Effects of Bank Stabilization on Regional Sediment Management (RSM)

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Abstract

Accumulation of sediment has and continues to be a major problem facing reservoir managers and stakeholders. Sediment accumulation can be reduced by either preventing sediment from entering the reservoir or by removing it once it has been deposited, typically by dredging and upland disposal. Sediment transported into reservoirs is generated from overland run-off and erosion of river beds and banks from upstream watersheds. This paper presents an analysis of bank stabilization as a means of regional sediment management within the U.S. Army Corps of Engineers (USACE) Kansas City District (NWK).

Introduction

USACE has a long history of streambank stabilization. Section 14 of the 1946 Flood Control Act, as amended, provides authority for USACE to plan and construct emergency streambank and shoreline protection projects to protect endangered highways, highway bridge approaches, and other nonprofit public facilities. These and similar projects have not historically counted the reduction in sediment loading to the river as a benefit during alternatives analysis. However, in many cases downstream projects including reservoirs, actively maintained navigation channels, and sensitive floodplain habitats can substantially benefit from the sediment reduction. This study includes analysis of two categories of streambank stabilization projects that differ in their level of robustness in the Kansas River Basin and Grand River Basin.

Kansas River Basin

The first category includes streambank stabilization projects built by the State of Kansas agencies upstream of Corps reservoirs in the Kansas River Basin. Many watersheds within the Kansas River Basin derive the predominant portion of their sediment load from erosion of beds and banks rather than from overland run-off (Juracek and Ziegler 2009). A disproportionate amount of the total bank-derived sediment comes from a limited number of tall banks with high erosion rates (USACE 2011). The Kansas Water Office (KWO) estimated that sediment load reduction through stabilization of these bank erosion "hot spots" could be as much as 21 times more cost effective than traditional reservoir dredging (Gnau 2013). Approximately 13 million cubic yards per year (M yd3/year) of sediment are deposited in Tuttle Creek, Milford, Kanopolis, Wilson, Harlan County, and Wakunda Lakes (Shelley et al. 2016). The State of Kansas has constructed miles of streambank stabilization in an effort to reduce the sediment loading to the reservoirs. These projects were built specifically for erosion reduction, not infrastructure protection, and are less robust (minimal or absent toe protection, fewer or absent keys.) Ten projects were analyzed in the study and reported in this paper.

Grand River Basin

The second category includes eight Section 14 streambank stabilization projects constructed by the Kansas City District Army Corps of Engineers upstream of ecologically sensitive floodplain habitats in the Grand River Basin. The purpose of these projects was to protect critical infrastructure, typically bridges and roads. The targeted banks were not as erosive, and significantly more rock was used in the projects when compared to the State of Kansas projects. Figure 1 shows a general location map of the bank stabilization projects. Figures 2 and 3 provide maps of the Kansas River and Grand River Basins, respectively.

