Surface Erosion by Overland Flow in the Redwood Creek Basin, Northwestern California—Effects of Logging and Rock Type

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ABSTRACT

Ninety sets of erosion-deposition pins were monitored on slopes in the Redwood Creek basin from the summer of 1974 to the summer of 1978. Mean rates of ground-surface lowering were obtained for forested and logged slopes on two bedrock types by adding measurements of erosion and deposition and calculating their arithmetic mean. Erosion and deposition related to the installation of pins caused elevation changes measured during water years 1977 and 1978 to be most representative of elevation changes that occur under forest cover and after logging on the different bedrock types. Measurements for water years 1977 and 1978 indicate that the mean rate of ground-surface lowering was 0.3 mm/yr on forested sandstone slopes, forested schist slopes, and tractor- and cable-yarded sandstone slopes. The mean rate of ground-surface lowering during water years 1977 and 1978 was 1.1 mm/yr on cable-yarded schist slopes and 4.6 mm/yr on tractor-yarded schist slopes.

The data collected in this study indicate that ground-surface lowering due to overland flow on forested sandstone slopes, forested schist slopes, and logged sandstone slopes is minor compared to the modern average rate of ground-surface lowering in the Redwood Creek basin. Ground-surface lowering due to overland flow on logged slopes underlain by schist, however, mobilizes enough sediment to make a significant contribution to Redwood Creek's extremely high modern sediment yield.

INTRODUCTION

Because the Redwood Creek drainage in northwestern California has one of the highest sediment yields in the conterminous United States (Janda and Nolan, 1979; Milliman and Meade, 1983), much attention has been focused both on naturally occurring erosion and deposition processes active within the basin and on the effects of logging on those processes. Although mass-movement features have been identified as major sediment sources in the Redwood Creek drainage basin (Harden and others, 1978), little is known about the movement of soil by overland flow on slopes. Soil moved by such processes as slopewash, rainsplash, and rilling can increase stream sediment yields (Kelsey and others, 1981). In addition, surface soils contain nutrients that affect soil fertility (DeByle and Packer, 1972).

From the summer of 1974 to the summer of 1978, 90 sets of erosion-deposition pins were monitored on slopes in the Redwood Creek basin. Primary objectives of this study were to document rates of erosion and deposition due to overland flow on slope surfaces, to assess the relative importance of different erosion and deposition processes, and to determine differences in rates of erosion and deposition on slope surfaces underlain by different bedrock types and subjected to different logging practices.

The area encompassed by this study is the downstream half of the Redwood Creek watershed (fig. 1). Redwood Creek drains an elongate, northwest-trending, 725-km^2 drainage basin in the Coast Ranges of northwestern California. Average hillslope gradient in the basin is 26 percent (Janda and others, 1975). Over 30 percent of the Redwood Creek drainage contains landforms that reflect former or current mass wasting (Nolan and others, 1976).

A northwest-southeast-trending fault, which is roughly followed by the main channel of Redwood Creek, separates the two principal types of bedrock in the basin (fig. 1) (Harden and others, 1981). Most slopes northeast of the fault are underlain by unmetamorphosed sandstone with interbeds of mudstone and conglomerate. Commonly, these sedimentary rocks are pervasively sheared. Most slopes southwest of the fault are underlain by fine-grained, well-foliated quartz-mica schist.

Within the study area, soils on sandstone slopes commonly belong to the Hugo and Melbourne soil series (Alexander and others, 1959–62). These soils are typi-

