

# INFLUENCE OF FOREST ROAD BUFFER ZONES ON SEDIMENT TRANSPORT IN THE SOUTHERN APPALACHIAN REGION

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**Abstract**—A gap exists in the understanding of the effectiveness of forest road best management practices (BMP) in controlling sediment movement and minimizing risks of sediment delivery to forest streams. The objective of this paper is to report the findings of investigations to assess sediment travel distances downslope of forest roads in the Appalachian region, relate sediment travel distances to BMP recommendations, and describe the deposition patterns within buffer zones. A total of 164 randomly selected sediment deposition zones were measured downslope of the road lead-off ditch structures for each forest. The mean distance sediment was deposited within buffer zones was 20 m for the Chattahoochee National Forest (Georgia) and 41 m for the Talladega National Forest (Alabama). Sediment transport distances were <30 m for 38 and 88 percent of sites evaluated on the National Forests in Alabama and Georgia, respectively. A small percentage (15 percent) of sediment from road sections terminated in streams downslope of the road sections in this investigation. Results indicate that current road BMPs are somewhat effective in reducing risks of road to stream connectivity in most cases. However, the deposition lengths within the buffers for both forests were >20 m which may exceed the buffer zone width requirements in the States in this investigation and many States in the United States. This research indicates that the connectivity issue requires additional research that specifically focuses on quantifying the fraction of forest road erosion reaching stream systems which include intermittent and perennial streams.

## INTRODUCTION

Nonpoint source (NPS) pollution issues related to forest activities (silviculture) are not as extensive as the leading source activities (agriculture, resource extraction, urban stormwater, and construction) (West 2002). However, NPS issues, particularly related to soil erosion and suspended sediment, are a major concern in forest resource management (Binkley and Brown 1993, Marion and Ursic 1993, Patric 1976) because water is a key product of the southern forests' resource (Sun and others 2004). Water-quality problems related to sediment from forested landscapes are difficult to address due to the difficulty in locating the sediment source. Upslope erosion and stormwater routing can increase sediment transport as storm runoff travels downslope through natural and artificial drainages toward critical streams (Grace 2007; Swift 1985, 1988). These artificial drainages, i.e., culverts, roads, road sideslopes, and roadside drainage ditches, are often conduits for storm runoff and sources for accelerated erosion losses. The forest road prism is identified as a major contributor to NPS issues related to forest activities and have the potential to elevate NPS problems (Grace and Clinton 2007). Forest roads provide access to perform management prescriptions which make them critical elements in most forest management activities. Forest roads are beneficial in many aspects; however, roads can also result in environmental impacts on the nation's watersheds (Grace 2002b, Lane and Sheridan 2002). Water-quality issues related to sediments have been and continue to be a concern in forest road management strategies (Brown and others 1993, Grace 2005b, Neary and others 1989, Riedel and others 2004).

The forest floor is an effective filter of stormwater runoff from forest road systems based on previous short-term

erosion and water-quality studies (Haupt 1959, Swift 1986). It is recognized that the forest floor can reduce sediment delivered to stream systems due to increased infiltration and trapping sediments. However, the trapping characteristics of the forest floor are temporal and diminish with each significant subsequent storm as sediment encroaches on forest water systems (Grace 2002a). Consequently, road systems can eventually have direct connectivity to streams resulting in degraded water quality. It is for this reason that forest roads continue to be reported as one of the major sources of sediment that reaches stream channels on forest lands (Van Lear and others 1998). Quantifying the extent and magnitude of sediment transport from forest roads has eluded scientists due to the complexity in assessing sediment transport across the forest floor and difficulty in defining the hydrologic connectivity between roads and streams.

Previous research has investigated factors influencing the movement and quantity of sediment traveling across the forest floor (Grace 2005a, Haupt 1959, Packer 1967, Swift 1986, Trimble and Sartz 1957). Researchers have presented several characteristics related to forest roads that can influence the distance sediment travels downslope and suggested minimal widths of buffer areas adjacent to forest streams. Based on this research, primary characteristics influencing sediment deposition distances are related to road section area, slope, and obstacles in the storm runoff flow path. Unfortunately, a gap remains in the understanding. The fundamental question that has not yet been answered is, "Do current management practices disconnect roads from stream systems and other water bodies?" This work reports an investigation to assess the movement of sediment from road systems in the Southern Appalachians and presents special issues related to the connectivity and the role of the

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forest buffer in minimizing the connection of forest roads and streams in this sensitive region.

