HARVESTING IMPACTS ON STEEP SLOPES IN VIRGINIA

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Abstract: Ten tracts in the mountains of western Virginia were intensively sampled to determine the type and extent of soil disturbance from ground-based logging and the attendant erosion risk. Average slopes for the tracts ranged from 21 to 43 percent. Logged slopes exceeded 50 percent. All tracts surveyed were logged prior to the push for voluntary Best Management Practices and had been completed at least three months before the survey was conducted. Two logging methods were observed: skidding overland directly from stump to roadside, and the use of bladed skid trails. Overland skidding, when topography permits, was found to cause less disturbance and soil compaction. High risk of soil movement and erosion was associated with a relatively few, high-risk, spots left after harvesting, rather than the general application of the system.

INTRODUCTION

The increasing demand for Appalachian forest products, both lumber and pulpwood, coupled with increased environmental awareness, has renewed interest in the impacts of ground-based logging systems on steep slopes. Alternative systems such as helicopter, balloon and cable ways may find limited application on sites were the combination of volume, value, and ecological sensitivity can justify the additional expense required. Rubber-tired skidders with their advantages of cost, flexibility, modest skill requirements, and reduced weather sensitivity are the most economical means of removing timber from moderately steep (30-40% slopes) sites and will likely remain the method of choice from an operational standpoint.

The harvesting impacts of ground systems on these sites fall into three broad categories: those which increase erosion risk, those which reduce site productivity, and those which alter the aesthetics of the tract. Erosion risk increases as a result of removing the forest cover (a largely unavoidable consequence of timber harvesting), removing the litter layer, opening of drainage channels up and down the slope, and altering soil structure to the extent that infiltration rate is reduced. Soil compaction is perhaps the greatest threat to site productivity, especially if root penetration is inhibited and soil porosity is lost. Logging alters the canopy profile, but the most objectionable impacts are the exposure of mineral soil, imposing straight lines of haul roads and skid trails on the natural topography and leaving broken stems and piles of debris.

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The literature is replete with articles describing the impacts of harvesting on various soil types (Dickerson 1968, Dryness 1965, Froelich et al. 1981, Krag and Webb 1987, Mace 1970, Reinhart et al. 1963, Reisinger et al. 1988, Willis 1971). The diverse nature of forests, forest soils, past land management practices, and research objectives make it nearly impossible to draw broad generalizations from this research base. Harvesting technology has changed rapidly over the period of this research as well. Direct-drive machines of the early 70's have been supplanted by power-shift transmissions. Hydrostatic drive machines are becoming more common. Each advancement in drive trains alters the manner of soil machine interaction.

Major changes have occurred in tire and track design as well. Tire widths have increased, carcass construction has improved, and tread designs have been adapted to specific applications. Undercarriage design, balance, and drives for crawler tractors have improved over the same period. Soil effects have often driven these design changes. Lumping a new power-shift machine mounted on wide tires into the same category as a pre-1970's, direct-drive machine on modified agricultural tires negates much of this effort.

The change in technology has expanded the range of harvesting options. Wood form may range from log length to full tree. The ability to skid along the contour on steep slopes has increased, landing size and location can be better adapted to the terrain, and forest road designs altered to take advantage of more powerful and maneuverable trucks.

The fundamental divisions of the forestry profession often insulate those concerned with the effects of operations on the forests from those concerned with reducing those effects. The silviculturist is measuring the impacts of a technology that is at best current, more likely already superseded, on stand development. The harvesting specialist--whether forester, engineer or other professional--is concerned with the impacts of current and future technology and practices. The two can normally exist in blissful isolation until an external disturbance focus an interaction.

The recent move to Best Management Practices has been such a destabilizing influence. The various states have been involved in developing guidelines for forestry operations either voluntarily or at the direction of their legislatures. The basis for these guidelines has been a mix of published research findings, experience, and what the state next door is doing. The fit with the current activities and local conditions is seldom tested except by empirical methods based on improvement in the environmental variable of interest.

This study was structured to assess the harvesting impacts from current ground-based operations on slopes greater than 30 percent in the mountains of central Virginia. The objectives of the study were:

a. to document the form and extent of soil disturbance and compaction associated with conventional operations.

b. to identify this disturbance with specific forms of causality in planning, operation and closure, and;

c. to make recommendations for reducing these impacts in future operations.

