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Experimental Log Weirs 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 that they can use to address existing erosion issues and protect their property from further erosion. This 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 log weirs as a potential technique for controlling excessive streambank erosion. The goal of the log weir technique is to save money over the traditional bendway weir approach by using logs as opposed to using large amounts of rip rap to build the traditional rock weirs. This reduces the costs associated with a weir approach while attempting to stabilize the streambank. Five projects were constructed at four separate MDC Conservation Areas using log weirs. The projects were built between July 2005 and May 2007 and all experienced multiple high-flow events.

The log weir technique had mixed results. The initial project on Jakes Creek failed before the other projects were built. Jakes Creek failed because the streambank keys (area where the log is anchored in the streambank to hold it in place) were not strong enough to hold the logs in place during high stream flows. The lessons learned about key strengths from that failure were applied to the four projects built later. Changes included burying at minimum half the log in the key and to protect the surface of the key with shot rock (quarry rock not graded out to a specific size) to prevent erosion. These alterations helped two of the projects succeed, but the other two projects failed for different reasons. Both projects built on California Branch worked as designed. They moved the thalweg away from the streambank and got enough deposition at the toe and between the weirs to bury the majority of the weirs. The Dry Branch project failed due to improper layout of the weirs during construction. Incorrect spacing and construction angles for weirs four and five resulted in the complete failure of weirs five and six at the lower end of this project. The Mill Creek project failed for multiple reasons: the instability of the reach caused by a head-cut that had recently moved through the system, a change in how the key material was protected with shot rock, and erosion that occurred downstream of the last weir. All four of the projects built after the Jakes Creek project had erosion downstream of the last weir, but the project on Mill creek was the only one where erosion caused the failure of the most downstream weir.

Overall only two of the five projects stabilized the eroding streambank during the course of the study. The failures seen at the other three projects appear to be the result of inadequate key strength, incorrect weir placement, and erosion downstream of the last weir. The information gained from all five projects indicates that this approach has only limited potential as a stabilization technique. Modifications could be made to add additional strength to the key, but they have not been tested so their limitations are unknown and they would not address the need for a professional design in laying out the weirs. The log weir technique is also affected by the limitations associated with the size of logs that will be needed depending on the size of the streambank. If streambank height exceeds 10 feet tall or the channel needs to be moved more than 15 feet, this approach becomes impractical due to the size of the logs required. The most important factors in using the log weir technique are the strength of the key, the distance the thalweg needs to be moved by the weirs, the height of the streambank, proper placement and spacing of the weirs, and a stable stopping point on the downstream end of the project. The log weir approach should not be attempted by a landowner without the assistance of experienced professionals and currently is not an approach we would recommend to landowners.

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

Technique

One of the more commonly used techniques in streambank stabilization is bendway weirs. A traditional bendway weir is a rock structure that is keyed into the streambank and extends upstream into the channel at approximately a 20-degree angle perpendicular to the streambank. Bendway weirs alter the direction of flow away from the eroding streambank and push it back to the center of the channel. The goals of this approach are to protect the toe of the streambank from further erosion, promote deposition of sediment at the toe of the streambank, and shift the thalweg (deepest part of the channel) away from the streambank. They are effective on streams of all sizes, use less rock than earlier types of rock barbs (Derrick 1996, Biedenharn et al. 1997, Northcutt 1998, Sotir 1998, Johnson 2003), and have been adapted successfully to smaller streams (Derrick 1996, Derrick 1998, Smith and Wittler 1998, Wittler and Andrews 1998). The costs associated with a bendway weir project include the price of rock ($3-$15 per ton), cost of rock transportation ($4-$10 per ton), heavy equipment operation ($50-$150 per hour) to install the weir, and the cost of consulting with a professional engineer to design the structure. These costs exceed what most landowners can afford without considerable cost-share support. As a result, while bendway weirs offer a potential solution to erosion problems their associated costs make them unavailable to many landowners.

This study tested log weirs as a potential alternative to bendway weirs. The log weir experimental technique was designed to be a cost-effective approach to potentially achieve the same goals as a bendway weir project. The cost reduction comes from using logs that are available onsite or nearby to build the weir and a small amount of shot rock to protect the log's key instead of using large amounts of rip rap to build the entire weir. The objectives of this study were to examine the performance of the log weirs and determine: 1) the extent of continued erosion or deposition at the toe of the streambank, 2) if the slope of the streambank is reduced following construction, 3) if the log weirs maintained their position during high flow events, and 4) if log weirs are a cost effective alternative to bendway weirs.

STUDY SITES

Log weirs were evaluated at five locations on stream 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 10 feet. The availability of on-site logs of manageable size dictated these stream size and bank height limitations. In addition we looked for sites where the curvature of the streambank made a weir approach the appropriate choice for the stabilization technique. Selected stream segments were located on Jakes Creek on Lead Mine Conservation Area (LMCA) in Dallas County, Dry Branch on Union Ridge Conservation Area (URCA) in Sullivan County, Mill Creek on Peck Ranch Conservation Area (PRCA) in Carter County, and California Branch received two of the five projects on Little Indian Creek Conservation Area (LICCA) in Franklin and Washington Counties. River and project site details are located in Table 1. Area maps showing the locations of the conservation areas in Missouri and the project locations within those areas are provided in Appendix 1.

METHODS

Log Weir Design

The log weir approach was designed to stop erosion by directing flow away from the streambank toe like a bendway weir project. The weir approach is often used when the curvature of the bend is so tight (highly curved) that armoring the streambank with rock would lock it into an unstable configuration, whereas weirs move the thalweg changing the curvature of the bend to a more stable configuration. Weirs are built to be ⅓ to ½ the streambank height tall and extend across approximately half the channel at approximately a 20 degree angle upstream from perpendicular. Weir spacing is determined by the curvature of the streambank, but should be spaced no more than four times the length of the upstream weir (Derrick 1996). Weir spacing should be reduced as the radius of the curvature of the bend gets smaller. Tighter bends will require a higher number of weirs and those projects will have a higher cost as a result.

The log weir projects were built according to the guidelines used to build a bendway weir project; however, they were not designed with the help of an engineer and instead were built based on the height, angle, and spacing guidelines described above. Each weir was built to be ⅓ to ½ the streambank height tall,

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

	Jakes Creek	Dry Branch	Mill Creek	California Branch 3	California Branch 4
River Basin	Niangua	Chariton	Current	Meramec	Meramec
Physiographic Region	Salem Plateau	Chariton River Hills	Ozark Plateau	Salem Plateau	Salem Plateau
Stream Order	4	3	3	2	2
Reach Gradient	26 ft./mi	22 ft./mi	28 ft./mi	64 ft./mi	64 ft./mi
Watershed Area	27 mi^2	3 mi^2	14 mi^2	1.5 mi^2	2.1 mi^2
Bank Height	8 ft.	8 ft.	6 ft.	6 ft.	8 ft.
Bank Length	300 ft.	200 ft.	125 ft.	85 ft.	125 ft.
# of Weirs	8	6	5	3	4

so the diameter of the trees used must achieve that height or we had to stack two logs on top of each other to achieve the needed height. The logs used to build the weirs had to be long enough to extend across approximately half the channel at approximately a 20 degree angle upstream from perpendicular, and still have half their length buried in a key trench cut into the streambank to hold them in position (Figure 1). Once the log or logs were put in place, the material excavated to dig the key trench was packed back on top of the logs and at all but one project shot rock was used to coat the surface of the key to help protect it from erosion.

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 first log weir project was installed on Jakes Creek in July 2005. The project consisted of eight weirs, each made from two logs stacked on top of each other and cabled together to achieve the desired weir height. The next log weir project was built in June of 2006 on Dry Branch. The Dry Branch project consisted of six weirs each made from two logs stacked on top of each other to achieve the desired weir height. The Mill Creek log weir project was built in January 2007and consisted of five weirs each made from a single log. There were two log weir projects built on California Branch. The upstream project (California Branch Site 3) was built in May 2007 and consisted of three single log weirs. The second log weir project built on California Branch (Site 4) was constructed in May 2007 and is located approximately a mile downstream of the other log weir project. The project consisted of four single log weirs. California Branch becomes a losing stream between site 3 and site 4. As a result California Branch Site 4 had a separate Levelogger® recording flow data from the one used for California Branch site 3.

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 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, a longitudinal profile of the channel thalweg, and a longitudinal profile through the center of the projects weirs. All transects ran from a benchmark on the eroding streambank to the top of the gravel bar across the channel, except for California Branch site three. Those transects started on the opposite streambank and ran to the top of the eroding streambank. Transects were located halfway between the weirs, and downstream of the last weir for the initial project at Jakes Creek. Changes were made after that project was constructed and at the other four projects the tran-

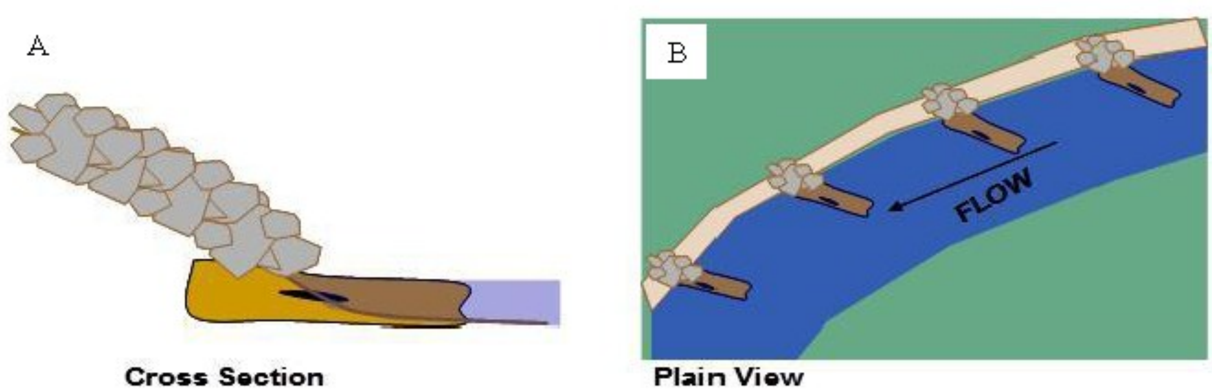

Figure 1. (A) Cross section and (B) plain view of a generic experimental log weir project.

sects were located down the center of each weir, halfway between the weirs, and downstream of the last weir. 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. The weir longitudinal profile started at the transect located downstream of the last weir and was surveyed through the center of each weir to just upstream of the first weir. Project features including the toe of the streambank, top of the sloped bank, wetted channel, gravel bars, opposite streambank, 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) placed away from the stream to monitor flow. The Levelogger® is a pressure transducer that uses changes in pressure to track changes in stage. 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

Jakes Creek

The Jakes Creek project did not use rock to protect the key and instead just had the material that was removed to dig the key trench packed back into the trench to hold the logs in place. Prior to any of the other log weir projects being built, a high-flow event occurred on Jakes Creek on April 29-30, 2006 following an approximately 3 inch rain event. The rain event brought the stage to a height of 6.29 ft. (Figure 2), which represented a 4.5 ft. rise over the average flow during the previous week. The stage height represents a flow just under the top of the eroding bank. This high flow event caused extensive damage to the project which resulted in its failure.