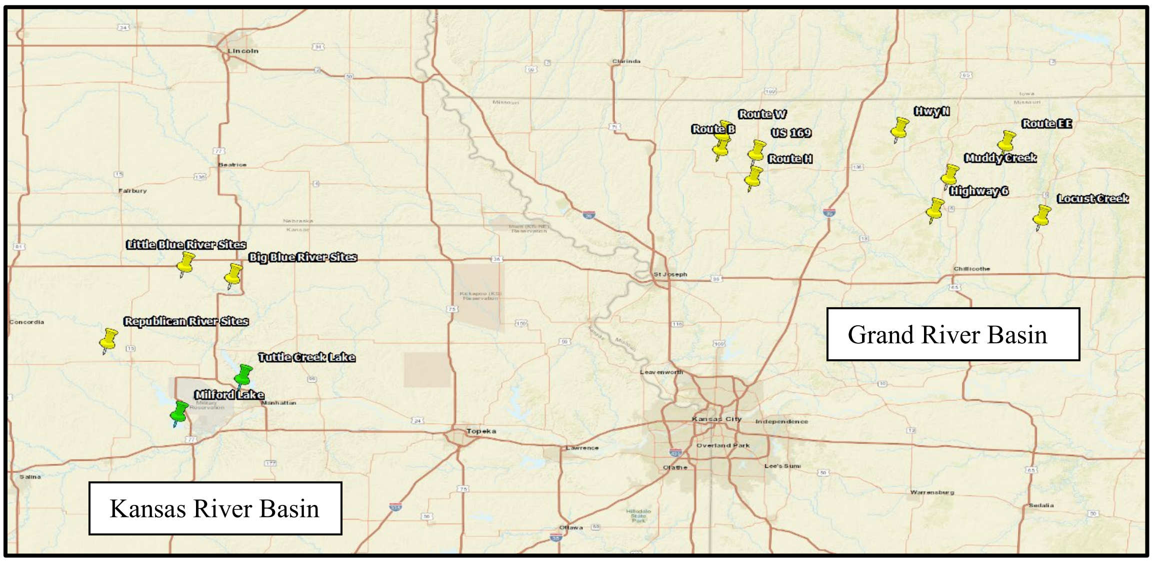

Figure 1. General location map of streambank stabilization projects
(Green Pins = Reservoirs, Yellow pins = Project Sites).

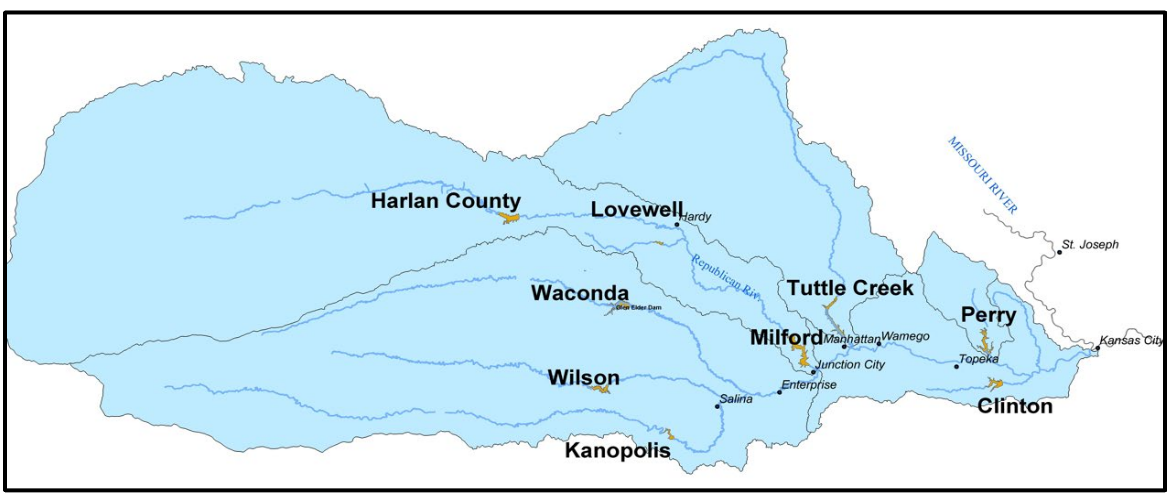

Figure 2. Kansas River Basin map.