METHODS AND PROCEDURES

The cooperators in the project--Georgia Pacific, Nekoosa Packaging, the U.S. Forest Service, and Westvaco--were asked to submit a list of tracts from the central Virginia region which had been or would be clearcut between September 1988 and September 1989 by ground-based systems, and which had average slopes in excess of 30 percent. The tracts were to be "forwarded" without consideration of the apparent "quality" of the logging job. Twenty-nine tracts were identified, of which 10 were selected for detailed study. The final selection attempted to assure a diversity of ownership, soil type, season of harvest, equipment, harvesting strategy, and skidding practices (Tables 1 and 2). None of the tracts was visited prior to selection. The contractors performing the harvest did not know the tracts were to be included in a study of this type. Virginia was updating its Best Management Practices activity at the time the tracts were cut, but compliance was still voluntary and inspections had not begun. Consequently, there was no indication that "special" precautions were taken by the contractor or crew during the harvest.

Designated skid trails are commonly recommended for steep terrain (Froelich et al., 1981). The research basis for much of this has come from the Pacific Northwest or Scandinavia (Wasterland 1987). The alternatives had not been fully tested on Appalachian forests. The 29 tracts provided were roughly evenly split between those harvested using designated bladed trails and those skidded overland. The split was maintained as an important variable in the study.

Tract orientation relative to the contour appears to be a major factor in determining which method will be used. Two of the tracts were harvested by the same contractor, using different skidding methods. Tracts laid out with the long axis running perpendicular to the contour were skidded using overland methods; tracts with the long axis parallel to the contours required bladed skid trails.

The cooperators provided maps and description of each tract. Additional information pertaining to soils, weather conditions during and following the harvest and other descriptive material was collected. A two-person study team visited each tract during the summer of 1989. The general characteristics of the tract were documented: the location of roads, landings, skid trails, rock outcrops, streams, and drainages, along with other gross tract features. This was supplemented by circular plots, 20 feet in diameter installed at 50-foot intervals along contours. The area encompassed by these plots ranged between 5 and 8 percent of the tract surface area, depending upon the amount of land area reserved for wildlife plots, streamside management zones, or deemed unloggable because of rock outcrops, bluffs, or low timber quality.

Table 1.--Summary of physical study-tract characteristics.

Tract	Soil Type	Ownership	Rainfall During Harvest	Average % Slope	Size (acres)	Aspect
A	silt loam and stoney loam[1]	industry	13.59 in. 3 months	43	11.0	west
B	shaly silt loam[2]	industry	11.53 in. 4 months	33	15.7	north
C	sandy loam to loamy sand[3]	public	14.12 in. 4 months	35	16.1	northwest
D	stoney, fine sandy loam[4]	private	12.02 in. 3 months	21	*20.8	northwest
E	sandy loam to loamy sand [3]	public	13.45 in. 4 months	27	40.4	southwest
F	sandy clay loam silt loam [5]	public	6.84 in. 3 months	29	18.0	southeast
G	shaly silt loam[2]	industry	22.65 in. 4 months	37	19.8	east
H	stoney, fine sandy loam[6]	public	17.12 in. 3 months	25	23.5	northwest
I	stoney, fine sandy loam[4]	private	22.70 in. 4 months	28	39.0	northwest
J	shaly silt loam[7]	public	13.46 in. 3 months	31	19.9	east

[1]Sequoia and Dekalb.
[2]Berks-Weikert.
[3]Leetonia.
[4]Edneytown.
[5]Landig-Berks.
[6]Edneytown-Peaks-Thurmond.
[7]Berks-Weikert-Rushtown.

Table 2.--Summary of study-tract harvest characteristics.

Tract	Season of Harvest	Skid Trail Type	Equip. (make/ model/tire size)	Skid Direction	Cubic Feet Harvested (per acre)
A	summer	overland	Timberjack 240E 23.1x26	15% uphill 85% down	2332
B	fall	overland	Timberjack 240E 23.1x26	96% uphill 4% down	3421
C	winter	overland	CAT 518 23.1x26	1% uphill 99% down	1509
D	spring	overland	Timberjack 230D 23.1x26	80% uphill 20% down	1734
E	summer	overland	John Deere 640 23.1x26	65% uphill 35% down	602
F	winter	bladed/ overland	CAT 518 18.4x34	35% uphill 65% down	1702
G	summer	bladed	Timberjack 450 23.1x26	95% uphill 5% down	2266
H	spring	bladed/ overland	Timberjack 230/ 450 18.4x34	94% uphill 6% down	2293
I	summer	bladed	Cat 518 23.1x26	2% uphill 98% down	2301
J	spring	bladed	John Deere 18.4x34	92% uphill 8% down	1072

