Forest road sideslopes and soil conservation techniques

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ABSTRACT Forest road sideslopes have been identified as one of the major sources of erosion losses from managed forest systems. Stabilization by vegetation has shown the greatest potential for mitigation of soil erosion on forest road sideslopes. Sediment and runoff production from a wood excelsior erosion mat, native species vegetative mix, and exotic species vegetative mix were investigated on a newly-constructed road during a two-year study. Sediment and runoff production were significantly reduced on both the cut slope and fill slope by the treatments. Vegetative treatments showed more than a 30% reduction in sediment production between the two study years. The erosion mat treatment showed increased vegetation cover and relatively insignificant sedimentproduction for both years of the study.

Key words: Conservation practices, forest management, forest roads, ground cover, slopes, soil erosion, surface runoff.

Erosion from undisturbed forest lands is typically less than the geologic erosion rate of less than 0.30 t/ha/yr (0.13 t/ac/yr) (Beasley 1979; Patric 1976; Smith and Stamey 1964; Yoho 1980). However, high levels of soil erosion can following road construction that disturbs the forest cover and forest floor. Forest roads are recognized as a major source of erosion from forested lands across the United States (Patric 1976; Elliot et al. 1994), historically accounting for as much as 90% of all sediment produced from forest land (Anderson et al. 1976; Hoover 1952; Megahan 1972).

Erosion from forest roads is a major concern in forest management due to the capability to cause adverse environmental effects (Binkley and Brown 1993; Reid and Dunne 1984). Roads accelerate erosion by increasing slope gradients and interrupting normal drainage patterns, which concentrates overland flow into ditches and channels. Erosion produced from forest road systems eventually reaches and degrades the quality of stream systems. Sediment from forest roads can shorten the life of reservoirs, degrade drinking water, and clog spawning beds. Sediment losses from forest roads require special attention because sediment can be carried directly to waterways through ditches and crossings.

The key to reducing the amount of sediment delivered to waterways is to identify the source of erosion. The best erosion mitigation practices can be achieved through careful planning, location, design, construction, and maintenance of forest roads. Sediment is produced from all components of the road prism: traveled way, cut slope, fill slope, and ditching. In sloping terrain, forest road sideslopes account for as much as 50% of the road prism area and have the greatest potential for soil erosion. Road sideslopes have been reported to account for 70 to 90% of the total soil loss from the disturbed roadway area (Swift 1984b). Considering the impact road sideslopes have on the forest ecosystem, quantifying and mitigating erosion and sedimentation resulting from sideslopes is elemental in designing sustainable forest systems.

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Previous work

Soil erosion and runoff production are influenced by many factors, although local rainfall, soil characteristics and land management are major contributors. Rainfall energy, intensity, and amount influence soil detachment and transport (Wischmeier and Smith 1958). Wischmeier (1962) concluded that soil erosion is influenced by factors encompassed by the erosion index, rainfall distribution, soil characteristics, slope length and steepness, and land management (productivity level, residue management, cultural operations, and conservation practices). Land management is one of the factors that can be altered to reduce erosion losses. Surface cover is one land management characteristic that can be managed to control erosion by reducing soil detachment and transport. Vegetation cover is reported to be an important deterrent to soil erosion by reducing raindrop impact (Osborn 1955) and runoff energy.

Experiments in the southern Appalachians during the mid-1930s explored road bank stabilization after 0.15 to 0.30 m (6 to 12 in) of bank soil were lost from steep banks (Hursh 1935). Research showed practical and simple procedures for road bank erosion control were sod strips along the contour, root clumps of honeysuckle along the contour, grass seed, stake and brush wattles, and wood litter and debris. Hursh (1938, 1939, 1949) recommended mulching as a minimal requirement for road bank stabilization. Mulches were the simplest and least expensive stabilization method. Hursh (1942) found that slopes were stable during most of the year but could be unstable during the winter months due to sloughing and erosion caused by alternate freezing and thawing. The investigator stated that a slope has to be made stable by vegetation or some mechanical means to prevent surface soil movement. This work concluded that vegetation established on cut banks would mask disfiguring scars and reduce future costs associated with maintenance.

The effect of surface cover on soil loss was also evaluated using different combinations of rock and surface litter with a rotating boom rainfall simulator (Benkobi et al. 1993). The investigation concluded that 100% coverage with combinations of rock and surface litter offered the best protection of the soil against erosion.

