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TIME DISTRIBUTION OF RAINFALL

by

Robert A. Putt

A Research Report
Presented to the Graduate Committee
of Lehigh University
in Candidacy for the Degree of
Master of Science
in
Civil Engineering

Lehigh University
1977

CERTIFICATE OF APPROVAL

This research report is accepted and approved in partial fulfillment of the requirements for the degree of Master of Science.

December 22, 1977
(date)

Professor ~~in~~ Charge

Chairman of Department

ACKNOWLEDGMENTS

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The author would like to thank Dr. Robert L. Johnson for his guidance during the research work and his assistance in the report writing process. The Lehigh University Computing Center is also to be acknowledged for the agreeable accommodations.

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LIST OF SYMBOLS AND ABBREVIATIONS

a,b,c	Rainfall equation constants
A	Area contributing to runoff, acres
C	Coefficient of surface runoff
cfs	Cubic feet per second
i	Rainfall intensity, inches per hour
ppt	Precipitation, inches
r	Fractional location of peak storm intensity
Q	Runoff flowrate, cfs
t	Time into storm, minutes
T	Duration of storm, minutes
t_a	Time after storm peak, minutes
t_b	Time before storm peak, minutes
τ	Fraction of storm duration
Y	Fractional storm precipitation

ABSTRACT

Design rainfall hyetographs were studied for use in hydrograph simulation models. Use of the EPA SWMM program calibrated for a runoff basin in Allentown, Pennsylvania, shows that the pattern of the storm has a great effect on peak runoff rates. An advanced peak storm results in substantially lower runoff rates than a delayed peak storm. The decline of soil infiltration capacity with precipitation time is the prime cause of this phenomenon.

Three different design storm patterns were developed for Allentown. A pattern based on Soil Conservation Service methods produces a 30-minute hyetograph with a 5-year frequency which starts at 1.56 inches/hour, increases to 6.24 just before the middle, and decreases to 1.32 inches/hour. A hyetograph with the same duration and frequency but based on methods of Keifer and Chu starts at 1.44 inches/hour, increases to 6.12 just after the middle, and decreases to 1.56 inches/hour. A design storm based on historical records increases from 1.96 inches/hour initially to 3.70 just after midpoint, decreasing to 1.98 inches/hour. All three storms have the same total volume of rainfall but the Keifer-Chu pattern produces the largest peak runoff rate. The other two produce runoff peaks nearly equal to each other.

The historical pattern was based on data from large storms of all durations. The wide scatter of the data points was greatly reduced when only long duration storms were analyzed. These however produced a storm pattern identical to that from all durations. Comparisons with

smaller sized storms indicated that these smaller storms have peak intensities occurring earlier in time, therefore producing less critical runoff rates. Comparisons of patterns from analyses of data from six stations across Pennsylvania indicate that the eastern part of the state has storms with peaks that occur after the middle of time while those of the western part occur before the middle of time.

INTRODUCTION

Extensive development by modern man has led to the numerous conveniences which we utilize every day. It has also been the direct cause of many problems, one of which is a tremendous increase in stormwater runoff. Most of this increase has been because of the impervious cover of buildings, roads, and parking lots over the land. Smaller increases are caused by replacing trees, brush, and wild growth with short well-manicured lawns. The general practice has been to rapidly transport this runoff via storm sewers to receiving streams or lakes in order to reduce the possibility of flooding in the immediate area. This solution technique may itself cause serious flooding and quality problems in the receiving stream. This study concerns the impact of storm patterns used in design since the precipitation and resulting runoff are the first step in solving these problems.

For the most part, storm sewer design has been done by engineers using the rational method. The rational formula states that

$$Q = CiA \qquad (1)$$

where Q = peak runoff rate, cfs,

C = coefficient of overland flow,

i = average rainfall intensity over a duration equal to time of concentration, in/hr,

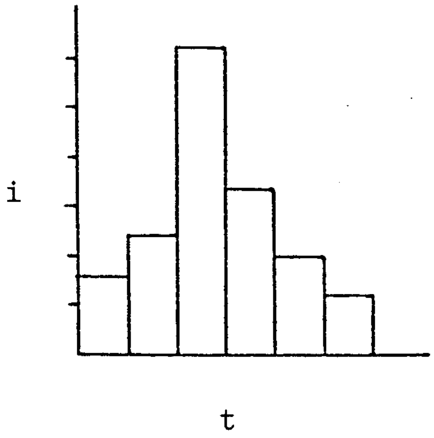
A = contributing area, acres.

This method is simple to use but it does have some shortcomings. It is only "rational" in the sense that the units are compatible because an acre-inch/hour is nearly equal to one cfs. There is not really any rational theoretical basis; the method is entirely empirical in stating that the peak runoff rate is simply some percentage of the precipitation rate. The rainfall-runoff phenomenon is too complicated to be adequately described by this formula.

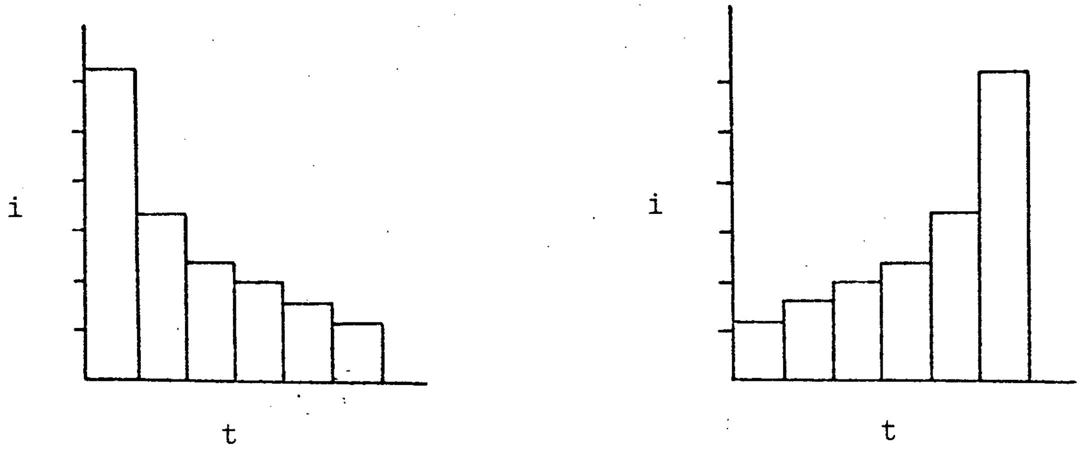
In recent years there has been increasing development of hydrograph type models which utilize the power of high speed digital computers. These hydrograph models can provide much more information for decision makers and can be effectively used in the design process. Hydrograph methods have a sound theoretical basis by using a mass balance type approach of subtracting all other losses from precipitation to arrive at runoff, all three quantities being functions of time. Hydrograph methods also allow for more accurate land use descriptions and provide not only flowrates as a function of time, but also total volumes of runoff which can be used in the design of additional facilities such as retention basins. The hydrograph model requires more input data, including the development of a design storm hyetograph, which is the major subject of the remainder of this paper.

Importance of Rainfall Pattern

The pattern with which precipitation falls can have a significant effect upon the amount and rate of runoff that results. This can best be shown with an example. Figure 1 shows three possible rainfall patterns. The advanced peak and delayed peak storms are the two limiting extremes with the intermediate peak storm falling somewhere between them.



Intermediate Peak



Advanced Peak

Delayed Peak

Figure 1

Rainfall Pattern Definition

Use was made of the EPA SWMM program and the calibrated input data for the College Heights Boulevard (CHB) storm sewer system in Allentown, Pennsylvania (1,2,3). The model was executed using each shape of the rainfall hyetograph shown in Fig. 1. The results of these computer runs show that even though the total amounts of rainfall and the durations are the same for the three cases, the resulting flowrates are appreciably different.

Table 1
Peak Runoff for Different Rainfall Patterns

Storm Type	Peak Total Surface Runoff (cfs)	Peak Flow at System Outlet (cfs)
Advanced	385	370
Intermediate	480	470
Delayed	640	525

Table 1 and Fig. 2 through Fig. 7 show what would be expected; that the further into the storm duration that the peak intensity occurs, the larger is the rate of runoff. This occurs as a result of the decrease in the infiltration capacity of the soil from a maximum value at the onset of rainfall to a minimum value when fully saturated. The effect in this drainage system is very great because of the low percentage of impervious area. As the impervious area fraction increases, the effect of storm pattern on runoff rates decreases because of the decrease in the amount of infiltration.

