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ASSESSING ARID RANGELAND HYDROLOGIC RESOURCES[1]

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Abstract.--One approach for evaluating the consequences of various land management practices is to use computer models which are verified on selected highly instrumented representative areas. The input variables to the models are varied and the effect of the changes observed. Models discussed include precipitation, runoff, and erosion processes.

INTRODUCTION

The arid rangelands of the world have a past history of land misuse coupled with low precipitation and a general low soil fertility. These lands represent a sizeable portion of many countries, and with proper management techniques, can provide significant quantities of food and fiber. With the fragile ecological balance of these areas, inappropriate range management techniques can cause irreversible damage to soil resources which are often critically limiting. The present relatively low economic value of these lands precludes extensive onsite assessment or field-scale testing of the multitude of alternate uses or management practices for their potential effects on the hydrologic resources.

Computer simulation is a technique which permits a rapid evaluation of various proposed land management practices. Models are developed and verified from data collected on selected highly instrumented representative areas. With the models verified, the input variables representing proposed range improvement or management practices are selectively varied and the hydrologic effects of the changes observed. Hydrologic models range from relatively simple statistical approaches to highly complex mathematical relations. The success of any model for predicting the effects of management practices depends upon the validity of the basic concepts and the ability of the model to describe conditions at ungaged sites. Following is a limited discussion of some of the models used for representing precipitation variations, surface runoff, and soil losses by water erosion.

PRECIPITATION

The limited rainfall in arid lands is a result of many complex atmospheric processes. As a result, the rainfall over a given area is extremely variable in quantity and intensity, both in time and space. An accurate physically based model of rainfall processes is not presently available. Thus, statistical models developed from historical precipitation records are used most frequently (Renard and Brakensiek, 1975).

Probability Model

In many places of the world, it has been shown that a simple Markov chain probability model can be used to indicate the frequency distribution of rainfall events (Caskey, 1963; Feyerherm and Bark, 1965; Gabriel and Neumann, 1962; Hershfield, 1970; and Woolhiser et al., 1972). This model assumes that the probability of rain occurring on a given day is only a function of the occurrence or nonoccurrence of rain on the previous day.

Smith and Schreiber (1973, 1974) were able to show that these simple Markov chain models could describe the probabilities of the number of wet days in the summer thunderstorm season (June through September) in southeastern Arizona (fig. 1), and the total summer rainfall (fig. 2). This type of information is useful for the selection of range plants which might have specific moisture requirements during the growing season.

By considering storms of sizes above some required threshold level, Smith (1974) showed it was possible to estimate the frequency of storm events of various sizes. Probability models, while relatively simple, do have the disadvantage of not being able to anticipate on a yearly basis the extreme events or periods caused by short term climatic fluctuations.

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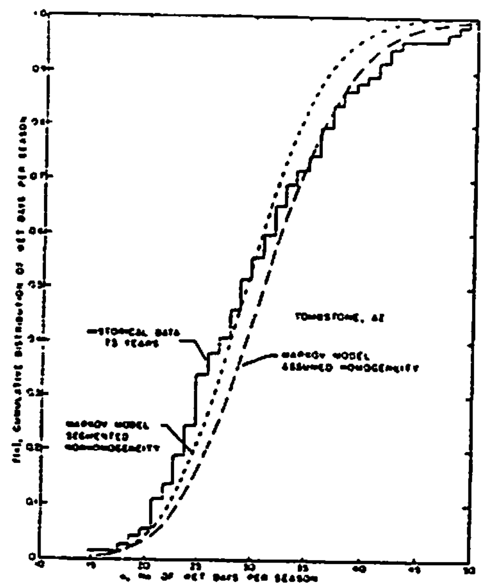

Figure 1.--Predicted and observed cumulative distribution of the number of wet days per season at Tombstone, Arizona (from Smith and Schreiber, 1973).