Studies in the Rocky Mountain region reported that the application of erosion control practices reduced sediment yields from the forest road prism. On-site sediment yield reductions with erosion control techniques suggest possible reductions of total sediment production by 60% from fill slopes, 2.5% from traveled ways, and 15% from the cut slope and ditch (Cline et al. 1981). This partitioning was based on comparisons between erosion reduction factors given by this research and previously reported for individual components of the road prism.

The amount of reduction that can be achieved with various erosion control treatments on cut and fill slopes has also been estimated by Burroughs and King (1989). Six treatments were identified as erosion control treatments: straw with asphalt tack, straw with net, straw, erosion control mats, wood chips or rock, and hydro-mulch. Sediment production decreased with increasing ground cover.

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Hydro-mulch was least effective in reducing sediment production unless used with some type of fiber tackifier.

Eight mulching treatments were evaluated on fill slopes for their effectiveness in promoting grass establishment by Dudeck et al. (1970). The treatments evaluated were an emulsified polymer, compost, wood cellulose, jute netting, excelsior, and asphalt-anchored mulches of excelsior, wood shavings, and bark dust. Treatments with an excelsior mat or jute netting yielded the best grass coverage. Asphalt tackifier produced inferior grass establishment.

Investigations evaluating sediment production from road sideslopes has shown that sediment production is greatest immediately following construction, but decreases over time (Bethlahmy and Kidd 1966; Burroughs and King 1989; King 1984; Megahan 1974; Megahan et al. 1991; Swift 1985). The first few rainstorms after construction were reported by King and Gonsior (1980) to cause 100 to 10,000 times the normal sediment loading into streams. In the Zena Creek study in Idaho, sediment production increased to 38.3 t/day/km* of road (109 t/day/mi^2 of road), 1,560 times greater than undisturbed sediment production rates (Megahan and Kidd 1972). Sediment yield during the first year was 84% of total sediment yield during a 6-yr study period.

Forest road sideslopes have been identified as the major contributors to total sediment yield following road construction. Application of erosion control techniques can reduce sediment yields from these vulnerable surfaces by as much as 60% on road sideslopes. Research has shown that some type of cover must be used to control road sideslope erosion and establish permanent vegetation. Most BMP guidelines recommend use of mulch for critical situations to hold seed in place for successful vegetative establishment of 75% cover (Alabama Forestry Commission 1993). Vegetation establishment is reported to give the greatest reductions in sediment yields over time from sensitive disturbed road prisms.

Objectives

This investigation focuses on mitigation treatments on cut and fill slopes as a means of controlling sediment yield from the road prism. This study's objective was to test over a 2-yr period the hypothesis that there are differences in the efficacy of three commonly applied erosion control treatments: native species vegetative mix, exotic species vegetative mix, and exotic species vegetative mix anchored with an erosion control mat. Treatments also were compared between study years to determine if efficacy increased with time.

Shoal Creek study

The study site is located on the Shoal Creek District of the Talladega National Forest in Cleburne County near Heflin, Ala. The test soils are in the Tatum series, a fine loamy mixed-thermic Typic Hapludult. A 0.10 to 0.15 m (4 to 6 in) silt loam surface layer overlays a red clay loam subsoil 0.50 to 0.55 m (20 to 22 in) thick. The cut slopes were primarily the exposed subsoil, while the fill slopes were composed of a mixture of the surface soil and subsoil. Infiltration rates were estimated for the cut slope and fill slope at 19.1 and 18.6 mm/hr (0.75 and 0.73 in/hr), respectively, for bare soil based on rainfall and runoff measurements. The study area receives an average of 1,400 mm (54 in) of annual precipitation, of which the long-term precipitation record shows that 70% falls from September to March.

The mid-slope half-bench crowned road with inside ditching was constructed during the summer of 1995 with a 15% grade with west-facing 2.2:1 (45% slope) and 1.5:1 (67% slope) cut slopes and fill slopes, respectively. The study was initiated immediately after construction during late summer 1995 and was intensively monitored through the subsequent (rain season) fall and winter (Sept. 21, 1995 to March 18, 1996). Monitoring was re-initiated during the fall of 1996 and intensively monitored for a second fall-winter period (Oct. 10, 1996 to April 8, 1997).

All erosion control treatments were hand-seeded Sept. 16, 1995, one week after road completion. Grass erosion control treatments also were mulched with a Fescue hay mulch applied at a rate of 4.5 t/ha (2 t/ac). Fertilizer and lime applications were applied at a rate of 1.0 t/ha (0.45 t/ac) of 13-13-13 fertilizer and 4.5 t/ha (2 t/ac) of agricultural limestone. The following treatments on both the cut slope and fill slope of the newly-constructed forest access road in a randomized complete block experimental design were studied:

1) ***Native*** species. Native species plots were seeded with a mixture of big bluestem *gerardii)*, little bluestem ***(Andropogon scoparius)***, and Alamo switch grass *(Panicum virgatum)*, each at a rate of 11 kg/ha (10 lb/ac).