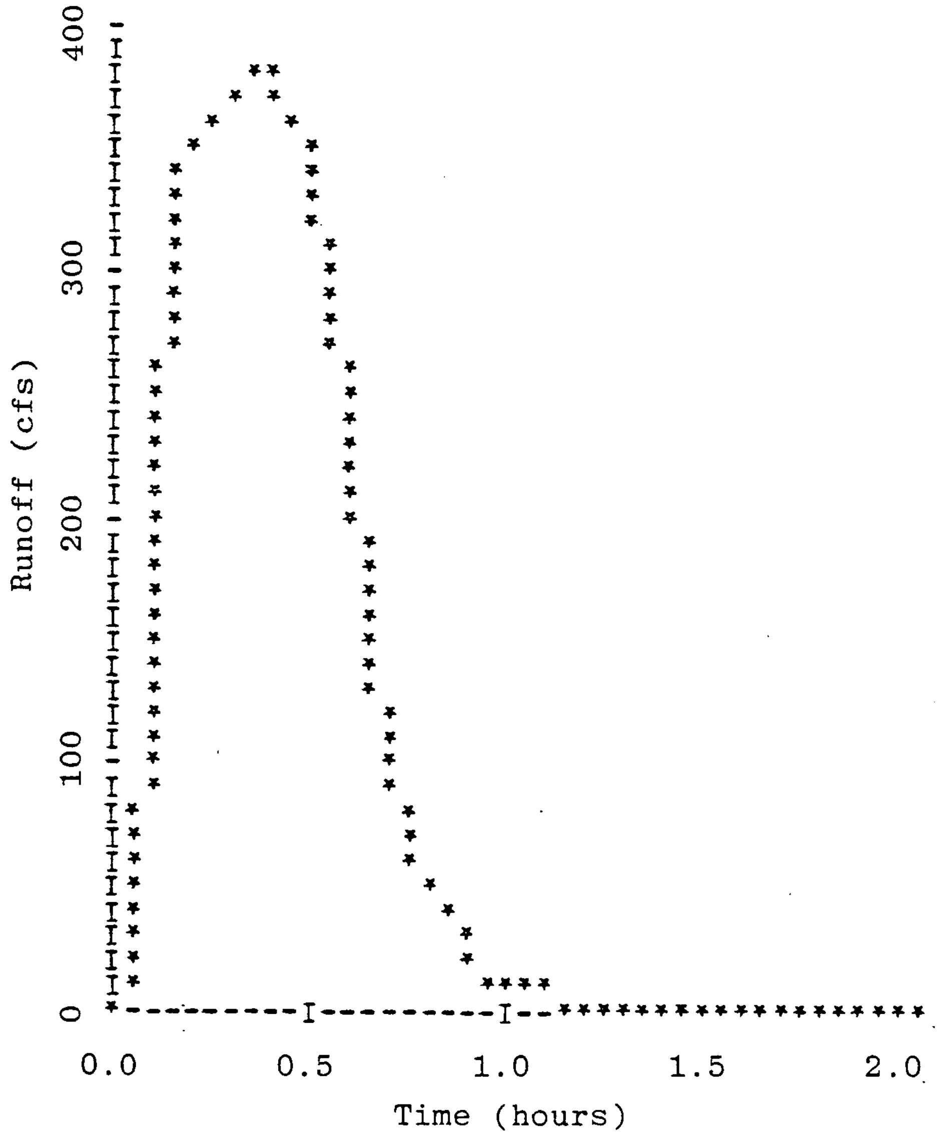


Figure 2

Total Runoff Hydrograph from Advanced Peak Storm

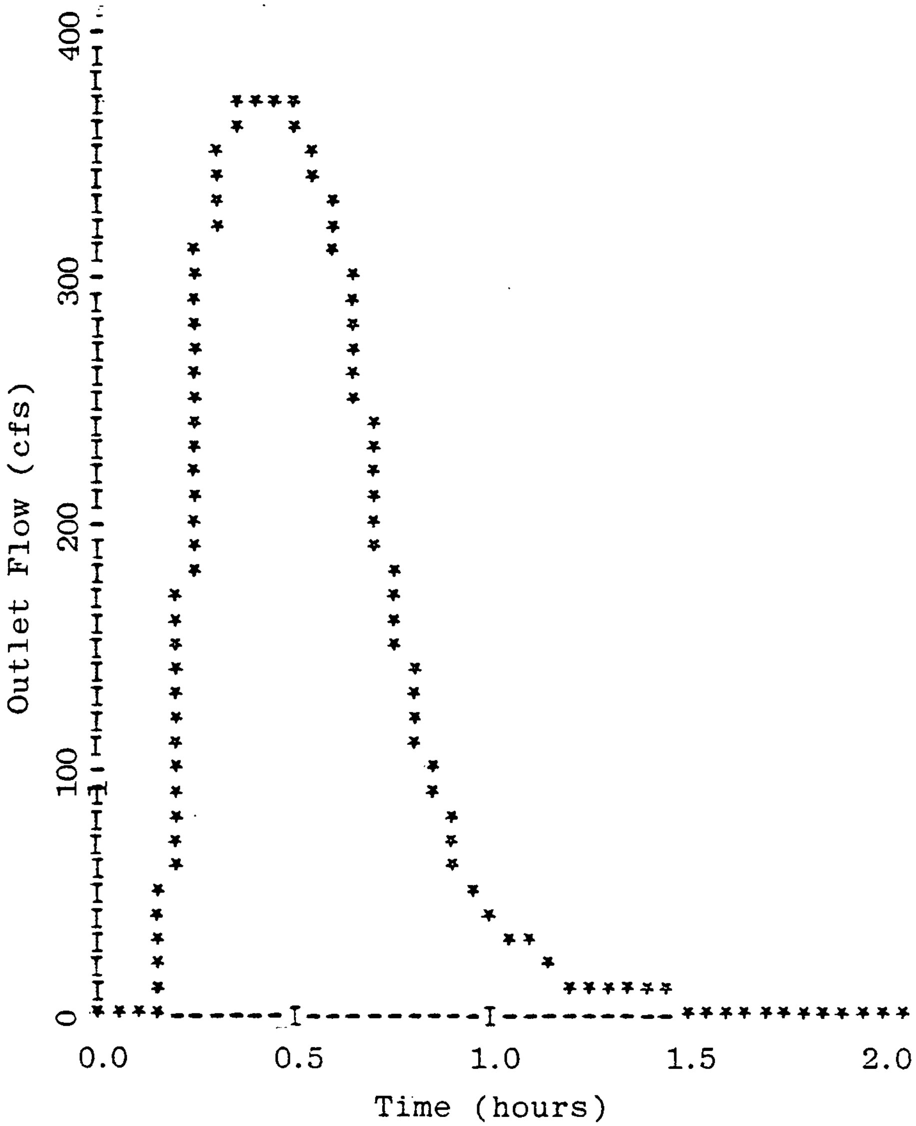


Figure 3
Outlet Hydrograph from Advanced Peak Storm

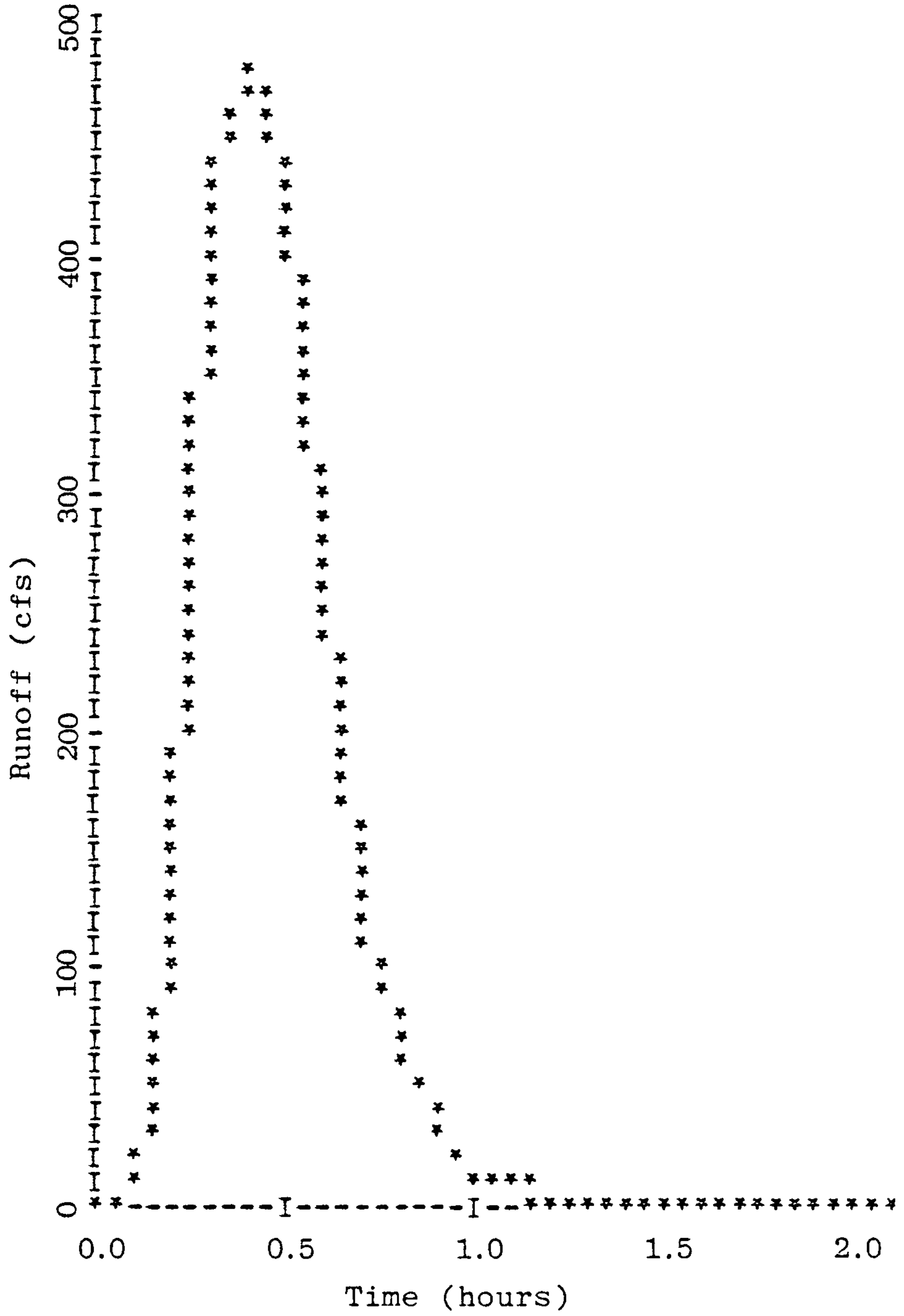


Figure 4
Total Runoff Hydrograph from
Intermediate Peak Storm

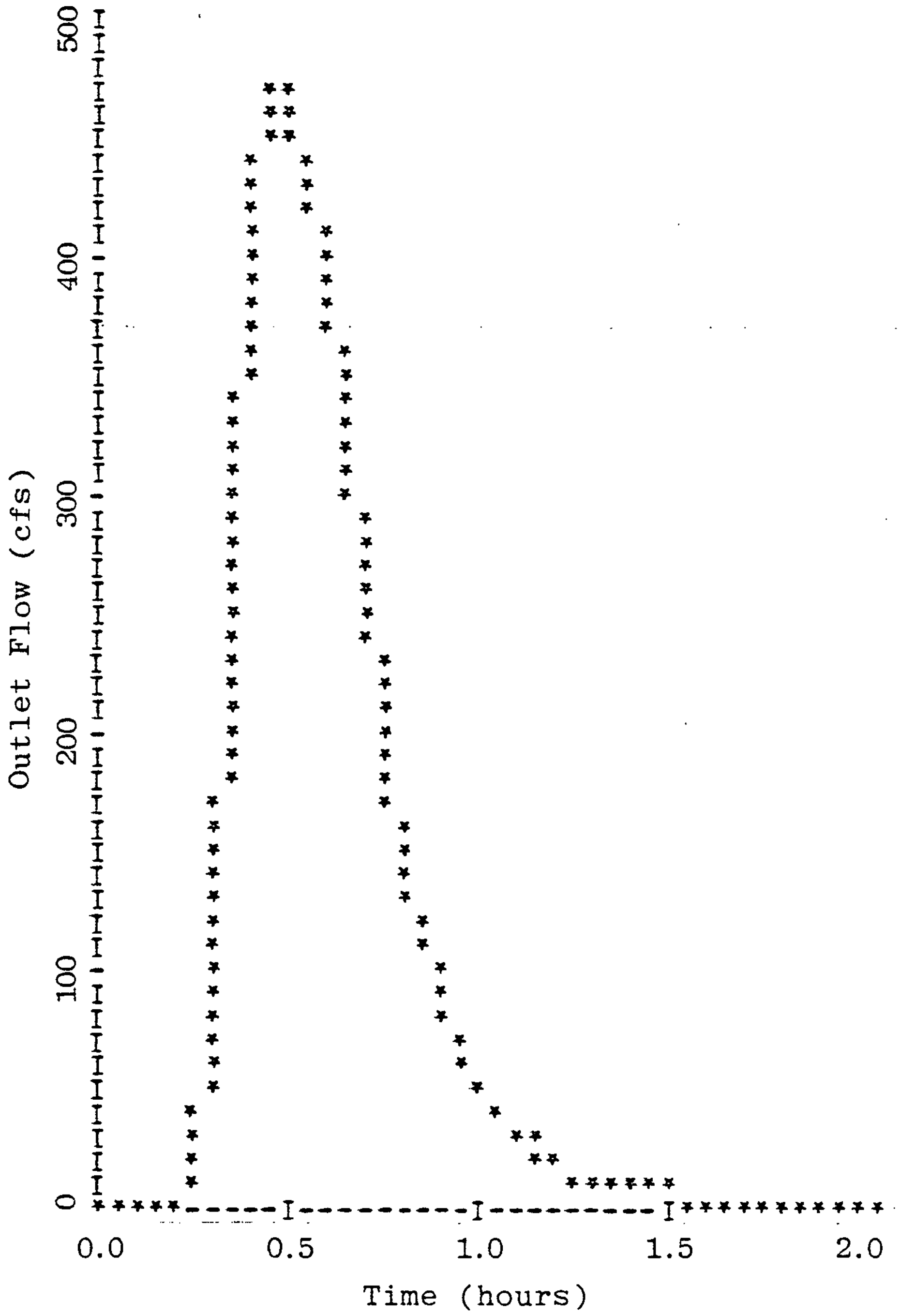


Figure 5
Outlet Hydrograph from Intermediate
Peak Storm

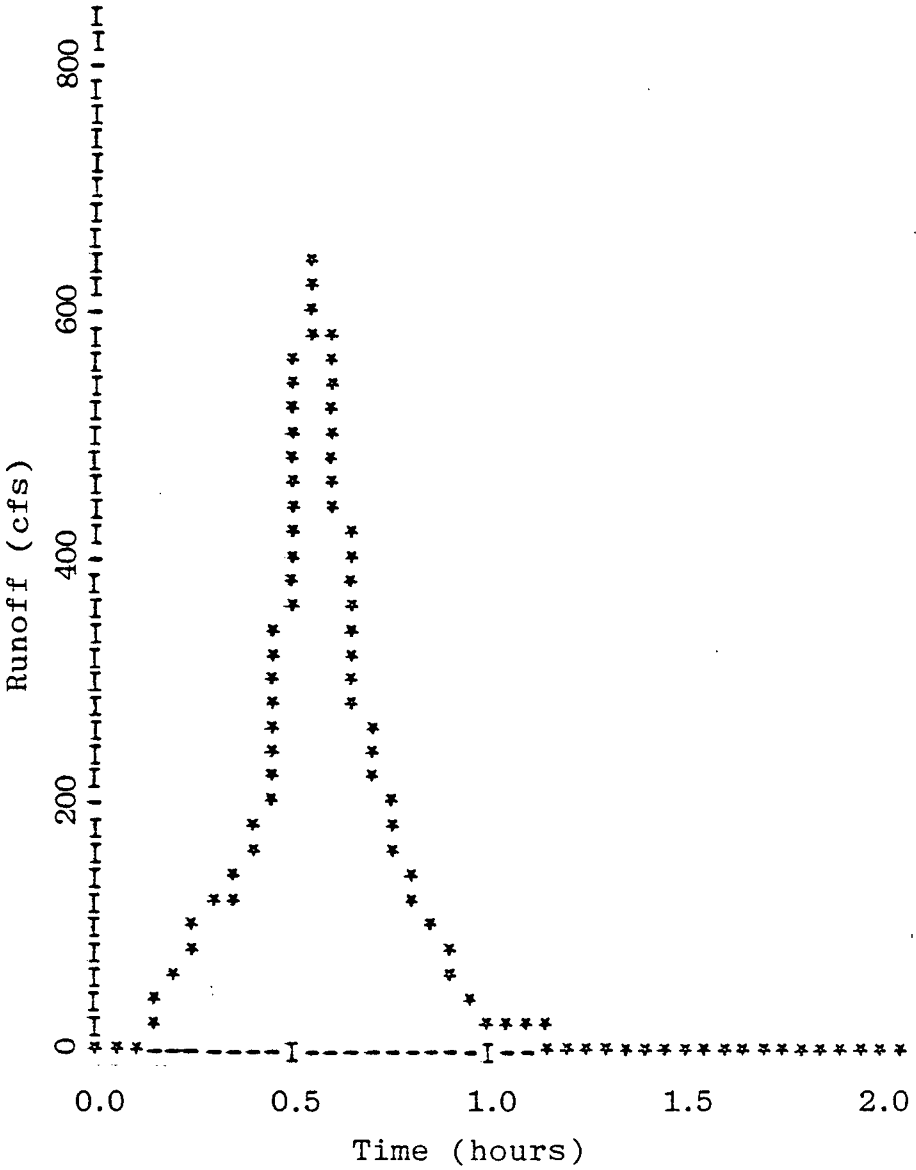


Figure 6
Total Runoff Hydrograph from Delayed
Peak Storm

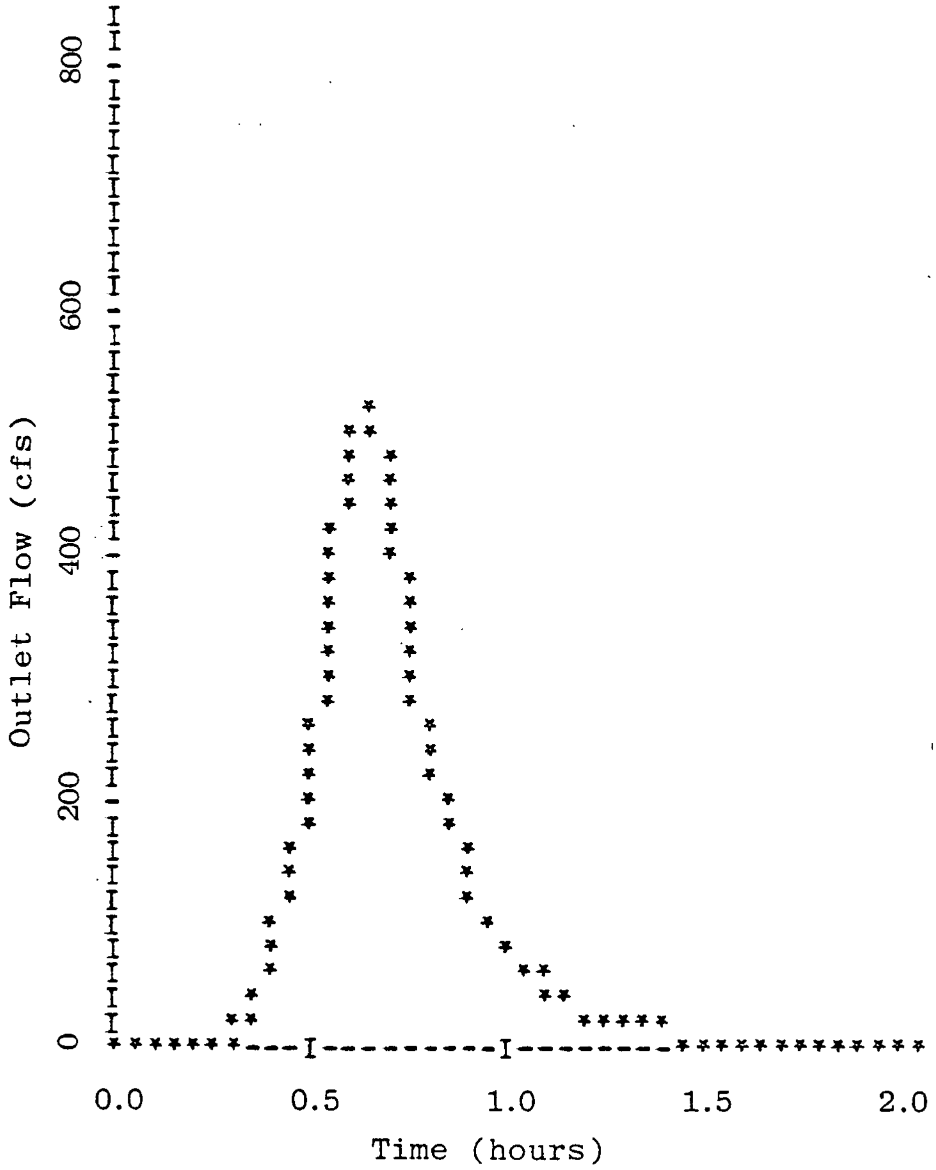


Figure 7
Outlet Hydrograph from Delayed
Peak Storm

DESIGN RAINFALL PATTERNS

The problem of obtaining a design storm hyetograph is now seen to be quite important, but it can also be somewhat involved. After choosing the frequency or return period and duration for the design storm, either by judgement or by administrative decree, the total amount of rainfall is then easily obtained from U. S. Weather Bureau Technical Paper No. 40 (TP 40) (4). The problem is then one of determining how to distribute this rainfall within the time period. What should the various intensities be for the smaller intervals within the storm and in what sort of pattern should these various intensities be arranged? There are several different approaches to solving this most interesting problem.

Modified SCS Method

One method for obtaining a design storm pattern is set forth by the Soil Conservation Service (SCS) (5). A type II distribution is defined for most of the continental United States, excluding the west coast for which the type I is applicable. Although the SCS pattern was developed for a 24-hour duration and is based on average values of rainfall for many stations, the procedure can easily be adapted for a shorter duration and a particular location.

