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RAINFALL-RUNOFF RELATIONSHIPS FOR A SMALL SEMIARID WATERSHED, WESTERN FLANK SAN ANDRES MOUNTAINS, NEW MEXICO

by

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INTRODUCTION

Geomorphologic and paleohydrologic studies in the Southwest require an appreciation of modern rainfall-runoff relationships on the semiarid piedmont slopes typical of the region. Much information on the hydrology of such watersheds has been derived from research conducted by the Southwest Watershed Research Center of the Agricultural Research Service at their Walnut Gulch Experimental Watershed, Tombstone, Arizona (Renard, 1970). Although Walnut Gulch drains an area of about 60 sq mi, many arroyos on piedmont slopes are smaller than this, draining areas of less than 10 sq mi. These small watersheds have received less attention and little is known of their hydrology. The purpose of this paper is to present and interpret hydrologic data for such a watershed in Dona Ana County, New Mexico.

The data presented were collected during the period June 1972 to December 1973 in conjunction with a research project of the U.S. Army Atmospheric Sciences Laboratory, White Sands Missile Range, directed by the senior author. The project objectives, study area, and results were described in greater detail by Stone (1973) and Miers and Oey (1975). In that project two watersheds were instrumented: Cottonwood Draw and Ropes Draw. Because runoff rating curves were only obtained for Ropes Draw, this paper is restricted to a discussion of data from that watershed. Ropes Draw is located about 25 mi northeast of Las Cruces and lies in the portion of the missile range occupied by the Agricultural Research Service's Jornada Experimental Range and the San Andres Wildlife Refuge (Fig. 1). The western flank of the San Andres Mountains was selected as the study area for reasons of easy access, availability of useful previous works, abundance of water wells, backlog of hydrometeorologic data, and suitable regional setting.

REGIONAL SETTING

Details of the geology of the study area are given elsewhere in this guidebook and are not treated here. Generally, Ropes Draw is situated on the western flank of the San Andres Mountains, a westward-tilted fault block bounded on the east by the Tularosa Basin and on the west by the Jornada del Muerto Basin. The San Andres Mountains rise about 4,000 ft above the adjacent basin floor and reach a maximum elevation of 8,239 ft at San Andres Peak (Fig. 1). In the vicinity of Ropes Draw, the mountains consist mainly of Paleozoic carbonate rocks, sandstone, and mudstone (Bachman and Myers, 1969). The piedmont slopes of the San Andres Range are quite complex, consisting of numerous geomorphic surfaces (Gile and Hawley, 1968; King and others, 1971). The caliche horizons

associated with these surfaces probably control infiltration and ground water movement, at least on the inter-arroyo divides. The piedmont slopes consist mainly of alluvial sand and gravel. The basin floor consists of various alluvial, lacustrine, and eolian bolson-fill materials.

Soils of the region generally include mollisols in the stable areas along the mountain front, aridisols on the stablest portions of the piedmont slope and basin floor, and entisols on the young, steep, less stable slopes (Maker and others, 1971).