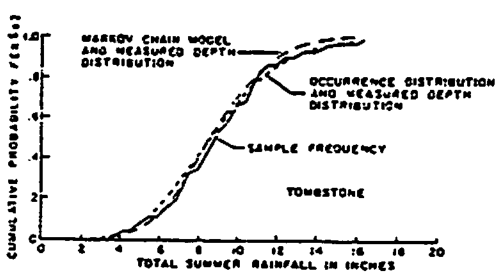

Figure 2.--Measured and simulated distribution of total summer seasonal rainfall at Tombstone, Arizona (from Smith and Schreiber, 1974).

Simulation Model

In many areas, it may be desirable to extend point rainfall data to larger areas and predict the areal distribution of rainfall quantities or intensities. Osborn et al. (1980) developed a computer model for simulating rainfall occurrence and amount on ungaged watersheds in Arizona and New Mexico up to 58 mi^2 in size with elevations between 1000 and 7500 feet. The model was developed using available rainfall records from USDA, Science and Education Administration (SEA) experimental watersheds and the National Weather Service raingage network in Arizona and New Mexico. This model can generate rainfall input data for use on ungaged areas (within the model verification area) where actual precipitation data are limited. Model testing has shown that it reproduces storm characteristics for both airmass and frontal-convective thunderstorms.

Figure 3 shows a storm event on the Walnut Gulch Experimental Watershed in southeastern Arizona. The rainfall model can simulate this type of storm and estimate point rainfall for any location within the subwatershed or a total volume across the entire area. This model can also simulate storm cell movement across the watershed and multiple storm events within a 24-hour period.

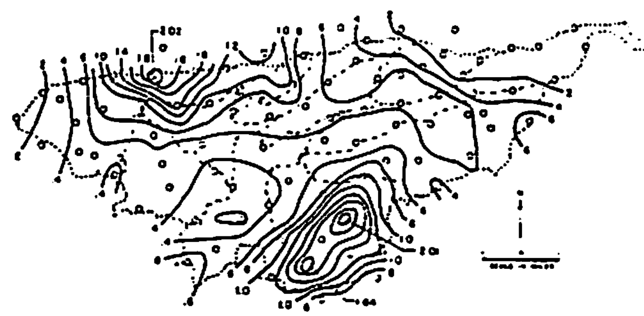

Figure 3.--Isohyetal map of the 31 August 1968 storm on a Walnut Gulch watershed.

Simulation models are useful tools but have a disadvantage of requiring relatively large computer capacities. With the simulation programs, it is possible to determine probability distribution functions of point rainfall or isohyetal projections of seasonal or annual precipitation.

RUNOFF

Runoff prediction procedures for a given amount of rainfall have ranged from simple to rather difficult and complicated techniques (Renard, 1977). Procedures used at the Southwest Rangeland Watershed Research Center include the SCS curve number method and the more involved nonlinear kinematic runoff models where an infiltration equation is used to estimate precipitation excess, and this runoff is then routed over planes to channels (Lane et al., 1978).

SCS Curve Number

The U.S. Department of Agriculture, Soil Conservation Service (SCS) has developed a runoff-predicting model (curve number) based not only on rainfall amounts, but also on watershed characteristics such as soil-cover complexes and antecedent moisture conditions. The hydrologic soil groups are divided into four classes based on infiltration and soil water movement characteristics. The cover groups are determined by land use and treatment classes. Land use varies from row crops to dirt roads with most of the divisions associated with various agricultural uses. Treatment classes consist of straight row cropping, contouring, and terracing. The land use and treatment of an area are further divided into three hydrologic conditions--poor, fair, or good. Knowing these watershed characteristics, one can, by using tables and graphs provided in the SCS Hydrology Handbook (USDA, SCS, 1971), determine a watershed runoff curve number (CN). From this curve number, the watershed runoff can be determined for a given rainfall amount. The runoff from the curve number procedure can be computed by the following equations

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \qquad (1)$$

$$CN = \frac{1000}{10 + S} \qquad (2)$$

where Q is the runoff in inches, P is the rainfall in inches, and S is the potential maximum retention.

However, when the curve number method was applied to small plots on a semiarid rangeland watershed of southeastern Arizona, the runoff predicted using handbook curve numbers underestimated actual runoff (Simanton et al., 1973) (table 1).

Table 1.--Runoff curve numbers developed for Walnut Gulch plots[1].

