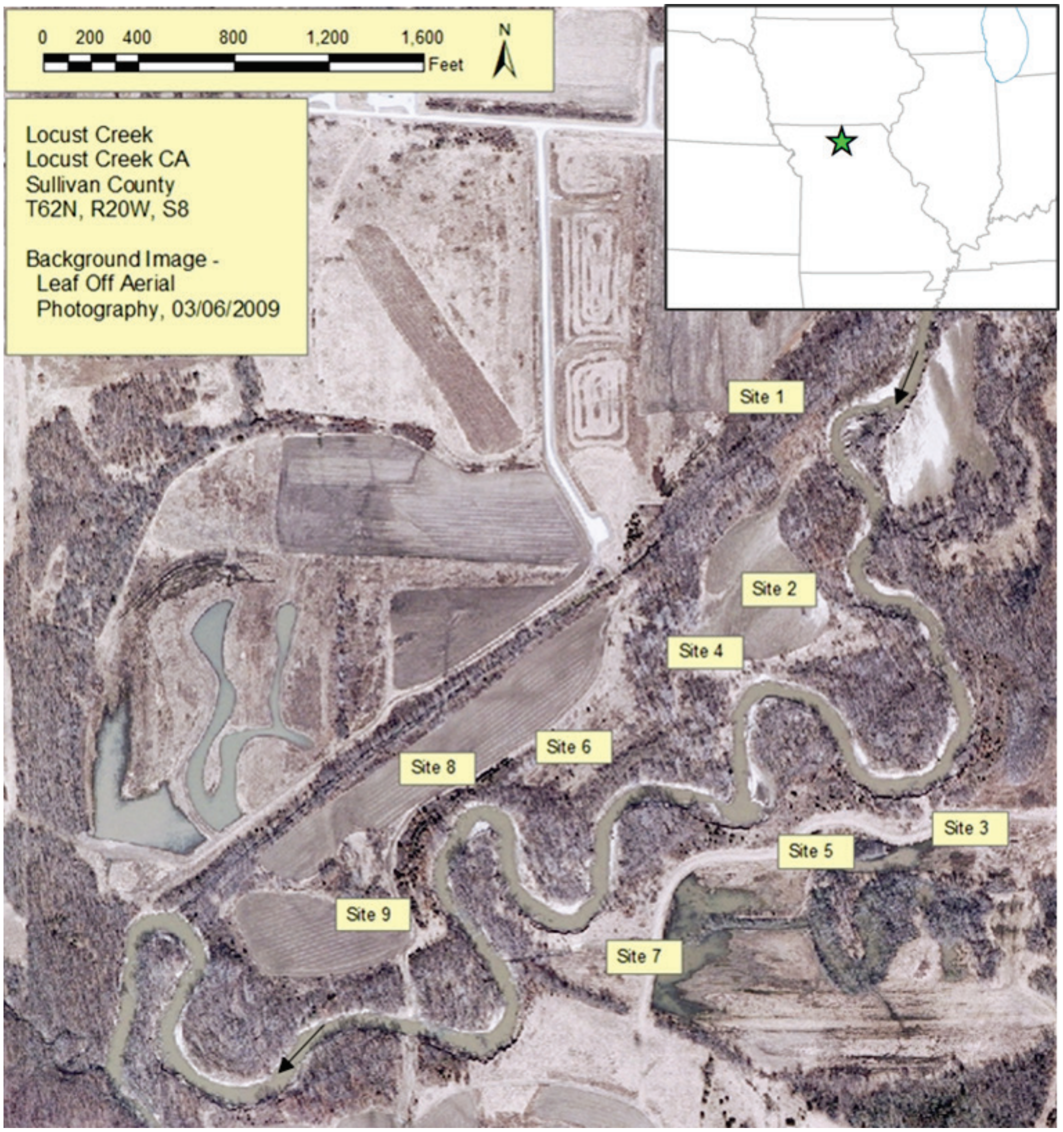


Table 1. Summary of streambank stabilization sites.

Site	Date built	Stabilization method
1	May 1988	Hardwood tree revetment
2	October 1988	Stream bank revegetation
3	April 1988	Cedar tree revetment
4	August 1997	Hardwood tree revetment
5	March 1992	Willow pole Revetment
6	August 1994	Hardwood tree revetment
7	November 1993	Cedar tree revetment
8	October 1989	Cedar tree revetment
9	October 1989	Stone grade control

Sites 1 and 2 were not analyzed or included in this report. MDC has periodically monitored the remainder of these sites. As indicated in the subsections that follow, MDC repaired several of the sites in the first few years after construction. Monitoring continued until 2003. USACE personnel (i.e., the authors of this report) visited the site with MDC personnel on 10–11 December 2019.The subsections that follow contain descriptions of the constructed projects and evaluations of site conditions over time for Sites 3–9.

1.3.1 Site 3

At Site 3, a total of 126 cedar trees were anchored in a double-row revetment, and bank revegetation, consisting of willow posts and stakes, was used to stabilize the top of bank. The revetment was one-third to one-half the height of the bank and was anchored with helical earth anchors, No. 9 wire, and 3/16-inch cable. The project was first installed in April of 1988. Between 1990 and 1992, additional trees were added to replace trees removed by flooding. This was one of the first cedar tree revetment projects constructed by MDC. They determined that two-thirds of the bank height needed to be protected and that duckbill anchors performed better than helical anchors (Fantz et al. 1993).

During the December 2019 survey (Figure 4), Site 3 had nearly vertical banks and no evidence of any remaining revetment. Some recently collapsed trees protruded into the creek, and only sparse vegetation grew along the bank.

Figure 4. Site 3 in December of 2019. *Left* photo is looking upstream, and *right* photo is looking downstream.

1.3.2 Site 4

A hardwood tree revetment (Figure 5) was constructed at Site 4 in August of 1997. It consisted of 50 pin and shingle oak trees that were 20–25 feet long and were anchored in a single row. Additionally, the bank was given a slope of 3:1, and critical areas of the top of bank were seeded with grass and protected with an erosion-control blanket. Willow plantings were added in November of 1997.

The revetment was initially successful in establishing vegetation along the bank, as seen in the 1998 photo that was taken a little less than a year after construction (Figure 5). However, the banks were nearly vertical and had little vegetation by December of 2019. None of the revetment was found during the 2019 survey.

Figure 5. Site 4, looking downstream. The *top left* photo was taken in 1997, before construction of the revetment. The *top right* photo was taken in 1997, immediately after construction. The *bottom left* and *bottom right* photos were taken in 1998 and 2019, respectively.

1.3.3 Site 5

A willow pole revetment was constructed at Site 5 in February of 1992. No revetment remained as of the December 2019 survey. A sandbar had formed on the outside of the bend (Figure 6), presumedly during the 2019 flood flows.

Figure 6. Site 5 in December of 2019.

1.3.4 Site 6

The double-row hardwood tree revetment at Site 6 (Figure 7) was constructed in 1994 from 35 shingle oak trees that were 20–35 feet long. Lost trees were replaced in 1996 and 2000. At the December 2019 visit, none of the revetment remained; the banks were nearly vertical and had only sparse vegetation growing on them.

Figure 7. Site 6. The *top left* photo was taken in 1994, just before construction began. The *top right* photo was taken just after construction was completed. The *bottom left* and *bottom right* photos were taken in 2001 and 2019, respectively.

1.3.5 Site 7

At Site 7, a willow pole revetment was constructed in 1992 and failed shortly thereafter. A cedar tree revetment was then constructed in November of 1993. It consisted of 97 cedar trees in a double-row revetment. They were anchored with 6-inch, stemless, arrowhead anchors and 3/16-inch steel cable. The revetment covered two-thirds of the bank height. Additionally, 650 trees were planted in the riparian corridor in 1994. A total of 31 additional trees were added to repair the revetment after bank failures in 1994 and 1995. A 1996 survey indicated that 11 additional trees needed to be replaced.

The streambank was actively eroding in 1993, prior to installation (Figure 8). However, after the revetment was installed in May of 1994, the bank remained stable until at least 2004. In December of 2019, the banks were steep and eroding, vegetation had been completely removed, and no revetment remained.

Figure 8. Site 7, looking downstream. The *top left* photo was taken in 1993, before construction of the revetment. The *top right* photo was taken in 1994, just after construction. The *bottom left* and *bottom right* photos were taken in 2000 and 2019, respectively.

