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Experimental Back-sloping with Vegetation Establishment as an Erosion Control Option for Missouri Streambanks

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EXECUTIVE SUMMARY

Missouri landowners dealing with streambank erosion problems are searching for affordable and effective techniques they can use to address existing erosion issues and protect their property from further erosion. The search is complicated because the eroding streambank is often a symptom of a larger problem occurring elsewhere within the watershed. Consequently, finding an effective erosion control method can be difficult for a landowner unless they receive appropriate professional assistance. The limitations of currently available methods in terms of high cost, difficult installation, or inapplicability to larger stream systems have caused landowners to try techniques that are ineffective and may lead to increased instability.

As a result, the Missouri Department of Conservation (MDC) decided to evaluate five different streambank stabilization techniques. The back-sloping with vegetation establishment approach was evaluated as a potential alternative to a longitudinal rip rap toe project for controlling excessive streambank erosion. The back-sloping approach is designed to reduce erosive forces acting on the eroding streambank by back-sloping the streambank which gives it a higher width to depth ratio and establishing vegetation that will decrease velocities by adding roughness and stabilize the streambank with root systems over the long-term. Back-sloping reduces the slope of the eroding streambank to a 3:1 horizontal to vertical ratio by removing streambank material. The exposed soil is then covered with erosion control fabric and planted with vegetation to stabilize it over the long-term. Five back-sloping with vegetation establishment projects were distributed among five streams located on four MDC conservation areas across Missouri. The projects were built between September 2006 and January 2009 and all experienced multiple high flow events.

This technique had mixed results. Three of the five projects have either failed or sustained damage and vegetation establishment has been slow to nonexistent on four of the five banks. The California Branch and Fiery Fork projects were the two most successful back-sloping projects, but have also been tested by the fewest number of high flow events. The California Branch project maintained its sloped angle, even though it was built with a steeper slope than was intended. The Fiery Fork project was not a good test of the technique because immediately after project construction the thalweg shifted away from this streambank for reasons that had nothing to do with the project. The Starks Creek project had some toe erosion, but the project has maintained the bank's slope. However, the Starks Creek project remains vulnerable to complete failure due to limited vegetation establishment at the site. The two projects built on Union Ridge Conservation Area on unnamed tributaries of Spring Creek have both failed. The project on the eastern tributary has suffered significant toe erosion at the apex of the bend downstream and the western project failed due to toe erosion that occurred along the entire length of the project.

Overall just one of the four projects that was actually a good test of the technique has been successful in stabilizing the bank. The projects that failed did so because the vegetation did not become established quickly and the erosion control fabric was not strong enough to protect the bank. Given these results, careful consideration would have to be given before using this approach. While this approach did save money compared to a traditional approach, its lack of success and the need for repairs could quickly eliminate those savings. The most significant factors limiting the usefulness of this technique are the fact that it is inappropriate for tight bends and its reliance on the quick establishment of vegetation, particularly trees, in determining whether or not the project has any chance at being successful long-term. As previously recommended in the literature, this approach appears to have merit as a supplement to other types of toe protection, but has little or no application as a stand-alone technique.

Keywords: streambank stabilization, erosion, erosion control, stream, landowner assistance

INTRODUCTION

Background

Erosion and deposition are natural and essential components of all stream systems. Erosion and deposition provide nutrients, create habitat diversity, and allow for channel adjustment to natural and anthropogenic stream alterations at multiple scales within the watershed (Van Haveren and Jackson 1986, Cramer et al. 2000, Fischenich and Allen 2000, Schmetterling et al. 2001, Price and Karesh 2002). However, human activities have altered many stream systems to a point that they can no longer maintain a natural form (Henderson 1986, Biedenharn et al. 1997, Church 2002, Washington State Aquatic Habitat Guidelines Program 2002). Such disturbances result in channel instability, excessive rates of erosion, and deposition.

The amount of erosion that occurs is dependent on the balance between the relative erodibility of channel material and the strength of hydraulic forces acting upon that material. Streambank stability and erosion resistance are also influenced by vegetation, physical features, and soil composition. Hydraulic forces acting on the streambank are controlled by factors such as vegetation, flow regime, sediment supply, channel gradient, and other watershed characteristics. The interactions of these factors control the natural erosion rates of a stream keeping it in a quasi-balance called dynamic equilibrium (Leopold et al. 1964, Bates 1998, Fischenich 2001a, Church 2002). A stream in dynamic equilibrium can sustain some disturbance without altering its natural state (Fajan and Robinson 1985, Henderson 1986, Gore and Shields 1995, Fischenich 2001b). Dynamic equilibrium is lost when there is an imbalance between flow regime, sediment supply (amount and type of materials), stream power (capacity of the stream to move sediment), and streambank strength, which are often influenced by human activities.

Activities such as urbanization, channelization, channel armoring, dredging, or construction of dams, levees, roads, and bridges may cause a loss of dynamic equilibrium and initiate excessive erosion. Vegetation clearing in the riparian zone may also result in loss of dynamic equilibrium at local or watershed scales (Bohn and Buckhouse 1986, Henderson 1986, USDA-NRCS 1996, Grubbs et al. 1997, Caverly et al. 1998, Simon and Steinemann 2000, Price and Karesh 2002, Shields and Knight 2003). Activities affecting the riparian vegetation along a stream can result in streambanks that are less stable, less cohesive, and more easily eroded (Bohn and Buckhouse 1986, Meadows 1998). Riparian vegetation is also critical to slowing flood waters from overbank flows, and its removal can cause increased erosion during floods.

Once a channel becomes unstable, accelerated erosion will occur through a variety of site specific mechanisms. Understanding the causes and mechanisms of the erosion is vital prior to attempting a streambank stabilization project if long-term stability is to be achieved (USDA-NRCS 1996, Biedenharn et al. 1997, Bates 1998, Meadows 1998, Kondolf et al. 2001, Washington State Aquatic Habitat Guidelines Program 2002). Disturbances at all scales activate physical processes within the streambank that result in accelerated erosion. Typical mechanisms of streambank failure include: 1) toe erosion, 2) surface erosion, 3) local scour, 4) mass failure due to overly saturated soils, 5) subsurface entrainment via groundwater seepage, 6) avulsion (major channel movement) after high flow events or due to excessive aggradation, and 7) ice scour (Henderson 1986, Grubbs et al. 1997, Bates 1998, Palone and Todd 1998, Washington State Aquatic Habitat Guidelines Program 2002). Streambank stabilization projects should use techniques that address the onsite mechanism(s) of streambank failure, but also should consider the fundamental causes of streambank failure for long-term stability (Cramer et al. 2000, Simon and Steinemann 2000).

Understanding which factors have been altered is critical before trying to address erosion problems. Some factors to consider for site-specific treatments include: 1) channel bed stability, 2) streambank height, 3) streambank material, 4) bed gradient, 5) flow regime, and 6) curvature of the stream (Bowie 1982, Derrick 1996, Gray and Sotir 1996, Fischenich and Allen 2000, Fischenich 2001a, Moses and Morris 2001). The factors listed above interact to determine the rate and type of erosion that occurs at a site and whether or not a certain technique is appropriate (Leopold et al. 1964, Li and Eddleman 2002). Once the fundamental cause and mechanism of failure has been identified, an appropriate approach can be determined for addressing the problem. The best approach may be cessation of the activity causing the problem and allowing the system to recover on its own. Unfortunately, addressing the overall problem and allowing for natural recovery may not be an appealing option in all situations, and a stabilization project may be necessary (Roper et al. 1997). In addition, if the erosion poses a threat to infrastructure or other valuable resources then an engineered stabilization project may be needed. Regardless of the stabilization technique, the ultimate goal should be to slow erosion enough to allow for the growth of a dense, woody riparian corridor to increase the likelihood of long-term streambank stability.

If a streambank stabilization technique is going to be used, it is critical to determine which technique is most appropriate for that situation prior to implementation. Techniques that are appropriate in one situation may not be appropriate in another. Therefore, prior to using new techniques, stream managers must determine the types of situations where they are, and are not, appropriate. To do this, we must understand the hydraulic forces acting upon the streambank and affecting its stability, and the technique's ability to address those forces and affect the streambank's resistance to erosion and its stability.

Missouri Streams

The majority of rivers and streams in Missouri have been dramatically altered over the last 200 years by human activities. These alterations have caused numerous problems including channel instability and excessive erosion. Sediment is considered the largest pollutant of our streams and is one of the most challenging and costly environmental hazards in the United States (Bowie 1982, Henderson 1986, National Research Council 1992, Becker 1993, Waters 1995, Biedenharn et al. 1997, Kauffman et al. 1997).

In a survey conducted in 1991 by Larsen and Holland (1991), 49% of Missourians indicated they wanted to see more emphasis put on river and stream conservation. Weithman (1994) found in another poll in 1994 that three of the five most important aquatic resource issues were the protection of water quality, legislation to protect streams, and assistance to landowners in solving stream problems. The importance of the state's river and stream resources to its residents makes dealing with erosion problems a high priority.

Missouri landowners dealing with streambank erosion problems are searching for affordable an effective techniques they can use to address existing erosion issues and protect their property from further erosion. The search is complicated because the eroding streambank is often a symptom of a larger problem occurring elsewhere within the watershed. Consequently, finding an effective erosion control method can be difficult for a landowner unless they receive appropriate professional assistance. The limitations of currently available methods in terms of high cost, difficult installation, or inapplicability to larger stream systems have caused landowners to try techniques that are ineffective and may lead to increased instability. The lack of documented technique evaluations makes it difficult to determine what techniques are available and whether or not they have application in Missouri streams. This information gap is considered the largest obstacle to improve the performance of streambank stabilization projects (Simon and Steinemann 2000). Monitoring watershed and channel conditions before and after project installation is a priority to determine effectiveness of the technique. Unfortunately, most erosion control projects have not been monitored after installation. Improved monitoring is needed to learn from previous applications and improve future project designs (Simon and Steinemann 2000, Kondolf et al. 2001, Shields and Knight 2003). Only through moni-

Table 1. River and site details for the five back-sloping projects. The watershed area is for the area located upstream of the site only and not the entire watershed.

