# INTRODUCTION

## Storm Types

The type of rainstorm that most frequently produces flash floods in Illinois and the United States is very localized and produces a large amount of rainfall. According to Changnon and Vogel (1981), these storms usually last from 3 to 12 hours, significantly affect fewer than 400 square miles, and have l- to 4-hour rainfall totals in excess of 3 inches. Changnon and Vogel's study indicates that approximately 40 of these storms will occur in an average year in Illinois, or about one for every 1,500 square miles of territory. These storms cause serious local flooding problems for farmers (crop damage) and urban areas, and interfere with small-reservoir operations.

Individually, the most damaging flood-producing storm experienced in Illinois is a larger version of the storm described above and occurs on the average of about once in two years within the state (Huff, 1986). These "blockbuster" storms generally last from 12 to 24 hours, produce extremely heavy rainfall over a 2,000- to 5,000-square-mile area, and typically create 10- to 12-inch amounts of rain at the storm center. Rainfall amounts in excess of the 100-year recurrence-interval value of point rainfall commonly encompass areas of several hundred square miles about the storm's center.

A substantial portion of the maximum point rainfalls recorded in the 83-year sample used in the present study occurred in storms of this type. Although they are rather rare occurrences, they may occur in clusters. For example, two of the three storms that occurred in 1957 took place within two weeks of each other. On the other hand, there have been times when no blockbuster storm was observed for several consecutive years.

Other flood-producing storms, affecting relatively large areas ranging from the size of a county to 20,000 or more square miles, result from a series of moderately intense showers and thunderstorms that occur intermittently for periods of 1 to 10 days. Many of these individual storms would produce little or no damage by themselves, but collectively they can cause urban drainage systems to overflow and creeks and rivers to swell beyond capacity. This can result in both localized and widespread flooding.

The frequency distributions of heavy rainfall resulting from the storm systems described above are of importance to engineers and others involved in designing and operating structures that can be affected by these events. Consequently, this Illinois study has concentrated on determining rainfall frequency relations over a wide range of storm periods or partial storm periods (5 minutes to 10 days) and recurrence intervals (2 months to 100 years). This large-scale study was considered necessary to meet the widespread needs for rainfall frequency information, both at present and in the foreseeable future.

## Rationale for the Study

The present study has used a much larger and longer sample of Illinois precipitation data than was available for previous studies such as the United States studies by Yamell (1935), Hershfield (196 1), and Miller, Frederick, and Tracey (1973), and the previous Illinois study by Huff and Neil1 (1959). The present study used data for an 83-year period (1901-1983) collected at 61 Illinois precipitation-reporting stations, in addition to data from nearby stations in the surrounding states. Such a relatively large sample has permitted us to provide greater spatial detail than was possible in previous studies. Furthermore, the 83-year sample should provide more accurate estimates of the various frequency distributions, particularly for relatively long recurrence intervals of 25 years or more.

Some specific needs led to the undertaking of this study. First, Illinois frequency relations had not been updated since 1959-1961 (Huff and Neill, 1959; Hershfield, 1961). Second, further stimulation for the study resulted from recent findings (Huff and Changnon, 1987) that an apparent climatic trend operated on the frequency distributions of heavy rainstorms in Illinois from 1901-1980. Third, increased flooding in northern Illinois since the late 1970s (Changnon, 1983) has generated concern about the accuracy of existing design rainfall values. Fourth, for some hydrologic applications, a need exists for seasonal frequency relations that were not previously available but that are an integral part of the present study.

A fifth need is for definition of the natural variability in rainfall frequency relations between locations in small areas of approximately homogeneous rainfall climate. A method for quantitatively assessing this dispersion was developed as part of this study. A method for evaluating the probability of "outlier" values that tend to distort the true frequency relations has also been developed as part of the present study.

## Analytical Methodology

The three paragraphs that follow the conversion table (see below) were abstracted largely from Huff and Neil1 (1959). The statements are as valid today as they were 30 years ago when the Water Survey undertook its initial study of the frequency distribution of heavy storm rainfall in Illinois. That is, a combination of statistical techniques, guided by available meteorological and climatological knowledge of atmospheric processes, provides the best approach to this area of study.

All the results in this report are expressed in the English system of units. It is anticipated that hydrologists and others who use the information will continue to use the English system in the foreseeable future. The following conversion table can be used in converting English units to metric units.

**Conversion Table**

| *Multiply* | *By* | *To obtain* |
|---|---|---|
| Inch (in.) | *25.40* | Millimeter (mm) |
| Mile (mi) | 1.609 | Kilometer (km) |
| Square mile ($mi^2$) | 2.59 | Square kilometer ($km^2$) |

If the physical laws governing the inception and distribution of precipitation were completely understood, it would be unnecessary to resort to many of the statistical approaches now used by meteorologists and hydrologists to estimate the future distribution of storm rainfall. However, even the basic physical processes involved in the production of precipitation in the atmosphere have not been adequately defined or evaluated at present, although considerable research is being directed toward defining and evaluating them. Consequently, a researcher investigating precipitation frequency relations is forced to depend primarily on application of statistical methodology to samples of observational data that are hoped to be representative of the population distribution.

