Effectiveness of naturally-occurring riparian forest buffers and grass filter strips at buffering concentrated flow from row crop fields to streams in northeast Missouri

by

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Table of Contents

Abstract

An inventory of the composition and density of tree and shrub species in naturally-occurring forest buffers and a survey comparing buffering of concentrated flow paths (CFPs) by natural forest buffers and grass filter strips was conducted along first and second order streams flowing through 11 farms in three northeast Missouri watersheds. These watersheds had been previously studied with geographic information systems (GIS) to determine the extent of naturally-occurring forest or grass riparian areas. In an effort to understand the composition of naturally occurring forest buffers in this region, forest buffers on 7 farms were inventoried for tree species, saplings, seedlings, and shrub and forest floor cover. Results indicated stands of mixed species and size, however, stocking rates were lower than recommended for designed riparian forest buffers by the U.S. Department of Agriculture Natural Resources Conservation Service. CFPs were observed and measured at the natural forest buffer sites on the 7 farms and along government-sponsored grass filters on 4 additional farms. Results from the survey examining 74 CFPs occurring in row crop fields found that natural forest buffers dispersed flow from 80% of CFPs before they reached the stream, and grass filter strips dispersed 100%. This was based on the guidelines that a buffer was considered successful if the CFP channel ended at the buffer edge or within the buffer before reaching the stream. Where CFPs extended through the buffer, as an integrated channel, buffers were considered to be ineffective, and sediment was lost to the stream channel. Using measured widths and depths of the 74 observed CFPs found along 17.6 km of crop field/buffer edge it was estimated that 473 metric tons of soil moved to the riparian buffers via CFPs since the last tillage. Of the 473 metric tons, 97 metric tons of sediment were estimated lost to stream channels, all of which occurred in natural forest buffers. In addition, 33 CFPs or classic gullies were observed in the natural

forest buffers without grass filters and 27 CFPs or classic gullies in the forested areas with grass filter strips. The latter gullies appeared to no longer be actively eroding because of the grass filters. However, the number of gullies found in the forest buffers suggests that these narrow natural forest buffers do not effectively buffer surface runoff without an adjacent grass filter. Results suggest that the presence of higher densities of rooted vegetation and the wider buffer areas of grass filter strips are responsible for the higher percentage of buffered CFPs. Data collected from these farms, along with previous research detailing the effectiveness of grass filter strips, suggest that adding a grass filter strip along narrow natural forest buffers may improve water quality by reducing sediment loss to streams.

Chapter 1. General Introduction

Introduction and project description

Riparian buffers are considered a valuable conservation practice that can mitigate pollution and degradation of streams and lakes. After reviewing the current state of riparian buffer knowledge, Lowrance et al. (2002) called for more research in the following areas: 1) the efficacy of buffers in numerous regions around the U.S.; 2) evaluations at the field, farm, and watershed scale; 3) studies examining the effects of incentive-based buffer programs; and 4) examination of various buffer widths and different plant communities as buffers for trapping surface runoff and effectively converting channelized flow from fields into diffuse flow. Much research to date has studied the effectiveness of engineered or designed buffers, much of it at the plot-scale level (Lee 1999, 2000; Rankins et al. 2001; Schmitt et al. 1999). Less emphasis has been placed on the effectiveness of naturally-occurring strips of riparian forest or grass in reducing non-point source pollution.

Since the review by Lowrance (2002), numerous studies, a few of them listed here, have further expanded the knowledge about riparian buffer function. Examples include Dosskey et al. (2002), Ducros and Joyce (2003), Helmers et al. (2005a, 2005b), Lee et al. (2003), Lin et al. (2004), Schultz et al. (2004), and Zaimes et al. (2004). Herring et al. (2006) studied three watersheds in northeast Missouri remotely using a geographic information system (GIS). The study used a watershed-scale approach to determine the extent and width of existing forest and grass riparian areas. The goal was to target priority areas where buffers did not exist as well as areas where existing buffers could be improved or enhanced.

The aim of the study presented in this thesis was to use field and farm scale observations to expand on conclusions drawn from the study by Herring et al. (2006). Naturally-existing forest buffers were compared with grass filter strips, installed with incentive programs offered by the United States Department of Agriculture Natural Resources Conservation Service (USDA-NRCS) and USDA Farm Service Agency (USDA-FSA). The study consisted of two field observation projects: 1) an inventory of naturally-existing forest buffers along headwater streams to understand the tree, shrub, and forest floor composition of these forest buffers; and 2) the examination of soil movement from concentrated flow paths (CFPs) draining to the naturally-occurring forest buffers and USDA-NRCS approved grass filters with the goal of comparing the effectiveness of the two buffer types in intercepting and dispersing concentrated flow paths. Based on other studies examining buffer effectiveness (Dabney et al. 2006, Daniels and Gilliam 1996, Dosskey et al. 2002, Helmers et al. 2005a, Lee et al. 1999, 2003, Rankins et al. 2001, Schmitt et al. 1999), this study worked from the assumption that if a riparian buffer, either forest or grass filter strip, can disperse the concentrated flow path so that surface runoff moves across the buffer as dispersed flow, the buffer will reduce a percentage of sediment and associated nutrient and chemical pollutants coming to the buffer in the concentrated surface runoff. If the concentrated flow path is not dispersed by the buffer it will be continuous to the stream channel and deliver its total load of sediment, nutrients and chemical pollutants to the stream.

Study Location

The study was conducted along first and second order streams, located on 11 farms in the same three sub-watersheds of the 754,723 ha Mark Twain Lake/Salt

River watershed in northeast Missouri studied by Herring et al. (2006). Figure 1.1 shows Crooked Creek (28,814 ha) and Otter Creek (26,709 ha) watersheds, which achieve fourth order designation (Strahler 1957) before entering Mark Twain Lake, while Long Branch Creek watershed (26,487 ha) achieves fifth order designation. The GIS stream information used to categorize stream order for this project was obtained from the University of Missouri's Center for Agricultural, Resource, and Environmental Systems (CARES).

According to Dames and Todd (2007), the major water quality concern for the Mark Twain Lake/Salt River watershed is severe soil erosion from cultivated land, which moves to streams. Excessive turbidity and siltation has impacted recreation by decreasing the abundance and diversity of aquatic life and has made boating more difficult. Finney (1986) estimated average annual sediment yield to Mark Twain Lake at 1,102,229 metric tons. Conservation practices utilized to reduce this yield will extend the time period before considerations regarding sediment removal from the lake are needed. Mark Twain Lake and 63 km of the Salt River are designated as public drinking water supplies, and supply water to a 13 county area which is further recognition of the importance of this lake and its water quality (Missouri Department of Natural Resources 1986, U.S. Army Corps of Engineers 2007).

Udawatta et al. (2004) discuss how claypan soils in central and northeast Missouri have a claypan existing between 10 and 80 cm below the surface and Ghidey and Alberts (1998) explain how runoff and soil losses from the Midwest claypan region are relatively high during the seasons of highest rainfall (spring to fall). Seobi et al. (2005) discuss how claypan soils have a shallow topsoil layer and a subsoil horizon with high clay content (claypan) which restricts downward water movement and enhances surface water, nutrient, and herbicide runoff. This region has been identified as a vulnerable area for pesticide and nutrient contamination of surface water by Lerch and Blanchard (2003). They analyzed water samples from 21 watersheds in southern Iowa and northern Missouri between 1996 and 1999 and found these watersheds to transport a disproportionately high amount of herbicide to both the Mississippi and Missouri rivers. They suggest that the region studied is highly vulnerable to loss of herbicide from fields to streams because of this combination of claypan soils and the timing of precipitation and herbicide application.

These circumstances show the relevancy of studies that examine the effectiveness of riparian buffers and other conservation practices in this region, aimed at reducing sediment loads and other pollutants to Mark Twain Lake and other water bodies. This study tested the hypothesis that where CFPs move to narrow, natural forest buffers (10 – 30 m in width), greater than 50% will continue through the forested areas as concentrated flow, rendering them ineffective as a buffer of surface runoff to streams. It was further hypothesized that where natural forest buffers have been enhanced with grass filter strips under USDA-NRCS and USDA-FSA sponsored conservation programs, CFPs will be intercepted and the concentrated flow dispersed within the grass filter strips, before reaching streams.

Thesis organization

This thesis is arranged in three chapters. The first chapter is an introduction to the topics covered and an introduction to the study area. The second chapter is entitled "Effectiveness of naturally-occurring riparian forest buffers and grass filter strips at buffering concentrated flow from row crop fields to streams in northeast Missouri," and has been prepared for submission to the Journal of Soil and Water Conservation. This chapter has been written with the goal of packaging both segments of the thesis, the forest buffer inventory and the concentrated flow work, into one chapter for submission to the journal. The final chapter serves as a general conclusion for the work conducted for this thesis.

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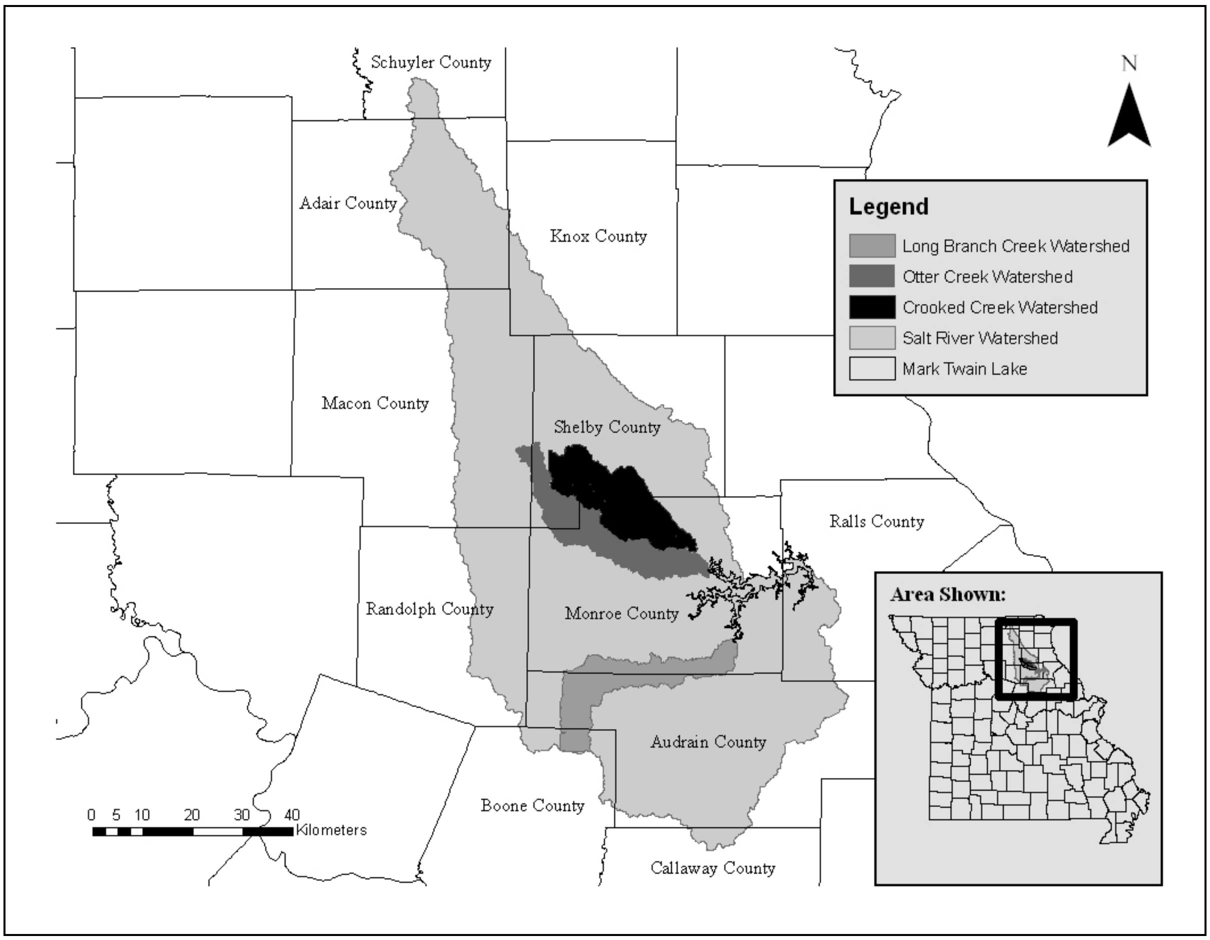
Figure 1.1

Map showing Crooked Creek, Otter Creek, and Long Branch Creek watersheds where all farms in the study were located. These watersheds are part of the larger Salt River watershed, shown here above the Clarence Cannon dam at Mark Twain Lake.



