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

FINAL REPORT

# Nonpoint Source Bank Erosion and Water Quality Assessment, James River at River Bluff Farm, Stone County, Missouri

*Field work completed May 2012- May 2013*

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## SCOPE AND OBJECTIVES

The James River Basin Partnership (JRBP) is working with a landowner to implement a conservation easement along the west bank of the James River in Stone County. 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. The Ozarks Environmental and Water Resources Institute (OEWRI) will complete a bank erosion and nonpoint modeling study to determine the annual bank erosion rates and related sediment and nutrient loadings to the James River for the 6 km (3.7 mi) long easement segment. Sediment released to the channel by erosion can supply excess nutrients to river and cause sedimentation problems downstream. Portions of the James River are listed on the 303 D list of impaired waters for nutrients, and phosphorus (P) has been identified as the limiting factoring in eutrophic conditions in the basin (MDNR, 2001).

Riparian easements remove the potential for future development or other disturbances that can increase runoff and nonpoint loads to the river. OEWRI will also evaluate the effectiveness of the 200 m long bank restoration project to stabilize an eroding bank and reduce nonpoint inputs. The purpose of this assessment is to evaluate the effects of the riparian easement implementation and bank restoration on long-term sediment and nutrient loads in the James River to support 319 requirements and the goals of the James River TMDL. The objectives of the assessment are:

(1) Complete a field survey of the channel and adjacent riparian areas to determine the size and shape of the channel, substrate characteristics, and bank conditions to support nonpoint load reduction procedures;

(2) Monitor short-term (1 year) bank erosion rates using repeat surveys of cross-section changes and erosion pin measurements at 11 transects within the project reach and focused on the bank restoration area;

(3) Determine historical (70 years) bank erosion rates using differences in channel and bank locations derived from aerial photographs from the 1950s and present. A GIS –based framework will be used to map channel locations and determine bank erosion rates;

(4) Determine the nutrient and metal concentrations in 30 soil samples collected from the eroding banks to calculate nonpoint loads to the channel due to bank erosion; and

(5) Calculate load reductions due to different scenarios based on (i) land use management and (ii) expected geomorphic adjustments of the channel bed and banks using sediment budgeting approaches and the nonpoint model STEPL (Spreadsheet Tool for Estimating Pollutant Load).

Subwatersheds for nonpoint modeling will include the contributing drainage areas to the west of the James River that include easement land areas and the tributary streams draining them.

## SITE DESCRIPTION

The James River Basin (3,768 $km^2$) drains portions of Webster, Greene, Lawrence, Christian, Douglas, Taney, Stone, and Barry counties in southwest Missouri (MEC 2007; Figure 1). Land use within the basin ranges from pasture/grassland in the upper basin, to urban/suburban in the middle portions of the basin, to mostly forest in the lower basin (MEC 2007). The study site is located in the Lower James River Basin approximately 23 km (14.3 mi) upstream of Galena in Stone County. The 7.6 km (4.7 mi) study reach begins at McCall Bridge near Ponce De Leon and extends downstream covering the entire 6 km length of the easement. The property where the easement was established is known as the River Bluff Farm that is located along the west bank of the river (Figure 2). The riparian easement contains extends 60-150 m (200-500 ft) from the center of the channel covering floodplain and bluff along the river and continues up the tributary valleys ranging from 30-60 m (100-200 ft) wide for a total of 87.8 ha (216.9 ac). Additionally, live willows were staked along ≈100 m of bank to help stabilize the bank and reduce erosion.

The underlying geology of the site is limestone and shale of Mississippian age in the uplands and along hillslopes with Ordovician age dolomite in the main and tributary valleys (Middendorf 2003). Upland and hillslope soils consist of gravelly colluvium over highly weathered residuum that can contain up to 80% chert fragments in the lower units (Gregg 2004). Small tributary valleys contain alluvial deposits composed of stratified layers of chert gravel and silty alluvium. Main valley bottomlands have relatively deep accumulations of silty alluvium over coarse gravel. Limestone bluffs are common where the river meets the valley margin and bedrock is often exposed in the bed of the stream at these locations. Channel substrate consists of coarse gravel and cobbles with boulders common near bluffs.

Bankfull channel geometry through this area was described by DeWitt (2012) with field data collected in the summer of 2011. The bankfull discharge was estimated to be 319 $m^3/s$ (11,264 $ft^3/s$) through a channel 69 m (226 ft) wide, 2.9 m (9.5 ft) deep, with a cross-sectional area of 196 $m^2$ (2,110 $ft^2$). The site is located halfway between two United States Geological Survey (USGS) gaging stations approximately 23 km upstream of the site at Boaz (07052250) and 23 km downstream at Galena (07052500) (Table 1). Gage records indicate the channel can contain 1.25-1.5 year recurrence interval flood, which is a typical flood frequency for alluvial rivers (Leopold et al., 1964). However, excess gravel deposited in “disturbance reaches” can cause lateral migration and bank erosion particularly in areas flowing into and out of bedrock bluffs (Saucier 1983; McKenney et al. 1995; Jacobson and Gran 1999).

## METHODS

A combination of methods was used to assess bank erosion contributions to water quality degradation to the river from this site at different spatial and temporal scales. Long-term bank erosion was assessed using both field surveys and aerial photograph interpretation over the entire study reach since the 1950s. Short-term bank erosion was assessed at the local-scale using erosion pins and repeat surveys at the site over a 1-year period. Finally, STEPL was used to model changes in water quality using different land use scenarios. Specific methods used for each of these approaches are detailed below.

### Reach-Scale Bank Erosion Assessment

For the reach-scale bank erosion assessment both field-based and aerial photography interpretation methods were used. Each method is described below:

#### Field-Based Assessment

The field assessment identified basic indicators of geomorphic process using a modified rapid geomorphic assessment at pre-selected points along the channel (Rosgen, 1996, Fitzpatrick et al., 1998). This specific assessment identifies channel units, bed morphology, bank conditions, and basic channel dimensions every 400 m (1,312 ft) along the study reach. Channel dimensions include bank heights from the thalweg that is representative of the bank conditions 200 m upstream and downstream of that point. The collection point is in the center of a channel cell that is represented by the information collected at that point. These data will be combined with erosion rates from historical aerial photography interpretations to estimate sediment contributions to the river.

#### Aerial Photography Interpretation

USGS aerial photos from 2008 were used as the base for rectification of 1952 historical aerial photography using a second-order polynomial transformation of 8 ground control points per image (Hughes et al., 2006). Root mean square error was 1 m for all photos with average test point error <2 m. Both banks were digitized for each photo series in ArcGIS for overlay analysis. A 400 m channel cell polygon feature was created with the location of the field-based assessment at the center of the cell (Figure 3). An average erosion rate between each photo series was calculated in each cell by creating an area of erosion within each using the digitized banks from each photo year and dividing that by the cell length. Bank erosion had to exceed the test point error of 2 m to be valid using this method.

#### Bank Erosion Calculations

Annual bank erosion was calculated using the following equation:

$$E_a = \sum (E_m * B_h * L_c * D_s) / P_y$$

Where:
$E_a$ = annual erosion (Mg)
$E_m$ = average erosion within all of the cell (m)
$B_h$ = mean bank height of cell (m)
$L_c$ = length of cell (m)
$D_s$ = bulk density of soil ($Mg/m^3$) from soil survey*
$P_{y\,=}$ difference in photo years

**Local Bank Erosion Monitoring**

Local bank erosion was monitored using both erosion pins and repeat surveys at the top of the bank along a 260 m (853 ft) reach of stream located 4 km (2.5 mi) downstream of McCall bridge within the study reach. On May 22, 2012 a total of 40, 46 cm (1.5 ft) long, 1.3 cm (0.5 in) diameter pieces of rebar were driven into the bank at 11 transects (3-4 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 7 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. If there was significant erosion to an extent the pin was completely missing, a value of 46 cm (1.5 ft) was recorded. Top of bank surveys were collected each time the erosion pins were measured using a total station to document changes in the bank line over the study period.

