USING STREAMBANK RESTORATION AND BEST MANAGEMENT PRACTICES FOR INPROVING WATER QUALITY WITHIN CRAWFORD BRANCH, IN ROBERTSON COUNTY, TENNESSEE

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Date 7 May 2004

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A Thesis

Presented for the

Masters of Science

Degree

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James O. Harmon, Jr.

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DEDICATION

My Thesis Research is dedicated

to my Wife Debby.

For all the times she said "yuck"

while assisting me with "Aquatic Critters",

but most of all for her love and support

during my pursuit of higher education.

List of Tables

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ABSTRACT

Nonpoint source (NPS) pollution continues to degrade our streams and decrease fishery resources. This study describes aquatic resources (lotic ecosystem) restoration and uses macroinvertebrate assessments to evaluate remediation success in Crawford Branch and Carr Creek in south Robertson County, Tennessee.

Five restoration sites on Crawford Branch and one reach on Carr Creek were chosen in 1996 for various in-stream and riparian best management practices (BMP's). Physical and geomorphological assessments and surveys were applied to all areas before and after habitat remediations.

Qualitative benthic macroinvertebrate surveys were employed at sites one and five of Crawford Branch before and after in-stream and riparian habitat remediation. While the overall results show that taxa richness and EPT richness has increased at both sites, due to the limited number of samples taken, the macroinvertebrate data does not conclusively determine that habitat remediations have significantly improved water quality.

The geomorphological surveys show that all sites, except site four, have been stable since remediations in 1997. Since 1998, BMP maintenance activities have been ongoing at site four and continues to have some erosion of the rip-rap toe. Nonetheless, streambank retreat at site four has been stopped. Initial cost for instream and riparian remediations was $28 per linear meter. At current costs, remediation has increased to $38 per linear meter. Local, state and federal cost-share programs are needed to support landowner participation in stream restoration projects.

TABLE OF CONTENTS

List of Figures

SECTION 1: INTRODUCTION

Effects of Nonpoint Source Pollution

Non-point source pollutants (NPS) are various forms of soil particles, excessive nutrients, and chemicals that are carried to local waterbodies. NPS develops from overland and sub-surface runoff or drainage through adjacent farmland, construction sites, industrial, commercial facilities, residential, recreational areas, or from within the actual aquatic system. The hydrology of urban streams changes as sites are cleared and natural vegetation is re-placed by impervious cover such as rooftops, roadways, parking lots, sidewalks, and driveways (The Federal Interagency Stream Restoration Working Group, 1998). Storm water runoff moves more rapidly over hard surfaces than over natural vegetation. Natural streams are dynamic and constantly change. Over time, streams that remain natural or unaltered will reach an equilibrium point, in which erosion at one point will be balanced by deposition at another (Henderson, 1986). Although erosion naturally occurs within streams, studies have shown that excessive NPS pollutants destroy aquatic systems by physically clogging habitats of various aquatic communities (Nunnally, 1978).

Siltation decreases the amount of dissolved oxygen for all organisms, significantly impacts overall water quality, and alters recreational and aesthetic enjoyment by reducing clarity and filling interstial spaces in the substrate (The Federal Interagency Stream Restoration Working Group, 1998). All land use practices and management activities within a given watershed directly impact the terrestrial–aquatic interface (Kondolf, 1996). Urban development and destruction of the riparian zone are the primary reasons for increased erosion and siltation of the aquatic systems. The riparian zone is the region that extends from the edge of a streambank toe interface, to several meters out into the adjacent floodplain.

Agriculturally, the riparian zone is known as a "conservation buffer strip." A healthy riparian zone consists of adequate natural grasses, shrubs, and trees with a network of well-developed root systems. The physical structure of the riparian ecosystem slows down overland flows and acts as a trap capturing sediment. The vegetative root systems uptake excess nutrients, stabilizes the streambank and channels during overbank flows (Rabeni and Smale, 1995). More important and lesser-known functions of the buffer zone are providing shade and appropriate water temperatures-ranges for various aquatic organisms, suppling coarse particulate organic matter for a more diverse food network, and balancing physiochemical parameters (pH, conductivity, dissolved oxygen, total dissolved solids, and nutrient levels) within the waterbodies. With all of the development activities within watersheds, one of the most important features to enhance and protect is the riparian buffer zone. Left natural and unaltered, this region will remove NPS pollution, maintain good water quality, and support the integrity of biological communities.

Streambank restoration is one of many direct best management practices (BMP's) used to decrease both natural and human activities that cause erosion and sedimentation within waterbodies. Streambank protection methods are designed to control erosion by stabilizing the bank or deflecting erosive flows (Henderson, 1986). Some direct methods include (one) sloping the bank on a 2:1 ratio, (two) placing rip-rap at the toe of the streambank to prevent undercutting or deflecting erosive flow back towards the thalweg of a stream, and (three) using bioengineering techniques (i.e., planting native vegetation forming brush mattresses, fascines, or planting shoots, posts, and stumps of various trees that are indigenous to wet areas to increase the riparian zone stability).

In addition, surface erosion control mats are often used for sediment control until natural vegetation can become established. In designing BMP structures for erosion control, there are many variables to consider such as land use activities within the watershed, economic, social, functionality, and how aesthetically pleasing will the final product be. That is, does it work, does it look good, and, most of all is it cheap? Unfortunately, once an area gets to the point that direct sediment and erosion control designs and plans have to be made, the situation is usually well beyond any method that could be considered "low cost." However, the costs of streambank restoration projects vary with site-specific conditions. Costs for excavations, restoration materials, and access to sites cause major differences in remediation costs of atypical structures and designs even within the same watershed (Henderson, 1986).

Biosurvey methods have a long-standing history for before and after monitoring of restoration sites (Osborn et al., 1986). Biosurvey methods include the assessment of numerous community measures or metrics to evaluate the biological integrity of the system. These metrics assess community richness, composition, tolerance or intolerance to pollutants, functional feeding relationships, and habitat quality (Arnwine et al., 2001). The state of Tennessee has established criteria for conducting rapid bioassessments in the various ecological regions, or ecoregions, across the state. There are seven different metrics that are responsive to disturbance factors within ecoregion 71 e that includes the area of this investigation. The metrics include: (1) percent clingers, a measure of the physical aspects of the environment such as habitat abundance, sedimentation, flow alteration, and substrate stability; (2) percent dominance, a relative abundance measure of the single most abundant taxon; (3) the North Carolina Biotic Index (NCBI), a weighted measure the overall tolerance of the entire benthic community; (4) percent Oligochaetes to Chironomids, a measure of the contribution of the more tolerant taxa to the community; (5) percent EPT, a relative measure of abundance of pollution sensitive aquatic organisms including Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddisflies); (6) taxa richness, the total number of taxa without regard to abundance; and (7) EPT richness, a measure of the diversity of these pollution sensitive taxa without regard to abundance (Arwine and Denton, 2001). Advantages of using benthic macroinvertebrates are as follows: (1) they have limited migration patterns which make them well-suited for site-specific impacts (upstream-downstream studies), (2) most species have complex one year or more life cycles and sensitive stages will respond quickly to environmental stresses, (3) many pollution intolerant species can be easily identified to the taxonomic family-level which allows interpretation of local environmental conditions, and (4) sampling is relatively easy and inexpensive (Barbour et al.,1999). It is also advantageous to use macroinvertebrate communities in habitat surveys since they are abundant in most streams, and are primary food sources for many recreational and commercially-important fish (Bottomlee, 1997).

A natural and well maintained riparian buffer zone within a watershed traps and limits NPS pollutants from entering waterbodies, stabilizes the terrestrial-aquatic ecosystem, supports the physiochemical parameters of good water quality, aids in wildlife habitat structure, increases the value of adjacent land and enhances community development.

Sulphur Fork Creek Watershed and Crawford Branch

The Sulphur Fork Creek watershed is located in Robertson, Montgomery, Cheatham, and Sumner counties of northern Middle Tennessee (Fig. 1). The Tennessee Department of Environment and Conservation (TDEC) has designated the watershed for domestic, industrial, commercial (livestock, irrigation and aquaculture), and recreational (fish, aquatic, and other wildlife) uses (Watershed Preauthorization Report, Sulphur Fork Creek Watershed, 1998). Robertson County is one of the top five counties for agricultural crops (tobacco, corn, wheat, and soybean) acreage (Tennessee Department of Agriculture, 1995). The Sulphur Fork Creek watershed drains 55,847-hectares and is located in the southern of Robertson County. Sulphur Fork Creek flows into the Red River at Port Royal, Tennessee.

Crawford Branch is a first order stream that flows into Carr Creek southeast of Springfield, Tennessee. Carr Creek is one of the largest tributaries of Sulphur Fork Creek. Land uses within this small watershed include residential and agricultural practices. Excessive erosion and NPS pollutants associated with construction and livestock are the two major pollution problems of the watershed.

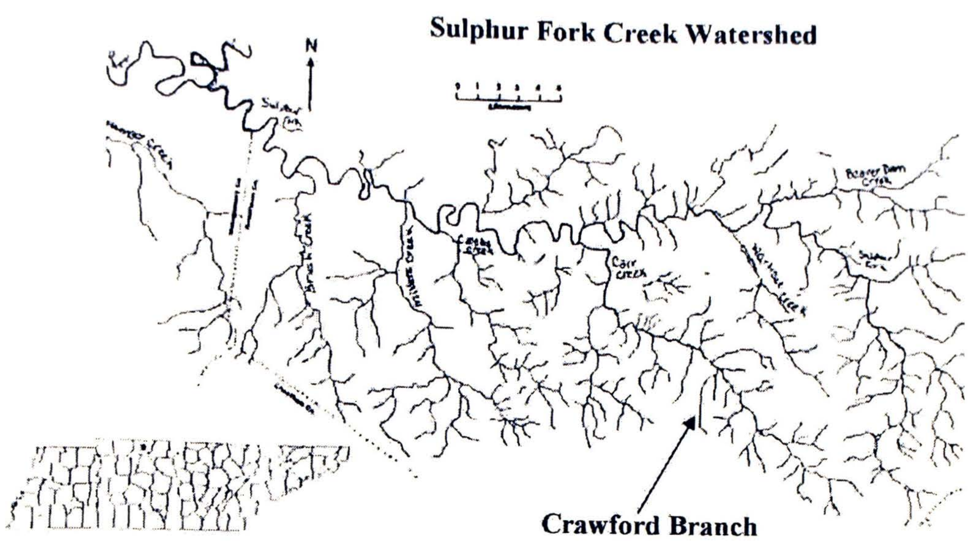

Fig. 1: Location map of Crawford Branch, Robertson County, Tennessee

Agricultural land usage in the Crawford Branch watershed is primarily pasturing and haying for cattle feeding operations. Sediment is the major NPS pollutant in this area. Erosion causes damage to crop and pasture yields, increases construction costs (need of higher quality BMP's), increases road-bank and bridge maintenance costs, impairs water quality, and greatly reduces aquatic and terrestrial wildlife habitat. An estimated 68,039 metric tons of sediment per year are either deposited in the bottomlands or enter the Red River (Watershed Preauthorization Report, Sulphur Fork Creek Watershed, 1988). Livestock entering the stream for watering purposes cause excessive NPS pollutant sources by trampling and browsing the riparian zone. The loss of vegetation, fecal material, nutrients, and pesticides affect water quality. This stress causes adverse effects on all aquatic fauna, and also deteriorate the quality drinking water, significantly increases the costs of development, and lowers the aesthetics and recreational values of adjacent land.

Goals of This Study

The purpose of this study is to develop multiple inexpensive best management practices (BMP's) for the restoration of the riparian zone of Crawford Branch in Robertson County, Tennessee. The goals of this study were to perform a descriptive study by conducting riparian habitat and aquatic macroinvertebrate assessments, and to determine general water quality on Crawford Branch within the Sulphur Fork Creek Watershed before and after restoration.

The goals were accomplished by performing an analysis of the aquatic macroinvertebrate communities at the upper and lower ends of the restoration area using measurements of total and EPT taxa richness. Total richness is the total number of taxa collected. EPT taxa richness is the total number of the sensitive Ephemeroptera, Plecoptera and Trichoptera collected. The riparian habitat was assessed by conducting a geomorphological (Brunton and tape) survey and mapping on paper by hand and referenced to aerial photographs.