	California Branch	Fiery Fork	Starks Creek	Union Ridge East	Union Ridge West
River Basin	Little Indian	Little Niangua	Little Niangua	Chariton	Chariton
Physiographic Region	Salem Plateau	Ozark Plateau	Salem Plateau	Chariton River Hills	Chariton River Hills
Stream Order	2	3	4	2	2
Reach Gradient	63.7 ft./mi	69.8 ft./mi	28.6 ft./mi	37.5 ft./mi	23.1 ft./mi
Watershed Area	1.44 mi^2	3.6 mi^2	34.7 mi^2	1.8 mi^2	3.9 mi^2
Bank Height	8 ft.	6 ft.	10 ft.	8-10 ft.	10-12 ft.
Bank Length	89 ft.	160 ft.	322 ft.	300 ft.	400 ft.

toring the long-term performance of a technique can stream managers determine when and where a technique is appropriate and identify its limitations.

Technique

Back-sloping an eroding streambank is a commonly used supplement to other streambank stabilization techniques. Back-sloping a streambank involves using heavy equipment to reduce the slope of the eroding streambank to a slope of 1:1 or less, protecting it with erosion control fabric, and planting terrestrial bottomland vegetation. Typically it has been used to address the loss of riparian vegetation or improve the performance of other streambank stabilization techniques and not as a stand-alone technique on banks with toe erosion (Bowie 1982, FISRWG 1998, North Dakota Forest Service 1999, CPYRMA 2000, Tennessee Valley Authority 2003). The costs associated with this technique will depend on the type of heavy equipment and fabric used. Reducing the streambank to a slope of 1:1 is considered the absolute minimum and most authors recommend using a slope of 2:1 or 3:1 if possible.

This project tested back-sloping with vegetation establishment as a stand-alone streambank stabilization technique. The back-sloping with vegetation establishment technique was designed to be a cost-effective alternative to a traditional longitudinal rip rap toe protection streambank stabilization project. Instead of trying to armor the toe of the streambank to protect it from erosion, back-sloping is designed to reduce erosive forces acting on the eroding streambank by providing a higher width to depth streambank ratio and establishing vegetation that would decrease velocities by adding roughness and stabilization of the streambank via root systems over the long-term. The objectives of this study were to examine the performance of back-sloping with vegetation establishment and determine: 1) the extent of continued erosion or deposition at the toe of the bank, 2) if the streambank maintained its constructed slope, and 3) if back-sloping with vegetation establishment was a cost effective alternative to longitudinal rip rap toe protection.

STUDY SITES

Back-sloping with vegetation establishment was evaluated at five locations on streams segments within MDC conservation areas. Sites selected for this technique were limited to streams of 4th order or lower and project sites needed to have streambank heights of no more than approximately 15 feet. Selected stream segments were on California Branch on Little Indian Creek Conservation Area (LICCA) in Washington County, an unnamed tributary of Fiery Fork on Fiery Fork Conservation Area (FFCA) in

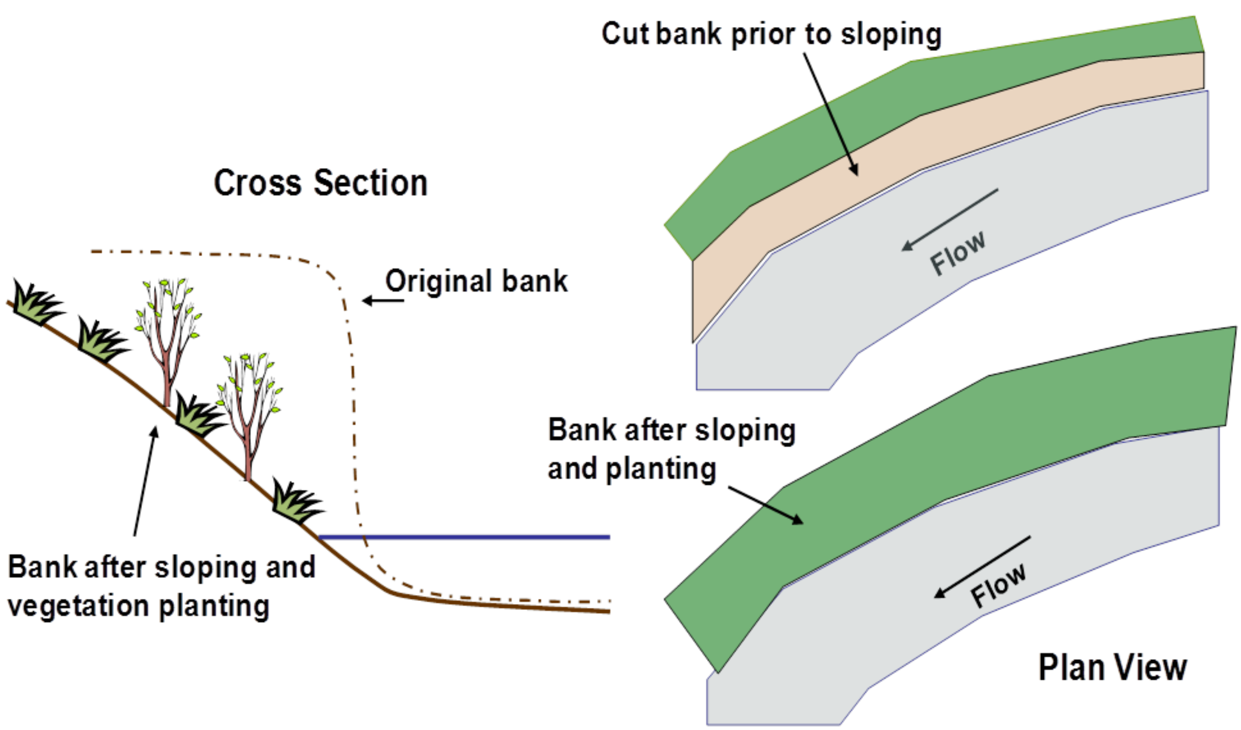

Figure 1. Cross sectional and plan view of a back-sloped bank.

Figure 2. Starks Creek back-sloping site. (A) Prior to project construction February 2006. (B) Sloping the streambank at a 3:1 angle October 2006. (C) Erosion control fabric being stapled to the streambank October 2006. (D) Tree planting March 2007.

Camden County, Starks Creek on Mule Shoe Conservation Area (MSCA) in Hickory County, an unnamed tributary of Spring Creek on Union Ridge Conservation Area (URCA) in Sullivan County that will be referred to as Union Ridge East, and a second unnamed tributary of Spring Creek on Union Ridge Conservation Area (URCA) in Sullivan County that will be referred to as Union Ridge West. River and project site details are located in Table 1. Area maps showing the locations of the conservation areas in Missouri and project locations within those areas are provided in Appendix 1.

METHODS

Back-sloping Design

The back-sloping and establishment of riparian vegetation technique was designed to reduce the forces acting on the streambank by spreading them out in the short-term and promoting the establishment of vegetation that will stabilize the streambank over the long-term. The goal for the back-sloping projects associated with this study was to reduce the slope of the eroding streambank to a 3:1 ratio (Figure 1). To accomplish slope reduction, all excess streambank material was removed from the site, loaded in a dump truck, and taken to an upland location. The exposed soil was then covered with C2 coconut fiber erosion control fabric and planted with perennial rye grass and trees to provide a ground cover until trees could become established (Figure 2). The C2 erosion control fabric comes in 7.5 ft. X 120 ft. rolls that were staked down with 6 inch x 1 inch x 6 inch staples to protect the bank. A total of 12 different tree species were then planted at a rate of more than 1500 per acre for all species combined at the five projects. Species planted were river birch, sandbar willow, buttonbush, false indigo, sycamore, cottonwood, roughleaf dogwood, gray dogwood, silky dogwood, deciduous holly, wild plum, and green ash.

The project design at each site varied based on the site specific conditions. In addition other changes to construction and design were made to account for lessons learned building earlier projects. The California Branch back-sloping with vegetation establishment project was built in May 2007. The California Branch project was built with the steepest slope of any of the projects. The streambank was only sloped to a 2:1 angle instead of the target slope of 3:1. The Fiery Fork back-sloping with vegetation establishment project was built in late January of 2009 and the erosion control fabric was put in place in early February of 2009. The Starks Creek back-sloping project was built in September of 2006. The Union Ridge East back-sloping project was built in August of 2007. The Union Ridge West back-sloping project was built in August of 2007.

Monitoring

Project monitoring consisted of pre-construction monitoring (to quantify reference condition prior to stabilization efforts), post-construction monitoring (to establish post-construction baseline for

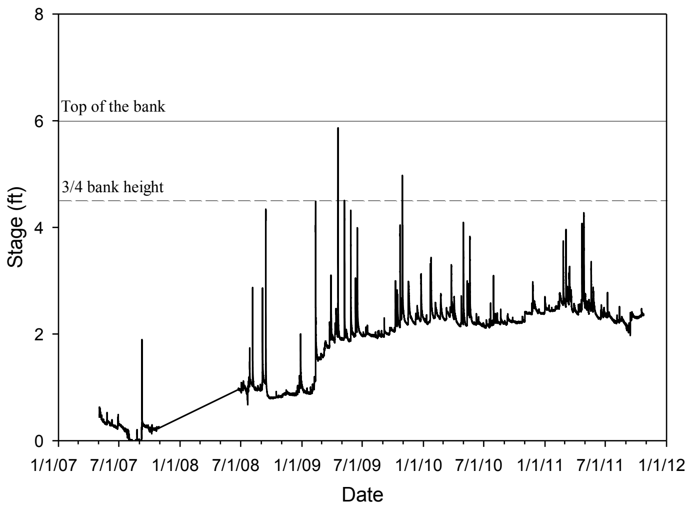

Figure 3. Levelogger® data from California Branch for 2007 through 2011. Data are missing from November 2007 until June 2008 due to a lost Levelogger®.

evaluation of future project performance), and post-flow monitoring (to determined project performed after high stream flow events). Post-flow monitoring was conducted on an annual basis following spring flow events and additionally following any flow events that caused significant changes to the projects. Each project was monitored through a minimum of five flow events that exceeded ¾ the height of the streambank and the streambank appeared to have become more stable, or project failure occurred.

