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EFFECTS OF BRUSH TO GRASS CONVERSION ON THE HYDROLOGY AND EROSION OF A SEMIARID SOUTHWESTERN RANGELAND WATERSHED

by

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INTRODUCTION

Grass forage on Western U. S. rangelands is a renewable natural resource utilized in red meat production. Increased nutritional and economic demands for agricultural products from the U. S. have dictated the need for greater and more efficient use of this and other natural resources. The Western U. S., excluding Alaska and Hawaii, contains 40% of the total U. S. land area (USDA, 1976). Of this, 243 million acres is pasture or rangeland, and only about 50 million acres of this is classified as good or better condition rangeland (USDA, 1974). Because of the large land area involved, a small increase in production per unit area would mean a large increase in production from the total area. Methods to increase agricultural output in the form of forage for increased grazing include mechanical treatments, vegetation manipulation, fertilization, and improved grazing and cattle management practices.

Vegetation manipulation, usually chemical or mechanical, is the quickest and, perhaps, the most economical method of increasing forage and consequent agricultural production of an area. Often, these manipulations or conversions are made without much concern for, or understanding of, the hydrologic consequences. These consequences can lead to a post-conversion condition that is more unproductive than the original condition and, often, downstream damage may be extensive.

This paper reports and discusses the hydrologic and erosion changes measured from a 110-acre semiarid watershed, which was converted from brush to grass cover by root-plowing and seeding. Data analyses include considerations of changes resulting from the vegetation conversion on the rainfall-runoff relationships, sediment yield, Universal Soil Loss Equation (USLE) factors, vegetation composition and trends, and forage and grazing capacity.

DESCRIPTION OF EXPERIMENTAL AREA

The watershed studied is located in southeastern Arizona near Tombstone, Arizona, and is part of the Walnut Gulch Experimental Watershed operated by the Agricultural Research Service. Before treatment, the watershed (designated No. 63.201) was typical of many thousands of acres of deteriorated semiarid rangeland found throughout southern Arizona, New Mexico and northern Mexico. The desert shrub vegetation was dominated by whitethorn (*Acacia constricta*), creosote bush (*Larrea divaricata*), and tarbush (*Flourensia cernua*) (Table 1). Soil of the watershed is a Rillito-Karro gravelly loam which is of the Typic and Ustlic Calciorthids subgroups. This soil complex is deep (55 inches), well-drained, medium and moderately coarse textured, and formed in calcareous old alluvium (Gelderman, 1970).

Precipitation, runoff, and sediment yield data were collected from the watershed from 1966 through 1976. Precipitation, measured in the area since 1955 with a 24-hour recording raingage, averaged about 13.5 inches annually, about 2/3 of which occurred from June through September. Storm runoff was estimated from recorded water level changes in a stock pond at the watershed outlet. Stock pond depth-volume curves were developed from annual topographic survey data, which were also used to determine sediment accumulation (Simanton and Osborn, 1973). Average annual runoff was about 7% of the annual precipitation, and occured only during the summer thunderstorm season.

WATERSHED TREATMENT

The watershed was fenced to exclude grazing, then root-plowed on the contour in June, 1971. Root-plowing consists of pulling a large, fixed cutting blade at the 12-to 18-inch depth beneath the soil surface to cut the brush roots below the plant crown. Eighty percent of the watershed was rangeland drilled to side-oats grama (*Bouteloua curtipendula*) in July, 1972. The remaining area was broadcast seeded to blue grama (*Bouteloua gracilis*) in August, 1972. Seeding dates were determined from soil-water availability curves developed for these semiarid rangelands (Tromble, 1974). Although optimum seeding time is usually immediately after brush removal because of the eliminated moisture competition

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from other vegetation; the 1 year's delay before seeding, caused by seed unavailability, did not seem to hinder grass establishment. The seeding was successful, and grass now dominates the watershed vegetative cover (Figure 1, Table 1).

