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PARTIAL AREA RESPONSE ON SMALL SEMIARID WATERSHEDS[1]

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ABSTRACT: Significant errors in estimating surface runoff and erosion rates are possible if a watershed is assumed to contribute runoff uniformly over the entire area, when actually only a portion of the entire area may be contributing. Generation of overland flow on portions of small semiarid watersheds was analyzed by three methods: an average loss rate procedure, a lumped-linear model, and a distributed-nonlinear model. These methods suggested that, on the average, 45, 60, and 50% of the drainage area was contributing runoff at the watershed outlet. Infiltrometer data support the partial area concept and indicate that the low infiltration zones are the runoff source areas as simulated with the distributed-nonlinear model.
(KEY TERMS: partial area response; variable runoff source areas; semiarid hydrology; hydrograph simulation; kinematic cascade model.)

INTRODUCTION

The term "partial area response" (variable source area response) is used to designate the response of a watershed when only a portion of the total drainage area is contributing runoff at the watershed outlet or point of interest. If the watershed is assumed to contribute uniformly over the entire area, while actually less than the entire area is contributing runoff, then the assumed specific runoff rates, expressed as runoff per unit area, are in error by the factor of the proportion of area contributing. The errors in estimating surface runoff rates could carry over into estimated values for mean shear stress and resulting erosion rates. Moreover, in studies of nonpoint processes, it is essential to identify the high runoff-high erosion areas of watersheds.

Partial area concepts evolved from consideration of more humid regions than those studied here (e.g., Hewlett, 1961; Dunne and Black, 1970; Patten, 1975, etc.). However, Arteaga and Rantz (1973) investigated the variable source area concept on a small semiarid watershed in central Arizona. Their results suggested that, on the average, 26% of the 132 ha watershed investigated by them was contributing runoff. More recently, Lane and Wallace (1976), using the Arteaga and Rantz approach, analyzed data from four

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semiarid watersheds ranging in size from 0.006 ha to 132 ha and found that for the watersheds studied, on the average, 26 to 80% of the areas were contributing runoff.

Hibbert (1976) lists three mechanisms of runoff generation from rainfall. Of these, only the first is thought relevant to the processes operating on the small semiarid watersheds of interest here. Hibbert (1976, p. 68) states one mechanism as:

> . . . where overland flow is generated by rain intensity exceeding infiltration capacity uniformly over the area or on portions of the watershed.

He goes on to state that this is usually not the case on forested lands, but on other lands where overland flow can be dominant, the partial area concept is still valid. Moreover, from our analyses, evidently the source areas depend on infiltration variability, storm characteristics, and hydraulic remoteness from the watershed outlet. Such results, while based on model assumptions and limited by available data, provide a working hypothesis on partial area response characteristics of small semiarid watersheds.

WATERSHED AND DATA USED

The Santa Rita Experimental Range, covering an area of about 200 square km about 50 km south of Tucson, was established in 1903 and is maintained by the Forest Service, USDA, for the purpose of studying the interrelationships of organisms, attributes, and processes of semidesert ecosystems (Martin and Cable, 1975). Recently several small experimental watersheds were established within the Range for the hydrologic study of various aspects of semiarid watersheds. These watersheds were equipped with flow measuring flumes, recording raingages, and infiltrometer plots. They are maintained and operated by the Southwest Watershed Research Center, USDA.

Rainfall and runoff data from one of these watersheds were used in this paper. The data were recorded in the rainy season of July-September 1975, in a 1.63 ha watershed identified as Santa Rita Watershed No. 1 (USDA No. 76.001). It has a roughly rectangular shape about 330 m long and 50 m wide (Figure 1). A well defined main channel extends through the lower half of the watershed for a length of 160 m and ends in a head cut. Several secondary channels drain the lower half (drainage density 0.029 to 0.038 m/m^2), whereas the upper half has no well defined channels. The slope of the main channel in the lower half is 3.6%. The average land slope in the lower half is 8.1% and 5.2% on the right and left bank of the main channel, respectively. The average land slope in the upper half of the watershed is 3.4%.

A storm event is defined as one in which a distinct peak is produced. For two events (August 12 and September 1) double peaked hydrographs were observed. Conforming to the definition adopted, each of these was separated into two single peaked hydrographs and listed separately in Table 1. Thus 10 storm events were available for the present study.