1.3.6 Site 8

Site 8, installed in October of 1989, was a double-row revetment built with 45 cedar trees that were 12 feet long. It was anchored with duckbill anchors and 3/16-inch steel cable. The revetment protected two-thirds of the bank height. Field photos were not available for this site, and USACE did not visit this site in December of 2019.

1.3.7 Site 9

Site 9 received streambank revegetation in March of 1987, a rock grade-control structure in July of 1989 (Figures 9 and 10), and a cedar tree revetment in October 1989. The grade control was constructed with 330 tons of riprap at the downstream end of the site (MDC n.d.). The cedar tree revetment was built with 67 cedar trees, each of which was 12–15 feet long, and was anchored in a double row using duckbill 88 earth anchors and 3/16-inch steel cable. Additional maintenance and tree planting took place from 1990 to 1996. A third row of 14 trees was added in 1992.

Figure 9. Site 9. Plan and cross-sectional view of the grade-control structure. (Image reproduced from MDC n.d., 15.)

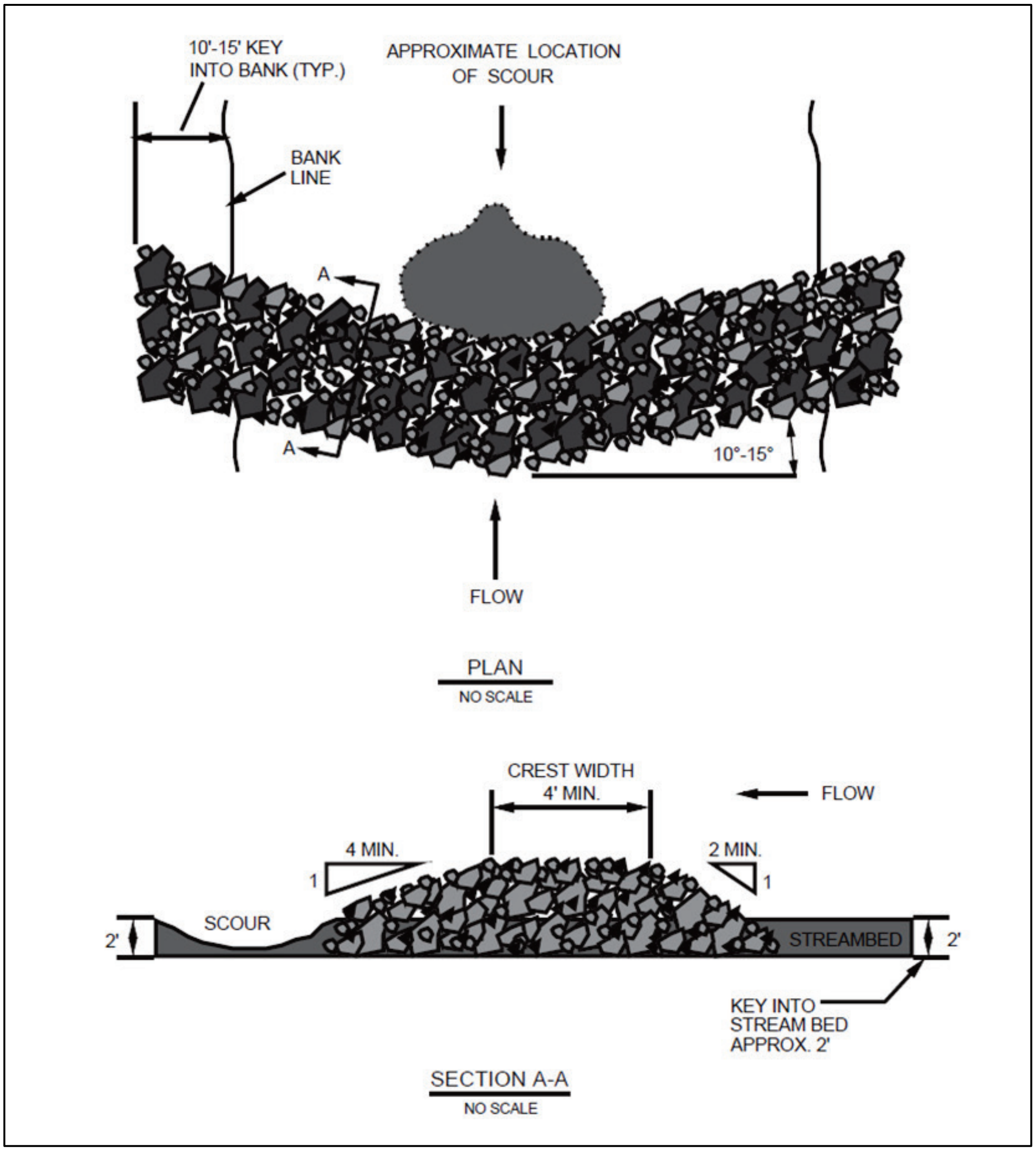
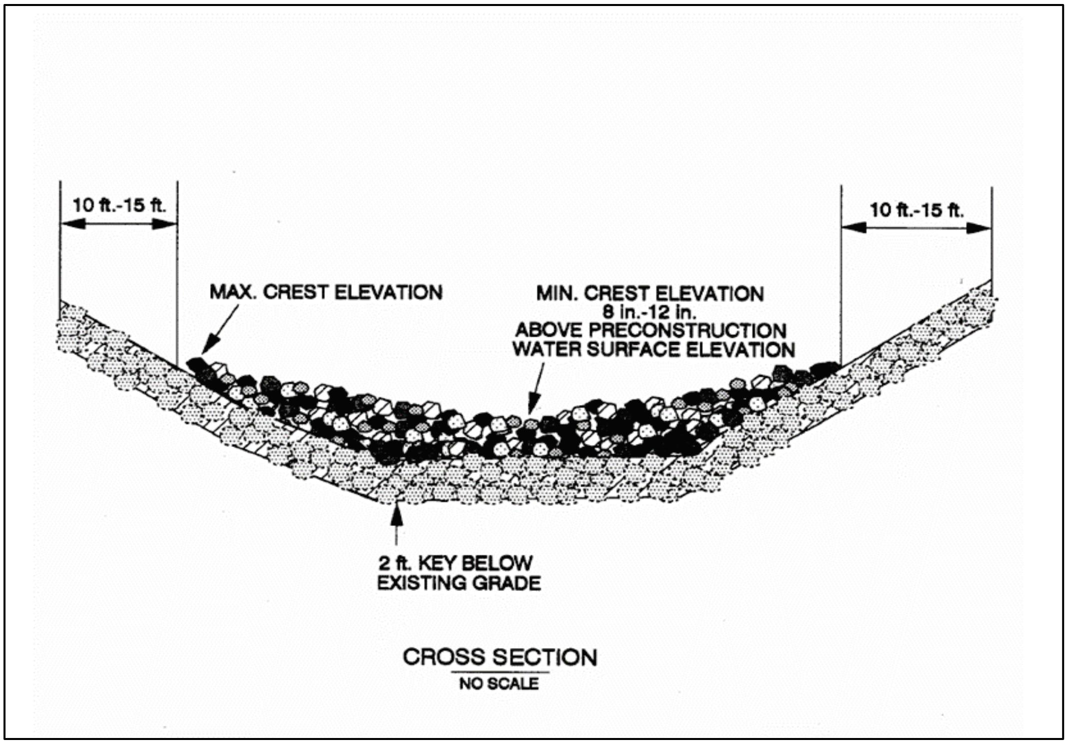


Figure 10. Cross-sectional view of a grade-control structure. (Image reproduced from MDC n.d., 16.)



As of the December 2019 visit, the bank at Site 9 was not as steep as those of the other sites, and the riparian corridor was better developed with mature trees (Figure 11). This was most likely the influence of the grade-control structure.

Figure 11. Site 9 in December of 2019, looking upstream.

2 Methods

At each site, bank erosion rates were quantified over three time periods that represented the preproject, with-project, and postfailure erosion rates. These rates were computed and compared through the following analyses: (1) hydrologic description of flows since construction, (2) comparison of aerial photographs, and (3) comparison of cross sections (both surveyed and lidar-derived).

2.1 Flow description

Erosion rates must be understood in the context of flows experienced over specified time periods. Two gages were available: a wire weight gage that measures peak flow and stage at Reger, Missouri, roughly 5 miles downstream, and a USGS gage that records stage and discharge at 15-minute intervals 25 miles downstream at Linneus.

