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Sedimentation associated with forest road surfacing in a bottomland hardwood ecosystem

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Abstract

Access systems are a necessary element of resource production in bottomland hardwood sites. However, road building may have a detrimental effect on hydrologic function of the site. This report &scribes initial results of a study designed to examine the effect of different road surfacing treatments on water quality.

Four Surfacing treatments installed on two test roads included native soil, native soil with vegetative stabilization, 6 cm of gravel, and 15 cm of gravel over geotextile. During the first flooding season periodic sampling measured floodwater suspended sediments and location of erosion and sediment deposition within the road prism. Initial results suggest that sediment movement was confined to the road right-of-way, w:h no statistically significant sedimentation effects detected beyond the clearing limits of the road. The study is continuing for another field season.

Keywords: Wetland forests; Logging roads; Water quality

1. Introduction

Forested wetlands are an important natural resource in the southern United States in terms of both water quality (Preston and Bedford, 1988) and resource production (McWilliams and Faulkner, 1991). Management of bottomland hardwood sites is important in order to maintain or enhance the ecosystem functions and provide access for productive use. However, access, in the form of forest roads, may conflict with water quality functions of the wetland ecosystem. Roads are commonly cited as the primary source of sediment associated with forest operations on upland sites (Panic, 1976) and in wetland forest operations (Askew and Williams, 1984). Road surfacing treatments and various forms of stabilization of the road prism are recommended practices for minimizing the generation of sediment from roads (Burroughs and Ring, 1989). While these recommendations are extended to application on wetland roads (Jackson, 1992), the underlying scientific basis comes from studies of road-building practice in upland forest sites with welldefined drainage patterns.

The erosion and sedimentation of roads is a complex process involving interactions among site hydrology. soils, climate, topography, and engineering treatments. Any of these elements may either enhance or restrain sediment movement. Two primary factors drive the basic process of erosion and sediment movement: the availability of material for transport and the capability of water to move the material. Both factors vary from site to site and even across the different elements of the road prism. Reid and Dunne (1984) examined both paved and grav-

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elled forest roads and concluded that a gravelled road surface, disturbed by traffic, is the source of over 99% of the sediment, while ditches and cutbanks contribute less than 1% of the sediment. Gravelling a road surface is a common method of reducing sediment production. Packer (1967) identified the percentage of stable surface aggregates greater than 2 mm as a critical factor in predicting road surface erosion. In a study on mountain roads, Swift (1984) compared bare soil; grassed; and 5, 15. and 20cm of gravel for a period of three years. The bare soil and 5 cm gravel treatments generated the most sediment, grass lost soil at one-half the rate of bare soil, and both 15 and 20 cm gravel treatments showed about one-tenth of the soil loss of the bare soil treatment. Kochenderfer and Helvey (1984) observed a similar trend among bare soil, 2.5 cm crusher run, 7 cm crusher run, and 7 cm washed gravel surfaces on a mountain road in the Appalachian region of the U.S. The 7 cm crusher run produced onequarter of the amount of sediment of the bare soil. section, while the 2.5 cm crusher run and 7cm washed gravel had about oneeighth the amount of sediment loss of bare soil.

As noted by Swift (1984), vegetative stabilization. of road surfaces can also achieve significant reductions in sediment generation. Best management practices (BMPs) (i.e. Georgia Forestry Association (1990) and Windsor (1989)) recommend the use of vegetative stabilization to reduce erosion and sedimentation where native cover will not establish itself quickly.

Wetland roads are considerably different from upland sites with regard to erosion potential and processes. Low gradients, high water tables, poorly defined natural drainage, and sheetflow during inundation events often characterize wetland sites. Trafficking of wetland roads generally occurs in the driest time of year whik upland roads are designed for either year-round or wet-season access. Concentrated ditchflow and sheetflow over till-banks transport sediment from upland roads, while in wetlands primary sediment transport occurs during flood events. These fundamental differences raise the question of whether road construction practices derived from upland sites am necessary or appropriate for wetland applications. This study was. designed to investigate the sedimentation effects of various road surfacing and stabilization treatments for wetland road construction.

