Methodology for evaluating post harvest erosion risk for the protection of water quality*

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Abstract

Poor forest harvesting practices can accelerate soil erosion, impact site productivity and decrease water quality. Post-harvest monitoring for the protection of water quality using visual inspections provides one rather subjective means for compliance monitoring. This study develops a method for quantitative analysis of potential erosion rates post-harvest using a Universal Soil Loss Equation (USLE) modified for forestry. To carry out an on-site inspection, the harvested area is divided into five disturbance areas: 1) landing area, 2) skid trails, 3) access roads, 4) cut-over, and 5) stream crossings. Erosion rates are estimated using the USLE in each of these areas, then combined to present a weighted average erosion rate for the whole harvest site.

The methodology was tested on 54 harvest sites in Virginia, USA, harvested between one to eight years ago, divided equally among three regions in Virginia. These regions are defined as Coastal Plain, Piedmont and Mountains. The weighted estimated erosion rates were significantly higher for the harvested areas in the Mountains (4.4 Mg/ha/yr) compared to the Piedmont (2.7 Mg/ha/yr) and Coastal Plain (2.5 Mg/ha/yr). In the mountains, the disturbance area contributing the greatest amount of potential erosion was the skid trails (54% of total), while the greatest potential contribution in the Piedmont came from the access roads (39%) and skid trails (39%). In the flatter coastal plain the cut-over area produced 74% of the estimated total erosion.

Keywords: Best Management Practices; Erosion; Harvesting; Non-point source pollution; Universal Soil Loss Equation

Introduction

In the USA there is no federal forest law that regulates the environmental performance of harvesting operations. There is however a federal water quality protection law that not only directly regulates point source pollution problems, but it also addresses the need to avoid non-point source pollution (Section 208 of the 1972 Clean Water Act). Non-point source pollution is defined as diffuse discharge entering receiving water in a diffuse manner at intermittent intervals based on rain and snowmelt (Novotny and Olem 1994). Accelerated soil erosion and subsequent sedimentation from harvesting operations is the primary forest water quality concern for forestry. Sediment is identified in the Clean Water Act as a pollutant. While sediment deposition in a water body is a natural geological process, accelerated deposition can lead to a reduction in water quality, which refers to the physical, chemical, and biological characteristics of water (Brooks *et al*. 1997). Sedimentation from timber harvesting has a potential to 1) impair fish habitat, 2) increase flooding potential, 3) create unusable drinking water, and 4) reduce visual clarity.

The major source of sediment from forest operations is generally construction and maintenance activities associated with roads (Anderson and Potts 1987; Askey and Williams 1984; Brown and Krygier 1971; Burns 1972). Anderson *et al*. (1976), Megahan (1980), Patric (1976), and Rothwell (1983) considered roads to be the major sources of erosion from forest lands, contributing up to 90 percent of the total sediment production from timber harvesting operations. Skid trails, like forest access roads, can also be a major sources of sediment (Rummer *et al*. 1997; Aust *et al*.1993).

While most states in the Pacific North West as well as in the New England region have adopted a regulatory approach to enforcing water quality impacts from forest operations, most Southern states have adopted a non-regulatory approach to improving environmental performance. The basis of this approach is in adopting forestry Best Management Practices (BMPs) to minimize potential impacts to water quality. All states have published, and regularly update their own BMP guidelines. To comply with US Environmental Protection Agency requirements, all have some form of post-harvest auditing or monitoring program to help enforce or improve or simply report on BMP implementation effectiveness (Yonce and Visser 2004).

BMPs are techniques or methods used by foresters and loggers to control non-point source pollution from harvesting activities. Forestry BMPs generally work as 1) prevention measures such as planning, policy, and management that avoid problems and 2) minimization measures which attempt to control problems such as road and skid trail engineering, and 3) amelioration measures which attempt to repair or ameliorate problems (e.g. streamside management zones) (US Environmental Protection Agency 1993).

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Most BMP manuals in Southeastern states focus on the following major issues: pre-harvest planning, access roads, decks, skid trails, stream crossings, harvest areas, and streamside management zones. BMP requirements will vary from site to site and range in size, function, and applicability for each phase of silviculture, from site preparation to access road closeout.