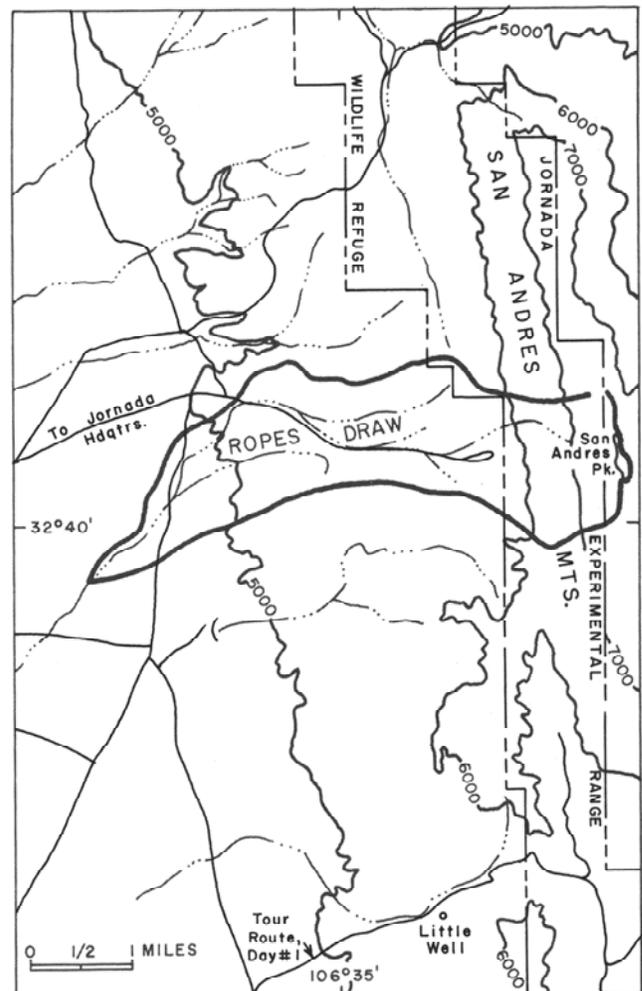


Figure 1. Map showing location and physiography of Ropes Draw watershed.

A vegetation survey of a portion of the Jornada Experimental Range, conducted in 1963, showed that mesquite constitutes 50.3 percent of the vegetation, creosote accounts for 14.2 percent, and tarbush 8.6 percent; the remaining 26.9 percent includes various other shrubby plants, cacti, yuccas, and grasses (Buffington and Herbel, 1965).

The average annual precipitation in the basin, based on 60 years of record (1914-1973) at the Jornada Experimental Range headquarters, is about 9 inches (King and others, 1971). The months of July, August, and September provide about 54 percent of the annual precipitation with monthly averages of 1.75, 1.68 and 1.45 inches, respectively. Average annual rainfall at mountain gages is generally greater than 10 inches (Miers and Oey, 1975). The average annual relative humidity for the region, as measured at New Mexico State University, is less than 50 percent. Annual pan evaporation is about 10 times the rainfall, averaging 97 inches at New Mexico State University and 90 inches at the Jornada Experimental Range headquarters. The basin is therefore arid (Houghton, 1972) and the mountains are semiarid.

Ground water resources of the region have been studied by King and others (1971). Additional data collected in 1972 by the U.S. Geological Survey for this study are summarized in Table 1. In the vicinity of Ropes Draw, the water table lies at a depth ranging from about 20 ft to more than 430 ft beneath the surface. A contour map of the water table (Fig. 2), prepared from the data in Table 1, compares favorably with that of King and others (1971). According to them, regional ground water flow in the Jornada del Muerto is toward the northwest. In the study area, however, the local flow direction is seen to be southwestward.

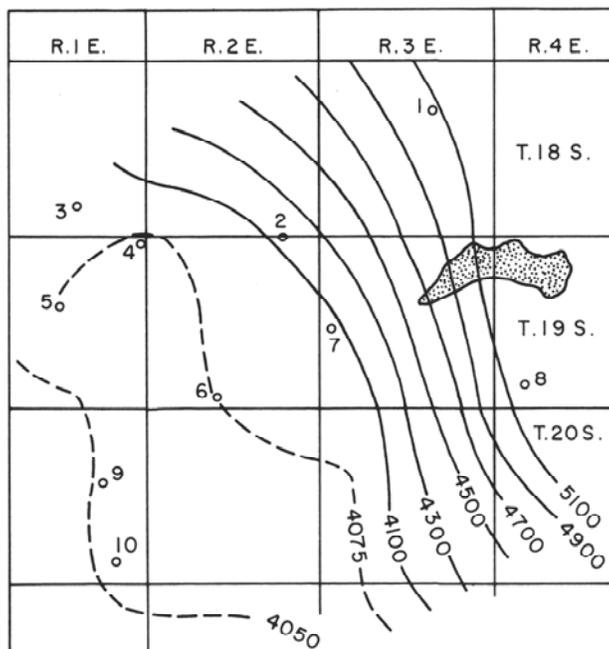


Figure 2. Map showing elevation of the water table in vicinity of Ropes Draw watershed (stippled); contour interval is 200 ft except in southwestern part where supplementary interval of 25 ft is used (dashed contours). Well numbers correspond to those in Table 1.

WATERSHED CHARACTERISTICS

Ropes Draw is a fairly well integrated, low density, third-order, ephemeral stream system heading in the San Andres Mountains and terminating about 6 mi downstream on their western piedmont slope. The drainage basin covers an area of about 5 sq mi or 3,181 acres. It is about four times as long as it is wide and is roughly crescent-shaped (Fig. 3). Although maximum relief for the watershed is about 3,700 ft, only about 825 ft of relief exists between the upper and lower stream gages.

