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Use of Unit-Source Watersheds for Hydrologic Investigations in the Semiarid Southwest[1]

D. R. KINCAID, H. B. OSBORN, AND J. L. GARDNER

Southwest Watershed Research Center, Tucson, Arizona

Abstract. The unit-source watershed is an intermediate step between plots, in which certain runoff generative processes can be isolated, and large watersheds, the yields of which are controlled by the hydraulics of their complex channel systems. Several unit-source watersheds have been instrumented within the Walnut Gulch experimental watershed in southeastern Arizona. Their comparative data indicate some basic hydrologic relationships between net runoff and size of drainage area, the significance of storm patterns, the relation of runoff and sediment yield to vegetational cover, and hydrograph characteristics. (Key words: Hydrology; watershed; southwestern United States)

INTRODUCTION

Studies by the Southwest Watershed Research Center are designed to provide information about effects of practical range conservation measures on the production of sediment and the yield of usable water from semiarid rangeland watersheds. One of the research approaches is isolation and analysis of factors affecting the generation and movement of runoff and sediment as related to watershed characteristics.

The unit-source watershed is an intermediate step in this approach between small plots, in which certain runoff and sediment generative influences can be isolated, and large watersheds, the yields of which are influenced by the hydraulics of their complex channel systems. A 'unit-source' watershed is defined as a natural drainage area that has relatively homogeneous soils and vegetation cover, that is subject to essentially uniform precipitation, and for which any geologic influences on the surface outflow are areally representative. *Amerman* [1965] defines a unit-source area as having, ideally, a 'single cover, single soil type' and as being 'otherwise physically homogeneous.'

Although compliance with these features is sought in selecting our unit-source areas, all the drainage areas under study support only native vegetational cover, and, consequently, there is probably greater variation than is usually implied by the term 'single cover.' Such variation is, however, held to the smallest possible amount.

Within our experimental watersheds in Arizona and New Mexico, we plan a minimum of 48 unit-source areas, of which 21 are already in operation (Table 1). Originally, it was thought that the maximum size of these areas might be as great as 1 square mile. Because of the small diameter of runoff-producing storms and because of variation in soil and vegetation, however, we have decided that the area should be considerably smaller and that the length of the area should be less than 1 mile. Selection of future unit-source areas, therefore, will be based on this revised concept.

Some unit-source areas under study are subtended by stock-watering ponds equipped with a water-level recorder. On others, the runoff is measured by means of a broad-crested V-notch weir. Single-stage automatic sediment samplers are installed at each runoff-measuring station. When possible, depth-integrated wading samples are taken to supplement records from the automatic samplers. Where the unit-source area drains into a stock pond, the bottom of the pond is resurveyed in the late spring of each year just before the runoff season (the ponds are often dry at this time), and the accumu-

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TABLE 1. Inventory of Unit-Source Watersheds

Location*	Name	Area, acres	Runoff Measuring Structure	Date Record Began		Predominant Cover			Primary Method of Sediment Measure
				Runoff	Precipitation	Brush	Grass	50-50	
WG	WG-4	560	Flume	1954	1954	X			Fixed sampler
WG	LH-1	2.8	V-weir	1962	1962	X			Fixed sampler
WG	LH-2	3.9	V-weir	1963	1963	X			None
WG	LH-3	8.3	V-weir	1963	1963	X			Fixed sampler
WG	LH-4	11	V-weir	1963	1963	X			Fixed sampler
WG	K-1	120	V-weir	1962	1962		X		Fixed sampler
WG	K-2	4.6	V-weir	1962	1962		X		None
WG	T-2	18	Pond	1959	1961	X			Pond survey
WG	T-7	376	Pond	1959	1954			X	Pond survey
WG	T-14	378	Pond	1960	1954		X		Pond survey
WG	T-20	128	Pond	1959	1956		X		Pond survey
WG	T-23	115	Pond	1960	1954	X			Pond survey
Saf	W-1	519	V-weir	1939	1939	X			Fixed sampler
Saf	W-2	682	V-weir	1939	1939			X	Fixed sampler
Saf	W-4	764	V-weir	1939	1939	X			Fixed sampler
Saf	W-5	723	V-weir	1939	1939		X		Fixed sampler
Mon	W-1	97.2	V-weir	1939	1939				Fixed sampler
Mon	W-2	40.5	V-weir	1939	1939				Fixed sampler
Mon	W-3	183	V-weir	1939	1939				Fixed sampler
AC	Tank		Pond	1962	1955			X	Pond survey
AC	Tank		Pond	1962	1955			X	Pond survey

* WG: Walnut Gulch; Saf: Safford, Arizona; Mon: Montano, near Albuquerque, New Mexico; AC: Alamogordo Creek, near Santa Rosa, New Mexico.

lated sediment is computed from the surveys.

When a unit-source watershed is instrumented, an inventory of the geology, soils, and vegetation is taken. Subsequent surveys of the vegetation are made as changes become apparent or are suspected.

SOME STUDY RESULTS

Measurements of runoff were made during the summer rainy seasons of 1963 and 1964 on four small unit-source watersheds at the Lucky Hills area within the Walnut Gulch experimental watershed near Tombstone, Arizona (Figures 1 and 2). These watersheds are physically associated with a set of experimental plots. Their comparative data indicate some basic hydrologic relationships.