In addition, two areas on Carr Creek totaling 154.2 m were restored. These areas were treated in the same fashion as Crawford with only slight variations and will be included for comparisons in technique and cost analysis.

Significance of Study

The Sulphur Fork Creek Watershed and its tributaries were listed in the late1990's by the State of Tennessee as being significantly impaired due to excess sediment (Watershed Preauthorization Report, Sulphur Fork Creek, 1988). The Crawford Branch monitoring program began in the mid 1990's to determine the significance of bank erosion as a sediment source and other land uses within the watershed. Assessments from the program were used to develop multiple inexpensive best management practices (BMP's) for private landowners, or other land managers to adopt for the reduction of sediments and other NPS pollutants and aid in improving local water quality. This study will contribute to the database for future studies within the Sulphur Fork Creek watershed in Middle Tennessee. All habitat assessments, maps and macroinvertebrate samples are being held at The Center for Field Biology, Austin Peay State University, Clarksville, Tennessee.

Description of the Study Area

Robertson County is located within the northern section of Middle Tennessee. The county is mostly within Level IV Ecoregions 71e (Western Pennyroyal Karst), although the small area in the southern portion of the county lies in ecoregion 71f (Western Highland Rim) (Arnwine and Denton, 2001). The soils within the project region are derived from limestone and consist mainly of Baxter, Mountview, Bodine, and

Dickson. The soils are characterized as alluvial silt loams with an average slope of two to five percent.

Crawford Branch, located mostly in the southcentral portion of Robertson County lies within the Western Pennyroyal Karst (71e) ecoregion. It is a typical class "C" stream, generally described as being a low gradient stream (slope of 2%) with sinuous, well-defined channels, riffle-pool configuration between every five-seven streambank widths, and associated with broad valleys (floodplains) with natural terraces (Rosgen, 1996). The banks of Crawford Branch were 3-4 m above the thalweg, the centerline of stream flow, and moderately exposed. In the mid 1990's the Sulphur Fork Creek watershed was listed by TDEC as a priority watershed (Kinsey, 1998). Cost-share programs such as Environmental Quality Incentives Program (EQUIP) were developed for various BMP's and streambank restoration projects.

In 1996, remediations of the Crawford Branch streambank began. At that time, there were several reaches of unstable and unvegetated soil banks that showed geomorphic signs of rapid retreat.

This loss of streambank caused fine sediment deposition in Crawford Branch and eroding of valuable agricultural land adjacent to the stream. Also, bank erosion undercut riparian trees contributing large woody debris to the stream channel. This caused the formation of log jams at the confluence of Carr Creek. The stream was divided into five monitoring sites. Those descriptions are as follows:

Site one

This sampling site, the futherest upstream, was located approximately 20 m downstream from the bridge on New Cut Road (Fig. 2). The project area was 40 m in length. The average height of the streambank was approximately 3 m. Livestock had free access to the stream. This created paths and caused major trampling of the sparse riparian vegetation. Especially during the wet seasons, the weight of the animals would develop holes that would further scour and erode due to flooding and receding waters. Also, excessive nutrients and bacteria from fecal material were present within the interstices of the limestone and cherty gravel streambed. The landowner placed large sections of concrete block material onto the streambank to prevent further erosion, scouring and loss of the existing bank. The riparian zone mainly consisted of fescue grass for livestock pasture and hay crops. The area was completely void of trees and shrubs and the farmer maximized the area by cutting as close to the top of the streambank as possible.

Site two

This project area was 26 m in length and located on the west bank opposite of site one (Fig. 2). The riparian zone was fairly diverse within this region. The face of the streambank was cut on a 90° vertical angle. The entire length of bank was gravel-soil, non-vegetated and fully exposed. During any erosive flow, sediment freely flowed from this region. The streambed was composed of large stones and limestone bedrock. The largest percentage of this reach was pooled water and contained only a minimum amount of aquatic habitat.

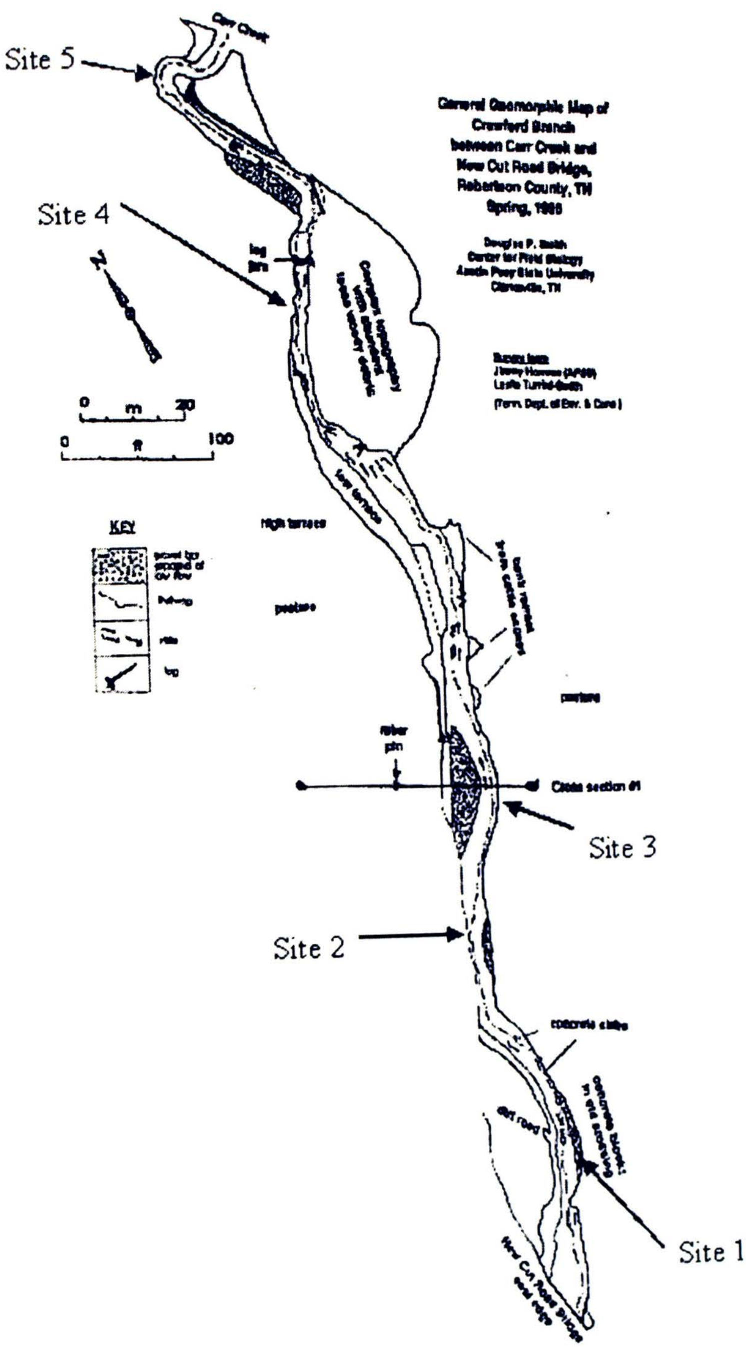

Fig 2: The 1996 Brunton and tape survey of Crawford Branch with sites one to five remediation areas.

Site three

Site three monitoring area was 25 m in length, and the height of the streambank to thalweg was 3 m. Before remediation took place, the streambank was cut on a 90° angle. The stream flow within this reach was shallow and over 90° percent riffle-erosive flow (Fig. 3).

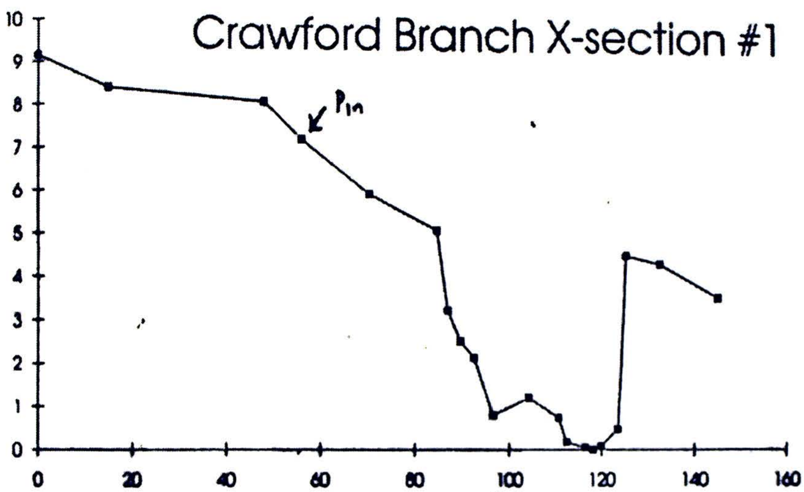

Fig. 3. The 1996 Cross-sectional survey of site three Crawford Branch.

The streambank was showing the classic mechanisms for bank failure including erosive attack at the toe, failure of the overlying bank (forming a wave-type action, Fig. 3), erosion of the banks (face of slope) caused by shear stress, or sloughing of streambanks by water seepage (sub-surface and overland flow) out of the bank, and freeze-thaw action of unvegetated and unprotected banks (shrinking and swelling of clay-type soils that are often associated with the riparian zone) (Henderson, 1986).

The streambed was composed of small cobble, gravel and sand. The riparian zone of site three was structured in the same fashion as site one. Site three was completely void of trees and shrubs and only grass/pasture existed as a buffer.

Site four

The sampling region of site four was approximately 30 m in length and the average height of the streambank to thalweg was 4 m (Fig. 2). Grass was the only riparian vegetation within this reach. Across from this monitoring area was a large depositional gravel and sand bar (Fig. 2). Large woody debris collected on the gravel bar and created a debris jam within the stream. This combination diverted the shallow, turbulent flow towards the unprotected bank causing massive cutting and erosion. The bank was cut on a 90° angle and began to take the form of a broad 'U" shape. The stream emptied into a pool-backwater area at the end of the project reach, and then took a sharp left-hand turn to continue downstream towards site five. Site four was also utilized for pasture and hay crops.

Site five

This area was one of the most devastated areas on Crawford Branch. Site five was 15.2 m in length and 4 m in height (Fig. 2). At the upstream end of this project area, a large tree sloughed from the streambank and was lying across the entire width of Crawford Branch. The largest portion of the tree root ball was blocking the flow of the steam diverting flow straight into the un-vegetated streambank. Over a period of time, the flow cut the bank into a deep, broad "U" shape. The center of the U-shaped bank was cut approximately five to six m back from its origin (Fig.2).

At the end of site five, the flow took another sharp left-handed turn where it joined Carr Creek. Grass was the only vegetation in the riparian zone of site five. Crawford Branch and Carr Creek bordered two sides of the project area. This area was a primary concern for the landowner. The region was not only losing land at a tremendous rate, but the landowner also manicured and maintained the region for a public access picnic area.

In the mid 1990's, the landowner brought Crawford Branch area to the attention of both Natural Resources Conservation Service (NRCS) and Tennessee Department of Agriculture (TDA) personnel stationed within Robertson County, Tennessee. In conjunction with NRCS and TDA, an Environmental Protection Agency (EPA) –319 NPS grant was awarded to Austin Peay State University (APSU), Center for Field Biology for restoration implemented on Sulphur Fork Creek watershed. The grant funded development, design and construction of BMP's to improve the water quality within the watershed, and funded workshops to provide for public awareness. The landowner received program funding. Tennessee Department of Agriculture (TDA) cost-shared the entire project on a sixty percent reimbursement contract. A small portion of the grant funded construction materials for BMP's and covered a portion of the restoration labor costs. Streambank restoration and riparian zone remediations of Crawford Branch began in 1996.

SECTION 2: METHODS AND MATERIALS

Habitat Assessment

The first general assessment of Crawford Branch was strictly visual and made by one of the local landowners. Cattle within the pasture/feedlot and eventual remediation project area had free access from either side to the stream. The browsing and trampling of the riparian zone, within the project site created numerous large areas of bare ground. During wet seasons, the composition of the streambank and surrounding riparian area became extremely soft and erosive. The hoofing of the animals, duration of time spent within the riparian zone, and the amount of animal foot traffic played key roles in causing erosion as well as bacterial problems for the overall water quality of Crawford Branch and Sulphur Fork Creek Watershed.

