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BRUSH CONTROL AND SEDIMENT YIELD

by

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ABSTRACT

Eight small watersheds in southeastern Arizona on the Santa Rita Experimental Range were instrumented in 1975 and 1976 to quantify the impact of mesquite control on runoff and sediment yield. Four pairs of contiguous watersheds, one treated and one for control, under four grazing practices were equipped with raingages, precalibrated supercritical runoff measuring devices and automatic sediment sampling equipment as a part of the experiments. Brush control was accomplished by girdling individual mesquite plants with diesel fuel in one of each pair of watersheds. Vegetation, runoff, and sediment yield changes are discussed and analyzed as a result of the experiments on one pair of the watersheds. The procedure used to synthesize the sedigraphs and annual yield is discussed for watersheds 1 (control) and 2 (treated).

INTRODUCTION

Vegetation composition manipulation has been proposed in Arizona for water yield enhancement for many years (Barr 1956, Ffolliott and Thorud 1974, Hibbert 1965, and Horton 1976). Research scientists in the US Forest Service have investigated the topic in small watersheds in numerous vegetation life zones from the more humid alpine areas to the drier chaparral zones. Converting from woody species to grass communities has generally been observed to enhance runoff. Such studies have not addressed what happens in more arid areas, nor have they addressed the erosion/sediment yield problem from such watersheds (Ffolliott and Thorud 1974).

In an effort to quantify the impact of vegetation manipulation in a more arid area (300-460 mm annual precipitation), watersheds in the Santa Rita Experimental Range 55 kms south of Tucson were instrumented in 1975 and 1976. The instrumentation consisted of a recording raingage, a precalibrated supercritical runoff flume (Smith et al. 1981), and an automatic total load sediment sampler (Renard et al. 1986). The experimental program consisted of four pairs of watersheds in different pastures. The pairs consisted of one watershed used as a control and one treated by girdling individual mesquite trees (*Prosopis velutina* Woot.) with diesel oil. No pretreatment water resource data were collected. It was assumed that hydrologic response changes would be reflected by different parameter values in a causal model.

In this paper, results are presented for one pair of watersheds, 1 and 2, with drainage areas of 1.64 and 1.77 ha, respectively (Fig. 1).

As the topographic maps illustrate, only the lower portion of each watershed has an incised drainage system. In earlier analysis on these watersheds, Lane et al. (1978) showed that significant errors in estimating runoff and erosion rates are possible where a watershed is assumed to contribute runoff uniformly over the entire area, when actually, only a portion of the area may be contributing, i.e., partial area response. Lane et al. (1978) showed that only 45 and 34% of watershed 1 and 2, respectively, normally contributed runoff. In subsequent analyses reported herein, this effect was ignored for lack of a definitive relation to describe the variable runoff area for different storm sizes.

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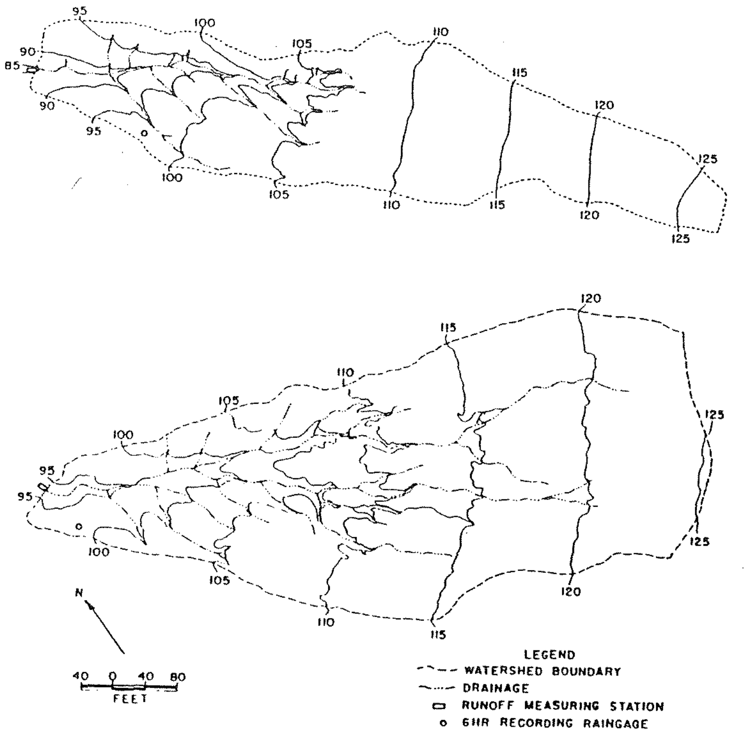