Chapter 2. Effectiveness of naturally-occurring riparian forest buffers and grass filter strips at buffering concentrated flow from row crop fields to streams in northeast Missouri

Modified from a paper to be submitted to *The Journal of Soil and Water Conservation*

Kris W. Knight, Richard C. Schultz, Cathy M. Mabry, Thomas M. Isenhart

Abstract

An inventory of the composition and density of tree and shrub species in naturally-occurring forest buffers and a survey comparing buffering of concentrated flow paths (CFPs) by natural forest buffers and grass filter strips was conducted along first and second order streams flowing through 11 farms in three northeast Missouri watersheds. These watersheds had been previously studied with geographic information systems (GIS) to determine the extent of naturally-occurring forest or grass riparian areas. In an effort to understand the composition of naturally occurring forest buffers in this region, forest buffers on 7 farms were inventoried for tree species, saplings, seedlings, and shrub and forest floor cover. Results indicated stands of mixed species and size, however, stocking rates were lower than recommended for designed riparian forest buffers by the U.S. Department of Agriculture Natural Resources Conservation Service. CFPs were observed and measured at the natural forest buffer sites on the 7 farms and along government-sponsored grass filters on 4 additional farms. Results from the survey examining 74 CFPs occurring in row crop fields found that natural forest buffers dispersed flow from 80% of CFPs before they reached the stream, and grass filter strips dispersed 100%. This was based on the guidelines that a buffer was considered successful if

the CFP channel ended at the buffer edge or within the buffer before reaching the stream. Where CFPs extended through the buffer, as an integrated channel, buffers were considered to be ineffective, and sediment was lost to the stream channel. Using measured widths and depths of the 74 observed CFPs found along 17.6 km of crop field/buffer edge it was estimated that 473 metric tons of soil moved to the riparian buffers via CFPs since the last tillage. Of the 473 metric tons, 97 metric tons of sediment were estimated lost to stream channels, all of which occurred in natural forest buffers. In addition, 33 CFPs or classic gullies were observed in the natural forest buffers without grass filters and 27 CFPs or classic gullies in the forested areas with grass filter strips. The latter gullies appeared to no longer be actively eroding because of the grass filters. However, the number of gullies found in the forest buffers suggests that these narrow natural forest buffers do not effectively buffer surface runoff without an adjacent grass filter. Results suggest that the presence of higher densities of rooted vegetation and the wider buffer areas of grass filter strips are responsible for the higher percentage of buffered CFPs. Data collected from these farms, along with previous research detailing the effectiveness of grass filter strips, suggest that adding a grass filter strip along narrow natural forest buffers may improve water quality by reducing sediment loss to streams.

Introduction

It has been well documented that riparian forest buffers and grass filter strips along streams, collectively called riparian buffers, can be effective environmental management tools. Riparian buffers can provide reduction of sediment, nutrients, and herbicides in surface runoff, increased infiltration, reduced groundwater nitrate, reduced stream bank erosion, carbon sequestration, and increased wildlife habitat

(Daniels and Gilliam 1996; Lee et al. 1999, 2003; Lowrance et al. 2002; Rankins et al. 2001; Schmitt et al. 1999; Schultz et al. 2004; Zaimes et al. 2004). This work has generally been reported from riparian buffers that were designed or engineered specifically as buffers, or from plot-scale experiments. There are, however, many kilometers of narrow, naturally-occurring forested and grass riparian areas acting as riparian buffers, and little is known about their effectiveness.

Several studies have examined natural riparian forests and their usefulness as riparian buffers. Lowrance et al. (1984) studied a coastal plain agricultural watershed in Georgia and found that natural riparian forest ecosystems are excellent nutrient sinks and buffer the nutrient loss from surrounding agroecosystems to streams. The study did not analyze surface nutrient movement because it was estimated that a large percentage of nutrient movement from the uplands to the riparian area in the studied watershed moved as subsurface flow. Peterjohn and Correll (1984) drew similar conclusions regarding the benefits of a natural riparian forest in a study in Maryland, and included surface runoff as a component of the study. Both studies suggested good water quality in the agricultural watersheds studied depends largely on the nutrient uptake and removal that a riparian forest can provide. In a study in North Carolina, Cooper et al. (1987) suggested approximately 90% of the sediment leaving agricultural fields was deposited in an adjacent forested riparian area, the majority remaining within 100 m of the crop field. However, 100 m is often wider than many naturally-occurring riparian buffers, especially in the agriculture dominated landscapes of the Midwestern U.S., and also wider than designed or engineered riparian buffers sponsored by government conservation programs (USDA Farm Service Agency 2006).

One way soil erodes and nutrients and contaminants bound to soil move is through surface runoff, especially as concentrated flow. Fangmeier et al. (2006)

describe rill erosion as the detachment and transport of soil by concentrated flow. Rill erosion leads to small eroded channels across the hillslope that can be covered by normal tillage operations and is the predominant form of surface erosion. Cooper and Gilliam (1987) also studied phosphorus (P) quantities in soils that had moved with sediment in surface runoff from crop fields to riparian forests. They found that concentrated runoff moving in rills and interrows in crop fields slowed and was converted to sheet flow at the field-forest edge. Sandy deposits at the field-forest edge were low in total P but smaller sediment particles, particularly clay particles, and most of the P was carried deeper into the riparian forest before deposition. They estimated over 20-25 years that 50% of the P leaving agricultural fields was removed by these riparian forests. However, these forests were wide, sometimes kilometers in width. The higher percentages of P were accumulated in areas such as flood plain swamps and intermittent stream areas deeper within the riparian forest, which suggests narrow forest buffers measured in tens of meters versus hundreds of meters or kilometers may be ineffective at buffering surface runoff. The USDA Natural Resources Conservation Service (USDA-NRCS) describes an ephemeral gully as a shallow channel formed by concentrated runoff between tillage operations, but unlike rills, erosion occurs to the tilled depth and therefore is considered larger than a rill. Ephemeral gullies can also be crossed with farm equipment and obliterated with tillage. This tillage appears to remove visible erosion but often leaves subtle depressions. During subsequent rainfall events, or in some cases, a single event, the tilled soil again erodes, recreating the ephemeral gully. Sediment delivery to streams from integrated (continuously connected) ephemeral gully systems are typically 50-90%. For ephemeral gullies in a non-integrated system, sediment delivery rates are lower, generally 20-50% (USDA-NRCS, 1998).

The term concentrated flow path (CFP) has been used in this study to describe the rills or ephemeral gullies observed in row crop fields. The term CFP is preferred because in many cases eroded channels are large enough to be considered an ephemeral gully because there is a visible depression in the landscape and they are eroded to the tilled depth. However, other eroded channels are smaller, still a single or branching channel but not eroded to tilled depth. CFPs can leave crop fields, moving through forest or grass riparian buffers, continuing as CFPs or becoming larger classic gullies as they make their way to stream. USDA-NRCS (2002) defines a classic gully as a channel cut by concentrated runoff that is deep enough to prevent normal tillage operations. Water commonly flows through the classic gully only during and immediately after rains or periods of snow melt. Where CFPs leaving crop fields continue as a CFP or classic gully through the riparian buffer to the stream, sediment delivery rates would remain at 50-90% as long as the channel remains continuous, or integrated.

The USDA-NRCS and USDA-Farm Service Agency (USDA-FSA) offer several programs to property owners wishing to reduce soil loss from crop fields and/or buffer streams from surface runoff pollution. These programs include conservation practices such as riparian forest buffers (CP-22), grass filter strips (CP-21), field borders, also called habitat buffers for upland birds (CP-33), and grassed waterways (CP-8). Grassed waterways are a practice occurring within the crop field designed to allow stable conveyance of runoff without causing erosion, while the other practices occur on the edges of the crop fields (USDA-NRCS 2000). The primary function of CP-21 and CP-22 practices are to remove sediment, nutrients and pollutants from surface runoff and subsurface flow to streams, while the primary function for the CP-33 practice is to provide habitat for quail and upland birds in cropland areas. However, secondary benefits of the CP-33 practice include reducing soil erosion from wind and water, increasing soil and water quality, and protecting and enhancing the on-farm ecosystem. The CP-21 practice includes grass and forb vegetation while the CP-33 buffers can be made up of grasses, forbs, and shrubs (USDA-NRCS 2004a, 2004b, 2005). The CP-22 practice includes a tree and/or shrub component (Zones 1 and 2) next to the stream in addition to a grass filter strip adjacent to the row crop field. The CP-22 practice does not include a grass filter strip if the practice is established where a stream is adjacent to pastureland. Additional goals for the CP-22 practice include shading and cooling water temperatures in streams, providing sources of detritus and large woody debris as habitat for aquatic organisms and wildlife, and mitigating flood damage by trapping debris and slowing flood waters (USDA-FSA 2006; USDA-NRCS 2004b). Table 2.1 shows the minimum and maximum width options for CP-21, CP-22, and CP-23 conservation practices.

Studies examining the effectiveness of riparian buffers at removing sediment, nutrient, and chemical pollutants have been generally positive. Lee et al. (1999) studied 6 m wide switchgrass (*Panicum virgatum*) and cool-season grass filter strips and found them to remove 78% and 75% of sediment, respectively. Switchgrass filter strips also removed 51% of total nitrogen, 47% of nitrate, 55% of total P, and 46% orthophosphate. Cool-season grass filter strips removed 41% of total nitrogen, 38% of nitrate, 49% of total P, and 39% of orthophosphate. Runoff for this study was simulated and dispersed to simulate sheet flow runoff. Lee et al. (2003) studied a 7 m wide switchgrass filter and a 16 m wide multi-species riparian buffer consisting of both a forest buffer and switchgrass filter. The switchgrass filter removed 95% of sediment, 80% of total nitrogen, 62% of nitrate, 78% of total P, and 58% of orthophosphate. The multi-species riparian buffer removed 97% of sediment, 94% of total nitrogen, 85% of nitrate, 91% of total P, and 80% of orthophosphate. Runoff for this study was from rainfall events and from a source area large enough to produce rill and interrill erosion. Rankins et al. (2001) studied the effectiveness of different grasses as filter strips at removing sediment and herbicides in surface runoff. The different grasses removed no less than 66% of sediment and no less than 59% of herbicide. Runoff was both natural and simulated and there was no discussion of any concentrated surface runoff. Schmitt et al. (1999) found that plots simulating grass filter strips, 7.5 and 15 m wide and planted to mixed grass species, removed 76-93% of sediment and 55-79% total P in runoff. However, the plots were less effective at reducing dissolved contaminants in runoff: atrazine 5-43%; alachlor 10-61%; nitrate 24-48%; dissolved P 19-43%; bromide 13-31%. Runoff for this study was simulated and was dispersed evenly across the plot, with no reference to concentrated flow.