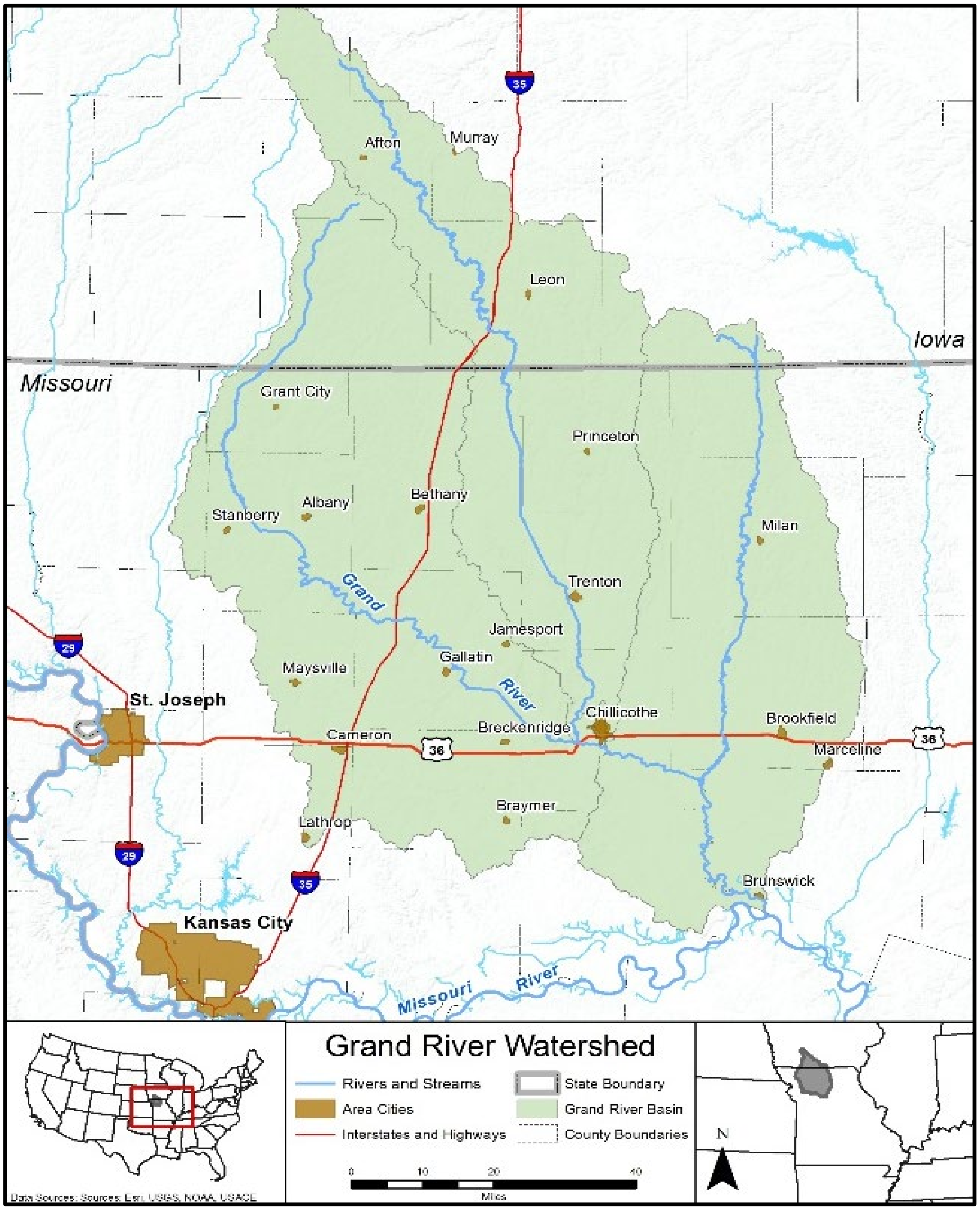

Figure 3. Grand River Basin map.

Study Analysis and Assumptions

COMPARISON TO DREDGING COSTS

A first approximation for the economic value of the streambank stabilization from an RSM perspective can be estimate by the cost to dredge an equivalent volume of sediment from a downstream reservoir. A 2016 hydraulic dredging project at John Redmond Reservoir removed 3 M yd^3 at a cost of \$20 M, or \$6.67/yd^3 (KWO 2016). Promising and potentially less expensive dredging techniques such as hydrosuction (Shelley 2017) and water-injection dredging are currently being analyzed for effectiveness on reservoirs within the Kansas River Basin. However, due to unknowns, limitations, and current regulatory hurdles associated with these methods, this study used a sediment removal cost of $6.67/yd^3 to assess the monetary value of reducing sediment loads via streambank stabilization. The additional benefits of stream bank stabilization that accrue to local landowners are not included.

SEDIMENT REDUCTION COMPUTATIONS

The reduction in sediment loading due to the construction of bank stabilization projects was computed in three steps. (1) Aerial photography from 1991 to 2008, along with the construction dates, provided an annual area erosion rate. (2) The annual area erosion rate was transformed into an annual volume using field measurements for bank heights. And (3) sediment size gradation samples were used to compute the volumetric erosion rate of only the wash load portion of bank sediments. Wash load that enters streams from eroding banks quickly transports downstream at approximately the same velocity as the water (Biedenharn 2006) and deposits in the reservoirs. Reducing the wash load results in a comparable near-term reduction in sediment loading to the reservoir. Conversely, a reduction in the coarse fraction of the bank material could take decades to translate into reduced sediment loading to the reservoirs. For this study, only wash load material is used for the volume estimates.

