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RIPARIAN FORESTS WITH AND WITHOUT GRASS FILTERS AS BUFFERS OF CONCENTRATED FLOW FROM CROP FIELDS

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Abstract: A vegetation inventory within naturally occurring forested riparian buffers (natural forest buffers) and a survey comparing buffering of concentrated flow paths (CFPs) by natural forest buffers with and without planted grass filters was conducted along first and second order streams in three northeast Missouri watersheds. Seven natural forest buffers without grass filters were inventoried and found to be composed of dense stands of mixed tree species with a forest floor cover comprised largely of unrooted woody plant debris, which does not adequately buffer concentrated runoff. Seventy-four CFPs were found in row crop fields along 10 natural forest buffers with or without grass filters established using USDA conservation practice standards. Natural forest buffers without grass filters dispersed 80% of CFPs before they reached the stream, while those with grass filters dispersed 100%. We estimated 473 metric tons of sediment moved to the buffers/filters via CFPs since last tillage. Nine of the 74 CFPs passed completely through natural forest buffers without grass filters, and accounted for 97 metric tons of the total estimated 473 metric tons. The average width of breached forest buffers without grass filters was 12.8 m, while the width of those not breached was 17.9 m. Average width of cool-season grass filters (CSGF) adjacent to forest buffers was 17.6 m, while average width of warm season grass filters (WSGF) was 22.1 m. These data, along with previous research, suggest that adding a grass filter along narrow natural forest buffers would improve water quality by reducing sediment loss to streams.

Key Words: Erosion; sediment transport; concentrated surface runoff; restoration

INTRODUCTION

Riparian buffers provide multiple environmental benefits to streams (Broadmeadow and Nesbitt, 2004; Lowrance *et al*., 2002; Schultz *et al*., 2004). Most of these benefits have been described from riparian buffers that were designed specifically as buffers, or from plot-scale experiments. Little is known about the ecological effectiveness of naturally occurring forested and grass riparian areas along streams, although it is often assumed they function much like designed riparian buffers. While Cooper et al. (1987) found that most of the sediment leaving agricultural fields was deposited within 100 m of the edge of the crop field in an adjacent natural forested riparian area, many naturally occurring riparian buffers along headwater streams in the agriculturally dominated landscapes of the Midwestern U.S are narrower than that. For example, in a study from Missouri, only 41, 53 and 66 percent of the stream lengths of first, second and third order streams, respectively, had riparian forest or other perennial plant community buffers as wide as even 61 m (Herring *et al.*, 2006). The ability of these narrow riparian forests, to capture nutrients and slow surface runoff, especially from concentrated flow paths (CFPs), has not been determined. CFPs carry sediment and nutrients to streams through both rill erosion and ephemeral gullies (USDA Natural Resource Conservation Service, USDA-NRCS, 1998).

Grass filter strips have been shown to be effective at reducing sediment, nutrients and herbicides from sheet or inter-rill erosion (USDA-NRCS, 2005; Lee *et al*., 2003; Rankins *et al.*, 2001). However, they and riparian buffers, individually, appear to be less effective when flow is from concentrated rill or ephemeral gullies (Dillaha *et al*., 1986; Dosskey *et al*., 2002; Helmers *et al.*, 2005). However, if grass filters are adjacent to naturally forested areas, research suggests that sediment loads from sheet and rill flow from adjacent crop fields can be reduced by 60-90% (Daniels and Gilliam, 1996).

In this study, we compared the environmental benefits associated with capturing surface runoff in narrow, naturally occurring forested riparian areas (natural forest buffers) with those associated with grass filters that meet USDA-NRCS criteria. The first objective of this study was to describe the vegetation composition in natural forest buffers along first and second order stream segments in northeast Missouri. The second objective was to compare the effectiveness of these natural forest buffers, with and without approved USDA-NRCS grass filters, to buffer CFPs from row crop fields to first and second order streams.

MATERIALS AND METHODS

The study was conducted in Crooked Creek (28,814 ha), Otter Creek (26,709 ha), and Long Branch Creek (26,487 ha) watersheds in the Claypan Prairie ecoregion of north-eastern Missouri (Figure 1) (Chapman *et al*., 2001). Crooked, Otter, and Long Branch Creek watersheds are 58%, 66%, and 71% row crop land, respectively. 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). Average annual precipitation for this region is 99-102 cm yr^{-1}, two-thirds of which falls between April and September (Watson, 1979; Young and Geller, 1995). The period of highest rainfall is also when most 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 (Lerch and Blanchard, 2003).