The soil surface characteristics within each plot were mapped and classified using a descriptive system adapted from Miller and Sirois (1986):

1. Undisturbed: Litter in place and undisturbed; no evidence of machine traffic or compaction.
   Subclasses: Non-soil (rock outcrops, stumps, etc.)
   Debris piles (slash over 30 cm deep)

2. Slightly disturbed -- any of the following three conditions:

a. Litter removed and mineral soil exposed
b. Mineral soil and litter mixed
c. Mineral soil deposited on top of litter to a depth of 5 cm
Subclasses: Compacted -- obvious depression caused by passage of log or machine
Debris piles

3. Severely disturbed: Surface soil removed and the subsoil exposed.

a. Cut or rutted soil remaining in its original location
b. Pushed or filled soil from harvesting or earthwork activities
Subclasses: Compaction -- obvious depression caused by passage of log or machine
Debris piles

4. Depression deposits: Sedimentation of soil in holes, troughs, or behind debris dams.

In addition, a cone penetrometer was used to measure differences in soil mechanical strength between the above categories and subcategories measured in each plot. If the entire plot was disturbed, an unimpacted measurement was taken from the nearest undisturbed area. (Penetrometer readings were not recorded for depression deposits because of the small area and major shift in soil structure with depth.) Slope was recorded at each plot center, and skid direction (uphill/downhill or along contour) was noted. Measurements of the depth of organic layer, soil texture, and other characteristics for each disturbance class were taken. Live brush density and the parameters required for the universal soil loss equation adapted to forested sites were recorded. Plots were installed in skid trails, landings and roads as well as the forest floor to assure all disturbance classes were documented.

A total of 1120 plots was established on the 10 tracts. These were further supplemented by measuring and documenting engineered earthworks, such as roads and landings, and non-engineered earthworks such as skidder blade work on skid trails or water bar construction. These on-the-ground measurements were supplemented by scaled measurements from aerial photographs taken of each tract.

RESULTS AND DISCUSSION

The Universal Soil Loss Equation was used to estimate potential soil movement, in terms of tons per acre per year, from each plot. Soil movement, estimated in this manner, means the soil is moved from its place of origin and should not be equated with potential stream sedimentation. The forest floors after harvest on most of the plots, had sufficient litter layer and micro topography to slow runoff and force deposition of much of the soil near the place of origin.

Figure 1 from Tract A shows the common pattern. No soil movement was expected for a majority of the plots and moderate movement for most of the others. Each tract contained a few plots with a very high risk. Five hundred fifty of the 1120 plots had an estimated zero risk of soil movement. Soil movements of less than 1 ton per acre per year were estimated for an additional 173 plots. Each tract contained a few "hot spots" with very high erosion risks. Maximum individual plot measurements for the 10 tracts ranged from a low of 6 tons per acre per year to a high of 158. These "hot spots," without exception, occurred on a road, landing, or skid trail. The values also reflect the risk during the first year after harvest and would decline rapidly as the tract revegetates, and exposed soil on roads, tracts, and landings are covered with grass.

