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WATER QUALITY EFFECTS OF FOREST ROADS IN BOTTOMLAND HARDWOOD STANDS

by

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Summary: Management of bottomland hardwood sites requires adequate access to support forest operations. A study conducted in a bottomland forest in central Georgia has evaluated the effect of forest road design on sediment movement and water quality. Five years of measurement indicate that a conventional crowned road design is a net sink for sediment, primarily due to settling in ditches. An alternative road design with a flat cross-section was a net source of sediment. Overall, the contribution of sediment from bottomland forest roads is minor in a major river floodplain.

Keywords: Roads, sediment, timber harvesting, wetlands

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INTRODUCTION

Forested wetlands are an important natural resource in the southern United States. This forest type provides important resource values through the production and use of timber, wildlife, and recreation. Bottomland forests are also important ecologically, serving critical functions which improve water quality through filtering of sediments and buffer peak flows. Active management of bottomland hardwood sites is important in order to maintain or enhance ecosystem functions and to provide access for productive use. However access, in the form of low-volume forest roads, may conflict with the beneficial water quality functions of the wetland ecosystem. Roads have been cited as the primary source of sediment associated with forest operations in wetlands (Askew and Williams, 1984). Because of this potential for environmental impacts, the Clean Water Act regulates road construction activities in wetland areas. If, however, the road is constructed and maintained in accordance with 15 specific best management practices (BMP's) the EPA provides an exemption to permitting requirements (40 CFR Part 232.3).

While the wetland BMP's are intended to protect water quality, they are stated in performance language (i.e., required outcomes) rather than specific guidance. For example, "... the fill shall be properly stabilized and maintained to prevent erosion ..." states a regulatory requirement but provides no information on how to properly stabilize fill material in wetland road construction. Additionally, most of the research studies on forest road construction and erosion control have been conducted in upland topography where erosion processes are significantly different from floodplain conditions. There is little scientific knowledge about the water quality effects of forest roads in bottomland stands.

In order to develop a better understanding of erosion processes and implementation of forest road design for bottomland stands, a study was established in a forested floodplain in central Georgia. The objective of the study was to measure sediment movement associated with forest road construction and use in a floodplain. Specifically, the study was intended to determine: (1) if road construction served as a source or sink for sediment in floodwaters, and (2) which road construction practices would effectively minimize adverse water quality impacts. The project was initiated in 1993 and this report summarizes results after six years of data collection.

The Flint River Study

The study is located on the Flint River near Reynolds, Georgia. As an alluvial, piedmont river, the Flint's sediment and nutrient loads tend to be high. Flooding occurs during the winter and spring with variable frequency and duration depending on weather patterns. Figure 1 shows the flooding history for the first four years of the study.

A typical flood event will last for several days.

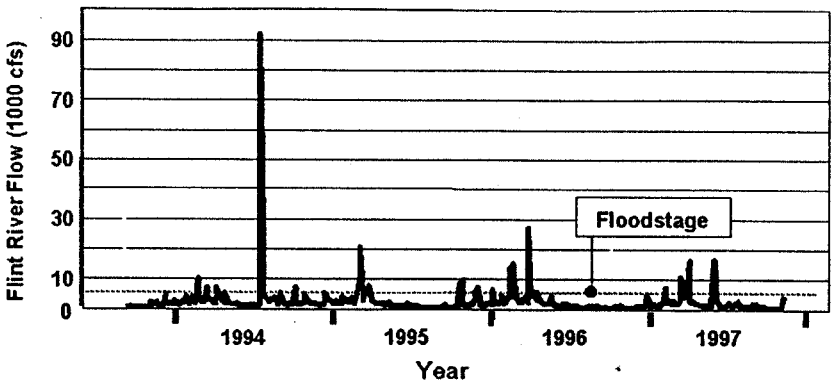

Figure 1. Flint River flow history during the study period.