Bank erosion was calculated for each transect that represented that portion of the bank using the following equation:

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

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

**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 will be 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. Default curve numbers (CN) within STEPL were used for the forest, pasture, and cropland land use. The curve number for the pasture land use was modified using appropriate curve numbers for a meadow in fair condition from TR-55 (USDA, 1986). Stone 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

### Long-Term Bank Erosion

River Morphology

Bedrock has a major influence on the channel along the 7.6 km long study reach. Bluffs form the right bank of the river along the easement for nearly half the reach length and bedrock can be found along the bed of the river frequently (Figure 4). Bedrock in the bed and along bluffs limits the ability of the river to meander and scour the bed and is typical of streams in the Ozarks (Pavlowsky, 2004). Field measurements taken in May 2012 the active channel width varies from about 60 m to 120 m (197-394 ft) in some places. The active channel refers to both the wetted part of the channel at low flow, but also the gravel bars located adjacent to the water, but set below the bank. The high active channel widths indicate areas where large bars are present in the channel. Bank heights vary from around 2.5-6.2 m (8.2-20 ft) through the study reach. Bank heights vary due to the age of the deposit from terraces that could be >10,000 years old to recently formed benches only formed over the last 100 years (Brakenridge 1981; Hajic et al. 2007; Owen et al. 2011). There was no bank present in areas with bluffs along the right bank, but in a few cases, such as between 0-0.8 km, banks did exist right at the base of the bluff. Bank heights measured in the field were used to calculate total sediment volume lost to erosion from the historical aerial photography analysis.

Reach-Scale Erosion since 1952

The majority of bank erosion along the easement property is concentrated in the middle section of the study reach from 1.6-4.4 km, while erosion in the remainder of the reach was relatively low. Total bank erosion estimated from the aerial photos and field measurements along the property by 400 m cell varied from 0 along the bluffs to 12,937 $m^3$ (16,818 Mg) in the cell between 4-4.4 km since 1952 (Table 2). Average erosion for the reach over the last 56 years was 3,017 $m^3$ and 3,921 Mg per cell. Total erosion for the entire 7.6 km reach was 57,314 $m^3$ and 74,508 Mg over the last 56 years. Annual sediment loss ranged from 0-300 Mg/yr by cell for an average of 70 Mg with about 65% coming from the area between 1.6-4.4 km (Figures 5 and 6). Annual sediment eroded per unit length of stream varies from 0-0.75 Mg/m/year by 400 m cell with an average of 0.18 Mg/m/yr.

Soil particles can bind P and other nutrients at relatively high concentrations, so bank erosion has the potential to release large quantities of P to the aquatic environment. Therefore, the spatial trends of P release will be the same as sediment release from bank erosion analysis stated above. For this study an average soil P concentration of 400 ppm was used (Owen et al, 2007). An estimated 29,803 kg of P have been released from bank erosion through this reach since 1952. Annual P release by bank erosion varies by 400 m cell from 0-120 kg/yr with an average of 28 kg/yr per cell (Table 2). Annual P loss from bank erosion per unit length of stream varies from 0-0.23 kg/m/year by 400 m cell with an average of 0.07 kg/m/yr.

**Local-Scale Erosion**

Study Period Hydrology

The 13 month study period was drier than normal with nearly 22 cm (8.5 in) lower rainfall totals than the 30 year average (Figure 7). The months of May-July 2012 and November-December 2012 were particularly dry. Rainfall did pick up in January having higher than normal rainfall for 4 out of 5 months in 2013. This rainfall pattern is reflected in the discharge of the river over the study period. Discharge at Galena was very low from May–September 2012 with no major runoff events (Figure 8). Between October and December one significant event that exceeded the 1-yr flood RI occurred (Table 3). However, since January, 4 significant events occurred in the river that exceeded the 1-yr flood RI with 2 events at or near the bankfull stage near the 1.25 and 1.5-yr RI. Discharges > than the 1-yr flood RI would be expected to be able to do the most geomorphic work in the river, such as gravel transport, bank saturation-collapse, and bank erosion along the toe.

Erosion Pin Monitoring

The rainfall-runoff pattern in the river is reflected in the timing and magnitude of bank erosion in the study reach. Very little erosion occurred up to when the pins were check on the 21st of November (Figure 9). Since the bank at this location was nearly vertical, the erosion that did

occur was likely due to bank failure likely not tied to water levels in the river. The erosion that was measured of the 21st of November was likely the result of the >1-yr flood that occurred in mid-October. This suggests that floods lower than bankfull have the ability to cause significant bank erosion. No erosion was recorded from November 21st to January 17th. Significant rainfall that began in late January through late April kept water in the river at levels where pin measurements could not be taken. Finally, after several months of high water in the river, extensive erosion had occurred over that period when pins were measured on May 17, 2013. Pins at transects 1, 2, 10, and 11 were all missing. The value of 0.46 m was recorded and should be understood to be a conservative estimate. Actual erosion was likely 2-3 times higher at these transects. All pin measurements and bank information is recorded in the Appendix.

Annual Sediment and Phosphorus Loss

Monitoring results show the majority of the bank erosion occurred in the upper 100 meters of the reach the area upstream of the willow stake section (Figure 10). The second highest amount of erosion occurred in the lower section of the reach and the lowest erosion in the middle section of the reach where the willow stakes were located. The upper section makes up 43% of the reach and consists of erosion pin transects 1-3 (Table 4). The upper section lost 218 Mg of sediment and 87 kg of P over the monitoring period, which is about 68% of the total lost for the reach. The middle section is 97 m long (≈37% of total) and includes pin transects 4-8. The middle section lost 24.3 Mg of sediment and 9.7 kg of P over the monitoring period, which is <8% of the total lost for the reach. The lower section includes pin transects 9-11 and is only 51 m long, which is about 20% of the reach. Here a total of 79.8 Mg of sediment and 31.9 kg of P was eroded, which is around 25% of the total lost for the reach. Rates of sediment loss per unit of bank ranged from 0.25 Mg/m in the middle section to 2 Mg/m in the upper section, with a total of 1.2 Mg/m for the reach. The P loss per unit of bank ranged from 0.1 kg/m in the middle section to 0.8 kg/m in the upper section, with a total of 0.5 kg/m for the entire reach.

**STEPL Modeling Results**

Soils within the easement area were categorized into 2 groups based on HSG, existing land use, and slope for use in the STEPL model. Group 1 consisted of soils in HSG B, already in meadow, with slopes generally less than 5% (Table 5). Group 2 are soils in HSG B, C, or D that are in forest and have relatively high slope. In all there are 87.8 ha (216.9 ac) within the easement area. Of that 33.8 ha (83.6 ac) are in Group 1, 36.9 ha (91.1 ac) in Group 2, and 17.1 ha (42.2 ac) of water. In Group 2, 9.2 ha (22.7 ac) are in HSG B, 16.2 ha (40 ac) in HSG C, and 11.5 ha (28.4 ac) in HSG D. The groups were used in different land use scenarios in STEPL.

Existing Conditions

STEPL results suggest most of the nutrients and sediment leaving the existing easement area is coming from the grasslands that are currently being managed for hay. The majority (52%) of the existing land use within the area is in forest, with the remainder in meadow. The meadow

conditions are described as grasslands protected from grazing and are typically hayed (TR55). Using the existing land use in the model, the nitrogen (N) load is 542 kg/yr, the P load is 145 kg/yr, and the sediment load is 194 Mg/yr (Table 6, Figure 11). Of this 496 kg/yr of N, 125 kg/yr P, and 177 Mg/yr sediment is coming from the grasslands in Group 1. Areas currently in forest have very low loads.

<u>Scenario 1 – 100% Woods (fair)</u>

Scenario 1 has 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. This scenario is what might occur if all of the easement land was converted into forest land use. STEPL annual load results are 78.4 kg/yr N, 33.8 kg/yr P, and 29.7 Mg/yr sediment. These results indicate around a 75-85% drop in nutrients and sediment in this scenario compared to existing conditions.

<u>Scenario 2 – 100% Meadow (fair)</u>

There is a dramatic jump in annual loads when the forest land cover is removed from the model. This scenario is what may happen if the entire easement area was converted to grassland managed for hay. Annual loads for this scenario are 1,214 kg/yr N, 287 kg/yr P, and 396 Mg/yr sediment. These estimates are around twice as high as loads modeled from existing conditions. These estimates suggest that grasslands managed for hay can have significantly higher annual nutrient and sediment loads than forested lands.