Plot group	Land use	Table derived curve number[2]	Data derived curve number[3]
Kendall (grass)	Ungrazed	79	93
Kendall (grass)	Lightly grazed	79	94
Lucky Hills (brush)	Ungrazed	87	91
Lamb's Draw (brush)	Grazed	81	86

[1] 6- x 12-ft plots.

[2] From tables in Hydrology Handbook (USDA, SCS, 1971).

[3] Actual rainfall-runoff data fitted to the curve number equation using the technique of least squared deviations.

The differences between the estimated and actual curve numbers from the plots were attributed to high rainfall intensity, absence of drainage networks, and the impact of small differences in antecedent soil moisture. In other climatic regimes, when rainfall intensity does not dominate the input to the hydrologic response of a watershed, the curve number model can be very useful in estimating runoff differences resulting from watershed treatments.

Partial Area Runoff

Hydrologists and engineers in the past have generally considered that runoff for a particular precipitation event was produced uniformly from the contributing watershed. Such assumptions were required because of the complexity of the processes and difficulty in solving equations to describe such processes. An assumption of uniform runoff may be adequate only when very small areas (i.e., < 1 acre) are involved or when the watershed is relatively homogeneous. This assumption is poor in arid and semiarid areas where the spatial variability of precipitation is dramatic (e.g., where air-mass thunderstorms are prevalent) and where the heterogeneity of the watershed is great. Recent investigations by Hewlett and Troendle (1975) and Lane et al. (1978) have illustrated the inadequacy of this assumption. The importance of partial area runoff knowledge is most significant in water quality programs.

When large watersheds are involved, the runoff from small watersheds must be routed to downstream points using the runoff estimates from small watersheds and the hydraulic conditions of the channel systems involved. In many ephemeral streams, runoff losses due to infiltration in the dry streambed can drastically alter the hydrograph shape and runoff volume (Renard, 1977).

EROSION

Erosion models can be very useful in estimating the soil resource loss or conservation associated with different management or cultural practices.

Universal Soil Loss Equation

One model widely used throughout the United States and other parts of the world is the Universal Soil Loss Equation (USLE). The USLE, developed by Wischmeier and Smith (1978), is intended to estimate the long-term average annual soil loss from agricultural fields. The equation is

$$A = R\,K\,L\,S\,C\,P \qquad (3)$$

where A is the estimated soil loss in tons/acre/yr, R is the rainfall erosivity factor, K is the soil erodibility factor, L is the slope length factor, S is the slope gradient factor, C is the cover and management factor, and P is the erosion control management factor. These factors reflect the major variables which influence erosion by rainfall and resultant overland flow. The equation is based on plot data collected from areas east of the 105th meridian in the United States. Although it is intended for use beyond the area it was developed for, special considerations are required for it to be successful in other areas (Brooks, 1976; and McCool et al., 1976).

The parameters needed to evaluate each

Table 2.--Annual soil loss (tons/acre) from three small Walnut Gulch subwatersheds

Year	Brushland					Grassland		
	R[1] factor	No. 103 (9.1 ac)[2] Predicted	No. 103 (9.1 ac)[2] Actual	No. 104 (11.2 ac) Predicted	No. 104 (11.2 ac) Actual	R factor	No. 112 (4.6 ac) Predicted	No. 112 (4.6 ac) Actual
1973	64	0.29	1.24	0.25	0.35	22	0.05	0.00
1974	79	0.36	2.17	0.30	0.75	77	0.22	0.01
1975	185	0.85	3.83	0.72	1.42	53	0.15	0.05
1976	30	0.14	1.08	0.12	0.31	114	0.33	0.37
1977	82	0.37	3.04	0.32	1.33	54	0.15	0.05
1978	45	0.21	0.89	0.17	0.08	25	0.07	0.00
1979	25	0.11	0.21	0.10	0.00	26	0.07	0.00
Avg.	73	0.33	1.78	0.28	0.61	53	0.15	0.07

[1]R = Hundreds of foot-ton inch per acre hour year.
[2]The watershed has an incised drainage network that contributed considerable soil loss.

equation factor are easily determined from handbooks and a minimum amount of field work. Factor values can be adjusted for local conditions, and a fair estimate of erosion can be made. Simanton et al. (1980) applied the USLE to three small watersheds in southeastern Arizona. Comparison of predicted and measured soil loss are presented in table 2.