When riparian buffer studies examine effectiveness related specifically to buffering pollutants from concentrated flow, the results are not always as positive. Daniels and Gilliam (1996) found that 6 m wide grass filter strips and grass filter strips plus forested areas reduced sediment load from sheet and rill flow by 60-90%. However, the study suggested that the best scenario for sediment and nutrient reduction was where sheet flow met nearly continuous grass cover at the footslope. Where concentrated runoff moved from crop fields through only forested riparian areas, nutrient and sediment loads were reduced very little. The study discusses how the main impediment to flow in forested ephemeral channels during winter and early spring is leaves, but during high runoff periods, those channels are scoured. They suggest these channels need continuous vegetative cover but this is not possible under a full forested canopy. As Stuart and Edwards (2006) summarize, forest floor cover made up of organic matter and woody plant debris protects against erosion from raindrops and throughfall drops from the forest canopy. As Daniels and Gilliam (1996) discuss, however, it would seem unlikely that this type of cover would provide protection against concentrated surface runoff. A solution suggested by Daniels and Gilliam (1996) was to disperse runoff in upland drainageways or disperse ephemeral channels at the footslopes so riparian buffers and filters receive dispersed runoff and are not overloaded.

After surveying 33 grass filters in Virginia, Dillaha et al. (1986) also found that concentrated flow from crop fields moving to riparian buffers was a problem. Concentrated flow crossed the grass filters in a few narrow areas, totally inundating the filters with sediment. Grass filters examined in this study ranged from 3 to 9 m in width, far less than recommended widths for CP-22 filters, or maximum widths for CP-21 or CP-33 practices. As Table 2.1 shows, however, minimum widths for CP-21 or CP-33 practices could be 6.1 and 9.1 m, respectively (USDA-FSA 2006). Dillaha et al. (1986) suggested that grass filters are probably not appropriate for fields with extensive areas of concentrated flow unless the grass filters extend up into the fields forming grassed waterways (USDA-NRCS 2000). Dosskey et al. (2002) looked at four farms in southeastern Nebraska and mapped concentrated flow runoff areas and pathways through riparian buffers. These buffers were not designed or engineered for filtering runoff and consisted of vegetation of mixed trees and grass (3 farms) and one farm with only grass. Estimating the sediment trapping efficiency with concentrated flow present in crop fields versus uniform runoff contacting the entire buffer area, the study suggested that concentrated flow to riparian buffers could greatly limit the filtering abilities of these buffers, removing only 15%, 23%, 34%, and 43% of sediment at the respective farms. Helmers et al. (2005a), however, found that despite converging flow, a field-scale vegetative grass filter trapped approximately 80% of the incoming sediment. This convergence was due to subtle, microtopographic features, however, and runoff was still relatively uniformly distributed. In a related study, Helmers et al. (2005b) used models to find that increased flow convergence in the crop field above the grass filter and within the grass filter would decrease the ability of the filter to retain sediment.

A study by Herring et al. (2006) used a geographic information system (GIS) to assess the riparian areas in Crooked Creek, Otter Creek, and Long Branch Creek watersheds in northeast Missouri. The study determined that a large percentage of streams in these watersheds had naturally occurring forest or grass riparian areas, although not always to USDA-FSA recommended riparian buffer widths (Table 2.1). For example, as Table 2.2 shows, averages for the three watersheds found that 64% of first order stream lengths and 76% of second order stream lengths were buffered to at least 30 m. Therefore, 36% of first order stream lengths and 24% of second order stream lengths have natural buffers less than 30 m in width. USDA-FSA (2006) recommends minimum riparian buffer widths of 30.5 m for the CP-22 practice and a maximum width of 55 m, unless USDA-NRCS specifically documents a wider buffer is needed to meet water quality needs. CP-21 and CP-33 practices can be enrolled to a maximum width of 37 m.

The issue is whether narrow natural buffers are providing the same environmental benefits produced by designed or engineered riparian buffers, or wider natural forest buffers like those studied by Cooper et al. (1987). With such a large percentage of first and second order streams naturally buffered in three northeast Missouri watersheds, even with narrow buffers less than 30 m wide existing, there may be assumptions from natural resource professionals and citizens that these streams are sufficiently buffered. The aim of this study was twofold. First, understand the vegetation composition of naturally-occurring forest buffers in northeast Missouri. Second, compare the effectiveness of natural forest buffers versus USDA-NRCS approved grass filter strips in buffering CFPs from row crop fields to first and second order streams. This study tested the hypothesis that where

CFPs move toward narrow, natural forest buffers (10 – 30 m in width), greater than 50% will continue through the forested areas as concentrated flow, rendering them ineffective as a buffer of surface runoff to streams. It was further hypothesized that where natural forest buffers have been enhanced with grass filter strips under USDA-NRCS sponsored conservation programs, CFPs will be intercepted and the concentrated flow dispersed within the grass filter strips, before reaching the narrow forest buffers and streams.

Materials and Methods

***Study area*.** The study was conducted in the same three sub-watersheds of the 754,723 ha Mark Twain Lake/Salt River watershed in northeast Missouri studied by Herring et al. (2006). Figure 2.1 shows Crooked Creek (28,814 ha) and Otter Creek (26,709 ha) watersheds, which achieve fourth order designation (Strahler 1957) before entering Mark Twain Lake while Long Branch Creek watershed (26,487 ha) achieves fifth order designation. The GIS stream information used to categorize stream order for this project was obtained from the University of Missouri's Center for Agricultural, Resource, and Environmental Systems (CARES). Stream lines had been digitized from black and white, one-meter resolution aerial photos taken in 1995. According to Dames and Todd (2007), the major water quality concern for the Mark Twain Lake/Salt River watershed is severe soil erosion from cultivated land, which moves to streams. Excessive turbidity and siltation has impacted recreation by decreasing the abundance and diversity of aquatic life and has made boating more difficult. Mark Twain Lake and 63 km of the Salt River are designated as public drinking water supplies, and supply water to a 13 county area which is further recognition of the importance of this lake and its water quality (Missouri Department of Natural Resources 1986, U.S. Army Corps of Engineers 2007).

The survey stream segments were located on 11 farms within Shelby, Monroe and Audrain counties in northeastern Missouri. Small portions of Otter Creek and Long Branch Creek watersheds also are located in Macon and Boone counties, respectively (Figure 2.1). This region has glacial deposits from at least two Pre-Illinoian glaciations that are usually overlain by loess. Parent material can be residual limestone and shale, glacial deposits, loess, or alluvial material (Watson 1979). The soils have developed well-defined horizons, often including a significant argillic or claypan horizon. Climate patterns have contributed to the make-up of soils in the region. Rainfall is a major soil forming factor as Shelby, Monroe and Knox counties receive an average annual precipitation of 99 cm (39 inches) per year, two thirds of which falls between April and September (Watson 1979). Similarly, Audrain county receives an average annual precipitation of 102 cm (40 inches) per year, 65 percent of which usually also falls between April and September (Young and Geller 1995).

Soils in this region formed under three types of vegetation: prairie, oak savanna, or deciduous forest. Land use changes since settlement in the early 1800’s have impacted the soils of northeast Missouri. Landcover information provided by CARES from 1995 shows Long Branch Creek watershed to be 71% crop land, Crooked Creek watershed 58%, and Otter Creek watershed 66%. These percentages represent row crop land area and do not include pasture land. Primary crops for this area are corn, soybeans, winter wheat, and grain sorghum, whose culture results in a significant portion of the year where the soil is bare and more susceptible to erosion from surface runoff (Watson 1979; Young and Geller 1995).

Claypan soils occupy millions of hectares in the Midwest, including northeast Missouri. Seobi et al. (2005) discusses literature showing claypan soils have a shallow topsoil layer and a subsoil horizon with high clay content (claypan) which restricts downward water movement and enhances surface water, nutrient, and herbicide runoff. Udawatta et al. (2004) hypothesized that claypan soils that restrict drainage would increase total P losses in runoff. They studied runoff events over seven years in northeast Missouri and found total P concentrations in runoff were consistently greater than the critical value established by the U.S. Environmental Protection Agency (Daniel et al. 1998). The study found that the majority of the P loss occurred during fallow periods.

The period of highest rainfall (spring to fall) in northeast Missouri is also the period when agrichemicals are applied and as a result the claypan region has been identified as an area vulnerable to pesticide and nutrient contamination of surface water by Lerch and Blanchard (2003). They analyzed water samples from 21 watersheds in southern Iowa and northern Missouri between 1996 and 1999 and found these watersheds to transport a disproportionately high amount of herbicide to both the Mississippi and Missouri rivers. They suggest that the region studied is highly vulnerable to loss of herbicides from fields to streams because of this combination of claypan soils and the timing of precipitation and herbicide application.

Site selection. Sites to be designated as natural forest buffers were selected by examining all first and second order streams in the three study watersheds using GIS to view aerial photos from 2003 and 2005. The study was limited to first and second order streams because research has suggested that buffers along larger rivers have relatively less impact on water quality and that buffering of watersheds should begin in the fields of headwater reaches where most of the runoff, sediment, and chemical pollutants first enter the stream channels in the watershed (Lowrance et al. 2002). Forests that averaged between 10 and 30 m wide on each side of the stream, when viewing aerial photos, were considered for the study. Sites were required to be at least 402 m (0.25 miles) long and were also required to have annual row crop farming immediately adjacent to the forested area. For all sites that met the above criteria, property owners were contacted. Permission was granted to access seven farms totaling 8.8 km of forest buffer for the forest inventory portion of the study. Three sites totaling 3.6 km were located in the Crooked Creek watershed, while two sites each were located in Otter Creek and Long Branch Creek watersheds, totaling 3 km and 2.2 km of buffer, respectively.

Grass filter strip (CP-21) sites in the three watersheds were located by contacting USDA-NRCS offices in the representative counties. Requirements for the grass filter strip sites were similar to the forest buffer sites. Sites were required to be along first and second order streams in the same three watersheds and adjacent to annual row crop fields. However, there was no requirement for the continuous length of the grass filter strips to equal 402 m (0.25 miles) because of the few sites available. Four sites met the selection criteria, three in the Otter Creek watershed totaling 10 km in length and one in the Long Branch Creek watershed totaling 0.9 km of stream. Property owners were again contacted and all agreed to participate in the study. One site and a small portion of a second site in the Otter Creek watershed were later determined to be enrolled in the CP-33 practice rather than the CP-21 practice originally sought. Areas enrolled in the CP-33 practice were planted to warm-season grasses and forbs, while the sites enrolled as CP-21 practices were planted to cool-season grasses, with the exception of one site in Long Branch Creek watershed which was enrolled as a CP-21 practice and planted with warm-season grasses and forbs. Areas enrolled as a CP-33 practice, all of which were located between a crop field and a riparian forest could also be considered for enrollment as a CP-21 conservation practice (personal communication, May 30, 2007, USDA-NRCS Resource Conservationist, Monroe County, MO). As a result, these areas were included in this study, referred to as grass filter strips, and provided an opportunity to compare warm-season grass filters with cool-season grass filters. It also provided the opportunity to analyze whether the CP-33 practice could provide the same environmental enhancements that have been shown by CP-21 and CP-22 practices. In all, the area used for the grass filter portion of the study was represented by a length of 10.9 km of grass filter, 7.5 km of which were cool-season grasses and 3.4 km that were warm-season grasses and forbs. Grass filter strips that were planted to cool-season grasses were established between 2001 and 2004. All grass filter strips planted to warm-season grasses and forbs had been established in the spring of 2006. Of the 10.9 km of grass filter strips used in the study, 8 km were enrolled as the CP-21 practice and 2.9 km were enrolled as the CP-33 practice. Table 2.3 summarizes the lengths of the various buffers used for the study.

