A NEW DESIGN TO EVALUATE EROSION AND SEDIMENT CONTROL

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ABSTRACT

Water quality issues surrounding sediment movement related to forest operations are a focus in forest management. The forest road system is a primary area of concern related to sediment movement because roads are a component of most forest operations. Controlling sediment movement is a common objective in most forestry best management practices (BMPs). However, there is a lack of information documenting the effectiveness of prescribed practices in reducing sediment loads from forest road systems. This is primarily due to the complexity of assessing the effectiveness of erosion and sediment control, stormwater control, and BMPs in the forest setting. Consequently, little sediment transport and BMP effectiveness information or data are available. Monitoring designs for effective evaluations of erosion and sediment control practices are critical to further reductions in sediment contributed from forest roads. This paper presents general engineering design aspects involved in evaluating erosion control, sediment control, and BMPs on the forest landscape. The paper discusses considerations involved with the selection of monitoring equipment and structures based on design storm and costs. Statistical considerations in the selection of an experimental design to optimize data collection and increase the probability of statistically valid results are presented. In addition, an innovative study design (real world) and application to address sediment control BMP issues will be reported. This study was initiated on the Tallulah District of the Chattahoochee National Forest that aims to evaluate the effectiveness of three road sediment control treatments (alternative BMPs) settling basins, sediment basin with riser control, and hay bale barriers in filtering sediment laden storm runoff. The BMP effectiveness study design utilizes stormwater samplers, trapezoidal flumes, automated flow level devices, flow dividers, and runoff tipping buckets to evaluate sediment transport through sediment control treatments. This design has the potential to set standards for forest road sediment control evaluations.

Key Words: design; forest roads; research; sediment control; storm runoff

INTRODUCTION

Water quality issues surrounding sediment movement related to forest operations are a focus in forest management. Sediment is a major concern because of its potential to reach stream systems (Authur et al., 1998; Binkley and Brown, 1993; Grace, 2005b). In addition to sedimentation risks, sediment can cause water quality degradation by transporting attached nutrient constituents directly to streams. In recent years, application of forest best management practices (BMPs) to protect water quality has become common practice for forest activities throughout the U.S. in response to the Clean Water Act. BMPs for forestry practices are recommended for all aspects of forest operations including streamside management zones (SMZ), stream crossings, forest roads, timber harvesting, forested wetland management, and reforestation. BMPs relating to forest roads are perhaps the most critical practices to influence environmental impacts of forest operations primarily because forest roads are a common component in most all forest management activities.

The lead-off ditch is commonly utilized to divert and disperse storm runoff from forest roads onto the forest floor. The forest floor has been presented as an effective filter of storm runoff by reducing the energy of runoff to transport sediment. However, the quantity of sediment filtered from suspension by the forest floor is still unknown and sediment deposition zones across the forest floor have been observed to be equivalent to SMZ width without some form of sediment control structure (Grace, 2004; 2005a). Sediment control structures such as basins, hay bale barriers, brush barriers, and rock checks can filter road runoff before it reaches the forest floor; thereby reducing the distance sediment is deposited downslope. As an example, consider Figure 1, sediment deposition zones develop downslope of the forest road lead-off ditch and over time creep closer and closer to stream channels. Sediment control structures located at the outlets of lead-off ditches can trap sediments at the road edge and reduce the quantity of sediment reaching the forest floor (Grace, 2002) and eventually stream channels (Figure 2). However, little work has been undertaken to investigate the effect of forest road BMPs on erosion, delivered sediment, and water quality.

Minimizing sediment movement is a common objective in forest management and is emphasized in most forest road BMPs. Roads are frequently cited as a major source of soil erosion on the forest landscape (Grace, 2005b; Yoho, 1980). However, investigations have not provided sufficient information on the impact of forest roads and the benefits of forest road BMPs on forest watersheds. Designs for effective evaluations of road erosion and sediment control practices are critical to further reductions in sediment contributed from forest operations. The purpose of this paper is to present design aspects and considerations involved in evaluating road erosion control, sediment control, and BMPs on the forest landscape. Issues and considerations involved with the selection of monitoring equipment, routing structures, and experimental design are presented and discussed. In addition, an innovative study design (real world) and application to address sediment control BMP issues related to forest roads is reported in this paper.

