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Functions and effectiveness of silvicultural streamside management zones in loessial bluff forests

Richard F. Keim[a,*], Stephen H. Schoenholtz[b]

[a]Oregon State University, Forest Engineering Department, Peavy 215, Corvallis, OR 97331, USA
[b]Mississippi State University, Department of Forestry, P.O. Box 9681, Mississippi State, MS 39762, USA

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Abstract

In the highly-erodible Deep Loess region of Mississippi, USA, we investigated functions and effectiveness of silvicultural Streamside Management Zones (SMZs) in protecting water quality from impacts of logging. Twelve first-order watersheds (3–13 ha) were treated in their entirety in one of the four ways: (1) Unrestricted harvest with no buffer, (2) Cable-only SMZ that allowed limited removal of logs from the buffer but no skidder traffic, (3) No-harvest SMZ that excluded all logging from the buffer, or (4) Reference that was unharvested. Logging removed 17% to 70% of hardwood sawtimber basal area in non-SMZ areas using group selection. For 15 months after logging, we monitored total suspended sediment (TSS), turbidity, temperature, pH, electrical conductivity, and dissolved oxygen. The unrestricted harvest increased TSS and the unrestricted harvest and cable-only SMZ treatments increased the temporal variability of TSS. Other water quality metrics were either unaffected by logging or effects were minor. Skidder traffic in the unrestricted harvest increased exposure of mineral soil in the riparian area immediately after logging by 1.4 to 2.0 times that of other treatments. After one year, mineral soil exposure was similar among all treatments, and after three years, herbaceous growth reduced mineral soil exposure in the unrestricted harvest to below that of unlogged riparian zones. Three years after logging, transects of erosion stakes revealed more soil movement in riparian zones of unrestricted harvest watersheds than in riparian zones of reference watersheds, but natural processes of erosion and deposition apparently overwhelmed any effects of logging on patterns of deposition and erosion in riparian zones. We used permanent stream channel cross-sections to monitor changes in channel morphology for one year after logging, and found that channels in unrestricted harvest watersheds changed by up to twice as much as did channels in watersheds with undisturbed riparian zones. Streams in logged riparian zones showed net aggradation and streams in unlogged riparian zones showed net degradation. Results indicate that SMZs did not serve to filter sediment from overland flow, but their effectiveness in reducing TSS was probably due to exclusion of disturbance to the forest floor near the stream and to the stream itself.

Keywords: Streamside Management Zone; Forestry Best Management Practices; Riparian Areas; Water quality; Sediment; Erosion; Loess Bluffs

*Corresponding author. Tel.: +15417370515; fax: +15417374316;e-mail: Richard.Keim@orst.edu

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1. Introduction

Streamside Management Zones (SMZs) are management tools intended to provide a buffer for streams against non-point source water pollution from agriculture, urbanization, or silviculture (Welsch, 1991). Many states have included SMZs as components of voluntary or mandatory Best Management Practice (BMP) programs in agriculture and forestry, often stipulating specific SMZ designs (Mississippi Forestry Commission, 1989; Belt et al., 1992). Most SMZs are strips of fixed width adjacent to streams where intensity of management is reduced. Effectiveness, however, can vary by topography, parent material of the soil, and hydrology (Comerford et al., 1992). For BMP programs to be effective, a better understanding of the mechanisms of SMZs is needed.

Sediment is the most important pollutant from forested lands (Douglass, 1975; EPA, 1980; Phillips, 1989). Streamside Management Zones are intended to prevent transport of sediment and nutrients into streams by overland flow from storm runoff. They are expected to slow delivery of runoff from storms by maintaining the forest floor, which provides a more tortuous path of flow than does exposed mineral soil (Hewlett, 1982). This expected loss of velocity can cause greater infiltration (Phillips, 1989), or will at least reduce the competence of runoff to transport suspended sediments (Adams, 1993). Cooper et al. (1987) verified this mechanism with two findings about riparian forests (analogous to SMZs) adjacent to agricultural land in North Carolina: (1) there was more sediment deposited at the edge of the forest than internally, and (2) larger particles of soil were deposited at the edge of the forest rather than internally. Both relationships suggest a loss of competence of storm flow for transporting sediment as it enters or flows through an SMZ. Because this function relies on Hortonian flow of runoff, however, SMZs are expected to be less effective when runoff is channelized (Belt et al., 1992), as may occur in recently logged land, where stormflow is generated mainly from skid trails (Dickinson, 1975). Effectiveness of SMZs in forestry may, therefore, be less than in agriculture where compacted, bare soil more often results in Hortonian flow. Hewlett (1982) proposed, though, that channelized flow from disturbed areas may disperse and infiltrate the soil upon entering an SMZ. For example, Wemple et al. (1996), in the Cascade Mountains of Oregon, found that runoff from 43% of road lengths eventually infiltrated before reaching streams.

Aside from reducing delivery of sediment from upslope, SMZs are also likely to improve water quality by reducing the amount of disturbance in the riparian zone. Hewlett (1982) proposed that SMZs may prevent increases of sediment from logging by excluding disturbed areas such as roads and skid trails from the source area for stormflow. This function likely exists even where soils are very susceptible to gullying.

Streamside Management Zones have proven effective for amelioration of poor water quality associated with agriculture in the Coastal Plain of the Southeastern U.S.A. (Lowrance et al., 1985, 1988), though their utility in silvicultural applications in the South is uncertain (Neary et al., 1993). Many researchers have proposed widths necessary to achieve water quality goals specific to other physiographic regions (Swift, 1986; Belt et al., 1992; Comerford et al., 1992), but there has been little attention to the Coastal Plain of the southern U.S.A. (Neary et al., 1993), and no published research or guidelines for SMZs in the Deep Loess region of the U.S.A..

