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C.T. Youngberg

Surface soil erosion is occurring on cutover forest lands in the Coast Range of Oregon. Although the contribution of fluvial erosion is generally limited, the extent of dry ravelling can be substantial. This sloughing of soil, organic material and rock on steep slopes, is apparently the dominant erosive force immediately following prescribed burning of clearcut lands in this region. Erosion averaging 224 m^3/ha was detected the first year following burns on steep slopes. Sixty-five percent of that yearly amount was displaced within 24 hours of the burn. Moderately sloping areas (<60%) on burned units displaced approximately one eighth (29 m^3/ha) the debris moved on steeper slopes in the year following burning. Upon removal of vegetation and litter through burning, the natural angle of repose for the soils studied appeared to be lowered to 60 percent; below that value debris displacement was limited. On unburned clearcut units the amount of debris displacement on slopes greater than sixty percent averaged 17 m^3/ha, which was one twelth of the surface erosion quantity found on similar burned plots. In undisturbed forested plots in similar topography, erosion was not detected.

The area contributing material to erosion catchment trough used in the study was relatively limited due to micro- and gross topographic variations and because of vegetative debris scattered across the slopes. The average distance of particle movement was found to be 5.4m on slopes over 60 percent and 1.1m on less steep slopes.

The information gained from this study was used to develop surface erosion predictive equations. Of the variables evaluated, percent vegetative cover at the time of sampling proved to be most important in explaining the variability in erosion. The amount of time since burning also is an important predictive variable. Slope, aspect, season, amount and intensity of precipitation, and the amount of slash contributing to high burn intensities and long durations all contribute to predicting surface erosion rates but to a lesser degree.

This study provides some indications of the quantity of debris being displaced following clearcutting and slash burning in mountainous terrain. The impact of this surface erosion on site productivity and stream sedimentation remains to be investigated.

EFFECTS OF SLASH BURNING ON SURFACE SOIL EROSION RATES IN THE OREGON COAST RANGE

by

KAREN ANN BENNETT

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Head of Department of Soil Science

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Dean of Graduate School

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INTRODUCTION

MANAGEMENT CONCERNS

In the past 10 years, mass soil movement has been emphasised as the primary erosion process occurring in the Coast Range. Mass soil movement includes a number of processes, i.e. debris avalanches, debris torrents, and slumps, all of which involve displacement of a large quantity of soil, often to considerable depths. Landslide scars and deposits are constant reminders to even the casual observer that mass soil movement is occurring and that the processes are often accelerated through management activities. The more subtle surface erosion processes that occur most rapidly when the surface is devoid of protective plant cover, i.e. following slash burning, can be overlooked. The amount of material transported by surface erosion may be excessive, yet there are seldom visible scars. Watershed management specialists of the Siuslaw National Forest have thus recently been concerned that the extent of surface erosion has not been considered adequately in evaluating the effects of management activities. 1/

1/ George Bush, personal communication.

Dry ravelling is a particular type of surface erosion that involves sloughing of soil, organic materials, and rock, on steep slopes during dry periods. Although dry ravelling occurs throughout the year, it is particularly enhanced by burning (DeBano et al., 1979). Burning often results in removal of the duff layer and loss of incorporated organic materials which bind soil aggregates. The resultant noncohesive soil is much less resistant to the forces of gravity acting upon it, and the rate of dry ravelling increases (DeBano et al., 1967). This increase can be measured during or immediately following a burn (Anderson et al., 1959; Krammes, 1960), yet dry ravel erosion is inconspicuous and often goes unnoticed.

Other types of suface erosion involve rain drop splash and the transport of soil and organic material by overland flow. Raindrops hitting soil surfaces that have been exposed by logging and burning can project individual soil particles down slope. Water moving over this bare and sometimes compacted soil surface cuts into the soil profile and carries sections of the surface soil down slope leaving behind rills or gullies. In Western Oregon, these surface erosion processes have been suspected to be largely associated with the relatively infrequent hard rains which pass through the area. The amount of soil displaced solely by these processes on steep mountainous areas of western Oregon has not been determined.

THE PROBLEM

Timber management is a high priority task on lands administered by public agencies in the Coast Range of western Oregon. A large portion of this land management responsibility lies in harvesting and reestablishing merchantable timber on the harvested sites. Prior to reforestation, the clearcut units are often burned, and it is this method of slash disposal that appears to accentuate surface erosion. Slash disposal on forest lands meets several objectives. First, slash removal is required by the Oregon Revised Statutes if it "exists in sufficient quantity to be a fire hazard and endanger life, property or adjacent lands" (Legislative Council Commission, 1979). Second, it is desirable from a reforestation standpoint to reduce slash loading for ease of planting and to reduce brush competition to maximize seedling survival (Stewart, 1978).

The lack of information available on surface erosion in the Coast Range and the suggested impacts of slash burning on surface erosion resulted in the development of this research project. The specific objectives of the research were:

1. To quantify the amount of surface erosion occurring on forested, clearcut, and clearcut-burned management areas;

2. To determine the composition of the surface eroded material and the distance it is being transported;

3. To evaluate the types of factors influencing the amount and timing of surface erosion.

The scope of the study was restricted to an examination of that erosion occuring within 20 months of management activities.

LITERATURE REVIEW

SLASH DISPOSAL

Slash disposal on forested land may be accomplished either by mechanical means or by burning (DeByle, 1976). One method of mechanical slash removal involves rolling or crushing debris to break up large chunks and render them more readily decomposible. This method, however, should only be employed on gently sloping (<35%) lands (Stewart, 1978). Another mechanical method involves yarding whole trees to a landing and piling the slash to one side. This slash can then either be chipped and redistributed on the slopes, hauled to a paper mill, or left for local fuelwood users.

Slash burning may be accomplished either by piling or broadcast burning. Broadcast burning is a desireable reforestation tool because it serves a number of purposes: reduction in plant competition; exposure of planting sites; rapid disposal of slash; and an initial increase in the availability of certain nutrients like nitrogen and phosphorus which are required for seedling establishment. However, the long term supply of these nutrients may be reduced by volatilization or leaching, during or after burning, and their depletion in the soil may cause reduced growth rates in the future (Austin and Baisinger, 1955). In addition to reducing soil nutrients, broadcast burning can accelerate surface erosion if the burn intensity is sufficient to expose bare mineral soil and degrade soil aggregation.

Piling and burning also opens up planting sites by reducing slash accumulation. However, undesirable soil compaction and scalping can occur by running tractors over the soil surface while clearing slash with a brush blade.

CONSEQUENCES OF HEAT

The method of burning affects the areal variation and magnitude of soil temperatures. Burning piled slash concentrates the heat in a few areas. Temperatures and depth of heat penetration in those areas are greatly increased (Humphreys and Lambert, 1965). Broadcast burning distributes the temperature increase over the entire unit, thereby reducing the heat build-up at any one spot. During broadcast burning low heat build up can also be promoted by burning downslope and hand lighting rather than using a drip torch suspended from a helicopter (DeBano, 1979).

Soil temperatures during burning determine the extent of soil damage resulting from a fire. Hosking (1938) found that at 100C - 200C non destructive distillation of volatile organic substances occurs. From 200C - 300C, 80 percent of the organic substances are removed by destructive distillation. At 300C ignition of carbonaceous residues begins, and at temperatures greater than 450C carbonaceous residues are completely consumed. Researchers report a reduction in surface soil organic materials of 40.0 to 75.5 percent depending on the severity of the burn (Dyrness et al., 1957, Austin and Baisinger, 1955).

In the process of altering organic materials in the soil during burning, certain chemicals may accumulate which affect the hydrologic response of the soil profile (DeBano and Rice, 1971). Percolation of water through the soil may be decreased by nonwettable layers which form after hydrophobic substances have volatilized during burning and migrated deeper into the soil profile where they condense. The condensation is due to large temperature gradients existing in the soil during burning.

The degree and extent of nonwettability varies with the intensity and duration of the burn and the texture of the underlying soil. Burning was found to increase water repellency in the 1-6 inch layer of a site in western Oregon (Dyrness, 1976). Under severe conditions the effect may penetrate 12 inches into the soil. Sandy soils have been found to be much more water repellent than silty and clayey soils under the same conditions (DeBano and Rice, 1971). The larger particle sizes are evidently coated more thoroughly by hydrophobic agents.

DeBano et al. (1967) suggested that there is a lower bulk density in nonwettable soils. This results in less dense packing of these soils and subsequently, dry ravelling occurs due to the loss of friction between particles. On slopes approaching the angle of repose this decreased resistance to surface movement may lower the slope angle at which dry ravelling occurs.

Infiltration rate, too, is affected by burning. Several investigators (Striffler and Mogren, 1971; Fuller et al., 1955; Neal et al., 1965; Tackle, 1962) reported a decrease in infiltration rates. Ferrell and Olson (1952) and Pillsbury (1953) reported that burning had no effect on infiltration rates. Scotter (1963) reported an increase in infiltration due to burning. Some of these differences may be explained by the variation in soil moisture at the time of sampling and/or the method of measuring infiltration. For example, Roundy et al. (1978) reported a decrease in infiltration when the soil was at field capacity and no change when the soil was dry. Reduced infiltration of water into a soil can lead to increased overland flow and surface soil erosion.

Several soil physical properties are also changed due to excessive heating of the soil during burning. Fusion of clay occurs following the removal of the water of hydration from between clay miceles ultimately resulting in coarser textured soils (Dyrness et al., 1957). Puri and Asghar (1940) report that this fusion increases aggregate stability to a point which aggregates cannot be disintegrated by ordinary methods of dispersion. Other researchers (Debano, 1979; Fuller et al., 1955) concluded that aggregate stability decreased due to burning. Consequently, desirable soil structure was not maintained contributing to the lower resistance of surface soils to the forces of erosion which may act upon them.

Several methods of monitoring soil temperatures have been employed. Maximum soil temperatures may be recorded by burying glass tubes containing organic compounds of known melting or fusion points (Beadle, 1940), or by burying ceramic tiles painted with temperature sensitive paints (Cromer and Vines, 1966). Each of these methods has its advantages and limitations. Air in the glass tubes may prove to have an insultating effect on the temperatures reaching the organic compounds. The sensitivity of the paint may not be sufficient for accurate records (Cromer and Vines, 1966). Neither give true readings due to short durations of temperature increases (Uggla, 1974). Both methods, however, provide an indication of relative soil temperatures obtained during fires.

The duration of the excessive heat within the soil should be measured because this significantly affects the degree of change in soil properties. Sophisticated thermocouple or thermoelectric pyrometer instrumentation may be used to determine continous temperatures and durations at specific soil depths (Cromer and Vines, 1966). However, this equipment may be limited for use in forested areas due to distance from meter to thermocouple installation.

Several researchers have investigated maximum soil temperature at various depths during burns (DeBano et al., 1979; Humphreys and Lambert, 1965; Isaac and Hopkins, 1937; Cromer and Vines, 1966). Most found that the heat from broadcast burning penetrated the soil to a depth of 5-8cm. Cromer and Vines (1966) however, indicated that under a burning pile, temperatures increase to a depth of 30cm.

Tarrant (1956) defines three classes of burn intensity: unburned, light burn, and severe burn. Sampling of 10 clearcut and burned areas throughout the Douglas-fir region showed that an average of 47 percent of the clearcut area was unburned, 47 percent was lightly burned, leaving a charred surface, and 3 percent was severely burned, producing a highly oxidized, baked soil surface. The remaining 3 percent of the area was exposed rock outcrop. It is important to consider the degree of burning in weighing the effects of slash burning on soil properties. Dyrness and Youngberg (1957) determined that severe burning was the only treatment that had any significant effects upon changes in the soil physical properties studied.