Post harvest inspections are typically carried out by the state foresters. Their primary concern is the identification of possible water quality infractions. In most Southern states both acute (sediment is actively entering the steam) or potential (a considerable amount of soil is exposed near a waterway and is likely to enter the waterway in the next rainfall event) is considered a violation of the water quality law. Regular post-harvest on-site inspections are simply visual and take a qualitative 'snap-shot' of current erosion problems (Yonce and Visser 2004). The decision as to whether the harvest area violates the water quality law is very subjective. Inspections usually occur within two months of the completion of harvest; erosion rates decline with time as the harvested site revegetates. Golden *et al*. (1984) and Dissmeyer (1980) stated that the average recovery time for harvest sites was approximately four years, but uncertainty exists regarding the exact length of time for full site recovery.

Since the protection of water quality is the primary concern when inspecting harvest operations, it would appear that the most direct and objective method for monitoring would be to measure water quality directly. Methods for measuring suspended sediment and bed-load are well established. However obtaining meaningful information from water quality samples can only be completed within the framework of a very intensive and long term study. A number of watershed scale studies have indicated at least 5 years of baseline (i.e. pre-harvest) data must be collected, the harvest carried out in well defined sub-catchments with approximately 10 years of post harvest data to provide meaningful results (e.g. Hornbeck *et al*. 1997; Kochenderfer *et al*. 1997; Swank *et al*. 1988). Information must be collected frequently to understand sediment loading variation relative to rainfall events. Such studies are an excellent source of information for understanding erosion and sedimentation changes associated with land-use activities. However, neither the time frame nor the costs associated with such a water quality monitoring programs make them feasible for routine harvest inspections.

An alternative to visual inspections is to use the USDA Forest Service's "A Guide for Predicting Sheet and Rill Erosion on Forest Land" (Technical Publication R8-TP 6). The USLE, developed at the National Runoff and Soil Loss Data Center established in 1954 (Wischmeier and Smith 1978), is one of the most widely used models to estimate erosion rates. Dissmeyer and Foster (1984) modified the original USLE to predict sheet and rill erosion from forest land. The USLE is founded on six principal components of erosion, which are multiplied together to achieve a predicted erosion rate for an area (Dissmeyer and Foster 1984; Wischmeier and Smith 1978). The USLE equation is:

Equation 1: $E = R \times K \times LS \times C \times P$

Whereby:

E Soil loss per unit area, usually as tons per acre per year.

R Rainfall and runoff factor: for Virginia ranges from 125 EI units/yr to 300 EI units/yr

K Soil erodibility factor: accounts for the variation in soils in tons/acre/year/unit of R/disturbance category.

L Slope length factor. Slope length factor reflect the influence that both gradient and the distance of that gradient has on erosion (whereby: $L = \lambda/72.6)^m$; λ = slope length in feet; θ = angle of slope in degrees; m = 0.5 for slopes $\geq$ 5 percent).

S Slope-steepness factor: accounts for the effect of gradient on a uniform slope on erosion as well as convex and concave slopes. $S = (65.41\sin^2\theta + 4.65\sin\theta + 0.065)$

C P Vegetative cover or land management factor based on the nine subfactors that help control erosion: 1) amount of bare soil, 2) canopy, 3) soil reconsolidation, 4) high organic content, 5) fine roots, 6) residual binding effect, 7) onsite storage, 8) steps, and 9) contour tillage.

There are noted limitations of the USLE when predicting erosion from forestland. For example, the USLE does not predict short-term wet weather events and does not predict sediment-loading rates downstream from a site, nor does it estimate the deposition of sediment in the stream (Dillaha 2000).

The following assessment procedure provides for a method of obtaining a weighted average erosion rate from the whole harvest area. This value can be used to assess the overall erosion risk of the site, can be used to set standards, and can be used to evaluate the performance of the harvesting operation in a quantitative manner. It takes into consideration that typically within a harvest area there are smaller areas with higher erosion risk (e.g. landing areas, skid trails), and larger areas (e.g. the cut-over) at lower risk. However it is the cumulative impact from the whole site that should be considered.

(Note: this project does not attempt to establish an acceptable threshold level that would differentiate acceptable from unacceptable environmental standards).

Assessment Procedure for Post Harvest Inspections

The first step is to break the harvest area into 'disturbance areas'. These disturbance areas also reflect the categorization in most southern state BMP manuals. They are: 1) AR - access roads, 2) ST - skid trails, 3) LA - landing area, 4) SC - stream crossings, 5) CO - cut-over (Figure 1 over page).