TABLE 1. Vegetation of Watershed No. 63.201

Pretreatment Species	% of Total Crown Cover	Post-treatment Species	% of Total Crown Cover
Acacia constricta	39.4	Bouteloua curtipendula	35.4
Larrea divaricata	23.1	Tridens pulchellus	13.0
Flourensia cernua	20.2	Bouteloua gracilis	12.2
Parthenium incanum	11.0	Eragrostis Lehmanniana	8.5
Zinnia pumila	3.4	Sporobolus contractus	3.8
Muhlenbergia Porteri	2.9	Zinnia pumila	3.7
Total	100.0	Acacia constricta	3.6
		Larrea divaricata	3.3
		Muhlenbergia Porteri	2.8
		Tridens muticus	2.3
		Aristida species	2.3
		Flourensia cernua	2.3
		All Forbs	1.6
		6 Remaining Grass Species	3.7
		2 Remaining Shrub Species	1.5
		Total	100.0

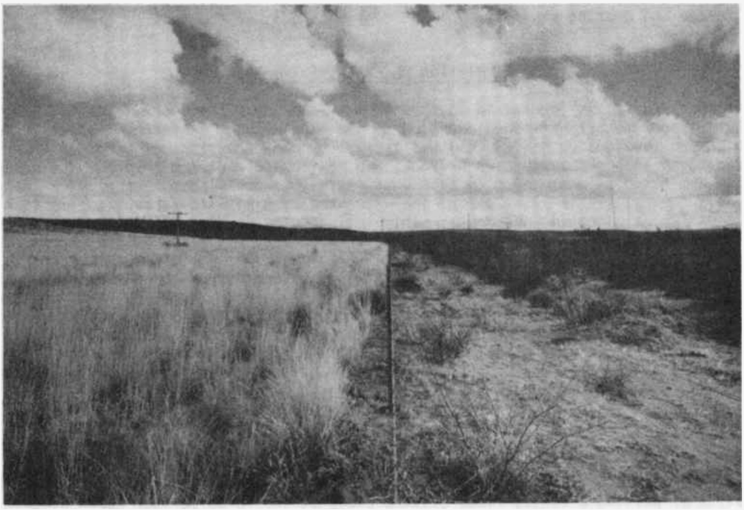

Figure 1 - Fence line contrast showing root-plowed, seeded area on the left and the brush dominated pre-treatment condition on the right.

DISCUSSION OF RESULTS

RAINFALL - RUNOFF

Rainfall variability and storm size should be included in any hydrologic studies where thunderstorm precipitation dominates the hydrologic input. Thunderstorm variability has long been recognized as the most influential factor in hydrologic and watershed studies in the southwestern United States (Osborn and Reynolds, 1963; Renard and Brakensiek, 1976). Associated with the rainfall variability is the variability of the USLE's rainfall factor (R) (Renard and Simanton, 1975). The R value is the number of erosion-index (EI) units (ft-tons/acre) in a normal year's rain and is a measure of the rainfall's erosive force. EI is the product of the total kinetic energy and the maximum 30-minute intensity of a storm (Wischmeier and Smith, 1958). Each storm's EI value is accumulated to obtain a yearly R factor. Log-normal probability distributions for summer rainfall and annual R of the treated watershed are presented in Figure 2. These distributions represent the 22 years of precipitation data from 1955 through 1976, and are useful in explaining some of the changes in the rainfall-runoff relationships associated with watershed treatment. From Figure 2, the summer rainfall expected 1 year out of two is about 7 inches. The average rainfall for the post-treatment period was 6.8 inches (Table 2), slightly less than the 50% probability. The average rainfall for the transition period was 9.3 inches. However, during the second year of the transition period (1972) there were 12 inches of summer precipitation. Based on Figure 2, this amount would be expected to occur on the average of once in 10 years. The gross effects of this rainfall variability set limitations on the conclusions regarding rainfall-runoff relationship changes. However, for the precipitation observed, there were significant changes in the rainfall-runoff relationships (Table 2).

