EFFECTS OF OFF-ROAD VEHICLE USE ON THE HYDROLOGY AND LANDSCAPE OF ARID ENVIRONMENTS IN CENTRAL AND SOUTHERN CALIFORNIA

By C. T. Snyder, D. G. Frickel, R. F. Hadley, and R. F. Miller

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SYSTEM OF MEASRUEMENT UNITS

This report provides both the English and the metric systems of units. The factors given in the following list were used to convert English to metric units.

English	*Multiply by*	*Metric*
acres	4.047×10^{3}	km^2 (square hectometers)
acre-ft (acre-feet)	1.233×10^{3}	m^3 (cubic meters)
acre-ft/mi^2 (acre-feet per square mile)	4.760×10^{2}	m^3/km^2 (cubic meters per square kilometer)
ft (feet)	3.048×10^{1}	m (meters)
in (inches)	.254	dm (decimeters)
	2.54	cm (centimeters)
	25.4	mm (millimeters)
in/h (inches per hour)	25.4	mm/h (millimeter per hour)
mi (miles)	1.609	km (kilometers)
pound/$inch^2$	70.42	gm/cm^2

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ABSTRACT

Two widely separated sites in California used for motorcycle hill-climbing were studied to evaluate the impact on the landscape and hydrology. At Panoche Hills in central California, an area formerly used by motorcycles together with an adjacent unused area were monitored from 1971 to 1975. Observations in both areas included measurements of precipitation, runoff, soil moisture, soil bulk density, plant cover, and erosion surveys. At Dove Spring Canyon in southern California erosion was measured on a site that is currently being used for motorcycle hill climbing.

At the Panoche Hills site, the area used by motorcycles produced about eight times as much runoff as the unused area. Similarly, sediment yield from the used area was 857 m^3/km^2, while the quantity of sediment from the unused area was not measurable by standard survey methods.

At the Dove Spring Canyon site, which is still being used for hill-climbing, erosion surveys show that degradation in trails has been as much as 0.3 m in the period 1973-75.

Compaction of soils and reduction of permeability appears to be the most serious hydrologic impact of motorcycle use at Panoche Hills. Increased bulk density of soils reduces depth of moisture penetration which deprives plants of moisture needed for growth.

INTRODUCTION

Statement of problem

Probably no single recreational activity has brought the California urban dweller into as much contact with the desert environment as the use of off-road vehicles (ORV), primarily motorcycles and dune buggies. The impact of these vehicles on the fragile desert ecosystems is easily seen in areas of concentrated use and even remote parts of the desert have not been spared entirely. The number of visitor days on public lands throughout California has increased at an almost unbelievable rate in the past 10 years. In a study by the Arid Lands Committee of the American Association for the Advancement of Science (Science, 1974, p. 500) it was estimated that in the Southern California desert alone, visitor days increased from 4.8 million in 1968 to 13 million in 1973. At about the same time (1967-1971) the number of motorcycles manufactured in the United States almost doubled (Carter, 1974).

As the number of vehicles in use increased, more and more questions were asked by the federal agencies that administer much of the desert land, and by conservation groups about the long-term impact of ORV on the environment. No ready answers were available, however, because of the lack of quantitative data on the effects of ORV on soil, plants, and water. In the late 1960's, the need for a quantitative evaluation of the impact of ORV on the public lands became apparent and the study described here was initiated by the U.S. Geological Survey in cooperation with the Bureau of Land Management. This report describes the study and evaluates some of the impacts of motorcycle use on semiarid and arid environments of central and southern California, respectively.

Location

The two study areas are located at Panoche Hills and Dove Spring Canyon. The Panoche Hills, foothills of the Diablo Range, lie on the western side of the San Joaquin Valley in Fresno County. The canyon area under study is a northward-trending tributary of Little Panoche Creek located about 3 airline miles (4.8 km) northeast of the town of Mercey Hot Springs. The site lies approximately 2,000 feet (610 m) above mean sea level. Its coordinates and legal description are: lat. 36°42'30"N., long. 120°48'05"W.; SE¼NE¼ sec. 18, T. 14 S., R. 11 E. (fig. 1).

The Dove Spring Canyon site is located in the NW¼SW¼ sec. 9, T. 29 S., R. 37 E., lat. 35°25'N., long. 118°00'W., in Kern County. Dove Spring Canyon heads on Pinyon Mountain, a small outlier several miles east of the Sierra Nevada range. This is a casual recreational area that lies outside the limits of Red Rock State Park, west of the New Los Angeles aqueduct and along either side of the original aqueduct.

Study objective

The purpose of this study was to obtain data that would help the Bureau of Land Management identify and quantify some of the effects of off-road vehicles on semiarid and arid environments. The primary objective

Figure 1.--Location of study areas in California.

of the Panoche Hills study was to evaluate the differences in surface runoff, erosion and sediment yield, soil moisture, soil density, and vegetative cover between used and unused areas. An additional objective was to determine the rate of recovery of the used area after use was discontinued. The primary objective of the Dove Springs Canyon study was to measure hillslope erosion on an area being actively used by off-road vehicles.

History of off-road vehicle use

Motorcycle use of the Panoche Hills study site began in 1968 and continued through 1970, at which time it was closed to all off-road traffic. The Bureau of Land Management reports that heaviest use occurred during a 4- to 6-week period each spring and fall, with little or no activity during the summer. During the periods of peak use, there were an estimated 2,000 motorcycles present on long weekends, with an average use density of 500 vehicles per weekend. Off-season use declined to an average density of 150 vehicles per weekend except for the rainy period in January and February, when the average dropped to 50 or 60 vehicles.

Motorcycle use in the Dove Spring Canyon area was first started in 1965 by small family groups and continued this way until the winter of 1967-68, when organized groups were allowed to use the area for trail rides and hill climbing. This widespread use was restricted sometime during the winter of 1968-69, at which time small-group use was resumed. Two types of hill climbing are practiced at Dove Spring Canyon; trail climbing on the north slope of the canyon, west of the old Los Angeles aqueduct, and area climbing on the south slope of the canyon. In trail climbing, use is concentrated on the steepest segments of the slope with areas between trails receiving relatively little use. In area climbing the entire slope is used, subjecting it to complete denudation. When the study was begun, there had been little or no use of the south slope, east of the old Los Angeles aqueduct. However, use of this slope has gradually increased from 1973 to the present (1975).

PANOCHE HILLS

Description of the area

The Panoche Hills have been uplifted along the western edge of the San Joaquin Valley. They consist of poorly indurated sedimentary rocks of the Cretaceous Panoche Formation with an overlying veneer of the Pliocene and Pleistocene Tulare Formation consisting principally of sandstone and conglomerate. Since uplifting began, the Hills have been deeply eroded into narrow, steep canyons separated by flat benches. Despite the fact that nearby canyons are steep and narrow, the canyon in the study area has less steep slopes and a floor wide enough to afford good physical conditions for motorcycle hill climbing.

The study area of about 25 acres (0.10 km^2) was fenced and divided into two small basins by constructing earth-fill dams on the canyon floor. The focal point of the study was the basin above reservoir 1 (fig. 2) with an

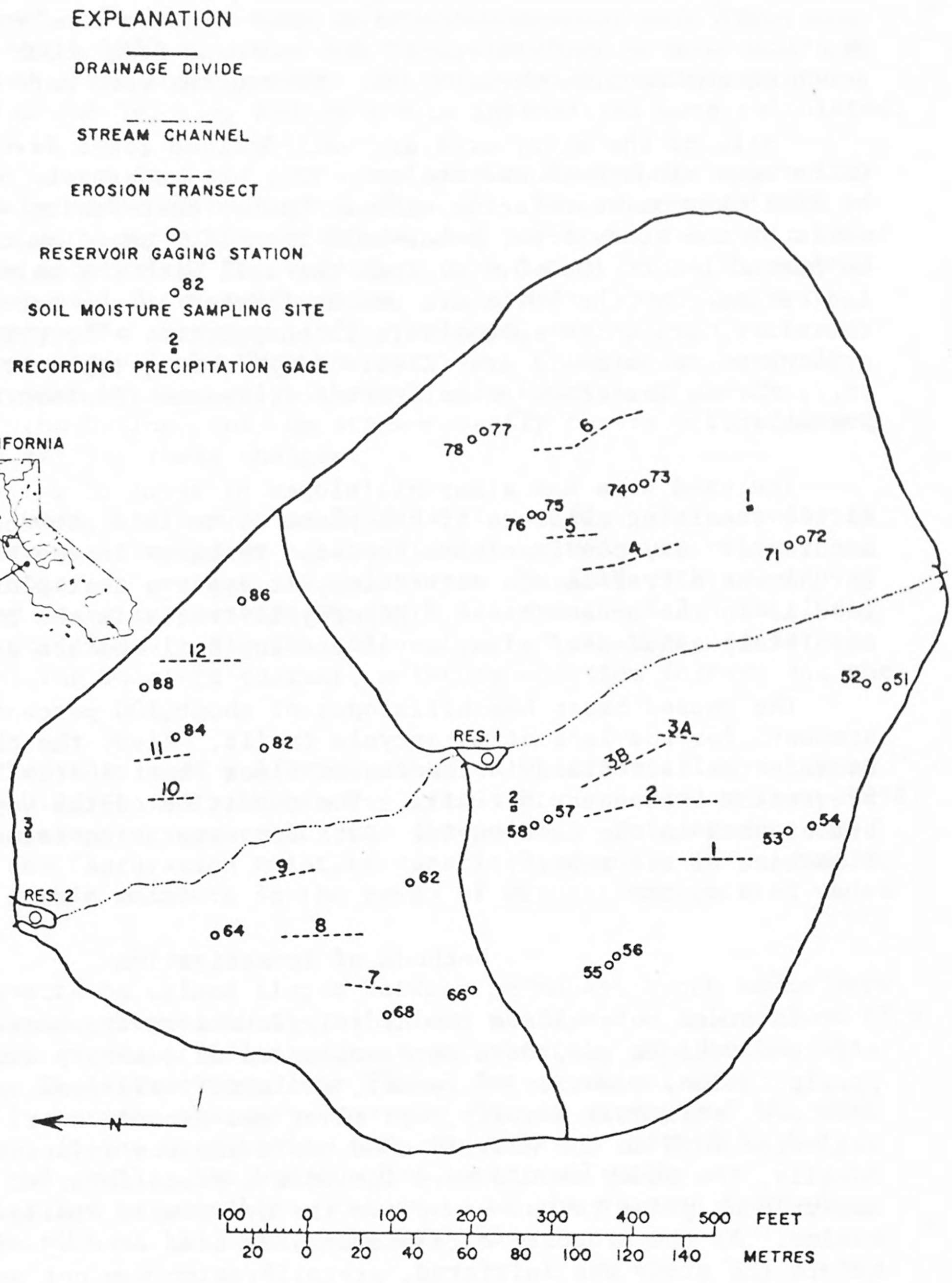

Figure 2.--Map of Panoche Hills study area showing locations of observation stations and sites.

area of about 12 acres (0.05 km^2) that had been the center for intensive motorcycle hill-climbing activity. Downstream from the heavily used basin, reservoir 2 (fig. 2) was constructed to delineate a drainage basin not used by off-road vehicles. This basin was used as a control to compare the natural environment and hydrologic conditions with those of the heavily used basin just upstream. A third reservoir was constructed upstream from the used area to isolate runoff and sediment from about 3 acres (0.01 km^2) south of the Panoche access road. No studies were made in the third basin.

Soils of the study area are well-drained loams developed from Calcareous sandstones and shales. They are moderately alkaline and tend to be shallower on west-facing slopes than on east-facing slopes. In most parts of the study area, a one-half inch (1.3 cm) diameter rod can be pushed 1-2 ft (0.3-0.6 m) into the soil with the palm of one's hand, indicating that the soils are unconsolidated in the natural state, and therefore, are quite susceptible to compaction. The principal plants growing on these soils are filarie (*Alfilaria*), rabbitbrush (*Chrysothamnus sp.*), Mormon Tea (*Ephedra californica*), fescue (*Festuca sp.*) and brome *Bromus sp.*).

