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Sediment Plume Development from Forest Roads: How are they related to Filter Strip Recommendations?

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Abstract. *Road systems on the nation's public lands are vital links; providing access to perform management prescriptions, fire management, and recreation opportunities. Sediment movement downslope of forest road systems is a concern because these sediments have the potential to reach stream systems. Filter strips and stream side management zones (SMZs) are recommended and implemented to minimize sediment delivery to stream systems. However, the effectiveness of these practices in controlling sediment movement and minimizing sediment plume development has seldom been assessed. This study was undertaken to assess sediment travel distances downslope of forest roads and characterize the factors influencing these distances. A total of 235 forest road turn-outs (lead-off ditches) were randomly selected on National Forests in Alabama and Georgia. Visible sediment plume lengths were measured for each selected site. Additional parameters quantified include downslope gradient, road section length, road width, and road gradient. The objective of this paper is to report the findings of the study assessing sediment plume development from forest road turn-outs. This paper also examines how the study results relate to suggested BMPs for forest operations below forest road turn-outs in Alabama and Georgia.*

Keywords. Roads, BMPs, Forestry, Alabama, Georgia, Assessment, Buffer Strips, Sediment

Introduction

Forest road systems are an elemental component in the implementation of forest management operations. However, research has shown that roads can have adverse impacts on the water quality on the forest landscape (Authur et al. 1998; Binkley and Brown 1993; Megahan et al. 1991). The forest road system has been identified by previous research as the major source of soil erosion on forestlands (Anderson et. al 1976; Patric 1976; Swift 1984; Van Lear et al. 1997). Furthermore, roads are cited as the dominant source of sediment that reaches stream channels (Packer 1967; Trimble and Sartz 1957; Haupt 1959).

Alternatives have been presented for roadway design (Hewlett and Douglass 1968; Nagygyor 1984), filter strip widths (Swift 1985, 1986), and control of sediments at drainage structure outlets (Grace 2002, 2003). Packer (1967) developed prediction equations for sediment flow distances below surface cross drains in the Northern Rocky Mountains for six soil groups. Obstruction type, average obstruction spacing, distance to first obstruction, contributing road length, and ground cover were identified as factors influencing sediment travel distances. A similar investigation was conducted in the Southern Appalachians investigating filter strip widths required to remove suspended road runoff sediments (Swift 1986). In Swift's (1986) study, sediment transport distances as great as 96 m were observed below the forest road prism. Sediment transport distances downslope of forest roads have also been investigated in the western region of the United States (Megahan and Ketcheson 1996). Transport distances below culverts, rock drains, and fillslopes were predicted for granitic soils based on gradient, flow obstructions, and source areas.

Sediment movement as it relates to forest road systems requires special consideration due to the potential for stream sedimentation by transported sediment. In addition to sedimentation risks, there exists an increased potential for pollution of stream systems by nutrients bound to transported sediment. Controlling sediments transported from the forest road is a priority in forest management strategies and state BMP guidelines in response to the potential for adverse water quality impacts of forest road systems.

BMP guidelines have drawn on previous research in an attempt to minimize the impact of forest road systems. Minimum filter-strip widths and streamside management zones (SMZs) are recommended to buffer the impacts of upslope forest activities and protect water quality. These SMZs (filter strips), relying on the high infiltration rates and surface roughness characteristic of the forest floor, serve as effective filters for storm runoff. However, the capacity and duration of filtering associated with the forest floor is relatively unknown. Specific questions need to be addressed to increase the probability of implementing ecologically acceptable techniques and technologies in forest operations. For example, does the capacity of the forest floor to filter sediment laden runoff reduce with time? If so, then the minimum distance required to filter road runoff likely increases as the capacity decreases. This critical gap in the understanding of sediment transport on the forest landscape needs to be bridged to maintain or improve forest water quality for future generations. Work is required to take the next logical step in understanding the state-of-the-art and the required science to achieve the goal of environmentally acceptable forest road systems.

Many factors contribute to the impact of forest road erosion on the forest landscape. Little work has been conducted investigating sediment transport distances downslope of forest road systems utilizing the forest floor as the primary sediment control. Quantifying sediment plume development downslope of forest turn-out (also known as lead-off ditch) structures can provide evaluation criteria for the acceptability of minimum buffer widths below forest roads. In addition, understanding sediment travel distances below forest roads may provide information critical to the development of sediment control methods and practices that reduce the potential for delivery of road sediments to forest streams.