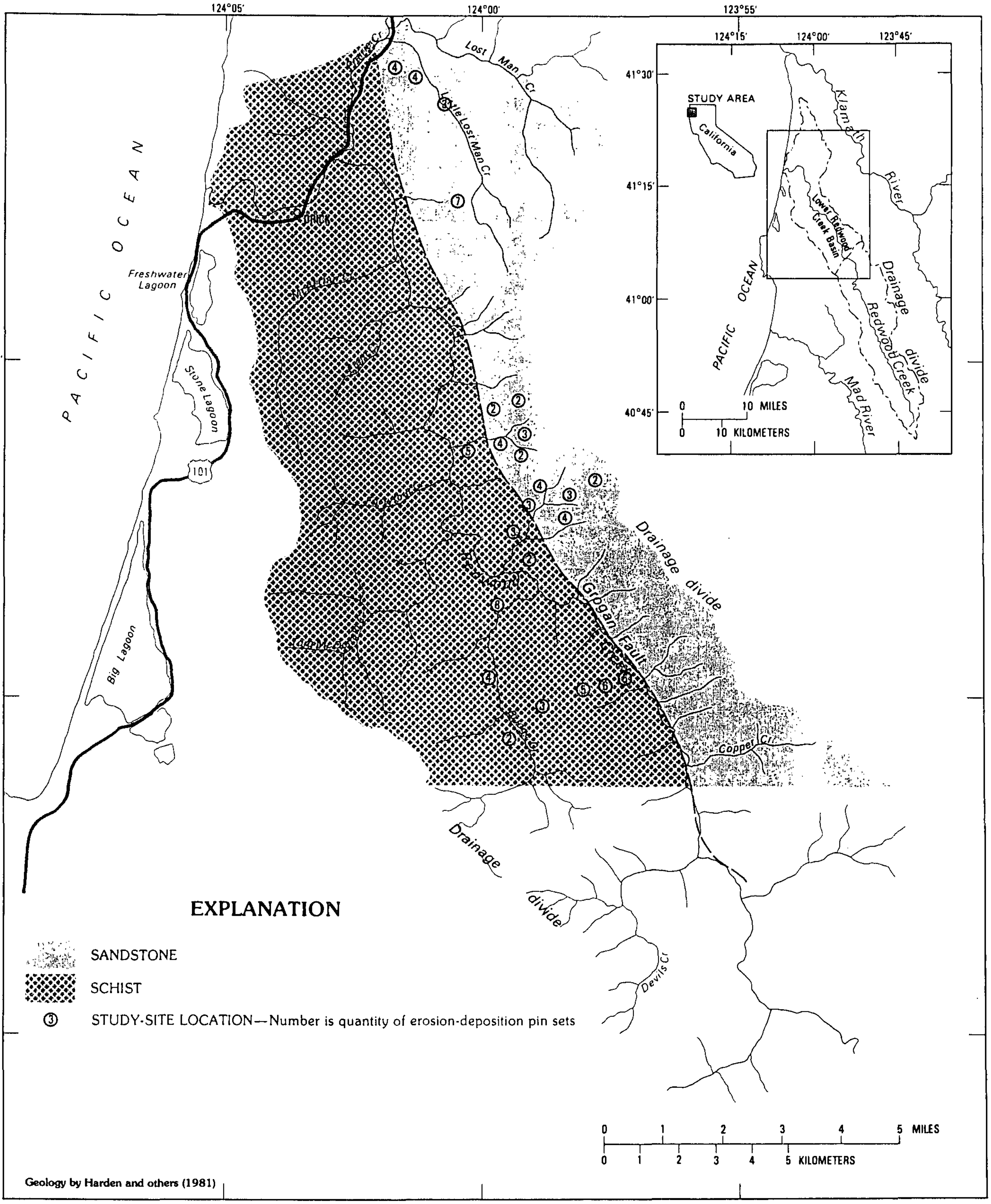

FIGURE 1.—Major bedrock types and study-site locations.

TABLE 1.—*Mean elevation changes and percentages of erosion and deposition attributed to different processes in different land use and bedrock categories*

[Negative mean elevation changes indicate ground-surface lowering. Years refer to water years]

Land use/bedrock category	Number of pin sets	Elevation change (mm)				Erosion during 1975–78 (percent)		Deposition[1] during 1975–78 (percent)	
		1975–76		1977–78					
		Mean	Standard deviation	Mean	Standard deviation	Gullying and rilling	Other processes	Shallow sloughing	Other processes
Forested/sandstone	14	−0.2	6.9	−0.6	4.8	5	95	6	94
Logged (tractor-yarded)/sandstone	33	2.1	20.3	−.6	6.2	5	95	17	83
Forested/schist	15	.2	3.9	−.6	5.9	0	100	0	100
Logged (cable-yarded)/schist	17	.3	11.8	−2.2	8.1	33	67	14	86
Logged (tractor-yarded)/schist	13	14.7	33.2	−9.3	14.9	31	69	13	87

[1] Does not include deposition by litterfall.

cally less than 1.25 m thick and have gravelly sandy clay loam to gravelly heavy loam textures (Laacke, 1979). Soils developed on schist commonly belong to the Masterson, Orick, and Sites series (Alexander and others, 1959–62). These soils are typically gravelly clay loams or clays up to 1.8 m thick (Laacke, 1979).