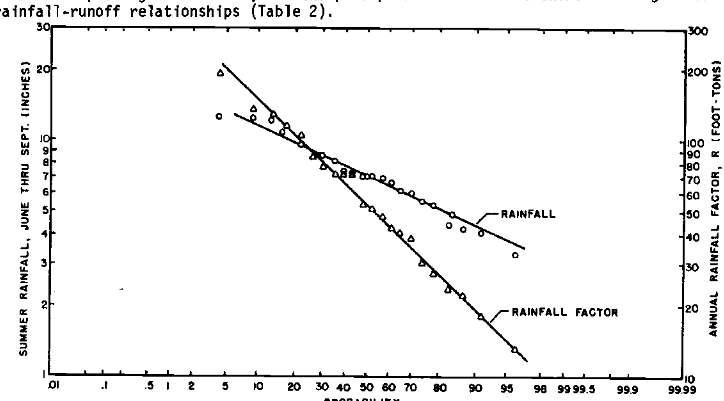

FIGURE 2. LOG-NORMAL PROBABILITY CURVES OF SUMMER RAINFALL AND ANNUAL RAINFALL FACTOR. RAINGAGE 63.002. 1955-1976.

TABLE 2. Runoff and Sediment Yields During 3 Periods of Watershed Change.

63.201
(1966 - 1976)

Period	AVG SUMMER PRECIP		AVG SUMMER RUNOFF Observed		Predicted Per 1 in Runoff		SEDIMENT YIELD Observed		Predicted Per 1 in Runoff	
	in	(mm)	in	(mm)	in	(mm)	Tons ac/yr	Tonnes ha/yr	Tons ac/yr	Tonnes ha/yr
Pretreatment (Brush Vegetation) 1966 - 1970	9.43	(240)	0.904	(23.0)	0.096	(2.44)	1.67	(3.746)	1.85	(4.150)
Transition 1971 - 1973	9.32	(237)	1.329	(33.8)	0.143	(3.63)	1.14	(2.557)	0.86	(1.929)
Post-treatment (Grass cover) 1974 - 1976	6.84	(174)	0.131	(3.3)	0.019	(0.48)	0.13	(0.292)	0.99	(2.221)

Runoff differences may be attributed to factors other than precipitation. Type and amount of vegetative cover are very important in determining watershed runoff amounts because of their role in affecting infiltration (Kincaid et al., 1966; Kincaid and Williams, 1966; Dixon, 1975). The relationship between vegetation and runoff can be implied from data presented in Figure 3. Until the root-plowing in 1971, the cumulative rainfall-runoff relationship was fairly constant. Just after root-plowing, the treatment effects (surface disturbances) apparently counteracted the loss in vegetation effects (the rainfall-runoff relationship remained constant). After 1 season's rainfall reestablished a watershed drainage network, the lack of vegetation contributed to a discernable runoff increase. After seeding and grass establishment, the effects of vegetation were reflected in a significant decrease in runoff rate. The combined effect of the root-plowing and revegetation for the combined transition and post-treatment 6 year period produced the same end point on the rainfall-runoff curve that would have been expected with no treatment (assuming the rainfall-runoff curve for the pretreatment condition remained constant).

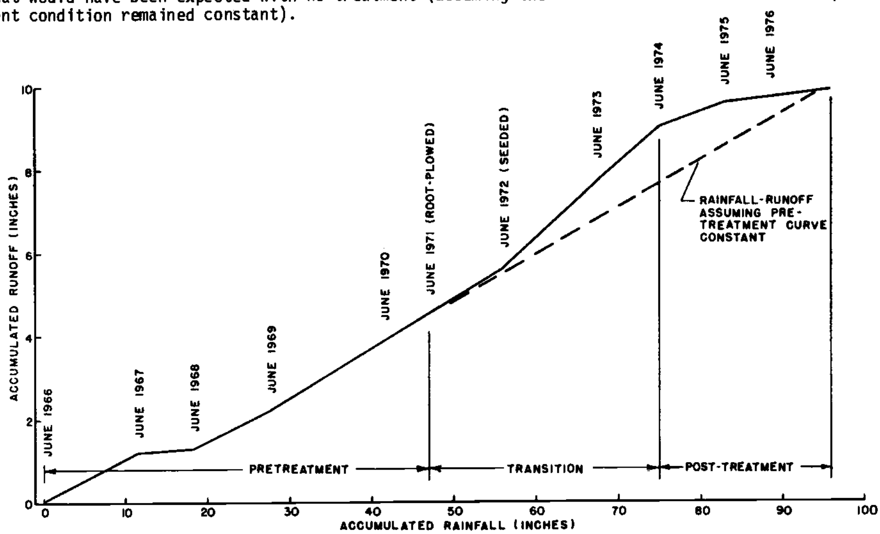

FIGURE 3. MASS RAINFALL-RUNOFF CURVES. WATERSHED 63.201, 1966-1976.

