Stream Channel Restoration in the Illinois River and Eucha/Spavinaw Watersheds to Protect Water Supply Reservoirs

Contract Number: ORF-09-0028-CW

Final Report

October 31, 2012

Submitted to:

OKLAHOMA CONSERVATION COMMISSION

2800 N. Lincoln Blvd. Suite 160, Oklahoma City, OK 73105

&

Oklahoma Water Resources Board

3800 N. Classen Blvd.

Oklahoma City, OK 73118

Prepared by:

Oklahoma State University

Department of Biosystems and Agricultural Engineering

Department of Agricultural Economics

Submitted by:

Dr. Jason R. Vogel – Assistant Professor
Oklahoma State University (OSU), Department of Biosystems and Agricultural Engineering (BAE)
Dr. Garey A. Fox – Associate Professor & Orville L. & Helen L. Buchanan Chair OSU, BAE
Dr. Daniel E. Storm – Professor, OSU BAE
Dr. Glenn O. Brown – Regents Professor, OSU BAE
Dr. Tracy Boyer – Associate Professor, OSU Department of Agricultural Economics (AE)
Jeri Fleming – Program Manager, OSU BAE
Rebecca Chavez – Research Engineer, OSU BAE
Erin Daly – Masters Student, OSU BAE
Alex Tobergte – Masters Student, OSU BAE
Admas Siyoum – Masters Student OSU AE

Table of Contents

1.0 DISTRIBUTION LIST

1. Judith Wilkins	Oklahoma Conservation Commission
2. Jennifer Wasinger	Oklahoma Water Resources Board
3. EPA Approving Official	U.S. EPA Regional VI
4. Dr. Jason Vogel	Oklahoma State University, BAE Department
6. Andrea Sherwood	Oklahoma State University Grants and Contracts

2.0 PERSONNEL AND RESPONSIBILITES

The organizations and personnel involved substantially in the Illinois River project from Oklahoma State University are shown in the table below.

Table 1. OSU Personnel and Responsibilities

Personnel	Contact Info	Project Title/Responsibility
Dr. Jason Vogel	jason.vogel@okstate.edu 405-744-7532	Project PI: Tasks 1, 3, 4 and 6, and Reporting
Dr. Dan Storm	dan.storm@okstate.edu	Project Co-PI: Task 2 Subtasks 2.1 and 2.2 and Reporting
Dr. Garey Fox	garey.fox@okstate.edu	Project Co-PI: Task 2 Subtasks 2.1 and 2.2 and Reporting
Dr. Tracy Boyer	tracy.boyer@okstate.edu	Project Co-PI: Task 2 Subtask 2.3 and Reporting
Jeri Fleming	jeri.fleming@okstate.edu 405-744-8395	Project Manager, Inspector, Report Leader, Outreach
Rebecca Chavez	rebecca.chavez@okstate.edu	Construction Inspector
Andrea Sherwood, Accountant III	andrea.sherwood@okstate.edu	Grants & Contracts Financial Administration

3.0 EXECUTIVE SUMMARY

The goal of this project was to build a partnership including Oklahoma State University (OSU) and cooperating agencies to prioritize and implement stream channel restoration projects in the Eucha/Spavinaw and Illinois River Watersheds. The specific objectives of the project included: (1) develop and implement a prioritization system based on current state of degradation, likelihood of long-term stability, ecosystem services preserved or created, and potential load reduction, (2) implement restoration projects on 7,000 linear feet of streambank at selected sites that take advantage of local resources including expertise, tools and natural materials, and (3) provide training so that local companies obtain knowledge and skills related to design and construction for natural stream channel restoration.

OSU, working with the University of Illinois and Oxford Geoscience (Oxford, MS), suggests how different stream orders should be repaired and what techniques would be most beneficial in reducing erosion. Specific recommendations for future streambank restoration and stabilization projects to consider include:

- ✓ the impact moisture content and a series of high-flow events have on streambank stability when considering stabilization methods to consider
- ✓ protection to prevent erosion of gravel subsoils; larger streams will require more resistive toe protection because of the large shear stresses at the toes
- ✓ combining young plantings with other stabilization techniques during restoration to make up for the limited tensile strengths of young, immature vegetation
- ✓ larger streams may be more costly to restore, but the water quality benefits may be greater because they generally have thicker silt-loam layers on the streambanks, which may contribute a large sediment load (particularly silts and clays)
- ✓ CONCEPTS modeling predicts that grade control measures may be more effective for lower-order streams, while hard armoring may be more effective on higher-order streams; this is also supported by the slope distribution mapping, which shows that the lower order streams generally had greater slopes.

However, no clear and general demarcation in terms of channel instability between different Strahler orders can be made, since channel instability depends on a feedback between planform configuration, hydrodynamics, bank erodibility, and spatial/temporal floodplain properties that is specific to the river of interest.

In general, Oklahomans are willing to pay an additional $85.63 for revegetated streambanks and over $16 for improvements in water clarity and increases in-stream species. However, they think they should be compensated by over $140 per year for decreases in water quality that make the water unsafe for wading and swimming. This shows that Oklahomans do place value on its water for recreational purposes and for maintaining water quality.

The state of Oklahoma's design-build best-value bid process was utilized and worked very well for this project. By using this process the designer and builder submitted one bid for both aspects of the work. This meant the designer and contractor would work together during the entire project. This also meant that the designer was onsite during construction to address any unexpected issues that might result in a change to the design. This project would not have been completed on time and within budget if we had not utilized the best-value design-build process.

Eleven sites totaling 6,657 feet were restored (very close to the ambitious 7,000 feet goal in the proposal), and construction was completed in four and a half months. The techniques used to restore the sites involved using local materials, mostly harvested on site or from a nearby quarry.

The contractor was from outside Oklahoma; however, this work had a large impact on the local economy. All equipment was rented from an Oklahoma company located in Muskogee, and the crew stayed in Tahlequah hotels and ate locally as well.

In addition to the streambank restoration prioritization and implementation activities, 21 outreach activities were completed that educated and/or trained over 1250 individuals on the principles and techniques of natural stream restoration. This also included a web site, one television show segment, one television news report, and four newspaper articles, all of which the number of contacts cannot be easily quantified.

This project has been successfully completed on time and within budget. The project team believes that this work has laid the groundwork for an expanding industry of natural stream restoration within Oklahoma. We are also very excited about the economic and environmental impact that the completed and future stream restoration projects can have in Oklahoma.

4.0 INTRODUCTION

4.1 BACKGROUND

Streambank instability and resulting erosion is a widespread problem throughout Oklahoma (Figure 1). Channel alterations, riparian degradation, increases in livestock or human traffic, and changes in land use have all contributed to bank instability.

Figure 1. Streambank erosion is a problem in urban and rural areas throughout Oklahoma.

Bank erosion can contribute significantly to sediment loading in streams and downstream reservoirs. In some systems, streambank erosion is estimated to be the most significant source of sediment. This sedimentation drowns or at least destabilizes fish habitat, contributes to downstream bank erosion, and can affect reservoir storage capacity. However, bank erosion can also contribute significantly to pollutant loading. Streambank sediments are often higher in nutrients and other pollutants than upland soils because of the role of riparian areas as a buffer zone. In the Peacheater Creek watershed in northeastern Oklahoma, streambank erosion was estimated to contribute between 15 – 110% of the phosphorous loading measured in the stream. Thus, erosion of streambank material may contribute more significantly to pollutant loading than erosion of an equivalent volume of material from upland areas.

Many efforts have been initiated to address the causes and sources of nonpoint source pollution in Oklahoma. These include education programs to increase awareness of the problem and encourage people to voluntarily change habits that can result in nonpoint source pollution. Efforts also include the implementation of best management practices to reduce the causes of nonpoint source pollution through things such as cost-share programs where the landowner contributes a portion of the cost of installation in order to better insure their commitment to maintenance of the practice.

While programs that implement best management practices in Oklahoma have proven successful much of the effort has focused in upland areas. Riparian areas have received lower levels of funding and even less funding is focused on activities that protect actively eroding streambanks. Riparian area protection can reduce pollutant loading by up to 90% while many other practices have a rate of 30 – 50%. This oversight is not due to the lack of significance of streambank erosion or to the lack of desire to address the problem, but related more to the cost of streambank erosion repair and the availability of experts who are trained to address the problems.

OSU and the Oklahoma Conservation Commission (OCC), as a result of working together on similar projects, possess the expertise and experience necessary for successful completion of this project.

OCC and OSU used an environmentally sound approach that applies the principles of fluvial geomorphology to restore the stream system as close as possible to natural stream morphology. This approach uses locally available, natural materials such as boulders from nearby quarries, smaller rock from the stream itself, and trees that are used in the stream as part of a structure or used as transplants along the bank. The materials are used in a manner that moves the stream back to its original channel and rearranges the natural flow path to take pressure off erosional areas (Figure 2). In addition, streambank slopes are re-designed so that, as the water rises during storm events, its force spreads out onto the floodplain, thereby diminishing the destructive force, rather than remaining in the channel and further threatening downstream banks, bridges, roads, and other development. Following growth of vegetation, the stream site appears natural to the untrained eye. However, as a benefit, pollutant loading to the stream has been significantly reduced and both aquatic and terrestrial habitat have been significantly improved.

Figure 2. Stream being restored to its natural configuration by moving gravel and taking pressure off the bank

This approach differs from more commonly used approaches such as armoring the bank with riprap. Additionally, application of the principles of fluvial geomorphology using natural materials has been shown to be more successful at long-term stabilization and requires approximately one quarter to one half the cost of a conventional streambank protection approach. These methods also allow the streams to fully function as a stream. Streams and rivers that function well, with healthy aquatic ecosystems, bring benefits to the entire region such as:

- ✓ Better flood control
- ✓ Less trash in and around local watersheds
- ✓ Higher property values adjacent to these beautiful amenities
- ✓ Higher quality stream valley trail systems for recreation such as walking, birding, and biking
- ✓ Wider, more lush buffer areas along streams

- ✓ Reintroduction of wildlife species
- ✓ Better protection of wetland areas
- ✓ Improved aesthetics for clean and well-functioning waterways
- ✓ Stabilized streambanks
- ✓ Reduced local pollution, and reduced pollution flowing downstream
- ✓ Improved habitat for fish, amphibians, insects, and other aquatic organisms that compose a balanced ecosystem food chain
- ✓ Cooler waters, which make it easier for fish to survive

To the extent feasible given the relatively short timeline of this project, the implementation of the restoration activities was timed towards low-flow conditions in order to minimize the impact of construction. The implementation is permitted through the U.S. Army Corps of Engineers and the Oklahoma Department of Environmental Quality as required to ensure that appropriate environmentally protective measure were taken and the design concepts structurally sound.

This project is critical to restoring and protecting water quality but also plays an important role in the local economy. This project input revenue into the local community by providing revenue to the local hotel industry, restaurants, equipment rental businesses, local hauling contractors and the local quarry. In addition, this project helped secure employment for staff at both the Oklahoma Conservation Commission and Oklahoma State University. This funding also served as match for the Conservation Reserve Enhancement Program (CREP) which increased the size of the program by at least $8 million. Three landowners enrolled in the CREP program as a result of this project, which will further protect and improve the water quality in the area. Another benefit will be the ability to sequester more carbon in the watershed due to the re-establishment of riparian buffers. These practices will help the State meet water quality goals and help reduce the impacts of climate change.

4.2 PROJECT AREA

The Illinois River and the Eucha/Spavinaw watersheds in northeastern Oklahoma are two of the State's highest priority watershed (Figure 3). Waterbodies in these watersheds serve as water supplies for the cities of Tulsa, Tahlequah, Jay and numerous other communities in the area. Reservoirs and numerous stream segments in these watersheds are listed on the State's Integrated Report as being impaired by nutrients and other related causes. As a result, State, Federal, Tribal and various other partners have focused efforts on improving water quality through upgraded wastewater treatment, nonpoint source controls, education, water quality monitoring, and numerous other cooperative efforts.

In particular, the U.S. Department of Agriculture Farm Services Agency, EPA Region 6, Oklahoma Conservation Commission, City of Tulsa, Oklahoma Scenic Rivers Commission (OSRC), the Delaware, Cherokee, and Adair County Conservation Districts, Natural Resources Conservation Service (NRCS) and other partners have begun various projects to address nonpoint source pollution to these waterbodies. These projects include transfer of poultry waste outside of the watersheds and other animal waste management techniques, improved pasture management, alternative water supplies, protection of riparian buffers, upgrading rural waste systems, and other practices to reduce nutrient, sediment, and bacteria loading to waterbodies.

While over $22 million has been directed to these watersheds, the focus has been on fencing livestock out of the streams and re-establishing the riparian areas and not on repairing actively eroding banks. The implemented practices will allow the streambank to passively erode to a stable configuration; however, this still involves active erosion and allows nutrients and sediment to continue to flow downstream exacerbating water quality problems before a stable configuration can be achieved. Therefore, active protection is necessary to adequately protect downstream waterbodies.

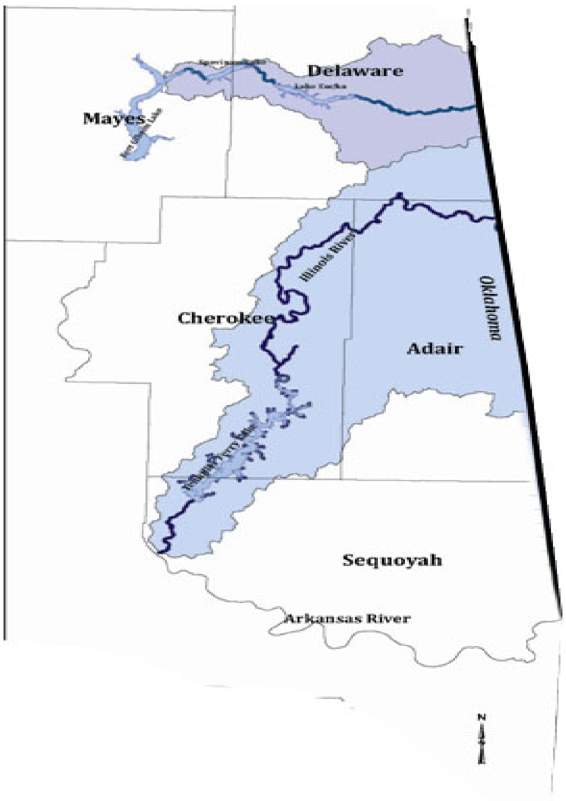


Figure 3. Eucha/Spavinaw and Illinois River Watersheds in Northeastern Oklahoma.

Another limitation to completion of stream channel restoration projects is that no single agency is responsible for completing or maintaining the projects and therefore, there is a lack of a centralized place to report streambanks in need of work. Oklahoma Cooperative Extension Service, Conservation Districts, NRCS, Oklahoma Department of Wildlife Conservation, OCC, U.S. Fish and Wildlife Service, and other agencies all receive requests for assistance from landowners who are concerned about eroding streambanks on their land. Although a number of agencies learn of potential sites, they don't always share these needs with other agencies or combine resources and cooperate to pursue funding to complete the work. In addition, agencies that complete stream channel restoration projects do not necessarily prioritize these projects based on need, likelihood of long-term stability, or potential load reduction due to implementation.

The objective of this project was to build a partnership of cooperating agencies to prioritize and implement stream channel restoration projects in the Eucha/Spavinaw and Illinois River Watersheds, with a goal of 7,000 linear feet of stream corridor restored. Agencies worked together to: 1) compile an initial list of potential restoration sites, 2) develop and implement a prioritization system based on current state of degradation, likelihood of long-term stability, ecosystem services preserved or created, and potential load reduction, 3) implement restoration projects at the selected sites that take advantage of local resources including expertise, tools, and natural materials, and 4) provide training so that local companies obtain knowledge and skills related to design and construction for stream channel restoration.

4.3 PROJECT TASKS

Task 1 – Compile a list of potential stream channel restoration sites from cooperating agencies

This list included stream name and legal information, length of the eroding bank, number of landowners involved, and other information as deemed necessary. The prioritization scheme from Task 2 was not able to be utilized for site selection for the project; however, the general prioritization variables utilized in Task 2 was utilized for site selection.

Task 2 – Develop a prioritization scheme to evaluate sites for potential restoration in the Eucha/Spavinaw and Illinois River Watersheds

While the Illinois River and Spavinaw Creek have a natural meander and high degree of sinuosity, changes in land use over the past 150 years may have resulted in accelerated rates of streambank erosion and lateral channel migration. These watersheds are characterized by cherty soils and gravel bed streams. The topsoil is typically a silt loam material but can be unstable when erosion of the underlying unconsolidated gravel leads to an undercut bank. For example, 48% of streambanks in the Eucha-Spavinaw watershed were classified as unstable based on available monitoring data (OCC, 2007.)

Subtask 2.1 – Geomorphic assessment procedure for prioritizing stream channel restoration sites

The first objective of this subtask was to conduct Rapid Geomorphic Assessments (RGAs) for stream sites on the Illinois River and Spavinaw Creek and their tributaries to develop a methodology to help determine the most beneficial location(s) to implement stream restoration projects. After taking quantitative and qualitative measurements on several reaches at five stream sites, bank erosion index (BEHI) and channel stability index (CSI) RGA was calculated to estimate the likelihood that each reach would be unstable. A new RGA would then be developed specifically for assessing streams in the Ozark ecoregion.

The second objective of this subtask was to characterize channel stability using high-speed video for approximately 150 stream miles of 3rd and 4th order streams. Data for 2nd order streams was collected from the ground. Results would be mapped and used to help parameterize a preliminary RVR Meander model enhanced with stream bank erosion algorithms from the USDA CONservational Channel Evolution and Pollutant Transport System (CONCEPTS) channel evolution model. Estimates for other required parameters would be based on available data or from the literature. The preliminary RVR Meander model would be used to identify 48 potential sites for detailed data collection and site characterization. Selection criteria included the distribution of sites in the fluvial network, spacing between sites, accessibility and landowner permission for detailed data collection, and relative channel stability.

Subtask 2.2 – Determining optimal stream order for streambank restoration implementation

The objective of this subtask was to evaluate the long-term effectiveness of streambank restoration projects in various regions of the watersheds. Detailed stream reach data would be collected at 48 sites identified in Subtask 2.1 Data required to populate the CONCEPTS model would be collected at these 48 sites. These data include the erodibility of the surface materials and the geotechnical strength of the streambank materials. Erodibility of cohesive materials would be determined through in situ testing using a submerged jet-test device. A minimum of two jet tests were conducted on each surface which may include bank-toe materials and various layers encompassing the streambank. If the materials were non-cohesive, erodibility would be determined based on the materials' particle-size distribution. Geotechnical strength (cohesion and friction) would be determined in each bank layer using a Borehole Shear Tester (BST). A core sample would also be collected within each layer, tested for ambient pore-water pressure, and used to characterize moisture content and bulk unit weight of the material. Bulk samples would be collected from each surface and in-situ material for determining particle-size distribution. Finally, a survey of each cross section would be obtained.

Subtask 2.3 – Valuation of ecosystem services and other benefits of potential water and ecosystem improvements from stream restoration practices in northeast Oklahoma

The objective of this subtask was to conduct on-site and mail surveys to determine values on ecosystem support services. Benefits from water use in Eucha/Spavinaw and Illinois River basin surface waters include municipal, domestic, industrial, agricultural, recreation, and other environmental benefits. Some of the uses for water such as recreational and wildlife do not have easily quantifiable or tangible values in the marketplace. Infrastructure investment in stream bank erosion and reducing nutrient loads can be costly, thus prioritizing potential benefits in terms of the types of benefits and the location of benefits can help to target resources most efficiently. This information would be used to inform policymakers and stakeholders of tradeoffs between competing uses of funds for environmental improvement.

