

Illustrating land cover change associated with erosion management of the Little Blue River, Kansas, USA

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Abstract

Erosion is a concern due to environmental degradation, loss of valuable cropland, increased sediment loads in aquatic systems, and reduced reservoir capacity. To manage erosion, riparian forest buffers and bendway weirs were installed in the Little Blue River, Kansas, during years 2002–2010. To illustrate land cover changes associated with management for upland and streambank erosion, indicated through terrestrial land gains, particularly of permanent tree cover relative to short-lived crop cover, we digitized 1 m orthoimagery. For the pretreatment interval of 1991–2002, we digitized streambank edges to approximate change in river area. Due to river dynamics, for the 2002 and 2014 interval before and after treatment, we used land ownership parcels as fixed locations to assess changes in land area and land classes for 24 treated and 24 untreated parcels, each parcel group totaling 1575 ha. We appraised two extents of the unified streambank for both years and all land in parcels rather than isolating the river from the surrounding watershed. During 1991 to 2002, treated land parcels lost terrestrial land, whereas untreated land parcels gained land. During 2002–2014, treated land had greater river and crop cover, and less tree cover than untreated land. For the entire extent, with similar trends for the unified streambank extent, by 2014, treated parcels gained 27.3 ha of terrestrial land compared to 4.6 ha gained by untreated parcels. Gains occurred in tree cover and losses in river water and sediments cover. In treated parcels crop cover decreased, whereas in untreated parcels crop cover increased. Streamflows decreased over time, likely contributing to streambank stability. Despite lack of documented cost-share agreements, in untreated parcels, landowners managed land by increasing tree cover to protect soil from erosion. All measurements were consistent with erosion followed by management for erosion through terrestrial land gains of tree cover.

KEYWORDS

agroecology, community-based, erosion, remote imagery, riparian buffer, riparian zone, weirs

1 | INTRODUCTION

Soil erosion and deposition are natural processes arising from water flow. However, sediment loads have increased in aquatic ecosystems, particularly from land in agricultural use, which may be cultivated within a few meters of streambanks (Beck et al., 2018; Dave & Mittelstet, 2017; U.S. Environmental Protection Agency [USEPA], 2000).

For example, the 2013–2014 United States assessment of national rivers and streams found that 22% of total length was of poor quality for sediments, 24% was of poor quality for vegetative cover, and 23% was of poor quality for disturbance (USEPA, 2020). Streambank erosion may contribute 20%–90% of sediment loads in water (Beck et al., 2018). Streambank erosion rates may vary due to adjacent terrestrial land use, disturbance, upland and

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riparian vegetation cover, topography, bank material composition and strength, river morphology, and discharge variables, among other factors (Bigham, 2020; De Rose & Basher, 2011). Hydrological networks have been modified and re-routed in agriculturally intensive landscapes of semi-impervious cultivated surfaces after conversion from infiltrative (“springy” or “spongy”) landscapes of historical vegetation and wetlands, resulting in less percolation into soils and greater overland flow or drainage tile flow (Andersen, 2000; Moore, 1917; Sass, 2008; Sass & Keane, 2016; Zaimes et al., 2006). Rapid removal of surface water to streams increases flooding and erosion (Meade, 2009; Sass, 2008; Simon & Rinaldi, 2000; Zaimes et al., 2006).

Restoration of riparian vegetation is a common stream management action to reduce upland and streambank erosion rates and sediment loads by slowing overland and floodplain water flow, improving infiltration rates, capturing soil and sediments, and enhancing bank shear strength through root interactions with the soil (Bigham, 2020; De Rose & Basher, 2011; Naiman & Décamps, 1997; Sass, 2008). Improved management that retains vegetative cover has reduced streambank erosion and upland soil erosion, which specifically arises from soil disturbance and bare ground exposure with low water infiltration rates due to crop cultivation (Meade, 2009; Sass & Keane, 2016; Williams & Smith, 2008; Zaimes et al., 2006). Relatively constant cover of vegetation protects soil resources, both along streambanks and in uplands (Bentrup, 2008; Bigham, 2020; Pollen-Bankhead & Simon, 2010). In particular, tree cover takes time to establish and is a more permanent indicator of soil protection than herbaceous vegetation. Trees supply deep root reinforcement to soils, offering greatest mechanical capacity, relative to grasses and shrubs, to support steeper slopes against shear stress and structural failure (Krzeminska et al., 2019; Sass, 2008). For example, Geyer et al. (2003) found that tree cover reduced erosion and the extent of streambank movement caused by large magnitude flooding during 1993, in Kansas, USA, compared with areas lacking woody vegetation cover in an agriculturally dominated landscape. Riparian forest buffers are a management practice documented to reduce magnitude of streambank erosion and total soil loss relative to land uses of crops and pastures (Fox et al., 2016; Sass, 2008; Zaimes et al., 2006).

High sediment loads and eventual sedimentation have ecological and economic consequences. Damage to aquatic systems results in reduced primary productivity through turbidity and also decreased growth, survival, and reproduction of aquatic organisms through both direct smothering, which causes mortality or injury, and loss of critical resources such as feeding and cover spaces after being filled by sediment (Huggins et al., 2008). Sediments also may create poor water quality through addition of fertilizers or toxic chemicals (Beck et al., 2018; Fox et al., 2016; Kansas, 2021). Ultimately, these cumulative changes impact fish and wildlife habitat (Bentrup, 2008). Erosion decreases the arable land base and soil productivity,

moving soil to fill reservoirs where water flow is impeded by dams (Fox et al., 2016). Sediment is an expensive public concern by reducing water storage capacity in reservoirs (Fox et al., 2016; Juracek & Mau, 2002). For example, total annual economic costs probably are in the range of tens of billions of US dollars in the United States after accounting for damages related to recreation, navigation, water storage facilities, municipal and industrial water users, water conveyance systems, flooding, and agriculture (Fox et al., 2016; Williams & Smith, 2008).