In addition to the results from Watershed 76.001, data from three other watersheds are used as a comparison. Data used here are from a small runoff plot on the Walnut Gulch Experimental Watershed in southeastern Arizona; a second small watershed (1.77 ha) on the Santa Rita Experimental Range (Wallace and Lane, 1976); and a 132 ha watershed in central Arizona near Apache Junction, Arizona (Arteaga and Rantz, 1973). Runoff on these watersheds is normally from summer thunderstorms, is ephemeral, and consists of surface runoff only.

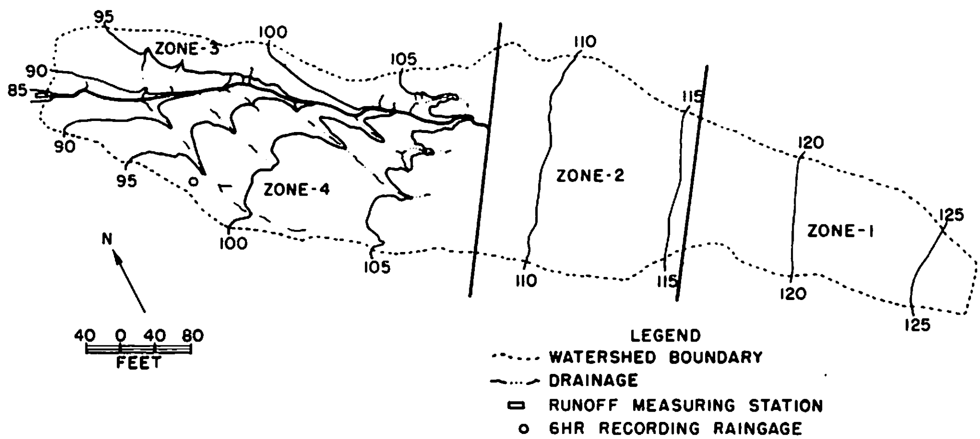

Figure 1. Topographic Map of Watershed 76.001.
(Contours refer to elevations in feet above an arbitrary datum.
Elevation 100 is approximately 3400 ft. mean sea level.)

For these last three experimental watersheds the data used were total storm rainfall and total runoff volume. For Watershed 76.001 the data consisted of rainfall hyetographs and the corresponding runoff hydrographs in addition to the storm totals. A 1:40 scale topographic map with one-foot contour interval (0.3 m) was available to define watershed topography and channel network (Figure 1).

PROCEDURE

Three different methods of analysis were used to examine the partial area concept. The methods are: (1) an average loss rate procedure, (2) a lumped-linear runoff model, and (3) a distributed-nonlinear model.

Average Loss Rate Procedure

If ϕ is the average loss rate (mm/hr) for a given watershed, then runoff-producing rainfall is that portion of the rainfall having an intensity which exceeds ϕ. Arteaga and Rantz

TABLE 1. Summary of 1975 Rainfall and Runoff Data, Watershed 76.001.

Storm No.	Date	Total Rainfall Duration (min)	Total Rainfall Depth (mm)	Total Rainfall Max. Intensity (mm/hr)	Runoff Hydrograph Volume (mm)	Runoff Hydrograph Peak Flow (mm/hr)	Rainfall Excess ϕ Index (mm/hr)	Rainfall Excess Duration (min)	Rainfall Excess Max. Intensity (mm/hr)
1	7.12.75	32	18.54	121.9	4.29	29.21	59.2	8	62.5
2	7.24.75	63	8.64	40.6	0.15	1.02	37.6	3	3.0
3	7.27.75	12	5.84	53.3	0.46	4.57	39.4	2	13.7
4	8.08.75	37	12.95	101.6	1.90	18.29	63.5	3	38.1
5	8.12.75	45*	22.10	83.8	1.75	14.99	42.4	4	41.4
6	8.12.75			114.3	5.13	28.45	35.3	9	80.0
7	9.01.75	154*	16.76	30.5	0.46	2.54	21.3	3	8.9
8	9.01.75			20.3	0.18	1.02	16.8	3	3.6
9	9.13.75	13	6.10	53.3	0.99	8.13	38.6	4	14.5
10	9.13.75	22	3.56	38.1	0.48	2.79	24.6	5	13.5

*Double peaked storms separated into single peaked hydrographs.

(1973) assumed the average loss rate, ϕ, to be related to the average intensity of runoff-producing rainfall, I_p, by the following equation:

$$\phi = \begin{cases} I & , I < I_c \\ a + bI_p, & , I_p \geqslant I_c \end{cases} \tag{1}$$

where:

ϕ = average loss rate (mm/hr),
I = rainfall intensity (mm/hr),
I_c = threshold intensity (mm/hr),
I_p = average intensity of runoff-producing rainfall (mm/hr),
a = intercept (mm/hr), and
b = slope of regression line (dimensionless).

