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ABSTRACT: After a fire burned the San Dimas Experimental Forest, near Glendora, Calif., in 1960, about 350 acres of brushland were converted to grass. Six years later, the frequency and extent of soil slips—a form of gravitational mass movement—on this acreage was compared with those on comparable sites where brush cover was recovering naturally after the fire. Both the area affected and the number of soil slips were about five times greater on the grass-covered areas than on the brush areas.

Soil Slippage Increased by Brush Conversion

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Water yield on steep mountain watersheds can be increased by removing the woodland-riparian vegetation from selected areas bordering stream channels and by converting from brush to grass on side slopes with deep-soil.[1] In determining the cost of such treatments and the corresponding value of the increase in water yield, the effects of conversion on soil stability must be considered.

Since 1958 a program to convert native chaparral vegetation to grass has been underway at the San Dimas Experimental Forest, near Glendora, Calif. In 1960 a wildfire burned the Experimental Forest. After the fire, shrubs on the deep soil areas of Monroe Canyon and Bell Canyon were sprayed with selective herbicides to help establish a seeded grass cover. Some of the converted areas had slopes steeper than 70 percent (which is greater than the angle of repose of the soil). The converted areas are on a variety of soil series, soil depths, and slopes. Included in this study were 38 acres of riparian clearing, 22 acres of fuel-breaks, 26 acres converted for miscellaneous vegetation and erosion studies, and 168 acres of conversions on side slopes for water yield improvement. They provide a good sample with which to evaluate the effects of conversion on soil erosion. By spring 1966, natural recovery on untreated control areas had brought the vegetation cover to about 65 percent.

After the fourth largest storm on record (over a 35-year period), which occurred November 21-25, 1965, we observed many soil slips on both converted areas and on untreated control areas which were recovering normally (fig. 1). These observations indicated that the soil slips occurred more often on the converted areas than on the control areas.

A soil slip--a form of gravitational mass movement--is a shear failure set in motion when the stress along the potential surface of rupture exceeds the resistance to shear along that surface. This unbalanced condition may be brought about by (a) an increase in the weight of the overlying material owing to the absorption of water; (b) a decrease in the resisting mass (i.e., undercutting a slope); (c) a decrease in shear strength of the material itself (may be caused by the absorption of moisture); and (d) shear stress set up by

[1]Hill, L. W., and Rice, R. M. *Converting from brush to grass increases water yield in southern California.* J. Range Manage. 16(6): 300-301. 1963.