2) Erotic species. Exotic species plots were seeded with Kentucky 31 tall fescue ***(Festuca arundinecea)*** at 28 kg/ha (25 lb/ac), Pensacola bahiagrass *(Paspalum notatum)* at 23 kg/ha (20 lb/ac), annual lespedeza ***(Lespedeza cuneata)*** at 6 kg/ha (5 lb/ac), and white clover *(Trifolium repens)* at 11 kg/ha (10 lb/ac).

3) ***Erosion*** mat. Erosion mat treatments were seeded with the exotic species mixture and covered with a wood excelsior erosion mat anchored in place with 15-cm-long (6-in) staples. The erosion mat is a machine produced mat with a photo degradable plastic net over the top side of the mat.

4) ***Control.*** The control had no mulch or seeding applications. Twelve plots, consisting of three blocks of the three treatments and a control, were located on the cut slope and another 12 on the fill slope. Bounded plots, 1.5 m x 3.1 m (5 ft x 10 ft), were used to isolate runoff within each plot from the surrounding slope. A gutter channeled runoff into a 130-L (34-gal) storage container (Figure 1). Minor modifications were made to gutter structure to allow flexibility during winter freeze-thaw cycles.

Analysis

Runoff volume was directly measured as the amount of runoff collected in the storage containers. Grab samples, 500 ml (0.530 qt), were collected from the standing water in each container for each sampling period. Grab samples were processed for gravimetric analysis using methods defined by Greenberg et al. (1992) to determine total suspended solids. Deposited sediment was collected by draining off container top water, rinsing the deposited sediment from containers, and transporting it to the laboratory. Deposited sediment was then dried to a moisture content of less than 1% (dry basis) and weighed. Total sediment yield was determined as the combination of suspended and deposited sediment fractions collected from containers. Surface cover was quantified eight times during the study by classifying 100 random points on each plot as either vegetation cover, debris cover, or bare.

Variables measured as independent variables in this experiment were rainfall amount, rainfall intensity, and percent vegetative cover. Monitoring of treatments began two weeks after road completion, before the first storm event. Rainfall amounts were recorded with a Universal recording rain gauge located on site (Figure 2). The fill slope and cut slope sediment yield data were analyzed

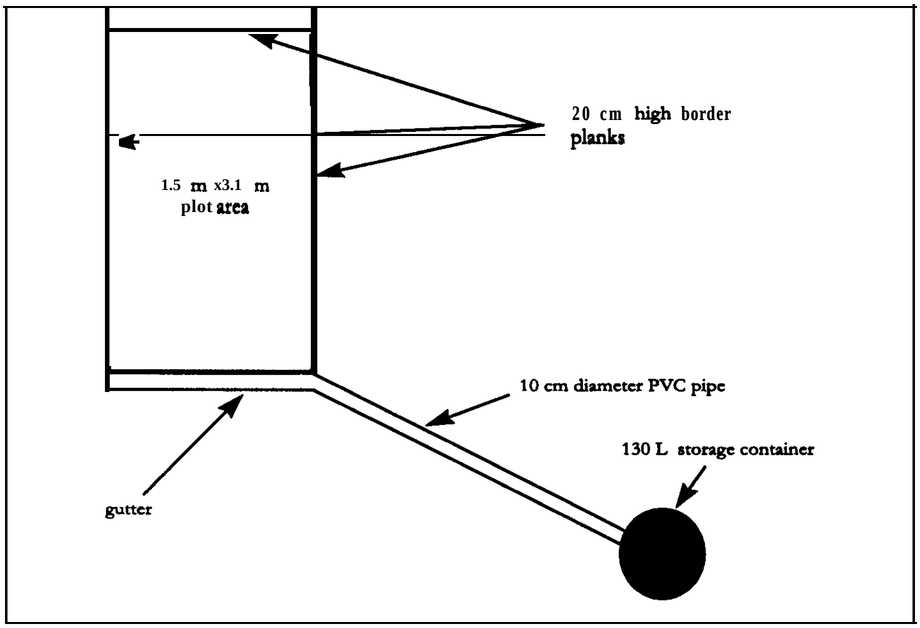

Figure 1. Individual plot design for field experiment showing specifications of the design.