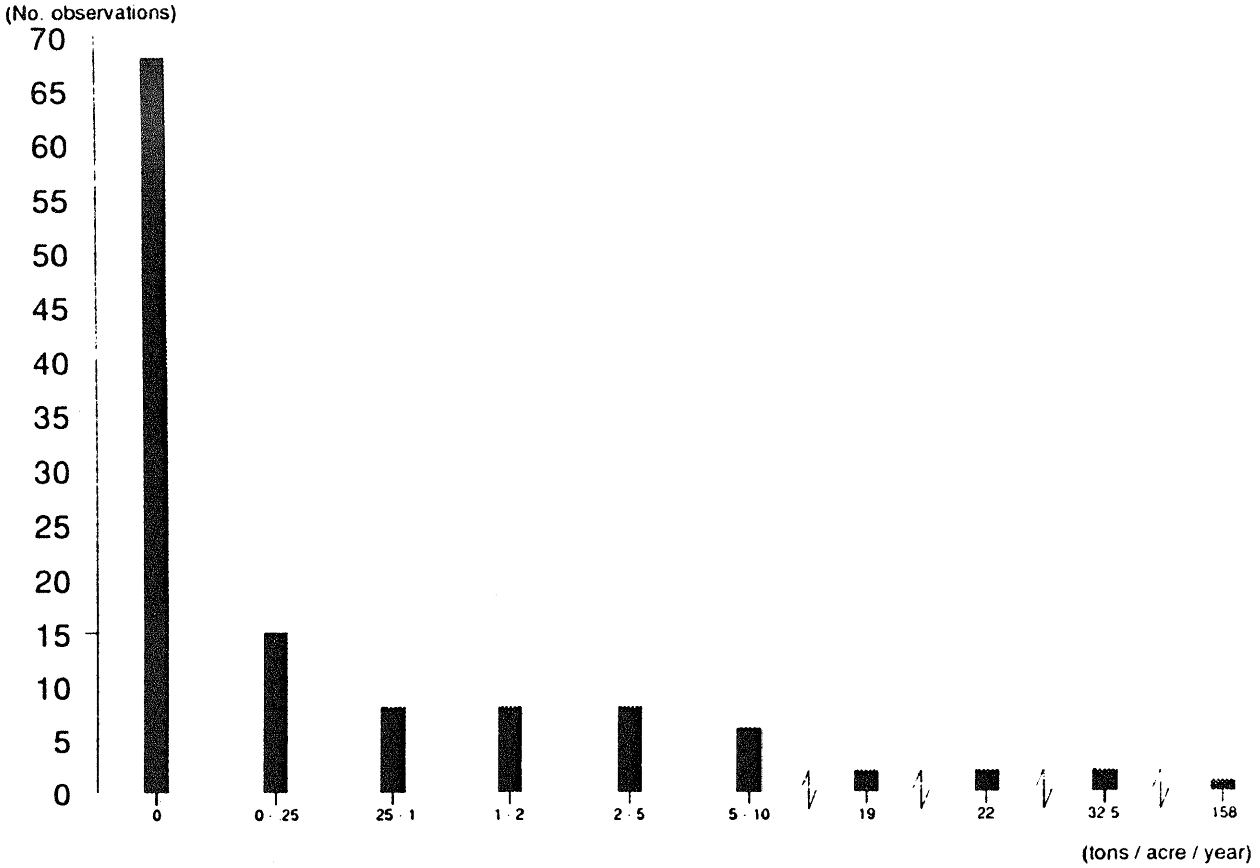

Figure 1. Frequency of potential soil movement estimates from the Universal Soil Loss Equation, based on estimates from 121 plots on Tract A.

Potential net soil loss (off-site sedimentation) was estimated for the entire tract using average values from plot data and a total tract parameter to estimate on-site storage. The results, shown in Figure 2, indicate that half of the tracts would lose less than 0.25 tons per acre during the first year after harvest. Only one of the tracts had an estimated loss of greater than 1 ton per acre per year. Tracts A through E were harvested using overland skidding methods, while F through J had systems of designated and bladed skid trail.