The production and distribution of precipitation are obviously dependent upon complex reactions in nature. Therefore we could find no firm basis for selecting in advance any one of the several commonly used statistical distributions (e.g., log-normal, Gumbel) as best for the analysis of Illinois frequency data. It did not seem logical to pass judgment when so little is known about the basic laws and processes **governing** rainfall distribution. Rather, it appeared that the selection of a statistical technique should be determined on the basis of the goodness-of-fit of raw data to each of several statistical distributions that appeared to be promising yardsticks for estimating future events. Consequently, we followed this approach throughout the investigation to establish annual and seasonal frequency relations.

Complete objectivity in establishing frequency relations was not possible because tests of several statistical methods showed that none was distinctly superior in fitting the data samples. Thus, in the final analysis, statistical distributions selected for computing annual and seasonal relations were based to some extent upon other available meteorological and climatological information. The results represent frequency estimates based upon analysis and evaluation of all information available during the investigation.

## Organization of the Report

Readers interested in the methods, analysis, and results of the study of potential climatic trends or fluctuations in the distributions of heavy rainstorms in Illinois should see Sections 1 and 2 of this report.

Those interested in how the frequency distributions of heavy rainfall events were derived and what the findings were should refer to Section 3, which provides information on the data used, the various analytical techniques and methods employed, and area1 mean frequency distributions for regions of similar precipitation climate. Section 3 also presents selected isohyetal maps that portray the statewide patterns of rainfall frequency for the recurrence intervals and rain durations most commonly used by hydrologists.

Section 4 provides information on urban effects on the frequency distributions of heavy rainstorms, with particular emphasis on the Chicago region. Section 5 describes the analytical methods used and the results obtained from an investigation of the natural variability about average frequency relations in ten sections of approximately homogeneous rainstorm climate. It also describes a study of the outlier values that are nonrepresentative of the normal frequency relations for a point or area and that tend to distort the true relationship.

For those interested in seasonal frequency distributions of heavy rain events, Section 6 provides such relations in Illinois for the four seasons and discusses the causes of substantial regional differences in the distributions. Section 7 discusses spatial and temporal characteristics of heavy storms not analyzed in the present study, which have been derived from other Illinois studies and which are important to users of heavy rainstorm climatology in the design and operation of water control structures.

A summary and conclusions pertaining to various phases of the present study are included in Section 8. Point rainfall frequency relations for 61 locations in the state are shown in Appendices A through E.

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# 1. TEMPORAL CHANGES IN HEAVY RAINFALL FREQUENCIES IN ILLINOIS

A major use of historical precipitation data has been to develop rainfall frequency relations for partial and total storm periods of various durations ranging from a few minutes to as much as 10 days. These relations are used primarily in designing water-related structures such as urban storm sewer systems, but they also have applications in other fields in which assessment of heavy rain events is essential (e.g., agriculture, climate change, and weather modification).

Hydrometeorologists have fit various statistical distributions to historical precipitation data to derive various design values such as the 24-hour rainfall expected to occur on the average of once every 5, 10, or 100 years. Derivations of such values have traditionally been based on the assumption that the historical sampling period has year-to-year variations, but that it is essentially stationary, without major temporal fluctuations or long-term trends during the typical design period of 50 to 100 years for most water-related structures (Yevjevich, 1977). Hydrometeorologists who have developed these frequency values usually have employed all available historical data, and their results reflect the length of period sampled.

Most users desiring rainfall frequency values rely on U.S. Weather Bureau Technical Paper 40 (Hershfield, 1961), which provides average relations throughout the United States. In a few cases, more detailed data and different analytical approaches have been applied to obtain more comprehensive spatial distribution patterns on a regional or state basis, such as those derived for Illinois (Huff and Neill, 1959). Few updates of previously determined frequency relations have been performed in the last 35 years, and, in general, the earlier studies, which are in widespread use today, remain the primary sources of frequency values.

In an earlier preliminary study by Huff and Changnon (1987), 1901-1980 data for 22 Illinois precipitation-reporting stations were used to investigate the possibility of a climatic trend in the distribution of heavy rainstorms in Illinois. Huff and Changnon compared the frequency distributions of 1-day and 2-day rainfall amounts, for recurrence intervals of 2 years to 25 years, for two 40-year periods, 1901-1940 and 1941-1980. They found substantial rainfall increases during the second 40-year period (1941-1980) for each recurrence interval tested in the northern part of the state, smaller increases in the west and central portions, and a slight decrease in the extreme southern and southeastern parts. Another study of Illinois climatic fluctuations by Changnon (1984a) revealed sizable shifts in precipitation and other weather conditions, including thunderstorms.

This line of inquiry was pursued further in our development of Illinois frequency relations from 1901-