Task 3 – Select sites for stream channel restoration

Prioritization of these sites also had to consider time allotted in this funding window. For this reason, certain high priority projects may be passed over for funding at this time due to time limitations and other complications. OCC obtained site permissions from all site owners selected for this project.

Task 4 – Implement stream channel restoration projects

The design, permitting, and capital construction for the restoration activities would be subcontracted to a qualified private firm. Bioengineering techniques would be used to repair the selected sites. Techniques used included installation of rock and log vanes, bank sloping and brush toes. In addition, revegetation would be done on each of the sites using native plants and grasses. Working together, all of these techniques would help restore the stream area to a more natural state and reduce erosion.

Task 5 – Complete pre- and post-implementation monitoring

The OCC was responsible for pre- and post-implementation monitoring of habitat and fish and macro-invertebrate population at the stream channel restoration sites. Pre-implementation fish and habitat assessment data collected at these sites will be compared with post implementation data, one year after completion, to document local impacts to the aquatic community from these improvements. An appropriate Quality Assurance Project Plan (QAPP) was completed and approved, with OWRB as the lead agency for approval.

Task 6 – Outreach

An important aspect of this project was to educate and train local stakeholders, engineers and contractors on the techniques used in the stream channel restoration projects so that after they are completed the local expertise exists to continue to restore more Oklahoma streams using the methods developed and demonstrated during this project. Therefore, four workshops were developed and delivered through the Oklahoma Cooperative Extension Service (OCES) to provide this training. Additionally, a series of videos was developed that can be delivered online and/or on DVD for future education by OCES and others.

Task 7 – Reporting

Project reporting included necessary annual reporting as required by the program, including quarterly, semi-annual or annual reports and concludes with this final report summarizing implementation work completed and potential impacts to water quality.

5.0 TASKS AND ACCOMPLISHMENTS

Task 1 – Compile a list of potential stream channel restoration sites from cooperating agencies

Several Oklahoma agencies, including the Oklahoma Conservation Commission, Oklahoma Department of Wildlife Conservation, Oklahoma Department of Transportation, Oklahoma Scenic Rivers Commission and the City of Tahlequah, identified 45 sites that might benefit from stream channel restoration. Below is a table (Table 2) of those initial sites. Ultimately the list was narrowed down to 12 sites as outlined in Task 3.

Table 2. List of 45 potential restoration sites

Descriptor	Stream Order	Stream	County	Approximate Size in Linear Feet
Private Property	1	Evansville Creek	Adair	100-1,000
Private Property	1	Unnamed tributary to Town Branch Creek	Cherokee	500
Kaufman Park	1	Unnamed tributary to Town Branch Creek	Cherokee	250
Head of History Trail Park	2	Town Branch Creek	Cherokee	300
Northeastern State University	2	Town Branch Creek	Cherokee	700
Sequoyah Park	2	Town Branch Creek	Cherokee	300
Ross Park	2	Town Branch Creek	Cherokee	500
Felts Park	3	Town Branch Creek	Cherokee	500
Private Property	2	Hogshooter and Cherokee Creeks	Delaware	700
Cherokee Nation	2	Dry Creek	Delaware	6 acres
Private Property	2	Tyner Creek	Adair	230
Private Property	3	Beaty Creek	Delaware	700
Private Property	3	Beaty Creek	Delaware	1,000
Private Property	3	Beaty Creek	Delaware	1,000-2,000
Private Property	3	Flint Creek	Delaware	1,500
Private Property	3	Flint Creek	Delaware	2,900
Private Property	3	Ballard Creek	Adair	doesn't show on aerial
Multiple Landowners	3	Beaty Creek	Delaware	
Multiple Landowners	3	Cloud Creek	Delaware	Unknown
Private Property	5	Barren Fork Creek	Cherokee	200-300
Private Property	5	Barren Fork Creek	Cherokee	450
Private Property	5	Barren Fork Creek	Cherokee	660
Private Property	5	Barren Fork Creek	Cherokee	660
Private Property	4	Spavinaw/Hog Eye Creek	Delaware	800
Private Property	5	Barren Fork Creek	Cherokee	1,900
Private Property	5	Barren Fork Creek	Cherokee	1,600
Private Property	4	Barren Fork Creek	Adair	2,020
Private Property	4	Barren Fork Creek	Adair	2,100
Private Property	4	Spavinaw/Cloud Creek	Delaware	3,257
Private Property	4	Spavinaw Creek	Delaware	3,800
Private Property	4	Spavinaw Creek	Delaware	6,700 feet north side; 7,000 feet

				south side
Private Property	4	Baron Fork and Tyner	Adair	3/4 mi. in one place and 1 1/4 mi. in another
Private Property	4	Barren Fork Creek	Adair	doesn't show on aerial
Private Property	6	Illinois River	Cherokee	200
OK Dept of Transportation, SH-10 @ Echota Bend boat ramp	6	Illinois River	Cherokee	250
Private Property	6	Illinois River	Adair	200-400
Stunkard Public Access Area	6	Illinois River	Cherokee	300-400
Peavine Public Access Area	6	Illinois River	Cherokee	300-400
Private Property	6	Illinois River	Cherokee	500
Private Property	6	Illinois River	Adair	500-750
Todd Public Access Area	6	Illinois River	Cherokee	660
OK Dept of Transportation, SH-10 @ Hanging Rock	6	Illinois River	Cherokee	1000
OK Dept of Transportation, SH-10 just north of US-62	6	Illinois River	Cherokee	1,500
Private Property	6	Illinois River	Cherokee	1,500-2,000
Private Property	6	Illinois River	Cherokee	1,750

Task 2 – Develop a prioritization scheme to evaluate sites for potential restoration

Subtask 2.1. Geomorphic Assessment Procedure for Prioritizing Stream Channel Restoration Sites – Rapid Geomorphic Assessments

Summary

High streambank erosion and failure rates on streams in the Ozark ecoregion of Oklahoma may be attributed to land use change and degradation of riparian areas. Numerous benefits may be achieved from streambank stabilization, but methods are needed to determine the most critical reaches for investing limited funds. Rapid geomorphic assessments (RGAs) have been used to aid in prioritizing stream reaches. This project (1) applied an existing RGA, the channel stability index (CSI), on several reaches along the Barren Fork Creek and Spavinaw Creek, and (2) modified the existing RGA to create an ecoregion-specific RGA called the Oklahoma Ozark streambank erosion potential index (OSEPI) for larger-order streams in the area. Aerial photography (2003 to 2008) was used to document recent lateral bank retreat for evaluating the RGA scores. Whereas the CSI provided a relatively simple, inexpensive way to identify reaches that should be further evaluated for stability, it failed to disaggregate unstable stream reaches. Limitations included not considering the streambank's cohesion and the difficulty in assessing some metrics. The OSEPI, which included

parameters to account for the streambank's cohesion and stream curvature, and had higher correlation with recent streambank erosion. These results indicate promise for the use of OSEPI in prioritizing reaches for future stabilization projects in the Ozark region of Oklahoma.

FIELD DATA COLLECTION AND ANALYSIS

Methodology

The methodologies employed in this study encompass a tiered approach, consisting of aerial reconnaissance techniques over broad areas to determine relative channel stability and intensive data collection at selected sites to quantify hydraulic and geotechnical resistance of the boundary sediments. Evaluations of relative channel stability were determined every one-mile of approximately 150 miles of channels and intensively at 47 sites selected by OSU. Intensive site selection was based on landowner permission and geographical location, to achieve even spatial distribution throughout the study area of the Illinois River and Spavinaw Creek stream systems. In all, 47 sites were selected for detailed *in-situ* testing of geotechnical bank properties (Table 3), the locations of which are illustrated in Figure 4.

Table 3. Distribution of intensive field sites where hydraulic and geotechnical resistance of the boundary sediments were measured.

Channel	Number of Sites
Barron Fork	5
Beaty Creek	2
Brush Creek	2
Flint Creek	3
Illinois River	4
Spavinaw Creek	4
Town Branch	4
Single-site, named tributaries	7
Unnamed tributaries	16

Estimating Percent Reach Failing using a modified Rapid Geomorphic Assessment

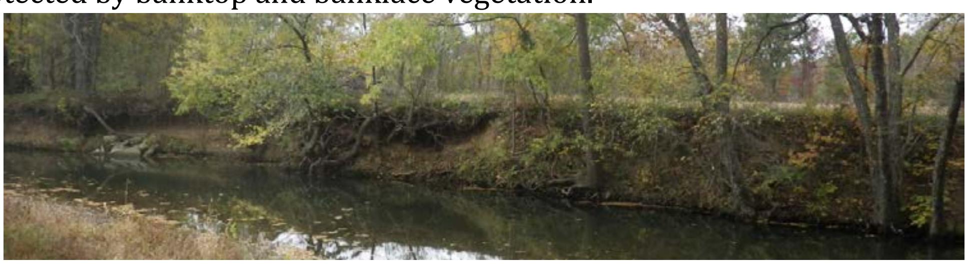
Reaches of the Illinois River and Spavinaw Creek stream systems were video recorded from a low-flying helicopter. Video recorders were geo-referenced with GPS enabling accurate determination of locations. From these videos it was possible to characterize active geomorphic processes and relative stability along different sections of the study reach, by observing bank failures, and areas of significant aggradation. Modified Rapid Geomorphic Assessments (RGAs; Bankhead and Simon, 2009) were conducted for two-kilometer reaches, establishing the longitudinal extent of recent streambank failures. This was quantified as the percent of the reach failing as estimated from the video taken during air reconnaissance. These percentages were broken into classes (0-10%, 11-25%, 25-50%, 51-75% and 76-100%) and used as a measure of the severity of bank instability. The distribution and extent of such bank instability can be visualized when classes are mapped. Photographs showing example reaches in these percent reach-failing classes are shown in Figure 5.

Figure 4. Location map of intensive field sites where geotechnical bank properties were investigated.

1. 11 to 25 % reach failing – localized failures occurring in this reach.

2. 26 – 50 % reach failing – failures are noticeable but do not dominate the reach.

3. 51 to 75 % reach failing – parts of this outer bendway are eroding, where not protected by banktop and bankface vegetation.



4. 76 – 100 % reach failing – in this photo, the entire outer bank is eroding through mass failure.

Figure 5. Examples of different percent reach-failing classes at various locations throughout the study area along the Illinois River and Spavinaw Creek stream systems.

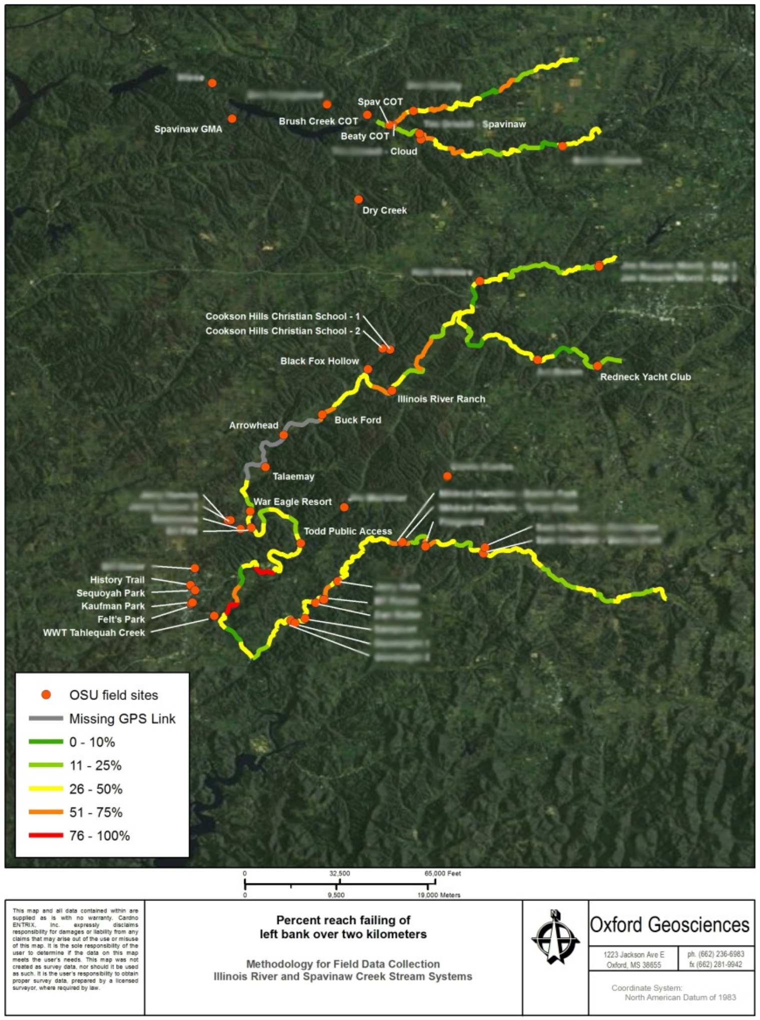
In-Situ Field Data Collection

As bank stability is a function of the strength of the bank material to resist collapse under gravity, measurements of the components of shearing resistance (or shear strength) were required. *In-situ* tests of the shear strength of bank materials at intensive sites were conducted using a Borehole Shear-Test device (BST; Lohnes and Handy, 1968). In addition, tests of the resistance of cohesive bank-toe materials to erosion by flowing water were carried out using a jet-test device (Hanson, 1990), or from the median particle size in the case of non-cohesive materials. Bank surveys were conducted at each site.

Results: Percent Reach Failing

The percent of each 2 kilometers reach with observed failures evaluated during aerial reconnaissance was plotted both on maps and graphically. The severity of erosion was broken in to five separate classes as a percentage of the two kilometers with observed mass wasting. Dark and light green (0 – 10% and 11 – 25% respectively) were representative of areas with no to little erosion present. Yellow was for areas of moderate erosion (26 – 50%), though not dominant, and orange and red signified areas of dominant or extremely high (51 – 75% and 76 – 100%) amounts of erosion over the length of the reach.

Maps of the two banks individually indicate very few 'hot spots' on the lower Illinois River where the greatest occurrences of mass failures (red) were present (Figure 6). When both banks are combined for average percent reach failing, the study area is dominated by moderate (yellow) amounts of mass wasting presently (Figure 7). The approximate average of all banks is 36%. This indicates for a given two kilometer reach, on average, one could expect a third of the banks to be actively eroding. Looking at trends moving along the channel, all streams but Flint Creek appear to be more stable as you move upstream (Figure 8). Flint Creek appears to be fairly consistent across the entire reach. The lower portion of the Illinois River appears to have more areas where erosion exceeds 50% for the reach then the rest of the River and the other reaches.



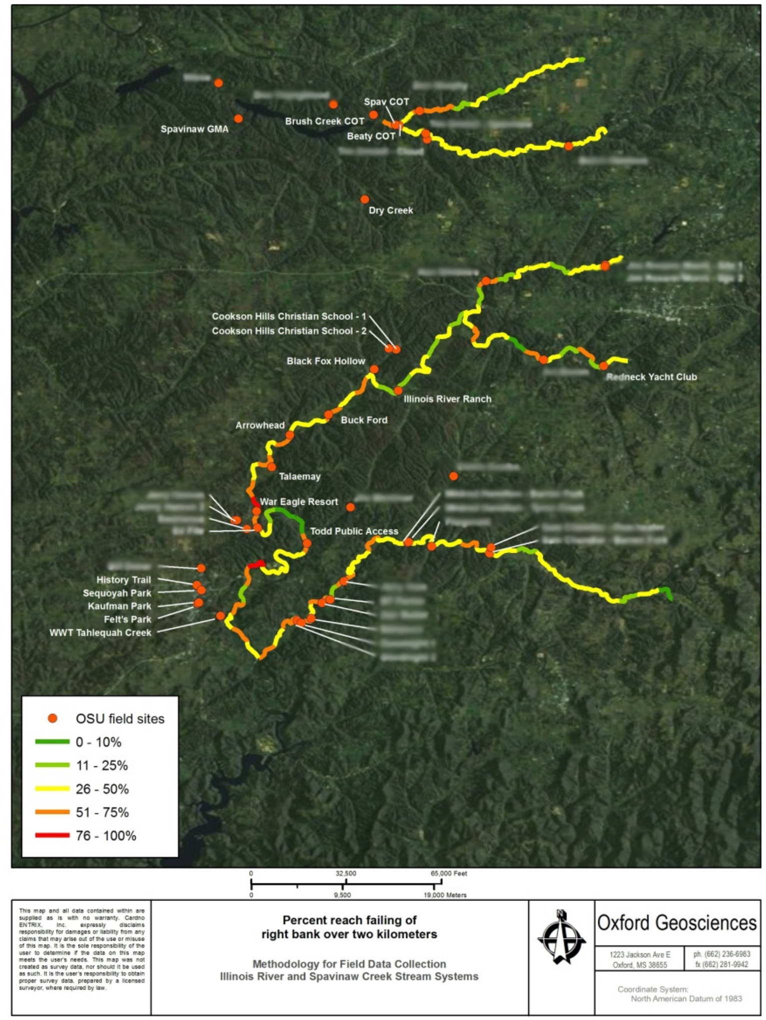


Figure 6. Left and right bank failures illustrate 'hot spot' areas of mass failure within the study reach.

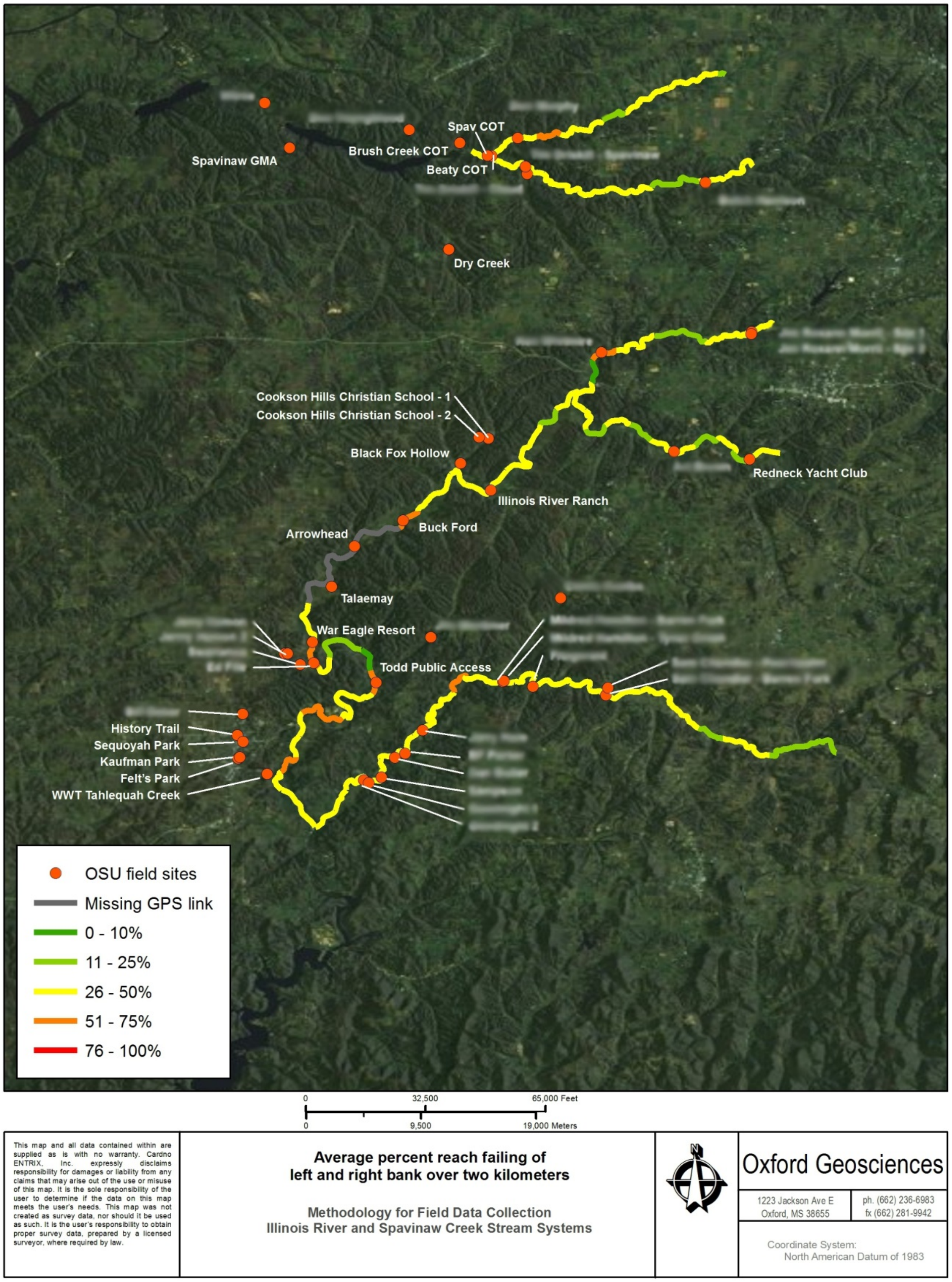


Figure 7. Average percent reach failing of left and right bank over two kilometer reaches. 26-50 % mass failure dominates the study area.