Objectives

Previous research has clearly defined forest road systems as the major contributor to forest soil erosion and water quality degradation in the United States. Quantifying sediment yields and transport distances below forest road systems will be elemental in designing environmentally acceptable forest road systems. This assessment is an attempt to quantify sediment transport distances downslope of forest road turn-outs in the National Forests of Alabama and Georgia. Specific objectives are:

- Measure visible sediment plume (deposition zone) lengths downslope of forest road turn-outs.
- Relate sediment travel distances observed to filter strip (SMZ) width recommendations for forest roads in Georgia and Alabama.

Methods

The study area consisted of the Conecuh, Talladega, and Tuskegee National Forests in Alabama and the Chattahoochee National Forest in Georgia. Roads with similar drainage characteristics and maintenance level were identified using maps, in consultation with Forest Service personnel, and reconnaissance. Crowned roads with native and gravel surfacing and roadside ditches draining to turn-out ditches were selected for evaluations. A typical road section used in the evaluation is given in Figure 1. Traffic intensity for roads in the investigation ranged from low to moderate.

Figure 1. Typical road section (crowned with turn-outs) used in the evaluation of sediment plume development downslope of forest roads.

Study sites, or forest road turn-out sections, for each road were identified, individually numbered, and tagged for measurement. Study sites were selected for the investigation based on site characteristics hypothesized to influence downslope sediment transport distances such as soil texture, downslope gradient, forest floor characteristics, and drainage structure (Table 1). A total of 235 sites were selected based on replications of three downslope gradients (low, moderate, and high), two soil textures (fine and coarse), two forest floor indices (low and high), and four road gradients.

Table 1. Description of study variables in sediment transport distance study.

Parameter	Category	Description
Downslope Gradient	Low	0 to 10 percent slope
	Moderate	11 to 30 percent slope
	High	31+ percent slope
Soil Texture	Fine	Sandy Loam – Sand Soils
	Coarse	Clay – Loam Soils
Road Gradient	Low	0 - 3 percent slope
	Moderate	4 - 5 percent slope
	High	6 - 9 percent slope
	Steep	10 + percent slope
Forest Floor Index	Low	Obstructions <= 2 cm
	High	Obstructions > 2 cm

Sediment plume lengths were taken as the length of the plume from the roadway edge (taken as the point where the turn-out intersected roadside ditch azimuth) to the farthest point of the visible plume. Road characteristics (road section length, width, and gradient) for each road section contributing to each plume were also measured. Road section length was taken as the slope length of the road section. The road width was determined as the average of measurements at three locations along the road section length. Road and downslope gradient were measured as percent slope using clinometers. Forest floor index (low or high) was categorized based on the condition of the litter layer and obstructions to flow. For example, flow paths with a litter layer and obstructions to flow were classified with a high forest floor index.

Results and Discussion

The effectiveness of turn-outs in controlling sediment movement from the road system is dependent on proper implementation of BMP recommendations. Turn-out spacing that exceeds the maximum recommended spacing would likely have the greatest potential to transport sediment greater distances into the forest stand. However, turn-out spacing recommendations for a given road gradient are greater for Georgia than Alabama based on BMP guidelines for forestry (Figure 2). One of the first parameters explored was how observed turn-out spacing in the assessment related to state recommendations. Observed turn-out spacing was fairly consistent with current state BMP recommendations. Turn-out spacing was equal to or less than recommendations 70 and 90 percent of the time for Alabama and Georgia, respectively. Based on this observed consistency with BMP recommendations, the distance sediment moves downslope from the road sections are expected to be minimized.