## METHODS

### Study Area Description

The investigation was conducted on the Talladega and Chattahoochee National Forest lands in the Southern Appalachians located in Alabama and Georgia, respectively. This area is contained within the Appalachian Blue Ridge Forests ecoregion and consists of temperate broadleaf and mixed forests. Average annual temperatures in the region range from 4 °C to 15 °C.

The Talladega National Forest (TNF) study area is located at approximately lat. 33° and long. 85° where the long-term average annual precipitation is 1400 mm. Slopes in the TNF study area ranged from zero to 60 percent. Elevation of the study area is approximately 400 m above mean sea level (MSL).

The Chattahoochee National Forest (CNF) study area is located at approximately lat. 35° and long. 83° in the Southern Appalachian Mountains. Long-term average annual precipitation is 1800 mm. Slopes on the study site ranged from 10 to 60 percent. The elevation of the CNF study area is approximately 900 m above MSL.

### Measurements

The initial phase of this investigation defined a representative sample of roads with similar construction standards,

maintenance levels, traffic intensity, and drainage characteristics based on site reconnaissance and in consultation with national forest personnel. The potential study roads were constrained to crowned roads with native surfacing drained by lead-off ditches. Road maintenance primarily consisted of biannual grading with periodic ditch maintenance. Roads in the investigation ranged from 5 to >20 years. However, the age of roads was a difficult parameter to characterize due to records being essentially unavailable for older roads (>20 years). Traffic intensity for roads in the investigation ranged from low to moderate with intermittent periods of high traffic during periods of management activities.

Lead-off ditch (or road section drainage) structures were randomly selected from seven roads at the CNF and six roads at the TNF. The study design was a completely randomized design within each forest where roads were selected at random and each road was subsampled by site. The number of sites (or observations) selected was based on the number of sites required for statistical validity determined by a Neyman approximation using procedures presented by Grace (2005b). A total of 164 sites, 88 for the CNF and 76 for the TNF, were measured in the Appalachian region with replications of factors hypothesized to influence sediment movement downslope. These factors included road section length, road width, road gradient, downslope gradient, forest floor index, soil texture, and deposition length. However, this report concentrates on deposition length measurements within the forest buffer zones. The statistical analysis consisted of testing for differences between the