Figure 1. Topographic Map of Watershed 1 and 2
(Contours refer to elevations in feet above an arbitrary datum.
Elevation 100 is approximately 3400 ft. mean sea level. 1 ft = 0.305 m)

Mesquite trees were killed on watershed 2 in 1974. Vegetation measurements made above the incised lower portions of the watershed indicated that prior to treatment there were 2.4 perennial grass plants/m^2. By 1986, perennial grasses had increased to 13.9 plants/ m^2. However, over the same period, the perennial grass density on the untreated watershed 1 increased from 3.3 to 15.0 plants/m^2. From 1974 to 1986, percent mesquite cover decreased from 6.2 to 0.0 on the treated watershed and increased from 6.7% to 7.6% on the untreated watershed. Total shrub cover on the treated watershed was 22.3% in 1974 and 16.9% by 1986. The untreated watershed had 18.0% shrub cover in 1974 and 26.0% by 1986. Analysis of variance of grass and shrub vegetation changes from 1974 to 1986 between the two watersheds showed no significant (P = 0.05) differences.

Unfortunately, the vegetation measurements only indicate changes on watershed areas not significantly contributing to runoff. Vegetation composition also changed in response to precipitation but we were not able to define a predictable pattern.

SOILS

Soil of the two watersheds is comprised mainly of a Comoro sandy loam. This soil is well-drained, 150 cm or more in depth and formed in recent alluvium weathered from mixed rock. The lower portions of the watersheds, which show evidence of accelerated erosion, consist of a Sonoita gravelly sandy loam soil. This soil is well-drained, 150 cm or more in depth, and formed in old alluvium weathered from granite and related acid igneous rock. The soil surface is covered by 15 to 35% gravel and up to 5% cobbles.

PRECIPITATION REPRESENTATIVENESS

The extreme variability of precipitation in southern Arizona is a problem in watershed studies. For example, Herschfield (1962) showed a coefficient of variation of annual precipitation of about 50% in southern Arizona, about the largest in the continental U.S. Thus, short hydrologic records can be suspect in the area. Knisel et al. (1979) used a "surplus-deficit" analysis to illustrate the departures of short precipitation records from long records. Such data for these Santa Rita Experimental Range watersheds were compared with US Weather Bureau data for the Tucson (University of Arizona) gage (Fig. 2).

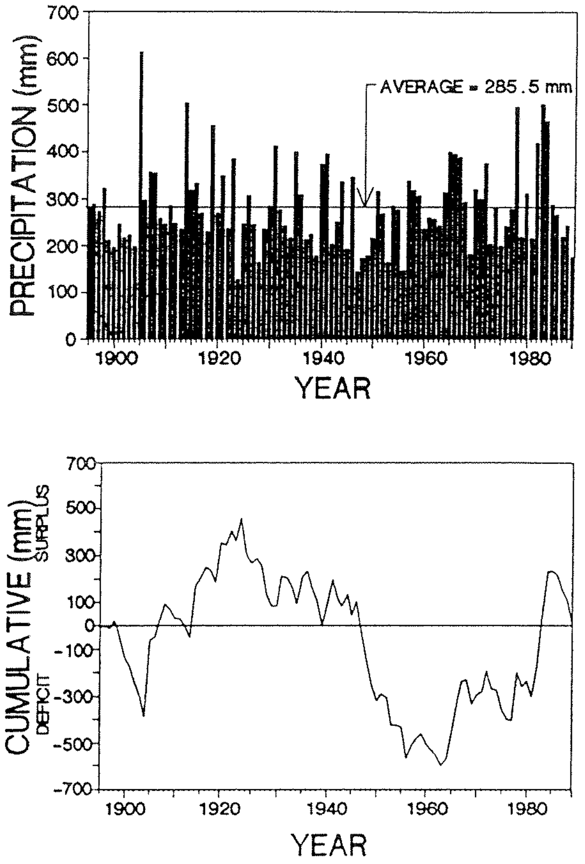

Fig. 2a. 1895-1989: Annual Precipitation and Cumulative Surplus and Deficit for Tucson (University of Arizona)