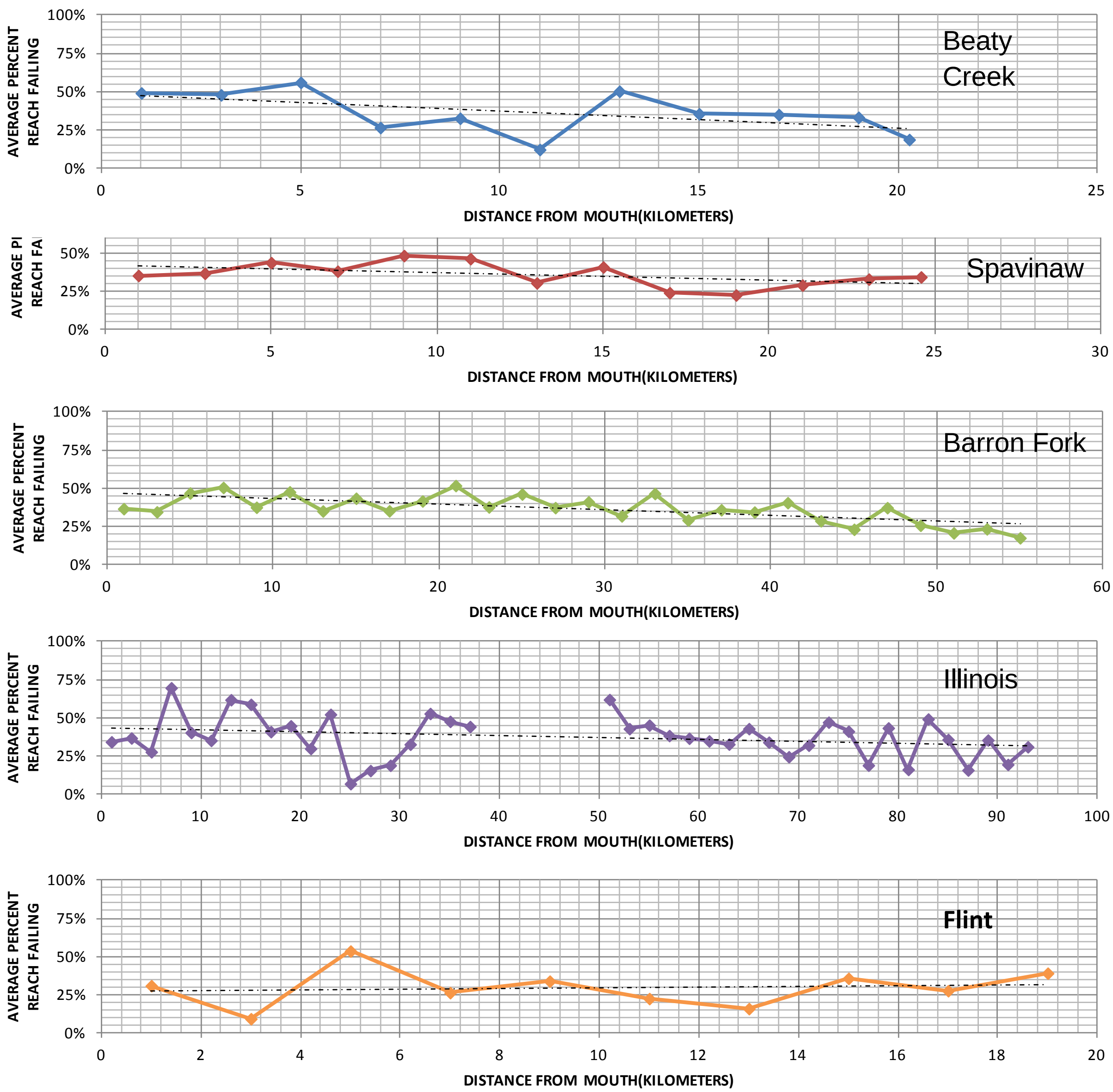


Figure 8. Average percent reach failing of left and right bank over two kilometer reaches for each channel flown using GPS-based aerial reconnaissance.

Conclusions

Two RGAs, the channel stability index (CSI) and the newly developed Oklahoma Ozark streambank erosion potential index (OSEPI), were used to assess potential stream stabilization reaches in the Ozark ecoregion of Oklahoma. OSEPI, a modified RGA, was proposed specifically for the Ozark ecoregion and did not include variables that were relatively homogenous throughout the region (e.g., streambed material and degree of constriction). Note that stage of the channel evolution model may be required in future applications of OSEPI when assessing streambanks across a range of stream orders. Therefore, OSEPI should not be used outside of this region without further testing. Twenty-three reaches at five sites were assessed and ranked according to each RGA to assess current streambank stability and aid in reach selection for streambank stabilization projects. Both RGAs met their intended purpose; they provided relatively simple, inexpensive, and quick ways to identify reaches that should be further evaluated for instability. The RGA scores from the CSI and OSEPI produced relatively poor relationships with recent lateral bank retreat estimates from aerial photography for all surveyed reaches, with R^2 of 0.21 and 0.29, respectively. Removing reaches unique in streambank soil type and stratification increased the R^2 value to near 0.45 for OSEPI. In general, OSEPI had the better correlation to streambank retreat, achieved a broader range of scores, and therefore better aided in differentiation among reaches.

References

ASTM, 1995. Annual Book of ASTM Standards: Section 4, Construction, v. 04-09. American Society for Testing and Materials: West Conshohocken, PA.

Bankhead, N. and Simon, A. 2009. Analysis of bank stability and potential load reduction along reaches of the Big Sioux River, South Dakota. USDA-ARS National Laboratory Technical Report No. 64.

Hanson, G. J. and Simon, A., 2001. Erodibility of Cohesive Streambeds in the Loess Area of the Midwestern USA. Hydrological Processes. Volume 15(1), 23-38 p.

Hanson, G. J., 1990. Surface Erodibility of Earthen Channels at High Stresses. Part II - Developing an in-situ testing device. Transactions of the ASAE. Volume 33(1): 132-137

Hanson, G.J., and Cook, K.R., 1997. Development of excess shear stress parameters for circular jet testing, American Society of Agricultural Engineers Paper No. 97-2227. American Society of Agricultural Engineers: St. Joseph.

Hoek, E. and Bray, J.D., 1977. Rock Slope Engineering. Spon Press. pp368.

Little, W. C., Thorne, C. R. and Murphy, J. B., 1982. Mass Bank Failure Analysis of Selected Yazoo Basin Streams. Transcripts of the American Society of Agricultural Engineering. Volume 25, 1321-1328 p.

Lohnes, R. A. and Handy, R. L., 1968. Slope Angles in Friable Loess. Journal of Geology. Volume 76(3), 247-258 p.

Lutenegger, J.A., and Hallberg, B.R., 1981. Borehole shear test in geotechnical investigations. ASTM Special Publication 740, 566-578.

Simon, A., Pollen-Bankhead, N. and Thomas, R.E., 2011. Development and Application of a Deterministic Bank Stability and Toe Erosion Model for Stream Restoration. In: Simon, A., S.J. Bennett, J. Castro and C.R. Thorne (eds.), Stream Restoration in Dynamic Systems: Scientific Approaches, Analyses, and Tools. American Geophysical Union: Washington.

Thorne, C.R., Murphey, J.B., and Little, W.C., 1981. Bank stability and bank material properties in the bluffline streams of Northwest Mississippi, Stream Channel Stability, Appendix D, Section 32 Program, Work Unit 7, U. S. Army Corps of Engineers, Vicksburg District: Vicksburg, Mississippi.

Subtask 2.1. Geomorphic Assessment Procedure for Prioritizing Stream Channel Restoration Sites – Preliminary RVR Meander Model

Summary

The main objective of this task was the development of a methodology to discriminate the level of protection against stream-bank erosion needed by stream order within the Illinois River and Spavinaw Creek watersheds in northeastern Oklahoma. Drainage network and Strahler order of all streams (Figure 9) were obtained from the National Hydrography Dataset Plus (NHDPlus) database (http://www.horizon-systems.com/nhdplus/HSC-wthMS.php). The principal Strahler order for Illinois River and Spavinaw Creek watersheds are, respectively, 6 and 4. Three different analyses were conducted as follows:

(1) Investigation of how channel planform metrics, channel bathymetric metrics, and meander stability change for varying Strahler order or drainage area;
(2) Investigation of how bed and bank material, bank erodibility, channel stability ranking, and geotechnical properties of banks change for varying Strahler order or drainage area; and
(3) Simulations with the river model RVR Meander (Motta et al., 2012) to produce two-dimensional hydrodynamic fields for the analysis by Oklahoma State University, to calibrate the critical shear stress of the toe bank material, and to define general migration trends for a subset of streams, characterized by a Strahler order from 2 to 6.

None of these methods allowed for the identification of a clear and general priority order in terms of channel instability for streams having different Strahler order. Planform analysis, based on the computation of the dominant curvilinear wavelength of the channel centerlines through Fourier analysis and application of the stability criterion proposed by Johannesson and Parker (1985) showed that all streams considered in the study are potentially unstable, i.e. their bends tend to grow. Analysis of maxima of centerline curvature signals did not provide any significant trend. In terms of bank erodibility, characteristics of the material at the toe of the banks (mostly gravel), which control the fluvial erosion of the banks, are similar throughout the Strahler orders.

RVR Meander simulations showed that channel instability depends on the interaction between planform configuration, hydrodynamics, bank erodibility, and spatial/temporal floodplain properties which is specific to the river of interest. In other words, all reaches analyzed present locations of potential bend instability, which can manifest or not according to local soil erodibility and bank and floodplain vegetation cover. In particular, it appears from aerial pictures that vegetation distribution may play an important role in mitigating or even stopping meander bend migration and could possibly be used as criterion to identify areas of intervention.

Hydrodynamic and meander migration computation on a river-by-river basis, supported by hydrodynamic data for validation of the computed flow field and detailed description of soil and vegetation distribution along the stream banks and on the floodplain, should guide future efforts to delineate a priority for bank protection intervention in the Illinois River and Spavinaw Creek watersheds in northeastern Oklahoma.

Watershed Description

Illinois River and Spavinaw Creek watersheds (Figure 9) lay in both Arkansas and Oklahoma. The Illinois River is a tributary of the Arkansas River and its drainage area is about 4,300 km^2. Spavinaw Creek drains approximately 1,050 km^2 in Arkansas and Oklahoma, of which 60% is in Oklahoma, and is a tributary of the Neosho River, which in turn is a tributary of the Arkansas River.

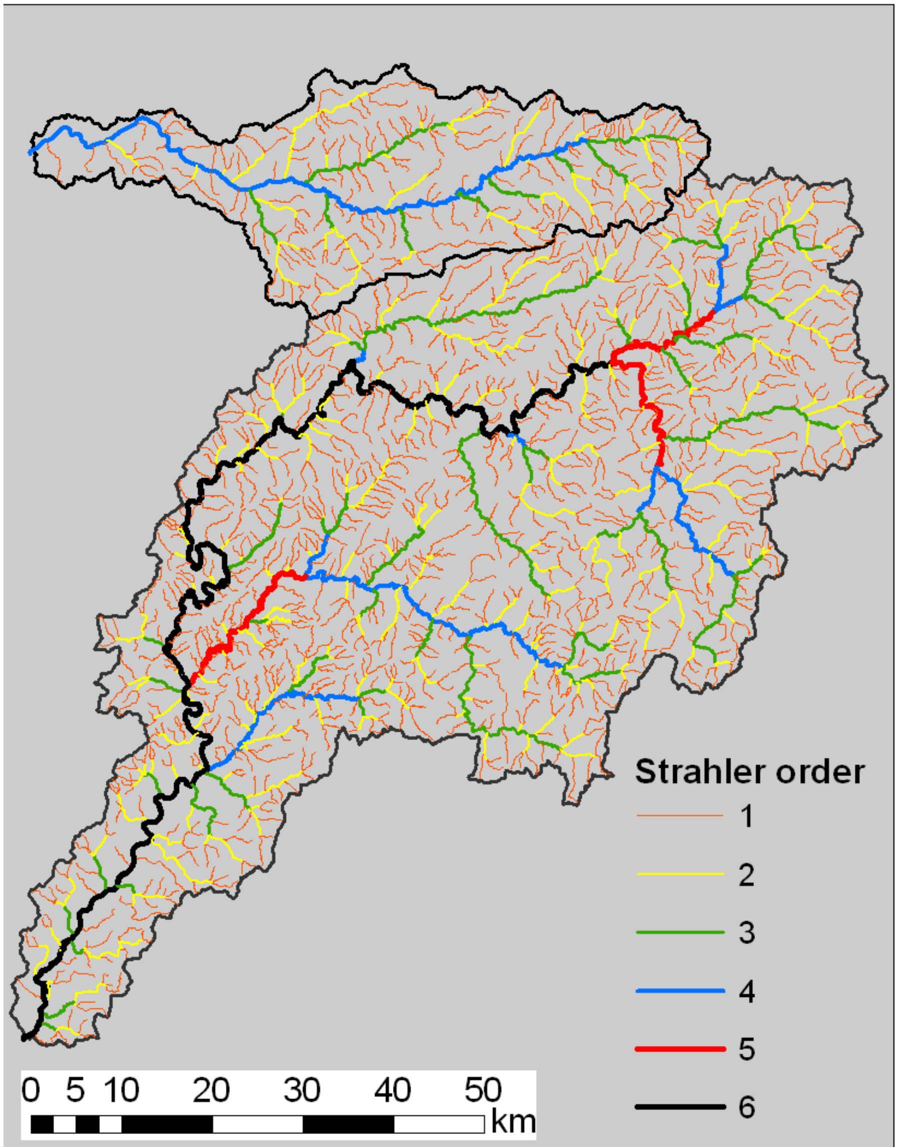


Figure 9. Strahler order of the streams in the Illinois River's and Spavinaw Creek's watersheds. Values are from NHDPlus database.

Hydrologic Data

From analysis of flows at all the USGS stations in the two watersheds, power-law fits were derived for mean annual, 50th and 99th percentile discharges against drainage area (Figure 10). It was assumed, from literature, that bankfull discharge (used in planform stability and meander-migration computations) is equal to the 99-th percentile discharge.

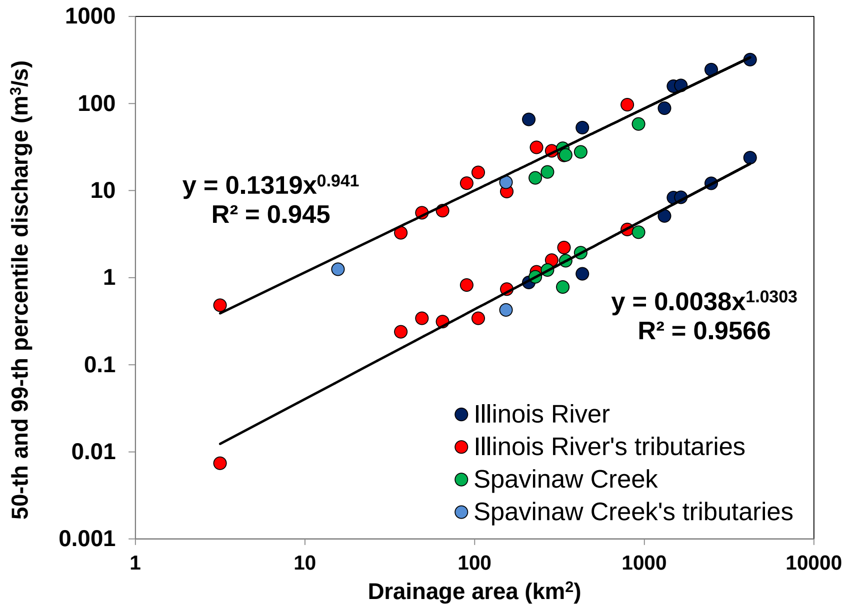


Figure 10. 50th and 99th percentile discharge against the drainage area.

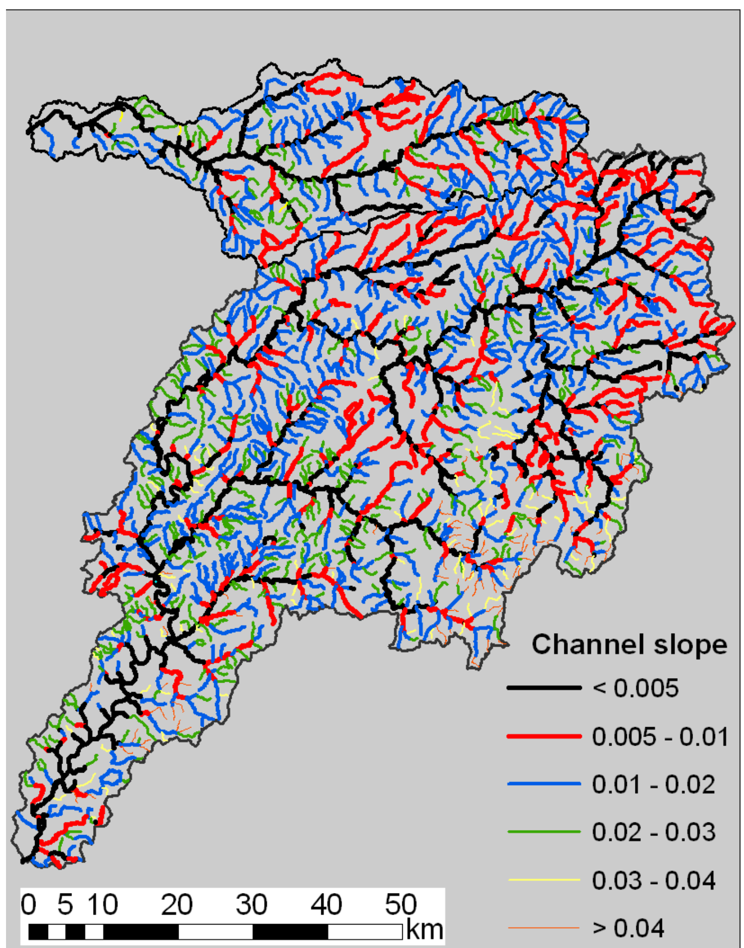


Figure 11. Channel slope of the streams in the Illinois River's and Spavinaw Creek's watersheds. Values are from NHDPlus database.