Monitoring consisted of physical surveying, Global Positioning System (GPS) mapping, photo points, and flow monitoring. The physical survey was conducted using a Trimble 5605 DR Total Station from 2005 -2009 and a Nikon Nivo 5.M Total Station from 2010 - 2011 to measure cross channel transects and a longitudinal profile of the channel thalweg. All transects for the Union Ridge West and Starks Creek projects ran from a benchmark on the eroding streambank to the top of the gravel bar or streambank across the channel. The California Branch, Fiery Fork and Union Ridge East projects all had transects that started on the opposite streambank and ran to the top of the eroding bank. Transects were evenly distributed down the length of the project. The longitudinal profile of the thalweg started at the head of the first riffle downstream of the project and followed the thalweg to the head of the first riffle upstream of the project. Project features including the toe of the bank, top of the sloped bank, wetted channel, gravel bars, opposite bank, benchmarks, and other features were mapped with a sub-meter accuracy GPS unit (Trimble Geo XT) to make a map of each site. In addition, the GPS unit was used to record locations where water depth was measured. These data were used to create a depth profile of the entire wetted channel area in ArcMap v9.3.1. Permanent photo points were established to create a visual record of changes in the project through time. Photos were taken at least twice a year and during all surveys. A Levelogger® (Solinst Gold Model 3001 LT F30/M10) was placed in the stream and paired with a Barologger® (Solinst Gold Model 3001 LT F5/M1.5) on the streambank to monitor flow. The Levelogger® is a pressure transducer that uses changes in pressure to track changes in stage. The Levelogger® can accurately track stage when paired with a Barologger® to account for changes in barometric pressure. The Levelogger®s were maintained in the stream channel year-round.

RESULTS

California Branch

Since construction, the California Branch project has been tested by only a few flow events greater than ¾ of the streambank height (4.5 ft., Figure 3). Following construction, the project was not tested by any flow events during the rest of 2007. In the spring of 2008, the project was tested by at least one and potentially multiple flow events that reached a stage of ¾ of the streambank height or higher. Unfortunately, the number and size of flow events are unknown because during a high flow event the Levelogger® was lost

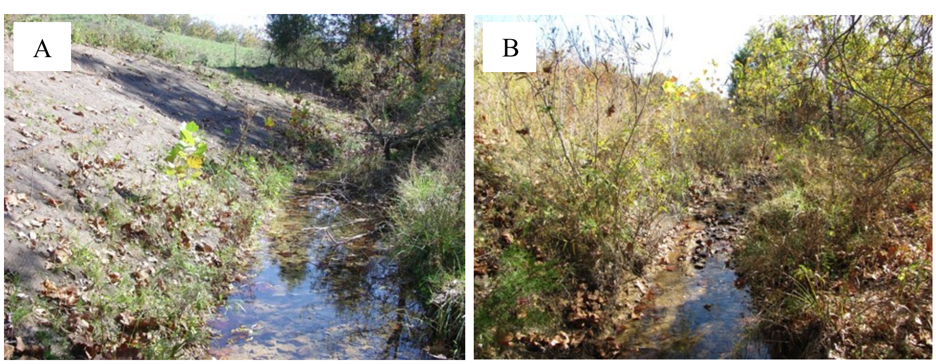

Figure 4. Looking upstream at the California Branch back-sloping project. (A) Post-flow October 2007. (B) Post-flow October 2011.

and not replaced until late June 2008. In 2009 there were four flow events that were greater than ¾ of the streambank height. In 2010 and 2011, there was not a single event that reached a stage greater than ¾ of the streambank height.

Photo monitoring demonstrates the effectiveness of this project since project construction in May 2007. The photos show that the sloped streambank has held its slope through its entire length since the project was completed (Figure 4). The pictures also show that while there were areas where vegetation establishment was slow, we now have vegetation established over the entire bank. However, tree establishment has remained slow and this is a concern that could affect the long-term stability of this project because the tree's root systems will be critical to stabilizing the soil of the bank.

In addition to photo monitoring, post-flow physical surveys were conducted and GPS maps were created each year from 2008-2011. The physical surveys consisted of four transects distributed evenly throughout the length of the project. Survey data show the streambank changes between the pre-construction survey, the post-construction survey, and the three post-flow surveys. The survey data illustrate that there has been very little streambank movement and almost no change in streambank slope from the post-construction survey to the 2011 post-flow survey (Table 2). The slope of the streambank has remained stable even though it was constructed steeper than planned.

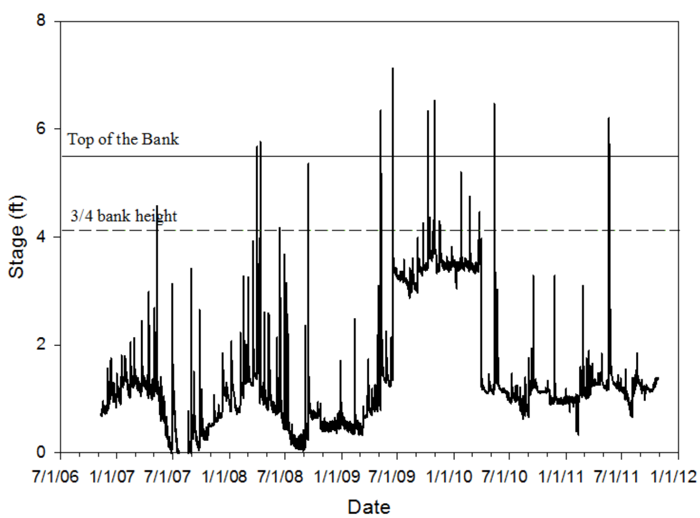

Figure 5. Levelogger® data from an unnamed tributary of Fiery Fork Creek for 2006 through 2011.

Fiery Fork

Since construction, the Fiery Fork project has been tested by multiple high flow events (Figure 5). Immediately following placement of the fabric, a small flow event reaching ½ the streambank height tested the project. No fabric was relocated nor any change in streambank stability noted even though no vegetation had been established on the bank. In May of 2009, a flow event went over the top of the streambank and caused the failure of the farm rock toe project located upstream and caused major changes to the channel (Figure 6). The flow event caused a shift in the thalweg at this site. The thalweg switched from running directly against the toe of the streambank to a previous high flow area behind the opposite gravel bar. An even larger flow event in June 2009 and two additional high flow events that occurred in September of 2009 helped lock the stream in its new configuration. By 2010 the flow was well established in the new location and additional flow events in 2010 and 2011 did not make any significant changes.

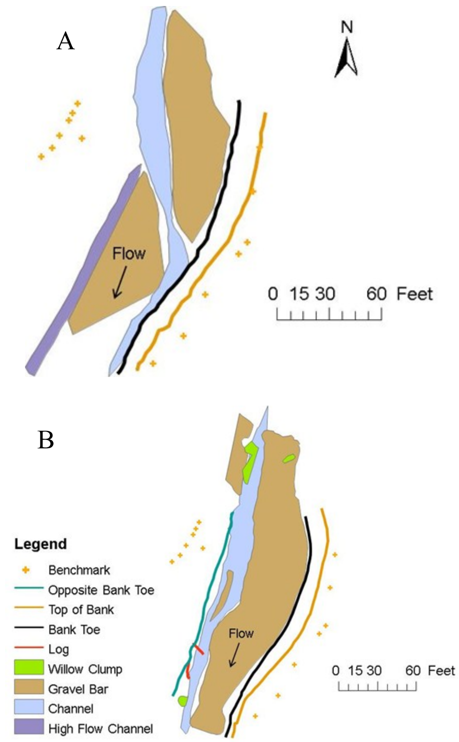

Figure 6. GPS maps of the back-sloping project located on an unnamed tributary on Fiery Fork CA. (A) Post-construction in February 2009. (B) Following channel shift in June 2009.