Ropes Draw flows across Paleozoic sedimentary rocks in the upper part of the watershed and across Quaternary alluvium in the rest of the watershed (Fig. 3). The alluvium is believed to be relatively thick on the piedmont slope based on logs of wells at the NASA White Sands Test Facility to the south and on a seismic profile made down Cottonwood Draw to the north. At the NASA site the alluvium is 200 to 450 ft thick upslope from the major block fault (Doty, 1963); along Cottonwood Draw, it is about 125 ft thick above this fault. Several lines of evidence suggest that the alluvium is thinner in the mountain portion of the watershed. A lip of bedrock (Abo Formation ?) crosses the channel just below the upper stream gage. Coarse conglomerate (Love Ranch Formation ?) crops out in the bottom of the unnamed arroyo just south of Ropes Draw at the mountain front. Standing water was observed at a depth of only about 20 ft in an old dug well (Little Well, Table 1) along this arroyo about half a mile behind the mountain front. A general idea of the lithology of the alluvium constituting the channel bottoms, and banks was provided by geophysical logs (gamma, density, neutron) of 20-ft-deep soil moisture holes drilled at the middle and upper stream gages (Fig. 4).

INSTRUMENTATION

A detailed description of the instrumentation of the Jornada project was given by Stone (1973) and need not be repeated here. In general, however, the instruments used in Ropes Draw included 4 recording rain gages, 3 nonrecording rain gages and 3 recording stream gages. Most of the instruments used were provided, installed and maintained by the U.S. Geological Survey under contract.

To insure records of as many flow events as possible, stream gages were placed along relatively straight reaches of channels on the bank which seemed to be favored by low flows. The site for the Ropes Springs rain gage coincides with that of a pan evaporation station installed near the headwaters of Ropes Draw. Upper Ropes stream gage was placed so that it lies at the upper edge of the piedmont slope, where the stream leaves the mountains (Fig. 5). Middle Ropes stream gage was positioned so as to lie downstream from the intersections of sizable tributaries with the main channel. Lower Ropes stream gage was installed as far downstream from the middle gage as possible.

PRECIPITATION

Reliable precipitation data are available for only a small number of storm events because of various instrument malfunctions, incomplete or questionable record printouts, and human error. The number of these storms which can be used is further reduced by the fact that runoff data are questionable or lacking for several events. The few storms for which rainfall-

Table 1. Records from wells in vicinity of Ropes Draw used to plot map in Figure 2.

Well name	Location	Depth (ft) to water table	Ht. of meas. pt. (ft)	Elev. of water table (ft)	Surface elev. (ft)
1. New	SW, NE, SE sec. 10, T. 18 S., R. 3 E.	113.15	+2.5	5049	5160
2. Turney	C, NW, NE sec. 2, T. 19 S., R. 2 E.	393.0	+1.5	4108	4500
3. Red Lake	NE, SW, SE sec. 27, T. 18 S., R. 1 E.	232.25		4088	4320
4. Middle	NE, NE, NE sec. 1, T. 19 S., R. 1 E.	236.22	+0.5	4069	4305
5. Wagoner	SE, SE, NE sec. 16, T. 19 S., R. 1 E.	309.71	+1.0	4073	4382
6. West Headquarters	NW, SE, NW sec. 33, T. 19 S., R. 2 E.	256.09	+1.5	4075	4330
7. Wooten	C, NE, NW sec. 19, T. 19 S., R. 3 E.	430.0+		4080-	4510
8. Little	NE, NW, SE sec. 31, T. 19 S., R. 4 E.	19.81	+0.5	5206	5225
9. Co-op	SE, SE, NW sec. 14, T. 20 S., R. 1 E.	305.0+		4058	4363
10. NMSU Ranch Headquarters	NW, NE, NE sec. 35, T. 20 S., R. 1 E.	291.84		4060	4352

runoff relationships can be determined are summarized in Table 2.

The storms involved are mainly local, convective, summer thundershowers. The times of occurrence of these storms range from 06:25 to 15:45 and are generally clustered around noon. The average time of occurrence for all summer storms on record is 12:40. This may be somewhat atypical because, according to Renard (personal communication), the mean time of occurrence for convective storms at Walnut Gulch is about 1600 hours. The duration of the storms listed in Table 2 ranges from .54 to 3.59 hours. Intensities, converted to hourly rates, range from .19 to .88 in/hr. For comparison, the greatest hourly intensity reported in the area is 2.77 inches, which occurred 29 August, 1935 (Houghton, 1972).