The initial study installation (Rummer et al. 1994) was designed to examine the effect of road surfacing material on soil movement in the road right-of-way (ROW). Two test roads were constructed in association with replicated 8-ha clearcuts in the summer of 1993. The roads were conventional crowned forest roads situated perpendicular to the direction of floodflow. Both of these Phase I test roads consisted of four separate sections surfaced with either: (1) 15 cm of gravel over a geotextile, (2) 5 cm of gravel, (3) native subgrade with vegetative stabilization, or (4) native subgrade only. These treatments were selected to present a range of source material available for erosional transport. Sediment and water sampling equipment was installed as described below.

In 1996, a review of initial data from the Phase I road (Rummer, Stokes, and Lockaby 1997 and Rummer 1997) indicated no significant difference in soil movement associated with the different surfacing treatments. However, several other observations were also noted:

1. A significant amount of soil disturbance was associated with the conventional road construction practices of clearing, grubbing, and shaping the roadbed. Root wads removed from the roadway contained large amounts of soil and were piled up along the ROW edge.
2. Soil movement in the ROW cross-section was affected by water velocity and the interaction of floodflow with the ditch and crown profile. Water flowing across the road removed some material at the crown, but deposited material in the ditches.

To further explore the erosional processes involved, a third test road (Phase II) was designed and constructed in the spring of 1996. The Phase II road was carefully located to avoid soft soils and ponds in the floodplain. It was oriented parallel to floodflow and built using a "zero-profile" design with no ditches or crown. The roadbed was cleared by cutting trees at ground level. There was no grubbing and only minimal shaping of the road surface to level the roadway. Construction disturbance was

confined within the 12-foot running surface. Logging traffic utilized the Phase II road during the summers of 1996 and 1997. Sampling instrumentation was installed on the Phase II road after logging was completed in the summer of 1997 and monitored for the next 2 water years.

METHODS

Data collection methods on both the Phase I and Phase II roads were similar. Along the test road sections, sediment generation and movement were assessed using three separate approaches. Composite water samplers located at the edges of the right-of-way were triggered by rising floodwater and collected 50-ml samples at 3-hour intervals throughout the duration of any flood event. Transects of erosion stakes installed on cross-sections of the road also allowed an assessment of sediment deposition/generation within the road limits by documenting elevation changes. Finally, sediment pans placed within the right-of-way trapped material to provide a relative indication of sediment movement. On the Phase II road, an additional water sampler was installed which collected discrete interval samples during floods. Figure 2 illustrates the sampling installation.