Net runoff versus size of drainage area. Watershed Lucky Hills 1 lies within and at the head of Lucky Hills 3. Ten 6 by 12 foot plots on LH-1 and LH-3 represent those areas. Watershed Lucky Hills 2 lies within and at the head of Lucky Hills 4. Twenty-four similar plots designated as TU-9, lying just off watershed Lucky Hills 4, characterize quite well the soils and vegetation of the Lucky Hills 2 and Lucky Hills 4 areas. Comparison of runoff from the plots and very small watersheds shows that, although the volume of runoff was greater in 1964 than in 1963, runoff decreased with an increase in drainage area in about the same proportion both years (Figure 3). There are three reasons for this phenomenon.

1. All runoff from the 6 by 12 foot plots resulted from overland flow. Because of the short length of flow (maximum 12 feet) little surface runoff from the upper end of the plot is absorbed at the lower end. On the other hand, even the smallest of the unit-source watersheds, Lucky Hills 1, has a well developed channel system that abstracts measurable amounts of water from surface flow.

2. Because of increased opportunity for infiltration on the longer slopes, considerable amounts of water are absorbed from overland flow before the channel system is reached. Soil moisture measurements show that lower sites on the area are generally wetter and moisture penetration is deeper because of these abstractions from overland flow. Comparison of soil moisture records from two of the thirteen soil moisture measuring stations on the Lucky Hills

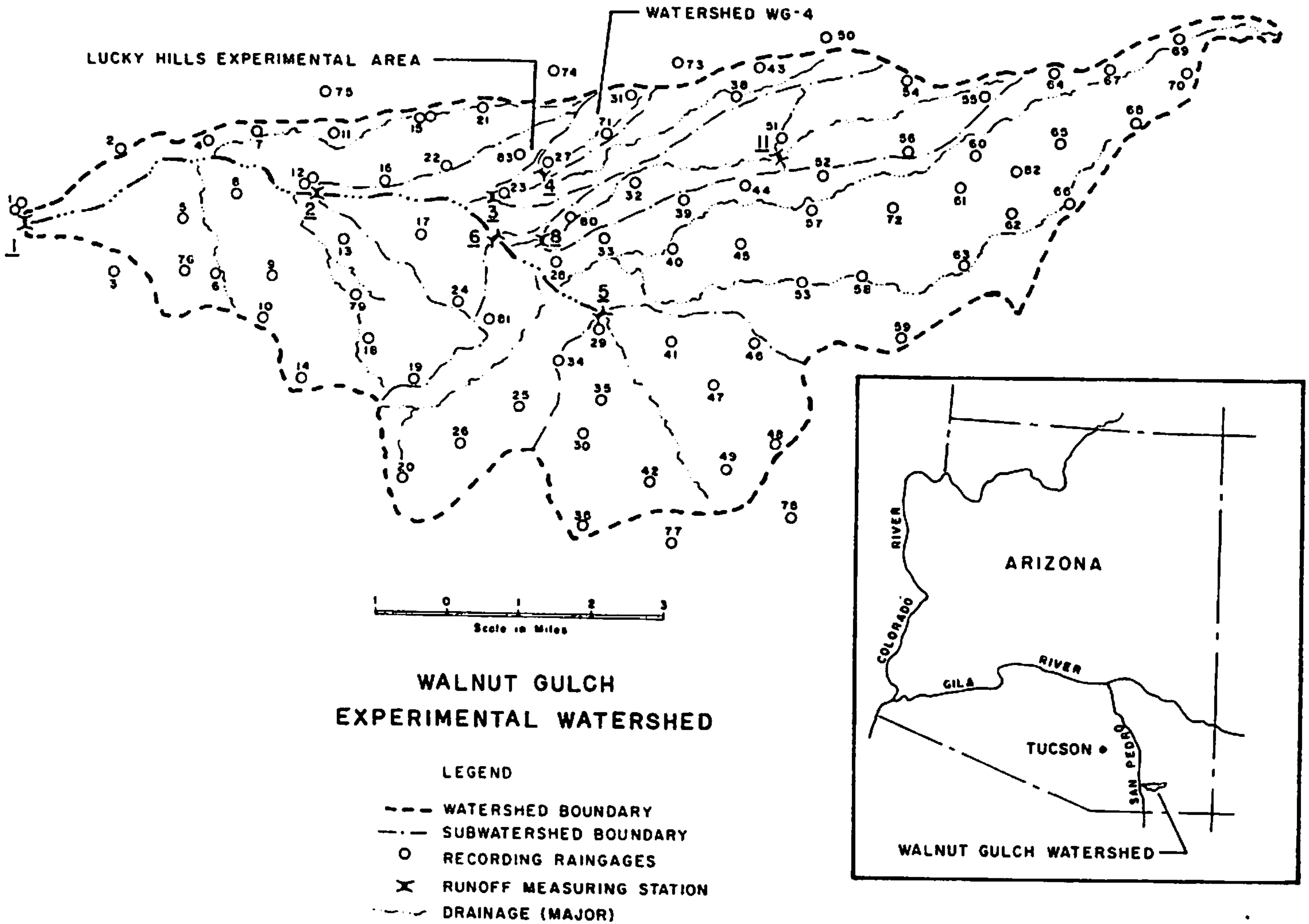

Fig. 1. Walnut Gulch experimental watershed.