The climate of the Redwood Creek watershed is characterized by mild, wet winters and dry summers. Yearly precipitation ranges from 1,800 to 2,300 mm and occurs almost exclusively from October to June. Rainfall during the study period was average or below average. Annual precipitation in the town of Orick near the mouth of Redwood Creek was 1,810, 1,440, 960, and 1,740 mm for water years 1975 through 1978, respectively (National Oceanic and Atmospheric Administration, 1974–78). The study period included a flood-producing storm in March 1975.

More than 65 percent of the Redwood Creek basin has been logged, mostly within the last 25 years (Harden and others, 1978). Timber was removed by using tractor-yarding and cable-yarding methods. On tractor-yarded slopes, logs are dragged to landings by tractors along tractor-constructed trails, whereas on cable-yarded slopes, logs are dragged or carried to landings by cables. Cable-yarding generally causes less soil disturbance and less compaction than tractor-yarding (Huffman, 1977).

Forested slopes in the study area are dominated by redwood (*Sequoia sempervirens*), Douglas-fir (*Pseudotsuga menziesii*), and dense understory vegetation commonly including oxalis (*Oxalis oregana*), sword fern (*Polystichum munitem*), and rhododendron (*Rhododendron macrophyllum*). Following logging, herbaceous vegetation dominates for approximately 5 years, after which shrubs become dominant (Muldavin and others, 1981). Plants that commonly grow in the bare soil exposed by logging include sword fern, oxalis, salal (*Gaultheria shallon*), rhododendron (*Rhododendron macrophyllum*), blueblossom (*Ceanothus thrysiflorus*), coyote brush (*Baccharis pilularis*), whipplea (*Whipplea modesta*), alder (*Alnus oregana*), tan oak (*Lithocarpus densiflora*), and Douglas-fir.

METHODS OF STUDY

Sites for erosion-deposition pin sets were selected on the basis of bedrock type and land use. Sets of pins were located on logged and forested slopes in both sandstone and schist terranes. Logged sites on schist included tractor-yarded and cable-yarded areas. Only tractor-yarded areas were available on sandstone slopes. At all logged sites, logging had been conducted within 5 years of the first measurement. Slope gradients of the study sites were mostly between 15 and 35 percent. A range of slope aspects was sampled.

Each pin set consisted of nine pins spaced 3 m apart. Each pin consisted of a 0.75-m length of 6.4-mm-diameter iron reinforcing bar that was pounded approximately halfway into the ground. Five pins extended along the slope contour. The remaining four pins were placed upslope and downslope of the second and fourth pins of the transverse line of five. Nine percent of the pins that were installed in 1974 were disturbed or destroyed between 1974 and 1978. The pins were measured during the summers of 1974, 1976, and 1978 by placing a 70-mm-diameter template on the ground surface and measuring the distance to the top of the pin. Measurements taken on the uphill and downhill sides of each pin were averaged. Repeated measurements of single pins showed an average difference of 2.0 mm between the individual measurements and their average. In 1976, the sites were inspected for signs of erosion by rilling and gullying and for signs of deposition by litterfall and shallow sloughing of surficial materials.

The study period was divided into two parts to deemphasize elevation changes related to the installation and initial presence of the pins. Means and standard deviations of elevation changes observed at the pins in each land use and bedrock category during the first 2 and the last 2 years of the study (table 1) were calculated by using equations for clustered sampling populations (Snedecor and Cochran, 1967, p. 513–515). Deposition attributed solely to litterfall was not considered an elevation change in these calculations because litterfall does not reflect the movement of soil and rock material. Mean

TABLE 2.—*Probabilities of statistically significant difference between mean elevation changes during water years 1977 and 1978 in different land use and bedrock categories*

[The significance of the difference between means was calculated by using a two-sample *t* test]

Land use/bedrock categories to be compared		Probability of significant difference (percent)
I	II	
Forested/sandstone	Logged (tractor-yarded)/ sandstone	Less than 50
Forested/sandstone	Forested/schist	Less than 50
Forested/schist	Logged (cable-yarded)/ schist	Less than 50
Forested/schist	Logged (tractor-yarded)/ schist	93
Logged (cable-yarded)/schist	Logged (tractor-yarded)/ schist	86

elevation changes indicate the average net thickness of surficial material removed from or added to different slope surfaces. The statistical significance of differences between means was established by using a two-sample *t* test (table 2).