Photo points show how the weirs shifted and the resulting erosion that occurred at the lower end of the project (Figure 3). Weirs five, six, and seven all failed completely and weir four was a partial failure (Table 2). Weir three held, but had some erosion of the key. Only weirs one, two, and eight showed no substantial changes after the flow event. Because the weirs shifted position and were no longer at an angle that directed flow away from the streambank and were instead at an angle that directed flow towards the streambank, they caused a large amount of erosion between the weirs. The survey data documented the streambank erosion that occurred (Table 3). The largest erosion occurred on transects four through eight.

GPS maps created in August 2005 (after initial construction) and May 2006 (after failure) illustrate the relative changes that occurred throughout the site due to the flow event (Figure 4). To address future erosion at this site the decision was made to remove the project and replace it with a different type of project. The project failed because the keys (the area where the logs were buried in the streambank) were not strong enough to hold the logs in place during high flow events. As a result all future log weir projects were modified to strengthen the keys by ensuring that at least half the length of the log was buried in the streambank and by adding large shot rock to the keys

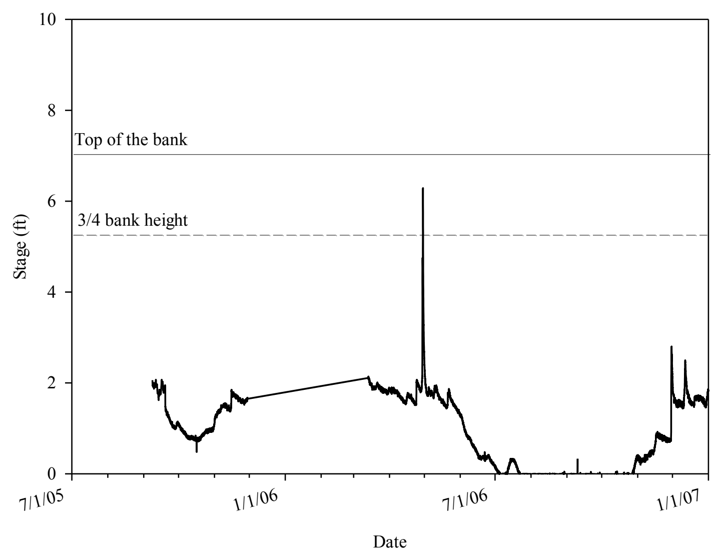

Figure 2. Levelogger® data for Jakes Creek from 2005 through 2006.

to help hold the logs in place.

Dry Branch

Dry Branch was constructed using the lessons learned at Jakes Creek. Dry Branch was the first project to use shot rock to protect the weir keys and bury at least ½ of each log in the key. The project has experienced a large number of high flow events (Figure 5).

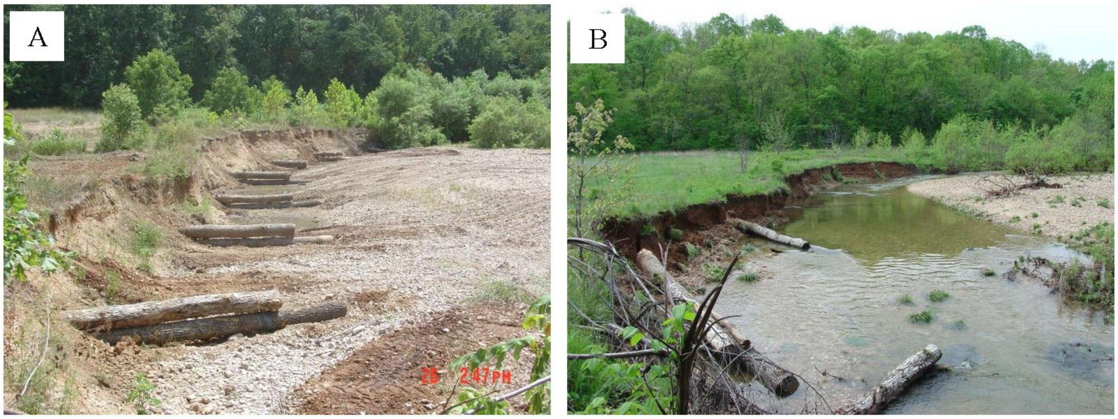

Figure 3. Jakes Creek log weir project. (A) Post-construction looking upstream July 2005. (B) Post-failure looking upstream April 2006.

In the spring of 2007, the project withstood two high flow events between ¾ the height of the streambank and the top of the streambank and one flow that went over the top of the streambank. The largest flow event caused the failure of a shot rock weir project located approximately a ¼ mile upstream. Although some of the rock protecting the keys of the log weir project did get washed away, the streambank survived without damage. Additional flow events in 2008 caused the project to be eroded between weirs four and five. Unfortunately, the size of these events is unknown because the Levelogger® was lost and not replaced until June of 2008. Additional flow events in late summer and early fall of 2008 were also not recorded because a second logger was lost and not replaced until November of 2008. In 2009, Dry Branch had three flow events that reached a stage above ¾ of the streambank height and a fourth that went over the top of the streambank. In 2010, the project was tested by three flow events that went over the top of the streambank and three other events that were greater than ¾ of the streambank height. In 2011, there was a single flow event that reached a height equal to the top of the streambank.

The flow events that occurred in 2009 continued the erosion process that had started at the base of weir five in 2008. The 2009 flows caused the failure of weir six with the logs being completely washed away. The 2010 flow events resulted in continued erosion at the lower end of the project, and weir five was completely washed away. Photo monitoring shows extensive erosion between weirs four and five and at the base of weir five in 2008. In 2009, the erosion shifted downstream to the streambank between weirs five and six and caused the failure of weir six. In 2010, weir five was completely washed away and there was extensive erosion downstream of weir four even though upstream of weir four the project has protected the streambank (Figure 6). The cause for this failure and the erosion is the design of the project. The spacing between weirs four and five was too far given the tight curvature of the bend. Flow coming off weir four was not redirected enough to hit weir five in the correct place, resulting in a large amount of erosion at the base of weir five and the eventual complete failure of weirs five and six.

Table 2. Comparison of weir angles for the Jakes Creek log weir project at construction and after failure following first flow event.

Weir	Initial Angle (○)	Post-flow Angle (○)	Change in Angle (○)
1	104	109	+ 5
2	121	109	- 12
3	102	101	- 1
4	102	71	- 31
5	106	100	- 6
6	103	48	- 55
7	99	30	- 69
8	120	117	- 3

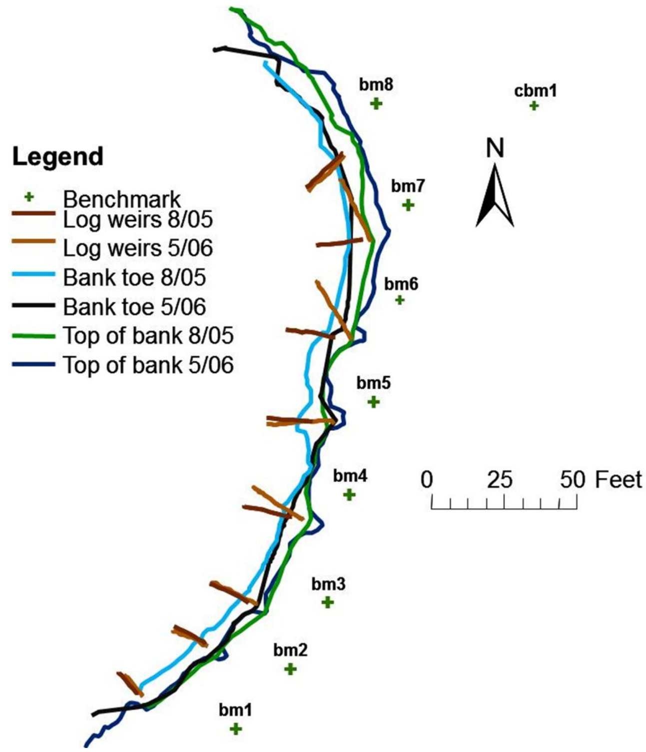

Figure 4. GPS map of the Jakes Creek log weir project showing the position of the weirs, top of the bank, and toe of the streambank post-construction (August 2005) and post project failure (May 2006).

Bank changes due to erosion are documented between the post-construction survey and the post-flow surveys. Large amounts of erosion occurred at the lower end of the project, while the upper end has remained stable (Table 4). There has been erosion at both the top and toe of the streambank for almost every transect. In general, this movement has led to a decrease in streambank slope upstream of weir four and an increase downstream of weir four. The problem is the amount of erosion that has occurred, particularly from transect eight downstream. Those transects saw as much as 30 ft. of erosion at the top of the streambank and 40 ft. at the toe of the streambank. Additional erosion occurred in 2011, but since the project was already considered a failure no additional surveying was conducted.

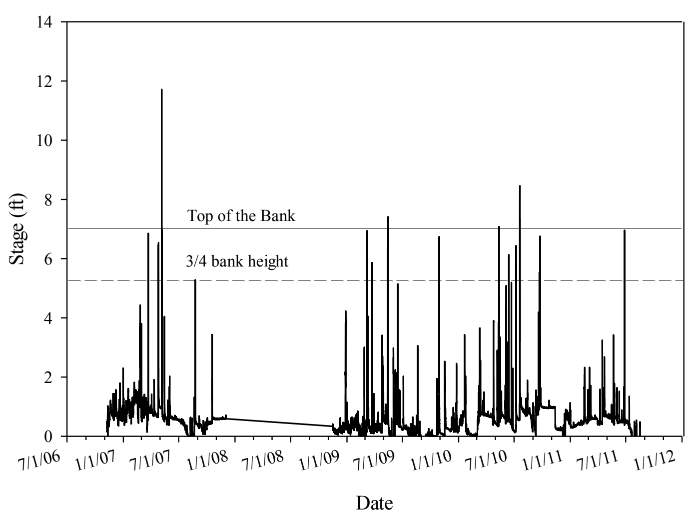

Figure 5. Levelogger® data from Dry Branch for 2006 through 2011. Data are missing from December 2007 until November 2008 due to the loss of two Levelogger®s.