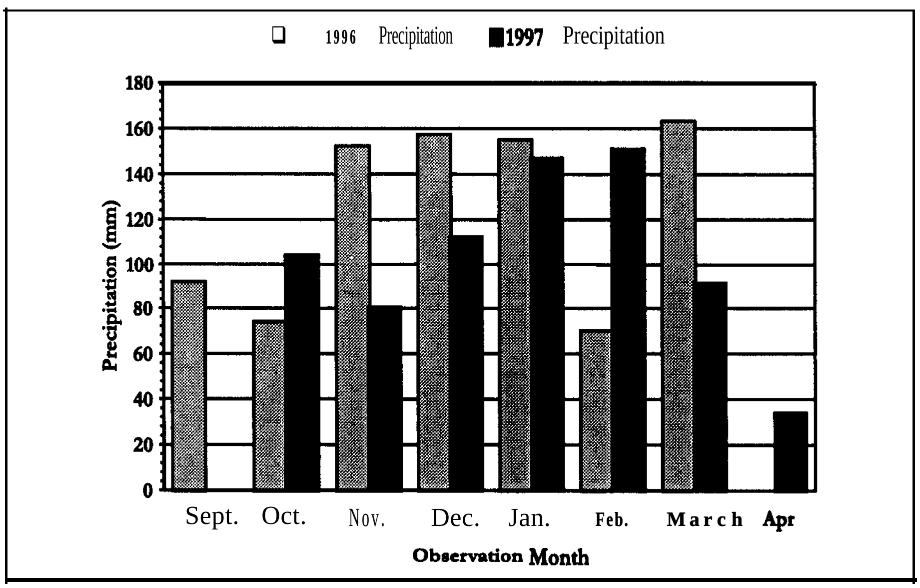

Figure 2. Observed precipitation during study periods.

as a repeated measures randomized complete block design.

Dependent variable measurements, runoff volume, and sediment yield per depth of precipitation, were repeated over time. The dependent variables were tested as functions of treatment effects, rainfall amount and intensity, percent cover, and treatment age. Individual treatment means were tested for within subjects effects ($\alpha = 0.05$), where repeated measures analysis of variance indicated significant differences.

Results and discussion

Fast initial growth and quick cover is essential for vegetative treatments to minimize soil movement from roadside slopes. This is especially true for newly-constructed roadside slopes due to the potential for accelerated soil losses during the first few rainstorms. Soil on newly-constructed roadside slopes is often loose compared to undisturbed natural slopes. With cut and fill slope construction, roadside slopes also are initially void of the vegetation and ground cover that protects surface soil from raindrop splash and surface flow.

The test roadside slopes were seeded and mulched two weeks after road construction in September 199 5. Vegetative cover for the seeded plots ranged from 1 to 29% during the first winter (Table 1). The Kentucky fescue found in the erosion mat and exotic species treatments germinated in early October and afforded some protection during the first winter. The white clover and bluestem used in the exotic species treatment and native species treatment, respectively, also had some germination in early October. However, despite good germination, the seeding was too late for the vegetation to establish and spread. Reductions in soil movement during the first winter season were likely caused by debris cover as opposed to vegetative cover.

Debris cover, composed of mulch, fallen leaves, and wood debris, likely accounts for varying soil loss reductions during this initial winter period. Debris cover for seeded plots ranged from 43% on exotic species treatments to 100% on erosion mat treatments. The high percentage of debris cover on the erosion mat treatments was expected to retard soil loss by slowing runoff. By the same token, the lack of debris cover on bare control plots would have given no protection against raindrop splash and eventual soil movement.

All treatments were broadcast re-seeded in April 1996 to compensate for late season seeding the previous year. Grass treatments began to spread during May 1996, and by November 1996, vegetative cover for the seeded treatments ranged from 51 to 82% with the erosion mat treatment having the highest percent cover. In August 1997, the vegetative cover for seeded treatments ranged from 57 to 93% with the erosion mat continuing to show the highest grass establishment. The native species treatment had the greatest increase in vegetative cover from the first year coverage (1% on cut slope and 8% on fill slope) to the second year with 57 and 77% on the cut slope and fill slope, respectively.

Data from both study years suggests that sediment yield was influenced by the amount of surface cover. Previous work reports that ground cover decreases sediment yield and runoff by intercepting raindrops and filtering runoff (Swift 1984a; Hursh 1935). Treatments with a high percent cover exhibited the greatest mitigating effects on both sediment yield and runoff on the cut slope. Cut slope sediment yields and runoff decreased with increasing percent cover for all treatments. The control treatments, which were allowed to naturally re-vegetate to examine the true effect of mitigation treatments, had the lowest percent cover. The erosion mat treatments had the

Table 1. Ground cover after road construction for treatments.