Figures 4a and 4b illustrate changes in runoff for a given precipitation event when all the storms are considered individually. The curve number method used in Figure 4a was developed from the Soil Conservation Service National Engineering Handbook (SCS, 1971). The modified linear regression technique (Diskin, 1970) was developed specifically to treat data where some of the independent data (precipitation) produced zero data (runoff) in the dependent variable (Figure 4b).

From Figure 4a, the pretreatment curve number (CN) for the watershed is 78, which converts to about 0.06 inch of runoff from a 1-inch rainfall. The transition period CN is 84, or 0.15 inch of runoff from a 1-inch rainfall. The post-treatment CN is 77, or 0.05 inch of runoff from a 1-inch rainfall. The differences in runoff between the pretreatment and transition periods and between the transition and post-treatment periods are more and less, respectively, but there is very little difference in runoff between the pre- and post-treatment periods.

Figure 4b represents the curves developed from a modified linear regression technique developed to interpret rainfall-runoff relationships when many of the runoff values are zero. Two findings are significant in this figure. The first is a considerable decrease in runoff associated with the post-treatment as compared to the pre-treatment and transition periods. The second finding is that the rainfall threshold for runoff initiation is about 20% greater during the transition period than during the pre- and post-treatment periods. Also, the rainfall thresholds of the pre- and post-treatment periods are equal. These rainfall threshold changes indicate that the watershed surface storage and drainage network, disturbed by root-plowing, held water during the smaller rainfall events. However, this disturbance was not enough to compensate for the loss of vegetative cover which caused the runoff increase from the larger events. The fact that the pre- and post-treatment periods' rainfall threshold was the same but the post-treatment period runoff was much less once this threshold was passed is again consistant with the results from Figure 2, where the flatness of the post-treatment curve associated with an increase in grass vegetation represents a decrease in runoff.

Although the results from the curves of Figure 4a and 4b are consistant, there was no significant difference in runoff between the pre- and post-treatment when the data were fitted by the curve number method, but there was a significant difference (95 percent level) when the modified linear regression was used. This was probably because of the very low coefficient of determination associated with the post-treatment data fit of Figure 4a using the curve number method. The low coefficient of determination for the post-treatment rainfall-runoff relationship may indicate that a new equilibrium watershed

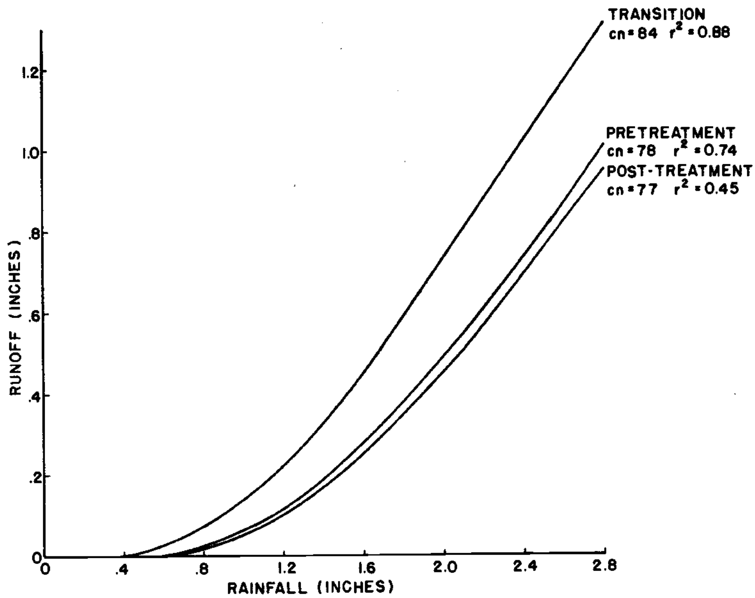

FIGURE 4a. RAINFALL VS. RUNOFF. SCS CURVE NUMBER.