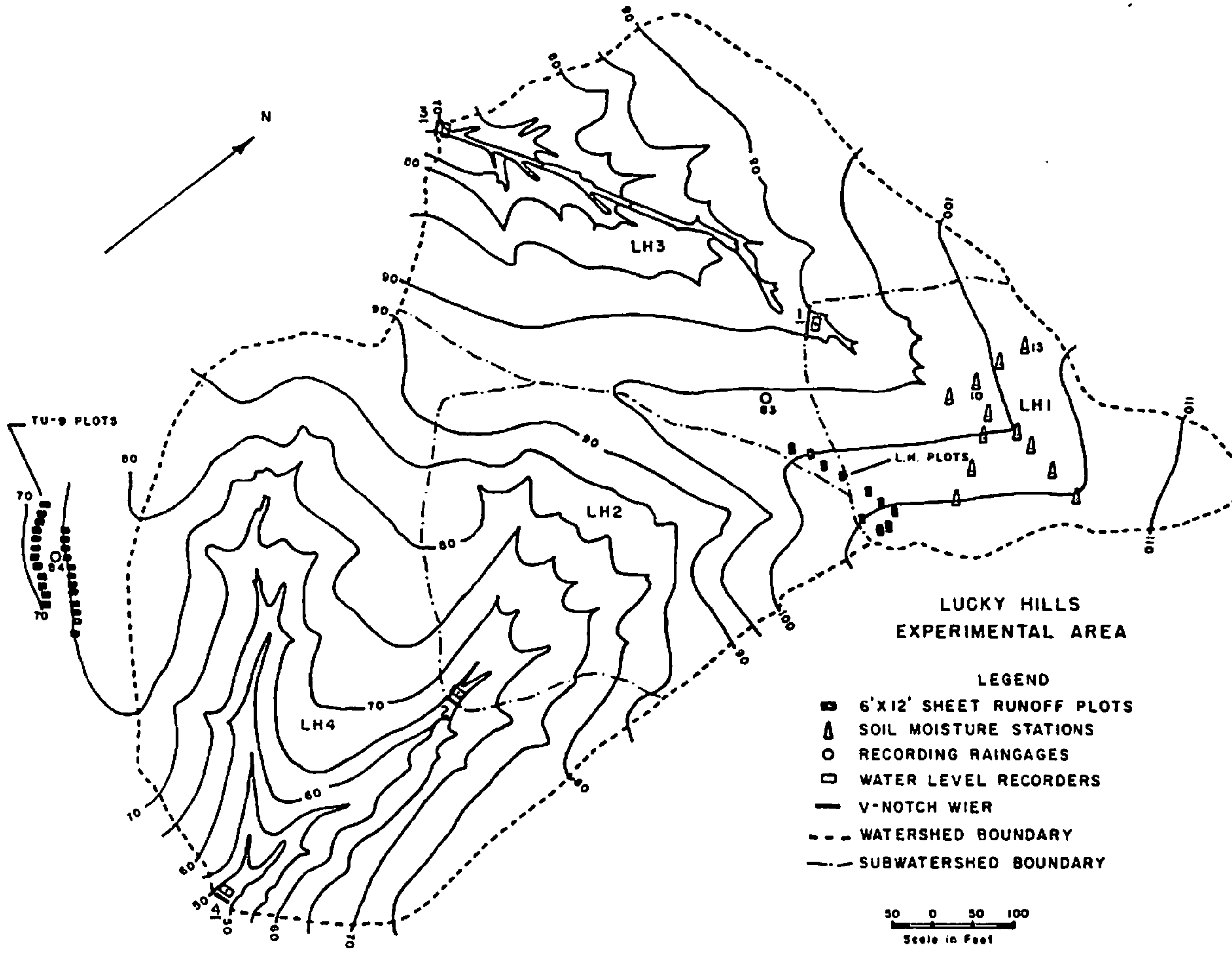

Fig. 2. Lucky Hills experimental area.