The used area has steep hillslopes of about 65 percent. There is little remaining evidence of the plant cover that probably existed before motorcycle use, but from some isolated remnants in the vicinity of large shrubs where traffic was restricted, it appears that plant cover was once as good as in the unused basin. Motorcycle trails in the used area were completely denuded of plant cover and top soil and are deeply rilled.

The unused basin has hillslopes of about 100 percent, which probably accounts for the lack of motorcycle trails. Also, the channel in the unused area is incised in the canyon floor about 10 ft (3 m) deep thus preventing cross-canyon trails. The condition of the vegetation is much better than in the used basin. Data for vegetation transects is summarized elsewhere in the report.

Methods of investigation

In order to evaluate the hydrologic and environmental impacts of off-road vehicle use, data were collected on quantity and intensity of precipitation, quantity of runoff, sediment yield from upland slopes, soil moisture, soil bulk density, and plant and ground cover. These data were collected both in the heavily used basin and the adjacent unused basin. Ideally, the study should have included a precalibration period--a period of measurement prior to use--to prove the hydrologic similarity of the two basins. As the proposed site had already been used by off-road vehicles before the study was initiated, precalibration was not possible without damaging an additional area. Instead, the study was conducted during the recovery period after heavy use, and hydrologic similarity of the two basins was assumed. The locations of the precipitation gages, water-stage recorders, soil-moisture stations, and erosion transects are shown in figure 2.

Precipitation was measured by three gages equipped with digital recorders. The gages were located near the upstream and downstream boundaries of the two basins and were approximately 180 ft (55 m) below the highest segments of the basin divides (fig. 2). Gages 1 and 3 were on west-facing slopes and gage 2 was on an east-facing slope. Gages 1 and 2 were approximately 470 ft (143 m) apart and gages 2 and 3 were 600 ft (183 m) apart. The gages were in continuous operation from February 1971 to April 1975 and recorded the accumulated precipitation at 5-minute intervals. From these values, the total daily precipitation, storm precipitation and 5-, 15-, and 30-minute intensities were calculated.

Runoff and sediment from the two areas were collected in reservoirs at the downstream boundary of each area (fig. 2). The reservoirs were equipped with digital water-stage recorders that monitored reservoir water levels at 5-minute intervals. The recorders were in operation throughout the year except for periods of malfunction. Reservoir capacities were determined by topographic surveys. Inflow volumes were calculated from stage-capacity curves developed from the surveys. Changes in reservoir capacity as determined by successive surveys were considered as the sediment yield of the basins, and the stage-capacity curves were adjusted when necessary to reflect these changes.

Soil samples were obtained at each of 24 sites (fig. 2). Insofar as possible, each site was sampled at a time of maximum moisture content and again at minimum moisture content. Samples were obtained with a 2-in (5.08 cm) diameter auger in consecutive depth increments of 3.9 in (1 dm) to a depth of 47 in (12 dm). All the soil extracted was retained for the purpose of determining moisture content, moisture-sorption forces, and the bulk density.

Each oven-dried sample of soil was saturated with distilled water as prescribed by the U.S. Salinity Laboratory staff (Richards and others, 1954) and its moisture content at saturation was determined. This measure was obtained because the "saturation moisture capacity" of soils is related to their ability to retain moisture in the range of wetness encountered under field conditions.

Erosion transects on upland slopes between permanent bench marks were established to measure changes in the hillslope profile due to overland flow. In 1971, surveys were made of 12 transects approximately parallel to the surface contours. These transects (see fig. 2 for location) were distributed equally between the east- and west-facing slopes and the used and unused basins. In the used basin, care was taken to establish the transects across the trails, the undisturbed intertrail areas and prominent rills insofar as possible. Resurveys of the erosion transects were made in the spring of 1973 and again in 1975.

Plant cover was measured with the step-point method described by Evans and Love (1957). Essentially this method entails recording the kind of ground-surface cover intercepted by a pin dropped at each step along a predetermined route. One-hundred-step transects were run at eight of the soil sampling sites in 1971 and at four of the sites in 1975. For this study, rock, grass, annual forbs, mormon tea, rabbitbrush and bare soil were recorded.

Results of the investigation

The data collecting program was started in February 1971 after dam construction, installation of recorders, and surveys of the reservoirs and erosion transects were completed. The period from February 1971 to November 1972 was marked by drought that was broken dramatically by a series of runoff-producing storms in November 1972. As a result, the dams were breached and the record of these events is complete. By late summer 1973, the dams were repaired and the collection of surface-water data resumed. Since that time, winter storms have produced runoff to both reservoirs in December 1974, and in January, February, and April 1975.

Precipitation

The total daily precipitation and the maximum 5-, 15-, and 30-minute intensities for events exceeding 0.3 in (7.6 mm) are summarized in table 5. In the intensity column of table 5, the values to the left of the dash indicate the time interval, in minutes, for which the intensity is given. Intensities less than 0.24 in/hr (6.1 mm/hr) are not shown.

The amounts recorded at three gages generally agree except for periods of gage malfunction. However, the amounts recorded by gage 2 tend to be slightly larger (0.01-0.04 in) (0.3-1.0 mm) than those recorded by the other two gages. Considering only the precipitation days when all three gages were operating properly, gage 2 recorded amounts larger than the other two gages on 49 (35 percent) of the days. For the same set of precipitation days, gage 3 recorded larger amounts than gages 1 and 2 on only 20 of the days, and gage 1 recorded larger amounts on only 16 of the days. A difference in exposure is one possible explanation for the larger amounts recorded at gage 2. Gage 2 is on an east-facing slope and may receive some protection from the prevailing winds that is not afforded gages 1 and 3.

About 95 percent of the precipitation at the Panoche Hills study area occurs during the winter season (October through April) with the greatest amounts occurring from November through February. Amounts recorded for the winter seasons (October through April) are as follows:

Year	Amount[1] (in)
1971-72	2.36
1972-73	12.78
1973-74	8.18
1974-75	9.39
Average	8.18

[1]Average of three gages.

Most of the precipitation events were smaller than one-half inch (12.7 mm) per 24 hours. Precipitation was recorded on 294 days during the period of record. One-tenth inch or less was recorded for 196 (67 percent) of the days and amounts greater than 0.5 in (12.7 mm) was recorded for only 13 days (fig. 3). The average annual precipitation received during the 4-year period from March 1, 1971 to February 28, 1975, was 8.37 inches (212.6 mm). The maximum precipitation recorded for a 12-month period from March through February was 11.25 inches (285.7 mm) in 1972-73. The minimum amount for a 12-month period was 5.30 inches (134.6 mm) in 1971-72.

Precipitation intensities were generally less than 0.5 in/hr (12.7 mm/hr) for 5-minute intervals and less than 0.3 in/hr (7.6 mm/hr) for 30-minute intervals. During the period of record, only five storms produced 5-minute intensities greater than 0.5 in/hr (12.7 mm/hr). Three of these storms produced runoff and the fourth one probably did but it occurred when the reservoir gages were not operating. The maximum 5-minute intensity was 2.40 in/hr (61 mm/hr) recorded at gages 2 and 3 on November 4, 1972. The storm of April 10, 1975, produced 5-minute intensities in excess of 1.08 in/hr (27.4 mm/hr).

Runoff

Runoff records are given in tables 1 and 2. The records are incomplete for the November 4, 1972 storm. The amount of inflow to the reservoirs after dam 1 failed was estimated on the basis of precipitation received after the failure. When dam 1 was reconstructed, its position and orientation were changed slightly with the resulting 1.73-acre (0.01 km^2) increase in the area of the used basin and a corresponding decrease in the area of the unused basin. The reconstructed reservoirs also had significantly larger volumes.

The differences in runoff from the two basins is striking. Ten runoff events occurred in the used basin while only five occurred in the unused basin. The total unit runoff (runoff volume per unit area) from the used basin was nearly eight times that from the unused basin. These differences are attributed to lack of vegetative cover and the high degree of soil compaction on the motorcycle trails. The effects of these conditions will be more fully discussed later in this report. A double-mass analysis of the runoff data showed no recovery trend of the used basin with respect to runoff-producing characteristics. If such a trend exists, it is not large enough to be detected by the measurement techniques used in this study.

A comparison of the runoff from the two basins and the associated storm characteristics are given in table 3. A storm is defined as a period of precipitation next proceding or including the runoff period and which is separated from other storms by 2-hour periods during which no precipitation was recorded. The intensity values given were calculated from the maximum amount occurring in a 5-minute recording interval during the storm period. The antecedent precipitation is the sum of the daily precipitation for 3 days prior to the day of the storm plus any amount that occurred prior to the storm on the same day. It is considered as an index of antecedent moisture conditions in the basins.

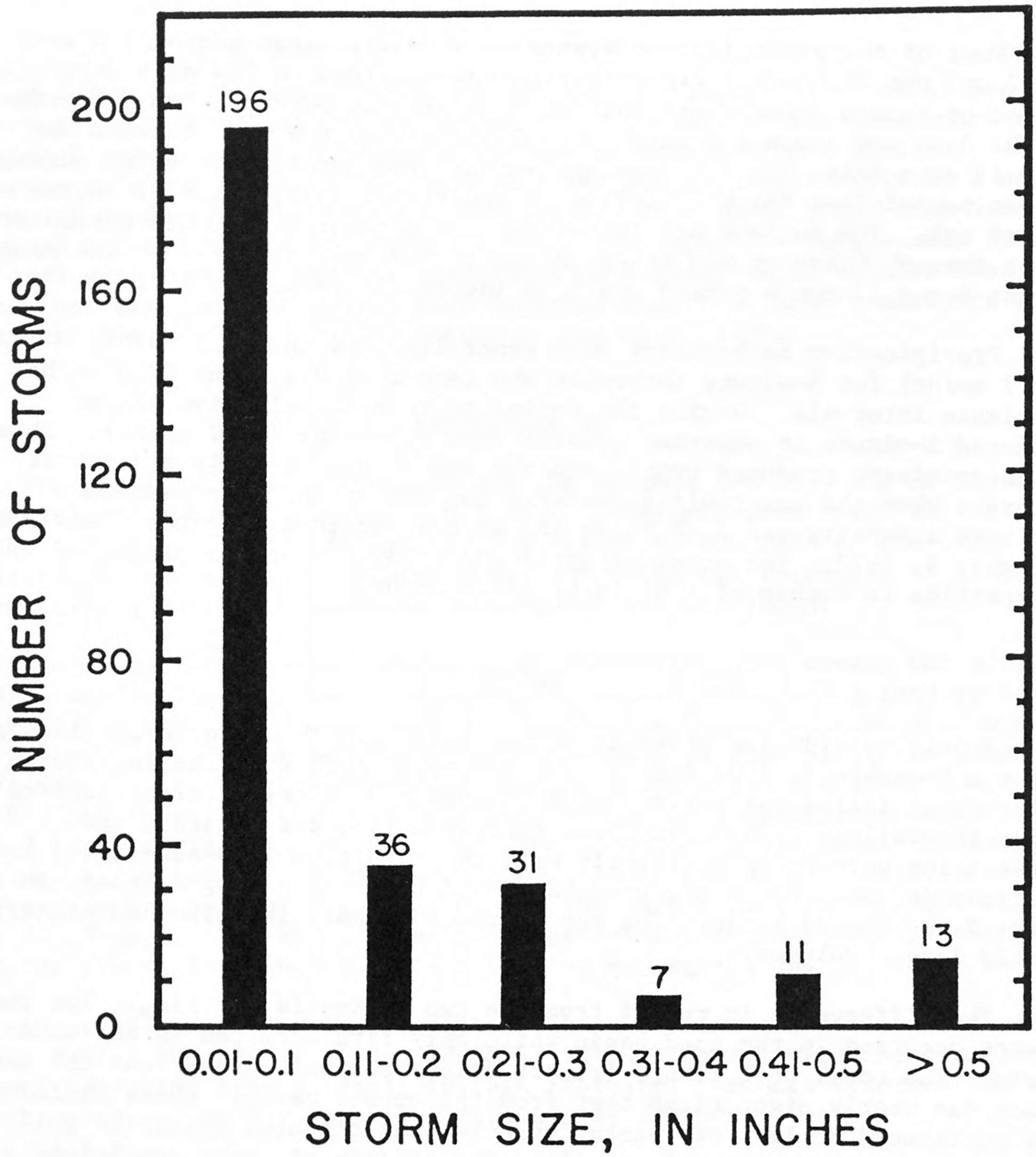

Figure 3.--Distribution of storms by size at Panoche Hills, 1971-75.

