SEDIMENT TRANSPORT INVESTIGATIONS ON THE NATIONAL FORESTS OF ALABAMA

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ABSTRACT

In recent years, increased concern and societal pressure have focused on environmental impacts of forest roads on soil erosion and water quality. Forest roads have been identified as the major contributor to sediment production from forested lands accounting for as much as 90 percent of all sediment produced from forest lands. This paper reports on two research studies on the National Forests of Alabama, which evaluate the effectiveness of sediment control alternatives from the forest road prism. Two of the most vulnerable components of the road prism, sideslopes and ditches, are considered in this work. Research evaluated the effectiveness of sediment control practices in mitigating sediment export. The first study, initiated in 1995, investigates the effect of three erosion control techniques on soil movement from cutslopes and fillslopes. Treatments consisting of a wood excelsior erosion mat, native species vegetation, and exotic species vegetation have been evaluated over the last 4 years. Treatments were detected to significantly affect sediment yield and runoff from the road sideslopes. The second study, initiated in 1997, evaluates the effect of selected techniques to control sediment movement in the forest turn-out ditch. The investigation compares sediment filtering and sediment export from the following selected treatments: sediment fence, settling basin, vegetation, and riprap.

Key Words: soil erosion; research; erosion control

BACKGROUND

The Forest Service has been involved in controversy and debate over its management of the public lands since its creation. Debates that originated in the 1890s over management philosophies raged on for 100 years and still continue to be debated. Forest Service chiefs beginning with Gifford Pinchot and continuing to the current chief, Mike Dombeck have been charged to manage the public lands to satisfy multiple uses. In 1998, USDA Forest Service Chief, Mike Dombeck, unveiled the agency's Natural Resource Agenda for the 21"' Century, which emphasizes four areas: watershed restoration and maintenance, forest roads, sustainable forest ecosystem management, and recreation. This agenda called for the development of a scientifically-based forest road policy that meets the needs of the American people.

Forest roads affect every aspect of forest management on the nation's public lands as well as state, industry, and private land holdings. The Forest Service road system alone is more extensive than the U.S. Interstate Highway System, consisting of over 600,000 km traversing the National Forests. The majority of roads in the Forest Service road system are over 50 years old and are constructed or maintained below standards. These lower standard roads were initially constructed for management activities such as harvesting and fire prevention, but have to serve a much different role. Revisions of the Forest Service timber management regime during the 1990s greatly reduced the activity for which the existing roads were designed, timber harvesting. Timber harvesting accounts for 0.5 percent of all forest road use in recent years. Despite the decline in use of forest roads for timber harvesting, traffic has increased more than 11 times the 1950s rate. The dramatic increase is attributed to an increase in vehicles' per day for recreational use from 137,000 in 1950 to 1,706,000 in 1996 (USDA Forest Service, 1999). Recreational use is expected to increase by an additional 64 percent by the year 2045.

In recent years, attention has been focused on the impact of management activities on watershed health on the nation's public lands. Soil erosion and stream sedimentation adversely affect the nation's water quality. Eroded sediment carries away nutrients, pesticides, and clogs reservoirs. Special attention is given to sediment transport from nonpoint sources resulting from forest management activities, such as forest roads. Forest road management is highlighted as a major area of potential adverse impacts from road construction and maintenance procedures on forested lands (Brinkley and Brown, 1993; Reid and Dunne, 1984). Forest roads have increased potential for soil detachment and transport, attributable to several factors: (a) area devoid of vegetative cover, (b) destruction of natural soil structure, (c) increased compaction, (d) increased slopes, (e) interception of surface and subsurface flow, (f) concentrated flow. Special design considerations are required to reduce the environmental impacts of roads on surface water quality.