Topographic Data

Channel slopes of the streams in the two watersheds were obtained from the NHDPlus database (

). As expected, slope decreases for increasing order. Furthermore, pattern and values are very similar for the two watersheds.

Field Characterization

Ground-based data were collected in three phases between October 2011 and May 2012 by Oxford GeoSciences and OSU (first phase) and OSU only (second and third phases) at 37 locations in the Illinois River watershed and 11 locations in the Spavinaw Creek watershed. Data collected at those locations included cross section and slope characterization, sediment characterization for bed and banks, critical shear stress and erodibility of bank material (using jet tests), cohesion and friction angle of bank material (using borehole shear tests), matric suction angle of bank material, channel stability ranking, and photographs. In addition, channel geometry parameters were available for 48 riffle sections in the Illinois River and 14 riffle sections in the Beaty Creek, which is a tributary of the Spavinaw Creek (Figure 12).

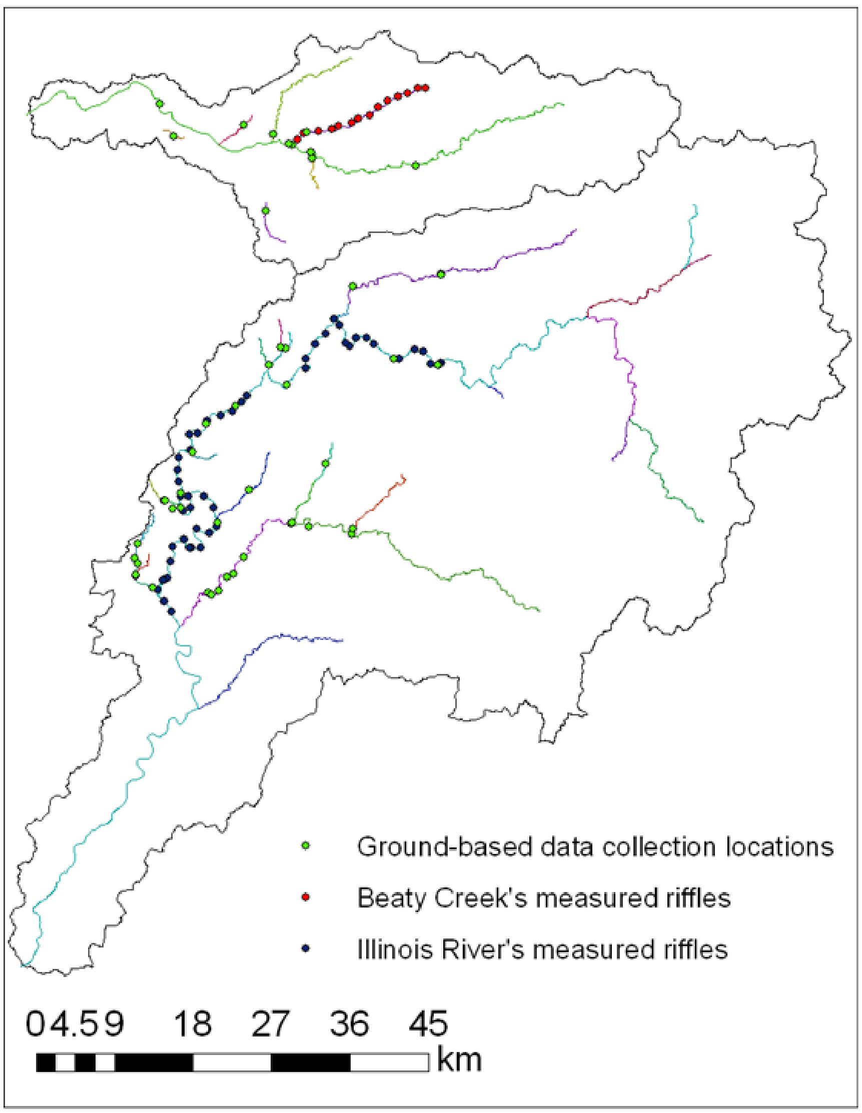


Figure 12. Streams of interest and locations of ground-based data collection and riffle measurement.

Results

Analysis 1: Planform, bathymetric, and stability characteristics as function of Strahler order and drainage area

In order to discriminate the level of protection needed by stream order within the Illinois River and Spavinaw-Creek watersheds in northeastern Oklahoma, three analyses were carried out. In this section, a study of 35 streams (all streams where ground-based data were collected, plus all 4th- and 5th- order streams where ground-based data were not collected) was carried out to investigate how channel planform metrics (length, curvatures, dominant centerline wavelength), channel bathymetric metrics (slope, bankfull width), and meander stability change for varying Strahler order or drainage area. Data obtained from this analysis were also used in the meander-migration simulations. There is a strong correlation between bankfull width (Figure 13) and bed slope (Figure 14) and drainage area.

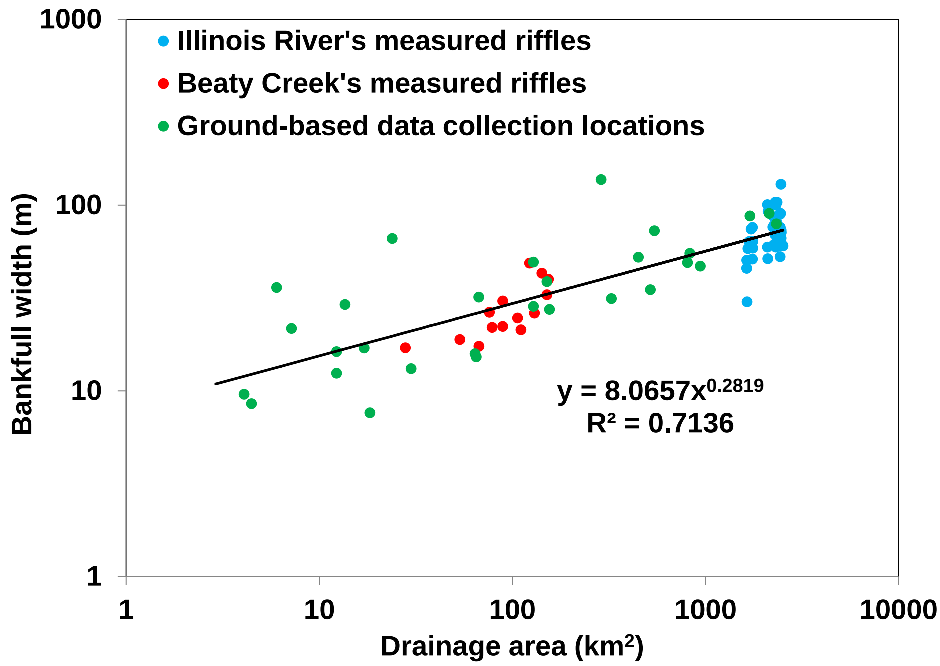


Figure 13. Bankfull width vs. drainage area. Each point corresponds to a ground-based data collection location or a riffle location on Illinois River or Beaty Creek.

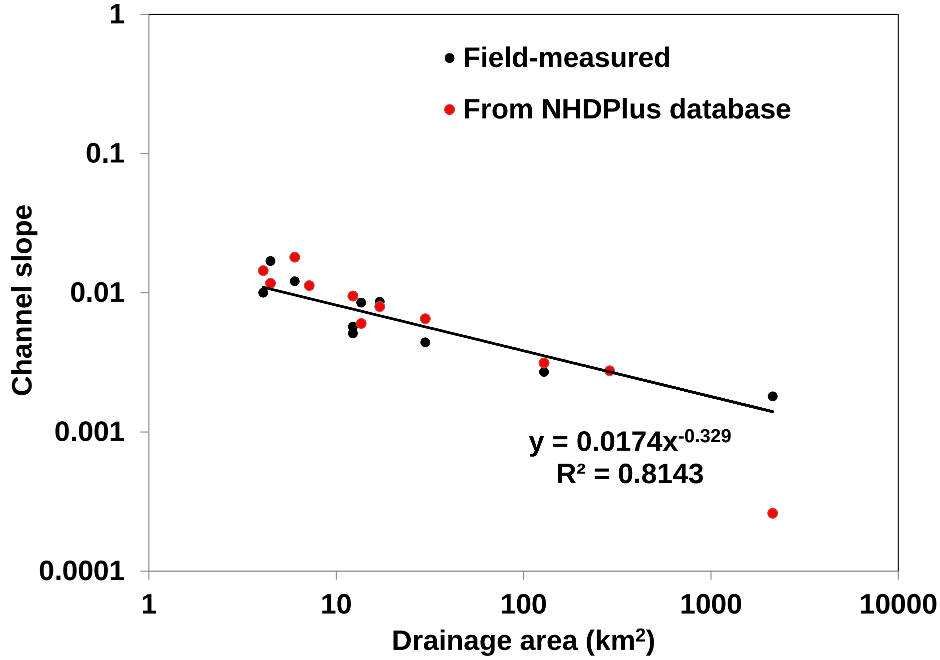


Figure 14. Stream slope vs. drainage area. Each point corresponds to a ground-based data collection location. The power-law fit is relative to the field-measured slopes.

The dominant curvilinear wavelength of centerlines, extracted using Fourier analysis, presents a general tendency to increase for increasing drainage area at the downstream end of the stream (Figure 15). The stability criterion by Johannesson and Parker (1985) shows that all streams considered are potentially unstable, i.e. their bends tend to grow (Figure 16). It is therefore not possible, with this analysis, to delineate a priority of bank protection intervention. Note that this analysis does not take into consideration the erodibility of banks and floodplain soils, which is instead done in Analysis 3. There is also a weak correlation between maximum curvature and drainage area at the downstream end of the stream. Therefore, curvature only cannot be taken as indicator for judging stream stability.

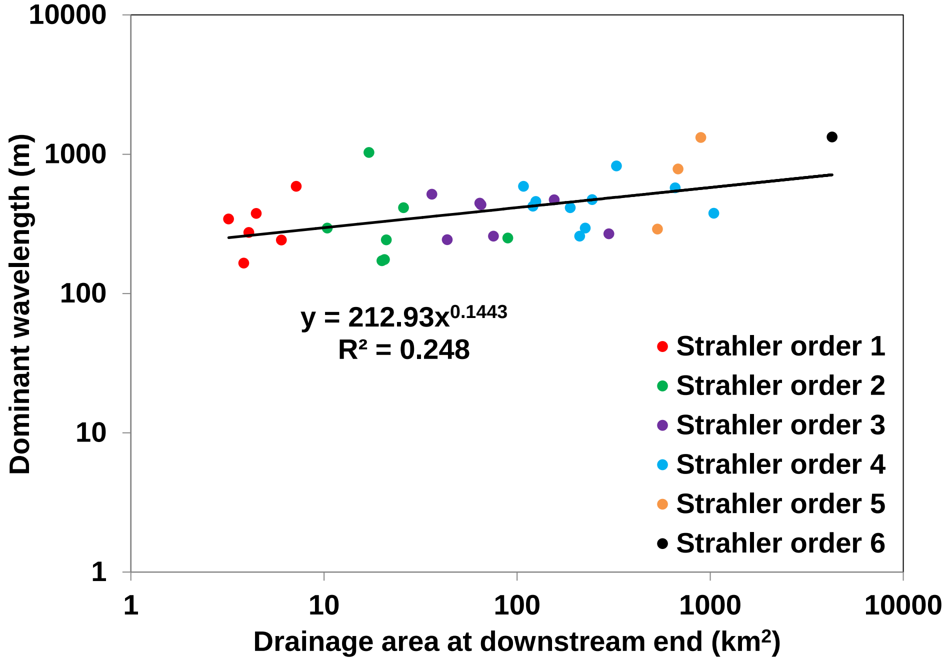


Figure 15. Dominant centerline wavelength vs. drainage area at the downstream end. Each point corresponds to a stream.

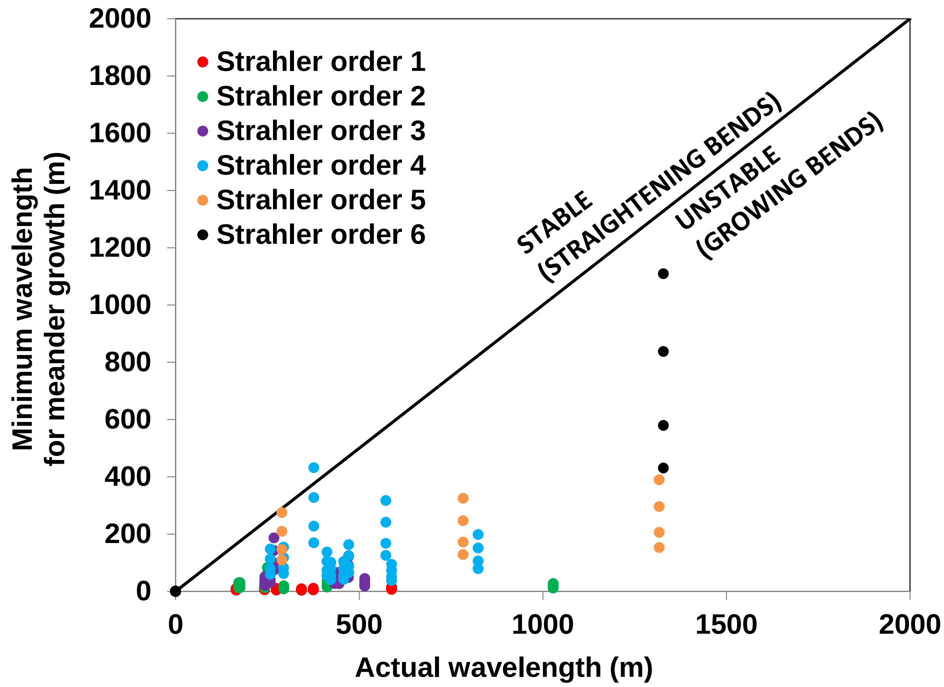


Figure 16. Stability diagram according to the theory by Johannesson and Parker (1985). Each point corresponds to a stream.

Analysis 2: Bed and bank characteristics as function of Strahler order and drainage area

In this section, a study of all streams where ground-based data were collected was carried out to investigate how bed and bank material, bank erodibility, channel stability ranking, and geotechnical properties of banks change for varying Strahler order or drainage area. D_{50} sediment size values for both bed and bank toe are typical of gravel and are in the same order of magnitude (Figure 17). Streams up to 3rd order or with low drainage area are characterized by just one bank material layer (mainly gravel). There is no significant correlation between erodibility values (of the cohesive upper layer, if present) and Strahler order or drainage area, whereas, as the Strahler order increases, bank vegetation cover generally decreases.

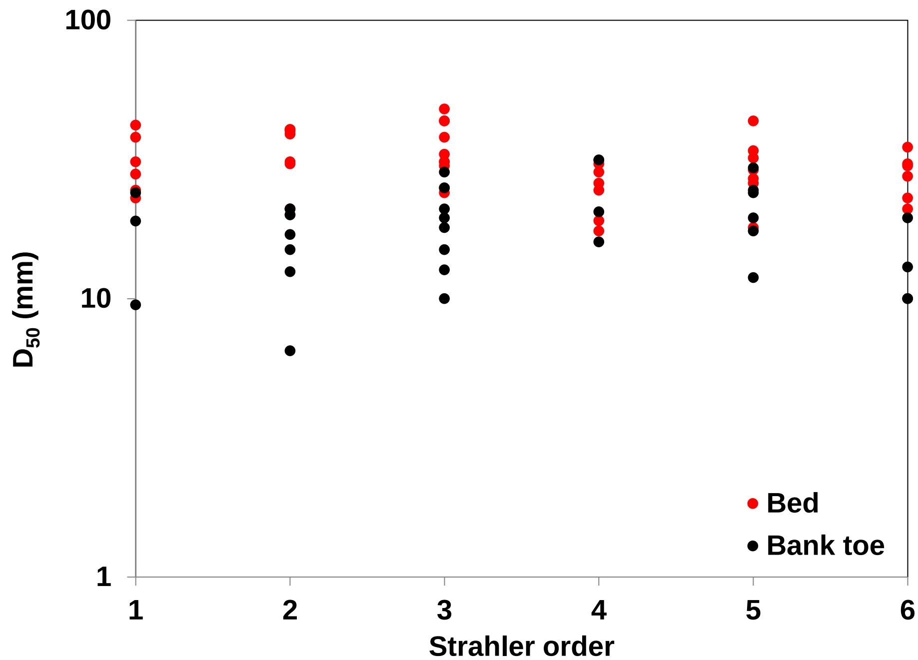


Figure 17. Median particle size D_{50} Vs. Strahler order. Each point corresponds to a ground-based data collection location.

Analysis 3: RVR Meander simulations

Meander-migration simulations were carried out with RVR Meander (Motta et al., 2012) for a subset of streams (Table 4) characterized by Strahler order from 2 to 6, in reaches where ground-based data were collected, to define general migration trends.

Hydrodynamics, bed topography, and meander migration were simulated using the model RVR Meander (Motta et al., 2012). It adopts a linear and analytical solution for computing hydrodynamic and bed topography fields and employs two alternative methods for bank erosion and meander migration: migration coefficient (MC) approach and physically-based (PB) approach. In both cases, the river is assumed to have a spatially-constant width, and this width is preserved as the river migrates.

In the MC migration approach, migration rates are proportional to the excess velocity at the outer bank with respect to the centerline of the river, through a dimensionless coefficient of proportionality that does not have any physical meaning and does not consider any threshold for bank erosion. Therefore, MC simulations provide an overall idea of migration trends, not of actual migration distances. The PB approach uses algorithms for streambank erosion (fluvial erosion, cantilever failure, and planar failure) of the US Department of Agriculture channel evolution computer model CONCEPTS (Langendoen and Simon, 2008).

Estimation of the critical shear stress and erodibility at the toe of banks was carried out at a private landowner location on Barren Fork (Figure 18), to match measured erosion from 2008 to 2010. For different plausible values of critical shear stress, the corresponding erosion-rate coefficient (or, equivalently, erodibility) was computed (Table 5).

Table 4. Characteristics of the streams modeled with RVR Meander.

Reach for RVR Meander simulation	Stream order	Sites	Flow discharge (m^3/s)	Channel width (m)	Channel slope (m/m)	Manning's roughness coefficient ($sm^{-1/3}$)
TownBranch_2_TQ1_RVR	2	TQ1	1.4	16	0.0076	0.045
TownBranch_2_TQ2_RVR	2	TQ2	1.4	16	0.0076	0.045
TownBranch_2_TQ3_RVR	2	TQ3	1.9	18	0.0068	0.045
BeatyCreek_3_RVR	3	BT1,BT2	12.4	33	0.0033	0.045
SpavinawCreek_4_SP1_RVR	4	SP1	30.5	41	0.0026	0.045
SpavinawCreek_4_SP2SP3_RVR	4	SP2,SP3	44.3	46	0.0023	0.045
BarrenFork_5_RVR	5	BF2,BF3,BF4,BF5, BF6,BF7	96.4	53	0.0019	0.045
IllinoisRiver_6_IL1IL2_RVR	6	IL1,IL2	160.6	65	0.0015	0.045
IllinoisRiver_6_IL3IL4IL5_RVR	6	IL3,IL4,IL5	244.1	71	0.0014	0.045
IllinoisRiver_6_IL6IL7IL8_RVR	6	IL6,IL7,IL8	244.1	72	0.0014	0.045

Table 5. Estimated erosion-rate coefficient and erodibility for different values of critical shear stress. The erosion-rate coefficient is given by erodibility multiplied by the critical shear stress.

