The Ozarks Environmental and Water Resources Institute (OEWRI)
Missouri State University (MSU)

FINAL REPORT

Nonpoint Source Bank Erosion and Load Reduction Assessment for the Wilson Creek 319 Riparian Corridor Easement Site, Greene County, Missouri

Field work completed April 2014- May 2015

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SCOPE AND OBJECTIVES

The James River Basin Partnership (JRBP) has implemented a riparian corridor easement on City of Springfield owned property along Wilson Creek, a major tributary of the James River. This conservation easement is part of a Section 319 Grant from the Missouri Department of Natural Resources and the Environmental Protection Agency Region VII designed to reduce nonpoint source pollution to the James River. In 2001, a Total Maximum Daily Load (TMDL) was developed for the James River that set nutrient limits and targets for both wastewater treatment facilities and urban nonpoint land use (MDNR, 2001). Efforts to control point sources through improved tertiary treatment have reduced nutrient concentrations in the Lower James River between 60%-70% (MDNR, 2004). However, nutrient concentrations still remain high in streams draining urban areas particularly during storm flows and Wilson Creek has a long history of water quality degradation associated with development (Petersen et al. 1998; Richards and Johnson 2002; Miller 2006; MEC 2007; Hutchinson 2010). The increase in impervious surface due to urban development changes hydrologic conditions in the watershed that result in increased flooding and erosion in local streams in the Springfield area (Pavlowsky 2004; Pavlowsky and Owen 2009; Pavlowsky and Owen 2010). Sediment released to the channel by erosion can supply excess nutrients to streams and cause sedimentation problems downstream (Owen et al. 2007; Owen and Pavlowsky 2008). By implementing conservation easements and restoring the riparian corridor, nutrients and sediment entering the stream by bank erosion and near-channel runoff can be reduced over time.

The Ozarks Environmental and Water Resources Institute (OEWRI) at Missouri State University was responsible for the bank erosion monitoring and nonpoint source pollution modeling portion of this project to determine the annual bank erosion rates and related sediment and nutrient loadings to Wilson Creek for the 1.17 km long easement segment. Riparian easements remove the potential for future development or other disturbances that can increase runoff and nonpoint loads to the river. The purpose of this assessment is to evaluate the effects of the riparian easement implementation and reduced bank erosion rates on sediment and nutrient loads in Wilson Creek to support 319 requirements and the goals of the James River Total Maximum Daily Load (TMDL) and future Wilson Creek TMDL. The objectives of the assessment are:

(1) Install and monitor bank erosion pins for 1 year using repeat measurements at 17 transects within the project reach;

(2) Calculate nonpoint loads of sediment and phosphorus to the channel due to bank erosion; and

(3) Quantify runoff load reductions from easement area using different scenarios based on (i) land use management using the nonpoint source pollution model STEPL (Spreadsheet Tool for Estimating Pollutant Load).

STUDY AREA

The Wilson Creek watershed is approximately 218 km^2 and drains the central and western areas of the City of Springfield in Greene County flowing south to the confluence of the James River in Christian County (Figure 1). This portion of Wilson Creek is within the 12-digit Hydrologic Unit Code (HUC) 110100020303 (Headwaters Wilson Creek = 130.4 km^2). The underlying geology of the area is the Burlington-Keokuk limestone of Mississippian age within which is formed a karst landscape where sinkholes, losing streams, and springs are common (Vineyard and Feder 1982; Thompson 1986). Soils of the valley bottom are silty-loam terraces with inset floodplains composed of 35-80% chert fragments in the subsurface horizons (Hughes 1982). Limestone bluffs are common where the stream meets the valley margin and bedrock is often exposed in the bed of the stream. Land use of the watershed ranges from high-low density urban in the upper watershed to residential, livestock grazing, and forage crop production outside the city limits.

The easement is located along the main channel of Wilson Creek between FR 156 and James River Expressway (Figure 2). United States Geological Survey (USGS) gaging stations are located just upstream of the site at FR 156, upstream of the site at Scenic Avenue, and downstream along South Creek (Table 1). These gages will be used in this study to look at discharge variability during the study and to calculate pollution loads. The upstream drainage area of the segment is 81.3 km^2. The total area of the easement is 9.8 ha, with 4.0 ha on the east side and 5.8 ha on the west side. With the exception of a few standing pools, the channel in this reach is dry. Bedrock is common along the bed and there are several knickpoint features in the bed that create local scour and erosion. The stream is adjacent to bedrock bluffs at the beginning and end of the reach. In general, the riparian corridor consists of a thin line of mature trees, but the banks show signs of slight-moderate erosion throughout. More severe erosion occurs in localized areas where there is little riparian vegetation and where cattle have entered the stream or have been loafing along the banks.

METHODS

The influence on water quality from establishing a riparian buffer along an easement was assessed by predicting the reduction of nutrients and sediment input to the stream from both bank erosion and runoff from the land area within the easement along the channel. Bank erosion was assessed at the local-scale using erosion pins and repeat surveys at the site over approximately a 1-year period to quantify existing erosion rates for the study reach. Runoff water quality was modeled using STEPL to predict changes from different land use scenarios. Specific methods used for each of these approaches are detailed below.

Bank Erosion Monitoring

Bank erosion was monitored using 17 erosion pin arrays over the 1,170 m reach between Farm Road 156 and James River Expressway from April 17, 2014 through May 5, 2015 (383 days). A total of 52, 46 cm (1.5 ft) long, 1.3 cm (0.5 in) diameter pieces of rebar were driven into the bank at 17 transects (2-4 pins per transect) along the bank to within 15 cm (0.5 ft) of the end. Each pin represented a different part of the bank depending on the bank angle and bank material. Each pin was measured eight different times throughout the year. If erosion had occurred, the measurement was recorded and the pin driven back to within 15 cm of end. If no change or deposition occurred, the measurement was recorded and the pin was left alone. Cross-sectional surveys were collected at each pin array for bank height information and to assign specific pins to corresponding bank sections. The length of bank each pin array represents follows the sub-reaches that were identified in an earlier geomorphic assessment conducted at the site (Owen et al 2012). Bank erosion was then calculated at each transect that represented that portion of the bank using the following equation:

$$E_a = \sum (E_t * B_L * D_s)$$

Where:

E_a = annual erosion (Mg)

E_t = total transect erosion (m^2) = $\sum (E_p * B_h)$

E_p = total pin erosion (m)

B_h = bank height represented by individual pin (this is variable by transect)

B_L = length of bank represented by the transect (m)

D_s = bulk density of soil (Mg/m^3) from soil survey (1.4 g/cm^3, from Hughes 1982)

The average phosphorus concentration of 359 mg/kg for floodplain soils was used to calculate the total P load coming from bank erosion in the study reach. The average phosphorus concentration was calculated from a total of 50 samples collected at two different sites along Wilson Creek upstream of the wastewater treatment plant (Rodgers, 2005). Samples were collected at exposed cutbanks along the channel in 10 cm increments and were sent to ALS Chemex Laboratory (Sparks, Nevada) for hot aqua-regia extraction and geochemical analysis by inductively coupled plasma-atomic emission spectroscopy (ICP-AES).

STEPL Water Quality Model

STEPL is a customizable spreadsheet-based model for use in Excel. Using simple algorithms, it calculates nutrient and sediment loads from different land uses and the load reductions from the implementation of BMPs. Annual nutrient loading is calculated based on the runoff volume and pollutant concentrations. The annual sediment load from sheet and rill erosion is calculated based on the Universal Soil Loss Equation (USLE) and the sediment delivery ratio. Accuracy is primarily limited by the wide variability in event mean concentrations (EMCs) across watersheds since EMCs drive the water quality calculations.

For this study, load results of existing conditions were compared to several scenarios that change the hydrological and nutrient management characteristics of the site. Hydrological inputs into the model are controlled by soils information supplied by the user. Soils within the easement area were identified, clipped, and areas calculated using ArcGIS. The Hydrological Soil Group (HSG) was assigned to the appropriate soil mapping unit. Combined curve numbers were calculated using techniques outlined in TR-55 (USDA, 1986). Greene County Missouri and the Springfield Regional Airport were selected within the STEPL user interface for rainfall and runoff data. Built-in default nutrient and sediment concentrations were used for each land use category within each scenario.

RESULTS AND DISCUSSION

Bank Erosion Monitoring

Study Period Hydrology

The study period was drier than normal with nearly 18 cm (≈7 in) lower rainfall totals than the 30 year average (Figure 3). The months of November 2014-April 2015 were particularly dry, however the area did receive snow fall that was not included in this analysis. Rainfall did exceed the 30-yr average by at least 2 cm in only three months June 2014, October 2014, and May 2015. The study site has intermittent flow, but typically receives runoff >50% of the time (Table 1). During the study period, seven events occurred that were near the 1-yr flood RI and one flood event occurred that exceeded the 1.5-yr flood RI (Table 2, Figure 4). Discharges near or > than the 1-yr flood RI would be expected to do the most geomorphic work in the river, such as gravel transport, bank saturation-collapse, and bank erosion along the toe. Overall, the study period was drier than normal with small, frequent flood events.

Erosion Pin Monitoring

The majority of the total bank erosion occurred in the middle section of the study reach where the channel was not confined by bedrock, however, significant bank erosion was measured throughout the study reach indicting the channel is not stable and still adjusting to upstream hydrologic changes. Total bank erosion for the study period was 564 Mg/yr with 202 kg/yr of phosphorus (P) loss over that time (Table 3). Over the study period bank erosion supplied between 0.09-1.04 Mg/m/yr with an average of 0.52 Mg/m/yr from all pin array segments. Losses of P due to bank erosion ranged from 0.03-0.38 kg/m/yr with an average of 0.21 kg/m/yr. The highest erosion rates, ≈ 1 Mg/m/yr, were measured in the middle of the study reach between stations 14,600-14,700 m (Figure 5). When taking the length of the segment each pin represents, nearly 57% of the erosion occurs in the middle section of the study reach between stations 14,300-14,700 m (Figure 6). Around 21% occurs in the upper section and about 22% occurs in the lower section of the study reach. However, lateral migration and widening of the channel at both the upper and lower section of the study reach is limited by bedrock. This indicates the entire reach is still adjusting to watershed disturbance and/or to flood magnitude and frequency changes due to climatic shifts in rainfall. While no large floods occurred over the study period, this suggests smaller, more frequent events have the ability to cause significant bank erosion in urbanized watersheds. Erosion was measured along the entire channel though the easement area, but confined in places by bedrock suggesting the stream is still adjusting to upstream disturbance.

STEPL Modeling Results

For the purpose of this model the study area was divided into an east and west easement and soils and land use were classified in each. About 92% of the soils in the east side are classified as hydrological soil group (HSG) B soils with the remainder in HSG C (Table 4). Along the west side of the channel about 57% of the soils were in HSG B and the remaining 43% in HSG C. This soil classification was used to generate curve number (CN) values that were combined with different land use scenarios in STEPL to calculate pollutant loads.

<u>Existing Conditions</u>

STEPL results suggest nutrients and sediment leaving the existing easement area is fairly uniform from easements on both sides of the channel. Using the existing land use in the model, the P load is 14.5 kg/yr, the nitrogen (N) load is 85.4 kg/yr, and the sediment load is 15.5 Mg/yr (Table 5, Figure 7). The loads are fairly even between the two easements. This is because the west easement is larger, but has more of the total area in woods than the smaller east side with more pasture. This holds true for all scenarios tested for this study.

<u>All Woods Scenario</u>

This scenario generates the lowest modeled loads of all of the scenarios and suggests adding forested areas to marginal agricultural land can reduce nutrient and sediment entering local rivers and streams from near-channel areas. This scenario is what might occur if all of the easement land was converted into forest land use, which is expected over time in the conservation easement areas. The annual STEPL load results for this scenario are 2.5 kg/yr P, 5.4 kg/yr N, and 1.5 Mg/yr sediment. These results indicate around an 83-94% drop in nutrients and sediment in this scenario compared to existing conditions.

<u>Row Crops/Pasture</u>

There is a dramatic increase in annual loads when the forest land cover is removed from the model and the site is converted to higher intensity agricultural land use. This scenario is what may happen if the HSG B soils were converted from pasture to row crops and the HSG C soils were converted from woods to pasture. Annual loads for this scenario are 63.1 kg/yr P, 257 kg/yr N, and 81.1 Mg/yr sediment. These estimates are 3-5x higher than loads modeled from existing conditions. This would be considered the worst case scenario for runoff water quality for near-channel lands.