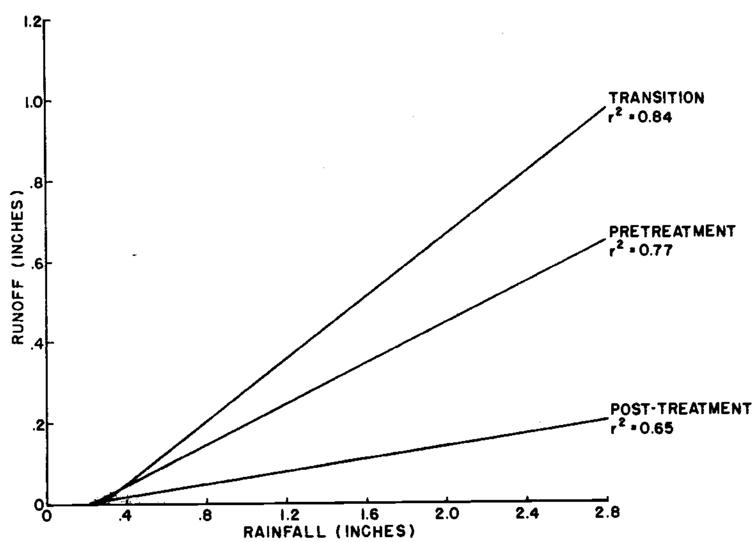

FIGURE 4b. RAINFALL VS. RUNOFF. MODIFIED LINEAR REGRESSION.

condition had not been established by the arbitrarily selected post-treatment date of June, 1974.

SEDIMENT

Average annual sediment yields during the three study periods are shown in Table 2. Measurement difficulties in determining pond volume changes, sediment bulk density, sediment delivery ratios, and unrecorded sediment removal made our actual results uncertain. Also, time-related changes in watershed roughness, drainage patterns, and erosion pavement all made the sediment yield analyses difficult. The time and environmental dependent changes and their effect on sediment yield can be hypothesized, but not until detailed and better controlled studies are made can they be adequately qualified or quantified.

One explanation for the uncertainty in the results could be changes in the erosion pavement and drainage network formation processes. Before treatment, the watershed probably had reached an equilibrium between rainfall and erosion pavement. That is, the erosion pavement had reached an amount governed by the most intense rainstorm experienced on the watershed. Also, the watershed drainage patterns, both rill and interrill, were similarly stabilized. After treatment, both the erosion pavement and drainage patterns had to reestablish according to the new watershed surface and most severe rainstorm experienced. This establishment did not occur at equal rates; thus, there are anomalies between runoff and sediment yields throughout the study period. Topographic conditions on the watershed immediately after root-plowing resembled those on a contoured plowed or terraced watershed. The vegetation was knocked down, the soil surface loosened, and small ridges formed parallel with the contour. The terrace effect produced by the contour ridges apparently reduced the sediment transport capacity of the runoff as it moved more slowly downslope. The reduced energy associated with this type runoff decreased the particle size of sediment moved, causing mostly finer sediment to move into the stock pond. Changes in stock pond volume due to the suspended sediment accumulation are difficult to determine from topographic surveys.

To help quantify sediment yield changes associated with treatment, the Universal Soil Loss Equation (USLE) parameters were evaluated for conditions pre- and post-treatment. These parameters include a rainfall factor (R), soil erodibility (K), cover (C), slope-length (SL), and erosion control practice (P). The applicability of the USLE to semiarid rangeland conditions seems possible for certain watershed conditions (Renard, Simanton, and Osborn, 1974). Values for the five USLE parameters for pre- and post-treatment periods are listed in Table 3. The USLE parameter values for the pretreatment period were measured immediately outside the treated watershed and were assumed to reflect the pretreatment watershed condition. USLE parameters were not determined for the watershed during the transition period.

TABLE 3. USLE Parameters and Sediment Yield

Condition	R	K	C[1]	SL[2]	P	Sediment Predicted (Tons/Acre/yr)	Yield Measured (Tons/Acre/yr)
	(Average)						
Brush (1966 → 1970)	88	.20	.08	.90	1	1.28	1.67
Grass (1974 → 1976)	47	.16	.15	.90	1	1.02	0.13

1 From SCS TR #51 (1972), Table 1: Brush - 50% Canopy Cover, Type W
60% Ground Cover (erosion pavement).

Grass - 0% Canopy Cover, Type G
30% Ground Cover (erosion pavement).