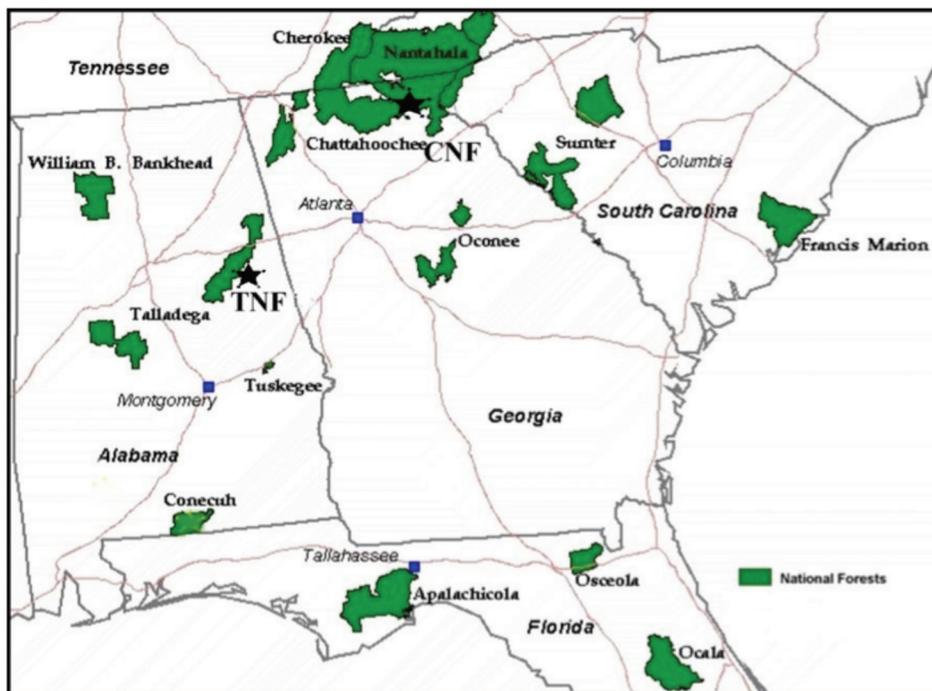


Figure 1—Location of study sites within the Southern Region highlighting the Talladega National Forest (TNF) site and the Chattahoochee National Forest (CNF) site.

national forests as a fixed factor with both roads nested within national forests and sites nested within roads as random factors. PROC MIXED (SAS Institute Inc. 2004) was used for the analysis of this mixed model. SAS TTEST procedures were used to test for differences in observed drainage structure spacing and best management practices (BMP) recommended drainage structure spacing.

The length that sediment deposition areas extended into the forest buffer was determined by first tracking the most remote deposition in the road stormwater flow path. Total deposition length was taken as the distance between the roadway edge and the most remote point of visible sediment deposition. The buffer distance from the road edge was also measured along the storm runoff flow path to determine the established buffer length for direct comparison with the observed deposition length.

## RESULTS AND DISCUSSION

Results from the 13 experimental roads on the TNF and CNF are presented in table 1. These data were evaluated based on two different components of concern in forest management. First, the results were analyzed to evaluate the effectiveness of implementation of forest road BMPs for the sites, e.g., determining the implementation of current BMPs for forest roads. Initially analyzing the data for implementation effectiveness minimized risks associated with interpreting differences in application and implementation of BMPs as differences in deposition patterns within buffers. Using this approach allowed a direct comparison of spacing

recommendations for a specific road section and observed spacing contributing to deposition within the buffers. Secondly, data were analyzed to evaluate the influence of buffers in trapping sediment eroded from contributing road sections on the forests. This procedure allowed comparisons of observed deposition within buffers with both recommended buffer strip widths and implemented buffer strip widths for the forests.

Previous research provides the guides for BMP recommendations for road drainage structure spacing that are a function of road gradient (Haupt 1959, Megahan and Ketcheson 1996, Swift 1986, Trimble and Sartz 1957). The observed mean drainage structure spacing for road sections was 55.5 and 43.1 m for the TNF and CNF road sections, respectively. The mean of recommended spacing for drainage structures for road sections on the TNF and CNF are 58.3 and 141.2 m, respectively. The drainage spacing and resultant drainage area for the TNF road sections were significantly greater than those for the CNF which is primarily attributed to the reduced road gradients (6.6 percent slope opposed to 4.4 percent slope) on the CNF road sections in the investigation ( $P = 0.042$ ) based on SAS MIXED procedures (SAS 2004). Analysis, using SAS TTEST procedures, also detected a significantly closer observed spacing than BMP recommendations for the CNF site ( $P < 0.0001$ ). No significant differences were detected between observed spacing and recommendation spacing for the TNF ( $P < 0.584$ ). A plot of the observed drainage structure spacing for each forest vs. BMP recommended lead-off or drainage structure spacing illustrates the consistent or less conservative spacing than

**Table 1—Means and statistics for road length, width, gradient, buffer gradient, and deposition length within buffer zones for the Talladega National Forest and Chattahoochee National Forest sites**

Parameter	<i>n</i>	Mean	Standard deviation	COV
Talladega National Forest				
Deposition length, m	75	41.2 a	22.1	53.3
Buffer gradient	76	23.4 b	11.3	48.4
Road gradient	76	6.6 a	4.2	62.8
Road length, m	76	55.5 a	36.6	66.1
Road width, m	76	3.0 a	0.8	27.9
Chattahoochee National Forest				
Deposition length, m	88	19.6 b	13.9	71.2
Buffer gradient	88	34.5 a	22.8	66.1
Road gradient	88	4.4 b	3.1	70.2
Road length, m	88	43.1 a	20.6	47.8
Road width, m	88	3.1 a	0.5	17.1

Mean values for a given parameter with the same letter are not significantly different between the forests at the 0.05 significance level.