The intensity and duration of a burn is not the same in any two areas. Several factors are responsible for the variability of temperatures in the soil. Fuel loading, the amount, size, and the compactness of the slash, is used in calculating fire intensities and duration (Humphreys and Lambert, 1965). Fire weather and fuel moisture however, largely determine the extent of fuel consumption and the subsequent intensity and duration of the burn. Ideal fire weather, that which would produce the least damaging soil temperatures, occurs at times of low relative humidity, low ambient air temperatures, low wind speeds, and when soil moisture conditions are high (DeBano, 1979).

The most important variable determining soil temperature increase at a specific depth is the soil moisture status (DeBano et al., 1979). The higher the water content in a soil, the lower the thermal diffusivity and the higher the thermal capacity. When water is present in the soil, the temperature at any particular depth does not exceed 100C until water has evaporated or moved to a lower layer. Soil physical properties also add to the variability of heat transfer in soils. Coarse textured soils have a higher thermal diffusivity. Therefore, heat can be transmitted to greater depths in a shorter period of time (Boyer and Dell, 1980).

RECOGNIZING SURFACE SOIL EROSION

The research cited above indicates the potential for several destructive effects resulting from slash burning. Many of the effects, such as loss of organic material, reduction of infiltration capacity, and the increase in nonwettability of the soil, can work together to accentuate the rate of surface erosion. Several other factors have been found to contribute to soil erosion processes. The percent vegetative cover is an extremely important variable - as percent vegetation increases, surface soil erosion decreases (Mersereau and Dyrness, 1972). Slope aspect also influences the quantity of erosion. Debris production is greater on south slopes than on similar north slopes, sometimes by as much as 16 times (Mersereau and Dyrness, 1972; Krammes, 1960; Anderson et al., 1959).

In mountainous lands, steep slopes often exceed the natural angle of repose. If vegetation is established, the soil remains intact. Upon removal of the vegetative support, however, soil is lost by both mass wasting and surface erosion processes. The amount of soil lost increases as slope gradient increases. In unburned clearcut units, Anderson et al. (1959) showed that 90 percent slopes yielded greater erosion rates than slopes of 70 percent. DeBano et al. (1979) found much greater erosion rates on 50 percent slopes than on 20 percent slopes. Hendricks and Johnson (1944) and Mersereau and Dyrness (1972) found that in burned clearcut areas, slopes greater than 70 percent exhibited higher erosion rates than slopes less than 60 percent. It appears here that the critical slope angle for high erosion rates is lowered possibly due to the removal of vegetation (Franklin and Rothacher, 1962) and below that gradient erosion rates are fairly constant.

Recognizing the indicators of surface erosion helps us understand the forces involved. Rills and gullies are obvious end products of fluvial erosion. Less subtle indicators include pedestals caused by raindrop splash, stilt-like roots or soil pavement, which remain after sheet erosion has occurred. On burned areas, unscorched collars on shrub stems - and exposed unscorched rock faces may indicate fluvial erosion.

The formation of dust clouds is a clear indicator of wind erosion. The evidence of soil pavement could also indicate removal of fines by wind. Windrowed soil and gravel and drifts of soil in road cuts are other indicators of wind erosion. Again, on burned areas unscorched roots, stems and rock faces may indicate wind erosion.

Gravity is a force which is often overlooked when evaluating erosive factors. Most obvious are the cones of sliding ravel that appear on slopes and in stream channels. Once again unscorched surfaces and stilt-like roots may be evident after soil is removed by gravitational erosion.

QUANTIFYING SURFACE SOIL EROSION

Recognition that surface erosion is ocurring leads naturally to attempts to quantify it. Several methods of measuring soil loss or displacement have been investigated (Gleason, 1953). One method involves a grid system of erosion pins which are monitored periodically. This method indicates a depth of soil loss from one area and the height of accumulation in another. The method is most useful for evaluating a maximum and minimum height, and is less effective in evaluating the ongoing processes. Another method employs collection troughs placed on or below slopes. Defining the area contributing to the trough may be a problem with this method. A third method utilizes tracers or radioactive particles sprayed on the soil surface to monitor rates and distances of soil movement. This method may aid in defining the contributing area in the collection trough method.

Surface soil erosion rates in areas which have been clearcut - but not burned range from .2 T/A/yr to 3.6 T/A/yr in California (Anderson et al., 1959) and up to 8 T/A/yr in Germany (Delfs et al., 1958). Natural erosion rates in these areas were not reported.

Erosion rates in burned clearcuts are usually higher than in unburned clearcuts. Debano (1979) found that 3.15 T/A/yr of material eroded the first year following prescribed burning compared to only 0.09 T/A/yr on similar unburned watersheds. Erosion rates in the clearcut-burned areas of the Oregon Coast Range within the first year of the burn have been found to vary from 113 T/A to 289 T/A/in 9 months following burning (Sartz, 1953). On the other hand, Biswell and Schultz (1957) saw no indication of surface runoff or erosion following prescribed burning in California.

Dry ravelling may be a prominent erosion process during and immediately after a burn. Values of 43 percent (Krammes, 1965) to 89 percent (Krammes, 1960) of the total first year erosion have been reported as dry ravel moved within a short period after burning.

STUDY DESIGN

THE ENVIRONMENT

The following study was carried out in the Coast Range of western Oregon, specifically on the Siuslaw National Forest within an area extending from Florence to Hebo and inland to Alsea (Figure 1).

Soils and Geology

The majority of the study area is underlain by the Flournoy Sandstone Formation (Table 1). This is a sequence of rhythmically bedded micaceous and arkosic sandstone and sandy siltstone units of middle Eocene age (Baldwin, 1976). Soils on Flournoy Sandstone are shallow on ridges and steep, moderately dissected sideslopes, to deep on toeslopes, terraces, and hummocky sideslopes. The surface horizons range from clay loam to gravelly loam (Badura et al., 1974; USDA, 1973).

A portion of the study area occurs on the Yachats Basalt formation. This formation includes subaerial porphyritic basalt, basaltic andesite, and rare dacite flows typically 3m to 6m thick (Baldwin, 1970). Soils from Yachats Basalts are shallow to moderately deep and form on steep, moderately dissected slopes. The surface soils have a loam texture (Badura et al., 1974; USDA, 1973).

The northern part of the study area occurs on the Nestucca Formation. This formation consists primarily of interbedded tuffaceous shaly siltstone and claystone, and feldspathic and basaltic sandstone

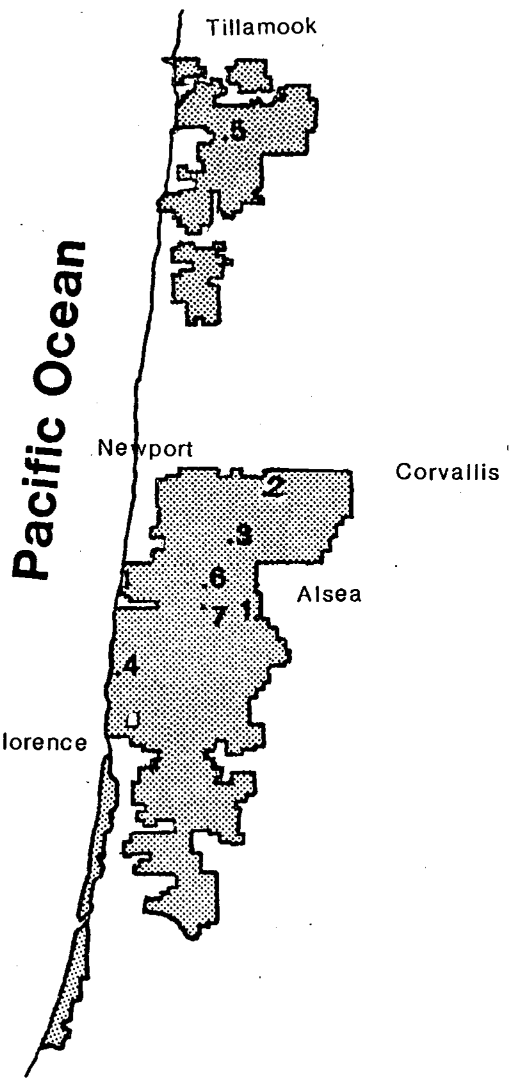

Figure 1. Map of research area indicating site locations

(Baldwin, 1976). Soils derived from this bedrock are shallow on smooth to moderately dissected slopes. The surface soils a have a loam to silt loam texture (Badura et al., 1974; USDA, 1973).

Vegetation

The dominent tree canopy, is Douglas-fir (*Pseudotsuga menziesii*) with western hemlock (*Tsuga heterophylla*), western redcedar (*Thuga plicata*), and red alder (*Alnus rubra*), as minor components (Table 2). The understory composition is variable, and determined by amount of moisture. Plant communities of vine maple (*Acer circinatum*) - salal (*Gaultheria shallon*), vine maple - sword fern (*Polystichum munitum*), or salmonberry (*Rubus spectabilis*) - sword fern dominated the understory in the study area (USDA, 1973).

Climate

The study area has a marine climate that is typical of the coastal area of Oregon. Winters are cool and wet, and summers are warm and dry. Inland ridges at elevations of 300m to 900m are the wettest. During the winter, considerable cloudiness and frequent rains occur as the moist air moving in from the ocean rises and cools. From October through May, more than 90 percent of the 200cm to 305cm of precipitation received in this area falls as rain. Daily precipitation of 6.4cm and monthly totals of 64cm are common during December and January, but hourly intensities are usually low. Snow makes up only a small part of this total and generally is not persistent (USDA, 1973). Winds generally are

Table 1: Soil, Land Type, and Geology of Selected Study Sites.

Site Name	USFS SRI Mapping Unit	SCS Soil Series	Geologic Formation
Minister Skyline	41	Bohannon	Flournoy
Chinquapin Feagles	41	Bohannon	Flournoy
Randall Savage	41	Bohannon	Flournoy
Heceta 426	54	Formader-Hembre-Klickitat Complex	Yachats
Basalt			
Gauldy Woods	51	Astoria-Hembre Association	Nestucca
Ryan Forested	41	Bohannon	Flournoy
Ryan Crab	41/43	Slickrock	Flournoy

Table 2: Stand characteristics of study sites prior to harvest.

	ORIGINAL STAND CHARACTERISTICS				
Site Name	DBH (Inches)	AGE (Years)	VOLUME (MBF/A)	COMPOSITION	Year of Harvest
Minister Skyline	27	130	95	Doug-fir Red alder	1979
Chinquapin Feagles	21	120	71	Doug-fir	1979
Randall Savage	19	110	82	Doug-fir	1979
Heceta 426	- information not available			-	1979
Gauldy Woods	23	60	30	Red alder, Doug-fir	1979
Ryan Forested	21	120	70	Doug-fir	N/A
Ryan Crab	21	120	70	Doug-fir, Red alder	1980

from the southwest, but easterly winds occur during late summer and early fall.

SITE SELECTION

Five study sites were selected from Siuslaw National Forest timber sale areas. The selection criteria for those sites were that the area had been clearcut and was to be burned during 1979 or 1980. In addition, one study site was selected which had been clearcut but would not be burned and another area was selected which was in a naturally forested condition. These sites are shown in Figure 1, their legal locations are given in Table 3.

Within each study site numerous small plots were located for installation of erosion monitoring equipment. Plots were randomly selected from those available on slopes of less than 50 percent, 50 to 70 percent and greater than 70 percent, and on upper, middle and lower or stream adjacent slope positions. Specific slope and land form data for each plot are given in Table 4.