Average runoff rate, $\overline{q}$ (in mm/hr) is expressed as

$$\overline{q} = I_p - \phi \tag{2}$$

Solving for ϕ and substituting into Equation (1) yields the following expressions for $\overline{q}$:

$$\overline{q} = \begin{cases} 0.0 & , I < I_c \\ (1 - b) I_p - a, & I_p \geqslant I_c \end{cases} \tag{3}$$

At rainfall intensity I_p for which the runoff rate changes from a nonzero value to zero, $I_p = I_c$ and $I_c = 1/(1-b)$. Solving for $a = I_c (1-b)$ and substituting in Equation (3) yields:

$$\overline{q} = \begin{cases} 0.0 & , I < I_c \\ (1 - b)(I_p - I_c) & , I_p \geqslant I_c \end{cases} \tag{4}$$

The parameters of Equation (4), namely b and I_c can be obtained from a plot of ϕ, computed for the entire area, versus the observed mean rainfall I_p for several storms. Arteaga and Rantz (1973) interpreted Equation (4) as indicating that (1–b) of the total area is the proportion of the total area contributing runoff. Also, they interpreted I_c as the average loss rate for the area contributing runoff.

Lumped-Linear Model (Unit Hydrograph Procedure)

The partial area concept also has some effect on the results obtained when the watershed is assumed to be a lumped system and analyzed using a unit hydrograph procedure. In this case, the input and output of the surface runoff system representing the watershed are considered to be concentrated at one point of entry and one point of exit, respectively. The areal distribution of the input, which is the rainfall excess, is thus disregarded. Nevertheless, the magnitude of the area contributing to direct runoff does affect the definition of the input to the system. If the area contributing runoff is smaller than the watershed area, the intensity, and sometimes also the duration of the rainfall excess hyetograph, will have to be increased to provide the same volume of input. This is true regardless of the method of separation of the rainfall excess from the total rainfall.

The changes in the shape of the rainfall excess hyetograph will, in turn, cause some changes in the shape of the unit hydrograph identified from this hyetograph, adopted as input to the surface runoff system, and the hydrograph of direct runoff, used as the output of the system. The only case where the unit hydrograph remains unchanged is when the rainfall excess is in the form of a single rectangular block, and remains so. Under certain circumstances, the change in the assumed contributing area changes only the height of the rectangular block representing the input without changing its duration. In these cases, the shape of the unit hydrograph will not change.

Using the simple ϕ-index method of separation of rainfall excess, the above argument is illustrated in Figure 2. These diagrams show the total rainfall and runoff curves for Watershed 76.001 for the events of 7/24/75, 7/27/75, and 9/13/75, respectively. Since there is no baseflow in this semi-arid watershed, the runoff curve is also the direct surface runoff and is adopted as the output of the system. The area enclosed by this curve represents the total volume of runoff. Assuming the area contributing to runoff to be either the entire watershed or only 50% of this area, it is a simple matter to find the value of the ϕ-index that will yield a total depth of rainfall which, multiplied by the contributing area, will be equal to the volume of runoff.

The ϕ-index corresponding to the two assumed contributing areas are shown in Figure 2, A and B, for the two storms. In the first case, the shape of the rainfall excess hyetograph does not change; only the magnitude of the ordinates has doubled. In Figure 2B, the increase in the magnitude of the rainfall excess ordinates is smaller than in the previous case, but the duration of the rainfall excess diagram is longer. The new value of total depth of rainfall excess, represented by the area between the ϕ-index line and the rainfall hyetograph, is in both cases double the total depth obtained when the contributing area was assumed to be the entire watershed.

Another possibility is illustrated in Figure 2C. In this case, the duration of rainfall excess remains constant but the ratio between the rainfall excess ordinates at different times changes. In the case illustrated, the rainfall excess is composed of two blocks, one of 2 minutes duration and the second of 3 minutes. The intensities of rainfall during these two periods are 13.5 and 0.8 mm/hr, respectively, when the contributing area is assumed to be 100%. If the contributing area is 50%, the corresponding intensities are 19.3 and 6.6 mm/hr, respectively. The total volume of rainfall excess produced in the two cases is of course the same. By assuming various ratios of partial contributing areas it is possible to obtain a number of pairs of input and output functions from the same original record. Assuming some model for the surface runoff system thus defined, a unit hydrograph can be derived for each such pair of input and output functions. In this study