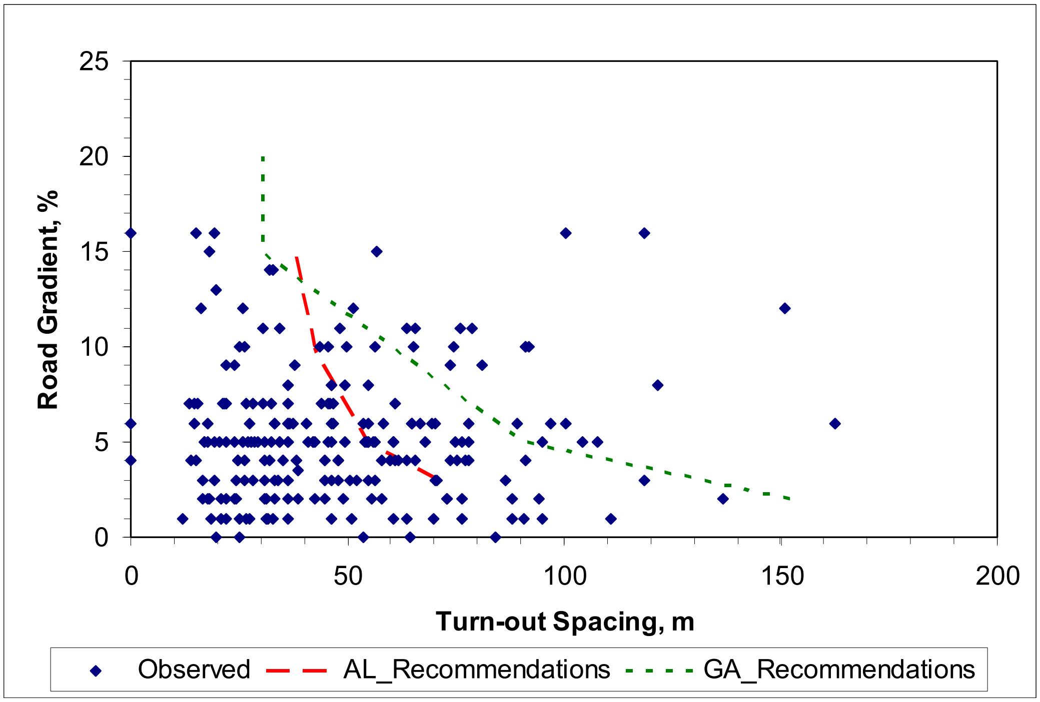

Figure 2. Observed turn-out spacing for road gradients plotted with recommended spacing based on BMP guidelines for Alabama (AL_BMPs) and Georgia (GA_BMPs).

Mean values for the National Forest districts combining texture classes and forest floor indices are presented in Figure 3. Plume lengths ranged from 3 to 140 m for all forest and had a mean length of 30 m. Mean road section length, widths, and gradients were similar for the forests in the investigation. Downslope gradients on the four forests in Alabama averaged 16 percent, whereas gradients on the National Forest district in Georgia had a mean value of 35 percent slope.

One of the questions in this investigation was how plume lengths related to BMP recommendations for streamside management zone (SMZ) widths. Alabama's general recommendation is a minimum SMZ width of 11 m for perennial and intermittent steams (Alabama Forestry Commission 1993). However, when wildlife is a major objective the minimum SMZ width is extended to 15 meters based on Alabama's BMPs for Forestry. Georgia's BMPs for forestry recommend minimum SMZ widths ranging from 6 to 15 m and 12 to 30 m depending on slope leading to intermittent and perennial streams, respectively (Georgia Forestry Commission 1999). Georgia's most sensitive streams (trout streams) require a minimum SMZ width of 30 meters.

