Time Distribution of Short Time Increment Rainfall for Engineering Design

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Abstract

The knowledge of the time distribution of short time increment rainfall is of vital importance in solving certain hydrologic problems, such as the design of urban storm sewer systems. One of the important characteristics of temporal distribution of rainfall used in hydrologic design is the average percentage mass curve of rainfall. Huff has proposed a method of generation of rainfall hyetographs based on the average percentage mass curves of rainfall data.

In the present study we have used Huff's method to investigate the time distribution of ten minute and hourly rainfall data from West Lafayette, Indiana. The historical storms were classified into four groups depending on the occurrence of peak rainfall in the first, second, third or fourth quartiles of the storm period. The time distribution of rainfall in each quartile was expressed as cumulative percentages of storm depth and storm duration in terms of probability levels. The time distribution graphs derived from West Lafayette data were compared with those obtained by Huff for the rainfall data from east-central Illinois and discussed. Histograms were developed for the different quartile storms and an example is presented to illustrate the method of generating the hyetograph for a given storm.

Introduction and Statement of Objectives

The short time increment rainfall depth values corresponding to given frequencies and durations are often used in the design of urban storm sewer systems. Although, total storm depth and duration for a given location can be obtained or approximated easily, the information about temporal distribution of a given storm of a particular duration is not easily available. Stochastic models such as the urn model of Grace and Eagleson (1) can be used for the determination of the time distribution or the hyetograph of a given storm. However, these methods require rather advanced knowledge of probability theory, the use of a digital computer and the correlation structure of rainfall. These methods are also of use mainly for large scale data generation. In practice, there are occasions when the engineer is interested in generating a few hyetographs of a design storm. In such circumstances, a simpler procedure is of greater utility. The method proposed by Huff (2) is one such procedure.

The primary objective of the present study is to demonstrate the use of "average percentage mass curve" for the generation of hyetographs. The concept of "percentage mass curve" is well known and an extension of the above concept is the average percentage mass curves developed by Huff (2) for different probability levels. The method is quite simple and the computations can be carried out on a desk calculator. The second objective is to compare the results obtained by Huff with those of the present study and to draw conclusions regarding the variability in time distribution characteristics of short time increment rainfall at different locations and different samples.

Data Used in the Study

The results presented herein were obtained by the analysis of two different sets of data collected from rainfall stations in West Lafayette, Indiana. The first set of data consists of ten-minute rainfall values measured from 1970 to 1972 by a raingage located in the Ross Ade Upper watershed at the Purdue campus. The second set of data is the hourly rainfall values measured at the Purdue Agronomy Farm from 1969 to 1973. The location of these two rainfall stations is shown in Figure 1. Rainfall measured only during the months April to October were used in the analysis.

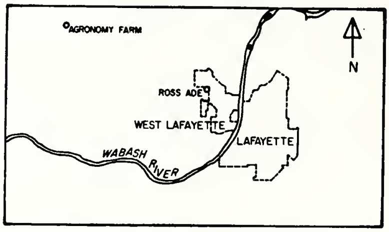

FIGURE 1. *Location of Stations*

The observed 10-minute and hourly rainfall values were separated into storms using the *critical lag* criterion of Grace and Eagleson (1). The critical lag τ_L was found to be 100 minutes for the 10-minute data and 15 hours for the hourly data by Rao and Chenchayya (3). The observed rainfall pulses were sequentially considered and when a period without rainfall of duration τ_L or greater appeared between two nonzero pulses, a new storm is said to commence. Thus, a *storm* is defined as a group of rainfall pulses preceded and followed by zero amplitude pulses of duration equal to or greater than the critical lag. The *storm interior* is the term used for the sequence of both zero and nonzero amplitude rainfall pulses of a storm and the sum of the magnitudes of the nonzero rainfall pulses of a storm is called the *storm depth.* In the present analysis, we have used only the storms with durations greater than 40 minutes for the ten-minute data and 4 hours for the hourly data. There were 174 and 133 storms respectively from the ten-minute and hourly rainfall data. The above storms and the storm interior values were used for investigating the time duration characteristics of rainfall at West Lafayette, Indiana.