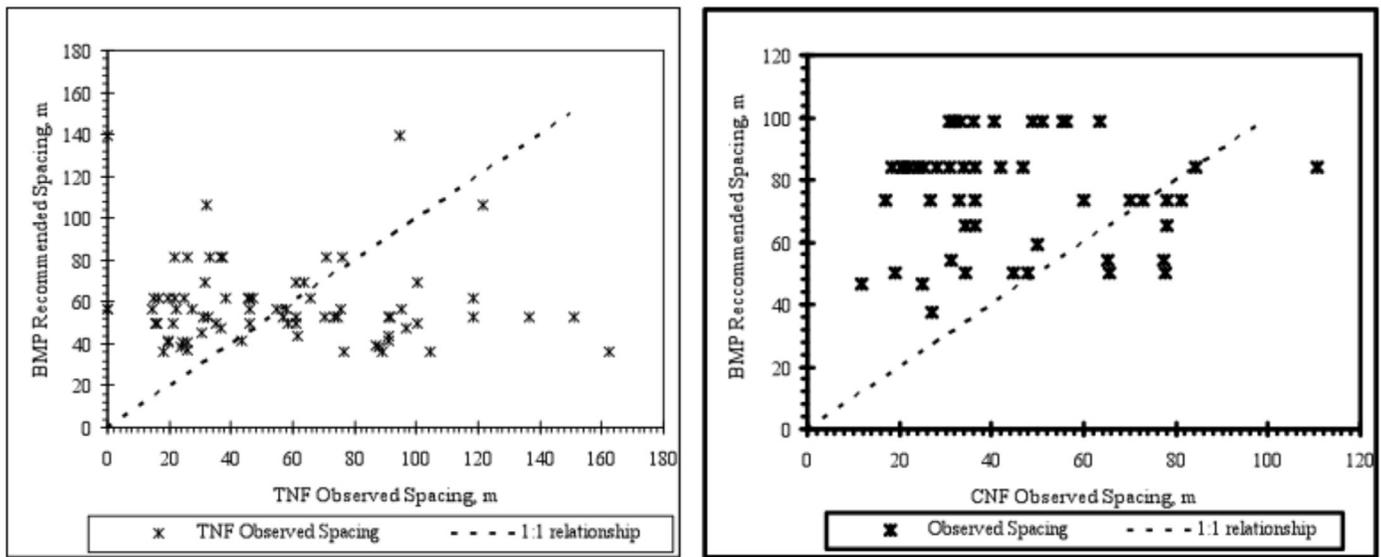


Figure 2—Observed drainage spacing for the TNF site (left) and the CNF site (right) versus BMP recommended spacing for each site.

recommended for the road sections in the investigations (fig. 2). The 1 to 1 line plotted along with data for each site represents consistency between observed and recommended spacing for road drainage structures; data points in perfect agreement would fall along this line. Observed spacing for the CNF was found to be more conservative than recommended drainage structure spacing for the majority (90 percent) of observations as indicated by points that fall to the left of the 1 to 1 line. Whereas, results show that only 59 percent of observed drainage spacing was more conservative than recommendations for the TNF. Based on these results, we would expect that deposition lengths within the buffers below road sections on both forests would be minimized due to consistent or closer (conservative) drainage structure spacing. Conservative spacing could be deemed as a built-in safety factor to maximize the distance that eroded sediment has to travel across the buffer to reach critical stream systems. Conservative spacing typically results in less drainage area contributing to each storm runoff pathway which translates to reduced energy to detach and transport sediment in the flow path. The combination of reduced energy to detach and transport sediment and reduced stormwater runoff from road sections results in decreased sediment deposition volumes and distances within buffer zones adjacent to streams. However, this was not always the case based on the analysis and results presented later in this paper.