Table 2 shows the peak stages and flows from 1987 to 2019 at the Reger, Missouri, gage. The annual peak in 2019 exceeded all years except for 1993. Thus, the December 2019 site visit should be understood as taking place after a very significant high-flow event. No instantaneous or daily data were available for this gage.

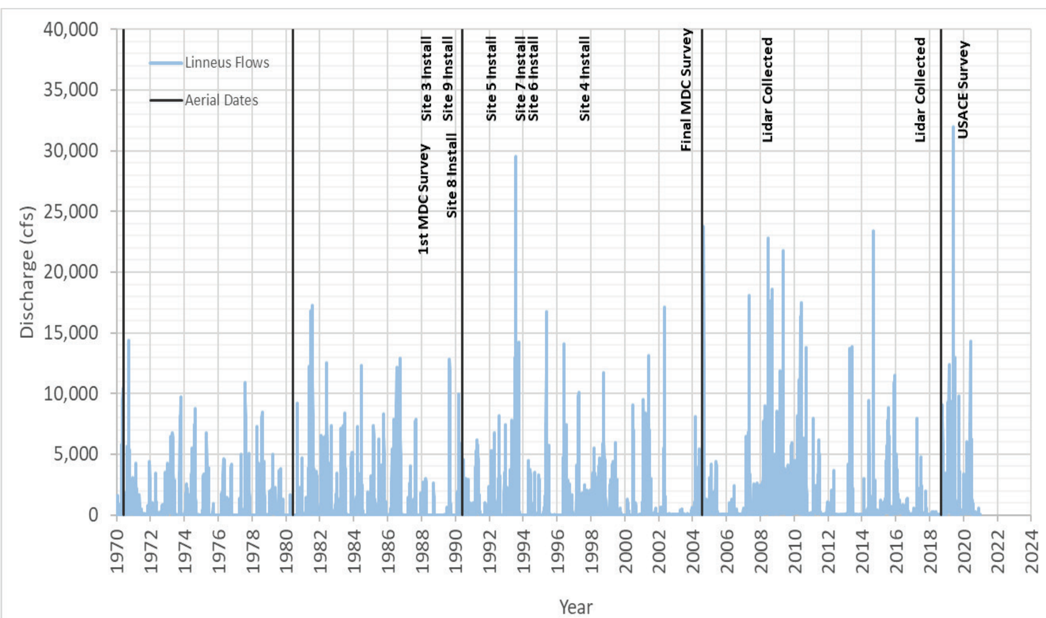
Table 2. Peak stage and discharge at the Reger, Missouri, gage on Locust Creek.

Date	Discharge (cfs)	Stage (ft)	Date	Discharge (cfs)	Stage (ft)
12/20/1987	1,900	8.53	8/29/2004	9,500	19.3
5/29/1989	2,320	8.53	4/12/2005	2,420	18.95
1990 (day unknown)	3,940	11.13	6/11/2006	919	5.37
5/5/1991	10,800	17.38	5/8/2007	4,720	12.95
4/19/1992	4,470	11.83	7/26/2008	10,200	20.03
7/7/1993	19,700	21.88	5/16/2009	7,810	17.38
10/9/1993	2,710	9.53	6/6/2010	5,770	14.53
5/26/1995	7,820	18.13	2/17/2011	2,840	9.7
5/28/1996	8,030	17.03	5/3/2012	2,110	8.23
4/17/1997	3,890	11.83	4/19/2013	7,660	17.2
4/2/1998	3,800	11.43	9/10/2014	5,490	14.12
10/7/1998	6,390	15.13	7/17/2015	3,060	10.12
6/26/2000	1,800	7.55	12/14/2015	4,080	11.92
11/8/2000	–	9.33	4/6/2017	3,300	10.55
5/14/2002	6,390	15.43	9/7/2018	1,840	7.65
5/11/2003	391	3.75	5/26/2019	12,300	22.02

Because shear stress tends to reach a maximum at the top of bank in channels, like Locust Creek, with a wide floodplain, sustained flows near the top of bank can induce more erosion than higher, shorter duration out-of-bank events. Peak flow is therefore not necessarily the best metric for comparing time periods.

Daily flow measurements were not available at the Reger gage but were available 25 miles downstream at the gage near Linneus, Missouri. Figure 12 represents the daily flow at the USGS gage at Linneus. The horizontal line indicates two-year discharge, estimated as 9,270 cubic feet per second (USACE 2020). Dates of aerial photographs are also noted. The number of days the daily flow exceeded the two-year discharge was used to set the erosion rates over differing time periods into hydrologic context. Flows shown in Figure 12 were recorded at a downstream gage and do not represent flows experienced by the project. However, the flows recorded at the gage represent the best estimate of the relative frequency of high-flow events over different time periods.

Figure 12. Daily flow rate on Locust Creek at Linneus, Missouri.



2.2 Cross section analysis

MDC monitored the sites and periodically surveyed stream cross sections at the locations shown in Figure 13. The MDC data collected at the sites was supplemented with lidar (when available) and the data collected from the cross sections surveyed during the December 2019 site visit. Figures 14 through 20 present the data.

Note that only historical MDC data are presented for Site 8 because MDC did not resurvey this site after 1995. Likewise, USACE did not survey at Site 8 during the December 2019 site visit.

Figure 13. Locations of MDC cross sections for monitoring sites.

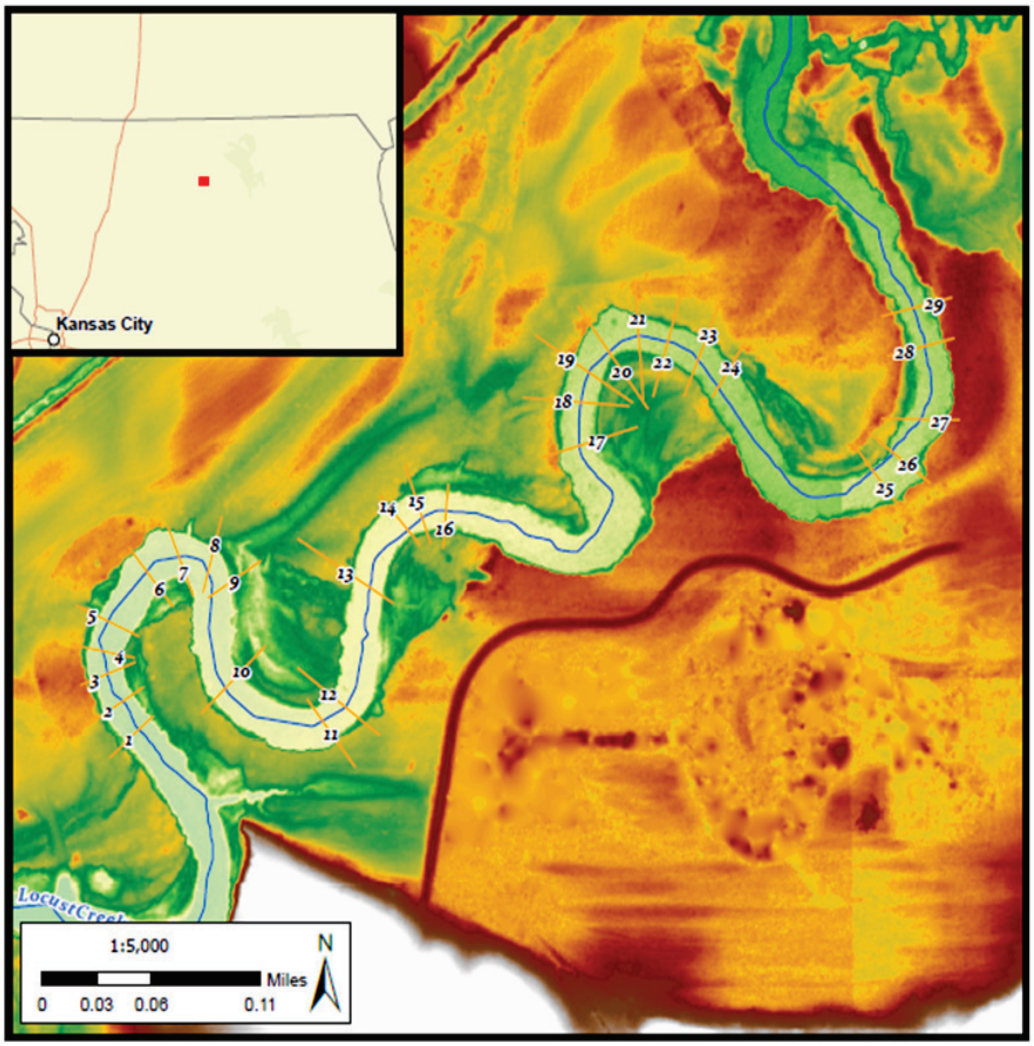


Figure 14. Site 3 transect 5. Lidar transects indicate water surface rather than channel bottom.