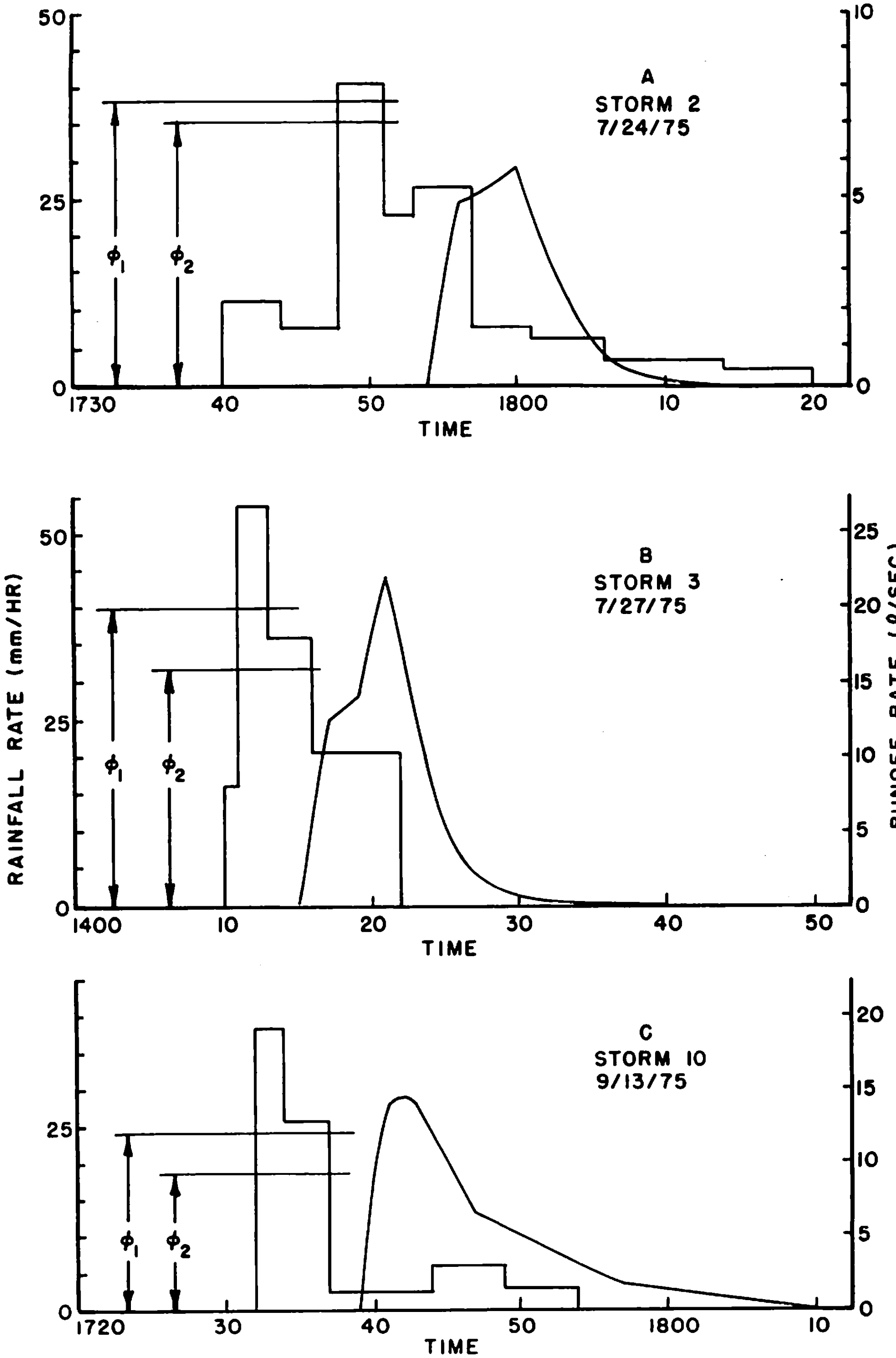

Figure 2. Examples of Rainfall Excess Patterns with 100% (ϕ_1) and 50% (ϕ_2) of the Watershed Area Contributing Runoff. (Similar results are obtained with a time varying infiltration function.)

the relation between input and output was assumed to be linear, and the model adopted is the Nash (1957) cascade of linear reservoirs model. This model is characterized by the number of reservoirs, N, and their storage constant, K. The 1-min. unit hydrograph is next used to compute a predicted hydrograph. Comparing this to the observed hydrograph a measure of goodness-of-fit, such as W, the mean of the absolute deviations of computed and observed runoff rates, can be computed as a function of contributing area.