The recent trends in forest road use are likely to continue and forest roads will be expected to be a vital component in the pursuit of the elusive multiple-use forest. The relatively new Natural Resource Agenda will demand progress in mitigating the environmental impacts of forest roads while still providing access for the enjoyment of the nation's public lands. This goal is complex because each component of the road prism (cutslope, fillslope, traveledway, and roadside ditch) has potential for accelerated soil erosion losses. The associated detrimental environmental impacts of forest roads must remain a point of concentration in future research. The greatest mitigation of the erosion processes is expected to be achieved through careful and considerate planning, location, construction, and maintenance of forest roads. Scientific information is required and alternative approaches need to be investigated in an attempt to preserve the environment for the enjoyment of future generations.

The understanding of forest road impacts on soil erosion and water quality will help promote economically and environmentally sensitive access systems for sustainable management of the National Forests of Alabama. The development of new/alternative approaches to control sediment export from the forest road prism is critical to forest managers because water quality issues wiil continue to be escalated in the near future. Two studies were undertaken on the National Forests of Alabama to evaluate and monitor existing forest road impacts on forest soil and water, explore alternative sediment control techniques, and evaluate alternative surface erosion control techniques.

ROADS AND FOREST SOIL AND WATER

Undisturbed forest lands have minimal erosion and sedimentation due to good surface cover from trees and understory which protects the soil from damaging storm energy. Surface cover provides dissipation of the energy associated with raindrop impact, which can dislodge soil particles. Forest floor litter, debris, and increased surface roughness provide for increased infiltration and decreased runoff to transport detached sediment. Undisturbed forest conditions are an anomaly in the U.S. due to the increased demand for forest products beginning in the 1950s. Forest management operations such as harvesting, thinning, site preparation, and road construction and maintenance can result in degradation of the forest soil and water. Operations can result in increased stormflow, suspended sediments, and nutrient concentrations. Disturbed forest lands are reported to have accelerated erosion losses as a result of these common forest management activities (Binkley and Brown, 1993; Waldbridge and Lockaby, 1994; Shepard, 1994; Lebo and Herrman, 1998).

Forest roads are considered the most detrimental forest management operations to forest water quality and soil erosion. Roads account for as much as 90 percent of all sediment produced on forest lands (Patric, 1976; Megahan, 1972). Elevated levels of erosion may occur following road construction and maintenance, which disturb the forest floor and forest cover. Sediment from roads can be carried directly to stream systems causing environmental damage by clogging spawning beds and shortening the life of reservoirs.

The initial problems associated with accelerated erosion losses from the road prism were reported during the 1930s. Hursh (1939) investigated alternatives for roadbank stabilization in the Southern Appalachian region. Methods to improve vegetation establishment on newly constructed road sideslopes were a major focus of this work. Mulching was presented as a simple, inexpensive, and usually successful method to establish vegetative cover in an attempt to control soil erosion. Expanding on this initial work, Hursh (1942) reported that stabilization of road sideslopes required coordination of engineering and vegetation estabiishment efforts. Planning and location of roads were considered to have a major influence on bank stabilization techniques. The investigator concluded that the establishment of vegetation on road sideslopes at reasonable cost would lower future maintenance expenses.

Following up on the initial work by Hursh, Swift (1984) measured soil losses from road prisms in the Southern Appalachian Mountains. The study showed that the road sideslopes were areas of potential large soil losses caused by inclined surfaces and reduced surface cover. The investigation evaluated soil losses from ¾ to 1 :1 cutslopes and 1:1 to 1 ¼:1 fillslopes. Soil losses were greatest during the first winter following construction. During the 4-month period following construction, the roadbeds produced 42 percent of their total soil loss for the 23-month study. Cutslopes and fillslopes yielded greater losses than the roadbeds during the first 4-month period, accounting for 52 and 82 percent of the 23-month cumulative total soil loss for cutslopes and fillslopes, respectively. Freezing and thawing cycles had a major influence on the winter soil losses. Grass establishment had an important role in controlling soil losses from the road prism.