Time Distribution Characteristics

The time distribution characteristics of rainfall were investigated by using Huff's method (2). In this method the historical storms are initially classified into four groups depending on the occurrence of peak rainfall in the first, second, third or fourth quarter of the storm period. The time-distribution of rainfall in each quartile is expressed as cumulative percentages of storm depth and storm duration in terms of probability levels from 10% to 90%. The probability levels are adopted because of significant variability in the time-distribution of rainfall from storm to storm. This classification of storms can be easily seen to be an extension of the percentage mass curve concept. However, the above method can be used much more easily than the other methods, such as those based on urn models for determining the internal distribution of rainfall given total storm depth and duration. The results obtained from the above method for the rainfall data from West Lafayette are discussed below.

The number and the percentage frequency of the quartile storms of the observed data are presented in Table 1. These results show that the maximum number of storms are of the first quartile category and the minimum number are in the third quartile category. The corresponding percentage mass curves are presented in Figure 2. The percentage mass curves at different probability levels for both the ten-minute as well as hourly data show the same general trends. The percentage mass curves shown in Figure 2 were compared with those prepared by Huff (2) for 30-minute rainfall data from east-central Illinois. A typical comparison between the percentage mass curves of the first quartile storms of hourly data from West Lafayette and those from Huff's data is shown in Figure 3. Obviously there is

Quartile	Ten Minute Data		Hourly Data	
	Number	Frequency (%)	Number	Frequency (%)
First	57	32.8	64	48.1
Second	56	32.2	31	23.3
Third	27	15.5	9	6.8
Fourth	34	19.5	29	21.8
Total	174	100.0	133	100.0

TABLE 1. *Percentage Frequency of Quartile Storms*

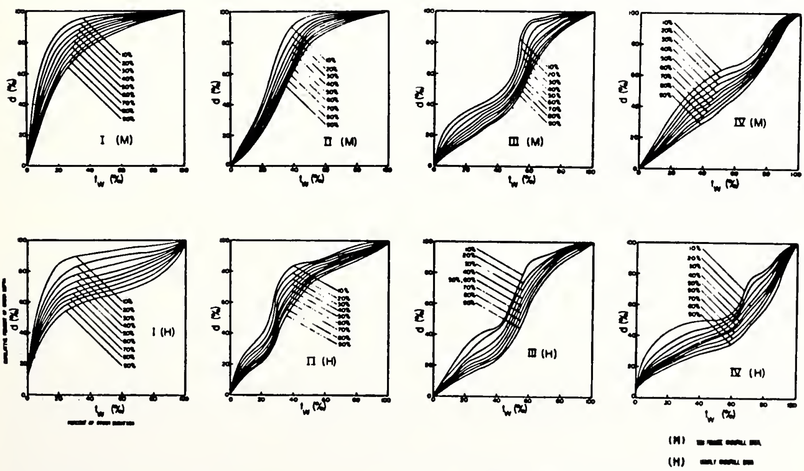

FIGURE 2. *Percentage Mass Curves Derived by Using Huff's Method*

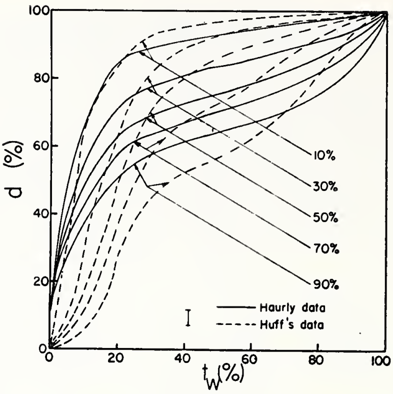

FIGURE 3. *Comparison of Average Percentage Mass Curves (I Quartile Storms)*

considerable difference between the percentage mass curves at the same probability levels. The comparative study of the percentage mass curves for the other quartile storms also showed similar differences. Although the above rainfall stations are located in similar climatic regions, the pronounced differences in the time distribution characteristics of rainfall may be attributed to the factors such as synoptic storm types, areal distribution, length and time step of the rainfall data considered in the analysis. For example, Huff used average rainfall data from a network of 49 recording gages distributed over an area of 400 square miles (1042 square kilometers) in east-central Illinois. The period of record was about 20 years. On the other hand, the data used in the present study were obtained from single rain gage measurements and the total period of the record is 5 years. Several other reasons similar to those discussed above can be cited for the obvious differences between the average percentage mass curves.