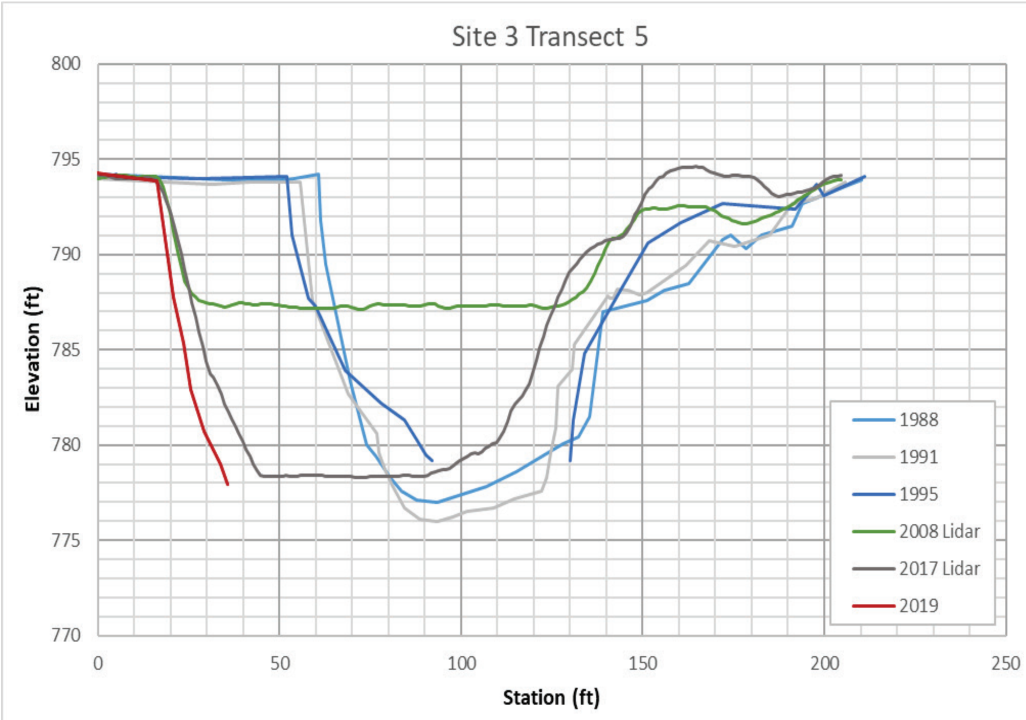


Figure 15. Site 4 transect 2. Lidar transects indicate water surface rather than channel bottom.

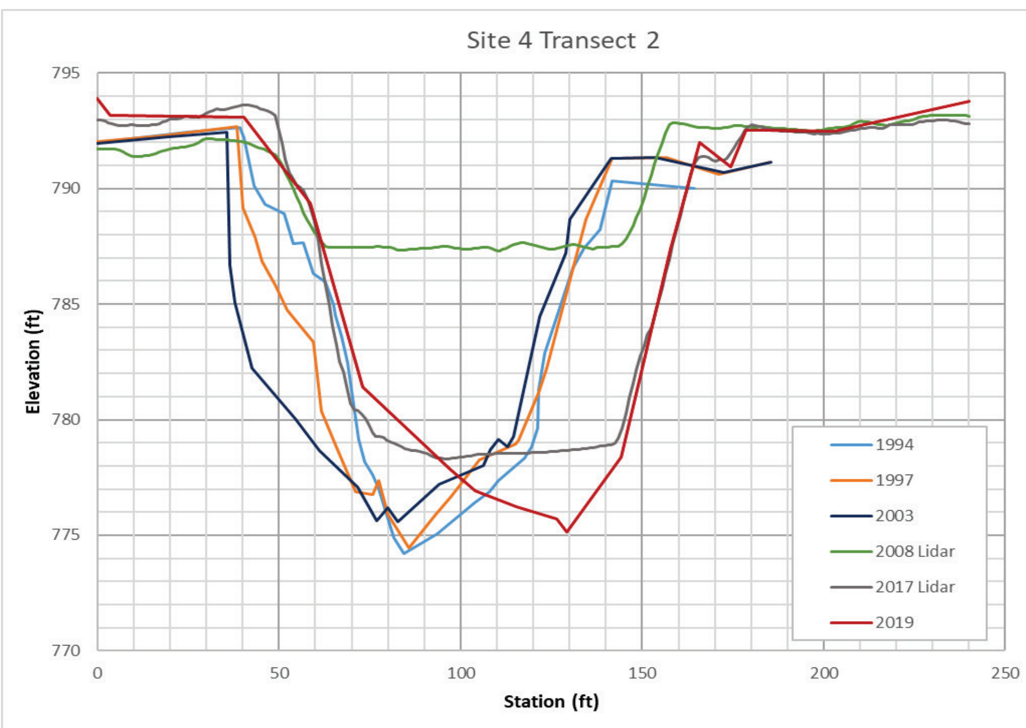


Figure 16. Site 6 transect 3. Lidar transects indicate water surface rather than channel bottom.

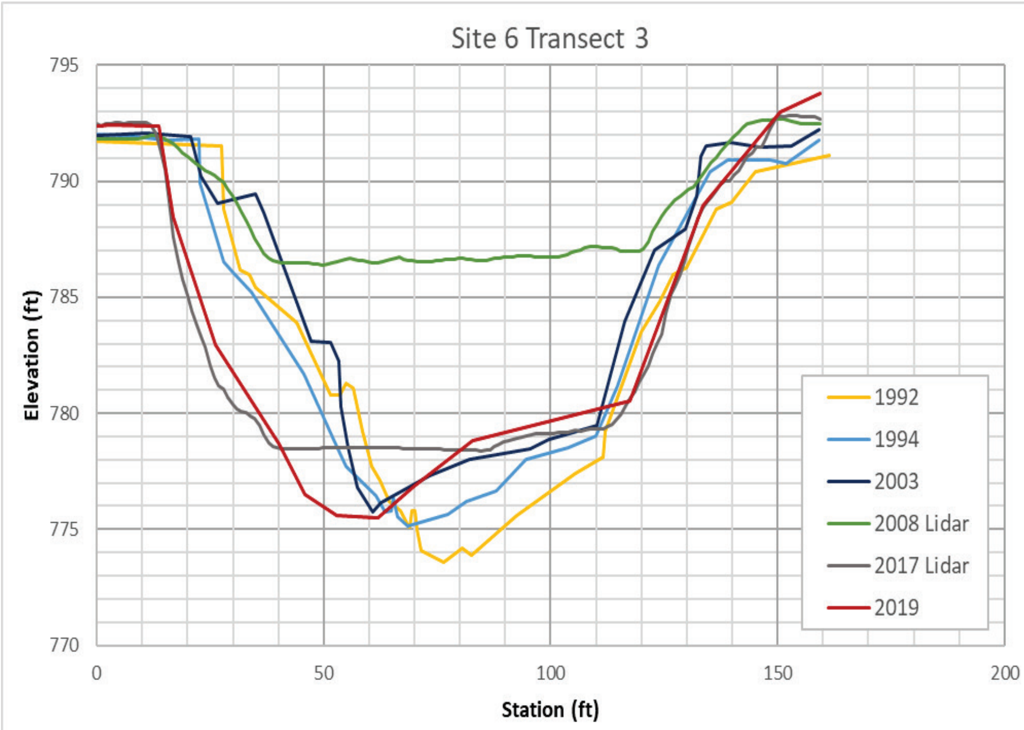


Figure 17. Site 7 transect 7. Lidar transects indicate water surface rather than channel bottom.