On-site, these areas are identified and the physical size of the area either measured or estimated. While Landing

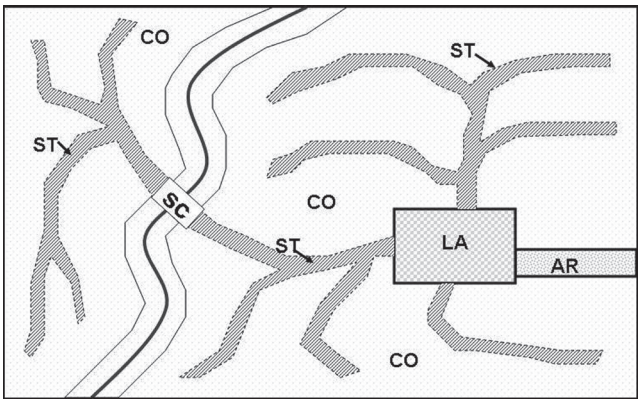

Figure 1. Schematic diagram of harvest area showing the delineation of 'disturbance areas'.

Area, Access Road and Stream Crossing can normally be measured directly, Skid Trail area is normally estimated using average skid trail width multiplied by measured length, and the Cut-Over area estimated by subtracting all the remaining areas from the total harvest area.

A USLE measurement is taken in each disturbance area present on site. Note that a given harvest area may not have a stream crossing or an access road on site, in which case they are simply omitted. If a site is very varied, multiple USLE measurements can be taken to adequately cover a given disturbance area, and these values are then averaged.

These erosion estimate values can subsequently be used to provide a weighted average erosion rate (in Mg/ha/yr) for the whole harvest area The Average Weighted Erosion (AWE) can then be calculated by:

Equation 2: AWE =

$$\frac{\sum E_{AR} \cdot A_{AR} + E_{LA} \cdot A_{LA} + E_{ST} \cdot A_{ST} + E_{CO} \cdot A_{CO} + E_{SC} \cdot A_{SC}}{\sum A_{AR} + A_{LA} + A_{ST} + A_{CO} + A_{SC}}$$

Whereby:
E_{xx} : is the estimated erosion rate using the USLE for disturbance area xx, and
A_{xx} : is the area of the disturbance area xx

Testing Procedure in Virginia

To test and utilize this post-harvest assessment methodology, a study was carried out in Virginia. Virginia has 6.1 million hectares of forest land, comprising roughly 61% of the total land area (Birch *et al*. 1998). Study tracts were selected from a Virginia Department of Forestry (VDOF) database containing all harvested tracts visited for random biannual audits between 1993 and 2002. For the purpose of protecting the environment, the VDOF harvest inspections classify each site into one of three categories; (a) no active sedimentation, (b) potentially active sedimentation, and (c) active sedimentation. To ensure a broad spectrum of harvested sites was obtained, six sites were randomly selected within each VDOF harvest classifications, for each of the three physiographic regions. Therefore, 18 sites were selected from each of three 'physiographic regions', defined as;

(a) Coastal Plain - characterized by very flat terrain,
(b) Piedmont - characterized by rolling hills, and
(c) Mountains - with steep broken terrain.

This resulted in a total of 54 study sites.

All of the selected sites were visited and the assessment methodology applied. The total area of the timber harvest for each site was obtained from VDOF audit maps. Each site was further broken down into the five 'disturbance areas'. An erosion estimate using the modified USLE was obtained for each of the disturbance areas at each study site, at a location that best reflected the average for the area, or multiple measurements taken.

In addition to the USLE information gathered, the type of harvest was recorded (broadly categorized as either clear-cut or partial cut), as was tract closure with gate (yes or no), and post harvest off-road vehicle (ORV) usage. Tract closure and off-road vehicle use was recorded to assess possible water quality problems that can not be associated with the previous harvesting activity. A site was considered gated if a permanent gated structure was present at the site that prevented vehicle access to the harvest area. Post-harvest ORV use was evaluated by classifying the level of vehicle traffic that had occurred since harvest.

The estimated erosion rate data collected was evaluated for normality (Gaussian distribution) via a frequency test. Upon determining that the data were Gaussian distributed (with slight skew to the right), the statistical software package SPSS[3] was used to perform the statistical analyses. The one-way Analyses of Variance (ANOVA) test was used to compare erosion rate means for disturbance categories between physiographic regions and for VDOF classifications. Scatter plots were incorporated to show erosion trends over time by disturbance category and physiographic province.