<u>Scenario 3 – 100% Pasture (fair)</u>

Modeled annual loads increase slightly when grazing is introduced into the model for all of the land within the easement area. In this scenario all land within the easement area is converted to pasture land from grazing. Annual loads increase to 1,444 kg/yr N, 304 kg/yr P, and sediment is the same at 396 Mg/yr. Again these are over twice as high as loads modeled from existing conditions. This suggests livestock can have a slight impact on nutrient loads in agriculture areas over those areas that are strictly managed for forage crops.

<u>Scenario 4 – 48% Cropland (row) and 52% Pasture (fair)</u>

Areas in cropland can significantly increase annual nutrient and sediment loads in agricultural areas. Model results from this scenario are 2,469 kg/yr N, 749 kg/yr P, and 1,101 Mg/yr sediment. Of this, 1,622 kg/yr of N, 577 kg/yr P and 883 Mg/yr of sediment would come from the 48% of the land in cropland only. These loads alone are higher than the other scenarios that included the entire easement area in the model. Conversion from existing hay and forest land use to cropland and pasture land use may increase nutrient and sediment loads by 4-5x within the easement area.

**Implications for Nonpoint Source Pollution Reductions**

Results of this study suggest conservation easements can reduce contributions of nutrients and sediment to the James River. Loads were estimated at Galena using recent data water quality data collected from 2007-2008 at the James River at Boaz and the Finley River at Seneca Bridge (Table 7, Hutchison, 2010). Annual load estimates at Galena are 150,957 Mg of TSS, 2,275 Mg of TN, and 97.1 Mg of TP. It should be noted loads estimated here are about 70-80% lower than the TMDL estimate for TP in 2001 (MDNR, 2001).

Using the nutrient and sediment yield estimates from the reach-scale erosion estimates for the entire main stem of the river show that over 30% of sediment and over 20% of the P entering the lake at Galena is from bank erosion. By extrapolating the reach-scale bank erosion by unit length for both sides of the river over 157 km nets 56,520 Mg of sediment and 22 Mg of P at Galena (Table 8). If the erosion pattern is similar for the entire river, this equates to 37% of the sediment and 23% of the P at Galena. While bank heights are lower in the upper portions of the river, we know little of the erosion rates in other areas. Due to the lack of data upstream, it was assumed erosion rates are similar for the entire main stem. If establishing a riparian corridor in conservation easement can reduce bank erosion by 25-50% and that was applied to the entire main stem of the river, the sediment load from bank erosion could be reduced 9-19% and P load from 5-11% at Galena.

Conservation easements produce much lower reduction in nutrients and sediment at Galena if they are applied to the entire length of river when looking at runoff generated compared to bank erosion. Again, due to lack of information upstream it was assumed the water quality runoff along the entire main stem of the river was similar to the existing conditions of the study reach. In this case 8,007 Mg of sediment, 22 Mg of N, and 6 Mg of P would be entering the river annually from runoff (Table 9). This accounts for 5-6% of the sediment and P, and 1% of the N at Galena. If conservation easements were applied to the entire river and that land converted into forest, the annual load from these areas would be 1,225 Mg of sediment, 3.2 Mg of N, and 1.4 Mg of P. That translates into a 4-5% reduction in P and sediment, and <1% reduction of N at Galena.

## CONCLUSIONS

The JRBP has implemented a conservation easement along the west bank of a 7.6 km study reach of the James River in Stone County. This study estimates the annual nutrient and sediment loads from runoff and bank erosion using a combination of field-based bank erosion monitoring, historical aerial photography interpretation, and STEPL water quality monitoring. There are 5 main conclusions from this study:

1. **Channel morphology and bank conditions measured.** Field-based rapid geomorphic assessment identified channel geometry and bank conditions every 400 m along the 7.6 km reach of the study area where the easement was established. This portion of the river is heavily influenced by bedrock that limits the ability of the channel to move laterally or down cut.
2. **Reach-scale bank erosion rates calculated since 1952**. Reach-scale bank erosion was determined by historical aerial photography interpretation coupled with field-based bank height measurements to determine the annual sediment and P load from this reach since 1952. A total of 74,508 Mg of sediment and 29,803 kg of P have entered the river from bank erosion over the last 56 years. That equals around 1,331 Mg/yr of sediment and 532 kg/yr of P. Average unit length loss from this section was 0.18 Mg/m/yr of sediment and 0.07 kg/m/yr of P. However, nearly 65% of the sediment and P is coming from only 2.8 km of the bank. This suggests properly placed and installed bank stabilization projects have the potential to significantly reduce nutrient and sediment inputs to the river.

3. **Short-term bank erosion was monitored at banks with highest amount of erosion**. Field-based erosion pin monitoring was conducted for 1 year over a 260 m long section of bank to look at erosion rates in the area of the easement with the highest erosion rates. Over the course of 1 year, 323 Mg of sediment and 129 kg of P were released from this area, mostly upstream of an area where willow stakes were established. Total unit length loss from this section was 1.24 Mg/m/yr of sediment and 0.5 kg/m/yr of P. Annual erosion rates in this area far exceeded rates from the historical aerial photo interpretation suggesting properly placed bank stabilization can have a significant impact on reducing sediment and P from entering the stream.

4. **STEPL water quality model created for easement area**. Results of the water quality model indicate nearly an 80% 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.

5. **Water quality model and bank erosion results applied to the entire river**. Conservation easements can be beneficial in reducing nonpoint source pollution by protecting banks from erosion and taking areas adjacent to the river out of agricultural production. The results of this study were applied to the entire main stem of the river with the assumption the same conditions exist upstream. Another assumption used was easements reduced bank erosion from 25-50% by eliminating agricultural production and development from the bank edge and the area was allowed to vegetate. The combined effect of water quality improvement

and bank erosion protection would be a 13-25% reduction in sediment and a 9-15% reduction of P entering Table Rock Lake at Galena.

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## TABLES

Table 1. USGS Gaging Stations on James River near Study Site

| ID | Name | Period of Record | Drainage Area ($km^2$) | Annual Mean Q ($m^3/s$) | 10% Exceeds ($m^3/s$) | 90% Exceeds ($m^3/s$) |
|---|---|---|---|---|---|---|
| 07052345 | Finley Creek below Riverdale, MO | Oct. 2001 to May 2005, Oct. 5 2005 to present | 676 | 7.1 | 15.1 | 0.62 |
| 07052250 | James River near Boaz, MO | Sept. 23, 1972 to Oct. 1, 1980; Oct. 1, 2001 to present | 1,197 | 14.8 | 30.9 | 1.9 |
| 07052500 | James River near Galena, MO | Oct., 1921 to present | 2,556 | 28.1 | 61.5 | 3.4 |

Table 2. Reach-Scale Erosion Results

| **Mid Cell (km)** | **Sed. ($m^3$)** | **Sed. (Mg)** | **Sed. (Mg/yr)** | **Sed. (Mg/m/yr)** | **P (kg)** | **P (kg/yr)** | **P (kg/m/yr)** |
|---|---|---|---|---|---|---|---|
| 0.2 | 7,336 | 9,537 | 170 | 0.43 | 3,815 | 68 | 0.17 |
| 0.6 | 106 | 138 | 2 | 0.01 | 55 | 1.0 | 0.00 |
| 1 | 0 | 0 | 0 | 0.00 | 0 | 0 | 0.00 |
| 1.4 | 0 | 0 | 0 | 0.00 | 0 | 0 | 0.00 |
| 1.8 | 5,387 | 7,003 | 125 | 0.31 | 2,801 | 50 | 0.13 |
| 2.2 | 1,122 | 1,458 | 26 | 0.07 | 583 | 10 | 0.03 |
| 2.6 | 3,073 | 3,995 | 71 | 0.18 | 1,598 | 29 | 0.07 |
| 3 | 9,927 | 12,905 | 230 | 0.58 | 5,162 | 92 | 0.23 |
| 3.4 | 8,590 | 11,167 | 199 | 0.50 | 4,467 | 80 | 0.20 |
| 3.8 | 6,064 | 7,884 | 141 | 0.35 | 3,153 | 56 | 0.14 |
| 4.2 | 12,937 | 16,818 | 300 | 0.75 | 6,727 | 120 | 0.30 |
| 4.6 | 0 | 0 | 0 | 0.00 | 0 | 0 | 0.00 |
| 5 | 0 | 0 | 0 | 0.00 | 0 | 0 | 0.00 |
| 5.4 | 0 | 0 | 0 | 0.00 | 0 | 0 | 0.00 |
| 5.8 | 2,699 | 3,509 | 63 | 0.16 | 1,404 | 25 | 0.06 |
| 6.2 | 0 | 0 | 0 | 0.00 | 0 | 0 | 0.00 |
| 6.6 | 0 | 0 | 0 | 0.00 | 0 | 0 | 0.00 |
| 7 | 73 | 94 | 2 | 0.004 | 38 | 0.7 | 0.002 |
| 7.4 | 0 | 0 | 0 | 0.00 | 0 | 0 | 0.00 |
| Total | 57,314 | 74,508 | 1,331 | 3.33 | 29,803 | 532 | 1.33 |
| Average | 3,017 | 3,921 | 70 | 0.18 | 1,569 | 28 | 0.07 |

