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MINIMIZING THE IMPACTS OF THE FOREST ROAD SYSTEM

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ABSTRACT

Sediment movement from forest road systems is a major concern in forest management due to the degrading impacts of stream sedimentation. Controlling sediment movement from road systems is a key objective to achieve the goal of reducing the impact of forest management activities. Sediment control systems minimizing sediment travel distances downslope are likely essential to reducing the environmental impact of road systems. The USDA Forest Service Southern Research Station initiated a study in an attempt to evaluate alternative means of filtering sediment laden road runoff before it reaches the forest floor on the Tuskegee National Forest in Alabama. The effectiveness of four alternative road sediment control treatments: vegetation, riprap, sediment fences, and settling basins (detention ponds), in reducing sediment export to the forest floor were evaluated over a 42-month period. The sediment basin, sediment fence, and vegetation treatments were similar in efficacy to reduce runoff concentrations with 89, 85, and 66 percent reductions. Riprap was significantly less effective than the sediment basin and sediment fence in reducing concentrations over the study period. The findings suggest that the sediment basin and sediment fence treatments, with concentration reductions greater than 80 percent, may have some applicability as primary sediment control structures on forest road turn-outs.

Key Words: forest roads; sediment control; soil erosion; suspended sediments

INTRODUCTION

Forest roads provide access to perform management prescriptions which make them critical elements in most all forest management activities. Forest roads also provide access for recreation (driving for pleasure) on the nations public lands accounting for the single largest recreation use on National Forests (USDA-FS, 1999). Clearly, forest roads are beneficial in many aspects; however, roads also present environmental impacts on the nation's watersheds.

Forest road systems are frequently cited as one of the major sources of sediment that reaches stream channels on forestlands (Brinkley and Brown, 1993;

Anderson et al., 1976; Haupt, 1959; Trimble and Sartz, 1957). Roads and skid trails have been identified as a major contributor to increased turbidity of water draining logging areas resulting in increases from 4 to 93 parts per million (Hoover, 1952). Forest roads have been found to have erosion rates from one to three orders of magnitude greater than similar undisturbed areas (Megahan, 1974) and perhaps account for as much as 90 percent of all forest erosion (Megahan, 1972). Forest roads can also cause soil erosion and stream sedimentation, which adversely impact on the nation's water quality (Authur et al., 1998).

The forest floor, used as a filter strip, has been established as an effective filter of sediment laden runoff from forest road systems based on short-term erosion and water quality studies (Haupt, 1959; Megahan and Ketcheson, 1996; Swift, 1986). The forest floor can reduce sediment delivered to stream systems by slowing runoff and trapping suspended sediments. However, the trapping characteristics of the forest floor diminish with each significant subsequent storm as sediment plumes encroach on forest water systems. Based on this hypothesis, sediment control systems serving as primary control structures to minimize sediment travel distances downslope are likely the key to reducing the environmental impact of road systems. The purpose of this paper is to present and discuss the findings of a study conducted to assess the effectiveness of alternative sediment control treatments in a 42-month field experiment. Findings from analysis of variance are reported from four selected sediment control treatments on effectiveness in reducing runoff concentrations and delivered sediment over the study period.

STUDY METHODOLOGY

Site Description

This study was conducted on the Tuskegee National Forest in Macon County near Tuskegee, Alabama (Grace, 2002a). The long-term average annual precipitation is 1300 mm with a 10-year, 24-hour storm amount of 165 mm. Soil on the study site is mapped as Norfolk loamy sand, a loose sand surface soil over a loamy sand subsoil. Slopes on the study site ranged from 3 to 12 percent. The road used in the investigation had originally been constructed 20 years earlier to perform management prescriptions. The road was crowned with ditching and traversed an uneven aged managed pine stand consisting primarily of longleaf pine (*Pinus palustris Mill.*). In 1997, the study road was re-constructed to incorporate turn-out design and spacing meeting specifications recommended by Alabama's Best Management Practices for forestry. These specifications were consistent with specifications recommended by most southern state best management practices for forestry (Grace, 2002b).