FIELD MONITORING OF EROSION

Metal troughs were used to monitor erosion on the study sites. Each trough was constructed of 24-gauge galvanized steel sheet metal cut in .61m strips, 1.22m long and bent in the middle at 90 degrees. Three of these units were screwed together in the field. The sides consisted of 22-gauge galvanized steel sheet metal pieces which were cut into right triangles with the ends flanged for added strength. The final product was a trough 1.83m long (Figure 2).

Table 3: Legal location and vegetative management status of selected sites.

Unit Name	Legal Location	Vegetative Status
1. Minister Skyline	SE1/4NW1/4 Sec. 24 T.15S., R.9W	c/c - burned
2. Chinquapin Feagles	SE1/4NW1/4 Sec. 17 T.12S., R.8W.	c/c - burned
3. Randall Savage	SE1/4SE1/4 Sec. 27 T.12S., R.9W.	c/c - burned
4. Heceta 426	NW1/4NE1/4 and NE1/4NW1/4 Sec. 5, T.17S., R.11W.	c/c - burned
5. Gauldy Woods	NE1/4SW1/4 Sec. 31, T.4S., R.9W.	clearcut
6. Ryan Forested	S1/2NW1/4 Sec. 24 T.15S., R.10W.	forested
7. Ryan Crab	S1/2SW1/4 Sec. 13 T.15S., R.10W. N1/2NW1/4 Sec. 24 T.15S., R.10W.	c/c - burned

Table 4: Topographic Characteristics of Selected Plots

Site Name	Plot #	Percent Slope	Slope Position
Minister Skyline	1	80	M
	9	112	U
Chinquapin Feagles	2	84	U
	3	78	M
	4	78	L
	10	88	L
Randal Savage	5	96	U
Heceta 426	6	78	M
	7	76	M
Ryan Crab	OA3	46	U
	OB4	22	U
	OB5	36	U
	OC6	35	U
	OC7	35	M
	OD1	50	M
	OD3	36	U
	XA10	55	M
	XA17	60	M
	XB17	86	U
	XB25	78	M
	XC1	76	M
	XC4	78	U
	XD3	65	M
	XD7	60	U
	A2	112	U
	A9	88	L
	B5	82	M
	B6	90	L
	C2	122	U
	C5	88	L
	D1	100	L
	D2	92	M
Gauldy Woods	11	90	L
	12	105	L
	13	84	L
	14	100	L
	15	82	L
	16	112	L
	17	70	U
Ryan Woods	20	55	M
	21	66	M
	22	82	U
	23	84	U
	24	42	M
	25	46	M

Figure 2. Field installation of erosion trough.

Each trough was installed prior to burning by clearing an area 1.83m across the slope and .61m up and down the slope using a pulaski and/or sand-vik. A shallow depression .63cm deep was then excavated so that the trough fit snugly on the hillside and was not raised by roots or organic debris below it. Metal posts were driven into the slope to support the back of the box.

After installation of the erosion catchment trough, the following site parameters were recorded: an occular estimate of the amount of preburn slash (see "Predictive Models" for further explanation); percent slope; slope position; aspect; and an occular estimate of percent live vegetation providing surface area protection.

Broadcast burning was carried out on five of the units (Table 5). The slash fires were ignited by hand lighting the top unit border and lighting the rest of the unit by helicopter.

Temperatures generated by the burn were measured at each plot in two of the burned sites by installing clay wedges streaked with strips of Tempilaq^{O}, a temperature-sensitive paint. The wedges were installed one foot upslope from the middle panel of the trough. Each wedge was pushed into the ground to a depth of 12.7cm with 2.5cm remaining above the ground surface. Disturbance of the soil was consciously kept to a minimum to avoid formation of a tiny envelope of air around the clay wedge which might have conducted the heat at much higher rates than that of the soil media.

Table 5: Burn Information of Selected Sites.

Site Name	Unit Size (acres)	Vol. Preburn Slash (T/A)	Date Burned	Burn Weather Information Air. Temp. (°F)	Humidity (%)	Windspeed (mph)
Minister Skyline	73	75	8/14/79	75	40	5
Chinquapin Feagles	47	16	9/8/80	70	40	6
Randall Savage	34	56	8/20/79	80	40	8
Heceta 426	200	*	9/24/79	*	*	*
Gauldy Woods			- unburned -			
Ryan Forested			- unburned -			
Ryan Crab	167	65	8/22/80	72	40	4

*Information not available.

As soon as possible after burning, the contributing area of each plot was determined by placing several bands of different colored glass beads, having a density of 2.6 gm/cc, across the slope above the trough. The lateral boundary of bead placement was determined by walking toward the trough at several elevations above and to the side of it while displacing material downslope. When the displaced material neared the outside edge of the trough, a flag was implanted and that point was assumed to be the lateral boundary. At times, it was possible to use natural barriers such as logs, berms, and/or slope breaks to mark the boundary of the contributing area. Microtopographic variations in slope configurations were not accounted for, although they may affect soil movement.

Bead movement was monitored by noting their presence in the collection trough. At the end of the sampling period, the slope distance from the box to the location of the farthest colored band which contributed beads to the box was determined. This distance was converted to horizontal distance using percent slope. The angle which corresponded to the lateral boundary on each side of the box was determined. With these three measurements, the contributing area was calculated using trigometric functions.

All burned plots were sampled the day after the burn. Some were sampled at weekly intervals for the first month thereafter. Monthly samples were collected at each plot for the remaining nineteen months of study. Estimates of percent vegetation remaining or reestablishing following the burn were made on each sampling date.

The volume of soil collected in each trough was determined with a calibrated bucket. Stones, rocks, and recognizeable organic debris like cones, leaves, and twigs greater than 76.2mm were removed from the trough before volume measurements were taken.

LABORATORY MEASUREMENTS

Subsamples of the total debris volume were taken for laboratory determination of percent organic materials, percent coarse mineral fragments, and particle size analysis of the fine fraction (<2mm).

Laboratory analyses were completed by the OSU Physical Characterization Laboratory. Samples were oven dried for 24 hours at 60C to remove moisture while maintaining the organic composition of the sample. After dividing the samples for replicate analysis and weighing, the samples were passed through a 2mm sieve and the coarse (>2mm) and fine (<2mm) fraction separated. The coarse organics were then separated from the coarse inorganic fraction by floating off the organics. Percent by weight of the total for each fraction was recorded. Fine organics were separated from the mineral fraction by taking a random 4g sample from the sifted sample and igniting it in a muffle furnace at 343C for six hours. This process removed fine organic materials; the weight of the remaining sample represented only the fine mineral component. Percent of fine organics was extrapolated to represent the entire sample and recorded.

STATISTICAL APPROACH

Several statistical techniques were used to analyze the data. Frequency distributions of erosion rates were plotted as histogram. Monthly average erosion rates were calculated and plotted as a function of time. Scatter plots of erosion rate versus the independent variables of slope, burn treatment, percent vegetation, preburn slash, aspect, precipitation, time, and season. These graphs suggested that plots of the natural log of erosion rate versus each independent variable would be virtually linear. A predictive model of erosion rates was then constructed using these variables and their interactions, but after elimination of multicollinearity (Neter and Wasserman, 1974).

RESULTS AND DISCUSSION

The material referred to as "debris" in the following sections is the material collected in the erosion catchment troughs and is composed of:

1. an organic fraction - this includes organic materials less than 76.2mm in diameter divided into coarse (>2mm) and fine (<2mm) organics;

2. a mineral fraction - inorganic materials less than 76.2 mm in diameter divided into coarse (>2mm) and fine (≤2mm) material.

MANAGEMENT INFLUENCES AND EROSION

Erosion in naturally forested areas was not detected (Figure 3). However, much organic debris greater than 76.2mm in diameter accumulated in the erosion catchment troughs from litter fall and possible lateral movement. Van Zon (1980) studied erosion in forested areas of Luxembourg and found that soil particles may become attached to organic material through splash erosion and by the action of burrowing animals. In this way soil was transported down slope at a rate of 1.2mm/1000yrs. The amount of exposed soil in the forested area studied here was not determined and transportation by these processes does not appear to be a significant factor in such undisturbed Pacific Northwest forests.

During clearcutting activities, the amount of soil disturbance is variable depending on such factors as the yarding system employed, soil type, slope, and percent vegetation. If soil is exposed, the opportunity for soil erosion is enhanced. This is documented by the erosion rates obtained in the clearcut unburned units (Figure 3). On areas where slash was accumulated and some of the natural shrubs and

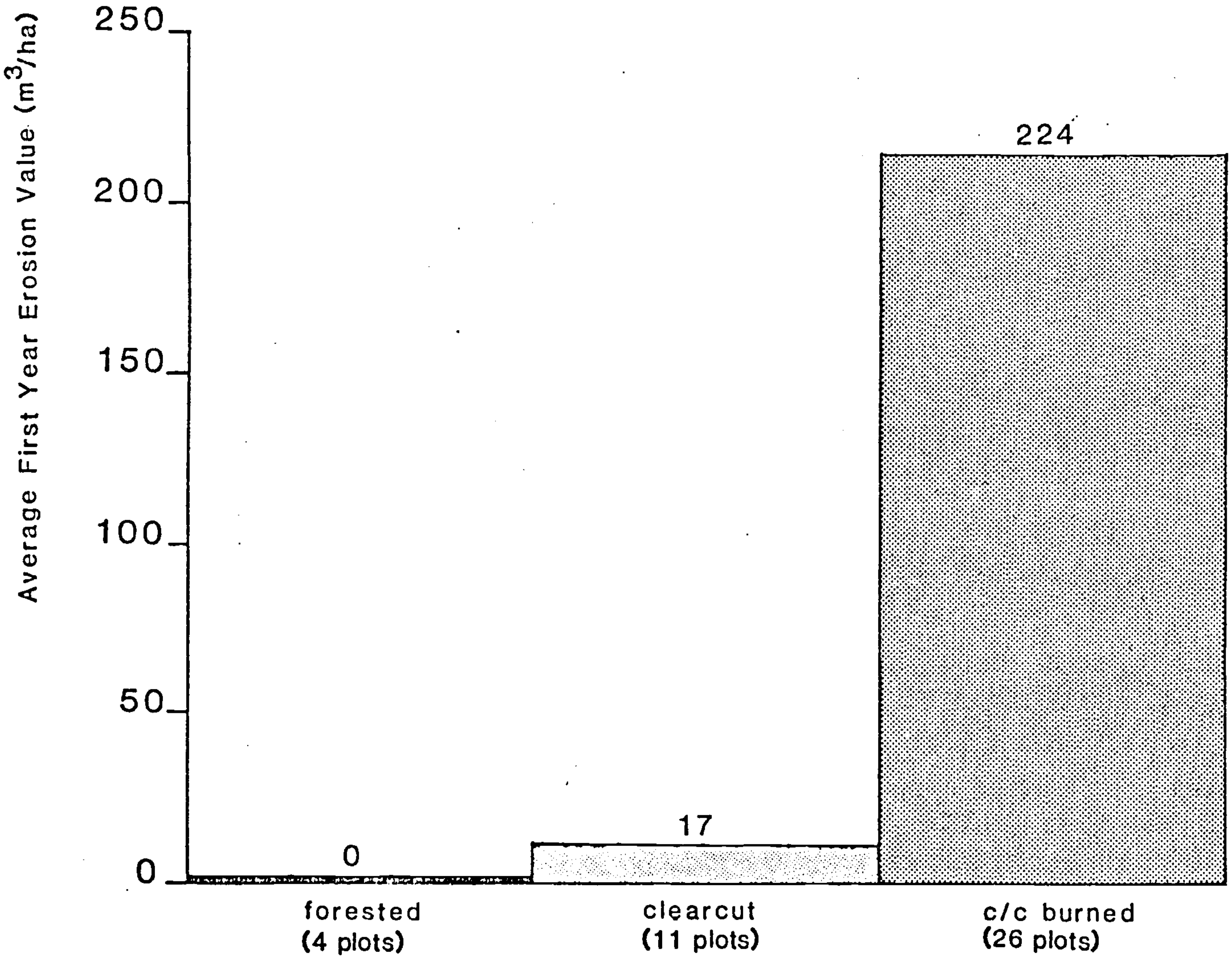

Figure 3. Comparison of average first year erosion values and vegetative management practices

ferns remained intact, the first annual erosion rates amounted to an average of $5m^3$/ha. Movement in these areas occurred mostly during the wet winter season.