DESIGN CONSIDERATIONS

The lack of information documenting the effectiveness of prescribed practices (or BMPs) in reducing sediment and nutrient loads from forest roads and watersheds is primarily due to the complexity of assessing the effectiveness of road erosion and sediment control, stormwater control, and BMPs in the forest setting. Special considerations are required in designs to evaluate and control forest road stormwater. Considerations such as monitoring methods, equipment selection, routing stormwater, and optimal experimental design are critical in effective evaluations of sediment control from forest roads.

Effective evaluations of sediment control and trapping efficiencies provided by a specific treatment are dependent on the ability to measure stormwater runoff without influencing the results. Evaluation of sediment control typically involves quantifying the amount of sediment trapped (or retained) by a treatment or practice. An optimal design to evaluate sediment retained would minimize or eliminate the influence of the measurement method on experimental results. Monitoring methods that are less intrusive are preferred but are often more expensive.

Flow quantification is often one of the difficult components of a design to investigate forest road sediment control practices. The difference in a flow meter and a runoff tipping bucket for flow measurement is an example of the tradeoffs often involved in evaluating sediment control. A flow meter allows measurement of flow characteristics (i.e., velocity and/or depth) with the use of a relatively small sensor which has little influence on the stormwater energy or capacity to transport sediment. However, flow measurement with a runoff tipping bucket, though at one-tenth the cost for a typical flow meter setup, alters stormwater flow characteristics. This makes the runoff tipping bucket inappropriate in investigations of sediment control for flow measurement at the inlet of treatments, but attractive for outlet flow measurement