Variability in the R factor is more pronounced than the rainfall variability because the term not only includes rainfall depth, but also rainfall intensity. Although the summer R value constituted at least 95% of the annual total, the annual value was used because annual R is most commonly used in the USLE. The annual R 50% probability, from Figure 2, is around 52, with a 22 year range of 13 to 190. The average R for the post-treatment period was 47. The average R for the pretreatment period was 88 and the transition period had an average R of 96. In fact, the transition period had the largest annual R value of the 22 year period.

The soil erodibility (K), cover (C), and erosion control practice (P) were the parameters changed by the treatment. These changes were expected because of the disturbance of the soil surface and plant cover. The K term was determined from a nomograph procedure utilizing five soil properties--organic matter, very fine sand and silt, sand, structure, and permeability (Wischmeier et al., 1971). Of these, organic matter was the only one measureably changed because of treatment. The percent organic matter increased from 1.1 pretreatment to 2.2 post-treatment. With these organic matter changes, the K term changed from 0.20 pretreatment to 0.16 post-treatment, a 20% decrease.

The C term, reflecting vegetation type and density, was determined from specially prepared tables (SCS TR 51, 1972). The C term was expected to decrease because of the increase in ground cover associated with grass. However, because erosion pavement was assumed to be part of the ground cover, as suggested by Osborn et al. (1976), and this cover decreased from 60 to 30% between the pre- and post-treatment periods, the C term increased from 0.08 to 0.15, or nearly 90%.

Using the best estimates available for the five USLE parameters, the predicted sediment yield for the pretreatment period was within 30% of the measured yield. However, the predicted yield for the post-treatment period was almost 8 times that measured; probably because of the watershed change caused by the root-plowing. This watershed change should be reflected in the erosion control practice (P) term. Because no values are available for the root-plowing, seeding practice, the P term can only be estimated by solving the USLE using the known sediment yield and the other USLE parameters for the post-treatment period. Solving for P using the 0.13 tons/acre/yr, measured during the post-treatment period, gave a P value of 0.13. This value is less than the 0.50 recommended by Wischmeier and Smith (1965) for a contouring practice, but near the value of 0.15 that they recommended for contour listing. This type of analysis is limited because the effects of the root-plowing, seeding treatment are dynamic.

VEGETATION

The primary purpose of the brush to grass conversion was to relate the changes in vegetation to changes in forage production or animal carrying capacity. Before treatment, the watershed was dominated by low forage-value brush which comprised about 97% of the total vegetative cover (Table 1), and had a grazing capacity of about 2-3 animal units (AU)/section/yr. After root-plowing and seeding, the dominant vegetation was grass, comprising about 85% of the total cover. A grazing study was initiated in the early spring of 1975 to determine the effect of brush to grass conversion on the area's grazing capacity. Twenty-two Hereford cattle grazed 80 acres of the root-plowed area for 2 months in the early spring of 1975. This was equivalent to 29 AU/section/yr., and was almost 3 times greater than the pretreatment carrying capacity. Twenty-four cattle grazed the same 80-acre area for two months in the early spring of 1976. This was equivalent to 32 AU/section/yr., over 3 times the pretreatment carrying capacity. Vegetation measurements made before each of these grazing periods indicated no significant change in either vegetation composition or percent crown cover. However, different grazing systems using this large number of AU may have a detrimental effect on the vegetation composition and crown cover.

SUMMARY

Brush to grass conversion of a semiarid rangeland watershed can have pronounced effects on the hydrology, erosion, and animal carrying capacity of the treated watershed. The extent and direction of these effects depends mainly on the rainfall characteristics after the conversion. Data from this study indicated runoff increased during the transition period and decreased once grass became established. There was a decrease in sediment yield from the watershed following the vegetation conversion.

Because of the many factors involved and the variabilities of these factors, many years of observations are needed to accurately describe the hydrologic effects of watershed conversion. The conversion effects on the erosion or sediment yield from a watershed are even more difficult to describe because of the difficulty in measuring sediment yield. Also, the many complicated interactions involved in the erosion and sedimentation processes make short-term analysis difficult. Erosion pavement formation is only one interaction in a semiarid environment that may take years to stabilize. Limited water and a relatively short growing season make the vegetative component of the conversion another time-dependent variable. Although the brush to grass conversion was successful, the full benefit will only be realized if the new vegetative condition can withstand the rigors of climatic extremes and grazing pressure. The new condition must also show a positive effect in the conservation of the soil and water resource, upon which it and man depends.