Forest buffer inventory. The Missouri NRCS recommends a minimum of one inventory location for every 4 ha or three locations per field/site, whichever is more, when estimating woodland stocking rates in riparian areas (USDA-NRCS 1999). Sample locations to inventory the present composition of tree, sapling, seedling, and shrub species at forest buffer sites were laid out every 134 m in GIS along the forest buffer-crop field interface to easily find the locations when using a global positioning system (GPS). The distance between locations ensured there were at least three locations per site as suggested by USDA-NRCS. Since forest buffers were on each side of the stream, two plots were established directly across the stream from each other to account for any potential difference in forest buffer composition. A total of 74 forest inventory locations were identified on the 7 forest buffer sites. Figure 2.2 shows an example of how inventory locations were laid out in GIS for the forest inventory.

Actual sample plots were positioned in the field after using a GPS to locate the sample location. The center point of each plot was then located halfway between the top of the stream bank and the edge of the forest canopy adjacent to the crop field. Another plot was located directly across the stream channel, again halfway between the top of the stream bank and edge of the forest canopy adjacent to the crop field. This plot layout was used because of the variation in buffer width and the desire to place the center of each plot at the midpoint of each buffer. Sample plots were 0.008 ha (0.02 acre) circles with a fixed radius of 5.08 m. This size and type of plot was used to fit the width of the narrow forests and not capture trees on both sides of the streams as a prism plot sampling system may have done.

Plots were inventoried in September and October of 2006 before leaves dropped. At each plot tree species and diameter at breast height (dbh) were recorded for all trees >2.5 cm dbh. Species and diameter were also recorded for saplings defined as <2.5 cm diameter and >1.5 m tall. Understory shrubs were identified to species and assigned to one of eight cover classes for each plot, as done by Mabry (2002): 1 = 1-2 individuals or clusters with <5% cover, 2 = few to many individuals with <5% cover, 3 = numerous individuals throughout the plot with <5% cover, 4 = 5-15% cover, 5 = 16-25% cover, 6 = 26-50% cover, 7 = 51-75% cover, 8 = 76-100% cover. Within each sample plot, four smaller plots were used to measure seedling density (<2.5 cm dbh and <1.5 m in height). Four 0.0004 ha (0.001 acre) circular plots with 2.28 m diameters were located in each of the four cardinal directions 2.5 m from the center of the larger sample plot. Seedling species were recorded at 296 of these smaller plots at seven sites.

In March of 2007, the percent forest floor cover was determined on the same plots where the seedlings had been measured the previous autumn. Percent cover was partitioned into rooted vegetation (woody plants, grass, forbs/weeds), woody plant debris (leaves, twigs, branches), bare soil, and total cover using the same percent cover scores used for the shrub characterization. One of the seven sites was excluded due to extensive understory damage from cattle and tree removal since the site had last been visited, leaving 256 smaller plots to sample. No other sites had experienced cattle grazing in more than 5 years, and 5 of the 7 sites had not experienced grazing in more than 15 years.

Concentrated flow survey. In late March and the first day of April 2007, concentrated flow surveys were completed at six of the seven forest buffer inventory sites. Again, the site that was heavily disturbed by cattle and tree removal between October 2006 and March 2007 was excluded since no other sites in the study had experienced such damage. Surveys were also completed at the four grass filter sites. Altogether, 17.6 km, 6.7 km of forest buffer and 10.9 km of grass filter strip, were evaluated for the concentrated flow survey.

March and April were chosen because this represented a time period when CFPs were easily visible and spring tillage and planting had not yet started. Also, the fields had not been tilled since the previous spring and in some cases where no-till farming was being practiced, even longer. This allowed the maximum time for CFPs to develop over the past year or more. At one forest buffer site, the crop field adjacent to the forest buffer on one side of the stream was tilled prior to our survey in preparation for spring planting and was therefore excluded from the concentrated flow survey portion of the study.

The interface between the crop field and forest buffer or grass filter strip were walked and CFPs were identified as any visible eroded flow path or channel in the crop field meeting the buffer/filter. CFPs and/or sediment deposition areas that stopped in the crop field before reaching the buffer/filter edge were not considered for this study. CFPs that extended into the buffer/filter were followed to see if they extended through the buffer/filter and to the stream. Stream banks and forest buffers were also walked and surveyed to determine if there were CFPs or classic gullies that had developed in the buffers or filters but whose field source was not evident.

The length of CFPs identified in the field was measured by pacing, and widths and depths were measured with a tape at four points along the CFP: top, one third, two thirds and bottom of the CFP. In cases where the CFP extended into the buffer/filter, the bottom was considered the point where the CFP left the crop field and entered the buffer/filter. Where only the sediment deposition area interfaced with the grass filter or forest buffer, the bottom of the CFP was considered the last point where an eroded flow path or channel was present. For the top and bottom of the CFPs, measurements were made 0.3 m (1 ft) below the top and above the bottom of the CFP to avoid trying to take a measurement at the nick point (top) or point where deposition was already occurring (bottom). Depth measurements were taken from the center of the CFP channel width, except in obvious cases where the depths were different across the bottom of the CFP. In those instances, three depth measurements were taken along the bottom of the CFP, at ¼, ½, and ¾ across the width of the channel, and averaged. Ephemeral gullies have nearly vertical sides and therefore a top and bottom width measurement is not significant (USDA-NRCS 2002). Therefore, width measurements were made across the top of each CFP channel. Again, in obvious cases where a channel was more V-shaped, efforts were made to measure the channel width at the bottom and top of the channel, and average the measurements. CFPs were traced upslope only as far as a channel was present. In other words, if a CFP became discontinuous, the first break in the channel was considered the top of the CFP. If the CFP divided in two or more channels, efforts were made to measure the volume of each channel. The four measurements for width and depth along each CFP were averaged and then combined with the total length measurement to estimate the total volume of each CFP. The location of both the top and bottom of the CFP were recorded with GPS. A measurement of slope was also taken from the bottom of the CFP, or edge of the crop field if the CFP extended past the field edge, to the top of the CFP. Measurements were recorded for the distance the CFP or sediment deposition area extended into the forest buffer or grass filter strip. Also, the width of the forest buffer from the crop field edge to the stream bank edge was measured at all CFPs. For grass filter strips, a width measurement was taken at each CFP for the grass filter, and separately for the forest area between the filter strip and the stream bank.

Soil loss calculations. Length, width, and depth measurements of CFPs were used to quantify the amount of soil movement since the last time the CFP was covered by tillage operations. Average bulk density of soil and calculations were based on a USDA-NRCS (2002) publication for estimating soil loss from gully erosion. The calculation $E = V \times 1442 / 1000$ was used where V is the volume in cubic meters, 1442 is the average weight of soil in kilograms per cubic meter, 1000 is the weight in kilograms per metric ton, and E is equal to metric tons of soil erosion or loss since the last tillage. For CFPs that stopped at the edge of buffer/filter, or stopped within the buffer/filter before reaching the stream, the soil was considered to only have moved to the buffer/filter. For CFPs with a continued or integrated channel to the stream, soil moved from the CFP was considered lost to the stream. Only soil movement or loss associated with the crop field portion of the CFP was considered in this study.

Biomass sampling. In May and July 2007, above-ground biomass and woody plant debris for the forest buffers and grass filter strips were determined at all 74 CFP locations. This was done with the goal of understanding whether the amount and type of vegetation present where a CFP meets a buffer or filter is related to whether the CFP continues through the buffer or stops at or within the buffer. All forest buffer and grass filter CFP sites were sampled in late May and the warm-season filter strips were again sampled in late July to obtain biomass samples more representative of peak growth. GPS was used to locate the bottom of each CFP, or point where the CFP interfaced with the buffer/filter. In some instances, where no-till farming had been practiced and the crops were just emerging, CFPs were still visible but in other locations the CFPs had been covered by tilling prior to planting and/or the crops were tall enough that the CFPs were no longer clearly visible. In cases where a CFP was no longer visible, which was generally the case, the GPS location was used to locate the biomass sample plot.

A 0.0004 ha (0.001 acre) circular plot was located at the edge of the natural forest buffer or grass filter for CFPs that stopped at the buffer/filter edge. For CFPs that had channels or sediment deposition areas extending into the buffer/filter, but not all the way to the stream, the plot was located immediately below the channel/sediment in the vegetation that eventually stopped the CFP. For CFPs that extended all the way to the stream channel, a plot was randomly placed either downstream or upstream of the CFP at the edge of the buffer/filter. This upstream/downstream determination was randomly selected before visiting the site. This procedure was judged appropriate to determine the nature of the vegetation that was at the CFP location originally before being removed by erosion. For each plot, percent cover scores were taken for woody stems, grass, weeds/forbs, woody plant debris (leaves, branches, etc.), and total cover. The same percent cover scoring system was used as in the forest floor and shrub cover characterization described earlier. Also, at each plot, two 0.25 m square plots were randomly located halfway between the center point and outside edge of the larger plot in two of the four cardinal directions. The two cardinal directions used were randomly selected for each plot prior to arriving at the plot. In these plots vegetation was clipped to the bare ground and woody plant debris gathered. Vegetation was separated into categories of grass, weeds or forbs, and woody plant debris. The harvested and separated vegetation was placed in brown paper bags and dried for 48 hours at 60 degrees Celsius (140 degrees Fahrenheit). Dry vegetation was weighed, and weights of both samples of the same vegetation type from each plot were averaged. In addition to biomass results for weed/forbs, grass, and woody plant debris, a category for total biomass was included by summing the averaged total from each individual vegetation category for each plot.

Statistical analysis. JMP 6.0 (2005) was used to conduct one-way analysis of variance (ANOVA) tests in comparing slope, length, and volume/size of CFPs, against four different buffer categories/treatments: forest buffer (FB), cool-season grass filter (CSGF), warm-season grass filter (WSGF), and non-buffered (NB). The NB category represents CFP channels that were integrated, or extended entirely through the buffer/filter to the stream channel. Also, CFP slope, length and volume/size were compared between farms using ANOVA to account for any differences between sites. Buffer width analyses using Tukey-Kramer procedure were performed where the average width of buffer/filter was based on measurements made at each CFP (JMP 6.0 2005). The Tukey-Kramer procedure was also used to compare CSGF and WSGF categories for the average percentage of the grass filter width where a CFP channel or sediment deposition area was present and to compare mean biomass amounts of rooted vegetation between buffer types. For ANOVA analysis, Levene's test was used to determine if the variances were equal. If variances were considered unequal, Welch's ANOVA test was used for obtaining a p-value (JMP 6.0 2005).