In general, the USLE seemed to overpredict soil loss for years with small runoff events and underpredict soil loss for years with large runoff events. The USLE can be used to estimate the impact on soil loss rates caused by changing management or cultural treatments. By adjusting the factors to reflect estimated changes in K, C, or P, a fair estimate of potential soil loss can be obtained for the proposed management or treatment.

An example of such an application is taken from a study conducted on a 110-acre watershed in southeastern Arizona. This subwatershed of the Walnut Gulch experimental watershed was root-plowed and seeded in 1971 (Simanton et al., 1977). To help quantify soil loss changes associated with the treatment, the USLE parameters were evaluated for the pre- and post-treatment periods. Parameter values, soil loss prediction, and measured soil losses are presented in table 3.

The soil erodibility (K), cover (C), and erosion practice (P) were the parameters changed by the treatment. The changes in K and C were expected because of the disturbance of the soil surface and plant cover. The change in P was due to the root plowing treatment which resembled a contour listing treatment for which a parameter value of 0.15 is used. The small difference between predicted and measured soil loss indicates the usefulness of the USLE for estimating erosion consequences of different range management programs.

Sediment Yield Equation

The sediment yield of a watershed is the summation of the erosion from all sources within the watershed, including erosion from channel beds and banks, headcuts, etc., minus the deposition of sediment between the erosion sources and the watershed outlet. Deposition generally occurs when there is insufficient energy to transport the eroded sediments such as occur when land slope decreases, roughness increases, or as a result of man's activities which are intended to create deposition such as bank protection, grade stabilization structures, debris or detention basins, and water storage reservoirs. Thus, estimating sediment yield from areas larger than a few acres is a

Table 3.--USLE and soil loss from a small experimental watershed converted from brush to grass cover

Condition	USLE factors					Soil Loss	
	R (Avg)	K	C	SL	P	Predicted (tons/ac/yr)	Measured (tons/ac/yr)
Brush (1966-1970)	88	0.20	0.08	0.90	1.0	1.27	1.67
Grass (1974-1976)	47	0.16	0.15	0.90	0.15	0.15	0.13

very complicated problem requiring knowledge of both the runoff rate and amount and the ability to assess the erosion and deposition under a wide variety of conditions within the basin.

Physically based models to predict the many cause-effect relationships within the basin have, in the past, received only limited attention. There are, however, a variety of empirical equations which are site specific or have had limited testing beyond the area for which they were developed. Thus, these relationships required from the user a great deal of familiarity with the method and the area for which the estimates were required. As such, the practicing sedimentationist might more correctly be classified as an artist in his trade.

Renard (1980) used four sediment yield relationships to compare predicted and measured yield on nine small watersheds on the Walnut Gulch experimental watershed. Of the four empirical equations used (Flaxman, 1972; Dendy and Bolton, 1976; PSIAC, 1968; and Renard, 1972), the method developed by a subcommittee of the Pacific Southwest Interagency Committee (PSIAC) appears to give the best results (table 4). Furthermore, this method, which uses nine parameters, can readily be used to evaluate changing land use or conservation practices on sediment yield. In the other methods, indirect reflections of changing land use can be made by projecting changes in runoff or other parameters which are used to arrive at the estimate. In all the methods tested, quantification of the changes associated with land use are truly subjective, and thus, would be classified as an art.

Within USDA's Science and Education Administration, a group of scientists and engineers are developing models to assess nonpoint pollution from both field-sized areas and from heterogeneous small watersheds. The effort for the field-sized areas has culminated in a model called CREAMS (Chemical, Runoff, Erosion, and Agricultural Management Systems (Knisel et al., 1980) which enables simulation of the hydrologic cycle with analytical routines to account for erosion/sediment yield and the chemicals used in agricultural areas. The computer program, although quite involved, can be used without calibration for predicting nonpoint pollution from many management systems using parameter values specified in the user manual. The companion effort for the basin-size areas is presently in progress.