As dredging of sediment deposited in reservoirs is costly, preventative measures to reduce sedimentation are both ecologically and economically beneficial. Preventative investments include upland soil conservation and streambank stabilization, through vegetation restoration and streambank management techniques combined with in-stream structures. Riparian vegetation reduces nutrient and soil losses from agricultural fields, and provides unique riparian habitat, along with other ecosystem services (Bentrup, 2008). Riparian areas represent a small percentage of landscapes, but they are disproportionately productive and contain distinctive vegetation and wildlife assemblages (Hanberry et al., 2021; Jones et al., 2010). Federal and state programs incentivize riparian buffers through cost-share agreements that offset establishment costs and loss of income from land taken out of crop (USDA Farm Service Agency [USDA FSA], 2022; USDA Natural Resources Conservation Service [USDA NRCS], 2022). Furthermore, landowners benefit by preserving land from erosion (Williams & Smith, 2008). Riparian plant roots provide mechanical reinforcement to streambanks, strengthening streambanks against shear stress, whereas other streambank management techniques include toe rock (i.e., rock riprap) and bank shaping (Bigham, 2020; Pollen-Bankhead & Simon, 2010). Instream structures, encompassing bendway weirs, impermeable spurs, and rock vanes, increase streambank strength and minimize forces acting on streambanks (Abad et al., 2008; Bigham, 2020). Bendway weirs are low structures positioned typically in a series and angled upstream toward the flow (Abad et al., 2008; Bigham, 2020).

Recently, Kansas, USA, has focused on streambank stabilization as a remedy for sediment accumulation in reservoirs (Layzell et al., 2022; Rahmani et al., 2018). For example, nearly half of the storage capacity of Tuttle Creek Lake reservoir has been filled by sediment since 1962; the total estimated cost of removing sediment from the reservoir is >\$1 billion USD (\$1.6 billion in 2021; Williams & Smith, 2008). The Little Blue River, a tributary of the Big Blue River in northeast Kansas, above the Tuttle Creek Lake reservoir, was a source of rapid erosion (Figure 1; Balch & Emmert, 2007). Landowners were made aware of financial assistance opportunities through Environmental Quality Incentives Program for stabilization work and Conservation Reserve Program for riparian forest buffers (USDA FSA, 2022; USDA NRCS, 2022). To stabilize streambanks of the Little Blue River at sites with rapid erosion and limited riparian vegetation, bendway weirs

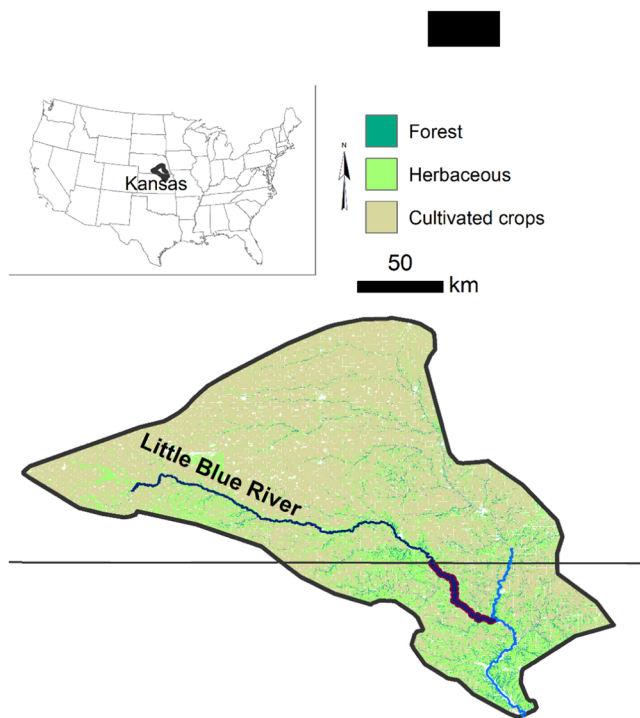


FIGURE 1 The Big Blue River watershed in Kansas and Nebraska, with the Little Blue River study area in Kansas (outlined in purple) and 2001 NLCD land cover classes (Homer et al., 2020).

(with rare use of rock vanes) in combination with 30.5 m riparian forest buffers, along with streambank management techniques of toe rock and bank shaping, were completed on land parcels during 2002–2010 (Balch & Emmert, 2007).

Riparian vegetation, streambank management, and in-stream structures reduce erosion from adjacent land or streambanks, connecting private and public dollar savings to the establishment of ecologically beneficial investments (Bigham, 2020; Layzell et al., 2022; Russell et al., 2021). Riparian forest buffers are a well-documented mechanism to stabilize banks and reduce magnitude of bank erosion, severely eroded bank lengths and areas, and soil loss compared to crop and pasture cover (Meade, 2009; Naiman & Décamps, 1997; Sass, 2008; Zaimes et al., 2006); therefore, riparian vegetation is a major component of different bank stability assessments (Sass, 2008). Spatially continuous data during different time intervals, from remotely sensed imagery, permit change detection in land area and land cover classes, which supply indicators of soil and streambank stability through increased terrestrial land area, particularly long-lasting tree cover that provides great shear strength for bank stabilization against structural failure (Krzeminska et al., 2019; Zaimes et al., 2006). Our objective was to compare digitized areas of river and adjacent treated and untreated landowner parcels over time to directly measure land cover change associated with management of erosion from land and streambanks, in an integrative study of both a river and surrounding land use. Increased terrestrial land area, particularly through more permanent tree cover instead of short-lived crop cover, relative to river water and sediments

area served as the indicator of streambank stability. In the case of the Little Blue River, the river was dynamic (Figure 2) and we did not attempt to measure river points or segments (e.g., 1.5 meander wavelengths upstream and downstream of stabilized locations with exclusion of segments of channel migration and oxbow formation; Russell et al., 2021). Consequently, we developed an approach to directly measure land cover change in fixed land parcels, from the perspective of erosion management in streambanks and land adjacent to streambanks, rather than an isolated focus on streambanks alone. Using orthoimagery, we measured change in Little Blue River streambanks during 1991–2002 based on digitized bank edges, to provide a basic baseline for the erosion noticed before management for streambank stabilization. Then we digitized land classes for 24 treated and 24 untreated land parcels of equal areas along the Little Blue River during 2002 and 2014. For one extent to assess streambank management, we compared changes in the digitized land class area within the united streambanks of 2002 and 2014, plus an additional 60 m buffer to each side. For another extent to assess overall erosion management, we compared changes in land class area within all of the treated and untreated parcels. We also examined streamflows over time, although we did not investigate the influence of every potential factor that may have changed, affecting erosion rates.