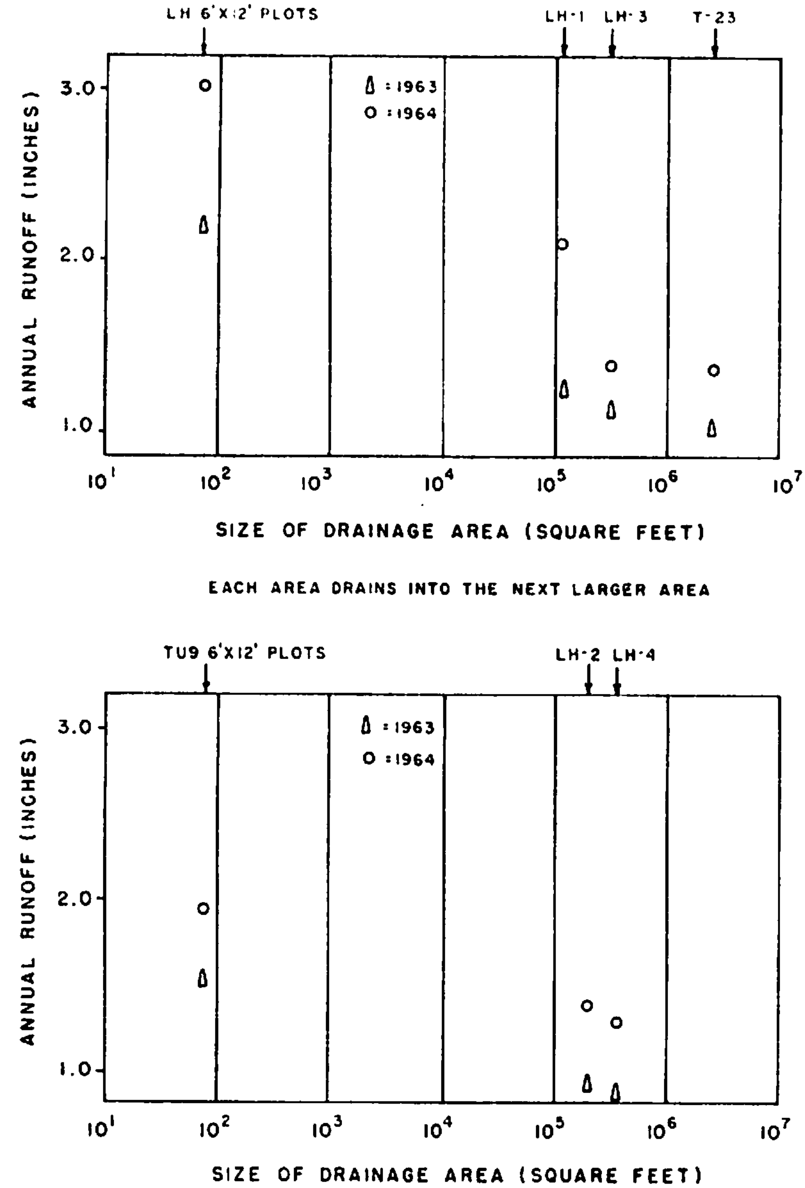

Fig. 3. Annual runoff versus size of drainage area.

1 watershed illustrates this phenomenon (Figure 4). Station 10, which is 125 feet downslope from station 13, had considerably more soil moisture during the rainy season and for some time thereafter.

3. On watershed areas, in contrast to the condition usually prevailing on plots, normal undulation of the land surface results in greater depression storage, which reduces runoff and increases infiltration.

Significance of storm patterns. For study of land and vegetation influences on runoff, the useful size of a unit-source watershed is limited by the small areal extent of runoff-producing summer thunderstorms [*Osborn and Reynolds*, 1963]. The four Lucky Hills watersheds total 19.3 acres. The two recording rain gages (83 and 84) on these watersheds are situated 900 feet apart (Figure 2). Adjacent to the Lucky Hills watersheds is watershed WG-4, which is

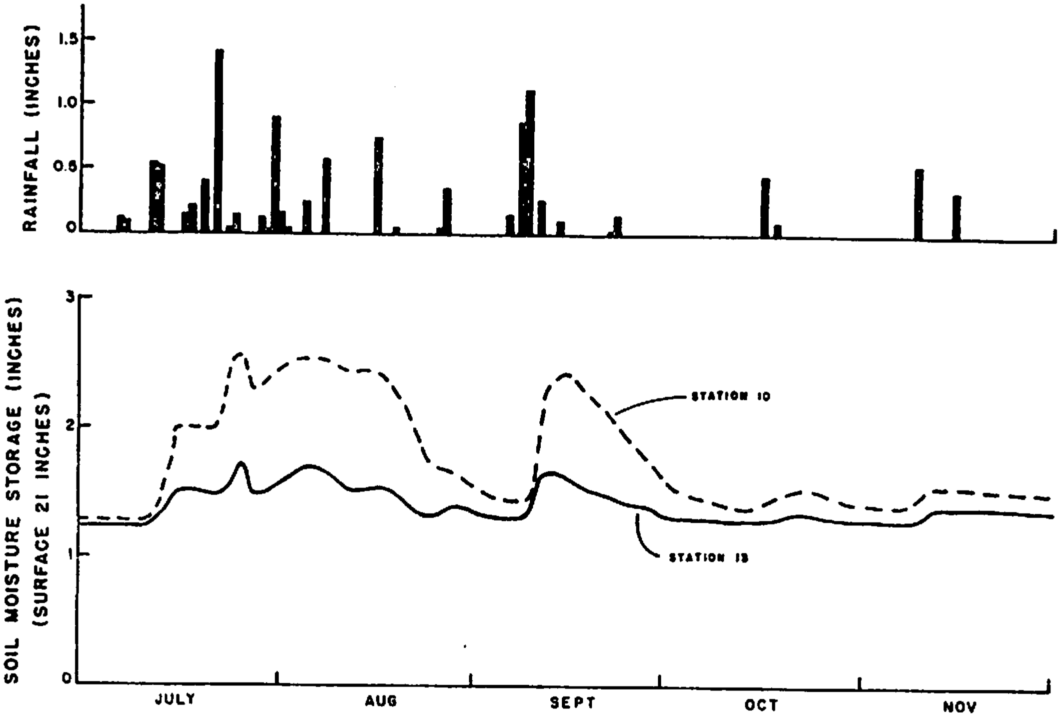

Fig. 4. Lucky Hills unit-source area, rainfall and soil moisture, 1964.

the largest area to be considered a unit-source watershed within the Walnut Gulch drainage system. Watershed WG-4 is about 2 miles long and ½ mile wide, and comprises 560 acres, most of which is brushland (Figure 1, Table 1). There are three recording rain gages on this watershed. Rain gage 27 is at the outlet and is less than ½ mile from rain gages 83 and 84 on the Lucky Hills area. Rain gage 71 is 1 mile from rain gage 27, and rain gage 31 is still another mile away at the head of the WG-4 watershed. Generally, the two rain gages on the Lucky Hills watersheds record about the same depths and intensities of precipitation (Table 2). The three gages on WG-4 watershed, however, show much greater variation.