For the purpose of this study, wash load was defined as the grain size for which 10% of bed mixture is finer (Einstein 1950). Sediment samples were collected during field assessments and analyzed for particle size. One requirement in the wash load definition is that bed samples are not collected at low flows (Einstein 1950). Due to low flow conditions during sampling for this study, the particle size and percentage of bank material constituting wash load is likely conservatively low, which will lead to an underestimate of the sediment reduction from the bank stabilization. Figure 4 presents the results of the size gradation analysis of the bed and banks.

ROCK QUANTITIES

Design documents listing the quantity of rock used during construction were available for seven of the of the 10 State of Kansas projects. Rock quantities for the remaining three projects without design documents were estimated using a relationship between project length and rock quantity developed from the seven projects with known rock quantities. Only one of the 10 State of Kansas projects had information available for the volume of earthwork required during construction, so a relationship was developed between the quantity of rock used and volume of earthwork required from the Section 14 projects. Due to the varying level of design of the eight Section 14 projects constructed in the Grand River Basin, only the four projects with known rock and earthwork quantities were used in the sediment reduction analyses. Estimated project costs are calculated by summing the cost to purchase and place rock, assumed to be $50/ton, and the cost to perform earthwork, assumed to be $6.40/yd^3. These prices are based on recent cost estimates developed within the Kansas City District for similar projects in the same vicinity. While the estimated project costs in this study (on average $65 per linear foot) are a simplified presentation of actual costs, they fall within the anticipated costs to implement stream bank stabilization (USACE 2011). For each project, the annual erosion volume rate was multiplied by the percent of the bank material computed to be wash load to estimate the reduction in wash load. This quantity was then multiplied by $6.67/yd3 (KWO 2016) to estimate the annual cost to dredge an equivalent quantity of sediment.