2 | METHODS

2.1 | Imagery

To measure land cover change associated with erosion and management for erosion, we used 1 m orthoimagery of Digital Ortho Quarter-Quadrangles (DOQQ; NAD 1983 UTM Zone 14N projection) from available years of 1991, 2002, and 2014, which matched before and after treatments (Kansas Data Access & Support Center, 2021). The 1991 and 2002 images were black and white, single-band images. The 2014 imagery was in color, with three bands (i.e., visible colors), and a resolution of 0.3 m that we re-sampled to 1 m to be consistent. Orthophotos are aerial photographs that are geometrically corrected for topographic variation and with a coordinate system (i.e., “orthorectified”). We selected leaf-off imagery to reduce error from canopy and shadows. The other benefit of winter imagery was that less precipitation occurred than during other seasons; that is, 7.2 cm during winter as opposed to 24.3 cm during spring out of 80.1 cm annual precipitation (during 1991–2020; 4 km resolution PRISM Climate Group, 2023) in the land parcel extent (see below); therefore, precipitation during winter was likely to be less influential on water levels.

2.2 | Land ownership parcels and samples as fixed locations for measurement

Rather than comparing dynamic rivers, we measured landowner parcels as a stable reference area. Land

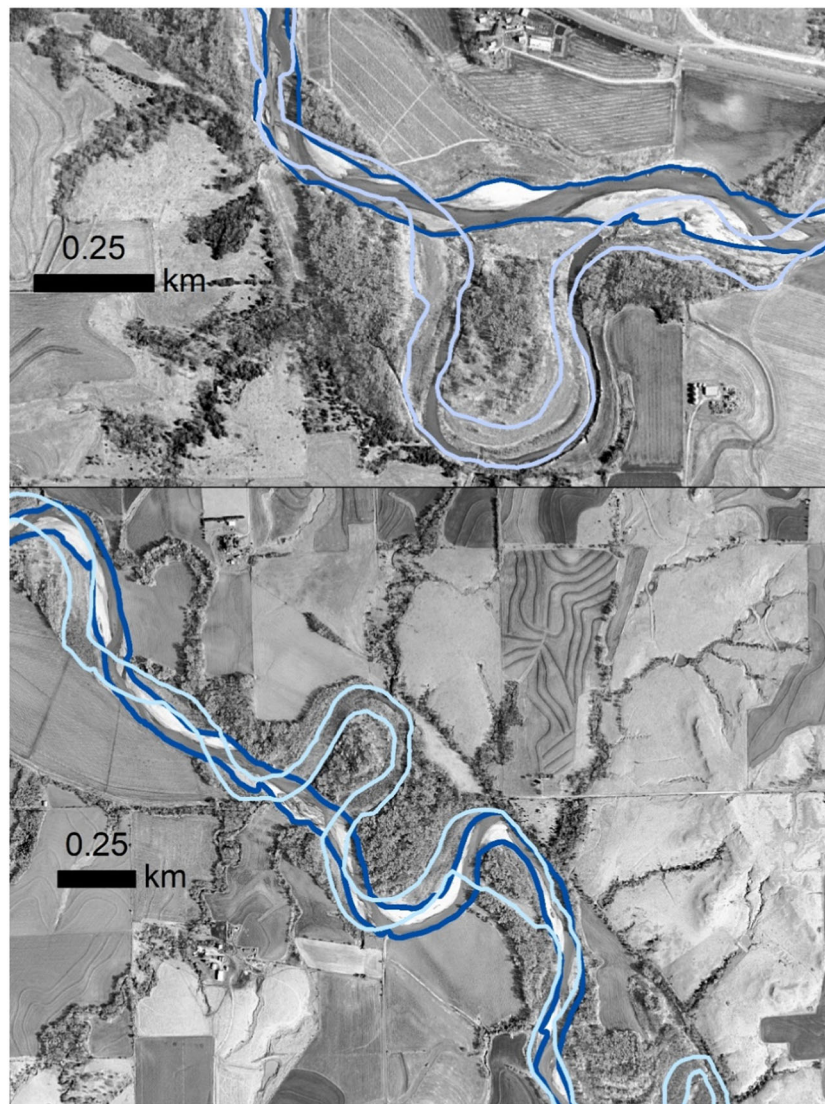


FIGURE 2 Two examples of dynamic movement of the Little Blue River between 1991 (light blue) and 2002 (dark blue) with 2002 orthoimagery.

ownership samples consisted of 24 treated and 24 untreated land ownership parcels, each parcel group totaling 1575 ha (treated parcel area mean = 66 ha and SD = 37 ha; untreated parcel area mean = 66 ha and SD = 34 ha). There were 158 total land ownership parcels, totaling 7635 ha, along the Little Blue River, of which 26 land parcels had stabilization projects completed by 2010, clustered at meander bends (Figure 3). We excluded from analysis land parcels where treatments extended across ownerships due to shared meander bends. To identify potential untreated samples for comparison with the treated parcels, we added randomly spaced points (at least every 300 m apart). From the land parcels at random points, we removed land parcels with treatments planned or applied later than 2010 (constructed 2014 and later), and also land parcels that were located at straighter reaches of the river, shared a meander or immediately downstream of treatments, or no longer adjacent to the river. The parcels were a variety of shapes and sizes, and to balance total acreage, we removed

two treated parcels that were <10 ha and two untreated parcels that were closest in area to the difference between the total treated area and untreated area, resulting in 24 samples each and 1575 ha of land with and without known treatments, for a total extent of 3150 ha.