Table 1.--*Storm runoff measured in Panoche Hills reservoir 1*

[Location.--Lat. 36°42'30"N., long. 110°48'05"W., NE¼ sec. 18, T. 14 S., R. 11 E., northeast of Mercey Hot Springs, California.

Drainage area.--0.017 mi^2 or 11.09 acres - 1971 to 1972.
0.020 mi^2 or 12.82 acres - 1973 to 1975.

Records available.--March 3, 1971, to November 4, 1975
September 13, 1973, to April 30, 1975.

Gage.--Digital water-stage recorder.

Runoff and discharge determination.--Contents of reservoir and volume of inflow computed from stage-capacity curve of the reservoir.

Capacities of reservoir at spillway elevation are as follows:
May 1971 - 0.85 acre-ft; May 1973 - 3.21 acre-ft; April 1975 - 3.17 acre-ft.

Maxima.--Maximum storm inflow 0.250 acre-ft or 12.50 acre-ft per square mile, February 1-2, 1975.

Remarks.--Records fair. Dam was breached during storm of November 4, 1972. No record from November 5, 1972, until September 13, 1973, when dam repair and reinstallation of gages was completed]

Date[1]	Inflow stored (acre-ft)	Spill (acre-ft)	Total inflow		
			Acre-ft	Acre-ft per mi^2	Inches
1971					
April 14	0.019	0	0.019	1.10	0.020
December 26	.034	0	.034	2.00	.038
For year	.053	0	.053	3.10	.058
1972					
November 4	[2].222	0	.222	13.059	.245
For year[3]	.222	0	.222	13.059	.245
1974					
January 7	.005	0	.005	.25	.005
December 3	.015	0	.015	.75	.014
For year	.020	0	.020	1.00	.019
1975					
February 1-2	.250	0	.250	12.50	.234
March 5	.001	---------	.001	.05	.001
March 7	.005	0	.005	.25	.005
April 8	.004	0	.004	.20	.004
April 10	.054	0	.054	2.70	.050
For year	.314	0	.314	15.70	.294

[1]No record from November 4, 1972, to September 13, 1973. No runoff during the remainder of 1973.

[2]Measured inflow, 0.184 acre-foot. Estimted inflow to reservoir after failure of dam, 0.038 acre foot.

[3]Partial year.

[4]Partial year. Record discontinued April 30, 1975.

Table 2.--*Storm runoff measured in Panoche Hills reservoir 2*

[Location.--Lat. 36°42'30"N., long. 120°48'05"W., NE¼ sec. 18, T. 14 S., R. 11 E., northeast of Mercey Hots Springs, Calif.

Drainage area.--0.013 mi^2 or 8.57 acres - 171 to 1972
0.010 mi^2 or 6.84 acres - 1973 to 1975

Records available.--March 3, 1971, to November 4, 1975
September 13, 1973, to April 30, 1975

Gage.--Digital water-stage recorder.

Runoff and discharge determinations.--Contents of reservoir and volume of inflow computed from a stage-capacity curve of the reservoir.

Capacities of reservoir at spillway elevation are as follows:
May 1971 - 0.57 acre-ft; May 1973 - 1.17 acre-ft; April 1975 - 1.17 acre-ft.

Maxima.--Maximum storm inflow of record 0.039 acre-ft or 3.00 acre-ft (estimate) per square mile, November 4, 1972.

Remarks.--Records fair. Dam was partially breached during storm of November 4, 1972. No record from November 5, 1975, to September 13, 1973, when dam repair and reinstallation of gages was completed]

Date[1]	Inflow stored (acre-ft)	Spill (acre-ft	Total inflow		
			Acre-ft	Acre-ft per mi^2	Inches
1972					
November 4	[2]0.039	0	0.039	3.00	0.056
For year	.039	0	.039	3.00	.056
1974					
Janury 7	.0009	0	.0009	.082	.002
December 3	.0003	0	.0003	.027	<.001
For year	.0012	0	.0012	.109	.002
1975					
February 1-2	.0110	0	.0110	1.0	.019
April 10	.0010	0	.0010	.09	.002
For year[3]	.0120	0	.0120	1.09	.021

[1]No runoff in 1971. No record from November 4, 1972, to September 13, 1973. No runoff during remainder of 1973.

[2]Measured inflow, 0.032 acre-foot. Estimated runoff to reservoir after failure of dam 1, 0.007 acre-foot.

[3]Partial year. Record discontinued April 30, 1975.

Table 3.--*Surface runoff and associated precipitation at the Panoche Hills study area*

	Precipitation				
	Storm[1]				
	Total (in)	Maximum 5-minute intensity (in/h)	Antecedent precipitation (in)[2]	Runoff (in)	
				Used area	Unused area
1971					
April 14	0.66	0.54	0.23	0.020	0
December 26	.54	.36	.16	.038	0
1972					
November 4	1.00	2.40	0	.245	.056
1974					
January 7	.81	.12	.78	.005	.002
December 3	.56	.42	.98	.014	<.001
1975					
February 1-2	2.07	[3] .36	[3]2.18	.234	.019
	2.30	[4] .48	[4]2.50		
March 7	.28	.24	.43	.005	0
April 8	.18	.42	.40	.004	0
10	.40	1.20	.27	.050	.002

[1]Storm precipitation is that which occurred nearest the time of the runoff event and may have lasted more than 1 calendar day. Storms were separated by 2-hour periods in which no precipitation was recorded.

[2]Total precipitation that occurred for up to 3 days before the storm.

[3]Basin 1; average of gages 1 and 2.

[4]Basin 2; gage 2.

The recorded periods of runoff resulted from various combinations of total storm precipitation, intensity, and antecedent precipitation. Not one of these precipitation variables is clearly the dominating cause of runoff at Panoche Hills. Examination of the three largest storms illustrates this. The largest storm (total storm precipitation was 2.07 in or 52.5 mm) produced a moderate 5-minute intensity of 0.48 in/hr (12.2 mm/hr) and the antecedent precipitation was only 0.13 in (3.3 mm). The second largest storm (1.0 in or 25.4 mm) produced a maximum 5-minute intensity of 1.20 in/hr (30.5 mm/hr) and there was no antecedent precipitation. The third largest storm produced only 0.81 in (20.6 mm) of precipitation and its maximum 5-minute intensity was only 0.12 in/hr (3.1 mm/hr) but the antecedent precipitation was 0.78 in (19.8 mm). In each case a different storm variable was dominant. These three storms produced runoff from both study basins.

The storms that produced the smallest volumes of runoff may provide an indication of the minimum values of the three precipitation variables (total precipitation, intensity, antecedent precipitation) required to produce runoff in this area. The storm values for the smallest runoff events in each basin are as follows:

Event date	Storm precipitation (in)	Maximum 5-minute intensity (in/h)	Antecedent precipitation (in)	Runoff (in)
		Used basin		
March 5, 1975	0.42	0.36	0	0.001
Apr. 8, 1975	.18	.42	.40	.004
		Unused basin		
Jan. 7, 1974	.81	.12	.78	.002
Dec. 3, 1974	.56	.42	.98	.001
Apr. 10, 1975	.40	1.20	.40	.002

It appears that if the values of two of the three variables approximate or exceed 0.4 in (10.2 mm), runoff is likely in the used basin but not in the unused basin. In the unused basin, runoff occurred when values of two of the precipitation variables approximated 0.4 in (10.2 mm) and the third variable was significantly greater than 0.4 in (10.2 mm). It appears that if one variable is less than 0.4 in (10.2 mm), the other two must be significantly greater than 0.4 in (10.2 mm) for runoff to occur in the unused basin. Based on these observations, it is probable that runoff occurred in both basins during the periods of November 10-15, 1972, and February 11-12, 1973, and in the used basin on January 4, 1973. There is no record of such events because of the damage to the measuring reservoirs on November 4, 1972.

Sediment yield and erosion transects

The 1971-72 sediment-yield record was lost during the storm of November 4, 1972. Failure of the dams resulted in a complete loss of the sediment deposited up to that time. Therefore, the period of record for sediment yield at Panoche Hills extends only from May 1973 to April 1975.

From September 1973 to April 1975, seven storm produced inflow to reservoir 1 from the used basin totalling 0.334 acre-ft (412 m^3) or 16.70 acre-ft/mi^2 (7,950 m^3/km^2). A total of 0.36 acre-ft (444 m^3) or 1.80 acre-ft/mi^2 (857 m^3/km^2) of sediment was deposited in reservoir 1 during this 2-year period. In the same period, only four storms produced inflow to reservoir 2 (from the unused basin) totalling 0.013 acre-ft (16 m^3) or 1.2 acre-ft/mi (571 m^3/km^2). Sediment yield to reservoir 2 was so small that it could not be detected by the measurement technique used.

The purpose of the erosion transects was to measure surface changes due to sheet erosion and rilling. The results of typical transect surveys are shown in figure 4. These four transects represent east- and west-facing slopes in the used and unused basins. The remaining eight transects showed about the same degree of surface change as those shown in figure 4. Apparently the short length of the study and low precipitation did not produce erosional changes that could consistently be detected with the measurement techniques.

In a similar erosion study in the Panoche Hills area, W. B. Bull (written commun., 1972) measured erosion rates of 3.4 mm $\pm$ 1 mm (0.13 in $\pm$ .04 in) in a 4-year period on hillslopes in undisturbed areas. Figure 4 shows (transects 2-A and 6) that the motorcycle trails have become a focal point for rill development. In addition, piping and headcuts have developed on the steep slopes adjacent to the stream channel in the motorcycle-use area. The cause and effect relationship between the trails and the rills is evident from casual inspection as there has been little or no development of rills outside the trails. Also, there has been almost no rilling and no piping within the unused area. Figure 5 shows four photographs of rilling and piping in the motorcyle-used basin at Panoche Hills. It is apparent that under the climatic regimen existing in the Panoche Hills all the erosion processes will continue to operate in the used basin although they may be slower if restricted access is continued.

Soil-moisture characteristics

The ability of soil to absorb and retain water has a significant effect on the hydrology and vegetation of an area. Precipitation that does not infiltrate the soil either evaporates or becomes surface runoff. Water that infiltrates the soil is adsorbed to the soil particles by a force that varies with particle size and the quantity of water. Fine-grained soils have a larger capacity for water than coarse-grained soils and the water is held by a much greater force in a relatively dry soil than in a wet one.

The unit force with which a soil retains water is called the moisture-sorption force and is expressed as pF in this report. A pF value is the logarithm of the height in centimetres of a column of water that exerts a unit force at its base equal to the moisture-sorption force. Thus, pF 3 indicates a column of water 1,000 cm (394 in) high or a unit force of 1,000 gm/cm^2 (14.2 lb/in^2). The methods used to determine soil-moisture content and pF values are described by McQueen and Miller (1968). Since the moisture-sorptive force is a function of soil wetness (quantity of water in the soil), pF is an index of wetness and of the relative availability of soil moisture to plants. A high pF value indicates a small quantity of soil moisture that is relatively difficult for plants to remove.