Percentages of erosion measured during water years 1975 through 1978 that were attributed to rilling and gullying were calculated for each land use and bedrock category by dividing the amounts of erosion shown by pins in rills and gullies by the total amounts of erosion measured (table 1). Percentages of deposition measured during water years 1975 through 1978 that were attributed to shallow sloughing were calculated for each land use and bedrock category by dividing the amount of deposition shown by pins surrounded by slough material by the total amounts of deposition attributed to processes other than litterfall.

VARIATIONS IN SURFACE EROSION DURING THE STUDY PERIOD

Mean elevation changes measured during the first half of the study period differ from those measured during the second half in all land use and bedrock categories, although some of these differences are not statistically significant owing to large standard deviations of the elevation changes. Generally, there is a trend toward more erosion relative to deposition during the second half of the study period. The standard deviations of all categories were smaller during the second half of the study period than during the first half. Field observations in 1976 revealed accumulations of soil behind some of the erosion-deposition pins. Accumulations of soil also were observed behind small pieces of organic debris that were caught on pins. These types of deposition, which are related to the installation of the pins, were most prevalent during the years immediately following pin installation and probably account for the marked contrast between net deposition during the first half of the study period and net erosion during the second half of the study period in most of the land use and bedrock categories. The higher standard deviations of elevation changes in water years 1975 and 1976 relative to water years 1977 and 1978 may also reflect soil deposition behind pins in the years immediately following pin installation. In addition, the December 1975 storm may have contributed to those high standard deviations by causing considerable soil mobility during the first half of the study period. In recognition of the problem of deposition behind pins in the years immediately following pin installation, elevation changes measured during water years 1977 and 1978 are considered most representative of elevation changes that typically occur in different land use and bedrock categories.

SURFACE EROSION ON FORESTED SLOPES

Data collected on forested slopes indicate that, under natural conditions, ground-surface lowering due to overland flow takes place at similar rates on sandstone and on schist slopes. There was slightly more evidence of erosion by rilling and gullying, and of deposition by shallow sloughing of surficial materials, on forested sandstone slopes than on forested schist slopes during water years 1975 through 1978 (table 1). For both forested sandstone and forested schist slopes, gradient apparently had no effect on either erosion or deposition.

EFFECTS OF LOGGING ON SURFACE EROSION

Rates of ground-surface lowering were similar on logged and on forested sandstone slopes during water years 1977 and 1978 (table 1). In contrast, greater rates of ground-surface lowering were measured on cable-yarded and particularly on tractor-yarded schist slopes than on forested schist slopes during the same period. Differences in mean elevation changes during water years 1977 and 1978 on schist slopes in the different land use categories are statistically significant despite large standard deviations (tables 1, 2). Greater elevation changes on the logged schist slopes were due, at least in part, to mobilization by gullying and rilling of a larger quantity of soil on those slopes (table 1). Significant relations between either erosion or deposition and slope gradient were not apparent in the data collected on logged sandstone and schist slopes.

Rates of ground-surface lowering on schist slopes subjected to logging were higher than on forested schist slopes, probably because of the compaction of surficial materials and the exposure of bare soil. Increases in overland flow result from compaction and from the removal of forest litter, which is more permeable than the soil below it (DeByle and Packer, 1972). The removal of vegetation and litter increases the vulnerability of soils to detachment and transport by rainsplash and overland flow (Rice and others, 1972). In addition, depressions created during logging can concentrate runoff and promote rill and gully erosion on logged slopes. The greater degree of ground disturbance associated with tractor-yarding, as opposed to cable-yarding (Huffman, 1977), may be responsible for the greater ground-surface-lowering rates on tractor-yarded than on cable-yarded schist slopes.

Several factors may cause logging to have more of an effect on surface erosion of schist slopes than of sandstone slopes. Schist soils are more susceptible to surface erosion than soils developed on sandstone in the Redwood Creek drainage because the schist soils have a lower sand content, a higher percentage of silt and clay, blockier structure, and lower permeability (Marron, 1982). All these characteristics lead to larger values of the commonly used soil-erodibility factor K, as determined by using nomographs developed by Wischmeier and others (1971). These erodibility characteristics may not be significant under forest cover, where soils are held by roots and protected by litter, but may gain importance following the disruption and exposure of soils by logging.