Photo monitoring illustrates the change in the channel at this location. Photos taken from May 2009 and June 2009 show the dramatic shift in the channel that took place following the first flow event. Photos from 2010 show vegetation establishment and lack of flow near the project streambank (Figure 7). The physical surveys demonstrate how the thalweg shifted away from the streambank following construction

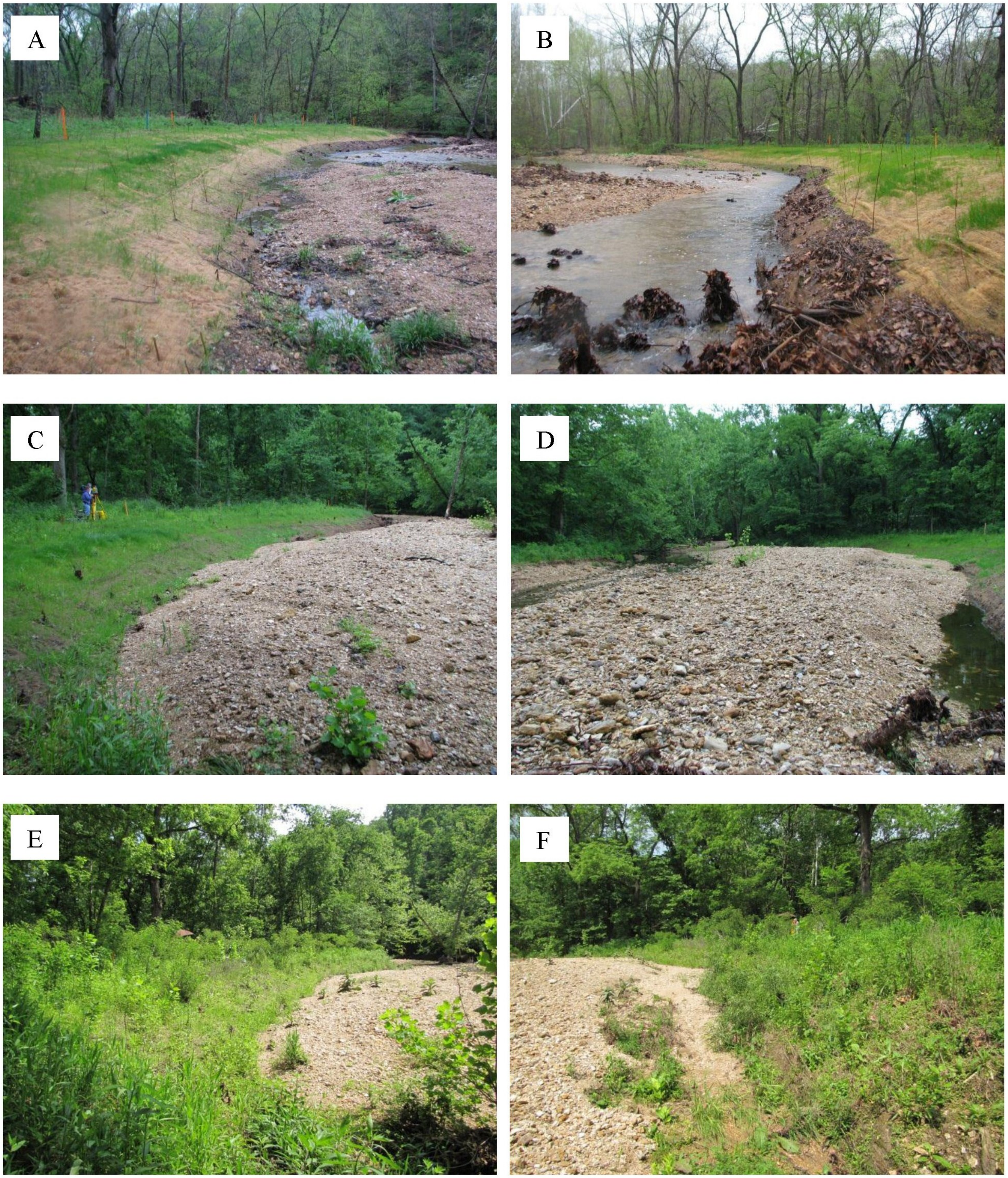

Figure 7. Fiery Fork back-sloping project. (A) Looking downstream May 2009. (B) Looking upstream May 2009. (C) Looking downstream June 2009. (D) Looking upstream June 2009. (E) Looking downstream May 2011. (F) Looking upstream May 2011.

Table 2. Streambank movement and changes in streambank slope due to erosion at the California Branch back-sloping and vegetation project between the post-construction survey in May 2007 and the final survey in June 2011. Erosion is represented by negative movement in the streambank and deposition is represented by a positive movement in the bank. Transect numbers increase as you move downstream.

	Top of streambank Movement (ft.)	Toe of streambank Movement (ft.)	Bank Slope 5/2007	Bank Slope 6/2011
Transect 1	1.36	-1.87	0.39	0.40
Transect 2	0.84	0.56	0.51	0.54
Transect 3	1.90	0.03	0.53	0.61
Transect 4	4.30	-0.30	0.44	0.62

(Figure 8). The shifting of the thalweg away from the streambank resulted in a project that is no longer a good test of the technique.

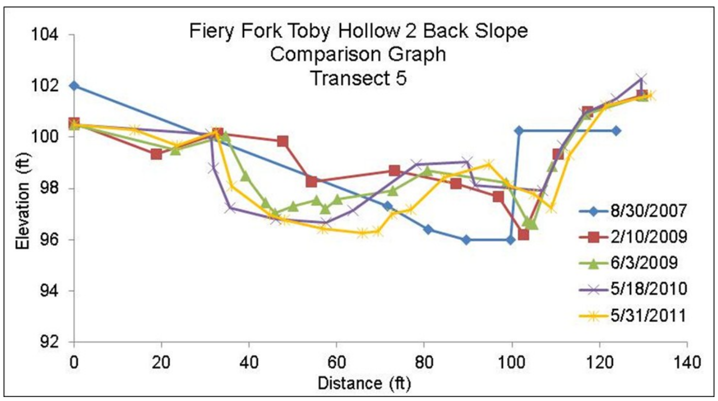

Figure 8. Physical survey data for transect five for the pre-construction survey (8/30/2007), post-construction survey (2/10/2009), and three post-flow surveys (6/3/2009, 5/18/2010, and 5/31/2011).

Starks Creek

The Starks Creek project has been tested by numerous flows that went over the top of the eroding streambank since construction (Figure 9). In addition to the flows shown on the graph, there were at least two flow events between April and June 2007 that were not recorded because of a malfunction with the Levelogger® in late March that was not detected until July. During 2008, the project was tested by 10 flow events greater than ¾ of the height of the streambank (7.5 ft.) and five more flow events greater than the top of the streambank (10 ft.). Three of the five flow events that went over the streambank topped out at a stage greater than 12 ft. All three represented a 10 ft. rise over the average stage during the previous week. The first of these flow events caused the failure of the gravel roll with back-sloping project that was located immediately upstream and caused a change in how the stream approached the back-slope project (Figure 10). In 2009, the high flow events and changes to the channel continued to occur. Three more flow events occurred in 2009 that exceeded the top of the bank. Included in this was a flow with a stage over 14 ft. which represents the highest flow recorded at this site during the study. In 2010 and 2011, there was only a single flow event in each year that reached a stage above the top of the bank.

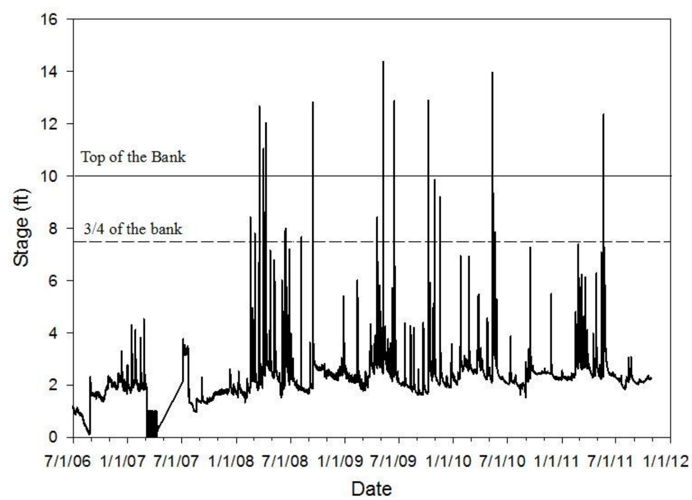

Figure 9. Levelogger® data from Starks Creek for 2006 through 2011. Data are missing from March 2007 until July 2007 due to a Levelogger® malfunction.

Photo monitoring gives a good visual representation of how the sloped streambank has held up against numerous high flows despite the slow establishment of vegetation and changes in the stream morphology above the project (Figure 11). The channel cut through the upstream streambank and gravel bar and now approaches the project from further downstream than it did before. The change in the stream's approach to the project contributed to erosion at the lower end, but has not resulted in a significant increase in streambank slope. Details on streambank movement along each transect are shown below

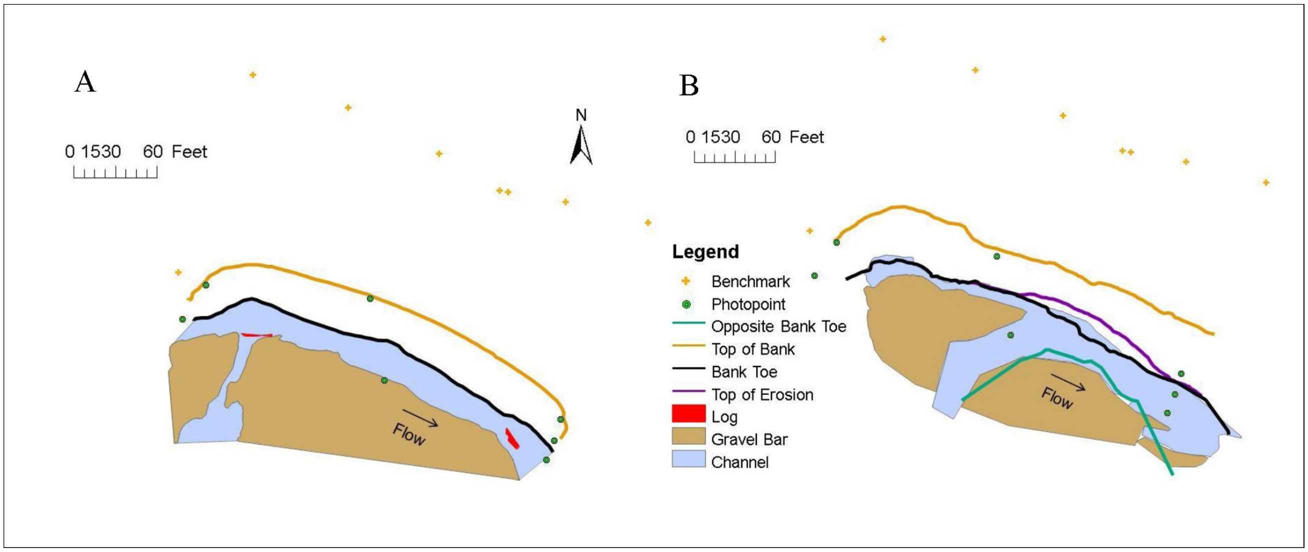

Figure 10. GPS maps of Starks Creek channel along the back-sloping project. (A) October 2006. (B) July 2011.