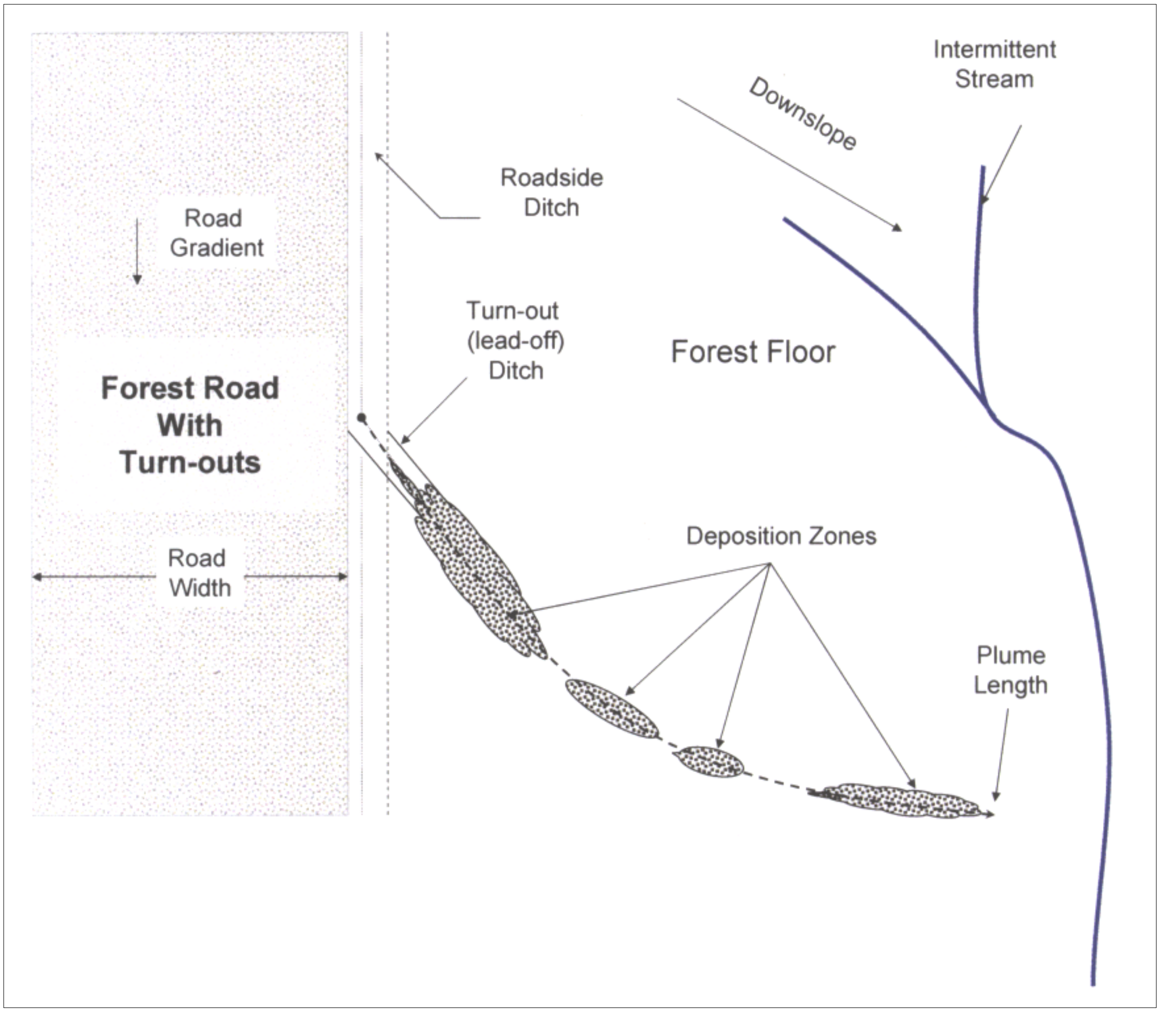

Figure 1. Diagram of forest road with lead-off ditch structure and sediment deposition downslope.

where a change in flow characteristics would be acceptable.

Another important, if not the most important, consideration in designing to evaluate forest road erosion and sediment control is the experimental design. The experimental design is critical in the initial (design) and final (analysis) phases of the monitoring and evaluation process. The experimental design guides or establishes the number of plots, how the plots are distributed over the experimental area, number of observations required to determine performance of practices, and the statistical procedures involved in analyzing data. An efficient design will minimize cost associated with any evaluation by minimizing the number of experimental setups, the monitoring time period, and the data analysis time required for a successful evaluation. Whereas, a poor experimental design cannot only increase cost involved with the evaluation but also result in the inability to make statistical conclusions regarding the performance of the evaluated treatments.

A DESIGN EXAMPLE FROM THE FIELD

Methods

The study site is located within the perimeter of the Coleman River Wildlife Management Area on the Tallulah District of the Chattahoochee National Forest near Dillard, Ga. (Figure 3). This study area is nested within the southern Appalachian Mountains at 35 ° latitude and 83 ° longitude with an elevation of 900 m (3000 ft). The design storm (return period) for the study