The objectives of this study were to (1) evaluate effectiveness of silvicultural SMZs in mitigating sediment delivery to streams in the Deep Loess region of Mississippi (Fig. 1) and (2) determine the functions of silvicultural SMZs. We hypothesized that SMZs would (1) slow overland flow, thereby reducing competence for transporting sediment and removing sediment from stormflow and/or (2) cause a greater percentage of overland flow to infiltrate. We also hypothesized that SMZs would function by excluding disturbances and sources of sediment from locations near the stream that are more likely to become part of the storm flow source area. We evaluated the effects of SMZs by measuring water quality in the stream, morphology of stream channels, exposure of mineral soil within the riparian area, and deposition of sediment and soil erosion within the riparian area. The study site in the steep and erodible Deep Loess was chosen in part because effects of logging on water quality and effects of SMZs have the potential to be large in this region.

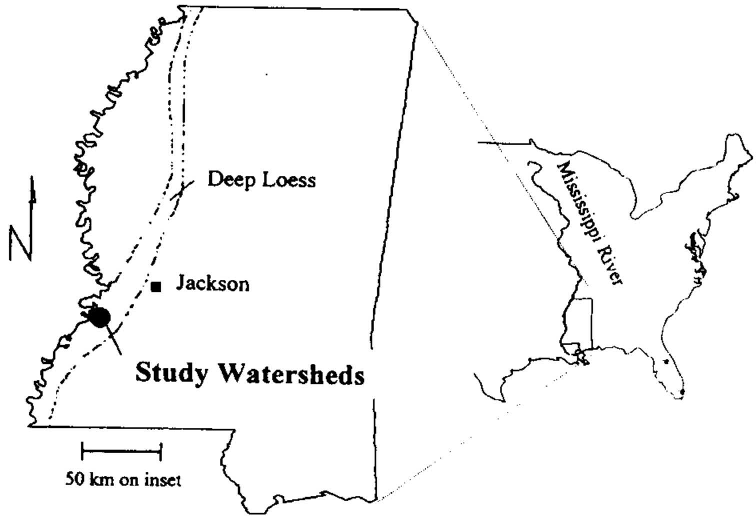

Fig. 1. Location of the study watersheds shown in an inset of the State of Mississippi, U.S.A. The watersheds are at approximately 91°W longitude, 32°N latitude.

2. Methods

2.1. Study site and treatments

In the lower Mississippi Valley (from the Ohio River to Louisiana), deposits of loess are associated with the retreat of Wisconsin-age glaciers (≈12 000 years b.p.), and are mostly on the eastern, leeward side of the Mississippi River (Wascher et al., 1947). Thickness of deposits may be up to 30 m (Snowden and Priddy, 1968), but decreases rapidly with increasing distance from a western bluff near the origin of loess (Frazee et al., 1970). These deposits are fertile and their physical properties result in water relationships favorable for commercial hardwood silviculture (Johnson, 1958). Important sawtimber species include red oaks (*Quercus* spp.), yellow-poplar (*Liriodendron tulipifera* L.), green ash (*Fraxinus pennsylvanica* Marsh.), and American basswood (*Tilia americana* L.). Site index for cherrybark oak (*Quercus pagoda* Raf.) in deep loess can exceed that of southern pines (*Pinus* spp.) on their most productive sites.

First-order watersheds dominate the landscape in the highly dissected deep loess. There is a high density of small streams in a dendritic network, and many large, active gullies (Wascher et al., 1947), which probably reflect both the high natural erosivity of loess and 130+ years of logging and conversion to and from agriculture. Stream channels in loess are unstable and are characterized by multiple knickpoints migrating upstream, incising into the loess (Grissinger and Murphy, 1982). Many higher-order channels flow in the underlying sandy coastal plain sediments, but most first-order streams are in highly erodible loess. Because the smallest channels are most unstable and because the dense drainage pattern means that logging is often close to a stream, the potentials for nonpoint source sedimentation are probably greatest in first-order watersheds. For this reason, we used the first-order watershed as the unit of interest in this study.

Twelve similar first-order watersheds with intermittent streams near the western bluff of the deep loess in Claiborne County, Mississippi, USA (Fig. 1) were selected for SMZ treatment (Table 1) and placed in three blocks in a randomized complete block design. Thickness of loess deposits is up to 25 m on the study watersheds (Bicker et al., 1966), but is much less on watersheds farther from the bluff; the blocks accounted for these variations in thickness. Hillslopes within individual watershed riparian zones were from 10 to 100%, and averaged 39% (Table 1). Topography is relatively flat near the stream (5–10 m) because loess tends to erode into U-shaped valleys (Flint, 1957).

Gradients of stream channels were from 0.02 to 0.08 (Table 1), were moderately entrenched to entrenched, of

Table 1

Size, pre- and post-harvest basal area, stream gradient, mean hillslope in riparian area, number of erosion stake transects, and number of stream channel cross-sections for first-order watersheds in deep loess.

Watershed	Block[a]	Size (ha)	Stream gradient (%)	Hillslope in riparian area (%)	Treatment	Pre-harvest basal area (m^2 ha^{-1})			Post-harvest basal area (m^2 ha^{-1})			Erosion transects (#)	Stream channel cross sections (#)
						SMZ	Non-SMZ	Overall	SMZ	Non-SMZ	Overall		
1	I	5.7	8	33	Unrestricted harvest	–	–	13.5	–	–	11.2	17	10
2	I	8.6	4	43	Cable-only SMZ	16.1	24.8	21.3	15.9	16.5	16.3	27	12
3	I	3.4	8	40	No-harvest SMZ	19.5	31.4	25.3	19.1	20.4	19.7	14	6
4	I	8.4	2	30	Reference	–	–	18.4	–	–	18.4	21	9
5	II	4.5	6	38	Unrestricted harvest	–	–	23.4	–	–	14.7	17	9
6	II	13.4	3	41	Cable-only SMZ	22.5	17.2	19.1	20.4	9.0	12.6	44	14
7	II	7.2	3	30	No-harvest SMZ	26.2	17.2	20.9	24.1	10.1	15.2	20	8
8	II	6.2	3	43	Reference	–	–	23.9	–	–	23.9	21	8
9	III	5.5	5	39	Unrestricted harvest	–	–	18.6	–	–	14.7	19	6
10	III	4.0	8	45	Cable-only SMZ	16.1	23.4	20.7	13.8	11.7	12.6	12	6
11	III	4.1	7	44	No-harvest SMZ	21.6	30.1	27.8	21.6	9.0	12.6	11	6
12	III	8.7	2	42	Reference	–	–	23.9	–	–	23.9	36	6

[a] Block III is nearest the western bluff of the deposit of loess; block II is farthest.