Treatments

Turn-out sections were hand seeded immediately following road construction work with a mixture currently recommended by the National Forests of Alabama. The seeding mixture consisted of annual lespedza (*Lespedza cuneata*) at 5.6 kg/ha, Pensacola bahiagrass (*Paspalum notatum*) at 22.5 kg/ha, white clover (*trifolium repens*) at 11.2 kg/ha, and Kentucky 31 fescue (*Festuca arundinacea*) at 28.1 kg/ha. Fescue hay mulch and 13-13-13 fertilizer were hand applied at a rate of 4.5 t/ha and 1.0 t/ha, respectively.

A total of 12 road turn-out ditches with similar topography and drainage were selected and randomly assigned to receive one of the four sediment control treatments. The experimental design uses three replicates of four sediment control treatments (Figure 1) applied within a 3 m length at the outlets of turn-out ditch sections. Treatments evaluated in this investigation include:

1) *Vegetation.* Treatment consisted of the seeding, mulch, and fertilizer scheme above applied throughout the treatment length.

2) *Riprap.* Treatment consisted of a 31 cm thick layer of No. 1 coarse aggregate.

3) *Sediment Fence.* Treatment consisted of a sediment fence placed perpendicular to flow from turn-out ditch outlets.

4) *Settling Basin.* Treatment consisted of basins with an 11 m^3 (38 mm of runoff storage) design capacity with dimensions 3.1 m x 3.5 m x 1 m.

Measurements

The sampling design utilizes stormwater samplers, runoff diversion walls, sediment filter bags, and erosion stakes to evaluate sediment transport through sediment control treatments (Figure 2). Treatment effectiveness in reducing runoff concentrations was measured using stormwater samplers located at the inlet (inflow) and the outlet (outflow) of sediment control treatments. The stormwater samplers were activated with 2 mm of ditch flow and collected composite samples of each flow event. At the