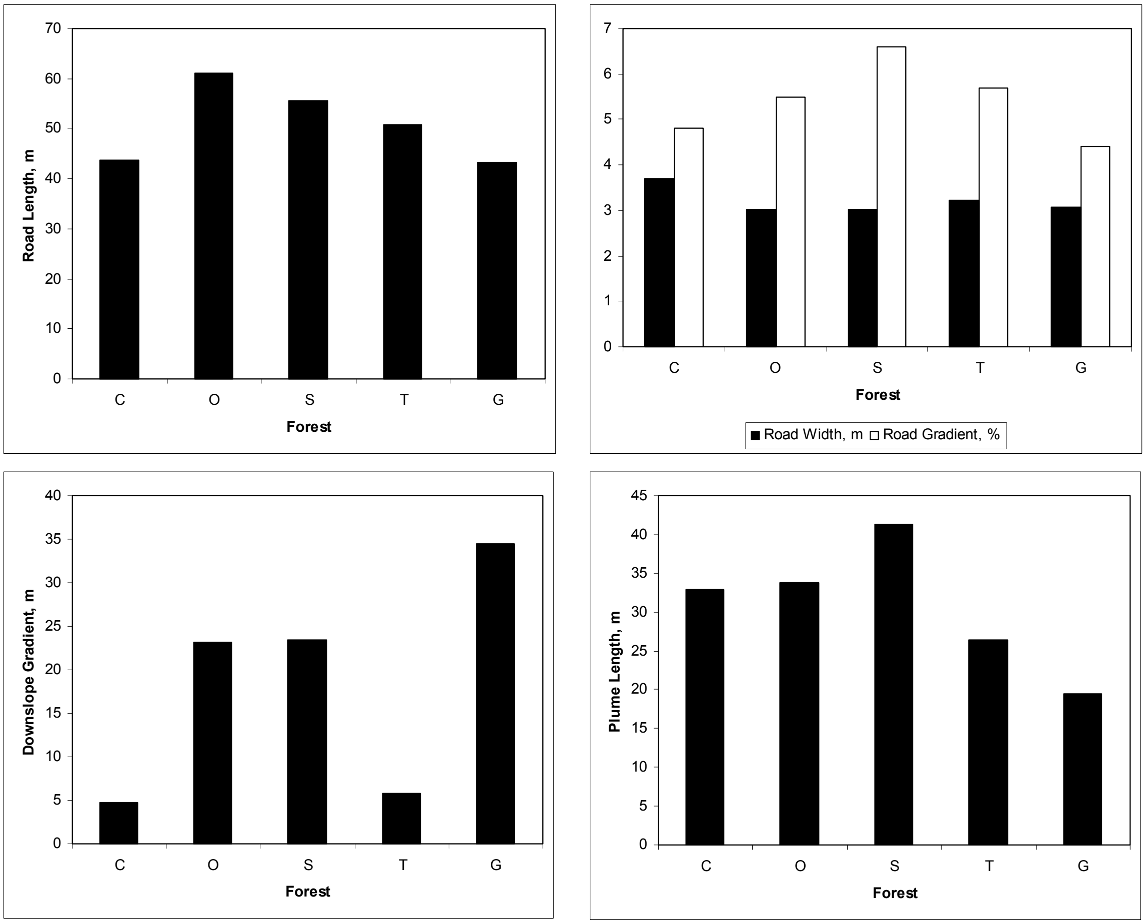

Figure 3. Average road length, road width, road gradient, downslope gradient, and plume length for each forest. (C=Conecuh, (O =Oakmulgee, S=Shoal Creek,

Observed plume lengths for given downslope gradients were compared to the most stringent minimum SMZ width recommendations for Alabama and Georgia (Figure 4). This meant comparing plume lengths to recommendations for SMZ widths for streams in Alabama with wildlife as an objective and trout streams in Georgia. Results of this comparison revealed that plume lengths were generally less than the minimum recommended SMZ width for trout streams in Georgia (30 meters). Of the 88 plumes measured on the Chattahoochee National Forest, 88 percent had lengths less than 30 meters. Only three percent of the plumes had lengths greater than 50 meters (Figure 5). In contrast, plume lengths observed in Alabama exceeded 30 meters for 50 percent of the plumes quantified in this investigation. Ninety-three percent of the plume lengths exceeded Alabama's minimum SMZ width with wildlife as an objective (15 meters) (Figure 5). Only five percent of plume lengths in this investigation were within the 11 meter width recommended for perennial and intermittent streams in Alabama.

Downslope gradients (or topographic relief) likely had an influence on the development of sediment plumes as evaluated in this work. Sediment plume lengths were difficult to evaluate on the steeper gradients (> 20 percent) primarily due to the differences in runoff energy as runoff traveled downslope. Sediment deposition on these steeper gradients was primarily in areas with obstructions or locations where the gradient was not as steep. This phenomenon resulted in a patch work of sediment deposition zones (illustrated in Figure 6). That is, zones of sediment deposition were followed by zones without deposition (slope lengths with greater gradients). The sediment deposition zones were tracked downslope to a point were there was no visible sediment deposition. The distance to the most remote visible sediment deposition zone was taken as the sediment plume length in this evaluation.

