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Area-Depth Studies for Thunderstorm Rainfall in Illinois

by

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AREA-DEPTH STUDIES FOR THUNDERSTORM RAINFALL IN ILLINOIS

F. A. Huff and G. E. Stout

Abstract—The areal distribution of individual-thunderstorm rainfall on three small watersheds in central Illinois was investigated. Curves were fitted (for individual storms) for the maximum rainfall over certain sizes of area versus the size. These curves generally show maximum rainfall data to have a linear relationship to the square root of area.

Introduction--For many engineering purposes, a detailed knowledge of area-depth relations for small areas is essential. Few detailed data for areal units under 300 sq mi have been pub-

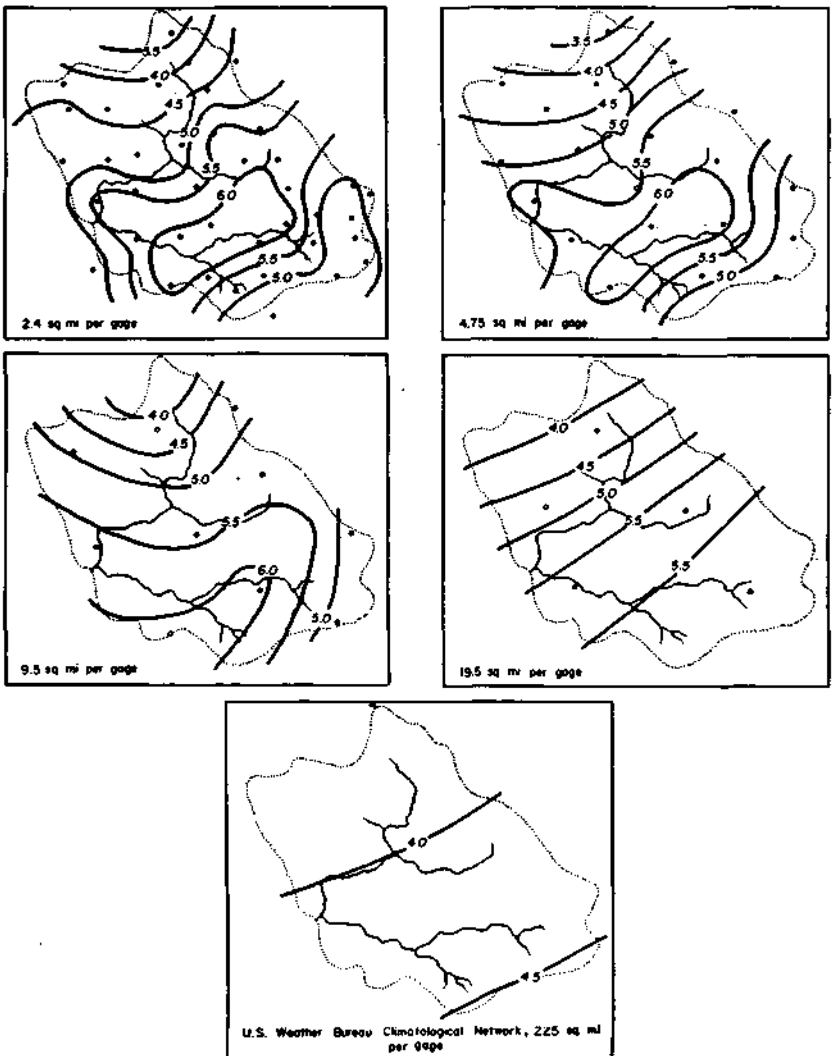

Fig. 1--Effect of gage density on isohyetal pattern, storm of July 16-17, 1950

lished. Rain-gage networks of density sufficient to define area-depth relations accurately from isohyetal maps for such small areas are uncommon. While publications of the MIAMI CONSERVANCY DISTRICT [1936] and the U. S. CORPS OF ENGINEERS [1945] include data on small watersheds, the data are limited due to the relatively sparse rain-gage spacing employed. The concentrated networks employed in this study were designed for collecting more precise data.

In an effort to obtain concrete information on the characteristics of the area-depth curve for small watersheds, thunderstorm-rainfall data collected on three densely-gaged networks [HUDSON, STOUT, and HUFF, 1952] in central Illinois during 1948-50 were analyzed. These three networks consisted of 7, 20, and 46 gages on basins of 5.2, 95, and 280 sq mi, respectively. Prior to the thunderstorm season of 1950, the 95-sq mi network was increased to 40 gages. The necessity for concentrated networks to obtain detailed isohyetal patterns and thereby minimize interpolation errors in the construction of area-depth curves is illustrated by the series of isohyetal maps in Figure 1. These maps were drawn for the same storm on the 95-sq mi basin using the various gage densities indicated.