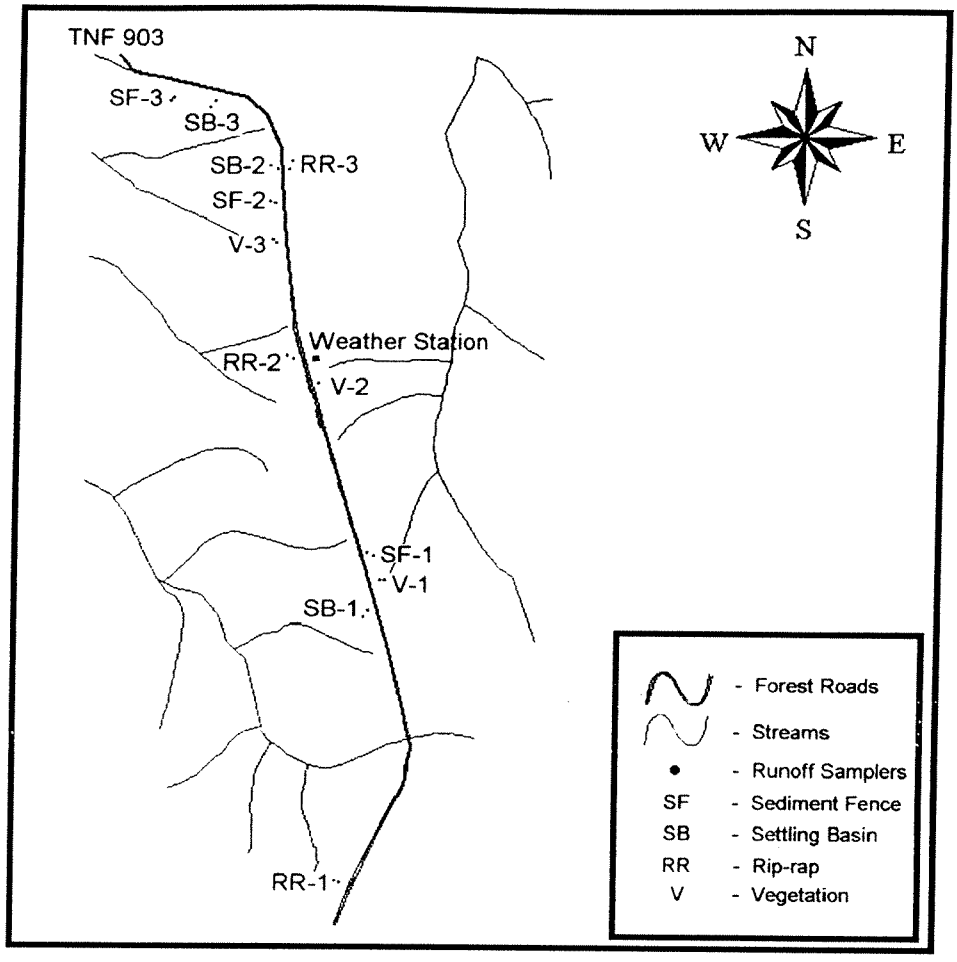

Figure 1. Study site and field layout of sediment control study.

conclusion of flow events, samples were collected and suspended sediments were determined in the laboratory using gravimetric filtration by procedures defined by Greenberg and others (1992). Runoff volumes for turn-out sections were estimated based on rainfall at the site taking into account abstractions and infiltration based on the SCS curve number method for each associated road section. Concentration reduction of each associated treatment was determined by comparing differences in inflow and outflow runoff concentrations for each sampled flow event.

Sediment transported through the treatments was also evaluated by diverting runoff leaving the treatments into 1 micron filter bags using diversion dams. The diversion dam ensured that all runoff leaving treatments either passed through filter bags or infiltrated in an area upslope of the diversion dam (Figure 2). Filter bags were periodically collected, oven dried at 105 °C, and weighed to determine the fraction of sediment delivered to bags. Erosion stakes, installed in a uniform grid in the area upslope of the diversion dam, were used to quantify sediment deposition onto the forest floor by measuring elevation changes. Volume of sediment on the forest floor upslope of the diversion dam was used to determine weight of deposited sediment based on density measurements. Total sediment delivery below treatments was determined as a combination of sediment delivered to bags and sediment deposited on the forest floor upslope of diversion dams.

A weather station located on site collected precipitation depths, precipitation intensity, ambient temperature (°C), and soil moisture from August 1997 through December 1998. The weather station used a