SUMMARY

The water resource assessment for any watershed is especially difficult because of the many differences in the climatic, physiographic, and land uses affecting the resources. The situation is especially acute on most arid and semiarid rangelands because of a paucity of data. For this reason, land managers, environmentalists, and hydrologists are resorting to simulation techniques in which models calibrated on areas with available data are used to simulate the resources for unmeasured areas. Furthermore, if such calibrated computer models are physically based, the effects of alternate land uses or, for example, improved range management practices, can be evaluated with considerable confidence.

Precipitation, a highly variable quantity in most rangelands, can be simulated if some relationships are known for the distribution of wet and dry days, the distribution of storm depths, and the areal extent of individual storms. For example, Markov chain probability models have been widely used to simulate the distribution of wet/dry days and a mixed exponential distribution for rainfall depths at a point.

Table 4.--Measured and predicted sediment yield for select semiarid rangeland watersheds (Renard, 1980)

Location designation	Drainage area (ac)	Measured yield	Predicted yield (ac-ft/mi^2/yr)			
			PSIAC	Dendy/Bolton	Flaxman	Renard
201 (brush)	109	0.49	0.29	0.83	-0.180	0.68
201 (grass)[1]	109	0.13	0.19			
207	274	0.11	0.18	0.73	0.049	0.61
208	228	0.13	0.16	0.75	0.313	0.62
212	842	0.11	0.30	0.62	0.142	0.53
213	394	0.09	0.18	0.69	0.375	0.58
214	372	0.37	0.38	0.70	0.154	0.59
216	87	0.70	0.42	0.85	0.249	0.69
216	208	0.51	0.28	0.76	0.341	0.63
223	108	0.30	0.29	0.83	0.085	0.68

[1]Converted from brush to grass cover in 1971.

Assessing the water resources of rangeland watersheds also requires estimating runoff. Again, much can be gained with models. The most widely used technique for such an assessment is the curve number method of USDA's Soil Conservation Service. The method involves using precipitation amounts and a technique for estimating the associated runoff for various soil/cover complexes. When used and correlated with actual data in southeastern Arizona, differences between predicted and actual runoff were attributed to storm characteristics and differences in the drainage networks. With increasing watershed size, additional losses of water in the stream channel require using increasingly complex methods such as hydraulic routing of water from upstream points. This operation can best be accomplished with computer models.

One of the most widely used soil erosion models is the Universal Soil Loss Equation (USLE). The model was developed to estimate the long-term average soil loss from agricultural fields in the eastern United States. Preliminary evaluation of the model on three small watersheds in southeastern Arizona showed an overprediction of soil loss for years of small runoff events and an underprediction for years with large runoff events. The USLE adequately predicted the soil loss resulting when a brush watershed was converted to grass. Sediment yield equations that include all sources within a watershed have received only limited attention because of the difficulty in assessing the erosion and deposition under the wide variety of topographic and soil conditions which occur in most basins. Of four equations evaluated, an empirical equation developed by the Pacific Southwest Interagency Committee best represented sediment yield from 9 small watersheds in southeastern Arizona.

Efforts on developing prediction models for assessing nonpoint pollution for both field-sized areas and heterogeneous small watersheds are being undertaken by a group of scientists and engineers in the USDA's Science and Education Administration. This model is designed to be used without calibration for evaluating the effects of management systems on nonpoint source pollution. Modeling techniques represent a relatively inexpensive tool for assessing the present and future condition of our arid rangeland resources.

RESUME

La determinación de los recursos de agua para cual quiera cuenca hidrológica es especialmente difícil por la diferencia de clima, de topografía y de usos de la tierra que efectan los recursos. La situación es especialmente aguda en la mayor parte de los pastos áridos y semiáridos por los datos limitados. Por esta razón, gerentes de la tierra, personas interesadas en el ambiente, y hidrológicos están recurriendo al uso de técnicas de simulación con modelos que son calibrados para áreas con datos disponibles y son usados para simular los recursos de áreas sin medidas. Además, si la calibración de los modelos para uso en calculador son basados fisicamente, los efectos de usos alternativos de la tierra o, por ejemplo, el mejoramiento de las practicas de manejar los pastos se puede examinar con considerable confianza.