2.3 | Change in river area and land parcel area during 1999, 2002, and 2014

We produced a rough estimate of change in the river area during the pre-stabilization interval when erosion was detected. For 1991 and 2002, we hand-digitized the Little Blue River banks (Figure 2). For each year, we drew edge-of-bank lines to quantify the area of the streambank. Additionally, we approximated change in land areas within land parcels by excluding area within banks. That is, based on digitizing the edge-of-bank lines, we measured the area within banks for the rivers and area outside of banks for

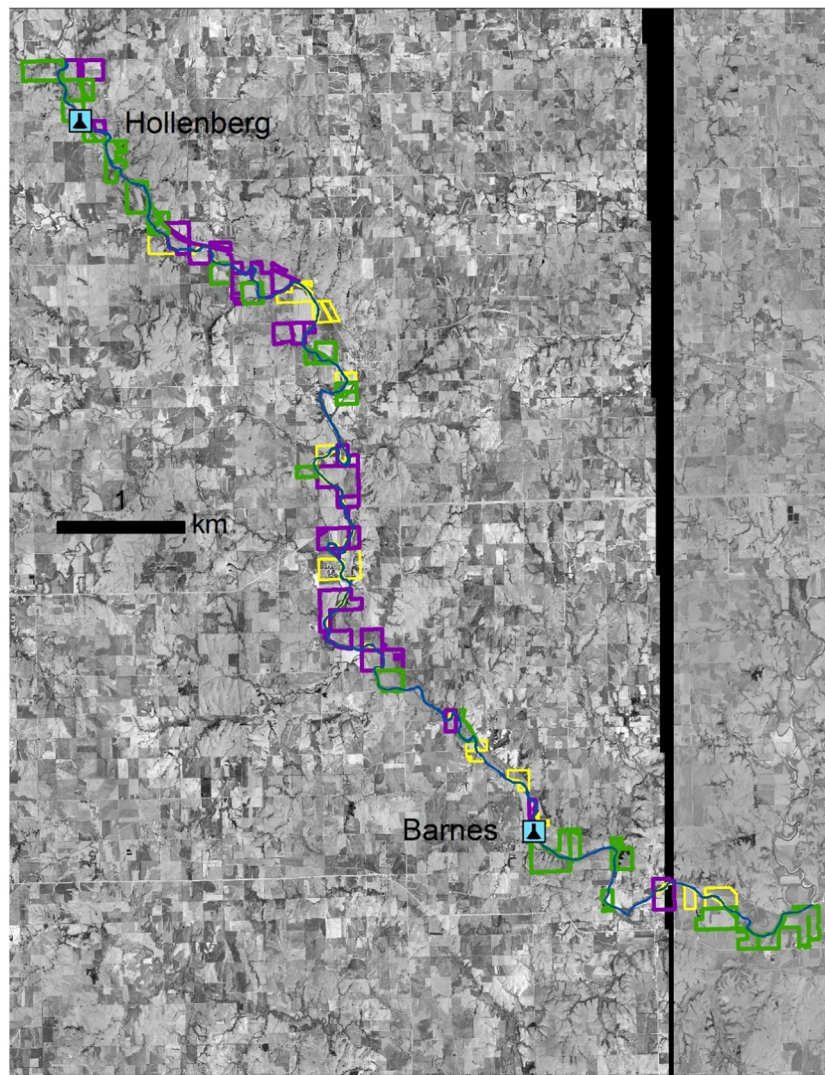


FIGURE 3 Treated (purple; treatments completed by 2010) and untreated (green) parcels, and parcels treated after 2013 (yellow), with 2002 orthoimagery background for the Little Blue River, and stream gauges of Hollenberg and Barnes, Kansas.

land parcels. We also digitized banks of the Little Blue River during 2014 to examine change in river area, but not land parcels.

2.4 | Change in river area and land parcel area during 2002 to 2014

To more accurately measure change in land cover area during the 2002 to 2014 interval of before and after treatment, we hand-digitized land cover of the 48 treated and untreated land parcels to use as fixed locations. We drew land classes of tree, herbaceous, crop, water, barren (i.e., the bare ground, nonwater area within streambanks, which we distinguished from nonvegetation area outside banks), and developed land (Figure 4). Crop and herbaceous classes generally were distinguishable based on visible row lines (i.e., images were during winter after harvest) and color differences, but large balanced

fluctuations between these two classes indicated that the classes reversed over time.

We compared the digitized areas at two different extents: in the extent of within and adjacent to the unified streambanks and for the entire extent of the parcels. To assess change in river area after streambank stabilization, we examined land cover change in the extent of the united river channels during 2002 and 2014 with an additional 60 m to each side; 60 m was the approximate river width. For this extent, we determined the total area of each landcover class and by treated and untreated areas, and then relativized area to percentages for an equal basis of comparison. Treated areas had greater area within this extent (i.e., unified channels with 60 m to each side) of 356 ha (23% of 1575 ha) as opposed to 314 ha (20% of 1575) in the untreated areas, but the area within this extent of all nontreated land (including parcels not sampled) only totaled 361 ha; that is, treated parcels and selected untreated parcels had greater river exposure. To assess