Residential/Commercial

Modeled annual N loads would increase when the easement areas are converted to higher intensity urban developments, but P and sediment loads would actually decrease over existing conditions. In this scenario HSG B soils were converted from pasture to commercial development and the HSG C soils were converted from woods to ¼ acre residential development. Annual loads of N increased over the existing conditions to 102.9 kg/yr. However, phosphorus and sediment loads actually decreased in runoff to 12.7 kg/yr of P and 4.1 Mg/yr of sediment. This scenario may produce less overall P and sediment, but it will increase runoff and cause increased flooding. Again, this is in runoff from the land within the easement area and doesn't take into account other problems of urban development such as downstream flooding and channel erosion.

Implications for Nonpoint Source Pollution Reductions

Results of this study suggest conservation easements can significantly reduce contributions of nutrients and sediment to Wilson Creek. Loads were estimated at the confluence of Wilson Creek and South Creek which is the 12-digit HUC 110100020303 (Headwaters Wilson Creek = 130.4 km^2). The nutrient and sediment loads were calculated using recent water quality data collected from 2008-2009 at the Wilson Creek at Scenic and a recently completed study with data collected from 2012-2015 study at South Creek near Highway FF (Table 7, Hutchison 2010; Owen et al. 2015). Annual load estimates at the outlet are 3,808 Mg of TSS, 73.0 Mg of TN, and 11.7 Mg of TP. Recent water quality data and loads from the upper Wilson Creek watershed are used to compare with load reduction from easement implementation.

Using the nutrient and sediment yield estimates from the site specific erosion estimates for the main stem of Wilson Creek between the confluence of Jordan and Fassnight Creek to the confluence of South Creek (9.9 km) suggests that more sediment (125%) is eroded from bank erosion than leaves the watershed outlet. Additionally, P contributions from bank erosion account for about 15% of the annual load at the watershed outlet. The erosion estimate exceeds the outlet load, however, all sediment eroded from banks in this section does not necessarily make it to the watershed outlet. This is only an estimate of bank erosion contributions compared to the entire load and doesn't take into account other sediment transport factors such as sediment pulsing or floodplain deposition. For example, present-day floodplain deposition rates are around 0.03 cm/yr along the study reach from a recent study (Vaughan 2014). However, it does suggest that bank erosion is a significant source of sediment to Wilson Creek. The upper Wilson Creek watershed has been developed for a long time and overland erosion rates are likely minimal. However, assuming 50% of the eroded sediment does reach the outlet, there would be about a 15-30% reduction in sediment and around a 2-4% reduction in P at the outlet. Results of this study suggest that implementation of a conservation easement could reduce erosion by 25-50% would significantly reduce sediment contributions to the lower watershed.

Conservation easements produce much lower reduction in nutrients and sediment if they are applied to the channel when looking at runoff generated compared to bank erosion. In this case 131.7 Mg of sediment, 0.73 Mg of N, and 0.13 Mg of P would be entering the river annually from runoff (Table 8). This accounts for only 3.5% of the sediment, 1.1% of the P, and 1% of the N leaving the watershed. If conservation easements were applied to the entire river and that land was converted into forest, the annual load from these areas would be 25.7 Mg of sediment, 0.1 Mg of N, and 0.04 Mg of P. That translates into around a 2.8% reduction in sediment, 0.9% reduction in P, and 0.8% reduction of N at the watershed outlet. Nutrients and sediment reduction in overland runoff is less significant than from reduced bank erosion at the watershed scale, however it can improve water quality at the local scale through less near-channel loads and can act a buffer between more intense land use and the stream.

CONCLUSIONS

The JRBP has implemented a 1.17 km conservation easement along both banks of Wilson Creek in Springfield, Missouri. This study estimates the annual nutrient and sediment loads from runoff and bank erosion using a combination of field-based bank erosion monitoring and STEPL water quality modeling. The results of this analysis are used to determine the load reduction attributed to the easement managed for sediment and nutrients. There are six main conclusions from this study:

1. **Bank erosion pins were installed along a 1.17 km reach of channel and monitored for over one year.** Bank erosion was monitored using 17 erosion pin arrays over the 1,170 m reach from April 17, 2014 through May 5, 2015. Bank erosion pin monitoring was combined with cross-sectional surveys to calculate total erosion volume and mass at each array. The length of bank each pin array represents follows the sub-reaches that were identified in an earlier geomorphic assessment conducted at the site.

2. **The study period was drier than normal overall but several low magnitude flood events occurred over the study period suggesting smaller, more frequent floods can cause significant erosion of banks in an urban watershed.** Rainfall during the study period was ≈18 cm lower than the 30 year average. While no large flood event occurred over the study period, 7 events did occur that were near or over the 1-yr flood RI with one exceeding the 1.5-yr flood RI. Discharges near or > than the 1-yr flood RI would be expected to be able to do transport gravel, cause bank saturation-collapse, and create high channel boundary shear stress causing bank erosion along the toe.

3. **Bank erosion estimates suggest the channel is still adjusting to the current hydrological regime, but the spatial distribution of erosion is limited by bedrock confinement.** Over the study period bank erosion supplied between 0.09-1.04 Mg/m/yr of sediment with an average of 0.52 Mg/m/yr from all pin array segments. When taking the length of the segment each pin represents, nearly 57% of the erosion occurs in the middle section of the study reach, 21% occurs in the upper section, and about 22% occurs in the lower section of the study reach. However, lateral migration and widening of the channel at both the upper and lower section of the study reach are limited by bedrock. These results suggest the entire reach is still adjusting to upstream watershed disturbance and/or to flood magnitude and frequency changes due to climatic shifts in rainfall.

4. **STEPL water quality model created for easement area**. Results of the water quality model indicate nearly a 90% reduction in the nutrient and sediment load from the easement area can be achieved if it was all established in forest land cover. Furthermore, the conservation easement prohibits the establishment of more intensive agricultural practices on the property that could increase the nutrient and sediment load in the runoff from the easement area by 3-5 times. However, the overall reduction to the watershed would be minimal.

5. **Bank erosion results applied to the entire upper watershed suggest sediment from bank erosion is a significant source of sediment to the lower Wilson Creek**. Sediment yield estimates were applied to the entire main stem of Wilson Creek from the confluence of Jordan and Fassnight Creek to the confluence of South Creek (9.9 km). Results show that more sediment (125%) comes from bank erosion than leaves the watershed outlet but does not account for all factors of sediment transport in streams, such as sediment pulsing and floodplain deposition. However, it does suggest that bank erosion is a significant source of sediment to Wilson Creek. Additionally, P contributions from bank erosion account for about 15% of the annual load at the watershed outlet. Results of this study indicate that implementation of a conservation easement could significantly reduce sediment contributions to the lower watershed.

6. **Water quality model applied to the entire upper watershed suggest sediment from bank erosion is a significant source of sediment to the lower Wilson Creek**. Conservation easements produce much lower reduction in nutrients and sediment if they are applied to the channel when looking at runoff generated compared to bank erosion. If conservation easements were applied to the entire river and that land was converted into forest, the annual load would translates into a 2.8% reduction in sediment, 0.9% reduction in P, and 0.8% reduction of N at the watershed outlet.

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TABLES

Table 1. USGS Gaging Stations in the Wilson Creek Watershed near Study Site

ID	Name	Period of Record	Drainage Area (km^2)	Annual Mean Q (m^3/s)	10% Exceeds (m^3/s)	50% Exceeds (m^3/s)	90% Exceeds (m^3/s)
07052000	Wilson Creek at Springfield, MO	May 1932 to Nov. 1939; June 28, 1973 to Sept. 22, 1977; June 4, 1998 to present	46.1	0.54	1.05	0.24	0.08
07052100	Wilson Creek near Springfield, MO	Sept. 21, 1972 to Sept. 30, 1982; May 28, 1998 to present	81.3	0.59	1.16	0.11	0.0
07052120	South Creek near Springfield, MO	May 29, 1998 to present	27.2	0.13	0.17	0.0	0.0

Table 2. Flood Recurrence Intervals for USGS Gaging Station 07052100 at FR 156. (from Owen et al. 2012)

Q-RI	Discharge (m^3/s)
1.005-yr	25.4
1.01-yr	28.4
1.05-yr	38.3
1.11-yr	44.9
1.25-yr	54.3
1.5-yr	64.8
2-yr	77.9

Table 3. Erosion Pin Monitoring Results

Pin Array #	Segment Length (m)	Avg. Erosion (m^2)	Sediment Eroded (m^3)	Sediment Eroded (Mg)	P to Stream (kg)	% of Total	Annual Sed. Erosion Per Unit Length (Mg/m/yr)
1	36	0.56	20.2	28.2	10.1	4.8	0.73
2	76	0.07	5.5	7.7	2.8	1.3	0.09
3	61	0.07	4.5	6.3	2.3	1.1	0.10
4	61	0.43	26.4	37.0	13.3	6.3	0.56
5	48	0.42	20.2	28.3	10.2	4.8	0.55
6	58	0.19	11.2	15.6	5.6	2.6	0.25
7	58	0.80	46.2	64.7	23.2	10.9	1.04
8	53	0.72	37.9	53.0	19.0	9.0	0.94
9	30	0.50	14.9	20.8	7.5	3.5	0.64
10	58	0.56	32.4	45.4	16.3	7.7	0.72
11	32	0.56	17.9	25.0	9.0	4.2	0.72
12	121	0.49	59.6	83.4	29.9	14.1	0.64
13	91	0.34	31.1	43.5	15.6	7.4	0.44
14	33	0.07	2.2	3.1	1.1	0.5	0.09
15	89	0.54	47.9	67.1	24.1	11.3	0.70
15.5	235*	0.10	24.2	33.9	12.2	5.7	0.13
16	31	0.66	20.5	28.8	10.3	4.9	0.86
Total	**1,170**		**422.8**	**591.9**	**212.5**		
Total/yr			**402.7**	**563.8**	**202.4**		

Table 4. Description of Soils in Easement Area

Soil Description	HSG	Area (ha)
<u>East</u>		
Goss-Gasconade Complex, 3 to50 percent slopes	C	0.3
Cedargap silt loam, 0 to 3 percent slopes, frequently flooded	B	3.7
Total		4.0
<u>West</u>		
Dapue silt loam, 0 to 3 percent slopes, occasionally flooded	B	0.6
Goss-Gasconade Complex, 3 to50 percent slopes	C	2.5
Cedargap silt loam, 0 to 3 percent slopes, frequently flooded	B	2.7
Total		5.8

Table 5. STEPL Modeling Results

Scenarios	Group	Land Use (Condition)	CN	TP (kg/yr)	TN (kg/yr)	TSS (Mg/yr)
Existing Conditions	East	91.6% Pasture/8.4% Woods	69.1	7.4	44.5	8.2
	West	56.9% Pasture/43.1% Woods	69.4	7.1	40.9	7.3
All Woods	East	100% Woods	56.2	1.0	2.1	0.6
	West	100% Woods	61.5	1.5	3.3	0.9
Pasture/ Row Crops	East	91.6% Row Crops/8.4% Pasture	78.1	31.3	119.2	41.4
	West	56.9% Row Crops/43.1% Pasture	78.4	31.8	137.9	39.7
Residential/ Commercial	East	8.4% Residential/91.6% Commercial	91.2	4.9	45.7	1.7
	West	56.9% Residential/43.1% Commercial	88.1	7.8	57.2	2.4

Table 6. Annual Nutrient and Sediment Loads

Station	Ad (km^2)	TSS Load (Mg)	TN Load (Mg)	TP Load (Mg)
Scenic	46.1	1,391	32.0	3.0
SH FF	27.2	747	8.9	3.5
Total	73.3	2,138	40.9	6.5
Yield		29.2 Mg/km^2/yr	0.56 Mg/km^2/yr	0.09 Mg/km^2/yr
Outlet	130.4	3,808	73.0	11.7

Table 7. Estimated Reductions in Sediment and P from Bank Erosion

	TSS	TP
Annual Load Outlet (Mg)	3,808	11.7
Load per Unit Length (Mg/km/yr)	482	0.173
Total from Bank Erosion (Mg/yr)	4,770	1.71
% at Outlet	125	14.6
Load reduction at 25% BMP efficiency (Mg/yr)	1,193	0.43
Reduction at Outlet	31.3	3.66
Load reduction at 50% BMP efficiency (Mg/yr)	2,385	0.86
Reduction at Outlet	62.6	7.32

Table 8. Estimated Reductions in Sediment and P from Runoff

	TSS	TN	TP
Annual Load At Outlet (Mg/yr)	3,808	73.0	11.7
Existing Conditions			
Load per Unit Length (Mg/km/yr)	13.3	0.074	0.013
Total from Easements (Mg/yr)	131.7	0.73	0.13
% at Outlet	3.5	1.0	1.1
Forest			
Load per Unit Length (Mg/km/yr)	1.3	0.005	0.002
Total from Easements (Mg/yr)	25.7	0.1	0.04
% at Outlet	0.7	0.1	0.3
% Reduction at Outlet	2.8	0.9	0.8