For six of the eight largest runoff-producing storms in 1964, the maximum depth for a 10-minute interval varied 100% or more between two of the three gages on WG-4. Because of this

TABLE 2. Total and Maximum 10-Minute Depths of Rainfall at Five Recording Gages for Eight Storms in 1964 on the Walnut Gulch Experimental Watershed

		Total Depth, inches					Maximum Depth in 10 Minutes, inches				
		Lucky Hills Gage Nos.		Watershed WG-4 Gage Nos.			Lucky Hills Gage Nos.		Watershed WG-4 Gage Nos.		
Date	Time of Beginning	83	84	27	71	31	83	84	27	71	31
7/13	1500	0.51	0.39	0.28	1.23	0.93	0.21	0.20	0.12	0.53	0.45
7/22	1845	0.86	0.91	0.64	0.72	1.07	0.44	0.41	0.39	0.40	0.80
7/31	1430	0.46	0.51	0.40	0.33	0.24	0.20	0.23	0.19	0.15	0.21
8/8	2000	0.58	0.55	0.68	0.30	0.18	0.31	0.34	0.28	0.22	0.15
8/16	1530	0.75	0.80	0.81	0.43	0.24	0.53	0.42	0.41	0.36	0.20
8/27	0130	0.37	0.43	0.35	0.46	0.53	0.14	0.18	0.12	0.23	0.30
9/8	1730	0.86	0.90	0.69	0.60	1.06	0.40	0.41	0.33	0.25	0.63
9/9	2400	0.97	0.86	1.00	0.87	1.10	0.41	0.38	0.44	0.42	0.42

great variation in rainfall, it becomes difficult to separate the effects of variations in precipitation from those of watershed characteristics on runoff from WG-4. Therefore, unit-source watersheds selected for study in the Southwest should be considerably less than 1 square mile in area, and less than 1 mile in length. WG-4 and other similar size watersheds will be listed as unit-source watersheds only for comparison of longer periods (possibly 5 years or more) of record for precipitation and runoff. Conclusions based on short periods of record or on selected individual events will be restricted to smaller watersheds.

Hydrograph characteristics. Runoff hydrographs from unit-source watersheds are rather symmetrical. Typically, runoff-producing precipitation begins suddenly, lasts for only a few minutes, and stops abruptly. There is very little 'tailing off' on the hydrograph of the resulting runoff. Hydrographs for events in 1963 on Lucky Hills watershed 2 illustrate the relative symmetry of hydrographs from the small watersheds (Figure 5). In comparison, hydrographs for events from large, complex watersheds show more abrupt rises and relatively long recessions (Figure 6).

Relation of runoff to type of vegetational cover and soil. Thus far only 4 years of good record are available, and rainfall-runoff relationships are vague. Plotting of rainfall versus runoff, storm by storm, produced widely scattered results, mostly because of irregularity in rainfall intensity and storm-cell location [*Fletcher*, 1961; *Greene and Sellers*, 1964; *Osborn*, 1964].

Maximum annual runoff and 4-year-average runoff were greater from the grass-covered watersheds than from those having predominantly brush cover (Table 3*a*). However, the maximum annual precipitation and 4-year-average precipitation also were greater on the grass-covered watersheds, and when the runoff for 4 years is subtracted from the precipitation for the same period the retention amounts are almost equal (Table 3*b*). This strongly suggests that the runoff is more dependent on the character of the rainfall than on watershed influences.

TABLE 3*b*. Differences between Precipitation and Runoff, Grass versus Brush

Watershed	Predominant Vegetation	Precipitation Minus Runoff, inches: 4-Year		Maximum 1 Year	
T-20	Grass	26.2	26.3	9.8	9.8
T-14	Grass	26.4		9.9	
T-23	Brush	25.2	26.4	7.8	7.7
T-7	Brush	27.7		7.7	

The smaller the area studied, the more uniform is the rainfall per storm, and vegetation and soil effects that are difficult to determine on large areas become more apparent. There has been significantly less runoff from the Lucky Hills 2 and 4 unit-source watersheds than from the Lucky Hills 1 and 3 watersheds. An attempt was made to determine a probable cause. Rainfall distribution was rather uniform for each storm over the Lucky Hills area, as indicated by the two recording gages (83 and 84) and six nonrecording gages.

The slopes of the drainage areas do not differ sufficiently from one another (Figure 2) to account for the differences in runoff observed. The aspect (orientation) of the drainage areas, as well as that of the 6 by 12 foot plots, does differ. As a result of prevailing wind or storm movement, this might be expected to cause a

TABLE 3*a*. Rainfall and Runoff from Four Unit-Source Watersheds within Walnut Gulch Experimental Watershed, 1961–1964

Watershed	Area, acres	Predominant Vegetation	Summer Precipitation: Total, in.	Summer Precipitation: Maximum Year, in.	Runoff: Total, in.	Runoff: Maximum Year, in.	Runoff: Other 3 Years, in.
T-20	128	Grass	31.6	12.9	5.37	3.12	2.25
T-14	378	Grass	30.5	12.1	4.14	2.18	1.96
T-23	115	Shrubs	29.0	9.1	3.82	1.33	2.49
T-7	376	Shrubs	29.0	8.3	1.31	0.58	0.73

