Estimating soil erosion on a timber harvest site

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Abstract

This paper highlights various methods for estimating soil erosion, with a focus on erosion modeling using the Universal Soil Loss Equation (USLE)-Forest model. The paper outlines how operational areas within a harvest site contribute differently to erosion potential and provides step-by-step guidance on applying USLE-Forest to estimate soil loss. It also emphasizes the role of forestry best management practices (BMPs) in minimizing erosion and promoting sustainable forest management.

Introduction

Erosion is the process where soil particles are moved from their original location by forces like water and wind. While soil erosion is a natural phenomenon, human activities such as improper timber harvesting, agricultural practices, and construction activities can greatly accelerate it. One of the primary contributors to this issue in forestry is the displacement of soil cover (trees and other vegetation), which occurs during logging operations. The construction of haul roads, skid trails, and stream crossings may also disturb soil cover and structure in ways that could increase the likelihood of accelerated water flow and associated soil movement.

The utilization of heavy machinery such as a feller-buncher for tree felling, grapple skidder for transporting cut trees to the landings, loader and delimber for processing and loading trees, dozer for clearing haul roads and landings, and trucks for transportation of trees from the forest to mills is integral to modern timber harvesting operations (Parajuli et al., 2020). These machines can highly alter soil conditions, affecting soil structure, bulk density, porosity, and permeability (Parajuli et al., 2022). The extent and severity of soil erosion caused by timber harvesting can vary depending on several factors, including soil characteristics, topography, the type of harvesting machinery used, and the timing of operations (Image 1 and Image 2). Erosion can reduce soil fertility, making it more difficult for forests to regenerate, and may also lead to negative environmental consequences such as degraded water quality if sediment is transported into nearby waterways. Given these potential impacts, careful harvest planning and the implementation of forestry best management practices (BMPs) before, during, and after timber harvesting are essential to minimizing soil disturbance and reducing the risk of erosion. When properly applied, BMPs help maintain soil integrity, protect water quality, and promote sustainable forest operations (Parajuli et al., 2025; Rijal et al., 2023). Implementing forestry BMPs according to specific site conditions and harvesting methods is crucial. Furthermore, understanding and quantifying soil erosion on timber harvests is also essential to ensure the land's sustainability and fertility for future use. A careful assessment of site conditions and well-planned and properly carried out harvesting operations that follow adequate BMPs are key to keeping the soil healthy and reducing soil erosion and sedimentation. A field guide to the minimum requirements for logging Best Management Practices in Kentucky can be found here

Best Management Practices in Kentucky

Image 1: Excessive rutting on a site that was harvested when the soil was saturated. Forestry BMPs were not followed.

Image 2: Soil erosion on a forest road. Forestry BMPs were not followed in that no water diversion devices (waterbars and turnouts) were installed.

Operational areas within a harvest site

A harvest site can be categorized into different operational areas (Image 3).

1. **Forest roads:** Roads are constructed to provide access to forested areas for log truck access along with other objectives such as recreation and fire management.
2. **Skid trails:** Skid trails are created to drag (i.e. skid) or move logs or other forest products out of a harvest area using specialized machinery, such as skidders and forwarders. Skid trails and forest roads are most vulnerable to soil erosion due to the frequent movement of machinery.
3. **Deck/landings:** Areas designated for processing harvested timber, including activities such as sorting, loading, and chipping. These are high-traffic zones where skidders frequently deliver logs and log trucks are actively loaded.
4. **Stream crossings:** Points where forest roads or skid trails cross over streams or other waterways to access timber on the other side. If poorly designed or maintained or not removed (temporary crossings), stream crossings can significantly impact water quality and aquatic habitats. Stream crossing approaches are critical areas to protect since they provide a direct path for runoff to reach the stream.
5. **Stream-side management zones (SMZs):** Designated areas along streams and other waterways where specific forest management practices are implemented to protect water quality, aquatic habitats, and other ecological values. Some management techniques in these areas typically call for leaving a buffer of trees on both sides of the stream, harvesting may be allowed up to a specific crown cover percentage or basal area, no cutting of bank trees, and many other techniques that will protect water resources.
6. **Harvest area:** Timber harvest area, excluding roads, skid trails, decks, SMZs, and stream crossings.

Image 3: A harvest site.

Determining soil erosion from a harvest site

Over time, various methods have evolved to determine soil erosion rates, balancing simplicity with precision (Table 1).