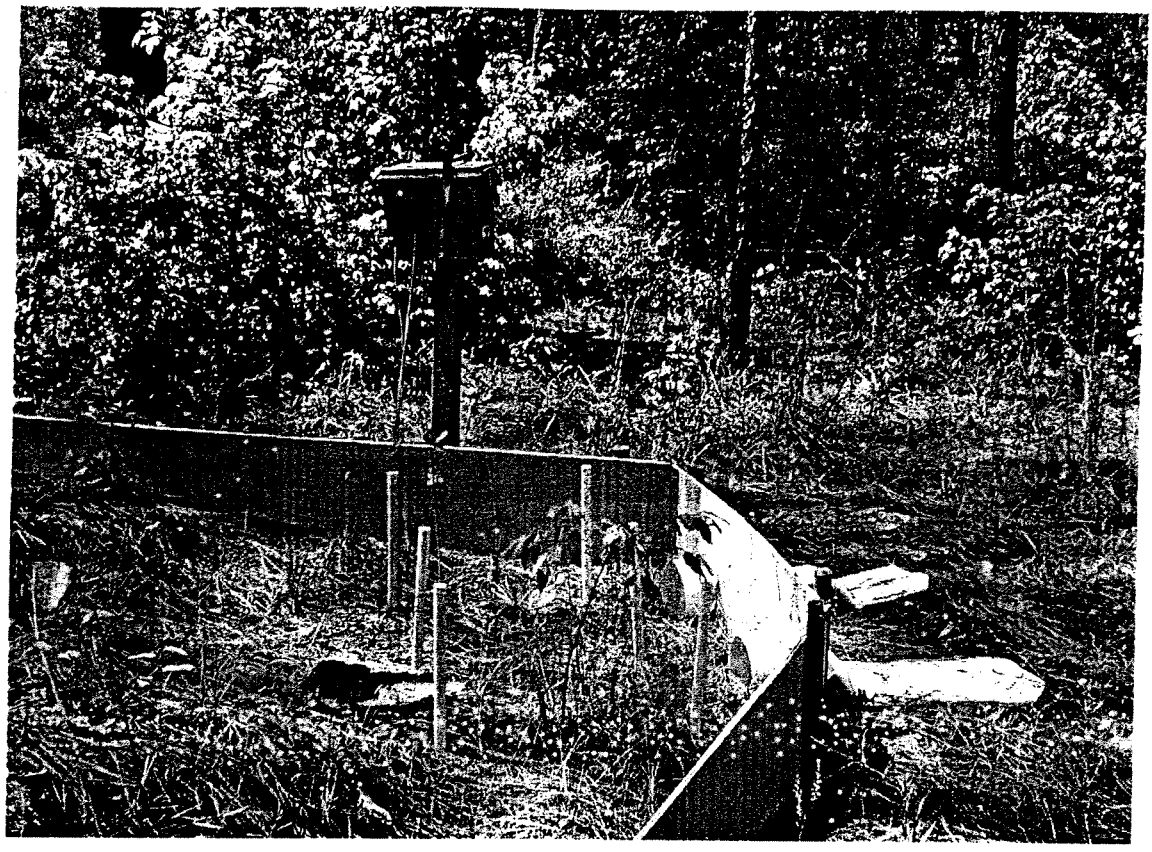

Figure 2. Diversion area for measurement of total delivered sediment below sediment control treatments.

data logger to record input signals from a tipping bucket rain gage sensor, temperature probe, and a soil moisture sensor. In December 1998, temperature and soil moisture measurement was discontinued.

Statistical Analysis

Inflow and outflow concentration data for each associated treatment were considered as a paired sample for flow events. Treatments with inflow, but no outflow were considered 100 percent efficient in reducing runoff concentrations for a given flow event. Paired differences between inflow and outflow concentrations, mean concentration reductions, and total sediment delivery from each associated treatment were analyzed separately using general linear modeling (GLM) procedure (SAS, 1988). Independent variables considered in the analysis were treatment method, inflow concentration, and precipitation. Duncan Multiple Range Tests were used to test treatment means (α = 0.05), where analysis of variance indicated significant differences.

RESULTS

A total of 90 flow events were recorded during a 42-month period from August 28, 1997, to March 17, 2001. Flow events sampled in the study were defined as storm events large enough to result in flow from at least one turn-out section in the experiment. Precipitation depths during the period ranged from 5.1 to 210.0 mm with a mean depth of 42.0 mm (Figure 3). Storm intensities ranged from 0.25 to 31.0 mm/hr with a mean intensity of 4.2 mm/hr. Storm intensity information was available for only 60 of the 90 events due to weather station malfunction. Weather station data were unavailable during three periods during the study, events 27–29, 36–40, and 54–74. Manual rain gage data from a backup system on site was used during these periods where weather station data were unavailable.