Results and Discussion

Forest buffer inventory. Figure 2.3 shows results from the forest buffer inventory. Four hundred seventy-four trees were documented and are listed by species. Also shown are average diameters for each species and the mean for all species. The average stand diameter for all trees sampled was 16.3 cm (6.4 inches). Species that had diameters larger than the overall average included pin oak (*Quercus palustris*), shingle oak (Quercus imbricaria), red oak (Quercus rubra), bur oak, (Quercus macrocarpa), honey locust (*Gleditsia triacanthos*), silver maple (*Acer saccharinum*), shagbark hickory (*Carya ovata*), willow (*Salix*) species, and river birch (*Betula nigra*). Species below the average included elm (*Ulmus*) species, cherry (*Prunus*) species, hackberry (*Celtis occidentalis*), black walnut (*Juglans nigra*), osage orange (*Maclura pomifera*), mulberry (*Morus*) species, hawthorn (*Crataegus*) species, boxelder (*Acer negundo*), swamp white oak (*Quercus bicolor*), and bitternut hickory (*Carya cordiformis*). There were an average of 129 trees per hectare (52 trees per acre) across all plots. There were also an average of 309 saplings per hectare (125 saplings per acre) and 6,182 seedlings per hectare (2,503 seedlings per acre). Table 2.4 shows the species and distribution of both saplings and seedlings observed in the study. The quantities of sapling and seedlings indicate that regeneration of tree species should not be a concern. However, these naturally-occurring forest buffers likely will not maintain the same oak overstory dominance after the present overstory oak die. Given that oak species, specifically pin oak

(*Quercus palustris*), were the dominant overstory tree, it would be expected that oak seedlings and saplings would also be abundant. Oak seedlings ranked third among all species, and saplings ranked fifth with only 12 saplings observed. This scenario is occurring across much of the eastern deciduous forests and likely results from a lack of low intensity fire disturbance in which oak seedlings and saplings previously thrived while many competing species were removed (Brose et al. 2001). Without this disturbance, oak seedlings are shaded by understory trees and shrubs and can no longer thrive. Other reasons for oak seedling and sapling decline might include overpopulation of browsers such as white-tailed deer (Brose et al. 2001).

Table 2.5 shows information gathered for shrub species observed as well as average percent cover for shrubs by site and for all plots. Average shrub cover for the 74 sample plots was less than 5% cover, but shrubs were found in 92% of plots. Forest floor percent cover scores from March 2007 were averaged for all 256 plots observed. Total cover was greater than 95%, consisting of woody stems, grass, forbs/weeds, and woody plant debris such as leaves, twigs and branches. Bare soil accounted for less than 5% of the forest floor. However, woody plant debris (leaves, twigs, branches, etc.) made up more than half of the total cover (51-75%), which is cover that is not anchored like rooted vegetation and likely would not provide adequate resistance to surface runoff, as discussed by Daniels and Gilliam (1996). Rooted vegetation such as trees or shrubs, grass, or forbs/weeds represented the remaining 20-44% percentage of forest floor cover.

USDA-NRCS (2004b) encourages high plant densities in Zone 1 (unmanaged forest area adjacent to stream) of the riparian forest buffer practice (CP-22). A density of 549 residual trees per hectare with an average dbh of 5.1-15.2 cm is recommended or 222 trees per hectare in the 20.3-30.5 cm dbh class. Given that the average dbh of 16.3 cm recorded in this study falls between 15.2 cm and 20.3 cm, it can be suggested from the USDA-NRCS (2004b) information that a residual stand goal for the observed forests should be between 222 and 549 trees per hectare. The average of 129 trees per hectare observed falls short of this range, suggesting a higher stocking rate would be necessary to meet the residual stand goals of USDA-NRCS (2004b). USDA-NRCS suggests this stocking rate in part to achieve the intended purpose of trapping debris and slowing flood waters. Because the streams surveyed are all headwaters streams, there would likely be less concern for damaging debris movement and flooding. This would be a concern lower in the watershed, in bottomland areas where concerns of flooding are significant, and debris can move in larger channels, causing damage to property or structures. Personal observation suggests that even with the lower stocking rate, stream channels in the forest buffer areas were at least partially shaded and the forests were providing organic material and woody debris to stream channels. These narrow natural forest buffers are also providing some amount of stream bank stabilization, although studies have not yet examined what amount of stream bank erosion is taking place in this region, and if increasing stocking levels near stream banks is warranted.

While stocking rates for these natural forest buffers could be increased to meet USDA-NRCS recommendations, perhaps the goal for these headwater riparian buffers should be removal of sediment and pollutants from surface runoff coming from row crop fields, given the potential for surface runoff in claypan soils of this region. Rather than increasing the stocking rates of these riparian forests to USDA-NRCS recommended levels, current or even lower stocking rates than those observed would allow more light through the forest canopy, encouraging more rooted ground cover vegetation to grow. This would help to slow and disperse surface runoff and increase infiltration. This relates to work by Lin et al. (2004) who have recommended a cool-season grass filter of tall fescue and brome under trees. Based on their studies in the lab and greenhouse, this design provides high herbicide bioremediation and also high nitrate removal ability. In addition, they also suggest a switchgrass filter adjacent to the row crop field that would be expected to reduce sediment movement and also slow flow rates coming to the riparian buffer. Discussed next are the merits of implementing grass filters alongside these natural forest buffers.

Concentrated flow survey. Seventy-four CFPs were observed in crop fields along the 17.6 km of natural forest buffer and grass filter strip surveyed. Of those, 45 were observed along the 6.7 km of natural forest buffers (FB) and 29 along the 10.9 km of grass filter strips. Figure 2.4 shows the CFPs at one of the grass filter sites used in the study. Of the 29 CFPs observed along grass filters, 21 were along warm-season grass filter strips (WSGF) and 8 were along cool-season grass filter strips (CSGF). No CFPs were observed at one site, the CP-21 WSGF site in the Long Branch Creek watershed. Because of this, all WSGF data reported in the remainder of this paper are synonymous with the CP-33 conservation practice and all CSGF data are synonymous with the CP-21 conservation practice.

Statistical results show there was no evidence of significant difference ($p > 0.05$) for CFPs between the four riparian treatment categories (FB, CSGF, WSGF, NB) for mean slope, length, or volume of CFPs. In addition, when comparisons were made for CFPs between the farms where CFPs were observed, there was also no evidence of significant difference ($p > 0.05$) for mean slope, length, or volume of CFPs. One farm was not included in this comparison because only one CFP was observed at this site and therefore a comparison of mean CFP dimensions using ANOVA was not appropriate. No other site had fewer than 3 CFPs present. This was also the same farm where a portion of the site was not surveyed because of early tillage which further impacted the average CFP dimensions that would have been found at this site. The results are important because they show that the average slope, length, and volumes of CFPs are not significantly different between buffer types or sites. Riparian buffers also would not be expected to have an influence on these parameters as the CFPs develop upslope of the buffers. Also, precipitation records averaged from Mark Twain Lake and Moberly, Missouri between April 1, 2006 and April 1, 2007, indicate below average precipitation for the year preceding this concentrated flow survey. Precipitation for this period was 85.6 cm (33.7 inches). This would suggest that the CFPs observed in late March and the first day of April 2007 would likely occur in any year of average precipitation, with perhaps more erosion occurring with average or greater annual precipitation amounts.

It should be noted that CFPs were found in 11 different soil types. This was determined by analyzing the top and bottom points of the CFP recorded with GPS and correlating these with soil survey information using GIS. Some CFPs occurred in only one soil type, while others crossed over into two or more soil types. Only one soil type, Keswick loam, was listed as having a slope greater than 10% (Watson 1979; Young and Geller 1995). CFPs were observed primarily in the following soils: 59% in Leonard silt loam; 22% in Keswick loam; 20% Mexico silt loam; 9.5% in Leonard silty clay loam. Other soil types were seen in less than 5% of all CFPs observed.

The survey for CFPs also found 39 grass waterways in the crop fields connecting to the FB or grass filter strips. This is important because the presence of these waterways decreased the number of CFPs observed since grassed waterways are shaped, graded and planted to suitable vegetation to stabilize concentrated runoff without causing erosion or flooding (USDA-NRCS 2000). However, some were in poor condition with 5 of the 39 grass waterways having CFPs along the edge of the waterway which were later covered by tillage and planted to crops, and were therefore counted as part of the 74 CFPs observed.

Of the 74 CFPs surveyed, 39, or 53% of CFPs, were located in crop fields that were terraced. This is important because it shows that even where terraces are located in fields, CFPs can form between the last terrace and the edge of the field. However, only 5% of the CFPs observed in fields with terraces continued through the buffer areas, whereas 20% of CFPs in non-terraced fields continued through the buffers. Although not significantly different, mean CFP lengths in fields without terraces were 56.5 m and 42 m in fields with terraces. This may suggest that terracing reduces the lengths of CFP that develop, however, further research would be needed to understand the importance of terraces and the effect on CFP movement through buffers.

Volume estimates for all 74 CFPs indicate that 473 metric tons of soil had moved downslope toward the riparian areas since the last tillage. Figure 2.5 shows pictures of a CFP in March 2007 during the CFP survey and the same location again in May 2007 after tillage and corn planting covered the CFP. Table 2.6 shows average CFP size and Table 2.7 shows the amount of soil movement associated with different buffer types (FB, WSGF, CSGF) and the amount of soil erosion that was not buffered (NB) because the CFP channels were integrated all the way through the buffers to the stream channel. Only 9 of the 74 observed CFPs were in the NB category, and all occurred at FB sites. Field measurements estimated that these 9 CFPs accounted for 97 metric tons of soil loss. This assumes that 100% of soil eroded from the CFP made it through the integrated channel network to the stream, whereas research discussed earlier suggests that the actual sediment delivery rates may be 50-90%. Table 2.7 shows the percentage of CFPs buffered or dispersed by different buffers. The FB strips buffered 80% of CFPs and the grass filter strips (both WSGF and CSGF) buffered all the CFPs coming to them. It can be assumed that even though CFPs are buffered and flow dispersed, a percentage of sediment and pollutants would remain suspended and move through the grass filter strips or forest buffers to streams. This can be assumed because even in studies where surface runoff arrives at the buffer as dispersed runoff, not all pollutants are removed (Lee et al 1999, 2003; Rankins et al. 2001; Schmitt et al. 1999). The amount of sediment and other pollutants continuing through the buffer would be of particular concern in forest buffer areas where CFPs were dispersed only several meters from the stream channel. However, for the purpose of remaining consistent, if a CFP was not continuously integrated or connected to the stream, the buffer was deemed to be serving a purpose. As Dabney et al. (2006) notes, it is wrong to assume that even very narrow buffers do not improve water quality.

One explanation for CFPs having integrated channels through the narrow forest buffers may be the low percentage of rooted vegetation on the forest floor compared to that found in a grass filter. However, from personal observation, many areas along the natural forest buffer sites have a narrow cool-season grass area or densely vegetated area along the edge of the forest buffer at the interface with the crop field because of increased sunlight. Like Daniels and Gilliam (1996) found, this may be important for dispersing 80% of CFPs when reaching the forest buffer. However, if the concentrated flow can move through this narrow area, erosion may take place in soils under the less protected forest floor, as seen in the NB instances.

To investigate what amounts of vegetation are at various buffer edges, and attempt to understand why grass filters appear to better disperse CFPs, biomass was collected from the edge of the buffers/filters at CFP locations. Table 2.8 shows the mean amounts in grams of dry biomass in different vegetation types from CFP locations at different buffer types. While the FB and NB areas had the highest woody plant debris biomass, and therefore high amounts of total biomass, the woody plant debris biomass is not rooted plant material. When looking at the forb/weed+grass category, representing rooted plant material, CSGF and WSGF areas had higher mean biomass when compared to FB and NB areas, although these differences are not statistically different. Likely, because these samples were taken at the edge of the buffer/filter, biomass amounts of rooted vegetation for the FB and NB areas are more than what would be seen under the forest canopy closer to the stream, due to increased sunlight at the forest edge. As mentioned before, if concentrated flow can make it through the FB edge, it may begin to erode the forest floor and then connect to the stream channel. Conversely, a grass filter's rooted vegetation should remain consistent throughout the filter. Data from Table 2.8 represents biomass samples gathered in May 2007, except for the WSGF area which was gathered in late July 2007, considered to be more representative of peak growth for warm-season grass filters.