Distributed-Nonlinear Model (Kinematic Cascade)

The kinematic wave equations are the simplified stage-discharge equation and the continuity equation,

$$Q = \alpha h^m \tag{5}$$

$$\frac{\partial h}{\partial t} + \frac{\partial (uh)}{\partial x} = q(x,t) \tag{6}$$

where:

Q = local discharge (m^3/sec, mm/hr),
h = local flow depth (m),
α = coefficient expressing slope and resistance, and
m = exponent in the assumed relation;
u = local velocity (m/sec),
x = distance in direction of flow (m),
t = time (sec, hr), and
q = lateral inflow rate (m^3/sec/m).

Equations (5) and (6) are used to describe the kinematic wave model (Henderson and Wooding, 1964; Wooding, 1965a, b, and 1966). If watershed topography and channel network are modeled as a cascade of planes and channels in a logical flow sequence, and the kinematic wave equations for overland flow and open channel flow can be solved for each element in the cascade, the resulting mathematical model is called a kinematic cascade model (Kibler and Woolhiser, 1970). A statistical procedure for fitting cascades of planes and channels to topographic data as described b y Lane, Woolhiser, and Yevjevich (1975) is used to determine parameters of the kinematic cascade model used here.

Watershed 76.001 was divided into 4 zones as shown in Figure 1. These zones were chosen so as to be relatively homogeneous within each zone with respect to average slope, drainage density, and mean length of first order streams (Table 2). As shown in Table 2, each of the four zones is modeled as a plane and the channel network is represented by a single channel corresponding to the main channel of the watershed. Although this cascade of planes and a single channel represents a simplified model, it corresponds to the geomorphic subzones as described above. Moreover, each plane (zone) receives a different rainfall excess pattern (including zero rainfall-excess) so that the model is also well structured for simulating partial area response. For example, if only the lower zones nea: the main channel and watershed outlet were contributing, we might assume that zones 3 and 4 were contributing, while zones 1 and 2 were not. This assumption is based, in part, on infiltrometer data as described later.

TABLE 2. Characteristics of the Simplified Kinematic Cascade Model for Watershed 76.001.

				Selected Geomorphic Features of Watershed Subzones		
Element in Cascade	Area (ha)	Length (m)	Slope	Drainage Density (m/m^2)	Average Slope	Mean Length of 1st Order Channels (m)
Plane-1 (Zone 1)	0.38	104	0.034	--	0.034	-
Plane-2 (Zone 2)	0.45	70	0.034	--	0.034	-
Plane-3 (Zone 3)	0.26	17	0.081	0.029	0.081	7
Plane-4 (Zone 4)	0.55	36	0.051	0.038	0.051	26
Channel 5	--	155	0.036	--	--	-

ANALYSIS AND RESULTS

Average Loss Rate Procedure

Results obtained by the average loss rate procedure using data from the four watersheds are shown in Table 3. These values were obtained by plotting ϕ versus I_p for the storms considered for each watershed and using Equations (1) and (4). Apparently, the proportion of area contributing, (1–b), decreases as watershed area increases, but the values of (1–b) are only approximate values since they represent averages from small samples. The threshold rainfall intensity to begin producing runoff, I_c, may vary with area, as the change between values in rows 1 and 2 of Table 3 indicates. However, this was not evident for the three larger watersheds. Both the threshold and proportion of contributing area are expected also to vary with precipitation characteristics, antecedent moisture, time of season, etc. Trends mentioned above for changes of 1–b and I_c, with area should be considered as qualitative averages only.

Finally, (1–b) varied with the area for the watersheds as expected. This is because the thunderstorm rainfall of the type common on these watersheds is of limited areal extent, and as the watershed size increases some parts of the watershed may receive significantly different rainfall. Consequently, the proportion of watershed area contributing runoff (1–b) would decrease as watershed area increases. However, the situation for the threshold intensity, I_c, is not as obvious. In these watersheds, channel network and volume of alluvium in the channels increase as watershed area increases. Therefore, we might expect I_c to increase with increasing watershed area. However, each watershed may have contributing areas, close to the point of measurement, independent of watershed size.

TABLE 3. Relation Between Proportion of Contributing Area, Threshold Intensity, and Watershed Area.