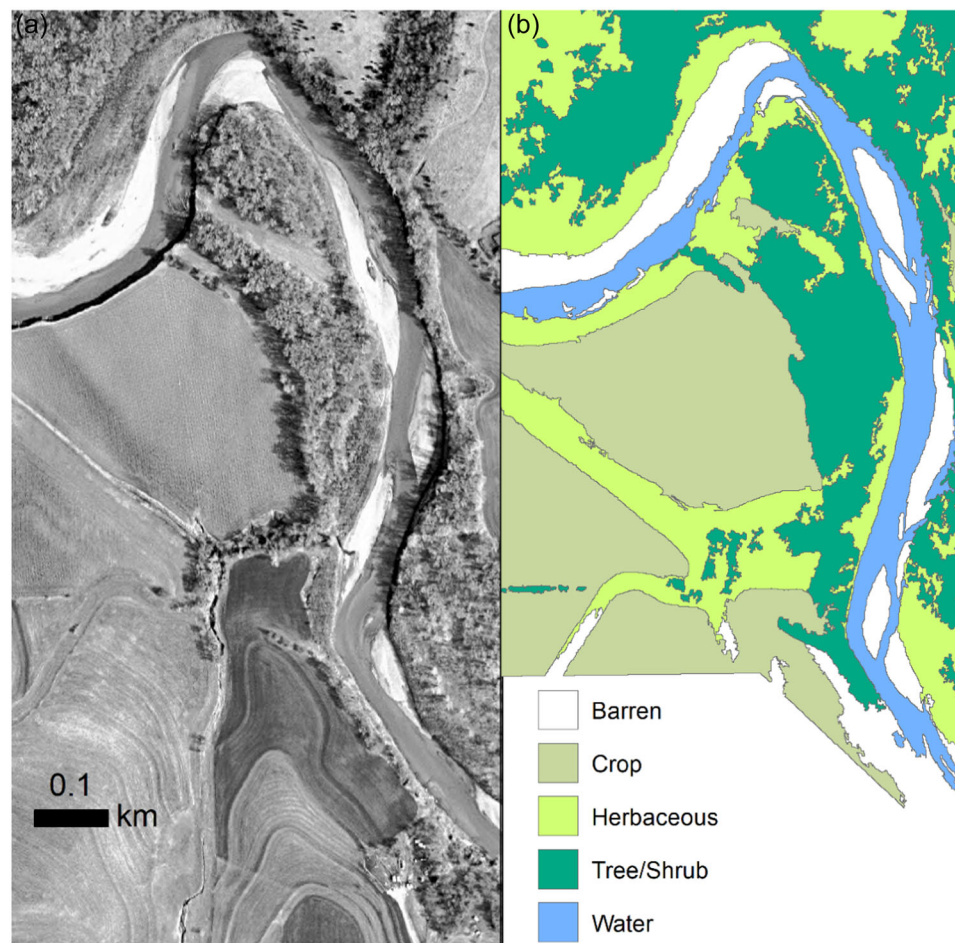


FIGURE 4 The 2014 orthoimagery for one treated parcel, with bendway weirs (a) and digitized land cover classes (b).

change in land area by treatment for overall erosion management, we compared treated to untreated areas to account for the entire land parcel of upland, riparian and riparian buffer, and aquatic area without applying a fixed extent. For this extent, we determined the total area of each landcover class and by treated and untreated areas, and also provided area percentages.

2.5 | Accounting for streamflow and drought

Among other factors, streamflow influences erosion rates. Bank erosion may follow rapid recession of high flow events (Keane & Sass, 2017; Sass & Keane, 2016) and low magnitude but more frequent flows may erode the bank toe and steepen the bank, which results in instability and bank failure (Simon & Curini, Darby, et al., 2000). Although conditions are variable and not likely to be repeated, we considered changes in mean streamflow and drought during 1991–2014 for the land parcel area.

We calculated mean discharge values for time intervals of spring 1991 to winter 2002 and spring 2002 to winter 2014, to account for streamflow during imagery years. We extracted streamflow discharge (cubic meters per second;

m³/s) at Little Blue River stream gauges: Hollenberg (upstream) and Barnes (downstream; Figure 3; U.S. Geological Survey [USGS], 2023). To determine trends and significance, we calculated annual (i.e., to remove seasonal trends) discharge values for years 1992–2013 (i.e., full years) and then applied the nonparametric Mann–Kendall method to assess trends (zyp package; R Core Team, 2023). We applied prewhitening to remove serial correlation that may lead to overestimation of the significance of a trend and rejection of the null hypothesis of no trend (Zhang & Zwiers, 2004). We then applied changepoint detection, to determine if the two intervals were different, with two methods for changepoints (changepoint package with PELT algorithm, Killick & Eckley, 2014; *t*-test in cpm package, Ross, 2015; R Core Team, 2023). Sequential change detection identifies points at which statistical properties of a time series of observations change. We examined annual changes because changepoint detection will detect seasonal changes.

The Palmer Drought Severity Index (PDSI) has strong relationships with both soil moisture and streamflow that may be used as a proxy of annual mean streamflow when streamflow is unavailable (Dai et al., 2004), and PDSI often is compared with tree growth (Hanberry, 2021). The

PDSI approximates balance between precipitation and temperature, expressed in values generally ranging from -6 to 6 , with values below -3 representing severe to extreme drought. We calculated PDSI values (2.5° grid; Dai et al., 2004) for time intervals of spring 1991 to winter 2002 and spring 2002 to winter 2014. We also calculated PDSI values for years 1992–2013, to test for trends and changepoints.

3 | RESULTS

3.1 | Change in river area and land parcel area during 1999 and 2002

Based on digitizing the edge-of-bank lines of the Little Blue River channel, between 1991 and 2002 (pretreatment), the area within banks decreased by 33.6 ha. Dynamic movement produced cutoffs in meander bends, shortening the river length from 149 to 143 km and reducing area from 507 to 473 ha (Figure 2). Only about 70% of the within-bank river area remained the same during this interval. After excluding digitized river areas in land parcels, between 1991 and 2002, or pretreatment, the land parcels that were targeted for treatment lost in aggregate 5.3 ha of terrestrial land, not within the stream banks. Conversely, the untreated land parcels gained 15.2 ha of terrestrial land, not within the stream banks. The river was more stable during 2002–2014, with 88% of the within-bank river area remaining the same and the length and measurements similarly were constant at 143 km and 478 ha during 2014.