Table 3. Flood Recurrence Intervals for USGS Gaging Station at Galena (1922-2012).

| Q-RI | Discharge ($m^3/s$) |
|---|---|
| 1.05-yr | 180 |
| 1.11-yr | 236 |
| 1.25-yr | 323 |
| 1.5-yr | 430 |
| 2-yr | 572 |
| 2.33-yr | 641 |

Table 4. Erosion Pin Monitoring Results

| **Section** | **Section Length (m)** | **% of Total** | **Pin Array #** | **Sediment Eroded ($m^3$)** | **Sediment Eroded (Mg)** | **P to Stream (kg)** | **% of Total** |
|---|---|---|---|---|---|---|---|
| Upper | 112 | 43.1 | 1 | 86.1 | 111.9 | 45 | 34.7 |
| | | | 2 | 68.5 | 89.1 | 36 | 27.6 |
| | | | 3 | 13.4 | 17.4 | 6.9 | 5.4 |
| | | | *Total* | *168.0* | *218.4* | *87.3* | *67.7* |
| Middle (Willow Stakes) | 97 | 37.3 | 4 | 0.7 | 0.8 | 0.3 | 0.3 |
| | | | 5 | 0.7 | 4.2 | 1.7 | 1.3 |
| | | | 6 | 3.2 | 1.3 | 0.5 | 0.4 |
| | | | 7 | 1.0 | 0.6 | 0.3 | 0.2 |
| | | | 8 | 0.5 | 17.3 | 6.9 | 5.4 |
| | | | *Total* | *6.1* | *24.3* | *9.7* | *7.5* |
| Lower | 51 | 19.6 | 9 | 5.4 | 7.0 | 2.8 | 2.2 |
| | | | 10 | 24.3 | 31.5 | 13 | 9.8 |
| | | | 11 | 31.8 | 41.3 | 17 | 12.8 |
| | | | *Total* | *61.4* | *79.8* | *31.9* | *24.8* |
| **Reach Totals** | **260** | **100** | **1-11** | **235** | **323** | **129** | **100** |

Table 5. Description of Soils in Easement Area

| Soil Description | HSG | Area (ha) |
|---|---|---|
| <u>Group 1</u> | | |
| Hootentown silt loam, 0 to 3 percent slopes, rarely flooded | B | 12.4 |
| Horsecreek-Jamesfin soils, 0 to 2 percent slopes, occasionally flooded | B | 5.5 |
| Pinerun-Waben complex, 0 to 5 percent slopes | B | 1.5 |
| Pinerun gravelly silt loam, 0 to 3 percent slopes, occasionally flooded | B | 11.4 |
| Pinerun silt loam, 0 to 3 percent slopes, occasionally flooded | B | 2.8 |
| Pomme silt loam, 3 to 8 percent slopes | B | 0.2 |
| Total | | 33.8 |
| <u>Group 2</u> | | |
| Alred-Gatewood complex, 15 to 35 percent slopes, stony | B55/C40/D5 | 0.4 |
| Clarksville-Scholten-Hailey complex, 3 to 15 percent slopes | B72/C28 | 1.2 |
| Gasconade-Gatewood-Rock outcrop complex, 15 to 50 percent slopes | C40/D60 | 8.7 |
| Gatewood-Moko complex, 15 to 35 percent slopes, very rocky, very flaggy | C65/D35 | 17.4 |
| Hailey-Rueter complex, 15 to 35 percent slopes, very rocky | B | 4.2 |
| Mano-Ocie complex, 3 to 15 percent slopes | C | 1.1 |
| Rueter-Gasconade-Rock outcrop complex, 15 to 60 percent slopes | B55/C5/D40 | 0.4 |
| Rueter-Hailey complex, 35 to 60 percent slopes, rocky | B | 3.8 |
| Total<br>(B/C/D) | | 36.9 |
| <u>NA</u> | | |
| Water | NA | 17.1 |

Table 6. STEPL Modeling Results

| Scenarios | HSG | Group | Land Use (Condition) | Area (ha) | CN | TP (kg/yr) | TN (kg/yr) | TSS (Mg/yr) |
|---|---|---|---|---|---|---|---|---|
| Existing | B | 1 | Meadow (Fair) | 33.8 | 58 | 495.9 | 125.0 | 177.1 |
| | B | 2 | Woods (Fair) | 9.2 | 60 | 9.9 | 4.2 | 4.2 |
| | C | 2 | Woods (Fair) | 16.2 | 73 | 19.8 | 8.6 | 7.0 |
| | D | 2 | Woods (Fair) | 11.5 | 79 | 16.1 | 7.1 | 5.2 |
| 1 | B | 1 | Woods (Fair) | 33.8 | 60 | 32.6 | 13.9 | 13.3 |
| | B | 2 | Woods (Fair) | 9.2 | 60 | 9.9 | 4.2 | 4.2 |
| | C | 2 | Woods (Fair) | 16.2 | 73 | 19.8 | 8.6 | 7.0 |
| | D | 2 | Woods (Fair) | 11.5 | 79 | 16.1 | 7.1 | 5.2 |
| 2 | B | 1 | Meadow (Fair) | 33.8 | 58 | 495.9 | 125.0 | 177.1 |
| | B | 2 | Meadow (Fair) | 9.2 | 58 | 148.3 | 39.2 | 56.6 |
| | C | 2 | Meadow (Fair) | 16.2 | 71 | 310.1 | 69.3 | 92.9 |
| | D | 2 | Meadow (Fair) | 11.5 | 78 | 260.0 | 53.7 | 68.9 |
| 3 | B | 1 | Pasture (Fair) | 33.8 | 69 | 596.9 | 132.6 | 177.1 |
| | B | 2 | Pasture (Fair) | 9.2 | 69 | 175.7 | 41.3 | 56.6 |
| | C | 2 | Pasture (Fair) | 16.2 | 79 | 368.4 | 73.7 | 92.9 |
| | D | 2 | Pasture (Fair) | 11.5 | 84 | 302.9 | 56.9 | 68.9 |
| 4 | B | 1 | Cropland (Row) | 33.8 | 78 | 1,622 | 577.0 | 883.1 |
| | B | 2 | Pasture (Fair) | 9.2 | 69 | 175.7 | 41.3 | 56.6 |
| | C | 2 | Pasture (Fair) | 16.2 | 79 | 368.4 | 73.7 | 92.9 |
| | D | 2 | Pasture (Fair) | 11.5 | 84 | 302.9 | 56.9 | 68.9 |

Table 7. Annual Nutrient and Sediment Loads at Gages

| Station | Ad (km2) | TSS Load (Mg) | TN Load (Mg) | TP Load (Mg) |
|---|---|---|---|---|
| Finely | 676 | 6,103 | 371 | 8 |
| Boaz | 1,197 | 104,520 | 1,302 | 64 |
| Total | 1,873 | 110,623 | 1,673 | 72 |
| Yield | | 59.1 Mg/km$^2$/yr | 0.89 Mg/km$^2$/yr | 0.04 Mg/km$^2$/yr |
| Galena | 2,556 | 151,060 | 2,275 | 102 |

Table 8. Estimated Reductions in Sediment and P from Bank Erosion

| | TSS | TP |
|---|---|---|
| Annual Load Galena (Mg) | 151,060 | 102 |
| Load per Unit Length (Mg/km/yr) | 180 | 0.07 |
| Total from Bank Erosion (Mg/yr) | 56,520 | 22.0 |
| % at Galena | 37.4 | 21.5 |
| Load reduction at 25% BMP efficiency (Mg/yr) | 14,130 | 5.5 |
| Reduction at Galena | 9.4 | 5.4 |
| Load reduction at 50% BMP efficiency (Mg/yr) | 28,260 | 11.0 |
| Reduction at Galena | 18.7 | 10.8 |