Watershed (1)	Area (ha) (2)	Number of Storms (3)	Proportion of Area Contributing Runoff (1 – b) (4)	Threshold Intensity I_c (mm/hr) (5)
Walnut Gulch Runoff Plot 63.33	0.006	8	0.78	11.9
Watershed 76.001	1.64	8	0.45	19.3
Watershed 76.002	1.77	6	0.34	21.6
Queen Creek Watershed	132.	11	0.26	19.6

(Adapted from Wallace and Lane, 1976.)

Lumped-Linear Model

Using data available for ten storms on the Santa Rita Watershed, the influence of changes in the assumed magnitude of the partial area was investigated. Since there were no means of determining directly what was the actual ratio of contributing area to the total area of the watershed, A_c, four such ratios were assumed: 1.00, 0.75, 0.60, and 0.50. For each of these ratios, the rainfall excess was computed by the ϕ-index method and with the Philip (1957) equation to produce a volume of rainfall excess equal to that of the surface runoff for each storm considered. The results are summarized in Table 4. The table lists, for each of the four partial area ratios used, the duration of rainfall excess T and the value of the ϕ-index for the ten storms. The ϕ-index is listed for each storm to correspond with the illustrations in Figure 2. The three types of results discussed above are all represented. There is a case where both the duration and the shape of the rainfall excess hyetograph do not change (storm No. 2), a case where the duration remains constant but the shape changes (storm No. 10), and cases where both the duration and the shape of the hyetograph change. For each of the original 10 runoff hydrographs considered as outputs, there were 4 separate rainfall excess hyetographs corresponding to the 4 partial area ratios. The relationship between input and output was assumed to be linear and the model adopted for the unit hydrograph was the simple cascade of linear reservoirs, characterized by the number of reservoirs, N, and their storage constant, K.

TABLE 4. Optimization Results for the Lumped-Linear Model, Watershed 76.001, 1975 Data.

A_c = 1.00			A_c = 0.75			A_c = 0.60			A_c = 0.50		
T (min)	ϕ (mm/hr)	W/Q_p	T (min)	ϕ (mm/hr)	W/Q_p	T (min)	ϕ (mm/hr)	W/Q_p	T (min)	ϕ (mm/hr)	W/Q_p
8	59.2	0.029	8	48.5	0.030	9	38.9	0.027	11	30.7	0.031
3*	37.6	0.048	3*	36.6	0.048	3*	35.8	0.048	3*	34.8	0.048
2	39.4	0.065	5	35.3	0.059	5	33.3	0.061	5	31.5	0.061
3	63.5	0.060	6	53.3	0.061	8	48.5	0.045	8	43.7	0.047
4	42.4	0.052	4	33.8	0.060	5	26.2	0.055	5	19.0	0.056
9	35.3	0.051	9	23.9	0.033	15	14.5	0.028	20	8.9	0.029
3*	21.3	0.045	3*	18.5	0.045	3*	15.5	0.045	8	14.2	0.038
3*	16.8	0.062	3*	14.5	0.062	8	15.0	0.057	8	14.5	0.055
4*	38.6	0.074	4*	33.3	0.074	7	29.5	0.072	7	26.7	0.073
5	24.6	0.052	5	22.6	0.050	5	20.8	0.049	5	18.8	0.049

*Shape of hyetograph is one rectangular block, for cases so marked.

The optimal value of these parameters was determined by a search technique using the mean absolute deviation between observed and computed runoff rates as the objective function. Values of N were not confined to be integers, and in the search procedure they were incremented in units of 0.25. Values of K were incremented in units of 1.0 min. Optimal values of the parameters varied between N = 1.75 and 4.00 and between K = 2.0 and 5.0 min. Values of the ratio W/Q_p (optimal value of the objective function W to the observed peak flow ordinate Q_p) are given in Table 4 for each storm and each partial area ratio.

The values of the optimal relative mean absolute deviation W/Q_p varied from a low value of 0.027 (2.7%), to a high value of 0.074 (7.4%). Considering each storm separately, we noted the following. There were 8 storms in which the changes due to the use of a partial area reduced the value of the relative mean absolute deviation; for 3 storms the reduction was small, but for the other 5 reductions were large. For the 2 remaining storms, the value of relative absolute deviation remained constant for 1 storm and actually increased for the other storm. The 1 storm for which the relative mean absolute deviation remained constant is storm No. 2, in which the duration of rainfall excess was short (3 min.) and the shape of the hyetograph did not change for all 4 values of partial area used.