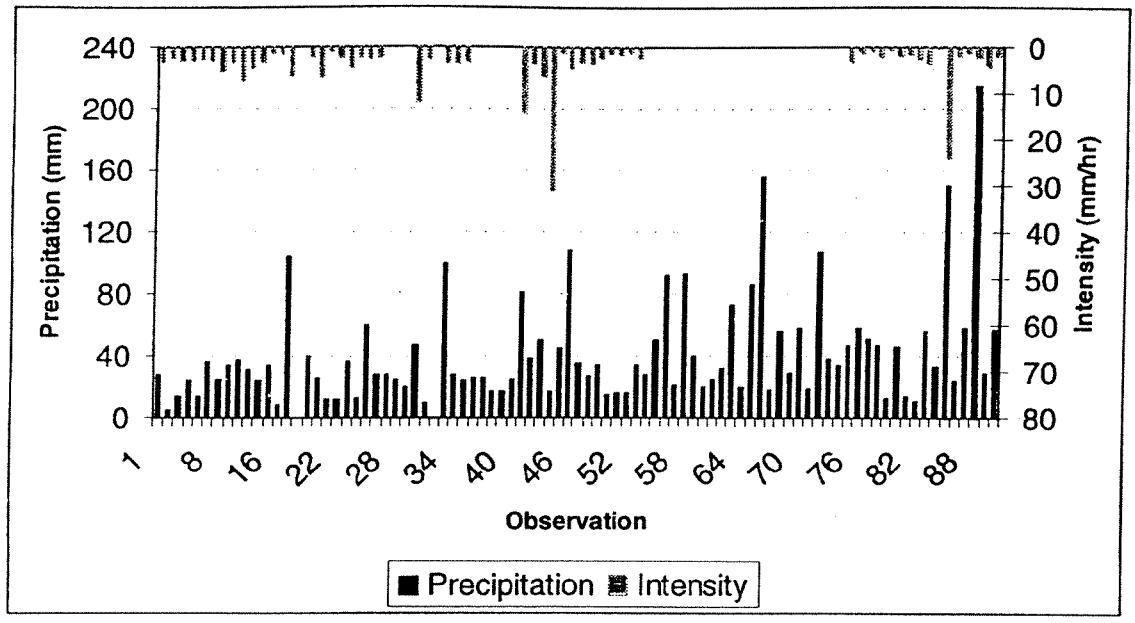

Figure 3. Precipitation at Tuskegee site during the study period.

Treatment method significantly influenced runoff concentration paired differences based on analysis of variance (ANOVA) (p-value < 0.0001). The sediment fence treatment had the greatest concentration paired difference of all treatments in the investigation (Table 1). Vegetation had the second greatest concentration paired differences with nearly 75 mg/L less than the sediment fence treatment. Concentrations from the sediment basin and riprap treatments were statistically similar, but significantly less than the sediment fence and vegetation treatments. The results from the analysis of paired differences would suggest that the sediment basin treatment was one of the least effective treatments, although this was not the case. The sediment basin and to some degree the sediment fence treatments were 100 percent effective in reducing runoff concentrations in most events. However, treatments had greatly reduced efficiencies during storm events greater than the design storm (38 mm).

Analysis of mean concentration reductions shows the influence of treatments on sediment control. Mean concentration reduction data take into account the

Table 1. Mean Concentration Paired Differences from Sediment Control Treatments.

Treatment	N *	Mean (mg/L)	Duncan Grouping ^
Sediment Fence	110	297	A
Vegetation	109	222	B
Sediment Basin	128	149	C
Riprap	109	125	C

* Maximum N possible was 270 (90 flow events x 3 replicates), however each flow event didn't result in flow from all treatment and replicate combinations.

^ Means with different letters are significantly different at the 0.05 significance level using Duncan's Multiple Range Tests.

overall effectiveness of treatments during events without confounding effects of storm events greater than the design storm. Concentration reductions over the 42-month period were influenced by sediment control treatments based on analysis of variance (p-value = 0.003). The sediment basin, sediment fence, and vegetation treatments showed no significant differences in mean concentration reductions, but showed reductions of 89, 85, and 66 percent, respectively (Table 2). The vegetation treatment was detected as statistically similar to the riprap treatment which had a mean concentration reduction of 34 percent over the study period. Riprap was found less effective than both the sediment basin and sediment fence treatment in reducing runoff concentrations.