Beginning in the mid 1990's, Governmental Cost-Share programs such as Environmental Quality Incentives Program (EQUIP) were developed to assist landowners in controlling NPS pollutants within 303(d) priority watersheds. The 303(d) list was structured by the State of Tennessee, and consisted of impaired streams due to excessive sediment. Sulphur Fork Creek and all its tributaries are on the 303(d) list.

Geomorphological Survey

Geomorphology is the study of surface forms of the earth and the processes that develop those forms (Federal Interagency Stream Restoration Working Group, 1998). For streams, there are three basic geomorphic processes involved with flowing water: 1) erosion, the detachment of soil particles, 2) sediment transport, the movement of detached soil particles by flowing water, and 3) sediment deposition, the settling of eroded soil particles to the bottom of a water body or left behind as water recedes.

Storm events (rain) and snowmelt wash soil particles into the waterbodies from adjacent plowed fields, construction sites, and various urban landscapes. Nutrients and toxic chemicals can attach to soil particles and be carried into surface waters where the pollutants can settle with the sediment or become dissolved in the water. Excessive sediment deposition can smother macroinvertebrates, eggs of fish, frogs, and other aquatic organisms. Sediment particles can also restrict the supply of oxygen to water by increasing turbidity and reducing transparency (Henderson, 1986).

The slope of a channel is defined as the stream's longitudinal profile, and is considered one of the most important factors to consider in designing stream restorations. Slope directly impacts the velocity, stream competence (largest particle that a stream can move under any given set of hydrologic conditions), and power. These attributes drive the processes of erosion, sediment transport, and deposition, which develop the channel shape and pattern (Henderson, 1989).

Crawford Branch, like most other streams within the Level IV Ecoregion 71e, the Pennryroyal Karst Plain (Arnwine and Denton, 2001), is defined a class "C" stream (Rosgen, 1996). The slope is less than 2%, with point bars, broad well - defined floodplains, and rifle-pool bed morphology. Riffles are formed where the stream bottom is higher in elevation relative to areas upstream or downstream. The deeper areas are defined as pools. At normal flow, stream velocity decreases within the pool regions. As a typical class "C", the riffle: pool ratio is located about every five to seven stream width at bankfull discharge. To further define this, take the average width of a given stream, multiply by 5 – 7, and that distinguishes the location of riffles.

Stream flow can vary from no flow, as seen in ephemeral or intermittent drains to flooding rivers. Two important aspects of flow to consider when restoring streams are duration and frequency. Duration is the probability that normal stream flow will be equaled or exceeded . Frequency is the probability that stream flow will be exceeded or not within a year. The primary influence of variable stream flows is on the biotic and abiotic processes that determine the structure and dynamics of stream ecosystems (Federal Interagency Stream Restoration Working Group, 1998). High flows are not only important for sediment transport, but also reconnect the channel with the adjacent floodplain.

In 1996, Crawford Branch was mapped at a scale of 1:2540 (Fig. 1) using a tape and Brunton compass technique between the downstream edge of New Cut Road Bridge and the confluence with Carr Creek (Smith, 2003). The entire area was also photographed and surveyed. A benchmarked channel cross section was surveyed in

1996, 1999, and 2003 (Fig. 3). Several reaches of the streambank were unstable, un-vegetated, with banks showing geomorphic signs of rapid retreat. This was evidenced by the presence of sediment aprons at the toe of the streambank. The loss of streambank was producing fine sediment in the waters of Crawford Branch and Carr Creek. The fine sediment was also present within the "interstices" of limestone and cherty gravel substrate, which likely lead to local reduction in the quantity and quality of benthic macroinvertebrates and their predators.

Sampling Sites and Dates

Streambank erosion usually begins at the toe of the stream. Erosive flows remove the unstable soil and stone creating undercut banks. As undercutting continues, the upper portion of the bank overhangs, and begins to topple over in a "wave" type action. Without the appropriate level of riparian vegetation (various depths and networks of root systems to hold the soil in place), the natural flow of water simply carries massive sections of soil downstream. The cost of lost agricultural, recreational, industrial, and commercial land, and the detrimental effects (to humans, and wildlife habitat) to water quality such as cleanup, and pollution prevention of excessive siltation from eroded banks runs into the millions of dollars per year (Kinsey, 1998). Exposed streambanks are also further eroded by overland flow, freeze-thaw action, laminar flow of ground water, and debris (log and ice jams) being carried by flooding waters.

In 1996, five reaches of Crawford Branch between New Cut Road Bridge and the confluence of Carr Creek were selected for various streambank and riparian buffer zone remediation projects. The entire stream section was mapped prior to remediations at a scale of 1:2540 using a tape and Brunton technique (Fig. 2). A benchmarked channel cross section was surveyed in 1996, 1999, and 2003 (Smith, 2003). During the survey, visual and photographic assessments were also made and referenced to aerial photographs, topographical maps, and soil surveys to determine land uses and develop a complete habitat assessment.

Research and remediation work was placed on hold during 1998 to 2001. In 2001, remediation work was reinstated. During the time off, site four was completely destroyed by flooding waters. Remediations to site four were made to satisfy the requirements of an Aquatic Biology and Water Quality Control class being taken at that time. Some general maintenance repairs were completed to the riparian buffer zone. After a one-year period, macroinvertebrates were sampled at site five and site one on 27 October 2002 and 1 November 2002 respectively.

Site One

The flow of Crawford Branch deflected off of a gravel bar located 20 m downstream of New Cut Road Bridge and dead-ended into the upstream end of site one. Without any riparian vegetation to hold the soil in place, several large scour holes developed in the streambank. From an offsite project, the landowner obtained several large sections of broken concrete. The concrete sections were "dumped" into the scour holes by the landowner in an attempt to stop the excessive bank erosion and retreat.

While the idea was with good intent, most of the flow continued around the sections of concrete increasing velocity, and creating eddies between the bank and concrete causing increased scouring.

The planned remediations of site one began during the first week of July 1997 and were as follows: use a backhoe to spread the concrete sections out to get them flat against the steambank and anchor them into the streambed (one-half of the bottom layer of stone should be below stream grade) (Thompson, et. al., 1994). This created a layer of protection for the toe and prevented additional scouring and under-cutting of the streambank. Also, the sections of concrete were situated to add protection to the streambank above the splash zone. This process mimicked a widely used method known as conventional bank armoring (Fig. 4). Bank armoring basically involves rip-rap stone that is usually greater than 30 cm- in diameter and 45 to 50 kg, or of sufficient size to prevent washing downstream (Thompson et. al., 1994). Larger stone should be placed at the lower elevation to ensure that the largest crevices are available for aquatic habitat.

The upper portion of streambank was sloped on a 2:1 ratio to alleviate the physical stress of the over-hanging bank. From the top of the concrete sections, 13 trees were transplanted on 09, July 1997. The decision was made to transplant the trees late in the year due to un-seasonable cool temperatures. In 1997, the average temperature for the month of June was 18° C (United States Department of Agriculture National Agricultural Statistics Service, 1997).

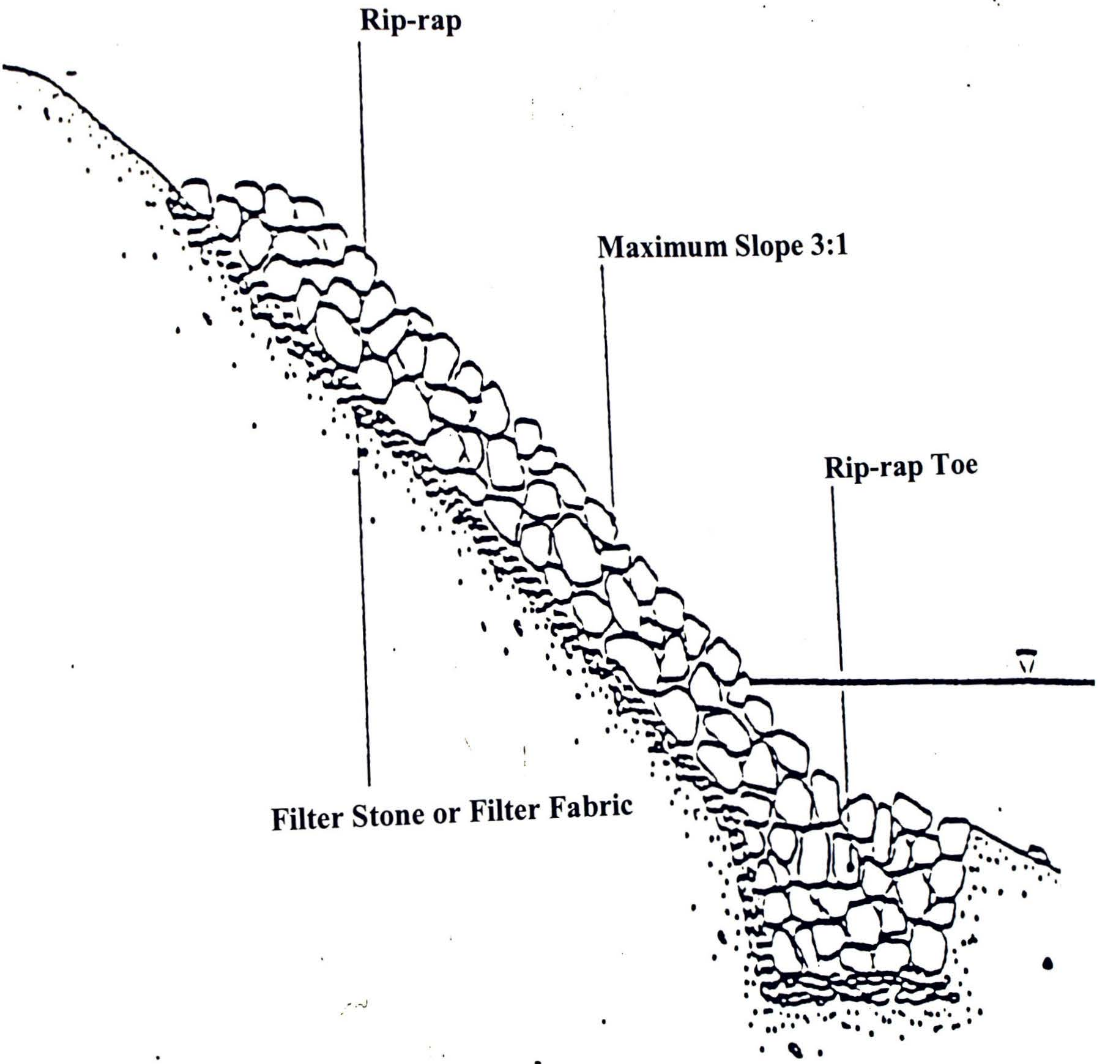

Fig. 4: Conventional streambank armoring and remediation

The transplanted trees consisted of *Salix nigra* (Black Willow), *Liriodendron tulipifera* (Yellow Poplar), *Aesculus* spp. (Buckeye), and other volunteer species were encouraged including *Plantanus occidentalis*_(Sycamore), *Acer negundo* (Box Elder), and *Populus deltodies* (Cottonwood) trees. Throughout site one project, grass seed was seeded to enhance the riparian buffer and cover the bare soil created when sloping the streambank. The grass buffer consisted of fescue, annual rye, and winter wheat. These three species of grass were chosen because all are cool season grasses, they germinate and grow quickly (provides quick cover on exposed soil), and they blended in with the surrounding vegetation used within the agricultural – hay field. Straw was then placed over the top of the seed for mulching purposes. Straw creates a mulch type layer that holds moisture, provides erosion control cover, and helps hold seed in place while germination and growth occurs.

During late fall 1997 to early spring 1998, the entire stretch of Crawford Branch and Carr Creek was planted with faculative wet or bottomland species of trees. The trees consisted of *Quercus spp.* (Cherry Bark, Shumard, and Willow Oaks), Yellow Poplar and *Cornus amomum* (Silky Dogwood). The trees were planted on the slope of the streambanks and within the adjacent hay field to "build" an appropriate riparian buffer zone.

With the riparian zone now consisting of trees, shrubs and grasses, the mixture added multiple depths of root systems that would hold the soil in place and provided shading and other variables to the aquatic systems and enhance wildlife habitat.