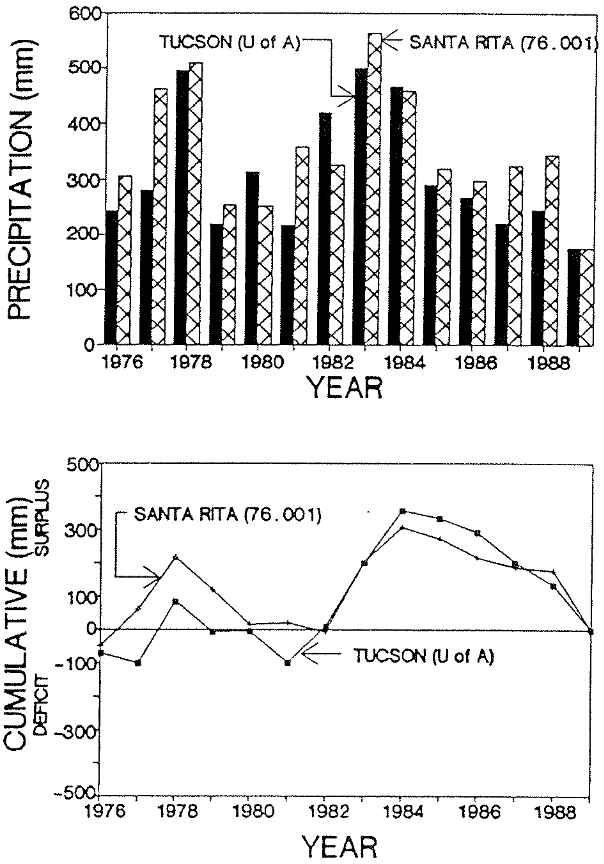

Fig. 2b. 1976-1989: Annual Precipitation for Santa Rita, RG76.001 (Average = 353 mm) and Tucson (University of Arizona) (Average = 311 mm) and Cumulative Surplus and Deficity

In Fig. 2a, the 94-year record for the University of Arizona station is presented in both the upper bar graph of annual values and in the lower cumulative surplus-deficit graph. Of particular significance is that the latter years, i.e., the period during which the Santa Rita watersheds were operated, were significantly wetter than the long term average (311 mm versus 285 mm) (Fig. 2b). Thus the precipitation and in turn, runoff and sediment yield, might be expected to be above average.

Short term precipitation amounts, provide better indicators of annual runoff than annual totals (Lane et al. 1984). To check whether the short 12-year precipitation records for the Santa Rita watersheds might be representative of longer records for other gages in the region, a frequency analysis was completed for annual maximum daily precipitation (Table 1) and annual maximum hourly precipitation (Table 2) using a computer program that fits the observed data with several frequency distributions (Reich et al. 1990).

Table 1. Annual maximum daily precipitation (mm) for Santa Rita (76.001), Walnut Gulch (63.024) and Tucson (University of Arizona) using log-normal distribution.

Probability	Station Santa Rita	 Walnut Gulch 63.024	 Tucson
0.99	13.5	13.2	12.2
0.90	22.6	20.1	20.6
0.80	26.9	23.1	24.6
0.50	37.6	30.5	34.8
0.20	53.1	39.9	48.8
0.10	63.2	46.0	58.2
0.04	76.5	53.3	70.4
0.01	96.5	64.3	88.6

Santa Rita (76.001) has a 12-year record, Walnut Gulch (63.024) has a 34-year record, and Tucson (U of A) has a 50-year record.

Table 2. Annual maximum hourly precipitation (mm) for Santa Rita (76.001) and Walnut Gulch (63.024) using log-normal distribution.

