2950 Niles Road, St. Joseph, MI 49085-9659, USA
269.429.0300 fax 269.429.3852 hq@asabe.org www.asabe.org

An ASABE Meeting Presentation

Paper Number: 1008434

Efficacy of Buffer Zones in Disconnecting Roads and Streams in the Coastal Plain

J. McFero Grace III, Ph.D., CPESC

USDA Forest Service, Southern Research Station, 521 Devall Dr., Auburn University, AL 36849-5418, jmgrace@fs.fed.us

Erika L. Davis, P.E.

USDA Forest Service, National Forests of Alabama, 2946 Chestnut St., Montgomery, AL 36107-3010, erikadavis@fs.fed.us

Written for presentation at the
2010 ASABE Annual International Meeting
Sponsored by ASABE
David L. Lawrence Convention Center
Pittsburgh, Pennsylvania
June 20 – June 23, 2010

Abstract. *Established forest BMPs rely heavily on the forest floor to disconnect upslope activities from stream systems. Optimizing the buffer length required to negate the storm runoff contribution of upslope activities has been a point of interest for soil scientist, hydrologist, and conservation professionals for the last century. Minimum buffer lengths have been recommended or mandated throughout the U.S; however, a gap exists in the understanding of the effectiveness of these practices in controlling sediment movement and minimizing risks of sediment delivery to forest streams. The fundamental question that has not yet been answered is, "Do current management practices disconnect forest road sediment and water?" This paper reports findings of investigations to assess sediment travel distances downslope of forest roads in the Coastal Plain of Alabama, relate sediment travel distances to BMP recommendations, and describe deposition patterns within buffer zones. Sediment deposition depths and lengths within buffers from randomly selected National Forest roads were measured downslope of road lead-off ditch structures. The mean distance sediment was tracked across the forest floor was 27 meters. Sediment transport distances were less than 30 m for 45 percent of sites evaluated in National Forests in Alabama. This paper also presents special issues related to the connectivity and the role of the forest buffer in minimizing the connection of forest roads and streams in this sensitive region.*

Keywords. Forest Roads, BMPS, Buffers, Soil Erosion, Sediment Delivery, Coastal Plain

Introduction

The nation's water resource is one of the most critical and valuable natural resources (Sun et al., 2004). High quality water is valuable for recreation opportunities, critical for aquatic life, and essential for human consumption. Soil erosion and subsequent nonpoint source pollution have been identified as a threat to water resources in the US (Binkley and Brown, 1993; Lane and Sheridan, 2002). Storm runoff from upslope sources can transport sediment (and attached nutrient constituents) directly to receiving streams and water bodies. These suspended sediments and nutrients can result in degraded water quality which can impact community water sources, aquatic organism habitats and ecosystems.

Agricultural, construction, and forestry best management practices are commonly utilized to minimize impacts of human activity. Perhaps the most broadly applied BMP in both agriculture and forestry is filter strips (Pinho et al., 2008). Filter strips consist of vegetated filter strips (VFSs) and conservation buffers in agriculture; and riparian zones, buffer zones, and streamside management zones (SMZs) in forestry. The value and effectiveness of these zones in minimizing the impacts of upslope activities to adjacent streams and water resources have been documented in previous literature (Kloppel et al., 1997; Knoepp and Clinton, 2009; Mickelson et al., 2003; Patty et al., 1997; Swift, 1984).

Forest buffers and filter strips exhibit optimal characteristics for water quality protection (Yates and Sheridan, 1983). These characteristics include vegetative cover to reduce the energy of raindrop impact, increased surface roughness to slow storm runoff, and increased infiltration capacities to reduce the quantity of surface runoff to transport soil and attached nutrients (Grace, 2005). However, the bulk of the understanding of the effectiveness of buffers has been gained through short-term investigations at primarily the small plot or field-scale. The long-term effectiveness and benefits of forest buffer zones in minimizing soil erosion and nonpoint source pollution problems is still unknown. Better information on the efficacy of forest buffer zones in trapping sediment and nutrients suspended in storm runoff would contribute to sustainable water quality protection in forest road management.

Site specific data (soil types, gradient, and dimensions) correlating to the effectiveness of buffer zones is useful in the field to the next generation of forest engineers. With this information road managers can more effectively use existing BMPs. This information can assist in proper placement of road drainage structures during maintenance and reconstruction activities, and supports the proper balance between road and forest management.

