increased [illegible]ortance for the March, Ap [illegible]. May forecasts, while Road Creek, a low-altitude snow course, decreased in importance for the same forecast dates. While all data did not indicate the relationships this strongly, the overall picture revealed a stable relationship among snow course coefficients. Also, the sum of the snow course coefficients tended to become smaller as the beginning forecast date advanced, that is, the sum of the coefficients was larger for a March-July forecast than for a May-July forecast. This can be expected in a viable forecast equation since less area is covered by snow later in the year.

We used only snow-water content and runoff volume as parameters in this study. This does not preclude the introduction of other important hydrologic parameters since the residual errors produced by the optimization can be regressed against other parameters using normal statistical methods to further reduce forecast errors. The major disadvantage of the optimization procedure is the need to obtain water content data from all snow courses in a drainage basin.

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Impact of five postfire salvage logging systems on soils and vegetation

GLEN O. KLOCK

ABSTRACT—The impact of five traditional and advanced logging systems on soil surface disturbance, erosion, and understory vegetation was compared under postfire salvage conditions on the east slope of the Cascade Mountains. Traditional systems included tractor skidding over bare ground and cable skidding. Advanced systems included skyline, helicopter, and tractor skidding over snow. Traditional logging systems caused more severe soil surface disturbance and consequent erosion than advanced systems.

ALTHOUGH wildfire creates an ugly forest, it normally does not destroy the timber. Use of this wood is desirable. In the haste to salvage fire-killed trees, however, logging operations are often poorly designed. Environmentally sensitive areas that become the center of salvage activities require forest management practices that insure full environmental protection. One approach is to use logging systems that have minimum impact on the soil resource. New systems can significantly limit forest roads and reduce the soil erosion hazard.

For identification purposes, I defined two classes of timber harvest yarding systems: traditional and advanced. Traditional systems include tractor and cable skidding (jammer and some high-lead operations). Advanced systems include helicopter yarding and over-snow tractor skidding. Although skyline logging, where the log is lifted off the ground during yarding, has been used for a number of years (*13*), I classify it as advanced because of recent equipment developments.

My study compared the impact on soils and vegetation of these five postfire salvage timber harvest systems across the steep, unstable slopes of north central Washington. The results provide guidelines for forest managers who seek to maximize forest use with a minimum of environmental impact.

Study Area

During July and August 1970, more than 48,500 hectares of the Wenatchee National Forest in north central Washington were burned by lightning-caused fires (*11*). The burn included the Entiat Experimental Forest, a study area representative of much forested land east of the Washington Cascade Range Crest (*1*), and several adjacent watersheds.

My study area included two watersheds in the experimental forest, Burns and McCree, and the Brennegan watershed, which lies immediately east of the experimental forest. These watersheds cover about 485, 567, and 1,000 hectares, respectively. No roads had been constructed on the McCree or Burns watersheds before the fire. Main access roads had been constructed on Brennegan.

Helvey (*7*) and I (*8*) described the study area watersheds in the Entiat River Basin. Briefly, the area has a steep and rugged relief dissected by numerous tributary streams. Watershed elevations range from 550 meters to more than 2,100 meters at the headwaters. Mean slope is about 50 percent, but slopes of 90 percent are common. The base rock in the watersheds is a Mesozoic grandiorite, deeply weathered where exposed. Soils are formed from weathered granodiorite colluvium covered by volcanic ash and pumice. Soil depth ranges from a few inches to more than 6.1 meters. Vegetation types range from *Pinus ponderosa/Purshia/Agropyron* at lower elevations to *Pseudotsuga menziesii/Calamagrostis rubescens* at higher elevations.

The experimental forest was initially established to study the influence of vegetation manipulation on water yield and to test advanced skyline logging systems on steep slopes with low timber volume. Fire-oriented studies began after the fire. Logging plans were modified for a timber salvage sale.

The Study

The area of the study, part of which is shown in figure 1, included all of the Burns and McCree watersheds and the east-facing slope of Brennegan. Data also were obtained for skyline yarding on a small area of the west-facing slope of Brennegan that was logged in the late fall of 1972. The rest of the study area was logged during the winter and spring of 1972.