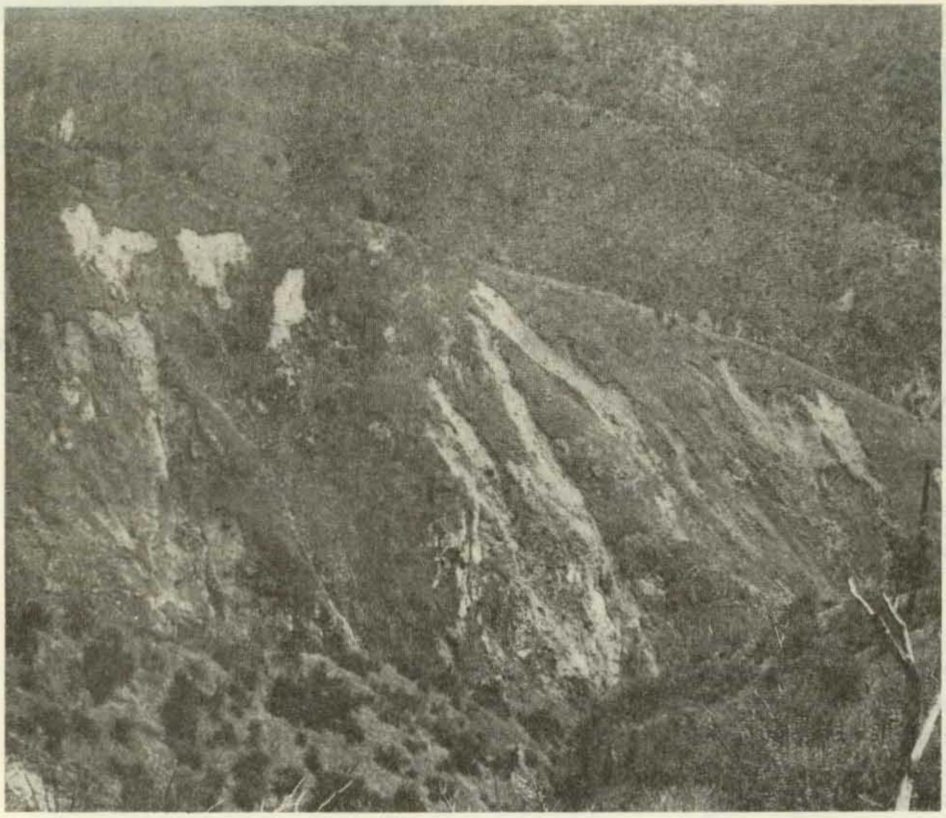

Figure 1.--*Soil slips on a steep side slope in the converted area.*

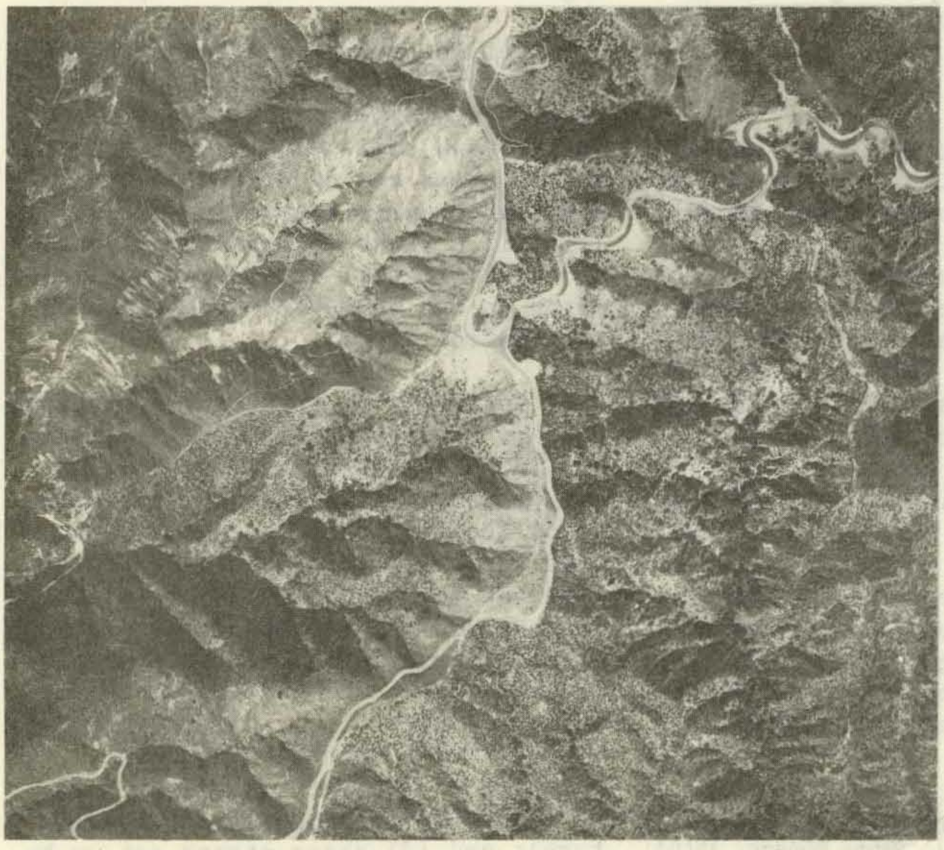

Figure 2.--*A portion of the converted and control areas in the soil stability study. Denser vegetation grows on the north facing slopes in the unconverted areas.*

swelling of rootlets under osmotic pressure.[2] The soil slips studied at the Experimental Forest were characterized by a semicircular headscar and a narrow rectangular to spoon-shaped area of bare soil and rocks. Usually little accumulation of soil formed at the base of a soil slip. Often soil was transported directly into stream channels.