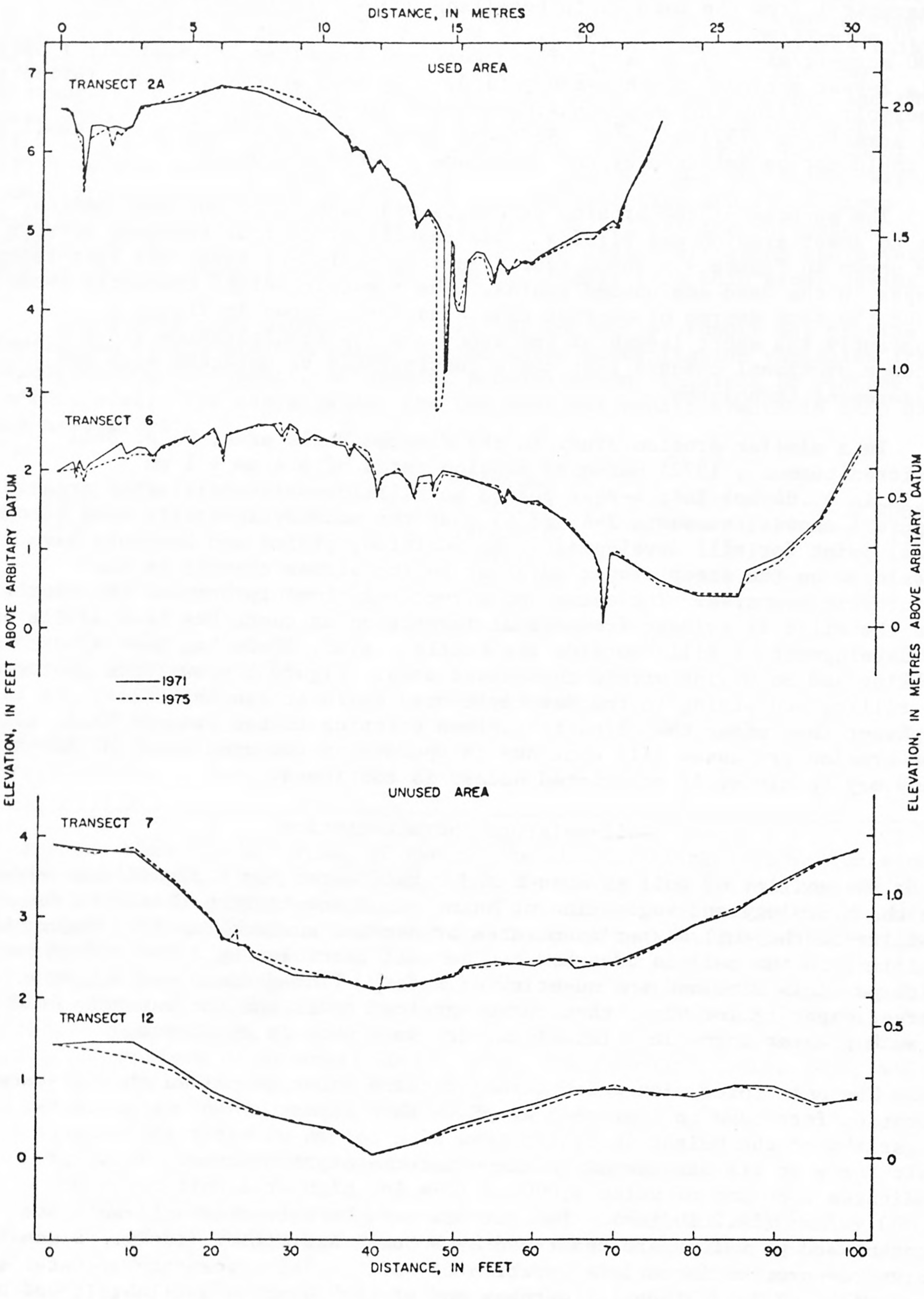

Figure 4.--Typical erosion transects at Panoche Hills.

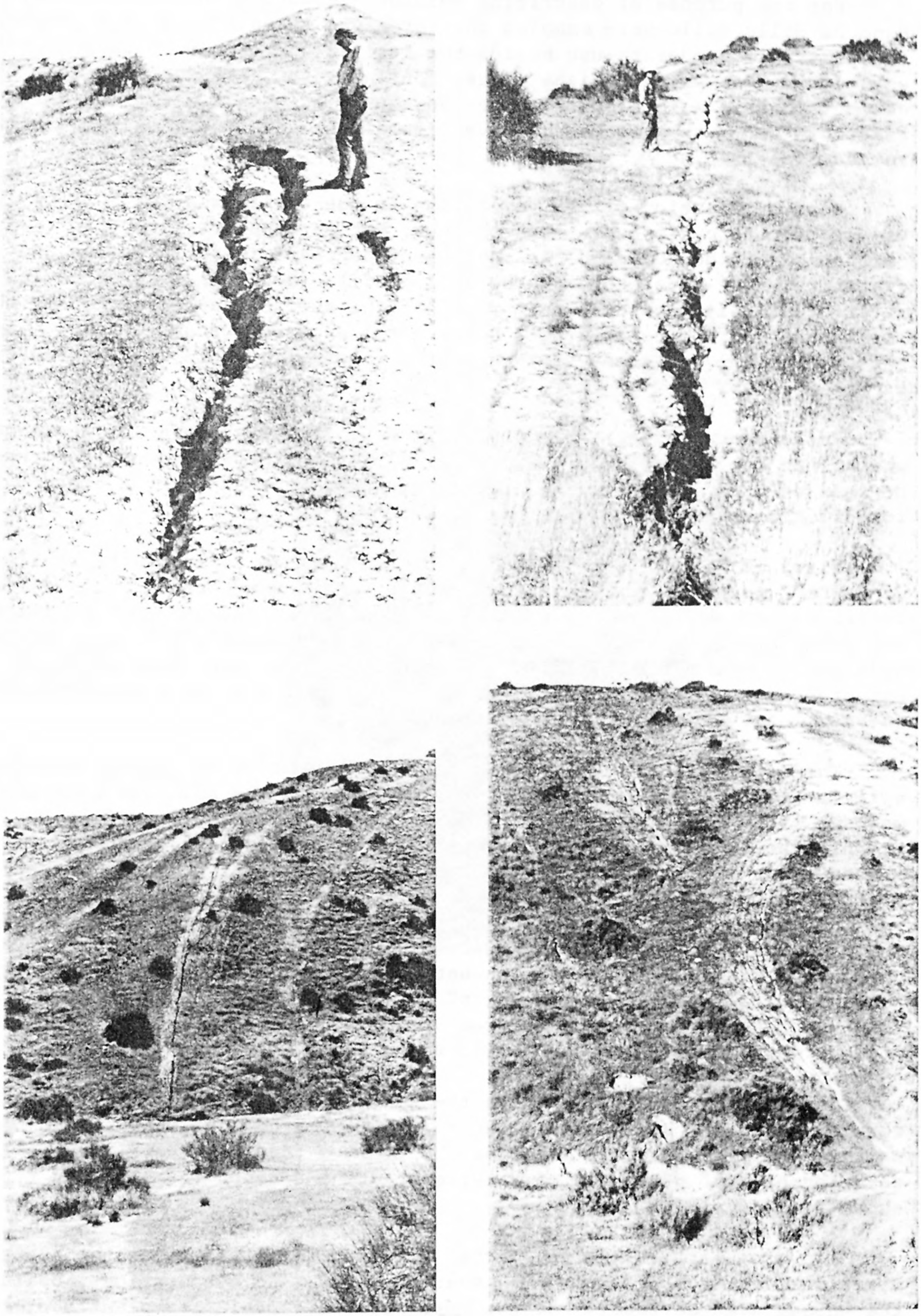

Figure 5.--Typical rilling and piping caused by trailing in the Panoche Hills.

For the purpose of describing moisture-retention characteristics, the Panoche Hills soils were sampled for three use types. These were heavey-use in the trails, moderate-use beside the trails, and nonuse in basin 2. Each use type was sampled at eight sites, four near the base and four near the top of the slopes. A total of 24 sites were sampled on six different dates. Figures 6 and 7 show representative view of use and nonuse sampling sites, respectively.

Near eradication of the vegetation on the trails was the most obvious effect of motorcycle use. Less obvious, but perhaps more important, was the compaction of the soil and the subsequent decrease in infiltration and distribution of water through the soil profile (wetting). As a result, much water previously used by plants runs off the surface, as evidenced by the eight-fold difference in runoff between the used and unused basins. Under this condition, the recovery rate of the vegetation would be expected to be extremely slow.

The measured effects of motorcycle use are illustrated in figures 8 and 9, which show the variation of soil bulk density and pF with depth for three degrees of use. In each case, the data points represent the average values for all sites sampled on the indicated date.

Figure 8 shows the bulk density of the surface soils of the trails to be 37 percent greater than that from soils of the unused areas. This difference decreases somewhat erratically to less than 12 percent at depth of 1.2 m, but is nonetheless, evidence of compaction to depth over 1 meter. Although a decrease in the bulk density of the surface soils over time might be expected, a comparison of bulk densities of the first and last samplings (4-year interval) showed no such trend.

The effect of this compaction on the movement of the water through the soil is shown by the relation of pF to depth when the soil was near maximum wetness (fig. 8). In the upper 7 dm (27.5 in) of the soil profile, the highest degree of wetting (low pF, average value 3.24) occurred in the unused areas where compaction was least, and the least wetting (high pF, average value 3.42) occurred on the trails where compaction was greatest. This difference in pF represents approximately a 50 percent difference in actual moisture-sorption force (g/cm^2). The degree of wetting of soils beside the trails generally falls between the values of these use-types. Below 7 dm (27.5 in), the highest pF was found in the nonuse type. This reversal may be due to the removal of additional water by vegetation, a process not occurring on the trails where vegetative cover is minimal.

The effects of compaction on the amount of water available for plant use were investigated by measuring the soil-moisture content when it was near its maximum and again when it was near the minimum for the year. The resulting relationships of pF (index of water content) and depth for each use type are shown in figure 9.

The area between the two curves approximately represents the quantity of water removed from the soil each year by plants and evaporation. Soils in the unused area obviously had the most water available for plant use; the trail soils had the least and the soils beside the trails had an intermediate

Figure 6.--Motorcycle trail and less disturbed area typical of in-trail and beside-trail sampling site with easterly exposure.

Figure 7.--General aspect of undisturbed area with easterly exposure.

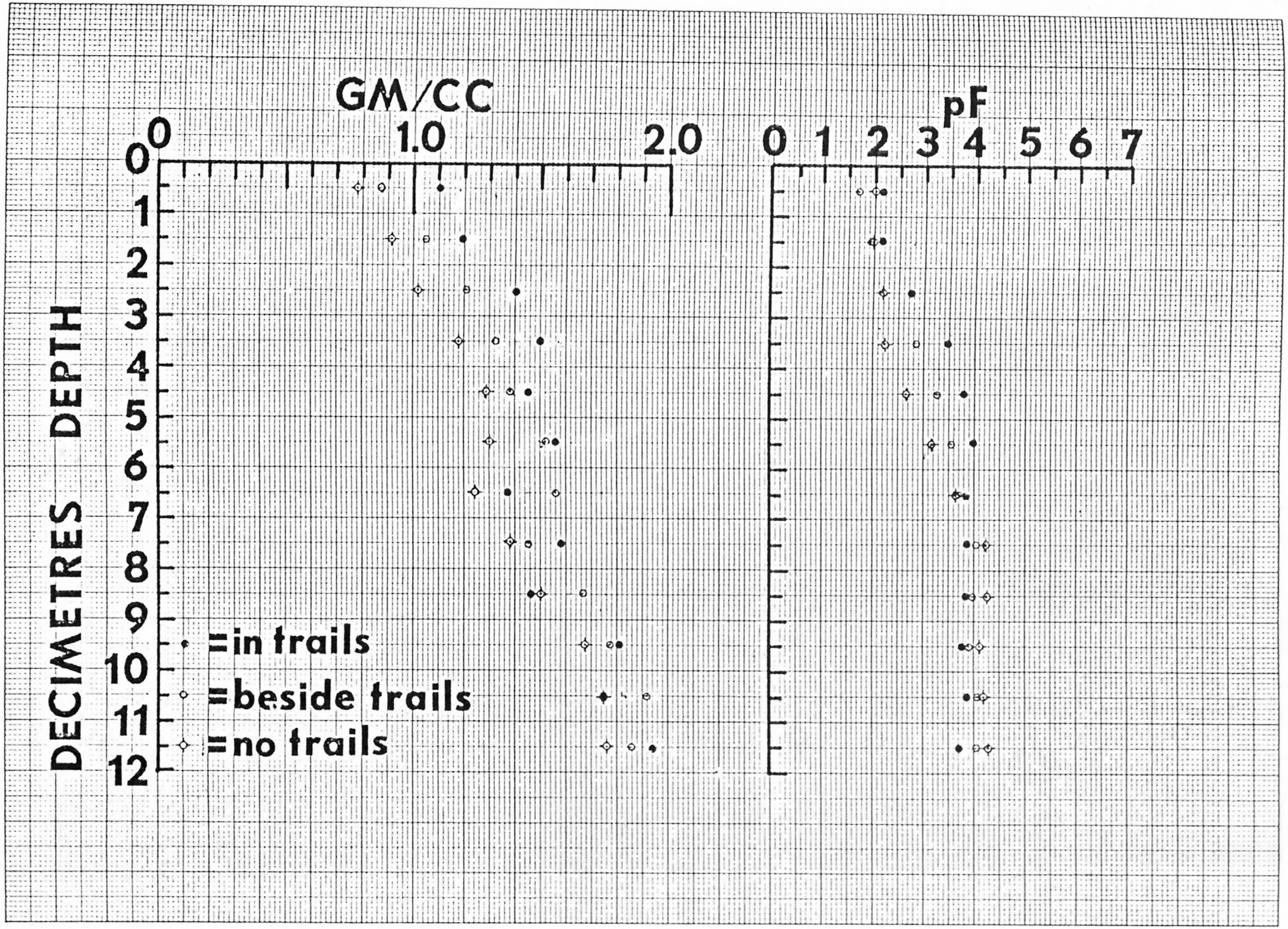

Figure 8.--Variation of average bulk density and pF with depth for three degrees of use.