Table 9. Estimated Reductions in Sediment and P from Runoff

| | TSS | TN | TP |
|---|---|---|---|
| Annual Load Galena (Mg/yr) | 151,060 | 2,275 | 102 |
| Existing Conditions | | | |
| Load per Unit Length (Mg/km/yr) | 25.5 | 0.071 | 0.019 |
| Total from Easements (Mg/yr) | 8,007 | 22.3 | 6.0 |
| % at Galena | 5.3 | 0.98 | 5.9 |
| Forest | | | |
| Load per Unit Length (Mg/km/yr) | 3.9 | 0.01 | 0.004 |
| Total from Easements (Mg/yr) | 1,225 | 3.1 | 1.3 |
| % at Galena | 0.81 | 0.14 | 1.2 |
| % Reduction at Galena | 4.5 | 0.84 | 4.7 |

## FIGURES

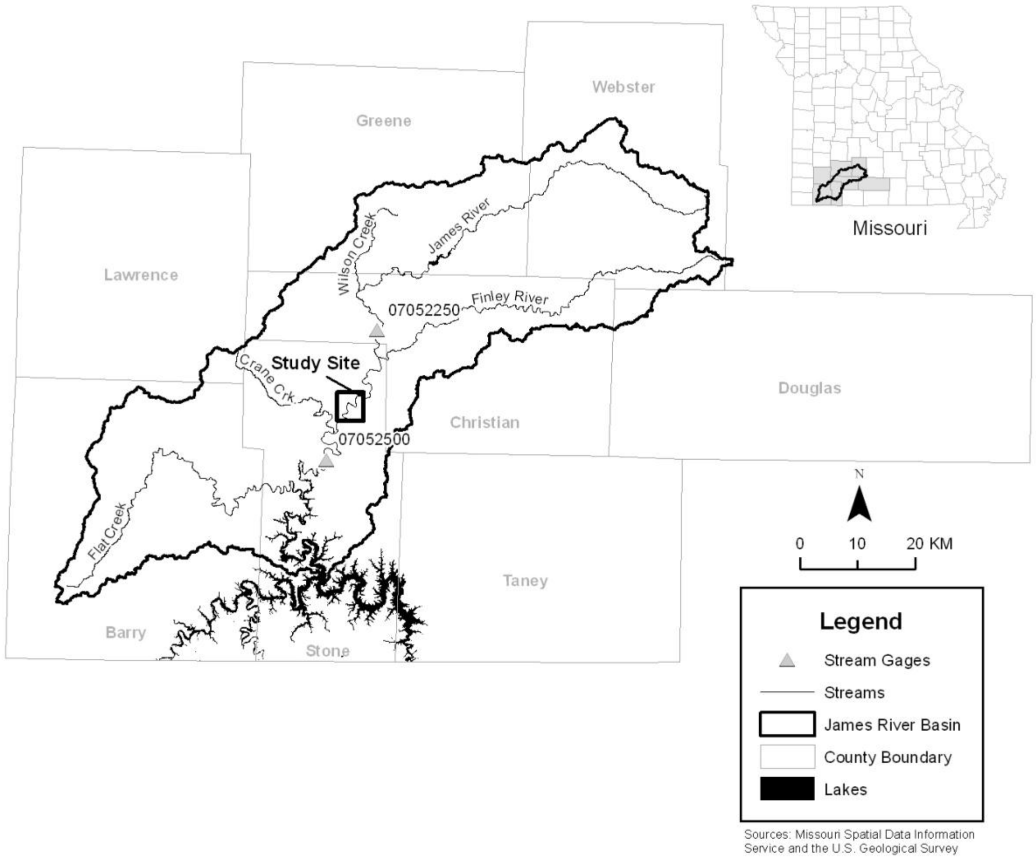


Figure 1. James River Basin.

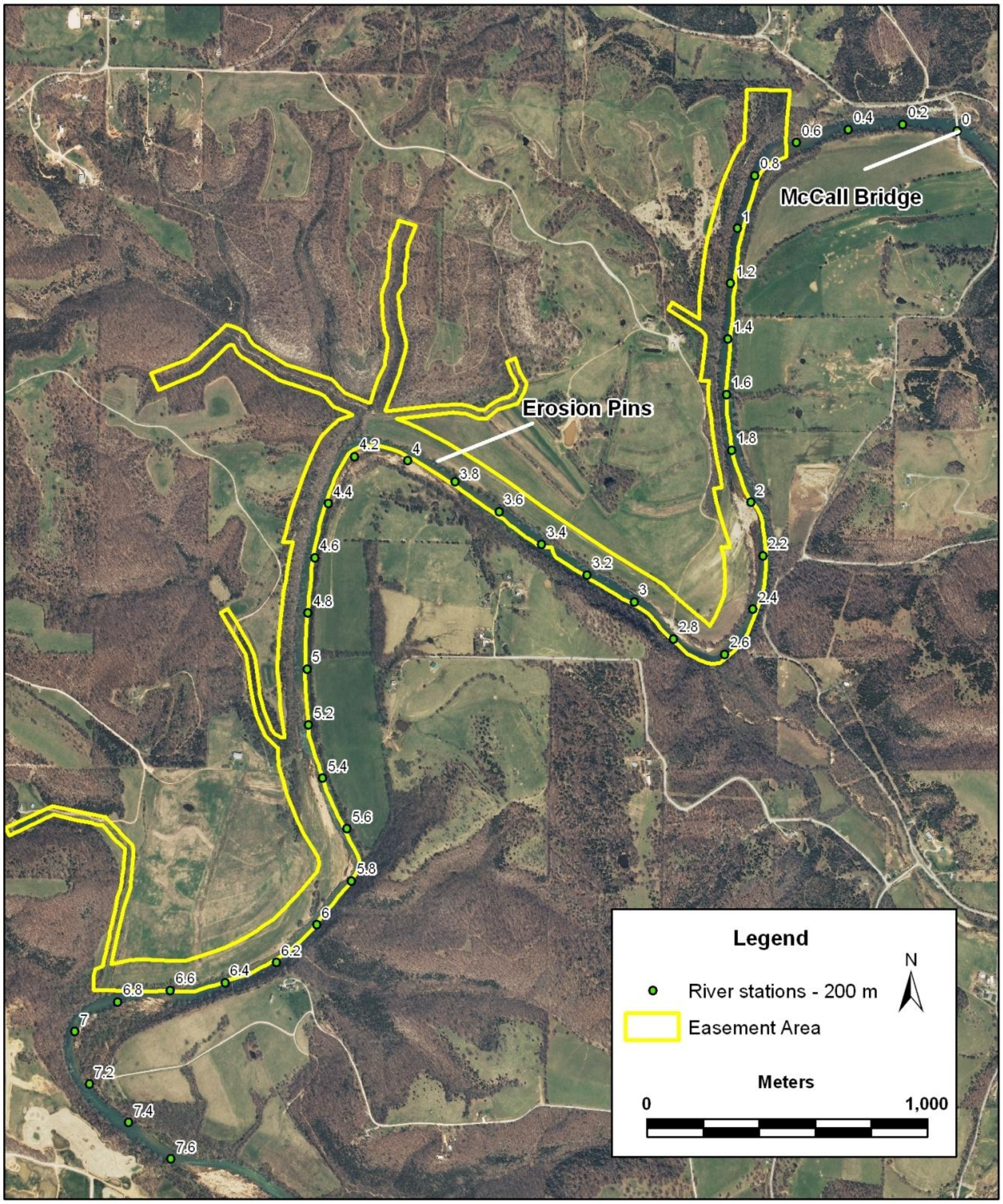


Figure 2. Study area map.