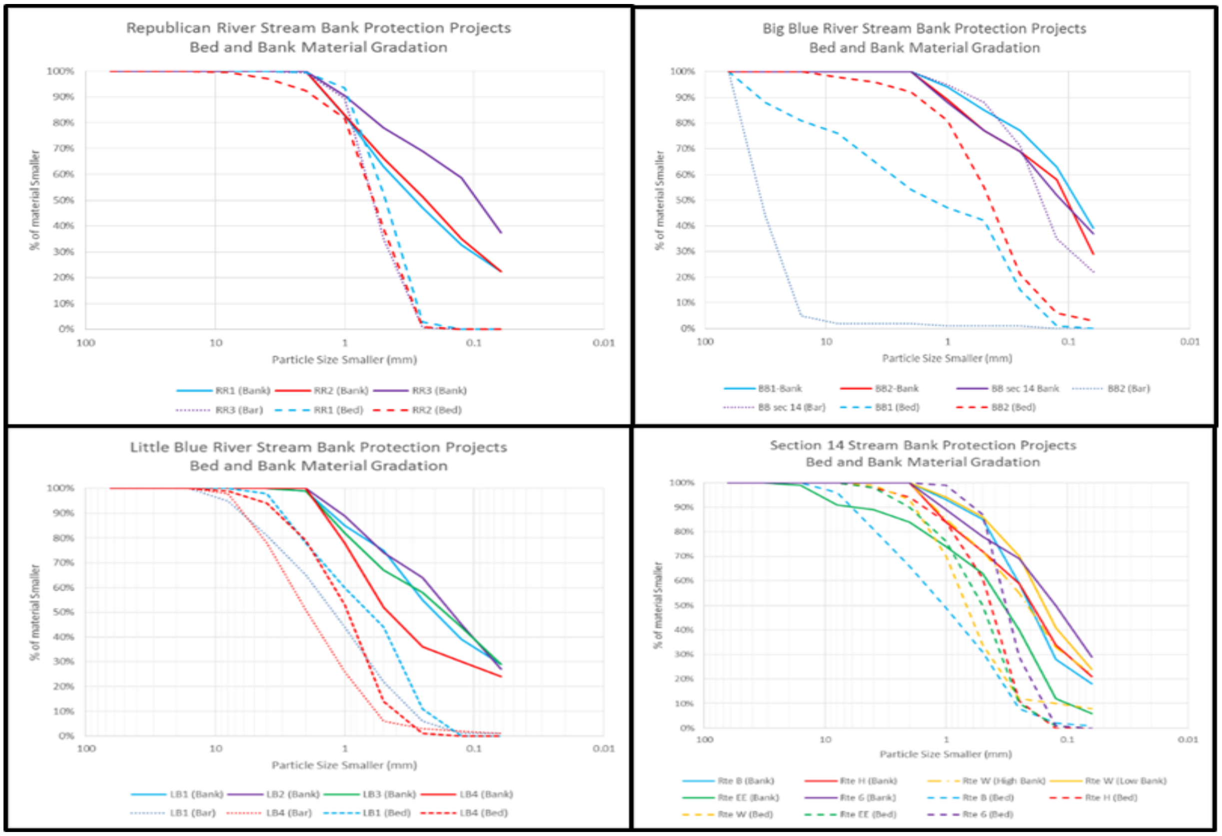

Figure 4. Bed/bank sample gradations

Study Results

Tables 1-4 provide results of the sediment reduction and project cost analyses and Figures 5-8 show the location of the projects sites. As seen, the 10 State of Kansas bank stabilization projects upstream of Corps reservoirs are estimated to be on average 14 times more cost effective than reservoir dredging, assuming a 20-year design life. For the four Section 14 projects in the Grand River Basin designed to protect infrastructure, bank stabilization is estimated to be approximately equal to the cost of reservoir dredging over a 20-year period. In fact, the actual sediment reduction benefits from these Section 14 projects result from decreasing negative impacts to ecologically sensitive floodplain habitats downstream. Sediment removal from these habitats would be much more expensive than the $6.67/yd3, and also comes at the expense of having to damage the habitat to remove the sediment. Project costs are much higher for the Section 14 projects than the State of Kansas projects due to failure risks. Section 14 projects are an emergency action to protect critical infrastructure and require much more robust design than the State of Kansas projects, whose failure would not jeopardize critical infrastructure.