This study was designed to investigate the impact of the forest buffer on sediment transport below forest roads in the Coastal Plain region of Alabama. The study is a component of a cooperative study initiated by the USDA Forest Service in 2002 to develop a better understanding of the influence of forest road management on storm runoff from road drainage structures and the factors contributing to sediment transport distance across the forest floor. The primary objectives of this study were to: (1) assess sediment travel distance downslope of forest roads in the Coastal Plain of Alabama; (2) relate sediment travel distance to BMP recommendations; and (3) describe the deposition patterns within buffer zones. The factors contributing to sediment transport distances from National Forests in Alabama and Georgia (Grace, 2005b) and the influence of forest buffers in the steep topography of Southern Appalachian watersheds (Grace and Zarnoch, In Press) are presented in previous works.

Methods

Study Area Description

The study was conducted on two National Forests nestled in the Coastal Plain region of Alabama. The two National Forests utilized in this investigation were the Conecuh National Forest and the Tuskegee National Forest. The Tuskegee National Forest, hereafter referred to as Tuskegee, is located at approximately 32^o latitude and 85^o longitude in Macon County, Alabama. The Tuskegee receives a long-term average annual precipitation of 1300 mm, essentially all of which falls as rainfall. Soils on the Tuskegee study area are primarily Norfolk loamy sand with 0 to 12 percent slopes. The Conecuh National Forest, hereafter referred to as Conecuh, is located at approximately 31^o latitude and 86^o longitude near Andalusia, Alabama in Covington County. The Conecuh has a long-term average annual precipitation of 1520 mm, essentially all of which falls as rainfall. Soils in the Conecuh are primarily Florala, Orangeburg, and Dothan series soils which are sandy loam Coastal Plain soils with slopes ranging from 0 to 12 percent. Permeability of these Conecuh soils is consistent with the Tuskegee soils and range from 50 to 150 mm hr^{-1} in their original condition.

Forest Characteristics

The 2004 National Forests in Alabama Forest Management Plan reports that the Conecuh National Forest (Conecuh) consists primarily (52 percent) of Upland Longleaf Pine Forests and Woodland, while the Tuskegee National Forests (Tuskegee) consists of River Floodplain Hardwood Forest and Dry and Dry-Mesic Oak-Pine Forests at 34 and 36 percent, respectively. Upland Longleaf Pine forests in the Gulf Coastal Plan have a stand density of 25 to 43 trees per hectare (of trees with a breast height diameter greater than or equal to 13 cm) and on average 37 percent canopy gap. The ground cover for this forest type is predominately herbs and low shrubs (bluestem in this location) (USDA, 1997). River Floodplain Hardwood Forest have a stand density of less than or equal to 66 trees per hectare with small canopy gaps, however are very prone to periodic flooding (USDA, 1997). The Dry and Dry-Mesic Oak Pine Forest type has the same stand components as River Floodplain; however, the understory is replaced with berries, vines, grasses, and ferns (USDA, 1997).

The National Forest System roads are managed for public safety, recreation, timber, resource protection and administrative access. Roads designed for current or future timber sale access are near or past their life expectancy. That equates to the need for reconstruction to stabilize sub-base and base course in addition to replacement of the surface course. In their current state roads are experiencing more erosion than when initially constructed and maintained. Out of the approximately 3990 km of road on the National Forests in Alabama, approximately 466 km and 68 km are on the Conecuh and Tuskegee, respectively. The US Forest Service has primary maintenance responsibility for the roads on both forests.

Study Measurements

A representative sample of roads with similar topography, construction standards, drainage characteristics, maintenance level, and traffic intensities (average daily traffic) were defined during the initial phase of this investigation through reconnaissance and consultation with National Forest personnel. The road design was constrained to crowned roads with native and graveled surfacing drained by road lead-off ditches. Maintenance on sample roads consisted of bi-annual grading in combination with periodic ditch maintenance. This maintenance was consistent with the Forest Service's Road Maintenance Management System (RMMS) Level 3 objective of maintaining the road for travel by a prudent driver in a passenger car; however, driver comfort and convenience are not priorities for this level of road. Traffic intensities on the sample roads ranged from low to moderate with periodic high intensity traffic during management activities or recreational hunting. Potential study roads were well established and ranged in age from 5 to greater than 20 years.