The storm of November 21-25, 1965 produced 11.09 inches of rain; 7-1/2 inches of this total fell in 15 hours, at an average rate of .50 inches per hour for 15 hours. During this period, the watersheds received a 10-minute sustained maximum intensity of 1.98 inches per hour. This storm occurred 1 week after a gentle rain of 7.95 inches. About 9 inches of rainfall are needed to saturate the soils in the Experimental Forest watersheds. From November 26 to December 21, 1965 four storms dumped 2.14 inches of rain. Then from December 28 to 29, in 21 hours 6.19 inches of rain fell; 4-3/4 inches fell in 8 hours, at an average rate of .60 inches per hour for the period. The maximum 10-minute intensity recorded was 1.38 inches per hour. After both the November 21-25 and December 28-29 storms considerable damage to stream channels occurred owing to the high flows. Many roads were closed because of soil slips.

THE STUDY

To study the extent of soil slips, all areas that had been converted from brush to grass were marked on a soils map. Within this area, soil types were delineated on a basis of soil series, slope class, and depth class. The minimum area delineated was 2-1/2 acres. Similar soil types were located in unconverted areas (hereafter referred to as the control areas) and marked on the soils map. In this fashion each converted acre of a particular soil series, slope class, and depth class was paired conceptually with an identical unconverted site. Within the limitations of the soils map, this procedure insured that the only difference between the converted and control areas was the vegetation. The correspondence between the two types of areas was close. We found that 354 acres of converted area were matched with 358 of control area (table 1). These data were then transferred to aerial photographs (scale 1:5,000) that had been taken (February--March) of both converted and control areas (fig. 2).

The entire area within the delineated treated and control sites was inspected on the photos and the number of slips in each soil type counted. The percent of the area which had slipped in each soil type was determined with a grid overlay (table 1).

RESULTS

The converted area contained about five times as many soil slips and five times the percent area in soil slips as the control area (table 1). An individual soil slip was defined as an eroded area having a semicircular headscar which existed above the rectangular to spoon-shape area of bare soil or rock. Often individual soil slips would coalesce, forming a massive area of exposed subsoil and rock. These contiguous slips were most prevalent in the converted area.

Of the 354.1 acres of converted area examined, 29.7 acres--or 3,428 square feet per acre--were found to be in soil slips. The control area had only 6.4 acres out of 357.7 acres studied in soil slips or 779 square feet per acre.

[2] Leopold, L. B., Wolman, M. G., and Miller, J. P. *Fluvial processes in geomorphology*. 522 pp. San Francisco: W. H. Freeman & Co. 1964.

Table 1.--*Area and number of soil slips, by soil type, San Dimas Experimental Forest*

Soil type[1]	Acreage in type		Slips per acre		Relative area in slips	
	Converted	Control	Converted	Control	Converted	Control
	Acres		*Number*		*Percent*	
B/3R1-1	4.5	5.7	0	0	0	0
A/1R1-2	8.7	9.2	0	0	0	0
A/3R0-2	4.1	4.4	.49	0	1.3	0
A/3R1-2	26.3	26.8	.15	0	.3	0
A/2R1-3	81.0	77.2	1.98	.32	6.0	1.1
A/3R1-3	70.9	73.5	2.34	.38	9.4	1.7
B/3R1-3	10.8	11.2	.74	.09	2.4	< .1
Ac/4R1-3	33.4	30.9	1.74	.06	8.6	.3
A/1R1-4	57.4	54.8	4.48	1.46	13.0	5.1
Ac/1R1-4	23.9	24.4	4.39	.70	13.4	1.8
Ac/2R1-4	33.1	39.6	3.41	.48	13.5	2.6
Total	354.1	357.7	--	--	8.4	1.8
Average	--	--	2.46	.48	--	--

[1]Soil symbols: The soils were mapped according to standard soil series criteria. Each series has been tentatively designated by a capital letter. The small 'c' shows that the soil is colluvial. The first numeral in the denominator is the soil depth class, the R1 is the rockiness class and the last numeral is the slope class. Source: Crawford, J. M. *Soils of the San Dimas Experimental Forest.* U.S. Forest Serv. Pacific SW. Forest & Range Exp. Sta. Misc. Paper 76. 20 pp., illus. 1962.