FIGURES

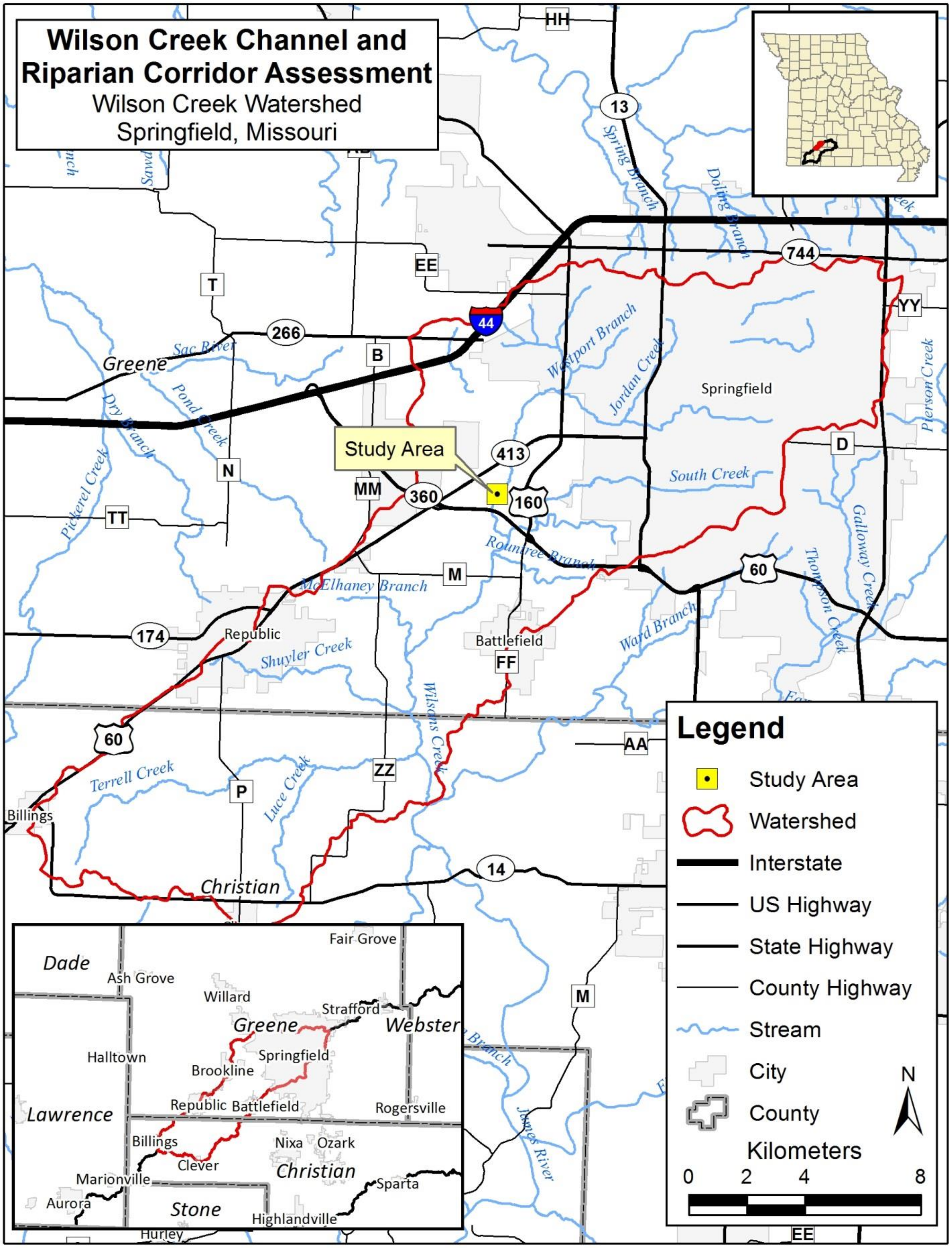


Figure 1. James River Basin.

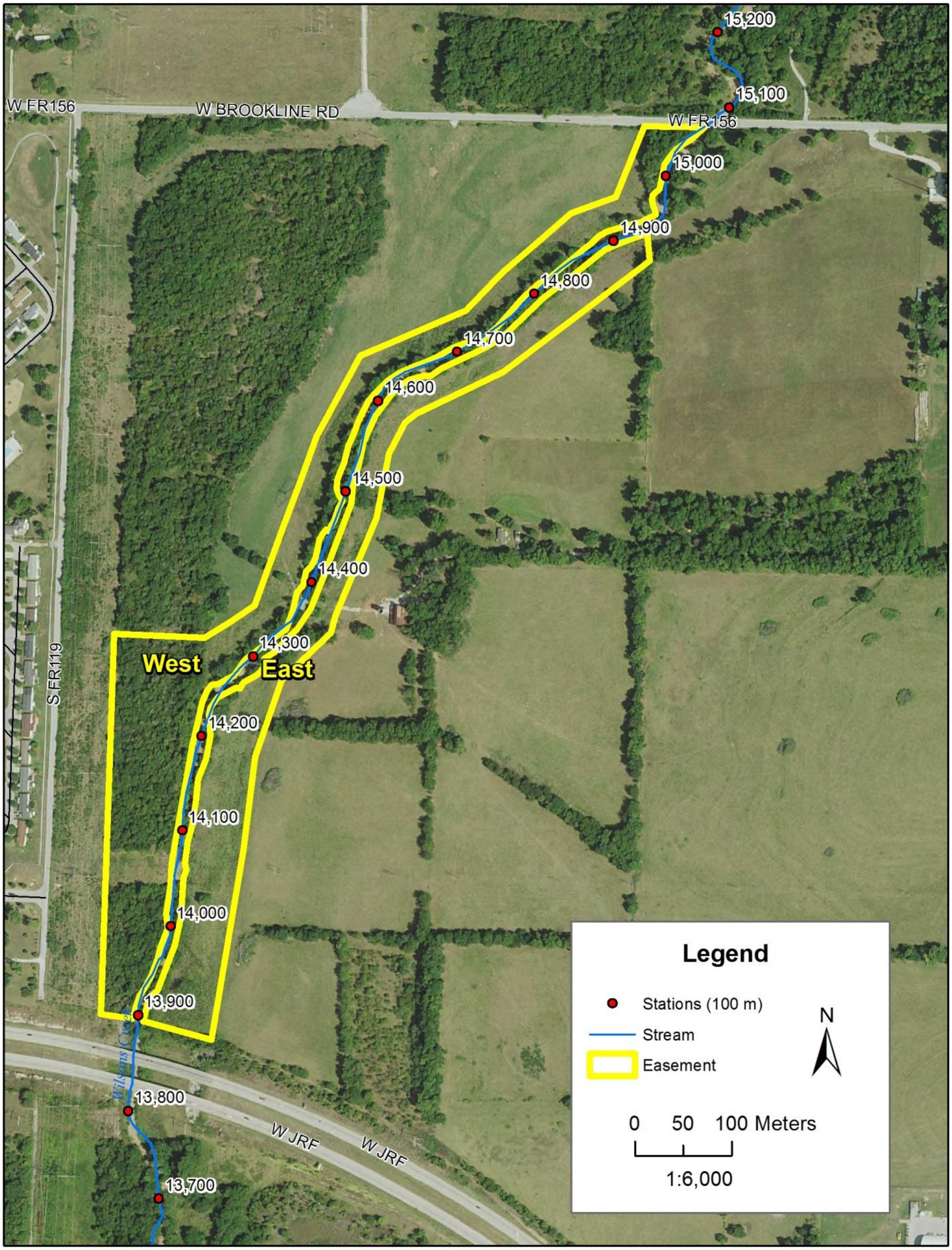


Figure 2. Study area map showing east (4.0 ha) and west (5.8 ha) easement areas.

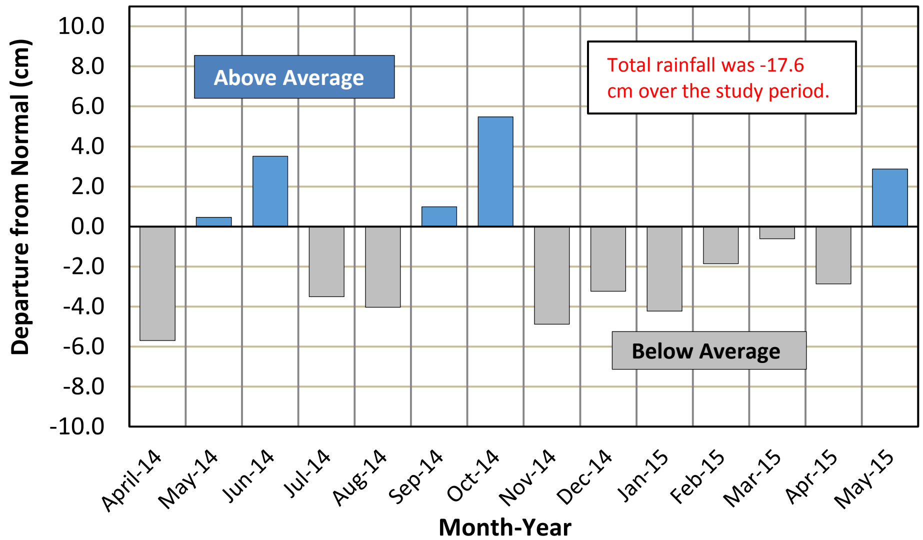


Figure 3. Monthly rainfall departure from normal over study period.

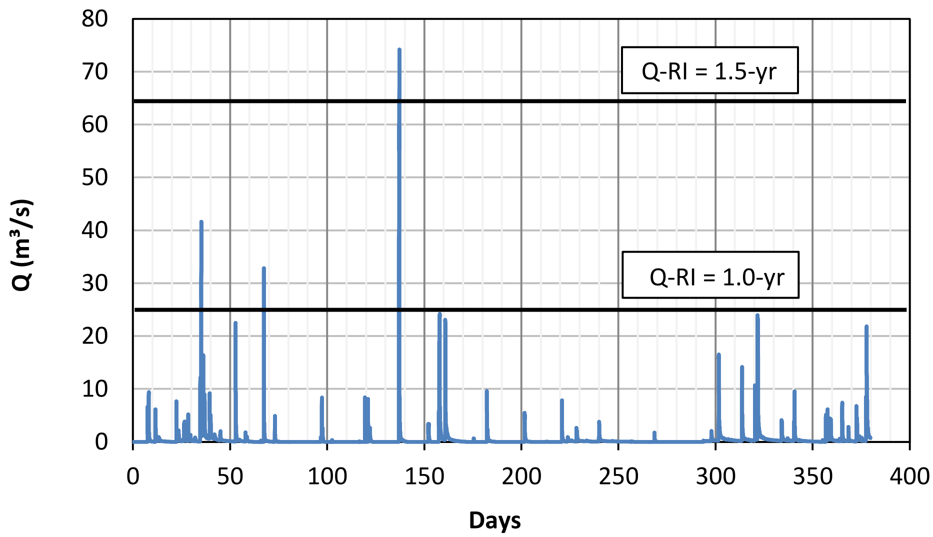


Figure 4. Discharge at USGS station #07052100 at FR 156 over the study period.

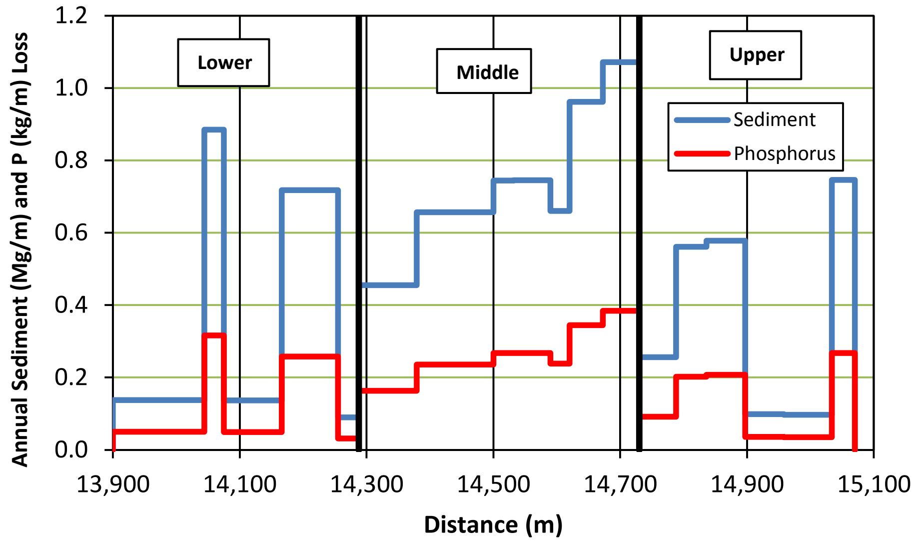


Figure 5. Annual per unit length sediment and P loss from bank erosion in study reach.