In the fall of 1970, all three watersheds were aerially seeded with a grass mixture to reduce erosion. The McCree and Burns watersheds were fertilized with 55 kilograms of nitrogen per hectare. The Brennegan watershed was not fertilized. Tiedemann and Klock (*15*) found essentially no difference in the total live vegetative cover, which averaged about 10 percent of the surface in 1971. The fire had destroyed all forest floor litter.

Five logging systems were used in the timber salvage: helicopter, tractor skidding over bare ground, tractor skidding over snow, cable skidding, and skyline (Wyssen skycrane). The cable skidding was a combination of jammer and high lead similar to the jammer system. Jammers typically skid logs by cable to a road or landing from a maximum reach of about 120 meters. The high-lead system was similar to the operation reported by Megahen and Kidd (*10*). This system, with its 23-meter tower, normally did not have enough deflection to adequately lift the log. Logs were skidded up to 240 meters, both uphill and downhill.

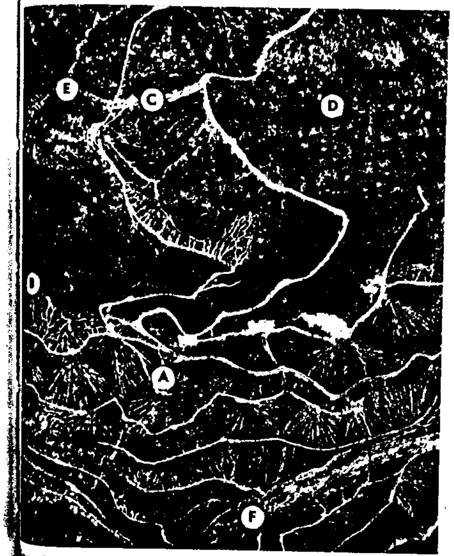
Table 1. Percent of study area harvested by each yarding system and number of sample plots within each individual area.

System	*Total Logged Area (%)*	*Number of Sample Plots*
Helicopter	48.8	1,336
Tractor skidding on snow	24.2	534
Tractor skidding on bare ground	4.0	279
Cable skidding	20.1	497
Skyline	2.9	255

Timber salvage on the Burns and McCree watersheds was designed for minimum impact on soils and vegetation while providing necessary access to research installations on the experimental forest. To achieve this objective, 15.3 kilometers of high-grade main haul road were constructed in 1971. Slopes less than 30 percent were logged with a tractor, slopes up to 40 percent by tractor skidding over a snowpack, and slopes over 30 percent (except 30-40 percent over snowpack) by an aerial method. The sale contractor used a helicopter for these slopes.

Tractor and cable skidding systems were used on the east face of the Brennegan watershed.

About 52,000 cubic meters of timber were harvested from the Burns-McCree sale and 45,000 cubic meters from the Brennegan sale. Material as small as 50 centimeters dbh was salvaged. Average volume per hectare was about 50 cubic meters (8,600 board feet per acre). Volumes of timber removed per acre varied with each harvest system, reflecting both the operator's selection practice and higher stand volumes in some locations, such as the valley floor. Generally, highest volumes per acre were removed by tractor and smallest by helicopter.



ure 1. Aerial view of soil disturbance on part of the study area. gging systems are cable skidding (A), tractor skidding over bare und (B), tractor skidding over snow (C), and helicopter yarding McCree Creek is shown at (E) and Brennegan Creek at (F).

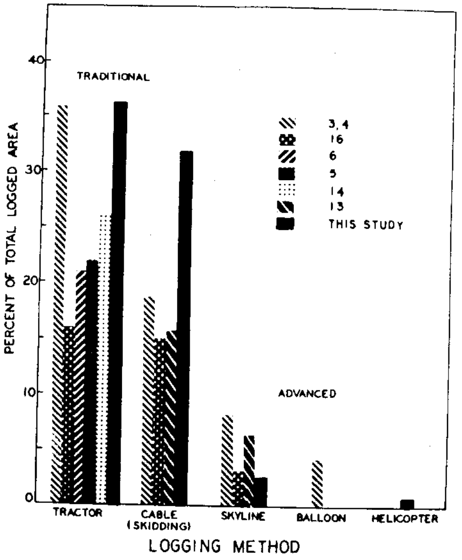


Figure 2. Severe soil surface disturbance measured for several logging methods by seven different studies in the western United States.

Glen O. Klock is a research soil scientist at the Pacific Northwest Forest and Range Experiment Station, Forest Service, U. S. Department of Agriculture, Wenatchee, Washington 98801.