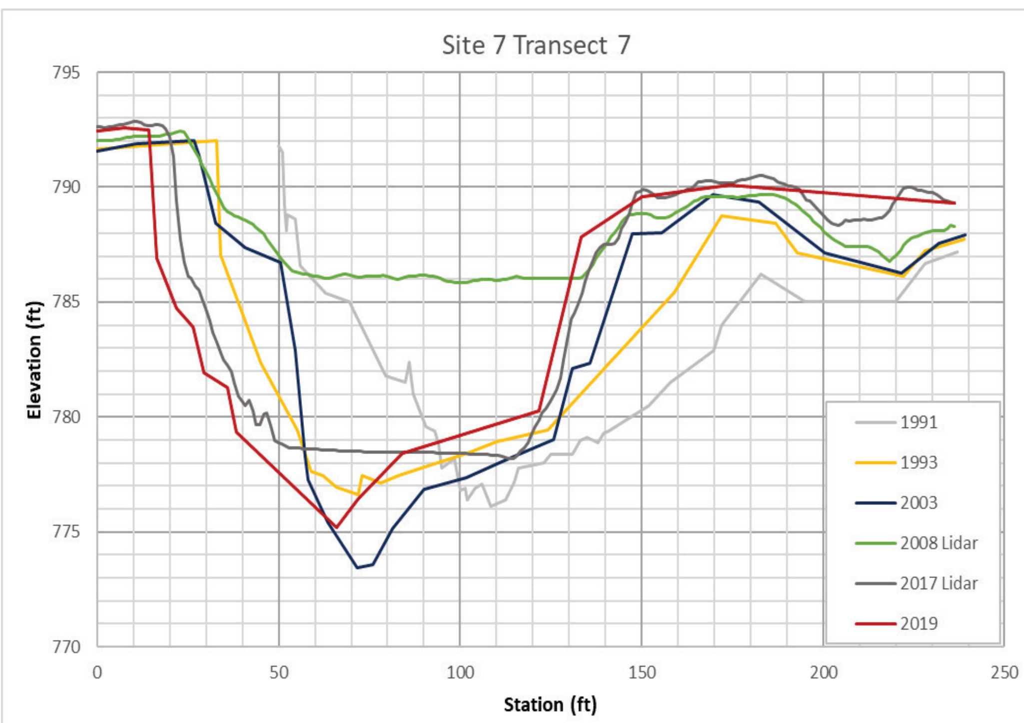


Figure 18. Site 8 transect 1. (Image reproduced from Matheney n.d., 19.)

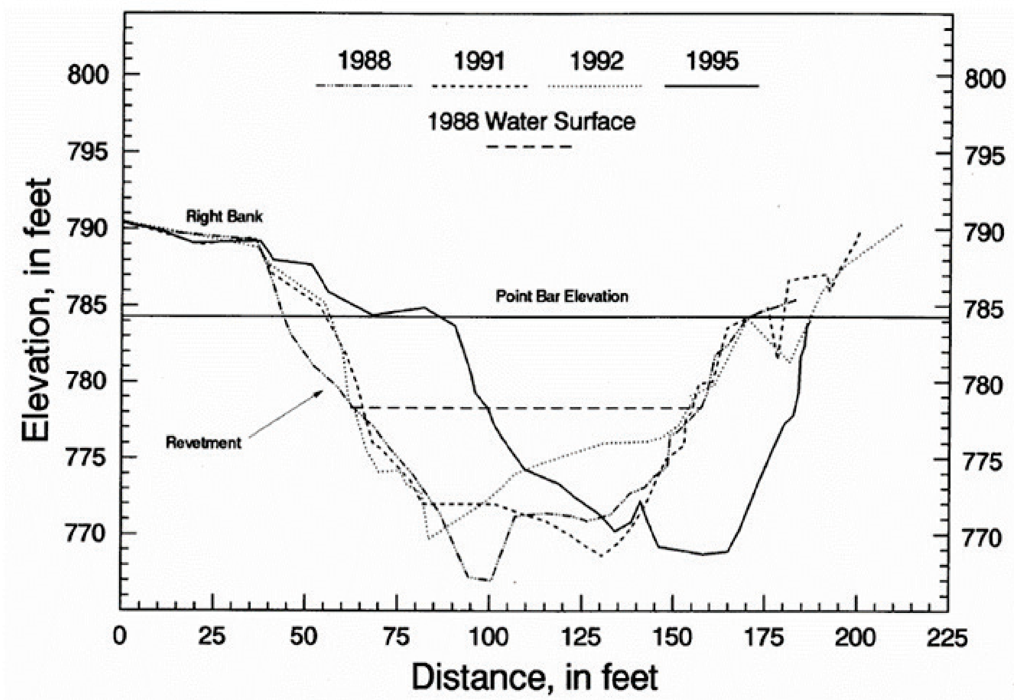


Figure 19. Site 8 transect 3.

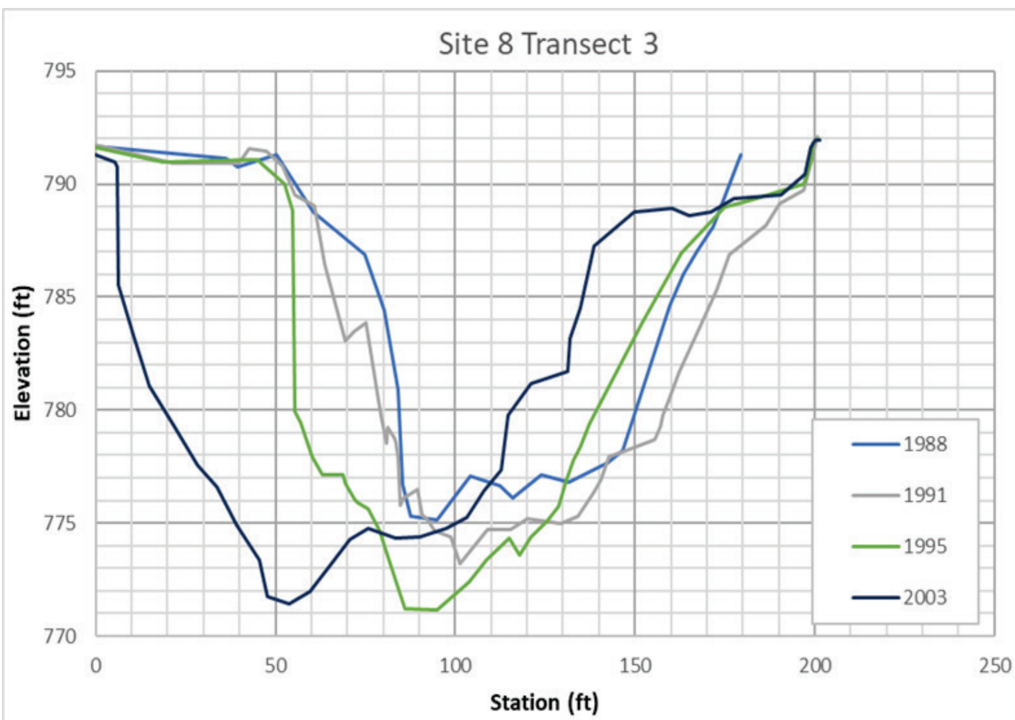
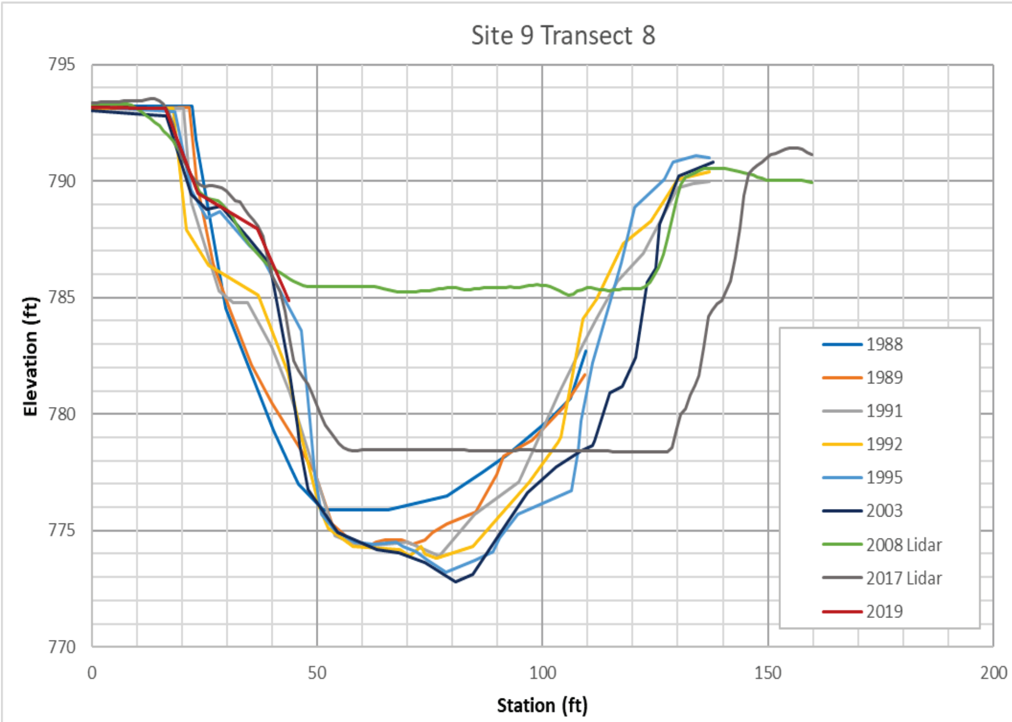


Figure 20. Site 9 transect 8. Note that the 2019 survey collected data on the left bank, but the revetment was installed on the right bank. Lidar transects indicate water surface rather than channel bottom.