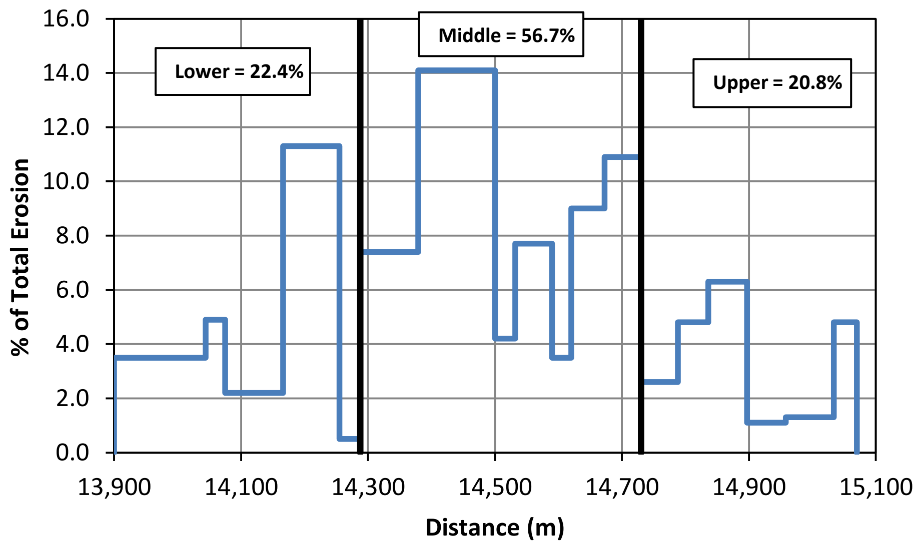


Figure 6. Percent of total erosion for the study reach.

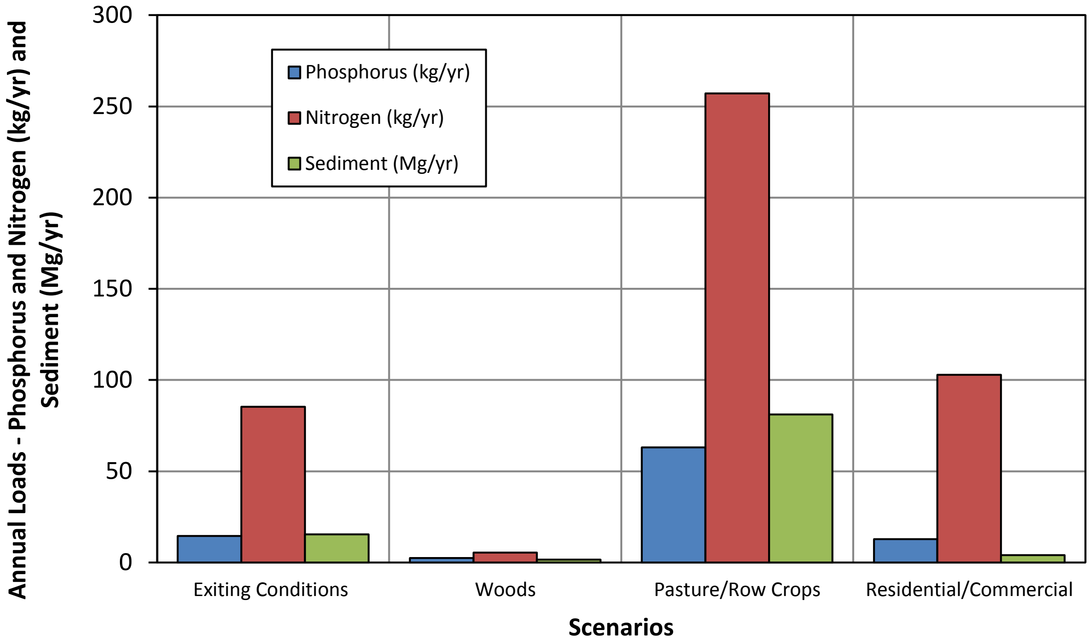
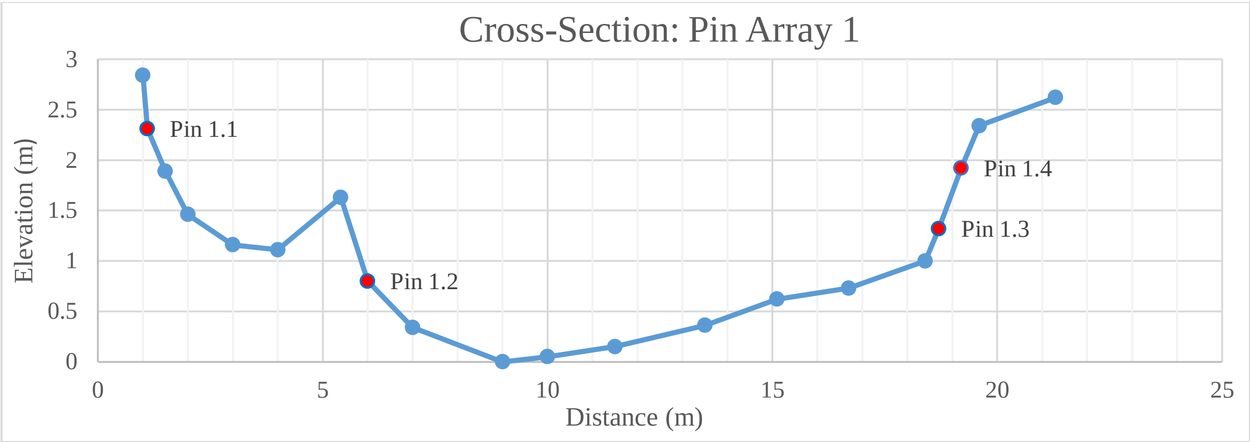


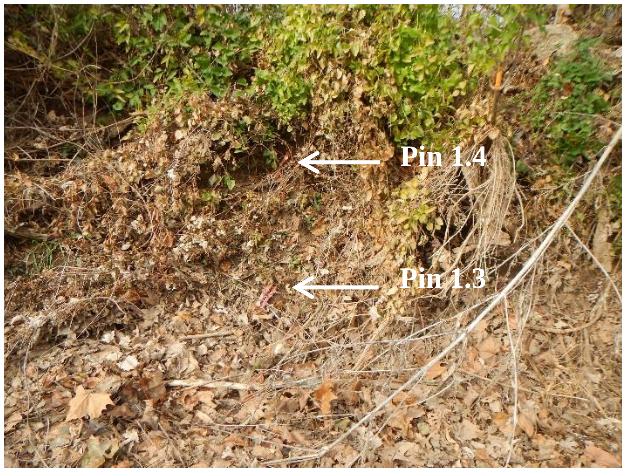
Figure 7. Annual nutrient and sediment loads from easement area from STEPL model.

APPENDIX



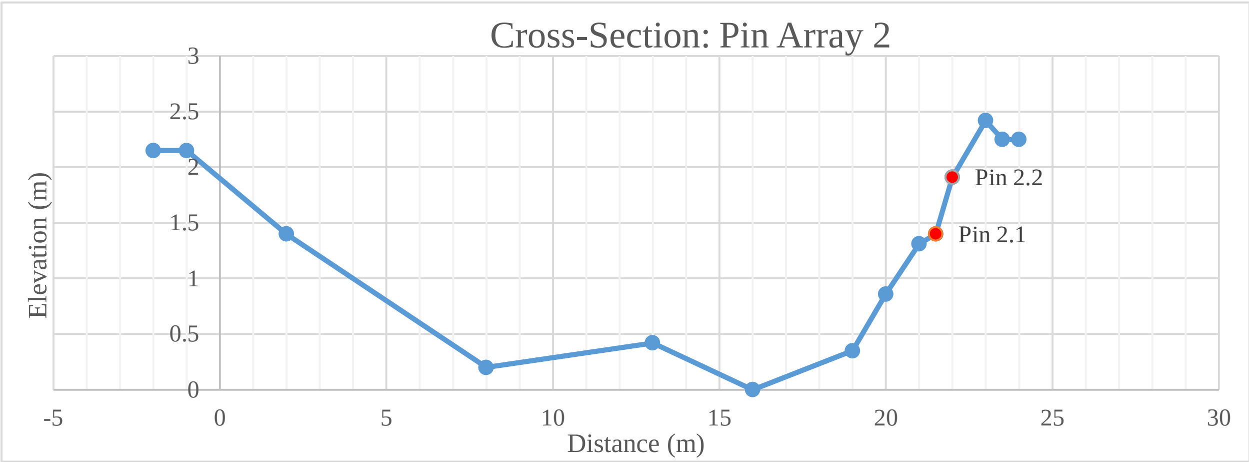
Left Bank

Right Bank

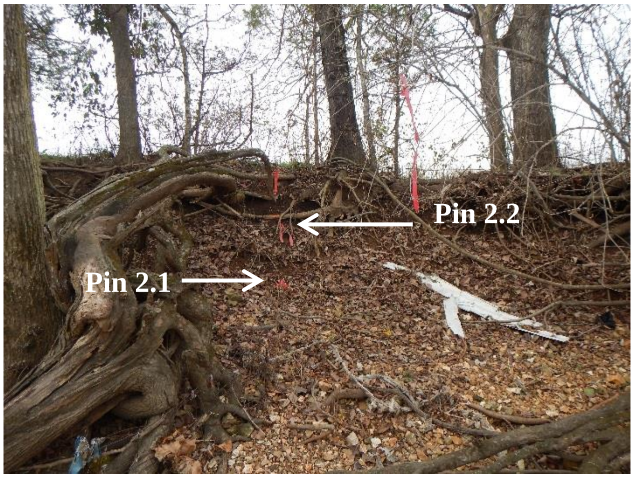


Pin Array 1. Erosion measurements by date.

Pin #	**6/20/2014**	**9/4/2014**	**10/8/2014**	**11/10/2014**	**12/3/2014**	**1/16/2015**	**2/25/2015**	**5/5/2015**	**Total Erosion (cm)**
1.1	0	10	11.5	0	0	0	0	0	21.5
1.2	6	0	1.8	0.2	1	4	2.5	4	19.5
1.3	2	0	0.6	7	0.2	0.5	0	0	10.3
1.4	2	0	0	0	0	0	0.5	0	2.5

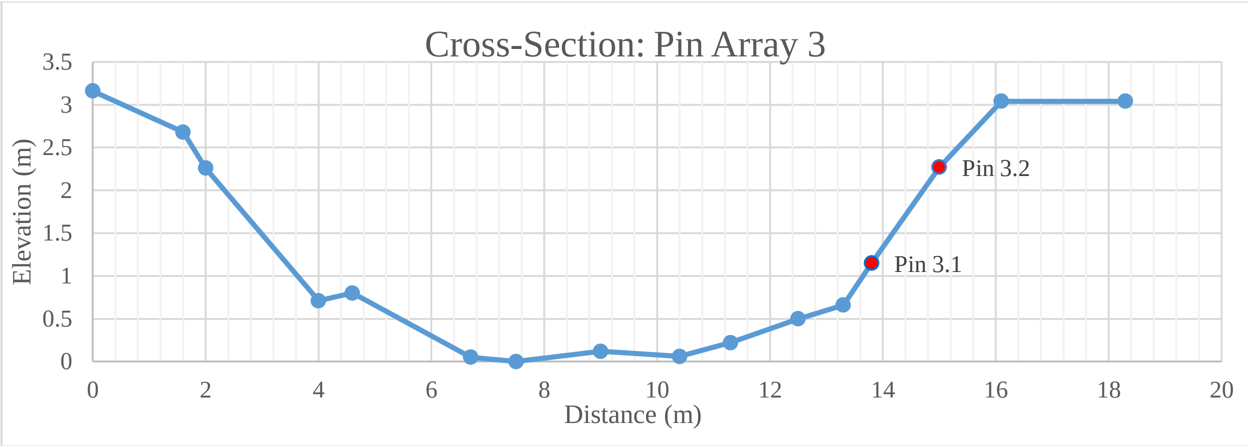


Right Bank

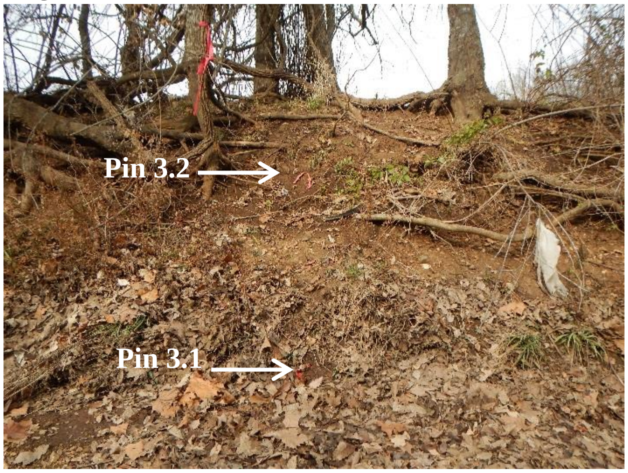


Pin Array 2. Erosion measurements by date.

