EVALUATION OF ROAD APPROACHES TO FOUR DIFFERENT TYPES OF STREAM CROSSINGS IN THE VIRGINIA PIEDMONT

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Abstract—Erosion potential was estimated for road approaches during 4 phases of a timber harvesting scheduled for 23 stream crossings in the Virginia Piedmont. The objectives of this study were to: (1) examine four different types of stream crossing structures (steel bridges, pole bridges, standard culverts, and reenforced fords) in order to determine if the type of stream crossing affects erosion potential and (2) evaluate the potential erosion associated with the stream crossing approaches using the Water Erosion Prediction Project (WEPP) for forest roads and the forestry version of the Universal Soil Loss Equation (USLE). An unbalanced replication resulted in six replications of each crossing, except pole bridges (7) and fords (4). Results indicate that any of the stream crossings may be appropriate if located, installed, and maintained properly. However, we found that approaches associated with culverts had the potential for the highest soil loss rates as estimated by both WEPP (46.2 tons per acre per year) and USLE (85.8 tons per acre per year). Both of these models showed a general decrease in the potential for erosion from the during harvest phase to the postroad closure phase.

INTRODUCTION

Stream crossings can produce a number of water-quality pollutants, but sediment is usually the primary concern. Research indicates that roads create more pollution, in the form of sediment, than harvesting activities. Furthermore, stream crossings are the most frequent sources of sediment introduction (Rothwell 1983). Road construction and associated stream crossings are common activities for conventional harvest operations. Sediment produced at stream crossings originates from two primary sources: the stream crossing structure itself and the road approaches to the crossing (Taylor and others 1999). Locating the least steep approaches for stream crossings and choosing good locations are common best management practices (BMP) recommended for minimizing sediment pollution. The potential for water-quality impacts other than sediment also exist at stream crossings. Nutrients attached to sediment particles, which are transported directly to stream systems, may also present additional nonpoint source problems in forested watersheds (Grace 2005).

METHODS

Study Site Description

Stream crossings evaluated in this study were restricted to the Piedmont region. The Piedmont developed due to erosion and has a gentle slope from the mountains to the Coastal Plain (Daniels and others 1973). The interior of the province typically has a gently rolling landscape with moderate relief bounded by steeper, deeper valleys of the modern streams (Daniels and others 1973).

Most study sites were located on private properties that were under contract or land owned by MeadWestvaco or Huber Engineered Woods. Stands harvested ranged from mixed hardwood with white oak (*Quercus alba*) and yellow-poplar (*Liriodendron tulipifera*) to loblolly pine (*Pinus taeda*) plantations. A range of road classes were used to acquire all four types of stream crossings, ranging from skid trails (class IV roads) to permanent haul roads (class II to III roads).

Data Collection

Field visits were conducted during four different phases of the harvesting operation: prereopening/preinstallation, postinstallation/preharvest, during harvest, and postroad closure. Stream crossings were associated with permanent haul roads, temporary haul roads, or skid trails.

Data were collected to predict erosion from both the entrance and exit approach to the stream crossing. Weather information, slope length, slope width, slope percent, slope shape, road management, and soil texture were collected to estimate the approach erosion values with the Water Erosion Prediction Project (WEPP) (Forsyth and others 2005). The Universal Soil Loss Equation (USLE) model was also used to predict erosion from the approaches. Estimated soil erosion is represented by the following equation for USLE:

Estimated soil erosion = A (tons per acre per year) = $RKLSCP$

where
R = rainfall and runoff index
K = soil erodibility
LS = slope length and steepness
CP = cover-management practice factor for untilled and tilled forest land

The *CP* factor has several subfactors that influence the estimate such as bare soil, residual binding, soil reconsolidation, canopy, steps, onsite storage, invading vegetation, and high organic matter content (for untilled only) (Dissmeyer and Foster 1984).

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Erosion prediction models were used to estimate the amount of sediment being contributed from road approaches each year on a per-acre basis. WEPP version 2006.5 is a computer-based model published by the U.S. Department of Agriculture, Agricultural Research Service. This model is used to estimate sheet and rill erosion (Forsyth and others 2005). Inputting weather station, slope, road management, and soil texture information in this program allows it to predict erosion (tons per acre per year). The program was run to predict erosion for a 10-year period and obtains an average soil loss value. The USLE manual was the other main source of information to calculate the predicted soil loss. This model is effective for predicting sheet and rill erosion on forest land (Dissmeyer and Foster 1984).