However, this iteration of tree plantings within the riparian areas of Crawford Branch and Carr Creek would only be one of many to come.

Site Two

Site two project area was 25 m in length and was located on the "opposite" bank of site one (Fig. 2). The area consisted of a well-developed riparian area, and bank sloping was not necessary. For the most part, the stream within this reach was a slow moving deep pool. However, the streambank was mostly gravel soil and became severely eroded from flooding and receding waters. The remediations of site two were as follows: at the upstream end of the project, a log deflector (Fig. 5) was constructed to deflect the erosive flow back towards the thalweg and away from the exposed bank (Fig. 2).

Small 1 m x 2 m *Juniper virginiana* (Red Cedar) trees were cut from adjacent farmland and used for revetment of the streambank toe (Fig. 6). Cedars were used for their dense foliage, resistance to decay, they were readily available and they are able to trap fine sediment. The cedar trees were anchored with rebar and 0.95 cm cable. The cable was attached to the trees and posts by "looping" it and using clamps to secure the cable.

The rebar was driven into the streambank with a post driver to "pull" the cable tight and secure the cedar trees to the toe of the bank to create the revetment (Thompson, et al., 1994). Other important tips when using cedar revetments include cutting live trees (for obvious reasons), the diameter of the tree's crown should be about 2/3 the height of the streambank, and the tallest and most compact trees that can be easily handled should be used. When placing the tree at the toe, the cut-off trunk faces upstream, and one study

(Thompson et al., 1994) suggested cutting off the truck as close to the bottom of the main foliage as possible to better overlap the trees (Fig. 6). The cedars also added habitat for fish and other aquatic organisms to an otherwise "sterile" area. Large (rip-rap) rock that averaged twelve inches in diameter was placed on top of the cedar revetment to further add protection for the 90°degree cut bank and provide additional wildlife habitat. Since the vegetation was already highly developed, no additional plantings were added to the riparian zone.

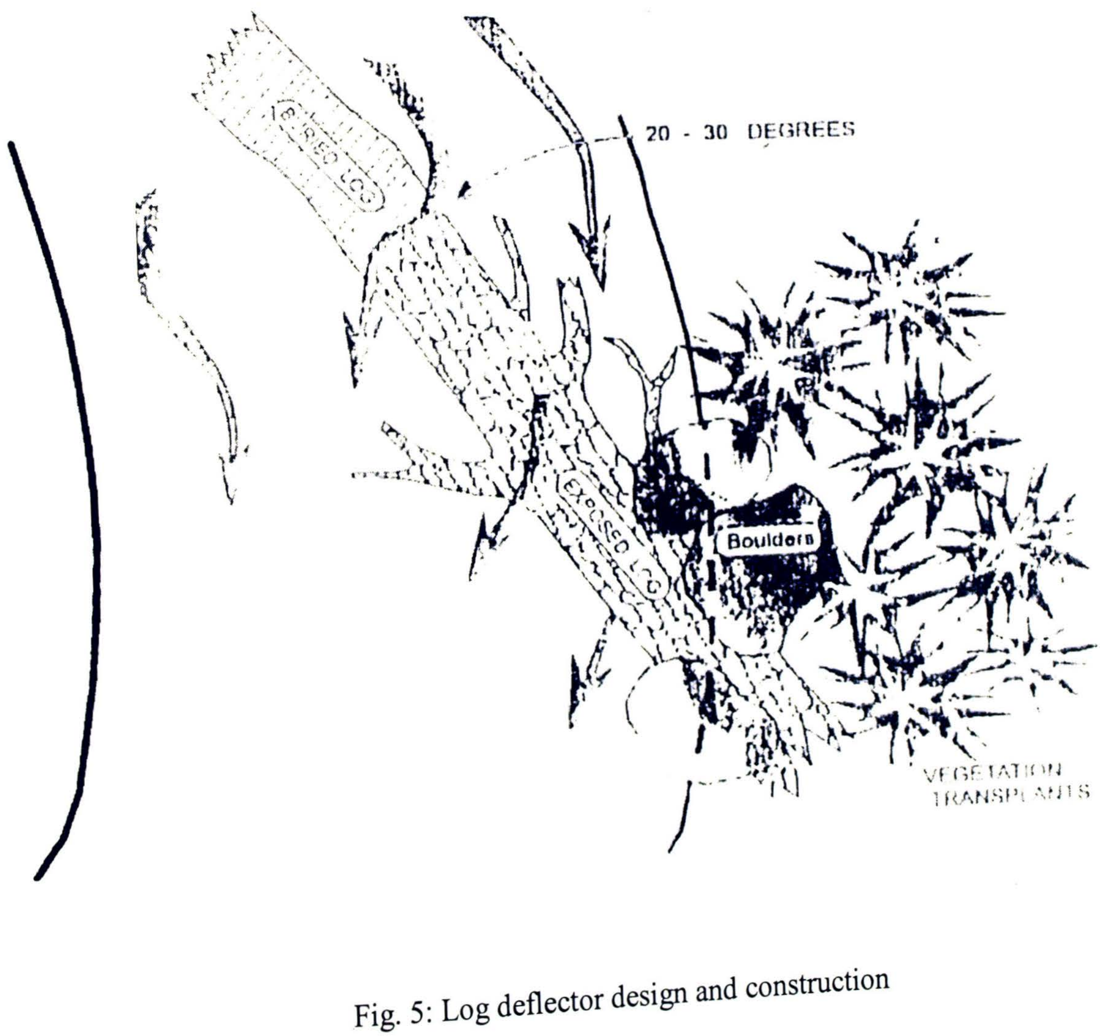

Fig. 5: Log deflector design and construction

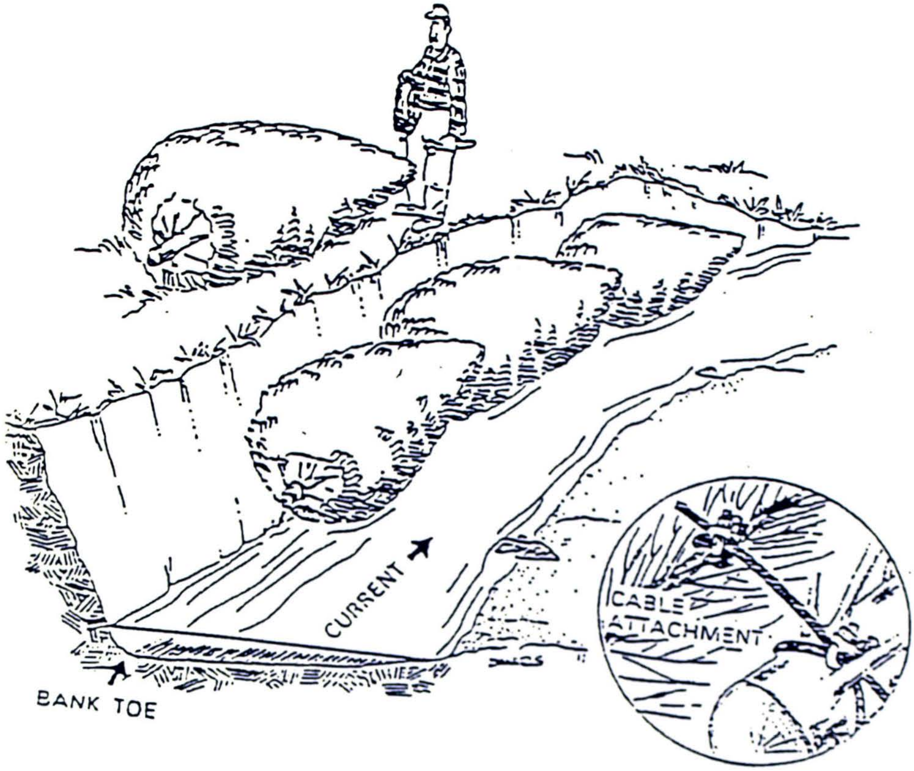

Fig. 6: Cedar tree revetment design and construction

Site Three

Site three project area was 25 m in length and was located on the same side as site one (Fig. 2). This area did not contain any trees or shrubs. Only grasses existed within the riparian buffer zone, and the root systems were not deep enough or "structured" well enough to hold the soil in place. The stream flow throughout the project area was straight, the water was shallow (average < 0.24 m), ninety percent (90%) all riffle, and the substrate was composed of small to large cobble.

Due to the lack of riparian vegetation, during flooding and normal flows, large blocks of soil would "slough off", or experience tractive (shear) stress. This type of stress varies with the function of stream flow and depth (Stream Restoration Corridor, 1998). As a result, the streambank was cut into a 90° degree angle, became fully exposed, and the soil loss created a slight "U" shape into the landowners property (Fig. 3). Remediations to site three consisted of placing geotextile fabric and large rip-rap at the toe of the bank. The upper portion of the bank was sloped to a 2:1 ratio.

The riparian buffer zone was planted with trees and grasses. Black Willow trees were cut into posts and planted interspersed with the rock and face of the streambank. Additional trees, Buckeye, Sycamore), and Yelow Poplar were also transplanted to this site on the 7 June 1997. Fescue, annual rye, and winter wheat were sown in the same manner and for the same function as for site one.

Site Four

The original plan for site four was to anchor the toe of the bank with large rip - rap and plant trees in the riparian zone to enhance root systems to hold the bank in place. During the years 1998-2001, site four was severely damaged from flooding and receding waters. Also, the landowner leased out the hay cutting rights to a local farmer. The riparian area was never established at site four, or any other site of Crawford Branch or Carr Creek due to the continual cutting of the area for hay. In 2001, site four was re-visited and damage was assessed to develop a new plan for remediation. At that time, the project area had eroded so severely, the streambank was in broad "U" shape and cut on a ninety (90°) degree angle from the stream to the top of the bank. All of the limestone rock originally placed at the toe was completely washed away. Again, no riparian vegetation existed meaning there was nothing available to hold the soil in place.

At the end of the project site, the landowner had a fence built to separate the existing feedlot – hay field from an established picnic area built along Crawford Branch and Carr Creek. The landowner was not only losing the aesthetics and money value of the property, but he was also losing the utility, money in materials and time in construction of the fence.

Remediations that took place in 2001 consisted of sloping the entire 38 m stretch of streambank, placing surface erosion control matting (Pyramat) at the toe, and anchor the mat with large rip-rap. The rock was also used to construct three deflectors (Fig. 1 and 7) or spurs to direct the water away from the streambank. The spurs were constructed to maintain the flow in the thalweg and further prevent undercutting of the bank. Facultative wet species of trees were planted to enhance the riparian zone. *Arundinaria gigantea* (River Cane) cuttings were planted near the rock toe into the stream and into a gravel bar on the opposite side of the project site. This enhanced root system network (River Cane spreads by rhizomes) to hold the soil, stabilize the toe of the bank, and to also add stability to the loose un-consolidated material of the gravel bar. Grass seeding was applied to enhance buffer zone BMP's

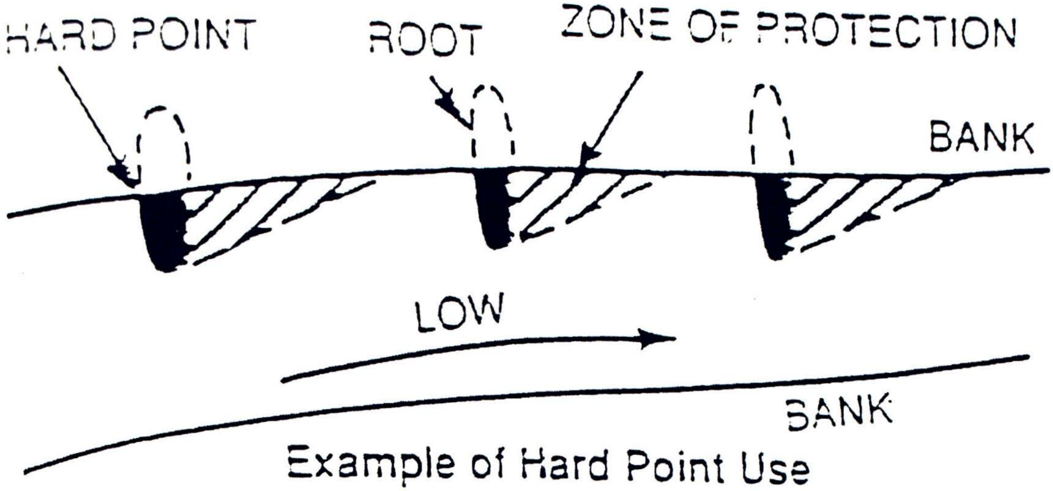

Fig. 7: In-stream deflector design and construction

Site Five

The site five project area is located within the picnic area that the landowner constructed. The original problem within this site was that a large. Buckeye tree washed out of the bank and fell across the stream (Fig.1). The tree diverted stream flow around the tree and root wad, and diverted the flow straight into the streambank. With the bank already compromised, the flow simply followed around the root wad and created a broad 15 m "U" shape in the bank.