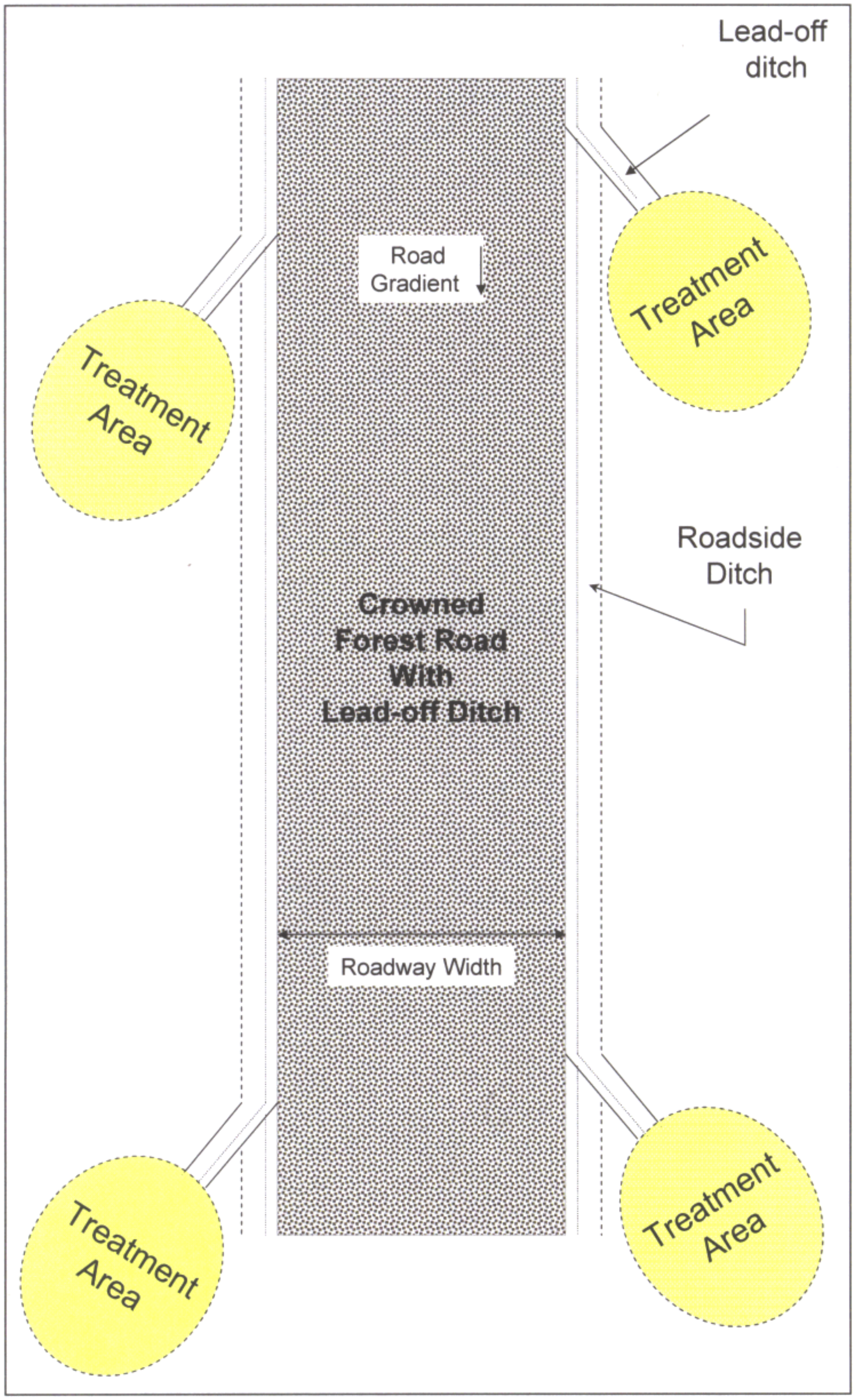

Figure 2. Illustration of treatment (BMP) locations for lead-off ditch structures to minimize sediment movement.

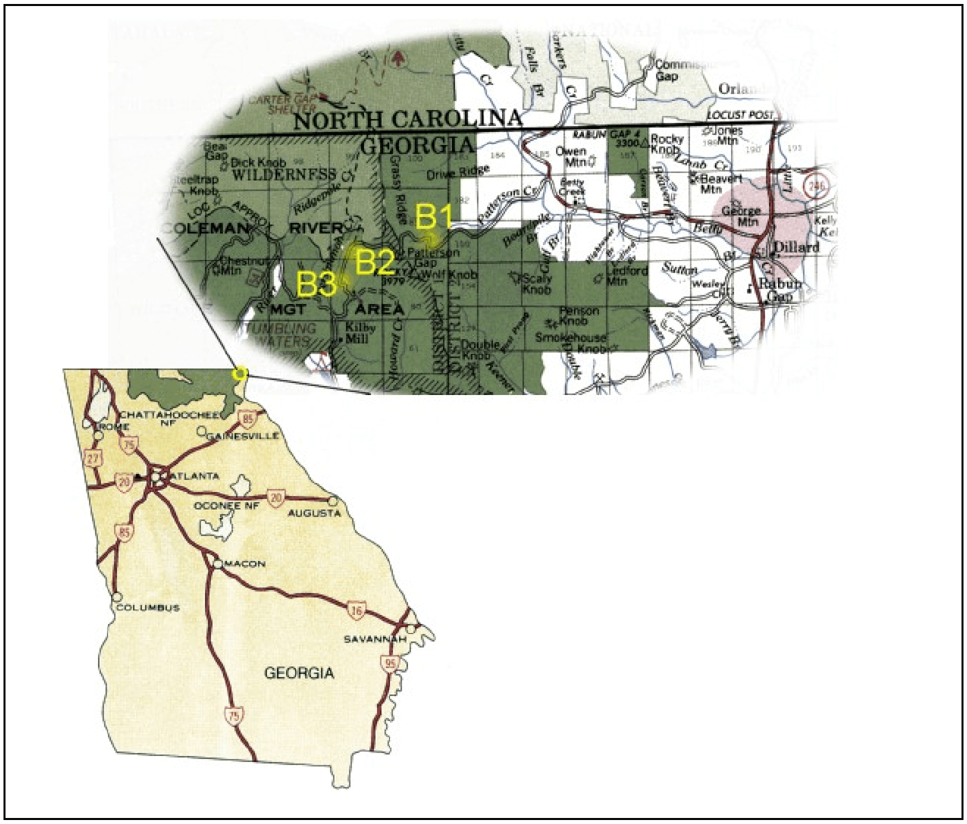

Figure 3. General location of study road in the southern Appalachian region. The locations of experimental blocks are also given as B1 = Block 1, B2 = Block 2, and B3 = Block 3).

site was a 25 year storm with a storm intensity of 198 mm/hr (7.8 in/hr) for 24-hour storm.