The representative sample of roads for this study consisted of 11 roads for the two National Forests with 7 roads on the Conecuh and 4 roads on the Tuskegee. Following the selection of a representative sample of roads, each potential road section and associated lead-off structure (constituting a potential study site) was individually numbered by site within each study area. Study sites consisted of road sections between drainage structures, the lead-off ditch drainage structure draining the road sections, and the storm runoff flow path. The distance of sediment deposition onto the forest floor was defined in this study as the most remote location of visible sediment deposition along the stormwater flow path from the roadway edge. The buffer zone width from the road edge was taken as the width of the buffer zone measured along the stormwater flow path to allow direct comparison with the observed deposition lengths.

The study design was a completely randomized design within each study area (Tuskegee and Conecuh). In this design, roads were randomly selected from the representative sample of roads and each selected road was sub-sampled by site. The number of sites required for statistical validity was determined by a Neyman approximation as defined by Grace (2005b). A total of 57 sites, 39 for the Conecuh and 18 for the Tuskegee, were selected and measured in the Coastal Plain region of Alabama for the purpose of this study. Data were analyzed by testing for differences between study areas as a fixed factor in the experiment with roads nested within the study areas and sites nested within the roads both as random factors. The mixed model was analyzed using SAS Proc MIXED (SAS, 2004). Analysis of observed drainage spacing required performing SAS TTEST procedures to test for differences in relation to BMP recommended drainage spacing.

Results and Discussion

Forest road lead-off spacings are recommended as a function of road gradient based on previous research which relates spacing to the distance that sediment travels into buffer zones. The spacing, to a large part, is a function of the potential energy of storm runoff to detach and transport sediment from the road surface, i.e. erosion. Increased grades increase the storm runoff velocity for a given slope length and increase the energy of runoff to detach and transport sediment. Similarly, increased spacing directly influences the drainage area and storm runoff volume. The increased storm runoff volume in turn increases the energy of storm runoff in terms of velocity.

Deposition length means and descriptive statistics for the 11 experimental roads in this study are given in Table 1. The mean observed sediment deposition lengths of 32.3 and 26.6 m for the Conecuh and Tuskegee study areas, respectively, were not detected as significantly different (P=0.175) by the SAS MIXED analysis of variance (SAS, 2004). Analysis of sediment deposition lengths also detected no significant differences for the Conecuh and Tuskegee study areas for mean road length (P=0.353), road width (0.472), and road gradient (P=0.427) were not significantly different for the Conecuh and Tuskegee study areas based on SAS MIXED procedures (SAS, 2004). The mean BMP recommended lead-off spacings (LOR) were not significantly different for the Conecuh and Tuskegee study areas at 61.7 and 58.7 m, respectively (P=0.578). The statistical similarity of the study areas in relation to the abovementioned road characteristics and deposition lengths resulted in combining the dataset for these Coastal Plain areas for further analysis.

Noting the nearly identical mean road and downslope gradient describes the topography for these roads and the forest in general. The roads on these forests are not typically fill sections but lay on the same grade as the buffer zone. Sediment transport velocities should not be excessive as it impacts the effectiveness of the buffer zones. It could also indicate that sediment deposition lengths might actually be longer but due to the nearly flat topography sediment may have initially traveled farther but due to ponding retreated to the distances measured during the study in some instances.

Table 1. Means and descriptive statistics for deposition length within buffer zones, downslope gradient, road variables, and spacing recommendations for the Conecuh and Tuskegee Forests.

Variable	N	Mean	Std. Dev.
Conecuh			
Deposition Length, m	36	32.3	10.1
Road Length, m	39	43.7	20.6
Road Width, m	39	3.5	1.4
Road Gradient, %	39	4.8	2.2
Downslope Gradient, %	39	4.8	2.4
LOR, m	39	61.7	13.9
Tuskegee			
Deposition Length, m	18	26.6	10.7
Road Length, m	18	50.7	30.9
Road Width, m	18	3.2	0.6
Road Gradient, %	18	5.7	2.6
Downslope Gradient, %	18	5.8	2.6
LOR, m	18	58.7	15.9

We compared observed road lengths in the study to the LOR values for the study areas to determine if the observed spacing, synonymous with road length, were consistent with BMP recommendations. The comparison of observed versus recommended spacing is critical in interpreting the results of the relationship between observed deposition lengths and BMP recommended minimum buffer zone widths discussed later in this paper. Understanding the suitability of observed spacing in relation to BMP recommendations for spacing allows conclusions to be drawn related to the suitability of BMP recommendations for minimum buffer zone widths in the study areas.