The first step is to determine the required design storm duration and the time intervals to be used. The next determinations are the rainfall volumes for different time durations ranging from the time interval value to the total storm duration. These are obtained for the desired return period from TP 40. The total rainfall for the entire storm is distributed into the time intervals so that all of the statistical rainfall-duration relationships are held. This produces a range of rainfall values, from high to low, the sum of which is the total storm precipitation. To arrange into a pattern, the highest value is placed in the interval just before the midpoint of the storm and the second highest value is placed next in time. The third highest is placed just before the highest and the fourth just after the second. This continues until the entire storm is built.

A 30-minute storm with a return period of 5 years is easily developed for Allentown using this procedure. Thirty minutes was chosen for the duration because it is the approximate time of concentration for the CHB storm sewer system and 5 minutes was chosen for the time interval. TP 40 (4) gives the 5-year precipitation values for 30 and 60-minute durations and lists the 5, 10, and 15-minute duration rainfalls as percentages of the 30-minute amount. Figure 8 was then developed to determine the rainfall amounts for durations of 20 and 25 minutes. Table 2 shows these total precipitations for the various durations and the individual interval values from high to low.

Table 2
5-Year Frequency Precipitation for Allentown

Duration (minutes)	Σ Ppt (inches)	Δ Ppt (inches)
0	0.00	
5	0.52	0.52
10	0.80	0.28
15	1.00	0.20
20	1.16	0.16
25	1.29	0.13
30	1.40	0.11

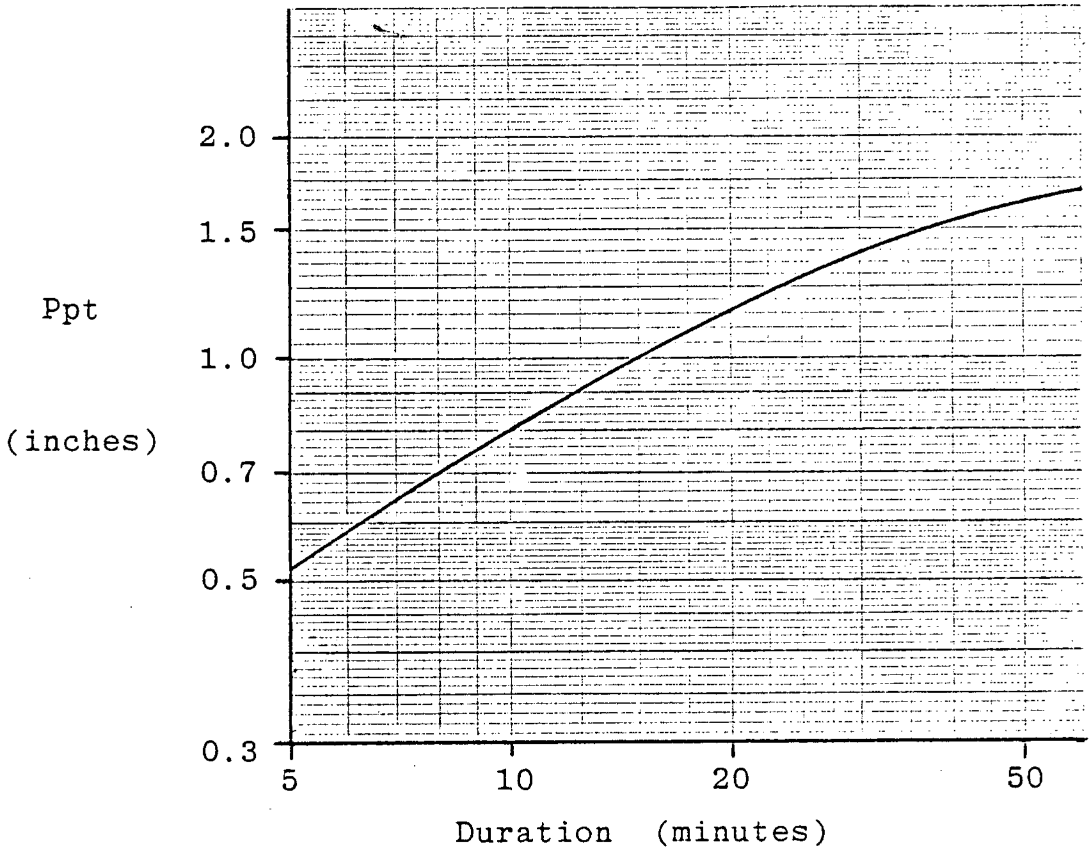


Figure 8

Allentown 5-Year Frequency Rainfalls

The different interval precipitation values listed in Table 2 are then arranged in the previously described pattern as shown in Table 3.