Two processes may contribute to these erosion rates. Visual observation of pedestal formation indicated splash erosion was occurring. The amount of erosion directly attributable to this process, however, was not determined. Needle ice formation was also observed. This erosion process results in downslope displacement of the elevated soil particles. The latter process is not traditionally thought to be a part of surface erosion in the Coast Range, due to the mild maritime climate. Winter temperatures do reach freezing in the mountains, and the moist conditions, especially on stream adjacent slopes, provide ideal conditions for the formation of needle ice. Again, the amount due to this type of erosion was not determined. Evidence of overland flow such as rills and/or stilt-like roots, was not detected in the unburned clearcut plots.

One trough was installed on a compacted skyline yarding trail. The amount of erosion from this area greatly exceeded other areas of the unburned clearcut amounting to 133 m^3/ha for the first year. Most of this erosion came in November and January, suggesting a fluvial system of debris production, but the exact processes were not determined, and without replication, it is difficult to evaluate further.

Including the above trough, in determination of average surface soil erosion rates on clearcut unburned plots, the average erosion for the first year is $17m^3$/ha. This is a high average for the plots studies but compacted skyline yarding trails and other exposed areas are present in clearcuts and the erosion from such areas should be accounted for.

The major debris production occurred on clearcut and burned plots (Figure 3). Erosion rates from burned plots on slopes of 22 to 60 percent were significantly less ($p<.01$) than rates on slopes greater than 60 percent. Slopes less than or equal to 60 percent eroded at an average rate of 29m^3/ha the first year. Slopes with a gradient greater than 60 percent produced an average erosion rate of 224 m^3/ha the first year (Table 6).

Figure 4 shows that the frequency distribution of erosion rates on burned units is skewed to the right. In a case such as this, the median would more properly represent the central tendency of the erosion rate. Confidence limits in this case are developed around the median. For slopes greater than 60 percent we can be 95 percent sure that the first year median erosion rate falls between 85 m^3/ha and 221 m^3/ha. On slopes less than or equal to 60 percent the median erosion rate for the first year probably falls between 13 m^3/ha and 41 m^3/ha.

Although displacement of such large quantities of debris was observed, it is useful to look at the relative quantity of each debris component. The data in Figure 5 suggests that most of the debris from the steep slopes is coarse mineral fragments. Should this material reach a water course, these fragments could be transported in the stream as bedload and supply a source of gravel for spawning beds or be broken down into fine mineral fragments. The proportion of very fine mineral and organic material eroded is low, however, there could be a reduction in site

Table 6: Monthly Average Erosion Values (m^3/ha) for clearcut burned plots.

Month	<60% Slope	% of first year Total	>60% Slope	% of first year Total	% of 20 month Total
1 (Collected within 24 hrs of burn)	10	35	147	65	64
2	0	0	12	5	5
3	2	7	17	8	7
4	2	7	9	4	4
5	9	31	11	5	5
6	1	3	4	2	2
7	1	3	8	4	3
8	3	10	12	5	5
9			-	-	-
10			4	2	2
11			0	0	0
12					
First Year Total	29*		224		97
13			-		-
14			1		.5
15			0		0
16			3		1
17			2		1
18			0		0
19			0		0
20			1		.5
20 Month Total			231		

*This figure is the projected erosion value for the first year based on rates for slopes less than or equal to 60 percent.

- missing data

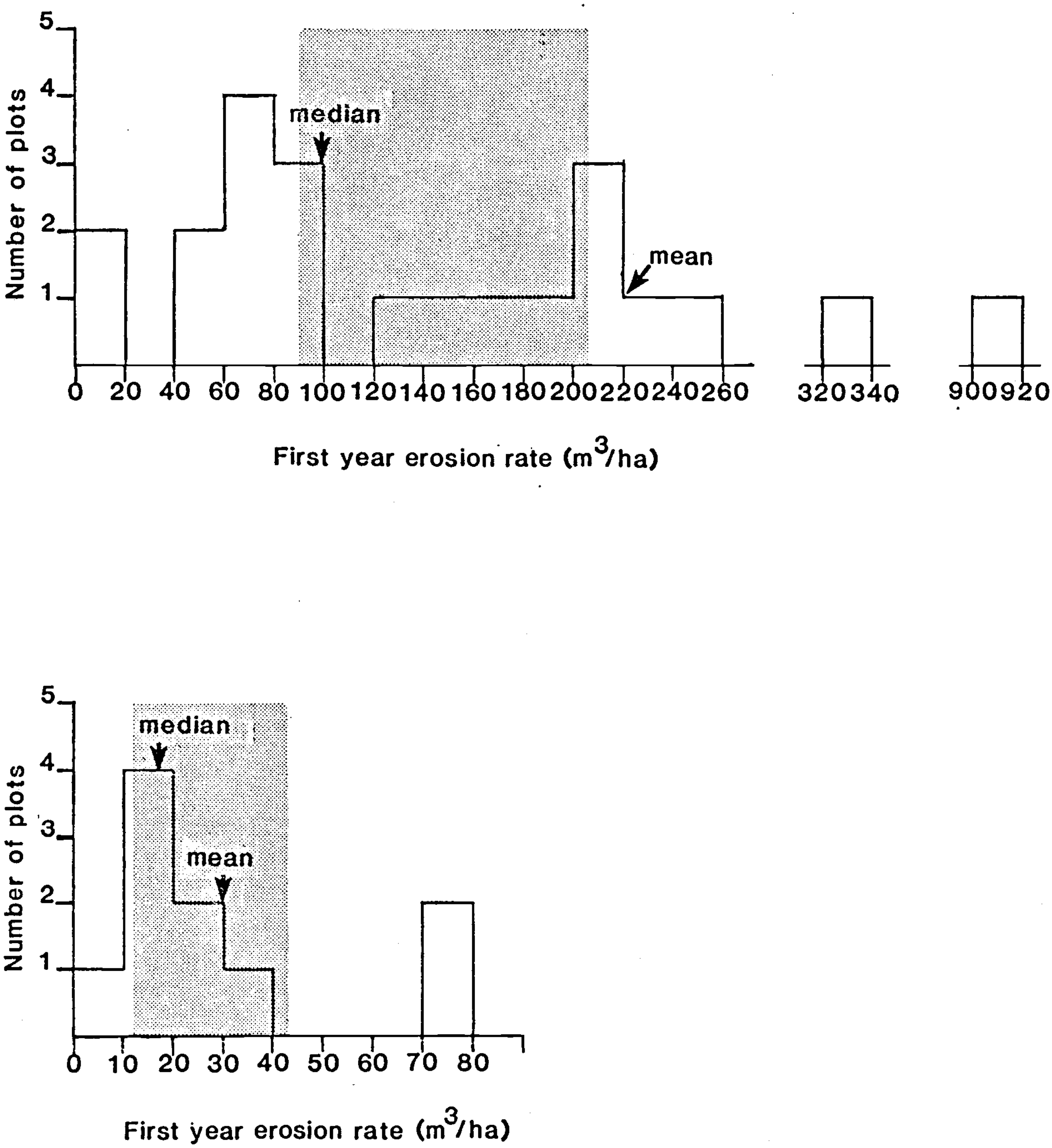

Figure 4. Frequency histogram of first year erosion rates on burned plots, slopes >60 percent (top) slopes ≤60 percent (bottom). Confidence limits indicated by shaded area.

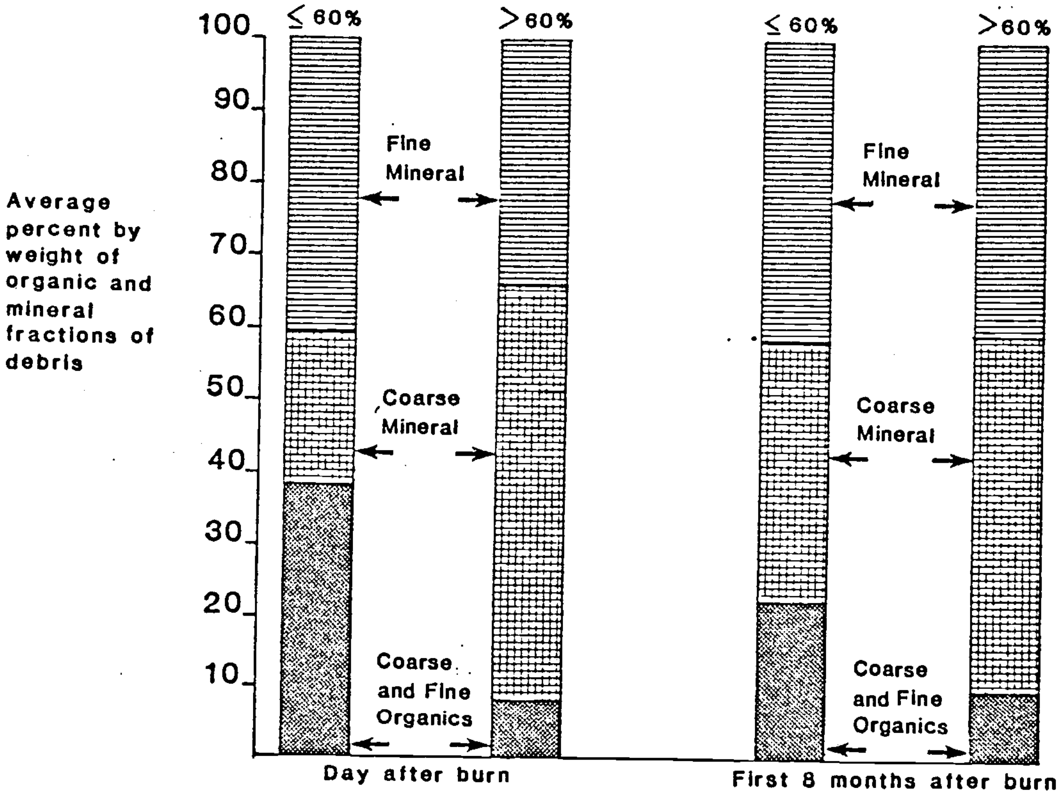

Figure 5. Composition of eroded debris from burned plots.

productivity. Cation exchange sites, important for nutrient exchange, on clays and on organic materials, are being displaced and/or lost. This is especially important on steep slopes where the less highly developed soils are initially low in these constituents. Should these materials reach a water course, they would be transported as suspended sediment, settling out at low flows and possibly clogging pores in gravel bars rendering them unsuitable for spawning areas.