–: Inventory for non-SMZ treatments was not taken separately.

low to moderate sinuosity, and had substrates of silt, occasionally sand where they had eroded into underlying coastal plain sediments. In Rosgen (1994) classification, they were A6, G5, G6, B5, and B6 streams. The active channels were 1.5 to 3 m wide.

The silvicultural system in place on the research watersheds, common in the deep loess, is uneven-aged management for high-quality hardwood sawtimber and hardwood pulpwood, as described by Hodges (1995). Harvests of groups up to one ha or of individual trees to approximately 50% of basal area are done on a cycle of 10 to 15 years, combined with post-logging manual injection of herbicide in undesirable species. The research watersheds were all under this system for at least 30 years prior to treatment, and all had been last logged 12 to 15 years prior to treatment. Each non-reference watershed was selectively logged between January and April 1994 to meet silvicultural goals, which resulted in levels of harvest that varied spatially both within and between watersheds (Table 1).

Within each block, one watershed was randomly selected to be treated in its entirety with each of the following treatments: (1) Unrestricted harvest – normal operation with no restrictions on removal of basal area or trafficking by logging equipment within the riparian zone. (2) Cable-only SMZ – outside the SMZ, log as unrestricted harvest. In an SMZ 30 m wide on each side of the stream, removal of basal area was restricted to 20% and trafficking by equipment was prohibited. Removal of logs from the SMZ was accomplished by cables on skidder winches. (3) No-harvest SMZ – outside the SMZ, log as unrestricted harvest. No removal of basal area or trafficking by equipment was allowed within an SMZ 30 m wide on each side of the stream. (4) Reference – no logging. A wide (30 m) SMZ was selected in order that any effects of SMZs would likely be fully realized. The width of 30 m was the widest possible for removal of logs by winches on skidders. The 20% removal of basal area in the cable-only SMZs represents a harvest of conservatively half of normal intensity; it was chosen arbitrarily.

For this study, logging procedures standard for industrial forestry operations in the loess bluffs were followed. Trees were felled and topped by chainsaw, and tree-length or partially bucked logs were removed to loading areas on ridgetops by rubber-tired skidders, which were equipped with both a grapple and a winch with 30 m of cable. Skid trails were constructed as necessary with a bulldozer or skidder blade. No effort was made to control construction of skid trails, which were located by the choice of the loggers. Skid trails commonly paralleled stream channels and crossed them, sometimes on small dams constructed of debris. After logging, bulldozers constructed water bars on all skid trails, and all trails were seeded with grass. Basal area reduction by harvesting non-SMZ areas averaged 39% and basal area reduction within cable-logged SMZs averaged eight percent. There was some minor loss of basal area in no-harvest SMZs from logging damage and imperfect observation of marked boundaries by loggers (Table 1).

2.2. *Measurements*

Water quality was monitored for 15 months after treatment (April 1994 to August 1995) at the outflow of each watershed by automatic samplers, grab samples, and spot checks with a water quality meter. Each water sampler (Isco model 2900 water samplers, Isco Inc., Lincoln, NE, or samplers built in-house) took one sample of 10 ml of water/h (regardless of stream discharge), which was added to a composite sample. Every two weeks, a well-stirred subsample of 200 ml of composite sample was withdrawn and filtered in the laboratory for total suspended sediments (TSS) (APHA, 1987). In addition, a grab sample of 200 ml was taken from each stream every two weeks, and filtered for TSS by the same method. At intervals of two weeks, turbidity was measured with a portable nephelometer (LaMotte model 2008, LaMotte Company, Chestertown, MD or Monitek model 21PE, Monitek Inc., Hayward, CA), and pH, temperature, dissolved O_2, and electrical conductivity of the stream were measured with a portable water analyzer (ICM series 51000 portable water analyzer, Industrial Chemical Measurement Division of Perstorp Analytical, Hillsboro, OR).

For grab samples of TSS and for measurements of water quality, all four watersheds in each block were visited consecutively, and blocks were visited in the same order every time. This method partitioned effects (unmeasured) of diurnal fluctuations of water quality in the ANOVA by assigning them as differences by block.

Erosion stakes (as described by Brooks et al., 1991) were placed in transects perpendicular to each stream channel. Each erosion stake was a PVC pipe, 1 m long and 2.5 cm in diameter, with a mark 25 cm from the top. Immediately after treatment, stakes were driven vertically into the ground so the mark was flush with mineral soil on the uphill side. Transects consisted of six stakes; the first stake was 5 m from the bank of the stream, and each subsequent stake was 5 m further from the bank, so that the last stake was at the edge of the SMZ, 30 m from the bank. Transects were placed 40 m apart, varying in number depending on watershed size (Table 1). Erosion stakes were examined one year (March 1995) and three years (December 1996 – April 1997) after treatment, and the level of mineral soil relative to the mark was recorded.

Erosion stake data were parameterized into (1) net deposition/erosion (all measurements of deposition and erosion analyzed together); (2) gross deposition (measurements of erosion excluded from analysis); (3) gross erosion (measurements of deposition excluded from analysis) and (4) gross soil movement (absolute value of all measurements). As examples, a stake with soil 1 cm above its original mark showed net deposition/erosion of 1 cm, gross deposition of 1 cm, no value for gross erosion, and gross soil movement of 1 cm. A stake with soil 2 cm below its original mark showed net deposition/erosion of −2 cm, no value for gross deposition, a gross erosion value of 2 cm, and gross soil movement of 2 cm.

Immediately after treatment, percent exposed mineral soil was estimated within a 1 m^2 frame randomly positioned approximately 2 m to the right of each erosion stake. Observations of exposed mineral soil were made in exposure classes in 10% increments, plus classes of 3% and 97% exposure, similar to Gnegy's (1991) estimation system of weed coverage. Low, herbaceous plants, grass, humus in the O_i layer (Guthrie and Witty, 1982), and humus in the O_e layer were included as cover, but humus in the O_a layer was not. Estimations were repeated 1 year and 3 years after treatment, but no effort was made to duplicate exact positions of the frame from previous measurements. We chose to use exposure of mineral soil as an index of erodibility because the degree to which mineral soil is exposed is directly related to soil particle detachment by rainfall or drip from the canopy (EPA, 1980).