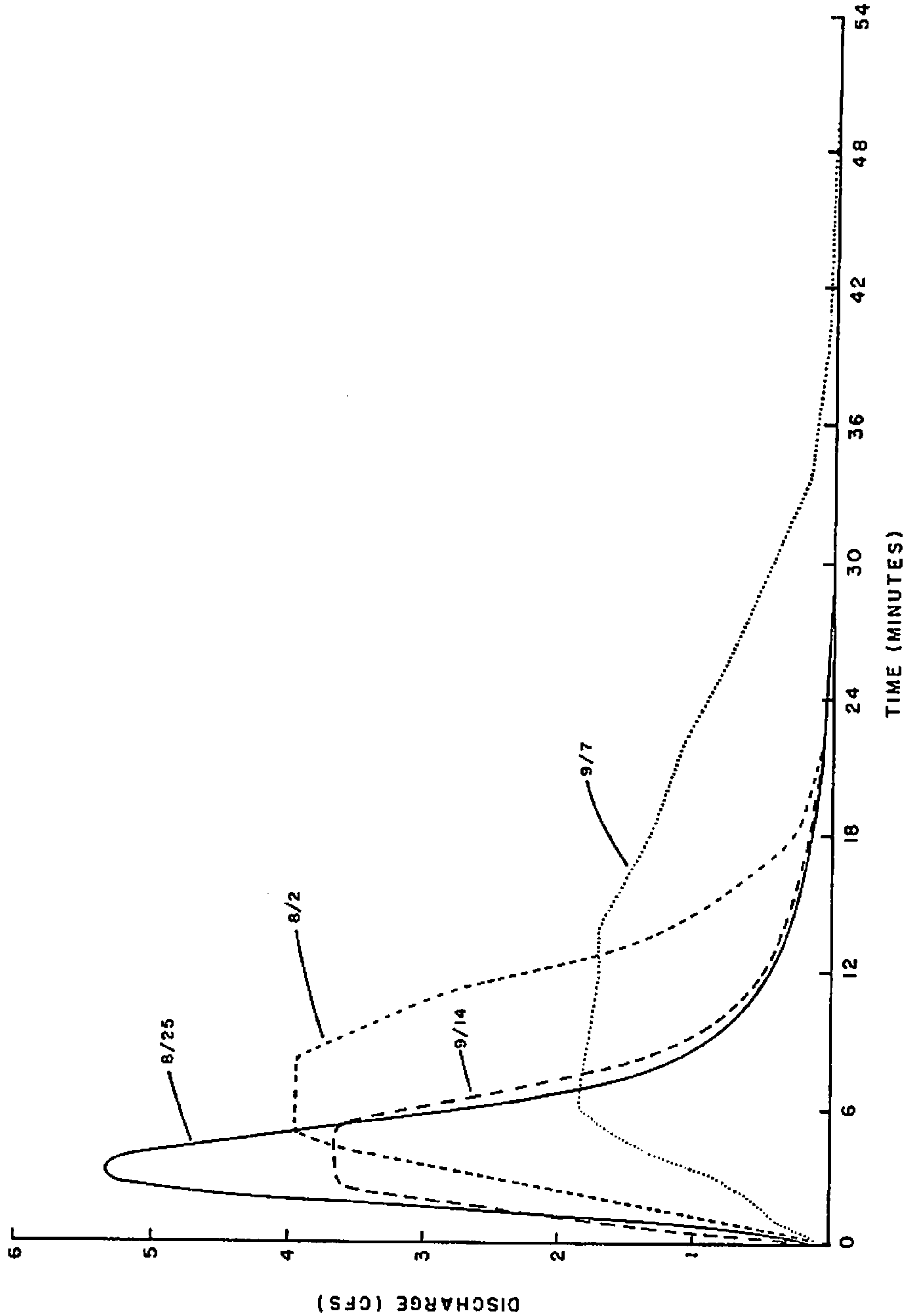

Fig. 5. Hydrographs for LH-2 Walnut Gulch 1963 storms on August 2, August 25, September 7, and September 14.