The Initial Flush

Within 24 hours of burning the clearcut areas, a large amount of debris moved into the catchment troughs (Table 6). This initial flush accounted for an average of 65 percent of the total first year erosion rate on slopes greater than 60 percent. On slopes less than or equal to 60 percent an average of 35 percent of the first year erosion rate is produced within a day of the burn.

Dry ravelling is believed to be the major process involved in debris movement during this period. Fire resulted in reduction of the duff layer to less than .32cm and charred the remaining organics producing a blackened surface. In some areas the duff was completely removed and the soil was baked, resulting in a highly oxidized surface. Mineral soil in most of the burned areas, however, appeared to be in the former condition. Although the entire duff layer was not removed, heat did penetrate into the surface soil (Table 7). According to Hosking (1938) heat of the magnitude reached in plots during burning, is capable of distilling volatile organic compounds and sending them lower in the soil profile where they condense. The resultant surface soil is a dry,

Table 7: Depth (cm) of heat penetration into soil at various temperatures.

% Slope	Slope Position	93	149	205	260	371	538	Total First Year Erosion m^3/ha
		Temperature (Celsius)						
122	Upper	?	3.0	2.3	0.9	S	S	229
112	Upper	?	2.0	S	S			320
110	Lower	?	4.0	3.0	1.6	2.7	2.0	74
92	Mid	?	3.6	2.2	S	S	S	192
90	Lower	1.0	S	S				80
88	Lower	S	S	S				200
86	Upper	?	8.5	3.5	S	S	S	213
84	Upper	3.0	2.3	S	S			17
82	Mid	?	2.2	1.1	S	S	S	918
78	Mid	S	S	S				82
78	Mid	2.5	2.5	2.0	1.3			65
78	Lower	2.5	2.5	2.0				58
76	Mid	?	3.5	1.3	S	S		86
60	Upper	?	5.1	5.0	S			71
55	Mid	?	6.0	3.5	S	S	S	23
50	Mid	S	S	S	S			10
46	Upper	?	1.5	0.2				16
36	Upper	?	5.2	5.5				19
36	Upper	?	4.0	1.5	0.6	S		10
35	Upper	S	S	S	S			18
35	Mid	?	4.0	3.0	S	S	S	21
22	Upper	S	S					31

? = The temperature sensitive paint was removed apparently by moisture in the soil.
S = Temperatures of this magnitude were reached at the soil surface but did not appear to penetrate into the soil.

unconsolidated mass which is evidently subject to the forces of gravity which aids in transporting individual particles downslope. Another mechanism which may be involved in this initial flush of debris is the winds created by the fire. These winds often have enough force to move logs and other slash which results in dry ravelling through mobilization of stored material or by initiating a small avalanche.

If this initial movement of material could be eliminated or reduced, the contribution of dry ravelling to surface erosion might be negligible. On steep slopes (over 60 percent) another 5 percent of the erosion during the first year occurs prior to the onset of the wet season. Movement of this debris could be caused by wind or gravity. The exact mechanism was not determined. The additional movement did not occur on slopes less than 60 percent. Apparently, there is insufficient downslope gravitational force on the lower slope gradients to move debris without the added effect of wind and slash movement.

SUBSEQUENT MOVEMENT

The remaining 30 percent of the first year erosion on slopes greater than 60 percent occurred during the wet season while 65 percent occurred during this period on slopes less than 60 percent (Figure 6). Several conditions were observed which indicated the processes active in initiating debris movement on these slopes during this period.

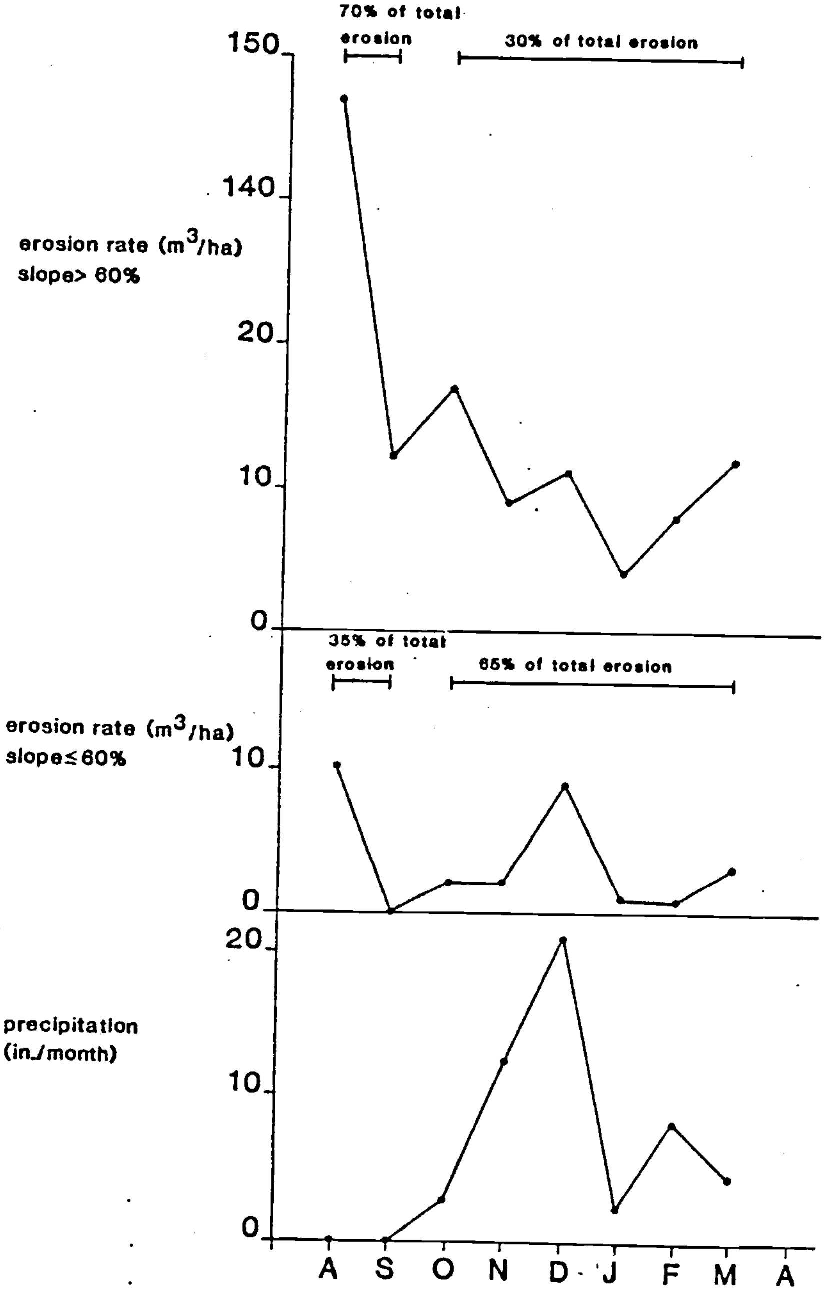

Figure 6. Erosion rates in burned plots and monthly precipitation values.

The lack of sampling immediately prior to and following precipitation events makes it impossible to distinguish the quantity of debris contributed by the various processes. Fluvial erosion certainly must have occurred as evidenced by the observation of rills and pedestals. It was observed that wind initiated sliding of debris by dislodging gravels which triggered an avalanching effect. These ravel slides were also observed to be occuring in the absence of wind, at which time gravity must have been the dominant force. Movement of unconsumed slash initiated dry ravel slides, and further contributed to the displacement of debris. A study by Krammes and Osborn (1969) in southern California indicated that at least one third, and perhaps as much as three-quarters of the wet season erosion was actually occurring as dry ravel between rainstorms.

The composition of debris transported during the year varied with slope class. Debris transported on slopes greater than 60 percent contained more coarse fragments than on gentler slopes (Figure 7). These fragments represented from 41 to 68 percent by weight of the eroded material. The content of coarse fragments in the eroded sample peaked first in September and again in January and February. The percentage of coarse fragments in the material eroded from slopes less than or equal to 60 percent demonstrated a similar pattern of transport although the percent by weight in the sample was lower. At the lower slope gradients coarse fragments occupied 21 to 53 percent by weight of the eroded material.

The percent of organic materials in the eroded debris showed a different pattern. More organics were collected in samples obtained from slopes

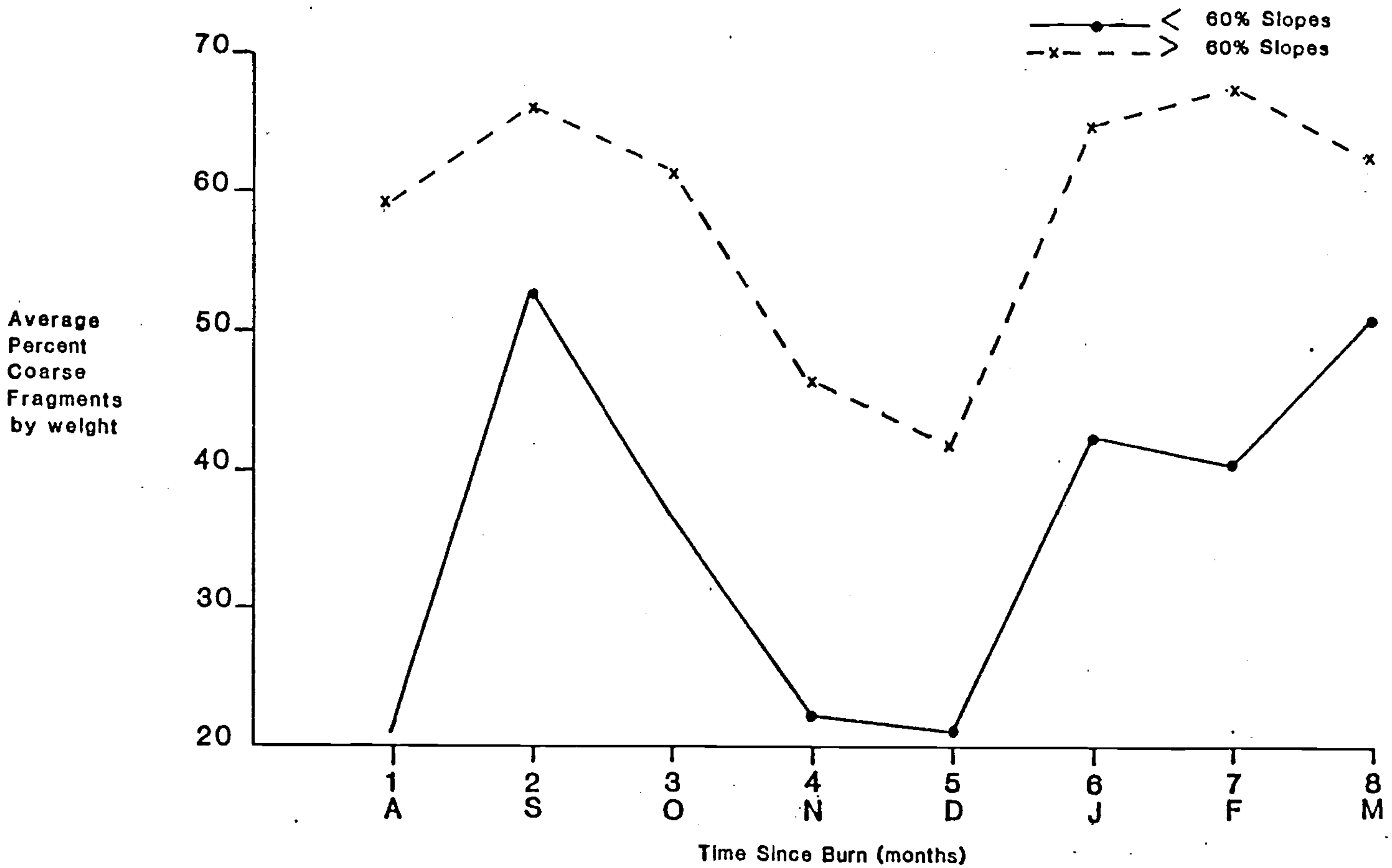

Figure 7. Percent Coarse Fragments in eroded debris versus time since burn.

less than or equal to 60 percent. The concentration of organic materials in the debris eroded from these slopes was high (37%) following the initial burn with a relatively constant drop over time except for one peak in December. On these slopes organic debris composed 14 to 37 percent by weight of the transported material. On slopes greater than 60 percent only 6 to 12 percent by weight of the transported material was organic. The concentration of organic materials on these slopes was relatively constant over time, the low level indicative of the inherent soil composition (Figure 8).