La precipitación, una cantidad muy variable en la mayor parte de pastos, se puede simular si se saben unas relaciones como la distribución de la cantidad de lluvia y la extención de lluvia. Por ejemplo, los modelos de Markov de cadena de probabilidad an sido usados extensiblemente para simular la distribución de días con lluvia y sin lluvia y para distribución exponencial mesclada para el nivel de la lluvia en un punto.

Para examinar los recursos de agua de los pastos de la cuenca hidrológica se requerir estimar el escurrimiento. En esto tambien pueden ayudar los modelos. La técnica usada mas para estas determinaciones es el métado de numeros de curba utilizada por el Servício de Conservación de Suelos del Departamento de Agricultura de los Estados Unidos (USDA Soil Conservation Service). El métado usa la cantidad de lluvia y la técnica para estimar el escurrimiento asociado con varios complejos de suelos y cubertura. Cuando se usa y se correlaciona con datos del sudeste de Arizona, diferencias entre la predicción y lo actual se atribuilen a los característicos y las diferencias en el sistema de drenaje de la cuenca hidrológica. La determinación de la agua adicional que se pierde en los arroyos requierre el uso de métados mas complejos como el derrotero matemático de la agua por los arroyos. Esta operación se puede mas bien cumplir con modelos usando calculador.

Unos de los modelos mas usados de erosión de suelos es la ecuación universal de perdición de suelos (Universal Soil Loss Equation - USLE). El modelo se desarrollo para estimar el promedio de término largo de perdición de suelo de sembrados en el este de los Estados Unidos. El ensay preliminario de este modelo útilizo tres pequeñas cuencas hidrológicas en el sudeste de Arizona y resultó en una alta predicción de suelos perdidos para años con pequeños escurrimientos y en una baja predicción para años con grandes escurrimientos. La USLE adecuadamente predico el suelo que se pierde cuando una cuenca hidrológica cubierta con arbustivos se fue convertida a una cubierta con zacate. La ecuación de producción de sedimento que abraza todas las fuentes entre una cuenca hidrológica a recibido solamente poca atención por la dificultad de determinar la erosión y la disposición por la grande variabilidad de condiciones topograficas y de suelos que ocurren en la major parte de las cuencas. De las cuatro ecuaciones examinadas, una ecuación empírica desarrollada por el Comite Interagencia Pacífico Sudoeste (Pacific Southwest Interagency Committee) represento mejor producción de sedimento de nueve pequeñas cuencas hidrológicas en el sudeste de Arizona.

Esfuerzas para el desarrollo de modelos para áreas del tamaño de sembrados y pequeñas cuencas hidrológicas heterogeneas se a emprendido por un grupo de científicos y ingenieros de la Administracion de Ciencia y Educacion del Departamento de Agricultura de los Estados Unidos (USDA Science and Education Adminstration). Este modelo es designado para usarse sin calibración para examinar sistemas que manejan la fuente de contaminación sin punto. Técnicas de modelos representan un instrumento módico para determinar las condiciones presentes y futuras de nuestros recursos de pastos áridos.

LITERATURE CITED

Brooks, F. L. 1976. Use of the Universal Soil Loss Equations in Hawaii. In Soil Erosion: Prediction and Control. Special Publication 21, Soil Conservation Society of America. pp 22-30.

Caskey, James E. 1963. A Markov chain model for the probability of precipitation occurrence in intervals of various length. Monthly Weather Review 91(6):298-301.

Dendy, F. E., and G. C. Bolton. 1976. Sediment yield-runoff drainage area relationships in the United States. Journal of Soil and Water Conservation 31(6):264-266.

Feyerherm, A.M., and L. D. Bark. 1965. Statistical methods for persistent precipitation patterns. Journal of Applied Meteorology 4: 320-328.

Flaxman, E. M. 1972. Predicting sediment yield in western United States. Journal of Hydrologic Division, American Society of Civil Engineers 98(12):2073-2085.

Gabriel, K. R., and J. Neumann. 1962. A Markov chain model for daily rainfall occurrence at Tel Aviv. Quarterly Journal of the Meteorological Society 88:90-95.