Analyses

Data analysis was performed using the Number Cruncher Statistical System (Hintze 2004). Analysis of variance tests were done at the $\alpha = 0.10$ level. The Tukey-Kramer multiple comparison test was used to show significant differences of the four types of stream crossings at the $\alpha = 0.10$ level.

RESULTS

Evaluation of the erosion rates associated with the approaches to the various stream crossings using the WEPP model indicated no significant differences between the four stream crossing types for the preinstallation phase (*P*-value = 0.201), postinstallation/preharvest phase (*P*-value = 0.89), or postroad closure phase (*P*-value = 0.15). However, the during harvest phase resulted in significant differences between the four stream crossings (table 1) (*P*-value = 0.07). During harvest, culvert crossing approaches resulted in significantly more estimated erosion (46.2 tons per acre per year) than the ford, pole bridge, or steel skidder bridge (18.6, 21.6, and 29.7 tons per acre per year, respectively) (table 1). Higher estimates at the preinstallation phase may be due to preexisting road construction conditions for culvert, ford, and steel bridge stream crossings.

Estimation of the erosion rates associated with the approaches to the studied stream crossings using the USLE model indicated no significant differences between the four stream crossing types for the preinstallation phase (*P*-value = 0.16). However, the preharvest/postinstallation phase (*P*-value = 0.08) and the during harvest phase (*P*-value = 0.0006) resulted in significant differences between the four stream crossings (table 2) Also, the postroad closure phase resulted in significant differences in approaches among the four crossings (table 2) (*P*-value = 0.055). During harvest, approaches associated with culvert crossings resulted in significantly more estimated erosion (85.8 tons per acre per year) than the ford, pole bridge, or steel skidder bridge (23.4, 4.5, and 18.7 tons per acre per year, respectively) (table 2). Culverts, fords, and steel bridges showed a decrease in estimated erosion (50.5, 20.6, and 15.6 tons per acre per year, respectively) at the postroad closure phase. Pole bridge approaches increased from the during harvest phase estimated erosion rate of 4.5 to 10.3 tons per acre per year following road closure. Although significant differences of approaches were realized for the preharvest/postinstallation phase, the Tukey-Kramer multiple comparison test was unable to detect groups due to a limited sample size.

DISCUSSION

Water Erosion Prediction Project Estimates of Approach Erosion

Failure to detect differences in erosion estimates between treatments prior to installation of the crossings indicates that the subsequent treatments were being installed on relatively similar sites, which can be expected due to low disturbance before construction or harvesting activities. Each of the four types of stream crossings had at least one crossing that was installed with preexisting road conditions. Ford crossings had more preexisting crossings and approaches than any other crossing type. These preexisting conditions probably contribute to the higher levels of estimated erosion rates at the prereopening/preinstallation phase (table 1). Field observation and evaluation showed that the WEPP model projected a large amount of annual soil loss on approaches due to cover management practices and slope grade and length, during harvest. Absence of rock or gravel, except within the streamside management zone (SMZ) where the stream crossings were installed, caused higher erosion potential

Table 1—Mean values of the four stream crossing types during each sampling period as predicted by the WEPP model

	Sampling periods			
Stream crossing type	Prereopening/ preinstallation	Postinstallation/ preharvest	During harvest	Postroad closure
	tons per acre per year (tonnes/ha/year)			
Culverts	10.7 (24.0) ns	26.2 (58.7) ns	46.2 (103.5) a[a]	24.4 (54.7) ns
Fords	22.2 (49.7) ns	15.8 (35.4) ns	18.6 (41.7) b	19.9 (44.6) ns
Pole bridges	6.2 (13.9) ns	23.0 (51.5) ns	21.6 (48.4) b	11.8 (26.4) ns
Steel bridges	11.9 (26.7) ns	22.1 (49.5) ns	29.7 (66.5) ab	25.5 (57.1) ns

WEPP = Water Erosion Prediction Project; ns = none significant.

[a] Lower case letters indicate statistical significance at the $\alpha = 0.10$ level.

Table 2—Mean values of the four stream crossing types during each sampling period as predicted by the USLE model

Stream crossing type	Sampling periods: Prereopening/ preinstallation	Postinstallation/ preharvest	During harvest	Postroad closure
	------------------------------------ *tons per acre per year (tonnes/ha/year)*			------------------------------------
Culverts	3.8 (8.5) ns	34.4 (77.1) ns	85.8 (192.2) a[a]	50.5 (113.1) a
Fords	2.7 (6.0) ns	9.8 (22.0) ns	23.4 (52.4) b	20.6 (46.1) ab
Pole bridges	0.1 (0.22) ns	1.7 (3.8) ns	4.5 (10.1) b	10.3 (23.1) b
Steel bridges	2.2 (4.9) ns	34.2 (76.6) ns	18.7 (41.9) b	15.6 (34.9) ab

USLE = Universal Soil Loss Equation; ns = none significant.

