

SPATIAL DISTRIBUTION CHARACTERISTICS OF RAINFALL RATES IN ILLINOIS

F. A. HUFF AND W. L. SHIPP

Illinois State Water Survey, Urbana, Illinois 61801

ABSTRACT.— A convenient method of describing the spatial distribution of storm rainfall rates for hydrological and meteorological applications is through the construction of area-depth envelope curves. From these, the rainfall rate equalled or exceeded over any fractional part of a sampling area can be determined. This method was used in the analyses of 1-minute rainfall data from 29 warm-season storms on a 50-gage network of 100 mi² in 1952-1953. These storms yielded 3142 area-depth curves of 1-minute rates, which closely approximate the instantaneous storm rainfall distribution on the sampling area. Furthermore, consecutive 1-minute area-depth curves provide both a space and time measure of storm rainfall rate variations in a single family of curves. From these data, first approximations of the frequency distribution of rainfall rates in Illinois warm-season storms were obtained and a typical time-space distribution model of rainfall intensity for such storms was developed.

The distribution of storm rainfall rates has important hydrological and meteorological applications. In hydrology, this knowledge is pertinent in establishing urban storm drainage systems while in meteorology it provides basic cloud physics information. Additionally, adequate climatological knowledge of rainfall rate may provide a useful tool in the evaluation of weather modification experiments or in the design of communication equipment.

The purpose of this study was not to establish climatological means or frequencies in view of the restrictions in sample size and sample randomization; rather, the aim was to provide first approximations which could be used where quantitative information on rainfall rate is needed. Both time and space characteristics were investigated.

DATA USED

In this study, 29 warm-season storms (April-October) were analyzed for 1-minute rainfall amounts. The data were collected in a 50-gage network on 100 mi² in east central Illinois during 1952-1953. The primary criteria for storm selection was the availability of radar data for the date of the storm. These storms yielded 3142 minutes from which the basic analyses were made.

The 1-minute rates were obtained from recording raingages with enlarged orifices and 6-hour charts which allowed reading amounts in 0.001 inch per minute (Huff and Neill, 1957). These gage charts were time synchronized to enable accurate time analysis.

ANALYSIS PROCEDURES

A convenient method of defining the spatial distribution of storm rainfall rates is through the computation of area-depth envelope curves. From these curves, the 1-minute rainfall rate equalled or exceeded over any fractional part of the sampling area can be determined. These rates closely approximate the instantaneous storm rainfall characteristics on the sampling area. Furthermore, consecutive 1-minute area-depth curves provide both a space and time measure of storm rainfall rate variations in a single family of curves.

In a uniformly distributed network of raingages, the area-depth envelope curve is constructed from a ranking of raingage values from high to low. Otherwise, the curve is determined from planimetry of network isohyetal maps.

AREA-DEPTH RELATIONS

First, a frequency distribution of area-depth envelope relations on the 100 mi² was determined from the 3142-minute sample. Results are summarized in Fig. 1, in which the rainfall rate equalled or exceeded is related to cumulative percent of the sampling area for various percentages of the minutes making up the sample. Thus, the 5-percent curve shows the rainfall rate equalled or exceeded in the 5 percent of the minutes with the heaviest rainfall rates for any fractional part of the area enveloped in the range from 2 percent to 98 percent of the area. Since this network encompasses 100 mi² a range from 2 mi² to 98 mi² is included. It should be understood that

the fractional areas in Fig. 1 are not fixed. That is, the 2 percent of the area with heaviest rates may change in location from minute-to-minute within storms as well as between storms. It specifies the heaviest rates experienced any place on the network in a given minute.

Interpretation of Fig. 1 is illustrated by referring to the 2 percent of the area with heaviest 1-minute rates in the 29 storms. There, it is seen that 5 percent of the 3142 minutes had rates equaling or exceeding 4.6 in/hr. This decreased gradually to 0.36 in/hr in the 50 percent of the minutes with heaviest rates, and to 0.04 in/hr when 95 percent of all minutes were included. Similarly, over 50 percent of the area, 5 percent of the minutes had a rate of 0.5 in/hr or greater, and this decreased to 0.03 in/hr for the upper 50 percent of the minutes, and to less than 0.01 in/hr when 95 percent of the 3142 minutes were included.