Natural forest buffers 10-30 m wide and lengths of at least 402 m, without adjacent grass filters, were selected by examining aerial photos of all first and second order streams in the three watersheds using GIS. Property owners of farms totaling 8.8 km of buffers that met these criteria granted permission to access them. In addition, forest buffers with adjacent grass filters were located by contacting USDA-NRCS offices and were considered if the grass filter was established as either a grass filter strip (CP 21) or field border (CP 33) (USDA-NRCS, 2008). Except for length, the same site requirements as for the natural forest buffers without adjacent grass filters were used. These sites varied from 380 m to 2,800 m in length. All property owners with these grass filter strips agreed to participate in the study. Forest buffers with adjacent field borders were planted in warm-season grasses and forbs, and are referred to as warm-season grass filters (WSGF) while the sites enrolled as grass filter strips were planted to cool-season grasses and are referred to as cool-season grass filters (CSGF); WSGF and CSGF sites are referred to collectively as grass filter sites. The total length of forest buffers with CSGF was 7.5 km and with WSGF was 3.4 km. CSGF were established between 2001 and 2004, and WSGF was established in spring 2006.

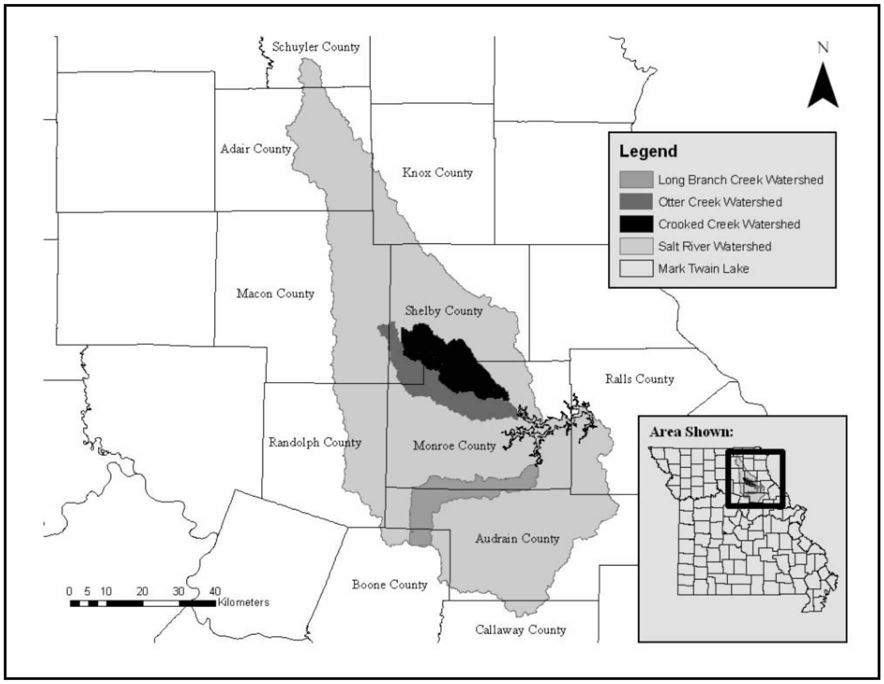

Figure 1. Map showing the location of Crooked Creek, Otter Creek, and Long Branch Creek Watersheds.

Natural forest buffer inventory plots (74 total) were placed every 134 m along the 402+ m length of buffer to ensure a minimum of 3 plots as suggested by USDA-NRCS (n.d.). The center point of each plot was placed halfway between the top of the stream bank and the edge of the forest canopy adjacent to the crop field. Sample plots were 0.008 ha (0.02 acre) circles with a fixed radius of 5.08 m. Plots were inventoried in September and October 2006 before leaf fall. In 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: 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 (<2.5 cm dbh and <1.5 m in height) density. Circular plots of 0.0004 ha (0.001 acre) with 2.28 m diameters were located at each of the four cardinal directions 2.5 m from the center of the larger sample plot. Seedling species were recorded in 296 of these smaller plots. In March 2007, forest floor cover was inventoried at 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. All but one site had not had cattle grazing for more than 5 yr, and 5 of the 7 sites had not been grazed in more than 15 yr.

The term concentrated flow path (CFP) is used in this study to describe the rills or ephemeral gullies observed in row crop fields. In late March and early April 2007, CFP surveys were completed by walking 6.7 km of natural forest buffers without grass filters and 10.9 km of natural forest buffers with grass filters. March and early 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. CFPs were identified as any visible eroded flow path or channel in the crop field which intersected a 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 natural forest buffers were also surveyed to determine if there were CFPs that had developed in the buffers but whose field source was not evident.