Buffer widths could also explain why CFPs continue through narrow forest buffers. Mean widths of grass filter strips (WSGF and CSGF) at CFP locations were not significantly ($p > 0.05$) wider than natural forest buffers at CFP locations that were not buffered (NB). However, this was considering only the grass width. Every grass filter strip also had a natural forest buffer between the grass filter strip and stream. When adding this natural forest buffer width to the grass filter strip width, there is evidence of a significant difference ($p < 0.05$), compared with the mean NB width. The results are not the same when comparing the mean buffer widths at CFP locations for FB sites versus NB (also forested sites). There was no evidence of significant difference ($p > 0.05$) in mean buffer widths between these two categories. Figure 2.6 shows the mean buffer widths at CFP locations for different buffer categories that have been discussed. All this information points to the idea that the amount of rooted vegetation and buffer width may have an important impact on whether a CFP will be buffered.

In the grass filters, CSGF (CP-21) sites were covered by both tall fescue (*Festuca arundinacea*) and/or timothy (*Phleum pratense*) species. WSGF (CP-33) areas were planted to a combination of forbs, little bluestem (*Schizachyrium scoparium*), and sideoats grama (*Bouteloua curtipendula*) which were all present. In addition at these WSGF sites, switchgrass (*Panicum virgatum*) and a cool-season grass, foxtail (*Setaria faberi*), were present. There was no significant difference ($p > 0.05$) in how far the CFP channel or sediment deposition area extended into CSGF and WSGF sites. In CSGF sites CFPs or sediment deposition areas extended in on average 16.5% of the total filter width while in the WSGF they extended across 14.2% of the width. These percentages may be of concern when considering the ages of the grass filters, especially the WSGF. CSGF sites had been established in 2001, 2002, and 2004. WSGF sites were established only one year prior to this study, in spring of 2006. Given that after one year of establishment, CFPs and their sediment deposition areas are on average extending into 14.2% of the WSGF, observations should be made at these sites each year to examine the effectiveness of the grass filters at buffering CFPs. If CFPs continue through a grass filter strip, the USDA-NRCS (2005) would recommend regrading and reseeding, in order for the grass filter strip to perform at maximum efficiency. Concerns are not limited to the CP-33 practice. One particular CFP at a CSGF (CP-21) site stands out where the grass filter was considered effective because the channel portion of the CFP ended at the field edge but the sediment deposition area continued nearly through the entire width of the grass filter. These areas are likely what Dillaha et al (1986) considered to be ineffective, when they described how Neibling and Alberts (1979) found that grass filters become buried with sediment, and subsequent movement of sediment into the filter results in a wedge-shaped deposit of sediment through the filter. In this case, the grass filter strip had obviously trapped large amounts of sediment. However, during subsequent flow events, the grass filter effectiveness was likely reduced. Returning to the filter in late May, the grass had grown up vigorously through the sediment in most of the deposition area. In areas such as these, if grass had not grown back, sediment removal may have been recommended as well as reseeding at a high rate to maximize the effectiveness of the grass filter. This type of situation may also call for in-field conservation practices to improve the effectiveness of the grass filter.

Other concerns about the CP-33 (WSGF) practice being used as a deterrent to CFPs were discovered during this research. Results for percent cover scores where the CFP intersected with the grass filter show average percent cover for CP-22 (CSGF) sites total 97% cover in late May. WSGF sites had an average of 69% total cover in July. Grass cover for CSGF sites was 76-100% but WSGF sites had grass cover of 26-50%. Bare soil, weeds/forbs, and woody plant debris each totaled less than 5% at CSGF sites. At WSGF sites, weed/forb cover was 5-15%, woody debris less than 5%, and bare soil averaged 31%. While the grass+weed/forbs cover together total 31-65% for the WSGF sites, this is not a great deal higher than percent cover scores of 20-44% for rooted vegetation under the forest canopy for the forest floor examined in late March. However, as Dabney et al. 2006 reviews, certain grasses such as switchgrass have high hydraulic roughness. This would provide more resistance to surface runoff, which slows surface runoff and allows more contact time with the grass filter for dispersal, infiltration or sediment trapping. USDA-NRCS (2004a) suggests maintaining vegetation in CP-33 field borders to at least 80% cover, however, USDA-FSA (2006) suggests that seeding for CP-33 field borders should occur at much lighter rates than for CRP practices aimed at soil conservation and water quality enhancement. This is likely because the primary goal for the CP-33 program is to promote habitat for upland birds which prefer less dense vegetation for habitat, especially for nesting and brood rearing. However, this may be cause for concern when discussing using this practice as a buffer to concentrated surface runoff.

Data was also collected for CFPs or larger classic gullies found not in the crop fields but within all forest buffers. These were found by walking the stream bank edge since not all could be seen from the crop field–buffer edge. At grass filter sites, CFPs were found within the natural forest buffers between the grass filter strip and stream channel. CFPs continued to the stream channel, sometimes extending through the entire width of the forest buffer but never extending into the grass filter. At grass filter sites these CFPs appeared to no longer be active as they likely developed prior to the grass filter being planted and were no longer receiving surface runoff directly from the crop field (Figure 2.7). At forest buffer sites, many CFPs appeared to be active and scoured with bare soil present from recent concentrated flow. Along the 10.9 km of stream with grass filter strips, there were 27 CFPs occurring in the natural forest buffer. Along the 6.7 km of natural forest buffers without grass filters surveyed, 33 CFPs were observed, including the 9 CFPs discussed earlier that were connected with the cropfield CFPs that were not buffered to the stream. The presence of numerous CFPs within the narrow forest buffers are again an indicator that alone, these narrow forest buffers are not providing adequate buffering to surface runoff. Surface runoff may move through the forest buffer a short distance before converging at a CFP within the forest buffer, or may receive no filtering at all given that some CFPs extent across the entire forest buffer width. Dabney et al. (2006) suggest that CFPs like those observed in the forest buffers may carry runoff that moves along the field edge after being redirected by berms created from tillage. Again, grass filters can create a buffer between surface runoff from crop fields and CFPs in the forest buffers.

In addition to the CFPs mentioned above, during field observations, classic gullies at the bottom of grassed waterways were also observed. These were grass waterways that extended from the crop fields to stream channels, intersecting with forest buffers or grass filters. At natural forest buffer sites, 13 of these grassed waterway gullies were observed, and another 8 at the grass filter sites. This indicates that grassed waterways are doing the job of moving runoff from the fields, but in some cases (21 of 39), not slowing runoff enough to prevent headcutting and erosion at the base of the grassed waterway where it connects with the riparian buffer and stream channel.

Summary and Conclusions

This study examined riparian buffers along first and second order stream segments, located on 11 farms in northeast Missouri. This study tested the hypothesis that where CFPs occur in upland row crop fields, and move to narrow, natural forest buffers, the majority (>50%) of CFPs would continue through these forested areas, rendering them ineffective as a buffer of surface runoff to streams. It was further hypothesized that where natural buffers have been enhanced with grass filter strips under USDA-NRCS sponsored conservation programs, CFP channels would be intercepted and flow dispersed within the filter strips before reaching streams.

Results did not support the first hypothesis in that 80% of CFPs that flowed to natural forest buffers were dispersed or buffered according to the parameters of the study. This percentage may have been lower had it not been for terracing and grassed waterway practices occurring on these farms. Twenty percent of CFPs were not buffered and continued to the stream channels, resulting in an estimated 97 metric tons of soil loss to streams. Numerous CFPs or classic gullies were observed occurring in the forest buffers with and without grass filters, eliciting more concerns about the effectiveness of narrow forest buffers. The presence of these CFPs or classic gullies in the forest buffers, even where concentrated flow is not evident in the crop fields, suggests that runoff is converging and moving through natural forest buffers with little buffering. The second portion of the hypothesis was not rejected as all CFPs from crop fields were dispersed by grass filters. Grass filters were also providing a buffer between the crop field and natural forest buffers where CFPs or classic gullies were present. Even on farms with conservation practices such as terracing and grass waterways, CFPs are still occurring, causing soil loss from crop fields to riparian areas, suggesting the need for more conservation practices both in the row crop fields and at the edge of fields. Crooked Creek, Otter Creek, and Long Branch Creek watersheds contain approximately 759 km of first and second order streams, according to data obtained from CARES. Given the ability of grass filters to disperse and buffer concentrated flow paths from crop fields as demonstrated in this study, adding more grass filter strips in these watersheds could reduce the sediment loads in these watersheds.

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Table 2.1

Minimum and maximum buffer widths for various types of incentive-based government buffer programs (USDA-FSA 2006).

Buffer Type	Minimum Width (m)	Maximum Width (m)
Grass Filter (CP-21)	6.1	36.6
Riparian Buffer (CP-22)	30.5 or 30% of geomorphic floodplain, whichever is less	54.9
Field Borders (CP-33)	9.1	36.6

Table 2.2

Existing forest and/or grass riparian buffers in Crooked Creek, Otter Creek, and Long Branch Creek watershed in NE Missouri. Information reported by Herring et al. (2006).

Stream order	Buffer Width (m)	% Stream length buffered			
		Crooked Creek	Otter Creek	Long Branch	Mean
1	15	85	76	66	75
	30	75	63	54	64
	46	59	46	37	48
	61	52	39	31	41
2	15	93	88	76	86
	30	86	78	65	76
	46	74	63	48	62
	61	65	53	41	53

Table 2.3

Lengths of various buffer types (FB = natural forest buffer, CSGF = cool-season grass filter, WSGF = warm-season grass filter, CP-21 = grass filter strip, CP-33 = habitat buffer for upland birds or field border) used in this study.

Buffer Type	Distance Surveyed (km)
FB	8.8
Grass Filter Total (All Types Surveyed)	10.9
CSGF	7.5
WSGF	3.4
CP-21	8.0
CP-33	2.9
Total	19.7

Table 2.4

Species and number of saplings observed at 74 tree inventory plots. Also, species and number of seedlings observed at 296 smaller seedling and forest floor inventory plots, located within the larger tree inventory plots.

Saplings	Number Observed	Seedlings	Number Observed
Celtis occidentalis	40	Prunus species	294
Juglans nigra	37	Celtis occidentalis	124
Prunus species	33	Quercus species	122
Ulmus species	28	Ulmus species	63
Quercus species	12	Carya species	35
Carya species	9	Gleditsia triacanthos	24
Acer negundo	5	Zanthoxylum clava-herculis	23
Acer saccharinum	5	Fraxinus species	19
Fraxinus species	5	Juglans nigra	17
Gleditsia triacanthos	4	Acer saccharinum	10
Zanthoxylum clava-herculis	4	Unknown	5
Maclura pomifera	1	Morus species	4
Morus species	1	Acer negundo	1
Unknown	1		
Total Saplings	185	Total Seedlings	741
Saplings/hectare	309	Seedlings/hectare	6,182

Table 2.5

Shrub species observed and percentage of 74 plots they were observed. Also, shrub percent cover averaged for each site and across all plots.

Species	**Percent of Plots Shrub Observed**
Symphoricarpos orbiculatus	80%
Ribes species	49%
Sambucus canadensis	31%
Rosa species	19%
No shrubs present	8%
Cornus species	4%
Rhus species	4%
Amorpha fruticosa	1%
Site	**Percent Cover**
1	<5% (1-2 individuals or clusters)
2	<5% (few to many individuals)
3	<5% (numerous individuals)
4	<5% (numerous individuals)
5	5-15%
6	16-25%
7	<5% (numerous individuals)
Average for all plots	<5% (numerous individuals)

Table 2.6

Average dimensions for 74 CFPs observed.