TYPES OF SOIL SLIPS

Before categorizing the types of soil slips it is well to recall the comment of Sowers and Sowers[3] that "in most cases a number of causes exist simultaneously, and so attempting to decide which one finally produced the failure is not only difficult but also incorrect." Nonetheless, we were able to distinguish three types of soil slippage: (a) shear zone at rooting depth of vegetation (fig. 3); (b) shear zone at bedrock or subsurface rock layers (fig. 4); and (c) shear zone at clay subsoil layer. Saturation of the soil mantle appeared to have contributed to each type of slippage.

Type 1.--The soil mass seemed to slip at the interface of the lower depth of maximum root concentration and the underlying subsoil. This slip generally occurred from 9 to 14 inches below the soil surface. Soil slippage occurred under both perennial and annual grass covers.

Type 2.--This type of soil slip was not as prevalent as Type 1 and generally occurred on the shallower soils.

Type 3.--Only a few of the soil slips examined were of this type. There are only a few areas with a clay subsoil in the Experimental Forest.

EFFECT OF SLOPE

Within both the converted and control areas, the number of soil slips increased as the slope increased (table 2). In the converted area the number of slips increased rapidly from slope class 2 (40 to 54 percent) to slope class 3 (55 to 69 percent) and slope class 4 (greater than 70 percent). On the other hand, in the control

[3]Sowers, G. B., and Sowers, G. F. *Introductory soil mechanics and foundations.* 228 pp. New York: MacMillan Co. 1951.

Figure 3.--*Type of soil slip in which the shear zone occurs at interface between grass roots and subsoil.*