SAS TTEST procedures detected no significant differences in the observed spacing and the recommended spacing for these study areas (P=0.881). This indicates that the observed spacing was suitable to address BMP desired qualities (or quantities) related to road lead-off spacing in the study areas. It should be noted that observed spacing, and to a lesser extent LOR, was highly variable due to road length is a function of road gradient. This variability is evident by the relatively large standard deviations for the road length parameter for Conecuh (20.6 m) and Tuskegee (30.9 m). High variability in the road length parameter likely influenced the power to detect differences in the observed spacing and LOR in this study. Results of this study indicate that lead off spacing in the two study areas was consistent with Alabama's BMPs for lead-off spacing (Figure 1). Observed lead-off spacing was less than or equal to BMP recommended spacing for 70 percent of the sites in this study. The consistency in observed lead-off spacing and recommended practices indicates that care was taken to minimize the environmental impacts of these road systems. It should be noted that the road design standards likely required 100 percent adherence to BMP recommendations and the goal of the implementation for lead-off spacing was complete adherence to BMPs. However, maintenance over the life of the roads in this study may have resulted in alterations to the original lead-off spacing. The lead-off spacing that exceeded the BMP recommendations (30 percent of the lead-off spacing) is likely the result of failure to maintain the existing road structure/template due to differences in maintenance operators and frequency of maintenance operations. For example, the lead-off spacing for many of the lead-offs exceeding the recommended BMP spacing were nearly twice as wide as recommended. This could indicate that lead-off structures were neglected during the maintenance of road drainage (Figure 1). If this was the case, then the distance that sediment was transported onto the forest floor for these sites would be extended due to the increased storm runoff energy and the additional sediment available for transport due to wider spacing.