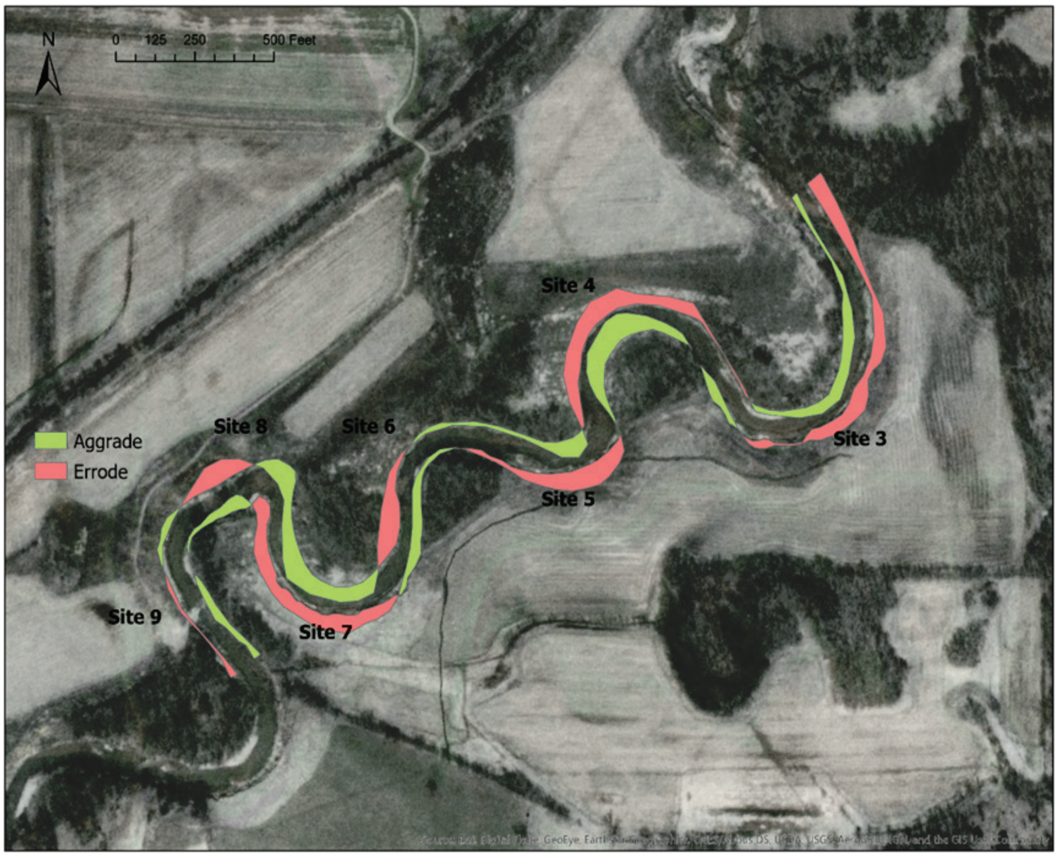


The volumetric erosion rate was computed using the surveyed cross-section data. Most of the sites had data from preproject cross sections and multiple sets of cross sections from after the project was constructed. However, because the projects were constructed in different years, no single year contained all the cross sections. The 1994 and 2003 data sets were the most extensive. Additional cross sections were added from the 1992 to 1996 data sets to fill in missing 1994 data, which resulted in a total of 20 locations over which a volume change was computed. The cross-section data were then imported into the Cross-Section Viewer software, version 3.1.3.0 (Shelley & Bailey 2018), which was used to calculate the longitudinal volume change. Volume change between two locations is computed as the average cross-sectional area change at the upstream and downstream bounding cross sections multiplied by the longitudinal distance between the cross-section locations. See Shelley and Bailey (2018) for a more detailed explanation.

2.3 Aerial photo analysis

The combined sediment reduction benefits at all the sites were quantified by estimating the erosion and deposition volumes using aerial imagery and the surveyed cross sections. Aerial photos from 1970, 1980, and 1990 were obtained from MDC (Appendix) and geo-referenced in ArcGIS. Bank lines were also digitized from 2004 and 2018 aerial photos available on Google Earth. The bank lines were traced for each of the years, and the surface area of erosion and deposition was calculated for each time period (Figure 21).

Figure 21. Image, taken in 1990, showing areas of erosion and aggradation estimated using aerial photos.



The dates of the aerial photographs allowed for the computation of erosion and deposition over multiple time periods. The time period from 1970 to 1980 was used to estimate preconstruction erosion rates. Between 1980 and 1990 was also mostly preproject because the first project was not constructed until 1988. The time period between 1990 and 2004 was when most of the projects were built and when the majority of revetments were still in place. After 2004, the projects were no longer being maintained or monitored. At some point after 2004, most of the projects failed. As explained previously, as of the December 2019 site visit, no revetments remained.

The surface area changes (Figure 22) were multiplied by average bank heights derived from the cross sections to compute a volumetric erosion rate. Separate heights were used for the erosional and depositional sides of the channel.

3 Results

Table 3 presents the results of the hydrologic analysis over the time periods bounded by aerial photographs. The designations of *with-project* and *postfailure* indicate the conditions of most of the banks for the majority of the time period. The years of construction varied through the early 1990s. Likewise, based on cross-sectional evidence, the dates of failure varied through the early part of the failing/postfailure period.

The preproject conditions from 1970 to 1980 experienced the lowest number of days exceeding a two-year flow, which (as shown later) resulted in lower erosion rates. Conversely, the 1980 to 1990 preproject period experienced more frequent higher flows. Combining both of these preproject periods yielded an average of 2.5 days per year on which the recorded flow exceeded the calculated average flow, which was very similar to the 2.4 days per year calculated for the failing/postfailure time period.

Table 3. Days exceeding 9,270 cfs on Locust Creek at Linneus, Missouri.

Time period	Designation	Total days exceeded	Average days exceeded/year
1970 to 1980	Preproject	11	1.1
1980 to 1990	Preproject	39	3.9
1970 to 1990	Preproject	50	2.5
1990 to 2004	With-project	42	3.0
2004 to 2018	Failing/postfailure	33	2.4

The cross-section analysis indicated 6,567 cubic yards of degradation from the 1994 to 2003 data sets. This equates to an average of 730 cubic yards per year. Figure 22 provides the longitudinal cumulative volume change.

Figure 22. Longitudinal volume change, approximately 1994–2003. Labels give the site and downstream cross section number.