Pearson's correlation analysis was used to determine if type of cut, level of ORV use and whether the tract was gated correlated to erosion rates for each disturbance category. Multiple linear regression was used to determine if time was a significant predictor for erosion parameters. T-tests were used to determine the significance of type of cut, ORV use, and gated on estimated erosion rates.

Results and Discussion

Implementation of Assessment Methodology

Overall, this method for quantitative analysis of potential erosion rates post-harvest was readily implemented on site. A harvest area can be evaluated on average in 1-2 hours, assuming a basic map showing total harvested area is available. It showed to be reliable and repeatable. An average weighted erosion estimate can be determined and used to compare harvest system environmental performance. Additionally, data gathered for the individual disturbance areas can be used as a management tool to minimize overall impact.

Erosion rates by disturbance area

Estimated erosion rates for each disturbance area at all the sites are summarized and presented in Table 1. Erosion rates ranged from 0,001 Mg/ha/yr to 270 Mg/ha/yr.

Table 1. USLE estimated erosion rates as recorded at the sites. Note; all study areas had a 'cut-over' area (n=54), but not all had skid trails (n=50) or stream crossings (n=25) etc.

Disturbance Area	# of obs. n=54	Average (Mg/ha/yr)	5th Percentile	95th Percentile
Landing Area	47	7.9	0.010	34.6
Skid Trail	50	11.2	0.002	67.3
Access Road	46	21.1	0.102	73.2
Cut-Over	54	0.6	0.003	2.8
Stream Crossings	25	20.8	0.031	90.7

The greatest estimated erosion rates were measured on either access roads or skid trails (Figure 2), with general characteristics being very steep, severely eroding with little or no vegetative cover, and with no water control structures.

Figure 2. Skid trails bulldozed into the hillside that are not rehabilitated after harvest will be a source of erosion. Applying the USLE to the he skid trail shown in the picture in resulted in a predicted erosion rate in excess of 50 Mg/ha./yr.

Erosion Rate Based Upon Ratio of Disturbance Category to Total Tract Area

The soil erosion rates calculated using the USLE and presented are estimated annual erosion rates in Mg/ha/yr, but these values do not account for the ratio or percentage of that disturbance area to the whole harvested site. The average weighted erosion rate (in Mg/ha/yr) that accounts for the erosion from each disturbance area relative to the area it occupies (Equation 2) within a tract is presented in Figure 3. At each harvest area a USLE value was obtained in a neighboring un-harvested forested 'control' area (if available) for comparison, and the average of these values is also shown in Figure 3.

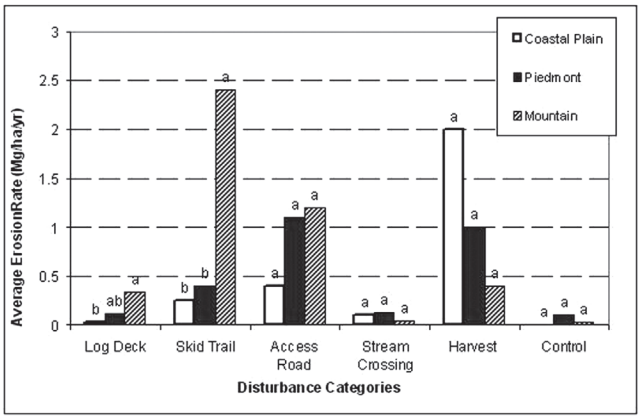

Figure 3. Average erosion rate contribution to the total weighted erosion rate (in Mg/ha/yr) by each disturbance area, split out by physiographic province. Note that the different letters associated with each column reflect statistically significant difference.

There were significant differences in erosion rates for log decks and skid trails disturbance categories. The high skid trail erosion rates in the Mountains are a result of both greater unit area erosion and greater percentage of skid trails, which on average were 5% of total tract area compared to the 2% found in the other physiographic regions. The harvest area disturbance category contributed the greatest amount of erosion in the Coastal Plain.

Physiographic Differences

There were large variations in estimated erosion rates between and within provinces (Figure 4).