To evaluate rainfall-runoff relationships, mean basin rainfall must be determined. Two methods were employed to determine this value (Fig. 6): a modified individual area-altitude weighted mean method (Whitmore and others, 1961) and the isohyetal method (Linsley and others, 1958). In the first

method, the mid-altitude topographic contours between successive rain gages were used as boundaries for segmenting the watershed. A given segment was then assigned the precipitation value recorded at the gage within it. The average rainfall over Ropes Draw then is expressed by:

$$R = \frac{a_1 r_1 + a_2 r_2 + a_3 r_3}{A_1 + a_2 + a_3}$$

where R = mean basin rainfall, a_n = area of segment n, and r_n = rainfall measured in segment n.

For the 17 July 1973 storm (Table 2) an R value of 2.039 inches was obtained by this method.

In the isohyetal method, rainfall contours (isohyets) were employed as segment boundaries. A given segment was then assigned the average rainfall value of the bounding isohyets (Fig. 6). For the 17 July 1973 storm (Table 2), an average basin rainfall value of 2.036 inches was obtained by the isohyetal method. The values obtained by the two methods agree very well, differing by only .003 in.

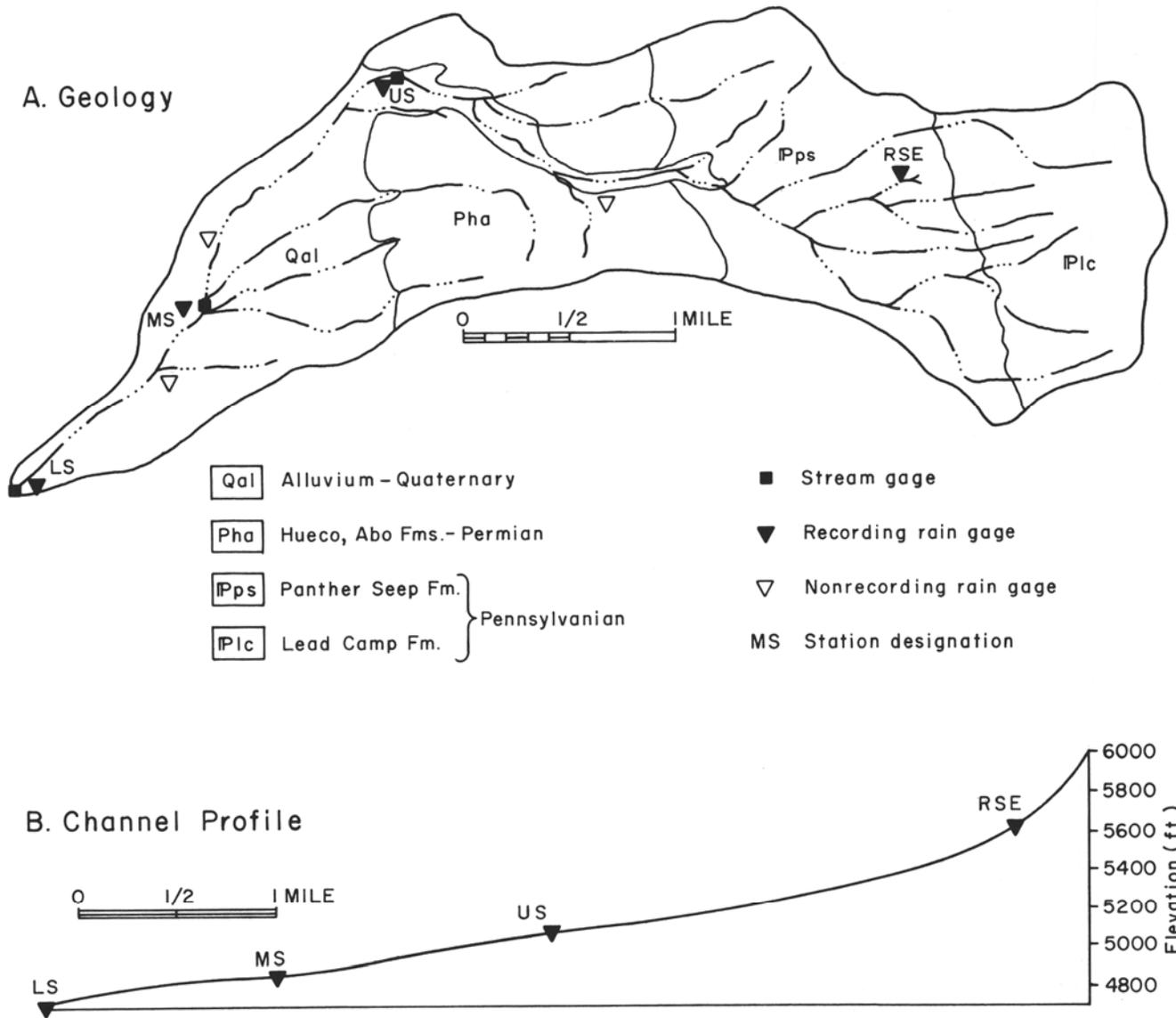


Figure 3. Geology, distribution of instruments, and longitudinal profile at Ropes Draw: A) geologic map (after Bachman and Myers, 1969).

B) channel profile. Station designations: LS = lower stream gage, MS = middle stream gage, US = upper stream gage, RSE = Ropes Springs evaporation station.

RUNOFF

Direct runoff values (Table 2) were derived by converting stage heights at stream gages to discharge by means of rating curves (Fig. 7). These curves were constructed by the U.S. Geological Survey from indirect slope-area measurements. Direct runoff from storms ranges from 5.64 to 17.81 acre-ft or .037 to .067 inch. Peak discharge ranges from 55 to 367 cfs.