Morphology of stream channels was measured by cross-sections established in each stream prior to treatment, then remeasured 1 year after treatment. One cross-section was established per 30 m of stream channel, resulting in 6 to 14 cross-sections in each watershed (Table 1). Each cross-section was marked by an iron bar on either side of the stream, outside the active fluvial area, as by Olson-Rutz and Marlow (1992). A cross-sectional diagram was produced by recording transverse horizontal and vertical location of breaks in slope in the stream channel between the bars. From these diagrams, changes in cross-sectional area, thalweg elevation, and horizontal thalweg location were calculated. Positive changes in thalweg elevation correspond to aggradation, and negative changes in thalweg elevation correspond to degradation at that cross-section. Gradients of streams through entire watersheds were measured using a surveyor's level, and slopes within SMZ riparian areas of 30 m were measured with a clinometer.

2.3. *Statistical analyses*

We used ANOVA and the least significant difference (LSD) test to separate means for all analyses. Because we expected high natural variability to cause the power of the experiment to be low, we made observations of significance at $\alpha = 0.10$. We included gradient of the stream and slope in the riparian zone as covariables in ANOVAs for all metrics of water quality, but removed them when they were not significant so as to conserve degrees of freedom. The distributions of observations of TSS were log-normal. Because of this, and because the objective was to separate effectiveness of SMZ treatments and not to estimate the effect of SMZs, TSS observations were transformed to rank and analyzed nonparametrically (see also Thas et al., 1998). Standard parametric ANOVA tests were performed on these data, a method that approximates (Conover, 1980). We used the SAS statistical software package (SAS Institute, 1990) for all analyses.

3. Results and discussion

3.1. *Effects on water quality*

Despite a much lower stream flow during dry periods in the late summer (Table 2), time of the year

Table 2
Rainfall during the period of the study. Values are monthly means weighted by distance from three nearby rain gauges (Source: U.S. National Weather Service pers. comm.)[a]

Year	Total	Rainfall by month (mm)											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1994	1621	272	169	172	98	185	178	128	57	43	152	41	125
1995	1364	105	65	194	240	105	33	136	42	56	121	107	160
1996	1446	166	41	187	154	135	187	98	95	92	89	91	111
1997		144	249	95									
Long-term mean for Jackson	1406	133	119	148	141	128	81	115	96	90	83	122	150

[a] Gauges are U.S. National Weather Service gauges 227132 Port Gibson, MS (11 km southeast), 229216 Vicksburg Military Park, MS (36 km northeast) and 168163 St. Joseph, LA (23 km southwest).

did not significantly affect any metrics of water quality ($p > 0.10$). As a result, we used means pooled across all time periods for all analyses.

The SMZs functioned to prevent increases of streamwater TSS from logging during 15 months following harvest (Table 3). In grab samples (taken at haphazard times relative to rainstorms), the unrestricted harvest and cable-only SMZ had higher TSS than the no-harvest SMZ and reference. In machine samples, which included storm events, the unrestricted harvest had higher TSS than any other treatment. The statistical difference in TSS between cable-only and no-harvest SMZs evident in the grab samples was not discernable in data that included storm flows (machine sample data). Although greater numerical differences in TSS existed between the two treatments in machine samples than in grab samples, their ranks were statistically similar. This may be an indication that both types of SMZ functioned similarly during storms.

In addition to higher TSS, logging, especially the unrestricted harvest and cable-only SMZ, apparently increased the variability of TSS. Standard deviations of grab-sample and machine-sample TSS range from two to seven times higher for unrestricted harvest and cable-only SMZ treatments than for unharvested reference watersheds (Table 3). Brown (1983) also described this phenomenon in reporting that logging increased both amount and variability of TSS in small streams of the Oregon Coast Range. Great variability in TSS indicates potential for storms with large sediment discharges and may indicate instability of soils and stream channels in the watershed.

There were no statistically detectable effects of the SMZ treatments on other metrics of water quality (Table 4), but there were some trends that may have

Table 3
Effects of four SMZ treatments on mean total suspended sediments (TSS) for 15 months following logging in the deep loess region of Mississippi

Treatment	Mean grab-sample TSS[c,d] (mg l^{-1})	Mean rank, grab samples ($N = 305$)	Mean machine-sample TSS[d,e] (mg l^{-1})	Mean rank, machine samples ($N = 243$)
Unrestricted harvest	244.2 (769.3)[f]	182.6 a[g]	664.4 (1396.4)	155.2 a
Cable-only SMZ	272.0 (541.6)	168.0 a	515.2 (2441.6)	114.2 b
No-harvest SMZ	147.4 (298.0)	134.6 b	197.0 (366.4)	112.3 b
Reference	83.7 (128.0)	127.5 b	228.1 (534.8)	110.3 b

[c] Values are means of biweekly sampling in each watershed.
[d] Differences among treatment means are not significant at the $\alpha = 0.10$ level.
[e] Values are means of biweekly composite samples in each watershed.
[f] Values in parentheses are standard deviations.
[g] The letters a and b represent significant differences among means at the $\alpha = 0.10$ level.