During the peak of logging operations in March 1972, warm temperatures on a heavy snowpack created erosive conditions at elevations below 1,067 meters. Serious soil movement was observed, particularly in the area of roads. In the early morning hours of June 10, an intense rainstorm (about 7.6 centimeters of rainfall in 3 hours) struck the slopes of all three watersheds causing considerable sheet, gully, and channel erosion. A similar storm occurred on August 15.

Survey data were obtained in October 1972 on randomized plots measuring 0.37 square meter. Plot location was established by numbering 100-foot elevation contours from the bottom to the top of the area logged on each watershed and randomly selecting six contours from the more than 20 available. Randomized plots were located along each designated contour with an average distance between plots of about 13.7 meters. A plot frame defining the sample point was dropped immediately in front of the recorder after the preselected distance along each contour was traversed. Three recorders were used independently of each other on different contours.

At each plot, the method of timber harvest, extent of soil disturbance, evidence and cause of erosion, and type and amount of surface covered by vegetation were measured generally following the classification established by Dyrness (*2*). Soil disturbance levels were undisturbed (litter and topsoil still in place), slightly disturbed, and deeply disturbed (surface soil removed and subsoil exposed). Erosion levels were absent, erosion caused by natural overland flow, and erosion caused or associated with timber harvest activity. Vegetative ground cover levels were no cover, 1 to 25 percent cover, 26 to 50 percent cover, 51 to 75 percent cover, and 76 to 100 percent cover.

Table 2. Percent of the study area in total road prisms and landings.

Watershed	*System*	*Main Roads*	*Spur Roads*	*Landings*	*Total Area*[a]
		%			
Burns	Helicopter and tractor skidding	2.7	1.4	0.4[b]	4.1
McCree	Helicopter and tractor skidding	2.8	2.1	0.4[b]	4.9
Brennegan	Cable and tractor skidding	2.8	14.1	—	16.9

[a] Areas could be categorized as having severe soil surface disturbance.

[b] Helicopter unloading pads.

Table 3. Soil surface disturbance, evidence of erosion, and vegetation and slash cover for study area.

	Traditional Systems		*Advanced Systems*		
Class	*Tractor, Bare*	*Cable Skidding*	*Helicopter*	*Tractor, Snow*	*Skyline*
	% of total logged area				
Soil disturbance:					
Undisturbed	26.2	23.5	88.0	66.0	74.8
Slight disturbance	37.6	44.5	11.3	24.1	22.4
Severe disturbance	36.2	32.0	.7	9.9	2.8
Erosion:[a]					
Absent	61.5	55.7	70.8	76.3	[b]
Associated with fire alone	7.8	3.2	25.8	10.3	[b]
Associated with fire and logging	30.7	41.1	3.4	13.4	[b]
Vegetative ground cover:					
No cover	9.6	21.0	4.3	5.5	9.7
1- 25%	60.0	60.4	49.9	53.7	62.7
26- 50%	20.4	12.9	25.1	22.3	18.5
51- 75%	6.7	5.1	13.6	12.6	7.1
76-100%	3.3	.6	7.1	5.9	2.0

[a] Information given here indicates presence of erosion, not severity. Natural erosion on the helicopter-logged area is caused by overland flow on extremely steep slopes. The amount of downslope soil movement was minimal because site was not disturbed.

[b] Disturbance measurements were made immediately following logging, and the area had not been subjected to erosive conditions.

Table 1 shows the total number of survey plots and total area harvested by each system. Although I did not attempt to make the ratio of survey plots proportional to the area of operation for each technique, randomization of sampling plot location apparently gave a proportional coverage.

Table 2 shows the area in roads for each watershed as determined from aerial photographs. The 12 percent greater area in spur roads in the Brennegan watershed reflects the increased road requirements for cable skidding relative to other yarding systems.

Results and Discussion

The conservation feature of the advanced timber harvest systems compared with the traditional systems becomes apparent in the amount of soil disturbance and erosion associated with yarding. The advanced timber harvest systems left 88.0, 66.0, and 74.8 percent of the soil surface area undisturbed, compared with 26.2 and 23.5 percent for the traditional systems (Table 3). More significant is that severe disturbance was 0.7, 2.8, and 9.9 percent for the advanced systems, compared with 36.2 and 32.0 percent for the traditional methods.