Pin #	**6/20/2014**	**9/4/2014**	**10/8/2014**	**11/11/2014**	**12/3/2014**	**1/16/2015**	**2/25/2015**	**5/5/2015**	**Total Erosion (cm)**
2.1	0.1	2	0	1.5	0.5	0	0	0	4.1
2.2	0	0	1.6	1.2	0	0	0	2.5	5.3

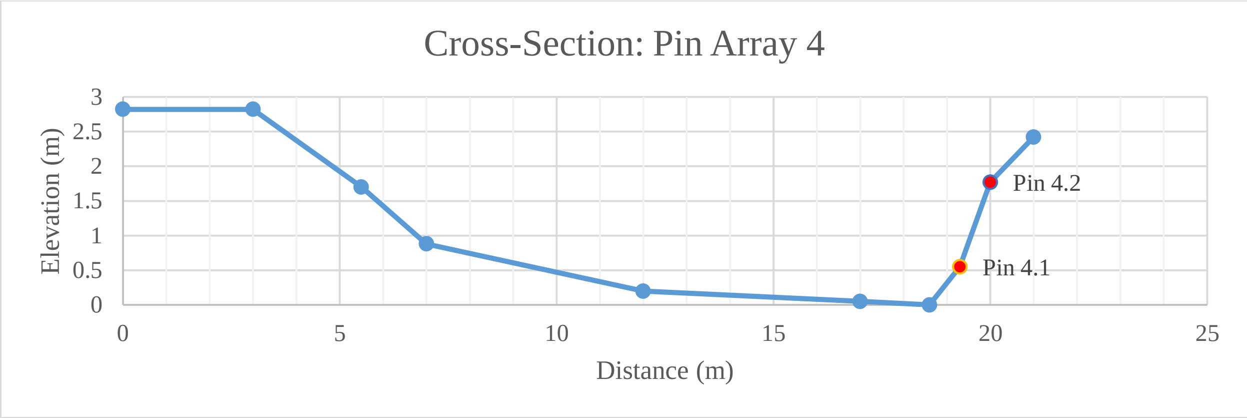


Right Bank

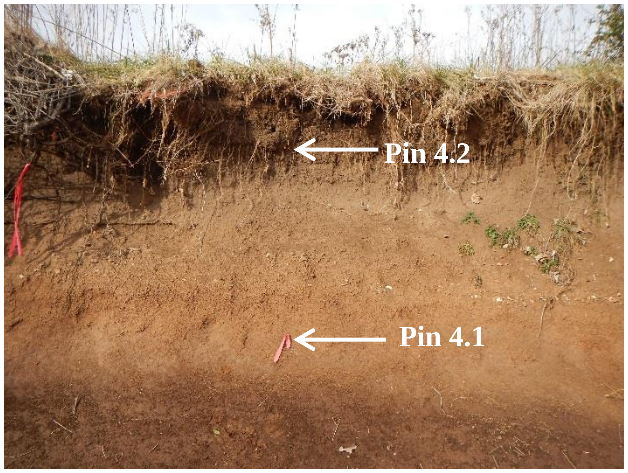


Pin Array 3. Erosion measurements by data.

Pin #	**6/20/2014**	**9/4/2014**	**10/8/2014**	**11/10/2014**	**12/3/2014**	**1/16/2015**	**2/25/2015**	**5/5/2015**	**Total Erosion (cm)**
3.1	0	0	0	0.2	0.5	0	0.5	0	1.2
3.2	2	0	1.7	0.9	0	0	0	0	4.6

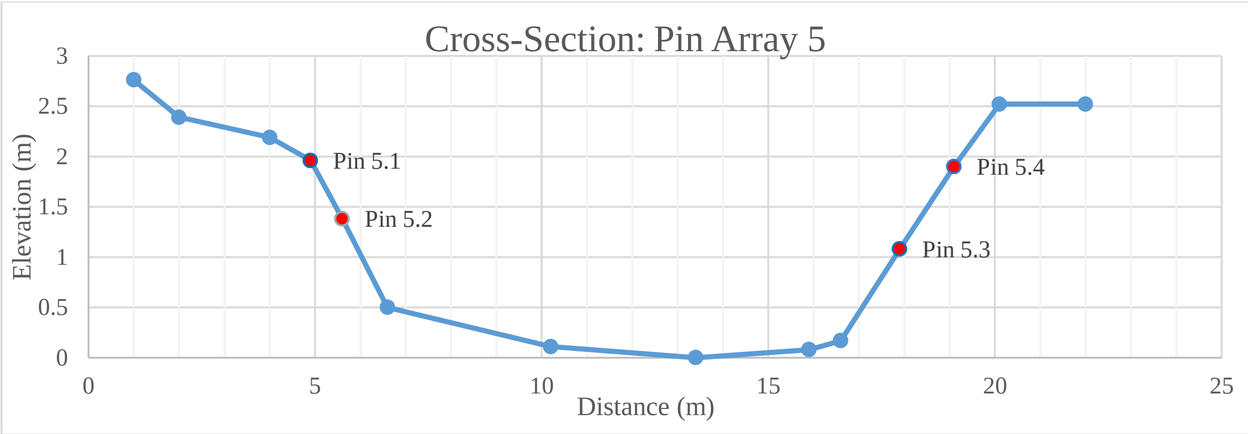


Right Bank

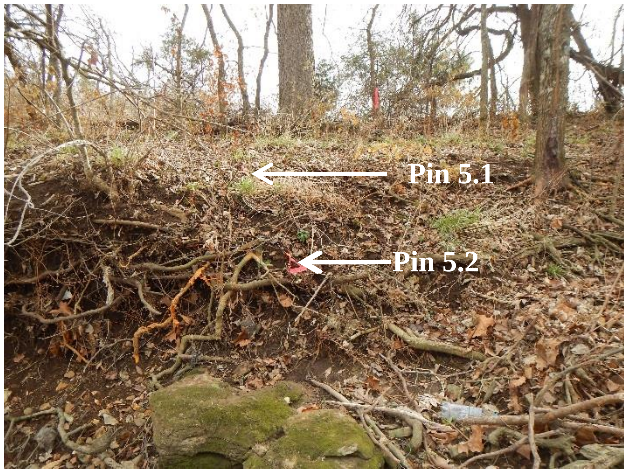


Pin Array 4. Erosion measurements by date.

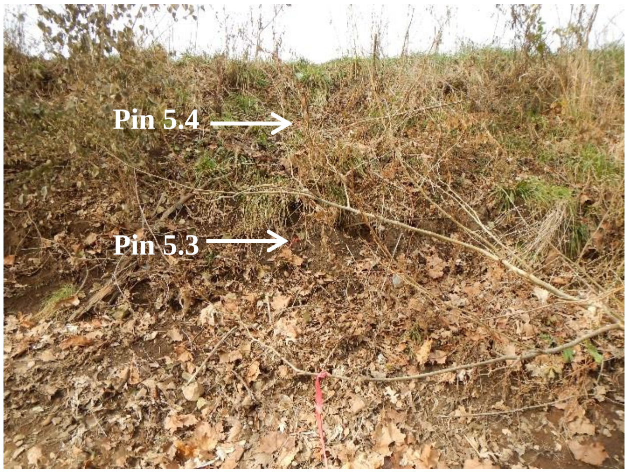
Pin #	**6/20/2014**	**9/4/2014**	**10/8/2014**	**11/10/2014**	**12/3/2014**	**1/16/2015**	**2/25/2015**	**5/5/2015**	**Total Erosion (cm)**
4.1	0.5	2.5	4.7	7.8	0	0	0	0	15.5
4.2	1	0.5	3.1	0.1	0.3	0	11	0	16



Left Bank

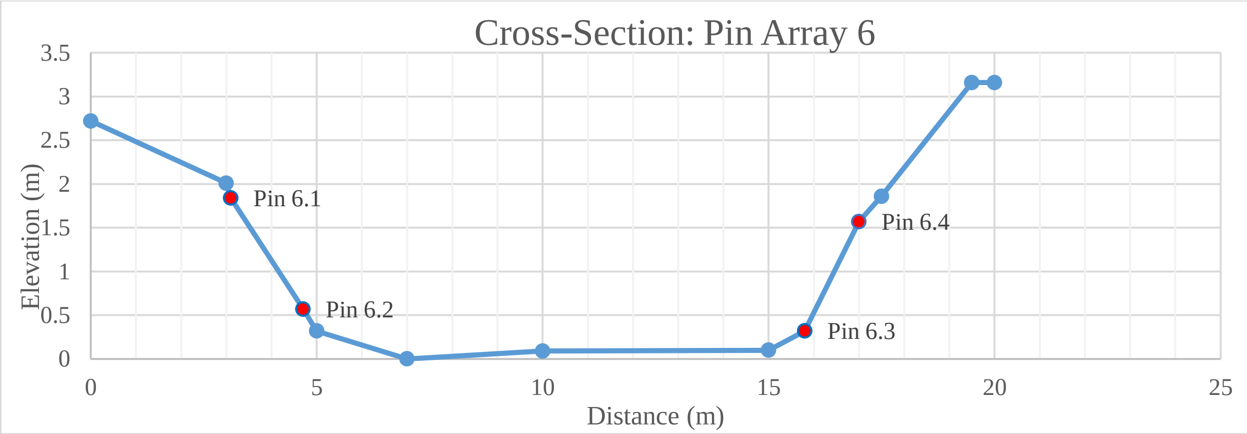


Right Bank



Pin Array 5. Erosion measurements by date.

Pin #	6/20/2014	9/4/2014	10/8/2014	11/10/2014	12/3/2014	1/16/2015	2/25/2015	5/5/2015	Total Erosion (cm)
5.1	1	0	0	5	0	0	0	0	6
5.2	1	0	1.5	0.5	3	0	0	0	6
5.3	11	3	4	0	0	0	0	0	18
5.4	0	0	3	0.8	0.2	0	0	4	8



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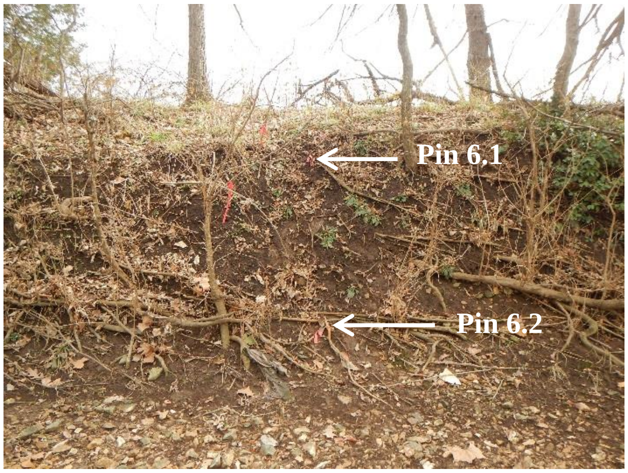

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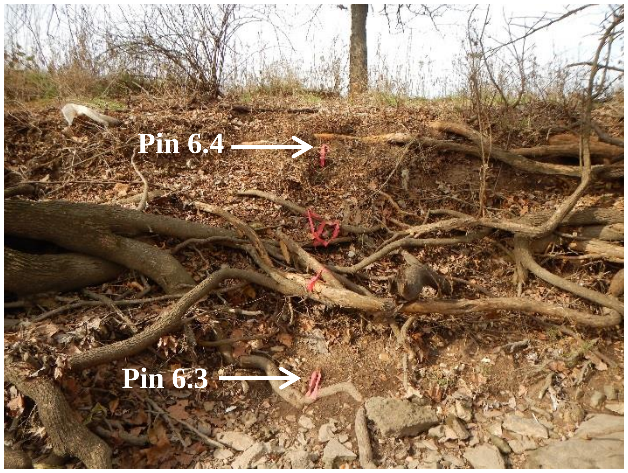
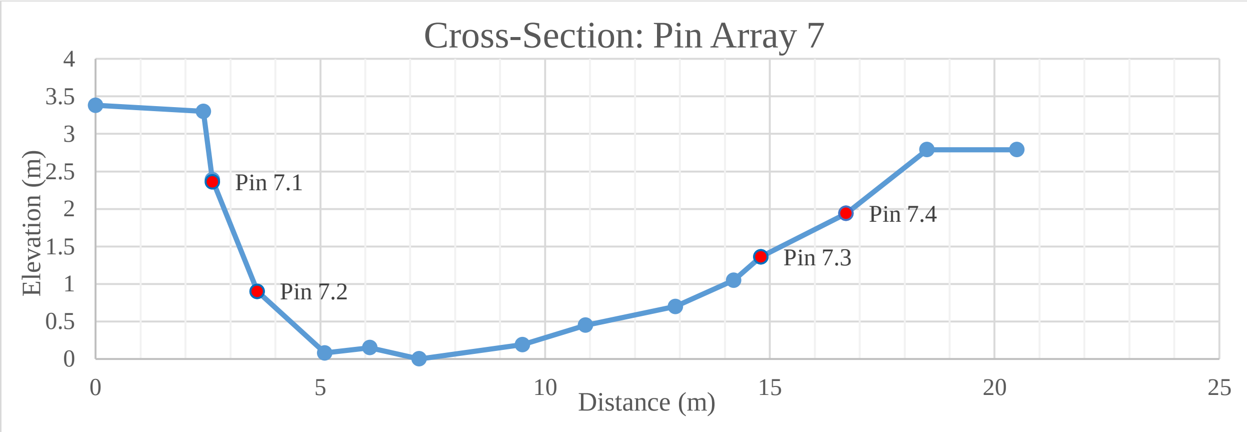


Pin Array 6. Erosion measurements by date.