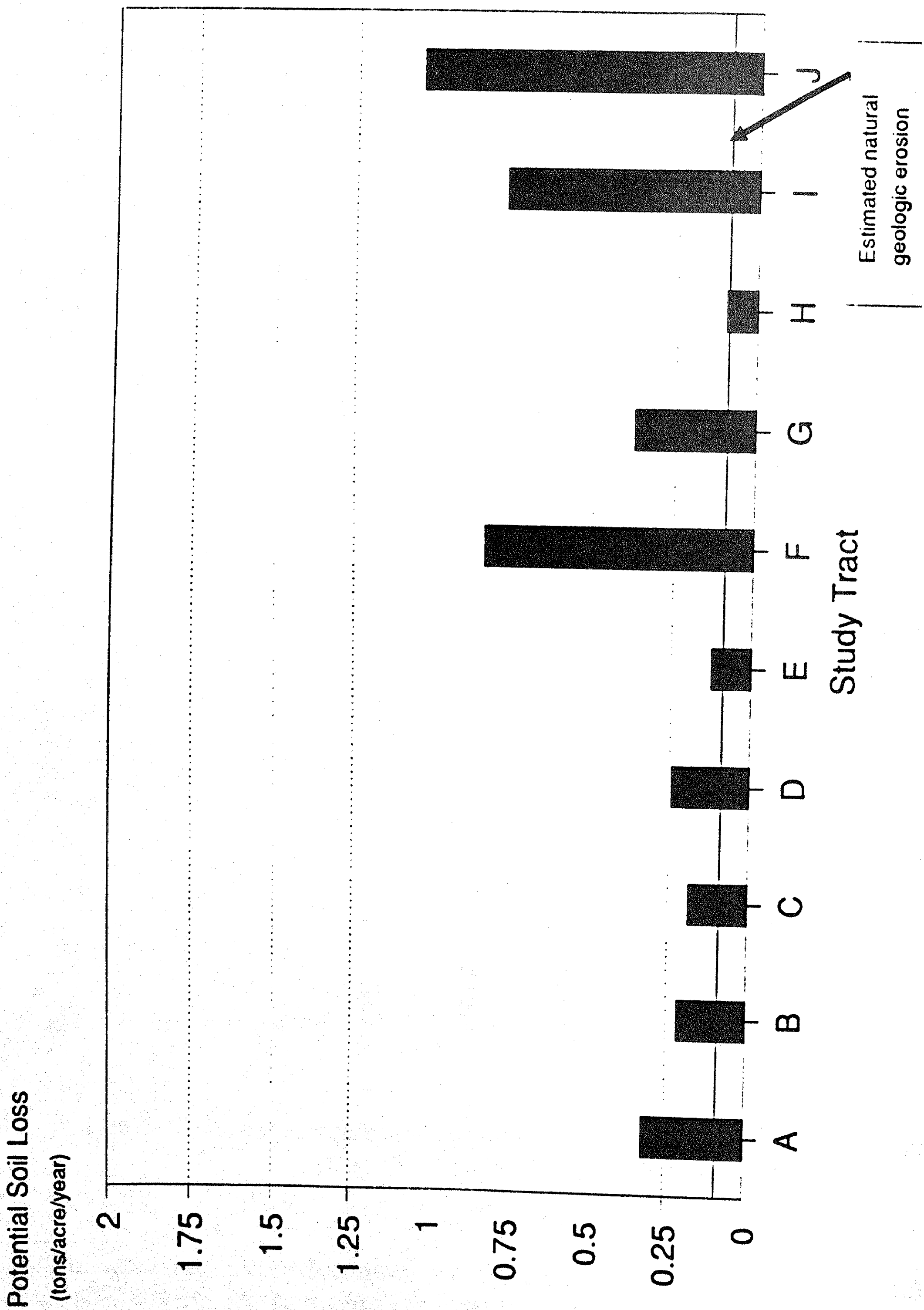

Figure 2. Potential soil loss estimates using the Universal Soil Loss Equation modifies for forested land.

Table 3 was developed by averaging the soil loss estimates for each of the sample plots to develop a tract average rate of soil movement. To demonstrate the importance of tract closure, the average was recalculated assuming the two and five highest risk plots were treated, reducing the movement risk to another zero. In most cases, treating the two highest risk sites reduced the average by 30 to 50 percent. Treating the five worst sites results in virtual elimination of soil movement on many of the tracts.

Table 3.--Potential soil movement estimates in terms of median, arithmetic average, and treated averages using field plot data.

Tract	Median	Arithmetic Average	*Added Closure Average	**Intensive Closure Average
A	0	3.37	2.10	1.49
B	0.04	2.86	2.21	1.90
C	0	0.41	0.27	0.14
D	0	0.37	0.27	0.12
E	0	0.21	0.12	0.05
F	O	1.08	0.83	0.58
G	O	2.94	2.01	1.06
H	O.01	1.17	0.60	0.42
I	O	1.01	0.66	0.45
J	O	1.17	0.26	0.04

* Arithmetic average assuming the two highest soil movement estimates equal zero.
** Arithmetic average assuming the five highest soil movement estimates equal zero.

SUBSOIL DISTURBANCE

Harvesting activities disturbed less than 30 percent of the tract area on all of the 10 tracts (Table 4). No differences could be found when overland skidding was compared with designated trails.

Table 4.--Comparison of undisturbed area (%) on tracts with overland skid trails and bladed skid trails using a rank sum test.