Critical shear stress (Pa)	20	25	30	35
Erodibility (cm^3/N-s)	1.74	2.34	3.54	7.28
Erosion-rate coefficient (m/s)	3.49E-05	5.84E-05	1.06E-04	2.55E-04

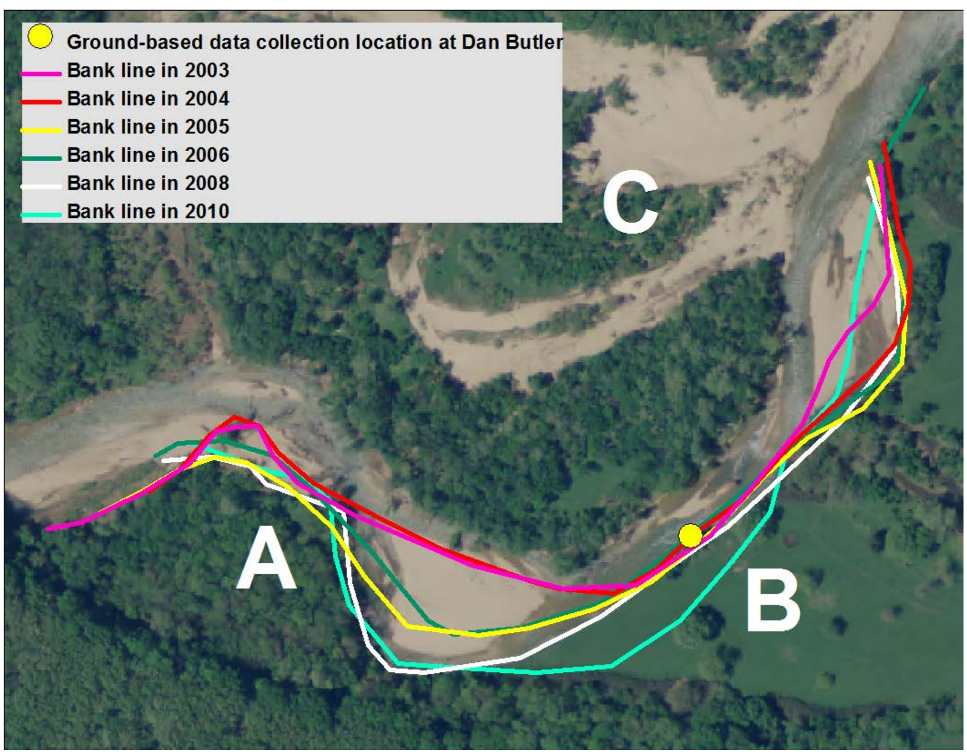


Figure 18. Bank erosion at a private landowner property on Barren Fork. Flow is from right to left. Aerial picture is for year 2008. Bank lines were manually digitized.

Meander migration was simulated over a time period of 10 years, with a time step of 0.2 years, using the bankfull discharge as modeling discharge. In the case of PB approach, an intermittency factor of 1% was used. For the MC migration approach, a typical value of dimensionless migration coefficient of 3E-07 was used to identify general migration trends and critical locations, depending only on the hydrodynamic field. The PB approach allowed accounting for the impact of the actual bank erodibility on meander migration rates and patterns; given that multiple possible pairs (critical shear stress, erodibility) are admissible from calibration (Table 4), a few possible pairs were considered for the simulations (Table 5). Furthermore, it was observed from aerial pictures for different years that vegetation may play an important role in mitigating or even stopping meander bend migration (Figure 19). In order to account for this, alternative scenarios were considered where the estimated erosion-rate values were reduced by factors of 10 and 100 (Table 6). Reduction factors are arbitrary because a complete understanding of the physical process behind it is missing at this point.

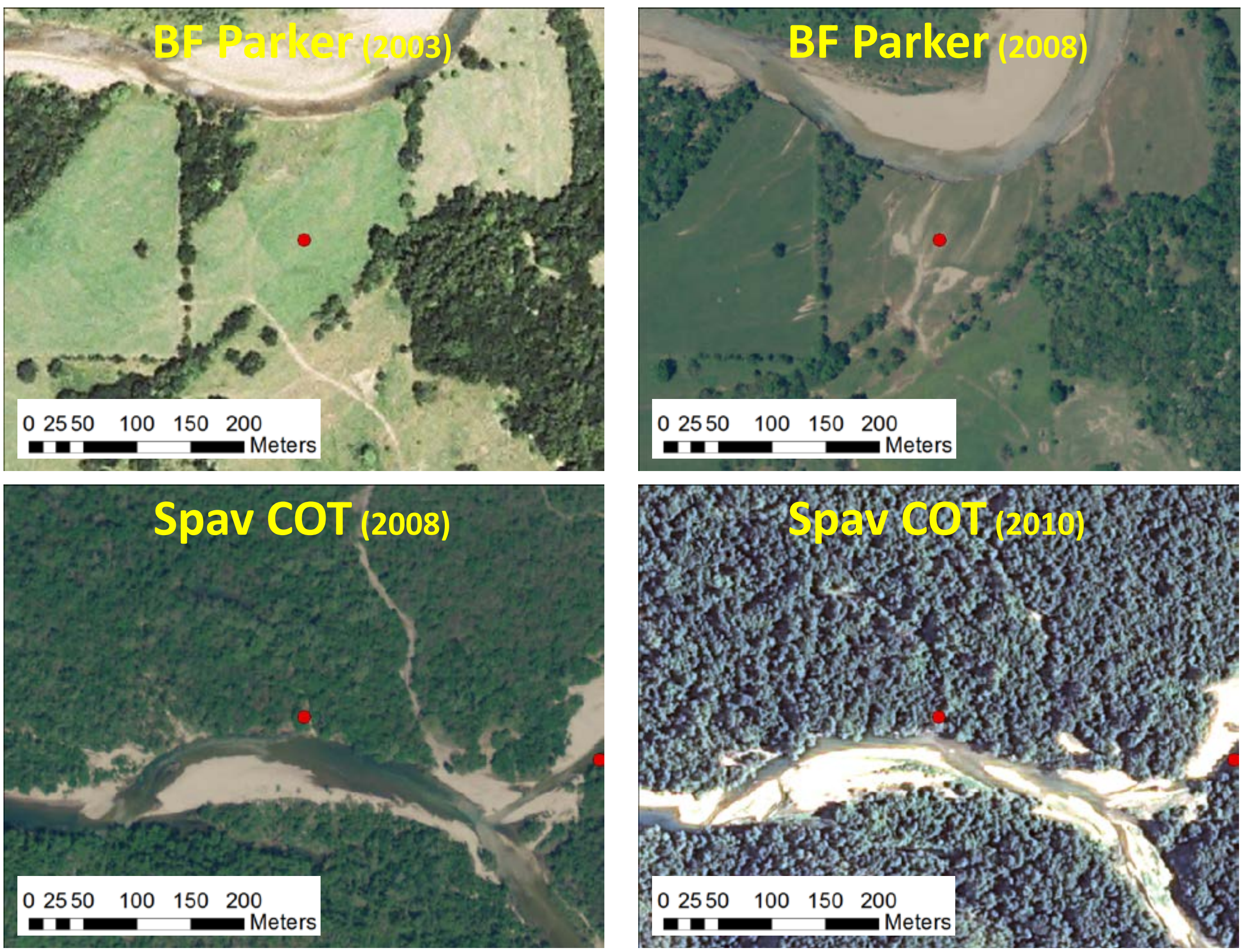


Figure 19 Examples of impact of vegetation on historic meander migration. At a private landowner property on Barren Fork, migration in unvegetated bank and floodplain is significant. At location Spav COT on Spavinaw Creek, no migration is observed.

Table 6. Combinations of erodibility parameters for the simulations of meander migration.	No vegetation impact		Low impact of vegetation (erosion-rate coefficient reduced by 10)		High impact of vegetation (erosion-rate coefficient reduced by 100)	
Erodibility scenario	1	2	3	4	5	6
Critical shear stress (Pa)	20	30	20	30	20	30
Erosion-rate coefficient (m/s)	4E-05	1E-04	4E-06	1E-05	4E-07	1E-06

Simulations were run for the 10 reaches in (Table 6)**Error! Reference source not found.** using both approaches. For the PB approach, six different combinations of erodibility parameters were considered (Table 6). The following figures only show a subset of the simulations, for the 3rd-order Beaty Creek (reach "BeatyCreek_3_RVR" in Table 4) and 6th-order Illinois River (reach "IllinoisRiver_6_IL3IL4IL5_RVR" in Table 4), respectively representing a low- and high-order stream.

Beaty Creek presents a potential to develop higher-frequency meanders where only hydrodynamics is taken into account (MC simulation in Figure 20Figure 2). When considering the effect of vegetation in the PB simulation (Figure 21, erodibility scenario 4), only few critical locations are present. No significant migration occurs at a private landowners (BT1) and Beaty COT (BT2) locations, as already observed in the past few years from aerial pictures. Illinois River shows less potential in terms of changing its meander wavelengths (Figure 22). However, if it could migrate in absence of vegetation (Figure 2Figure 3, erodibility scenario 1), it would present many critical locations like the private landowners (IL4), where indeed the river migrated in the previous years. On the other hand, in presence of vegetation (Figure 23, erodibility scenario 3) the river instability would be reduced.

In light of these and other simulations, we cannot make a clear and general demarcation in terms of channel instability between different Strahler orders, since channel instability depends on a feedback between planform configuration, hydrodynamics, bank erodibility, and spatial/temporal floodplain properties that are specific to the river of interest.

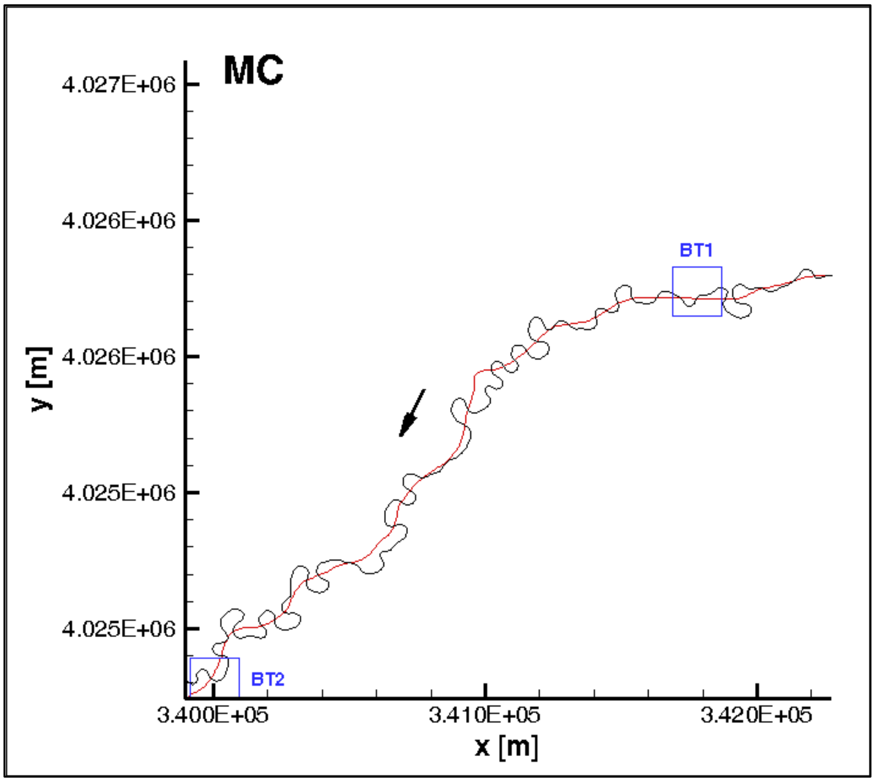


Figure 20. Meander migration simulation for the 3rd-order Beaty Creek (reach "BeatyCreek_3_RVR" in Table 4) with MC migration approach. Initial channel centerline is red, migrated centerline is black. BT1 = private landowner location, BT2 = Beaty COT location.

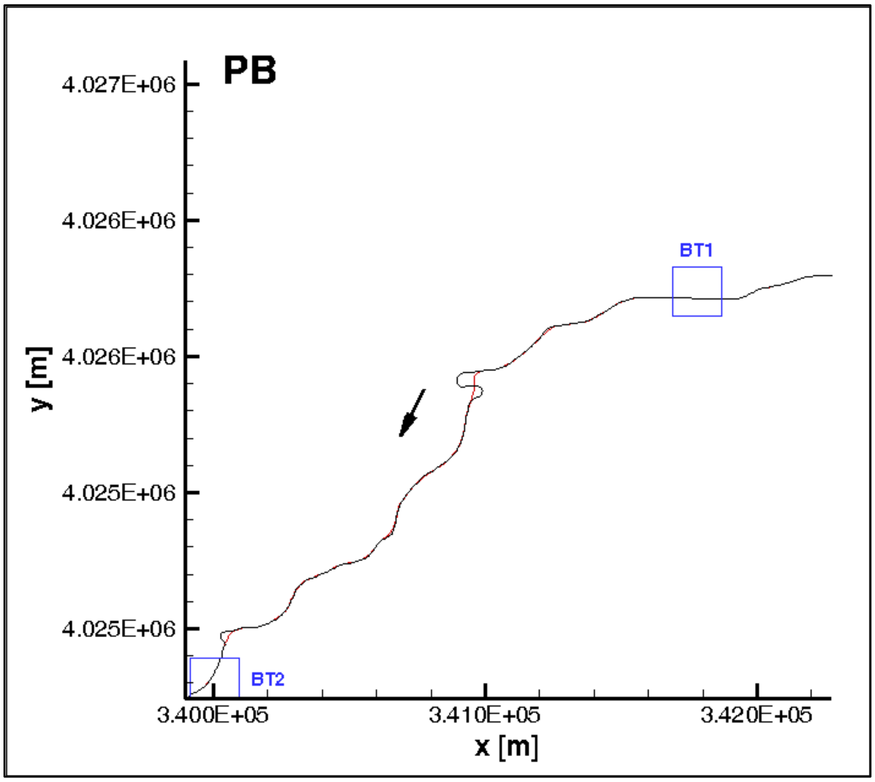


Figure 21. Meander migration simulation for the 3rd-order Beaty Creek (reach "BeatyCreek_3_RVR" in Table 4) with PB migration approach (erodibility scenario 4). Initial channel centerline is red, migrated centerline is black. BT1 = private landowner location, BT2 = Beaty COT location.

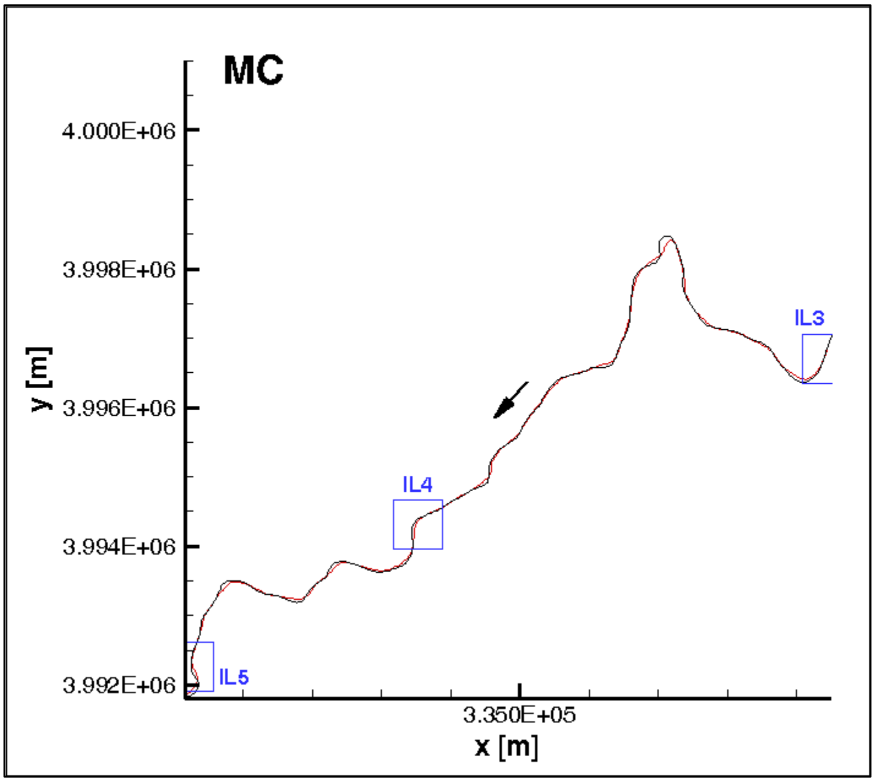


Figure 22. Meander migration simulation for the 6th-order Illinois River (reach "IllinoisRiver_6_IL3IL4IL5_RVR" in Table 4) with MC migration approach. Initial channel centerline is red, migrated centerline is black. IL3 = Illinois River Ranch, IL4 = private landowner location, IL5 = Arrowhead.

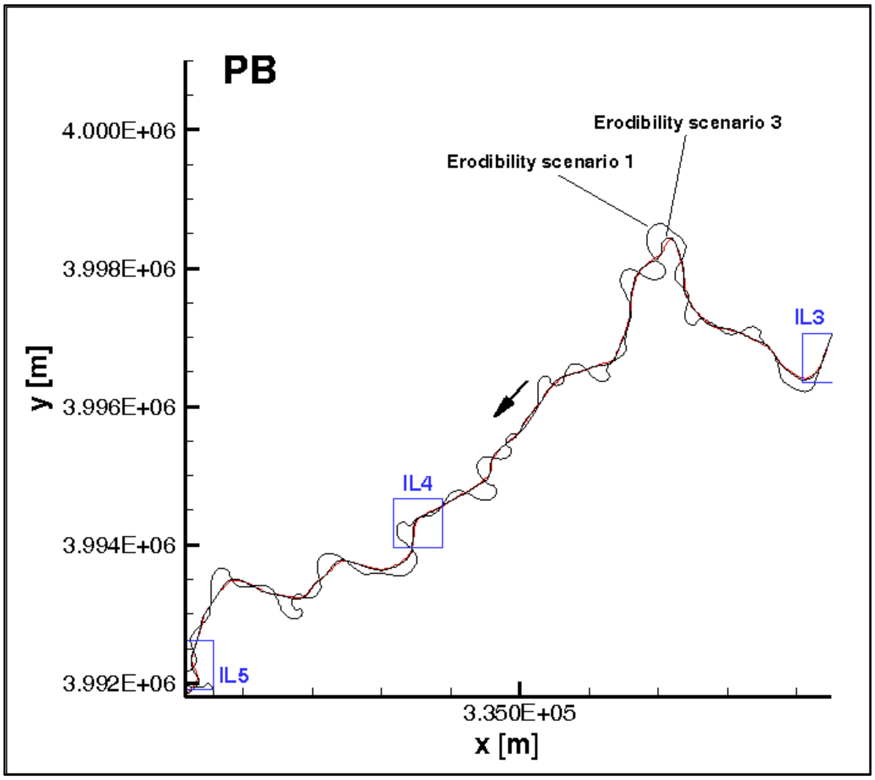


Figure 23. Meander migration simulation for the 6th-order Illinois River (reach "IllinoisRiver_6_IL3IL4IL5_RVR" in Table 4) with PB migration approach (erodibility scenarios 1 and 3). Initial channel centerline is red, migrated centerline is black. IL3 = Illinois River Ranch, IL4 = private landowner location, IL5 = Arrowhead.