3.2 | Change in extent within 60 m of united river channels during 2002–2014

After classification of land parcel cover, we examined land cover change in the unified extent of the river channels during 2002 and 2014, with an additional 60 m to each side (Table 1). For this extent during the time interval, terrestrial land class percentage increased by 4.6 percentage points, because the tree class increased from 25.3% to 30.8% of area, arising from a decrease in combined water and barren (i.e., river channel sediment) classes from 23.1%

to 19.4% and also the crop class decreased from 14.5% to 12.4% of area. In total, 34% of the classes changed, resulting in the overall transfer of area from water and crop classes to the tree classes.

Treated areas had total greater area within this extent (see methods section), which was reflected in a greater percentage of combined water and barren classes than the untreated areas. In addition to greater total area, crop class percentages were greater and tree class percentages were lower in treated areas than in untreated areas. Both treated and untreated areas increased in tree class percentage during the time interval, from 19.5% to 26.4% of treated area and from 32.6% to 36.6% of untreated area. Both treated and untreated areas decreased in combined water and barren class percentage in this extent during the time interval, from 39.8% to 32.5% of treated area and from 36.7% to 35.3% of untreated area. Additionally, both treated and untreated areas decreased in crop class percentage during the time interval, from 16.4% to 12.7% of treated area and from 12.5% to 12.3% of untreated area.

3.3 | Change in entire extent of digitized treated and untreated parcels during 2002–2014

For the entire extent during 2002–2014, terrestrial land class percentage increased by 1 percentage points, due to increased tree land class percentage (+1.8%) arising from a decrease in combined water and barren classes (−1%) and also combined crop and herbaceous classes (−0.7%; Table 2). For the entire extent of the treated parcels, treated parcels overall gained about 27.3 ha of land classes (i.e., crop, tree, and herbaceous classes), which is the area that the river channel lost (i.e., combined water and barren classes within the riverbanks). The tree class gained by 31.5 ha, and the crop and herbaceous land classes combined decreased by 4.3 ha; in contrast, the crop class decreased by 19 ha and the herbaceous class increased by 14.6 ha. No treated parcels lost land area to the river channel.

The entire extent of the untreated parcels overall also gained land area, at 4.6 ha (i.e., crop, tree, and herbaceous class area relative to water and barren class area). The tree

TABLE 1 Land cover class percentages and change in all area, treated area, and untreated area for the united river channels, with an additional 60 m to each side, of the Little Blue River, KS, during 2002 and 2014.

Class	All area			Treated area			Untreated area		
	2002	2014	Change	2002	2014	Change	2002	2014	Change
Crop	14.5	12.4	−2.1	16.4	12.7	−3.7	12.3	12.1	−0.2
Herbaceous	22.0	23.3	1.2	24.2	28.4	4.2	19.6	17.5	−2.1
Tree/Shrub	25.3	30.8	5.5	19.5	26.4	6.9	31.9	35.8	3.9
Water	23.1	19.4	−3.7	22.9	19.0	−3.9	23.3	19.7	−3.6
Barren	14.9	14.1	−0.8	16.9	13.5	−3.4	12.7	14.8	2.2

TABLE 2 Land cover class area (ha), percentages, and change for all 48 land parcels, 24 treated parcels, and 24 untreated parcels of the Little Blue River, KS, during 2002 and 2014.

	All parcels			Treated parcels			Untreated parcels		
	2002	2014	Change	2002	2014	Change	2002	2014	Change
Area									
Crop	1757.2	1750.9	−6.3	943.8	924.9	−19.0	813.3	826.0	12.7
Developed	11.3	9.2	−2.1	5.3	4.6	−0.6	6.0	4.5	−1.5
Herbaceous	655.4	638.4	−17.0	300.9	315.6	14.6	354.5	322.8	−31.7
Tree/Shrub	455.1	510.4	55.3	173.8	205.4	31.5	281.3	305.0	23.7
Barren outside banks	3.3	5.3	2.0	1.8	2.5	0.7	1.5	2.8	1.3
Water	166.9	140.5	−26.5	89.1	74.0	−15.1	77.8	66.5	−11.3
Barren within banks	99.3	93.9	−5.4	59.9	47.7	−12.1	39.4	46.2	6.8
Percentage									
Crop	55.8	55.6	−0.2	59.9	58.7	−1.2	51.7	52.5	0.8
Developed	0.4	0.3	−0.1	0.3	0.3	0.0	0.4	0.3	−0.1
Herbaceous	20.8	20.3	−0.5	19.1	20.0	0.9	22.5	20.5	−2.0
Tree/Shrub	14.5	16.2	1.8	11.0	13.0	2.0	17.9	19.4	1.5
Barren outside banks	0.1	0.2	0.1	0.1	0.2	0.0	0.1	0.2	0.1
Water	5.3	4.5	−0.8	5.7	4.7	−1.0	4.9	4.2	−0.7
Barren within banks	3.2	3.0	−0.2	3.8	3.0	−0.8	2.5	2.9	0.4

TABLE 3 Results of Mann–Kendall statistical test.

	<i>p</i>	Trend
Streamflow, Hollenberg station	0.14	decreasing
Streamflow, Barnes station	0.01	decreasing
PDSI	0.5	decreasing

Abbreviation: PDSI, Palmer Drought Severity Index.

class gained by 23.7 ha. Crop and herbaceous classes combined decreased by 19 ha; the crop class increased by 12.7 ha and the herbaceous class decreased by 31.7 ha. Only five untreated parcels lost land area to either water or barren land within the stream channel, although generally this appeared to be an effect of river meandering.