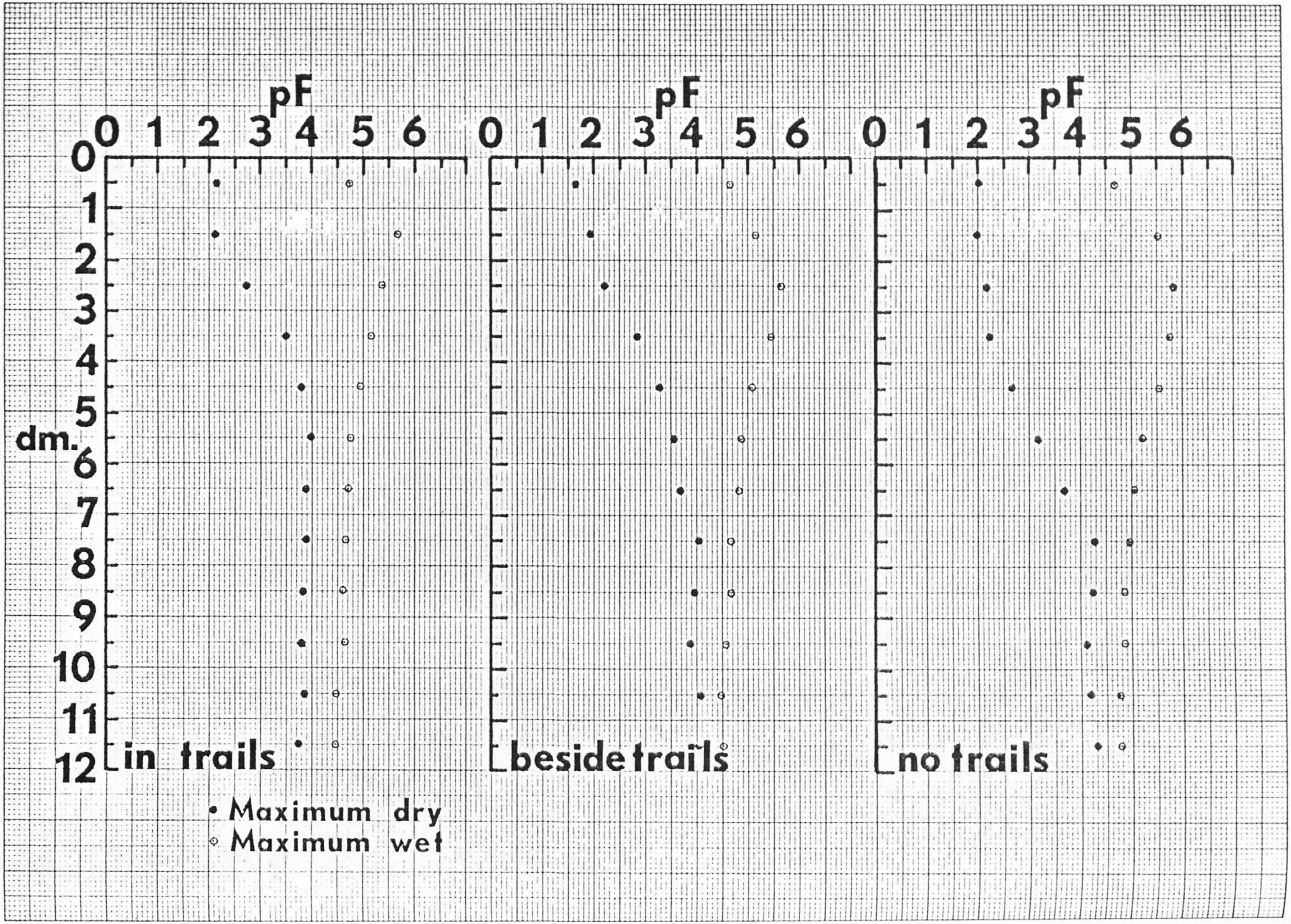

Figure 9.--Variation of average pF values with depth at maximum and minimum of wetness.

amount. Actual amounts of water in the 12-dm (47.2 in) columns of soil represented by figure 9 are 17 cm (6.7 in) in the unused area, 15 cm (5.9 in) for beside-trail sites and 14 cm (5.5 in) for in-trail sites. Thus, 20 percent more soil water was available to plants in the unused area than in the trail areas.

Figure 9 shows that a smaller quantity of water enters the trail soils and that the water is less easily distributed through the soil profile. Since reduction of soil pore size resulting from compaction by the motorcycles is the reason for this reduced water intake, it follows that the recovery potential of vegetation on the trails is limited unless there is a reduction of the bulk density of the surface soils. The introduction of additional water into the soil could initiate a natural soil-bulking process, which should result in gradually increasing the depth and degree of soil wetting to pre-use levels. This could be accomplished by a treatment that breaks the hardened surface soil and retains water on the slope instead of allowing it to run off.

Vegetative cover

Extreme alteration of the vegetative cover by off-road vehicles is evident. The trails were completely denuded leaving raw erosion scars marking the slopes. Even the intertrail areas were damaged, making the contrast with the unused basin more pronounced. Since the study began in 1971, the entire area has been fenced and neither motorcycle use or livestock grazing has been permitted. The only disturbance to the land surface during the study period has been the formation of rodent trails, which are quite numerous in some parts of the study basins.

A summary of the ground-cover measurements is given in table 4. The herbaceous vegetation consists mainly of filarie with minor amounts of annual grasses. The amount of rock measured was generally 5 percent or less so that the percentage bare soil approximates 100-percentage vegetative cover.

Analysis of these data with regard to the hydrologic effects of the motorcycle use make it clear why runoff and sediment yield are so much higher on the used basin. At the beginning of the study, the average percentage bare soil in the used basin was 55 percent and in the unused basin it was only 31 percent. Other studies in arid regions (Branson and Owen, 1970) show that an increase in runoff is highly correlated with an increase in bare soil.

The greatest change in vegetative cover during the study period occurred on the trails of basin 1. Here the cover improved from about 20 percent in 1971 to about 39 percent in 1975. Most of the improvement was due to an increase of filarie. During the same period, the vegetation in the unused area only increased from 66 to 75 percent. Note that in spite of a sizeable increase by the end of the study, the vegetative cover on the trails was still only slightly more than one-half that of the unused area. The improvement of the cover in the unused area may be an indication of the effect of grazing on vegetation in the Panoche Hills area.

Table 4.--*Percentage of ground cover in Panoche Hills basins, 1971-75*

	Basin 1 (used)									
	East-facing slope				West-facing slope				Basin average[2]	
	In trails		Beside trails		In trails		Beside trails			
	1971	1975	1971	1975	1971	1975	1971	1975	1971	1975
Woody vegetation										
Mormon Tea	T	T	3	2	0	0	0	3	3	3
Rabbitbrush	T[1]	6	3	3	0	0	0	T	1	3
Herbaceous vegetation	27	30	71	70	13	42	44	52	37	58
Total vegatation	27	36	77	75	13	42	44	55	42	65
Bare Soil	72	64	23	25	83	53	44	42	55	32
Rock	1	T	T	T	4	5	2	3	3	3

	Basin 2 (unused)					
	East-facing slope		West-facing slope		Basin average[2]	
	1971	1975	1971	1975	1971	1975
Woody vegetation						
Mormon Tea	4	4	1	2	3	2
Rabbitbrush	2	1	T	1	3	6
Herbaceous vegetation	71	77	57	57	60	67
Total vegetation	77	82	58	60	66	75
Bare soil	22	18	41	39	31	23
Rock	1	0	1	1	3	2

[1]T indicates presence but less than 1 percent.

[2]These values obtained from random transects crossing whole slope and are not averages of the other values in this table.

Measurements of the plant cover on the trails provide an indication of the time required for full recovery. If recovery were to continue at the measured rate (5 percent per year), it would take about 7 additional years (11 years total from beginning of study) for the plant cover on the trails to equal that of the unused area in 1975. However, as discussed previously in this report, there are indications that the vegetation will not recover to this extent unless a decrease in the bulk density of the soils in the trails occurs first.

The ground-cover measurements clearly show that, in this area, east-facing slopes support significantly more vegetation than the west-facing slopes. In only one instance (in-trails, 1975) was the value for west-facing slopes slightly greater than that for the east-facing. More abundant vegetation on the east-facing slopes reflects greater quantities of more readily available soil moisture.

In contrast, the largest increase in plant cover, during the study period, occurred on west-facing trails rather than east-facing. The reason for this is not clear but may be simply that the vegetation was initially so sparse (13 percent) on the west-facing trails that conditions were more favorable for the establishment of additional plants. Apparently, the quantities of vegetation will eventually reach an equilibrium with quantities of soil moisture available in the soils on both both exposures. The vegetation can, therefore, increase depending on moisture availability, but thereafter most improvement would be expected on the east-facing slopes where less soil water is removed by solar energy.

The equilibrium quantities would be different for each use-type and would tend to increase as soil bulk densities decrease. Equilibrium quantity values are indicated by the plant-cover measurements on the west-facing slopes. These are 60 percent for the unused area, 55 percent for the areas beside the trails, and 45 to 50 percent on the trails. These values suggest that there may be some additional improvement of the plant cover on the trails but little, if any, improvement beside the trails unless soil bulk densities are reduced.

DOVE SPRING CANYON

Description of area

Dove Spring Wash, an east-trending ephemeral stream, occupies the floor of Dove Spring Canyon. The valley is bordered by low hills that are mantled with a weathered granite lithosol. The friable surface material breaks down quite easily under mechanical impact and leaves a coarse, sandy detritus. This mantle greatly reduces runoff by absorbing most of the precipitation falling on it. The vegetation is sparse and consists primarily of desert shrubs, Joshua trees *(Yucca brevifolia)*, and some annual grasses on north-facing slopes.

