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Empirical Investigation of Curve Number Technique

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Introduction

Design requirements of hydrologic analysis are often met by establishing a frequency distribution for some flow characteristic. Most watersheds are ungaged, so flow-frequency distributions are commonly estimated from frequency distributions of a rainfall characteristic. Schaake, et al. (6; see also Ref. 1, 4, 5, and 7), investigated the rational method as a transformation from rainfall to runoff frequency distributions. The curve number method will be investigated as a similar transformation.

Curve Number Technique

The curve number technique of the United States Department of Agriculture (USDA) Soil Conservation Service (SCS) is widely used to estimate runoff volume from rainfall depth. The runoff relation was developed by assuming that the ratio of runoff to rainfall excess is equal to the ratio of water retained during runoff to the potential amount that could be retained during an extremely long storm. This relation can be expressed as

$$\frac{Q}{(P - I_a)} = \frac{(P - I_a) - Q}{S}; \quad P > I_a \qquad (1)$$

in which S = potential maximum retention; Q = actual accumulated runoff; P = potential maximum runoff (accumulated rainfall, $P > Q$); and I_a = the initial abstraction.

Algebraic manipulation results in the runoff equation

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S}; \quad (P > I_a) \qquad (2)$$

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TABLE 1.—Watersheds Tested

Watershed (1)	USGS station number (2)	Area, in square miles (square kilometers) (3)	Mean annual precipitation, in inches (centimeters) (4)	Years of record (5)
Sandusky River (Upper Sandusky, Ohio)	04-1965	299 (774)	34.16 (86.8)	1922–1960
Chattooga River (Summerville, Ga.)	2B-3980	193 (500)	55.64 (141.3)	1937–1960
Fox River (Wayland, Mo.)	5-4950	400 (1036)	34.42 (87.4)	1922–1960
South Fork, Salt River (Santa Fe, Mo.)	5-5050	298 (772)	39.38 (100.0)	1940–1960
Sonoita Creek (Patagonia, Ariz.)	9-4815	210 (544)	16.82 (42.7)	1930–1960

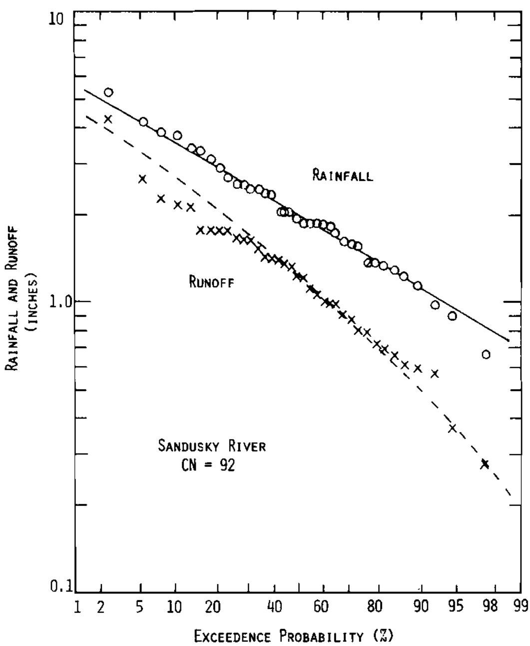

FIG. 1.—Distribution of Annual Maximum Event Rainfall and Runoff for Sandusky River, Upper Sandusky, Ohio, 299 sq miles (774 km^2) (1 in. = 25.4 mm)

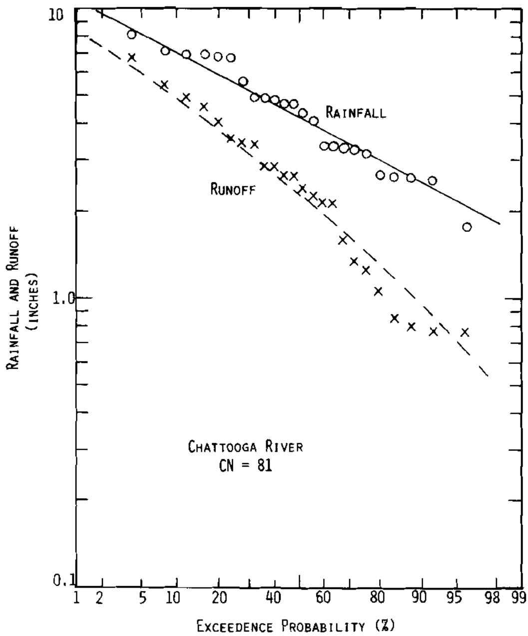

FIG. 2.—Distribution of Annual Maximum Event Rainfall and Runoff for Chattooga River, Summerville, Ga., 193 sq miles (500 km²) (1 in. = 25.4 mm)