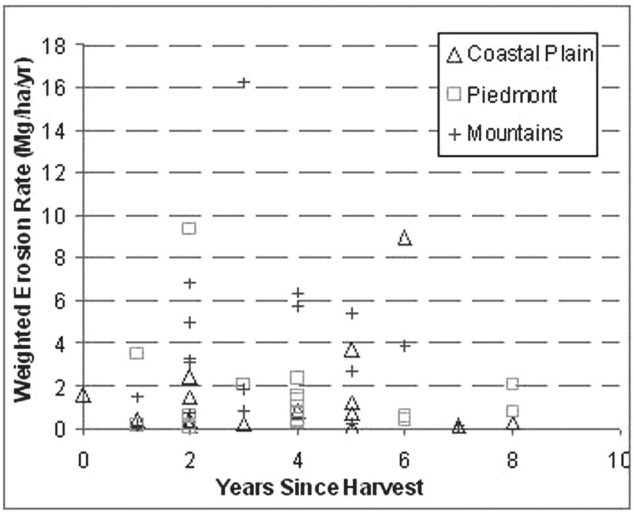

Figure 4: Average erosion rates for all sites surveyed by physiographic areas and time since harvest.

Average weighted erosion rates between physiographic provinces were compared, with the data showing the mountain area having a significantly higher erosion rate then either the Piedmont or the Coastal Plain (Table 2). Also shown are the disturbance category erosion rates as a percent contribution to the total weighted average.

Table 2. Estimated contribution of erosion rates by disturbance category (in percent) and the average weighted erosion rate and physiographic region (Mg/ha/yr).

	Access Road	Skid Trail	Landing Area	Stream Crossing	Cut-Over	Weighted Average
	Erosion rate contribution to weighted average (%)					Mg/ha/yr
Coastal Plain	15	9	1	2	74	2.7b
Piedmont	39	14	4	3	39	2.5b
Mountain	27	54	7	2	10	4.4a*

**Different lower case letters within a column represent a significant difference at the 0.05 level.*

In the Coastal Plain the disturbance area of cut-over contributed the greatest amount of erosion (74%) to the average weighted erosion rate. In the Piedmont both the cut-over and access road contributed the same amount of erosion (39%). Skid trails contributed over half (54%) of the soil loss in the Mountains.

The lack of vegetative cover on skid trails, access roads, log decks, and stream crossings in conjunction with steep slopes with long slope lengths increased erosion potential. From the field observations and results, it became obvious that harvesting closeout BMPs were often not effective in breaking slope lengths and establishing sufficient cover for many of the tracts sampled.

It is possible to classify the level of erosion from harvesting sites as being; 1) essentially recovered (< 1 Mg/ha/yr) as derived from undisturbed mixed forest erosion rates, 2) acceptable (1-5 Mg/ha/yr) derived from the acceptable level of soil loss from pastureland, 3) problematic (5-10 Mg/ha/yr) derived from the classification of mechanical site preparation, and 4) severe erosion (>10 Mg/ha/yr) derived from carelessly cultivated or steep fields in conjunction with active construction (Yoho 1980). The overall average estimated erosion rates from timber harvesting in Virginia are well within the acceptable limits of erosion from agricultural practices.

Benefits of Gated Tracts and Impacts of ORVs

A harvested site that is gated influences the amount of post-harvest traffic and therefore we can expect a reduction in erosion potential. The percent distribution of gated vs. non-gated tracts differs by physiographic province and the t-test indicated that there was evidence to conclude a decrease in the average weighted erosion rates if the tract was gated tract ($p=0.105$). There was a significant increase in erosion rates from the landing area ($p=0.065$) if a tract was not gated.

Not all tracts with gates were able to keep out unwanted traffic. Therefore, ORV usage was also determined. From the field evaluations the heaviest amount of ORV usage occurred in the Piedmont (22% of sites visited). Stream crossing erosion was influenced significantly by moderate ORV usage ($p=0.011$) versus no ORV usage and access road erosion was influenced significantly by heavy ORV usage ($p=0.038$) versus no ORV usage.

Conclusion

This project developed and tested a simple quantitative on-site assessment procedure for estimating a weighted average erosion rate using the Universal Soil Loss Equation (USLE) for recently harvested areas. The intended application is for either augmenting and or replacing the subjective visual post-harvest inspections, whereby the primary focus is on the protection of water quality and minimizing the impact on soil.

The method was trialed successfully in 54 locations in Virginia USA that had been harvested in the previous 8 years. The field trials indicated that erosion from skid trails were the single largest contributor of erosion on harvested tracts in the Mountains. However, the cut-over areas in the Coastal Plain contributed the most erosion out of all disturbance categories. On average, the harvested areas studied are not eroding at problem levels. Using the data captured should provide a good management tool for further refining harvest operations and Best Management Practices to further reduce erosion risk and protect water quality.

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