Fig. 1 does not include a sufficient number of storms to accept it as a true frequency distribution of rainfall rates. However, as indicated earlier, it does serve as a first approximation of the frequency distribution in warm season storms. Also, it provides quantitative information on the spatial variability of rates within a fixed area of 100 mi² and the degree of time variance of rates. For example, the 5 percent curve shows a spatial range from 4.6 to 0.07 in/hr as the area for which the enveloping rainfall rate is determined increases from 2 to 98 mi². Similarly, for the 2 percent of area with the heaviest rates in the 3142 minutes, the rate ranges from 4.6 in/hr to 0.04 in/hr between

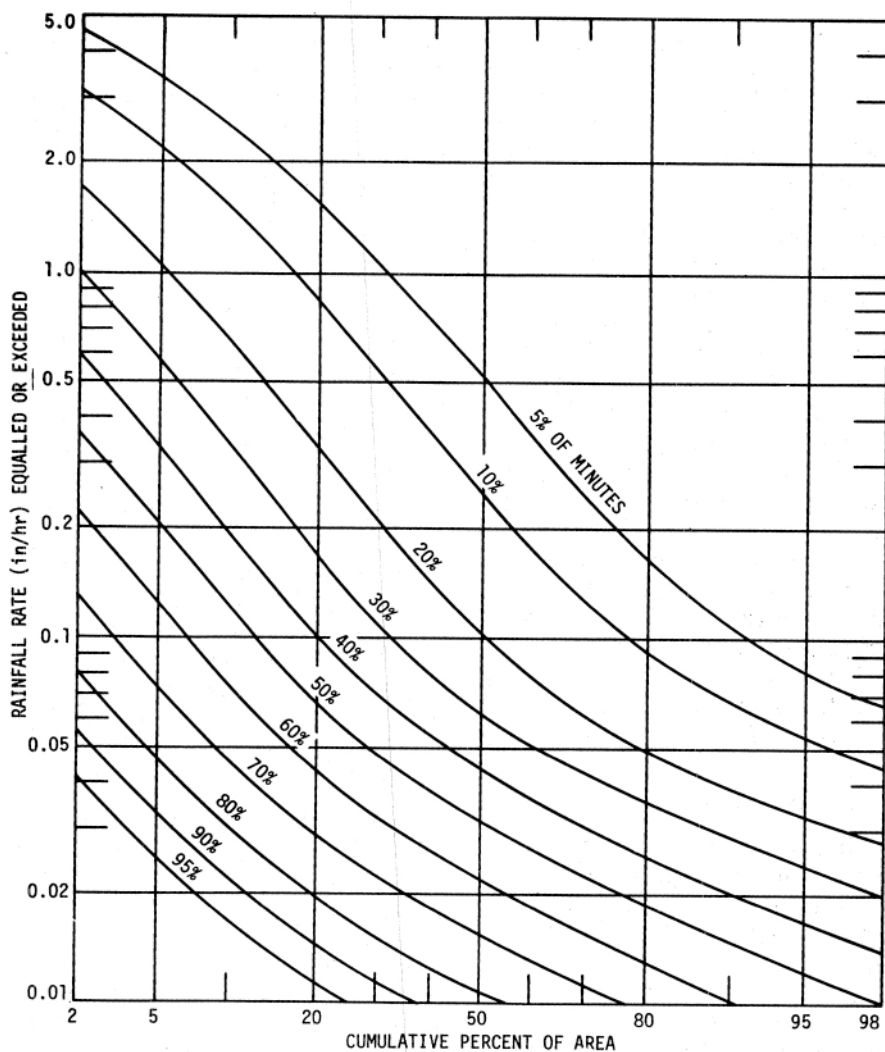


FIGURE 1. Frequency Distribution of Area-Depth Envelope Values.

5 percent and 95 percent of the total minutes.

The 3142-minute sample from 29 storms was used in making other analyses to define further the spatial distribution characteristics of rainfall rate, with particular emphasis

on the time variability in the spatial distribution. One result of these analyses is summarized in Fig. 2a (left). This figure shows a family of median area-depth envelope curves on the 100 mi² for selected percentages of the storms. The fami-

ly was derived in the following manner. For each storm, area-depth envelope curves of rainfall rate were calculated for each minute during the storm. At selected fractions of the 100 mi² area, the 1-minute rainfall rates for the storm were ranked from high to low. The median values from each storm were then used to construct the family of curves in Fig. 2. These curves were found to fit closely an equation of the form:

$$\text{Log } R_e = a + b A^{0.5} \quad (1)$$

where R_e is the enveloping rainfall rate, A is area enclosed, and a and b are regression constants.

Figure 2a provides a statistical model of typical area-depth curves of 1-minute rainfall rate in warm season storms of various intensity. Thus, the median rainfall rate distribution in the most intense storms in the 29-storm sample is portrayed by the curve for 5 percent of the storms. This curve shows the enveloping rainfall rate ranging from 3.8 in/hr over the 2 mi² of heaviest intensity to 0.03 in/hr over the entire 100 mi². Similarly, the 50 percent curve shows a range from 0.43 in/hr to less than 0.01 in/hr. These individual percentage curves provide a quantitative measure of the spatial variability in storms of varying intensity.

