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THREE-HOUR RAINFALL REQUIRED FOR FLASH FLOODING ON SMALL STREAMS

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1. INTRODUCTION

Each morning the Southeast River Forecast Center (SERFC) in Atlanta issues flash flood rainfall guidance values for use by Weather Service Forecast Offices and Weather Service Offices in Florida, Alabama, Georgia, North and South Carolina. The guidance contains forecasts for the 3-hour rainfall required for flash flooding on small streams within meteorological forecast zones. The 3-hour rainfall values are normally transmitted only in the morning, based on soil moisture conditions as of 7 am, since sufficient rainfall information is generally not available for revision of those values during the day. However, when rainfall is occurring the 3-hour guidance values are no longer applicable after the duration exceeds 3 hours. For example, if rain occurs over a 6-hour period, the required 3-hour rainfall value for flooding should be revised at the end of the first 3 hours of rainfall. But this is not practical due to lack of data and, also, in a continuing rainfall situation the revised values would be obsolete before they could be disseminated.

There are two reasons why rainfall occurring over a period of time longer than 3 hours can cause flooding on small streams, even though the required 3-hour value is not exceeded at any time during the longer rainfall duration. The primary reason is that water from previous rain is still in the channel when subsequent rainfall occurs. Fig. 1 shows discharge versus time for 1 inch of

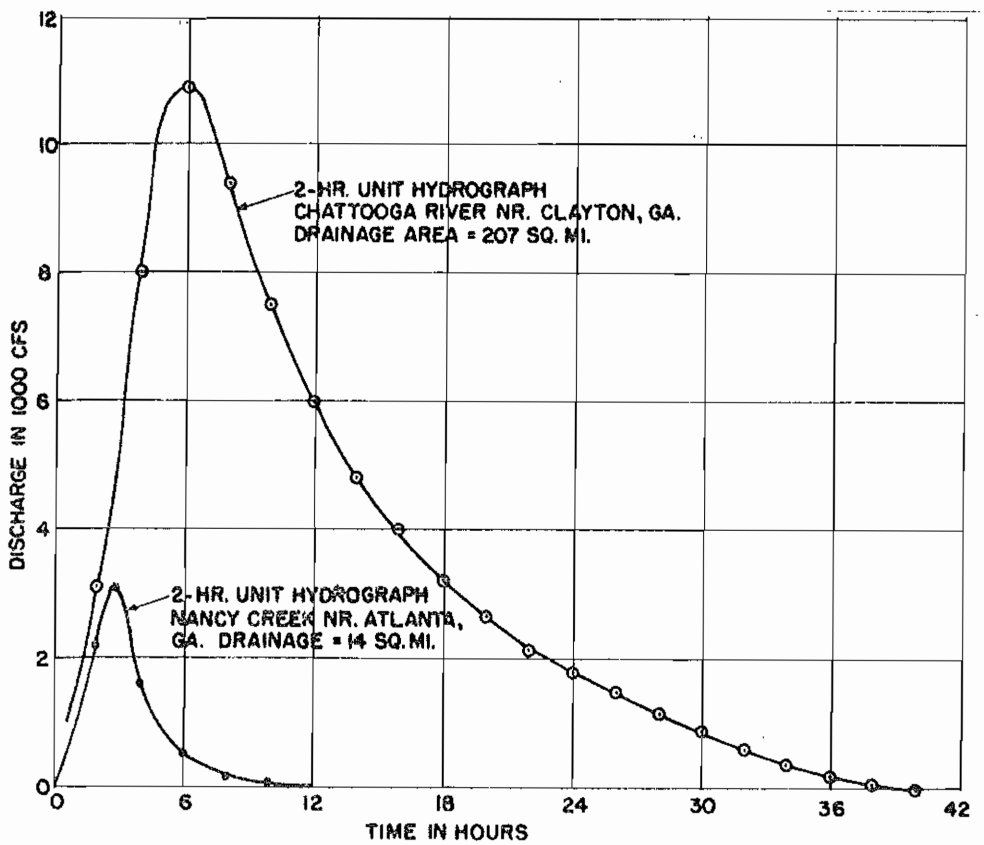

Fig. 1

runoff from 2-hour storm periods for Nancy Creek near Atlanta, Georgia and the Chattooga River near Clayton, Georgia. (Hydrographs produced by 1 inch of runoff from a specified time period are known as unit hydrographs.) The unit hydrograph in Fig. 1 show the considerable difference in the effects from previous rainfall between a large and a small flash flood area. Water is still in the channel of the Chattooga River near Clayton more than 36 hours after the end of rainfall. In the case of Nancy Creek, water remains in the channel only 10 hours after the end of rainfall. The drainage area above the Nancy Creek gage is only 14 mi^2 compared to 207 mi^2 for the Chattooga River gage. Both are considered flash flood areas with the crest occurring 1 hour after the end of rainfall for Nancy Creek and 4 hours after the end of rainfall for the Chattooga River.