One of the first steps in evaluating the effectiveness of the road BMPs was the estimation of peak flow. Several methods exist for peak flow estimation and include the Rational Method (McCuen, 1989; Wanielista, 1990), SCS TR-55 (SCS, 1986), mathematical and regression equations, and hydrologic models. The Rational Method was used for peak flow estimation in this design example. The Rational Method is given by the equation:

$$Q = C*I*A$$

where:

Q is the peak flow (cfs), C is the composite dimensionless runoff coefficient, I is the rainfall intensity (in/hr) for the design storm, and A is the watershed area (ac). Some of the design parameters and road characteristics are listed below:

Road Width = 4–6 m (13–20 ft).

Road Length = 50 m (164 ft).

Area = 0.04 ha (0.10 ac).

The estimated peak flow based on the Rational Method was 60 $m^3\ hr^{-1}$(0.59 cfs). This estimate is the design flow for the selection of sediment control and stormwater routing structures.

Experimental Design

Three blocks of three alternative forest road BMPs were utilized in the experiment: (1) sediment basin, (2) sediment basin with riser control, and (3) hay bale barriers. A randomized complete block (RCB) experimental design was utilized with treatments blocked on road location (Figure 4). The selection of the RCB design allows a minimized the number of experimental plots without sacrificing the precision of the results. The RCB design allowed blocking along road location which can provide more precise results

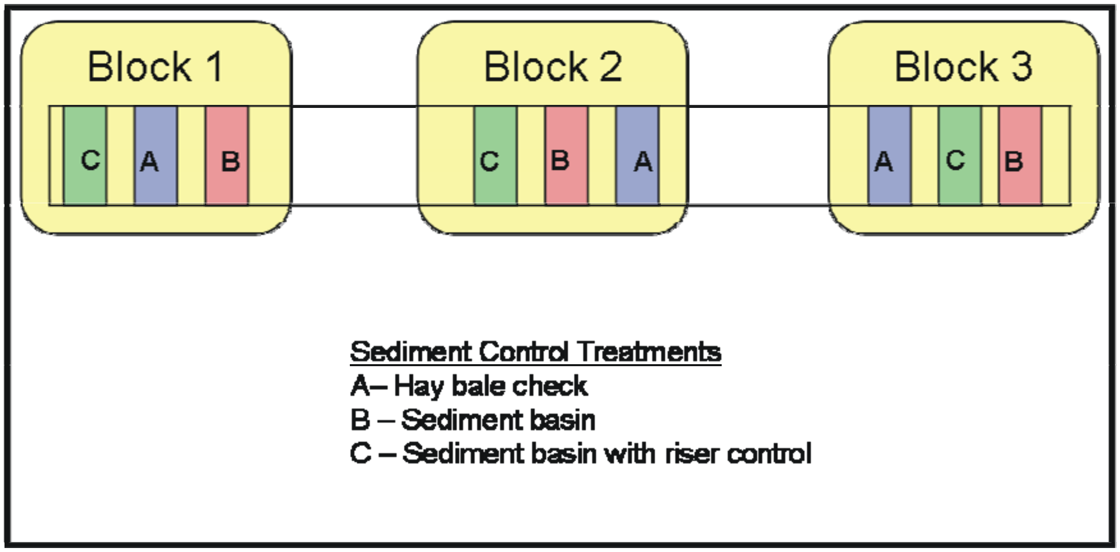

Figure 4. Randomized complete block (RCB) experimental design with blocking on road location to minimize experimental error variability.

than a completely randomized design of comparable size (Neter et al., 1996). The purpose of blocking is to sort experimental units into groups (blocks) that are as homogenous as possible with respect to the response variable in the experiment. For simplification, each treatment is randomly assigned within each block which increases the probability that any differences observed will be due to treatment and not to differences in road location (blocking criteria).