The relationship between rainfall and runoff is well shown in Figure 8, where precipitation and discharge for the 17 July 1973 storm are plotted against time for all stations. Several things are apparent in Figure 8. The runoff curves, like the rainfall curves, are multi-peaked. Major rainfall peaks are reflected in the hydrographs as major runoff peaks. Rainfall over the watershed is quite variable in intensity at a given time.

The percent runoff values given in Table 2 are a measure of rainfall-runoff relationships in Ropes Draw and were calculated as follows. Total discharge was converted to depth (inches) based on the watershed area. This depth was then

compared to mean basin rainfall. Runoff was found to range from 2.3 to 23.1 percent of the mean basin rainfall. This wide range in values reflects the influence of various storm factors including storm movement, storm duration, storm intensity, and time since last storm (antecedant moisture). For the storms given in Table 2, the average percent runoff is 8.42 percent. This is unnecessarily high because the 23.1 percent value for the 17 August 1972 storm is probably high owing to locally intense rainfall at the stream gage. Discounting that storm, an average percent runoff value of 4.8 percent is obtained. Even this value is unrealistic because only intense summer storms, and a very small number of them, are taken into account. The variety of values given in Table 2 is realistic but the apparent average is not.

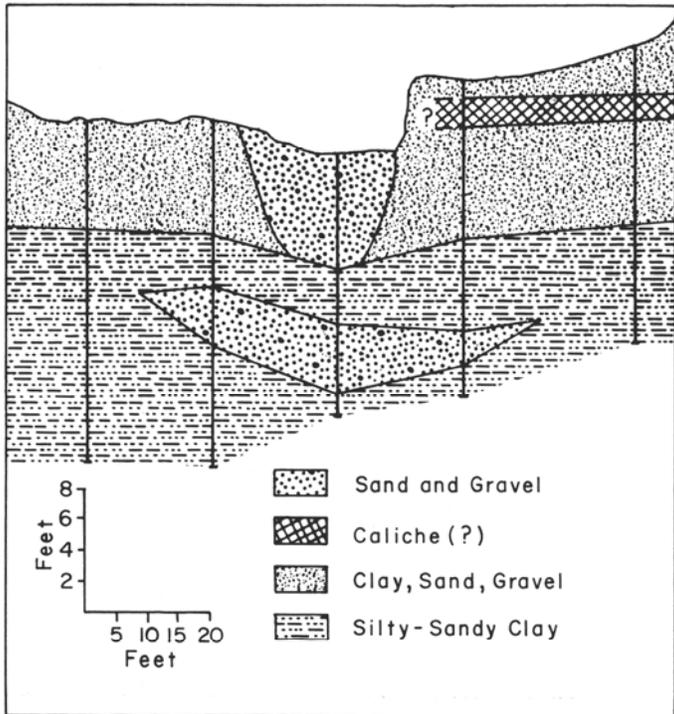


Figure 4. Generalized cross section of Ropes Draw at middle stream gage site based on geophysical logs of soil moisture holes.