A secondary reason for the greater effect of subsequent rainfall is the curvilinear relationship between rainfall excess and storm runoff. As rainfall continues and the accumulated rainfall excess increases, the runoff from an additional increment of rainfall is greater as the storm continues than it was at the beginning of the storm. This usually increases the flooding from a longer duration storm.

2. ADJUSTING INITIAL FLASH FLOOD GUIDANCE RAINFALL VALUES

In an attempt to solve the problem of adjusting the guidance estimate of rainfall required for flash flooding when durations exceed 3 hours, a study was made of rainfall required for flash flooding for durations of 1, 3, 6, 12, and 24 hours. The computations assumed that rainfall was evenly distributed with time. Flash flood tables for 19 stream gauges were used in the study. The data were separated into two parts according to the time required for drainage of storm runoff above the forecast point. For 7 of the forecast points, less than 12 hours were required for drainage of storm runoff while more than 24 hours were required for drainage for the other 12 forecast points. Computations were made from flash flood tables 1, 3, and 6, indicating wet, medium and extremely dry soil moisture conditions respectively.

The time from end of rainfall to crest stage for the 19 flash flood points used in this study varies from 1 to 8 hours with an average of 3.7 hours. The seven fast-draining areas had an average time to crest (after end of rainfall) of 2.1 hours, while the twelve slower-draining areas had an average time to crest of 4.7 hours. Drainage areas for the 19 points varied from 9 to 207 mi^2 with an average value of 48 mi^2. The average drainage area for the twelve slower-draining flash flood points was approximately 70 mi^2 while the average for the seven fast-draining points was 13 mi^2.

The SERFC plans to conduct a more comprehensive investigation of the problem of correcting the 3-hour required rainfall. A computer program is being written for this investigation. The program will use the rainfall-runoff relations and unit hydrographs for the flash flood areas rather than estimating the required rainfall from flash flood tables. A considerable number of additional flash flood forecast points will be used in the study. However, we do not anticipate any major revisions in the results obtained from the present limited study. Cedar Creek at Cedartown, Georgia (drainage area of 60 mi^2) will be used as an example of computations that will be performed by the planned computer study. Fig. 2 shows the rainfall excess-storm runoff relation used for this station and Fig. 3 shows the 3-hour unit hydrograph. (A variable unit hydrograph is used for discharges above flood discharge but the constant unit hydrograph applies until flood discharge is reached.) Figs. 4 and 5 show examples of the computed required rainfall for 6 hours and Fig. 6 shows an example for 12 hours. Computations were made only for wet soil moisture conditions which corresponds to Table 1 of our flash flood tables (soil moisture deficiency [SMD] = 0").