Probability	Station Santa Rita	 Walnut Gulch 63.024
0.99	7.3	9.1
0.90	13.7	14.7
0.80	17.0	17.5
0.50	25.4	23.9
0.20	37.8	32.8
0.10	46.7	38.6
0.04	58.7	46.2
0.01	77.0	57.2

Santa Rita (76.001) has a 12-year record and Walnut Gulch (63.024) has a 34-year record.

Table 1 shows that the maximum daily amounts for more infrequent events (e.g. 5- through 100-year frequency) are larger than those from the longer records on the Walnut Gulch Experimental Watershed near Tombstone, AZ and for the University of Arizona gage in Tucson. Furthermore, the maximum hourly precipitation on the Santa Rita range is 35% more for the 100-year storm than that on Walnut Gulch (Table 2) whereas the amounts for more frequent events are less. This further illustrates why we might expect long term average runoff and erosion to be less than those reported.

RUNOFF AND SEDIMENT YIELD

Precipitation and runoff data from the two watersheds in this study are considered to be excellent. The sediment concentration-transport-yield data are often less than adequate. For example, four conditions are encountered with some regularity: (1) known flow, no recorded hydrograph; (2) recorded hydrograph but no concentration data; (3) recorded hydrograph but insufficient concentration data throughout the hydrograph; and (4) recorded hydrograph with sufficient concentration data to define the sedigraph. Only two of events in the entire record were in condition 1, many small events were in condition 2 (the sampler mechanism is activated at flow depths larger than 60 mm) and represent a very small portion of the total yield, numerous events were in condition 3 and about 75 events were in condition 4. Stated another way 66% of the sediment yield for watershed 1 came from condition 4 events, whereas on watershed 2, 37% of the sediment yield was produced by condition 4 events. Figure 3a and 3b illustrate a condition 4 storm on watersheds 1 and 2, respectively.

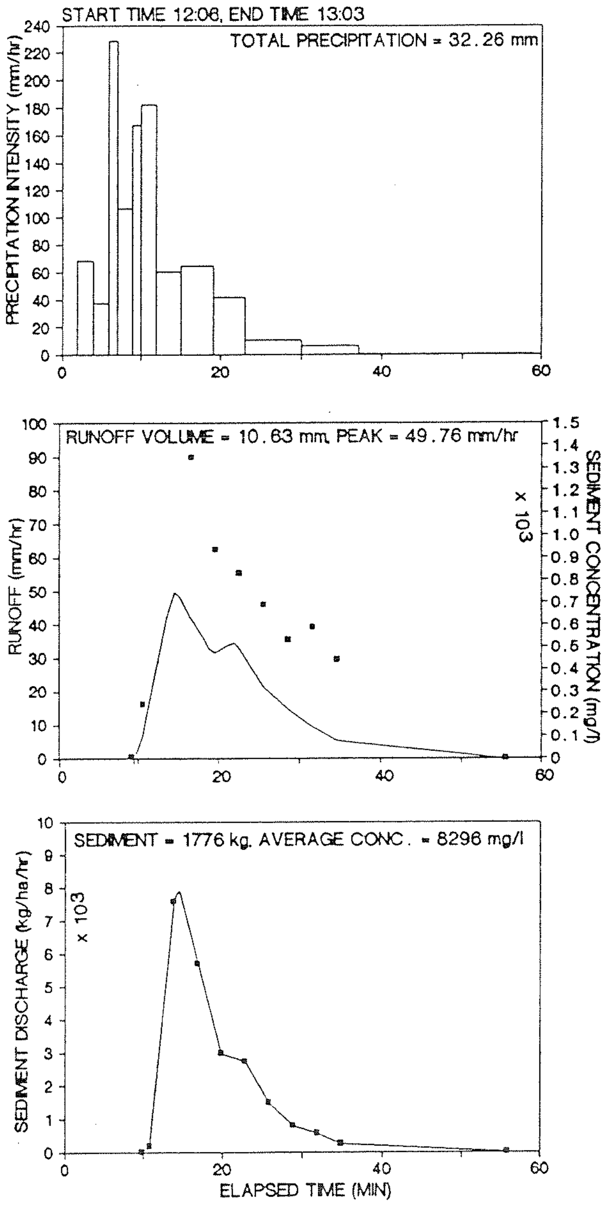

Figure 3a. Hyetograph, hydrograph, concentration data and sedigraph for watershed 1 on September 11, 1977.