A total of nine road sections with similar topography, hydrology, soils, forest cover, and road design (type, location, grade, and ditch) were identified for treatment measures. Road sections were re-constructed with uniform design characteristics (crowned road with roadside ditch) for all treatments. Lead-off ditches were constructed to drain runoff from the design road length of 50 m (164 ft). An illustration of a typical road section illustrating the general location of treatment areas in relation to lead-off ditch and roadbed is shown in Figure 2. Fescue mulch was hand applied at a rate of 5 t ha^{-1} (1.8 t ac^{-1}). Fertilization was accomplished with 10-10-10 fertilizer broadcasted at a rate of 1 t ha^{-1} (0.4 t ac^{-1}). Treatments were seeded at a rate of 60 kg ha $^{-1}$ (53 lbs ac^{-1}) with a mixture consisting of equal parts of; red fescue *(Festuca rubra L.),* tall fescue *(Festuca arundinacea Schreb.),* ryegrass *(Lolium perenne L.),* and red clover *(Trifolium pratense L.).*

Instrumentation

The design has an Extra Large (EL) 60 ° V Trapezoidal Flume with a 2 m (6 ft) approach section (Figure 5). The flume and approach are anchored by a concrete footing to decrease the probability of failure due to storms exceeding the design capacity. The 0.3 m (1 ft) EL 60 ° V flume is ideal for this type of flow application which requires accurate discharge measurement at both low and high head. Trapezoidal flumes were originally developed to measure flow in irrigation channels. The flume performs well in submerged situations and minimizes silt build-up upstream. The 0.3 m (1 ft) EL 60 ° V flume has a flow range from 0.02 to 160 m^3 hr^{-1} (0.0001 to 1.55 cfs).

Inlet flow measurement is accomplished by measuring water level within the trapezoidal flume with a submerged probe water level sensor located at the inlet of each channel section. The water level logger reads the pressure exerted on the water level sensor's diaphragm, calculates equivalent water depth, and records water depths at 5 minute intervals. Outlet flow measurement is measured by routing treatment effluent through a 5-to-1 flow divider in combination with a runoff tipping bucket (3 L (0.8 gal) per tip) (Figure 6). Trapping efficiency is evaluated by utilizing stormwater samplers at each runoff control structure at the inlet and outlet of the mitigation treatments.

Figure 5. Illustration of 0.3 m (1 ft) trapezoidal flume 1.8 m (6 ft) approach section, and instrumentation enclosure.

Figure 6. Illustration of outlet sampling location showing a 5-to-1 flow divider and runoff tipping bucket for flow measurement.

Stormwater samplers, activated with a flow depth of 0.01 m (0.4 in), collect composite runoff samples for each runoff event from which 500 ml (17 oz) grab samples are collected to determine total suspended sediment by gravimetric filtration.

Data Analysis

Sediment fluxes can be determined as a product of storm runoff concentrations and runoff volumes. Trapping efficiency of each associated treatment is determined by comparing inflow and outflow sediment fluxes and runoff concentration reductions. Storm events producing runoff at treatment inlets without flow at outlets are considered 100 percent efficient in trapping sediment. Data are analyzed using SAS GLM procedures (SAS 1988) as a RCB design.

SUMMARY

Sediment movement is a major concern in natural resource management. In addition to sedimentation risks associated with sediment movement, sediments can cause water quality degradation by transporting attached nutrient constituents directly to streams. Sediment movement from forest roads is a continuing area of concern in forest management. Application of road BMPs (including sediment control practices) is considered an effective means of reducing the environmental impacts of forest operations. However, the effectiveness of forest road BMPs is seldom investigated, primarily due to the complexity involved in evaluating forest road BMPs. This paper presents special design considerations and a design to evaluate forest road lead-off ditch structure sediment control treatments.

The BMP effectiveness study presented here was initiated during the fall of 2003 to evaluate three forest road lead-off ditch treatments using a randomized complete block design. The three treatments are a sediment basin, a sediment basin with riser control, and a hay bale barrier. Drainage structure and measurement devices were sized and selected based on a 25-year design storm. The design consists of water level sensors, water level recorders, trapezoidal flumes, flow dividers, and runoff tipping buckets to determine inlet and outlet discharge rates and sediment fluxes. The design utilized in this study of BMP effectiveness allows effective measurement of storm runoff volumes for both inlet and outlet stations.

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