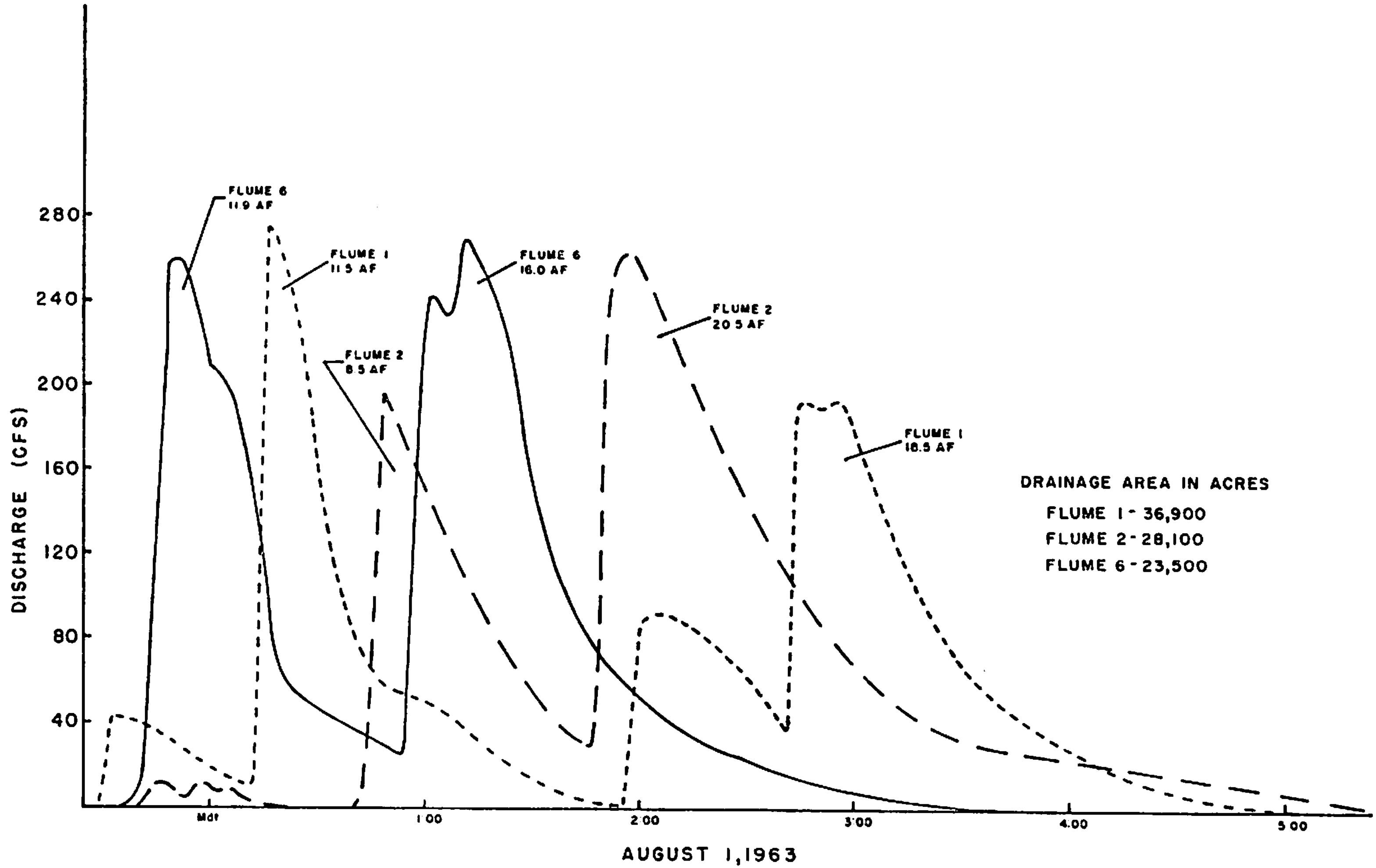

Fig. 6. Walnut Gulch watershed hydrographs for stations 1, 2, and 6, July 31 to August 1, 1963.

difference in runoff between the two areas for individual storms. The same relative difference was found, however, for all storms for two consecutive years (Figure 3). It is doubtful whether the observed differences in runoff could be entirely attributed to differences in orientation of the watersheds. The runoff-producing storms are convective and do not have a season-long directional pattern.

Analyses of the soils of the two areas showed that the upper 6 inches of soil on watersheds LH-2 and LH-4 averages 55% gravel, 33% sand, 5% silt, and 7% clay. Soil to a similar depth on watersheds LH-1 and LH-3 averages 40% gravel, 43% sand, 9% silt, and 8% clay. The soil on LH-2 and LH-4 is gray, is calcareous throughout, and is classified as a gravelly sandy loam. Soil on LH-1 and LH-3, also a gravelly sandy loam, is reddish, is less calcareous, and contains a slightly higher proportion of silt and clay than the LH-2 and LH-4 soil. It is doubtful whether the small differences in texture in the silt and clay range could account for the differences in runoff. The most important soil factor may be the coarser nature, especially the difference in gravel content, of the soil of watersheds LH-2 and LH-4.

Differences in basal area of the life forms of vegetation are not statistically different among the areas. Results of infiltrometer experiments and study of rainfall-runoff relationships on 6 by 12 foot plots indicate that there is a negative correlation between crown cover of plants (particularly shrubs) and surface runoff [*Kincaid et al.*, 1964]. Crown spread of shrubs is significantly greater on LH-4 than on the other three watersheds; it is significantly less on LH-1. Crown spread of half shrubs is significantly greater on LH-4 than on the other three watersheds.

Although more years of record are needed, it appears at this point that the differences in runoff observed among these watersheds are better correlated with amount of vegetation cover than with any other single factor.

Relation of sediment yield to grass cover. In 1961 and 1962, the soils and vegetation of four unit-source areas were sampled, with five sampling units in each area (Table 1, T-7, T-14, T-20, and T-23). Each sampling unit consisted of two parallel 100-foot Canfield line transects [*Canfield*, 1941], a record of species observed within 25 yards of the lines but not intercepted by them, and soil samples from a pit dug through the profile and situated midway between the lines.

Sediment measurements made by repeated surveys of the pond beds and sampling sediment depths furnished data for comparison of basal area of grass and average annual sediment accumulation (Table 4, Figure 7). The average annual sediment accumulation at pond 14 appears lower than might be expected. Pond 14 is one of the older ones on the Walnut Gulch watershed, but only the last 4 years' sediment accumulation was measured. Consequently, deposition before stabilization of the inlet channel was not included, and therefore the apparent average sediment yield could be expected to be lower than that for the other ponds, where total life accumulations were included.

There has been no discernible difference in runoff between watersheds with predominantly grass cover and those with predominantly brush cover. Sediment yield, however, is two or more times as great from the brush-covered watersheds as from the grass-covered ones.

To estimate sediment movement in the Lucky Hills area, steel rods were placed at 100-foot intervals up each drainageway. They were inserted into the ground so that 1 foot remained above the soil surface. A similar series of rods was

TABLE 4. Relation of Sediment Yield to Grass Cover (Basal Area)

Watershed	Watershed Area, acres	Time of Accumulation, years	Average Annual Accumulation, ft³	Sediment Yield from Area, surface inch	Basal Area of Grasses, % cover
T-7	376	19	11,613	0.0085	0.82
T-14	378	4*	5,832	0.0042	2.04
T-20	128	22	1,748	0.0038	2.80
T-23	115	5	5,460	0.0131	0.24

* Age of tank is considerably greater than this, but previous deposition has not been determined.