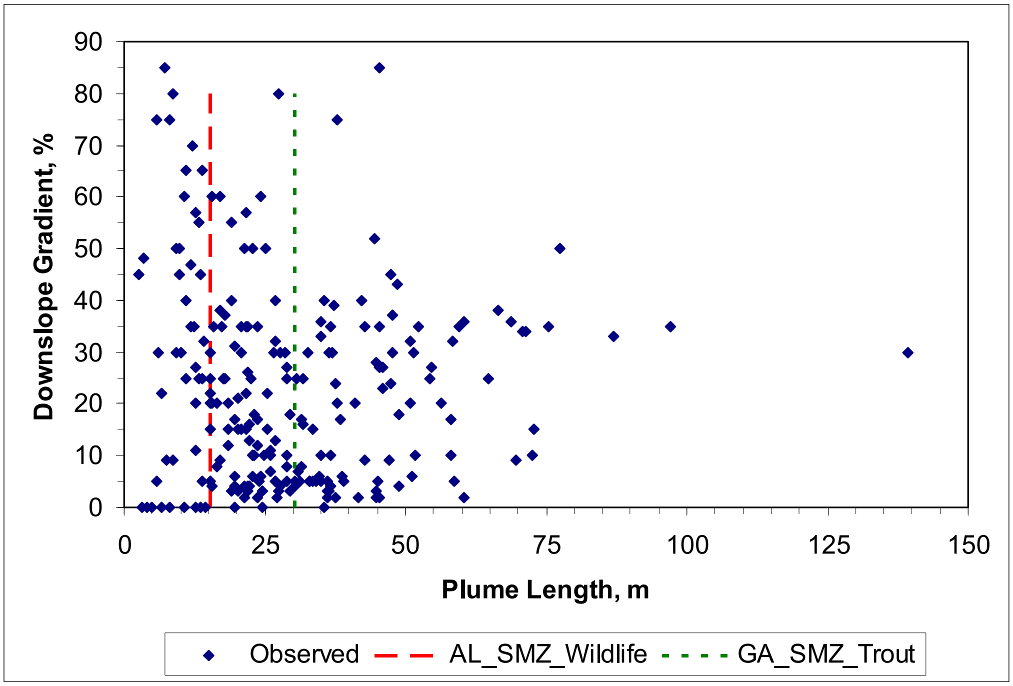

Figure 4. Observed plume lengths for various downslope gradients in Alabama (NFA) and Georgia (NFG) showing minimum streamside management guidelines for Alabama with the objective of wildlife (NFA_SMZ_Wildlife) and Georgia for trout streams (NFG_SMZ_Trout).

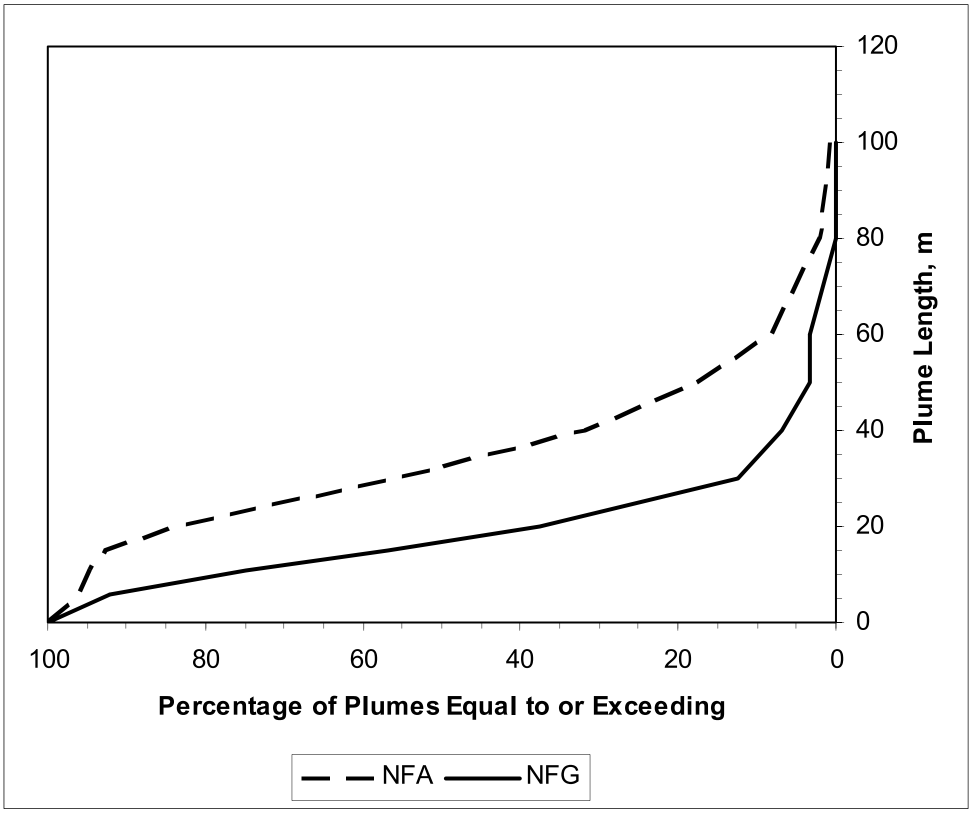

Figure 5. Plume length frequency curves observed on National Forests in Alabama (NFA) and the Chattahoochee National Forest in Georgia (NFG).