Soil erosion was prevalent across the burned watersheds as a result of overland flow following the severe summer rainstorms in 1972. Because it was difficult to separate erosion that occurred naturally from that attributed directly to logging, I added a class for erosion associated with logging. This class was identified by gullies following skid trails and tractor tracks or general washing and rilling of soil disturbed or exposed by logging. The extent of soil surface affected by erosion associated with logging ranged from 5.4 percent for helicopter yarding to 41.1 per cent for cable skidding (Table 3).

Although degree of erosion was not measured, soil movement and consequent channel sedimentation in the logged area was much more severe than in the undisturbed area. Many times, particularly in the area where cable and tractor skidding over bare ground were used, plot recorders noted severe gullies and loss of soil. At some locations, gully depth reached bedrock (over 0.6 meter), and up to 3.8 centimeters of soil were eroded from large areas on these slopes. Further erosion could be expected.

Total vegetation cover on all harvest areas was similar except in the cable-skidded areas (Table 3). Here the areas with no vegetation were over 100 percent more frequent than in any other area. As mentioned, Tiedemann and Klock (*15*) found essentially no difference in the vegetative cover between the three watersheds. The lower level of living vegetation in the cable-skidded area thus had to be caused by this logging method. This removal of vegetation by the cable skidding presumably accounted for the area's greater erosion.

Comparison With Other Studies

A number of studies have been made on the amount of severe soil surface disturbance caused by various yarding systems. Figure 2 compares the results of this study with six similar studies following logging on areas not affected by fire in the Pacific Northwest.

The amount of severe soil surface disturbance by tractor yarding found in this study on the east slopes of the Cascade Mountains is similar to that found by Dyrness (*2*) on the west slopes. Although cable skidding was second to tractor skidding in severe soil disturbance, cable skidding is usually used on steeper ground, so erosion may be greater with cable skidding than with tractor. Severe soil surface disturbance by cable skidding was probably greater in this study because understory vegetation and forest floor litter destroyed by the fire was not present to protect the shallow, unstable soil from skidding logs.

Advance yarding systems appeared to cause minimal severe soil surface disturbance in all studies. Less than 10 percent of the area yarded by advanced logging systems had severe surface disturbance, compared with 16 to 36 percent for the traditional yarding techniques (Figure 2). Adding the area of roads necessary for some cable skidding operations could raise the total area of severe soil surface disturbances to more than 50 percent.

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Important dates to remember

May 19-20
Land Use Conference
Denver, Colorado
Contact: Land Use Conference, 1321 Bannock Street, Denver, Colorado 80204

May 20-29
Second United Nations Symposium on the Development and Use of Geothermal Resources
San Francisco, California
Contact: UN Geothermal Symposium, P. O. Box 7798, San Francisco, California 94120

June 1-5
Twenty-second National Watershed Congress
Portland, Oregon
Contact: David Unger, 1025 Vermont Avenue, N.W., Washington, D.C. 20005

June 3-5
Purdue University Symposium on Machine Processing of Remotely Sensed Data
West Lafayette, Indiana
Contact: Carl Jenks, Stewart Center, Purdue University, West Lafayette, Indiana 47906

June 5-8
Fourteenth Biennial Wilderness Conference
New York, New York
Contact: Earthcare, 777 United Nations Plaza, New York, New York 10017

June 8-13
First Earth Resources Survey Symposium
Houston, Texas
Contact: Industrial Economics Research Division, Texas A & M University, Box 83 FM, College Station, Texas 77843

June 9-10
Environmental Law Shortcourse
Madison, Wisconsin
Contact: Robert Smith, University of Wisconsin—Extension, 432 North Lake Street, Madison, Wisconsin 53706

June 11-13
Environmental Impact Analysis Seminar
Madison, Wisconsin
Contact: Robert Smith, University of Wisconsin—Extension, 432 North Lake Street, Madison, Wisconsin 53706

June 11-14
Fontana Conservation Roundup
Fontana Dam, North Carolina
Contact: Robert Sloan, Fontana Village, Fontana, North Carolina 28733

July 13-17
National Water Supply Improvement Association Third Annual Meeting
Key Largo, Florida
Contact: NWSIA, P. O. Box 8300, Fountain Valley, California 92708

August 10-13
Soil Conservation Society of America 30th Annual Meeting
San Antonio, Texas
Contact: SCSA, 7515 Northeast Ankeny Road, Ankeny, Iowa 50021