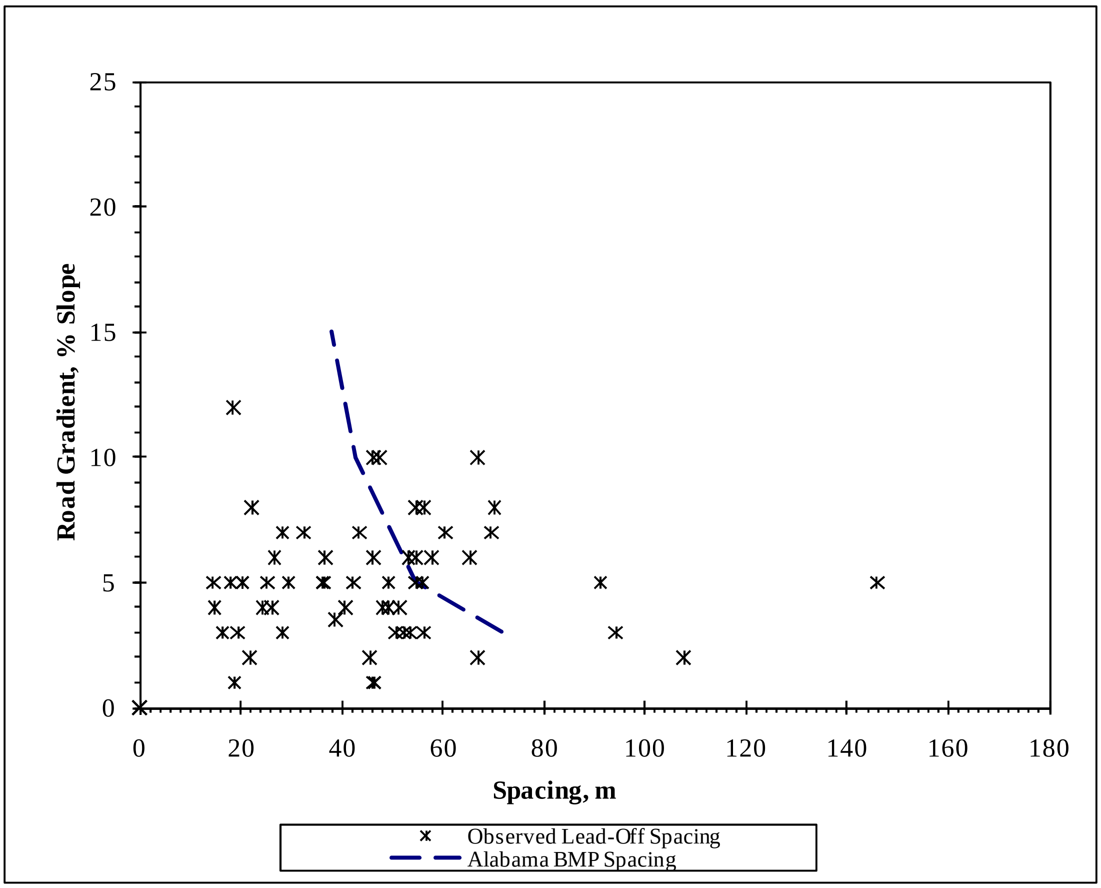

Figure 1. Observed lead-off spacing as a function of road gradient for the Conecuh and Tuskegee study areas in the Coastal Plain region of Alabama. Alabama's BMP recommended spacing is overlain as a point of reference.

The relationship between observed lead-off spacing and BMP recommended spacing can also be shown by plotting the relationship (Figure 2). Perfect agreement between observed lead-off spacing and BMP recommended spacing would result in points along the 1:1 relationship line. Points that fall to the right of the 1:1 line represent observed spacing wider than recommended by Alabama's BMPs. In contrast, points falling to the left of the line represent a more conservative spacing than recommended. In large part, spacing in this study was more conservative than recommended which is expected to act as a factor of safety in relation to distance sediment is transported into the buffer zones. These conservative lead-off spacings would be expected to result in sediment transport distances that were less than the Alabama BMP recommended buffer zones. These minimum buffer zone widths or streamside management zone widths are 11 m for perennial and intermittent streams and 15 m for management with a wildlife objective. However, this expectation is not supported by the data from this study. Observed sediment deposition lengths equaled or exceeded the most stringent minimum buffer zone width (with wildlife objective) for 92 percent of the Coastal Plain sites evaluated in this study (Figure 3).

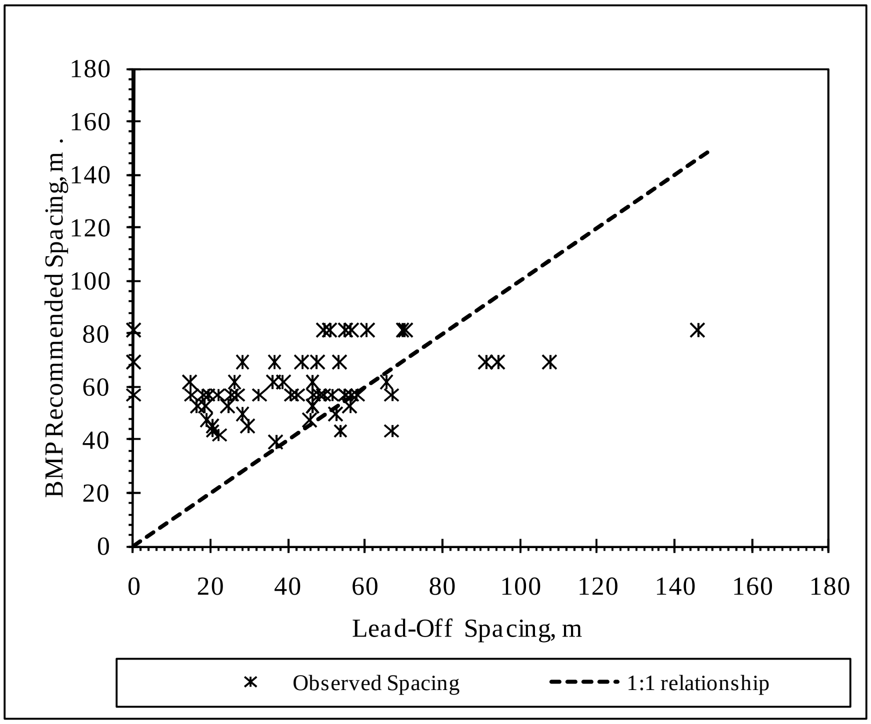

Figure 2. Relationship between observed lead-off spacing and BMP recommended spacing for the Conecuh and Tuskegee study areas.