During the first year after forest road construction, sediment yields averaged 38 $t/day/km^2$ (109 $tons/day/mi^2$) of road in the Zena Creek study area in Idaho, a value that is 1,560 times greater than undisturbed rates (Megahan and Kidd, 1972). Sediment yield during the first year was equal to 84 percent of the total sediment yield during the 6-year study period. The investigators concluded the following practices were necessary to effectively control surface erosion and sediment export downslope in the Idaho Batholith: a) immediate application of erosion control techniques; b) surface cover until vegetation establishment; c) use of debris barriers to reduce sediment export downslope.

Mitigation of soil erosion from all four components of the road prism, including traveled ways, fillslopes, cutslopes, and roadside ditches, was investigated by Burroughs and King (1989). Based on a review of the related literature, the investigators hypothesized that the effectiveness of erosion control techniques was directly related to the timing of application, type of treatment, rate of application, erodibility of the soil, gradient, and road design. The investigators evaluated six different erosion control treatments on fillslopes: straw with asphalt tack, straw with a net or mat, straw alone, erosion control mats, wood chips or rock, and hydromulch. Conclusions drawn were that the greater the ground cover, the more effective the erosion control treatment and the most effective treatment was straw with asphalt tack.

Sediment export from the forest road prism clearly presents risks associated with nutrient removal or relocation, transport of pesticides, road impairment, and stream degradation. Alternative road design characteristics have been presented to control the environmental impact of the forest road (Kochenderfer and Helvey, 1987; Cook and Hewlett, 1979; Gardner, 1978; Packer, 1967; Nagygyor, 1984; Reinhart et al., 1963; Swift, 1985; Hewlett and Douglass, 1968; Murphy, 1985). The design criteria that should receive major emphasis focus on controlling surface water as a means of mitigating erosion losses. Reducing the erosion energy of surface waters can greatly reduce the erosion process, sediment detachment and transport.

Research on road sediment transport and erosion control has been carried out on the traveledway, road sideslopes, and roadside ditch. As a result of this work, erosion control techniques are commonly applied to all components of the road prism and adequate filter strip widths are allowed in attempts to filter runoff before it reaches streams. The filtering capacity of the forest floor, however, is not boundless and decreases as sediment is dropped from sediment-laden runoff. In order to take a responsible role in the Forest Service Natural Resource Agenda, effective steps must be taken to evaluate and develop methods to control erosion at the source and contain sediment movement to the forest road prism. Conventional thinking has lead us to quick fix remedies which eventually, as most environmental decisions made without scientific basis, result in devastating economic, social, and environmental consequences for future generations. This work explores alternative approaches to solve the erosion problem on three of the most critical road components; cutslopes, fillslopes, and ditch. This work has begun to build a database on forest road erosion and mitigation approaches on the National Forests of Alabama. However, the impact of roads on erosion and sedimentation will continue to be a major concern in forest management. Erosion control alternatives considering economic, environmental, and social issues require further investigations in an attempt to design environmentally-sensitive forest road systems.

METHODS AND RESULTS

Shoal Creek Study

A study is being conducted to determine the effect of erosion control techniques on forest road sideslopes in central Alabama (Grace et al., 1998; Grace, 1999). The study road was a mid-slope half-bench crowned road with inside ditching which traverses a west-facing slope on the Shoal Creek District of the Talladega National Forest. The road was constructed in 1995 with 2.2: 1 cutslopes and 1: 1 fillslopes. The site was located in Cleburne County near Heflin, Alabama. The soil on the site was the Tatum series, a fine-loamy mixed-thermic Typic Hapudult.

The three erosion control treatments investigated were a native species mixture, exotic species mixture, and an erosion mat. Native species mixture was composed of big bluestem *(Andropogon gerardii)*, little bluestem *(Andropogon scoparius)*, and Alamo switch grass (*Panicum virgatum*), each at a rate of 11 kg/ha. The exotic species mixture consisted of Kentucky 31 tall fescue (*Festuca arundinecea*) at 28 kg/ha, Pensacola bahiagrass (*Paspalum notatum*) at 23 kg/ha, annual lespedeza (*Lespedeza cuneata*) at 6 kg/ha, and white clover (*Trifolium repens*) at 11 kg/ha. 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 staples. The control had no mulch or seeding applications.