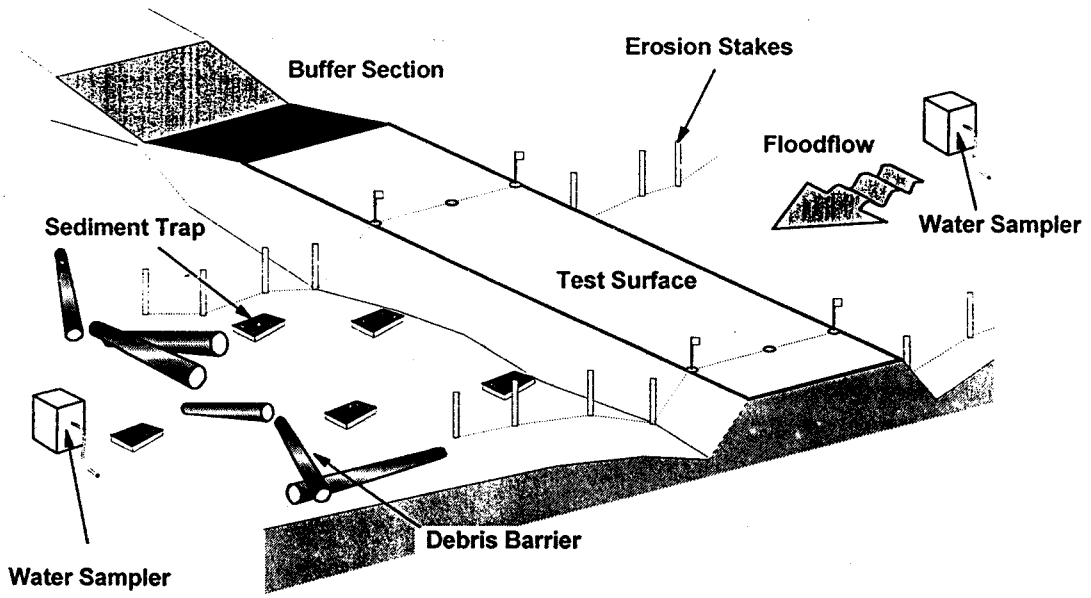

Figure 2. Typical sampling installation on test roads.

The erosion stakes were remeasured in June of each year to assess the deposition or generation of sediment across the road prism. Using the horizontal distance between stakes and the net change in surface elevation at each stake, it was possible to calculate the change in cross-sectional area. Figure 3 illustrates a typical cross-section measurement. Cross-section change was summed for three separate parts of the road prism: (1) from the upstream edge of the clearing limit to the upstream shoulder of the

road surface, (2) the roadway itself, and (3) from the downstream shoulder of the road to the downstream clearing limit.

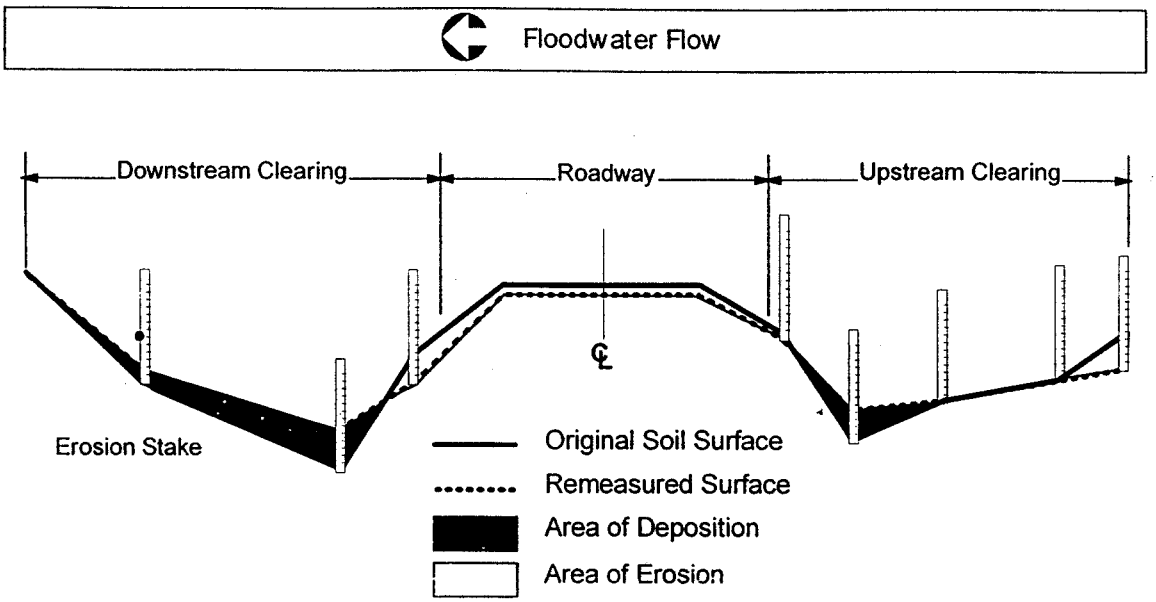

Figure 3. Calculation of cross-sectional changes due to erosion/deposition.

The sediment pans and water samplers were installed on the Phase I road for the 1994, 1995, and 1996 water years. On the Phase II road, the sediment pans and water samplers were installed for the 1997, 1998, and 1999 water years. The sediment pans were emptied each June and the deposited material was oven-dried and weighed to calculate an annual deposition quantity. Water samplers were emptied after each flood event and an aliquot of each sample was filtered to determine TSS. During two flood events, additional grab samples and water velocity profile measurements were taken to characterize conditions.