Conclusions

Three analyses were conducted to develop a methodology for prioritizing needed streambank erosion protection by stream order. However, none of the methods used allowed for the identification of a clear and general priority scheme in terms of channel instability for streams having different stream orders. From the analyses it was revealed that:

- ✓ curvature alone cannot be taken as an indicator for judging stream stability;
- ✓ there is no significant correlation between erodibility values and stream order or drainage area;
- ✓ preliminary RVR Meander simulations revealed that all reaches modeled presented locations of potential bend instability depending on local soil erodibility and vegetative cover.

In conclusion, hydrodynamic and meander migration computation on a river-by-river basis should guide future efforts to delineate a prioritization scheme for bank protection intervention provided hydrodynamics data for validation of the computed flow field and detailed description of the soil and vegetation distribution along the stream and flood plains are available.

References

Johannesson, H., Parker, G., 1985. Computed simulated migration of meandering rivers in Minnesota. Project Report No. 242 for Legislative Commission on Minnesota Resources. University of Minnesota, Minneapolis, Minnesota.

Motta, D., Abad, J.D., Langendoen, E.J., Garcia, M.H., 2012. A simplified 2D model for meander migration with physically-based bank evolution. Geomorphology 163-164, 10-25.

Langendoen, E.J., Simon, A., 2008. Modeling the evolution of incised streams. II: streambank erosion. Journal of Hydraulic Engineering 134 (7), 905–915.

SUBTASK 2.2 DETERMINING OPTIMAL STREAM ORDER FOR STREAMBANK RESTORATION IMPLEMENTATION

CONCEPTS Modeling

Introduction

The objective of this subtask was to evaluate the long-term effectiveness of streambank restoration projects in various regions of the Illinois River and Eucha-Spavinaw watersheds. Data collection from both watersheds was used in the USDA CONservational Channel Evolution and Pollutant Transport System (CONCEPTS) channel evolution model. A series of simulations was performed using CONCEPTS to evaluate the long term stability of current streambank restoration practices on different stream orders. Results from this subtask will be used to evaluate stream bank protection measures and the impact of partial stream bank protection scenarios on unprotected banks. This information will also be used to make recommendations on long term, cost effective streambank stabilization project locations and practices.

Data Collection and Model Setup

Detailed stream reach data required to populate the CONCEPTS model was collected at 48 sites. Locations for data collection were chosen based on accessibility and bank stability. A total of 37 sites were from the Illinois River watershed and 11 sites were from the Eucha-Spavinaw watershed (Figure 24) in order to distribute site numbers evenly based on watershed area.

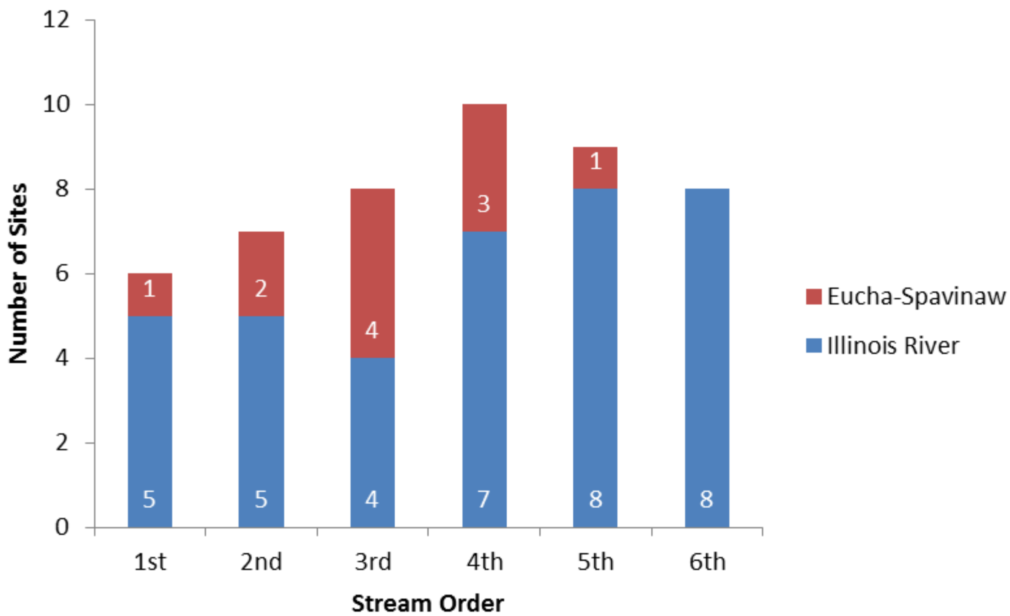


Figure 24. Site distribution by stream order and watershed.

Data collection at each of the 48 sites included a cross-sectional survey, a bed pebble count, a bank pebble count (if applicable), a Jet Erosion Test (if applicable), a Borehole Shear Test (if applicable), a Channel Stability Index, soil samples of the bed and the critical bank, site coordinates, and digital photos. Using these field data, reaches of varying stream orders were chosen to be modeled in CONCEPTS.

A separate model was created for each reach using data collected from the field and from the literature. Model calibration was needed in order to properly simulate streambank erosion processes, specifically fluvial erosion, at each site throughout the reach. This was accomplished using aerial imagery and results from the RVR Meander model. Each model was run over a period of four years from October 1, 2007 to October 1, 2011. This date range was chosen due to the availability of flow data from USGS stream gages and due to the wide range of storm events seen during this time.

For each model, a base scenario was run with the current cross sections and measured geotechnical parameters. From here, one highly unstable site from each reach was chosen to simulate stabilization practices. Three types of stabilization practices were simulated including grade control, toe protection, and vegetative plantings. Each practice was modeled by itself and in combination with the other practices. The grade control scenario consisted of reshaping the critical bank to have a 2:1 slope. Toe protection consisted of applying a layer of riprap to the bottom of the critical bank. The vegetative plantings scenario consisted of planting River Birch on top of the critical bank.

Conclusions

The cross-sectional evolution and cumulative sediment yield at the end of the four year simulation was analyzed for each model for each method of stabilization investigated. Based on CONCEPTS predictions, several general observations were made.

First, streambank erosion on these composite streambanks is a combination of both fluvial and geotechnical processes and is exacerbated during a series of high flow events compared to a single high flow event. Erosion of unconsolidated gravel leads to undercutting of the more cohesive silt loam material. Geotechnical failure of this silt loam material is dependent on the water content in the soil. Therefore, stabilization methods must account for both of these governing processes.

Secondly, because of the large erodibility of the gravel subsoils, toe protection was very important for impacting overall bank retreat. Care must be taken in using appropriate engineering design standards for the appropriate sizing of toe protection. Larger order streams will require more resistive toe protection because of the larger fluvial shear stresses.

Third, additional cohesive strength added by young, immature vegetation is limited. Vegetation plantings that utilize young plantings should be combined with other stabilization techniques while the vegetation establishes and increases in root tensile strength and the root area on potential failure planes. Additional understanding is needed on the role of vegetation plantings on the erodibility properties of the soil and therefore resistance to fluvial erosion. Only the geotechnical influence of vegetation is currently considered in CONCEPTs.

Fourth, larger order streams have much more extreme erosion events due to high flows and high streambanks, and therefore may prove to be more difficult and costly to stabilize. However, the benefits of stabilizing sites on higher order streams may outweigh the additional cost as there would be a significant reduction in sediment load, particularly silts and clays. Larger order streams in the area typically have much thicker silt loam layers on the composite streambanks.

Finally, the predicted cross-sectional evolution over time suggest that grade control measures may prove more effective on lower order streams, while hard armoring techniques, such as riprap, may be more effective on higher order streams.

SUBTASK 2.3 ECONOMIC VALUATION OF ECOSYSTEM SERVICES OF POTENTIAL WATER AND ECOSYSTEM IMPROVEMENTS IN NE OKLAHOMA

Background

Benefits from water use in Eucha-Spavinaw and Illinois River Basin surface waters include municipal, domestic, industrial, agricultural, recreation, and other environmental benefits. Some of the uses for water such as recreational and wildlife do not have easily quantifiable or tangible values in the marketplace. Infrastructure investment in stream bank erosion and reducing nutrient loads can be costly, thus prioritizing potential benefits in terms of the types of benefits and the location of benefits can help to target resources most efficiently.

Valuing ecosystems is critical since we do not attempt to quantify and prioritize values that are not normally traded in the market; therefore, they are essentially treated as if they were zero. Although these watersheds and others in Oklahoma have been the subject of contentious legal battles regarding the spread of chicken litter and related eutrophication of water bodies, little valuation of these ecosystems has been conducted. Previous work in the lower portions of these watersheds including Tenkiller Dam and the Lower Illinois trout fishery below Tenkiller Ferry dam have demonstrated that non-market values by recreators can be large. The value of trout fishing on the Lower Illinois River was $2 million per year (Prado 2007). In 2007, a statewide Oklahoma Lake travel cost study estimated the value of one trip to Tenkiller at $194/day (Mahasuweerachai, 2010) Furthermore, willingness to pay for surface water recreation on Tenkiller Lake declined with the water level and increased with probability of algal bloom (Roberts et al, 2008). Roberts et al. (2008) showed that users were willing to pay up to $12 per trip to be 100% certain that there would be no algal bloom during a visit to Lake Tenkiller.

When the quality of an environmental good is reduced, there may be no obvious market signals of the change in quality. Non-market and/or non-use values may be reduced, such as existence value or certain active-use values associated with aesthetics or recreation. The recreational value of recreationists may be captured by a method such as travel cost. However, when non-use values are impacted, only stated preference techniques, such as conjoint choice or contingent valuation, are able to capture the full impacts that include the both use and non-use values. Two methods were used to estimate non-market values for this survey. First floaters and recreators were randomly sub-sampled using on-site surveys to identify values and actual expenditures (Section 1). Second, a larger mail survey of randomly selected individuals from household addresses in Oklahoma was conducted to assess and prioritize the complete ecosystem values of users and non-users (Section 2).

Section 1: Travel Cost Method Methodology

The travel cost method uses actual behavior of site users to estimate a demand function for trips to a site. The cost of travelling to the site is assumed to be complementary to the users' value for the site and thus provides a lower bound for non-market use. The economic benefit is measured by estimating the consumer surplus for a site which is the area under the demand curve above the price line. In the case of the Illinois River, which has few nearby substitutes for Oklahomans, we estimate a single site value for visits as a function of travel costs and user demographics. Because we have truncation, that is no users with zero visits, we correct for overdispersion and truncation by using the Negative Binomial. Individuals also may travel to the Illinois River for multiple purposes, not just rafting alone. Therefore, we will allow for a shift in demand for individuals engaged in multiple activities (Loomis 2006). Other parameters considered were travel cost, age, party size, education and income as listed in Table 7.

Table 7. Variables and Definitions Travel Cost

Variable	Definition
lnTrip	Natural log of number of trips to the Upper Illinois River
TC1	TC1=Round Trip Mileage x IRS Reimbursment Rate (2012)
AGE	Age of respondent in years
AGESQ	Age of respondent in years squared
GENDER	1 if female, else 0
PARTSIZE	Number of individuals in the vehicle travelling to Upper Illinois
EDUCLEVEL	1 if completed college degree; else 0
MULT	1 if multi-purpose trip; 0 if only floating
MULT_TRIPC	MULT x Reported Trip Cost
POVERTY	if income level $19,999 (benchmark)
INCOME1	1 if income b/n $20,000 - $39,999; else 0
INCOME2	1 if income b/n $40,000 - $99,999; else 0
INCOME3	1 if income more than or equal to $100,000; else 0
WEEKEND	1 if Friday, Saturday and Sunday; else 0

Travel Cost Data and Results

An on-site survey was conducted during peak floating season May 23, 2012 through August 23, 2012. Surveys were manually distributed on twenty-nine randomly selected weekday and weekend dates during this period. Respondents were encountered on 23 days during the survey period. The data from these were used in the final travel cost analysis.

During the survey, all floaters present at each of the seven take-out locations on the Upper Illinois River (UIR) were surveyed using an on-site travel cost survey. Survey clerks started each survey day at a randomly chosen site and proceeded to travel north in a loop until all sites were surveyed for 50 minutes each. All floaters who had completed a float trip and were present during the 50 minutes a clerk was present were asked to fill out the on-site survey about their floating experience on this trip. The seven sites on the UIR include Arrowhead Resort, Eagle Bluff Resort, Peyton's Place, War Eagle Resort, Diamondhead Resort, Echota Access and Sparrow Hawk Resort. The on-site survey was conducted by undergraduate and graduate students from OSU. It consisted of general questions about the floating experience like: floating time, travel time, a rating of the quality of the ecosystem in UIR (Likert Scale), and total dollars spent on the floating trip. The total number of surveys collected was 489. Because some surveys had incomplete information (item non-response) or were missing key information, they were not in the final analysis. In the formal estimates, only 456 completed surveys were used in the travel cost model (TCM). After June 21st, 2012, the survey was altered to include gender as a response. In the first on-site survey administered, the variable for gender was omitted. Of the 456 completed surveys, 206 have gender variable used for the final analysis. Gender, however, was not a significant determinant of trips taken in the final analysis. Summary Statistics are given in Table 8.

Two negative binomial travel cost models were estimated and the results are given in Table 9 (SAS 9.2). Model 2 uses the subsample for GENDER, but since gender did not prove significant, we used results from Model 1 only. In Model 1, we found the variable for Travel Cost to be significant at greater than the 99% confidence level and to negatively affect the number of trips. The coefficient for Education is negative and significant at the 90% confidence level indicating that individuals who have completed a college degree take fewer trips than those who have less education. The coefficient on MULT, multipurpose trips is significant and positive at greater than the 99% confidence level, indicating individuals who both floated and engaged in other activities are more likely to take more trips. The coefficient estimated for the interaction of MULT and TC, multiple activity trips and travel costs is significant and negative at greater than the 99% confidence level. This means as the price of travel rises, multiple-use trip takers will take fewer trips compared to the float-only trip takers. Finally, the coefficient on WEEKEND is negative and significant at greater than the 99% confidence level indicating that on average, weekend floaters take fewer trips than weekday floaters. All categories of income, party size, and age proved to be insignificantly different from zero.

Using the results from model 1, we estimate the per trip consumer surplus for a floating trip to be $666.67 per group. Per person the value of recreation day floating for single purpose floating trips is $124 per trip when adjusted for party size of 5.37 people per group. The per-person, per recreation day estimates were obtained by dividing the consumer surplus per trip by the mean group size (party size). If we take into account multiple purpose trips to the Upper Illinois River, the estimated per-person, per-trip consumer surplus of $333 per group with an average party size of 4.56 equates to $73 per person per trip in 2012. Due to the discontinuation of the per person floater fee by the Scenic Rivers Commission which allowed for revenue collection and visitor counts by float operator, we used estimates of annual visitation for floating. Using the annual estimate of 125,000 to 150,000 visitors who float the River (Fite, 2012), we estimate total annual value of floating by assigning values proportionately to 57% of the use as multiple-purpose trips and the balance to float-only trips. The total annual estimated value to users of the River falls between $11,866,250 and $14,239,500 annually. This provides a lower bound for recreational value of the resource as it provides only floaters with single and multiple purpose trips. Second, it uses only estimated vehicle costs with no opportunity costs for time or foregone wages or other expenditures in the region.

Table 8. Summary Statistics of Floaters at the Illinois River for Travel Cost Study conducted during the summer of 2012.

	Full Data Set n=456		Data Set with Gender n=206	
Variable	Mean	Standard Deviation	Mean	Standard Deviation
lnTrip	0.66	0.81	0.64	0.80
TC1	$155.02	$211.64	$177.96	$278.16
AGE	31.79	11.40	29.48	11.14
AGESQ	1140.14	824.98	992.27	792.04
GENDER	-	-	0.59	0.49
PARTSIZE	5.37	4.65	5.77	5.18
EDUCLEVEL	0.41	0.49	0.34	0.48
MULT	0.19	0.40	0.20	0.40
MULT_TRIPC	$55.59	$182.70	$54.33	$142.83
INCOME1	0.22	0.42	0.26	0.44
INCOME2	0.47	0.50	0.41	0.49
INCOME3	0.17	0.38	0.15	0.37
WEEKEND	0.74	0.44	0.67	0.47

Table 9. Negative Binomial Travel Cost Estimates for Illinois River (LNTRIP Numbers

Dependent Variable, USD 2012)						
		(Full Data)		(Gender Included Data)		
Variable		Model 1		Model 2		
Intercept		-0.0325		-0.9205		
		(-0.5446)		(0.8256)		
Travel Cost		-0.0015***		-0.0011*		
		(0.0005)		(0.0006)		
Age		0.0074		0.0477		
		(0.0333)		(0.0518)		
Age Squared		-0.0002		-0.0008		
		(0.0005)		(0.0007)		
Gender				0.0702		
				(0.1660)		
PARTSIZE		-0.0124		-0.0058		
		(0.0138)		(0.0170)		
Education		-0.2113*		-0.2313		
		(0.1163)		(0.1747)		
Multi-Purpose		0.5733***		0.7861***		
		(0.1839)		(0.2405)		
Multi-Purpose*Trip Cost		-0.0015**		-0.0019**		
		(0.0007)		(0.0009)		
INCOME1		-0.0588		0.1148		
		(0.1839)		(0.2271)		
INCOME2		0.1008		0.3943*		
		(0.1694)		(0.2258)		
INCOME3		0.2510		0.3266		
		(0.1916)		(0.2451)		
WEEKEND		-0.3229***		-0.2376		
		(0.1154)		(0.1622)		
Dispersion		-0.1549		-0.2442		
		(0.0778)		(0.0789)		
Log Likelihood		-405.3441		-174.1565		
AIC		958.6775		427.0722		

* Asterisks indicate significance ($P < 0.1$ *, $P < 0.05$ **, $P < 0.01$ ***)

Section 2: Discrete Choice Methodology: Prioritizing tradeoffs in ecosystem services in the Illinois River, Barren Fork Creek, Tyner Creek, and Tahlequah Creek Ecosystems.

To value and prioritize potential restoration goals and sites, we must also consider that groups of non-users place a different value on ecosystem support services that have not been captured by previous studies.

Conjoint choice (cc) or discrete choice (dc) methodology was used to measure participants' willingness to pay for tradeoffs between cost, habitat, recreation improvements, and other site characteristics. Stated preference methods, such as discrete or conjoint choice methods allow respondents to choose from a set of pair-wise alternatives comprising a bundle of attributes at varying levels. The CC methodology is able to avoid many bias problems because it more closely mimics the actual consumer behavior of choosing among two or more competing goods based on a limited set of important attributes (Green and Srinivasan, 1978). In each question, the respondent must select their preference between two hypothetical goods with a limited set of attributes that may vary by quality or quantity. With each choice, the respondent is facing a tradeoff between attribute levels, and will select the bundle that maximizes their utility. As respondents make their choices between bundles, the utility associated with changes in the levels of specific attributes can be specified.

Methods

The survey responses were used to estimate a conditional logit model for ecosystem services in the Illinois River watershed (SAS 9.2 mdc was used). Utility is assumed to be a function of ecosystem services and fees. Attributes included water clarity levels (C), and improvement levels in instream habitat species numbers (H), recreational water use level – safe for wading only, Safe for Wading and Swilling and Safe for All Contact (RW^1, RW^2, RW^3), and streambank appearance levels (A). Finally, principal payment vehicle, and tax increases in US dollars on annual household incomes (T), was included. Attribute levels are shown on Table 9. A sample choice set is shown in Figure 25. Individuals were instructed to choose an option A, B, or C, no change in current levels. A random utility model for individual, i, was estimated.