Tract	Percent Undisturbed Area Using Overland Skid Trails	Tract	Percent Undisturbed Area Using Bladed Skid Trails	Rank
D	71			1.0
		G	74	2.5
		H	74	2.5
		F	75	4.5
		J	75	4.5
B	79			6.5
C	79			6.5
		I	81	9.0
A	81			9.0
E	81			9.0
Total Ranks:	32		23	

Areas characterized by slight disturbance ranged from 11 to 15 percent on nine of the tracts (Table 5). One tract had a low of zero percent resulting from an extensive bladed trail system which reduced machine travel over the site. These values correspond with the findings of Miller and Sirois (1986), who estimated that 13% of the area of tracts they studied were left in this condition.

Six to 14 percent of the tracts' areas were left in a severely disturbed condition. Severe disturbance was most commonly associated with the construction of skid trails rather than skidder damage. Water-bars, haul roads, and landings were major contributors as well. A significant difference (alpha < 0.008) between skidding methods was found using the Wilcoxon Rank Sum Test (Table 6). Overland skidding resulted in less severe disturbance. The values shown for overload skidding include the disturbance associated with water bar construction. Excessive use of waterbars on overland trails (following BMP formulas) often resulted in greater risk of soil movement than if they had been omitted.

No significant differences were found in the percentage of the areas in the non-soil category, under debris piles or covered with depression deposit between skidding methods.

The percent of the tract area in skid trails did vary between skidding methods (Table 7). Overland skidding resulted in less skid trail area then using bladed trails (alpha = 0.075).

Table 5.--Comparison of slightly disturbed area (%) on tracts with overland skid trails and bladed skid trails using a rank sum test.

Tract	Percent Slightly Disturbed Area Using Overland Skid Trails	Tract	Percent Slightly Disturbed Area Using Bladed Skid Trails	Rank
		I	6	1.0
E	11			3.0
		F	11	3.0
		H	11	3.0
A	12			5.0
B	14			6.5
		G	14	6.5
C	15			9.0
D	15			9.0
		J	15	9.0
Total Ranks:	32.5		22.5	

Table 6.--Comparison of severely disturbed area (%) on tracts with overland skid trails and bladed skid trails using a rank sum test.

Tract	Percent severely disturbed area using overland skid trails	Tract	Percent severely disturbed area using bladed skid trails	Rank
B	6			1.5
C	6			1.5
A	7			3.0
E	8			4.0
D	10			5.5
		J	10	5.5
		G	12	7.0
		I	13	8.0
		F	14	9.5
		H	14	9.5
Total Ranks:	15.5		39.5	

Table 7.--Percent of total study tract surface area in noticeable skid trails.

Tract	Tract Percent in Overland Trails	Rank
A	4	2.5
B	3	1.0
C	9	8.5
D	6	5.5
E	4	2.5
		Total 20

Tract	Tract Percent in Bladed Trails	Rank
F	6	5.5
G	9	8.5
H	7	7.0
I	5	4.0
J	10	10.0
		Total 35

Compaction

The slightly disturbed/compacted class included from 1 to 5 percent of the tract areas. The resulting small sample size made it difficult to assign significances to these data. Values in italics in Table 8 are based on a sample size of less than 10. While no tests of significance were attempted, the absolute values indicate that the field crew's ability to identify compaction was good.

SUMMARY

Using conventional ground skidding systems left between 70 and 80 percent of the surface soil on the 10 tracts in an undisturbed condition. Six to 15 percent of the area had been slightly disturbed, a condition which would increase the risk of soil movement on the tract but not impact tree growth. Some compaction did occur within the slightly disturbed classification, but the amount (1 to 3 percent of the tract area) was too small to develop inferences concerning tree growth or water infiltration. Six to 14 percent of the tracts were left in a severely disturbed condition, usually as the result of construction skid trails, haul roads and landings.

Table 8.--Average change in mechanical strength (psi) between paired data samples of the undisturbed class and listed class.

Slightly disturbed class (Tract)	A	B	C	D	E	F	H	I	J
% of tract occupied by this class:	12	14	15	15	11	11	11	6	15
(Depth inches):									
1	-4	0	5	*13	-2	0	*30	*20*	6
2	11	1	1	*29	-2	-3	*33	*34*	7
3	14	4	-7	*39	4	2	*50	*39*	9
4	*24	11	-26	*40	12	-11	3	*67*	-5
5	*40	5	-28	*27	6	-11	25	*76*	-25
6	*59	2	-31	*26	-8	-7	28	*71*	-24