Ninty-five percent of the erosion found in 20 months of study occurred during the first 8 months (Figure 9). Rice (1974) found that 70 percent of the long term sediment moved on chaparral watersheds occurs during the first year after fire. He determined that most of the increase in sediment after that time is from remobilization of existing erosion deposits, not from erosion of new areas.

Contributing Area

Total distance of debris movement is limited. Colored glass beads, used to trace movement, travelled from 0.3m to 15.2m, depending on slope steepness (Table 8).

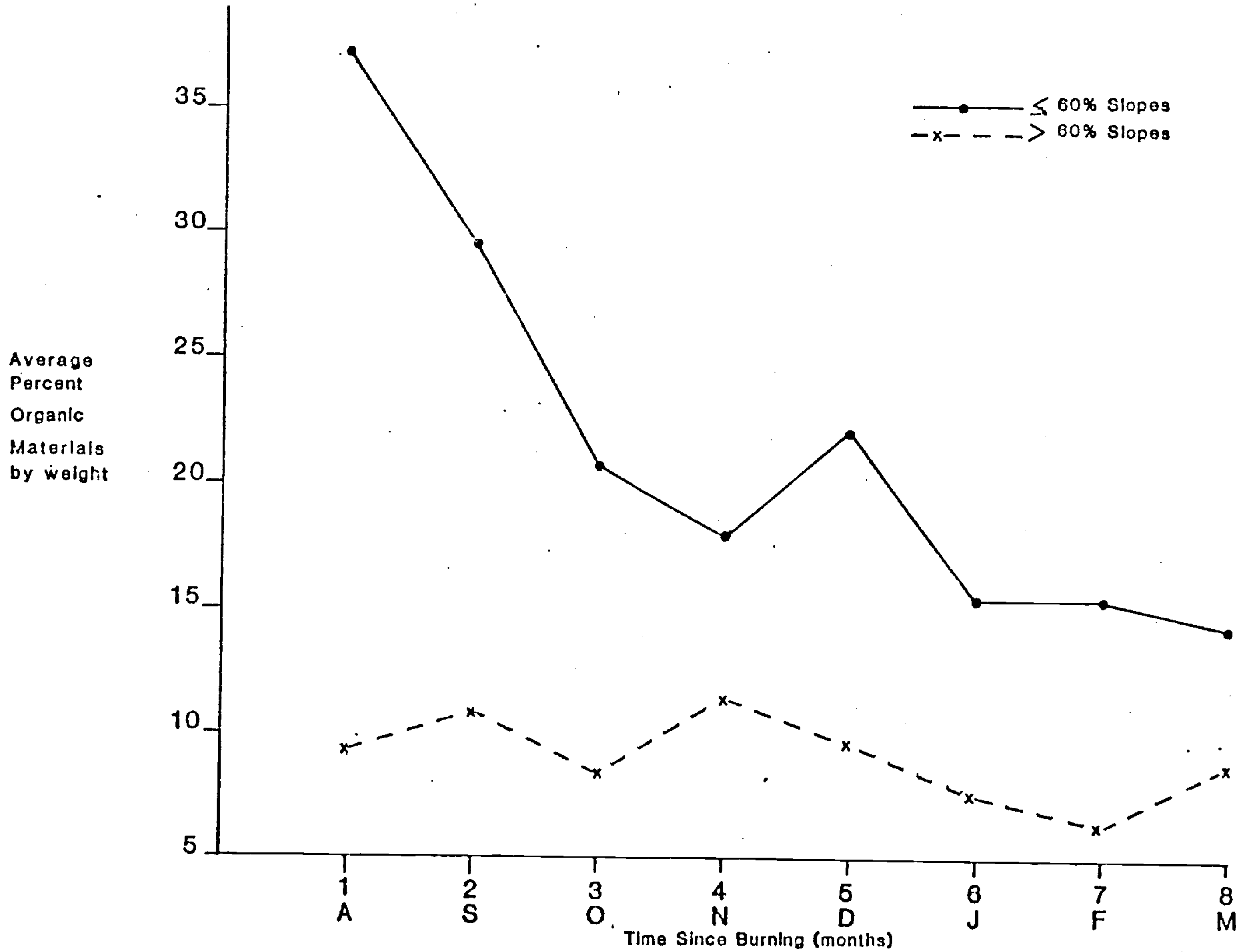

Figure 8. Percent Organic Materials in eroded debris versus time since burn.

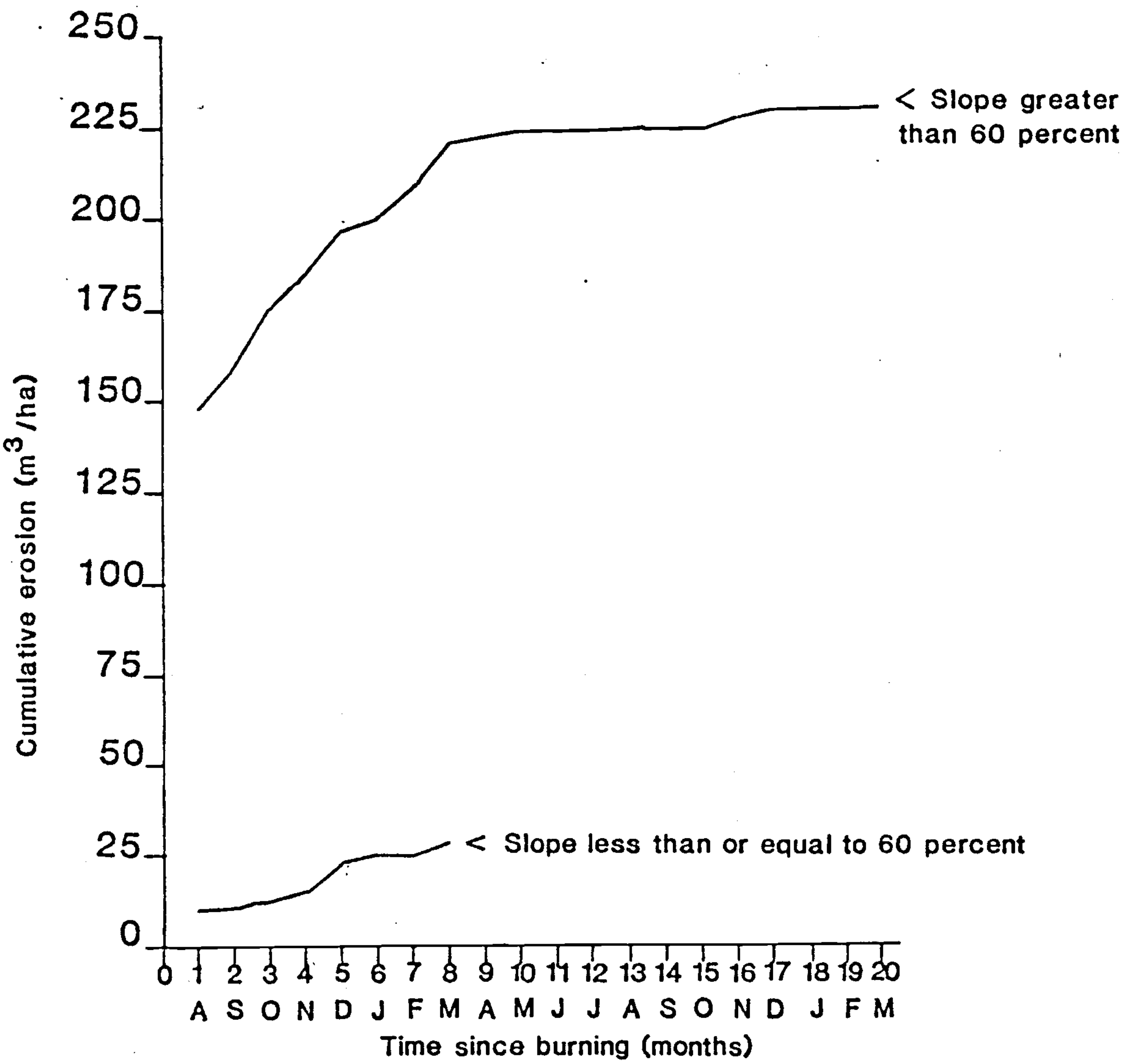

Figure 9. Cumulative erosion rates versus time since burning

Table 8: Distance of glass bead movement on burned plots.

% Slope	n	Distance Moved (m) Min.	Max.	Mean	Mode
≤60	10	0.3	2.4	1.1	0.9
>60	22	1.0	15.2	5.4	4.6

The maximum distance of bead movement at each plot over the entire period of sampling was used to convert the erosion rates to a per hectare basis. This could underestimate the amount of erosion occurring per acre clearcut and burned. Time was a critical factor in describing contributing area. During initial erosion events, when the majority of the erosion occurred, the eroded debris appeared to be moving from very short distances upslope. As time went on, the contributing area grew, while percent of total eroded material greatly decreased. Averaging the total amount of eroded material over the largest observed contributing area does not take into account the decreasing amount of erosion occurring on each additional portion of contributing area.

Another method of reporting erosion rates is to report cm^3/m of slope width (or trough opening). This value would eliminate the ambiguity inherent in identifying the contributing area. Both methods of reporting are used here (Table 9). The latter because it displays the actual volume collected and the former because it is a best estimate attempt to define the displacement on an area basis and because it is more meaningful to resource managers.

Table 9: Total volume of debris collected per meter of trough opening and projected volume displaced per hectare on varied vegetative management plots.*

Unit Name	Management Status	cm^3/m of Trough Opening	m^3/ Hectare	Length of Sampling
Minister Skyline				20 mos.
1	c/c - burned	44208	70.90	
9		191643	126.52	
Chinquapin Feagles				12 mos.
2	c/c - no burn	23572	132.30	
3		725	2.04	
4		3319	7.45	
10		4464	10.45	
2	c/c - burned	3096	17.38	8 mos.
3		23106	64.86	
4		25844	58.03	
10		28025	65.81	
Randall Savage				20 mos.
5	c/c - burned	27569	53.82	
Heceta 426				20 mos.
6	c/c - burned	16759	10.89	
7		104736	85.50	
Gauldy Woods				12 mos.
11	c/c - no burn	286	4.28	
12		140	4.90	
13		372	5.61	
14		276	4.13	
15		271	4.06	
16		419	6.29	
17		669	4.26	

Table 9 (Continued)

Ryan Crab				8 mos.
OA3	c/c - burned	1396	15.68	
OB4		2041	30.65	
OB5		1677	18.85	
OC6		3938	17.67	
OC7		475	21.32	
OD1		1068	9.56	
OD3		685	10.26	
XA10		4337	27.78	
XA17		4735	70.99	
XB17		18982	213.07	
XB25		33184	82.52	
XC1		37430	210.08	
XC4		33745	151.53	
XD3		21900	245.84	
XD7		4735	70.99	
A2		113848	319.52	
A9		58898	176.30	
B5		224886	918.04	
B6		30396	80.29	
C2		102108	229.26	
C5		111370	200.06	
D1		74625	74.51	
D2		107185	192.53	

* in both instances, factors for forested plots are zero.