Mean CFP Dimensions	
Length	48.6 m
Depth	6.9 cm
Width	89.3 cm
Volume	4.4 m^3

Table 2.7

Metric tons of soil movement and loss to riparian areas or to streams (NB) from concentrated flow paths (CFPs) along various buffer types. Riparian buffer types include: natural forest buffers (FB); warm-season grass filters (WSGF); cool-season grass filters (CSGF), and areas where the CFP channel cut all the way through the buffer thereby not buffering soil erosion (NB). A CFP is considered buffered if the channel of the CFP is not present through the entire buffer width, leading to dispersed flow at some point before or within the buffer.

Riparian Buffer Type	Number of CFPs	Soil movement to a buffer or loss (NB) in metric tons	Percent of CFPs buffered
All buffer types	74	473	88%
FB	45	370	80%
WSGF	21	84	100%
CSGF	8	20	100%
All grass filters	29	104	100%
NB (all FB)	9	97	0%

Table 2.8

Mean dry biomass weights in grams for different vegetation types in different buffer categories. Buffer categories are: cool-season grass filters (CSGF), warm-season grass filters (WSGF), natural forest buffers (FB), and locations at natural forest buffers where concentrated flow is not buffered by the natural forest buffer (NB).

	Biomass In Grams For Buffer Categories			
Vegetation Type	CSGF	WSGF	FB	NB
Forb/Weed	0.9	21.8	17.6	17.2
Grass	54.4	23.9	23.3	26.2
Forb/Weed+Grass	55.3	45.7	40.9	43.4
Woody Plant Debris	1.2	0.2	21.7	14.4
Total	56.5	45.9	62.7	57.8

Figure 2.1

Map showing Crooked Creek, Otter Creek, and Long Branch Creek watersheds where all farms in the study were located. These watersheds are part of the larger Salt River watershed, shown here above the Clarence Cannon dam at Mark Twain Lake.

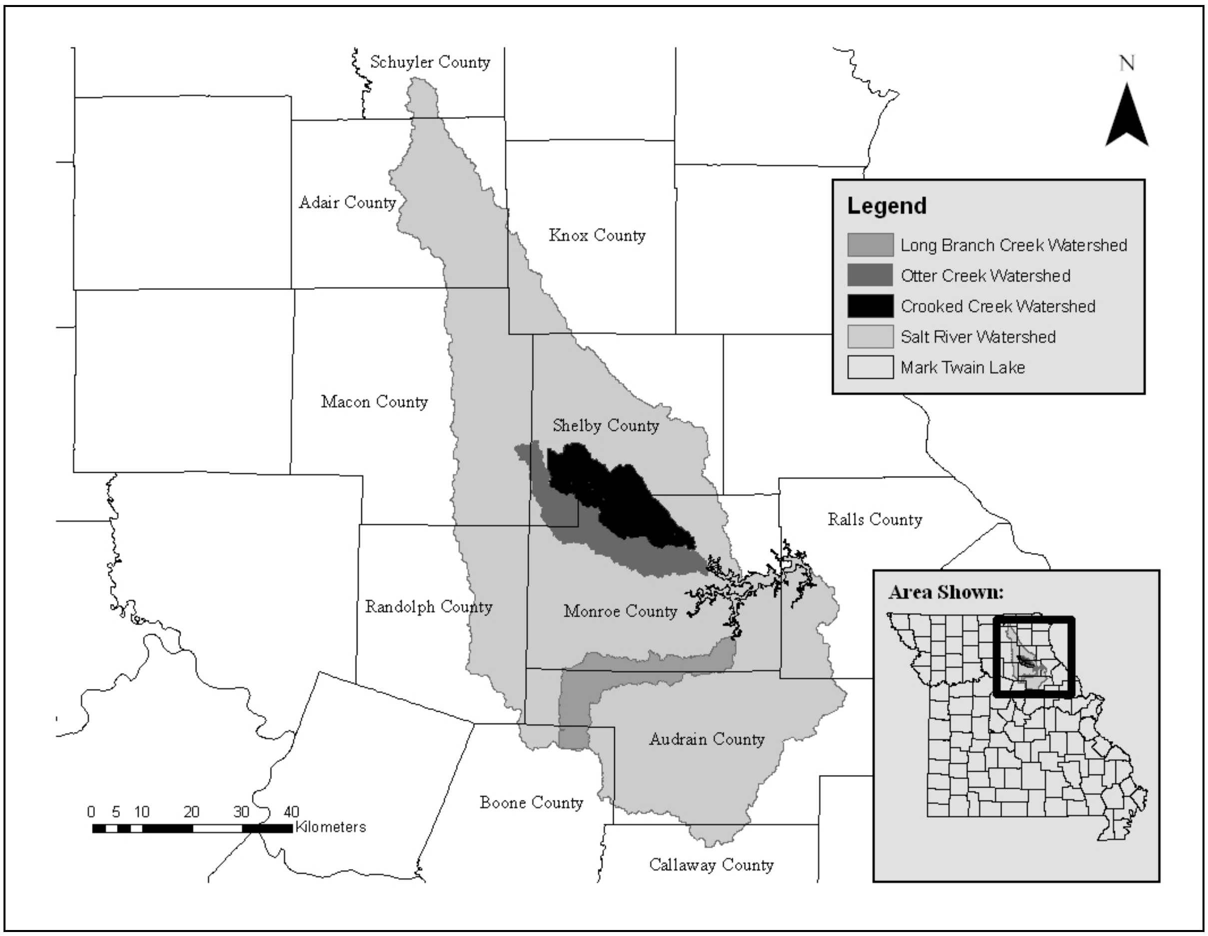

Figure 2.2

Map showing sample location layout for the forest buffer inventory at one natural forest buffer site. Sample locations were identified in GIS and located in the field using GPS. Center points of actual sample plots were located halfway between the stream bank and forest edge. The first set of plots, one on each side of the stream and directly across from each other, were located 10 m from the downstream end of the inventory site and subsequent plots were located 134 m apart.

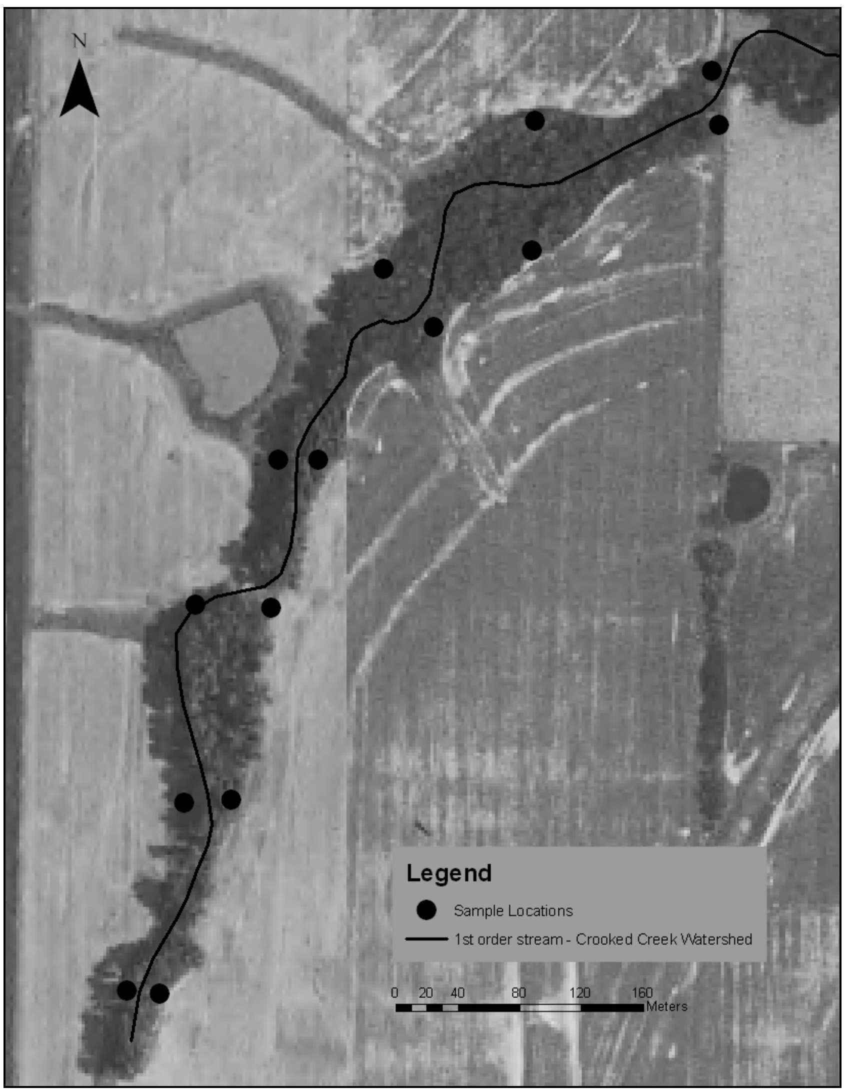

Figure 2.3

Species distribution for the 474 trees observed and average diameter for each species and for all species at natural forest buffer sites.

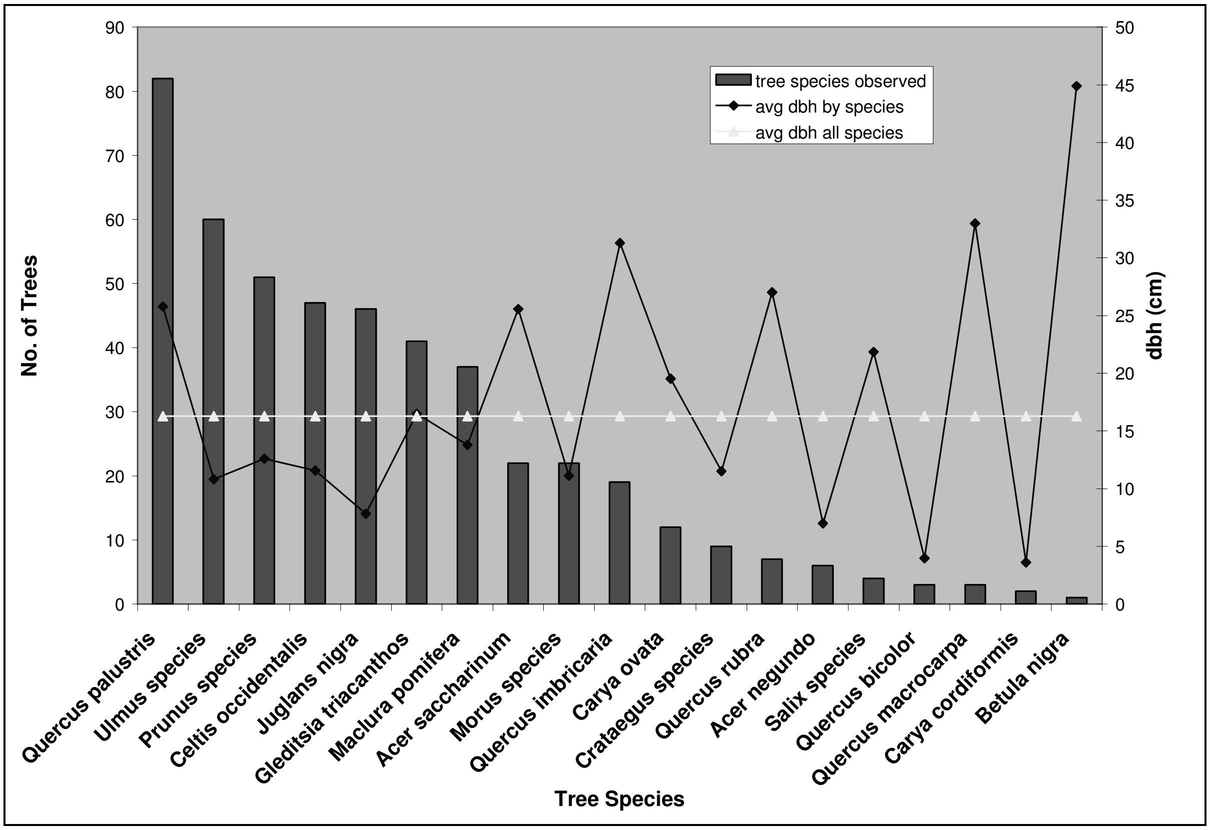

Figure 2.4

Concentrated flow paths (CFPs) observed at this site with a warm-season grass filter (WSGF) along two first order streams in Otter Creek watershed. The WSGF is just becoming visible in the bottom portion of this aerial photo where the two southernmost CFPs occur. In other areas, the WSGF is not yet visible as the filter was planted in spring 2006, around the same time the aerial photo was taken. The black circles represent GPS points from spring 2007, showing the top and bottom of the CFP, where it is stopped by the grass filter. The lines drawn between the points do not represent the actual flow path of the CFP.