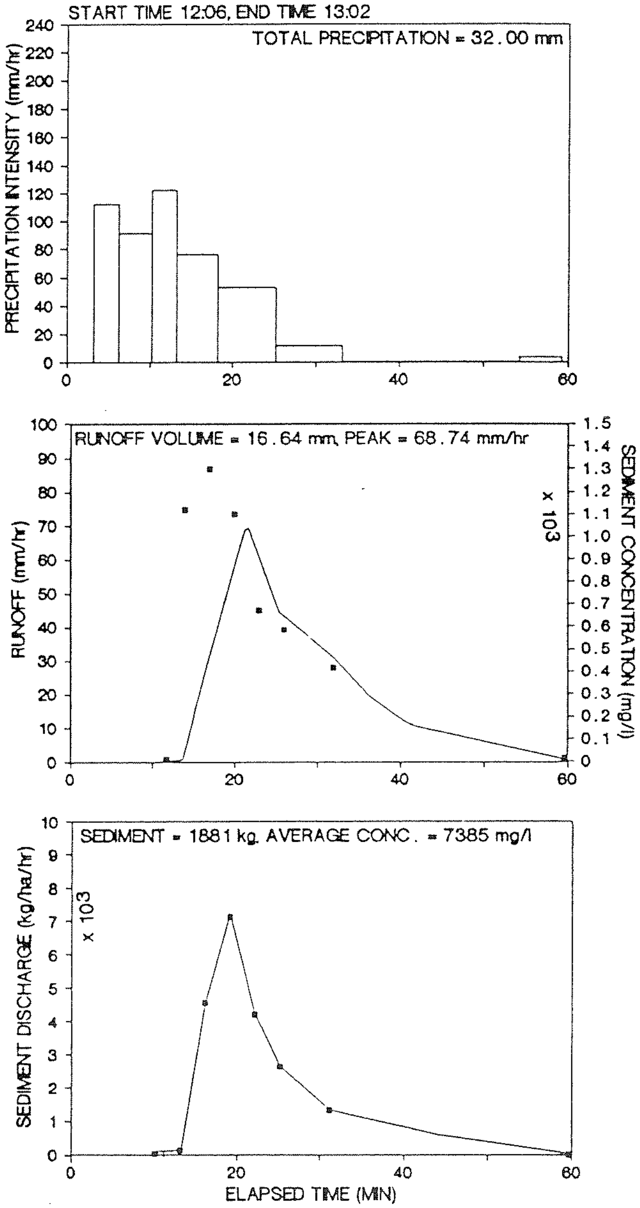

Figure 3b. Hyetograph, hydrograph, concentration data and sedigraph for watershed 2 on September 11, 1977.

The upper third of these figures are the hyetographs on each watershed as digitized from the cumulative recording raingage. The total precipitation depth is 32.26 and 32.00 mm for the watersheds. Runoff on the other hand was significantly different with 10.63 and 16.64 mm total runoff for watersheds 1 and 2, respectively. The squares in the center of each graph are the concentrations (mg/l) at specific times in the hydrograph. The lower portion of the graph is the sedigraph corresponding to the hydrograph with the squares being the transport corresponding to the concentration values. For this event, the total transport was only slightly greater on watershed 2 (1881 kg) than watershed 1 (1776 kg) despite the large differences in runoff volume.

Estimating Storm Soil Loss For Condition 1, 2 and 3 Events

To estimate the storm soil loss for conditions without adequate samples, several techniques were investigated as follows: (1) A simple two parameter model based on the notion of a linear reservoir with input proportional to the rate of rain splash erosion.

$$\hat{C}(t) = K_2 S(t) \tag{1}$$

$$R(t) = I(t)\,[I(t) - \varphi] \tag{2}$$

and

$$\int_{t_1}^{t_2} K_1 R(t)dt = \int_{t_1}^{t_2} \hat{C}(t)dt + [S(t_2) - S(t_1)] = \int_{t_1}^{t_2} \hat{C}(t)dt + \left[\frac{\hat{C}(t_2)}{K_2} - \frac{\hat{C}(t_1)}{K_2}\right] \tag{3}$$

where K_1 and K_2 are parameters to be optimized
$\hat{C}(t)$ is the predicted concentration at time t
$S(t)$ is the storage at time t
$R(t)$ is the product of rainfall rate and rainfall excess rate
$I(t)$ is the precipitation at time t
φ is the phi index, estimated for each event.