Mill Creek

The Mill Creek project also incorporated the lessons learned at Jakes Creek. Shot rock was used to protect the weir keys and at least ½ of each log was buried in the key. Mill Creek is a losing stream in the reach where this project was built, and therefore only has flow immediately following rain events. The first flow event to test the project occurred in September 2007 (Figure 7). During this event, the stream went from no flow to a stage of 5.5 ft., which is slightly under the top of the streambank. This flow event caused the key of weir four to be damaged (Figure 8). The washout of the key of weir four could have led to the eventual failure of the project; however, additional flow events in 2008 did not cause any more damage. In fact, the key area appeared to receive deposition during the 2008 flows. Unfortunately, the size of the spring 2008 events is unknown because the Levelogger® was lost and not replaced until July of 2008. In 2009, there were no high flow events recorded. In 2010, a single high flow event increased the size of the washout at weir four and started a small washout at

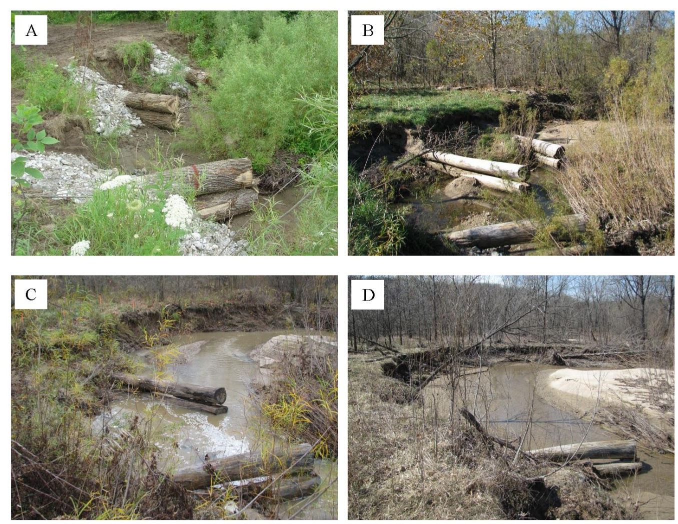

Figure 6. Dry Branch log weir project. Looking downstream at weirs four, five, & six. (A) Post-construction July 2006. (B) Post-flow October 2008. (C) Post-flow October 2009. (D) Post-flow March 2011.

Table 3. Streambank movement and changes in streambank slope due to erosion at the Jakes Creek log weir project between the post-construction survey in August 2005 and the post-failure survey in May 2006. 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 8/2005	Bank Slope 5/2006
Transect 1	0.0	- 2.5	1.21	1.94
Transect 2	0.0	- 2.4	1.20	1.77
Transect 3	0.0	0.0	1.37	1.27
Transect 4	- 0.7	- 3.1	1.99	4.26
Transect 5	- 2.4	- 1.0	2.62	1.67
Transect 6	- 4.2	- 3.0	0.90	0.65
Transect 7	- 5.6	- 1.6	1.75	0.93
Transect 8	- 5.8	- 3.4	2.11	1.18

the key of weir three (Figure 8). The washouts appeared to be a result of burying shot rock in the key material instead of using it to protect the surface of the replaced key material as was done at all the other projects. Mill Creek was the only project where this was done and the only place we saw key erosion in this form. Photos show the large area of erosion associated with the weir four key (Figure 9).

Despite the washout of the key of weir four and the smaller washout that occurred in 2010 at weir three, the project appeared to be functioning. Although the eroded key area continued to slowly expand in diameter, it was also filling back in with deposition making it shallower and allowing vegetation to become established. The thalweg had moved away from the toe and vegetation had begun to establish by the fall of 2010. In the spring of 2011 at least one and maybe multiple high flow events occurred during April and May. The exact size and number of flow events are unknown because the Levelogger® was lost. The flow event or events resulted in the failure of this project. Log weir one was broken off at the streambank and a large amount of erosion occurred at the downstream end of the project streambank that resulted in the loss of weir five. Following the high flow event in 2010 a log became wedged against log

Table 4. Streambank movement and changes in streambank slope at the Dry Branch log weir project between the post-construction survey in July 2006 and the post-flow survey in July 2010. 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. Transects 1, 3, 5, 7, 9, & 11 do not have changes in the streambank toe because the log weirs cover the toe.

	Top of streambank Movement (ft.)	Toe of streambank Movement (ft.)	Bank Slope 7/2006	Bank Slope 7/2010
Transect 1	-3.89	---	0.48	0.44
Transect 2	-3.15	-2.16	0.82	0.67
Transect 3	-0.58	---	0.50	0.51
Transect 4	-5.05	-0.99	0.91	0.60
Transect 5	0.52	---	0.51	0.59
Transect 6	-7.83	-2.70	0.77	0.53
Transect 7	-5.77	---	0.37	0.53
Transect 8	-14.69	-10.12	1.17	0.66
Transect 9	-22.41	---	0.33	0.62
Transect 10	-28.55	-28.19	0.73	0.75
Transect 11	-32.28	---	0.28	0.82
Transect 12	-28.11	-43.30	0.36	1.49

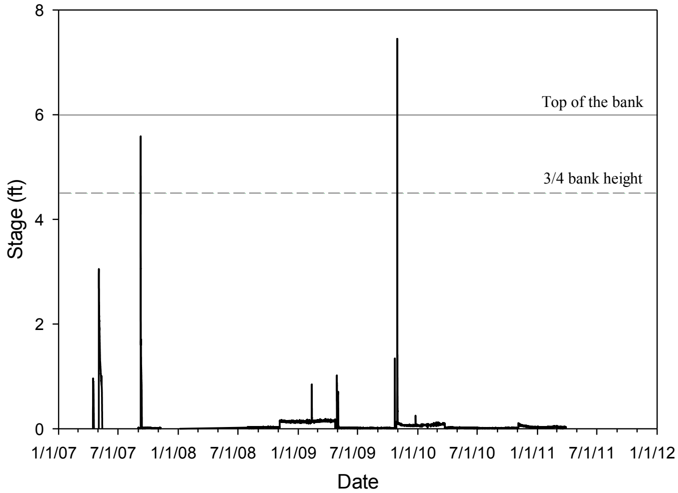

Figure 7. Levelogger® data from Mill Creek for 2007 through 2011. Data are missing from November 2007 until July 2008 and after March 2011 due to the loss of multiple Levelogger®s.

weir one. During the 2011 flow event, pressure exerted on the two logs and potentially other logs moving through the system resulted in log weir one breaking at the streambank (Figure 10). Additional logs are suspected to be involved because a log jam formed just downstream of the project following this flow event. A head-cut that moved through the system and is still active less than ½ a mile upstream of the project is the source of the woody debris moving through the system.

In addition to weir one breaking, a large amount of erosion occurred at the downstream end of the project that resulted in the loss of weir five (Figure 11). There has been erosion at the top of the streambank along all transects, but only transects five (key of weir three), seven (key of weir four), nine, and ten have shown dramatic erosion (Table 5). The movement of the toe of the streambank has resulted from deposition upstream of weir four and erosion downstream of weir four. The streambank movement has resulted in no change or a reduction in streambank slope for all but the last three transects. Although the project appears to be stable upstream of weir four, the erosion of weir four's key, the loss of weirs one and five, and the large amount of erosion just downstream of the project makes this project a complete failure.

California Branch Site 3

California Branch Site 3 incorporated the lessons learned at Jakes Creek. Shot rock was used to

Figure 9. Mill Creek log weir project. (A) Looking at weirs four and five following construction January 2007. (B) Looking at weir four key November 2007. (C) Looking at weir four key June 2009. (D) Looking at weir four key March 2011.

protect the weir keys and at least ½ of each log was buried in the key. The project was only tested by a limited number of flow events in 2008 and 2009 (Figure 12). Following construction in the spring of 2007, the project was not tested by any flow events

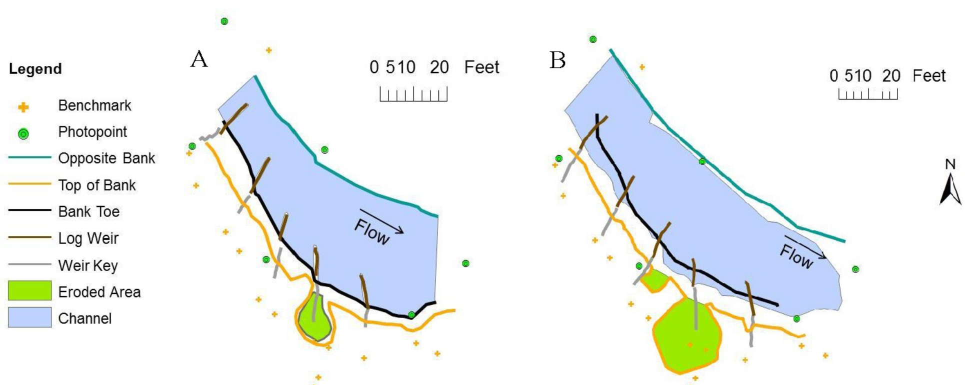

Figure 8. GPS map of Mill Creek log weir project (A) following first flow event in the summer of 2008 and (B) following high flow event in spring of 2010.

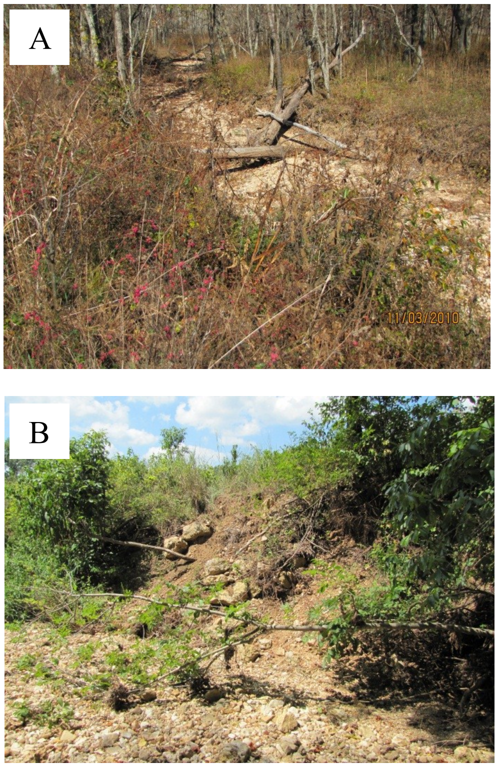

Figure 10. Mill Creek log weir project. (A) Looking upstream at weir one October 2010. (B) Looking at weir one's key following the log breaking off at the streambank July 2011.