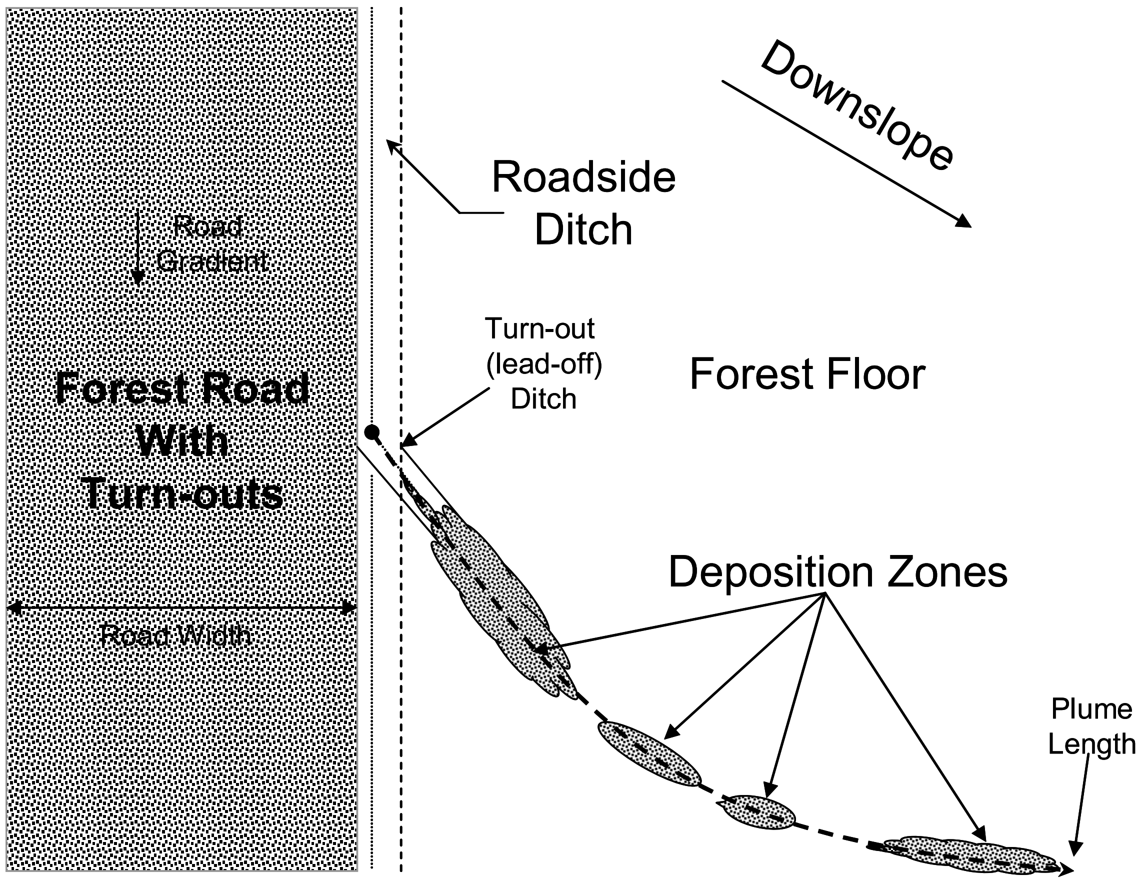

Figure 6. Illustration of sediment deposition zones characteristic of many of the steep slopes (>20 percent slope) evaluated in this study of downslope sediment movement from forest roads.

Conclusions

Sediment plume lengths were measured at 235 sites downslope from the outlet of road turn-out structures. Sites included a range of downslope gradients, road gradients, road section lengths, and flow path conditions. The initial analysis found that turn-out spacing was within BMP recommendations for 70 and 90 percent of the plumes evaluated for Alabama and Georgia, respectively. Sediment plume lengths ranged from 3 to 140 meters with a mean of 30 meters.

Forestry BMPs recommend a minimum SMZ width of 30 and 15 meters for Georgia (trout streams) and Alabama (with wildlife objectives), respectively. Based on this investigation, 88 percent of the sediment plumes measured in Georgia had lengths less than 30 meters. In Alabama, 50 percent of the plumes exceeded 30 meters in length and 93 percent of the plumes exceeded 15 meters. Many factors, in addition to those evaluated in this work, likely had an influence on measured sediment plume lengths. Intensity of road maintenance and the effect of downslope gradients on plume development are two factors that likely had an influence on observed plume lengths.

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