Table 4
Effects of four SMZ treatments on mean water quality measured biweekly for 15 months following logging in the deep loess region of Mississippi

Treatment	Turbidity (NTU)	Temp. (°C)	Electrical conductivity (μS)	pH	Diss. O_2 (mg l^{-1})
Unrestricted harvest	35.2 (39.3)[a]	16.3 (4.2)	694 (149)	7.8 (0.8)	6.8 (2.9)
Cable-only SMZ	36.5 (45.4)	16.3 (4.6)	655 (153)	7.8 (0.6)	6.1 (2.7)
No-harvest SMZ	37.5 (48.3)	16.2 (4.7)	631 (152)	7.8 (0.6)	6.2 (2.4)
Reference	28.3 (39.7)	17.0 (4.7)	619 (156)	7.7 (0.5)	6.0 (2.8)

[a] Differences among treatment means are not significant at the $\alpha = 0.10$ level. Values in parentheses are standard deviations.

been significant with larger sample sizes (increased intensity of sampling or more replication of treatments). Turbidity was 7–12 NTU higher in streams of logged watersheds than in reference streams, which would be expected due to higher TSS. There was, however, no significant relationship between TSS and turbidity ($p > 0.10$), suggesting that factors such as variations in stream substrate affected TSS and turbidity differently. Electrical conductivity of streamwater also increased by 12–75 μS with logging. Increased contact with exposed mineral soil may have resulted in higher electrical conductivity by more base-rich loess (Snowden and Priddy, 1968) dissolving in runoff from logged watersheds. Stream water temperature and dissolved O_2 were similar among streams in treated watersheds. This suggests that shading of stream channels was similar among treatments, as would be expected with selective harvesting.

3.2. Exposure of mineral soil

Treatment and position within the riparian zone interacted to affect exposure of mineral soil in the riparian zone immediately after treatment. At distances of 5 m and 10 m from streams, the unrestricted harvest resulted in more exposure of mineral soil than did the other treatments (Fig. 2). Within the unrestricted harvest, more mineral soil was exposed at 5 m

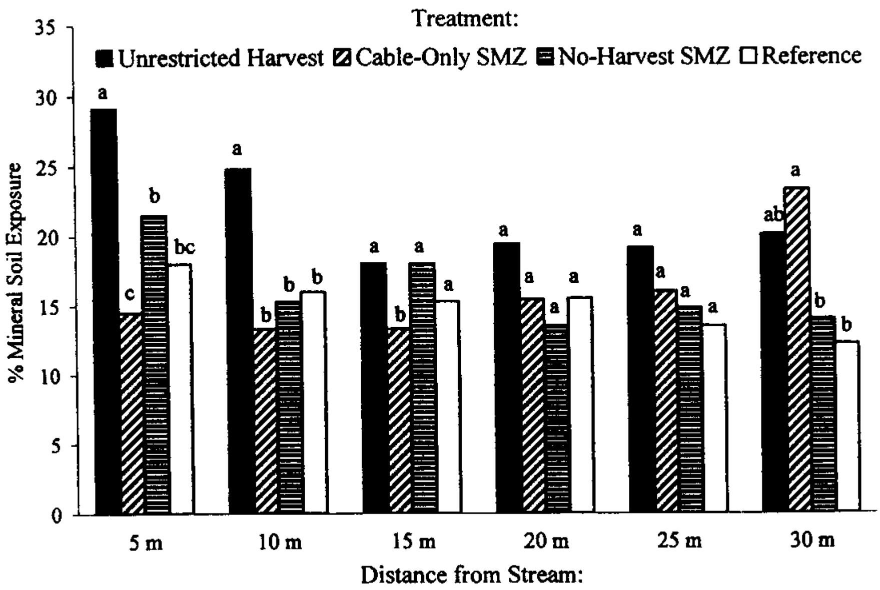

Fig. 2. Percent mineral soil exposure inside SMZs immediately after logging in the deep loess region of Mississippi. Groupings are by SMZ treatment for six distances from streams. Values are means of three replications. Letters indicate statistically similar values within each group at the $\alpha = 0.10$ level.

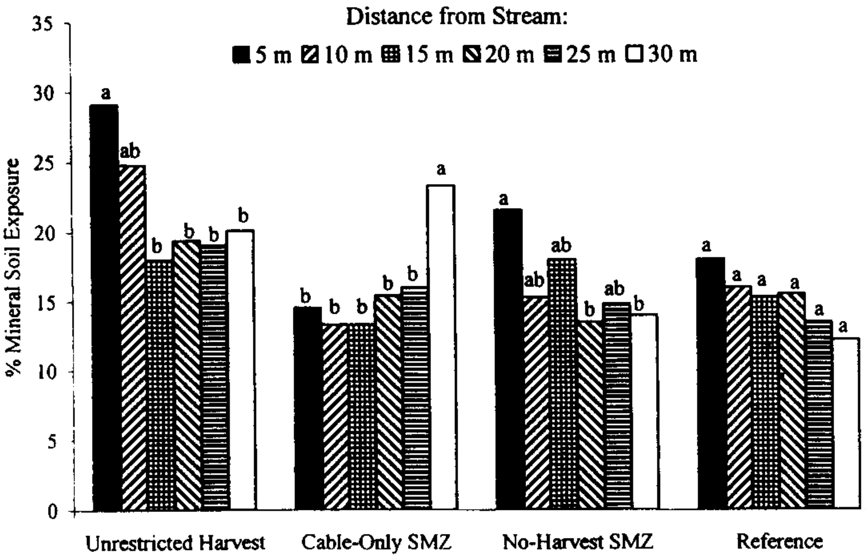

Fig. 3. Percent mineral soil exposure inside SMZs immediately after logging in the deep loess region of Mississippi. Groupings are by SMZ treatment for six distances from streams. Values are means of three replications. Letters indicate statistically similar values within each group at the $\alpha = 0.10$ level.

from streams than at distances ≥15 m from streams (Fig. 3). The unrestricted harvest resulted in highest exposure of mineral soil near the stream because this relatively flat terrain was a common location for skid trails.

At the edge of the riparian zone, 30 m from streams, exposure of mineral soil was higher in the cable-only SMZ than in the no-harvest SMZ or reference (Fig. 2), and within the cable-only SMZ, more mineral soil was exposed at 30 m from streams than any location closer to the stream (Fig. 3). The cable-only SMZ also resulted in less exposure of mineral soil than the no-harvest SMZ at 5 m from streams (Fig. 2). It is likely that concentration of traffic by skidders at the edge of the cable-only SMZ resulted in high exposure of mineral soil there. Much of the increased cover of the forest floor 5 m from streams in the cable-only SMZ treatment was from tops of harvested trees. These tops accumulated in the SMZ without being moved for skid trails, as commonly happened in the unrestricted harvest.