2. Methodology

The road surfacing study site is in the Flint River floodplain near Reynolds, Georgia. Hydric soils typified by the Chewacla series (Fluvaquentic Dystrochrepts) dominate the segment of the floodplain associated with the study. An uneven-aged, mixed

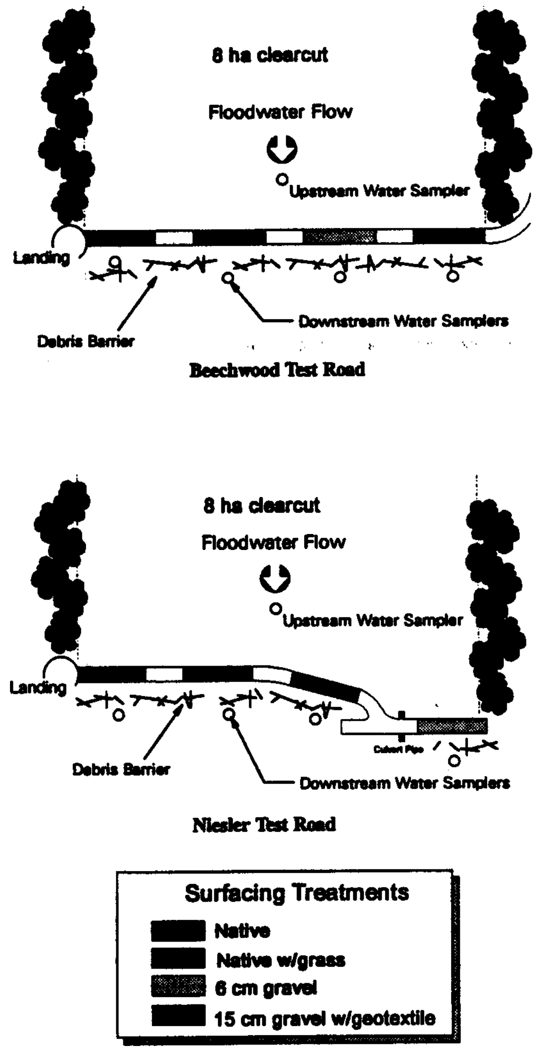

Fig. 1. Plan view of the test road layouts.

deciduous forest composed of red maple (*Acer rubrum*), sweetgum (*Liquidambar styraciflua*), swamp chestnut oak (*Quercus michauxii*), water oak (*Q. nigra*), willow oak (*Q. phellos*), tupelo (*Nyssa sylvatica*), and other associated species occupies the site (see also Lockaby et al., 1996). Georgia-Pacific Corporation, the landowner, has been managing this bottomland forest using a system of small (generally less than 12 ha) clearcuts that are naturally regenerated. Flooding occurs between winter and early summer, with frequency and duration varying in response to precipitation patterns. A cumulative duration for an average year would be approximately two months and would consist of multiple flooding events.

Two test roads, designated Beechwood and Niesler, were constructed in conjunction with 8-ha clearcut harvest treatments. Each road consisted of four surfacing test sections, each 45 m long separated by buffer sections (Fig. 1). Buffer sections were approximately 20m long and consisted of either a broad-based dip or a longitudinal crown to separate water between test sections. The four test sections on *each* road consisted of (1) native material, (2) native material with vegetative stabilization, (3) native material surfaced with 6 cm of gravel, and (4) geotextile with 15 cm of gravel cover. These alternative surfacing treatments were selected to present a range of exposed and disturbed soil conditions that may affect sediment generation from the road. Rummer et al. (1994) described the design and construction of the test road sections.

3. Water sampling

Floodwater samples were collected during flood events with automated composite samplers. The samplers collected 50 ml samples every 3 h while water was on the site. One sampler was located in the clearcut area upstream of the surfacing test sections. Additional water samplers placed at the downstream edge of the right-of-way clearing below each treatment allowed a comparison of suspended sediment in the floodwater before and after the water crossed the right-of-way clearing and the road surface. Each composite sample was subdivided into three subsamples for analysis. Water samples were analyzed for total suspended sediment (TSS) using gravimetric procedures (EPA, 1983). The water sampling scheme was established as a randomized complete block design with road surfacing treatments within blocks (sites) and each flood event as a replication.