Results of analysis--Most previous investigations of area-depth relations have been concerned with relatively large watersheds, employing much sparser networks than those utilized in this study. It has been observed that area-depth curves derived from isohyetal maps sometimes approach straight lines or flat curves when the logarithm of area is plotted against average rainfall. This often results from a liberal envelopment of points. Curved lines were obtained with the Illinois area-depth data in practically all cases when the data were plotted on semi-log paper with depth on the linear scale and area on the log scale.

Since a straight-line representation is desirable, several hypotheses were investigated in an effort to obtain an easily computed straight-line relationship. Within the limits tested for the three small basins, it was found that the data conformed closely to the general equation

$$Y = a + bX^{1/2}$$

where Y is average rainfall depth in inches, X is the area enveloped in square miles, and a and b are constants.

The area-depth curve is a two-dimensional representation of rainfall distribution over area, in which values of average rainfall within an isohyet are plotted against the area enveloped. The area-depth curve is constructed as though the highest value of rainfall occurred at one point, and lower values appeared (in an isohyetal representation) roughly concentrically around the higher values.

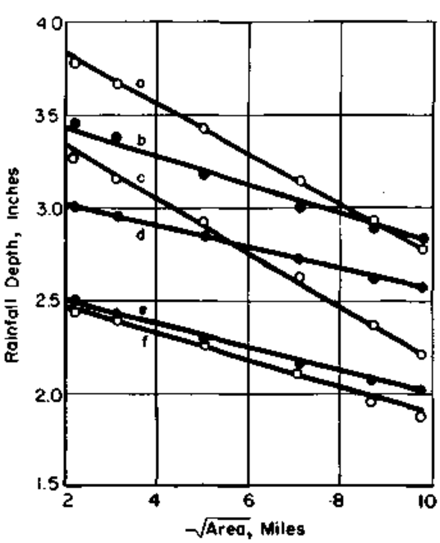

Fig. 2--Area-depth relations for the six heaviest storms, 1948-1950, over the 95-sq mi basin; (a) July 17, 1950; (b) June 13-14, 1949; (c) July 16, 1949; (d) June 18-19,1950; (e) June 14 (p.m.), 1949; (f) July 25, 1948

Rainfall may also be represented by plotting the value of each isopleth versus the mean distance from the center of the storm to that isopleth. If this is done for uniform rainfall-isopleth intervals, the slope of the resulting curve depicts the mean rainfall gradient across the isopleth corresponding to the abscissa. The mean distance is represented by the square root of the area enclosed by the isopleths.

For analysis purposes, values below one, five, and ten square miles, respectively, on the 5.2-, 95-, and 280-sq mi basins were not employed. It was felt that sufficiently accurate interpolations could not be made below these values. It is possible that the developed relation does not hold below these values, particularly for the single-celled, short-duration storms discussed later.

The data were tested on storms ranging from one to 18 hours' duration on the 95- and 280-sq mi basins, and for durations of 30 minutes to several hours on the 5.2-sq mi basin. Storms in which the basin mean rainfall equaled or exceeded 0.50 inch were used. These included 28 storms on the 95-sq mi basin, 19 on the 280-sq mi basin, and 18 on the 5.2-sq mi basin. Re-

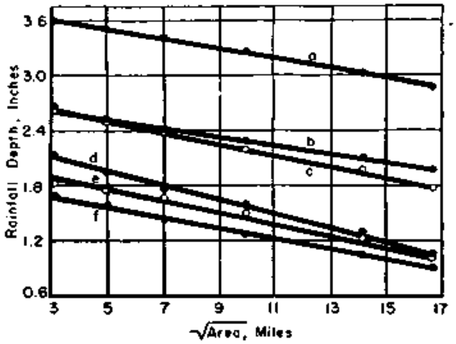

Fig. 3--Area-depth relations for the six heaviest storms, 1948-1950, over the 280-sq mi basin; (a) June 13-14, 1949; (b) June 14 (p.m.), 1949; (c) July 25, 1948; (d) July 21, 1949; (e) June 26, 1948; (f) June 23, 1948

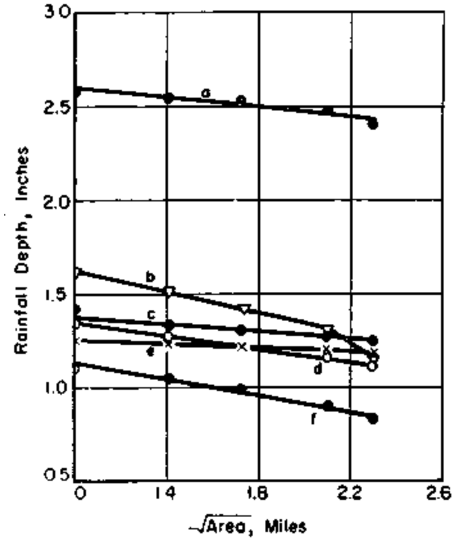

Fig. 4--Area-depth relations for the six heaviest storms, 1948-1950, over the 5.2-sq mi basin; (a) July 17, 1950; (b) July 6, 1949; (c) Oct. 21, 1949; (d) June 28, 1949; (e)May 19, 1949; (f)Aug. 17, 1949

suits for the six heaviest storms in each basin are shown in Figures 2-4.