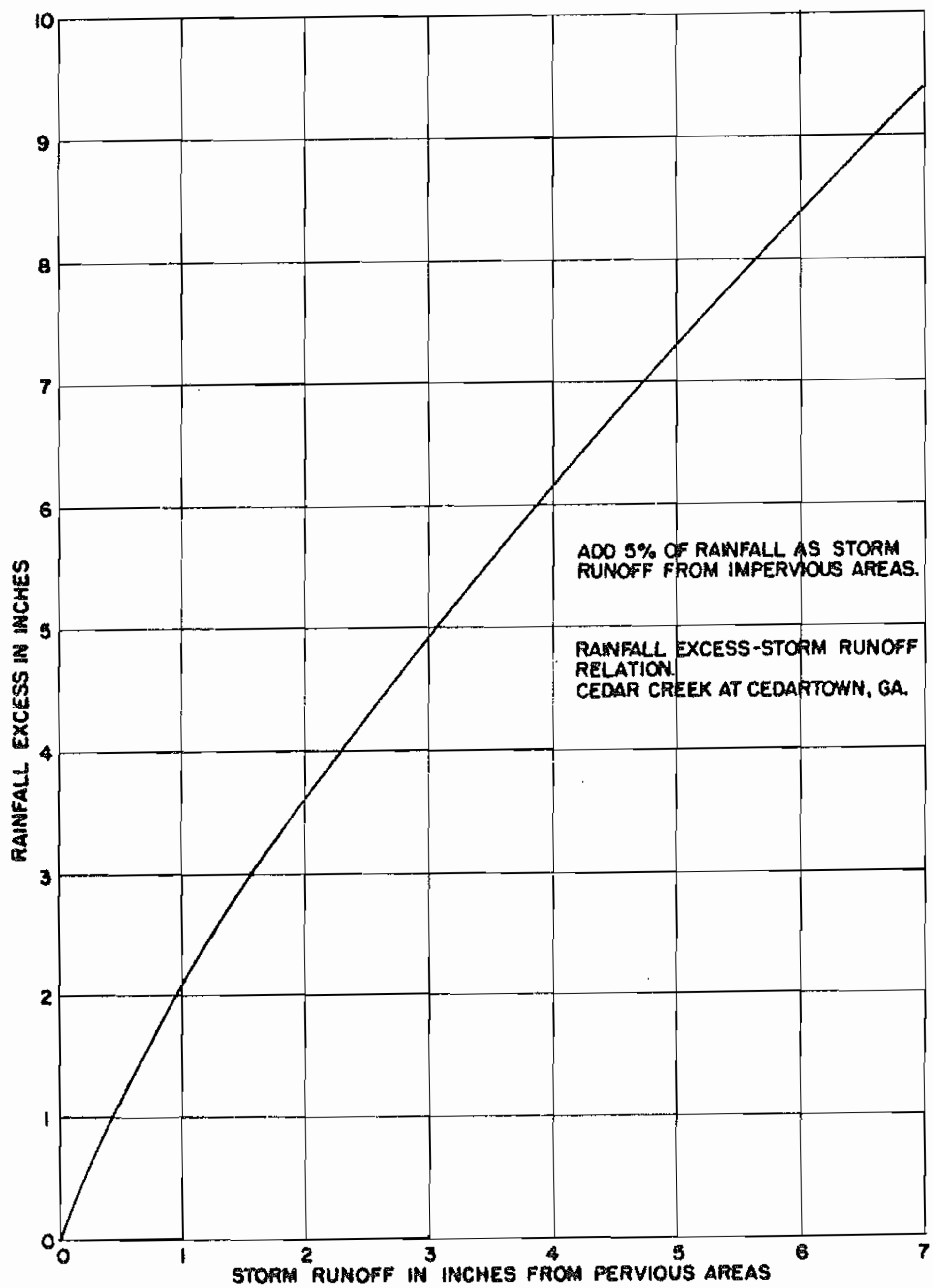

Fig. 2

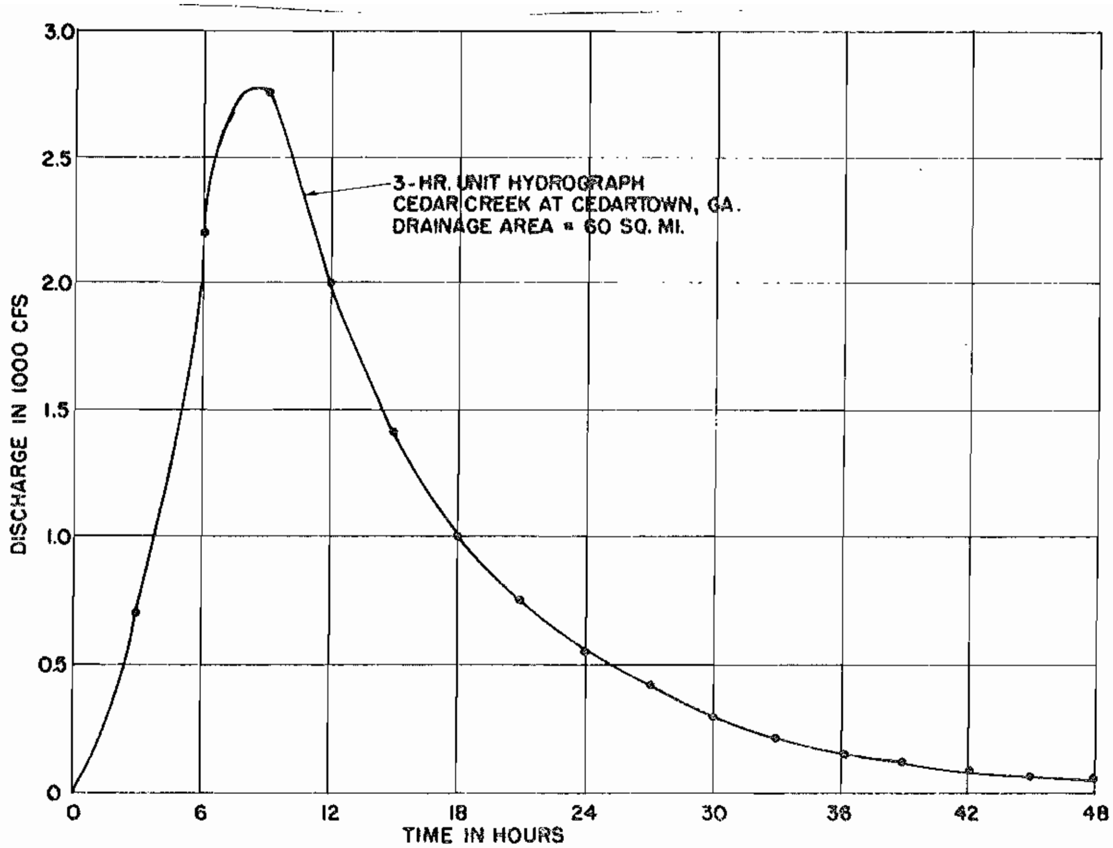

Fig.3

CEDAR CREEK AT CEDARTOWN, GA.
ASSUME SMD = 0.0"
REQUIRED 3-HR. RAINFALL FOR FLASH FLOODING = 1.65"