The large increases in carrying capacity caused by the conversion are very encouraging. Considering the large amount of semiarid rangeland areas of the world, of which the pretreatment area was typical, such rangeland conversion can have a tremendous impact on the agricultural and economic output.

REFERENCES CITED

Diskin, M. H. 1970. Definition and Uses of the Linear Regression Model. Water Resources Research, AGU 6(6):1668-1673.

Dixon, R. M. 1975. Infiltration Control Through Soil Surface Management. Proceedings Symposium on Watershed Management, Irrigation and Drainage Division, ASCE, Logan, Utah. pp. 543-567.

Gelderman,F. W. 1970. Soil Survey, Walnut Gulch Experimental Watershed, Arizona. Special Report USDA-SCS. 55 p.

Kincaid, D. R., H. B. Osborn, and J. L. Gardner. 1966. Use of Unit-Source Watersheds for Hydrologic Investigations in the Semiarid Southwest. Water Resources Research, AGU 2(3):381-392.

Kincaid, D. R., and G. Williams. 1966. Rainfall Effects on Soil Surface Characteristics Following Range Improvement Treatments. J. Range Mgt. 19(6):346-351.

Osborn, H. B., and W. N. Reyolds. 1963. Convective Storm Patterns in the Southwestern United States. Bull. IASH 8(3):71-83.

Osborn, H. B., J. R. Simanton, and K. G. Renard. 1976. Use of the Universal Soil Loss Equation in the Semiarid Southwest. Nat. Soil Erosion Conference, J. Soil and Water Cons. (In Press).

Renard, K. G., and D. L. Brakensiek. 1976. Precipitation on Inter-mountain Rangeland in the Western United States. U.S. and Australia Rangeland Hydrology Workshop, Boise, Idaho. p. 39-59.

Renard, K. G., and J. R. Simanton. 1975. Thunderstorm Precipitation Effects on the Rainfall-Erosion Index of the Universal Soil Loss Equation. Proc. Ariz. Sec., AWRA - Hydrology Sec., Ariz. Acad. Sci. 5:47-55.

Renard, K. G., J. R. Simanton, and H. B. Osborn. 1974. Applicability of the Universal Soil Loss Equation to Semiarid Rangeland Conditions in the Southwest. Proc. Ariz. Sec., AWRA - Hydrology Sec., Ariz. Acad. Sci. 4:18-32.

Simanton, J. R., and H. B. Osborn. 1973. Use of Stock Ponds for Hydrologic Research on Southwest Rangelands. Proc. Ariz. Sec., AWRA - Hydrology Sec., Ariz. Acad. Sci. 3:2-7.

Soil Conservation Service. 1971. National Engineering Handbook. Sec. 4, Hydrology.

Soil Conservation Service, U.S.D.A. 1972. Procedures for Computing Sheet and Rill Erosion on Project Areas. Tech. Rel. No. 51, Geology. 14 pp.

Tromble, J. M. 1974. Increasing Forage Production on a Semiarid Rangeland Watershed. Proc. Ariz. Sec., AWRA - Hydrology Sec., Ariz. Acad. Sci. 4:33-40.

Wischmeier, W. H., C. B. Johnson, and B. V. Cross. 1971. A Soil Erodibility Nomograph for Farmland Construction Sites. J. Soil and Water Conservation 26(5):189-192.

Wischmeier, W. H., and D. D. Smith. 1958. Rainfall Energy and Its Relationship to Soil Loss. Trans. Am. Geo. Union 39(2):285-291.

Wischmeier, W. H., and D. D. Smith. 1965. Predicting Rainfall-Erosion Losses from Cropland East of the Rocky Mountains. Agr. Handbook 282, USDA, ARS, Washington, D. C. 47 p.

United States Dept. of Agriculture. 1974. Opportunities to Increase Red Meat Production from Ranges of the U.S.A. USDA Inter-Agency Work Group on Range Production, Washington, D. C. 100 p.

United States Dept. of Agriculture. 1976. Agricultural Statistics, 1976, Washington, D. C. 613 p.