DISCUSSION

To evaluate the rainfall-runoff relationships obtained from the Jornada data, two comparisons were made: first, with the published annual water budget determined for the Walnut Gulch Experimental Watershed and second, with estimated runoff values obtained for Ropes Draw by the Soil Conservation Service (SCS) from their indirect runoff-prediction method. At Walnut Gulch it has been determined that of the 12 inches of precipitation falling on the watershed annually, only .25 in. actually runs off (Renard, 1970). Thus runoff is about 2.08 percent of the precipitation. The SCS method in-

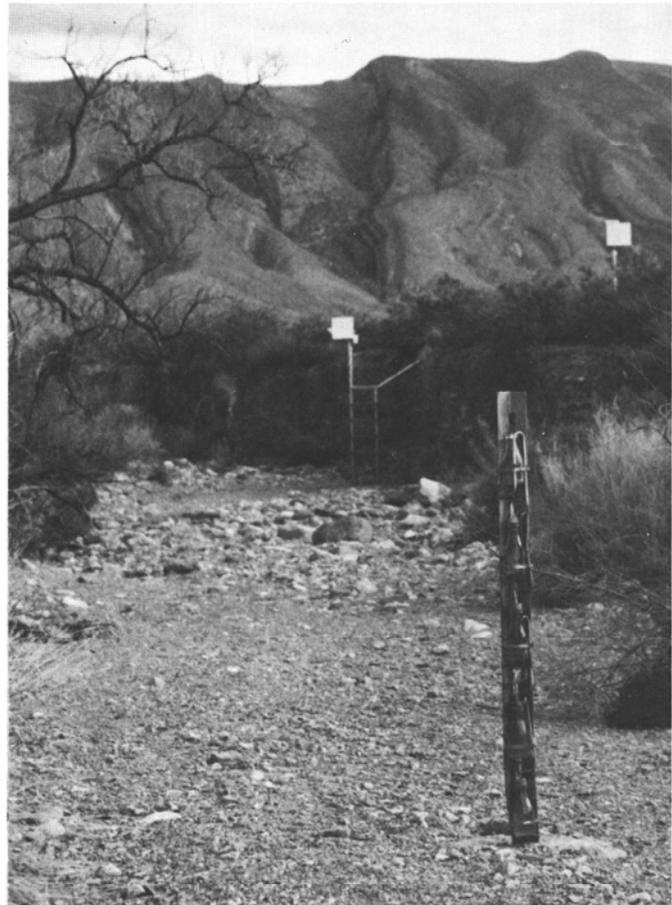


Figure 5. Upper Ropes Draw stream gage site, looking east, showing sediment sampler (foreground), stream gage, and rain gage (U.S. Army photo).

volves predicting the runoff from a standard 50-year, 24-hour storm. Such a storm would produce 3.2 inches of precipitation for the study area (Mockus, 1964). For that intensity the predicted runoff would be 63 percent of precipitation. For the 17 July 1973 storm (2.04 inches) the SCS method gives a runoff

Table 2. Rainfall and runoff data analyzed for Ropes Draw.

Storm event	Portion of basin analyzed	Ave. time of storm occurrence	Ave. duration (hrs)	Time since last storm (hrs)	Recorded Precipitation			Mean basin precip. (in)	Precip. intens. (in/hr)	Direct runoff (acre-ft)	Direct runoff (in)	Percent runoff	Peak discharge (cfs)
					middle (in)	stream (in)	U. evap. (in)						
17 Aug. 72	upper half	11:50 - 12:22	.54	9.1	.64	.04	.16	.30	5.64	.037	23.1	291	
17 Aug. 72	upper half	15:45 - 18:08	1.79	3.4	1.10	1.17	1.16	.65	10.24	.067	5.8	172	
27 Aug. 72	upper half	06:25 - 10:00	3.59	1.12	.85	.66	.70	.19	8.25	.054	7.7	55	
17 July 73	upper half	10:10 - 13:00	2.83	19.9	2.22	2.33	2.31	.80	8.12	.053	2.3	103	
17 July 73	all	11:00 - 13:20	2.33	19.9	.81	2.22	2.33	2.04	.88	17.81	.067	3.3	367