Although this model provided good fits to measured concentrations for single events, the parameters varied quite widely from event to event so it did not provide an estimator as good as a flow weighted mean concentration.

(2) Regression models were attempted which related storm soil loss to:

(a) R, the Universal Soil Loss Equation (Wischmeier and Smith 1978) rainfall-runoff factor for individual storms

(b) I(30), the maximum precipitation depth in 30-minutes

(c) P, Q and I_{max}.

Previous efforts (Simanton and Osborn 1983) on small watersheds on the Walnut Gulch Experimental Watershed near Tombstone, Arizona showed that the USLE R-factor gave good correlations with observed runoff and soil loss from individual flow events. Based on the current analyses and the earlier work, this model was used to estimate runoff and sediment yield from condition 1, 2, and 3 events. These estimates were included with measured values for condition 4 events to produce the summary data in Table 3. It is interesting to note that despite the close proximity (< 300 m apart), the two recording raingages showed generally greater precipitation on 2 than on 1 (7.5% difference). Though not significantly different ($P = 0.05$), the control watershed (1) had more average runoff (18.87 mm) than 2 (14.54 mm), the mesquite killed watershed and the mean annual sediment yield from watershed

Table 3. Summaries of annual data and statistics for the 13 year data set.

	Watershed 1 (Control)			Watershed 2 (Treated)			Ratio of Runoff Q2/Q1	Ratio of Sediment Yield QS2/QS1
	Rainfall mm	Runoff mm	Sediment Yield kg	Rainfall mm	Runoff mm	Sediment Yield kg		
76	305.6	11.2	943	296.2	11.1	1,359	1.00	1.44
77	463.3	39.6	5,959	429.8	46.9	6,756	1.18	1.13
78	510.5	30.6	4,086	550.9	32.3	3,638	1.06	0.89
79	253.5	4.6	937	261.9	2.3	553	0.50	0.59
80	250.9	7.6	1,390	266.4	2.6	652	0.34	0.47
81	358.1	40.0	4,249	389.1	29.9	4,149	0.75	0.98
82	324.9	16.2	3,143	357.4	10.9	923	0.67	0.29
83	564.4	36.8	3,018	641.1	17.9	2,705	0.49	0.90
84	459.0	11.0	2,407	507.7	3.5	2,125	0.32	0.88
85	317.7	1.4	680	360.7	Trace	238	0.00	0.35
86	296.4	9.6	1,283	357.9	4.6	1,041	0.48	0.81
87	323.8	10.8	1,739	355.3	8.3	896	0.77	0.52
88	343.7	25.9	3,511	383.8	18.6	1,603	0.72	0.46
Mean	367.1	18.9	2,565	396.8	14.5	2,049		
Std	95.7	13.3	1,536	106.9	13.6	1,782		
Min	250.9	1.4	680	261.9	0.0	238		
Max	564.4	40.0	5,959	641.1	46.9	6,756		

1 was greater (2565 kg) than 2 (2049 kg) as would be expected with the corresponding differences in runoff. On a unit area basis, watershed 1 had 1564 kg/ha whereas watershed 2 had 1158 kg/ha. Stated another way, watershed 2 had 26% less sediment yield than watershed 1, the untreated watershed.

Some rainfall simulator experiments were performed in the Santa Rita Experimental Range in 1987 and 1988 using a rotating boom simulator. Interestingly, the measured soil losses from the simulator plots (Dr. William Emmerich, unpublished data) are significantly lower than those measured from the experimental watersheds indicating that much of the sediment yield originates from channel/gully erosion in such environments (Osborn and Simanton, 1989).