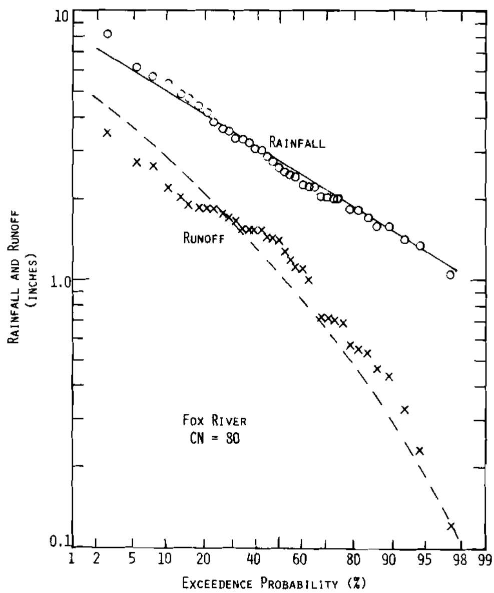

FIG. 3.—Distribution of Annual Maximum Event Rainfall and Runoff for Fox River, Wayland, Mo., 400 sq miles (1036 km²) (1 in. = 25.4 mm)

The potential maximum retention, S, depends upon the soil type, the cover and cultivation practice, and upon the antecedent moisture conditions. The initial abstraction was taken as $I_a = 0.2S$. The principles leading to Eqs. 1 and 2 and the procedure for estimating parameter S are detailed in Ref. 3. The SCS defines the curve number as

$$CN = \frac{1,000}{10 + S} \quad \text{(3)}$$

in which CN = the curve number—thus, the name. Eqs. 2 and 3 were developed by SCS for exclusive use with English units. The variables S, P, Q, and I_a must be expressed in inches of depth.

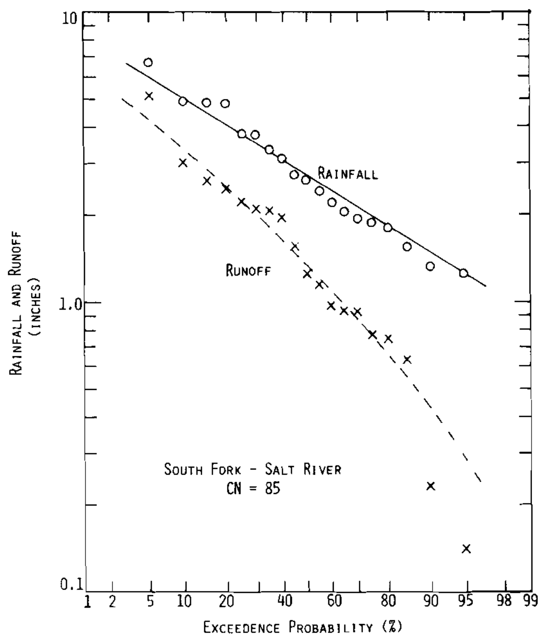

FIG. 4.—Distribution of Annual Maximum Event Rainfall and Runoff for South Fork of Salt River, Santa Fe, Mo., 298 sq miles (772 km²) (1 in. = 25.4 mm)

Because the procedure is easily applied to ungaged watersheds, the technique has been widely accepted. Tests verifying the procedure have not been widely published, however, which raises some questions concerning its validity. The approach applied to the rational method by Schaake, et al. (6; see also Refs. 1, 4, 5, and 7), can be used to investigate the validity of the curve number method. In the rational method approach it is usually assumed that the design peak runoff occurs with the same frequency as the rainfall intensity used in the computations. Following this logic, a relationship between the frequency distributions of rainfall and runoff can be assumed. In his Rational Formula calibration, therefore, Schaake, et al., used pairs of measured rainfall and runoff amounts corresponding to the same recurrence probability, rather than pairs from the same storm events.