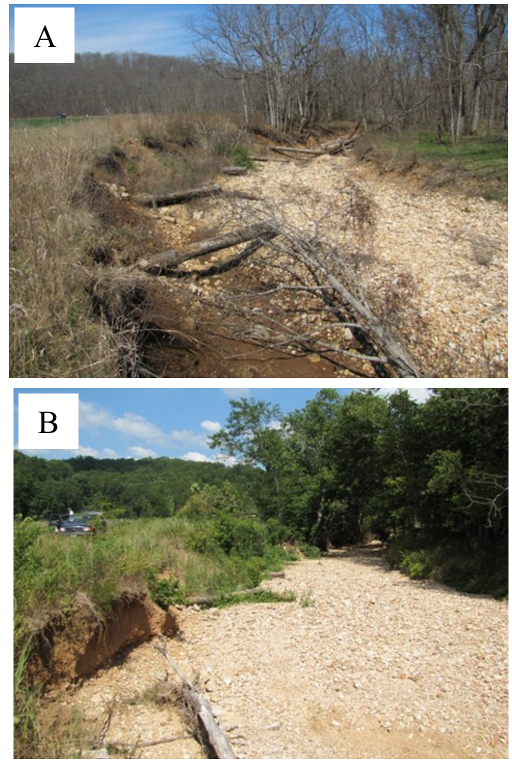

Figure 11. Mill Creek log weir project. (A) Looking upstream at the project March 2011. (B) Looking upstream at the project following the failure of weir five July 2011.

during the remainder of the year. In the spring of 2008, the project was tested by at least one flow event that reached a stage greater than ¾ of the streambank height. Unfortunately, the number and size of those flow events are unknown because during a high flow event the Levelogger® was lost. The Levelogger® was replaced in June 2008. Following replacement, there were no flow events greater than ¾ of the streambank height. In 2009, there were four flow events above ¾ of the streambank height. In 2010 and 2011, there were no flow events above ¾ of the streambank height. The project has withstood these few flow events and appears to be working.

Photo monitoring demonstrates the effectiveness of this project (Figure 13). Since construction, the thalweg has moved away from the streambank and sediment has been deposited over and between the weirs. The deposition has allowed for vegetation establishment at the toe and between the weirs, which is a good sign for the long-term stability of the project.

Following the flow events the thalweg has moved away from the streambank along the entire length of the project and deposition occurred between the weirs. Transect two gives a good illustration of the deposition of material at the streambank toe and the shifting of the thalweg away from the streambank that occurred (Figure 14). The channel shift occurred along the entire length of the project (Figure 15). The thalweg has moved away from the toe, streambank slope is decreasing, deposition has occurred, and vegetation is beginning to establish (Table 6). These trends indicate the project has a good chance of working long-term. Although the streambank has become

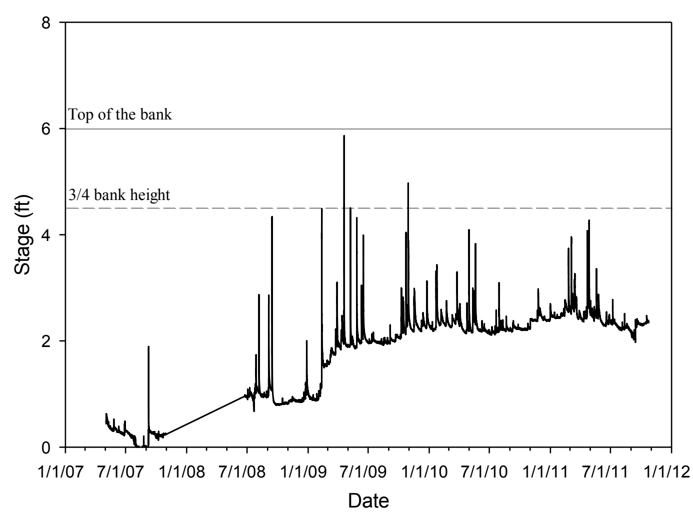

Figure 12. Levelogger® data from the upstream portion of California Branch where site 3 is located for 2007 through 2011. Data are missing from October 2007 until June 2008 due to a lost Levelogger®.

Table 5. Streambank movement and changes in streambank slope at the Mill Creek log weir project between the post-construction survey in January 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. Transects 1, 3, 5, 7, & 9 do not have changes in the streambank toe because the log weirs cover the toe.

	Top of streambank Movement (ft.)	Toe of streambank Movement (ft.)	Bank Slope 1/2007	Bank Slope 7/2011
Transect 1	-0.56	---	0.69	0.70
Transect 2	-1.51	-0.15	0.79	0.71
Transect 3	-1.62	---	0.67	0.61
Transect 4	-2.03	5.03	1.38	0.54
Transect 5	-7.91	---	0.66	0.24
Transect 6	-1.17	1.81	1.28	0.65
Transect 7	-27.84	---	0.77	0.20
Transect 8	-3.72	-4.51	1.68	2.33
Transect 9	-11.04	---	0.76	1.35
Transect 10	-16.83	-19.66	2.23	11.77

more stable through the length of the project, we have seen continued erosion and instability downstream of the last weir.

California Branch Site 4

California Branch Site 4, which incorporated what we learned at Jakes Creek into its design, was only tested by a small number of flow events in 2007 - 2011 (Figure 16). Following construction in the spring of 2007, the project was not tested by any flow events during the remainder of the year. In September 2008, there was a single flow event that reached a stage above ¾ of the streambank height. In 2009, the project was tested by two additional flow events that were greater than ¾ of the streambank height. In 2010 and 2011, there were no large flow events.

Photo monitoring since project construction in May 2007 gives a good visual representation of how the channel has changed since construction (Figure 17). The thalweg moved away from the streambank and sediment deposited over and between the weirs. Deposition has almost completely covered weirs one, two and three. In addition to the shift in the channel, there has been vegetation establishment along the streambank and in the deposition between the weirs, particularly upstream of weir three. Vegetation establishment is a good sign for the long-term stability of the project.

The GPS map gives an overhead view of the project and shows how the thalweg shifted away from the toe of the streambank (Figure 18). The channel moved away from the toe of the streambank throughout the entire length of the project. Transect two shows that shift (Figure 19). There has been streambank movement at both the top and toe of the streambank for all transects (Table 7). The changes led to a

Table 6. Streambank movement and changes in streambank slope due to erosion at the California Branch site 3 log weir 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. Transects 1, 3, & 5 do not have changes in the streambank toe because the log weirs cover the toe.

	Top of streambank Movement (ft.)	Toe of streambank Movement (ft.)	Bank Slope 5/2007	Bank Slope 6/2011
Transect 1	1.31	---	0.64	0.52
Transect 2	1.86	0.13	2.59	1.35
Transect 3	0.74	---	0.62	0.50
Transect 4	0.48	1.06	1.85	1.70
Transect 5	1.71	---	0.60	0.48
Transect 6	-3.76	-3.13	1.46	2.17

Figure 13. California Branch site 3 log weir project. (A) Looking downstream at project post-construction May 2007. (B) Looking downstream at the project October 2011.

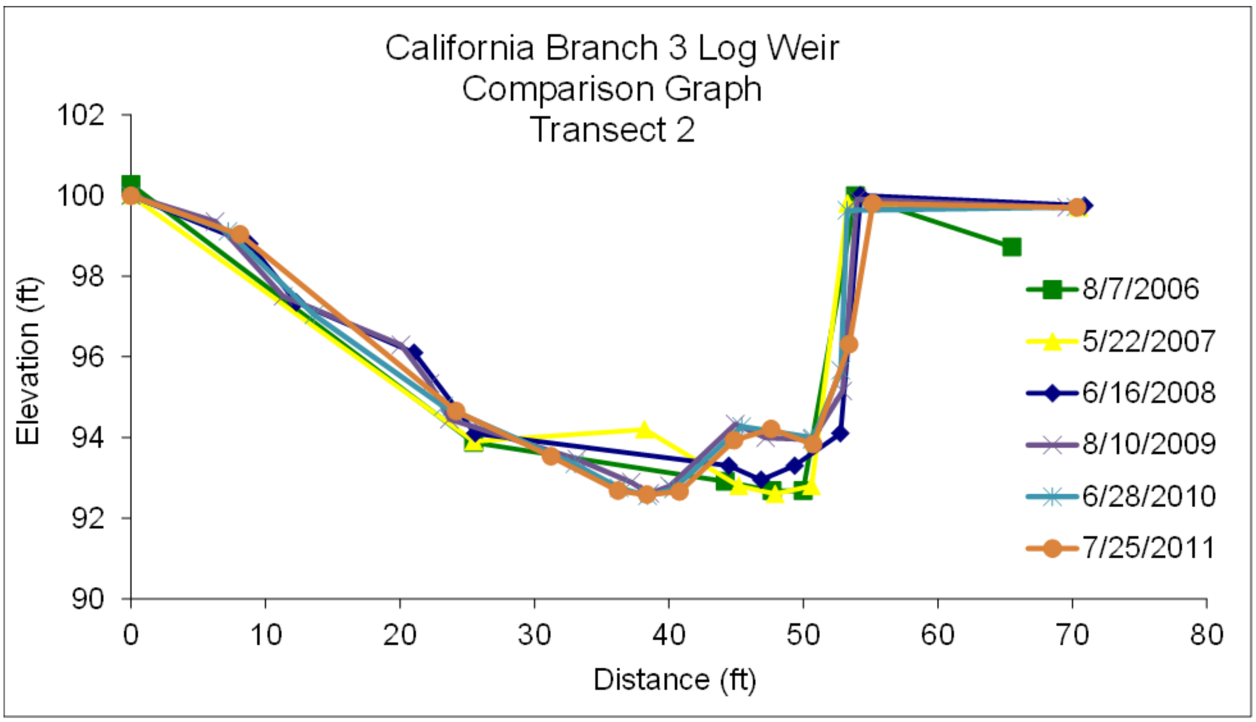

Figure 14. Physical survey data for transect two for the pre-construction survey (8/7/2006), post-construction survey (5/22/2007), and four post-flow surveys (6/16/2008, 8/10/2009, 6/28/2010, and 7/25/2011).