Observations in and adjacent to the incised channels on these watersheds revealed that the mesquite killed watershed (76.002) had more grass in the channel in the latter years of the study. This might well have a cause/effect relationship on the lower runoff and sediment yield.

The annual runoff and sediment yield ratios (watershed 2/watershed 1) are shown in the last two columns of Table 3. Of particular interest is that the ratios in the first few years are near unity and decrease appreciably in the later years. We hypothesize that vegetation cover conditions on watershed 2 took several years for new equilibrium conditions to establish (no grass seeding was done).

CONCLUSIONS

1. The precipitation during the period of monitoring is appreciably above the long term average.

2. Runoff from watershed 2 (mesquite killed) is less than that from the untreated control watershed despite the greater precipitation on the treated watershed.

3. Sediment yield from the treated watershed was 26% less than that from the untreated watershed based upon sampling and on estimation using the rainfall-runoff erosivity factor (R) from the Universal Soil Loss Equation.

4. The ratios of runoff and sediment yield for watershed 2 to 1 which initially were near unity decreased in time. We speculate that this decrease was associated with grass establishment in and adjacent to the ephemeral channels. These results are contrary to that observed in more humid forested watersheds in other places in Arizona following removal of forest cover.

REFERENCES

Barr, G.W. 1956. Recovering rainfall, more water for irrigation. Univ. of Arizona Dept. of Agric. Econ. 218 pgs.

Ffolliott, P.F., and D.B. Thorud. 1974. Vegetation management for increased water yield in Arizona. Technical Bulletin, Agric. Exp. Station, Univ. of Ariz. 38 pgs.

Hershfield, D.M. 1962. A note on the variability of annual precipitation. J. Applied Meteorology VI(4):575-578.

Hibbert, A.R. 1965. Forest treatment effects on water yield. *In:* International Symposium on Forest Hydrology. Nat. Sci. Found. Advan. Sci. Semin. Proc., Penn. State Univ., University Park, PA, Aug. 29-Sept. 10, 1965, Pergamon Press, N.Y. pp. 527-543.

Horton, J.S. 1976. Management of moist-site vegetation for water: Past history, present status, and future needs. PSIAC Report. 41 pgs.

Knisel, W.G., K.G. Renard, and L.J. Lane. 1979. Hydrologic data collection: How long is long enough? Proc. Am. Soc. of Civil Engrs. Specialty Conference on Irrigation and Drainage in the Nineteen- Eighties, pp. 238-254.

Lane, L.J., M.H. Diskin, D.E. Wallace, and R.M. Dixon. 1978. Partial area response of small semiarid watersheds. Water Resources Bulletin, AWRA, 14(5):1143-1158.

Lane, L.J., Romney, E.M., and T.E. Hakonson. 1984. Water balance calculations and net production of perennial vegetation in the northern Mojave Desert. J. Range Manage. 37(1):12-18.

Osborn, H.B., and J.R. Simanton. 1989. Gullies and Sediment Yield. Rangelands 11(2):51-56.

Reich, B.M., K.G. Renard, and F.A. Lopez. 1990. Alignment of large flood-peaks on arid watersheds. *In*: Proc. ASCE International Symposium on the Hydraulic/Hydrology of Arid Lands, San Diego, CA.

Renard, K.G., J.R. Simanton, and C.E. Fancher. 1986. Small watershed automatic water quality sampler. Proc. 4th Federal Interagency Sedimentation Conference, Vol 1, pp. 1-51 to 1-58.

Simanton, J.R., and H.B. Osborn. 1983. Runoff estimates for thunderstorm rainfall on small rangeland watersheds. Hydrology and Water Resources in Arizona and the Southwest. Office of Arid Land Studies, Univ. of Ariz. 13:9-15.

Smith, R.E., D.L. Chery, K.G. Renard, and W.R. Gwinn. 1981. Supercritical flow flumes for measuring sediment-laden flow. U.S. Dept. of Agric. Tech. Bull. No. 1655. 72 pgs.

Wischmeier, W.H., and D.D. Smith. 1978. Predicting rainfall erosion losses: A guide to conservation planning. USDA, Agriculture Handbook No. 537. U.S. Government Printing Office, Washington, D.C.