Method	Description	Typical Scale	Best For
Sediment Capture	Soil erosion can be measured by physically capturing sediment or monitoring soil level changes. One method uses durable pins inserted vertically into the ground to track erosion or deposition over time, based on changes in	Plot to small watershed	Ground-truthing, short-term erosion, small

	the exposed pin length. Common sediment capture techniques include runoff plots, Gerlach troughs, sediment traps/check dams, silt fences/straw bales, and sediment collection tanks.		experimental sites
Water Sampling	Measuring suspended sediments in runoff water. Common water sampling techniques include grab sampling and automatic water samplers.	Event-based / continuous	Storm event monitoring, water quality, sediment transport quantification
Tracer Techniques	Estimating past erosion by analyzing natural or artificial isotopes. Common tracer techniques include compound-specific stable isotopes (CSSI) and fallout radionuclides (FRNs).	Hillslope to watershed	Long-term cumulative erosion and source tracking
Geotechnical Tests	Quantifying soil's resistance to erosion under controlled hydraulic conditions. Common geotechnical testing techniques include the Jet Erosion Test (JET) and the Hole Erosion Test (HET / HET-P).	Lab or site-specific	Infrastructure design, levee/dam safety assessment
Erosion Modeling	Using empirical or physical models to simulate or estimate soil loss. Common techniques include USLE / RUSLE (Universal Soil Loss Equation), WEPP (Water Erosion Prediction Project).	Plot to regional	Long-term planning, scenario modeling, GIS-based erosion mapping

Of the various soil erosion estimation methods, this paper highlights erosion modeling, with a focus on the USLE-Forest model.

Erosion modeling: Erosion modeling is the least intensive method for determining erosion. Models include the Universal Soil Loss Equation (USLE)-Forest, Revised Universal Soil Loss Equation (RUSLE), and Water Erosion Prediction Project (WEPP). Among these models, USLE-Forest has been the most widely used for estimating erosion on timber harvest sites. This method was developed by Dissemeyer and Foster (1984) and estimates soil erosion through a series of steps, each considering different factors contributing to erosion. The USLE-Forest manual can be found here USLE Forest guideline .

Below are the specifics on using USLE-Forest for estimating soil erosion potential on harvest sites.

For estimating soil erosion using USLE-Forest, the six operational areas within a timber harvest site can be categorized into tilled (topsoil removed) and untilled groups (no topsoil removed). SMZs and harvest areas fall into the untilled group while the rest fall into the tilled group. Soil erosion needs to be estimated from each operational category in order to get the weighted overall average erosion from the harvest site. If you are only interested in a particular operational area and not the overall site, then you only need to focus on using USLE-Forest in that area.

All reference to Figures and pages refers back to the USLE-Forest manual (not in this article).

The equation for estimating erosion in USLE-Forest is:

Erosion rate (tons/acre/year) = R*K*LS*CP

Where,

1. **R (Rainfall and Runoff Index)**
   The amount of rainfall contributing to erosion is measured as the number of rainfall erosion index units. In Kentucky, this value varies from 150 in northern regions to 250 in the western region. USLE-Forest provides a rainfall index provided in Figure 1, page 3.

2. K (Soil erodibility)

Soil erodibility is a measure of a soil's susceptibility to erosion. Usually, it varies with the soil type, and the K value ranges from 0.1 to 0.5. To check the K factor for a particular harvest site, see page 36 in the USLE manual or visit the UC Davis Soil Web Page to input the harvest site location and locate the K-factor.

3&4. Slope length, slope steepness, and LS (slope length and steepness)

The combined influence of slope length and gradient on erosion is considered in this step. Field measurements of slope gradient can be done using a clinometer (percent slope), while slope length can be measured with a tape or by pacing. The values for LS factors can be found in Table 1, page 5, or Figure 3, page 6 in the USLE manual. For instance, with a slope of 5 percent and a length of 50 feet, the LS value is 0.379.

5&6. CP (cover - management practice factor for untilled and tilled forest land)

Operational areas need to be categorized as tilled or untilled and to obtain this value, you must evaluate the subfactors and multiply them together to get the CP value. If a subfactor is not applicable, assign it to a value of 1. The subfactors are given below.