Remediations to this site were as follows: geotextile fabric was placed at the bottom of the toe area. Large limestone rock was placed on top of the fabric. This was done to create a more solid bottom to hold fill dirt. The soil or spoil from sloping operations on Carr Creek moved to site five. The fill was dumped onto the rock and fabric mixture. Additional soil, rock and brush were added to "re-build" a native material streambank revetment (Fig. 8). Enough geotextile fabric was left at the toe region to "wrap" over the newly constructed toe, and provide a 3 m wide filter barrier between the rip-rap and streambank toe – stream interface. Limestone rock was then placed on top of the fabric to create a continuous had point for toe protection. Fascine bundles of River Cane were planted in rows from the top of the rock toe to the top of the streambank (Fig. 9).

Carr Creek

Two additional sites were restored on Carr Creek. These sites were remediated using the same design as those on Crawford Branch. These techniques will be compared to the site - specific designs used on Crawford Branch to determine what design is the most appropriate to be used in a wide range of areas.

Site one on Carr Creek was "pushed in" instead of sloped. The area had severely eroded and the landowner had expressed concern about "losing" more field soil. A bulldozer was used to push the top of the 90° cut bank towards the stream to develop a 2:1 sloped streambank. A trench was then shaped at the toe of the bank and rip-rap stone with an average diameter of 30 cm was placed for a continuous revetment. Various trees such as Cherry-bark and other species of oak, and tulip poplar were planted. Sycamore, Cottonwood, Black Willow and other trees, shrubs, and grasses have naturally colonized the area.

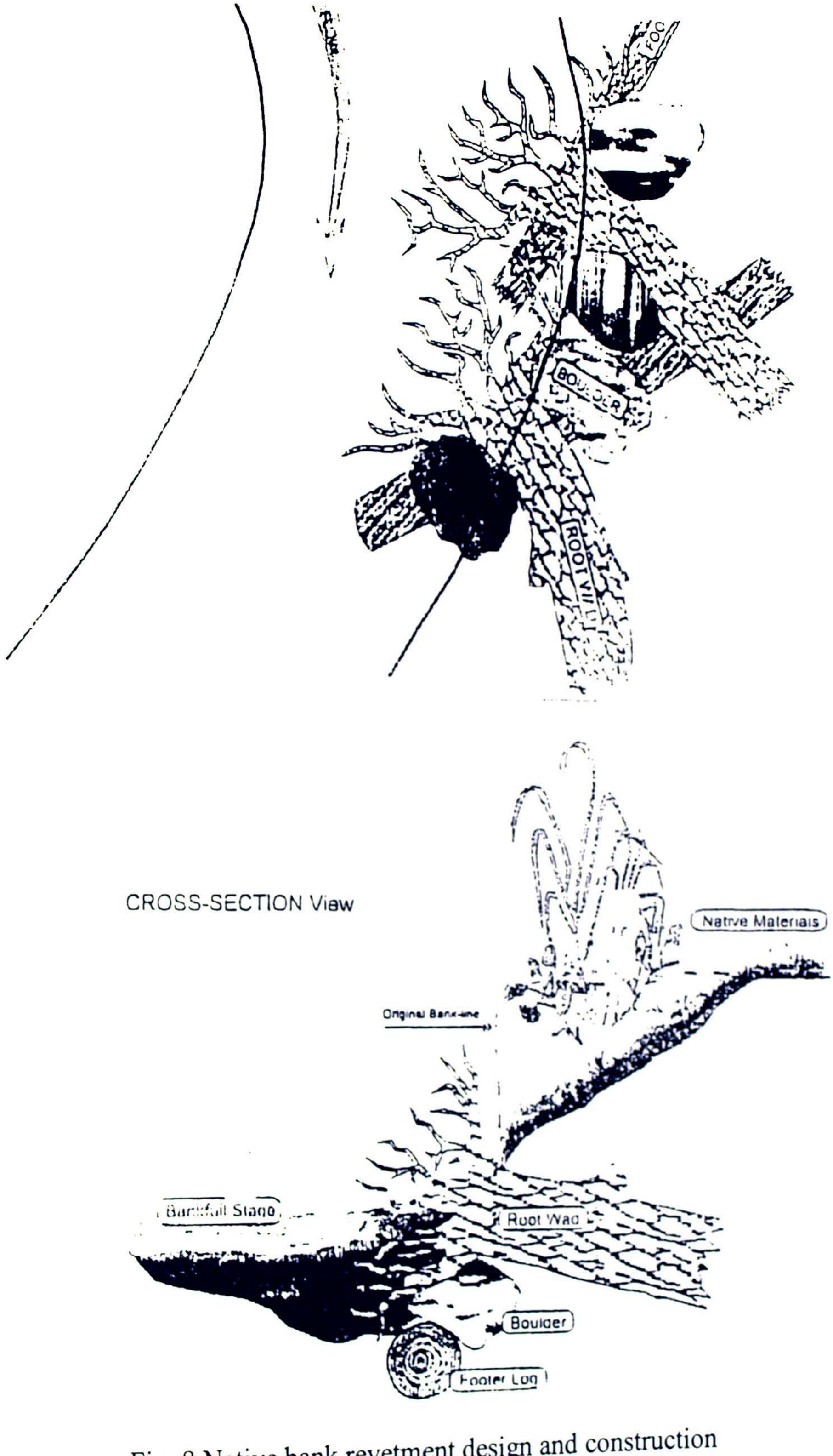

Fig. 8 Native bank revetment design and construction

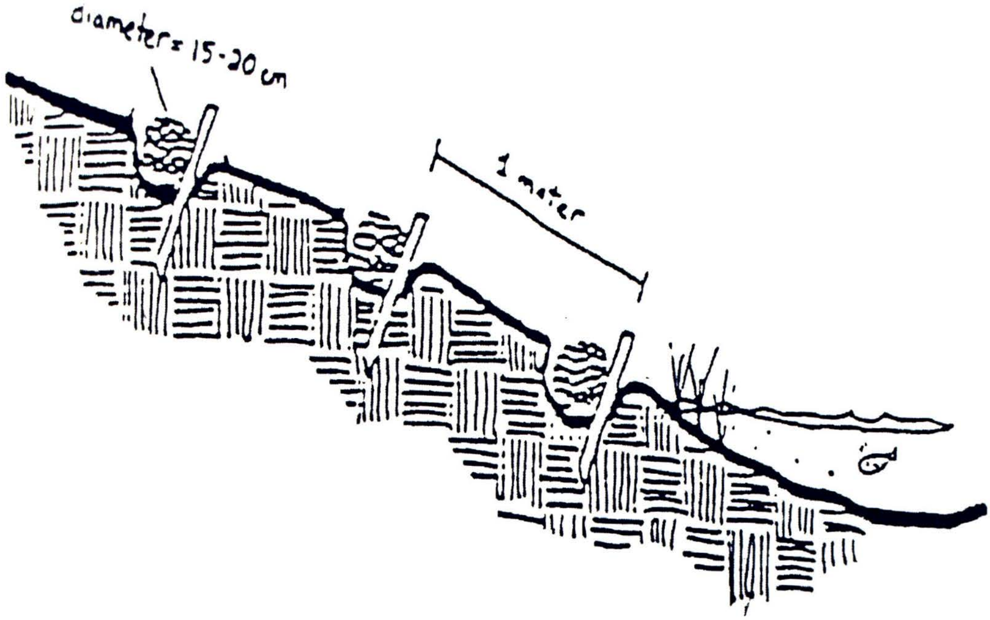

Fig. 9: Fascine bundle design and installation

As in sites three and four of Crawford Branch, site two of Carr Creek was sloped to a 2:1 ratio. Within the upper reach of this project site, a coconut fiber roll was used for toe stabilization and revetment. The fiber roll was 15.24 cm in diameter and 6 m in length. Rip-rap stone was placed along the length of the restoration area.

From the top of the revetments and up the slope of the streambank, a 4.6 m wide and 30.5 m length erosion control blanket was installed. The mat was straw based and weaved together by plastic netting. The erosion control mat was held in-place by 4.7 cm length wooden stakes. The stakes were placed in a diamond pattern. Trees and grasses were planted throughout the project site. Except for one different type of willow, Cork-

Screw Willow (*Salix matsudana*) the trees and grasses planted in site two consisted of the same species used in site one.

In all, 152.2 m of streambank on Crawford Branch and 154.2 m on Carr Creek were restored.

Benthic Macroinvertebrates

Two macroinvertebrate sampling sites were established within Crawford Branch. These were located at remediation sites one and five (Fig. 1). Site one stream reach (the upper reach) is 40 m in length and site five was 15 m.

Both project sites were sampled before and after streambank and riparian buffer zone remediation. Flags were placed on the opposite side of the bank to mark sampling sites so post-remediation samples would be taken from the same areas as pre-remediation samples. Initial samples were made on 17 April 1996. Post-remediation samples were completed on 1 November 1996.

Wildco trianglar-frame dip nets with 800 x 900 μm mesh openings (item # 425-K11, Wildlife Supply Company, Buffalo, New York) were used to sample riffles, pools, exposed root masses, and undercut banks. The dip net was the only sampler used for qualitative macroinvertebrate sampling and any bias due to sampler type would be applied equally to all samples and should not have affected the analysis.

The riffle sampling was conducted by standing upstream of the dip net opening, kicking the substrate to dislodge the aquatic organisms, and allowing the natural flow to carry the dislodged organisms into the net bag. Pool sampling was conducted by dragging the net upstream in a sweeping motion in areas that the substrate was limestone bedrock. In pool areas with small to large cobble, the net was swept upstream as the substrate was disturbed to dislodge the macroinvertebrates. Over-hanging root masses and undercut banks were sampled by jabbing the net into and back-scrapping the net underneath to dislodge and capture the aquatic organisms.

After collecting the macroinvertebrates, all samples were emptied into a collection pan. All visible organisms were removed, placed in a one-liter jar, and preserved with 80% isopropyl alcohol. In the laboratory, the macroinvertebrates were separated from any remaining sediment or foreign material by using zoom stereomicroscope with 7-45 X magnification.

Most of the aquatic insects were identified to the genus level, while other macroinvertebrates were identified to lowest practical taxon. Chironomids were identified to subfamily only. Merritt and Cummins (1996) was the primary taxonomic reference for aquatic insect identification. Pennak (1989) was used to identify other macroinvertebrate taxa.

The macroinvertebrates were evaluated using three metrics: (1) total taxa richness, (2) taxa richness of Ephemeroptera, Plecoptera and Trichoptera (EPT), and (3) the ratio of EPT to EPT + Chironomidae. These parameters are those recommended for qualitative sampling of streams within the Tennessee Valley (Karr and Chu 1999).

Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies) are the three orders of aquatic insects that have the most pollution sensitive organisms (Lenat, 1993). Richness of EPT is the total number of mayfly, stonefly and caddisfly taxa collected per sample. Low richness of EPT indicates poorer water quality and higher EPT richness indicates good water quality.

Most Dipterans, especially chironomids (midge larvae) can tolerate poorer water conditions (Lenat, 1993). The EPT to EPT + Chironomid richness ratio may also be used to determine levels of water pollution. A high richness of pollution-sensitive taxa (EPT) to a low richness of pollution tolerant chironomids is another indication of good water quality. The inverse would indicate poor water quality (Karr and Chu, 1999).

Statistical Analysis

A qualitative sampling method was used in collecting macroinvertebrates from sites one and five. Only one set of samples was collected during each sampling period, and therefore statistical analyses of the results are not possible. The macroinvertebrate sampling results will be used as a descriptive survey to compare before and after remediation to determine if the habitat restorations and erosion control methods may have improved water quality.