One year after treatment, exposure of mineral soil was not significantly different among treatments or positions within the riparian zone (Tables 5 and 6). Heavy growth of herbaceous plants during the first growing season after logging and leaf-fall in the autumn after the first growing season are likely explanations for this change.

Three years after treatment, the unrestricted harvest had less exposure of mineral soil than the no-harvest SMZ or the reference (Table 5). Continued growth of herbaceous plants in the logged riparian zones was probably responsible for this. Also, by year three, there was less exposure of mineral soil in all treatments at 5 m from the stream than any other position within the riparian zone, and there was more exposure of mineral soil at 25 m from the stream than at 5 m, 10 m or 15 m from the stream (Table 5). These differences are most likely due to topography in these U-shaped valleys, the steeper mid-slope position (25 m) does not collect colluvial organic matter or support herbaceous growth as well as the lower, flatter positions near the stream.

3.3. Deposition and erosion

Net deposition/erosion within the riparian zone was not significantly affected by treatment (Table 5) or transect position (Table 6). Overall, there was net deposition of 0.12–0.34 cm at all locations within in the riparian zones, the rate of which apparently did not decrease after the first year. The processes of

Table 5
Effects of SMZ treatments on mineral soil exposure, net deposition/erosion, net deposition, net erosion, and gross soil movement one year and three years after logging in the deep loess region of Mississippi[b]

Treatment	Mineral soil exposure (%)		Net deposition/erosion (cm)[c]		Gross deposition (cm)		Gross erosion (cm)		Gross soil movement (cm)	
	Year 1	Year 3	Year 1	Year 3	Year 1	Year 3	Year 1	Year 3	Year 1	Year 3
Unrestricted harvest	10.7 a[d]	14.4 b	0.20 a	1.85 a	0.43 a	3.42 a	0.22 a	2.42 a	0.63 a	3.42 a
Cable-only SMZ	11.2 a	17.7 ab	0.27 a	1.71 a	0.44 a	3.39 a	0.15 a	1.95 a	0.62 a	3.15 ab
No-harvest SMZ	11.5 a	21.1 a	0.23 a	1.99 a	0.41 a	3.17 a	0.16 a	1.76 a	0.61 a	2.99 ab
Reference	10.4 a	24.1 a	0.21 a	1.42 a	0.39 a	2.83 a	0.17 a	1.78 a	0.58 a	2.75 ~~a~~ b

[b] Values are means pooled across six different distances from the stream, 5–30 m.
[c] Positive values represent net deposition.
[d] The letters a and b represent significant differences among means at the $\alpha = 0.10$ level.

Table 6
Effects of distance from stream on mineral soil exposure, net deposition/erosion, net deposition, net erosion, and gross soil movement one year and three years after logging in the deep loess region of Mississippi[d]

Distance from stream (m)	Mineral soil exposure (%)		Net deposition/ erosion[e]		Gross deposition (cm)		Gross erosion (cm)		Gross soil movement (cm)	
	Year 1	Year 3	Year 1	Year 3	Year 1	Year 3	Year 1	Year 3	Year 1	Year 3
5	12.1 a[f]	13.2 c	0.34 a	1.56 a	0.52 a	3.15 a	0.16 a	1.93 a	0.64 a	3.00 a
10	10.8 a	19.3 b	0.12 a	1.36 a	0.38 bc	3.19 a	0.22 a	2.22 a	0.53 a	3.10 a
15	11.3 a	18.9 b	0.25 a	1.83 a	0.38 bc	3.15 a	0.12 a	1.70 a	0.63 a	2.96 a
20	10.2 a	21.6 ab	0.25 a	1.86 a	0.44 ab	3.26 a	0.19 a	2.25 a	0.54 a	3.25 a
25	10.4 a	23.7 a	0.12 a	1.62 a	0.32 c	3.11 a	0.18 a	1.72 a	0.64 a	2.85 a
30	10.9 a	20.6 ab	0.33 a	1.97 a	0.48 ab	3.25 a	0.17 a	1.93 a	0.70 a	3.20 a

[d] Values are means pooled across four SMZ treatments.
[e] Positive values indicate net deposition.
[f] The letters a, b and c represent significant differences among means at the $\alpha = 0.10$ level.

erosion or deposition did not dramatically slow with time after logging as we expected. This result indicates that net deposition is an ongoing process within riparian areas of the loess bluffs regardless of treatments.

One year after treatment, gross deposition was not significantly affected by treatment (Table 5), but was more at 5 m from streams than at 10 m, 15 m, and 25 m from streams (Table 6). Also, one year after treatment, gross deposition was more at the edges of the riparian zones (30 m from streams), than 5 m inside the riparian zones (25 m from streams), although deposition at 30 m from streams was not significantly more for treatments that included an SMZ than for treatments that did not. The decrease in deposition through the SMZ reported by Cooper et al. (1987) did not occur, but there is some evidence of preferential deposition at the edge of the SMZ. However, differences in deposition at that position were not higher in logged than in unlogged watersheds, indicating that topography and not effects from treatment may control deposition there. Gross deposition at positions nearer streams may be attributable to the relatively flat ground there. By year three, the differences of gross deposition among transect positions were no longer detectable. Also, by year three, there were no detectable effects of treatment on gross deposition, but a trend of more gross deposition with increasing logging was beginning to develop.

Gross erosion within the riparian zone was not significantly affected by treatment (Table 5) or transect position (Table 6). By year three, a trend of more erosion in logged riparian zones was becoming apparent, but it was not statistically significant. There were no discernable patterns of erosion by position within the riparian zone.

Differences in gross soil movement were not detectable one year after treatment, but by year three, the unrestricted harvest showed 24% more movement than the reference Table 5. This observation may indicate that, although exposure of mineral soil associated with logging had disappeared, the forest floor had not recovered to its pre-logging condition, and soil movement was greater within the more highly disturbed riparian zones. It may take longer to recover volume of forest floor than simple coverage of mineral soil, allowing erosion and deposition to continue. With reduced volume of forest floor, infiltration and roughness are likely reduced, resulting in a buffer that is less effective in removing sediment from overland flow and less effective in promoting infiltration than undisturbed forest floor (Phillips, 1989).