Thus, application of the partial area concept to a lumped representation of the surface runoff system has some advantages. For a given surface runoff hydrograph and a given total rainfall hyetograph, it is possible to arrive at a better agreement between observed and computed runoff hydrographs if the area contributing to runoff is considered to be smaller than the entire watershed area. This is due to the changes in the shape of the rainfall excess hyetograph associated with the lower values of the ϕ-index or other infiltration rates needed with the smaller partial areas. The conclusion is, of course, based on the particular watershed and model used herein, but it is probably true also in other cases.

Distributed-Nonlinear Model

The simplified model of Watershed 76.001 is composed of four planes and a single channel. A schematic outline of this model and the associated proportions of contributing area are shown in Figure 3. This model was applied to partial area analysis by considering the contributing area to be composed of only the lower two planes representing 50% of the area (see infiltrometer data, Table 6), or the lower three planes (77%), or all 4 planes shown in Figure 3. Optimal hydrographs from this model were obtained for each storm for 100%, 77%, and 50% of the watershed area contributing runoff. Hydrographs were optimized using a sum of squared errors objective function. With this objective function a hydrograph goodness-of-fit statistic is R_Q^2, the relative improvement over using the mean discharge as the hydrograph prediction. The value of this statistic tends to a value of $R_Q^2 = 1.0$ as the deviations between the observed and computed ordinates become smaller. A second statistic is the ratio of fitted peak discharge, $\hat{Q}_p$, to observed peak discharge, Q_p. Again, values approaching 1.0 indicate a good fit. Values of R_Q^2 and $\hat{Q}_p/Q_p$ increase as the proportion of contributing area decreases. However, this is not always true for each individual storm. In some cases, the statistics decreased slightly as A_c decreased, especially the peak discharge statistic $\hat{Q}_p/Q_p$. The reasons for the reversal of the overall trend on a few events (Table 5) is not apparent. However, the trends in means of the hydrograph statistics suggest a partial rather than entire area response.

Again these are optimization results for a particular simulation model. However, they do suggest a partial rather than entire area response with respect to hydrograph goodness-of-fit as the single criterion.

Infiltrometer Data

A sprinkling infiltrometer (Dixon and Peterson, 1964) was used to obtain infiltration data in each of the four zones on Watershed 76.001. Within each zone, two infiltrometer plots were selected. One plot, of each pair, was selected to have predominately grass cover, and the other plot in each zone was selected to be bare, with little or no vegetative cover. These data are summarized in Table 6. The average infiltration rate for 60 min., ϕ, was 29 mm/hr for the bare plots and 58 mm/hr for the grass plots. The average infiltration rate on zones 1 and 2 was 54 mm/hr, and on zones 3 and 4 it was 34 mm/hr. Therefore, although there was a good deal of variability in infiltration rates within each zone, there are also differences in infiltration rates between zones. The average infiltration rates in zones 3 and 4 were some 60% of the average rate in zones 1 and 2. This supports the contention that zones 3 and 4 are more likely source areas, as suggested by the distributed-nonlinear model, where infiltration rates are distributed over the watershed area.