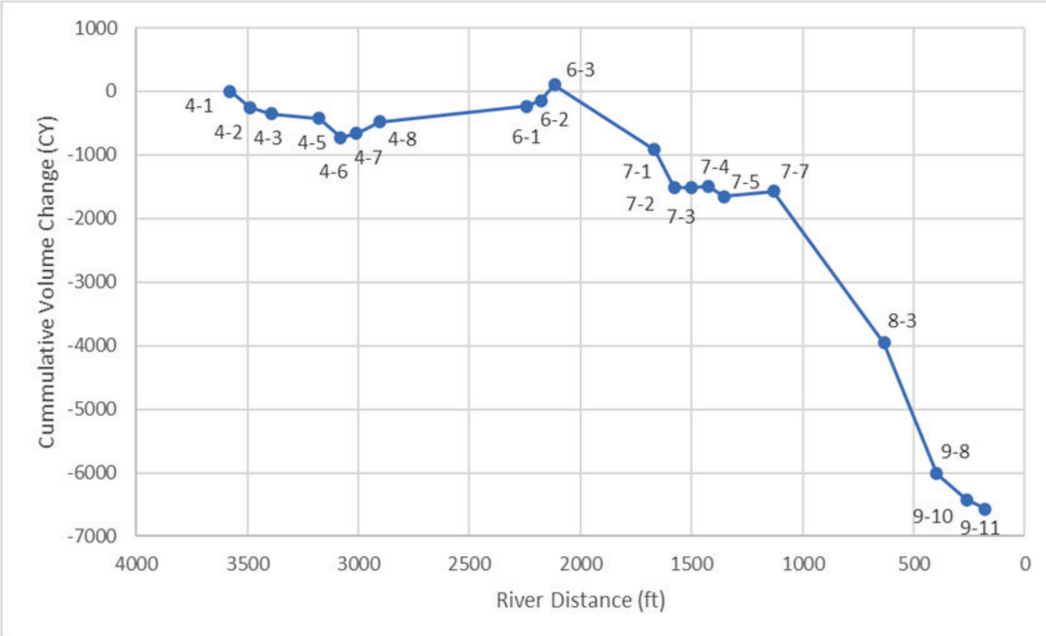


Table 4 gives the planimetric areas of erosion and deposition measured from the aerial photos. The results show that from 1970 to 1980, the reach was slightly depositional, with deposition being slightly greater than erosion. Then between 1980 and 1990, there was significantly more erosion than deposition. From 1990 to 2004, the amount of erosion was reduced, but it increased between 2004 and 2018.

Table 4. Planimetric areas of erosion and deposition from aerial imagery. Time periods are based on the availability of aerial photographs.

Time period	Eroded area (ac)	Deposited area (ac)	Annual eroded (ac/yr)	Annual deposited (ac/yr)	Net change (ac^2)	Annual net change (ac^2/yr)
1970 to 1980	3.19	3.48	0.32	0.35	0.29	0.03
1980 to 1990	4.29	1.97	0.43	0.20	−2.32	−0.23
1990 to 2004	3.33	2.75	0.24	0.20	−0.58	−0.04
2004 to 2018	4.66	2.47	0.33	0.18	−2.19	−0.16

Table 5 presents the volumetric erosion and deposition for each time period, based on the aerial photographs.

Table 5. Volumes of erosion and deposition from aerial imagery. Time periods are based on the availability of aerial photographs.

Time period	Eroded volume (yd^3)	Deposited volume (yd^3)	Eroded annual (yd^3/yr)	Deposited annual (yd^3/yr)	Net (yd^3)	Net annual (yd^3/yr)
1970 to 1980	90,132	90,042	9,013	9,004	−89	−9
1980 to 1990	119,984	50,968	11,998	5,097	−69,016	−6,902
1990 to 2004	93,908	69,882	6,708	4,992	−24,026	−1,716
2004 to 2018	131,653	65,478	9,404	4,677	−66,176	−4,727

Table 6 presents the net annual volumetric erosion in each time period, with 1970 to 1990 aggregated as a single preproject condition. As seen in Table 6, the with-project condition from 1990 to 2004 experienced the least net erosion, even though it experienced both the highest single peak flow and the most days per year exceeding the two-year flow.

Table 6. Net erosion compared to hydrology in preproject, with-project, and failing/postproject time periods.

		Flow at Linneus, Missouri		
Time period	Years	Largest daily flow (cfs)	Average flow (cfs)	Net annual erosion (yd^3/yr)
Preproject	1970 to 1990	16,993	681	−3,455
With-project	1990 to 2004	29,794	673	−1,716
Failing/postproject	2004 to 2018	23,733	482	−4,727

The with-project condition resulted in a 50% to 64% reduction in erosion, depending on whether the preproject or failing/postproject rate was used as the baseline.

4 Discussion

The with-project condition experienced a 50% reduction in erosion rate compared to the preproject condition. However, the actual project effectiveness was likely higher because the with-project condition experienced a much higher daily peak flow (i.e., 29,794 cfs compared to 16,993 cfs) and more days of two-year flows than the preproject period (Figure 12). In contrast, the failing/postproject condition experienced a daily peak flow (i.e., 23,733 cfs) that was more similar to that of the with-project condition. Compared to this condition, the with-project condition represented a 64% reduction in the annual erosion rate.

This analysis suggests that project features resulted in at least a 50% to 64% reduction in sediment input from bank erosion over a 14-year project life.

The results presented in Table 6 indicate that Locust Creek has since returned to high erosion rates. As of the December 2019 site visit, the banks were bare, steep, and actively eroding, with no evidence of prior stabilization.

5 Limitations

Unique conditions on Locust Creek may preclude the use of this research to estimate the effectiveness of cedar tree revetments on other rivers. First, the banks are approximately 17 feet high, which may be taller than typical streams considered for cedar tree revetments. Matt Matheney from the MDC commented,

> On smaller streams, the tree roots will usually reach to the stream toe and provide better stability than in larger streams, with taller bank heights. If the bank remains sloped with vegetation on the bank, that is great, but I don't think we expect that to happen long-term. Long-term, our expectations are that the revetment trees will go the way of the stream, and the forested corridor will provide the protection. (personal communication, 2021)

The size of Locust Creek exceeds the optimal size for this treatment, and the bank heights exceed the depths for which roots will offer much bank stability.

Second, the effects of the cedar tree revetments are comingled with the effects of the grade-control structure at Site 9. Grade-control structures prevent downcutting, provide additional toe stability, and can themselves reduce erosion rates. The site visit indicated greater stability at Site 9, upstream of the grade-control structure.

MDC records indicate that segments of the revetment were periodically replaced. Without maintenance, the treatment would have been less effective at stabilizing the banks.

Finally, each river exists in a unique geomorphic context. Locust Creek is still responding to its 1970s channel cutoff, and there are likely additional complex geomorphic thresholds that cannot be understood without detailed hydrologic and geomorphic study.

6 Conclusions

Field photographs, aerial photographs, and cross-sectional measurements were analyzed for nine bank stabilization sites in the LCCA. These analyses suggest the conclusions that follow:

1. The projects provided an approximately 50% to 64% reduction in erosion-derived sediment on the banks of Locust Creek for a period of approximately 14 years. However, some repairs occurred in the first few years, and the grade-control structure provided added benefit to the revetment sites by reducing the possibility of channel bed degradation.
2. The projects resulted in no discernible continued bank stability after the 14 years, with bank erosion returning to preproject levels and banks becoming vertical and unvegetated.
3. The quantified effectiveness and longevity are unique to this location. More investigation of additional sites is needed to determine general averages for effectiveness and longevity on the smaller streams for which cedar tree revetments are more common.

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Appendix: Additional Data

Figure A-1. Image from 2018, showing erosion and aggradation estimated using aerial photos from 2004–2018.

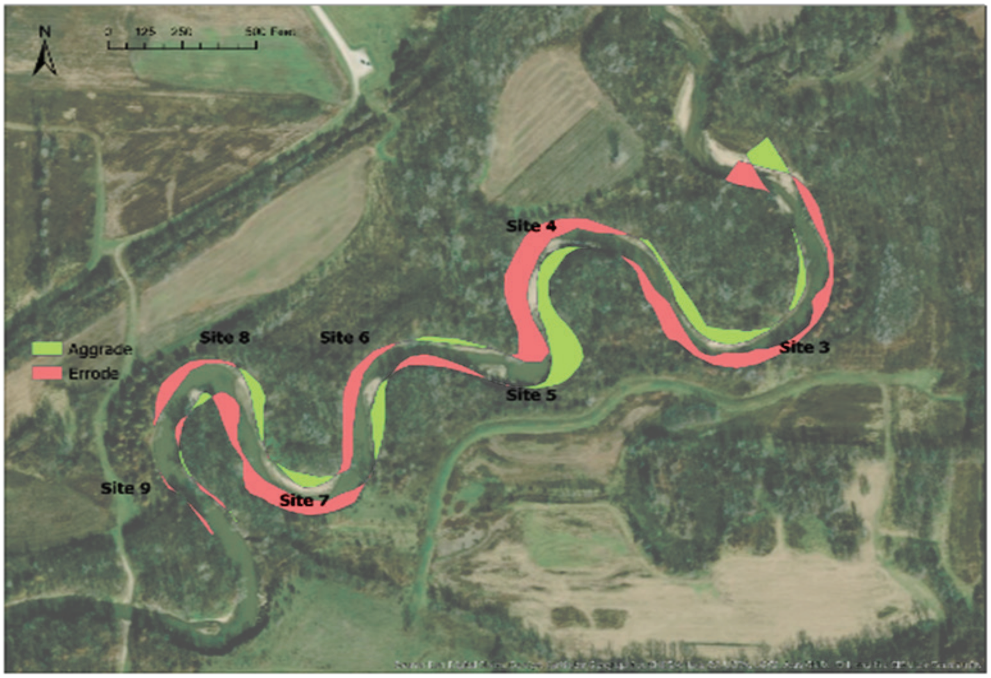

Figure A-2. Image from 1990, showing erosion and aggradation estimated using aerial photos from 1990–2004.