(Table 3). Even though there has been some erosion at the streambank toe (particularly transects two, four, five, and six) the slope of the streambank has remained relatively stable. The toe erosion that has occurred has prevented vegetation establishment on that portion of the streambank and has made this project vulnerable to further erosion and potentially failure.

Union Ridge East

Since construction, the Union Ridge East project has been tested by eight flow events that reached stages greater than ¾ the height of the streambank (6.75 ft., Figure 12). Following construction in the fall of 2007, the project was not tested by any flow events during the remainder of the year. In 2008, the project was tested by two flow events that went over ¾ the streambank height. The larger of these two events occurred on 7/24/2008 and topped out at a stage just less than the top of the streambank (9 ft.). This flow event represented a rise of 8 ft. over the average stage during the previous week. In 2009, the streambank was tested by only one greater than ¾ streambank height event. Following flow events in 2008 and continuing into 2009, areas of toe erosion began to develop. In 2010, the project was tested by four flows that reached stages above ¾ streambank height. The areas of toe erosion continued to increase in size to the point that the eventual failure of the project appeared to be assured. In 2011 the largest flow event we recorded tested the project and reached a stage over 10.5 ft. This flow caused additional erosion and the streambank continues to slowly fail. Vegetation has not become established enough to protect the streambank from continued erosion, and lack of vegetation along with the current level of erosion makes it unlikely the streambank will achieve stability. The

Figure 11. Photos of the Starks Creek back-sloping project. (A) Looking downstream at the project following construction in October 2006. (B) Looking downstream at the project in October 2011.

Table 3. Streambank movement and changes in streambank slope due to erosion at the Starks Creek back-sloping project between the post-construction survey in October 2006 and the final survey in July 2011. Erosion is represented by negative movement in the streambank and deposition is represented by a positive movement in the bank. Transect numbers increase as you move downstream

	Top of streambank Movement (ft.)	Toe of streambank Movement (ft.)	Bank Slope 10/2006	Bank Slope 7/2011
Transect 0	-3.86	1.26	0.43	0.35
Transect 1	-11.98	-0.03	0.33	0.27
Transect 2	-7.36	-4.04	0.31	0.25
Transect 3	2.42	-0.57	0.30	0.31
Transect 4	-2.87	-9.72	0.27	0.29
Transect 5	3.66	-3.84	0.24	0.26
Transect 6	5.47	-5.67	0.32	0.43

photo monitoring, which has occurred on multiple occasions since project construction in August 2007, gives a good visual representation that while the sloped streambank has held through most of its length, a large area of erosion has begun to develop in the lower half of the project (Figure 13).

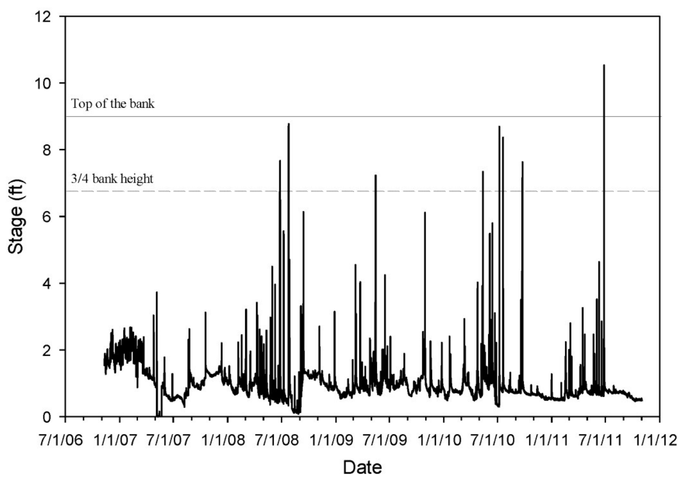

Figure 12. Levelogger® data from an unnamed east tributary of Spring Creek for 2006 through 2011.

Figure 13. Looking downstream at Union Ridge East back-sloping project. (A) Post-construction September 2007. (B) Post-flow October 2008. (C) Post-flow November 2010. (D) Post-flow July 2011.

The physical surveys, which were conducted post-construction and following flow events each year from 2008-2011, give details on streambank movement along each transect throughout the entire length of the project (Table 4). Transect six gives a good example of the large amount of toe erosion that has occurred since project construction (Figure 14). Erosion has occurred at the streambank toe along six of the eight transects, particularly transects four, five, six and seven, which are located from the apex of the bend through the downstream end of the project. This erosion has resulted in the failure of the project, despite the fact that the overall slope of the streambank has remained relatively stable. The overall size of the streambank has masked the toe erosion that has occurred and prevented any large change in the overall streambank slope. The slope at the toe itself did increase dramatically.

Union Ridge West

Following construction in the fall of 2007, the project was not tested by any flow events during the remainder of the year. In the spring of 2008, the project was tested by at least one and potentially multiple flow events that reached stages above the top of the streambank (12 ft.). Unfortunately, the number and size of those events are unknown because during a

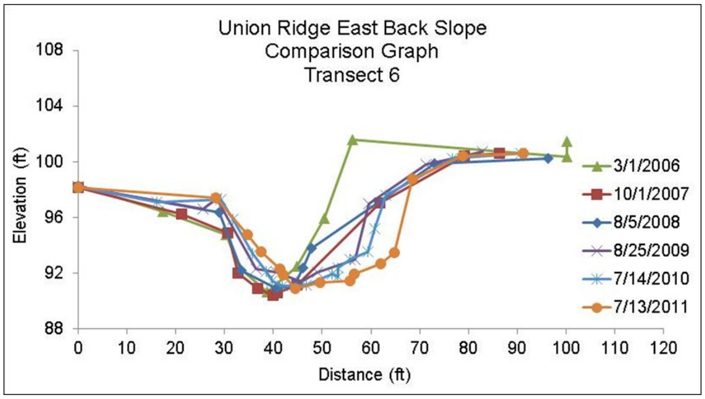

Figure 14. Physical survey data for transect six for the pre-construction survey (3/1/2006), post-construction survey (10/1/2007), and four post-flow surveys (8/5/2008, 8/25/2009, 7/14/2010, and 7/13/2011).

high flow event the Levelogger® was lost and not replaced until August 2008. A flow event that occurred between the first high flow and Levelogger® replacement initiated project failure. The toe of the streambank began to erode throughout the entire length of the project (Figure 15). In 2009, there was at least one and possibly multiple flow events that reached stages above the top of the bank. Unfortunately, the number and size of those events were once again unknown, as for the third time (also once prior to project construction) the Levelogger® that was placed in the stream was lost. This time the loss was not discovered until August of 2009. The flow events of 2008 and 2009 resulted in the complete failure of the project. Following the loss of the Levelogger® in 2009, the decision was made not to continue flow monitoring at the site since the project was already considered a failure.

GPS mapping and the physical survey data illustrate the extent of the erosion. The largest areas of toe erosion can be seen on the GPS map (Figure 16). The Union Ridge West project appears to have failed despite the sloping, because the erosion control fabric was not strong enough and the vegetation was not yet well enough established to protect the streambank toe from erosion during high flows. The streambank has eroded more than 15 ft. at seven of the nine transects and four of those have eroded more than 20 ft. (Table 5). Despite the large amount of erosion that has been seen at this site, there has been little change in overall streambank slope between the post-construction and final post-flow survey. The overall size of the streambank has masked the toe erosion that has occurred and prevented any large change in the overall streambank slope. The slope at the toe itself did increase dramatically and can be seen by looking at the transect graphs (Figure 17).

Figure 15. Looking upstream at the back-sloping project on the Union Ridge west tributary of Spring Creek. (A) Pre-construction November 2005. (B) Post-construction September 2007. (C) Project October 2008. (D) Project July 2011.

Table 4. Streambank movement and changes in streambank slope due to erosion at the unnamed east tributary of Spring Creek back-sloping project between the post-construction survey in October 2007 and the final survey in July 2011. Erosion is represented by negative movement in the streambank and deposition is represented by a positive movement in the bank. Transect numbers increase as you move downstream.

	Top of streambank Movement (ft.)	Toe of streambank Movement (ft.)	Bank Slope 10/2007	Bank Slope 7/2011
Transect 0	-4.22	0.46	0.35	0.32
Transect 1	-4.12	5.93	0.35	0.31
Transect 2	-0.55	-1.43	0.36	0.36
Transect 3	-1.81	-5.27	0.34	0.39
Transect 4	-0.47	-8.44	0.31	0.44
Transect 5	-4.57	-8.08	0.29	0.38
Transect 6	0.42	-14.86	0.26	0.39
Transect 7	0.81	-7.57	0.24	0.37

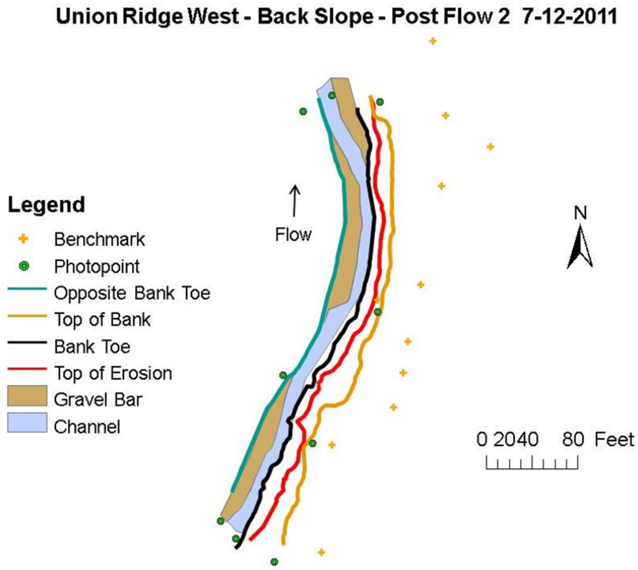

Figure 16. GPS map of the back-sloping project located on the unnamed west tributary of Spring Creek on Union Ridge CA.