The Dove Spring Canyon area borders the high desert region of south-eastern California in the rain shadow of the southern Sierra Nevada. The largest amounts of precipitation are usually received during the winter season with only occasional thunderstorms occurring during the summer. Average annual precipitation at Red Rock State Park, located 2 miles east of the

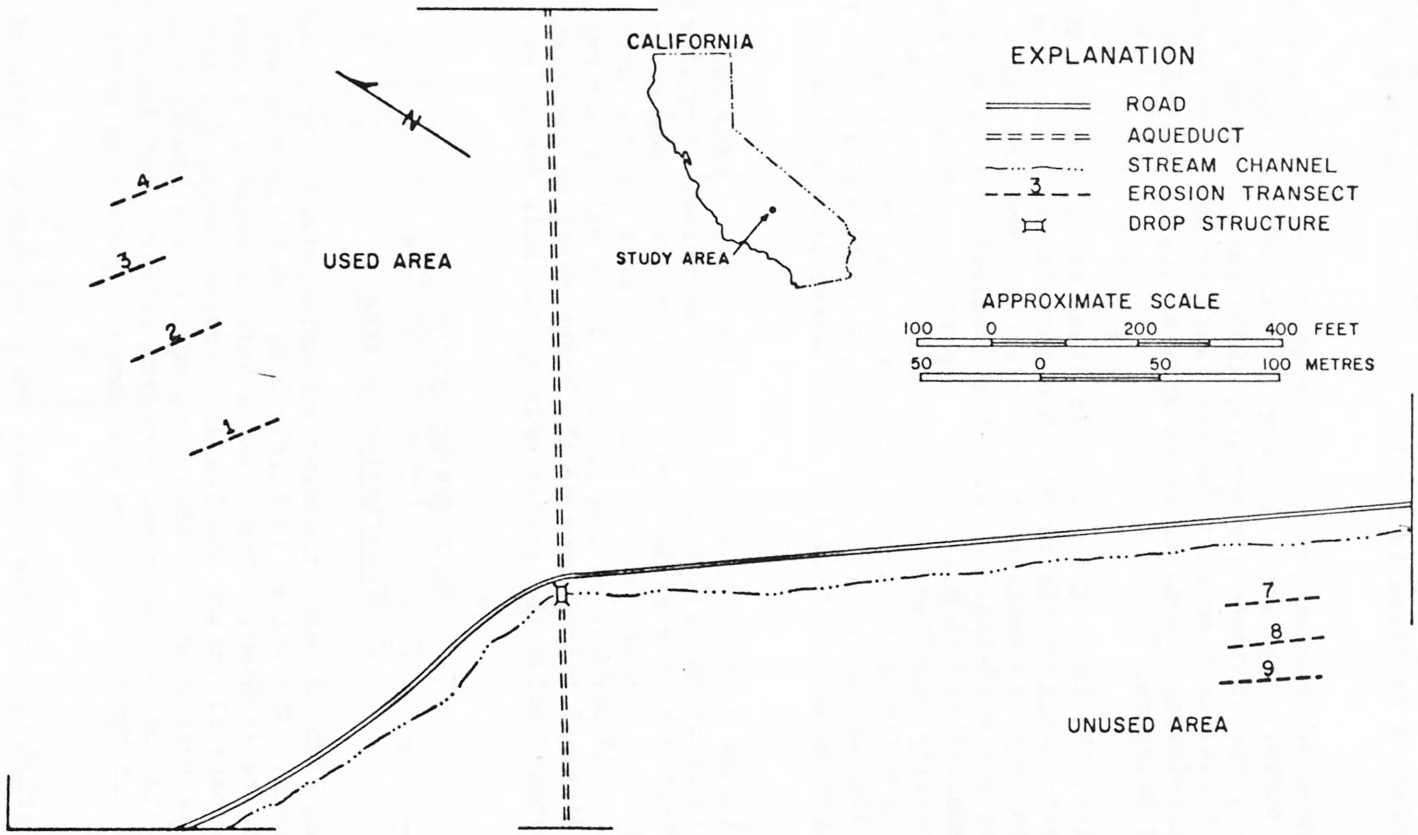

Figure 10.--Map showing locations of erosion transects at the Dove Spring Canyon study area

Dove Spring site was 5.4 in (138.2 mm) for the 3-year period 1973-75. A high-intensity storm in July 1974 was reported to have caused extensive flooding in the vicinity of Red Rock State Park. During September 1975, another large storm caused extensive erosion in the study area and resulted in at least one death.

Method of investigation

A heavily used area, such as Dove Spring Canyon, presents formidable problems for any investigator attempting continuous or repetitious measurement of the natural environment. Instrumentation is constantly subject to vandalism and site markers are in danger of being removed or damaged. For this reason, repeated surveys of established transects was the only type of measurement attempted at the Dove Spring site.

In order to make the steel pins marking the ends of the transects as unobtrusive as possible, the transects were located so that the pins could be placed next to large shrubs, rocks, or Joshua trees. This action afforded some help in relocating the pins as well. However, it also resulted in some loss of measurement precision because often the resulting altitudes of pins thus placed were less than the maximum altitude of the area between the pins, making exact realignment of the transects very difficult.

Originally five erosion transects ranging from 100 to 130 ft (30.5-39.6 m) in length were established across a heavily used trail west of the Los Angeles aqueduct and on the north side of the valley (fig. 10). These were placed perpendicular to the trails and, therefore, did not necessarily parallel the surface contours. The transects extended to the undisturbed area on either side of the trails. Two more transects were placed on a heavily used slope on the south side of the valley. These two transects and one of those on the north side could not be relocated and were never resurveyed.

Three additional transects approximately 130 ft (39.6 m) in length were established in an undisturbed area east of the aqueduct on a north-facing slope (fig. 10). These transects were to serve as a comparison with those on the used areas. However, each year this slope received more and more use until, in the spring of 1975, a well-established trail crossed all three transects. Therefore, these transects could only be used to show any deterioration with increased use. All the transects were established in October 1970, and were resurveyed five times at approximately 1-year intervals.

Results of the investigation

Figure 11 shows some typical results of the transect surveys. Transect numbers increased from the bottom to the top of the slope; that is, transect 1 was located near the bottom of the slope and transect 4 near the top in the used area (fig. 11). Transect 8 was located approximately midway up the unused slope.

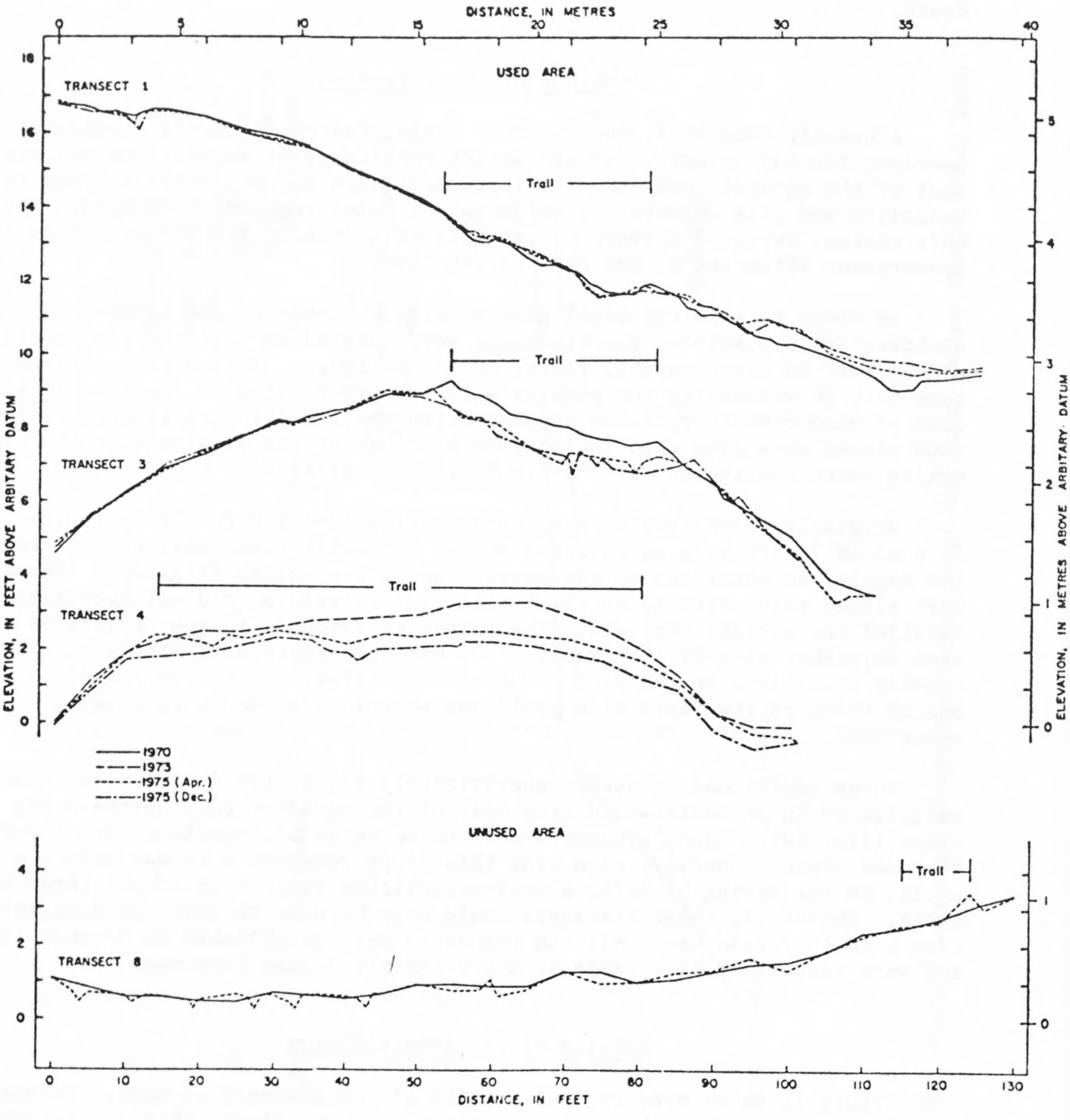

Figure 11.--Typical erosion transects at the Dove Spring Canyon study area.

The most significant changes were found in transects 3 and 4, located on the upper part of the used slope. Transect 3 shows a loss of 0.5-0.75 ft (0.15-0.23 m) of surface material from the trail areas since 1970. Transect 4 shows a loss of 0.75-1.00 ft (0.23-0.30 m) since 1973. Transect 1 shows little change in the trail section since 1970, but 0.2-0.3 ft (0.06-0.09 m) of material has been deposited on the right-hand side of this transect. The material was probably removed by a combination of mechanical action by the motorcycles and wind and water. The effect of the motorcycles is to eradicate the vegetation and loosen the soil material making it highly susceptible to wind and water erosion. Mechnical movement by the motorcycles along with the action of gravity also tends to move the soil material in a downslope direction.

The changes shown by transect 8 are not so striking, mainly because use of this slope has been low to moderate during the period of record. The most obvious change occurring on this slope is the gradual eradication of the vegetation, which of course is not shown by surface altitude measurements. Transect 8 does, however, show some initial rilling and some mechanical movement of material as evidenced by the ridge on the right side of the trail.

SUMMARY AND CONCLUSIONS

It is evident that off-road vehicles have had a damaging impact on the soil, plant cover, and hydrologic processes in the study areas. The severity of impacts is related to the intensity of use and, in arid or semiarid environments, the rehabilitation of damaged areas is constrained by availability of soil moisture.

In the Panoche Hills study, the basin used by motorcycles produced about eight times as much runoff as the unused basin. The large difference in rates of runoff between two adjacent basins is directly attributable to the reduction in plant cover and infiltration rates due to soil compaction in the heavily used area.

Similarly, sediment yield from the used basin was 1.8 acre-ft/mi^2 (857 m^3/km^2), while in the unused basin, the quantity of sediment delivered to the reservoir during the period 1971-75 was not measurable by standard survey methods. The erosion transects in the Panoche Hills study show only minor changes in surface elevation except in the rills developed along old trails where erosion is severe locally. Most of the sediment delivered to reservoir 1 probably came from rill erosion and bank cutting along the main channel.

In the Dove Spring Canyon study, which is still being used for hill climbing, surveys of erosion transects show both severe sheet erosion and mass movement of coarse material downslope. Erosion has been as much as 1.0 ft (0.3 m) in the period 1973-75.

The impact of motorcycle and dune-buggy use on plant cover was evident in the use areas at Panoche Hills and Dove Spring Canyon. There has been a marked recovery of plant cover (from 20 percent to 39 percent) in the trails at Panoche Hills with an accompanying reduction in percentages of bare soil since access was restricted in 1971. However, even after 5 years of nonuse, the trails of basin 1, which had been the center of motorcycle use, still have 58 percent bare soil compared with 23 percent in the unused basin. The recovery of plant cover has not been great enough to cause a measurable decrease in the amount of runoff from this basin.

Compaction of soils and reduction of permeability seem to be the most serious effects of motorcycle use in the Panoche Hills. The hydrologic effect of this action is to reduce the depth of moisture penetration in trails and to deprive plants of moisture needed for growth. Compaction was observed to depths of 1 meter or more, which means that the damage may be irreversible. However, it is possible that by breaking up the hard surface layer and impeding or preventing runoff, moisture penetration could be increased to pre-use levels.