3.4. Morphology of stream channels

Natural variation often overshadowed most effects of treatment on morphology of stream channels by reducing the power of the ANOVA, because aggradation and degradation are both naturally large in streams in the Deep Loess (Grissinger and Murphy, 1982). Nonetheless, we observed several consistent trends. Streams in unrestricted harvest watersheds showed more instability (absolute change in cross-sectional area) than streams in no-harvest SMZ watersheds and streams in reference watersheds (Table 7). There was also more absolute change in elevation of the thalweg in the streams of cable-only SMZ watersheds than in those of reference and no-harvest SMZ watersheds. The trend of net aggradation of channels (as evidenced by decreased cross-sectional area) in unrestricted harvest watersheds and cable-only SMZ watersheds may be explained by higher TSS; Satterlund and Adams (1992) cited increases of TSS as a potential cause of aggradation of stream channels. It is possible that increases in sediment from watersheds with logged riparian zones (unrestricted harvest and cable-only SMZ) (Table 3) led to net aggradation of stream channels, in contrast to stream channels in watersheds with unlogged riparian zones (no-harvest SMZ and reference), which showed (statistically insignificant) net degradation.

In addition to indirect changes by treatment, there were three instances of direct channel modification by logging equipment. In two unrestricted harvest watersheds, two cross-sections were in portions of the stream channel that were obliterated by skid trails, and another cross-section was nearly buried by debris which was placed in the stream to provide a crossing for skidders.

4. Conclusions

Although high variation in water quality naturally occurs in Deep Loess watersheds, the effects of logging and SMZs on water quality during the first year after logging were apparent. Streams in logged watersheds without SMZs had three times the sediment concentration of unlogged watersheds (see Table 3, grab samples and machine samples), whereas streams in logged watersheds with SMZs did not show increases of this magnitude. Changes of sediment concentration in unbuffered streams were most apparent in storm flow, and it was in these data that the sediment concentrations of streams buffered by SMZs were most similar to those of reference watersheds.

Table 7
Effects of SMZ treatments on morphology of stream channels one year after treatment in deep loess watersheds

Treatment	Change in x-sec. area[c] (cm^2)	Absolute change in x-sec. area (cm^2)	Change in thalweg elevation[d] (cm)	Absolute change in thalweg elevation (cm)
Unrestricted harvest	−866 a[e] (4574)[d]	2757 b (3708)	−0.4 a (9.8)	7.4 a[f] (6.3)
Cable-only SMZ	−168 a (2510)	1710 ab (1819)	−0.2 a (13.1)	8.9 a (9.5)
No-harvest SMZ	505 a (1792)	1214 b (1389)	3.9 a (5.8)	4.3 b (5.5)
Reference	238 a (1307)	915 b (944)	0.1 a (7.6)	4.7 b (5.9)

[c] Negative values indicate channel aggradation and positive values indicate channel degradation.
[d] Negative values indicate decrease in thalweg elevation (degradation) and positive values indicate increase in thalweg elevation (aggradation).
[e] The letters a and b represent significant differences among means at the $\alpha = 0.10$ level.
[f] Numbers in parentheses are standard deviations.

The cable-only SMZ was nearly as effective as the no-harvest SMZ in controlling TSS, but allowed more sediment in base flow. The increased TSS from logging corresponds with channel aggradation, especially in logged watersheds with no SMZ. Sediment stored in the channel as a result of this aggradation may serve as a source of increased sediment in stream water even after upslope effects of logging have diminished.

The SMZs apparently did not function to trap sediments from outside the riparian zone. There was no more deposition in riparian zones of cable-only SMZ or no-harvest SMZ watersheds than in riparian areas of unrestricted harvest or reference watersheds, and patterns of deposition within riparian zones were probably caused primarily by topography. The common gullies and susceptibility of loess to gullying may have contributed to this phenomenon by reducing Hortonian flow through the riparian zone. Additionally, both no-harvest SMZs and cable-only SMZs (1) reduced exposure of mineral soil near the stream, where erosion and formation of gullies is most likely to deliver sediment to the stream, and (2) eliminated direct disturbance of stream channels and banks by skidders. As evidenced by the trends of more soil movement with unrestricted harvest, effectiveness of SMZs in reducing sediment in stream water apparently resulted from reduced disturbance in the riparian zone.

In this silvicultural system of selective harvesting and with the apparent lack of Hortonian flow, SMZs do not function as effective filters for sediment, as evidenced by the lack of increased deposition of sediment within SMZs versus riparian zones of unlogged watersheds. Effectiveness of SMZs in ameliorating increases of TSS from logging appears to be due to reduced disturbance to the forest floor near the stream and to the stream channel itself, where disturbances are most likely to contribute to degradation of water quality (Hewlett, 1982). This suggests that SMZ prescriptions should focus on eliminating machine traffic within 10 m of streams, and that wide buffers that maintain high basal area are not critical to the function of buffers on first-order streams in deep loess.

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References

Adams, M.B., 1993. Movement of sediment and nutrients through riparian areas. In: Technical Workshop on Sediments, Corvallis, Or., Terrene Institute, Washington, pp. 41–44.

American Public Health Association, 1987. In: Clesceri, L.S., Greenberg, A.E., Trussel, R.R. (Eds.), Standard Methods for the Examination of Water and Wastewater, 17th ed. Washington.

Belt, G.H., O'Laughlin, J., Merrill, T., 1992. Design of forest riparian buffer strips for the protection of water quality: Analysis of scientific literature. Idaho Forest, Wildlife and Range Policy Analysis Group Report No. 8, pp. 35.

Bicker Jr., A.R., Dinkins Jr., T.H., Williams Jr., C.H., McCutcheon, T.E., 1966. Claiborne County Geology and Mineral Resources. Miss. Geol. Econ. Topogr. Surv. Bull. 107, 1–174.

Brooks, K.N., Ffolliott, P.F., Gregerson, H.M., Thames, J.L., 1991. Hydrology and the Management of Watersheds. Iowa Stae University Press, Ames. pp. 392.

Brown, G.W., 1983. Forestry and Water Quality, 2nd ed. Oregon State University, Corvallis, pp. 142.