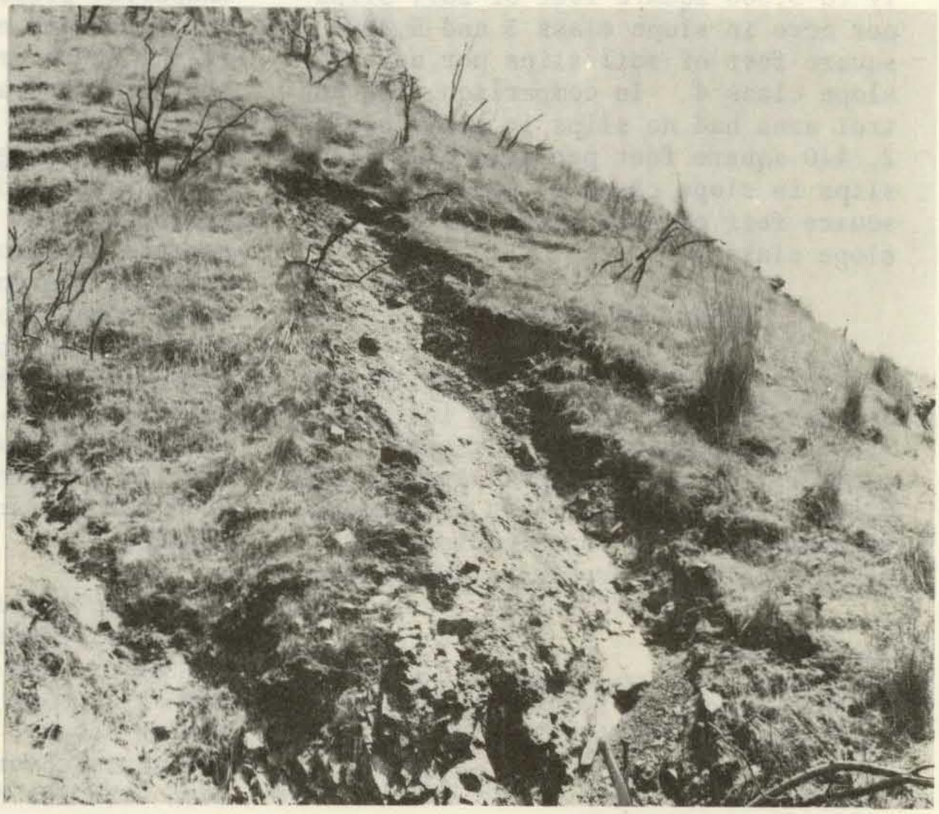

Figure 4.--*Soil slippage over underlying rock strata.*

areas soil slips were not found in slope class 2, and their increase in numbers was more gradual for slope classes 3 and 4 (table 2). The same trend is apparent if contiguous slips (individual slips which have coalesced) are counted as a single slip.

Table 2.--*Number of soil slips and percent of area in slips, by slope class*[1]

Slope class	Class interval	Slips per acre		Relative area in slips	
		Converted	Control	Converted	Control
	Percent	*Number*		*Percent*	
2	40-54	0.15	0	0.3	0
3	55-69	2.02	.25	8.0	1.0
4	>70	4.09	.88	13.3	3.2

[1]For soil series 'A' only.

The area in soil slips within a soil type also increased as the slope increased (table 2). For the converted area there were 130 square feet of soil slips per acre in slope class 2. This amount increased rapidly to 3,500 square feet of soil slips per acre in slope class 3 and 5,800 square feet of soil slips per acre in slope class 4. In comparison, the control area had no slips in slope class 2, 440 square feet per acre of soil slips in slope class 3, and 1,390 square feet of soil slips per acre in slope class 4.[4]

EFFECT OF SOIL DEPTH

Generally the number of soil slips decreased as the soil depth increased (table 3)--particularly for soil greater than 2 feet deep. And the area of soil slips decreased as soil depth increased. It is conceivable that deeper soils may produce a deeper cut and more debris. We are now making field surveys to determine the amount of debris produced from soil slips in the various soil types examined and to define more clearly the relationship between soil slips and site conditions.

Table 3.--*Number of soil slips and percent of area in slips, by soil depth class*[1]

Soil depth class	Class interval	Slips per acre		Relative area in slips	
		Converted	Control	Converted	Control
	Inch	*Number*		*Percent*	
1	0-11	4.02	1.10	11.6	3.6
2	12-23	2.70	.40	9.8	1.8
3	24-35	1.70	.27	5.8	1.7
4	36-47	1.74	.06	8.6	.3

[1]For soil series 'A' only.

EFFECT OF ASPECT

To study how effective native chaparral is in reducing soil slips, we compared areas having north and east aspects with areas of comparable soil depth having south and west aspects. Chaparral grows larger and denser on the north- and east-facing slopes than on the south or west aspects because of the more favorable microclimate. This difference was apparent in the study area even though the brush had not fully recovered from the fire of 1960. In the control area the south and west aspects had about five times as many slips as the north and east aspects. North slopes contained 440 square feet of soil slips per acre; the south slopes had 1,480 square feet of soil slips per acre. The heavier chaparral cover appeared to be more effective in reducing the number of slips than the sparse cover on the south slopes.

In the converted area this relationship between slips and aspect did not hold. The north-facing slopes had almost as many soil slips as the south-facing slopes, or a ratio of 1 to 1.3. The grass cover on the north slopes, even with its better environment for establishment, apparently was not much more

[4]Preliminary data from a more intensive follow-up study now in progress indicate that few slips occurred on slopes less than 80 percent. The slips reported in this note in the gentler slope classes are usually on small areas of steeper terrain included within the soil type boundary.

effective than the grass cover on the south slope areas in holding the soil.

EFFECT OF SOIL SERIES

Only two soil series were found on the converted areas. These are referred to as soil series A and B.[5] Generally the soils of series B are deeper, more developed, have a better structure, and are less rocky than the soils of series A. Only a small area of soil series B was examined. We found fewer slips and considerably less area in slips for this soil type than for soil series A in the same slope class (table 1). This difference indicates that soil series may be important in the occurrence of soil slips.