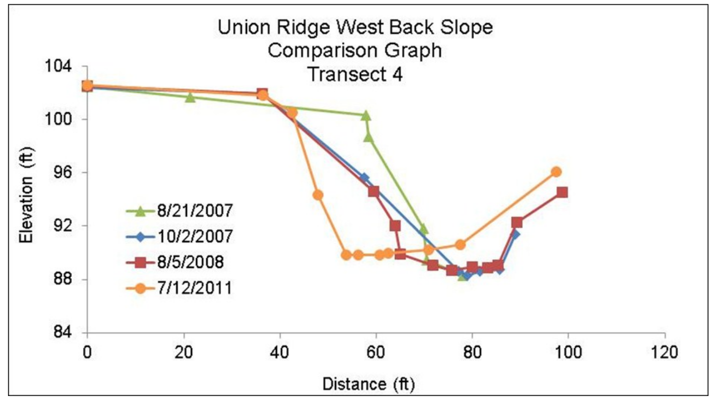

Figure 17. Physical survey data for transect four for the pre-construction survey (8/21/2007), post-construction survey (10/2/2007), and two post-flow surveys (8/5/2008 and 7/12/2011).

Technique Performance

Five back-sloping projects with vegetation establishment were installed between September 2006 and January 2009. These projects have had mixed results, including one successful project, one project that was never really tested by flow due to a shifting of the channel immediately following construction, one damaged project that has not yet failed or achieved stability, and two failures. The primary reason for failure or damage to these projects has been the slow establishment of vegetation on the bank. Secondarily, site selection has also been important to the success or failure of these projects. Putting one of these projects in a relatively tight bend is inappropriate.

The first objective for monitoring the back-sloping with vegetation establishment technique was to determine the extent of continued erosion or deposition of sediment along the streambank toe. Success in this objective would be determined by whether or not the sloping and fabric protected the streambank toe from continued erosion until vegetation was well enough established on the streambank to protect it from further erosion. The back-sloping with vegetation establishment technique did not protect the toe from continued erosion with four of the projects seeing at least some erosion at the toe of the bank. The California Branch project was successful, but even it saw some erosion of the toe. The erosion is slight and with vegetation establishment does not appear to be a reason for concern. At Starks Creek there has been

Table 5. Streambank movement and changes in streambank slope due to erosion at the Union Ridge West back-sloping project between the post-construction survey in October 2007 and the final survey in July 2011. Erosion is represented by negative movement in the streambank and deposition is represented by a positive movement in the bank. Transect numbers increase as you move downstream.

	Top of streambank Movement (ft.)	Toe of streambank Movement (ft.)	Bank Slope 10/2007	Bank Slope 7/2011
Transect X	6.88	-2.68	0.30	0.36
Transect 0	2.41	-16.37	0.29	0.51
Transect 1	-0.86	-4.67	0.36	0.34
Transect 2	-0.06	-15.13	0.34	0.46
Transect 3	0.02	-20.97	0.36	0.63
Transect 4	0.00	-23.25	0.33	0.70
Transect 5	1.12	-17.61	0.31	0.63
Transect 6	6.46	-22.10	0.22	0.45
Transect 7	-10.77	-20.45	0.43	0.58

erosion of the toe along five of the seven transects. The erosion at this site seems to have been accelerated by shifts in the channel morphology that altered the location and angle at which the channel approaches from upstream. The eastern unnamed tributary of Spring Creek on Union Ridge CA project has had extensive erosion of the toe along six of the eight transects. The erosion, which occurred from just upstream of the apex of the bend through the downstream end of the project, resulted in the complete failure of this project. The project located on the western unnamed tributary of Spring Creek on Union Ridge CA failed along its entire length after just a couple of flow events. The failure began so quickly that none of the vegetation that was planted at the project had enough time to become established; however, other back-sloping projects have experienced similar flow events prior to vegetation establishment and have survived without problems. The only site that did not experience at least some toe erosion was the Fiery Fork project. There has been deposition along the toe at all six transects at this site as a result of the flow switching to the other side of the channel and the development of a gravel bar in front of the bank. The Fiery Fork project was not a good test of this technique as an approach to streambank stabilization, because the thalweg shifted away from this streambank for reasons that had nothing to do with the project immediately after project construction.

The second objective for monitoring the back-sloping with vegetation establishment was to determine whether the streambank maintained the constructed slope or returned to an unstable angle. Three of the projects were able to maintain the slope even though two of those did sustain some toe erosion. At California Branch the streambank has maintained its sloped angle despite being built with a steeper slope than was intended. The Starks Creek project has experienced some erosion at the toe of the streambank for all transects, but so far that erosion has not resulted in changes to the constructed slope of the streambank or in project failure. The project located on the unnamed tributary of Fiery Fork has had no change in the slope of the streambank as the result of deposition that resulted from the thalweg shifting away from this bank. The failed project on the eastern unnamed tributary of Spring Creek has only had a slight increase in slope despite the toe eroding between 8 and 14 feet for several of the transects. The relative slight change in slope is due to the overall size of the streambank which has masked the toe erosion in the calculation of overall streambank slope. The slope at the toe itself did increase dramatically. So while the overall slope of the streambank has not been greatly affected, the slope of the lower third of the streambank has changed dramatically. The project located on the western unnamed tributary of Spring Creek on Union Ridge CA has had large increases in slope due to the almost immediate failure of the project along its entire length. A factor that may be affecting this stream more than other back-sloping projects is that it appears to be our most incised stream. The stream channel has experienced recent incision which has caused it to become very unstable. Although the head cut was past the reach where the site was located, the stream is still extremely unstable as a result of that head cut. Obvious signs of this instability include substantial erosion that is occurring throughout this reach of stream both upstream and downstream of our site as well as the aggradation of the bed we see between the 2008 and 2011 surveys.

Despite the importance of vegetation establishment to the potential success or failure of this approach it is not something that we actively monitored. All monitoring of vegetation was conducted qualitatively mainly using photo points. The vegetation establishment we saw was extremely slow, with nearby sites using other stabilization techniques and no tree planting actually establishing vegetation at a higher rate than these sites did. Only the Fiery Fork project had vegetation establish at a rapid rate. The two projects that failed both did so before the vegetation became well established. At both the California Branch and Starks Creek projects the remaining concern that could potentially affect long-term stability is the slow establishment of trees. In order for this technique to succeed in stabilizing the streambank long-term, vegetation establishment is essential. Currently we have good establishment of ground cover and shrubs at these sites but we are still lacking in tree establishment. The life expectancy of the erosion control fabric is 36 months; therefore the future stability of the streambank will be determined by the established vegetation. So while these projects have survived over the course of several years and numerous high flow events, the long-term stability is not yet secure because of the lack of vegetation establishment.

Technique Costs

This approach was intended to be a less expensive alternative to a traditional longitudinal rip rap toe protection project that would potentially still stabilize the streambank. In addition to examining how well the technique performed, it was also vital to determine the costs associated with the technique and what savings were realized when compared to a traditional rip rap approach. To determine the costs associated with the projects and the potential savings we calculated the costs of building the project three different ways at each site: the experimental back-sloping design, a traditional longitudinal rip rap toe protection design, and an experimental farm rock toe design using rip rap (Table 6). On average back-sloping saved $13.46 or 38% per foot over a traditional rip rap toe project and $3.12 or 12% per foot over the experimental farm rock toe approach using rip rap.

Despite the apparent savings provided by the back-sloping approach it may not be the best option for landowners. Two projects have failed, another project has seen significant erosion, and the other two projects while stable are still somewhat lacking in vegetation establishment. It is important to note that repair costs would quickly eliminate most if not all the savings associated with this approach. Additional equipment time and additional erosion control fabric at the failed Union Ridge West project, the failed Union Ridge East project, or at the damaged Starks Creek project, would quickly override any of the potential cost savings gained from using the experimental approach while also disturbing the vegetation that has been established. While the cost savings of the back-sloping approach versus a traditional rip rap toe is significant, there is only a small savings when compared with the experimental farm rock toe approach using rip rap. Also our lack of success in establishing riparian vegetation leaves the project more vulnerable to failure after the erosion control fabric breaks down, whereas a rock project affords more time and stability for riparian vegetation establishment.

DISCUSSION

The results from the back-sloping with vegetation establishment technique projects indicate that that this technique has little potential as a stand-alone streambank stabilization technique. The most significant limitation of this approach appears to be the limited number of locations for which it would actually be appropriate. Site selection is also essential to successful application of this technique. Back-sloping with vegetation establishment is not appropriate for tight bends and should only be applied in relatively straight reaches of stream. The two projects that were located on outside bends had immediate erosion and eventually failed. An additional site became an outside bend following a shift in the approach of the channel and following the shift saw a significant increase in the amount of toe erosion that was occurring at this site. It quickly became apparent that while the erosion control fabric did well protecting straight stretches of streambank and the upper portion of the streambank it could not hold up the forces acting on the toe of a streambank on an outside bend.

Another factor that appears to be important in terms of proper site selection is the soil of the bank. The soil of the streambank also plays a critical role in the success of the back-sloping because the quick establishment of vegetation, particularly trees, will determine whether or not the project is successful. While we did not do any soil sampling as part of this project observationally it was noticed that rocky or clay dominated soils or layers in the streambank had much slower vegetation establishment. As a result it may not be appropriate to apply this technique in rocky or clay dominated soils.

The goal of using this approach was to find a cost effective alternative to more expensive toe protec-

Table 6. Project costs based on three different approaches to stabilizing the streambank at each site and the average costs for each approach.