The length of identified CFPs was measured by pacing, and widths and depths measured with a tape at the top, one-third, two-thirds and bottom of the total length of the CFP. CFPs were traced upslope only as far as a channel was present. 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. 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 a sediment deposition fan met the grass filter or forest buffer, the bottom measurement of the CFP was made at the last point where a channel was present, just upslope of the sediment fan. The top measurement of the CFP was made 0.3 m below of the start of the channel to avoid trying to take a measurement at the nick point. The location of both the top and bottom of the CFP were recorded with GPS. Slope and depth of each channel were also measured from the bottom to the top of the CFP (USDA-NRCS, 2002). Finally, the distance the CFP or sediment deposition extended into the forest buffer or grass filter and the width of the buffer filter from the crop edge to stream edge were measured.

CFP measurements were used to estimate the amount of soil movement since the last time the CFP was covered by tillage operations. The four measurements of CFP width and depth were averaged and then combined with the total length measurement to estimate the total volume of each CFP. Average bulk density of soil and calculations were estimated using the formula $E = V(1442/1000)$, where V is the volume in m^3, 1442 is the average weight of soil in kg m^{-3}, 1000 is the weight in kg per metric ton, and E is equal to metric tons of soil erosion or loss since the last tillage. For CFPs that were dispersed at the edge of buffer/filter or stopped within the buffer/filter before reaching the stream, the soil was considered to be transported to the buffer/filter, not to the stream channel (USDA-NRCS, 2002). For CFPs with a continuous 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.

In May and July 2007, above-ground biomass, including rooted plant material and woody plant debris in the natural forest buffers and grass filters, was determined. These biomass samples were taken from the edge of the forest buffer/filter, where the CFP interfaced with the forest buffer/filter. This was done to determine whether the amount and type of vegetation present where a CFP meets a buffer/filter is related to whether the CFP continues through or stops at or within the buffer/filter. All natural forest buffer and CSGF sites were sampled in late May and the WSGF were sampled in late July to obtain biomass samples representative of peak growth. GPS data collected during surveys in March and April 2007 was used to locate the point where the CFP interfaced with the buffer/filter in cases where the CFP had been covered by tillage operations and was no longer clearly visible. 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 down-slope of the channel or sediment fan in the vegetation that eventually stopped the CFP. For CFPs that extended all the way to the stream channel, a plot was randomly placed on either side of the CFP at the field edge of the buffer/filter. 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 collected for woody stems, grass, weeds/forbs, woody plant debris (leaves, branches, etc.), and total cover using the same categories described for the forest floor and shrub cover characterization. Within the larger plot, two randomly located 0.25 m plots had vegetation clipped to the bare ground and woody plant debris gathered; vegetation was separated into grass, weeds/forbs, or woody plant debris categories. The harvested and separated vegetation was dried for 48 hours at 60^{o}C, weighed and averaged.

One-way analysis of variance (ANOVA) was used to compare the four buffer categories for slope, length, and volume of CFPs, with the farm as the treatment level to test for differences in CFP slope, length and volume. 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

Within the 74 sample plots, 474 trees were documented, distributed among nineteen species. The top 10 species in descending order were: *Quercus palustris*, *Ulmus* species, *Prunus* species, *Celtis occidentalis, Juglans nigra, Gleditsia triacanthos, Maclura pomifera, Acer saccharinum, Morus* species, *and Quercus imbricaria*. Average stand diameter for all trees sampled was 16.3 cm. There was an average of 788 trees ha^{-1} for all plots with a standard deviation of 550. There was also an average of 309 saplings ha^{-1} (SD 415) and 24,733 seedlings ha^{-1} (SD 39,356). Sapling and seedling frequencies suggest that the natural forest buffers are regenerating successfully, although they may not maintain the same oak overstory dominance after the present overstory oak die. As pin oaks (*Quercus palustris*) were the dominant overstory tree, more oak seedlings and saplings were expected. Oak seedlings ranked third among all species, and saplings ranked fifth with only 12 saplings.

Average shrub cover per plot for the 74 sample plots was < 5%, but shrubs were found in 92% of plots. Major shrub species included *Symphoricarpos orbiculatur*, *Ribes missouriense*, *Sambucus canadensis*, *Rosa multiflora*, *Cornus drummondii*, and *Rhus glabra*. Of the 256 forest floor sample plots, most had good cover to protect against raindrop impact, with 51-75% of the cover consisting of loose woody debris (leaves, twigs, branches, etc.), 20-45% rooted herbaceous plant cover, and < 5% bare ground. However, unrooted woody debris does not provide adequate resistance to lateral surface runoff (Daniels and Gilliam, 1996).