Hershfield, David M. 1970. A comparison of conditional and unconditional probabilities for wet- and dry-day sequences. Journal of Applied Meteorology 9:825-827.

Hewlett, J. D., and C. A. Troendle. 1975. Non-point and diffused water sources: A variable source area problem. Proceedings of the Watershed Management Symposium, Logan, Utah. American Society of Civil Engineers, p. 21-46

Knisel, W. G. 1980. Ed. CREAMS: A field-scale model for chemicals runoff and erosion from agricultural management systems. United States Department of Agriculture Conservation Research Report No. 26, 640 p.

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

McCool, D. K., M. Molinau, R. I. Papendick, and F. L. Brooks. 1976. Erosion research in dryland grain region of the Pacific Northwest: Recent developments and needs. In Soil Erosion: Prediction and Control. Special Publication 21, Soil Conservation Society of America. pp. 50-59.

Osborn, H. B., E. D. Shirley, D. R. Davis, and R. B. Koehler. 1980. Model of Time and Space Distribution of Rainfall in Arizona and New Mexico. ARM-W-14, U.S. Department of Agriculture, Science and Education Administration. 27 pg.

Pacific Southwest Inter-Agency Committee. 1968. Factors affecting sediment yield and measure for reduction of erosion and sediment yield. 13 pg.

Renard, K. G. 1972. Sediment problems in the arid and semiarid Southwest. Proceedings of the 27th Annual Meeting, Soil Conservation Society of America, Portland, Oregon. pg. 225-232.

Renard, K. G. 1977. Past, present, and future water resources research in arid and semi-arid areas of the southwestern United States. Australian Institution of Engineers 1977 Hydrology Symposium. p. 1-29.

Renard, K. G. 1980. Estimating erosion and sediment yield from rangeland. In Symposium on Watershed Management 1980, Boise, Idaho. American Society of Civil Engineers 1:151-163.

Renard, K. G., and D. L. Brakensiek. 1975. Precipitation on intermountain rangeland in the western United States. In Watershed Management on Range and Forest Land. Proceedings of the Fifth Workshop of the United States/ Australia Rangelands Panel, p. 39-59. Utah Water Research Laboratory.

Simanton, J. R., H. B. Osborn, and K. G. Renard. 1977. Effects of brush to grass conversion on the hydrology and erosion of a semiarid southwestern rangeland watershed. Hydrology and Water Resources in Arizona and the Southwest. American Water Resources Association, Arizona Section - Arizona Academy of Science, Hydrology Section, 7:249-256.

Simanton, J. R., H. B. Osborn, and K. G. Renard. 1980. Application of the USLE to southwestern rangelands. Hydrology and Water Resources in Arizona and the Southwest American Water Resources Association, Arizona Section - Arizona Academy of Science, Hydrology Section. (In Press).

Simanton, J. R., K. G. Renard, and N. G. Sutter. 1973. Procedures for identifying parameters affecting storm runoff volumes in a semiarid environment. USDA-ARS W-1, 12 p.

Smith, Roger E., and H. A. Schreiber. 1973. Point processes of seasonal thunderstorm rainfall. 1: Distribution of rainfall events. Water Resources Research 9(4):871-884.

Smith, Roger E., and H. A. Schreiber. 1974. Point processes of seasonal thunderstorm rainfall. 2: Rainfall depth probabilities. Water Resource Research 10(3):418-424.

Smith, Roger E. 1974. Point processes of seasonal thunderstorm rainfall. 3: Relation of point rainfall to storm areal properties. Water Resources Research 10(3):424-426.

U.S. Department of Agriculture, Soil Conservation Service. 1971. National Engineering Handbook, Section 4: Hydrology.

Wischmeier, W. H., and D. D. Smith. 1978. Predicting rainfall erosion losses - a guide to conservation planning. U.S. Department of Agriculture Handbook No. 537, 58 p.

Woolhiser, D. A., E. Rovey, and P. Todorovic. 1972. Temporal and spatial variation of parameters for N-day precipitation. Second International Symposium on Hydrology. Colorado State University, Fort Collins, Colorado.