Slightly disturbed/compacted class (Tract)	A	B	C	D	E	F	H	I	J
% of tract occupied by this class:	2	2	2	5	2	1	1	1	3
(Depth inches):									
1	*35*	*13*	*104*	*63	15	*25*	*33*	*139*	*106*
2	*90*	*26*	*132*	*70	28	*48*	*54*	*146*	*131*
3	*138*	*47*	*145*	*84	18	*110*	*56*	*191*	*119*
4	*137*	*57*	*98*	*79	42	*52*	*15*	*173*	*99*
5	*135*	*63*	*89*	37	23	*68*	*3*	*169*	*71*
6	*140*	*70*	*68*	*57	16	*63*	*14*	*169*	*91*

* represents values significantly different at the 95% confidence level.
(00) had less than ten observations within the sample.

Skidding method had an effect on both the extent of severe disturbance and the potential off-site sedimentation. Overland skidding resulted in significantly less severe disturbance and generally less risk of off-site sedimentation.

Most of the risk of soil movements was associated with a relatively few, very vulnerable spots on each tract. Additional closure effort to reduce this vulnerability would have cut the average soil movement risk nearly in half.

CONCLUSIONS AND RECOMMENDATIONS

Conventional, ground-based harvesting systems can be used on slopes greater than 30 percent in the central Virginia highlands without significant risk to water quality or subsequent stand development. A reasonable degree of care and management is assumed.

High-risk areas -- those with fine-textured soils, poor drainage, and low rock content should be avoided during wet weather. Harvesting contractors should be allowed some flexibility in scheduling or contract life to reduce the urgency of cutting these tracts when the risk of damage to both the site and the equipment is greatest.

Tract boundaries should be laid out to favor overland skidding on slopes of less than 45 percent. On slopes greater than 45 percent, safety and common sense dictate the use of blade skid trails.

Tract closure is an especially important means of reducing erosion and sedimentation risk. A few very vulnerable spots accounted for a large share of the estimated soil movement and soil loss. Waterbars, if properly installed can be quite effective in reducing these risks; overuse can increase soil loss. Other techniques of slowing water flow rates on roads and trails which require less soil disturbance should be investigated. Alternatives include using logging debris, siltation barriers, paper machine felts, or other products entering the market.

Vegetation is the ultimate protector of the site. Leaving the site in a condition such that trees, grasses, shrubs and forbs can quickly reoccupy the tract is the best solution to minimizing runoff and sedimentation.

LITERATURE CITED

Dickerson, B. P. 1968. Logging disturbance on erosive sites in northern Mississippi. USDA For. Serv. Res. Note SO-72.

Dyrness, C. T. 1965. Soil surface conditions following tractor and high-lead logging in the Oregon Cascades. J. For. 63:272-275.

Froelich, H. A., D. E. Aulerich, and R. Curtis. 1981. Designing skid trail systems to reduce soil impacts from tractive logging machines. For. Res. Lab., Oregon State Univ., Res. Pap. 44.

Krag, R. K., and S. R. Webb. 1987. Caribou Lake logging trails: a study of three harvesting systems on steep slopes in the central interior of British Columbia. For. g. Res. Inst. Can., Tech. Rep. No. 76.

Mace, A. C., Jr. 1970. Soil compaction due to tree-length and full-tree skidding with rubber-tired skidder. Sci. Jour. Ser. Pap. No. 7226, Univ. of Minnesota Agric. Exp. Stn., St. Paul, MN.

Miller, J. H., and D. L. Sirois. 1986. Soil disturbance by skyline yarding vs. skidding in a loamy hill forest. Soil Sci. Soc. of Am. J. 50(6):1579-1583.

Reinhart, K. R., A. R. Eschner, and G. R. Trimble, Jr. 1963. Effect on stream flow of four forest practices in the mountains of West Virginia. USDA For. Serv. Res. Pap. NE-1.

Reisinger, T. W., G. L. Simmons, and P. E. Pope. 1988. The impact of timber harvesting on soil properties and seedling growth in the South. Sou. J. Appl. For. 12(1):58-67.

Wasterland, I. 1987. Machine forces that damage trees and ground in thinning operations. Proc. Harvesting Machines and Systems Evaluation Workshop. Research Notes 108, pp. 187-197. Swedish Univ. Agric. Sci.

Willis, J. R. 1971. A case study of the effects of articulated rubber-tired skidders on soil physical conditions in Greene County, Georgia. M.S. Thesis, Univ. of Georgia.