For some purposes, one may be more interested in extreme rates rather than median or average rainfall rates to be expected in storms. The ranked 1-minute data for each storm can be used also to obtain a measure of the distribution of heavy

rates, and this has been done in Fig. 2b (center). Here, the area-depth envelope curves for the 10 percent of the minutes with heaviest rainfall in each storm were used to derive the family of curves. Interpretation of this family is the same as for Fig. 2a. Thus, in 10 percent of the storms sampled the area-depth envelope curve for the 10 percent of the storm with heaviest intensities had enveloping rainfall rates decreasing from 5.8 in/hr at 2 mi² to 0.3 in/hr over the entire 100 mi². All storms (100%) had rates of 0.42 in/hr or more on 2 mi² during the heaviest part of the storm but less than 0.01 in/hr when the entire 100 mi² is included. Together, Figs. 2a and 2b provide quantitative estimates of median and extreme rates likely to occur within and between typical warm season storms.

Fig. 2c (right) shows a family of curves similar to those in Fig. 2a. Method of determination was the same, except average rates rather than median rates were employed in development of the Fig. 2c, since some users may be more interested in this statistic. In this case, the family of curves was found to fit an equation of the form:

$$\text{Log } R_e = a + b A^{0.8} \quad (2)$$

Because of the extreme skewness in the distribution of 1-minute rainfall rates in 29 storms, substantial differences exist between the average and median sets of curves. The average curves show higher rainfall rates for a given area and given percent of storms.