The comparison of the observed and recommended spacing of road drainage structures addressed the adequacy of observed drainage spacing in satisfying the existing forest road BMP recommendations for the two forests in the investigation. Taking this into account, the sediment deposition patterns (deposition volume and length) are minimized below the forest road sections in the investigation based on the establishment criteria for the BMPs presented by previous research (Alabama Forestry Commission 1993, 2007; Georgia Forestry Commission 1999; Grace and Clinton

2007). The observed deposition lengths within buffers are presented for the TNF and CNF along with parameters hypothesized to influence the distance sediment travels into buffers toward stream systems (table 1). The mean distance that sediment was deposited in buffers downslope of road sections was 41.2 and 19.6 m for the TNF and CNF, respectively. Sediment deposition patterns within the buffers for the two forests were detected as significantly different at the 0.05 level of significance. In fact, sediment from road sections on the TNF encroached twice as far into the forest buffer than sediment from road sections on the CNF. This result is consistent with the results obtained from the spacing analysis which presented closer spacing of road drainage structures for the CNF road sections. The closer spacing resulted in reduced stormwater energy and runoff volume from the road sections on the CNF. Buffer gradient and road gradient were the only parameters, of those hypothesized to influence sediment deposition lengths in the buffers, detected as greater on the CNF in comparison to the TNF (table 1).

Surprisingly, road gradient was greater ( $P = 0.042$ ) for the TNF which has less relief than the CNF. This likely had the greatest influence on the distance sediment traveled into the buffers for the sites. The differences in road parameters for the forests are a function of both design and management strategies utilized at the forests. Gradients for road sections on the CNF were minimized during the initial road construction which is likely due to the topography having greater relief. At the same time, spacing or road length was minimized on the CNF either at initial construction or at some point thereafter with the installation of additional drainage structures at closer spacing. It is recognized that the reduced road gradients at the CNF resulted in sediment deposition lengths within the buffers approximately half that of the TNF which had greater road gradients ( $P = 0.042$ ) and reduced downslope gradients ( $P = 0.025$ ). However, the deposition lengths within the buffers for both sites were  $\geq 20$  m which

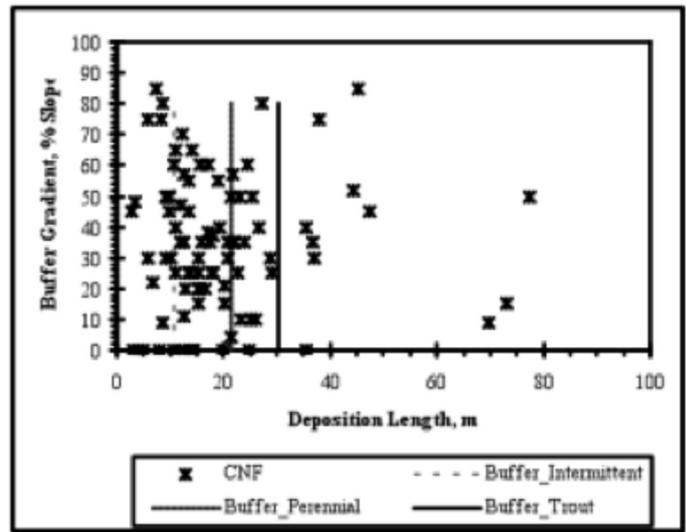
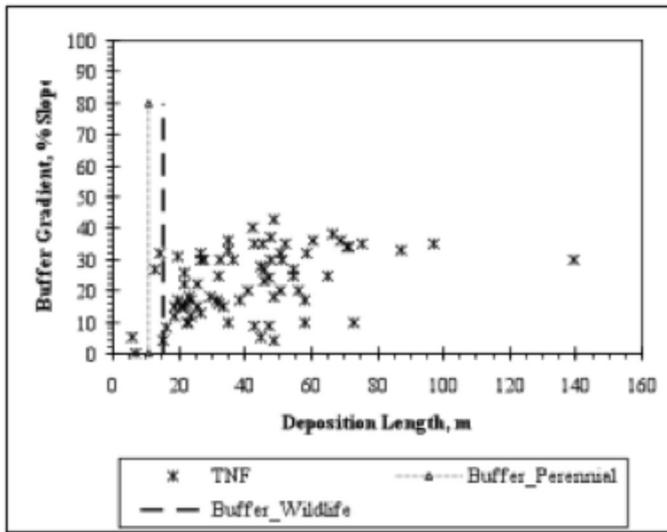