RESULTS

Erosion pins

Table 1 summarizes the average annual incremental cross-sectional changes measured from the erosion pins. For reference, a 1 cm change in elevation across the upstream or downstream areas would equate to a 0.091 m^2 change in cross-sectional area. Because the roadway is narrower than the clearing limits, a 1 cm change in elevation across the roadway would equate to a 0.037 m^2 change in cross-section. For both the Phase I and Phase II roads, the average value is based on measurement of 8 transects.

Table 1. Average Changes in Cross-sections for the Surfacing Treatments.

Water Year(s)	Mean Change in Cross-sectional Area (m^2)					
	Phase I Conventional			Phase II Zero Profile		
	Upstream	Roadway	Downstream	Upstream	Roadway	Downstream
1993-94	0.075	0.033	0.090			
1994-95	1.111	-0.046	0.106			
1995-96	-0.090	0.000	-0.123			
1996-97	0.041	0.006	0.020			
1997-98				-0.059	0.015	-0.003
1998-99	0.063	0.034	0.026	0.028	-0.036	0.035
1993-99	0.130	0.006	0.085	*	*	*
1997-99				-0.031	-0.021	0.032

On the Phase I conventional crowned road, there was a gain in cross-section (sediment deposition) with three exceptions. The roadway showed a loss in 1995, probably due to traffic and soil movement associated with maintenance work that year. The upstream and downstream areas also showed a loss (erosion) in 1996. Overall, the conventional road showed a net gain in cross-section for the six years of measurement equivalent to about 5 mm of deposition across the entire ROW. Most deposition occurred in the ditches and other depressions created during road construction.

The Phase II zero-profile road had a net loss in the cleared areas during the first year after harvest. While not disturbed by road construction, these areas were also not covered by vegetation in the first year. By the second year a dense stand of herbaceous growth covered the upstream and downstream areas and deposition was observed. The Phase II roadway showed some deposition in the first year and erosion in the second. Overall, for the two flooding seasons in the study, the zero-profile road was a net source for sediment.

Sediment Traps

The sediment trap data from the Phase I conventional road has been reported previously (Rummer 1997). Total sediment loading during 1994-95 was significantly higher than either 1993-94 or 1995-96. This probably reflects the 500-year flood event which occurred in July 1994. The Phase I sediment traps also showed decreasing loading further from the roadway. This is consistent with the erosion pin measurements which documented most sedimentation in the ditches next to the road.

On the Phase II zero-profile road, the sediment traps showed a significantly smaller amount of loading in the third year of study (Table 2), probably due to fewer flood events in the final year. In the 1997-98 year, the high sediment loading in the traps was associated with a loss of elevation measured at the erosion pins. However, in the

1998-99 year, the lower sediment loading in the traps was associated with a gain of elevation at the pins.

Table 2. Average sediment trap weights by flood season.

Water Year	Mean Sediment Trap Weight (g)		Duncan grouping[a]	
	Phase I	Phase II		
1993-94	41.3		*B*	
1994-95	218.0		*A*	
1996-97	80.1	278.31	*B*	*A*
1997-98		238.06		*A*
1998-99		12.69		*B*

[a] means with the same letter are not significantly different α=0.05

Water Velocity

During separate flood events, water velocity profiles were measured on both the Phase I and Phase II roads. These water velocities were not intended to represent average conditions or to be directly comparable between road treatments. However, the measurements do provide an illustration of the effect of the road design on water velocity.

The Phase I conventional crowned road was oriented perpendicular to the flood flow. Figure 3 illustrates a velocity profile based on average readings. Velocity increases as the flow is constrained by the crown of the road with the maximum values near the road centerline. The ditches, on the other hand, had low velocity readings.