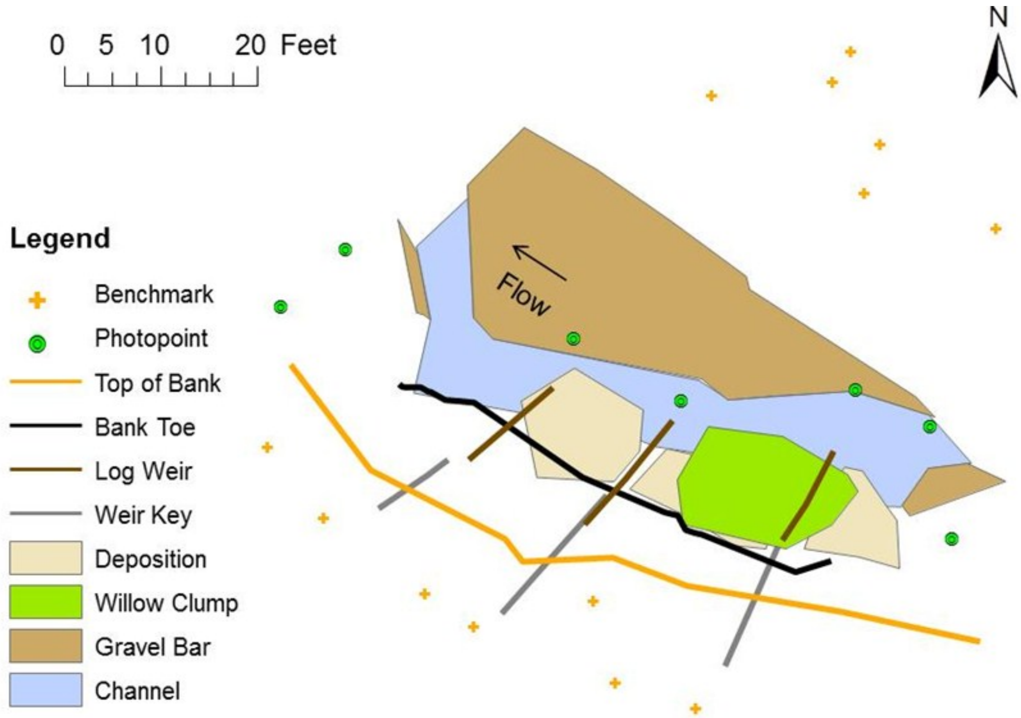

Figure 15. GPS map of the California Branch site 3 log weir project in July 2011.

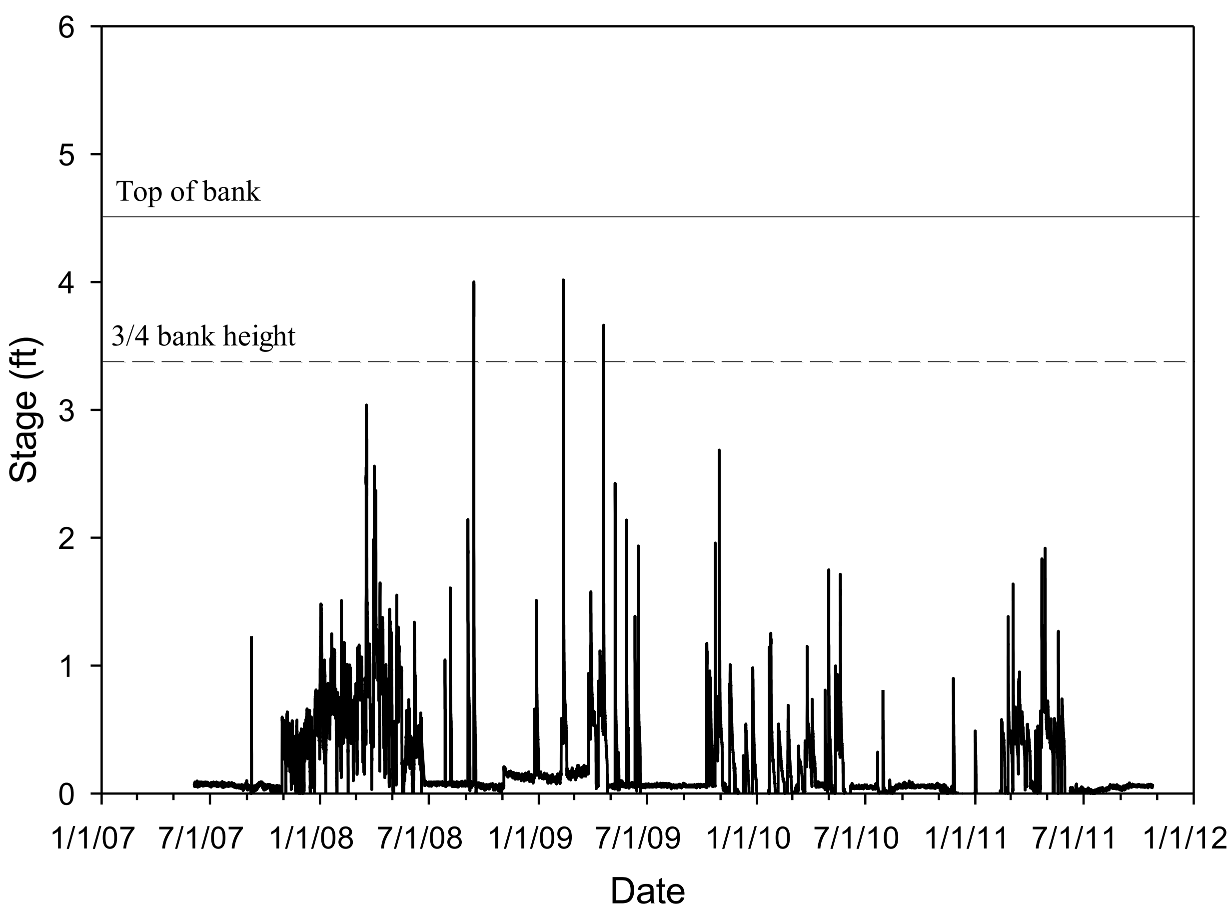

Figure 16. Levelogger® data from the downstream portion of California Branch where site 4 is located for 2007 through 2011.

decrease in streambank slope along five of the eight transects with the other three remaining virtually unchanged. Although the streambank has stabilized through the length of the project, we have seen continued erosion and instability downstream of the last weir.

Technique Performance

Five log weir projects were installed between July 2005 and May 2007. The log weir technique produced mixed results. The initial project failed due to a lack of key strength. The four projects constructed after that failure were modified based on what was learned at that site. Two of those projects have performed well, while the other two have been failures.

The first objective for monitoring the log weir projects was to determine extent of continued erosion or new deposition of sediment that occurred along the toe of the streambank between the weirs. To successfully achieve this objective the log weir project needed to move the thalweg away from the toe of the streambank out beyond the tips of the weirs and result in a large amount of deposition between the weirs at the toe that will protect the eroding bank. Of the five projects that were built, only two were successful at doing this throughout the entire length of the project. The initial project on Jakes Creek had extensive erosion at the toe between the weirs as a result of project failure. At Dry Branch, there was some erosion at the toe between all weirs and especially downstream of weir four where the failure occurred. The Mill Creek project had deposition at the toe between weirs upstream of weir four, but downstream of weir four there was extensive erosion resulting in the loss of weir five. The two California Branch projects both have had a significant amount of deposition at the toe and between the weirs and vegetation has started to establish at both sites at the toe and between the weirs. Overall the technique was successful at moving the thalweg and getting deposition at the toe for just two of the five sites.

The second objective of the monitoring was to determine if the streambank would achieve a stable slope through erosion of the upper part of the streambank while the toe was protected or deposition at the toe created a more moderate streambank slope. At Jakes Creek, there was actually a decrease in the slope of the streambank along most of the lower end of the project, but this was only because toe erosion caused the upper streambank to fail, so this was not a sign of increased stability. The Dry Branch streambank decreased in the slope upstream of weir four and increased in slope downstream of weir four, where the failure occurred. The same situation happened at Mill Creek where there was a decrease in the slope of the streambank upstream of the failure and an increase for all transects located downstream. The first California Branch project had a decrease in the slope of the streambank along five of the six transects. The only transect that increased in slope was the one located downstream of the last weir. At the second California Branch streambank the slope has decreased for five of the eight transects. The ones that did not decrease were located at the downstream end of the project again. At both California Branch sites the projects resulted in the stabilization of the reach where the logs were placed, but it increased erosion just downstream of the last weir. Increased erosion downstream of the last weir is a phenomenon that was seen at all five sites and contributed to the failure at two of the pro-

Figure 17. California Branch log weir project. (A) Looking upstream at project post-construction May 2007. (B) Looking upstream at the project October 2011.

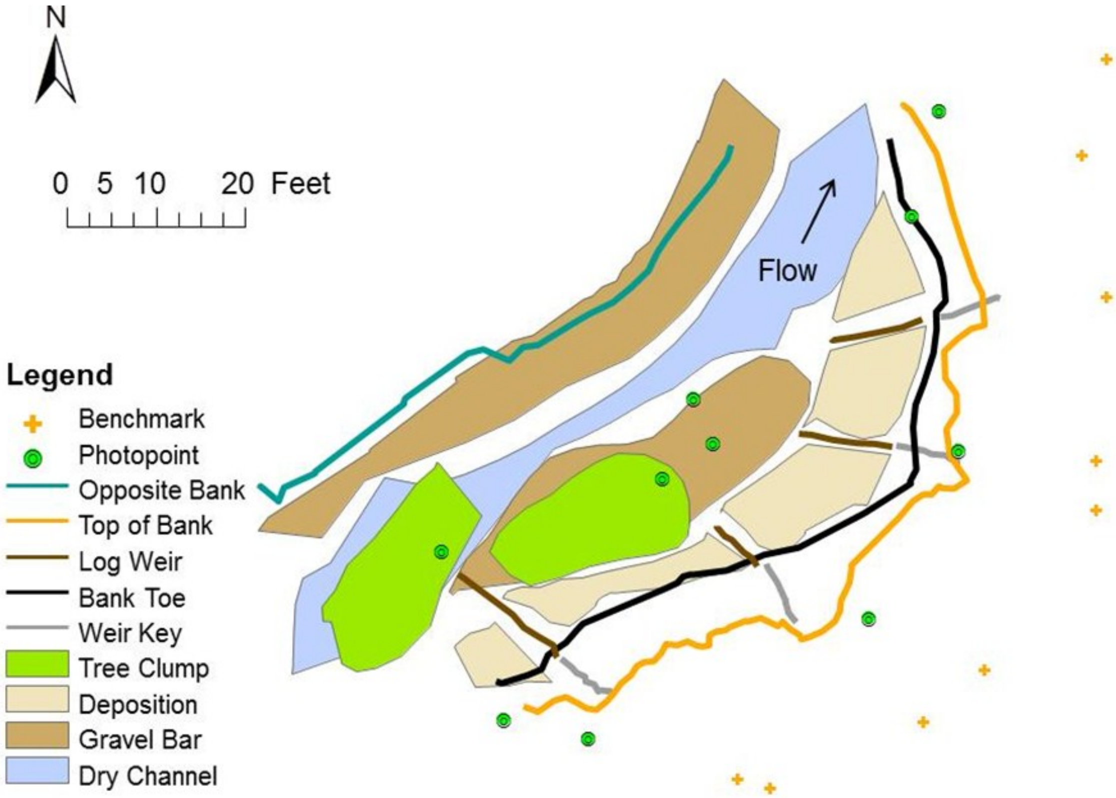

Figure 18. GPS map of the downstream California Branch log weir project in June 2010.