It is concluded that the effects of off-road vehicle use in arid and semiarid environments are both serious and of long duration. Criteria for selecting areas where continued off-road vehicle use may create the least impact should include consideration of topography, soils characteristics, plant species, and seasonal distribution of precipitation as it affects plant cover and soil moisture. North- and east-facing slopes generally have a more vigorous plant cover and soil-moisture regime and should be protected. South- and west-facing slopes generally have sparse plant cover and lower soil-moisture storage. Therefore, these slopes are generally not as valuable for grazing or wildlife habitat and might be suitable for ORV recreational use.

REFERENCES

American Association for Advancement of Science Committee on Arid Lands, 1973, Off-road vehicle use: Science, v. 184, p. 500-501.

Anon, 1971, ORRV, Off road recreation vehicles: Dept. Interior Task Force Study, Nov. 1971, 123 p.

Branson, F. A., and Owen, J. R., 1970, Plant cover, runoff, and sediment yield relationships on Mancos Shale in Western Colorado: Water Resources Research, v. 16, no. 3, p. 783-790.

Carter, Luther J., 1974, Off-road vehicles: A compromise plan for the California deserts: Science, v. 183, Feb. 1974, p. 395-399.

Evans, R. A., and Love, R. M., 1957, Step point method of sampling - a practical tool in range research: Jour. Range Management, v. 10, p. 208.

Richards, L. A., and others, 1954, Diagnosis and improvement of saline and alkali soils: Agriculture Handb. No. 60, U.S. Dept. Agriculture, 160 p.

Table 5.--*Precipitation record for the Panoche Hills study area*

Date	Rain gage 1			Rain gage 2			Rain gage 3		
	Daily precipitation (inches)	Maximum intensities[1]		Daily precipitation (inches)	Maximum intensities[1]		Daily precipitation (inches)	Maximum intensities[1]	
		interval (min)	precip-itation (in/h)		interval (min)	precip-itation (in/h)		interval (min)	precip-itation (in/h)
1971									
Mar. 12	0.29	5	0.36	0.30	5	0.36	0.35	5	0.36
		15	.24	----	15	.28		15	.28
25	.12	--	----	.13	--	----	.12	--	----
26	.01	--	----	.01	--	----	.02	--	----
28	([2])	--	----	.22	--	----	([2])	--	----
29	([2])	--	----	.13	--	----	([2])	--	----
Apr. 13	([2])	--	----	.24	--	----	.22	--	----
14	([2])	--	----	.48	5	.48	.53	5	.60
		--	----		15	.36		15	.48
		--	----		30	.28		30	.34
17	([2])	--	----	.22	--	----	.20	--	----
24	([2])	--	----	.02	--	----	.02	--	----
May 2	.12	--	----	.12	--	----	.12	--	----
6	.02	--	----	.03	--	----	.02	--	----
7	.47	5	.24	.45	5	.24	.43	5	.24
8	.07	--	----	.08	--	----	.07	--	----
11	.02	--	----	.02	--	----	.01	--	----
17	.01	--	----	.26	--	----	([2])	--	----
27	.20	--	----	([2])	--	----	.24	--	----
28	.13	--	----	([2])	--	----	.13	--	----

Table 5.--*Precipitation record for the Panoche Hills Study area*--Continued

Date	Rain gage 1			Rain gage 2			Rain gage 3		
	Daily precipitation (inches)	Maximum intensities[1]		Daily precipitation (inches)	Maximum intensities[1]		Daily precipitation (inches)	Maximum intensities[1]	
		interval (min)	precip-itation (in/h)		interval (min)	precip-itation (in/h)		interval (min)	precip-itation (in/h)
1971									
Oct. 17	0.25	--	----	0.26	--	----	0.28	--	----
Nov. 11	.06	--	----	.07	--	----	.06	--	----
12	.08	--	----	.09	--	----	.08	--	----
13	.02	--	----	.03	--	----	.02	--	----
28	.08	--	----	.08	--	----	.07	--	----
29	.02	--	----	.02	--	----	.03	--	----
Dec. 2	.03	--	----	.05	--	----	.04	--	----
3	.11	--	----	.14	--	----	.12	--	----
6	.11	--	----	.13	--	----	.12	--	----
9	.01	--	----	0	--	----	0	--	----
11	0	--	----	.01	--	----	0	--	----
12	.05	--	----	.06	--	----	.06	--	----
13	0	--	----	.01	--	----	0	--	----
14	.02	--	----	.01	--	----	.01	--	----
15	0	--	----	.01	--	----	.01	--	----
16	.01	--	----	([2])	--	----	([2])	--	----
21	.12	--	----	.12	--	-----	.09	--	----
22	.10	--	----	.15	--	-----	.13	--	----
23	.01	--	----	0	--	----	0	--	----

1971									
Dec. 24	0.02	--	----	0.04	--	----	0.02	--	----
25	.11	--	----	.14	--	----	.11	--	----
26	.52	5	0.48	.55	5	0.36	.49	5	0.36
		15	.36		15	.32		15	.32
		30	.26		30	.26		30	.26
27	.07	--	----	.05	--	----	.06	--	----
28	0	--	----	.03	--	----	0	--	----
29	.01	--	----	0	--	----	.01	--	----
31	.01	--	----	0	--	----	0	--	----
1972									
Jan. 12	.01	--	----	(2)	--	----	(2)	--	----
13	.01	--	----	(2)	--	----	(2)	--	----
23	.03	--	----	.03	--	----	.03	--	----
25	.05	--	----	.05	--	----	.05	--	----
27	.09	--	----	.09	--	----	.09	--	----
Feb. 2	.01	--	----	.01	--	----	0	--	----
4	.07	--	----	.07	--	----	.06	--	----
5	.09	--	----	.11	--	----	.10	--	----
Apr. 11	0	--	----	.01	--	----	(2)	--	----
12	.02	--	----	.01	--	----	(2)	--	----
15	(2)	--	----	.01	--	----	(2)	--	----
June 5	.04	--	----	(2)	--	----	(2)	--	----
6	.02	--	----	.02	--	----	.02	--	----
7	.02	--	----	(2)	--	----	(2)	--	----
Sept. 5	.30	5	.48	(2)	--	----	.30	5	.36
		15	.36		--	----		15	.28
		30	.26		--	----		30	.24

Table 5.--*Precipitation record for the Panoche Hills Study area*--Continued

Date	Rain gage 1			Rain gage 2			Rain gage 3		
	Daily precipitation (inches)	Maximum intensities[1]		Daily precipitation (inches)	Maximum intensities[1]		Daily precipitation (inches)	Maximum intensities[1]	
		interval (min)	precip- itation (in/h)		interval (min)	precip- itation (in/h)		interval (min)	precip- itation (in/h)
1972									
Sept. 6	0.01	--	----	([2])	--	----	([2])	--	----
Oct. 7	.01	--	----	0.01	--	----	([2])	--	----
8	0	--	----	0	--	----	.01	--	----
9	.22	--	----	.25	--	----	.22	--	----
14	.25	--	----	.28	--	----	.24	--	----
15	.01	--	----	.01	--	----	.01	--	----
16	.29	5	0.36	.31	5	0.36	.31	5	0.36
23	.01	--	----	.01	--	----	.01	--	----
Nov. 4	1.12	5	1.56	1.14	5	2.40	1.12	5	2.40
		15	1.00		15	1.16		15	1.20
		30	.62		30	.70		30	.72
6	.01	--	----	.01	--	----	0	--	----
7	.02	--	----	.02	--	----	.02	--	----
9	.01	--	----	0	--	----	0	--	----
10	.67	5	.36	.68	5	.48	.64	5	.36
		15	.24		15	.28		15	.20
11	.21			.23			.22		
13	.47	5	.24	.47	5	.24	.43	5	.36
								15	.28
14	.75	5	.48	.77	5	.36	.72	5	.48
		15	.36		5	.36		15	.36
		30	.34		30	.32		30	.32

1972									
Nov. 15	0.28	5	0.36	0.30	5	0.48	0.28	5	0.60
		15	.36		15	.40		15	.40
		30	.26		30	.30		30	.30
16	.06	--	----	.07	--	----	.06	--	----
19	.01	--	----	0	--	----	0	--	----
21	0	--	----	.01	--	----	.01	--	----
Dec. 3	.03	--	----	.03	--	----	.02	--	----
4	.10	--	----	.12	--	----	.10	--	----
5	0	--	----	0	--	----	.01	--	----
6	.17	--	----	.18	--	----	.19	--	----
7	.05	--	----	.04	--	----	.07	--	----
8	0	--	----	.03	--	----	.01	--	----
9	.01	--	----	0	--	----	0	--	----
10	0	--	----	.01	--	----	.01	--	----
11	.01	--	----	.01	--	----	0	--	----
14	.01	--	----	0	--	----	0	--	----
15	0	--	----	.01	--	----	0	--	----
17	.48	5	.24	.51	5	.24	.49	5	.24
18	.01	--	----	.01	--	----	.01	--	----
19	.01	--	----	.02	--	----	.01	--	----
20	.02	--	----	.01	--	----	.01	--	----
21	0	--	----	.01	--	----	0	--	----
22	.04	--	----	.04	--	----	.04	--	----
23	.01	--	----	.01	--	----	0	--	----
24	.03	--	----	.04	--	----	.03	--	----
1973									
Jan. 1	.02	--	----	([2])	--	----	([2])	--	----
3	.01	--	----	([2])	--	----	([2])	--	----

Table 5.--*Precipitation record for the Panoche Hills Study area*--Continued

Date	Rain gage 1			Rain gage 2			Rain gage 3		
	Daily precipitation (inches)	Maximum intensities[1]		Daily precipitation (inches)	Maximum intensities[1]		Daily precipitation (inches)	Maximum intensities[1]	
		interval (min)	precip-itation (in/h)		interval (min)	precip-itation (in/h)		interval (min)	precip-itation (in/h)
1973									
Jan. 8	0.72	5	0.48	([2])	--	----	([2])	--	----
		15	.36		--	----		--	----
		30	.26		--	----		--	----
9	.15	--	----	([2])	--	----	([2])	--	----
10	.01	--	----	([2])	--	----	([2])	--	----
13	.02	--	----	([2])	--	----	([2])	--	----
14	.02	--	----	([2])	--	----	([2])	--	----
15	.11	--	----	([2])	--	----	([2])	--	----
16	.32	5	.36	([2])	--	----	([2])	--	----
		15	.32		--	----		--	----
		30	.26		--	----		--	----
17	.01	--	----	([2])	--	----	([2])	--	----
18	.13	--	----	([2])	--	----	([2])	--	----
20	.18	--	----	([2])	--	----	([2])	--	----
25	.28	--	----	([2])	--	----	([2])	--	----
29	.05	--	----	([2])	--	----	([2])	--	----
30	.09	--	----	([2])	--	----	([2])	--	----
31	.04	--	----	([2])	--	----	([2])	--	----
Feb. 3	.05	--	----	([2])	--	----	([2])	--	----
4	.01	--	----	([2])	--	----	([2])	--	----
5	.14	--	----	([2])	--	----	([2])	--	----

1973										
Feb.	6	0.36	5	0.24	(2)	--	----	(2)	--	----
	7	.07	--	----	(2)	--	----	(2)	--	----
	8	.01	--	----	(2)	--	----	(2)	--	----
	9	.01	--	----	(2)	--	----	(2)	--	----
	10	.51	5	.24	(2)	--	----	(2)	--	----
			15	.24		--	----		--	----
	11	1.03	5	.36	(2)	--	----	(2)	--	----
			15	.24		--	----		--	----
			30	.20		--	----		--	----
	12	.46	5	.36	(2)	--	----	(2)	--	----
			15	.32		--	----		--	----
			30	.26		--	----		--	----
	13	.15	--	----	(2)	--	----	(2)	--	----
	14	.25	--	----	(2)	--	----	(2)	--	----
	16	.01	--	----	(2)	--	----	(2)	--	----
	18	.01	--	----	(2)	--	----	(2)	--	----
	24	.06	--	----	(2)	--	----	(2)	--	----
	26	.14	--	----	(2)	--	----	(2)	--	----
	27	.21	--	----	(2)	--	----	(2)	--	----
Mar.	3	.15	--	----	(2)	--	----	(2)	--	----
	4	.01	--	----	(2)	--	----	(2)	--	----
	6	.21	--	----	(2)	--	----	(2)	--	----
	7	.02	--	----	(2)	--	----	(2)	--	----
	8	.16	--	----	(2)	--	----	(2)	--	----
	10	.09	--	----	(2)	--	----	(2)	--	----
	11	.10	--	----	(2)	--	----	(2)	--	----
	19	.59	5	.24	0.63	5	0.36	(2)	--	----
			15	.20		15	.24		--	----
			30	.16		30	.18		--	----