Date	Type of cover	Percent ground cover							
			cut slope				Fill slope		
		Erosion mat	Native grass	Exotic grass	Control	Erosion mat	Native grass	Exotic grass	Control
Sept. 95	Vegetative	0	0	0	0	0	0	0	0
	Debris	100	80	57	0	100	61	47	0
Nov. 95	Vegetative	28	7	26	0	21	10	20	0
	Debris	72	76	57	0	79	62	46	0
Jan. 96	Vegetative	29	1	21	0	17	8	19	0
	Debris	70	68	55	0	78	60	43	0
May 96	Vegetative	43	43	20	6	18	52	22	5
	Debris	52	47	53	2	75	20	40	0
Nov. 96	Vegetative	60	51	55	14	82	77	77	19
	Debris	37	44	43	3	15	21	19	0
April 97	Vegetative	62	53	58	12	88	74	88	17
	Debris	36	34	31	0	9	13	12	0
Aug. 97	Vegetative	70	57	57	10	93	77	83	37
	Debris	29	12	12	0	1	1	1	0
Sept. 97	Vegetative	83	67	60	10	88	80	83	30
	Debris	15	27	28	10	8	18	3	7

greatest percent ground cover during the study periods and the lowest sediment yield and runoff, The control having less than 15 and 30% cover on the cut slope and fill slope, respectively, had the highest sediment yield and runoff.

Percent cover on the fill slope showed a similar trend to the cut slope results on sediment yields, but not for runoff. Fill slope runoff was highest for the treatment with the lowest percent cover, the control treatment. Although the erosion mat treatment had the highest percent cover, it yielded more runoff than the two grass treatments, which had lower percent covers. The fill slope native species treatment also had a higher percent cover than the exotic species treatment, but it also yielded a greater runoff. Fill slope runoff could have been influenced by subsurface hydrology or rooting properties, but these factors were not considered in this study.

The labor and material costs associated with installing erosion control techniques were determined using general costs estimates by the U.S. Department of Agriculture Forest Service (USDA-FS 1997). The exotic species treatment would cost $2,400/ha, while the native species treatment would be slightly more expensive at $2,900/ha. The erosion mat treatment would involve the same costs for seed application as the exotic species treatment, plus an additional cost for erosion mat material, erosion mat installation, and soil staples. The Forest Service estimates the cost of mat installation labor at 50% of the cost of the materials. The total cost of the erosion mat treatment would be $12,500/ha, more than four times the cost of the seeding treatments.

Sediment and runoff

First-year sediment yield for the erosion mat, native species, and exotic species treatments were 2.90, 13.2, and 4.76 t/ha (1.3, 5.9, and 2.1 t/ac) (Figure 3). In contrast, sediment yield from the control was 37.7 t/ha (16.8 t/ac) with a 213 mm (8.4 in) depth of runoff during the first year after road construction. Treatments had greater than 60% reductions in sediment yields in comparison to the control. Runoff volumes for the three treatments were similar to the trends noted for sediment yield. Treatments showed less than 30% reductions in runoff in comparison to the control (Figure 4).

During the second year after establishment, sediment yield from the control averaged 17.9 t/ha (8.0 t/ac) with a 205 mm (8.1 in) depth of runoff. In comparison to the cut slope control, the erosion mat, exotic species, and native species treatments, yielding less than 1.0 t/ha (0.45 t/ac), had greater than 90% reductions in sediment yield. Runoff from erosion treatments during the second year after establishment followed the same trend as sediment yield from treatments. The erosion mat, exotic species, and native species resulted in reductions in runoff of 63, 44, and 35%, respectively.

Accelerated sediment yields and runoff resulting from road construction have been reported to dramatically decrease with time (Burroughs and King 1989). Large reductions in sediment yield and runoff, attributed mainly to vegetative establishment, were observed in the second-year data. The largest reductions in sediment yield from the first year to the second year were found on the native species treatments with 90 and 98% reductions on the cut slope and fill slope, respectively (Figure 3). Sediment yield from native species plots during the second year dropped to levels near those of the erosion mat and exotic species treatments. This result was expected based on the slower establishment rate of the native species mixture. Second-year native species treatments had increased establishment which reduced sediment yield and runoff.

Exotic species treatments had reductions of 84 and 95% from initial sediment yields for the cut slope and fill slope, respectively. The cut slope erosion mat treatment showed a 70% reduction, while the fill slope erosion mat treatment had a 98% reduction in sediment yields during the two study periods. Reductions in sediment yields were also noted on the control treatments for the cut slope and fill slope, with 68 and 58% reductions, respectively. Less precipitation (17% less) during the second study period could also have had an effect on sediment yield reductions.