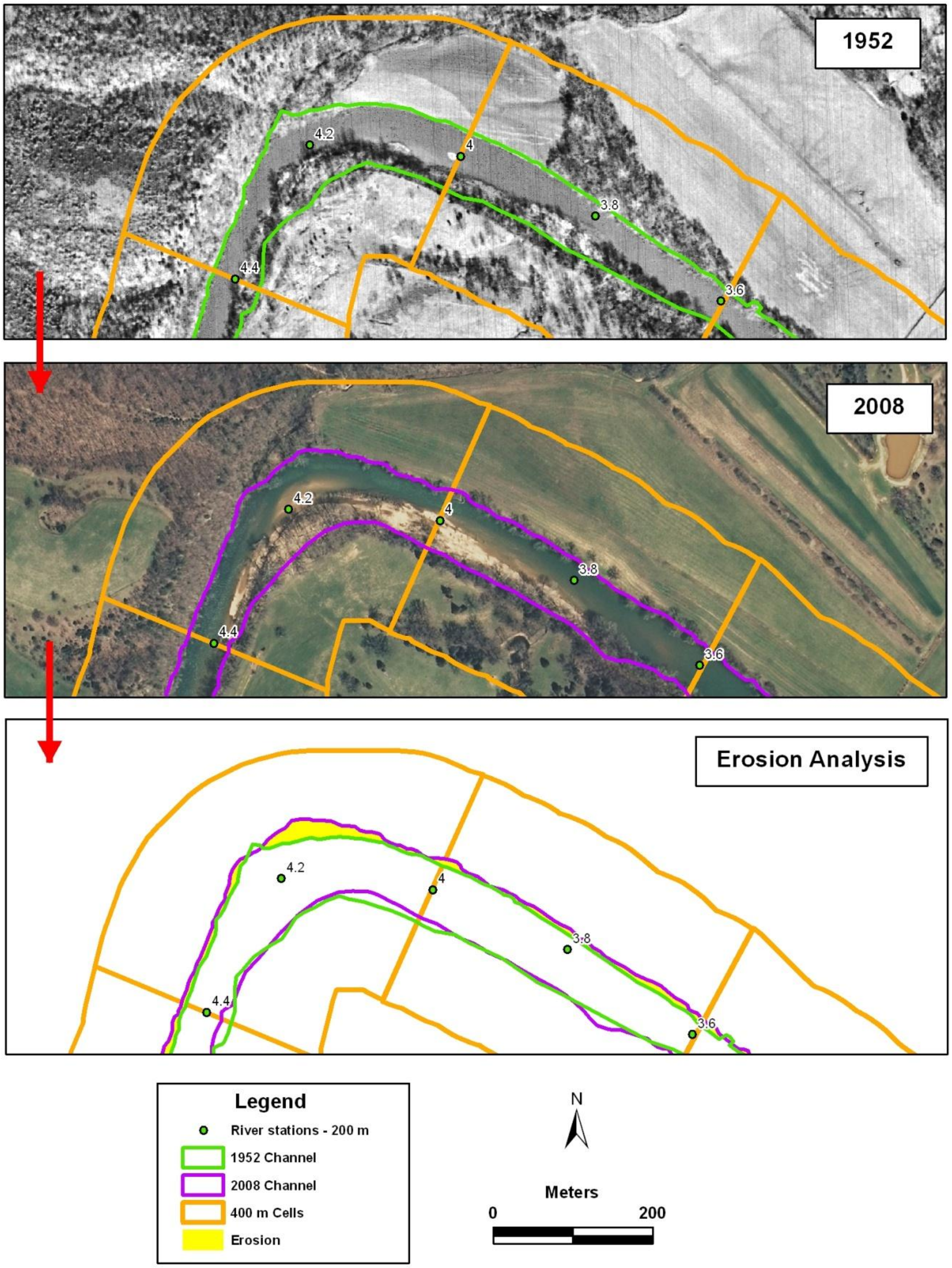


Figure 3. Aerial photo methods to define area of erosion since 1952.

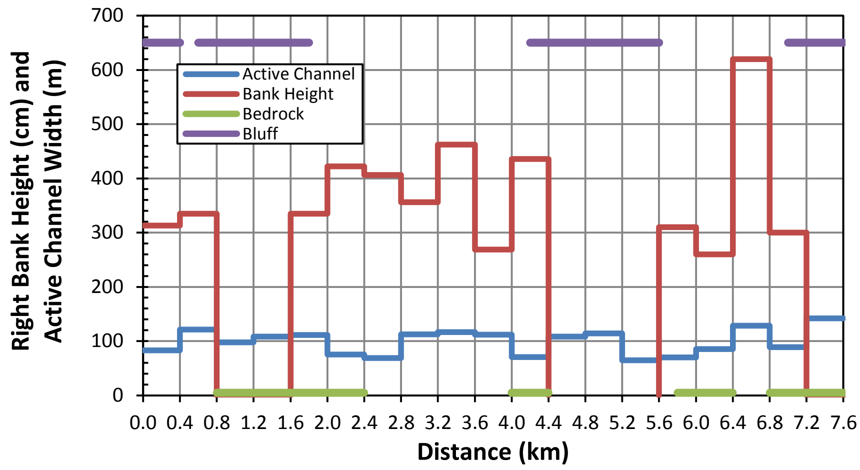


Figure 4. Bank and channel conditions in study reach.

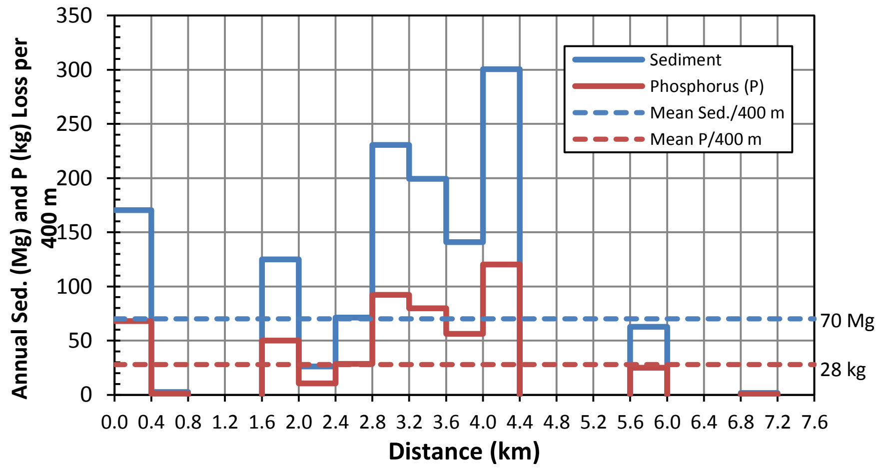


Figure 5. Annual sediment and P loss from bank erosion in study reach.

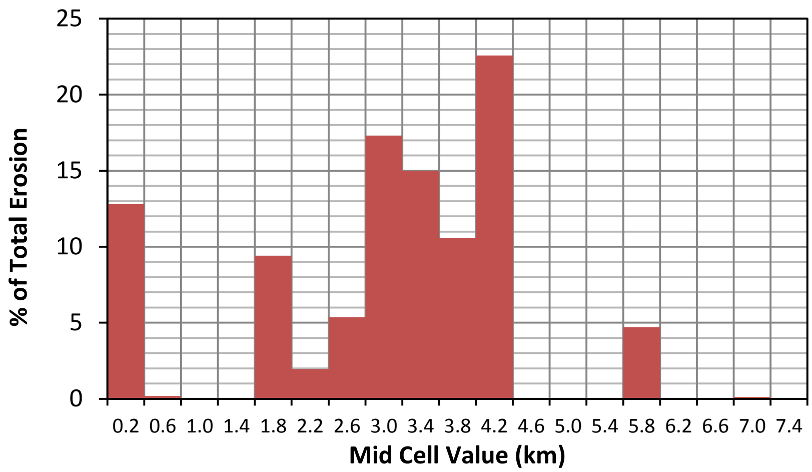


Figure 6. Percent of total erosion by cell.