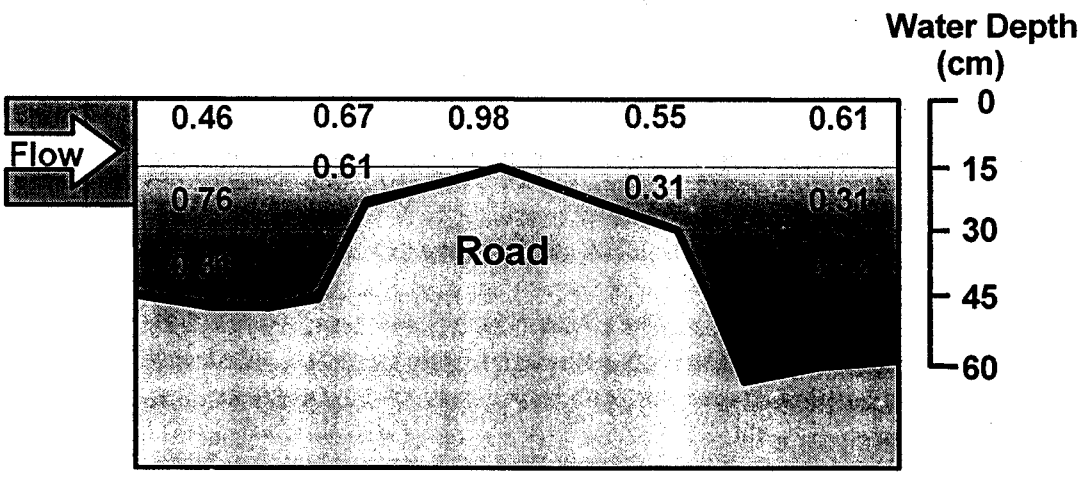

Figure 3. Water velocity (m/s) profile of a conventional crowned road.

The Phase II road, on the other hand, was oriented parallel to flow. Without a profile which constrained flow, the water velocity was similar across the entire road surface and varied little with water depth (Figure 4). However, the vegetative growth on the sides of the road had a significant effect in reducing water velocity.

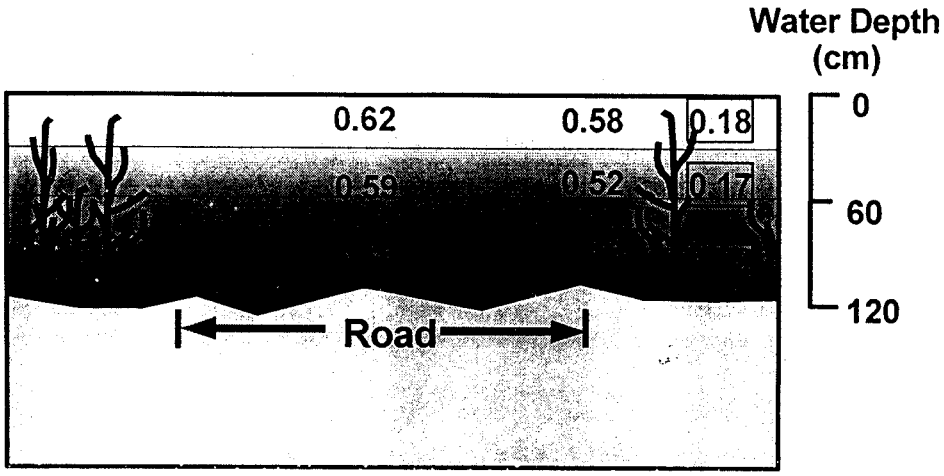

Figure 4. Representative water velocity (m/s) on the zero-profile road.

DISCUSSION

The results of this study indicate that forest roads in flooded conditions can serve as either a source or sink for sediment. The conventional crowned road design (Phase I), oriented perpendicular to floodflow acted as a sink for sediment as material accumulated in the ditches. The zero-profile road (Phase II), oriented parallel to flow, served as a source for sediment as the flow passed unrestricted down the length of the road. Assuming that all losses of elevation represent erosion (not settling), the Phase I road accumulated about 330 metric tons/km of road, while the Phase II road generated about 30 metric tons/km.