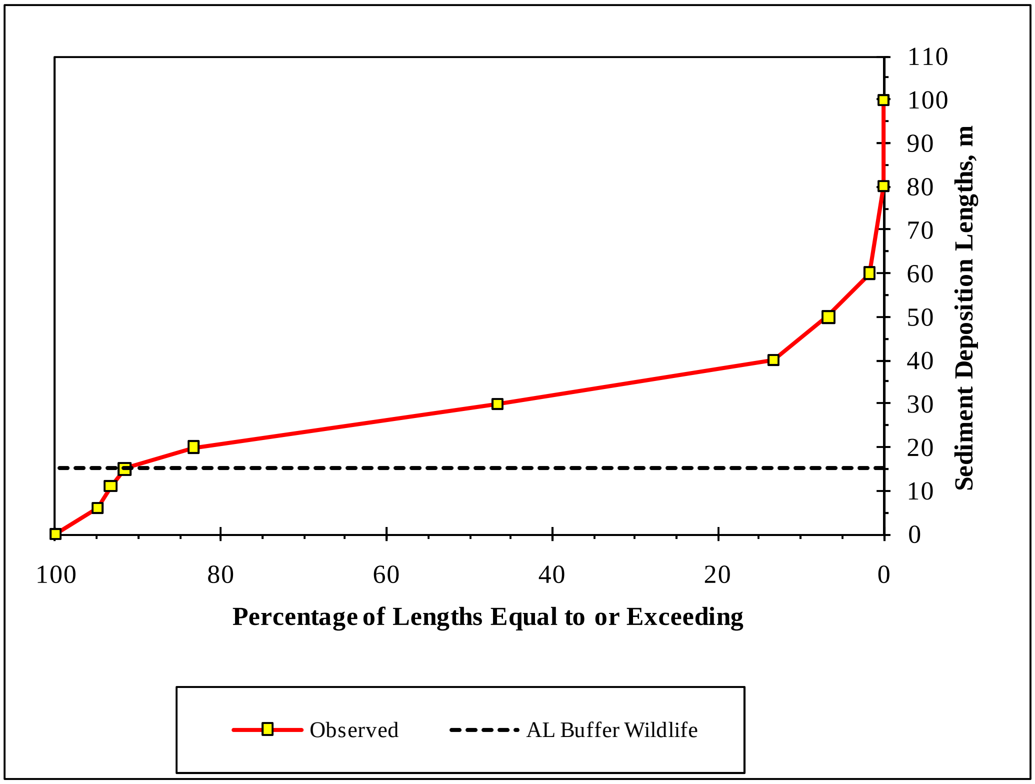

Figure 3. Frequency duration curve for buffer zone deposition lengths for the study roads in the Coastal Plain region. The BMP recommend minimum buffer width with a wildlife objective is provided as a reference line.

A small percentage, 8 percent, of the observed sediment deposition lengths were contained within the designated minimum buffer zone widths in this study. In fact, nearly 50 percent of the observed sediment deposition lengths were greater than twice the minimum recommended buffer width in this study. This data indicates that the minimum buffer width would result in failure rates (failure to contain road sediments) greater than 90 percent on these Coastal Plain sites. In a companion study in the Appalachian regions of Alabama and Georgia, Grace and Zarnoch (In Press) reported that less than 8 percent of a total of 164 road sections resulted in sediment deposition lengths that terminated in streams. However, Grace and Zarnoch (In Press) also reported similar percentages of deposition lengths exceeding Alabama's minimum buffer width recommendations. In contrast, the investigators reported that nearly 90 percent of sediment deposition lengths observed fell within Georgia's most stringent minimum buffer width for trout streams (30 m) based on the investigation in the Appalachian region.

The lead-off spacing for the road sections in the study was consistent with the BMP recommended drainage structure spacing with 70 percent of the spacing equal or less than recommendations. However, sediment was transported distances greater than the Alabama BMP recommended minimum buffer width with a wildlife objective for more than 90 percent of the road sections in this study.