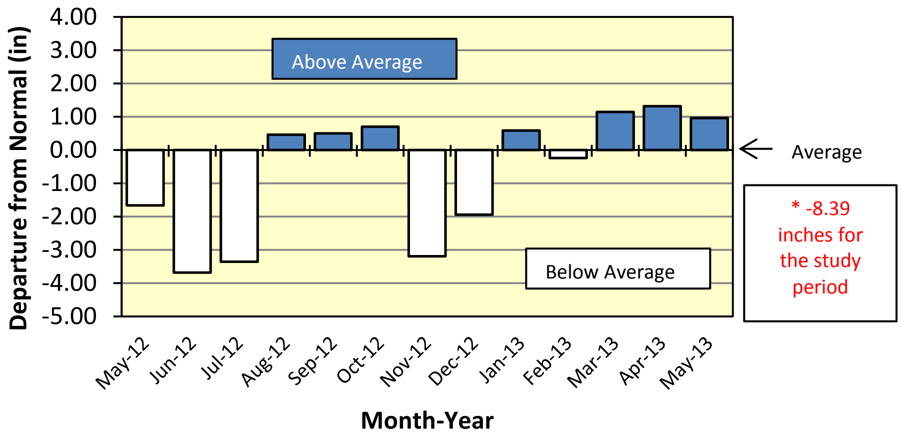


Figure 7. Monthly rainfall departure from normal over study period.

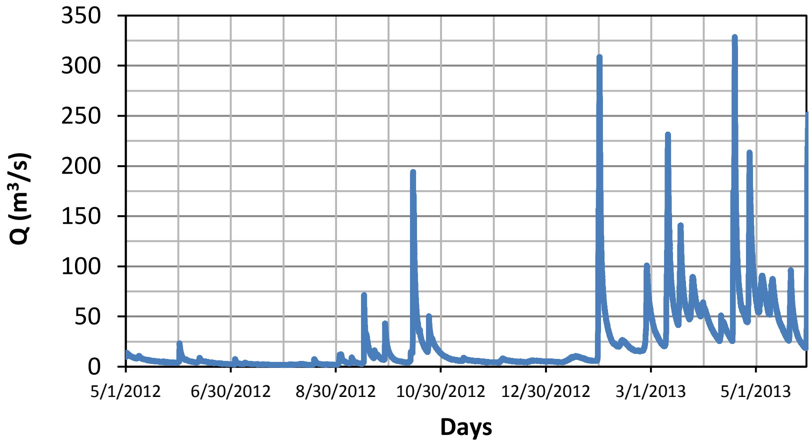


Figure 8. Discharge at Galena over the study period.

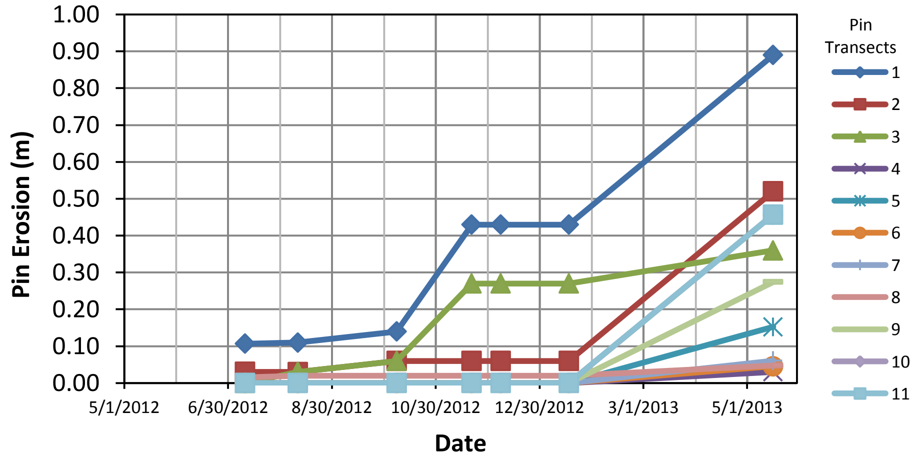


Figure 9. Cumulative erosion at pin transects.

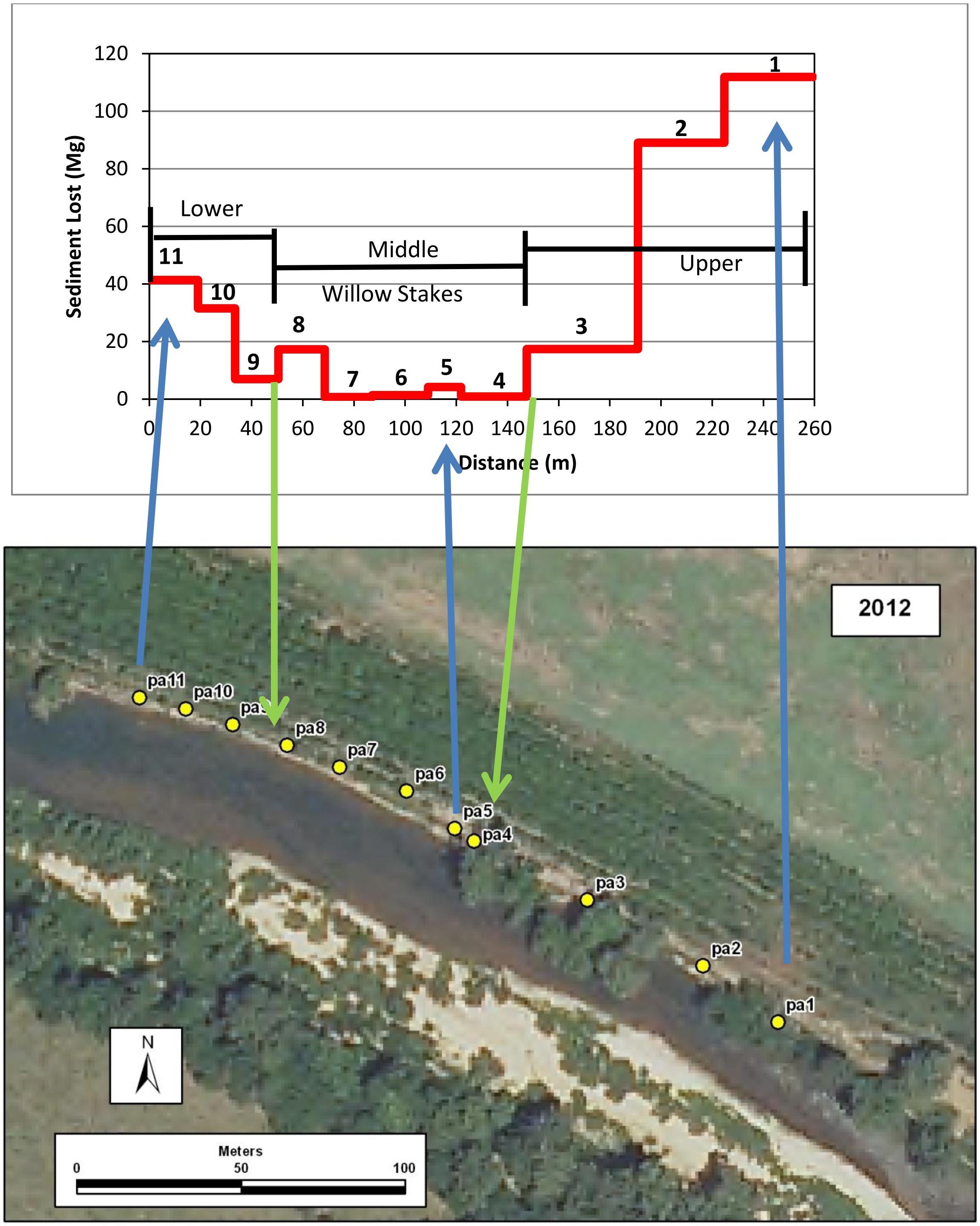


Figure 10. Total sediment loss from short-term bank erosion pin monitoring.