3.4 | Accounting for streamflow and drought

Considering streamflow over time, mean discharge values were 22.9 and 23.2 m³/s during spring 1991 to winter 2002 at Hollenberg and Barnes gauge stations, respectively, and 14.0 m³/s at both stations during spring 2002 to winter 2014. Streamflow at Hollenberg had a nonsignificant ($p = 0.14$; Mann–Kendall) decreasing trend, with no meaningful changepoints (i.e., either no year or every year; Table 3). However, streamflow at Barnes had a significant ($p = 0.01$; Mann–Kendall) decreasing trend, with no

meaningful changepoints (i.e., either none or every year). Drought conditions have effects on streamflow levels. Regarding drought, PDSI values were 1.2 during spring 1991 to winter 2002 and 0.5 during spring 2002 to winter 2014. These are middling values of neither drought nor pluvials; that is, near-normal to slightly wet (Maule et al., 2013). The PDSI values had a nonsignificant ($p = 0.50$; Mann–Kendall) decreasing trend, with no changepoints detected by either method.

4 | DISCUSSION

4.1 | Key findings

Riparian vegetation, streambank shaping, toe rock, and instream structures stabilize erosion (Bigham, 2020), either in streambanks or land adjacent to streambanks, and ultimately reduce sediment deposition in reservoirs. We compared surrounding land and river area change of the Little Blue River, Kansas, before and after treatments of riparian vegetation, bendway weirs, and additional streambank management techniques of toe rock and bank shaping due to rapid erosion before 2002. For 1991 and 2002, before treatment, we hand-digitized edge-of-bank lines to quantify the area of the Little Blue River. For 2002 and 2014, before and after treatment, we hand-digitized land cover of land parcels, which have fixed locations, and examined two extents: within and adjacent to the unified

streambanks and the entire extent of the parcels for a more integrative perspective. The main finding was that for the digitized stretch of the Little Blue River, all measurements were consistent with erosion followed by management for erosion by 2014 after treatment by 2010, based on increased terrestrial land area, particularly through more permanent tree cover instead of short-lived crop cover, relative to river water and sediments area as the measure of streambank stability. General change in the river channel before treatment, between 1991 and 2002, indicated terrestrial land loss in land parcels that were targeted for treatment and terrestrial land gain in untreated parcels. Change in land cover after treatment, between 2002 and 2014, showed that treated parcels gained more terrestrial land at 27.3 ha than untreated parcels, which still continued to gain terrestrial land area of 4.6 ha. Measurements illustrated that terrestrial land area increased though tree cover, which was a management response for erosion, with increased terrestrial land area and tree cover indicating stabilization of streambanks. To support streambank stabilization, accounts from landowners and field visits corroborate reduced erosion rates (Balch & Emmert, 2007; K. Bigham, Kansas State University, personal communication). Increased tree cover is a well-established practice to stabilize upland soils and streambanks, in this agricultural region and elsewhere (Geyer et al., 2003; Krzeminska et al., 2019; Sass & Keane, 2016; Zaimes et al., 2006). However, we measured terrestrial land area and tree cover, which replaced cover of river water and sediments, and did not directly measure erosion or causation for change; stream discharge decreased over time, which likely contributed to streambank stabilization.

A key discovery was that untreated land had been treated privately by landowners, despite the fact that they did not take advantage of cost-sharing agreements. Although the untreated parcels did not have streambank stabilization structures installed, terrestrial land area overall increased through greater tree cover. Only five untreated parcels lost terrestrial land area. Some combination of observation of erosion and treatment applications on neighboring lands and outreach was effective in changing land management practices to expand permanent land cover (Bentrup & Kellerman, 2004). Landowners may have either actively established trees or allowed land to become treed. Conversely, during this interval, the untreated parcels increased in crop cover, by 12.7 ha, whereas the treated parcels reduced in crop cover, by 19 ha. However, conversion between crop and herbaceous cover is common and indeed, some parcels had a wide oscillation between these two classes. Also, during 2002–2014, untreated land maintained less crop cover and more tree cover than treated land.

Restoration starting points of the treated and untreated parcels were different in that treated parcels were losing land before treatment. The digitized parcels were most susceptible to erosion due to greatest percentage area within the river channels and locations along outer meander bends compared to other parcels. Treated areas

had slightly greater area within this extent of 356 ha (23% of treated area) than 314 ha (20% of untreated sampled area) in the untreated areas. In addition to slightly greater total area, crop class percentages were greater and tree class percentages were lower in treated areas than in untreated areas. The land cover measurements for treated parcels aligned with need for treatments. We removed from analysis land parcels with treatments planned or applied later than 2010 (constructed 2014 and later), which had erosion issues. Nevertheless, this study contained parcels that had greatest river exposure, although the 48 digitized parcels were only 42% of the total area along the Little Blue River in Kansas (i.e., out of 158 land ownership parcels, totaling 7635 ha).

Many factors contribute to streambank erosion and stabilization (De Rose & Basher, 2011). Tree cover is a known mechanism to reduce erosion (Zaimes et al., 2006), and increased tree cover and terrestrial land area occurred throughout the parcel extent according to measurements of land cover. In addition to erosion reduction through land and streambank management, stream discharge rates decreased over time, which probably reduced streambank erosion. Streamflow decreases were continuous over time; that is, the two intervals of before and after treatment were not hydrologically differentiated, according to changepoint analysis. Although tree cover may have increased because of reduced streamflows, that was not likely to be a primary driver for tree cover increases. Historical riparian forests were able to coexist with historical hydrological regimes of free-flowing rivers. Trees were planted deliberately as part of treatments. Likewise, before change in management, trees likely were removed to increase crop cover. Tree establishment has occurred throughout the Great Plains following the advent of Euro-American settlement, with riparian networks as natural corridors for spread (Hanberry, 2021; Sass & Keane, 2016). Reduced streamflow, and equally drought, is not necessary for tree establishment; rather, tree cover develops in response to management decisions.