Comerford, N.B., Mansell, R.S., Neary, D.G., 1992. The effectiveness of buffer strips for ameliorating offsite transportation of sediment, nutrients, and pesticides from silvicultural operations. National Council of the Paper Industry for Air and Stream Improvement Technical Bulletin No. 631, pp. 48.

Conover, W.J., 1980. Practical Nonparametric Statistics, 2nd ed. Wiley, New York, pp. 493.

Cooper, J.R., Gilliam, J.W., Daniels, R.B., Robarge, W.P., 1987. Riparian areas as filters for agricultural sediment. Soil Sci. Soc. Am. J. 51, 416–420.

Dickinson, B.P., 1975. Stormflows and erosion after tree-length skidding on coastal plain soils. Trans. ASAE 18, 867-868, 872.

Douglass, J.E., 1975. Southeastern forests and the problem of non-point sources of water pollution. In: Ashton, P.M. and Underwood, R.C. (Eds.), Non-Point Sources of Water Pollution: Proceedings of a Southeastern Regional Conference, May 1-2, 1975, Blacksburg, Va. Virginia Water Resources Research Center, pp. 29–44.

Environmental Protection Agency, 1980. An Approach to Water Resources Evaluation of Non-point Silvicultural Sources (A Procedural Handbook). US EPA, USDA Forest Service. Interagency Agreement No. EPA-IAG-D6-0660.

Flint, R.F., 1957. Glacial and Pleistocene Geology. Wiley, New York, pp. 553.

Frazee, C.J., Fehrenbacher, J.B., Krumbein, W.C., 1970. Loess distribution from a source. Soil Sci. Soc. Am. Proc. 34, 296–301.

Gnegy's, J.D., 1991. Visual rating systems for target and crop species. In: Miller, J.H. Glover, G.R. (Eds.), Standard methods for forest herbicide research. Southern Weed Science Society, pp. 41–44.

Grissinger, E.H., Murphy, J.B., 1982. The present problem of stream channel instabiity in the bluf area of northern Mississippi. J. Miss. Acad. Sci. 27, 117–128.

Guthrie, R.L., Witty, J.E., 1982. New designations for soil horizons and layers and the new Soil Survey Manual. Soil Sci. Soc. Am. J. 46, 443–444.

Hewlett, J.D., 1982. Principles of Forest Hydrology. U. Georgia, Athens, pp. 183.

Hodges, J.D., 1995. The southern bottomland hardwood region and brown loam bluffs subregion. In: Barrett, J.W. (Ed.). Regional Silviculture. Wiley, New York, pp. 643.

Johnson, R.L., 1958. Bluff hills-ideal for hardwood timber production. South. Lumberman 197, 126–128.

Lowrance, R., Leonard, R., Sheridan, J., 1985. Managing riparian ecosystems to control nonpoint pollution. J. Soil Water Conserv. 40, 87–91.

Lowrance, R., McIntyre, S., Lance, C., 1988. Erosion and deposition in a field/forest system estimated using Cesium-137 activity. J. Soil Water Conserv. 43, 195–199.

Mississippi Forestry Commission, 1989. Mississippi's Best Management Practices Handbook, pp. 33.

Neary, D.G., Comerford, N.B., Swift, Jr., L.W., 1993. Land and riparian interactions with sediment in the southern United States. In: Technical Workshop on Sediments, Corvallis, Or., Terrene Institute, Washington, pp. 51–60.

Olson-Rutz, K.M., Marlow, C.B., 1992. Analysis and interpretation of stream channel cross-sectional data. North Am. J. Fish. Manag. 12, 55–61.

Phillips, J.D., 1989. An evaluation of the factors determining the effectiveness of water quality buffer zones. J. Hydrol. 107, 133–145.

Rosgen, D.L., 1994. A classification of natural rivers. Catena 22, 169–199.

Satterlund, D.R., Adams, P.W., 1992. Wildland Watershed Management, 2nd ed. Wiley, New York, pp. 436.

SAS Institute, 1990. SAS/STAT user's guide: version 6. SAS Institute Inc., Cary, N.C.

Snowden Jr., J.O., Priddy, R.R., 1968. Geology of Mississippi loess. Miss. Geol. Econ. Topogr. Surv. Bull. 111, 1–203.

Swift Jr., L.W., 1986. Filter strip widths for forest roads in the southern Appalachians. South. J. Appl. For. 10, 27–34.

Thas, O., Van Vooren, L., Ottoy, J.P., 1998. Nonparametric test performance for trends in water quality with sampling design implications. J. Am. Water Resour. Assoc. 34, 347–357.

Wascher, H.L., Humbert, R.P., Cady, J.G., 1947. Loess in the southern Mississippi Valley: Identification and distribution of the loess sheets. Soil Sci. Soc. Am. Proc. 12, 389–399.

Welsch, D.J., 1991. Riparian Forest Buffers. Function and Design for Protection and Enhancement of Water Resources. USDA Forest Service Northeastern Experiment Station NA-PR-07-91, pp. 20.

Wemple, B.C., Jones, J.A., Grant, G.E., 1996. Channel network extension by logging roads in two basins, western Cascades. Oregon. Water Resour. Bull. 32, 1195–1207.

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Erratum to "Functions and effectiveness of silvicultural streamside management zones in loessial bluff forests"☆ [Forest Ecology & Management, 118: 197–209]

Richard F. Keim[a,*], Stephen H. Schoenholtz[b]

[a]*Oregon State University, Forest Engineering Department, Peavy 215, Corvallis, OR 97331, USA*
[b]*Mississippi State University, Department of Forestry, P.O. Box 9681, Mississippi State, MS 39762, USA*

The publisher regrets errors in Tables 5 and 7 of the above article. The three errors are incorrect letters to denote statistical significance of data in tables. They are:

Table 5, last column (top to bottom): is now: a,ab,ab,a should be: a,ab,ab,b

Table 7, second column (top to bottom): is now: b,ab,b,b should be : a,ab,b,b

Table 7, last column (top to bottom): is now: a,a,b,b should be: ab,a,b,b

*Corresponding author. Tel.: +15417370515; fax: +15417374316; e-mail: Richard.Keim@orst.edu

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