Pin #	6/20/2014	9/4/2014	10/8/2014	11/10/2014	12/3/2014	1/16/2015	2/25/2015	5/5/2015	Total Erosion (cm)
6.1	0	0	1.4	0.2	0	0	0	0	1.6
6.2	1	0	1.2	0.8	0	0	0	1.5	4.5
6.3	0	0	0	6	3.5	0	0	0	9.5
6.4	1	0	1.2	0.1	0.7	0	0	0	3



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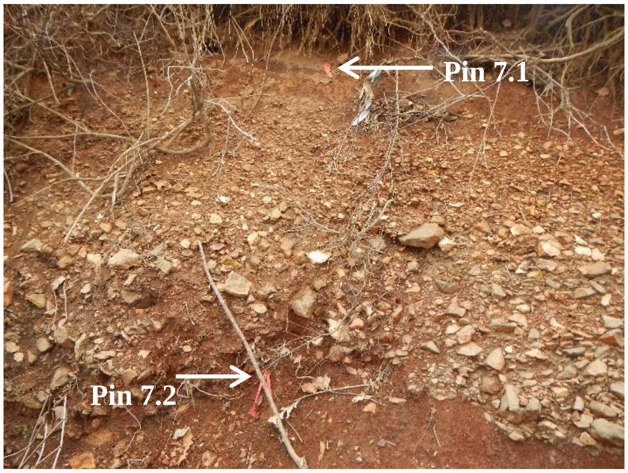

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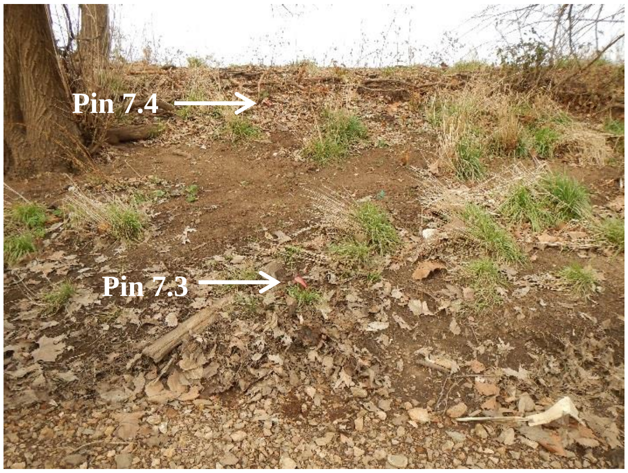
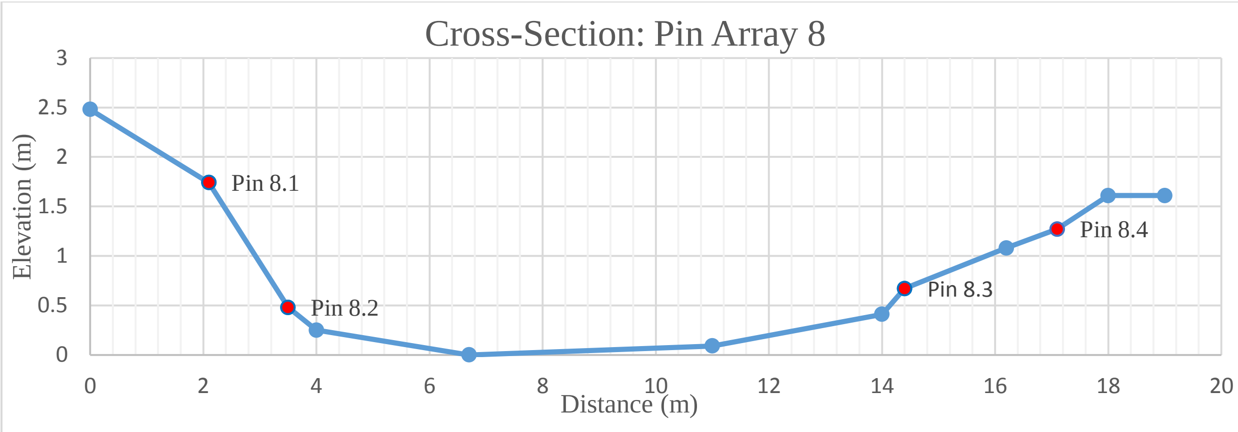


Pin Array 7. Erosion measurements by date.

Pin #	6/20/2014	9/4/2014	10/8/2014	11/10/2014	12/3/2014	1/16/2015	2/25/2015	5/5/2015	Total Erosion (cm)
7.1	13	0	0	8	0	0	1	6	28
7.2	2	7	2.2	1.8	1	0	0	0	14
7.3	1	0	2.1	0.6	0	0	0.5	0	4.2
7.4	2	0	0	2.4	0	0	0	2.5	6.9



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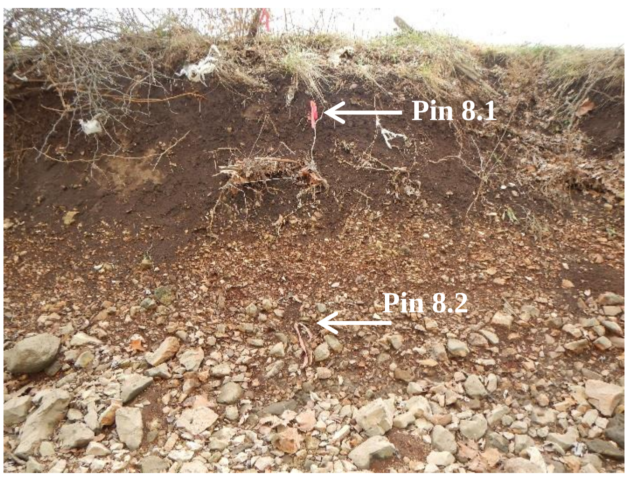

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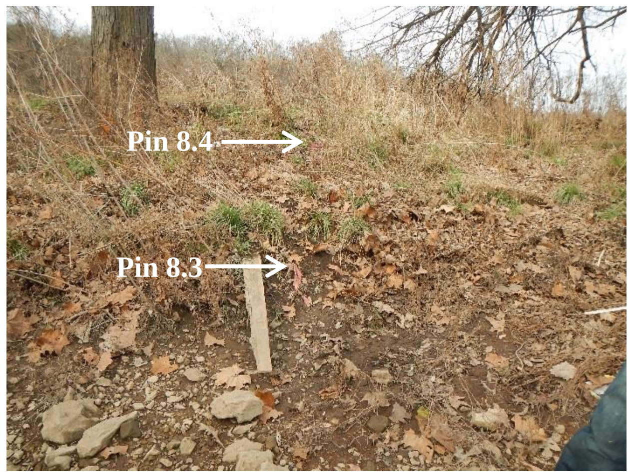
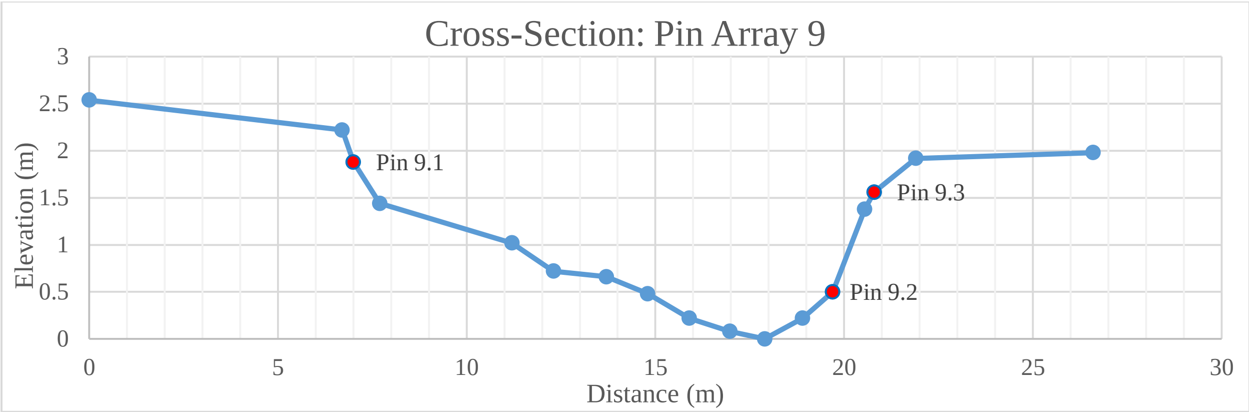


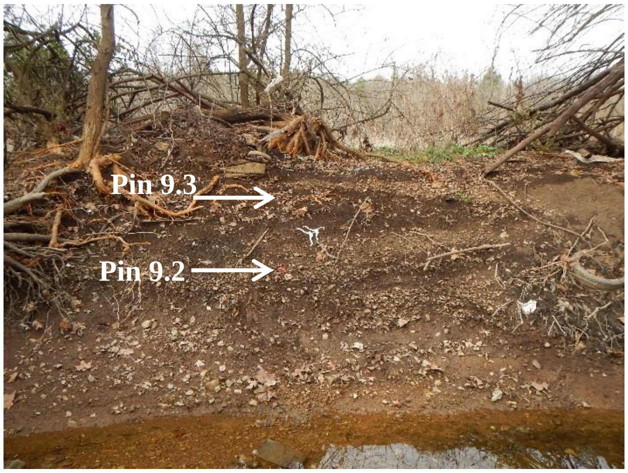
Pin Array 8. Erosion measurements by date.

Pin #	6/20/2014	9/4/2014	10/8/2014	11/10/2014	12/3/2014	1/16/2015	2/25/2015	5/5/2015	Total Erosion (cm)
8.1	22	0	1.5	0	0	0	0	16	39.5
8.2	4	0	0	5.5	0	0	0	0	9.5
8.3	0	2	0	3	0	0	0.5	1	6.5
8.4	0	0	4.5	0	5.2	0	0	0	9.7



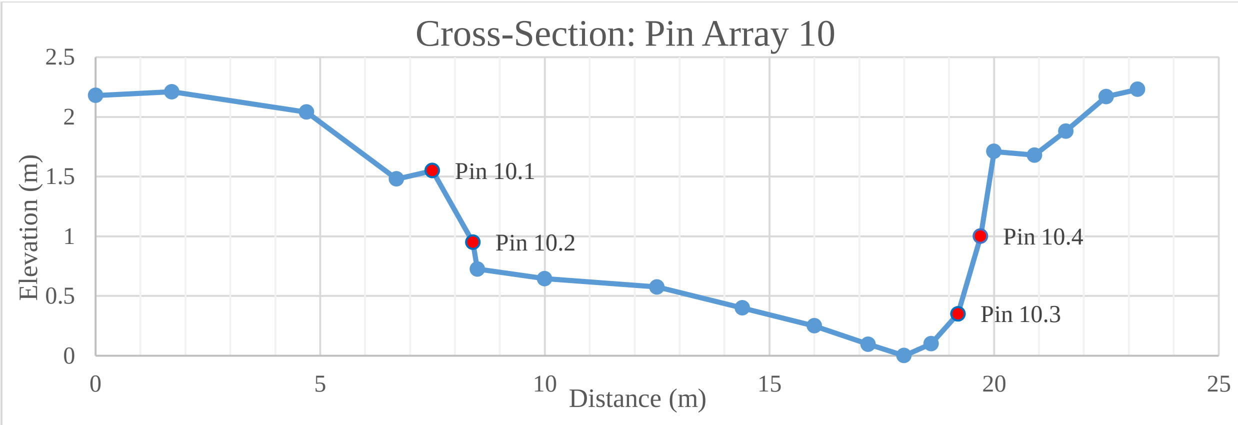
Left Bank

Right Bank



Pin Array 9. Erosion measurements by date.