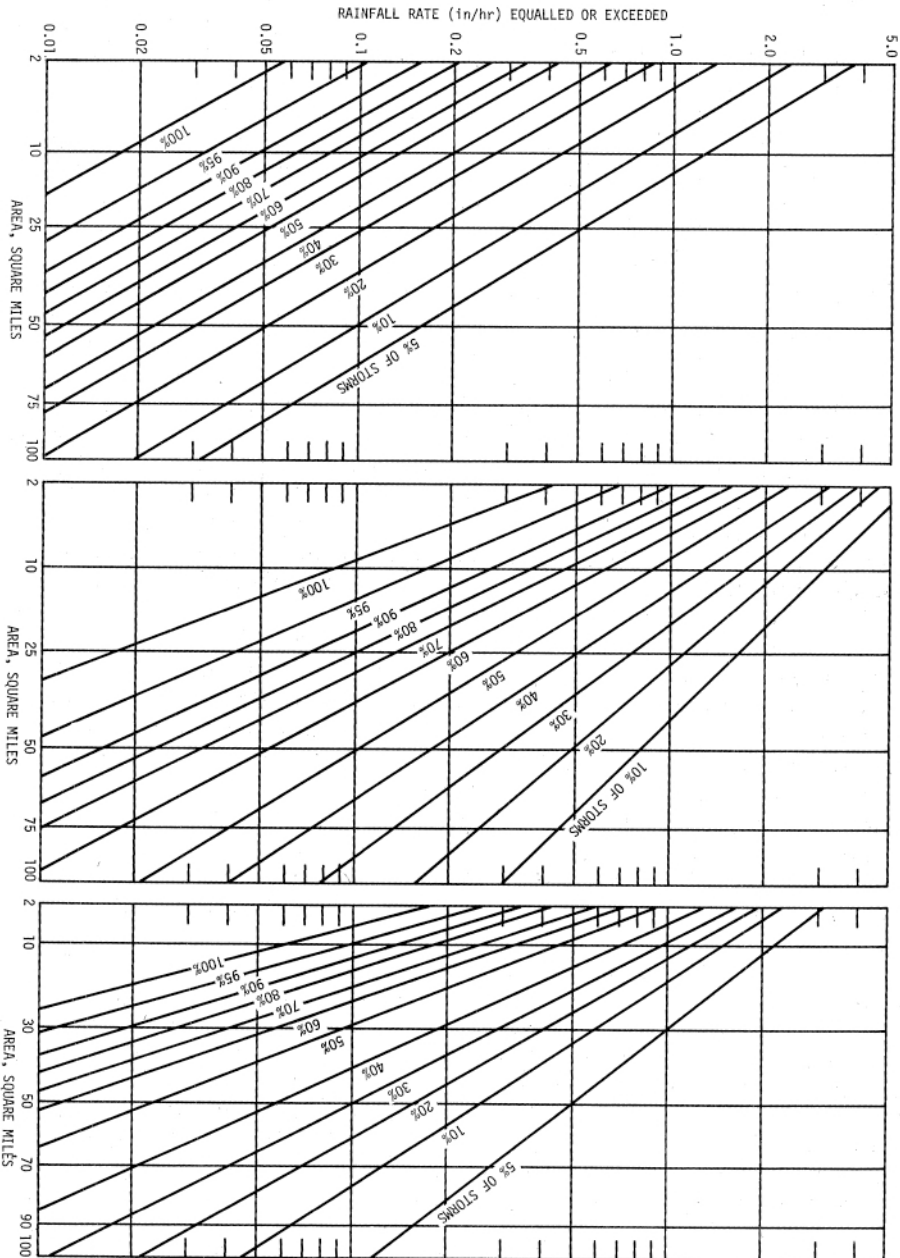


Fig. 3a (left) shows a median space-time distribution of storm rainfall rates derived from the 29-storm sample. It was obtained in the following manner. For each storm an area-depth envelope curve of rainfall rate was obtained for each minute. Thus, a family of curves similar to Fig. 2a was obtained for each storm. Then, the median curve for each 10 percent of the minutes from the 29 storms was used to construct Fig. 3a. Based on the 29-storm sample, Fig. 3a can be interpreted as a typical space-time distribution in warm season storms. Fig. 3b (right) provides the same type of information, but is based upon averages rather than medians.

Area-depth envelope relations were developed also for 25- and 50-mi² areas within the 100-mi² network. Characteristics of these envelope curves were similar to those for 100 mi², and, therefore, need no further discussion here.

SUMMARY AND CONCLUSIONS

This study has provided first approximations of the frequency distribution of rainfall rates in Illi-

nois warm-season storms and permitted development of a typical time-space distribution model of rainfall intensity for such storms. This information should provide useful knowledge for both hydrological and meteorological applications, especially in urban hydrology problems and in weather modification experiments.

Results indicate large rate changes frequently from minute-to-minute because of the steep rainfall gradients, small size, and short life-cycle of convective storm cells. Investigation showed little difference between the distributions over 25 mi² and 100 mi² areas.

ACKNOWLEDGMENT

This research was supported by the Bureau of Reclamation, U.S. Department of Interior, under contract no. INT 14-06-D-6575.

LITERATURE CITED

- HUFF, F. A. and J. C. NEILL, 1957. Frequency of point and areal mean rainfall rates. *Trans., American Geophysical Union*, 37(6):679-681.

Manuscript received, July 7, 1969

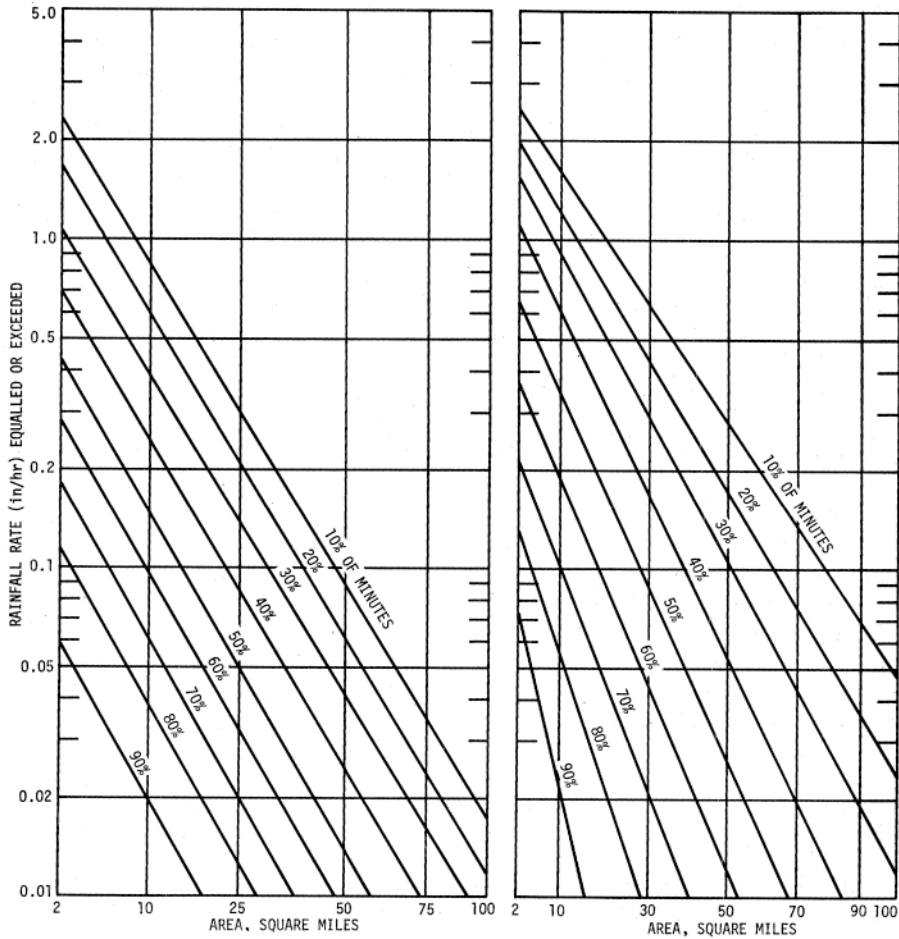


FIGURE 3. Area-Depth Storm Models Based on Median and Average Values.