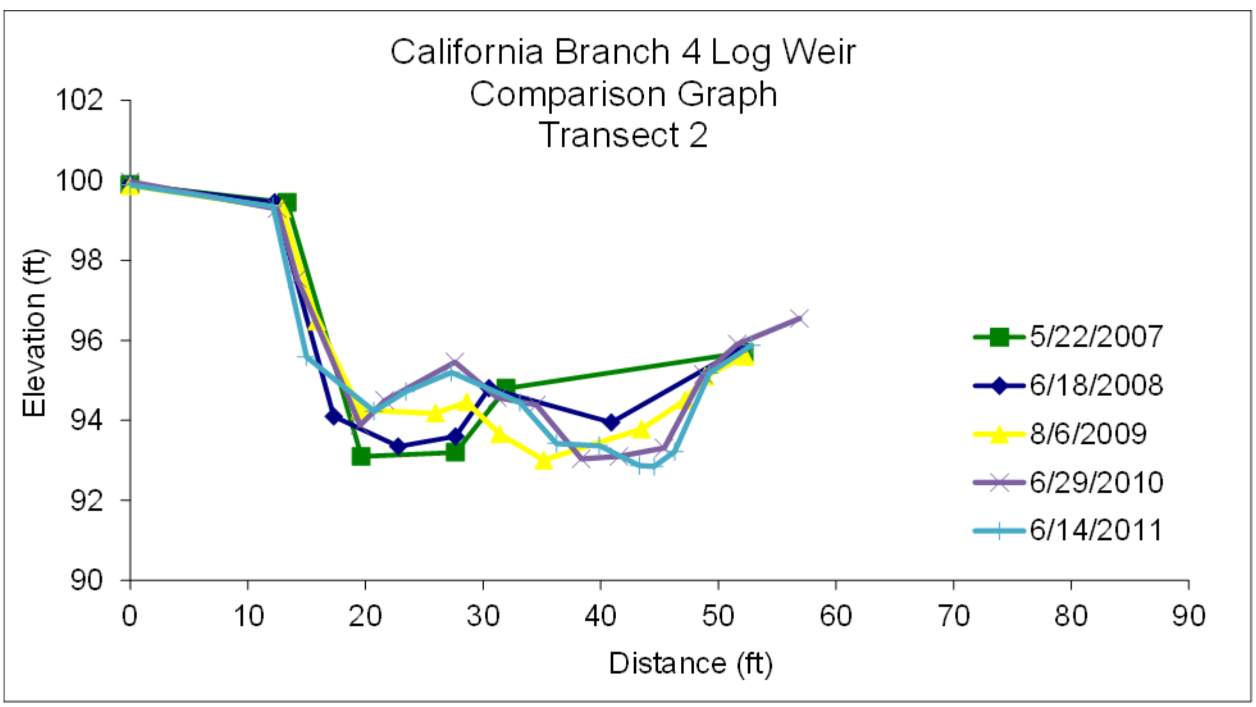

Figure 19. Physical survey data for transect two for the post-construction survey (5/22/07) and four post-flow surveys (6/18/2008, 8/6/2009, 6/29/2010, and 6/14/2011).

Table 7. Streambank movement and changes in streambank slope due to erosion at the California Branch site 4 log weir project between the post-construction survey in May 2007 and the final survey in June 2011. Transect numbers increase as you move downstream. Erosion is represented by negative movement in the streambank and deposition is represented by a positive movement in the bank. Transects 1, 3, 5, & 7 do not have changes in the streambank toe because the log weirs cover the toe.

	Top of streambank Movement (ft.)	Toe of streambank Movement (ft.)	Bank Slope 5/2007	Bank Slope 6/2011
Transect 1	-1.61	---	0.65	0.63
Transect 2	-1.21	1.08	1.01	0.60
Transect 3	0.10	---	0.50	0.52
Transect 4	-2.07	0.77	1.16	0.75
Transect 5	0.34	---	0.75	0.32
Transect 6	-4.05	-0.78	2.28	0.94
Transect 7	1.23	---	0.60	0.62
Transect 8	-2.78	-2.59	2.61	2.43

jects. For all five projects the weirs were laid out so that the effects of the weir should carry us to a stable point or help change the shape of the bend to make it more stable, however in all five cases we actually saw accelerated erosion below the last weir that made that area less stable than prior to project construction. Erosion indicates that when building a log weir project it is important to continue the project until you reach a stable point in the bank. Once again only two projects successfully addressed this objective to stop toe erosion and get deposition at the toe.

The third monitoring objective was to determine if log weirs maintained their position. Once again only at the two California Branch sites did all the logs stay in place and achieve this objective. At the Jakes Creek project, the logs only had about ⅓ of their length buried in the key and just the material that had been removed to dig the key trench was packed back on top of them to hold the logs in place. The Jakes Creek project failed during the first flow event that was greater than ¾ the streambank height. The cause of this failure was a lack of key strength to hold the logs in place. During the high flow event the key material appeared to liquefy. The result was there was nothing holding the logs at the appropriate angle. The logs rotated and instead of directing flow away from the streambank they actually directed flow toward the streambank causing large amounts of erosion and the complete failure of the project. Four of the eight weirs showed a large change in their angle and position. Information gained from this failure was used to make modifications to the technique before the other log weir projects were installed. The keys were strengthened by insuring that at least half the length of the log was buried in the streambank on all future projects and by adding large shot rock to the surface of the keys to protect the material and help hold the logs in place.

Following these modification the keys did a better job of holding the logs in place although we still had two projects fail. At both California Branch projects all the weirs maintained their position. At the Dry Branch project weirs one through four all maintained their position, but erosion at the downstream end of the project resulted in weirs five and six being completely washed away. The spacing between weirs four and five was too much given the tight curvature of the bend resulting in a large amount of erosion at the base of weir five and the eventual complete failure of weirs five and six. The Mill Creek project had weirs fail via two separate mechanisms and the keys of two other weirs were damaged by a third mechanism. The project suffered damage to the keys of weirs three and four during the high flow events. Despite the large amount of damage, the weirs maintained their positions and angles even through subsequent flow events. Weir one was lost when the log broke off at the bank. This occurred because of the large amount of woody debris moving through the system, caused by a head-cut located just upstream. Debris wedged against weir one and put enough pressure on the log during a high flow event that the log actually broke off at the streambank even though the key did not fail. Weir five also failed, due to erosion at the downstream end of the project that worked upstream until it took out the key of weir five. As a result three of the five projects failed to achieve this objective because of a variety of mechanisms.

Technique Costs

The log weir approach was intended to be a less expensive alternative to a traditional bendway weir project. 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 bendway weir approach. To determine the costs associated with the projects and the potential savings, we calculated the costs of building the log weir project and compared it to the costs of building a traditional bendway weir project at that site or an experimental farm rock weir project (Table 8). On average, the log weir project saved $17.87 per foot or 58.7% when compared to a traditional bendway weir project and $5.27 per foot or 29.5% over an experimental farm rock weir project built in the same location.

It is important to note, however, that repair costs can quickly eliminate most if not all the savings associated with this approach depending on the size of the repair and how often repairs need to be made. A complete failure such as Jakes Creek can result in a project having to be completely replaced and most likely will cost a landowner more than using a traditional method from the beginning.

DISCUSSION

We established the limitations of the log weir technique as an approach for stabilizing eroding streambanks. The results indicate that log weirs may have only limited potential as a streambank stabilization technique. Only two projects are still in place and appear to be working. Given the failure rate we saw and the additional expenses that would have resulted from repair, it is unlikely that someone would choose this technique over the traditional approach. The failures occurred for a variety of reasons.

The original failure at Jakes Creek (due to inadequate key strength) was addressed with modifications prior to construction of the other four projects. The changes focused on strengthening the weir's key area by burying at least half the log in the key and adding shot rock to protect the replaced key material from erosion. Following the modification the keys seemed to hold up better at the four remaining projects as all logs that stayed in place maintained their angles. The logs that failed did so because of erosion to the entire streambank and not due to a lack of key strength. The only damage to the keys at the four projects built after the modification occurred at the Mill Creek project. That project had rock shoved into the key material instead of being used to protect the surface of the key. This does not appear to be as effective as covering the surface as that project had multiple areas of key erosion. During the first flow event at the Mill Creek project, a large area of erosion occurred in the key of one of the weirs. A large pocket was created behind the streambank with the only access to the channel being the opening of the key. Even though the scour area has continued to enlarge during the multiple high flow events that have occurred since it was created, the weir itself has not failed. Key scour has also started to occur at another weir to a smaller degree. Mill Creek is the only project where we have seen this happen and it is the only project where rock was pushed into the key material instead of used to cover the surface of the key. Key strength is the most important factor to consider when using this approach. If the keys are not strong enough to hold the logs in place during high flow events, the project has little chance of succeeding and a traditional bendway weir approach should be used instead.

The Dry Branch failure appears to be due to the poor layout of the weirs during project design. These projects were designed and laid out using basic guidelines without the assistance of a professional en-

Table 8. Project costs (cost per linear foot of bank) for a log weir project compared to building a traditional bendway weir or an experimental farm rock weir project at the same site.

Site	Log Weir	Bendway Weir	Farm Rock Weir
Jakes Creek	$13.00/ft.	$39.29/ft.	$19.57/ft.
Dry Branch	$13.31/ft.	$24.60/ft.	$18.85/ft.
Mill Creek	$10.70/ft.	$37.57/ft.	$16.52/ft.
California Branch 3	$13.07/ft.	$24.88/ft.	$16.65/ft.
California Branch 4	$12.68/ft.	$25.76/ft.	$17.50/ft.
Average Costs	$12.55/ft.	$30.42/ft.	$17.82/ft.

gineer. The guidelines that were followed were that weirs needed to be between ⅓ to ½ the streambank height tall, extend across approximately half the channel at approximately a 20 degree angle upstream from perpendicular, and spacing was determined by the curvature of the bank, but was no more than four times the length of the upstream weir. Placement of the weirs is critical to success or failure of a project. The first weir needs to be placed immediately downstream of a stable point and succeeding weirs need to be spaced properly and with the correct angle so that flow does not erode the streambank behind them. Logs placed at the wrong angle will cause the failure of the downstream weirs or large amounts of erosion downstream of the project, even if that area previously appeared to be stable. There was only one project in which we experienced problems due to weir placement. Even though the staff laying out these weirs had many years of experience working with weir projects, we still had an issue at one site. For these reasons, landowners should not attempt one of these projects without the project being designed by an experienced professional.