Figure 3—Deposition lengths within buffer zones vs. buffer gradients for the TNF site (left) and the CNF site (right). The BMP recommended buffer widths are presented for perennial streams (Buffer\_Perennial), with a wildlife focus (Buffer\_Wildlife) for the TNF site, and trout streams (Buffer\_Trout) for the CNF site.

may exceed the buffer zone width requirements in the States in this investigation and many States in the United States.

Deposition data was compared to current forest road BMPs to gain a better understanding of the influence of forest buffer zones in this experiment on disconnecting roads from vital stream systems. A plot of deposition lengths in buffer zones vs. buffer gradients illustrates the relationship of deposition lengths to current minimum buffer zone widths recommendations for the two States in this investigation, Alabama and Georgia (fig. 3). Alabama's recommended streamside management zone (SMZ) widths are 11 m for perennial and intermittent streams and 15 m for management with a wildlife objective (Alabama Forestry Commission 2007) as represented by the vertical lines on figure 3. Georgia's recommended buffer zones range from 6 to 30 m based on slope approaching perennial, intermittent, or trout streams (Georgia Forestry Commission 1999). These BMP recommendations are also represented as vertical lines on figure 3. The majority of the deposition lengths within the buffers for the TNF are greater than the both SMZ width recommendations based on Alabama's BMPs for forestry. Specifically, 92 percent of deposition lengths into buffers observed at the TNF were greater than the most stringent Alabama SMZ recommendation of 15 m, and 62 percent of deposition lengths were >30 m (fig. 4). Conversely, results show that 88 percent of deposition lengths for the CNF were less than the trout stream minimum SMZ recommendation of 30 m. Sediment from a small percentage of road sections, 7 percent of TNF depositions, and 8 percent of CNF depositions emptied directly into streams. A t-test comparing the observed deposition lengths and BMP recommendations detected significantly ( $P < 0.0001$ ) greater deposition lengths in comparison to both the minimum (11 m) and maximum (15 m) buffer zone recommendations for the TNF. Results were mixed for the CNF, deposition lengths were significantly greater than

( $P < 0.0001$ ) minimum perennial stream (11 m) buffer zone recommendations and significantly less than ( $P < 0.0001$ ) the maximum trout stream (30 m) recommendations.

### Implications

Understanding the connectivity between roads and streams has been an area of focus of soil and water conservation engineering over the past 40 years. It is recognized that forest roads have increased risk associated with soil erosion and sediment delivery to stream systems. It follows that previous research has established forest roads as the major source of soil erosion from forest watersheds due to the many

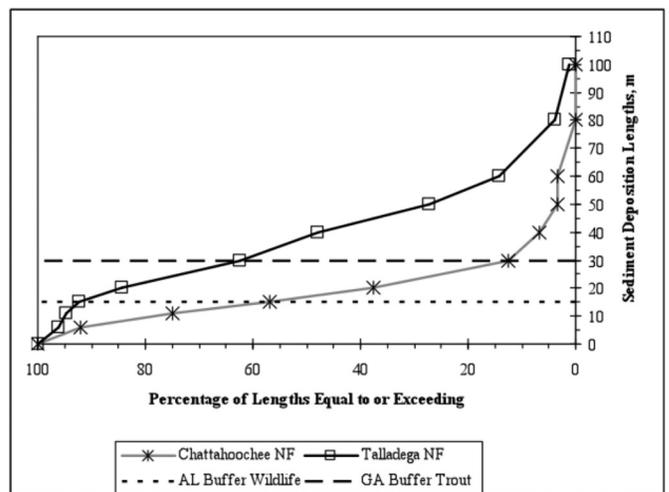


Figure 4—Buffer zone deposition length frequency duration curves observed for the TNF and CNF sites. BMP recommended buffer widths for Alabama with a wildlife emphasis and for Georgia trout streams are provided as reference lines.