Generation of Hyetographs

By knowing the storm depths and durations (such as those corresponding to a n year frequency) the hyetographs may be generated by the Huff's method. These are average hyetographs and an example of the computations is also given below. Presently we will consider only the characteristics of the hyetographs which may be obtained by Huff's method.

The histograms for the 10%, 50% and 90% probability levels for the first quartile storms are shown in Figure 4. The peak rainfall, by definition, occurs in the first quarter of the storm period at all probability levels. The intensity of rainfall exhibits an approximately exponential decrease with increasing storm duration. For example, the 50% probability histogram (Figure 4) indicates that in the first quartile storms of the ten-minute data, about 42% of the rainfall occurs in the first 10% of the storm period and about 90% of rainfall occurs in the first half of the storm period in 50% of the cases. The first quartile storms of hourly data shows that at 50% probability level,

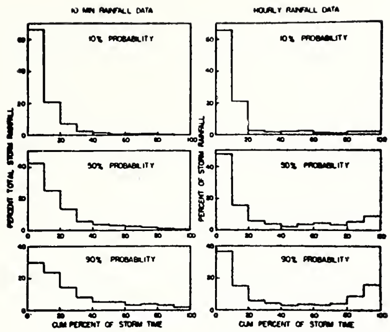

FIGURE 4. *Selected Histograms of First Quartile Storms*

about 48% of rainfall occurs in the first 10% of the storm period and about 75% of rainfall occurs in first half of the storm period.

The histograms of the second, third and fourth quartile storms at 50% probability level are presented in Figure 5 for the ten-minute as well as hourly data. A comparison between the histograms of 50% probability level of the first, second, third and fourth quartile storms (Figures 4 and 5) for the ten-minute data indicate that the magnitude of the peaks are decreasing from the first quartile to fourth quartile storms. The same variation is also observed from the histograms of 50% probability level of hourly data.

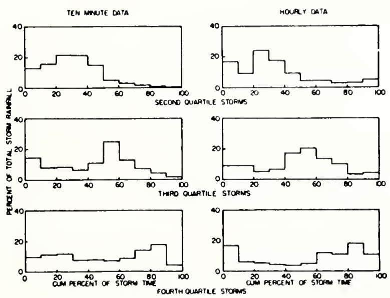

FIGURE 5. *Histograms at 50% Probability Level*

Example

Let us assume that we want to generate the hyetograph for a IV quartile storm of 14 hours duration and 1.5 inches (3.8 cm.) depth. The average hyetograph of the IV quartile storm at 50% probability level is shown in Figure 5 in terms of percent of total storm depth and storm duration. The hyetograph of the generated storm computed from Figure 5 at 50% probability level is shown in Figure 6. The hyetographs of the storm at other probability levels (for example 10% and 90%) may be obtained from Figure 2.

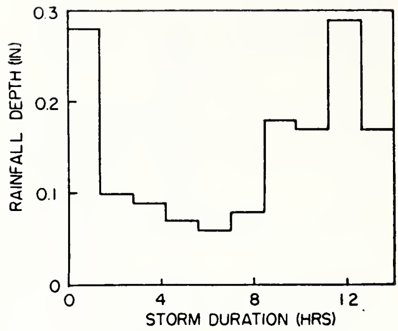

FIGURE 6. *Hyetograph of The Hypothetical Storm At 50% Probability Level*

If the rainfall peak within the storm is of concern in the design, the above procedure may be used to generate a first quartile storm, which would give a higher peak rainfall. Thus, the method is more flexible and can be used to generate hyetographs for all the quartile storms. If the probability of occurrence of the storm is known, the quartile category can be assigned in a probabilistic sense using the percentage frequencies of the quartile storms presented in Table 1. Further details may be found in Rao and Chenchayya (3).

Conclusions

The following conclusions can be presented from the foregoing analysis.

(1) The time distribution characteristics of short time increment rainfall from West Lafayette, Indiana, could be represented by the average percentage mass curves at different probability levels.

(2) In the West Lafayette area, first quartile storms occurred most frequently and third quartile storms most infrequently.

(3) The comparison of time distribution characteristics between rainfall data from West Lafayette and those of east-central Illinois reveals that although the rainfall stations are located in similar climatic regions, the time distribution of rainfall can be significantly different. However, the variability which may be attributed to sampling variations and to spatial effects need further study.

(4) The histograms developed from the percentage mass curves are quite useful to generate the hyetograph of a given storm.

Acknowledgements

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