The other complete failure occurred on Mill Creek. The failure was the result of a combination of factors. First, key erosion occurred at this site as discussed earlier, although it did not result in the failure of any of the weirs where the key erosion was seen. Second, woody debris moving through the system as a result of an active head-cut just upstream of this site caused weir one to break off at the bank. However, neither of these are the reason we ruled this project a complete failure. At all four projects built after we modified the technique to strengthen the keys, the projects generally did a good job protecting the area between the weirs, but actually accelerated the erosion occurring just downstream of the project. At best, several projects just shifted the area of accelerated erosion downstream. Erosion was extensive enough at Mill Creek to eventually lead to the loss of the last weir at that site, which is why we considered that project a complete failure. In addition this phenomenon contributed to the failure at Dry Branch. For all five projects the weirs were laid out based on general rules given to the project team by MDC engineers. Based on the rules we followed the effects of the weir should have carried us to a stable point or help change the shape of the bend to make it more stable. What we found, however; was accelerated erosion below the last weir at all five sites, making those areas less stable after the project was built than they were prior to project construction. As a result, if a log weir approach is used it is important to continue the project until you a reach stable point in the bank.

An additional factor that would need to be considered before applying this technique is the limitations inherent with using logs to build weirs instead of rock. Because log weirs need to have at least half their length buried in the key and cover at least a third of the streambank height, the size of the logs required makes a log weir project impractical once the streambank height exceeds 10 ft. tall or when the thalweg needs to be moved more than 15 ft. The limits of log size did not contribute to any failures, but it did limit our initial site selection process and would limit potential application of this approach.

The critical aspects in the usefulness of this technique appear to be the strength of the key, the distance the thalweg needs to be moved by the weirs, the height of the bank, proper placement of the weirs, and a stable stopping point on the downstream end. If any of these factors are out of balance at a site, then project failure is likely. So while this technique has shown potential for success, it has also demonstrated a large number of limitations. The requirements associated with site selection for this technique along with the difficulty associated with designing the project correctly make its usefulness and potential application for landowners very limited.

MANAGEMENT IMPLICATIONS

The information gained at all five sites indicates that this approach has only limited potential as a stabilization technique. Modifications could be made to strengthen the keys and carry the project to a stable point, but those modifications have not been tested, so their limitations are unknown and they would not address the need for a professional design in laying out the weirs. The techniques application is also limited depending on the size of streambank and the channel. So while there might be some potential on smaller streams for using this approach, the log weir approach should not be attempted without being designed by an experienced professional and at this time is not a technique we would recommend to landowners.

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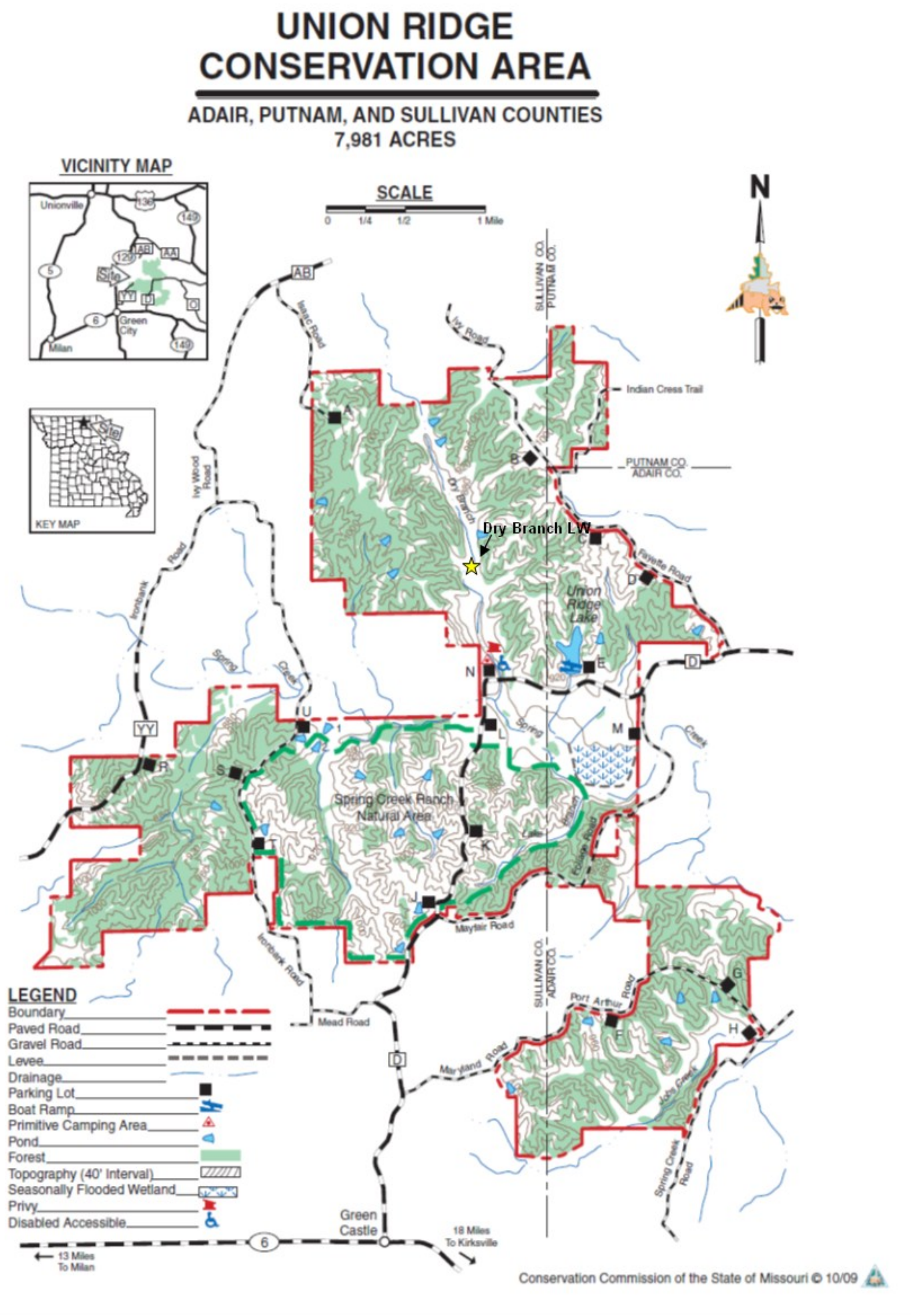
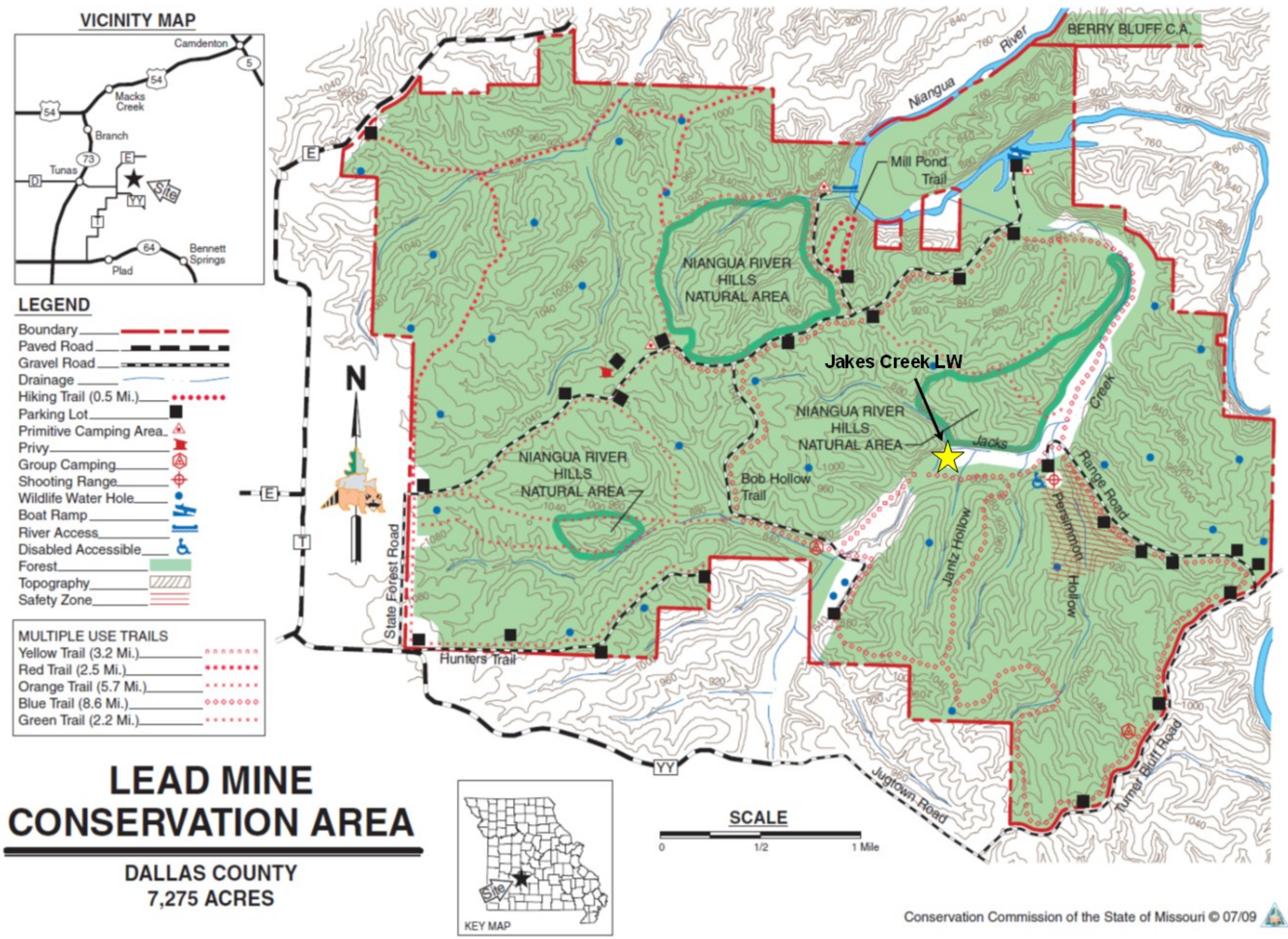
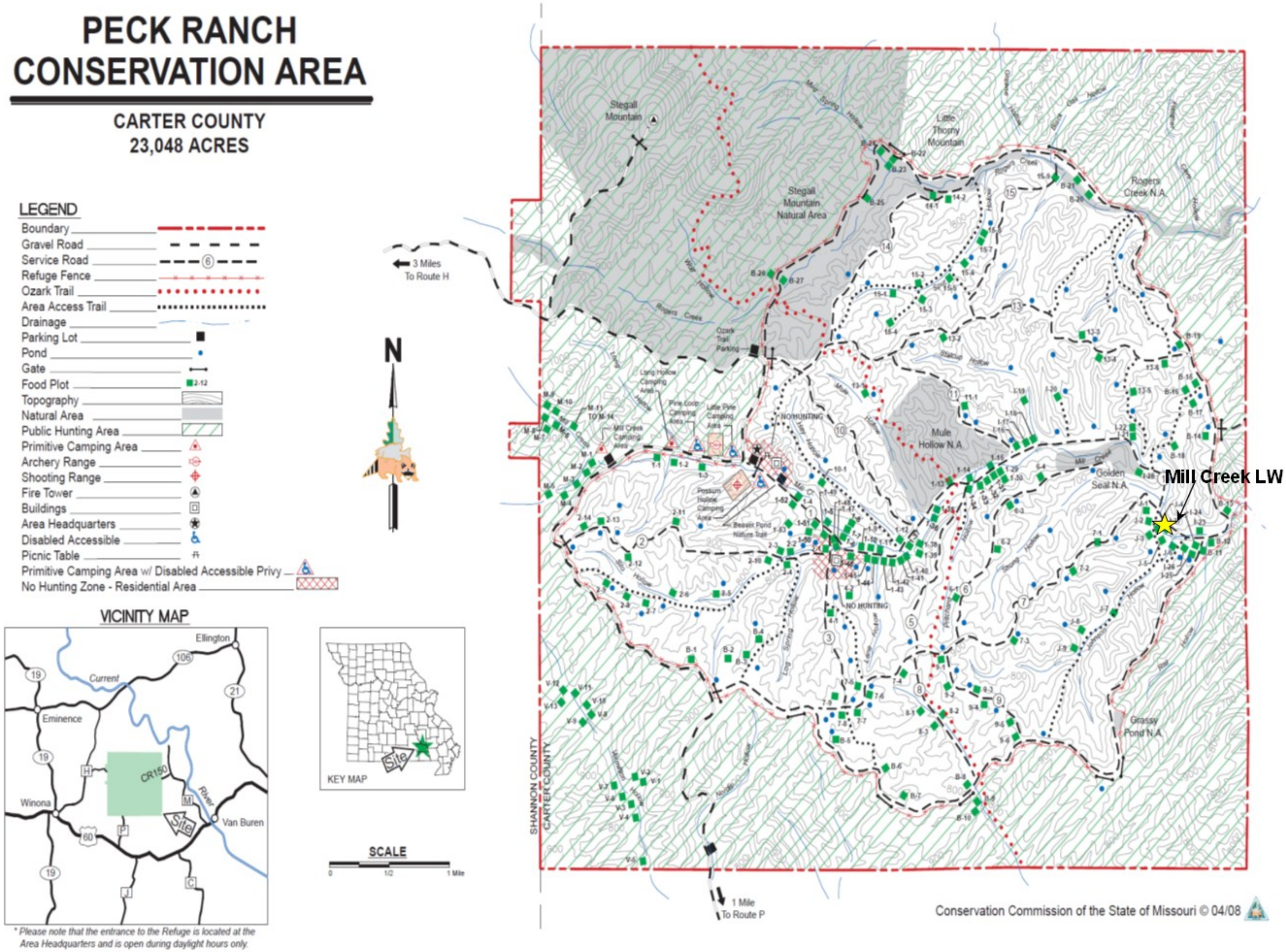
Appendices