SECTION 3

RESULTS AND DISCUSSION

Geomorphological Survey

Stream channels and their floodplains are constantly changing due to the water and sediment input supplied by the watershed (Darby et. al., 1996). Remediations to degraded streams require an understanding of watershed history, including natural events, adjacent land use practices, and other processes active in the watershed.

Many years of overuse and misuse of streams and riparian buffer systems have resulted in thousands of tons of soil loss (Thompson et al., 1994). Whether streambank erosion is natural or manmade, the first step is to understand stream dynamics and the causes for the site-specific problem. The problem may be as simple as not enough riparian vegetation to hold the soil in place, or it may be more complex due to changes within the watershed through human intervention.

Crawford Branch in Robertson County, Tennessee was listed by the State of Tennessee as being impaired due to excess sediment. In 1996, a physical assessment was initiated. The monitoring program was developed to determine the significance of streambank erosion as a sediment source. The stream was mapped, photographed, and surveyed.

Remediation Sites

Site One

The sections of concrete have remained in-place throughout the duration of the project. There has been no evidence of scour at the toe, on the slope of the streambank, or loss of any riparian buffer composition. This is largely due to the re-direction of erosive flow by the concrete (Fig. 10). The rough texture of the concrete has absorbed some of the energy from the stream and decreased its velocity at the bank. The concrete has acted as a rip-rap revetment and sediment has been deposited within the interstices. These areas have been colonized with Black Willow, Cottonwood, Sycamore, and various herbaceous plants and grasses. The revetment has also created niches for fish cover and breeding, extensive habitat for benthic macroinvertebrates and other aquatic organisms.

The concrete revetment was inexpensive since the landowner already had it on site. The only expense was the hourly cost of the backhoe to move and place the concrete. With the cost of the backhoe spread throughout the entire stream restoration, the cost for this one area was minimal. Since the project began, this area has been converted to a hay field. The grasses have done well however, this may have enticed the farmer to maximize the hay cutting. Through haying operations, there has been a continuous loss of the riparian zone. The riparian area has been planted with trees five different times from 1996 to 2002. After each planting, the trees have been completely destroyed by haying operations on Crawford Branch, and within two areas of Carr Creek a 26 m wide strip was cut over the top and down the slope of the streambank. This creates further difficulty when using rip-rap for in-stream remediation. Rock absorbs solar radiation and can increase stream temperatures, especially in un-shaded areas (Thompson et al., 1994). Increased temperature can negatively or positively affect the life cycles, tolerance ranges, or feeding and breeding habitats of aquatic and terrestrial organisms. However, the streambank slope of site one faces an easterly direction. Most of the mid to late afternoon sunlight is shaded out by the riparian zone on the opposite bank.

Site Two

This site contained the log deflector at the upper-most project area. A combination of cedar trees and rip-rap revetment was used for toe stabilization downstream of the deflector. Deflectors are one of the most common used methods of habitat restoration and streambank stabilization. They can be relatively inexpensive, modified for each location, and built from natural and local materials (Thompson et al., 1994). The hydrologic benefits from deflectors include: the formation of scour pools, shelter pools, and increases riffle-pool sequences. Studies have shown that fish production has doubled through the use of deflectors (Thompson et al., 1994). The deflector in site two has not only diverted thalweg away from the bank, but has created 0.5 m wide gravel bars that extend back upstream the full length of the left bank of site one (Fig. 7). Also, the deflector placement has resulted in development of a 1.5 m gravel bar along the opposite bank of site two that extends almost to site three (Fig. 10). This is slowly creating a more sinuous flow and increasing the residence time, velocities and depths of the channel reach.

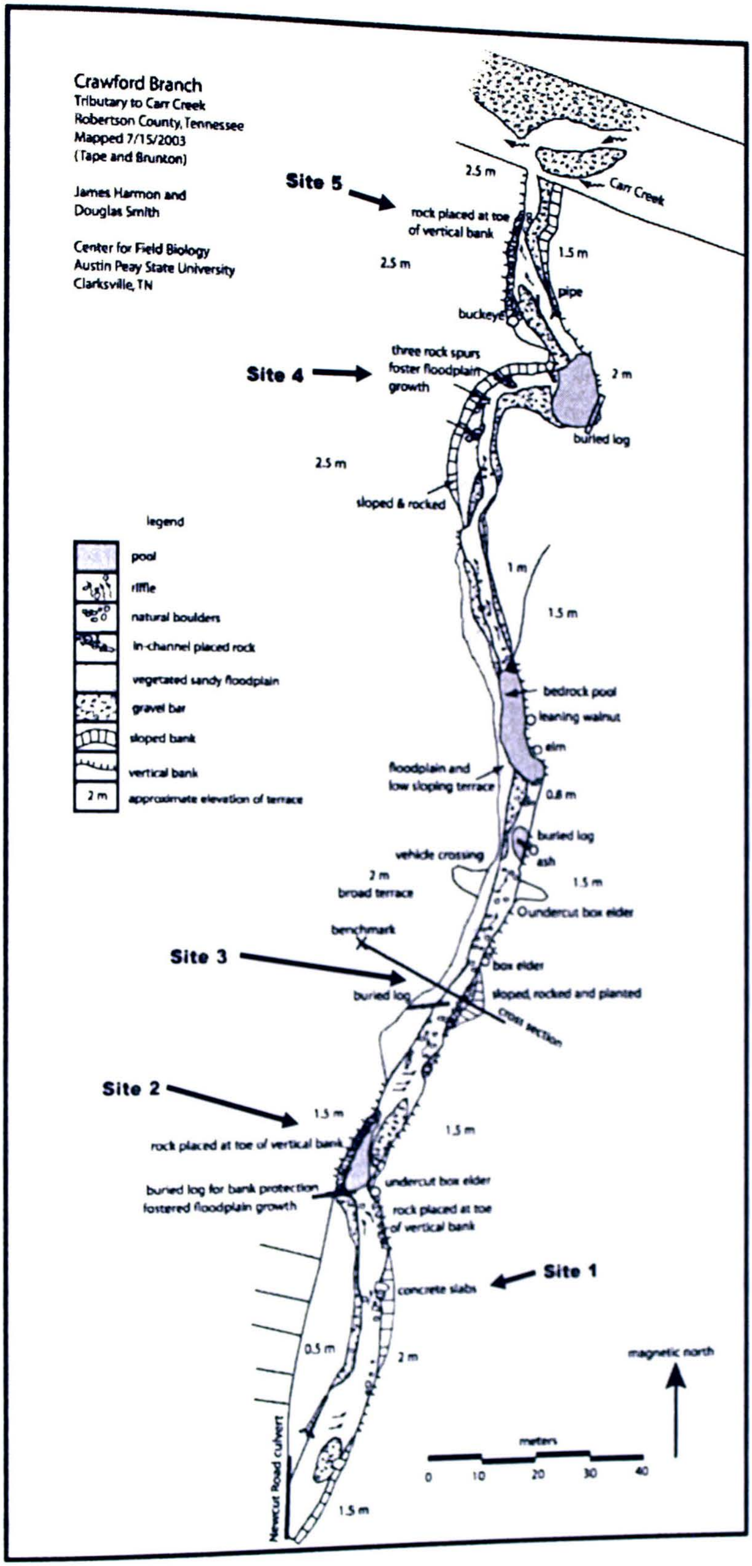

Fig. 10: The 2003 Brunton compass and tape survey of Crawford Branch.

A Red Cedar and rip-rap toe revetment was used at site two. Cedar trees are dense, contain more limbs than hardwood species, have good resistance to decay, and reduced flow to trap fine sediment. This type of revetment is commonly used on other streambank restoration projects (Thompson et al., 1994). In my experience, if cedar revetments are used in areas with full sun, the cut end must be fully submerged. If not the life expectancy and utility of trapping slit greatly decreases.

The cedars in site two were completely submerged and in deep shade. I am speculating that these two elements added to their resistance to decay. The water within this reach was a slow flowing deep pool. The substrate was made up of medium to large boulders and impacted with sediment. Before placement of the cedar and rock revetment, the area lacked good aquatic habitat. The various depths of limbs and branches added cover and substrate for minnows and other aquatic organisms. Rip-rap (limestone) rock with an average diameter of 30 cm was added to aid in "pinning" down the cedars and to add additional habitat. Throughout the years, there has been no loss of rock, and the composition of the cedars lasted over three years.

During the original restoration process, cedars were held into place by 0.95 cm rebar and cable. The rebar was driven flush into the top of the streambank. The only loss of sediment that has occurred within site two has been above the cedar-rock revetment. This is evident by the protruding rebar that was used in anchoring the cedar revetment in place. Flooding and receding waters have continued to strip soil and rock from this area. The riparian area within the site was dense and well developed. The cost of equipment, materials, and destruction of the existing riparian buffer zone greatly out weighed the small eroding area. This area could be treated by conventional means, which would include stacking rip-rap on the streambank until the entire area is covered.

Site Three

A benchmarked cross sectional survey was completed in 1996, 1999 and 2003 for site three (Fig. 11). In 1996, the streambank was actively retreating as evidenced by the fine sediment present within the interstices of the substrate and at the toe of the slope. Large blocks of soil were lost through shear stress and erosive flow undercutting the bank. The excessive input of sediment was likely leading to the reduction of benthic macroinvertebrates and their predators (Smith, 2003). The rip- rap toe has stopped the undercutting of the streambank, and lead to some scouring of the substrate. The thalweg is now 0.24 m deeper than that of 1996 (Fig. 10). By comparing Fig. 2, 9, and 10, the surveys show that the rock toe has stabilized the bank, with no net loss since 1999. The surveys also show a significant change within the cross section of site three.

The diverted flow has removed a gravel bar located within an incipient floodplain on the right side of the stream channel. The bank treatment has resulted in a straighter thalweg and volume reduction of the gravel bar (Smith, 2003). All seventeen transplanted trees within the riparian area have survived. The seeds of trees and herbaceous plants have germinated in the interstices of the rock and have further developed the riparian buffer zone. The additional vegetation includes trees such as cottonwoods, sycamores, box elders, and black willows. In addition, a variety of herbaceous plants have mixed in with the seeded grasses.

Fescue and other grasses have developed into a solid ground cover that extends from the existing hay land to the rip- rap revetment. The thick mat of grass has aided in trapping fine sediment in high erosive in-stream and overland flows. Throughout the years, the riparian zone of Crawford Branch and Carr Creek has been planted five different times. This was done to extend the buffer zone, increase the trapping and removal of sediment and nutrients, add wildlife habitat, shading for the stream, and create a mixture of un-even aged trees, shrubs.

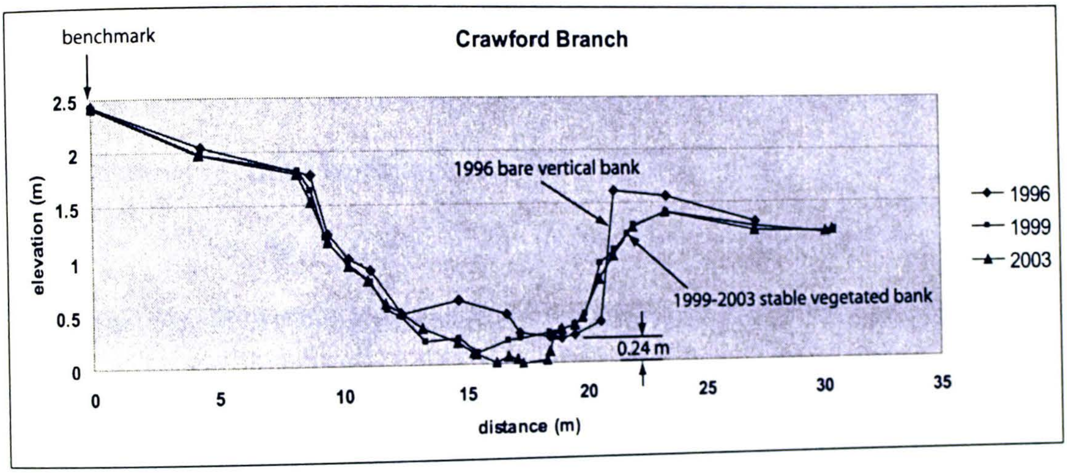

Fig. 11: The 1996-2003 Cross-sectional surveys of site three, Crawford Branch

A persistent problem is that the landowner is renting the land to a local farmer. That person is cutting the field for hay, and in doing so he is maximizing the field by cutting the riparian zone to the top edge of the streambank. The hay cutting has eliminated every tree planted in the buffer zone. The solution may be to fence the riparian area completely off the hay field. Fencing will eliminate the cutting of the riparian zone during haying operations. This will allow the vegetation to mature and develop, and increase the functions of: absorbing excess nutrients, trapping sediment and providing wildlife habitat. From past experiences, the fence needs to be placed within the five- year flood zone at a minimum. This will reduce damage from flooding waters and maintenance cost for repairs.