Weighted average erosion = (area of roads *erosion rate from roads + area of skid trails*erosion rate from skid trail +area of decks * erosion rate from decks + area of SMZs*erosion rate from SMZs + area of stream crossing *erosion rate from stream crossing + area of clear cut*erosion rate from clear cut)/ total harvest area

Example of erosion estimation using USLE-Forest method:

Untilled area

CP Subfactors for minimal disturbance
a. Bare soil, & Fine roots = 0.036

b. Canopy = 0.58

c. Steps = 0.93

d. Onsite storage = 0.8
e. High OM Content = 0.7

Tilled area

CP Subfactors for disturbed soils (roads)
a. Bare Soil, residual binding, soil reconsolidation = 0.045

b. Canopy = 0.58

c. Steps = 0.93

d. Onsite storage = 0.8
e. Invading vegetation = 0.87
f. Contour Tillage = 1

Total CP for untilled = 0.011 Total CP for tilled = 0.017

Once CP is calculated, multiply R, K, LS, and CP to get the estimated erosion value.

Estimated soil erosion for untilled soil = 200*0.17*0.379* 0.011= 0.140 tons/acre/year.
Estimated soil erosion for tilled soil =200*0.17*0.379*0.017= 0.22 tons/acre/year.

Management strategies to reduce soil losses

Estimating and preventing soil erosion is an important part of long-term forest management. Once you have knowledge of estimated soil erosion rates on a harvest site, you can take steps to reduce erosion. This might include planting cover crops, installing erosion control structures, water diversion devices, or reducing the amount of logging or other land management practices that can contribute to erosion. Implementing proper BMP is very important to minimize erosion from harvesting activities. Examples of BMPs implementation are shown in images 5 to 9. Properly implementing BMPs can greatly reduce the negative impact on soil conditions, lowering the risk of soil erosion. Appropriate management strategies are crucial to mitigate these risks and safeguard the soil, water quality, and surrounding ecosystems. See the following Extension articles for more information about forestry BMPs:

- Forestry Best Management Practices: Stream Crossings
- Timber Harvesting Guidelines for Forestry Best Management Practices
- Forestry Best Management Practices: Skid Trails

Image 5: Turnouts on forest roads.

Image 6: Use of forest residues to cover skid trails.

Image 7: SMZs, implemented to mitigate erosion, reduce sedimentation, and safeguard water quality.

Image 8: Mulch application on forest roads to stabilize soil.

Image 9: Water bars on forest roads, a measure designed to channel runoff and minimize water accumulation.

Conclusion

Timber harvesting, if not approached with care, can seriously affect the soil quality of your land. Soil erosion can have severe negative impacts on forest soil and, consequently, a forest ecosystem's overall health and productivity.

Understanding the factors contributing to erosion, such as the slope, soil characteristics, amount of rainfall, and soil cover, is essential. Landowners can employ simple visual inspections or advanced erosion models to estimate potential soil loss from a site and make informed decisions on managing their land.

Proper harvest planning and understanding of the land's characteristics are crucial for managing the land for long-term use. Implementing BMPs before, during, and after harvesting activities according to the site's specific conditions reduces the risk of soil erosion from the harvest site. These practices can range from constructing access roads and controlling the number of passes on skid trails to maintaining buffer strips of vegetation along streams.

References

Dissemeyer, G., & Foster, G. (1984). *A guide for predicting sheet and rill erosion on forest land. USDA Forest Service, State Priv. For. Tech. Publ*.

Parajuli, M., Cristan, R., Daniel, M. J., Rijal, A., Mitchell, D., McDonald, T., & Gallagher, T. (2025). Integrating high-resolution imagery, deep learning, and GIS to estimate soil erosion following timber harvesting. *Remote Sensing Applications: Society and Environment*, *37*, 101498. https://doi.org/https://doi.org/10.1016/j.rsase.2025.101498

Parajuli, M., Hiesl, P., Hagan, D., & Khanal, P. (2022). Logging Operations and Soil Compaction.

Parajuli, M., Hiesl, P., Smidt, M., & Mitchell, D. (2020). Factors influencing productivity and cost in the whole-tree harvesting system. *Clemson Cooperative Extension, Land-Grant Press by Clemson Extension*, *1079*, 1-8.

Rijal, A., Cristan, R., Gallagher, T., Narine, L. L., & Parajuli, M. (2023). Evaluating the feasibility and potential of unmanned aerial vehicles to monitor implementation of forestry best management practices in the coastal plain of the southeastern United States. *Forest Ecology and Management*, *545*, 121280.