Discrete Choice Data and Results

A randomized mail survey of ecosystem and recreational value following Dillman's (2002) methods for mail survey protocols was conducted using a first mailout on July 20, 2012, a follow-up postcard, and a replacement mailout within a month. Recipients were identified using a randomized subsample obtained through Survey Sampling International, a survey research firm. The response rate was 265 out of 1870 surveys or 14.17%. (OSU IRB Approval July 13, 2012, Application #AG1229) (Survey is Appendix B)

The conditional logit estimates are reported in Table 10. The marginal values of each attribute are given in Table 11 for each of the models. The estimation of the basic model with all respondents shows that all of the attributes are significant at greater than 99% confidence level. As expected, individuals are more likely to choose options that have greater water quality for each 3 foot increase, show improvement in in-stream habitat species, and are revegetated with natural habitat rather than having an eroded stream bank appearance. Coefficients with negative signs indicated that people are less likely to choose scenarios that are either not safe for wading and swimming or safe for wading only, as compared to the dropped attribute that the water is safe for all uses. Options with higher tax increases on household incomes are less likely to be chosen.

The marginal willingness to pay values in Table 11 are estimated by dividing the coefficient on each attribute by the estimated coefficient for the increase in annual household tax. The results show that individuals are willing to pay $85/year/household, for re-vegetation of eroded stream banks.

Willingness to pay to improve habitat species numbers by 10% is $16.77/year/household. Willingness to pay for each 3 foot increase in water clarity is $16.56/year/household. The estimated negative willingness-to-pay numbers indicate that Oklahomans on average must be compensated to accept degradation of water safety. To degrade water quality from safe for all uses to safe for wading required $134 dollars compensation. To degrade water quality from safe for all uses to unsafe for wading and swimming required compensation of $142/year. These values provide a prioritization of values which would prioritize removal of pathogens that require wading and swimming restrictions first, then restoration of eroded streambanks, and finally habitat and water clarity improvement. Scientifically, it is likely that streambank improvements that reduce erosion may also affect clarity and removal of pathogens, so we must be careful how to count the benefits from reducing streambank erosion if one action has several impacts. Creation of survey instruments that the public can comprehend without intensive pre-education, which might lead to bias anyway, presents a challenge for prioritizing inter-related water-degradation processes. From the discussion above, however, it is clear Oklahomans value improvements that personally affect their recreational use and enjoyment of the resource, rather than habitat or species improvement for non-use or bequest purposes.

The results of the discrete choice methodology provide a prioritization of ecosystem services in order to help to inform policymakers and stakeholders of tradeoffs between competing uses of funds for environmental improvement. This information is vital in the context of a geographic region in which restoration has been politically seen as a zero-sum game between market and non-market uses. Information on how users value surface water resources can help ensure efficient protection of the state's water resources and identify if there are winners and losers in any change of water policy.

Figure 25 Sample choice set from administered survey

<table>
<tr><th>Attribute</th><th>Option A</th><th>Option B</th><th>Option C</th></tr>
<tr><td>Water clarity (depth)</td><td>3 feet</td><td>9 feet</td><td rowspan="5">NO CHANGE:
I would rather keep the management of this river the way it is today</td></tr>
<tr><td>Improvement in instream habitat species numbers</td><td>10 %</td><td>20 %</td></tr>
<tr><td>Recreational water quality</td><td>Safe for wading only</td><td>Safe for all contact</td></tr>
<tr><td>Stream bank appearance</td><td>Eroded banks visible</td><td>Revegetated with native species.</td></tr>
<tr><td>Annual Household Income tax increase</td><td>$ 25</td><td>$ 100</td></tr>
<tr><td>I would choose (Please check only one)</td><td>☐ A</td><td>☐ B</td><td>☐ C (I would not want either A or B)</td></tr>
</table>

Table 10. Site attributes and levels for the discrete choice survey assessing respondents' willingness to pay

Attributes	Attribute levels
Water Clarity	0 feet
	3 feet
	6 feet
	9 feet
	12 feet
Improvement in in-stream habitat species numbers	0%
	10%
	20%
Recreational use	Safe for all contact
	Safe for wading only
	Not safe for wading and swimming or swimming (10% of season)
Stream-bank appearance	Eroded banks visible
	Revegetated with native species
Tax increase on Annual Household Income	$0
	$50
	$100
	$150
	$200

Table 11. Conditional logit regression results (standard errors in parentheses)

Variable	Basic model
Water Clarity	0.1292***
	(0.0356)
Improvement in in-stream habitat species numbers	0.1308**
	(0.0576)
Not Safe for wading and swimming	-1.1101***
	(0.1423)
Safe for wading only	-1.0516***
	(0.1319)
Stream-bank appearance (revegetated)	0.6679***
	(0.1140)
Tax increase on Annual Household Income	-0.0078***
	(0.0008)
Log likelihood	-802.2663
Number of Observations	844

* Asterisks indicate significance (P<0.1*,P<0.05**, P<0.01***)

Table 12. Annual Willingness to pay (WTP; US$)

Variable	Basic model mean WTP
Water Clarity	**$16.56**
Improvement in in-stream habitat species numbers	**$16.77**
Not Safe for wading and swimming	**-$142.31**
Safe for wading only	**-$134.82**
Stream-bank appearance	**$85.63**

Conclusions

The overall valuation of water use in the Upper Illinois River and Eucha-Spavinaw watersheds was able to provide preliminary information for prioritizing potential benefits in order to target resources more efficiently. The travel cost data revealed that the per-person value of recreation day floating was $124 per trip for single purpose trips, and the per-person value of recreation day floating was $73 for multi-purpose trips. This translates to an annual estimated user value range of $11,866,250 to $14,239,500 for recreational use of the Illinois River.

The discrete choice methodology revealed that individuals would prioritize the removal of pathogens requiring water use restrictions, restoration of eroded streambanks, and habitat and water clarity improvement, in that order. Ultimately, it is seen that Oklahomans surveyed value improvements that personally affect their recreational use rather than habitat or species improvements.

References

David Roberts, Tracy Boyer, and Jayson Lusk. 2008. "Environmental Preferences Under Uncertainty." *Ecological Economics.* 66:584-593.

Dillman, D.A. 2002. *Mail and Internet Surveys: The Tailored Design Methods*, 2nd Ed., New York: John Wiley and Sons, Inc.

Fite, Edward. Personal Communication. Oklahoma Scenic Rivers Commission. October 2, 2012.

Green, P.E. and V. Srinivasan. 1978. "Conjoint Analysis in Consumer Research: Issues and Outlook." *Journal of Consumer Research* 5(2):103 – 123.

Internal Revenue Services, Retrieved on September 20, 2012, from the link http://www.irs.gov/uac/IRS-Announces-2012-Standard-Mileage-Rates,-Most-Rates-Are-the-Same-as-in-July

Loomis, John (2006). A Comparison of the Effect of Multiple Destination Trips on Recreation Benefits as Estimated by Travel Cost and Contingent Valuation Methods. *Journal of Leisure Research*. 38(1): 46-60.

Mahasuweerachai, Phumsith. 2010. Essays on Demand for Water-Based Recreation in Oklahoma. Phd. Dissertation. Oklahoma State University.

Prado, B. 2006. *Economic Valuation of the Lower Illinois Trout Fishery in Oklahoma under Current and Hypothetical Management Plans*. Ph.D. Dissertation, Oklahoma State University;

Task 3 – Select sites for stream channel restoration

Originally 45 sites that would benefit from streambank stabilization and restoration were identified by several state agencies as identified in Task 1. OSU, OCC, city of Tahlequah and the Army Corps of Engineers conducted an additional site visit in April 2011 to narrow the list to those sites that would fit within the permitting and financing restrictions. Ultimately 12 sites were selected. (Table 13) The locations of the completed sites are mapped out in Figure 26.

Table 13. Final list of sites selected.

Site Number	Site	Channel	Initial Length Estimate (ft)	Width (ft)
1	Private Landowners	Town Branch Creek Tributary	375	20
4	Head of History Trail	Town Branch Creek	250	25
3	Sequoyah Park	Town Branch Creek	250	25
2	Felt's Park	Town Branch Creek	400	25
5	Kaufman Park	Town Branch Creek Tributary	300	15
7	War Eagle Resort	Illinois River	500	200
8	Private Landowner	Tyner Creek	230	100
6	Private Landowner	Barren Fork Creek	650	200
9	Peavine Public Access	Illinois River	350	200
10	Todd Public Access	Illinois River	650	200
11	Private Landowner	Illinois River	300	200
12	Illinois River Ranch POA	Illinois River	650	200

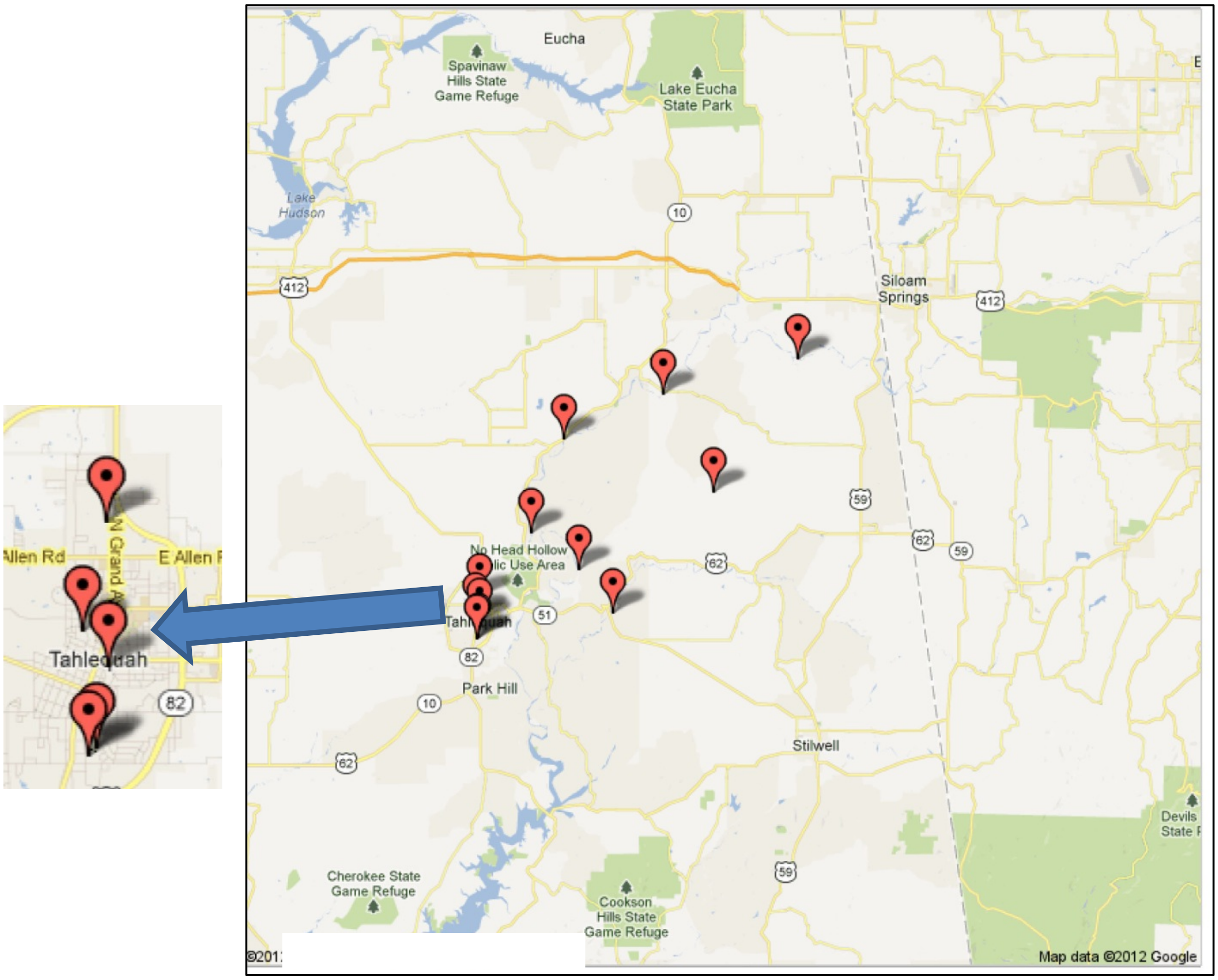


Figure 26. Locations of the twelve selected sites.

Task 4 – Implement stream channel restoration projects.

Initially Oklahoma State University (OSU) would be responsible for contracting the design and construction of the projects. However, after discussions about the State of Oklahoma's ability to do a design/build best value process it was determined that the Oklahoma Conservation Commission (OCC) should be responsible for the contracting process. OCC worked with the Department of Central Services (DCS) to use the design-build best-value bidding process. This would ensure that a qualified firm was selected and it was not just based on lowest bid. This further allowed the designer and builder to present a joint bid that would provide a designer on site during construction, so if changes needed to be made the decision could be made quickly.

Six firms submitted bids to DCS. After reviewing the applications and qualifications of those six firms, three firms, Cherokee CRC, North State Environmental and Lippert Brothers Inc. were selected for interviews. As a result of the interviews and the experience shown in doing natural stream restoration work using the fluvial geomorphology methods, North State Environmental was selected as the construction firm based on the best-value process. North State partnered with Stantec and Jennings Environmental to develop the designs for all of the sites. The contract was finalized in early January 2012.

In March 2012 the design and construction team conducted additional surveys of the sites during a time of heavy rainfall. This allowed the design-build (DB) team to experience each of the sites at bankfull or higher. While visiting Site 11, the private landowner on the Illinois River, it became apparent that this site would be difficult to repair in a way that would ensure success. At the same time the landowner was selling his property and the new landowner was not interested in having the work completed. It was decided that this site should be dropped and the money used at Kaufman Park to stabilize the lower section of the tributary. This was agreed to and Kaufman was expanded and Site 11 was removed.

While permitting was the responsibility of the DB team, it was determined that OSU and OCC had relationships with the permitting agencies and so OSU, working with OCC, completed the permitting process. Applications were filed for 10 of the sites under the Nationwide Permit 27 – Aquatic Habitat Restoration, Establishment, and Enhancement Activities permit. The application process included requests from the U.S. Fish and Wildlife Service, Oklahoma Biological Survey and the Oklahoma Department of Wildlife Conservation to ensure no threatened or endangered species were known to be in the area of work. None were identified. Further, the Oklahoma Archeological Survey was notified to identify any areas of archeological interest. Nine of the sites showed the possibility of something of significance near the area of proposed work. This required a site survey be done by an archeologist. The Natural Resource Conservation Service's state archeologist performed site visits on all identified locations. The visits included visual observation and shovel tests. Local informants were also consulted to help identify any potential objects. Nothing of significance was found and a letter was provided to OCC stating the results. Six tribes had known interests in the area and were provided notice by the Oklahoma Water Resources Board about the proposed projects. They were given 30 days to respond. The tribes contacted were the Cherokee Nation, Kialegee Tribal Town, Osage Nation, Wichita and Affiliated Tribes, Seminole Nation and the United Keetoowah Band of Cherokees. The only Tribe to respond prior to work being completed was the United Keetoowah Tribe. They asked for more information about the project, and once that information was given, they had no concerns. The U.S. Army Corps of Engineers issued the 10 permits.

The eleventh site's permit, the Illinois River Ranch POA was filed as an individual permit due to the size of the project. Filing an individual permit required that it be opened for public comment and required 401 Water Quality Certification from the Oklahoma Department of Environmental Quality. The permit was made public on August 1, 2012 and closed on August 20, 2012. Two comments were received. The first was from the Kickapoo tribe stating that if any human remains were found they should be notified. The second was from the U.S. Fish and Wildlife Service asking that a mussel survey be conducted to determine if mussels of concern are found in the project area. The two mussels surveyed for were the rabbitsfoot mussel and the Neosho mucket mussel. The mussel survey was conducted on August 30, 2012 by the U.S. Fish and Wildlife Service, Oklahoma Conservation Commission and the Oklahoma Department of Wildlife Conservation. No live mussels of concern were found in the project area and a letter from the U.S. Fish and Wildlife Service certifying this was received by the U.S. Army Corps of Engineers on August 31, 2012. The Oklahoma Department of Environmental Quality issued the 401 Water Quality Certification at the close of the public comment period. The individual permit was sent to the Oklahoma Conservation Commission on September 6, 2012 and construction began on that date.

The contractor was mobilized and began work at Site 1 on June 14, 2012. At least one OSU inspector was onsite during the construction phase of the project. Inspection duties included:

- ✓ Ensuring that the designs were correctly implemented in the field
- ✓ Ensuring that quality materials were used and collecting appropriate receipts

- ✓ Keeping a record of construction activity with a daily log
- ✓ Ensuring that safety was observed and practiced onsite
- ✓ Interacting with the public and other parties interested in the project by answering questions and explaining the purpose of the project.

The designs for each site varied with the needs for each site, and were constructed in the order shown in Table 14 below. The overall goals of the project were to minimize erosion of streambanks, control the grade of the stream bed and to enhance in-stream habitat through the use of various techniques and in-stream structures. All sites were stabilized with vegetation whether by seeding and matting or transplants. A more detailed account of each site is presented below.

Table 14. Time table of construction by site.

Site Number	Site	Channel	Start Date	Finish Date
1	Private Landowners	Town Branch Creek	6/14/12	6/19/12
4	Felt's Park	Town Branch Creek	6/20/12	6/27/12
3	Sequoyah Park	Town Branch Creek	6/27/12	6/28/12
2	Head of History Trail	Town Branch Creek	7/6/12	7/11/12
5	Kaufman Park	Town Branch Creek Tributary	7/9/12	7/23/12
7	Private Landowner	Tyner Creek	7/24/12	7/27/12
8	Private Landowner	Barren Fork Creek	7/24/12	7/27/12
6	War Eagle Resort	Illinois River	7/24/12	7/26/12
9	Peavine Public Access	Illinois River	7/23/12	7/23/12
10	Todd Public Access	Illinois River	8/6/12	8/10/12
12	Illinois River Ranch POA	Illinois River	9/6/12	10/9/12

Site 1 is private property with an ephemeral stream channel located adjacent to a housing development. The design length for this site was 698 feet. To alleviate the erosion of the banks on both sides (Figure 27 left), the channel alignment was moved away from the bank near the housing development and regraded to include pools and riffles (Figure 27 right). In-stream structures including a rock vane and a log j-hook were installed to redirect the water toward the center of the channel and control stream bed grade. The log j-hook and the toe wood also served as bank protection, while the added floodplain benches created more space for the water to move through the system without cutting into the banks during high flow events.


Figure 27. Site 1 before (left) and after (right).

Site 2 is a perennial stream located adjacent to head of the History Trail. At this point, the stream was experiencing major erosion problems with nearly vertical banks and was threatening infrastructure. A sewer line ran along the top of the bank approximately two feet from the edge and was in danger of being uncovered and potentially damaged. In addition the trail was also close to being washed out due to the amount of erosion that was occurring. The design length for this site was 252 feet and included reducing the slopes on the banks and adding a graded bankful bench. Two rock vanes were incorporated into the design for grade control with scour pools immediately downstream of each structure for energy dissipation and added habitat for fish.


Figure 28. Site 1 before (left) and after (right).

Site 3 is a 321 foot length of shallow perennial stream that runs through Sequoyah Park near the city government building. The park receives a lot of local traffic since there is a playground and there is easy access to the stream for children to play. This stream had a lot of undercutting of the banks and was threatening the stability of the trees growing adjacent to the stream. The design for this site consisted of regrading the banks and adding a point bar. A log j-hook was implemented for grade control in the stream and to provide bank protection.