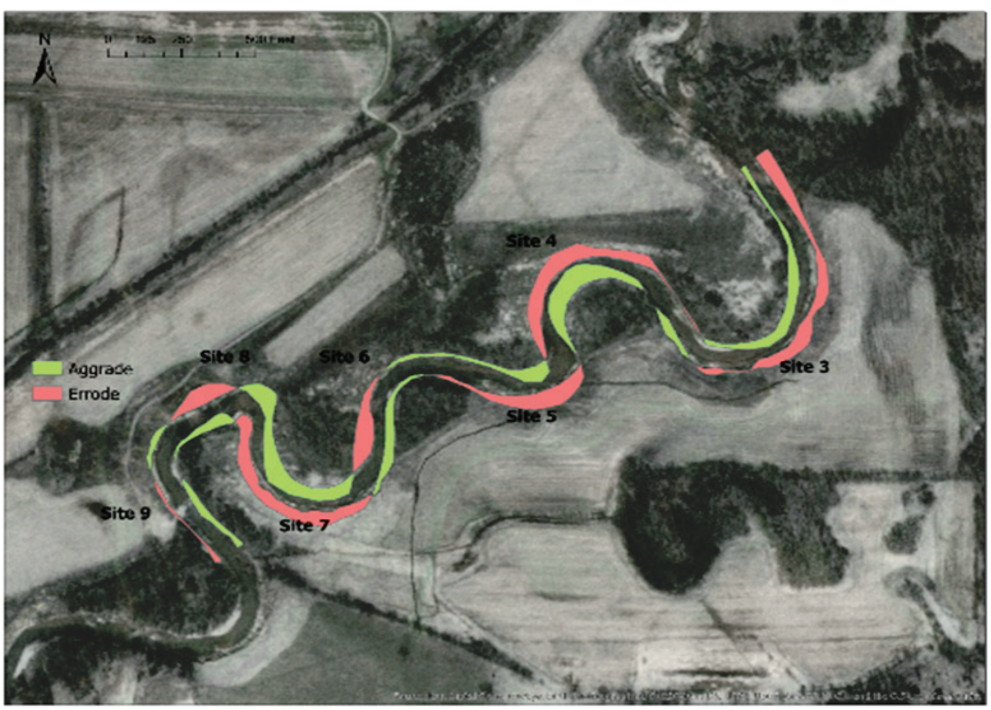

Figure A-3. Image from 1980, showing erosion and aggradation estimated using aerial photos from 1980–1990.

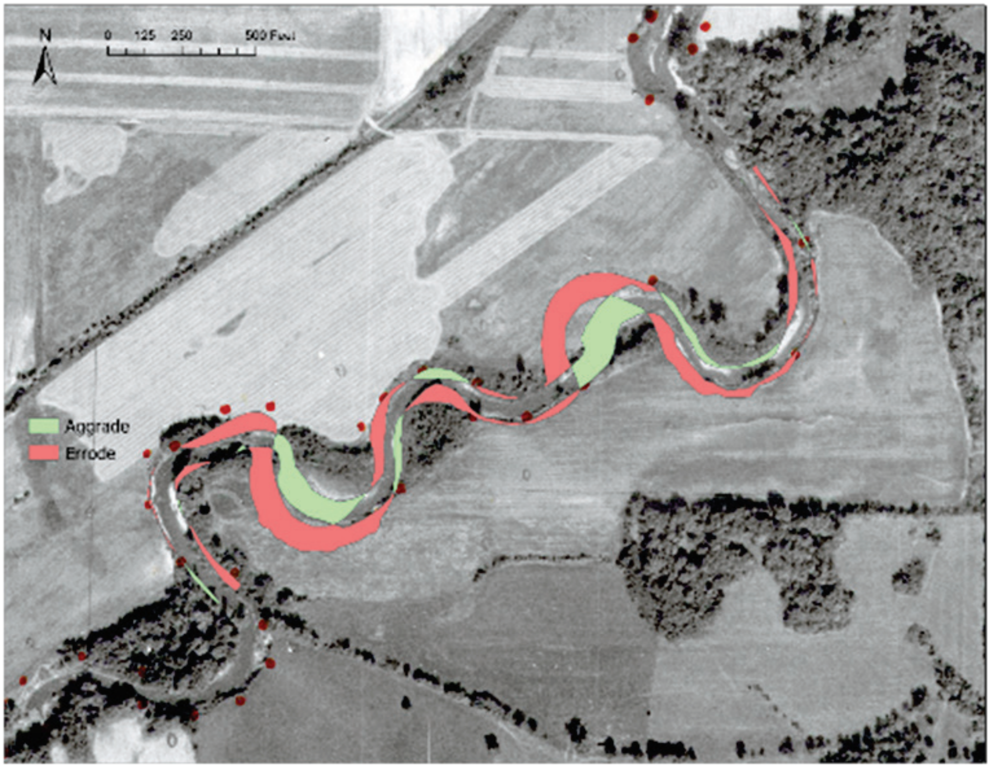

Figure A-4. Image from 1970, showing erosion and aggradation estimated using aerial photos from 1970–1980.

Table A-1. Average bank heights from surveyed cross sections.

Site	Outside bank height (ft)	Inside bank height (ft)
3	19	17
4	17	16
6	15	16
7	19	16
9	16	13

Table A-2. Cross Section Viewer results showing longitudinal cumulative volume change.

Downstream cross section	Downstream river distance (ft)	Upstream river distance (ft)	Control volume change (CY)	Cumulative volume vhange (CY)
4-1	3,577	3,577	0	0
4-2	3,489	3,577	−256	−256
4-3	3,394	3,489	−94	−350
4-5	3,178	3,394	−74	−424
4-6	3,081	3,178	−302	−727
4-7	3,008	3,081	62	−664
4-8	2,905	3,008	182	−482
6-1	2,242	2,905	249	−233
6-2	2,177	2,242	89	−144
6-3	2,118	2,177	246	103
7-1	1,669	2,118	−1,020	−917
7-2	1,579	1,669	−591	−1,508
7-3	1,501	1,579	−4	−1,513
7-4	1,426	1,501	22	−1,491
7-5	1,354	1,426	−159	−1,651
7-7	1,131	1,354	84	−1,567
8-3	634	1,131	−2,386	−3,953
9-8	398	634	−2,062	−6,015
9-10	264	398	−409	−6,424
9-11	179	264	−144	−6,567

Abbreviations

LCCA	Locust Creek Conservation Area
MDM	Missouri Department of Conservation
RSM	Regional Sediment Management
USACE	US Army Corps of Engineers

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14. ABSTRACT
The US Army Corps of Engineers Regional Sediment Management (RSM) program funded research to assess the longevity and effectiveness of cedar tree revetments for sediment reduction. Between 1988 and 1997, the Missouri Department of Conservation (MDC) constructed multiple cedar tree revetments, plantings, and a grade-control structure at an experimental stream management area on Locust Creek within the Locust Creek Conservation Area (LCCA). For the first few years, MDC also replaced missing trees as needed. MDC monitored these sites with photographs and cross sections until 2004.

This study evaluated bank stability on Locust Creek from 1970 to 2019 using aerial imagery, lidar, ground surveys, and a December 2019 site visit to estimate the areal change in streambanks and the volume of sediment eroded over the years. Based on their dates of construction, the project compared preproject, with-project, and postfailure conditions at each site. The project included cedar tree revetments, other hardwood revetments, plantings, and a grade-control structure. This research found a 50% to 64% reduction in erosion for approximately 14 years.

As of December 2019, all tree revetments had failed, and banks were bare and steep. The grade-control structure remained intact and continued to stabilize bed and banks immediately upstream.

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