The response of the different soil types to burning and (or) exposure to ash leachate also may cause greater postlogging surface erosion on schist than on sandstone slopes. Approximately half of the pin sets on both logged sandstone and logged schist slopes were on sites that had been burned after logging. Experiments by Durgin (1981) showed that both burning and the mixing of soils with ash leachate cause greater increases in the dispersion ratio of Sites soils, which commonly develop on schist in the study area, than of Hugo soils, which commonly develop on sandstone in the study area. Dispersed soils are more susceptible to transport by overland flow because they are more easily suspended in running water (Mitchell, 1976, p. 218–219). Durgin (1981) attributed the greater increases in dispersion ratios of the schist soils to their greater capacity for anion exchange.

IMPORTANCE OF SURFACE EROSION DUE TO OVERLAND FLOW

Measured rates of surface erosion help to quantify the degree to which sediment removed from slopes by overland flow contributes to the extremely high modern sediment yield of Redwood Creek. Measured rates of ground-surface lowering presented here are approximate owing to the high standard deviations of elevation changes (table 1) and the effects of the presence of vegetation and organic litter at certain study sites. The measured changes may overestimate soil removal because some of the measured lowering of ground surfaces may have resulted from the removal of vegetation and organic litter, rather than the removal of soil, by running water. This latter problem applies particularly to forested slopes, where approximately 80 percent of the measurements that showed erosion during water years 1977 and 1978 were made on vegetation or organic litter. In comparison, only 20 to 30 percent of measurements showing erosion during water years 1977 and 1978 on logged slopes were made on vegetation or organic litter.

Measurements made at erosion-deposition pins on forested slopes indicated a mean ground-surface lowering rate of −0.6 mm from the summer of 1976 to the summer of 1978. When divided by 2 to get a yearly rate, this value constitutes approximately 14 percent of the 2.1-mm/yr mean rate of ground-surface lowering in the Redwood Creek basin estimated by Janda and others (1975) by using recently measured sediment yields. The actual amount of soil transported to streams by surficial processes on the forested slopes is probably much less, considering the high percentage of measurements showing erosion that were made on vegetation and organic litter.

Measurements made at erosion-deposition pins on logged sandstone slopes also yielded a mean rate of ground-surface lowering that is small in relation to Janda and others' (1975) estimate of the modern mean rate of basinwide ground-surface lowering. Measurements at pins on cable-yarded schist slopes yielded a mean lowering rate that is approximately one-half of the basinwide mean. In contrast, the mean yearly rate of ground-surface lowering measured on tractor-yarded schist slopes is approximately twice the basinwide mean, which suggests that erosion by surficial processes on these slopes may be making a significant contribution to the modern sediment yield of Redwood Creek. For example, if one-quarter of the 19 percent of the Redwood Creek watershed that was logged between 1967 and 1978 (chap. C, this volume) consists of tractor-yarded schist slopes, then surficial erosion on these slopes may supply as much as 22 percent of the modern sediment yield of the creek.

CONCLUSIONS

Data from 90 sets of erosion-deposition pins monitored in the lower part of the Redwood Creek drainage basin between the summers of 1974 and 1978 show that rates of ground-surface lowering due to overland flow are related to land use and bedrock type. Measurements of elevation changes during the second half of the study period are considered more useful than measurements of elevation changes during the first half of the study period because the later measurements appear less influenced by erosion and deposition specifically related to the presence of pins.

Data collected on forested slopes indicate that ground-surface lowering due to overland flow is similar on forested slopes underlain by sandstone and by schist. Comparisons of data from logged and forested slopes indicate that schist slopes are more susceptible than sandstone slopes to logging-related increases in surface erosion due to overland flow. On the schist slopes, tractor-yarding was associated with greater surface erosion than cable-yarding. Both types of logging were associated with a greater degree of erosion by rilling and gullying on slopes underlain by schist. Mean rates of ground-surface lowering on forested sandstone, forested schist, and logged sandstone slopes are small in comparison to Janda and others' (1975) estimate of the modern, mean, basinwide rate of soil removal. Mean rates of ground-surface lowering measured on cable-yarded and particularly on tractor-yarded schist slopes, however, indicate that surficial erosion on these slopes may make a significant contribution to the extremely high modern sediment yield of Redwood Creek.

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