Figure 29. Site 3 before (left) and after (right).

Site 4 is a 453 foot reach of perennial stream located adjacent to Felts Park. This park also receives a lot of local traffic and safety was an issue due to significant erosion and undercutting of the bank abutting the park. Flow in the channel was shallow and habitat virtually nonexistent. To alleviate these problems, the channel alignment was moved away from the bank of the outerbend and deepened. Two log j-hooks followed by brush toes were constructed for grade control and bank protection. Bank slopes were regraded and floodplain benches were added to alleviate the pressure on the banks during high flow events. A double step cross-vane was constructed at the downstream end of the project for grade control. Scour pools were added downstream of each instream structure.


Figure 30. Site 4 before (left) and after (right).

Site 5 is a 574 foot reach of ephemeral stream channel located in Kaufman Park and behind the local Senior Citizens' center. As with the other sites, erosion and public safety were the major issues here. Also of note, the contractor brought in a second crew to be able to meet the project construction deadline by being able to work on sites simultaneously. However, both crews were active on this site due to the number of structures required. Seven constructed rock/log riffles were incorporated throughout the design for energy dissipation. Four were located at the upstream end of the project at various points along the meander bend of the channel. Two cross-vane structures followed for grade control and to ensure that flow was directed toward the center of the channel. A third cross-vane was located at the downstream boundary of the project. Between the second and third cross-vanes, were 3 log drop structures and 3 additional rock/log riffles. Streambanks were regraded with gentler slopes and floodplain grading was performed beginning just downstream of the first cross-vane structure to the end of the project site.

Figure 31. Site 5 before (left) and after (right).

Site 6 is a 301 foot reach of channel located adjacent to the Illinois River. This particular site is a popular resort for floaters and was experiencing significant erosion, as evidenced by vertical banks along the channel where the floaters enter and exit the water. To alleviate the problem, the channel was deepened slightly, the banks were regraded with gentle slopes, and a graded floodplain was added to give the channel more storage volume for high flow events. To further stabilize the bankful bench, several sycamore trees were transplanted and the owner purchased 10 Cyprus trees to plant on the bench and along the top of bank.


Figure 32. Site 6 before (left) and after (right).

Site 7 is 374 feet of perennial stream on Tyner Creek. The private landowner expressed concern about loss of acreage due to erosion and movement of the channel. The alignment of the channel was moved away from the eroding outer bank. The floodplain and point bar were regraded along with the bank slopes to give the stream more room for high flow events. A wood toe was also incorporated into the design for further bank protection and floodplain storage.


Figure 33. Site 7 before (left) and after (right).

Site 8 is a 453 foot stretch of perennial stream along Baron Fork Creek on private property. The property owners have experienced the loss of several acres of pasture due to the widening and movement of the channel centerline over a short period of time. The design for this site included realigning the channel, regrading the inner berm and point bar as well as the bank slopes. The floodplain was regraded and a bankfull bench was added for bank protection with added storage for high-flow events.


Figure 34. Site 8 before (left) and after (right).

Site 9 is located at the Peavine Hollow Public Access which is a 441 feet gravel bar along the Illinois River. The gravel from the bar is being carried downstream by the river and needs to be stabilized to maintain the access point. To do this, the contractor regraded the lateral bar. Other work at the site included regrading of the 2 boat ramps and access roads. While minimal physical changes were implemented at the site, the improvements are expected to cause a behavioral change by vehicle operators in the area that will decrease erosion and improve long-term sustainability of the site.


Figure 35. Site 9 before (left) and after (right).

Site 10 is located at another public access point called Todd Public Access. The scope of this site consisted of 432 feet along the Illinois River. There was severe sloughing of the nearly vertical banks, causing loss of land and posing a safety hazard as this is a public site. To relieve some of the pressure from the banks, a bankfull bench with wood protection was constructed. The floodplain was graded and the banks were regraded with a gentle slope. Other work at this site included improvement of the dirt access road to the river.

Figure 36. Site 10 before (left) and after (right).

Site 12 is 2,358 feet along the Illinois River at the Illinois River Ranch Property Owners Association (POA). This site has also experienced severe sloughing of the banks near the picnic area and has lost a significant part of that designated area. To stabilize the area, several techniques were implemented by the design engineer and the contractor. The thalweg of flow was moved away from the eroding bank and the banks were regraded with a gentle slope over the length of the project. A gravel point bar was created and graded at the upstream end of the project. The floodplain and lateral bar on the inner bank, along with the channel, were graded. Two 70-foot boulder barbs with boulder-bench sills were constructed to protect and stabilize the bank. A boulder toe was installed at the south end of the project. A bankfull/ inner-bench berm (with willows and sycamores incorporated into the bench) was constructed from station 7+50 to station 13+74, over the extent of the boulder barb locations.


Figure 37. Site 12 before (left) and after (right).

On August 21 – 22, 2012 a team from Oklahoma State University that included Dr. Jason Vogel, P.E., Sharla Lovern, P.E., Katie Beitz and Jeri Fleming along with Shanon Phillips and Gina Levesque from OCC inspected the 10 completed sites. The purpose of the inspection was to develop a punch-list for the contractor on the sites for which they were asking final payment. The contractor has completed the punch list on the 10 completed sites. A final inspection of all sites was held on October 29, 2012 with OSU, OCC, DSC and OWRB present.

Task 5 – Complete pre- and post-implementation monitoring.

The Oklahoma Conservation Commission is responsible for the pre- and post-implementation monitoring. Pre-implementation monitoring was conducted in two phases. The sites located in the city of Tahlequah were completed on June 11, 2012 (Figure 38) and the remaining sites were completed in July (before construction began at each site). OCC did a fish survey and habitat assessment (Figure 38) at each site and will repeat that process one year after completion of the project.

Figure 38. OCC staff identifying fish during their fish survey in June, 2012.

Task 6 – Outreach

Education and training were an important part of this project. Training and educating local stakeholders, engineers and contractors on the techniques used in the stream channel restoration projects will help ensure a local expertise exists. Educating people that are in a position to provide funding for natural stream restoration projects should translate into more dollars spent on repairing streams.

Outreach began in July 2011 with the development of a webpage dedicated to natural stream restoration. The site includes information about two of Oklahoma's projects, the Cow Creek Project and the Illinois River Project, news and background on what natural stream restoration is and how it differs from more conventional restoration techniques. It also includes news articles, fact sheets, handbooks and other relevant information and materials and may be viewed at: http://lid.okstate.edu.

OSU staff attended several conferences in Oklahoma providing information about stream restoration in general and the Illinois River project specifically. In addition, a two-day workshop was held in Stillwater on Nov. 8 and 9, 2011. This workshop included sessions on watershed hydrology, fluvial geomorphology, as well as sessions on native plants and a tour of the Cow Creek restoration site. From this workshop a list of people interested in these techniques was developed and used to help advertise additional workshops held during the project period. This particular workshop was not funded using ARRA monies but instrumental in developing contacts and educating the regulatory community. See Table 15 for a list of all education and outreach efforts.

Table15. **Education and Outreach Timetable**

Type of Education and Outreach Activity	Date	Number in Attendance
Stream Restoration Website developed	July 2011	
Booth at Oklahoma Floodplain Managers Association Conference	September 19 – 21, 2011	
Booth at Governor's Water Conference	October 18 & 19, 2011	350 attendees
Natural Stream Corridor Restoration and Enhancement Workshop (not paid for with ARRA funds)	November 8 – 9, 2011	43 attendees
Booth at Water Day at the Capital	February 13, 2012	
Booth at Oklahoma Association of Conservation Districts Annual Meeting	February 27 & 28, 2012	150 attendees
Booth at Cherokee Nation Environmental Conference	April 13, 2012	100 attendees
Article in Muskogee Phoenix	June 5, 2012	
News story on KJRH, a television station in Tulsa	June 11, 2012	
Article in The Northeastern (Northeastern State University newspaper)	June 12, 2012	
"Stream Restoration Inspection" Workshop	June 21, 2012	45 attendees
Field Day	July 13, 2012	40 attendees

Article in Tahlequah Daily Press	July 16, 2012	
Natural Stream Restoration Design Workshop	July 24, 2012	42 attendees
Presentation at 17th Annual ITEC Conference	August 7, 2012	53 attendees
News story on Sunup	August 11, 2012	
Field Day	September 12, 2012	57 attendees
Article in Tahlequah Daily Press	September 13, 2012	
Poster presented at Restoration of our Rivers Conference, Bentonville, AR	October 4 & 5, 2012	75 attendees
Invitation to speak at Stream Restoration in the Southeast: Innovations for Ecology Conference, Wilmington, NC	Speaking October 16 & 17, 2012	300 attendees
Illinois River Ranch Open House	November 9, 2012	TBD

A series of two workshops and two field days were held in 2012. The first workshop was designed to educate people who might be inspecting restoration projects. It was held in Tahlequah, OK on June 21, with 45 people in attendance. Speakers included Dr. Jason Vogel, Dr. Greg Jennings (owner, Jennings Environmental), Darrell Westmoreland (CEO of North State Environmental), and David Bidelspach, P.E., (lead designer, Stantec, Inc.). The morning session consisted of classroom type instruction and the afternoon was spent in the field performing inspections on work in progress(Figures 39 and 40).

Figure 39. Attendee learns how to check elevation at inspection workshop.

Figure 40. Dr. Greg Jennings explains the structure of a log j-hook and how they will inspect it to ensure it is at the proper grade and elevation.

The first field day was held on July 13. About 40 people joined OSU staff and Greg Jennings on a tour of both completed sites and sites under construction. The purpose of this field day was to show people how the structures work and how vertical banks can be sloped and protected until vegetation is re-established. Participants were provided before and after pictures of each site so they could see the change. Four completed sites were toured and one site that was under construction was visited (Figures 41 and 42).

Figure 41. Field day participants visited Site 5 – Kaufman Park while the lower section was under construction. The participants got to see how the contractor finished the work in sections to help reduce further erosion.

Figure 42. Field day participants visited Site 2 – Head of History Trail to see a cross vane and how the bank was built out to protect some sewer infrastructure buried near the top of the bank.

The second workshop was held on July 24 and focused on how to design a restoration project using natural methods. Forty-two people attended this workshop. The morning was spent in class with a presentation by Dr. Greg Jennings. Then participants were taken on a tour of three sites to discuss how they were designed. During lunch Shane Charlson with the U.S. Army Corps of Engineers Regulatory Division discussed applying for a Section 404 dredge and fill permit. After lunch participants went to Site 12 – Private Landowner, on the Illinois River to participate in a design charette. Construction on this site had not begun and participants were broken up into six groups to develop a design for this project and share their ideas (Figure 43).

Fig. 43. Participants in the design charette shared their ideas on how to repair and restore the Illinois River Ranch site.

The final field day was held on September 12, 2012. Approximately 57 people attended this tour of sites. The participants included OSRC commissions, OCC board members, a candidate for state representative, Oklahoma Department of Transportation bridge managers, the environmental divisions of two Oklahoma Tribes and other decision makers and interested citizens. The group visited three of the completed urban sites, the War Eagle site and then went to Site 12 – Illinois River Ranch (Figure 44) to see the construction underway. Greg Jennings and Darrell Westmoreland talked to the participants about the various structures that had been installed and how they were functioning.

Fig 44. Shanon Phillips, OCC Water Quality Director discussed the restoration projects and the impact they will have on water quality to attendees of the final field day.

The workshops resulted in a wide range of people becoming more familiar with natural stream restoration and the various ways it can be used both in an urban and a rural setting.

In addition to the workshops and field days, newspapers and television stations were contacted about the project. The Muskogee Phoenix, the Tahlequah Daily Press and the Northeastern did stories about the project before construction began. The Tahlequah Daily Press did two follow up stories. KJRH-Channel 2 from Tulsa featured two Tahlequah parks, Felt's and Kaufman in one of their news feature segments. They highlighted the effect erosion can have on infrastructure and public safety. OSU's SunUp program did a segment focusing on the effects of erosion on farmland (Figure 45). To view the SunUp episode visit http://sunup.okstate.edu/category/seg/2012seg/081112-streambank-conservation/?searchterm=restoration.

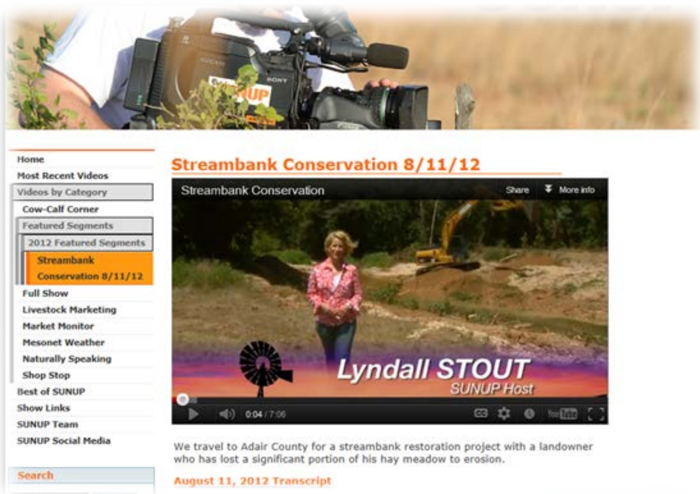


Fig 45. OSU's agriculture television show did a story on the impact of erosion to farmland and how restoration could minimize it.

A series of videos has been developed that can be used by Oklahoma Cooperative Extension Services and others as an educational and informational tool. The videos give information about the purpose of the various structures used and the benefits of natural stream restoration.

OSU and OCC staff were on site during the construction phase to answer questions from interested residents about this project. Several children stopped by almost daily to see the progress of the work on both the rural and urban sites. The outreach done in conjunction with the construction was an effective way to introduce and educate the general public about the benefits of natural stream restoration.

Task 7 – Reporting

Quarterly reports were submitted with each invoice beginning with the July – September 2011 invoice. Each report included a summary of what had been accomplished in each task to date. This final report will complete our reporting requirements.

6.0 SUMMARY AND LESSONS LEARNED

Summary

This project was funded through the Oklahoma Water Resources Board's CWSRF Green Projects Principal Forgiveness program. The loan, awarded to OCC, was available as a result of the American Recovery and Reinvestment Act. This project fulfilled some of the goals of the Act by providing either full or partial funding for over 10 employees at OSU who may not have otherwise remained employed. In addition, it provided funding for employees at OCC, the design firm and construction company. The impact to the local economy was significant with over 275 hotel nights over four months, food, equipment rental and supplies purchased locally. Most of the materials and supplies used on this project were made in America.

This project served its green purpose by repairing 6,657 feet of streambank that had significant erosion problems. By repairing these streambanks this project is reducing sediment and pollutant loads in one of Oklahoma's scenic river systems. Educating and working with area landowners has allowed OCC to begin the process of enrolling additional acreage in the Conservation Reserve Enhancement Program. This will help ensure that this project's benefits continue long-term by maintaining a healthy riparian system which provides additional benefits to the stream and the stream corridor. However, continued monitoring of the restored sites is important to help determine how much sediment is being kept out of the waterbodies. Information gleaned from additional monitoring of the sites can also be used in conjunction with the recommendation of how different stream orders should be repaired. Combining this information will be a useful tool in determining which techniques work best in particular stream orders.

OSU is now able to make recommendations to OCC and other agencies on how different stream orders should be repaired, and what the most beneficial techniques are to reduce erosion. Specifically, future streambank restoration and stabilization projects should consider:

- ✓ the impact moisture content and a series of high-flow events have on streambank stability when considering which stabilization methods to consider;
- ✓ to prevent erosion of gravel subsoils; larger streams will require more restrictive toe protection because of the large shear stresses at the toes;
- ✓ combining young plantings with other stabilization techniques during restoration to make up for the limited tensile strengths of young, immature vegetation;
- ✓ larger streams may be more costly to restore, but the water quality benefits may be greater because they generally have thicker silt-loam layers on the streambanks, which may contribute a large sediment load (particularly silts and clays);
- ✓ CONCEPTS modeling predicts that grade control measures may be more effective for lower-order streams, while hard armoring may be more effective on higher-order streams; this is also supported by the slope distribution mapping, which shows that the lower order streams generally had greater slopes.

This information can be used to identify and prioritize sites for future projects. This will help ensure Oklahoma spends its limited budget on sites that will provide the most benefit for the money.

The benefits of bank stabilization and stream restoration have been measured by improvements in water quality, terrestrial and aquatic habitat and reduced land loss. However, it has rarely been quantified in monetary terms; i.e. how much people are willing to pay for a restored stream system. This project has shown that in general, Oklahomans are willing to pay $85.63 per year for improvements to streambanks, and $16 per year for improvements in water quality and clarity. Additionally, Oklahomans think they should be compensated by $140 per year for the degradation of water quality. This information will be used to help inform decision makers that money spent on these types of projects provide a benefit to Oklahoma and that Oklahoman's do value the aesthetic and recreational uses of a stream

Additional information on the value of land lost, and the decrease in income resulting from land loss due to erosion would provide important information to better quantify the economic impact erosion has on landowners and the State. Developing a model to calculate that value is an important next step to help inform citizens and decision makers about the cost of erosion, not just as a water quality issue but also the economic impact it has on landowners.

One of the goals of this project was to educate a wide variety of people on the benefits of using bioengineering techniques to reduce erosion and repair streams to a more natural state. The purpose of the education and outreach component of the project was to help build a local expertise on the design and construction elements. Oklahoma has limited expertise in the area of natural stream restoration implementation. As a result of workshops, field days, on-site community education and conference events over 1250 individuals have been educated and/or trained on the principles and techniques of natural stream restoration. In addition, over 30,000 people have been introduced to the idea of natural stream restoration versus more conventional forms of restoration through newspaper articles, and television segments.

Partnerships have been formed between several state and federal agencies in part because of this project. These partnerships, of OCC, Oklahoma Department of Transportation, OWRB, Oklahoma Department of Environmental Quality, U.S. Army Corps of Engineers and OSU will help facilitate completion of additional restoration sites across Oklahoma.

Additionally, the city of Tahlequah is working to pass a bond issue that includes monies for additional stream work in their community. City officials have said that the four restoration sites completed in Tahlequah served as a spark for the City to continue improving Town Branch Creek and the land abutting it.

OCC, working with the Oklahoma Division of Capital Assets, Construction and Properties, used the State's new best-value bid process to help ensure the contractor was not necessarily just the lowest bidder, but rather the most experienced and provided the best value. OCC was also able to put the project out for bid as a design-build project. This allowed the designer and construction company to place one bid for both services. This ensured that the designer and builder had a relationship and allowed the designer to be on site during construction. This project would not have been completed on time and within budget if we had not utilized the best-value design-build process.

This project has been successfully completed on time and within budget. The project team believes that this work has laid the groundwork for an expanding industry of natural stream restoration within Oklahoma. We are also very excited about the economic and environmental impact that the completed and future stream restoration projects can have in Oklahoma.

7.0 ACKNOWLEDGEMENTS

Many people helped get this project completed within the required timeframe and we would like to extend a special thank you to them. We would like to also extend our thanks to the private landowners who allowed us work on their property to help improve water quality in their watersheds.

- ✓ OSU DASNR, Grants and Contracts
- ✓ OSU Grants and Contracts
- ✓ OSU BAE Finance
- ✓ OCC
- ✓ OWRB

- ✓ USACE
- ✓ DCS
- ✓ ODEQ
- ✓ NRSC
- ✓ OSRC
- ✓ City of Tahlequah
- ✓ North State Environmental
- ✓ Jennings Environmental
- ✓ Stantec