Pin #	6/20/2014	9/4/2014	10/8/2014	11/10/2014	12/3/2014	1/16/2015	2/25/2015	5/5/2015	Total Erosion (cm)
9.1	5	0	1.6	0	0.2	0	0	2.5	9.3
9.2	4	2	3	1.3	0	0	2	12	24.3
9.3	8	0	3	1	0	3	0	4.5	19.5



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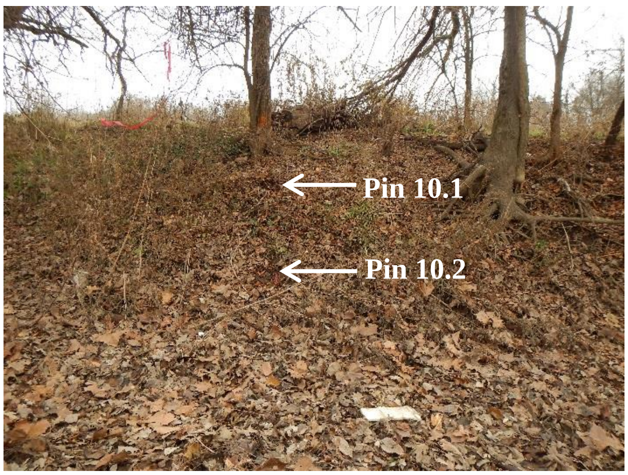

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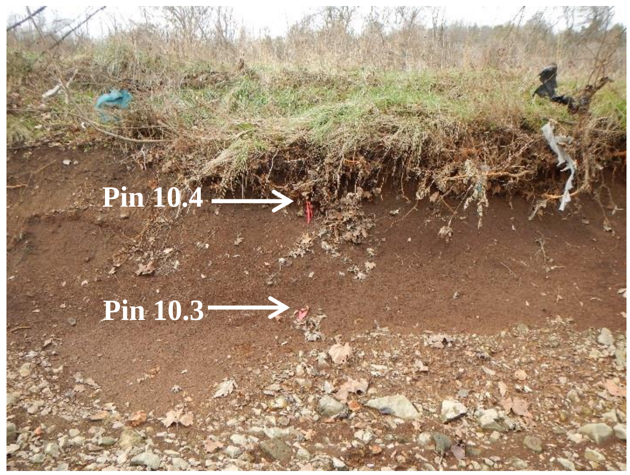
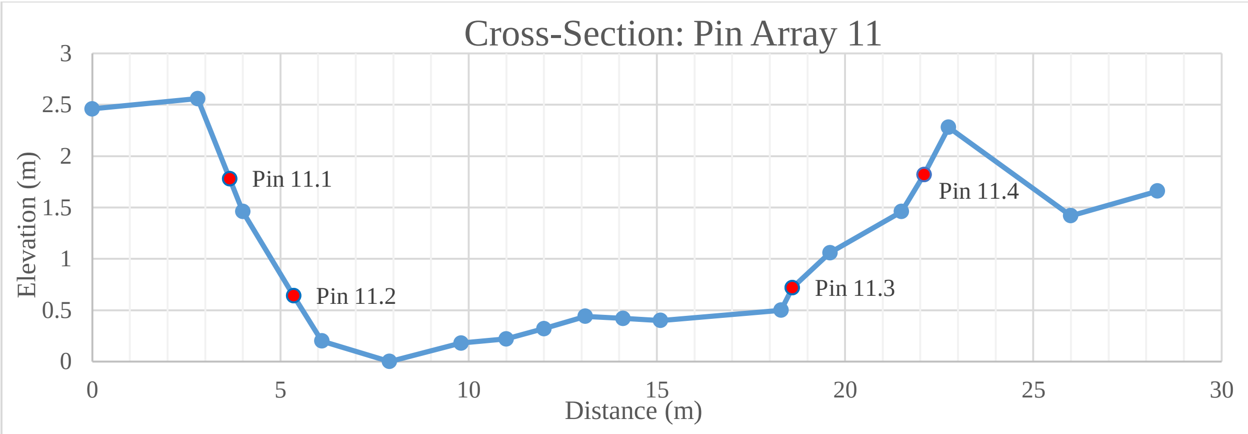


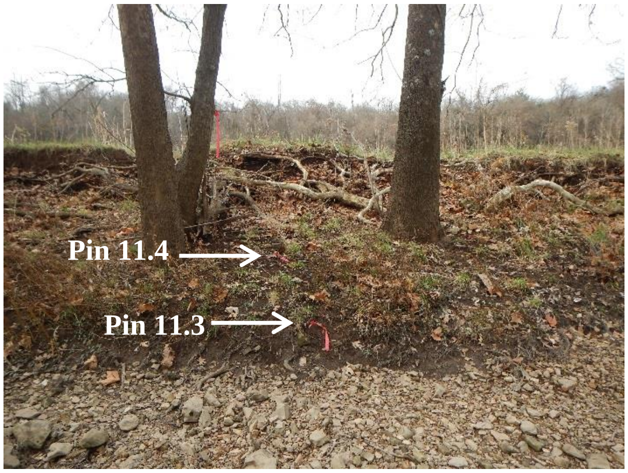
Pin Array 10. Erosion measurements by date.

Pin #	6/20/2014	9/4/2014	10/8/2014	11/10/2014	12/3/2014	1/16/2015	2/25/2015	5/5/2015	Total Erosion (cm)
10.1	0	0	2	0.8	0	0	1	2.5	6.3
10.2	7	0	0	8	0	0	0	0	15
10.3	0	4	3	0	0.3	0.7	4	7	19
10.4	5	9	1	2.3	0	0	2	10	29.3



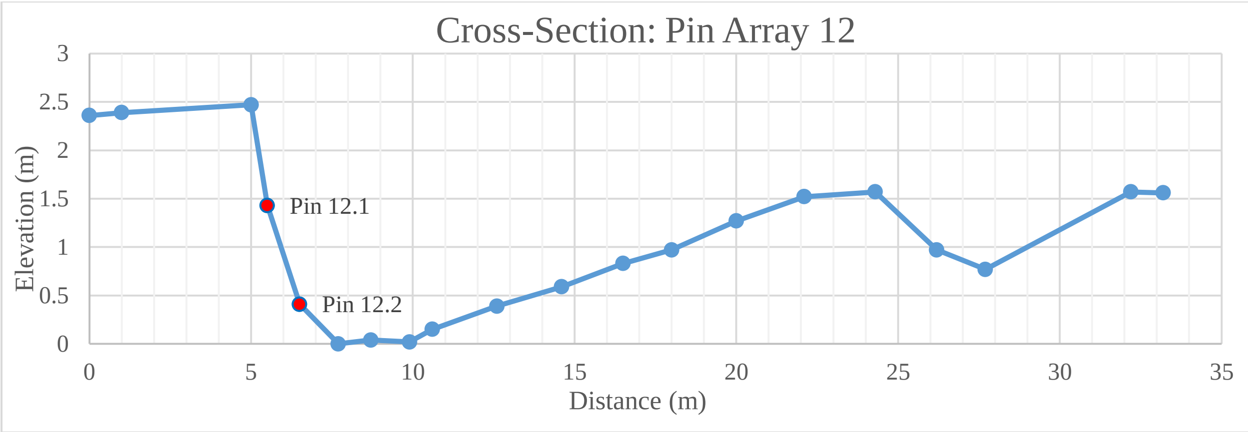
Left Bank

Right Bank

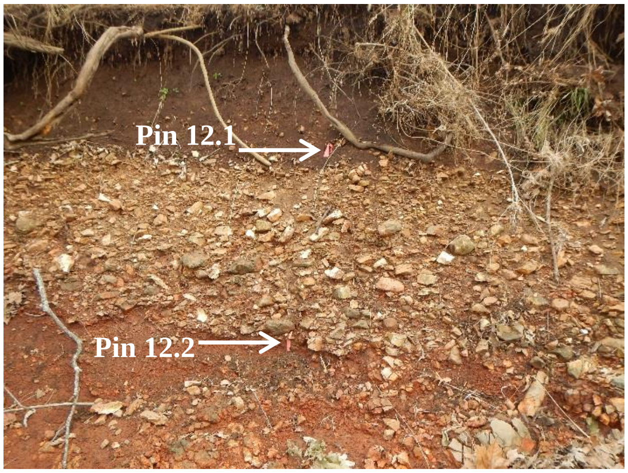


Pin Array 11. Erosion measurements by date.

Pin #	**6/20/2014**	**9/4/2014**	**10/8/2014**	**11/10/2014**	**12/3/2014**	**1/16/2015**	**2/25/2015**	**5/5/2015**	**Total Erosion (cm)**
11.1	0	17	0	3	0	0	0	1.13	21.13
11.2	4	0	0	0	0	0	3	3	10
11.3	5	0	1.7	0.5	0	0.3	0	1	8.5
11.4	3	0	3.3	0.8	0	0	0	3.5	10.6

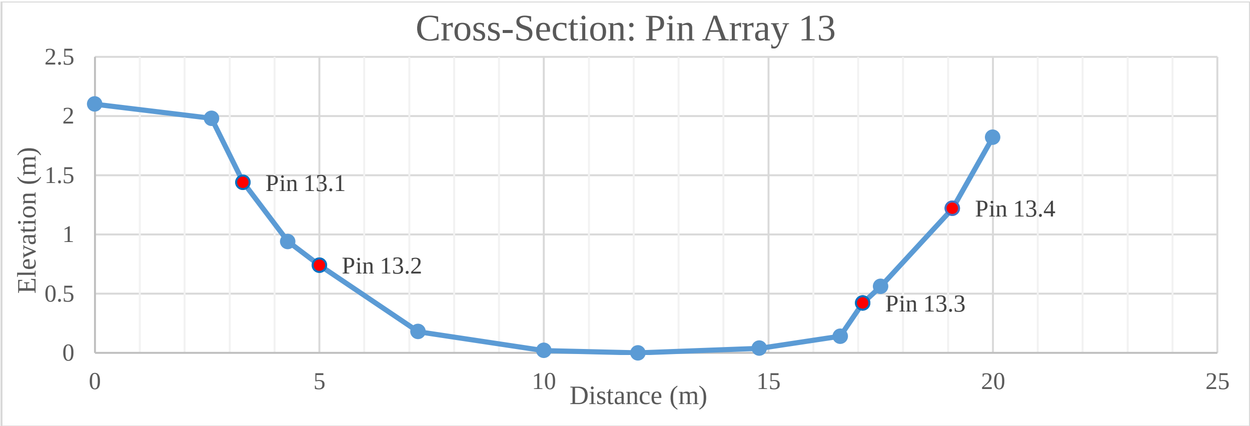


Left Bank



Pin Array 12. Erosion measurements by date.