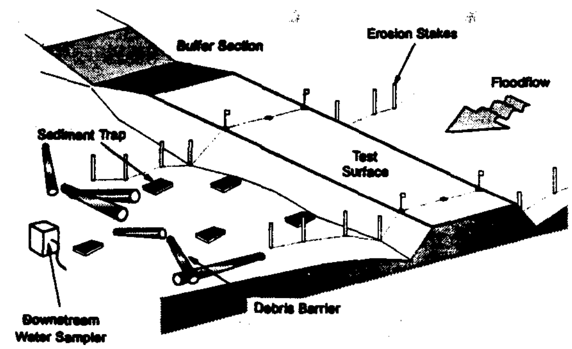

Fig. 2. Installation of sampling points on a typical cross-section.

Additional grab samples were collected during flood events along the test roads, access roads, and from local stream channels. During one flood event, water velocity was measured using a hand-held probe to characterize flow patterns in the Beechwood clearcut and along the test road sections.

4. Sediment traps

Five sediment traps were arranged on the downstream side of each test section (Fig. 2). Each trap consisted of a metal tray covered with a fabric bag. Sediment collected in the trays and on the outside of the bags during flood events. This method is an adaptation of sediment traps used on upland sites and may be a relative indicator of sediment deposition through settling or bedload movement on inundated sites. Two traps were located in the ditch, two on the roadbank, and *one* by the downstream water sampler. Gravimetric analyses yielded the total weight of sediment captured in each trap.

5. Erosion stakes

Sediment deposition/generation was also evaluated on each test road section using erosion stakes.

Two transects were established across the section. At every elevation break, a 19 mm PVC pipe was driven into the ground with 40 cm of pipe remaining above ground level. Remeasurements from the top of the stakes show deposition or erosion around the base of the stake. The results of the erosion stake data will be presented in a subsequent paper.

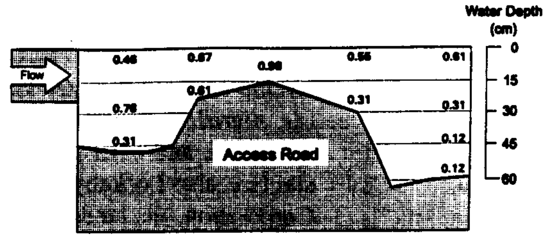

Fig. 3. Water velocity profile across the Beechwood access road.

6. Results

Data measupment stations were established in December 1993 and monitored through June 1994. Four distinct flood events occurred during this period. In early July, after the water samplers had been removed for the dry season, an unusually large flood event inundated the site. Large amounts of logging debris floated from the upstream clearcuts onto the road right-of-way. After drying, the accumulated flood debris was piled and burned in the roadways. The combined effects of the flood, overland transport of coarse debris, and disposal of material resulted in extensive disturbance of the test roads and the loss of nearly half the erosion stakes. The original sampling points have since been re-installed for further evaluation.

7. Total suspended sediment

Nine composite samples were obtained from the downstream automatic samplers during the six-month flooding season. Eight composite samples were also collected by the upstream samplers in the clearcuts for comparison. Flood levels never reached elevations that could be sampled on two of the road surfacing test sections on the Niesler road.

While the limited number of TSS samples precludes the intended statistical comparisons between surfacing treatments, some general observations can be made. Total suspended sediment values from the native surfaced section of the Beechwood road showed considerable variation over the flooding season ranging from about 90 mg L^{-1} in February to a high of 650 mg L^{-1} in March, declining to 450 mg L^{-1} by May. Average values in undisturbed control plots near the test roads ranged from 5 to 380 mg L^{-1} during this period.

One flood event produced enough flow for concurrent sampling at three of the four surfacing sections on the Beechwood road: The native-surfaced section averaged 90 mg L^{-1} for that event, while the seeded section and the 6cm gravelled section averaged 15 and 25 mg L^{-1}, respectively. Grab samples taken from the Flint River and an adjacent creek on the same day averaged 14 mg L^{-1}.