[a] Lower case letters indicate statistical significance at the $\alpha = 0.10$ level.

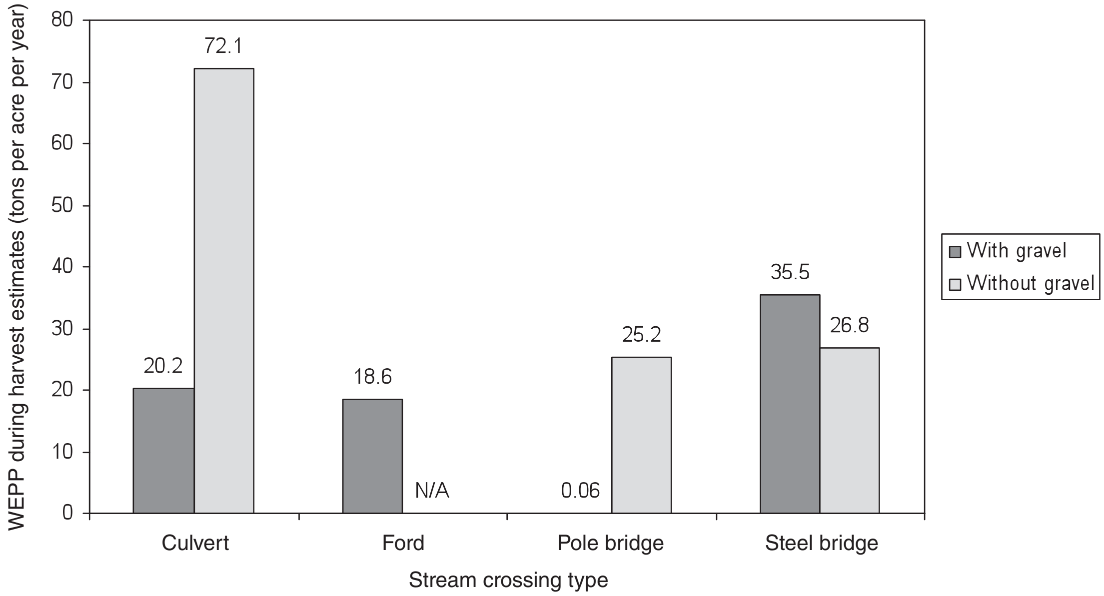

Figure 1—Water Erosion Prediction Project (WEPP) during harvest estimated erosion rates showing the differences in erosion rates for gravel/rock application to road approaches for each of the four types of stream crossings.

for some crossings (fig. 1). After harvest activities included implementing BMPs and reestablishing vegetation. Most stream crossing approaches decreased in WEPP erosion potential from the during harvest phase to the postroad closure phase with the exception of the ford stream crossing, which slightly increased (table 1).

Universal Soil Loss Equation Estimates of Approach Erosion

All stream crossings showed low-erosion potential, <4 tons per acre per year (9 mt/ha/year) (table 2) at the preinstallation/ prereopening phase. Postinstallation/preharvest mean erosion estimate values showed a *P*-value of 0.079 which revealed significance among crossing types. However, data recorded for this phase of harvest were limited due to factors such as immediate use of stream crossings and preexisting conditions of previously used crossings. USLE mean erosion estimates displayed a significant difference among stream crossing approaches during harvest. Approaches to stream crossing erosion means decreased from the during harvest phase to the after harvest phase with the exception of road approaches associated with pole bridge crossings (table 2). Possible explanations of this increase for pole bridge approaches from 4.5 tons per acre per year (10.1 mt/ha/year) during harvest to 10.3 tons per acre per year (23.1 mt/ha/year) after harvest are increases in bare ground and removal of natural vegetation. Often logging contractors will remove “rub” trees which are commonly used to change the direction of a skidder’s load of timber to minimize stream channel contact. This removal of trees adjacent to the approach decreases the amount of cover.

CONCLUSIONS

The evaluation of erosion potential from road approaches leading to 23 stream crossings throughout the harvest process allows the following conclusions to be drawn:

- Approaches associated with culvert stream crossings provide the highest potential for soil erosion of the four types of stream crossings studied as estimated by both WEPP—road model—and USLE—forestry version.
- Implementing BMP practices to reduce bare soil, increase the residual natural vegetation, and minimize slope length can help in maintaining low potentials for estimated erosion on an annual basis.

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