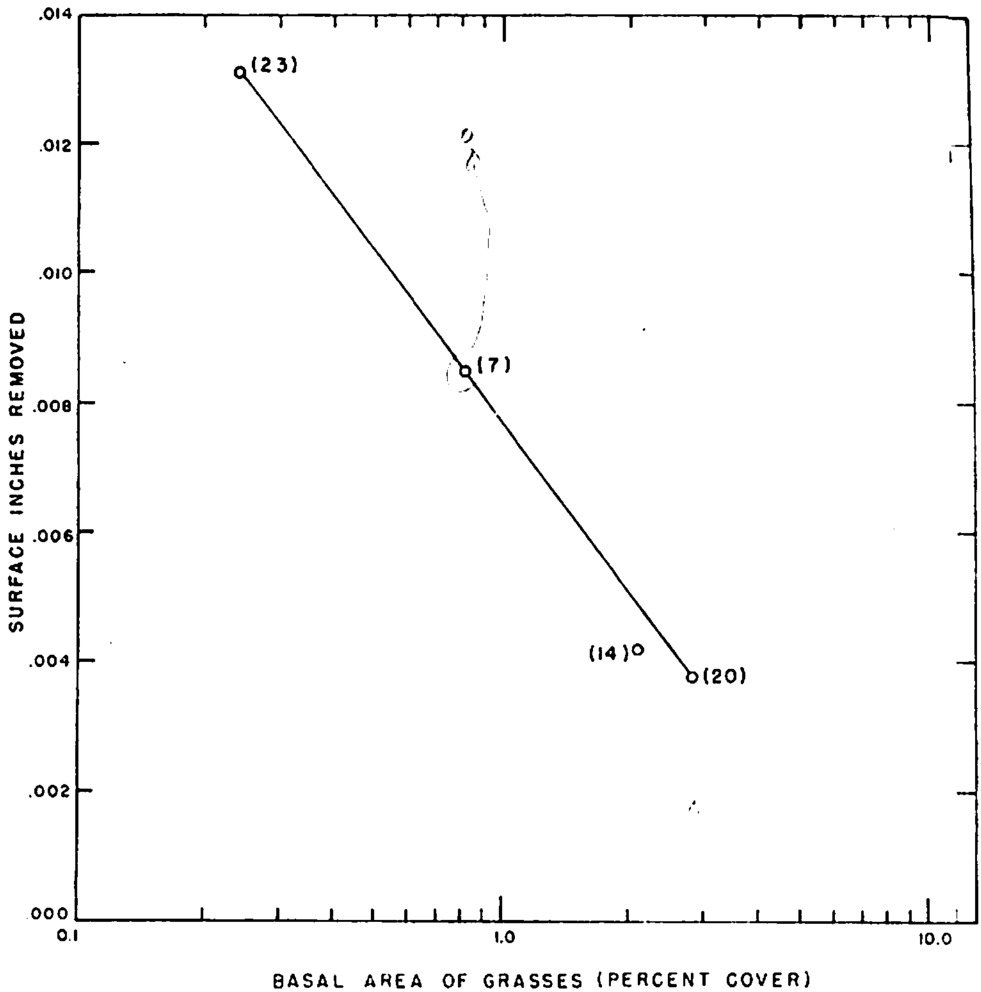

Fig. 7. Relation of sediment yield to basal area of grass. Stock pond numbers in parentheses.

placed up a ridge at 100-foot intervals. The rod exposures were measured after each storm. On September 17, 1964, after the summer rainy season, the markers on the ridge showed that there was generally no change in ground surface elevation, with a maximum erosion scour of 0.02 foot and a maximum deposition of 0.03 foot. The markers in the channels indicated that in some places as much as 0.13 foot depth of soil was removed from the upper ends of the gullies, and some sediment was deposited in the ponds above each weir. The maximum increase in surface elevation was 0.65 foot. The actual volume of sediment deposited above each weir is presently being determined by surveys. The deposition will be measured each year by surveys of the weir ponds; erosion will be followed by means of the markers; and sediment passing over the weirs will be estimated from fixed and wading samples.

SUMMARY

The unit-source watershed is proving to be a useful tool in investigations of water yield and sediment production from rangeland watersheds in the Southwest. Intensive instrumentation and study are possible on these small 'transition' watersheds. Early results of current studies have led to the following conclusions:

1. The small areal extent of individual runoff-

producing storms in the Southwest limits the useful size of unit-source watersheds to considerably less than 1 square mile.

2. Runoff per unit-area from watersheds of even a few acres is considerably less than that from 6 by 12 foot plots.

3. Runoff is more dependent on the nature of rainfall than on the type of watershed vegetation (predominantly grass versus predominantly brush).

4. Runoff varies with crown cover of vegetation and possibly with soil type, but these variations are difficult to determine because of other associated factors.

5. Sediment production appears to be greatly affected by differences in basal cover of grasses, and is much higher on predominantly brush-covered than on predominantly grass-covered watersheds.

It is hoped that analysis of the records from unit-source watersheds will lead to a model for precipitation-runoff from the more complex watersheds. Such an analog or digital model would be particularly useful in the Southwest, where comparatively few significant runoff events are recorded each year. Unit-source watersheds are being instrumented to represent several soil-vegetation complexes with a range of topographic features and channel characteristics.

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