Storms were classified according to duration and location for analysis purposes. Duration classifications used were: less than six hours, 6-12 hours, and over 12 hours. The storms were then classified according to whether the location of the storm core or area of heaviest rainfall was near the center or the boundary of the basin. Figure 5 shows the relationship between mean percentage of area and depth derived for storms with durations under six hours and with area of heaviest rainfall near the center of the basin. Figure 6 illustrates the same relation for each basin but for storms in which the heaviest rainfall occurred near the boundary of the basin.

Since most of the storms analyzed on the 95- and 280-sq mi basins were of several hours' duration, they were multicellular in nature. The multicellular storm has by definition a tendency toward greater areal uniformity than the single-cell storm. BYERS and Collaborators [1949] have shown that the single-celled storm is usually rather weak compared to the multicellular storm, and generally dissipates within less than one hour. However, exceptionally strong rainfall gradients may exist in these cells. Some limited tests of the single-cell type of storm were made for the 95-sq mi basin. Satisfactory agreement with the general equation was obtained in most cases. Results for a number of these storms chosen at random are shown in Figure 7.

Tests made on published area-depth data for the 8000-sq mi Muskingum Basin [U. S. WEATHER BUREAU, 1947] indicated the developed relation is not applicable to large basins.

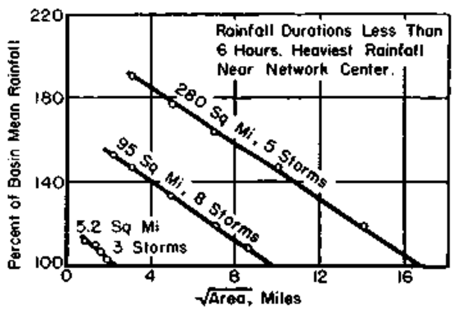

Fig. 5--Mean percentage area-depth relations based on three Illinois networks; storm data from 1948-1950

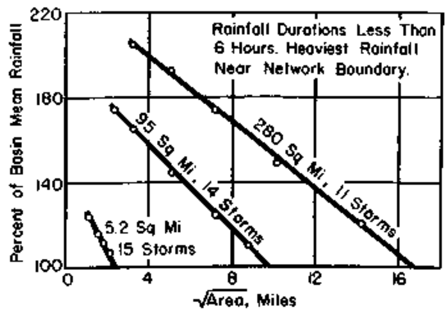

Fig. 6--Mean percentage area-depth relations based on three Illinois networks; storm data from 1948-1950

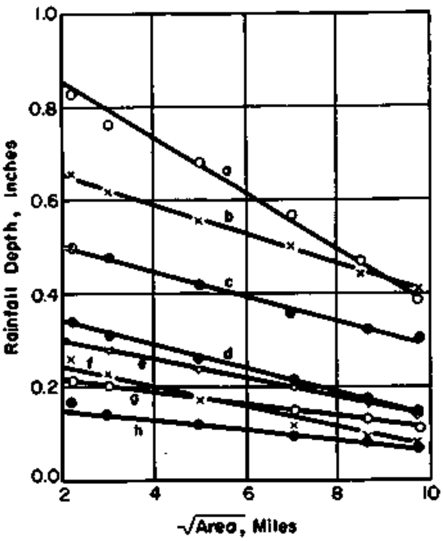

Fig. 7--Examples of area-depth relations for a single-cell type of storm over 95-sq mi basin; (a) June 16, 1950; (b) May . 21, 1950; (c) June 28, 1950; (d) May 4, 1950; (e) June 2, 1950; (f) July 31, 1950; (g) July 3, 1950; (h) June 12, 1950

Summary- -Analysis of three years of data on three small watersheds in central Illinois indicated that area-depth curves for thunderstorm rainfall approach a straight-line relationship when depth is plotted against the square root of the area. While the relationship apparently does not hold for large watersheds, it does appear applicable to basin areas up to 300 sq mi in the region studied. Further testing of the relationship for small basins is contemplated as more data are obtained from the several concentrated rain-gage networks operated by the Illinois State Water Survey.

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