It appears that erosion with floodwater is a transport-limited process. Deposition was occurring in the ditches of the Phase I road and on the shoulders of the Phase II road–areas where water velocity was reduced by micro-topography or vegetation. Slight erosion was occurring at the road crown of the Phase I and across the road surface of the Phase II roads–areas where flow was concentrated and water velocity was higher. Thus, to minimize water quality impacts of forest roads in bottomland stands, BMP's should focus on reducing water velocity (i.e., brush barriers, vegetative stabilization) or appropriately anchoring soil in higher-velocity areas.

Reducing the amount of exposed soil is not necessarily the best approach to avoiding water quality impacts. The Phase I road had significantly greater exposed soil from the construction activity, but was actually a sink for sediment. The Phase II road was designed and constructed to minimize soil disturbance, but ended up a net source of

sediment. If exposed soil is not in an area of concentrated flow there appears to be little concern for sediment movement.

Finally, to place the quantities of sediment in perspective, assume that all sediment movement occurs during 10 days of the year when floodwaters are moving through the bottomland stand. Further assume that the average flow of the river in flood is 311 m^3/s and the average TSS of the floodwater is 40 mg/l. A Phase I road would be removing 1.2 mg of TSS/l for each kilometer of forest road. Zero-profile roads would be adding about 0.12 mg of TSS/l for each kilometer.

The actual sediment loading of floodwater is a function of source availability and the transport capacity of the flow. Forest road construction can affect both parts of this process. Road construction can disturb soil and expose traveled surfaces to passing waters which may serve as sediment sources. Road construction can also affect water velocity and direction which may increase or decrease the transport capacity of the flow.

CONCLUSIONS

The results of this long-term study suggest that forest roads in bottomland stands are unlikely to significantly impact the TSS of passing floodwater. Areas of forest road which may serve as sources of sediment are offset by areas of forest roads which serve as sediment sinks.

Proper design can minimize any detrimental water quality impacts. It is important to understand, however, that the design functions of wetland forest roads are fundamentally different from the design functions of upland forest roads. The key factor affecting sediment generation and transport in bottomlands is flow velocity and direction. It appears that, in this particular floodplain, water quality impacts are transport-limited not source-limited. That is, water velocity controls the amount of suspended sediment in the floodwaters, rather than the availability of sediment. Thus, understanding where flow velocity will be greatest in a given road design and properly stabilizing exposed soil in these areas is the most important element in protecting water quality.

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REFERENCES

Askew, G.R. and T.M. Williams. 1984. Sediment concentrations from intensively prepared wetland sites. S. Jour. App. For. 8: 152-157.

Lockaby, B.G., R.G. Clawson, K. Flynn, R. Rummer, S. Meadows, B. Stokes and J. Stanturf. 1997. Influence of harvesting on biogeochemical exchange in sheetflow and soil processes in a eutrophic floodplain forest. Forest Ecology and Management 90: 187-194.

Rummer, Bob, Bryce Stokes, Graeme Lockaby and Robert Tufts. 1994. Design and installation of a study to assess water quality impacts of roadbuilding in a bottomland hardwood ecosystem. In: Proceedings of the Southern Regional Council on Forest Engineering Meeting, 15-17 March 1994, at Vicksburg, MS. Mississippi State University: Starkville, MS, pp. 16-22.

Rummer, Bob. 1997. Road design for low-volume roads in forested wetlands. Presented at the 1997 ASAE Annual International Meeting, Paper 97-5032. American Society of Agricultural Engineers. St. Joseph, MI. 8 p.

Rummer, Bob, Bryce Stokes, and Graeme Lockaby. 1997. Sedimentation associated with forest road surfacing in a bottomland hardwood ecosystem. Forest Ecology and Management 90: 195-200.