Site	Experimental Back-sloping Project	Traditional Longitudinal Toe Protection	Experimental Farm Rock Toe (Rip Rap)
California Branch	$24.65/ft.	$33.43/ft.	$24.81/ft.
Fiery Fork	$20.69/ft.	$29.35/ft.	$20.60/ft.
Starks Creek	$25.59/ft.	$39.55/ft.	$27.90/ft.
Union Ridge East	$19.24/ft.	$40.66/ft.	$28.86/ft.
Union Ridge West	$21.75/ft.	$36.33/ft.	$25.47/ft.
Average Costs	$22.41/ft.	$35.87/ft.	$25.53/ft.

tion techniques such as rip rap toe protection. While there was cost saving when compared to traditional rip rap toe protection projects, those savings were not as high as expected. The equipment required to slope the streambank and haul the excess dirt out of the floodplain makes this still a relatively expensive technique that has none of the durability of a rock project. Any repair work would quickly make it cost prohibitive for many landowners.

The results from the five locations where this technique was applied make it clear that the most important factor influencing the success or failure of this technique is the establishment of vegetation on the bank. In this study we attempted to plant a variety of fast growing trees at a high density with the hope of getting them established quickly to protect the bank. While the focus of this study was to monitor the performance of the back-sloping technique, one aspect we did not directly monitor was vegetation response. Photo points allowed us to track the overall vegetation response, but no direct measurements or quantification of vegetation response was made. In addition, while similar species and planting rates were used at each site, there was no plan developed to keep plantings similar between sites. If this approach is going to be used on a wider basis the work needs to be done to improve planting rates and species selection in order to get better tree growth and vegetation establishment than were seen in this study.

MANAGEMENT IMPLICATIONS

Application of the lessons learned from studying these five projects could result in modifications to this approach that might result in better success. Appropriate site selection will be critical in terms of not having a streambank with curvature, the stream's approach to the bank, and the soil's ability to allow for rapid vegetation establishment. Additional efforts to improve vegetation establishment will be necessary before using this technique on a wide basis. Without improved vegetation response the appropriate use of this technique will be limited to a supplement to other types of projects such as toe rock and not as a standalone technique. However, the cost of back-sloping the streambank in addition to the cost of some other type of toe protection project will also keep its use in this manner limited. The most significant factors limiting the usefulness of this technique are the cost of implementation, the fact that it is inappropriate for tight bends, and its reliance on the quick establishment of vegetation, particularly trees, in determining whether or not the project has any chance at being successful long-term. The limitations associated with this approach that we have observed should keep it from being applied by landowners. Back-sloping with vegetation establishment is not a technique that will be appropriate for most erosion issues facing landowners. So as previously recommended in the literature, this approach appears to have merit as a supplement to other types of toe protection, but has little or no application as a stand-alone technique.

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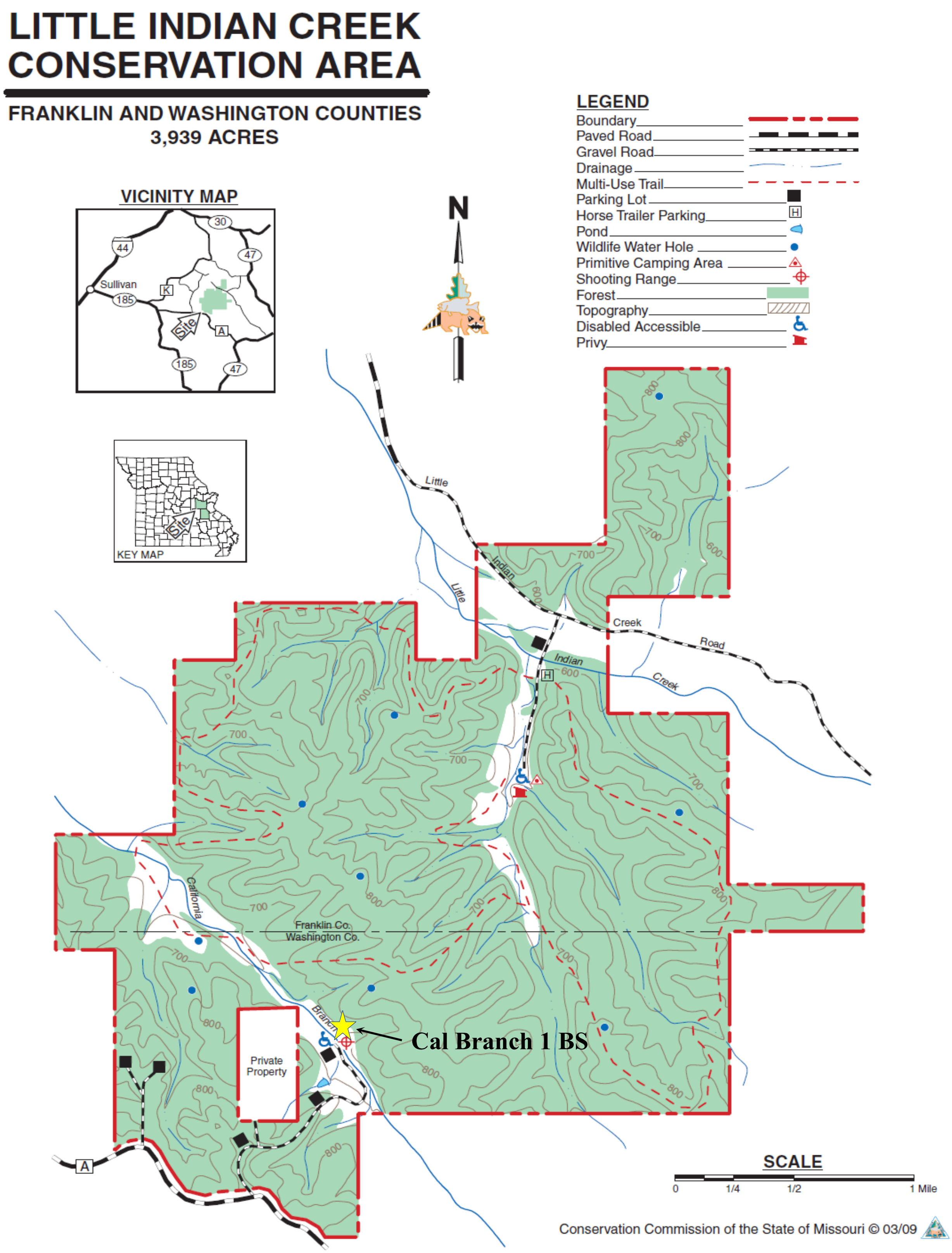
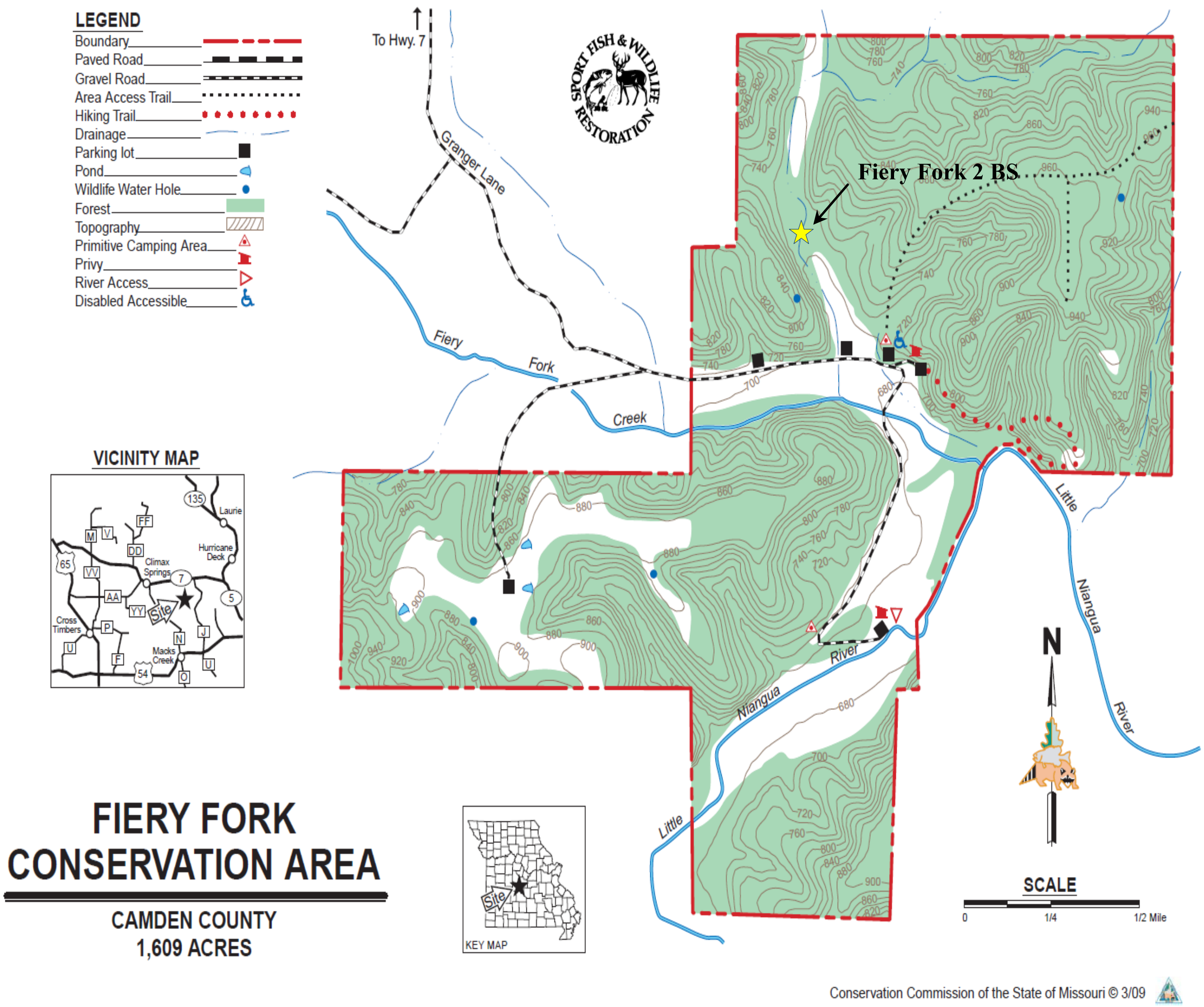
Appendices