Table 3
5-Year 30-Minute Design Storm
Modified SCS Method

Time (minutes)	Ppt (inches)	Intensity (in/hr)
0-5	0.13	1.56
5-10	0.20	2.40
10-15	0.52	6.24
15-20	0.28	3.36
20-25	0.16	1.92
25-30	0.11	1.32

This hyetograph is quite nonuniform, a direct result of maintaining the 5-year frequency for the peak rainfall intensity. The placement of the maximum precipitation interval before the middle is arbitrary. A more conservative approach might place it later in time.

Keifer-Chu Method

Another method for establishing a design storm is the synthetic storm pattern proposed by Keifer and Chu (6). The desired return period for the design storm must first be chosen. For this given frequency, the average rainfall intensity can be approximated as a function of storm duration by:

$$i_{avg} = \frac{a}{T^b + c} \qquad (2)$$

where i_{avg} = average rainfall intensity, in/hr,

T = storm duration, minutes,

a,b,c = constants.

The three constants need to be evaluated from values of i_{avg} versus T obtained from TP 40. After solving for the total precipitation, differentiating, and manipulating, an expression can be obtained for the instantaneous intensity, i, as a function of time, t, for a storm with a completely advanced peak.

$$i = \frac{a\left[(1-b)t^{b} + c\right]}{(t^{b}+c)^{2}} \tag{3}$$

This equation is adjusted for time before and time after the peak, when the peak intensity occurs at some intermediate time as in Fig. 9.

With r being the fractional location of the peak intensity, two expressions for instantaneous intensity can be developed.

Before the peak:

$$i = \frac{a\left[(1-b)\left(\frac{t_b}{r}\right)^{b} + c\right]}{\left[\left(\frac{t_b}{r}\right)^{b} + c\right]^{2}} \tag{4a}$$

and after the peak:

$$i = \frac{a\left[(1-b)\left(\frac{t_a}{1-r}\right)^{b} + c\right]}{\left[\left(\frac{t_b}{1-r}\right)^{b} + c\right]^{2}} \tag{4b}$$

Once a, b, c, and r have been determined, the design storm hyetograph can be developed by using these two equations. One way of evaluating a, b, and c is to assume a value for b and solve for a and c graphically. Then assume a different b and again solve for a and c. This is repeated until a good fit of the values from TP 40 is achieved. For the 5-year storm for Allentown assuming b to equal 0.80, a fairly

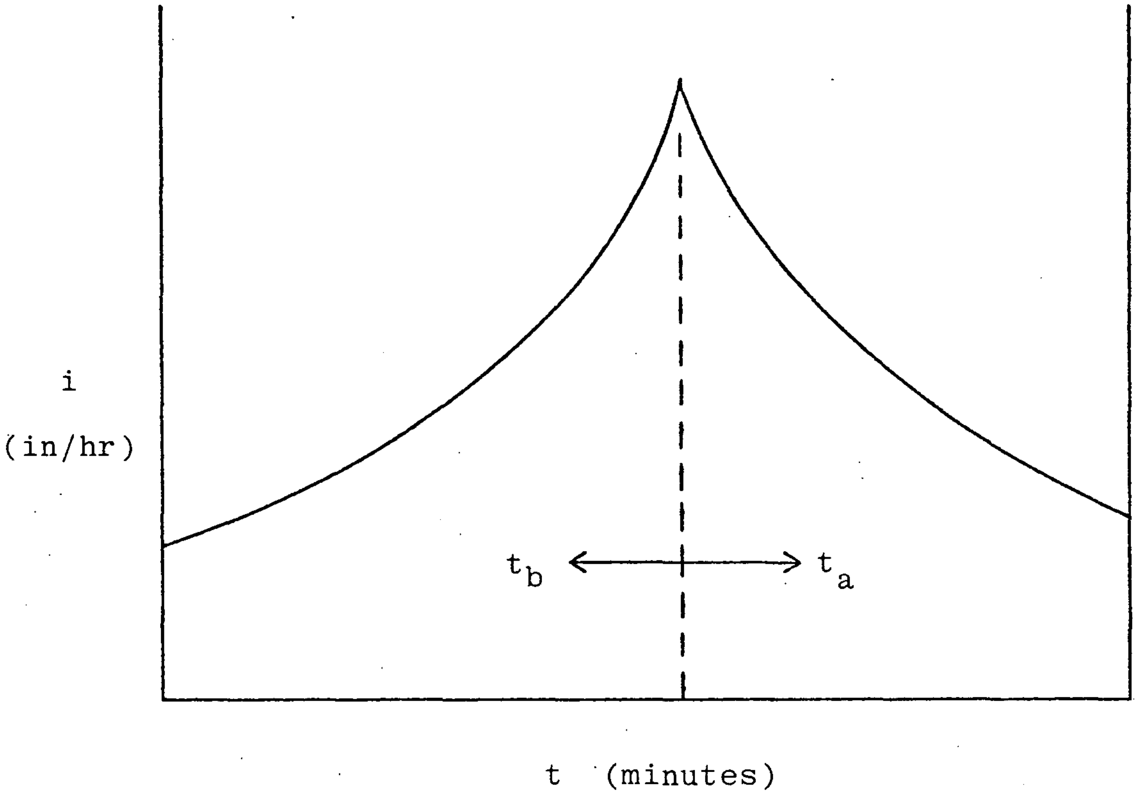


Figure 9

Storm Pattern With Intermediate Peak

(t_a= time after peak, t_b= time before peak) good representation is achieved with a = 56 and c = 5.4. Choosing a value of r = 5/8 (matching historical records, as will be shown subsequently), a rainfall hyetograph is developed for a 5-year storm with a duration of 30 minutes.

Table 4
5-Year 30-Minute Design Storm
Keifer-Chu Method

Time (minutes)	Ppt (inches)	Intensity (in/hr)
0-5	0.12	1.44
5-10	0.15	1.80
10-15	0.24	2.88
15-20	0.51	6.12
20-25	0.25	3.00
25-30	0.13	1.56

Historical Pattern

A third method of developing a design storm is to base the pattern on historical rainfall records. A magnetic tape containing all of the historical hourly precipitation data for six stations in Pennsylvania (Allentown, Erie, Harrisburg, Philadelphia, Pittsburgh, and Reading) has been obtained. A computer program, published by EPA (7), which reads the data, defines storm events, and calculates certain storm parameters has been adapted for the CDC 6400 system at the Lehigh University Computing Center (LUCC). This program identifies or computes for each storm event the year, month, day, storm duration, total precipitation, maximum 1-hour precipitation, the hour of maximum precipitation, number of days since the last storm, and the hour of the start of the storm. Certain storms are easily excluded, based on particular ranges of values of one or more of these parameters.

An addition has been made to this program to develop data points for a nondimensional plot of fractional storm precipitation versus fractional storm duration. When this is done for a number of storms, many data points are developed. A least squares fit of a polynomial curve can then be found for these points by using the LEAPS library program (8) available at the LUCC.

The EPA program was first executed with the Allentown rainfall data. To reduce the vast number of points that would be obtained from all storms to a smaller, more workable set, storm events with a total precipitation of less than 2 inches were excluded. These larger storms are the ones which will "test" a storm sewer system. The execution of the storm event program on the Allentown data, which covers 1948 through 1975, showed that there were 57 storms of at least 2 inches during this period. These 57 events produced 993 points for the graph of fractional storm precipitation versus fractional storm duration.

A LEAPS analysis of these points gave a fourth order polynomial curve of least squares fit of:

$$Y = 0.670\ \tau - 0.085\ \tau^2 + 1.894\ \tau^3 - 1.480\ \tau^4 \qquad (5)$$

The points and this line are shown in Fig. 10. The multiple correlation of the data to the line is 0.979 as computed by LEAPS.

Figure 10 has been developed using storms of all durations and there are a few points that are scattered quite far from the line. A breakdown into short and long duration storms will be shown later.