MANAGEMENT IMPLICATIONS OF BRUSH CONVERSION

The three most common reasons for converting from brush to grass are (a) to obtain additional forage, (b) to increase water yield, or (c) to improve fire control opportunities by building fuel-breaks. Any particular conversion may involve all of these benefits to a greater or lesser degree. When using brush conversion as a management tool the economic value of the possible benefits must be estimated and weighed against the costs. These costs will include both the direct cost of establishing and maintaining the conversion and the indirect costs resulting from the possible increase in erosion.

Conversions for range improvement are not likely to require much consideration of erosion costs. On slopes so steep as to be serious erosion hazards, conversion to cattle range is likely to be impractical.

Conversions for water yield improvement do not have this inherent slope limitation. First-priority sites are those next to stream channels.[6] Of second priority would be the remaining watershed area having soils 3 or more feet deep. In neither case is there any objection, from a water yield point of view, to converting steep slopes. Since the deeper soils will tend to occupy gentler terrain, however, areas desirable for conversion will tend to be more prevalent on the gentler slopes--except possibly in the riparian zone. In geologically young mountains, such as the San Gabriels in southern California, the steepest slopes will tend to be next to the actively downcutting stream channels. Soil slips that do occur there will have the least opportunity to stabilize before being transported from the watershed by streamflow.

Fuel-break conversions are most often on ridge tops. The ridges will usually be less steep than the general lay of the land within a watershed, but this advantage may be offset by the shallower soils likely to be found there. From our limited opportunity to observe slips on fuel-breaks we believe there is a risk of soil slippage whenever the clearing is broad enough to extend onto the concave side slopes.

Quite apart from the increased costs of conversion due to increased erosion on steep slopes, the direct costs will also increase as the slope increases. As Bentley points out: "The most effective and economical methods for each step of the conversion process--removing brush, sowing grass, and killing brush regrowth--involve the use of tractors and other ground equipment."[7] On slopes too steep

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[5]Crawford, J. M. *Soils of the San Dimas Experimental Forest.* U.S. Forest Serv. Pacific SW. Forest & Range Exp. Sta. Misc. Paper 76. 20 pp., illus. 1962.

[6]Hill, L. W. *The cost of converting brush cover to grass for increased water yield.* U.S. Forest Serv. Pacific SW. Forest & Range Exp. Sta. Res. Note PSW-2. 7 pp., illus. 1963.

[7]Bentley, J. R. *Fitting brush conversion to San Gabriel watersheds.* U.S. Forest Serv. Pacific SW. Forest & Range Exp. Sta. Misc. Paper 61. 8 pp., illus. 1961.

for tractors, hand labor costs will increase as slope increases. Consequently, to the extent to which management objectives permit, the economic desirability of conversion can be expected to diminish as the slope increases.

By way of an example, the gross acreage on the San Dimas Experimental Forest which is suitable for conversion is rather small. About 7 percent of the area would be suitable for grazing if converted. But only about 5 percent could be converted and used because of problems of accessibility. Land suitable for water yield conversion makes up about 7 percent of the Experimental Forest. If we assume that on side slopes greater than 55 percent the increase in erosion would offset water yield gains, only about 3-1/2 percent would be converted in practice. All but 1 percent of the area that is suitable for water yield conversion is included in the area that would be converted for grazing. If we assume that the fire control benefits would outweigh any additional erosion produced, a fuel-break system for the Experimental Forest would include an additional 7 percent of the area--bringing the total area suitable for conversion to 13 percent.

PLANNING FOR CONVERSION

Before determining whether a particular area is suitable for conversion the land manager will need to balance the possible benefits against the expected costs. If the area selected for conversion includes slopes much greater than 40 percent, site information should be coupled with climatic data (to estimate the probability of large slip-producing storms) for an estimate of the secondary costs due to increased erosion. Considering these costs will help the land manager reach a sound decision on the desirability of a particular conversion job.

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