Grace et al. (1998) initially showed that sediment yield reductions during the first 6-months could be expected following erosion control treatment application (Figure 1). The erosion mat treatment gave a 98 percent reduction in fillslope sediment yield as compared to bare soil control. The native and exotic species mixtures resulted in 66 and 93 percent reduction in sediment yield on fillslopes compared to the bare soil control. The cutslope sediment yields followed the same trends as observed on the fillslope.

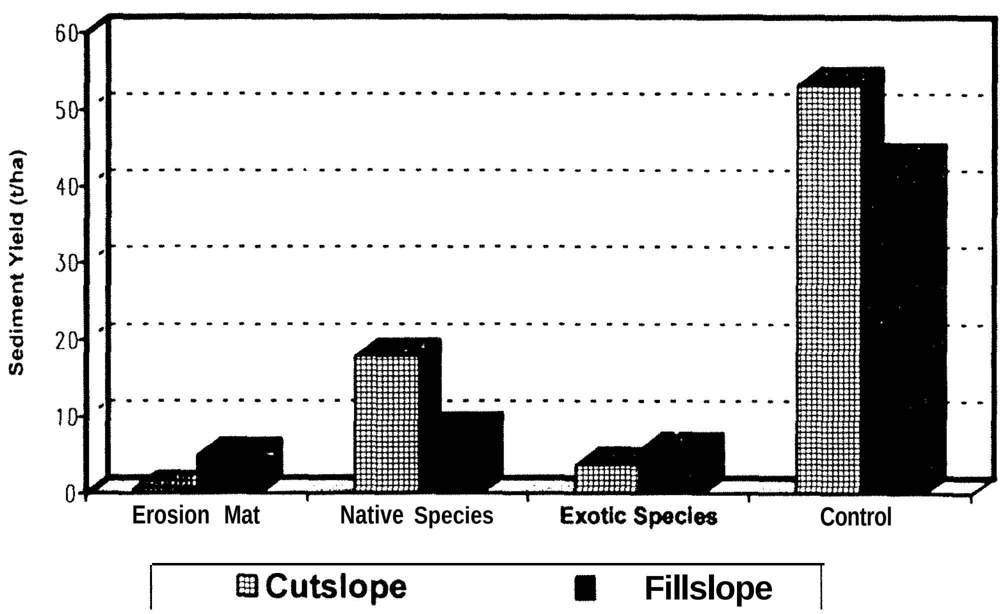

Figure 1. Sediment yield from Shoal Creek study during the first 6-month period (Grace and others, 1998.)

The erosion mat gave the highest reductions in sediment yields with a 88 percent reduction. The native and exotic species mixtures resulted in 81 and 87 percent reductions in cutslope sediment yields in comparison to the control. Runoff reductions of 17 and 37 percent were also observed on both the cut and fillslope erosion mat treatment, respectively. Runoff reductions from fillslope native and exotic species mixtures were 25 and 54 percent, respectively.

Grace's (1999) study further showed that sediment yield reductions increased for erosion control treatments over a 30-month study period. The investigator analyzed four 6-month-long post-construction periods: (1) O-6 months, (2) 12-18 months, (3) 19-24 months, and (4) 25-30 months. Sediment yield from the bare soil control treatments on the cutslope and fillslope averaged 100 and 76 t/ha, respectively, over the 30-month study period. All treatments evaluated in the experiment had significant yield reductions in comparison to the control treatment. The erosion mat treatment had greater than 97 percent reduction in sediment yield for all four study periods in comparison to the bare control. The native and exotic mixtures showed similar reductions in sediment yield for all study periods except the first period. The native and exotic species was statistically similar to the erosion mat for periods 2, 3, and 4, which suggest that vegetation establishment, is critical in erosion control. The sediment yields decreased exponentially following the initial 6-month establishment period, which is consistent with reports from similar work. Sediment yields were highest for all treatments and the control during the first 6-months following the construction (Figures 2 and 3). Cumulative sediment yields initially increase at a much greater rate during the first period but increases at a decreasing rate thereafter. The control on both the cut and fillslope continued to yield significantly greater sediment than all the treatments during periods 2, 3, and 4.