Pin #	6/20/2014	9/4/2014	10/8/2014	11/10/2014	12/3/2014	1/16/2015	2/25/2015	5/5/2015	Total Erosion (cm)
12.1	9	0	3.5	0.5	0	0	0	6	19
12.2	7	4	5	0	0	0	0	5.5	21.5



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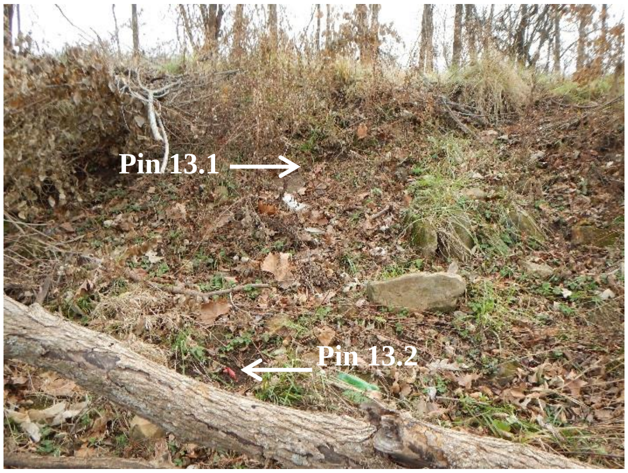
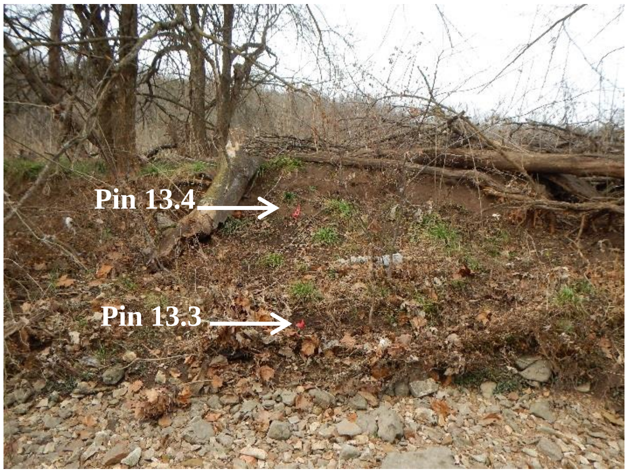
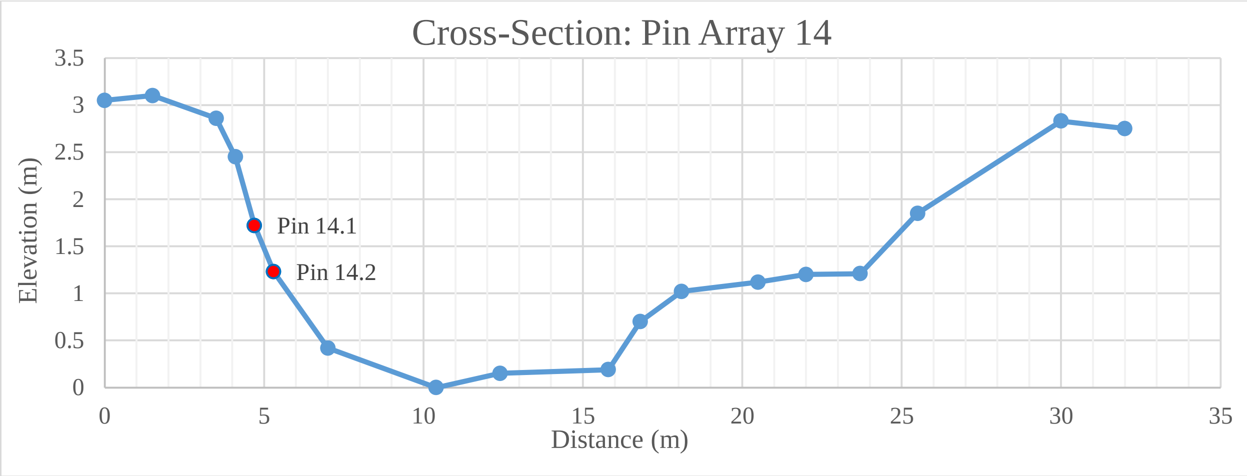


Right Bank

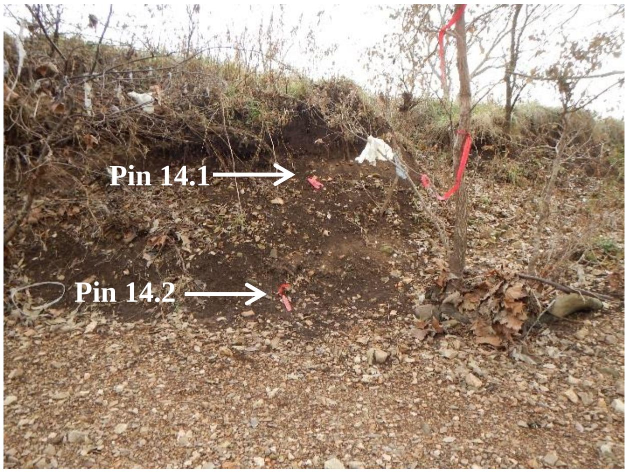


Pin Array 13. Erosion measurements by date.

Pin #	6/20/2014	9/4/2014	10/8/2014	11/10/2014	12/3/2014	1/16/2015	2/25/2015	5/5/2015	Total Erosion (cm)
13.1	2	0	0	4.5	0	0	0	0	6.5
13.2	4	0	0	3	2	0	0	0	9
13.3	4	0	1	0	5	3	0	2	15
13.4	3	0	0	5.5	0	0	0	1.5	10

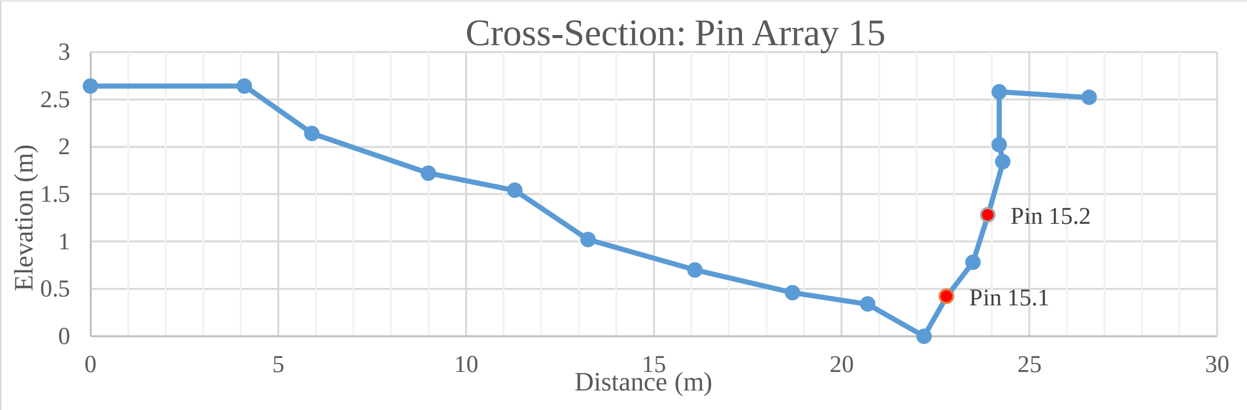


Left Bank

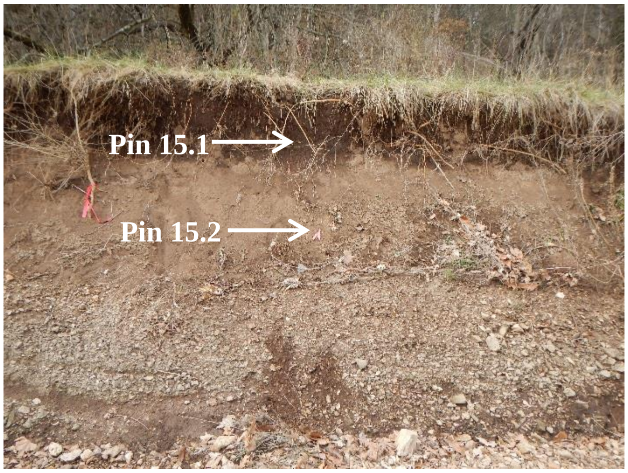


Pin Array 14. Erosion measurements by date.

Pin #	7/17/2014	9/4/2014	10/8/2014	11/10/2014	12/3/2014	1/16/2015	2/25/2015	5/5/2015	Total Erosion (cm)
14.1	0	0	0.5	2.2	0	0.5	0	0	3.2
14.2	0	0	0	0.5	0.5	0.5	0	0	1.5

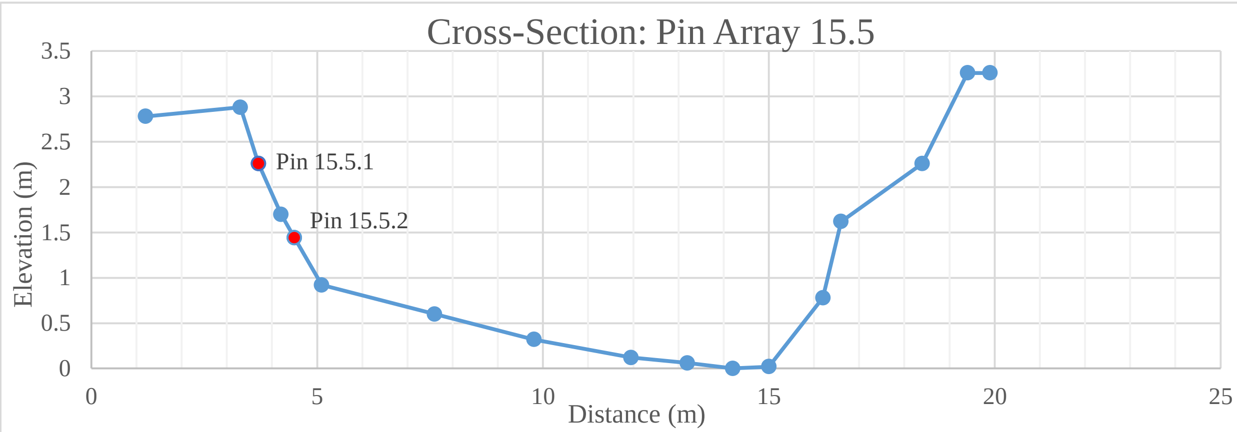


Right Bank



Pin Array 15. Erosion measurements by date.

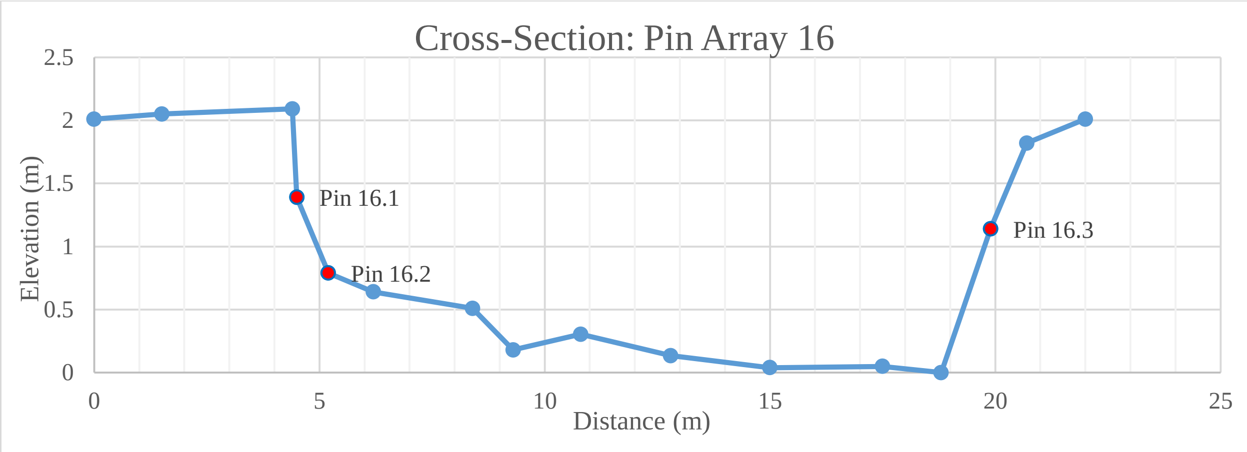
Pin #	6/20/2014	7/16/2014	9/4/2014	10/8/2014	11/10/2014	12/3/2014	1/16/2015	2/25/2015	5/5/2015	Erosion (cm)
15.1	5	10	0	0	1.4	0	0	3.5	5	24.9
15.2	1	1	0	2	5.1	0	2.8	5	2	18.9



Left Bank

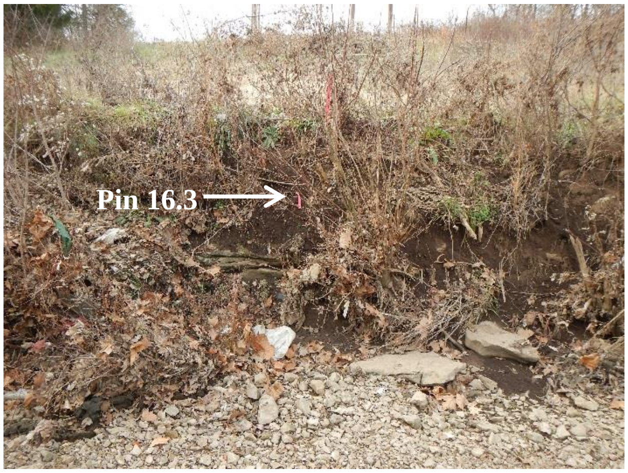
Pin Array 15.5. Erosion measurements by date.

Pin #	**6/20/2014**	**9/4/2014**	**10/8/2014**	**11/10/2014**	**12/3/2014**	**1/16/2015**	**2/25/2015**	**5/5/2015**	**Total Erosion (cm)**
15.5.1	2	0	3	0.5	0	0	0	0	5.5
15.5.2	0	0	1	0	0	0	0	4	5



Left Bank

Right Bank



Pin Array 16. Erosion measurements by date.

Pin #	**6/20/2014**	**9/4/2014**	**10/8/2014**	**11/10/2014**	**12/3/2014**	**1/16/2015**	**2/25/2015**	**5/5/2015**	**Total Erosion (cm)**
16.1	24	0	1	0.5	0	4	0	0	29.5
16.2	0	0	2.2	1	0	0	13	4	20.2