In this paper, Schaake's approach is applied to the SCS curve number technique. The curve number relation was investigated as a transformation from the frequency distribution for rainfall to that for runoff.

In a study sponsored by SCS, Dalrymple (2) published the rainfall and runoff volumes for annual maximum floods based on peak discharge. Even though Dalrymple's sample of data was chosen on the basis of maximum annual streamflow peaks, rather than maximum annual rainfall amounts or runoff volumes, the data were used for this study due to their ready availability.

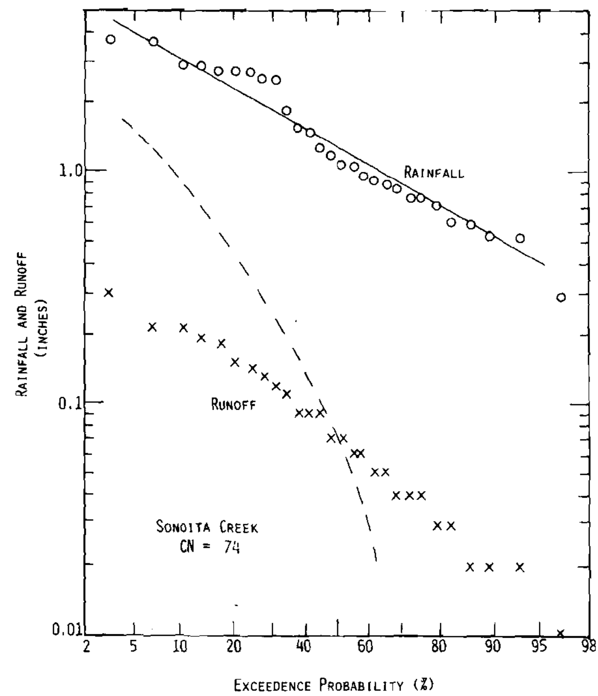

FIG. 5.—Distribution of Annual Maximum Event Rainfall and Runoff for Sonoita Creek, Patagonia, Ariz., 210 sq miles (544 km^2) (1 in. = 25.4 mm)

Five watersheds were selected to give a wide geographic distribution in the United States. Characteristics of these watersheds are shown in Table 1. Because the curve number runoff equation can only be expected to represent runoff from rainfall, the watersheds were selected to give few if any events resulting from snowmelt. The rainfall-runoff series used were censored to remove the few snow-augmented peaks. The published rainfall and runoff event-volumes were ordered by magnitude; a plotting position was established, and the values were plotted on log-normal probability paper, as shown in Figs. 1–5. Rainfall was assumed to follow a log-normal distribution and the line indicated was fitted, by the method of moments, to the rainfall data. The fitted rainfall distribution was transformed to the runoff distribution using Eq. 2 and $I_a = 0.2S$; the dashed line is the result. The curve number used for the transformation is indicated on each of the figures. No attempt was made to determine the optimal curve number; only a good visual fit was made.

Agreement is quite good in four of the cases. The Sonoita Creek watershed was not, however, amenable to fit by the curve number procedure. It is difficult to ascertain the reason for failure on the Arizona watershed. Similarly, it is difficult to determine the reason for success on the watersheds in the more humid regions. The relationship between initial abstraction, I_a, and potential maximum retention, S, is tenuous at best. (See, e.g., Fig. 10.2 of Ref. 3.) Possibly, this relationship is inappropriate in the arid west. In general, the fit was good where the water retained during runoff was a small fraction of the rainfall, but poor where the portion retained was large.

The preceding indicates that, within limits, Eq. 1 yields the appropriate shape for the runoff frequency distribution assuming lognormal rainfall distribution. It has not verified the curve numbers tabulated by SCS (3). A similar approach must be applied to singleuse watersheds to yield such verification.

Acknowledgment

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Appendix.—References

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