Modulating considerations include that downstream parcels may be affected by treatments on upstream parcels, some parcels received a greater area of streambank treatment, some treatments were not maintained or became less effective over time, and measurement error occurs. Land parcels are not independent, because downstream parcels are affected by upstream parcels. However, Russell et al. (2021) found that streambank stabilization was effective only at installation locations in the Cedar River, Nebraska. Treatments continued on other land parcels after 2014 in the Little Blue River, corroborating that erosion continued away from treated locations despite measured gains in terrestrial land area in this study extent. Some parcels received a greater area of streambank treatment than others. Streambank management may deteriorate over time without continued investment (Layzell et al., 2022; Russell et al., 2021). Repair work occurred on a few of the initial project sites, based on design lessons learned about rock weirs (D. Minge, NRCS, personal communication); for example,

a longitudinal rock line was added between the weirs and a rock chute or a grade stabilization structure was added to provide a stable outlet for field flood waters to reach the river. Lastly, measurement error occurs due to imperfect imagery and digitization (Layzell et al., 2022), although we did use leaf-off imagery for clearer images and re-sampled imagery to 1 m for consistent resolution when digitizing.

Although we were not able to measure change in stream depth, albeit the Little Blue River is shallow (stream gauge height of about 1–1.5 m, USGS, 2023; generally <0.5 m in depth, Balch & Emmert, 2007), evidence suggests that water levels did not affect digitization. Tree cover increased throughout the land ownership parcels, which will not be covered by water levels. Water levels did not cover tree lines or even the river sediment during either year. We counted the river area as the combined water and barren class of river sediments within streambanks. The area within the digitized bank edges was constant at 473 ha during 2002 and 478 ha during 2014, for the same length. Additionally, we compared imagery during winter, when precipitation was decreased and less variable than spring precipitation.

4.2 | Measurement of dynamics

The river channel and land classes were dynamic over time. During 1991–2002, river channel movement and cutoffs of meander bends shortened river length and reduced river area. Simply measuring the changed area of the river channel would be misleading for this river, when the river shortened during an interval of rapid change. Reduced river area may seem to indicate reduced erosion without the context of river movement. Only 70% of river area remained similar during this interval. The river was more stable during 2002 to 2014, with 88% shared acreage. About 35% of classes changed within the combined area of the 2002 and 2014 river channels, with an additional 60 m to each side.

Because of the inherent dynamics of rivers, and particularly this river, and land use along rivers, measurement of erosion is a challenge. Ground measurements occur at specific points, which can be difficult to maintain if streambanks are eroding rapidly (Balch & Emmert, 2007) or remain meaningful when the river changes course. Some of the channels shifted in location by 400–500 m. Remotely sensed measurements can encompass a more complete extent, but established standard methods for evaluating erosion have not been developed yet (Russell et al., 2021). For example, Russell et al. (2021: p. 1558) noted: “We initially considered evaluating the upstream and downstream segments using a constant downstream distance (e.g., 100 m). We rejected this approach because it precludes the comparison of analogous parts of the river's planform; consequently, it would produce incongruent data. The use of a constant distance, particularly a relatively short distance, might entail the collection of data from an entire meander at one location, only a partial meander at another location, and a straight stretch at a different location.” Russell et al. (2021) decided to compare

1.5 meander wavelengths upstream and downstream of stabilized locations with exclusion of segments of channel migration and oxbow formation. Rather than attempting to determine how to compare shifting meanders, we developed an approach to directly measure land area change in fixed land parcels, which had the benefit of capturing the landowner viewpoint and integrating the surrounding watershed rather than isolating change in the river only.

We can recommend two options for change detection using remotely-sensed imagery, to reduce time required for manual digitization of land parcels. If possible, waiting for four band imagery (red, green, and blue color, and near-infrared), with 1 m or finer resolution, will allow modeling of land cover classes. Automation reduces land classification from a time commitment of a few months to a few days with the only limitation of processing time that increases with the number of images (Hanberry & Hanberry, 2020). Change detection will become routine when four band imagery becomes available. However, if, as in this case, response to treatments that have occurred is a time-sensitive issue, manual digitization of the river channel during both the starting and end years of comparison, with the average river width to each side, will provide a shared but focused extent for comparison. Then, land parcels, or alternatively generated polygons, can be used to indicate where the river channel area has expanded over time relative to terrestrial land area for the shared extent.

5 | CONCLUSIONS

We measured land cover change from the perspective of fixed landowner parcels and showed that terrestrial land area increased through tree cover, which was a management response to erosion in the Little Blue River, Kansas and our metric of streambank stability. Measurements of terrestrial land gain through tree cover replacement of stream cover indicated overall stabilization of streambank erosion by 2014 after treatments were applied during 2002–2010 in the digitized area of the Little Blue River. Five untreated parcels lost terrestrial land area and treatments continued in other locations of erosion. In addition to documented investment in riparian buffers and rock weirs through cost-share agreements between public agencies and landowners, other landowners also managed their land to increase tree cover without entering into agreements. Increased tree cover alone as management was effective at maintaining terrestrial land area for those parcels overall during this interval, albeit treated areas were selected for greater erosion where additional treatments may be necessary for streambank stabilization. Streamflows decreased over time, which likely contributed to streambank stabilization but not increased tree cover. Although the minimum amount of stabilization effort to have maximum effects is unknown, particularly if streamflows exhibit trends over time, continued commitment to erosion management by both public land agencies and private landowners will reduce erosion of valuable land

and prevent a cascade of ecological and economic costs. Measurement of erosion management through riparian cover in shifting riparian systems is challenging both on the ground and remotely, but when four band imagery at 1 m or finer resolution becomes available, change detection will become routine.

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DATA AVAILABILITY STATEMENT

Digitized layers are protected for landowner privacy.

ETHICS STATEMENT

The authors assure that this article follows the core practices of the Committee on Publication Ethics.

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