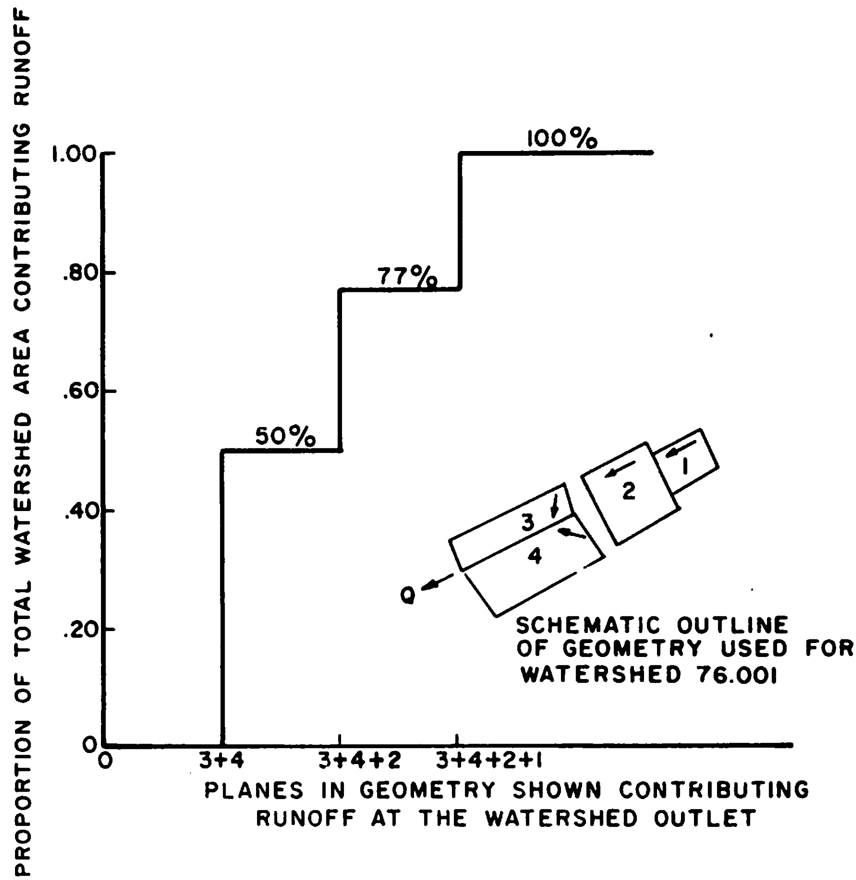

Figure 3. Relation Between Number of Planes and Proportions of Watershed Area Contributing Runoff.

SUMMARY AND CONCLUSIONS

The research reported here is an attempt to develop analysis techniques for partial area response on small semiarid watersheds. Results from the average loss rate equation were consistent for the four watersheds examined (Table 3). Results from the three procedures used were consistent for Watershed 76.001 (Table 7). These results, while somewhat qualitative, suggests a partial rather than entire area response as the indicated response for the range of data analyzed. Application of the analysis techniques, particularly the distributed-nonlinear model, seems warranted.

A procedure using rainfall and runoff volumes indicated that, on the average, approximately 45% of Watershed 76.001 contributes runoff at the outlet.

Two procedures using rainfall hyetographs and runoff hydrographs indicated that in individual storms from 40% to 100% of Watershed 76.001 contributes runoff at the outlet. The lumped-linear model indicated that, in most cases, 60% of the watershed contributes runoff. The distributed-nonlinear model indicated that, on the average, 50% or less of the watershed contributes runoff. Infiltrometer data tended to support the partial area concept as represented by the distributed-nonlinear model.

TABLE 5. Optimization Results for the Distributed-Nonlinear Model, Watershed 76.001, 1975 Data.

Storm No.	A_c = 1.00		A_c = 0.77		A_c = 0.50	
	R_Q^2	$\hat{Q}_p/Q_p$	R_Q^2	$\hat{Q}_p/Q_p$	R_Q^2	$\hat{Q}_p/Q_p$
1	0.96	0.89	0.95	1.00	0.94	1.06
2	0.30	0.22	0.14	0.40	0.80	0.71
3	0.65	0.63	0.70	0.59	0.75	0.65
4	0.54	0.64	0.64	0.58	0.88	0.83
5	0.76	0.92	0.78	0.76	0.80	0.73
6	0.71	0.96	0.75	0.83	0.84	1.32
7	0.77	0.90	0.80	0.95	0.62	1.23
8	0.07	0.34	0.61	0.64	0.76	0.92
9	0.84	0.90	0.87	0.82	0.82	1.27
10	0.79	0.77	0.90	0.94	0.88	0.92
Mean Values	0.64	0.72	0.71	0.75	0.81	0.96

TABLE 6. Summary of Infiltrometer Data for Each Zone on Watershed 76.001.

Zone and Plot Type	Average Infiltration Rate for 60 min. ϕ (mm/hr)	Best Fit Parameter for Philip Equation* A (mm/hr)	S (mm/hr$^{1/2}$)
1–B	34.0	17.8	18.0
1–G	70.0	62.5	6.6
2–B	36.0	9.6	26.7
2–G	75.0	52.6	22.1
3–B	18.0	6.4	23.9
3–G	56.0	37.8	17.8
4–B	28.0	2.0	30.0
4–G	32.0	10.7	20.1

*In the Philip (1957) infiltration equation, $f(t) = A + \frac{1}{2}St^{-1/2}$; A and S are parameters.
B = bare plot, G = grass covered plot.

TABLE 7. Summary of Results of Partial Area Analysis of Watershed 76.001 on the Santa Rita Experimental Range.

Procedure	Proportion of Contributing Area A_c	Remarks
Average Loss Rate Equation	0.45	Mean value based on analysis of 8 events
Lumped-Linear Model	0.60	Best value by optimization, A_c ranged from 0.50 to 1.00
Distributed-Nonlinear Model	0.50	Best value by optimization, A_c ranged from 0.50 to 1.00

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