Additional grab samples were collected together with water velocity measurements on another date. Six pairs of upstream and downstream grab samples were collected at a location on the main access road where concentrated flow crossed the road prism. A t-test of the difference between the paired samples showed no statistically significant difference between the upstream and downstream points ($P > T = 0.8477$), indicating no detectable increase in TSS as the water crossed the main access road. Sediment loading averaged 10 mg L^{-1} and water velocity measured at the road crown was nearly 1 m s^{-1} (Fig. 3).

Water velocities were also measured along the Beechwood test road and in the adjacent clearcut. During these measurements, floodwater completely covered the road surface. Flow generally paralleled the direction of the test road rather than crossing it and ranged from 0.2 to 0.5 m s^{-1}.

8. Sediment traps

The sediment traps were emptied three times during the flooding season, in February, April, and June. One observation was missed when a trap could not be located under the floodwater. Analysis of variance

Table 1
Comparison of sediment trap weights by position and road surfacing treatment

Treatment description	Mean sediment weight (g)	Duncan grouping [a]
Trap position		
Ditch	146.98	A
Roadbank	49.26	B
Sampler	31.26	B
Surfacing treatment		
6cm gravel	120.30	A
Native soil	88.28	AB
15cm w/geotextile	77.40	B
Native soil. seeded	59.03	B

[a] Means followed by the same letter are not significantly different at the $P = 0.05$ level.

was used to test the significance of the main effects of tract (Beechwood or Niesler), road surfacing treatment, and trap position (ditch, roadbank, or sampler) on sediment weight. Both surfacing treatment and trap position were significant at the 0.05 level while tract was not. The main effects accounted for about 35% of the observed variation in trapped sediment weight. A Duncan's multiple range test applied to the means (Table 1) indicated that sedimentation was significantly greater below the 6 cm gravelled sections and in the ditches. The traps located next to the downstream water samplers had the lowest mean sediment weights.

9. Discussion

While statistically rigorous comparisons among surfacing treatments cannot be made, it may be inferred from the existing data that it is unlikely that there are any significant differences owing to the surfacing materials. The sediment trap measurements found that there was no difference in sedimentation among the native, seeded, and 15 cm gravel with geotextile sections. Lower sedimentation rates were also observed at the water sampler locations and on -the downstream roadbanks.

The exception in the existing data is the significantly higher sedimentation recorded in the sediment traps placed in the 6cm test sections. The significance of this finding is largely due to values observed on the Niesler 6cm section. This test section was unique in that it was built by reconstruction of an existing subgrade. Because the subgrade was well-settled before surfacing, the 6 cm layer of gravel applied for the test did not embed into the subgrade. The looser layer of surfacing may have presented mom material to the passing floodwater for transport and deposition into the adjoining ditch.

Overall, sedimentation was higher in the ditch traps than on the roadbanks or by the samplers. This probably indicates that the carrying capacity of the floodwater is reduced in the ditches during flood events. The water velocity measurements showed that water velocity was lowest in the deeper parts of the profile. Since the energy of the water is proportional to the square of the velocity, the lower flow rates in the ditches represent considerably lower sediment carrying capacity. sediments will settle out of the floodwaters in these locations.

This is considerably different from the situation on upland roads. Ditches on upland roads carry concentrated flows and may need protection from accelerated erosion owing to scouring. In the bottomland roads observed in this study, the ditches primarily serve to receive run-off from the road surface when the road is not submerged. During flood events, the ditch areas will tend to accumulate sediment through settling.

Water velocity (and carrying capacity) is also probably responsible for the lack of differences among treatments. Velocities along the submerged test road surface were approximately half that of the concentrated flow sampled across the main access road. The grab samples from the concentrated flow indicated no significant sediment generation from the road surface. Thus, it is expected that there would not be significant sediment generation from mad surfaces that are exposed to much lower water velocities.

Given that the highest concentrations of sediment would be expected in the first year after road construction and use, this initial data should represent the greatest impact from the road installation. The disturbance associated with clearing the flood debris could be compared to road maintenance activity such as grading and ditch clearing. Remeasurements on the erosion stakes and continued monitoring of the site during the next flooding season should provide further insight to the appropriate stabilization of the road surface for forest roads in bottomlands.

Acknowledgements

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