Tuskegee Study

The effect of sediment control techniques applied to the forest road ditch was evaluated on the Tuskegee National Forest (Grace, 1998). The forest road evaluated was re-constructed, during a 2-week period in August 1997, to incorporate proper turn-out design and spacing. The crowned road with ditching was originally constructed 20 years earlier for forest management activities. The 1 -mile-long study road traversed an uneven-aged pine stand on the Tuskegee National Forest in Macon County near Tuskegee, Alabama. Soil on the study site is Norfolk loamy sand, ranging from 6 to 12 percent slope. The lo-year, 24-hour storm for the area is given as 165-mm. Rainfall

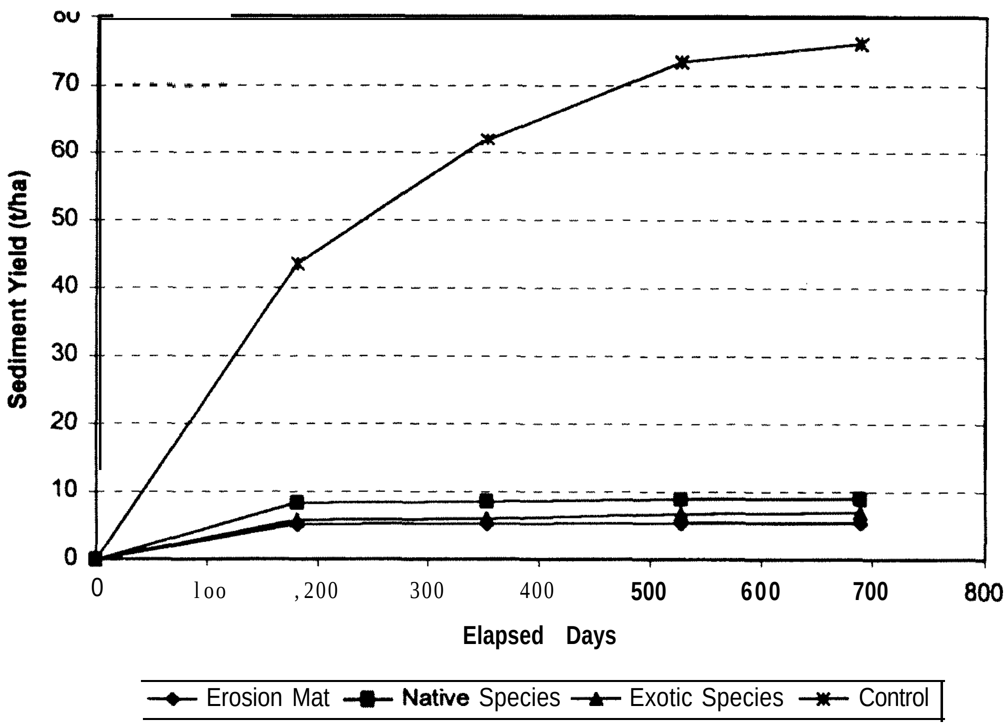

Figure 2. Cumulative fillslope sediment yield during Shoal Creek study.