Predictive Equations

A model was developed to predict erosion rates in each of three management alternatives.

Full model - A predictive equation for any area, regardless of previous management activities.

Clearcut/noburn model - a predictive equation for areas which have been clearcut.

Burn model - a predictive equation for areas which have been clearcut and burned.

Only one half of the experimental data was used to develop the predictive equation. This made it possible to test the equation on the remaining half of the data. A partial F test, significant at $p<.01$, determined the value of the equation in predicting erosion.

The following is a list of the variables used in the predictive equations. A short explanation of the numerical entry in the model is included.

Erosion (LN(E)) - determined as the natural log of erosion, in m^3/ha on a monthly basis.

Slope (SP) - the exact percentage, entered without a decimal point.

Burn (B) - enter 1 if burned, 0 if not burned.

Percent Vegetation (V) - an occular estimate of surface area protected by live vegetation, enter without a decimal point.

Preburn Slash (SL) - enter 1 for light, 2 for medium, and 3 for heavy.

Light: less than 25 percent of the unit covered with slash - mostly debris less than 3 inches, few logs over 9 inches.

Moderate: 25 to 50 percent of area covered with slash mostly 3 to 9 inches, few logs over 9 inches.

Heavy: over 50 percent of area covered with slash all sizes included, many logs over 9 inches.

Aspect (A) - the compass was divided into four sections dependent upon equal amount of insolation on the slopes (Frank and Lee, 1966).

Enter 1 for azimuth clockwise from 315° to 45°

Enter 2 for azimuth 45° to 90° and 315° to 270°

Enter 3 for azimuth 90° to 135° and 270° to 225°

Enter 4 for azimuth clockwise from 135° to 225°

Time (T) - entered as the natural log of the number of months since burning occurred plus .01 with the first sample (being the day after the burn) as month 1. Assume that in forested and clearcut areas, it has been 1560 months since the area was burned. This corresponds to the large forest fires which swept the Coast Range in the 1850's.

Precipitation - was divided into five sections. Data was obtained from the National Weather Service rain gage nearest each site. The first section included the number of days of zero precipitation (Z). Sections two through four were separated based on 24-hour intensities. These classes included: number of days of light precipitation (L) which was less than 1.7 inches/day; number of days of moderate precipitation (M) as 1.7 - 2.4 inches/day; and number of days of intense precipitation (I) events which exceeded 2.4 inches/day. These values correspond respectively to one year, three to nine year, and over ten year return periods for four hour events (Miller et al., 1973) An analysis of local hourly precipitation records for the period of this study indicated that the bulk of each storm was likely to be delivered in a four hour period. Most gages used in this study reported daily precipitation amounts only (Climatalogical Data, Oregon). This assumption was made that the bulk of the reported daily precipitation fell during a four hour period. Section five of this catagory included the total precipitation amount in inches for the period of sampling.

Season (S) - the calendar year was divided into seven seasons with January on one end and July on the other. February and December are entered as season 2, March and November as season 3, April and October as season 4, May and September as season 5, and June and August as season 6. It was believed that the environmental conditions of these grouped months was similar based on Weather Service data.

The clearcut/no burn model indicated that the following factors were important in predicting erosion on these plots: percent vegetation (V); a combination of season times total precipitation for the sampling period (ST); aspect (A); a combined effect of aspect and amount of slash (ASL); and a combination of aspect and percent vegetation (AV).

The multiple regression equation developed to predict erosion quantities in clearcut unburned units is:

Ln (Erosion) = 11.165 - 5.594 (A) - .264 (V) + .432 (ASL) + .058 (ST) + .077 (AV). The coefficient of multiple determination (R^2) for this equation is .7345.

The multiple regression equation developed to predict erosion for clearcut and burned areas is less adequate than the one developed for clearcut areas which have not been burned. Only 41 percent of the variability in the amount of accelerated erosion could be determined by the factors considered in the equation. The equation shows that, the natural log of erosion (Ln(E)) was a function of: percent vegetation (V), number of days of zero rainfall during the sampling period (Z), number of days of moderate rainfall plus the number of days of intense rainfall, all divided by the natural log of the number of months since the unit has been burned plus .01 (MIX); the amount of slash that had been burned (BSL); the natural log of the number of months since burning plus .01 (T); aspect times slope times season (ASPS); and the exponent of aspect times season ($2.178^{AS/30}$). The regression equation is:

$$Ln(E) = 13.734 - .026\,(V) + .098\,(Z) + .514\,(MIX) + .801\,(BSL) - 1.016\,(T) + .007\,(ASPS) - 15.068\,(2.178^{AS/30})$$

A third model was developed to predict erosion Ln(E) on any area regardless of previous management activities. This full model can accurately predict 59 percent of debris production. The variables considered important were: percent slope (SP), burn indicator variable (B), percent vegetation (V); number of days of zero precipitation (Z); amount of slash which was burned (BSL); the natural log of the number of months since the burn plus .01 (T);and season times the total precipitation of that sampling period (ST). The multiple regression equation to predict erosion is:

$$Ln(E) = -.172 + .036(SP) - 3.051(B) - .031(V) + .034(Z) + .827(BSL) - .922(T) + .027(ST)$$

$$R^2 = .5889$$

Several variables were particularly important in predicting amounts of erosion. The percent vegetation was found to be the most significant independent factor in predicting the variability of erosion in all models. There was a correlation, r = .8147, between percent vegetation and time since burning (Figure 10). This correlation resulted in time since burning explaining a lower percentage of the total variability in erosion rates than it would have if percent vegetation was not considered; however, it was still an important predictor of erosion rates. Slope was another important predictor of erosion but only in the models based on data from clearcut and burned plots.

On burned units, several variables were used to predict erosion. The amount of slash was an important variable in predicting erosion because it dealt with the intensity and duration of the burn. Percent slope, when combined with aspect and season influenced erosion rates especially on steep south slopes during the dry summer season.

The number of days with zero precipitation was also important. This could correlate with the fact that burning usually occurred during periods when rainfall was minimal. The large storms, those of moderate and high intensity were considered important only on burned units.

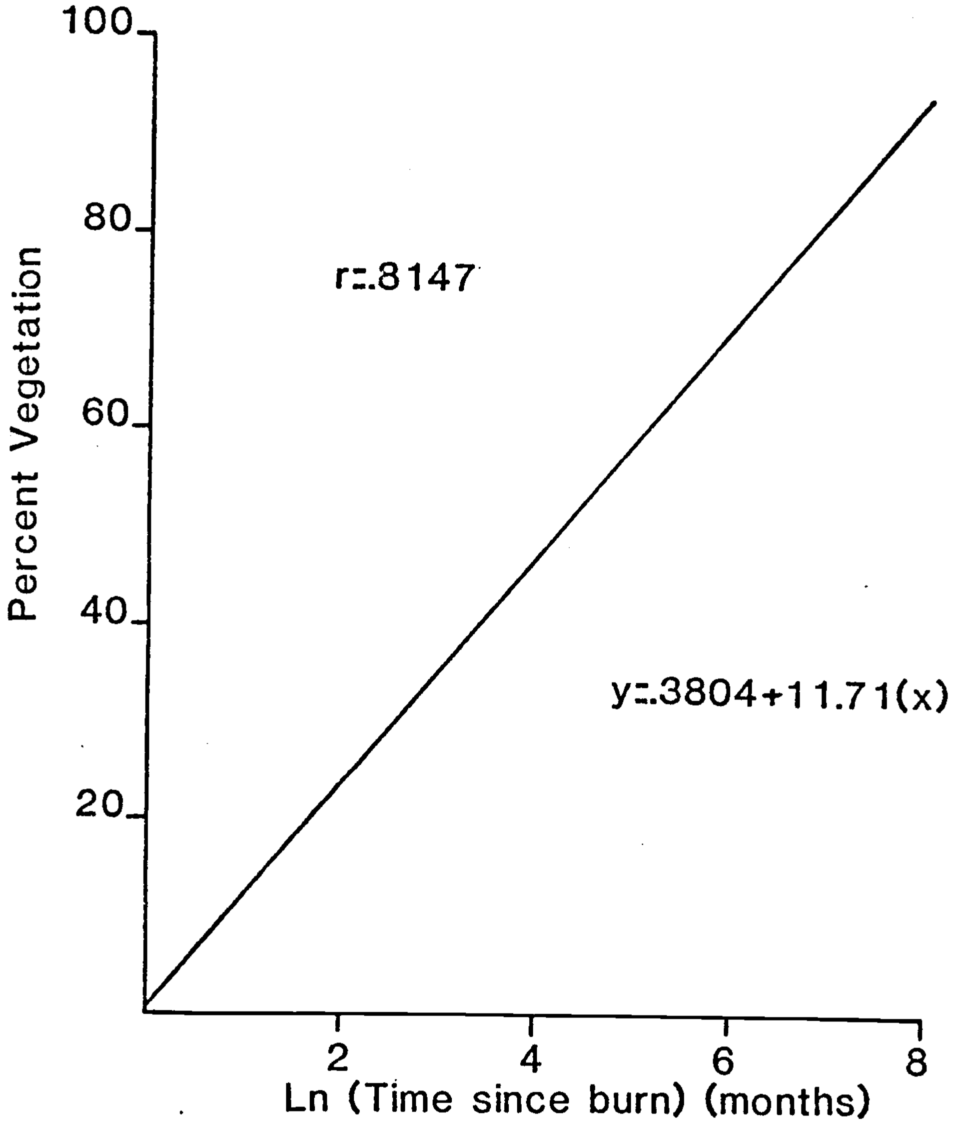

Figure 10: Correlation of percent vegetation and time since burning

Light precipitation events were not considered an accurate predictor of erosion. Total precipitation amounts were only important when in combination with season.

On clearcut - no burn areas, after considering the percent of vegetation and seasonal influence of precipitation events, aspect was found to be an important variable. In combination with the effect of aspect, the percent vegetation which was related to aspect was important. The amount of slash, also related to aspect, was a valuable predictor of erosion. The season also influenced the effect of aspect in predicting erosion.

As seen by the clearcut - no burn model, 73 percent of the variability in erosion could be explained. This model left 27 percent of the variability unidentified. Such factors as the amount of overland flow, the soil texture, or the type of vegetation, may help explain the remaining variability. These variables were not evaluated in construction of the model.

The results of the burn model show that additional variables would be valuable in predicting erosion. Only 41 percent of the variability in erosion could be explained by the variables analysed. The erosion processes already mentioned which were observed in the field, were not monitored in the study and therefore could not be included in the model construction.

One important variable in predicting erosion may have been the soil temperature reached during the burn. This variable was monitored on two of the clearcut burned areas studied (Table 7) but since it could not be applied to the entire study, it was not included in the construction of the model. Maximum temperature and an idea of penetration of that temperature would indicate the fate of organic materials in the soil. Duration of temperature increase would have perhaps been even more beneficial in understanding the effect of temperature on soil materials.

Soil textural variation may have also been a factor in predicting the amount of erosion. This variable was not considered at the time of analysis.

To illustrate the use of these models, I've run some hypothetical management situations using each model. The models should only be used to predict erosion on sites similar to the ones studies here. Table 10 indicates the limits for each variable in the model.

Table 10: Variable limits for reliability of predictive equations.