The geotextile used within this site added to the composition and the overall stability of the streambank. However, the site one area is just as stable as site three, but by not using geotextile or rip-rap, overall cost for site one was much cheaper than site three. Through the success of the restoration efforts, this site can easily be used for workshops and classes to raise public awareness and develop a better understanding for the importance of riparian buffer zones and water quality.

Site Four

This area received more damage and required more restoration than any other site on Crawford Branch. During the initial stages of remediation, the streambank was not sloped to relieve the stress of the overhanging bank. Rip- rap was placed at the toe, but was not 100% secured (i.e. there was no trenching or "tying in" of the rock on either end of the project site). The reason for this action was the landowner expressed the concern of "losing" more land to 2:1 sloping activities, a typical streambank restoration activity.

The rock was placed to act as a deflector and re-direct the thalweg back across a gravel bar located adjacent to site four (Fig. 2 and 10). A large percentage of the gravel bar's composition was loose, un-consolidated material (gravel, and some large sycamore trees). In other situations, such as site three, the rock deflector should increase the velocity of the water and erode the unconsolidated material. This action should also increase the depth, widen the channel, and prevent further erosion of the streambank. However, this did not happen. The gravel bar was higher in elevation, and deflected normal and flooding water flow towards site four. The erosive flow washed the rock downstream and severely scoured the unprotected bank. This site was completely left untended during 1998 to 2001. Restoration efforts were diverted to other project in the Sulphur Fork Creek watershed.

In 2001, research and restorations efforts in Crawford Branch were reinstated. After several years of erosion, site four became a 91 m U-shaped bank and took on the same appearance and form as site five had before restoration (see Fig. 2, site five – before remediation). Restructuring of site four included sloping the streambank on a 2:1 ratio, digging a trench or "trough" at the toe, and placing a geoweb type material called Pyramat in the trench and approximately 1.5 m up the slope. The mat was pinned to the slope using 15 cm long metal stakes. Limestone rock was placed in the trench for toe protection and up the slope enough to cover the mat.

From the top of the stone to 10 m out past the top of the streambank, grasses were seeded or trees were planted. River cane shoots were planted within the interstices of the stone revetment and in the adjacent gravel bar. Within weeks, the stone revetment had trapped enough fine sediment that the toe of the streambank is now extended into the stream an average of 1 m.

After several weeks, the project site experienced some mild flooding. The slope of the streambank above the revetment received some mild scouring. The Pyramat was exposed and roughly 2 m was "rolled" over in one area. However, the area that received the most damage was the downstream-most end of site four. Through sloping-remediation activities, the shape of the streambank still directs normal flow through a series of sharp turns (Fig. 9). A backwater pool has formed and created a habitat niche for aquatic organisms. During high flow, the thalweg dead-ends into the streambank. Shifting of the stone revetment has occurred. Once water receded from the first flood, three stone spurs or deflectors were constructed to divert flow away from the bank (Fig. 9). I speculate that the stablization of the gravel bar by large vegetation with well-established root systems is still too great to erode. The deflectors may divert flow and protect the toe, but the gravel bar may not "give" and cause entrenching of the stream through this region.

The riparian zone was planted with various oaks, silky dogwood, and tulip poplar. Also through natural habitation, several trees such as cottonwood, sycamore, box elder, and other herbaceous plants developed throughout the area. The trees within the riparian zone have been damaged by hay cutting operations.

Since remediation work was completed in 2001, monitoring of site four has continued and was completed by undergraduate students working with the Austin Peay State University, Center for Field Biology. Upon review of their work schedules, it has been determined that several tons of rock have been used within the revetment to replace what has been washed out by fluctuating stream flows. The vegetative cover on the slope of the streambank needs more attention. The river cane planted at the toe and within the revetment is doing well, but more trees with various root systems need to be added to "hold" and maintain the composition of the area.

Site Five

Site five is another major success story. The fascine bundles of river cane have sprouted, spread by rhizome, covered the streambank, and held it in place (Fig. 9). The streambank has compacted well. The area was rebuilt with excess soil from sloping activities on Carr Creek. The bank has not been compromised in any way (no shear stress). There has been no movement or net loss in the rock toe revetment. Additional trees such as buckeye, box elder, sycamore, and cottonwood have taken root and are growing well throughout the area. Various oaks, tulip poplars, and silky dogwoods were planted to increase diversity and "re-build" the riparian zone.

One major problem does exist within site five. This area is still being used as a picnic area and all trees planted within the riparian buffer have been damaged due to hay cutting practices. The landowner had also compounded the issue by "grooming" the area for picnicking. Other than possibly fencing the area off and advising the landowner of these problems will persist.

Another reason for the reduction in erosion to all sites of Crawford Branch and Carr Creek is the fact that the landowner has eliminated the cattle within the hay land

Carr Creek

Carr Creek remediations were all a complete success. The rip-rap toe revetment in both sites collected sediment and vegetation seeds that germinated and added to the diversity of the riparian zone. The uppermost portion of this reach, the rip-rap toe revetment has trapped enough sediment to develop a 3 m (average) wide incipient floodplain. The rip-rap is only in contact with the stream during periods of elevated flow. The coir fiber roll within the lower portion also trapped sediment. The roll was originally 15 cm in diameter and 6 m in length. Currently, the roll is completely covered over by sediment. Advantages of using the fiber roll instead of rip-rap are: they are a form of "soft" armoring, they can be more aesthetically pleasing, vegetation can be planted directly into them, they are easy for one individual to use, or they do not require heavy to install, and humans and wildlife can maneuver over them with more ease. Disadvantages of the coir fiber rolls include: they do cover as much area (width or length) as rip-rap, the rolls have to be staked down and ease of this task will be dependent on depth to bedrock, and the cost of one roll in 1996 three hundred dollars. This cost was equal to, if not more than, the cost of one load (twenty-four tons) of rip-rap delivered on-site. Plus the rip-rap supplied three times the coverage in length, and at a minimum of twice the coverage in width. The user-friendly portion of the coir fiber rolls significantly out competes the rip-rap. However, the cost to purchase the same amount of coir fiber rolls it would take to get the coverage supplied by the rip-rap would be astronomical. Also, the heavy equipment is already on-site for streambank sloping and re-contouring operations. If the equipment operator can place the rip-rap toe revetment as they are working on sloping operations (Slope, place, and slowly move down the project area), this will greatly reduce the overall cost of using stone for stabilization.

Other product comparisons that should be made include the Pyramat, geotextile fabric, and straw based surface erosion control mat. The Pyramat is made of plastic and contains slots in which grass and other vegetation can grow. This product was used at site four alone and donated to the research by APSU. Therefore no cost has been estimated however, it is more expensive than geotextile, there is less material per roll than geotextile, and the material is harder to work with. Both the Pyramat and geotextile requires metal stakes that increases the cost, and both are structurally permanent which decreases aesthetics and reduces the term bioengineering (use of "natural" products).

A surface erosion control mat was used on the lower portion of Carr Creek. This product was also donated and not include in the cost analysis. Plastic netting holds the straw and the mat together. However, the netting is biodegradable. Also, the plastic netting holds the straw in place on severe slopes and provides even ground coverage. This is a better option than loose straw that can wash away during weather events. The mat requires less labor than straw. Straw requires hauling, cutting the strings and hand placing. Some disadvantages of the plastic netting are: it is more expensive than bales of straw, in 1997 one roll was thirty six dollars, and small mammals, reptiles, and other wildlife can become entangled in the netting.

Macroinvertebrates

Macroinvertebrates samples were collected at remediation sites one and five before and after habitat remediation. The following metrics (Table 1) were derived from the raw macroinvertebrate data (Appendix Tables A1-4).

Table 1: Summary of metric generated for macroinvertebrate samples. April 17, 1996 samples were collected before remediations of Crawford Branch. November 1, 1996 samples represent samples collected after remediations. Samples were collected on September 14 and October 27 2002 following repair of site four.

	17 Apr 1996		1 Nov 1996		14 Sep & 27 Oct 2002	
	Site one	Site two	Site one	Site two	Site one	Site two
Total taxa	21	15	24	25	30	24
EPT richness	11	5	9	11	14	8

Total taxa remained steady or increased since restorations. The target index scores for taxa richness in Bioregion 71e range from "excellent" (taxa richness > 23), "good" (16-23), "fair" (8-15), and "poor" (< 8) (Arnwine and Denton, 2001). Before habitat restoration, sites one and five rated "good" and "fair," with scores of 21 and 15, respectfully. After restorations in 1996, site one and five increased to an "excellent" rating. For both collection periods that took place in 2002, (after repair work to site four) the taxa richness has steadily increased and remained within the excellent rating. For

EPT richness, the target index scores within bioregion 71e are greater than 7 is "excellent," 5-7 is "good," 3-4 is "fair," and less than 3 is "poor." Before remediations, site one has a score of 11, which ranks it as "excellent." Site five has a score of 5, which is rates it as "good." After remediations, site one has a rating of 9 and therefore maintained an "excellent" rating. Site five has increased to 11, which is "excellent." After site four remediations in 2002, sites one and five had EPT richness scores of 14 and 8, respectfully. Both sites remained in the "excellent" rating.

COST ESTIMATES

The original construction work on the five Crawford Branch sites and the two sites on Carr Creek totaled $4,344.61 dollars. Table 2 summarizes project cost. Appendix tables A4 – A5 provide total project costs. The coir fiber roll was donated in the interest of product analysis, and therefore was not include in the overall project cost.

Table 2: Summary of project costs for Crawford Branch and Carr Creek, 1997 and 2001. The 2004 cost are estimates for remediation. Amounts are in U.S. dollars.

Summary of remediation cost: Crawford Branch 152.2 m and Carr Creek 154.2 m 1997 and 2001						
Dates	Bulldozer/hr.	Dump truck/hr.	Backhoe/hr.	Rip-rap	Labor/hr.	$/linear m
1997	55	45	45	1,009.16	9	28
2001*	65	35	65	639.62	Student	33
2004	75-80 est.	45	70	743.68	Student	38

* Two different companies worked on Crawford Branch between 1997 & 2001. The 2004 estimate is from the company used in 2001.

This total cost includes a backhoe for sloping operations, a bulldozer for land smoothing and streambank shaping (site one Carr Creek was "pushed in" to achieve 2:1), dump truck to haul excess soil from sloping operations to site five Crawford Branch to "fill in" the area and re-construct the streambank, another dump truck was used by an independent truck driver to deliver the rip-rap stone, and labor costs. The total amount of streambank restored on Crawford Branch was 152.2 m, and 154.2 m for Carr Creek, respectfully. Since the project areas are almost identical in length, it is estimated that each site cost approximately $2,172.31 dollars. Taking the total cost of the projects, and dividing by the total lengths, it is estimated to cost roughly $28 per linear meter to restore the streambanks.

As a cost comparison, 2001 remediations and repairs to 91 m of Crawford Branch at site four was a total of $3,037. This was roughly $33.40 per linear meter. The difference in costs is $864.06, and for a total of 63 m less streambank restored. The cost includes a backhoe, dump truck, one operator, and construction materials (rock, etc.). As in 1996-97, and all hand labor activities was provided by APSU students. However, in 2001, the restorations to site four were done so to satisfy the requirements for an Aquatic Biology and Water Quality Control Class project. All heavy equipment work was contracted and all hand labor activities was provided by APSU students.

Services of all types typically increase yearly. Through phone calls and some research, the following increase has been determined. Today's cost is estimated to be

$38 per linear meter or a total of $3,463. Since 1996, cost of remediation has increased by approximately $10 dollars per linear meter.