Precipitation was 862 mm (34 in) for the first study period and 719 mm (28 in) for the second study period (Figure 2). To adjust for differences in precipitation for the two study periods, the data were analyzed on the basis of sediment yield per depth of rainfall (Table 2). Repeated measures analysis of variance ($\alpha = 0.05$) on both slopes for the two study periods detected treatment effects and study period as significant

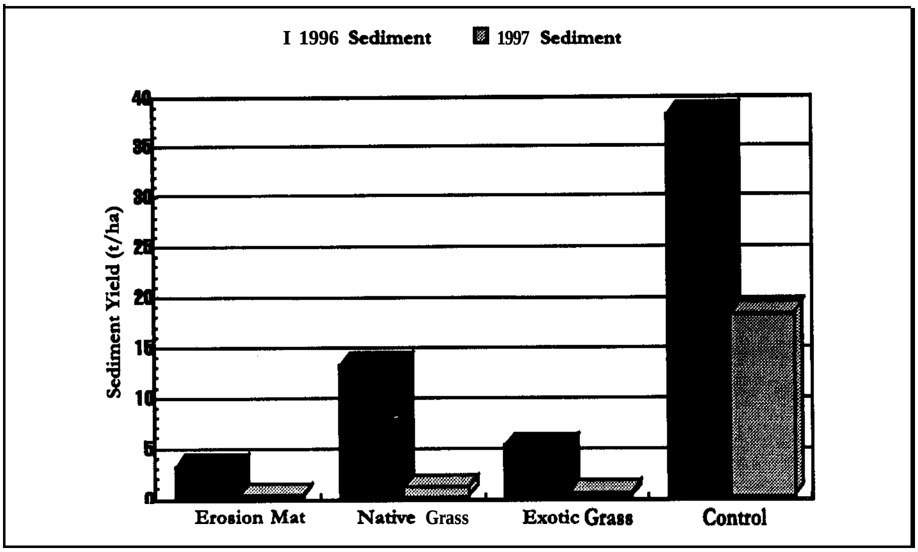

Figure 3. Sediment yield from treatments during study periods.

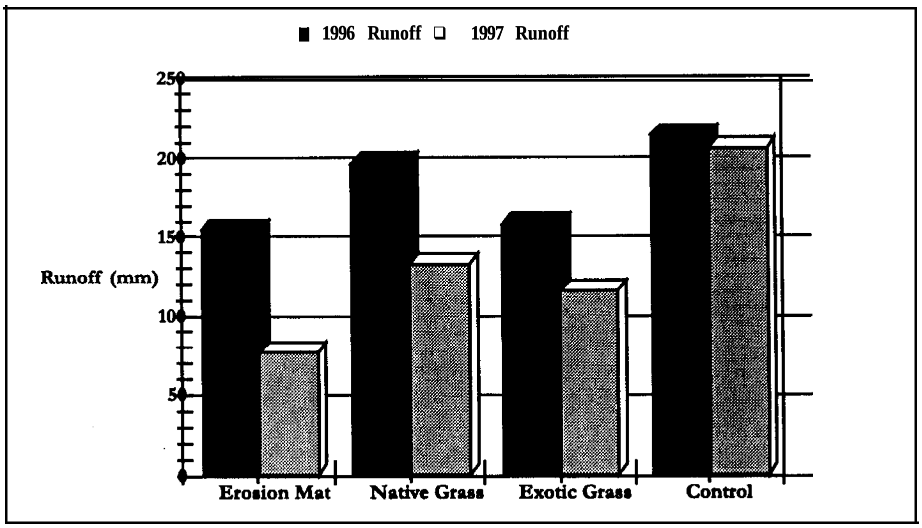

Figure 4. Depth of runoff from treatments during study periods.

variables in sediment yield and runoff. The first six-month study period produced significantly greater sediment yield than the second six-month study period for both the cut and fill slope (Table 2). Tests on individual treatment means for within subjects effects (α = 0.05) show that sediment yields from the native species and control treatments during the second study period were significantly lower than the first study period, with the erosion mat treatments showing the lowest sediment yield during both study periods. Runoffs from the native species and control treatments were also significantly higher during the first study period. The second-year erosion mat treatments had significantly less runoff than all other treatments, with a mean runoff depth of 4.5 mm (0.20 in.).