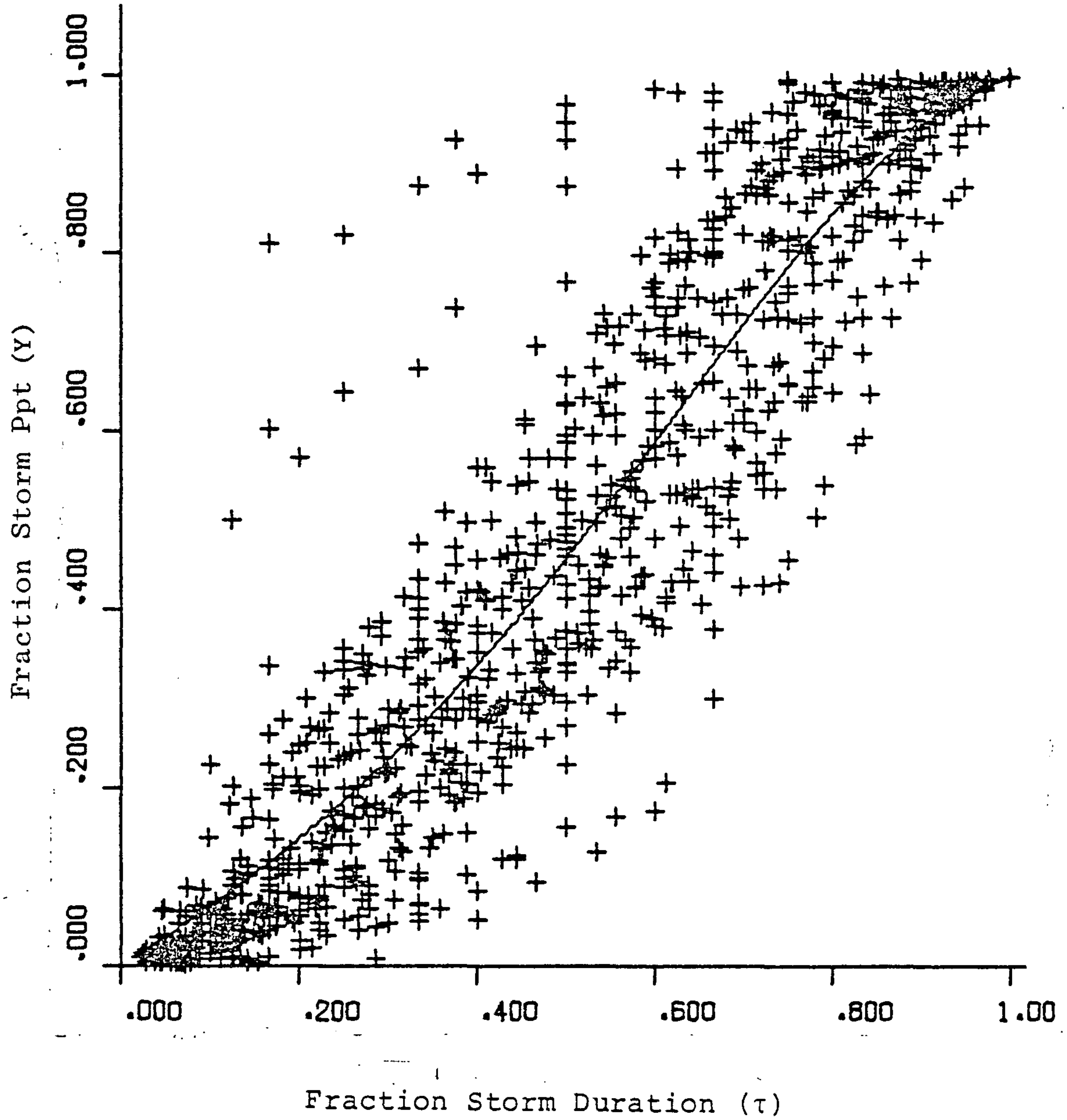


Figure 10
Allentown Storm Data,
Greater Than Two Inch Storms

The point of maximum slope of the best fit line, or the peak rainfall intensity, has been found by setting the second derivative equal to zero and solving for τ. This produces a fractional time of peak intensity of 0.625 or 5/8. This is the value which was used for r in developing the design storm hyetograph by the Keifer-Chu method in the preceding section. The actual slope of the line at this point has been found by putting $\tau = 0.625$ into the first derivative. This maximum slope is 1.34 which means that the peak intensity of a storm following this pattern is 1.34 times the average intensity. It is evident that a pattern based on this equation will produce a much more uniform hyetograph than either of the two previous methods. A 5-year storm with a 30-minute duration (total rainfall of 1.40 inches) and this historical pattern is developed in Table 5.

Table 5
5-Year 30-Minute Design Storm
Historical Pattern

Time (minutes)	Fraction of Ppt	Increment	5-Year Ppt (inches)	Intensity (in/hr)
0-5	0.117	0.117	0.164	1.96
5-10	0.266	0.149	0.209	2.50
10-15	0.458	0.192	0.269	3.23
15-20	0.678	0.220	0.308	3.70
20-25	0.882	0.204	0.286	3.43
25-30	1.000	0.118	0.165	1.98

Comparison of Methods

One might expect the most uniform intensity storm, the historical pattern, to produce smaller peak runoff rates than the other design hyetographs, SCS and Keifer-Chu. All three have the same total amounts of precipitation but the SCS and Keifer-Chu hyetographs have considerably higher maximum rainfall intensities. Execution of the SWMM program on the CHB system has been done using each of these three design storms as input hyetographs. Table 6 and Fig. 11 through Fig. 16 show some of the results.

Table 6
SWMM Results of CHB System for Three Different Design Storms

Hyetograph	Total Runoff Volume (cu ft)	Peak Runoff Rate (cfs)	Peak Flow at Outlet (cfs)
SCS	717,000	475	465
Keifer-Chu	700,000	520	504
Historical	660,000	470	442

The Keifer-Chu hyetograph produces the largest rate of runoff and largest routed pipe flows as should be expected. This hyetograph has a peak rainfall intensity about the same as the SCS hyetograph, but occurs after the midpoint in time. The SCS maximum intensity occurs before the middle, at which time the infiltration capacity is higher, resulting in a lower peak runoff rate. The peak intensity of the historical hyetograph occurs at the same time as that of Keifer-Chu, however its magnitude is considerably smaller. This is the cause of the lower peak runoff rate produced by the historical pattern.

Figure 17 shows cumulative precipitation versus time curves for these three storms. It also has two curves which envelop all of the data points in Fig. 10. This graph shows the previously mentioned fact that the best fit historical curve is considerably more uniform than SCS or Keifer-Chu curves. However it also shows that the two latter curves are far from being the most critical pattern that could possibly