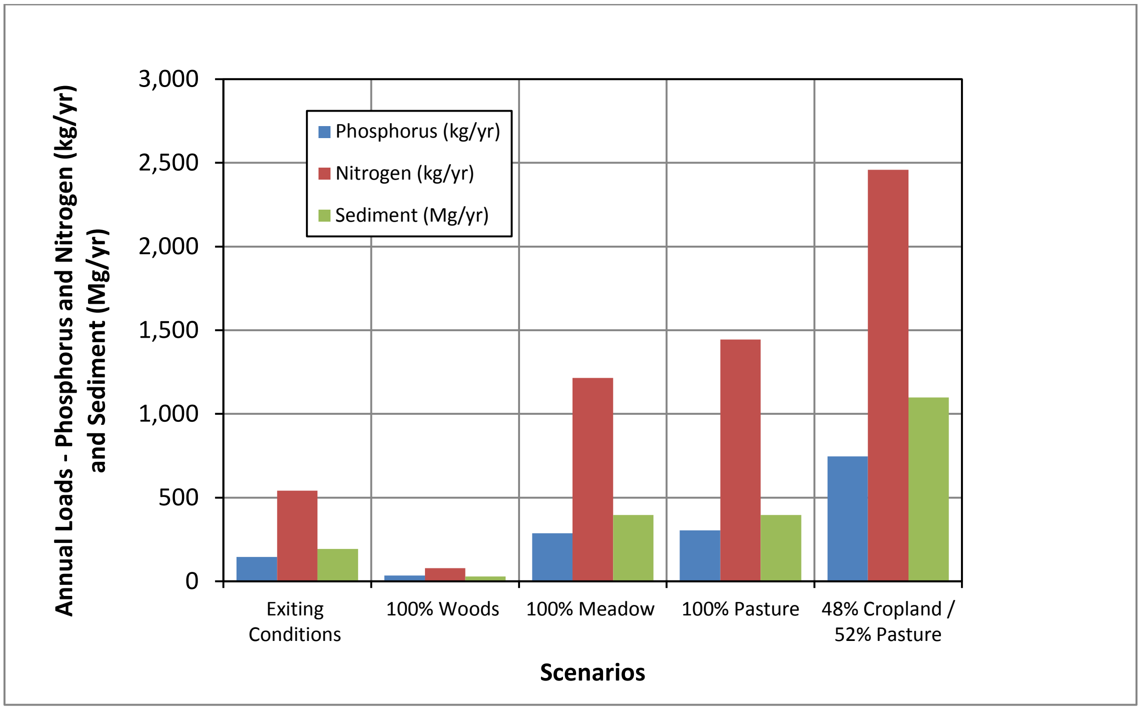


Figure 11. Annual nutrient and sediment loads from easement area from STEPL model.

**PHOTOS**

Photo 1. Bank survey, May 2012.

Photo 2. Erosion pin transect, May 2012.

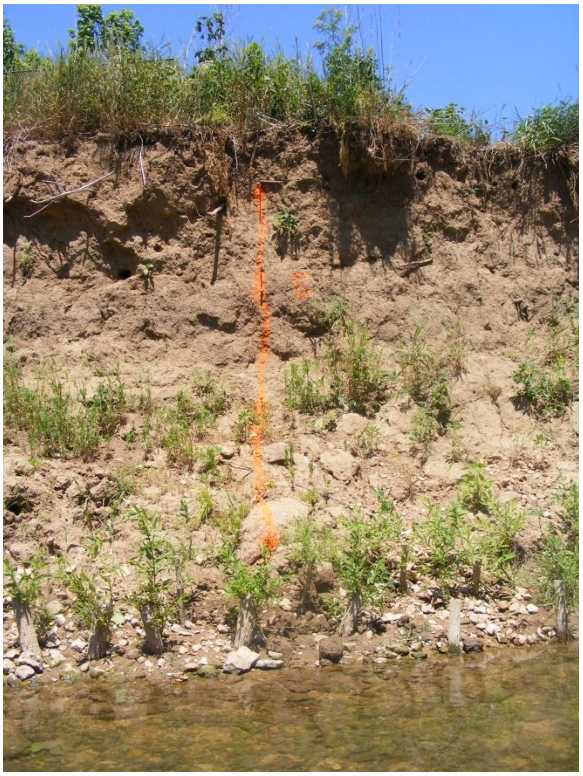

Photo 3. Erosion pin transect with live willow stakes at the base, May 2012.

Photo 4. Erosion pin measurement, July 2012.

Photo 5. Erosion pin transect 10 at low flow, July 2012.

Photo 6.  Bank survey, December 2012.

Photo 7.  View upstream of transect 5, with dormant willows, January, 2013.


Photo 8.  Erosion pin transect 4 at high flow, willows under water, May 2013.

Photo 9. Roots exposed immediately following bank erosion from recent floods, May 2013.

Photo 10. Recently downed tree after bank failure, May 2013.

Photo 11. Time Series Photo 1 - May 2012.

Photo 12. Time Series Photo 2 - October 2012.


Photo 13. Time Series Photo 3 - January 2013.


Photo 14. Time Series Photo 4 - May 2013.

# APPENDIX

| Pin Array | Pin # | Total Pin Erosion (m) | Bank Height (m) | % of Bank | Bank Length (m) | Volume Eroded ($m^3$) | Mass Eroded (Mg)* |
|---|---|---|---|---|---|---|---|
| 1 | 1 | 0.457 | 4.36 | 63.1 | 34.7 | 43.6 | 56.7 |
| | 2 | 0.457 | 4.36 | 10.5 | 34.7 | 7.3 | 9.4 |
| | 3 | 0.884 | 4.36 | 26.3 | 34.7 | 35.2 | 45.7 |
| 2 | 1 | 0.457 | 4.36 | 63.1 | 33.7 | 42.4 | 55.1 |
| | 2 | 0.457 | 4.36 | 10.5 | 33.7 | 7.1 | 9.2 |
| | 3 | 0.457 | 4.36 | 10.5 | 33.7 | 7.1 | 9.2 |
| | 4 | 0.518 | 4.36 | 15.8 | 33.7 | 12.0 | 15.6 |
| 3 | 1 | 0.061 | 4.36 | 63.1 | 43.5 | 7.3 | 9.5 |
| | 2 | 0.305 | 4.36 | 10.5 | 43.5 | 6.1 | 7.9 |
| | 3 | -0.168 | 4.36 | 10.5 | 43.5 | | |
| | 4 | -0.091 | 4.36 | 15.8 | 43.5 | | |
| 4 | 1 | 0.000 | 4.06 | 29.6 | 25.7 | | |
| | 2 | 0.030 | 4.06 | 20.5 | 25.7 | 0.7 | 0.8 |
| | 3 | -0.107 | 4.06 | 23.0 | 25.7 | | |
| | 4 | -0.030 | 4.06 | 26.9 | 25.7 | | |
| 5 | 1 | 0.000 | 4.13 | 22.2 | 12.87 | | |
| | 2 | 0.046 | 4.13 | 23.4 | 12.87 | 0.6 | 0.7 |
| | 3 | 0.030 | 4.13 | 26.7 | 12.87 | 0.4 | 0.6 |
| | 4 | 0.152 | 4.13 | 27.7 | 12.87 | 2.2 | 2.9 |
| 6 | 1 | 0.000 | 4.15 | 27.0 | 21.88 | | |
| | 2 | 0.046 | 4.15 | 24.6 | 21.88 | 1.0 | 1.3 |
| | 3 | -0.122 | 4.15 | 48.4 | 21.88 | | |
| 7 | 1 | 0.000 | 3.61 | 30.5 | 18.5 | | |
| | 2 | 0.030 | 3.61 | 24.0 | 18.5 | 0.5 | 0.6 |
| | 3 | 0.000 | 3.61 | 15.6 | 18.5 | | |
| | 4 | -0.168 | 3.61 | 29.9 | 18.5 | | |
| 8 | 1 | 0.457 | 3.80 | 31.6 | 18.08 | 9.9 | 12.9 |
| | 2 | 0.213 | 3.80 | 19.7 | 18.08 | 2.9 | 3.8 |
| | 3 | 0.061 | 3.80 | 11.8 | 18.08 | 0.5 | 0.6 |
| | 4 | -0.213 | 3.80 | 36.9 | 18.08 | | |
| 9 | 1 | 0.274 | 3.65 | 31.5 | 17 | 5.4 | 7.0 |
| | 2 | 0.000 | 3.65 | 24.6 | 17 | | |
| | 3 | 0.000 | 3.65 | 43.9 | 17 | | |
| 10 | 1 | 0.457 | 3.65 | 31.5 | 14.5 | 7.6 | 9.9 |
| | 2 | 0.457 | 3.65 | 24.6 | 14.5 | 6.0 | 7.7 |
| | 3 | 0.457 | 3.65 | 22.0 | 14.5 | 5.3 | 6.9 |
| | 4 | 0.460 | 3.65 | 22.0 | 14.5 | 5.4 | 7.0 |
| 11 | 1 | 0.457 | 3.65 | 31.5 | 19 | 10.0 | 13.0 |
| | 2 | 0.457 | 3.65 | 24.6 | 19 | 7.8 | 10.1 |
| | 3 | 0.460 | 3.65 | 43.9 | 19 | 14.0 | 18.2 |