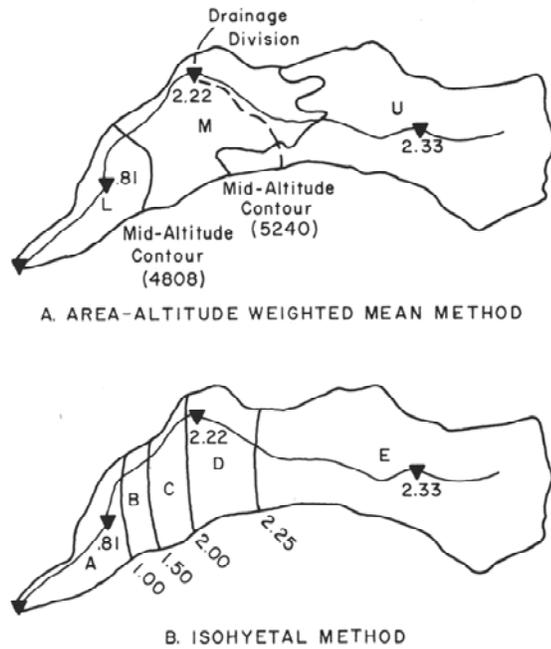


Figure 6. Maps showing methods used to determine mean basin rainfall for Ropes Draw: A) area-altitude weighted mean method (3 segments: L—assigned precipitation at lower stream gage site, M—assigned precipitation at middle stream gage site, U—assigned precipitation at Rope Springs evaporation station); B) isohyetal method (5 segments: A through E—assigned mid-isohyet precipitation values).

of 1.02 inches or 50 percent. The actual measured runoff for this storm was .067 in. or 3.3 percent of the rainfall. This value is comparable to the average annual runoff at Walnut Gulch but is much lower than that predicted by the SCS method.

The reason for this discrepancy may be that the SCS method does not adequately allow for transmission loss. According to Renard (1970, p. 17) transmission loss, by infiltration of runoff waters into the porous materials of stream beds, is one of the most important factors in evaluating ephemeral streams. The SCS Engineering Handbook (Mockus, 1964) points out that transmission loss can account for major runoff reduction, especially if what is termed the "climatic index" of the watershed is less than 1.0. Climatic index is determined as follows:

$$C_i = 100 \frac{P_a}{(T_a)^2}$$

where P_a = average annual precipitation and T_a = average annual temperature.

For Ropes Draw P_a is 9.0 inches and T_a is 60° F (King and others, 1971; Houghton, 1972), giving a climatic index of 0.25, so transmission loss would be expected to be great for

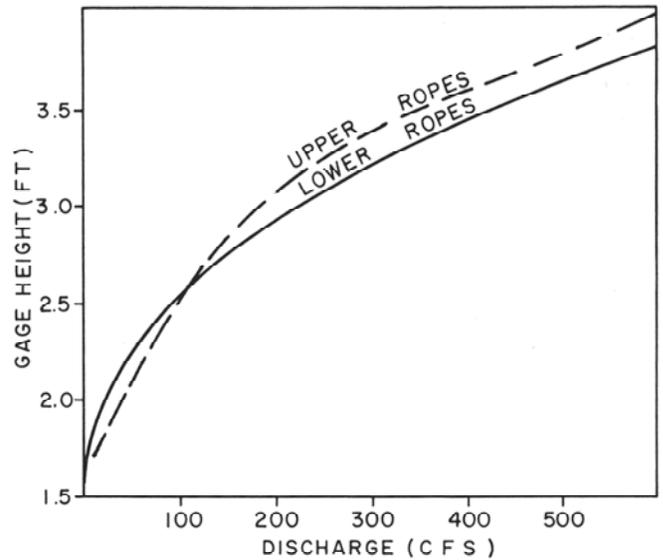


Figure 7. Stage-discharge rating curves for the lower and upper stream gages, Ropes Draw.

Ropes Draw. The steep rising limbs of the hydrographs in Figure 7 are probably a manifestation of this transmission loss.

A comparison of the runoff from the upper and lower portions of the watershed is also interesting. The only storm for which this is possible is that of 17 July 1973. From Table 2 it is apparent that a greater percentage of rainfall from this storm ran off in the lower part of the watershed than in the upper part. This is the reverse of what might be expected in view of the assumption made above that the alluvium is thinner in the upper or mountain part of the watershed and would be quickly saturated to produce large runoffs. However, if the bedrock is fractured and/or porous, there would still be considerable loss through the channel even with a thin alluvial cover. It should also be noted that the bedrock dips downstream; thus bedding planes and partings are optimally exposed for receiving runoff waters. Also, if there was considerable scouring in the mountains before the last depositional cycle, the alluvium could be much thicker there than originally assumed and the bedrock lip and outcrop cited could merely be associated with the most resistant bedrock layers. Further work would be required to determine the bedrock position in the upper or mountain portion of the watershed.