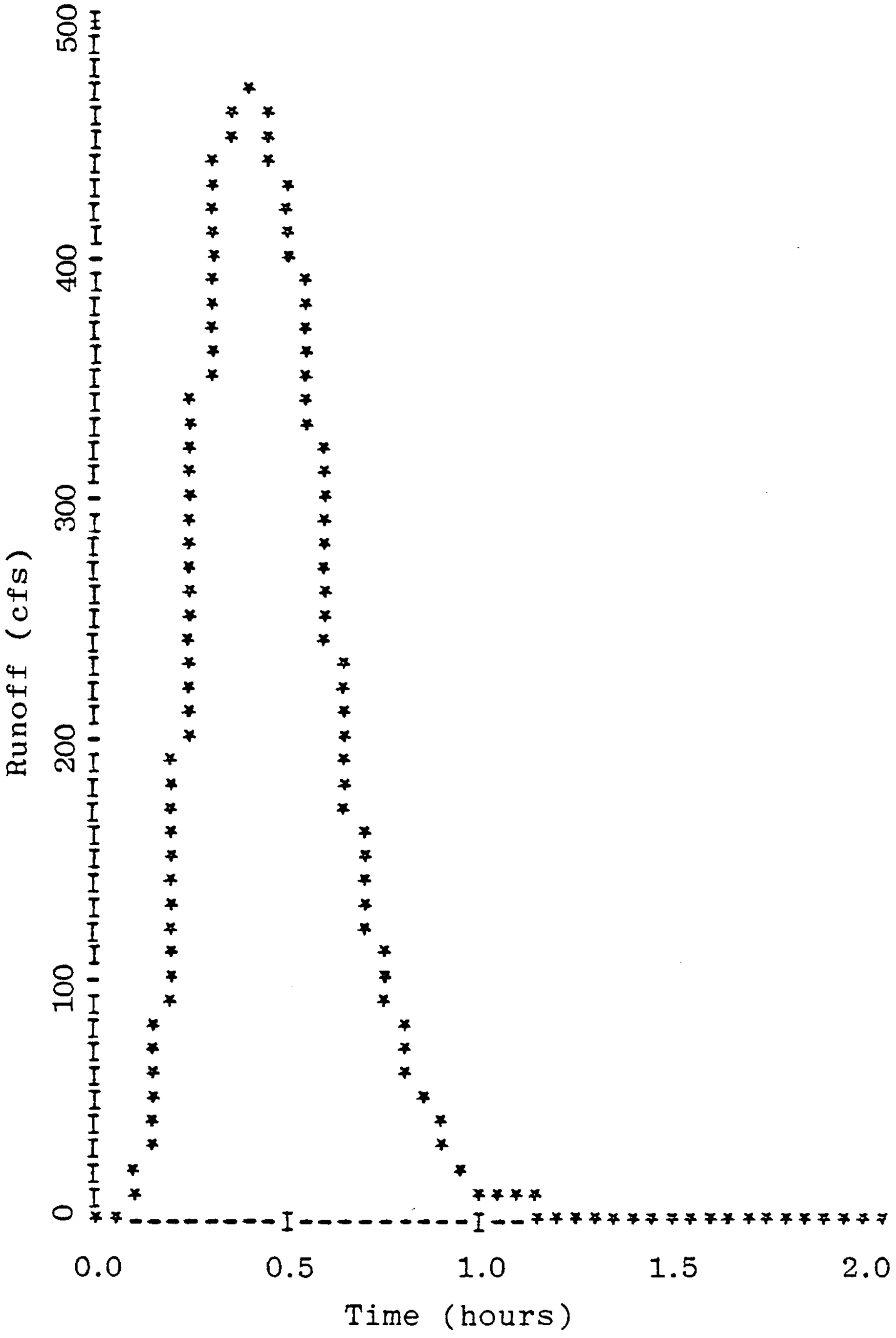


Figure 11

Total Runoff Hydrograph from Modified SCS

5-Year 30-Minute Storm

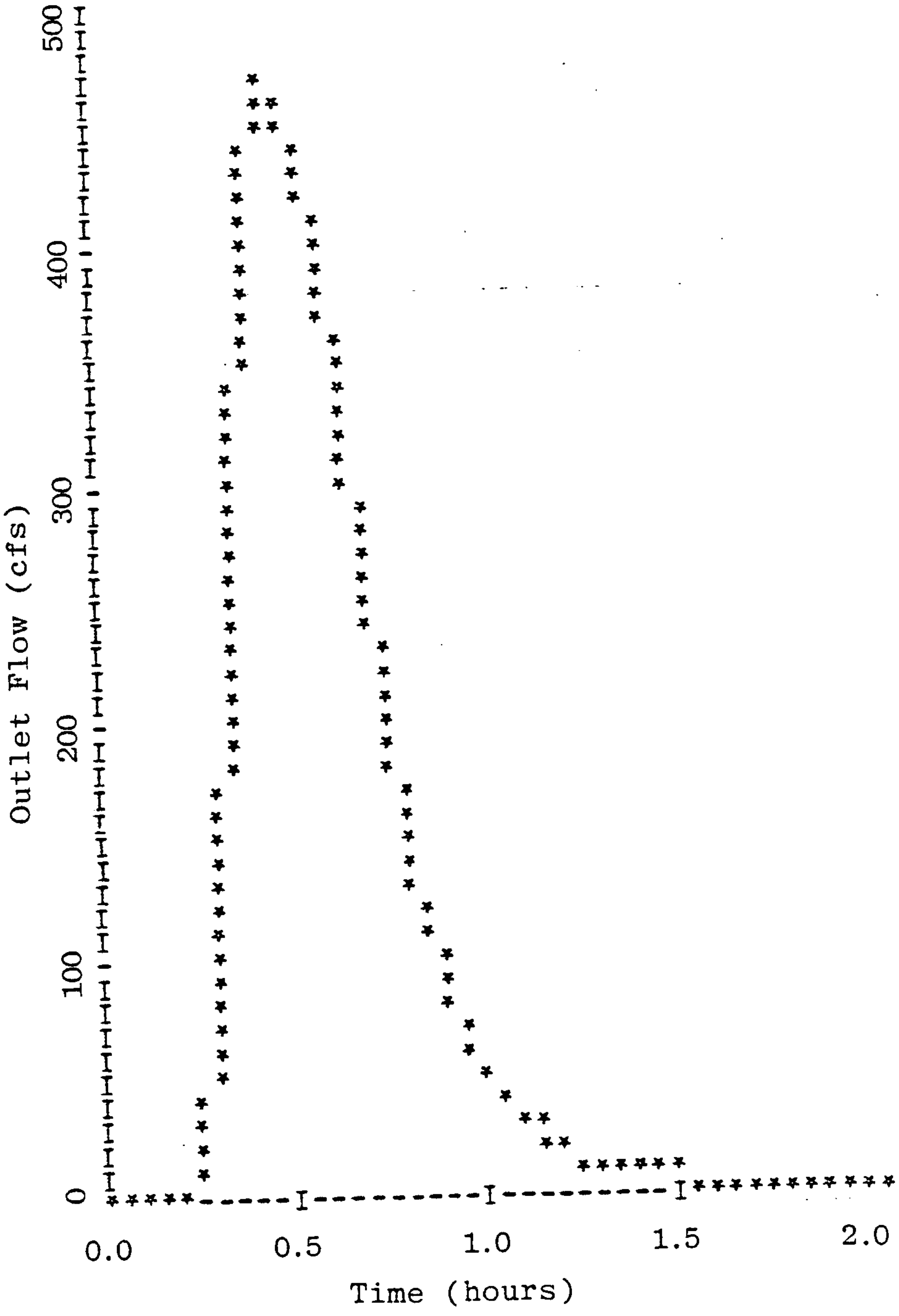


Figure 12
Outlet Hydrograph from Modified SCS
5-Year 30-Minute Storm

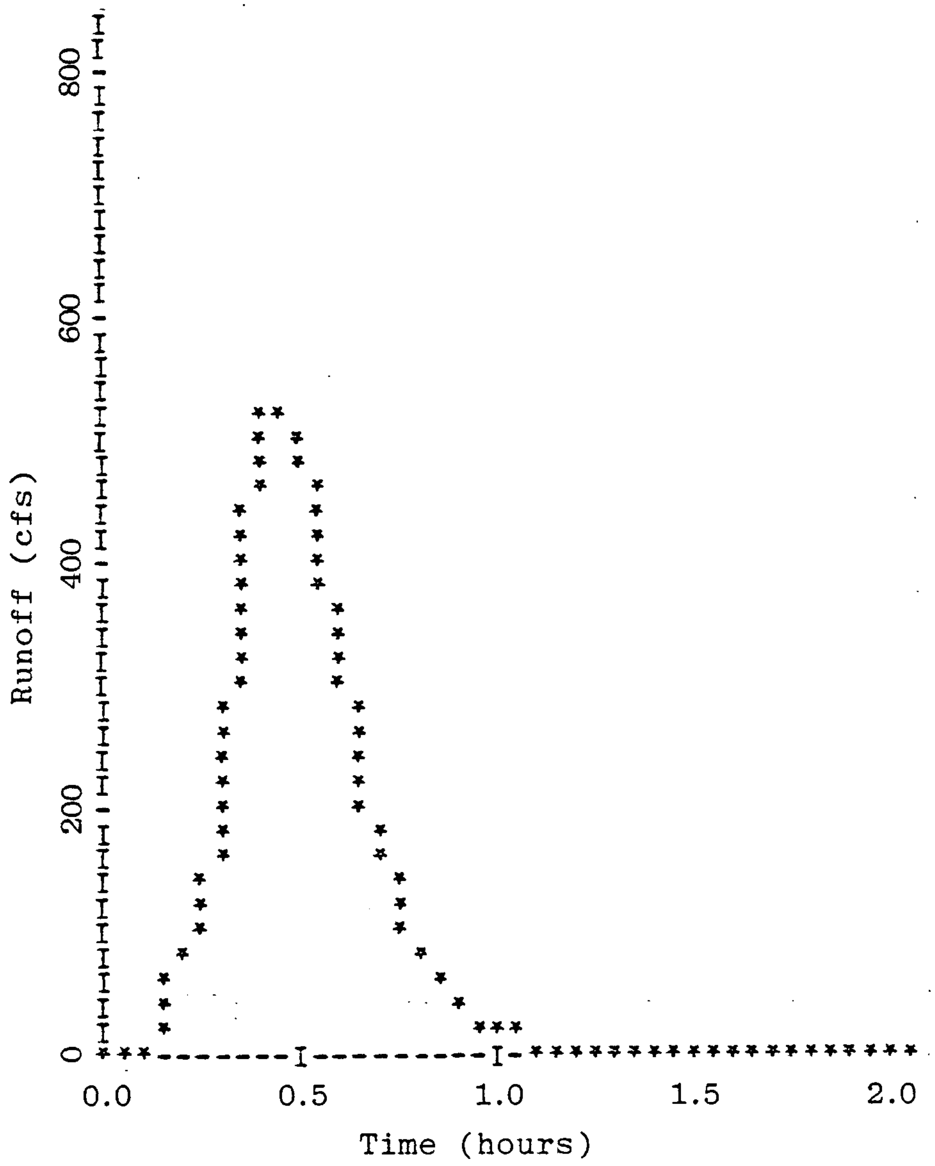


Figure 13
Total Runoff Hydrograph from Keifer - Chu
5-Year 30-Minute Storm

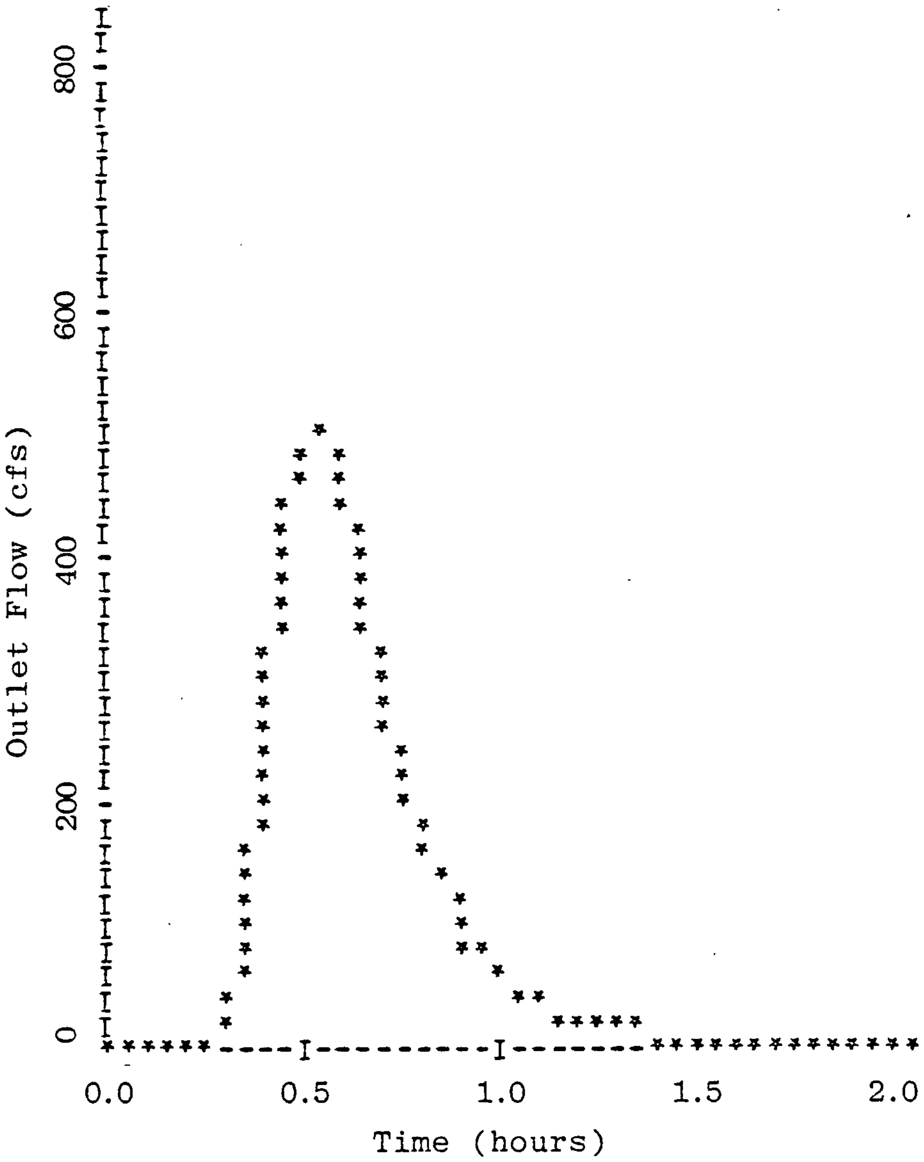


Figure 14
Outlet Hydrograph from Keifer - Chu
5-Year 30-Minute Storm

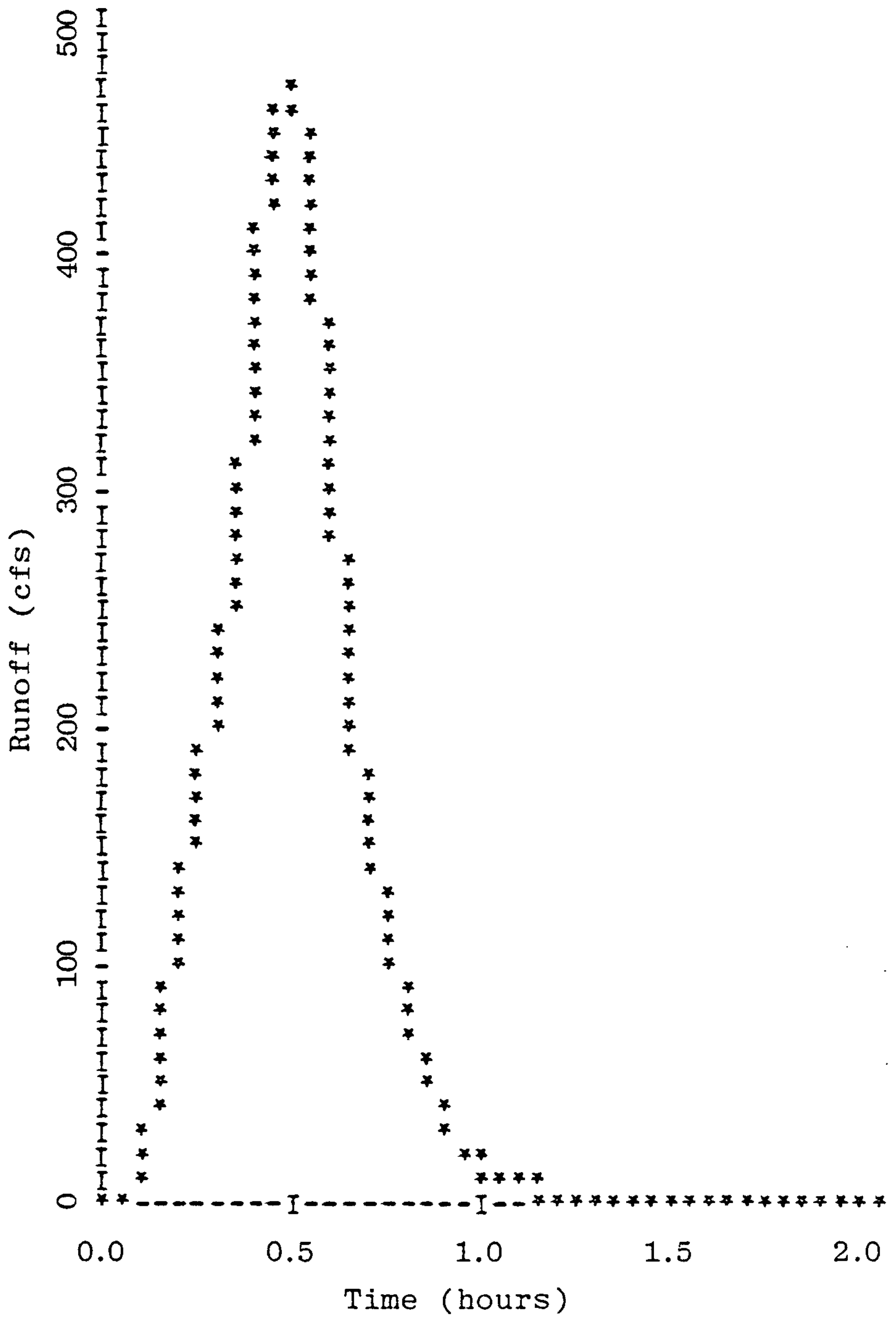


Figure 15
Total Runoff Hydrograph from Historical
Pattern 5-Year 30-Minute Storm

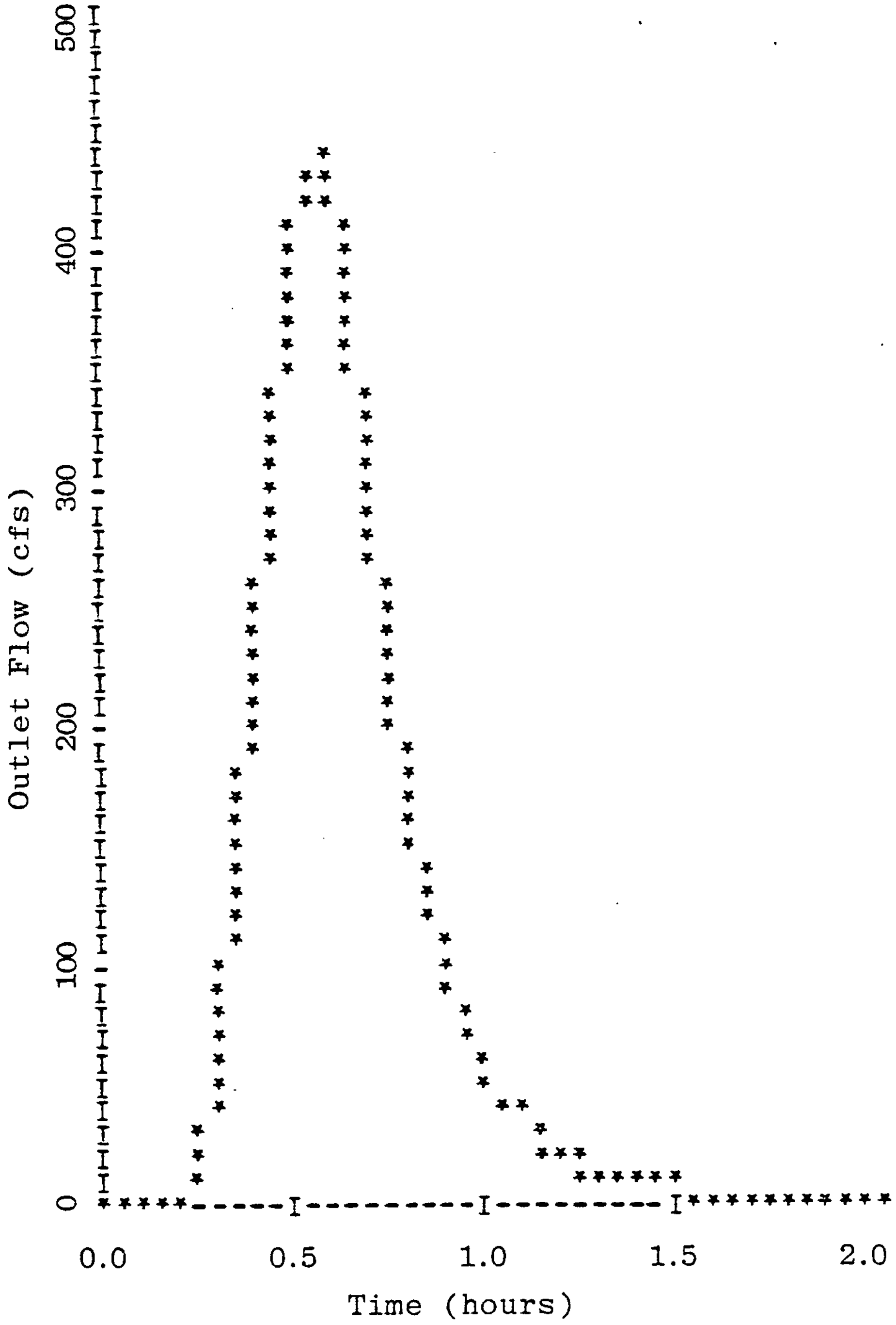


Figure 16
Outlet Hydrograph from Historical Pattern
5-Year 30-Minute Storm

occur within the historical bounds. The most critical pattern would follow the lower envelope until just after the midpoint in time and would then suddenly jump up to the upper envelope in a short time period. Such a pattern might, however, be slightly unrealistic. Because the SCS and Keifer-Chu curves are well within the bounded envelope curves, they are easily within the realm of possibility, even though they might appear, at first glance, to be quite drastic.

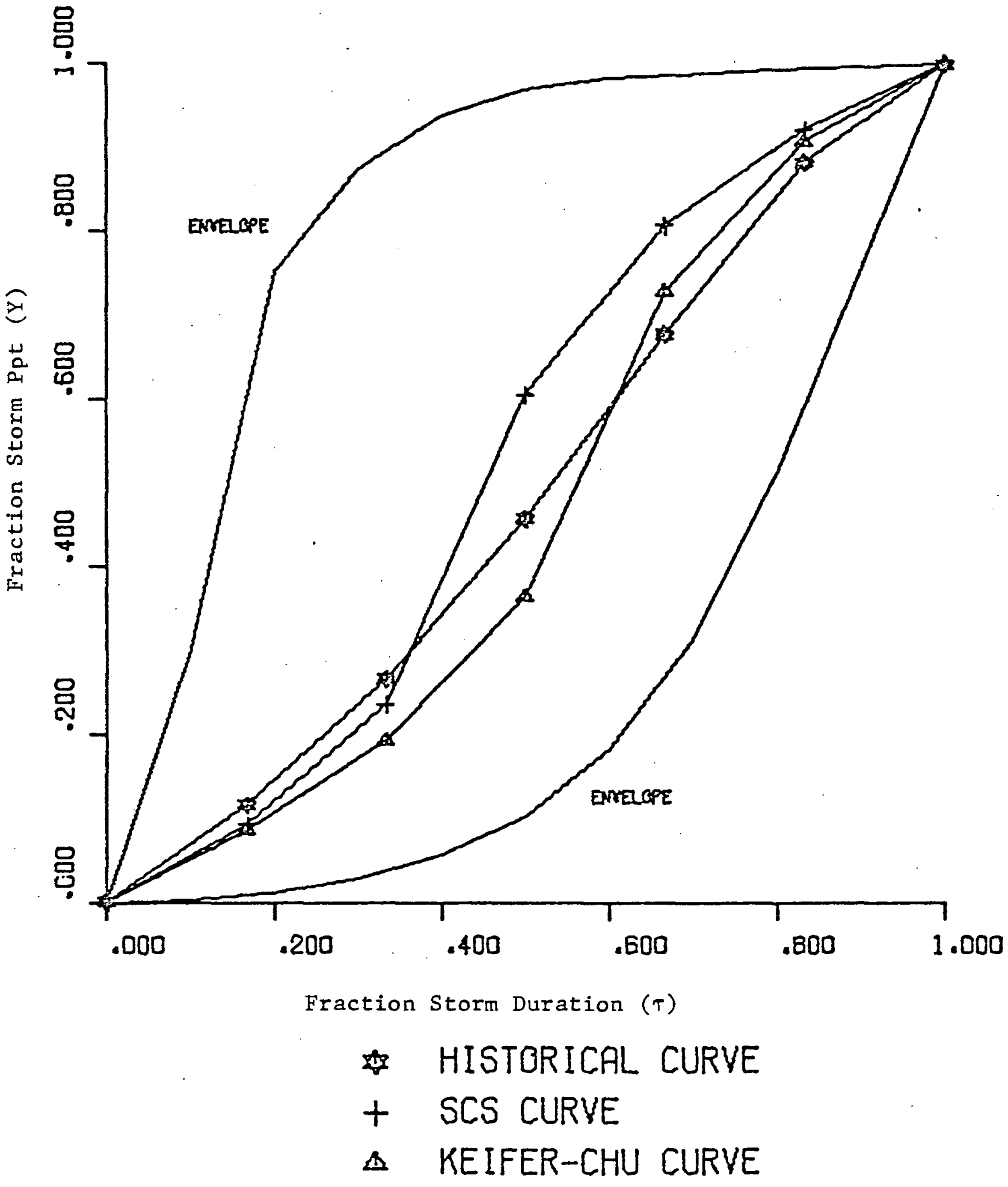