Treatment method was also detected as significant in the analysis of delivered sediment data (p-value < 0.0001). The sediment basin yielded 24 kg of sediment, which was significantly less than the vegetation and sediment fence treatments (Table 3). However, the sediment basin was statistically similar to riprap in delivered sediment during the study period. The riprap treatment was also statistically similar to the vegetation and sediment fence treatments. The vegetation treatment, a treatment with the least detention time for storm runoff than all other treatments, yielded 49 kg of sediment over the study period.

CONCLUSIONS AND DISCUSSION

Study findings show that treatment method was significant in the analysis of variance for concentration paired differences, mean concentration reductions, and delivered sediment. Comparison test revealed that the effectiveness of treatments varied depending on response variable considered in the analysis of variance model. Analysis detected more differences between individual treatment means for concentration paired differences than for mean concentration reductions and delivered sediment, the other two response variables considered in the experiment.

Table 2. Mean Percent Reductions Yielded by Sediment Control Treatments.

Treatment	N *	Mean Concentration Reductions (%)	Duncan Grouping ^
Sediment Basin	126	89	A
Sediment Fence	108	85	A
Vegetation	95	66	AB
Riprap	104	34	B

* Maximum N possible was 270 (90 flow events x 3 replicates), however each flow event didn't result in flow from all treatment and replicate combinations.

^ Means with different letters are significantly different at the 0.05 significance level using Duncan's Multiple Range Tests.

Table 3. Mean Total Delivered Sediment from Sediment Control Treatments.

Treatment	N	Mean Delivered Sediment (Kg)	Duncan Grouping*
Vegetation	3	49	A
Sediment Fence	3	46	A
Riprap	3	35	AB
Sediment Basin	3	24	B

* Means with different letters are significantly different at the 0.05 significance level using Duncan's Multiple Range Tests.

The findings revealed that there was no difference in the sediment basin, sediment fence, and vegetation mean concentration reductions. The riprap treatment was less effective in reducing concentrations for all treatments except the vegetation treatment. In a result inconsistent with findings of the concentration reduction analysis, the riprap treatment was second only to the sediment basin in reducing delivered sediment. Delivered sediment downslope of treatments was expected to be inverse of the mean concentration reduction results presented in this paper. Treatments with the greatest mean concentration reductions would be expected to have less delivered sediment downslope of treatments. This relationship was not observed with the riprap treatment which had one of the smallest mean concentration reductions but was similar to the sediment basin treatment in delivered sediment. The effect could be due to infiltration achieved as flow traveled across the treatments in the experiment. The effect perhaps supporting this assumption, treatments promoting more infiltration through detention time also had greater reductions in delivered sediment. However, this assumption cannot be explored further since outflow volumes were not measured in this experiment.

Sediment movement from road systems continues to be a topic of concern in forest management. Previous research has shown that roads can be a problematic area on forested watersheds in relation to erosion (Grace, 2002c) and stream sedimentation (Megahan, 1972; Authur et al., 1998). Filter strips have shown the capacity to capture sediment moving across the forest floor in the short-term, however data are lacking supporting the long-term efficacy of filter strips to control road runoff. Filtering capacity of filter strips on the forest landscape, as with any filter, likely decreases in time with increased loading.

Alternative sediment control is likely a long-term solution which supports sustainable forest management. In this scenario, filter strips could be used as an emergency containment area in conjunction with alternative sediment control systems as the primary control structure. Utilizing alternative sediment control systems, similar to those investigated in this study, would likely reduce the risk of storm runoff and sediment reaching stream systems. Results of the study indicate that the sediment basin and sediment fence treatments with concentration reductions greater than 80 percent show promise in reducing runoff concentrations and sediment movement from road systems.

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