Table 5.--*Precipitation record for the Panoche Hills Study area*--Continued

Date	Rain gage 1			Rain gage 2			Rain gage 3		
	Daily precipitation (inches)	Maximum intensities[1]		Daily precipitation (inches)	Maximum intensities[1]		Daily precipitation (inches)	Maximum intensities[1]	
		interval (min)	precip-itation (in/h)		interval (min)	precip-itation (in/h)		interval (min)	precip-itation (in/h)
1973									
Mar. 21	0.19	--	----	0.21	--	----	([2])	--	----
22	.01	--	----	0	--	----	([2])	--	----
30	.06	--	----	.06	--	----	([2])	--	----
Apr. 13	.08	--	----	([2])	--	----	([2])	--	----
May 30	.01	--	----	.02	--	----	0.02	--	----
Oct. 11	.49	5	0.24	([2])	--	----	.49	5	0.24
12	.14	--	----	([2])	--	----	.14	--	----
26	.10	--	----	([2])	--	----	.10	--	----
Nov. 8	.02	--	----	.02	--	----	.01	--	----
11	.13	--	----	.13	--	----	.11	--	----
12	.24	--	----	.24	--	----	.26	--	----
13	.10	--	----	.09	--	----	.10	--	----
14	.07	--	----	.07	--	----	.07	--	----
17	.23	--	----	.21	--	----	.23	--	----
18	.03	--	----	.03	--	----	.04	--	----
20	.08	--	----	.09	--	----	.08	--	----
22	.25	--	----	.27	--	----	.25	--	----
23	.03	--	----	.03	--	----	.03	--	----

1973									
Nov. 24	0.05	--	----	0.05	--	----	0.05	--	----
25	.02	--	----	.02	--	----	.02	--	----
30	.18	--	----	.21	--	----	.18	--	----
Dec. 1	.37	5	0.24	.38	5	0.24	.41	5	0.24
		15	.24		15	.24		15	.24
3	.01	--	----	.01	--	----	.01	--	----
5	.01	--	----	.01	--	----	.01	--	----
6	.01	--	----	.01	--	----	.01	--	----
7	.01	--	----	0	--	----	0	--	----
8	.02	--	----	.03	--	----	.02	--	----
9	.01	--	----	.01	--	----	.01	--	----
13	.04	--	----	(2)	--	----	.05	--	----
15	.01	--	----	(2)	--	----	.01	--	----
16	.01	--	----	(2)	--	----	0	--	----
17	0	--	----	.01	--	----	.01	--	----
21	.44	5	.24	(2)	--	----	.39	5	.24
25	.01	--	----	(2)	--	----	0	--	----
26	.14	--	----	(2)	--	----	.09	--	----
27	.16	--	----	(2)	--	----	.12	--	----
31	.20	--	----	(2)	--	----	.15	--	----
1974									
Jan. 1	.01	--	----	(2)	--	----	(2)	--	----
3	.02	--	----	(2)	--	----	.04	--	----
4	.50	--	----	(2)	--	----	.46	--	----
5	.02	--	----	(2)	--	----	.01	--	----
6	.32	--	----	(2)	--	----	.25	--	----
7	.82	--	----	[3].26	--	----	.75	--	----
11	.01	--	----	.02	--	----	.01	--	----
12	.01	--	----	0	--	----	0	--	----

Table 5.--*Precipitation record for the Panoche Hills Study area*--Continued

Date	Rain gage 1			Rain gage 2			Rain gage 3		
	Daily precipitation (inches)	Maximum intensities[1]		Daily precipitation (inches)	Maximum intensities[1]		Daily precipitation (inches)	Maximum intensities[1]	
		interval (min)	precip-itation (in/h)		interval (min)	precip-itation (in/h)		interval (min)	precip-itation (in/h)
1974									
Jan. 13	0.01	--	----	0.01	--	----	0	--	----
16	.03	--	----	.04	--	----	.04	--	----
17	.02	--	----	.03	--	----	0	--	----
18	0	--	----	0	--	----	.01	--	----
19	.01	--	----	0	--	----	0	--	----
20	.02	--	----	.03	--	----	.02	--	----
31	.03	--	----	([2])	--	----	([2])	--	----
Feb. 12	.10	--	----	.10	--	----	.10	--	----
13	0	--	----	.01	--	----	0	--	----
15	.01	--	----	.01	--	----	0	--	----
16	.03	--	----	.03	--	----	.03	--	----
19	.02	--	----	.02	--	----	.03	--	----
21	.02	--	----	.03	--	----	.03	--	----
22	.01	--	----	.02	--	----	0	--	----
28	.01	--	----	.01	--	----	.04	--	----
Mar. 1	.11	--	----	.11	--	----	.11	--	----
2	.19	--	----	.24	--	----	.22	--	----
3	.23	--	----	.23	--	----	.21	--	----
7	.19	--	----	.30	--	----	.38	--	----
8	.23	--	----	.26	--	----	.20	--	----
11	0	--	----	.01	--	----	.01	--	----

1974									
Mar. 17	0	--	----	0.01	--	----	0.01	--	----
18	.01	--	----	0	--	----	0	--	----
23	0	--	----	.01	--	----	([2])	--	----
24	.01	--	----	0	--	----	([2])	--	----
25	[4].15	--	----	.27	--	----	.28	--	----
27	[4].02	--	----	.16	--	----	.15	--	----
28	.59	5	0.24	.64	5	0.24	.63	5	0.24
		15	.24		15	.24		15	.24
		30	.24		30	.24		30	.22
30	.08	--	----	.08	--	----	.09	--	----
Apr. 1	[4].07	--	----	.24	--	----	.26	--	----
9	[4].01	--	----	.21	--	----	.23	--	----
18	[4]0	--	----	.06	--	----	([2])	--	----
20	0	--	----	.01	--	----	([2])	--	----
23	.02	--	----	.04	--	----	.05	--	----
July 9	.20	--	----	.21	--	----	([2])	--	----
Oct. 1	([2])	--	----	.06	--	----	([2])	--	----
2	([2])	--	----	.08	--	----	([2])	--	----
7	.02	--	----	.02	--	----	([2])	--	----
27	.06	--	----	.07	--	----	([2])	--	----
28	.31	5	.48	.36	5	.60	([2])	--	----
		15	.36		15	.44			
		30	.28		30	.26			
29	.01	--	----	.01	--	----	([2])	--	----
31	.24	--	----	.26	--	----	([2])	--	----
Nov. 1	.03	--	----	.03	--	----	([2])	--	----
7	.01	--	----	0	--	----	([2])	--	----
8	0	--	----	.01	--	----	([2])	--	----

Table 5.--*Precipitation record for the Panoche Hills Study area*--Continued

Date	Rain gage 1			Rain gage 2			Rain gage 3		
	Daily precipitation (inches)	Maximum intensities[1]		Daily precipitation (inches)	Maximum intensities[1]		Daily precipitation (inches)	Maximum intensities[1]	
		interval (min)	precip-itation (in/h)		interval (min)	precip-itation (in/h)		interval (min)	precip-itation (in/h)
1974									
Nov. 11	0.01	--	----	0	--	----	(2)	--	----
16	.01	--	----	.01	--	----	(2)	--	----
17	0	--	----	.01	--	----	(2)	--	----
18	.01	--	----	0	--	----	(2)	--	----
21	.13	--	----	.15	--	----	(2)	--	----
28	.01	--	----	(2)	--	----	(2)	--	----
Dec. 2	.32	--	----	.30	--	----	(2)	--	----
3	1.18	5	0.36	1.28	5	0.48	(2)	--	----
		15	.32		15	.40			
		30	.32		30	.36			
4	.02	--	----	.02	--	----	(2)	--	----
8	(2)	--	----	.01	--	----	(2)	--	----
12	.01	--	----	.01	--	----	(2)	--	----
13	0	--	----	.01	--	----	(2)	--	----
15	.03	--	----	.03	--	----	(2)	--	----
16	.01	--	----	.01	--	----	(2)	--	----
27	.16	--	----	.25	--	----	.20	--	----
28	.09	--	----	.09	--	----	.11	--	----
30	.02	--	----	.02	--	----	.01	--	----

1975										
Jan.	6	0	--	----	0.01	--	----	0.01	--	----
	8	.04	--	----	.05	--	----	.05	--	----
	10	.01	--	----	.02	--	----	.02	--	----
	11	.02	--	----	.01	--	----	.01	--	----
	12	.01	--	----	.01	--	----	0	--	----
	13	.01	--	----	(2)	--	----	0	--	----
	16	(2)	--	----	(2)	--	----	.01	--	----
	29	.01	--	----	.01	--	----	(2)	--	----
	31	.11	--	----	.12	--	----	(2)	--	----
Feb.	1	1.32	5	0.24	1.89	5	0.48	(2)	--	----
			15	.16		15	.40		--	----
			30	.12		30	.36		--	----
	2	.54	5	.36	.61	5	.48	(2)	--	----
			15	.32		15	.44		--	----
			30	.28		30	.40		--	----
	5	.01	--	----	.01	--	----	0	--	----
	6	.08	--	----	.08	--	----	.08	--	----
	7	.28	--	----	.31	--	----	.28	--	----
	8	.16	--	----	.18	--	----	.17	--	----
	9	.05	--	----	.05	--	----	.06	--	----
	10	.01	--	----	.01	--	----	.01	--	----
	11	0	--	----	.01	--	----	0	--	----
	12	.05	--	----	.04	--	----	.06	--	----
	13	.42	5	.24	.43	5	.36	.42	5	0.24
	25	.01	--	----	(2)	--	----	(2)	--	----
Mar.	4	0	--	----	(2)	--	----	.01	--	----
	5	.42	--	----	(2)	--	----	.42	--	----
	6	.01	--	----	(2)	--	----	.02	--	----
	7	.27	--	----	(2)	--	----	.29	--	----
	8	.07	--	----	(2)	--	----	.09	--	----

Table 5.--*Precipitation record for the Panoche Hills Study area*--Continued

Date	Rain gage 1			Rain gage 2			Rain gage 3		
	Daily precipitation (inches)	Maximum intensities[1]		Daily precipitation (inches)	Maximum intensities[1]		Daily precipitation (inches)	Maximum intensities[1]	
		interval (min)	precip-itation (in/h)		interval (min)	precip-itation (in/h)		interval (min)	precip-itation (in/h)
1975									
Mar. 10	0.20	--	----	(2)	--	----	0.20	--	----
11	.06	--	----	(2)	--	----	.07	--	----
13	.09	--	----	(2)	--	----	.11	--	----
15	.03	--	----	(2)	--	----	.03	--	----
16	.01	--	----	(2)	--	----	.01	--	----
21	.07	--	----	0.08	--	----	0	--	----
22	.03	--	----	.04	--	----	0	--	----
23	0	--	----	.01	--	----	0	--	----
24	.06	--	----	.06	--	----	.05	--	----
25	.09	--	----	.10	--	----	.02	--	----
31	.01	--	----	(2)	--	----	(2)	--	----
Apr. 4	.19	--	----	.24	--	----	(2)	--	----
5	.07	--	----	.04	--	----	(2)	--	----
6	.04	--	----	.05	--	----	(2)	--	----
7	.08	--	----	.09	--	----	(2)	--	----
8	.17	--	----	.20	--	----	(2)	--	----
10	.40	5	1.20	.41	5	1.08	(2)	--	----
		15	.96		15	.88		--	----
		30	.50		30	.64		--	----
12	.01	--	----	0	--	----	(2)	--	----
14	(2)	--	----	.07	--	----	.08	--	----

1975									
Apr. 15	([2])	--	----	0.14	--	----	0 14	--	----
16	([2])	--	----	.09	--	----	.06	--	----
24	([2])	--	----	.05	--	----	.05	--	----
25	([2])	--	----	.05	--	----	.02	--	----

[1]Intensities less than 0.24 inch per hour not shown.
[2]No record.
[3]Value for partial day.
[4]Partial amount only due to gage malfunction.

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