FIGURE 17
ALLENTOWN RAINFALL PATTERNS

COMPARISON OF HISTORICAL DATA PATTERNS

Because the historical data points in Fig. 10 show a lot of scatter and the flexible computer program permitted exclusion of storms based on any parameter, some additional historical curves have been developed for analysis and comparison.

The first variation was to divide the 2-inch storms into those with short and those with long durations. The dividing point was placed at 20 hours which nearly cut the number of data points into equal halves. These points and their least squares fit curves are shown in Fig. 18 and Fig. 19. The two curves are nearly identical, therefore they both compare well with the curve for all the points, Fig. 10. This is shown by an examination of the curves and also by the table of curve values which follows.

Table 7
Historical Patterns of Allentown Storms Greater than Two Inches

Fractional Time	Fractional Cumulative Ppt for All T	T < 20 hours	T > 20 hours
0.0	0.000	0.000	0.000
0.1	0.068	0.068	0.068
0.2	0.143	0.142	0.145
0.3	0.234	0.229	0.236
0.4	0.338	0.333	0.342
0.5	0.458	0.455	0.461
0.6	0.589	0.589	0.589
0.7	0.722	0.727	0.718
0.8	0.846	0.854	0.838
0.9	0.944	0.952	0.938
1.0	1.000	1.000	1.000