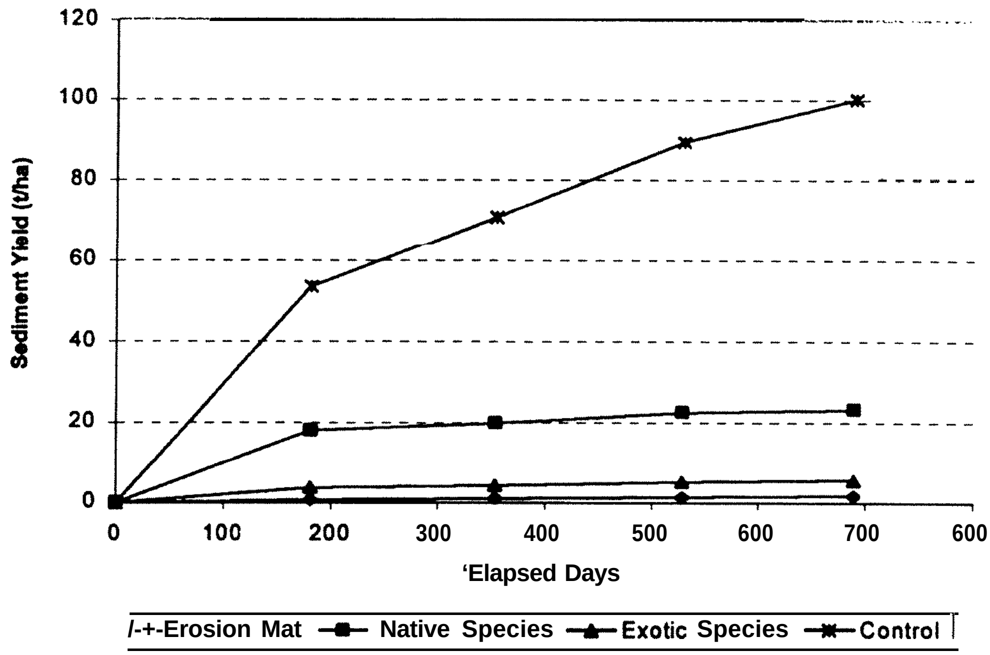

Figure 3. Cumulative cutslope sediment yield during the Shoal Creek study.

characteristics, ambient temperature, and soil moisture were recorded by a weather station located on site. Runoff volumes in turn-out sections were estimated based on runoff emanating from road sections, taking into account interception and infiltration based on the SCS curve number method for each associated road section and roadside ditch.

Four sediment control techniques with similar topography, soils, and drainage were used in this experiment: (1) vegetation, (2) riprap, (3) sediment fences, and (4) settling basins. Ditch treatments were hand seeded with a mixture of Pensacola bahiagrass (*Paspalum notatum*), annual lespedza (*Lespedza cuneata*), white clover (*Trifolium repens*), and Kentucky 31 fescue (*Festuca arundinacea*). Sediment export from the road prism was measured using a runoff sampler at the inlet and outlet of each turn-out ditch structure (Figure 4). Sediment delivery downslope onto the forest floor was investigated using filter bags of known pore size to collect total sediment delivered to the forest floor. A diversion dam was placed below the mitigation treatments to direct runoff to l-micron filter bags. Filter bags were periodically collected, dried, and weighed to determine delivered sediment.

The collected sediment directly relates to the quantity of sediment exported into filter strips below each turn-out treatment. Forest floor elevation changes determined from erosion stakes were used to calculate sediment weight. The total sediment exported from the road prism was determined as a combination of sediment collected in filter bags and sediment deposited on the forest floor above the diversion dam.

Grace (1998) reported runoff sediment concentration reductions ranging from 44 to 85 percent of original inflow concentrations. The settling basin yielded the greatest reduction in runoff concentration with an 85 percent reduction from inflow concentration. The sediment fence produced a 64 percent reduction from inflow concentration. The vegetation and riprap treatments were the least effective in reducing runoff concentration with 45 and 44 percent reductions from inflow concentrations, respectively. The settling basin also had the least amount of sediment to be deposited on the forest floor below the treatment area (Figure 5). Consistent with the concentration results, the sediment fence was next effective in reducing the amount of sediment deposited on the forest floor below treatments. The vegetation and riprap treatments had the greatest fraction of sediment deposited on the forest floor below the treatments.