The trends in fill slope sediment yield and runoff were similar to those observed for the cut slope (Table 2). Fill slope control treatments had significantly higher sediment yields than all other treatments, with the first study period control treatment having the highest sediment yield. During the second study period, sediment yield was significantly lower than the first study period. The control treatment runoff also was significantly higher during both study periods than all other treatments with the second year production being the greatest. Decreased runoff during the second study period for the erosion mat and native species treatments could be due to increased infiltration and evapotranspiration resulting from increased vegetation.

Conclusions

Sediment yields, adjusted for rainfall, from **all** erosion control treatments decreased during the second study period. Runoff yields decreased on all erosion treatments, except the fill slope exotic species and control treatment. The erosion mat was most effective in reducing soil losses from both cut and fill slopes during the second study period. The native species treatment was found to be more effective in mitigating losses during the second study period than during the first study period. Also, sediment yield from the native species treatment was not significantly different from that of the fill slope erosion mat treatment during the second study period. The increased effectiveness of native species treatments is attributed to increased vegetative establishment by the second study period. Fill slope stabilization was accomplished at a faster pace than stabilization of the cut slope based on the data from the two study periods (1996 and 1997). The fill slope erosion mat and native species treatments showed greater capacity to reduce sediment yield and runoff with significantly lower losses. The control (bare) continued to lose large amounts of sediment from both slopes during the second study period.

Precipitation had an effect on sediment yield differences during the two periods under investigation, but analysis showed significant treatment effects. Sediment yield from erosion control treatments during the second study period was significantly less than from all treatments during the first period. Fill slope runoff was significantly less for the erosion mat and native species treatments during the second period than during the first period.

Significant reductions in both sediment yield and runoff were detected on both slopes during the second year. Analysis showed that there was a time effect on sediment yield and runoff from the three treatments used in this investigation. Some treatments showed a greater time effect than others with the native species showing the greatest reduction between the two study years. Previous research has reported, consistent with these findings, sediment yield from new slopes decreases as the slopes age.

In this initial study, erosion control treatments provided reductions in sediment yields from road sideslopes in comparison to an untreated control; however, further study is necessary to determine sediment delivery rates to streams. Additional work with detailed tracking of sediment movement downslope and actual sediment delivery rates to streams from the forest road prism is required to

Table 2. Sediment and runoff production means for both study periods (1996 and 1997).

Treatment	Sediment yield (g/mm)	n	Runoff depth (mm)	n
Cut slope				
Erosion mat 96	1.50	39	13	39
Native grass 96	35.0	39	18	39
Exotic grass 96	7.20	39	17	39
Control 96	76.0	39	16	39
Erosion mat 97	0.50	30	4.5	30
Native grass 97	3.60	30	17	30
Exotic grass 97	1.20	30	14	30
Control 97	36.0	30	19	30
Mean 96	10.9A*	156		
Mean 97	2.78'	120		
Fill slope				
Erosion mat 96	8.50	39	11	38
Native grass 96	16.0	39	13	38
Exotic grass 96	12.0	39	8.0	37
Control 96	81.0	39	17	38
Erosion mat 97	0.30	30	11	30
Native grass 97	0.30	30	10	30
Exotic grass 97	0.60	30	9.0	30
Control 97	42.0	30	22	30
Mean 96	8.0A**	156		
Mean 97	2.7B**	120		

. Duncan's grouping for cut slope (Means with same letter are not significantly different, alpha = 0.05)
** Duncan's grouping for fill slope (Means with same letter are not significantly different, alpha = 0.05)

better understand the effect of mitigation techniques on the road prism.

REFERENCES CITED

Alabama Forestry Commission. 1993. Alabama's Best Management Practices for Forestry. Alabama Forestry Commission: Montgomery, AL.

Anderson, H.W., M.D. Hoover, and K.G. Reinhart. 1976. Forest and water: Effects of forest management on floods, sedimentation, and water supply, PSW-18. USDA Forest Service: San Francisco, CA.

Beasley, R.S. 1979. Intensive site preparation and sediment losses on steep watersheds in the Gulf Coastal Plain. Soil Science Society of America Journal 43: 412-417.

Benkobi, L., M.J. Trlica, and J.L. Smith. 1993. Soil loss as affected by different combinations of surface litter and rock. Journal of Environmental Quality 22:657-661.

Bethlahmy, N., and W.J. Kidd Jr. 1966. Controlling soil movement from steep road tills, INT-45. USDA Forest Service, Intermountain Research Station: Ogden, UT.

Binkley, D., and T.C. Brown. 1993. Forest practices as nonpoint sources of pollution in North America. Water Resources Bulletin 29(5):729-740.