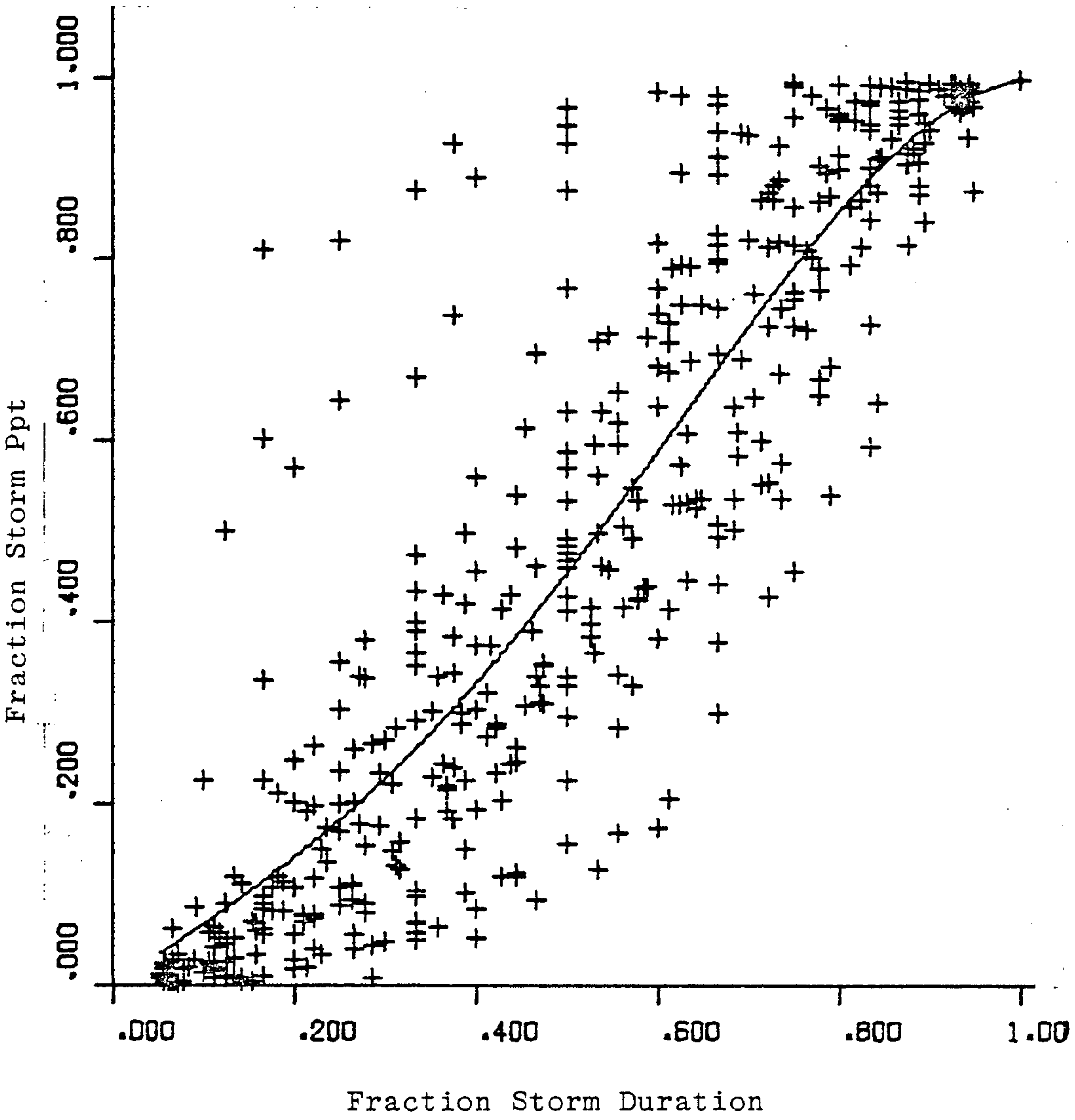


Figure 18

Allentown Storm Data, Greater Than Two Inches,
Less Than 20 Hours

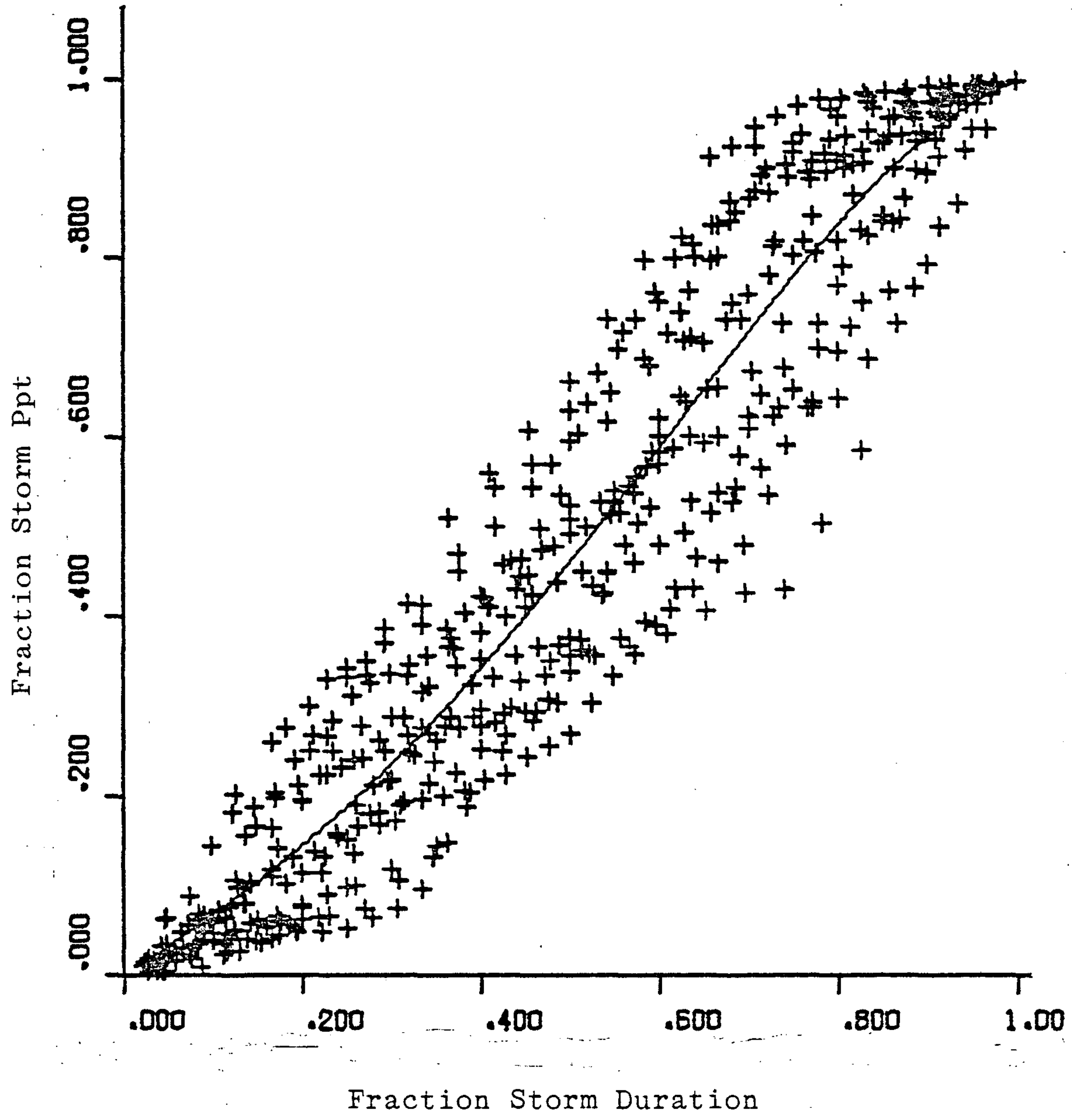


Figure 19
Allentown Storm Data, Greater Than Two Inches,
20 Hours and Longer

One difference to be noted between Fig. 18 and Fig. 19 is the scatter of the points. The data from the longer duration storms are much more confined and closer to the line. This fact is confirmed by the multiple correlations of the two sets of data to their respective lines. The longer duration storms have a multiple correlation as calculated by LEAPS of 0.986 while that for the shorter storms is 0.971. This may be because the storms of only a few hours duration could easily produce data points which do not really indicate their true distributions. These problems are smoothed out by the large number of points generated by a longer duration storm. If a smaller time interval than 1 hour were used to break down the shorter duration storms so that each storm generated the same number of data points, it is suspected that the band of points for all storms might well be as narrow as that of Fig. 19. This would dramatically close in the envelope curves shown in Fig. 17 which might then closely bound the SCS and Keifer-Chu curves.

Comparisons were also made with smaller sized storms. No storms with a total precipitation less than 1.0 inch were considered. The precipitation volume intervals examined were 1.0 to 1.4, 1.4 to 2.0 inches, all storms greater than 1.0 inch and the previously examined greater than 2.0 inch storms. Table 8 shows substantial differences among the least squares polynomial curves of the various size intervals.

Table 8
Historical Precipitation Patterns for Storms at Allentown

Fractional Time	Fractional Cumulative Ppt > 1.0 in	1.0-1.4 in	1.4-2.0 in	> 2.0 in
0.0	0.000	0.000	0.000	0.000
0.1	0.057	0.051	0.058	0.068
0.2	0.143	0.139	0.149	0.143
0.3	0.251	0.253	0.262	0.234
0.4	0.373	0.381	0.388	0.338
0.5	0.502	0.513	0.520	0.458
0.6	0.631	0.642	0.649	0.589
0.7	0.753	0.760	0.769	0.722
0.8	0.861	0.862	0.871	0.846
0.9	0.946	0.944	0.951	0.944
1.0	1.000	1.000	1.000	1.000

The smaller size storms appear to be slightly less uniform than the 2.0 inch and larger storms. The peak intensities of the smaller storms occur earlier in time than that for the larger storms. The maximum slope of the 1.0-1.4 inch storms occurs at a time of 0.452, the 1.4-2.0 inch storms at 0.464, and the 2.0 inch storms at 0.625. The greater than 1.0 inch storms, which include all of the former, have a peak which occurs exactly at the midpoint of time, 0.500. However, the pattern derived from the 2.0 inch and larger storms should be chosen for design storm purposes for two reasons. First is the fact that a 1.0 inch storm is quite small when the design basis may be a 5 or 10 year storm event. The larger events are the ones that are generally considered in design. Another reason is that this pattern with the peak after the middle produces higher runoff rates and makes design more conservative while still maintaining historical guidelines.

Analyses of the storms with more than 2.0 inches of rainfall were also performed on the data from the five other Pennsylvania stations. Table 9 and Table 10 shows how the historical rainfall patterns vary across Pennsylvania.

Table 9
Historical Storm Patterns for Six Pennsylvania Stations

Fractional Time	Fractional Cumulative Ppt for Station Indicated Allentown	Philadelphia	Reading	Harrisburg	Pittsburgh	Erie
0.0	0.000	0.000	0.000	0.000	0.000	0.000
0.1	0.068	0.068	0.061	0.064	0.082	0.071
0.2	0.143	0.154	0.132	0.146	0.192	0.167
0.3	0.233	0.255	0.220	0.246	0.318	0.278
0.4	0.338	0.367	0.327	0.362	0.451	0.397
0.5	0.458	0.487	0.451	0.489	0.581	0.518
0.6	0.589	0.608	0.588	0.621	0.702	0.636
0.7	0.722	0.727	0.726	0.750	0.808	0.747
0.8	0.846	0.838	0.854	0.864	0.895	0.847
0.9	0.944	0.934	0.953	0.952	0.961	0.937
1.0	1.000	1.000	1.000	1.000	1.000	1.000

Table 10
Peak Precipitation Intensities from Historical Patterns

Station	Fractional Peak Time
Allentown	0.625
Philadelphia	0.547
Reading	0.622
Harrisburg	0.564
Pittsburgh	0.369
Erie	0.434

A definite variation can be seen across the state. The eastern stations (Allentown, Philadelphia, and Reading) have very similar patterns and all have peak intensities occurring after the middle. Reading is slightly less uniform while Philadelphia is a little more uniform than Allentown. Harrisburg also has a similar pattern. However the two western stations (Pittsburgh and Erie) have decidedly different patterns than Allentown. These two stations both have their peak intensities occurring before the middle, with Pittsburgh being especially early. Design storms based on these historical patterns for these two cities would probably result in slightly lower peak runoff values than would be obtained from the patterns of the eastern cities. It is possible that these different patterns reflect different types of storms. The eastern cities are probably influenced more by coastal storms and hurricanes, especially when only considering the larger storms. The two western cities might have more of the midwestern thunderstorm type of event. These different types of storms could very well have different general patterns.

SUMMARY AND CONCLUSIONS

With the recent increased attention being given to stormwater management, the use of runoff and flow simulation models on high speed digital computers is becoming more widespread. The input of a design storm into such a model is one of the problems that is faced. The pattern of the rainfall as well as the individual interval intensities has been shown to be important.

Three methods of developing a design storm have been shown. They are a modified SCS method, a Keifer-Chu synthetic pattern, and a historical pattern. The modified SCS and the Keifer-Chu methods produce nearly identical storms if the peaks are placed at the same locations. This is because both methods are based on the design frequency rainfalls down to the interval duration. The Keifer-Chu method produces a better distribution of rainfall about the peak but is a considerably more complicated procedure. In any case the peak should probably be placed somewhere shortly after the midpoint of time to produce a semi-conservative model while remaining realistic.

The design storm based on historical data tends to be a much more uniform storm than the previous two. This results in slightly smaller peak runoff rates. Therefore this type of design storm may easily result in a less conservative model when compared with the others. This approach may be entirely reasonable, though, for many applications. Precipitation is not something that is patterned by hard and fast physical laws. The plots of historical data show that there is a lot of random variation in the storm patterns, but there are also limits within which the data fall. Design of stormwater collection and conveyence systems requires at least some decisions based on qualitative judgement. Certain drainage areas and problems may require the use of a more critical type of design storm than other areas where the risk of damage may not be so great. Judgements of this sort are certainly necessary because one cannot pick a rainfall pattern and say, "This is how it always rains."

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