Crawford Branch and Carr Creek remediations involved about 154 linear meters each. At today's prices of $38 per linear meter, to re-construction the same areas would cost $11,704. The difference in cost for 1996 restorations and those in 2001 is at a minimum of $7,360 (approximately 60% increase).

SECTION 4

CONCLUSIONS

By all geomorphological surveys, the remediation sites have remained stable since construction in 1996 (Fig. 11). To appropriately design a streambank restoration project, habitat assessments should be completed. This will aid in determining the exact problem or problems in a given area.

Coir fiber rolls are an effective way to "naturally" stabilize the toe regions of streambanks. This technique is better known as "soft" armoring. However, the cost of the fiber rolls in 1996 was three hundred dollars. This was for a 2.36 cm diameter by 6 m long section. In 1996, the cost of one tri-axle dump truck load of rip-rap (about 24 tons) plus delivery charges was a little over \$200. Using stone saves at a minimum of one \$100 and stone will cover three times the linear distance of a fiber roll.

Cedar trees are also effective "natural" toe revetments. However, there use is limited to areas with abundant riparian vegetation. A combination of both shade and being submerged I believe, prevents the trees from drying out. The longer the cedar needles remain pliable, the more they can trap sediment and provide aquatic habitat.

Rip-rap is a hard armoring technique that is frequently used in restoration projects. Many dislike the usage due to the aesthetic problems. However, the stone creates a continuous deflector, and maintains the stream flow within the thalweg. The stone prevents further incising of the banks by erosive flow and traps sediment and seeds of local vegetation. Vegetation can grow through the crevices to further stabilize the streambank. A disadvantage of using rip-rap is the costs that include purchase and hauling stone, and hiring equipment to put it in place.

The riparian vegetation plantings used should be native to the area. Native species are easy to establish from seed, transplant, or propagate from cuttings. Care must be taken when using obligate wet species. The roots of these species must be able to reach the water table. For Crawford Branch, the riparian plantings occurred during five intervals. All riparian plantings were destroyed through hay cutting operations. For a riparian area to be truly successful trees, shrubs and grasses are needed to create a network of root systems for soil stabilization. As the vegetation matures and dies, various aged saplings, shrubs and grasses are needed to provide successional growth to maintain the stability of the area.

Qualitative sampling for macroinvertebrates, the correct methods and protocols must be followed and all appropriate metrics applied. Data from one or two metrics can be misleading. It is common for one metric to change in response to impact while others remain unchanged. If only one metric is used (e.g., % EPT), the stream may be assessed as improved when it actually had elevated organic enrichment (Arwine and Denton, 2001). Only by using all appropriate metrics can a clear picture of the benthic community be achieved. In this case, a more rigorous macroinvertebrate sampling design may have resulted in a more reliable and statistically testable set of data. Nonetheless, the data collected for this study suggest that the stream remediations employed in Crawford Branch resulted in improvements of the macroinvertebrate community.

Throughout the years the cost for remediation has risen sharply. This is the major reason that restorations must begin with habitat assessments. An assessment must include the feasibility of the project. The obvious questions are: what, when, where, and how. Another important aspect is public awareness. Without workshops, classes, seminars, or field tours, the average person may never realize how much they can directly impact the streams, watersheds or the environment in general. By elevating public awareness, the need increases, and therefore the availability for cost-share programs increase. There are a few programs available through the federal, state or local watershed groups. Still, the bottom line is that streambank restoration is too expensive for most landowners to fund. Without monetary assistance, the average landowner will not tackle this type of project and deterioration of water quality will continue.

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APPENDIX

Raw data of macroinvertebrate communities sampled in Crawford Branch,

Robertson County, Tennessee 17 April and 1 November 1966

and 14 September and 27 October 2002

Table A1-A3: Summary of taxa found at each site during Spring and Fall seasons 1996 in Crawford Branch, Robertson County, Tennessee. Taxa summaries are also representative of before and after habitat restorations. Site 1 and 2 macroinvertebrate collection are equal to site 1 and site 5 habitat restoration areas.

Table A1

Crawford Before 17-Apr-96	Site 1	Site 2	Total
ODONATA			
Calopteryx	2	8	10
Argia	1		1
CRUSTACEA			
Lirceus	3	1	4
EPHEMEROPTERA			
Eurylophella	10	1	11
Caenis	9	6	15
Ephemerella	1		1
Isonychia	43	1	44
Stenonema	37		37
PLECOPTERA			
Amphinemoura	15	4	19
Beloneuria	1		1
MEGALOPTERA			
Corydalus		6	6
HEMIPTERA			
Microvelia	1	1	2
COLEOPTERA			
Psephenus		6	6
Stenelmis	1		1
Ancyronx		1	1
Cymbiodyta		1	1

Table A1: continued

TRICHOPTERA			
Ceratopsyche	1		1
Cheumatopsyche	3	3	6
Chimarra	8		8
Hydropsyche	3		3
DIPTERA			
Simulium	3	2	5
Tabanus	1		1
Chironomidae			
Orthocladinae	27	14	41
Tanypodinae	9	2	11
Chironominae	9		9
Pupae	2		2
Total Individuals	190	57	**247**
Total Taxa	**21**	**15**	**25**
Total EPT	**11**	**5**	**11**

Table A2

Crawford After 1-Nov-96	Site 1	Site 2	Total
ODONATA			
Calopteryx	2	8	10
Argia	1	2	3
Stylogomphus		1	1
OLIGOCHAETA	4	1	5
CRUSTACEA			
Lirceus	5	2	7
EPHEMEROPTERA			
Eurylophella	10	1	11
Caenis	6	10	16
Ephemerella	1		1
Isonychia	116		116
Stenonema	132	41	173
Baetis		1	1
Paraleptophledia		1	1
PLECOPTERA			
Leuctra	15	1	16
Acronruria	1		1
MEGALOPTERA			
Corydalus	6	3	9
Nigronia	2		2
Chauliodes		1	1
HEMIPTERA			
Microvelia		6	6
Rhagovelia	1	1	2
COLEOPTERA			
Psephenus	9	10	19
TRICHOPTERA			
Ceratopsyche	9	3	12
Cheumatopsyche	15	8	23
Chimarra	50	14	64
Hydropsyche	33	15	48
Pycnopsyche		2	2
Triaenodes		1	1

Table A2: continued

DIPTERA			
Simulium		1	1
Antocha	1		1
Tipula	3	1	4
<u>Chironomidae</u>			
Orthocladinae	6		6
Tanypodinae	1	1	2
Chironominae	1		1
Total Individuals	419	135	554
Total Taxa	**24**	**25**	**32**
Total EPT	**9**	**11**	**15**

Table A3

Crawford After After Site 4	14 Sept. 02 Site 1	27 Oct. 02 Site 2	Total
ODONATA			
Calopteryx	7	3	10
Argia	14	3	17
Stylogomphus		3	3
Gomphus	8		8
Macromia		1	1
Enallagma		8	8
OLIGOCHAETA	20	1	21
CRUSTACEA			
Lirceus	50	155	234
EPHEMEROPTERA			
Tricorythodes	4		4
Caenis	28		28
Ephemerella	1		1
Isonychia	61	43	104
Stenonema	32	42	74
Baetis	10		10
Acentrella	3	16	19
Procloeon	3		3
Acerpenna	1		1
Stenacron	1	2	3
Choroterpes	1		1
PLECOPTERA			
Leuctra	9	4	13
Acronruria	1		1
MEGALOPTERA			
Corydalus	25	5	30
Nigronia	10	5	15
HEMIPTERA			
Microvelia	4		4
Rhagovelia	4	3	7
Belostoma		1	1

Table A3: continued

COLEOPTERA			
Psephenus	7	12	19
Stenelmis	1	1	2
Optioservus		1	1
Hydroporus		2	2
Helichus		1	1
TRICHOPTERA			
Cheumatopsyche	107	51	158
Chimarra	110	57	167
Hydropsyche		2	2
DIPTERA			
Hemerodomia	2		2
Antocha	2		2
Chironomidae			
Orthocladinae	1		1
Tanypodinae	14		14
Pupae	1		1
Total Individuals	554	422	976
Total Taxa	**30**	**24**	**38**

Table A4: Crawford Branch and Carr Creek Habitat Restoration Costs 1997

Date	Backhoe	Ind. Haul	Bulldozer	Rip-rap	Labor	Materials	Total Hrs.	Daily Cost
05 Jun	$225	$153		$291.13	$45		5	$714.13
06 Jun	$225	$148	$110	$280.82	$54		5	$817.82
07 Jun	$157.50		$110		$63		3.5	$330.50
09 Jun	$225	90*	$192.50		$63		5	$570.50
10 Jun	$157.50	$231.95		$437.21			3.5	$826.66
13 Jun	$45						1	$45.00
20 Jun					$36		4	$36.00
21 Jun	$135						3	$135.00
29 Jun	$45		$27.50				1/0.5	$72.50
30 Jun					$27		3	$27.00
07 Jul	$202.50		$110		$76.50		4.5/2/8.5	$389.00
08 Jul	$180		$110			$36/Straw Mat	4.0/2.0	$326.00
12 Jul					$36	$18.5 Grass	4	$54.50
Totals	$1,597.50	$622.95	$660	$1,009.16	$400.50	$54.50	53.5	**$4,344.61**

Streambank area restored: Crawford Branch = 152.2 meters and Carr Creek = 154.2 meters.
Crawford Branch: 152.2/$4,344.61 = $28.5/ linear meter and Carr Creek: 154.2/$4,344.61 = $28.5/linear meter.
Cost of Equipment: Backhoe per hour:$45, Bulldozer:$55, Dump Truck:$45.
* Equipment operator used dump truck for 2 hours on 09 June 1997. Rock hauled by independent hauler.
Hand labor cost $9/hr. The remaining labor was supplied by APSU Center for Field Biology Students.
Cost of rip-rap plus delivery was ~ $12/ton.

Table A5 Crawford Branch Site 4 Restorations and Maintenance 2001-2003
Site 4 restoration: 91 meters in length. Cost includes:
Backhoe: $65 per hour at 25.5 hours for a Total = $1,657.50
Dump Truck: $35 per hour at 20.75 hours for a Total = $726.25
Labor was supplied by APSU students - No charge. Other materials include grass seed @ $13.
Rip-rap total: 48.64 tons at a total cost: $639.62. This charge includes delivery ~ $13 per ton.
Total Cost: $3,036.38, Total Area treated: 91 meters, or $33 per linear meter.
2004 Cost Comparison of Site 4
Backhoe: $70 per hour, Dump Truck is $45 per hour, and rip-rap is $743.68 delivered.
2004 Costs: $3,462.43 or $38 per linear meter.
Crawford Branch: 152.2 meters @ $38/ linear meter = $5,783.6
Carr Creek: 154.2 meters @ $38/ linear meter = $5,859.6
1997 Total Cost: $4,344.61 2004 Total Cost: $11,643.2 Difference: $7,298.59

VITA

James O. Harmon, Jr. was born in Montgomery County, Tennessee on April 20, 1964. He attended Montgomery Central elementary and high schools and graduated in 1982. After working in construction for several years, he decided to make his love of the great outdoors work in his favor. In 1989 he enrolled at Austin Peay State University. In December 1995, he received Bachelor of Science degrees in Agricultural Science and Biology and a minor in Chemistry. January of 1996, he started the Master of Science degree in Biology also at Austin Peay. During his first semester he worked as a teacher's assistant for the Biology Department, and the next as a research assistant in the Center of Field Biology at Austin Peay State University. He left the program in 1997 for employment at the Montgomery County Soil Conservation District as a Soil Conservationist. After three years of service at the County, Mr. Harmon secured employment as a contracted Land Condition Trend Analysis Coordinator (LCTA) - Biologist at Fort Campbell Military Installation, Kentucky. Through this employment, he was offered the opportunity to return to Austin Peay State University and complete the remaining classes necessary to fulfill his requirements for a Master of Science degree in Biology, which was academically complete in December 2003. He finished all requirements for the Master's of Science degree in Biology May 2004.

Mr. Harmon remains employed as the Land Condition Trend Analysis Coordinator at Fort Campbell, Kentucky.