Appendix 1: Area Maps




LEGEND
Boundary
Paved Road
Gravel Road
Area Access Trail
Hiking Trail
Drainage
Parking lot
Pond
Wildlife Water Hole
Forest
Topography
Primitive Camping Area
Privy
River Access
Disabled Accessible
To Hwy. 7
Granger Lane
SPORT FISH & WILDLIFE RESTORATION
Fiery Fork 2 BS
Fiery Fork Creek
Little Niangua River
VICINITY MAP
KEY MAP
Site
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SCALE
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1/4
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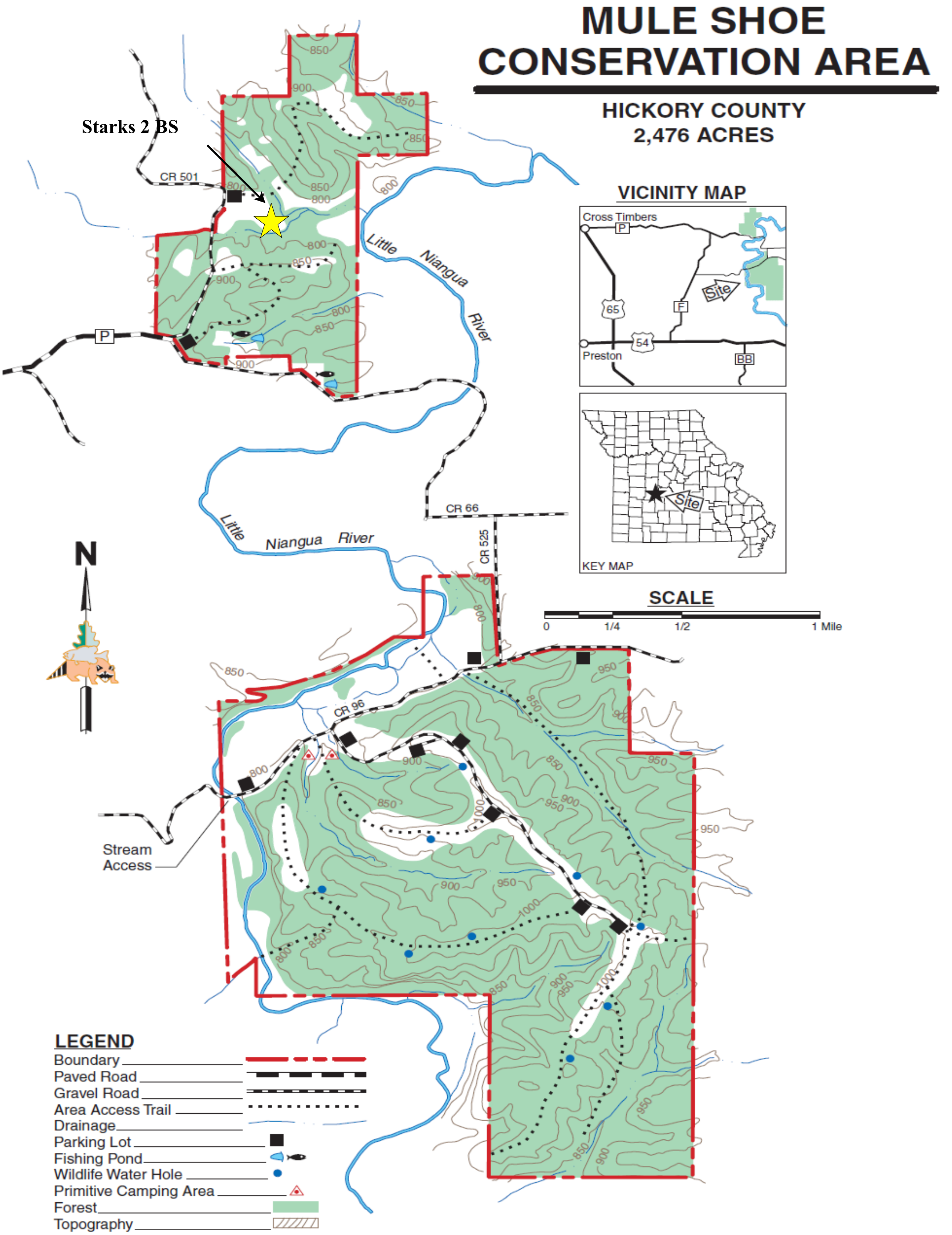
FIERY FORK CONSERVATION AREA
CAMDEN COUNTY
1,609 ACRES
Conservation Commission of the State of Missouri © 3/09



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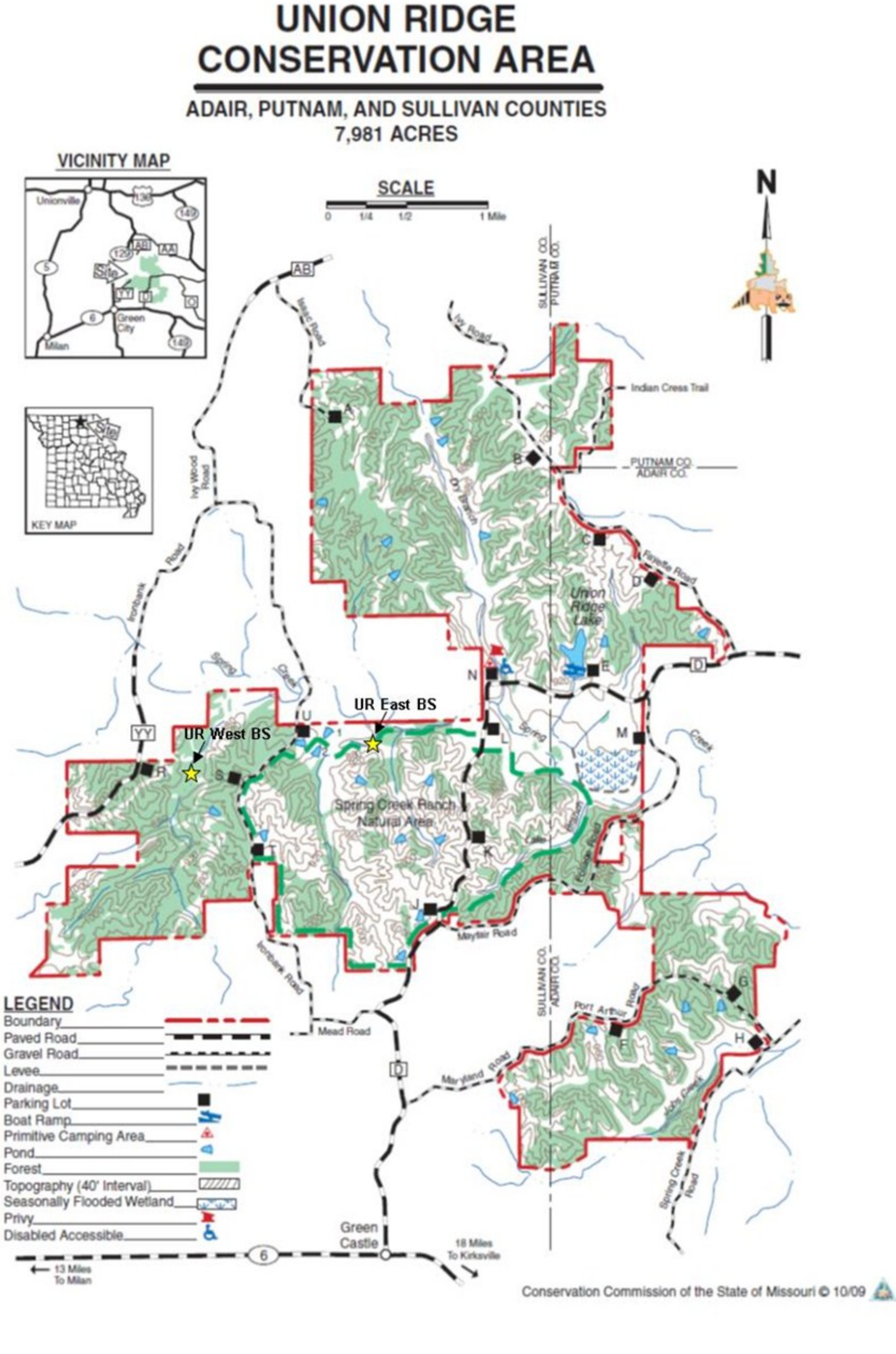
UNION RIDGE
CONSERVATION AREA
ADAIR, PUTNAM, AND SULLIVAN COUNTIES
7,981 ACRES
VICINITY MAP
Unionville
Site
Green City
Milan
KEY MAP
SCALE
0 1/4 1/2 1 Mile
N
Indian Cress Trail
SULLIVAN CO.
PUTNAM CO.
ADAIR CO.
Ivy Road
Isaac Road
Ivy Wood Road
Ironbank Road
Dry Branch
Fayette Road
Union Ridge Lake
Spring Creek
UR East BS
UR West BS
Spring Creek Ranch Natural Area
Maylair Road
Mead Road
Port Arthur Road
Maryland Road
Spring Creek Road
Green Castle
18 Miles To Kirksville
13 Miles To Milan
LEGEND
Boundary
Paved Road
Gravel Road
Levee
Drainage
Parking Lot
Boat Ramp
Primitive Camping Area
Pond
Forest
Topography (40' Interval)
Seasonally Flooded Wetland
Privy
Disabled Accessible
Conservation Commission of the State of Missouri © 10/09

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