The settling basin treatment shows the greatest potential to reduce sediment export from the forest road prism in this study. During most storm events,

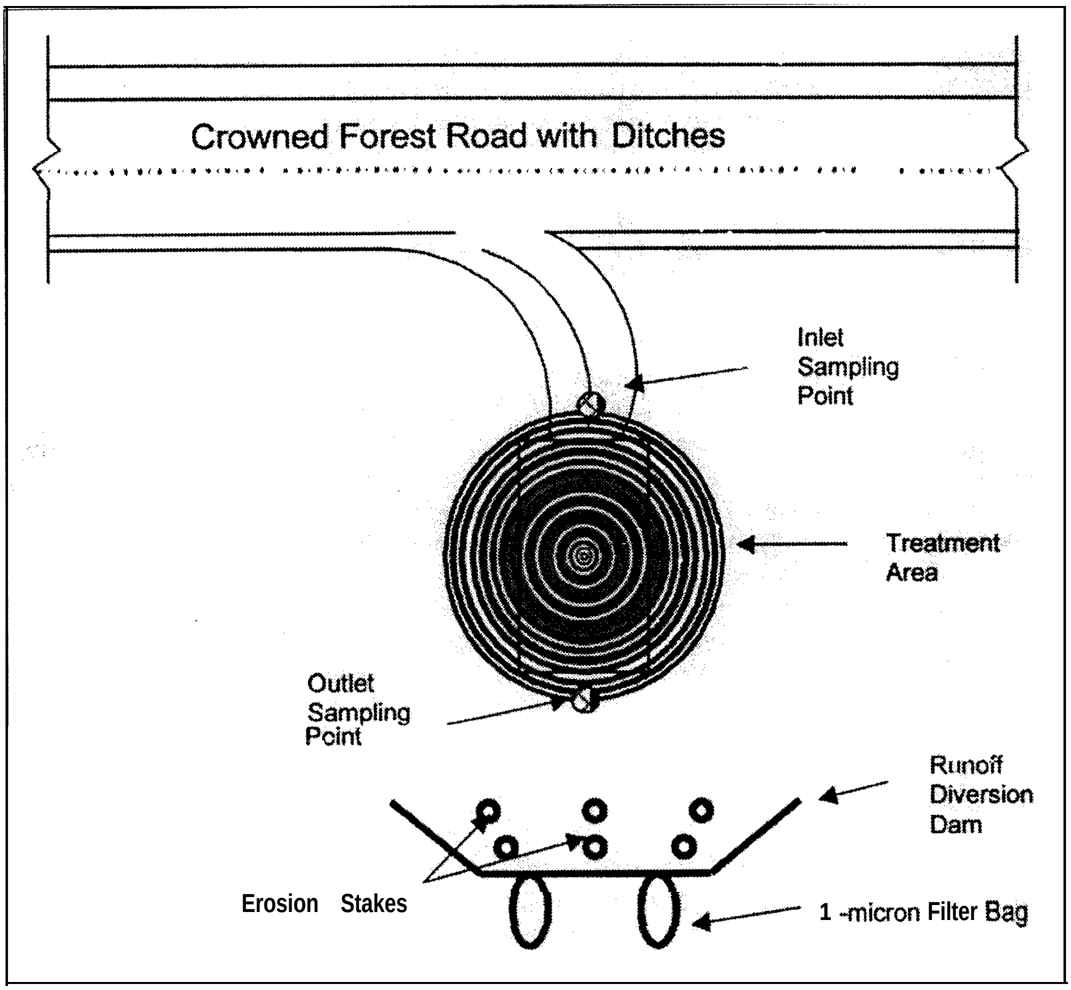

Figure 4. Tuskegee study treatment area layout.