Summary and conclusions

This study examined the influence of buffer zones in trapping sediment emanating from forest road lead-off structures on two National Forests in the Coastal Plain region of Alabama. The objectives in this study were to assess sediment travel distances downslope of forest roads in the Coastal Plain of Alabama, relate sediment travel distances to BMP recommendations, and describe the deposition patterns within buffer zones. We examined sediment deposition downslope of 57 road sections from 11 roads on two National Forests in the Coastal Plain region of Alabama. Drainage structure (Lead-off ditch) spacing existing on the forest roads in this study was compared to existing BMP recommendations for drainage spacing to gain a better understanding of the efficacy of BMP recommended minimum buffer widths for Alabama in mitigating the downslope movement of sediment. There was no significant difference in sediment transport distances for the Conecuh and Tuskegee study areas. Additional research is required to understand the long-term effectiveness of buffer zones particularly those related to forest roads and provide scientific support for current buffer zone width recommendations. This research will be useful in the fine tuning of the National Forests of Alabama road maintenance program and revising BMPs to improve the effectiveness and efficiency of existing methods. Future research should focus on defining the acceptable level of sediment introduction into buffer zones and risks associated with sediment leaving buffer zones. A better understanding is required related to the efficacy of the forest floor in minimizing sediment transport distances and sediment delivery to vulnerable stream systems.

References

Binkley, D., and T. C. Brown. 1993. Forest practices as nonpoint sources of pollution in North America. Water Resources Bulletin 29(5): 729-740.

Grace, J.M. III and S. Zarnoch. In Press. Influence of forest road buffer zones on sediment transport in the Southern Appalachian Region. 15th Biennial Southern Silvicultural Research Conference, 17-19 November 2008, Hot Springs, AR. USDA Forest Service, Southern Research Station, Asheville, NC.

Grace, J.M. III. 2005. Forest operations and water quality in the south. Transactions of the ASAE 48(2): 871-880.

Grace, J.M. III. 2005b. Factors influencing sediment plume development from forest roads. In: Proceedings; Environmental Connection 05, Conference 36 of the International Erosion Control Association; 20-24 February 2005; Dallas, TX. International Erosion Control Association; Steamboat Springs, CO. 221-230.

Knoepp, J.D. and B.D. Clinton. 2009. Riparian zones in the Appalachian headwater catchments: carbon and nitrogen responses to forest cutting. Forest Ecology and Management 258( ): 2282-2293.

Kloppel, H., W. Kordel, and B. Stein. 1997. Herbicide transport by surface runoff and herbicide retention in a filter strip – Rainfall and runoff simulation studies. Chemosphere 35(): 129-141.

Lane, P.N. and G.J. Sheridan. 2002. Impact of an unsealed forest road stream crossing: water quality and sediment sources. Hydrol. Process. 16: 2599-2612.

Mickelson, S.K., J.L. Baker, and S.I. Ahmed. 2003. Vegetative filter strips for reducing atrizine and sediment runoff transport. J. Soil and Water Consv. 58(): 359-367.

Patty, L., B. Real, and J.J. Gril. 1997. The use of grassed filter strips to remove pesticides, nitrate, and soluble phosphorus compounds from runoff water. Pesticide Science 49( ): 243-251.

Pinho, A.P., L.A. Morris, C.R. Jackson, W.J. White, P.B. Bush, and A.T. Matos. 2008. Contaminant retention potential of forested filter strips established as SMZs in the Piedmont of Georgia. J. Am. Water Res. Assn. 44(6): 1564-1577.

SAS Institute. 2004. SAS OnlineDoc 9.1.3. SAS Institute, Cary, NC.

Sun, G., M. Riedel, R. Jackson, R. Kolka, D. Amatya, and J. Shepard. 2004. Influences of management of Southern forests on water quantity and quality. In: Chapter 19; Pp. 195-234; Gen. Tech. Rep. SRSÂ–75. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station.

USDA, 2004. Revised Land and Resource Management Plan, National Forests in Alabama. R8-MB 112A, January 2004. U.S. Department of Agriculture, Forests Service, National Forests in Alabama.

USDA. 1997. Guidance for Conserving and Restoring Old Growth Forest Communities on National Forests in Southern Region. Report of the Region 8 Old Growth Team. June 1997. U.S. Department of Agriculture, Forest Service, Washington DC.

USEPA. 2003. National Management Measures to Control Nonpoint Source Pollution from Agriculture. EPA 841-B-03-004, July 2003. U.S. Environmental Protection Agency, Washington, D.C.

Yates, P. and J.M. Sheridan. 1983. Estimating the effectiveness of vegetated flood plains/wetlands as nitrate-nitrite and orthophosphorus filters. Agricultural Ecosystems and Environment 9:303-314.