USDA-NRCS (2004) encourages high plant densities in the unmanaged forest area adjacent to stream in the riparian forest buffer practice. The average of 788 trees ha^{-1} (avg. 16.3 cm dbh) found in this study is higher than the 550 trees ha^{-1} (16 cm dbh) suggested as the stocking rate for riparian forest buffers (USDA-NRCS, 2004). The higher stocking rate observed in this study results in little perennial herbaceous forest floor cover except at the edge of the buffer where sunlight can provide enough energy for ground cover plant growth. While there are many species of shade-tolerant ephemeral species that may grow in these stands, their short lived morphology does not provide the persistent frictional surface needed to slow surface runoff.

Of the 74 CFPs observed, 45 were along the 6.7 km of natural forest buffers without planted CSGF or WSGF and 29 along the 10.9 km of natural forest buffers with grass filters (Table 1). Presence of CFPs in crop fields was not related to buffer types but rather slope, soil type, and cropping and conservation practices in crop fields (Figure 3). There were no significant differences in CFP metrics ($p > 0.05$) between the CFPs in the crop fields along any of the four riparian treatment categories (natural forest buffer without grass filter, forest buffer with CSGF, forest buffer with WSGF, forest buffer without grass filter and a breakthrough CFP). These results are important because they show that the average slope, length, and volumes of CFPs were not significantly different across any of the sampled sites. Additional information about CFP dimensions is shown in Table 2.

Table 1. Lengths, average widths and number of concentrated flow paths (CFPs) intercepted by naturally occurring forest buffers with and without planted grass filters (CSGF = cool-season grass filter, WSGF = warm-season grass filter). Numbers in parentheses are widths of the grass filters only.

Buffer Type	Distance Surveyed, km	Average Width (Grass filter only), m	# of CFPs
Natural Forest Buffer Without Grass Filter Not Breached by CFP	8.8	17.9	36
Natural Forest Buffer Without Grass Filter At Locations Breached by CFP	NA*	12.8	9
Forest Buffer + CSGF or WSGF	10.9	37.7	29
Forest Buffer + CSGF	7.5	35.5 (17.6)	8
Forest Buffer + WSGF	3.4	40.0 (22.1)	21

*Widths were measured at the point where the CFP breached the buffer. These portions were subsequently classified as not buffered.

Table 2. Average dimensions for 74 CFPs intersecting natural forest buffers with and without planted grass filters. Observations were in late March and early April 2007 in three watersheds in the Claypan region of northeastern Missouri.

Concentrated Flow Path (CFPs) Dimensions							
	Maximum	Upper Quartile	Median	Lower Quartile	Minimum	Mean	Standard Deviation
Length (m)	362	58	36	21	1.5	48.6	49.3
Depth (cm)	38	8	6	4	2	6.9	4.9
Width (cm)	412	102	78	49	20	89.3	62.0
Volume (m^3)	69	4	2	0.6	0.06	4.4	9.7
Slope (%)	10	4.5	4	2	1	3.7	1.98

Volume estimates based on all 74 CFPs indicate that 473 metric tons of soil had moved downslope to the buffers/filters since the last tillage. All 29 of the CFPs that intersected the forest buffers with grass filters were dispersed by the grass filters. However, nine of the 45 CFPs (20%) observed along the natural forest buffers without grass filters were not dispersed and passed completely through the natural forest buffers (Table 3). Volume estimates of soil loss from those nine CFPs equaled 97 metric tons, of which 50-90% was delivered to the stream channel (USDA-NRCS, 1998). One explanation for CFPs having continuous channels through some of the forest buffers without grass filters was their narrow width (12.8 m). In comparison, the average width for forest buffers without grass filters where the CFPs did not breach the buffer was 17.9 m. Those with a CSGF filter averaged 35.5 m wide and those with a WSGF which averaged 40.0 m (Table 1, Figure 4). Another reason 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 edges of the natural forest buffer sites had a narrow buffer of cool-season grass or dense annual weeds because of increased sunlight. This may help explain why 80% of CFPs were still dispersed by the forest buffers.

To investigate vegetation density 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. While natural forest buffers had the highest average woody plant debris biomass, and therefore high amounts of total biomass, the woody plant debris biomass was not rooted plant material and could be washed away by concentrated surface runoff. If only rooted vegetation is considered, then grass filters had the highest total average biomass (Table 3). While grass biomass was much higher in the CSGF, we assume that both grass and forb biomass in the WSGF would increase as it matures.