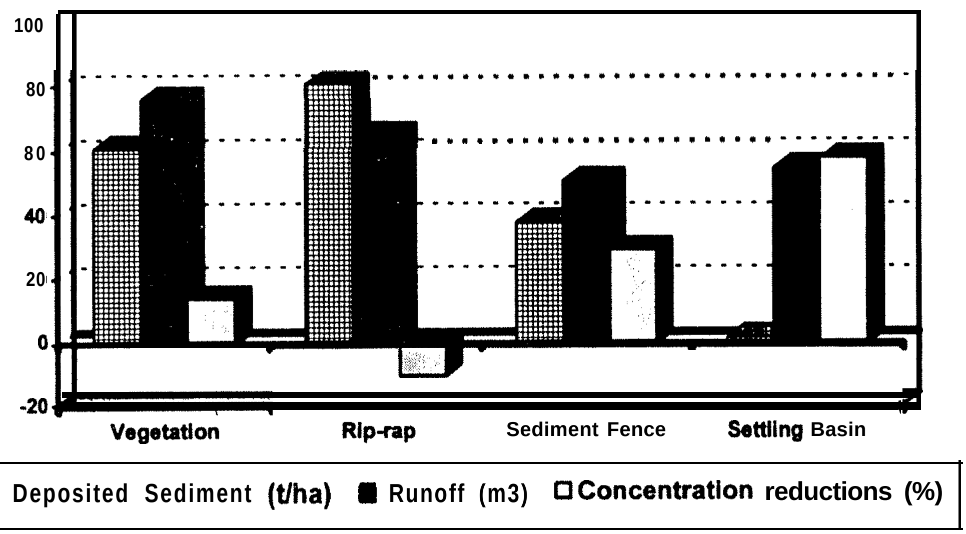

Figure 5. Runoff and sediment yield for the Tuskegee study.

sediment moved from the forest road prism is trapped in the settling basin thereby preventing further downslope movement of sediment. The benefits of settling basins were two-fold: reduced sediment deposition and greater runoff concentration reductions than all other treatments. The vegetation and riprap treatments were least effective in filtering sediment laden runoff. The vegetation treatment had few obstructions to slow the runoff, which likely leads to greater runoff energy and suspended sediments than the other treatments in this experiment. The riprap treatment effectively reduced outflow concentrations during small storm events but large events flushed deposited sediment through the system, which resulted in extremely high outflow concentrations for these events. The large events, which acted as a system flushing in the riprap, accounted for the increase in average outflow concentrations above the values of the inflow concentrations. In essence, the riprap treatments behaved as a source of sediment during large storm events.

CONCLUSIONS

In the Shoal Creek study, all treatments were effective in reducing sediment yield from the road sideslopes. The erosion mat treatment gave the largest reductions in sediment yield with reductions greater than 98 percent during the first 6-months of the study. Reductions greater than 80 percent were observed for all three treatments only one year after road construction. Sediment yield decreased to minimal quantities by the end of the 30-month study period. Sediment yield during the first 6-months following construction accounted for greater than 75 percent of total sediment yield over the 30-month period. The sediment yields from controls were greatly accelerated through the entire period. The results of this work are consistent with results reported from other geographical areas.

Based on the results of the Shoal Creek study and previous work in the area of road sideslope erosion, it became clear that alternative methods of sediment control needed to be investigated. Sediment control as a means of reducing the environmental impact of forest roads led to an experiment in alternative methods to control sediment export on the Tuskegee National Forest. All treatments in the sediment export study, except the riprap treatment, reduced runoff concentrations. The settling basin was most effective in reducing runoff concentrations and sediment deposited on the forest floor. The next most effective treatment in reducing sediment exported to the forest floor was the sediment fence treatment.

Previous work has established that sediment yield is greatly accelerated following disturbance and return to an acceptable level within a short period of time. The gap in the understanding is evident when we try to define “acceptable level” and “short period.” Sufficient scientific information is not yet available to define “acceptable level” of sediment yields from forest road prism components. Time required for sediment yields to stabilize following forest road management activities can range from months to several years, which further complicates the road erosion issue.

The road erosion studies conducted on the National Forests of Alabama concentrated on quantifying sediment yield following forest road management activities and investigating sediment control techniques to reduce environmental impacts. The two studies discussed examine relatively short periods of time (less than 3 years), but assessment of the effectiveness of erosion control treatments is a long-term process. These experiments will continue to be monitored to establish long-term sediment yield rates from sediment control techniques. Additional research is required to develop and evaluate sediment control alternatives applied to forest road systems.

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