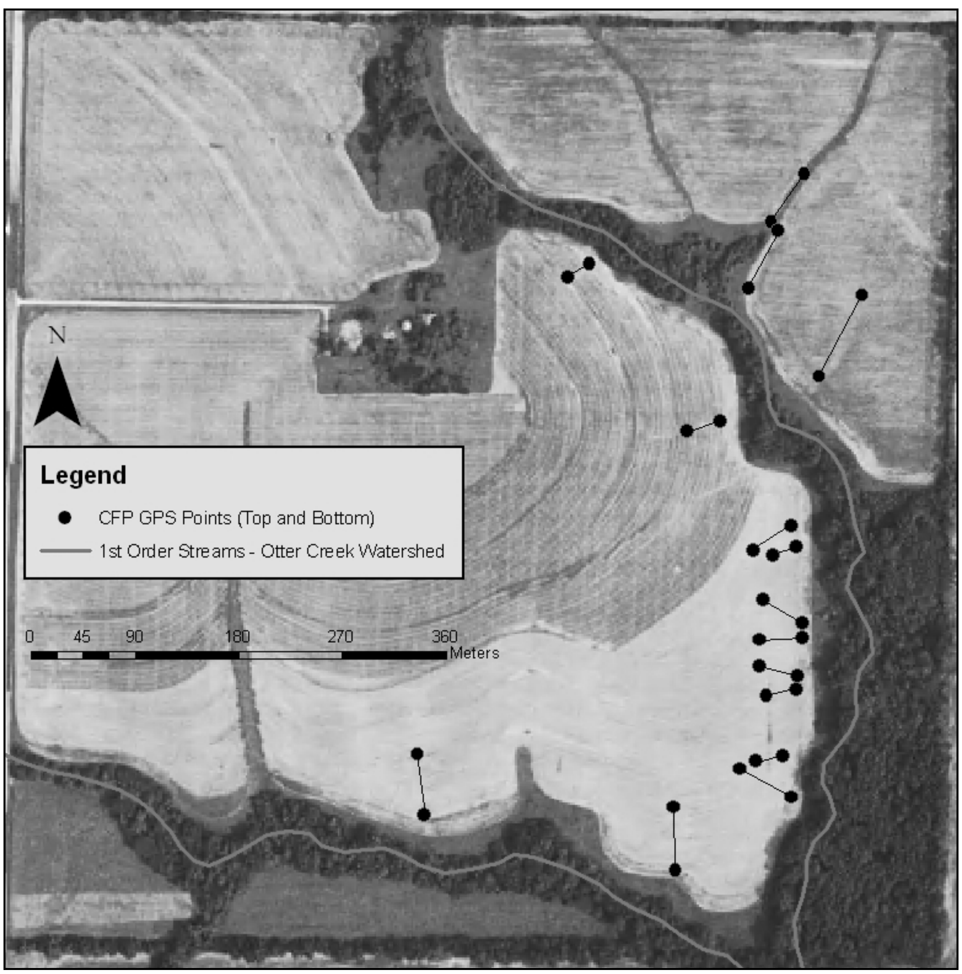

Figure 2.5

Two pictures showing the same CFP area, the picture to the left taken in March 2007 before spring tillage, and the picture to the right taken in May 2007 after spring tillage and corn planting. The tree located in the upper right hand corner of each picture is useful for comparison purposes.

Figure 2.6

Mean buffer widths for the various buffer categories analyzed. Buffer widths were measured where each CFP interfaced with buffer/filter. Buffer types include: grass filters including the natural forested buffer between the grass filter strip and stream (GF +forest area); grass filters where only grass portion is considered (GF); forest buffers (FB); and areas where a CFP channel continued all the way to stream channel and no effective buffer was present. (NB).

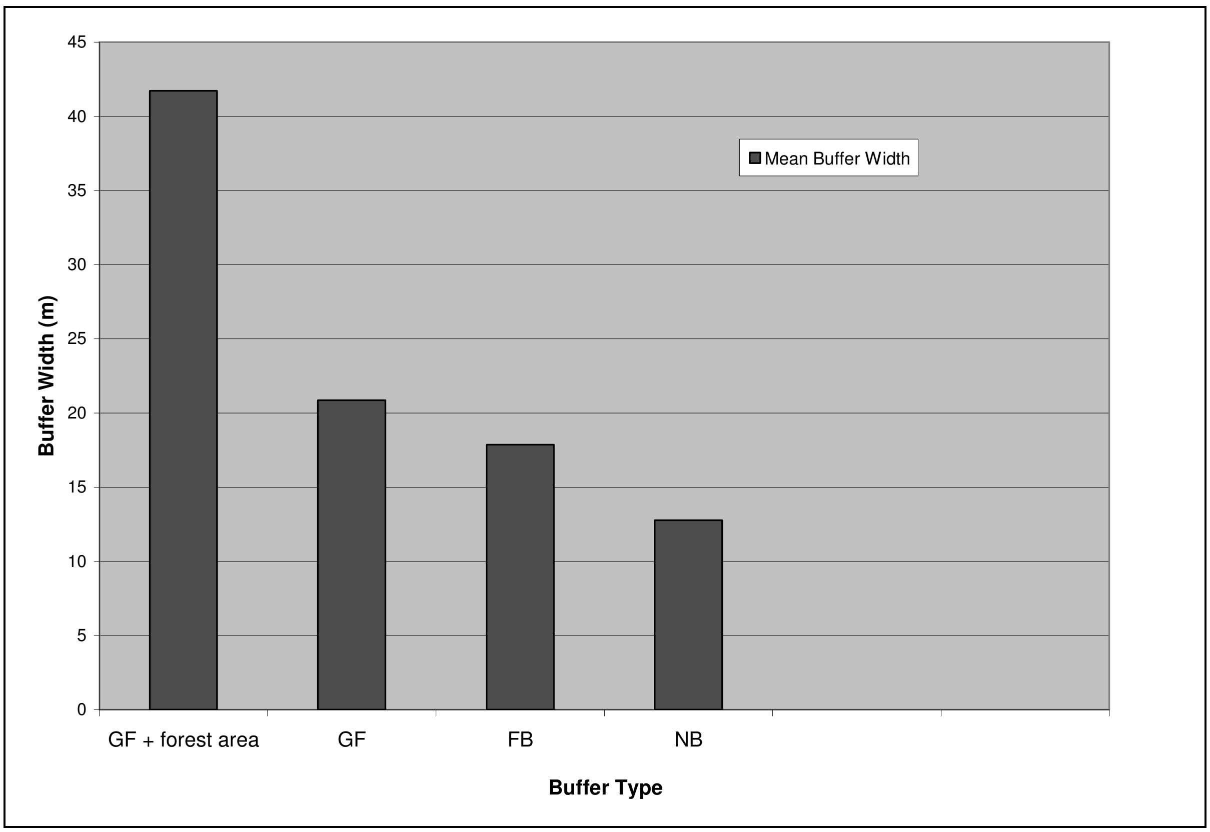

Figure 2.7

A grass filter strip between a crop field and a natural forest buffer. The head cut of a classic gully that connects to the stream channel through the forest buffer is shown. Prior to the establishment of the grass filter strip, the classic gully likely had a direct connection to surface runoff coming from the crop field.

Chapter 3. General Conclusion

Summary of results

This study examined riparian buffers along first and second order stream segments, located on 11 farms in northeast Missouri. The study was designed to address several suggestions for riparian buffer research as presented by Lowrance et al. (2002): 1) evaluate buffers at the field, farm, and watershed scale; 2) examine the effects of incentive-based buffer programs; and 3) examine various buffer widths and plant communities as buffers for trapping surface runoff and effectively converting channelized flow from fields to diffuse flow. This study tested the hypothesis that where concentrated flow paths (CFPs) occur in upland row crop fields, and move to narrow, natural forest buffers, the majority (>50%) of CFPs would continue through these forested areas, rendering them ineffective as a buffer of surface runoff to streams. It was further hypothesized that where natural buffers have been enhanced with grass filter strips under USDA-NRCS sponsored conservation programs, CFP channels would be intercepted and flow dispersed within the filter strips before reaching streams.

Results did not support the first hypothesis in that 80% of CFPs that flowed to natural forest buffers were dispersed or buffered according to the parameters of the study. This percentage may have been lower had it not been for terracing and grassed waterway practices occurring on these farms. Twenty percent of CFPs were not buffered and continued to the stream channels, resulting in an estimated 97 metric tons of soil loss to streams. Numerous CFPs or classic gullies were observed occurring in the forest buffers with and without grass filters, eliciting more concerns about the effectiveness of narrow forest buffers. The presence of these CFPs or classic gullies in the forest buffers, even where concentrated flow is not evident in the crop fields, suggests that runoff is converging and moving through natural forest buffers with little buffering. The second portion of the hypothesis was not rejected as all CFPs from crop fields were dispersed by grass filters. Grass filters were also providing a buffer between the crop field and natural forest buffers where CFPs or classic gullies were present. Even on farms with conservation practices such as terracing and grass waterways, CFPs are still occurring, causing soil loss from crop fields to riparian areas, suggesting the need for more conservation practices both in the row crop fields and at the edge of fields. Crooked Creek, Otter Creek, and Long Branch Creek watersheds contain approximately 759 km of first and second order streams, according to data obtained from CARES. Given the ability of grass filters to disperse and buffer concentrated flow paths from crop fields as demonstrated in this study, adding more grass filter strips in these watersheds could reduce the sediment loads in these watersheds.

Recommendations for future research

More research is needed to support or refute results described in this study, specifically by visiting more farms and streams and by doing so, observing more grass filters, forest buffers and CFPs. It would be important to further study pollutant levels in surface runoff moving through grass filters and forest buffers, especially downslope of CFPs in row crop fields. It would also be important to conduct more extensive research determining the effectiveness of CP-33 field borders in buffering or dispersing concentrated flow and surface runoff, especially field borders that have been in place longer than one year. This is suggested because of the low density of grass and other rooted vegetation observed in field borders observed in this study.

Finally, as Dabney et al. (2006) have described, work needs to be done exploring the effectiveness of combining edge-of-field and in-field buffers to disperse concentrated flow and prevent erosion.

As for land managers and landowners, grass filters should be more widely considered as a practice to enhance naturally-occurring forest buffers. Where grass filters have been implemented, checks need to be made to ensure grass filters are not being overwhelmed by concentrated flow. Where they have been overwhelmed, steps should be taken to fix the problem by grading, reseeding, or looking for other solutions such as pairing in-field buffers with grass filters or finding other ways to disperse the concentrated flow before it reaches the grass filter.

References

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