Table 3. Mean dry weights for vegetation types in buffer categories. Buffer categories are: natural forest buffers with planted cool-season grass filters (CSGF) or warm-season grass filters (WSGF); natural forest buffers without grass filters (NFB) that were not breached; and locations in natural forest buffers completely breached by concentrated flow path channels (NFB/NB).

	Biomass For Buffer Categories (g)			
Vegetation Type	CSGF	WSGF	NFB	NFB/NB
Forb/Weed	0.9	21.8	17.6	17.2
Grass	54.4	23.9	23.3	26.2
Woody Plant Debris	1.2	0.2	21.7	14.4
Total	56.5	45.9	62.7	57.8
Total minus Woody Plant Debris	55.3	45.7	41.0	43.4

The CSGF sites were covered by tall fescue (*Festuca arundinacea*) and/or timothy (*Phleum pratense*) species while the WSGF areas were planted to a combination of forbs, little bluestem (*Schizachyrium scoparium*), sideoats grama (*Bouteloua curtipendula*), and switchgrass (*Panicum virgatum*). There was a large amount of foxtail (*Setaria faberi*), a cool-season annual grass species, present. In CSGF sites, CFPs or sediment deposition areas extended an average of 16.5% into the total filter width while in the WSGF they extended across 14.2% of the width on average. These percentages may be related to the young ages of the grass filters, especially the WSGF. CSGF sites had been established in 2001, 2002, and 2004, and WSGF sites were established in the spring of 2006, one year prior to this study. Annual observations should be made at these sites to determine the effectiveness of the grass filters at buffering CFPs. As the WSGF matures, the vegetation potentially could become more effective at slowing water at the field edge and depositing more sediment ahead of the filter, but the low percent cover scores for grass and high bare soil percentages in the WSGF may persist. The primary goal for the field borders is to promote habitat for upland birds which prefer less dense vegetation for habitat, especially for nesting and brood rearing. USDA-FSA (2006) suggests seeding for field borders be at much lighter rates than for CRP practices aimed at soil conservation and water quality enhancement. Future research should examine whether the lower seeding rates of field borders has an impact on their ability to disperse or buffer surface runoff or concentrated flow compared to other practices with higher seeding rates.

We also examined CFPs that formed exclusively within the natural forest buffers. These received their runoff from crop fields but no gullies had formed in the crop field. These CFPs were likely formed by sheet flow from the crop fields that converged and ran along the forest buffer edge before breaking through into the buffer. Twenty-four CFPs were observed originating within the 8.8 km of natural forest buffers without grass filters. Many of these CFPs appeared to be active, receiving runoff from the crop fields even though no associated CFPs were evident in the adjacent crop fields. Although 27 CFPs were also found originating within the forest buffers with grass filters, most of these CFPs appeared to no longer be active as they likely developed prior to the grass filter being planted and were no longer receiving significant concentrated surface runoff from the crop field. The presence of numerous CFPs within the natural forest buffers again underscores that these narrow forest buffers are not providing adequate buffering to surface runoff if they are not also associated with grass filters.

SUMMARY AND CONCLUSIONS

Stocking rates for tree species in the naturally occurring forest buffers were greater than recommended rates by USDA-NRCS for riparian forest buffers. While these dense stands provide flood protection and shading and organic material to the streams, their high density seems to restrict the amount of rooted perennial herbaceous ground cover that is needed to provide resistance to surface runoff. Future studies should examine methods for manipulating these buffers to increase the amount of shade tolerant herbaceous species or more shade intolerant grasses and forbs.

Natural forest buffers with grass filters dispersed or buffered 100% of CFPs observed while natural forest buffers without grass filters dispersed or buffered 80% of CFPs. Based on volume estimates of the CFPs, 376 metric tons of soil moved to and were trapped by some of the natural forest buffers without grass filters and by all of them with grass filters. Ninety-seven metric tons were estimated lost to streams at natural forest buffer without grass filters where CFP channels were continuous to the stream. These forest buffers were only 12.8 m wide compared to the 17.9 m width for the forest buffers without grass filters and forest buffers with CSGF (35.5 m) or with WSGF (40.0 m) that trapped CFPs. These results suggest that width is a critical factor at determining buffer efficacy.

The three watersheds in our study area contain approximately 759 km of first and second order streams. The abundance of natural forests along these streams does provide substantial buffering capacity. However, given the ability of grass filters to disperse and buffer concentrated flow paths from crop fields as demonstrated in this study, adding more grass filters to compliment natural forest buffers could reduce the sediment loads in these watersheds.

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