factors that increase the potential for erosion losses from forest roads (Grace 2005b, Luce and Black 2001). However, sediment delivery from forest roads has not been as well studied and existing literature fails to directly link forest road erosion upslope to sediment delivery rates to downslope stream systems. The connectivity issue continues to require additional research that specifically focuses on quantifying the fraction of forest road erosion reaching stream systems which include intermittent and perennial streams. This research needs to additionally aim to determine the capacity of the forest floor filter or buffer zones, understand factors influencing this connectivity, and gain a better understanding of the benefit of sediment control in the connectivity issue.

In this investigation, the effectiveness of BMP recommended buffer zone widths in filtering and containing the sediment from forest roads within the forest buffers varies widely. Nearly 90 percent of the deposition lengths into the forest buffer at the CNF site were less than the most stringent buffer width recommendation of 30 m. Conversely, the most stringent buffer width recommendation of 15 m at the TNF site contained <10 percent of the deposition from upslope road drainage structures. Fortunately, the buffer zone widths at both sites exceeded the recommended buffer zone width recommendations and therefore had a built-in safety factor. These conservative buffer zone widths on both sites were quite effective in containing the majority of the sediment transport from adjacent roads in this investigation. This is supported by the fact that the investigation revealed that only a small percentage of the road sections emptied directly into streams at the sites.

Based on the findings of this investigation, buffer zone width recommendations require additional research to establish science-based support for existing recommendations. The fundamental question that must be addressed is "What percentage of buffer failure is acceptable environmentally, socially, and economically?" Answering this question would allow research to define buffer widths that satisfy the goals set forth by policy. Secondary questions that require consideration are "Is the acceptable level of buffer failure 75 percent, 50 percent, or 10 percent?," "What is the design period for buffer recommendations?," and "Are there alternative sediment control practices that can be utilized to minimize the buffer widths and risks associated with buffer failure?"

## CONCLUSIONS

A total of 164 road sections and drainage structures from 13 roads from 2 forests in the Appalachian region were investigated to determine the influence of buffer zones sediment transport from forest roads in the region. Drainage structure spacing was similar to the recommended spacing for the TNF and closer than recommended for roads on the CNF. The TNF had greater road gradients than the CNF despite the fact that the CNF was at higher elevation and had greater relief. Decreased road gradients and closer spacing of drainage structures on the CNF resulted in a decreased drainage area and stormwater runoff volume which likely had the greatest influence on the shorter distance sediment traveled across the CNF buffer zones. In fact, CNF mean

deposition length was 20 m which is less than half the mean of 41 m observed for the TNF deposition lengths.

The analysis revealed that the buffer width recommendations for the sites were somewhat effective in containing the sediment movement within the buffers. These results indicate that current BMPs are effective in most cases but may not be sufficient in all instances. Consequently, more than 90 percent of the observed deposition lengths exceeded the most stringent Alabama width recommendations on the TNF. The mean deposition length into buffers for TNF was greater than both the minimum (11 m) and maximum (15 m) BMP recommended buffer widths. Fortunately, forest managers or road engineers ensured that risks were minimized by having a built-in safety factor on buffer recommendations in the form of increased buffer widths below road sections. In contrast to the TNF results, only 8 percent of the deposition lengths exceeded the most stringent Georgia width recommendations on the CNF. The mean deposition length into buffers for CNF was less than both minimum and maximum BMP recommended buffer width. These results also revealed that a total of 12, or 15 percent, of the 164 road sections in this investigation had direct connectivity to stream systems.

This work has highlighted the need for additional research related to forest road buffer zone width. This research should focus on providing scientific support for current buffer zone width recommendations or the definition of science based buffer zone widths that consider risks associated with buffer failure. Future research and discussion needs to categorize the potential for buffer zone breaches associated with established recommendations; define the environmental, social, and economic risks associated with sediment extending beyond buffer zones; and define the acceptable level of sediment export from the buffers.

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