Burroughs, E.R. Jr., and J.G. King. 1989. Reduction of soil erosion on forest roads. INT-264. USDA Forest Service, Intermountain Research Station: Ogden, UT.

Cline, R., G. Cole, W. Megahan, R. Patten, and J. Potyondy. 1981. Guide for predicting sediment yields from forested watersheds. USDA Forest Service, Northern and Intermountain Region: Ogden, UT.

Dudeck, A.E.. N.P. Swanson, L.N. Mielke, and A.R. Dedrick. 1970. Mulches for grass establishment on fill slopes. Agronomy Journal 60(6): 810-812.

Elliot, W.J., R.B. Foltz, and M.D. Remboldt. 1994. Predicting sedimentation from roads at stream crossings with the WEPP model. Paper No. 947511. American Society of Agricultural Engineering (ASAE): St. Joseph, MI.

Greenberg, A.E., L.S. Clesceri, and A.D. Eaton, ed. 1992. Standard Methods for the Examination of Water and Wastewater. 18th edition. American Public Health Association: Washington, DC.

Hoover, M.D. 1952. Water and timber management. Journal of Soil and Water Conservation 7: 75-78.

Hursh, C.R. 1935. Control of exposed soil on road banks, Technical Note 12. USDA Forest Service, Southeastern Forest Experiment Station: Asheville, NC.

Hursh, CR. 1938. Mulching for road bank fixation, Technical Note 31. USDA Forest Service, Southeastern Forest Experiment Station: Asheville, NC.

Hursh, CR. 1939. Road bank stabilization at low cost, Technical Note 38. USDA Forest Service, Southeastern Forest Experiment Station: Asheville, NC.

Hursh, C.R. 1942. The naturalization of roadbanks, Technical Note 51. USDA Forest Service, Southeastern Forest Experiment Station: Asheville, NC.

Hursh, C.R. 1949. Climatic factors controlling roadside design and development. In: Proc. Highway Research Board, National Research Council: Washington, DC.

King, J.G. 1984. Ongoing studies in Horse Creek on water quality and water yield, Technical Bulletin 435. National Council of the Paper Industry for Air and Stream Improvement: New York, NY.

King, J.G,. and M. Gonsior. 1980. Effects of forest roads on stream sediment. USDA Forest Service, Intermountain Research Station, Forestry Sciences Laboratory: Moscow, ID.

Megahan, W.F. 1972. Logging, erosion, sedimentation — Are they dirty words? Journal of Forestry 70: 403-407.

Megahan, W.F. 1974. Erosion over time on severely disturbed granitic soils: a model, INT-156. USDA Forest Service, Intermountain Forest and Range Experiment Station: Ogden, UT.

Megahan, W.F., and W.J. Kidd. 1972. Effect of logging roads on sediment production rates in the Idaho Batholith, INT-123. USDA Forest Service, Intermountain Forest and Range Experiment Station: Ogden, UT.

Megahan; W.F., S.B. Monsen, and M.D. Wilson. 1991. Probability of sediment yields from surface erosion on granitic roadfills in Idaho. Journal of Environmental Quality 20:53-60.

Osborn, B. 1955. Effectiveness of cover in reducing soil splash by raindrop impact. Journal of Soil and Water Conservation 10(1):70-76.

Patric, J.H. 1976. Soil erosion in the eastern forest. Journal of Forestry 74(10):671-677.

Reid, L.M., and T. Dunne. 1984. Sediment production from forest road surfaces. Water Resources Research 20(11):1753-1761.

Smith, R.M., and W.L. Stamey. 1964. Determining the range of tolerable erosion. Soil Science 100(6):414-424.

Swift, L.W. Jr. 1984a. Gravel and grass surfacing reduces soil loss from mountain roads. Forest Science 30(3):657-670.

Swift, L.W. Jr. 1984b. Soil losses from roadbeds and cut and fill slopes in the southern Appalachian Mountains. Southern Journal of Applied Forestry 8(4):209-215.

Swift, L.W. Jr. 1985. Forest road design to minimize erosion in the southern Appalachians. In: B.G. Blackman (Ed.) Proceedings Forest and water quality: A mid-South symposium. University of Arkansas: Little Rock, AR.

Wischmeier, W.H. 1962. Storms and soil conservation. Journal of Soil and Water Conservation 17(2):55-59.

Wischmeier, W.H., and D.D. Smith. 1958. Rainfall energy and its relationship to soil loss. Transactions of the American Geophysical Union 39(2):285-291.

Yoho, N.S. 1980. Forest management and sediment production in the South, a review. Southern Journal of Applied Forestry 4:27-36.