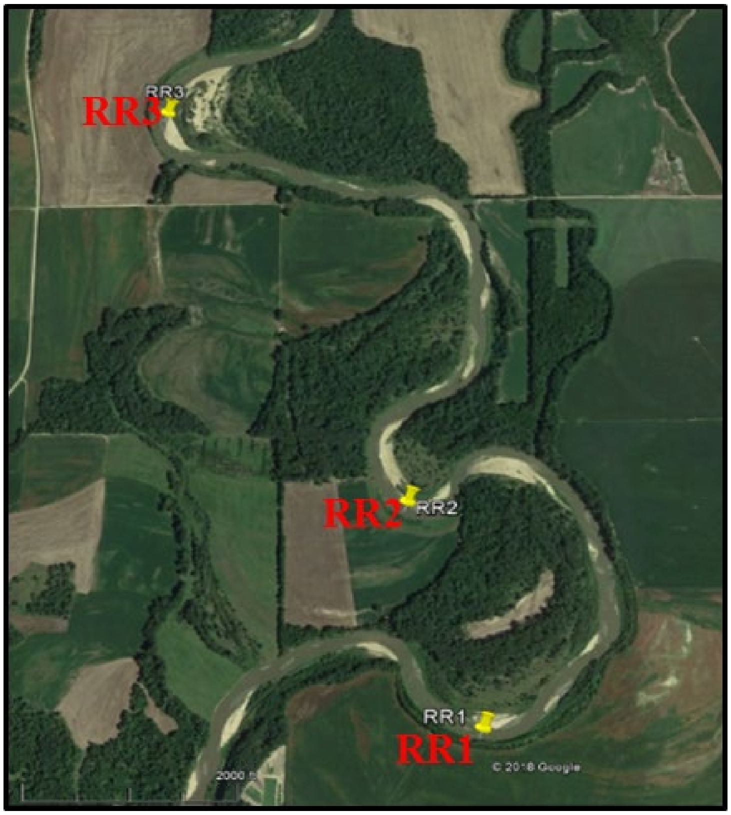

Figure 5. Republican River Project Location Map

Table 1. Republican River Sediment Reduction and Project Costs

Republican River			
Site Identifier	RR1	RR2	RR3
Year Constructed	2004	2006	2004
Erosion Area (ac)	7.5	5.5	10.6
Bank Height (ft)	13.8	13.8	13.8
Erosion Rate (yd^3/yr)	12,700	8,200	18,100
% Bank Wash Load	71%	55%	49%
20-year Wash Load Reduction (yd^3)	180,340	90,200	62,100
Quantity of Rock (ton)	1,844	1,685	1,727
Volume of Earthwork (yd^3)	706	645	661
Estimated Project Cost	$97,000	$88,000	$91,000
20-Year Wash Load Dredging Cost	$1,200,000	$600,000	$410,000

Figure 6. Big Blue River Project Location Map

Table 2. Big Blue River Sediment Reduction and Project Costs

Big Blue River			
Site Identifier	BB1	BB2	BB3
Year Constructed	2003	2010	2010
Erosion Area (ac)	6.2	3.8	2.3
Bank Height (ft)	20.3	19.4	22.3
Erosion Rate (yd^3/yr)	16,900	7,000	4,800
% Bank Wash Load	72%	61%	60%
20-year Wash Load Reduction (yd^3)	243,360	85,400	57,600
Quantity of Rock (ton)	993	*1,164**	*744**
Volume of Earthwork (yd^3)	380	446	285
Estimated Project Cost	$53,000	$61,000	$39,000
20-Year Wash Load Dredging Cost	$1,620,000	$570,000	$380,000

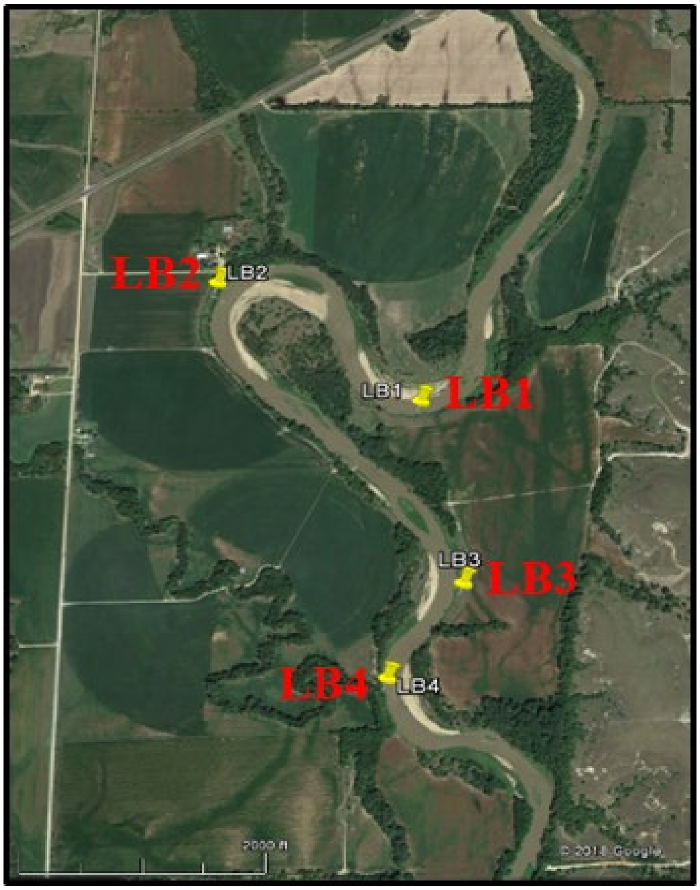

Figure 7. Little Blue River Project Location Map

Table 3. Little Blue River Sediment Reduction and Project Costs

Little Blue River				
Site Identifier	LB1	LB2	LB3	LB4
Year Constructed	2002	2004	2002	2011
Erosion Area (ac)	7.2	7.1	1.5	2.0
Bank Height (ft)	21.0	21.0	17.9	21.0
Erosion Rate (yd^3/yr)	22,000	18,500	3,900	3,900
% Bank Wash Load	54%	62%	57%	52%
20-year Wash Load Reduction (yd^3)	237,600	229,400	44,460	40,560
Quantity of Rock (ton)	1,017	*1,080**	2,016	1,121
Volume of Earthwork (yd^3)	390	414	772	429
Estimated Rock Cost	$53,000	$57,000	$106,000	$59,000
20-Year Wash Load Dredging Cost	$1,580,000	$1,530,000	$300,000	$270,000