Variable	
Percent Slope	22% - 122%
Management Status	forested or clearcut
Preburn Slash	low, medium, or high
Burn Status	burned (sites burned only in fall) or not burned
Aspect	any
Percent Vegetation	0 - 100
Time since burning	during burn to 1560 months
Days of zero precipitation	5 - 100
Season	any
Days of light precipitation	1 - 110
Days of moderate precipitation	0 - 3
Days of intense precipitation	0 - 3
Total precipitation (inches)	0.1 - 46.5

A. Use of clearcut/no burn model:

$$Ln(E) = 11.165 - 5.594(A) - .264(V) + .432(ASL) + .058(ST) + .077(AV)$$

Problem: What is the difference in erosion rates on a clearcut area between the wet season and the dry season?

Situation 1:

Site Information	Model Entry
south slope	4
60 percent vegetation	60
heavy slash	3
December (season)	2
25 inches of rain	25

$$= 11.165 - 5.594(4) - .264(60) + .432(12) + .058(50) + .077(240)$$

$$= 11.165 - 22.376 - 15.84 + 5.184 + 2.9 + 18.48$$

$$= -.4870$$

Erosion = .6 m^3/ha

Situation 2:

Site Information	Model Entry
south aspect	4
60 percent vegetation	60
heavy slash	3
July (season)	7
0 inches of rain	0

$$Ln(E) = 11.165 - 5.594(4) - .264(60) + .432(12) + .058(0) + .077(240)$$

$$= 11.165 - 22.376 - 15.84 + 5.184 + 18.48$$

$$= -3.387$$

Erosion = .0338 m^3/ha

These situations indicate that there is more erosion during the wet season than during the dry season on unburned clearcuts.

B. Use of burn model:

$$Ln(E) = 13.734 - .026(V) + .098(Z) + .514(MIX) + .801(BSL) - 1.016(T) + .007(ASPS) - 15.068(2.718^{AS/30})$$

Problem: Does the aspect of the slope burned result in varying degrees of debris production? Is that rate of erosion maintained over time?

Situation 1:

Site Information	Model Entry
0% vegetation after burn	0
40 days of zero rain	40
0 intense storms	0
moderate slash	2
day after burn	.0099
south slope	4
September (season)	5
75% slope	75

$$\begin{aligned} Ln(E) &= 13.734 - .026(0) + .098(40) + .514(0) + .801(2) - \\ &\quad 1.016(.0099) + .007(1500) - 15.068(1.95) \\ &= 13.734 + 3.92 + 1.6 - .01 + 10.5 - 29.38 \\ &= 0.364 \end{aligned}$$

Erosion = $1.4 m^3/ha$

Situation 2:

Site Information	Model Entry
same as above except	same as above except
north slope	1

$$\begin{aligned} Ln(E) &= 13.734 - .026(0) + .098(40) + .514(0) + .801(2) - \\ &\quad 1.016(.0099) + .007(375) - 15.068(1.181) \\ &= 13.734 + 3.92 + 1.6 - .01 + 2.625 - 17.7935 \\ &= 4.076 \end{aligned}$$

Erosion = $58.9 m^3/ha$

Situation 3:

Site Information	Model Entry
2% vegetation recovered	2

0 days of zero rain	0
2 intense storms	1.82
moderate slash	2
3 months after burn	1.10
north slope	1
December (season)	2
75% slope	75

$$\begin{aligned} Ln(E) &= 13.734 - .026(1.82) - .098(0) + .514(.67) + .801(2) - \\ &\quad 1.016(1.10) + .007(150 - 15.068(1.069) \\ &= 13.734 - .047 + .344 + 1.602 - 1.1176 + 1.05 - 16.108 \\ &= -0.5426 \\ \text{Erosion} &= 0.58\ m^3/ha \end{aligned}$$

The above situations indicate that there is more erosion on north slopes than on south slopes. Situation 3 indicates that 3 months after the burn, even during the heaviest rains, there is less erosion on north slopes than there is the day after the burn.

This test of the burn model indicates that north slopes produce much more erosion than south slopes. Researchers in the past have found the opposite to be true (Mersereau and Dyrness, 1972). A plot of Ln (erosion) vs. aspect in burned plots shows a fair correlation ($r=.60$) indicating a slightly greater debris production on south slopes. However, in unburned areas a plot with a correlation of $r=-.50$ indicates slightly more erosion on north slopes (Figure 11).

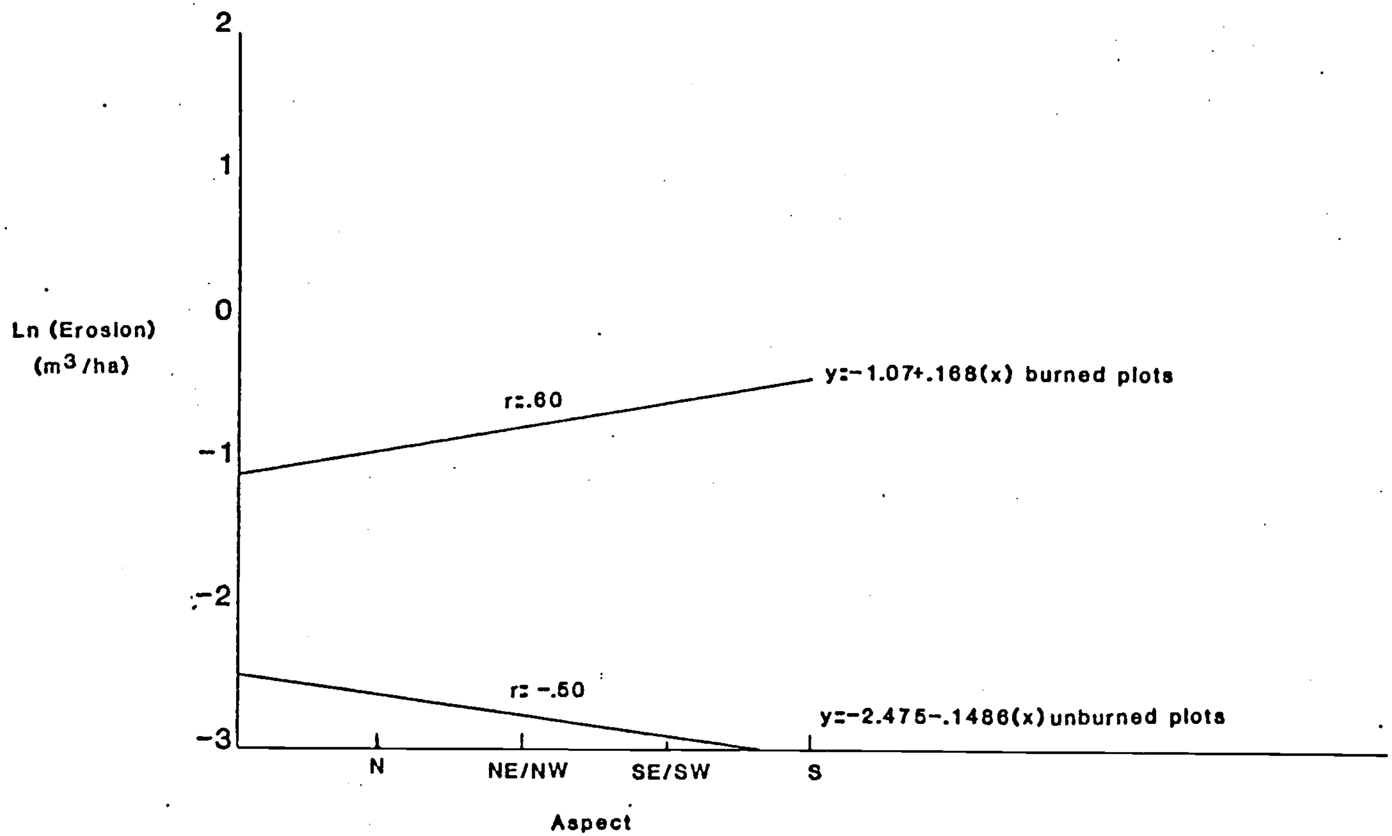

Figure 11. Relationship of Ln (Erosion) to aspect on burned and unburned plots

Use of Full Model:

$$Ln(E) = -.172 + .036(SP) - 3.051(B) - .031(V) + .034(Z) + .827(BSL) - .922(T) + .027(ST)$$

Problem:

There is a 90 year old timber stand due for harvest. Should it be burned?

Situation 1:

Site Information	Model Entry
75% slope	75
burned	1
September (season)	5
0% vegetation left	0
40 days of zero rain	40
moderate slash	2
0 inches of rain	0

$$Ln(E) = -.172 + .036(75) - 3.051(1) - .031(0) + .034(40) + .827(2) - .922(.0099) + .027(0)$$

$$= -.172 + 2.7 - 3.05 + 1.36 + 1.65 - .009$$

$$= 2.479$$

Erosion = 11.9 m^3/ha

Situation 2:

Site Information	Model Entry
75% slope	75
not burned	0
September (season)	5
70% vegetation	70
40 days of zero rain	40

moderate slash	2
0 inches of rain	0

$$\text{Ln}(E) = -.172 + .036(75) - 3.051(0) - .031(70) + .034(40) + .827(0) - .922(7.35) + .027(0)$$

$$= -.172 + 2.7 - 2.17 + 1.36 - 6.797$$

$$= -5.059$$

$$\text{Erosion} = 0.006\ m^3/ha$$

These situations indicate that if an area is burned in September there is more erosion than if it is not burned.

This model fails to account for the amount of debris moved in clearcut units. One major assumption is that it has been 130 years since the last burn. When that many months is used in the equation, it really weights the equation toward zero erosion.

SUMMARY AND CONCLUSIONS

Management of mountainous terrain in the Coast Range of Western Oregon can effect the amount of surface soil erosion that occurs in this area. No soil erosion was detected in the one naturally forested area studied here. Unburned clearcut areas exhibited erosion, the quantity varying with the amount of area disturbed by logging. Burning a clearcut area resulted in the greatest quantities of surface soil erosion. In the latter two management situations, eroded debris was found to be moving into the erosion catchment troughs from only short distances upslope. Burning had very little effect on erosion on slopes less than 60 percent. An average displacement of $29 m^3/ha$ the first year is within the range of debris displaced in clearcut unburned areas. The majority of the first year erosion from these gently sloping areas was experienced during wet season movement.

Slopes greater than 60 percent appear to be dominated by a different erosion process than that which occurs on more gentle terrain. On the steep slopes, sixty-five percent of the first years erosion is produced within 24 hours of the burn. This suggests gravitational movement by dry ravelling as the dominant erosion process. After 20 months of monitoring it was found that 97 percent of the erosion occurred within the first year.

The composition of the eroded debris varied with the time of year and the percent slope. The observed debris composition helps explain the processes involved in erosion under various conditions.

Predictive equations were developed to help resource managers determine the consequences of certain decisions regarding burning. These equations indicate that several factors including, most importantly, percent vegetation, time since burning, and slope, are influencing the rate of erosion in an area that has been clearcut and broadcast burned.

Because of its relationships with site productivity and water quality land managers should attempt to minimize surface soil erosion whenever possible. Limiting burn intensities particularly on steep slopes should help reduce this type of erosion on forest lands.

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APPENDIX

APPENDIX I: CONVERSION FACTORS

Metric Unit	X	Conversion Factor	=	English Equivalent
m^3/ha		.53		yd^3/acre = T/acre
m		3.288		feet
cm		.394		inch
mm		.0394		inch
^oC		$\frac{9}{5}\,^oC + 32$		^oF