Although several more years of record would be required for modeling purposes, the data presented do represent actual measurements of modern hydrologic conditions on typical semiarid piedmont slopes and should therefore be useful in geomorphologic and paleohydrologic studies in the Southwest.

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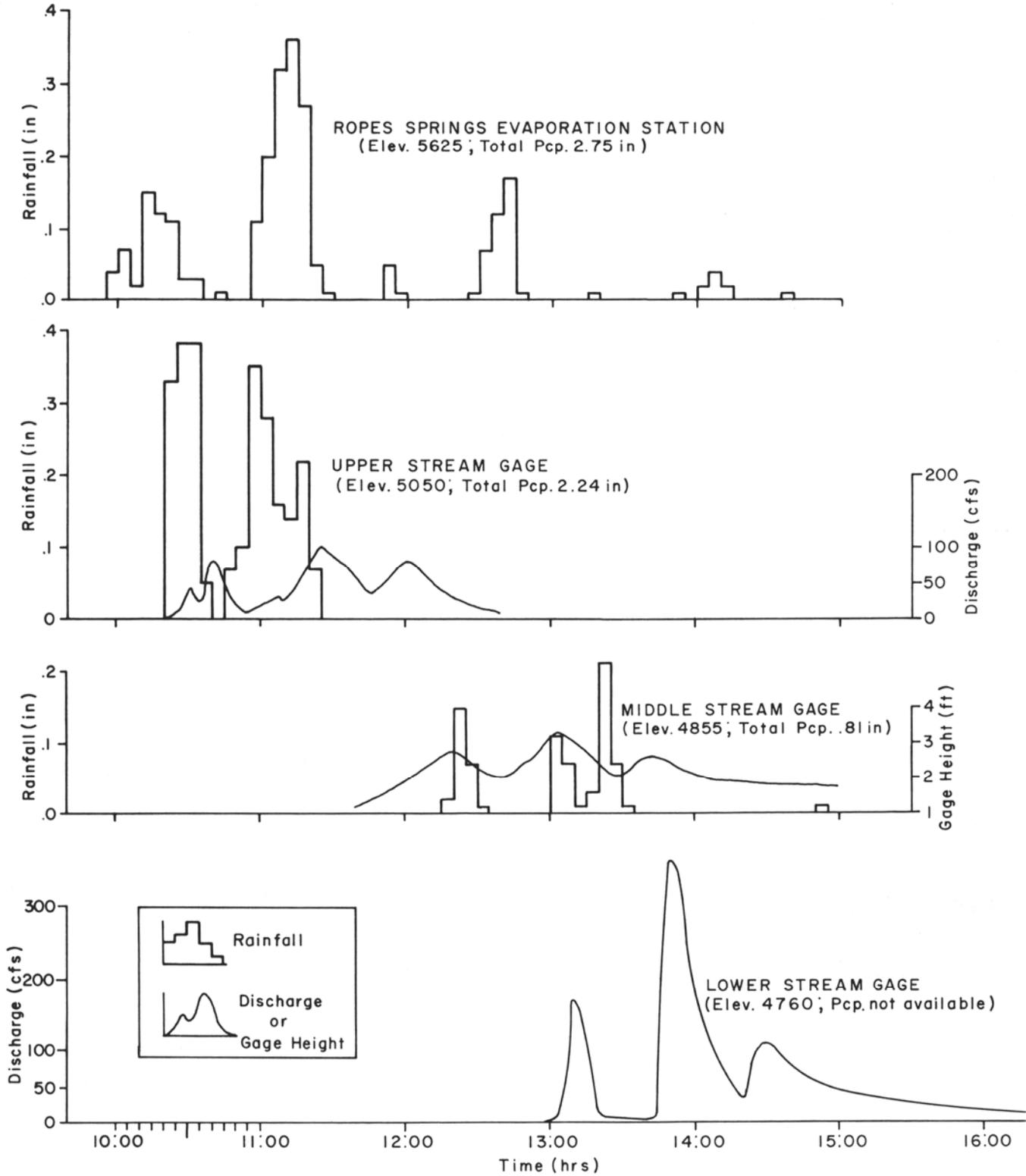


Figure 8. Rainfall histograms and flood hydrographs of 17 July 1973 storm, Ropes Draw.

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