Figure 7. Section 14 Project Location Maps

Table 1. Republican River Sediment Reduction and Project Cost

Section 14 (Grand River Basin)				
Site Identifier	Highway 6	Route B	Route EE	Route N
Year Constructed	2005	2012	2011	2013
Erosion Area (ac)	2.4	0.2	1.2	1.2
Bank Height (ft)	25.0	16.0	24.0	26.0
Erosion Rate (yd^3/yr)	10,756	323	3,098	2,961
% Bank Wash Load	54%	55%	55%	56%
20-year Wash Load Reduction (yd^3)	116,200	3,500	34,100	33,200
Quantity of Rock (ton)	10,900	5,140	5,230	4,362
Volume of Earthwork (yd^3)	2,658	1,365	3,520	1,527
Estimated Project Cost	$562,000	$257,000	$261,500	$218,100
20-Year Wash Load Dredging Cost	$780,000	$20,000	$230,000	$220,000

Conclusion

This study included analysis of bank stabilization as a means of regional sediment management using assessments of 18 projects within the Kansas River and Grand River Basins. This study also distilled lessons learned from project successes and failures, which will be available in an upcoming technical note. Based on this analysis, the cost of constructing bank stabilization projects similar in design to the State of Kansas projects will offset the cost of dredging an equivalent volume of material within 1-2 years, with most projects functioning for decades. Of the State of Kansas projects analyzed in this study, stabilization of erosion hot spots is, on average, 14 times more cost effective than traditional dredging over a 20-year assumed life. For the Section 14 projects, the dredging cost approximately equals the project cost; however, these projects will likely last beyond the assumed 20 year life. The Section 14 projects were economically justified based on benefits to critical infrastructure alone.

References

Biedenharn, S., C. Thorne, and C. Watson. 2006. Wash load/bed material load concept in region sediment management. Proceedings of the Eighth Federal Interagency Sedimentation Conference (8thFISC). Reno, NV. https://pubs.usgs.gov/misc/FISC_1947-2006/pdf/1st-7thFISCs-CD/

Einstein, H. A. 1950. The bed-load function for sediment transportation in open-channel flows. U.S. Department of Agriculture, Soil Conservation Service, Technical Bulletin No. 1026. Washington, DC. https://naldc.nal.usda.gov/download/CAT86201017/PDF

Gnau, C. 2013. Streambank stabilization effectiveness on Little and Big Blue Rivers. Presentation at the Governor's Conference on the Future of Water in Kansas. October 25, 2013.

Juracek, K. E. and A. C. Ziegler. 2009. Estimation of sediment sources using selected chemical tracers in the Perry Lake Basin, Kansas, USA: International Journal of Sediment Research. v. 24, pp. 108-125. https://doi.org/10.1016/S1001-6279(09)60020-2

KWO. 2016. John Redmond Reservoir dredging fact sheet. Kansas Water Office. http://www.kwo.org/Projects/JRDredging/JRRD%20Fact%20Sheet.pdf

Shelley, J., M. Boyer, J. Granet, and A. Williams. 2016. Environmental benefits of restoring sediment continuity to the Kansas River. ERDC/CHL CHETN-XIV-50. Vicksburg, MS: U.S. Army Engineer Research and Development Center. http://hdl.handle.net/11681/20279

Shelley, J. 2017. Tuttle Creek Lake Hydrosuction Assessment. CENWK-EDH-R Memorandum for Record, 21 September, 2017. U.S. Army Corps of Engineers, Kansas City District.

USACE. 2011. Kansas River basin regional sediment management Section 204 stream and river channel assessment. Prepared by Gulf South Research Corporation and The Watershed Institute for the U.S. Army Corps of Engineers, Kansas City District. http://cdm16884.contentdm.oclc.org/cdm/ref/collection/p16884coll78/id/144