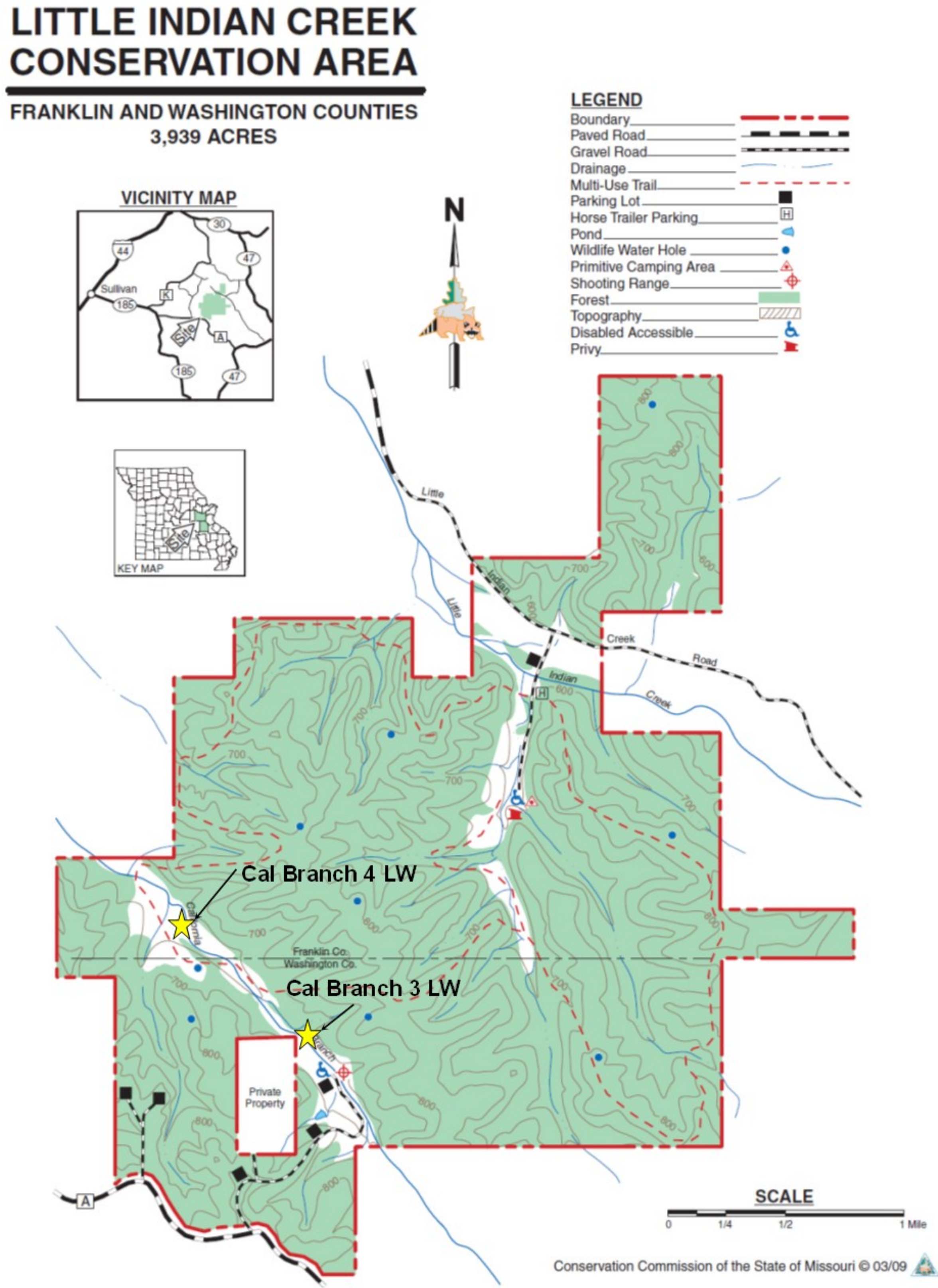
Appendix 1: Area Maps





VICINITY MAP
Camdenton
Macks Creek
Branch
Tunas
Site
Bennett Springs
Plad
LEGEND
Boundary
Paved Road
Gravel Road
Drainage
Hiking Trail (0.5 Mi.)
Parking Lot
Primitive Camping Area
Privy
Group Camping
Shooting Range
Wildlife Water Hole
Boat Ramp
River Access
Disabled Accessible
Forest
Topography
Safety Zone
MULTIPLE USE TRAILS
Yellow Trail (3.2 Mi.)
Red Trail (2.5 Mi.)
Orange Trail (5.7 Mi.)
Blue Trail (8.6 Mi.)
Green Trail (2.2 Mi.)
LEAD MINE
CONSERVATION AREA
DALLAS COUNTY
7,275 ACRES
KEY MAP
Site
N
State Forest Road
Hunters Trail
BERRY BLUFF C.A.
Niangua River
Mill Pond Trail
NIANGUA RIVER HILLS NATURAL AREA
Jakes Creek LW
Jacks Creek
Bob Hollow Trail
Jantz Hollow
Persimmon Hollow
Range Road
Turner Bluff Road
Jugtown Road
SCALE
0
1/2
1 Mile
Conservation Commission of the State of Missouri © 07/09


PECK RANCH CONSERVATION AREA
CARTER COUNTY
23,048 ACRES
LEGEND
Boundary
Gravel Road
Service Road
Refuge Fence
Ozark Trail
Area Access Trail
Drainage
Parking Lot
Pond
Gate
Food Plot
Topography
Natural Area
Public Hunting Area
Primitive Camping Area
Archery Range
Shooting Range
Fire Tower
Buildings
Area Headquarters
Disabled Accessible
Picnic Table
Primitive Camping Area w/ Disabled Accessible Privy
No Hunting Zone - Residential Area
VICINITY MAP
Ellington
Current
Eminence
Winona
River
Van Buren
CR150
Site
* Please note that the entrance to the Refuge is located at the Area Headquarters and is open during daylight hours only.
KEY MAP
Site
SCALE
0
1/2
1 Mile
N
3 Miles To Route H
1 Mile To Route P
Stegall Mountain
Stegall Mountain Natural Area
Little Thorny Mountain
Rogers Creek N.A.
Mule Hollow N.A.
Golden Seal N.A.
Grassy Pond N.A.
Ozark Trail Parking
NO HUNTING
SHANNON COUNTY
CARTER COUNTY
Mill Creek LW
Conservation Commission of the State of Missouri © 04/08


LITTLE INDIAN CREEK
CONSERVATION AREA
FRANKLIN AND WASHINGTON COUNTIES
3,939 ACRES
VICINITY MAP
Sullivan
Site
KEY MAP
Site
N
LEGEND
Boundary
Paved Road
Gravel Road
Drainage
Multi-Use Trail
Parking Lot
Horse Trailer Parking
Pond
Wildlife Water Hole
Primitive Camping Area
Shooting Range
Forest
Topography
Disabled Accessible
Privy
Little Indian Creek Road
Little Indian Creek
Cal Branch 4 LW
Franklin Co.
Washington Co.
Cal Branch 3 LW
Private Property
SCALE
0
1/4
1/2
1 Mile
Conservation Commission of the State of Missouri © 03/09

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