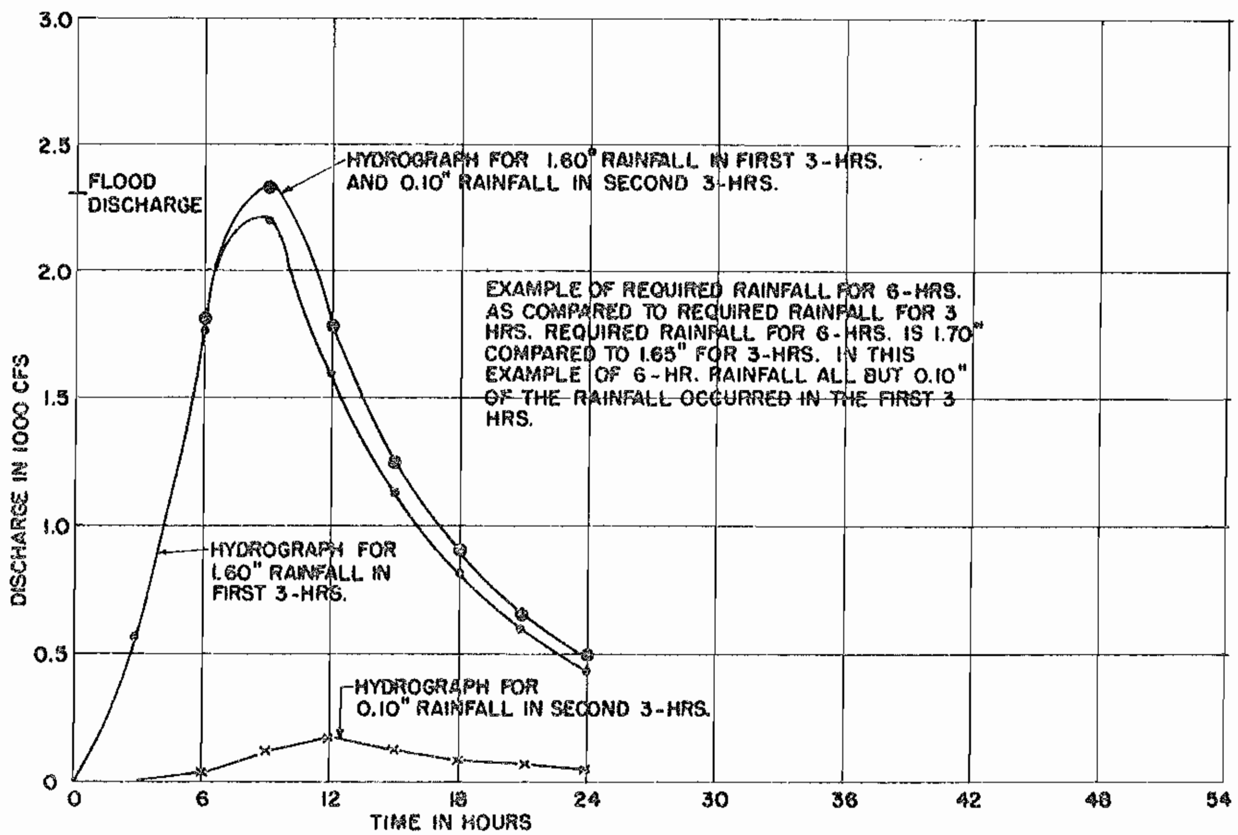

Fig. 4

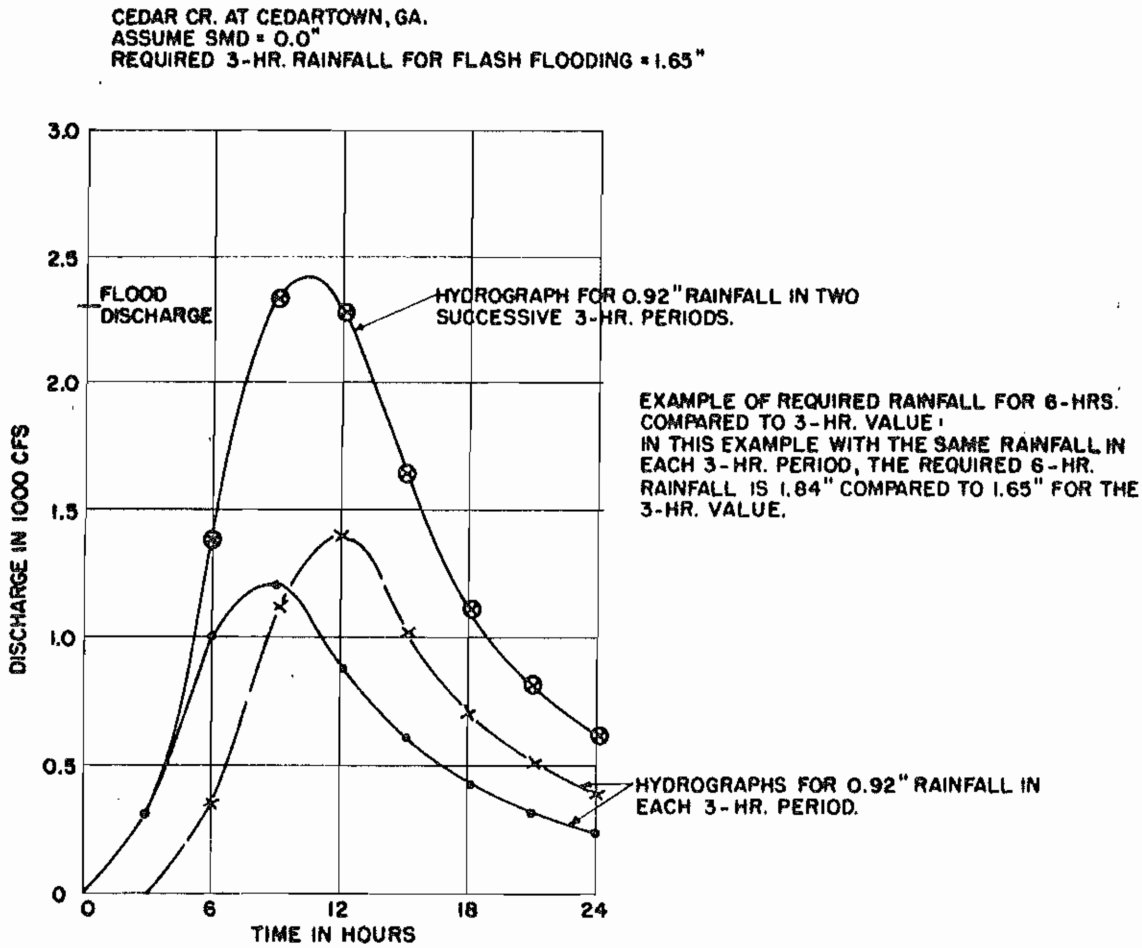

Fig. 5

Fig. 4 illustrates the required rainfall for 3 and 6 hours when the rain during the initial 3 hours was only 0.05" less than that required in 3 hours for flooding (i.e. 1.60" versus 1.65"). In this case only an additional 0.10" in the second 3 hours was required to produce flood discharge. The difference in the required 3- and 6 hours rainfall amounts was only 0.05". For this situation the use of the initial required 3-hour rainfall of 1.65" for the second 3-hour period would be completely invalid since the actual required rainfall for the second period was only 0.10". The example in Fig. 4 indicates the possible error that might be introduced by the assumption that rainfall is evenly distributed with time. Fig. 5 shows the required rainfall for 3 and 6 hours when this assumption is made. In this example a rainfall of 0.92" was required in each 3-hour period with a total 6-hour rainfall of 1.84". The difference in the required 3 and 6-hour rainfall amounts in Fig. 5 is 0.19", compared to a difference of 0.05" for the extreme case of Fig. 4. This indicates that the assumption of rainfall evenly distributed with time will give reasonably accurate results. Use of the initial 3-hour required rainfall of 1.65" for the second 3-hour period would be considerably in error even for the example of Fig. 5 since the required 3-hour rainfall for the second period was only 0.92".

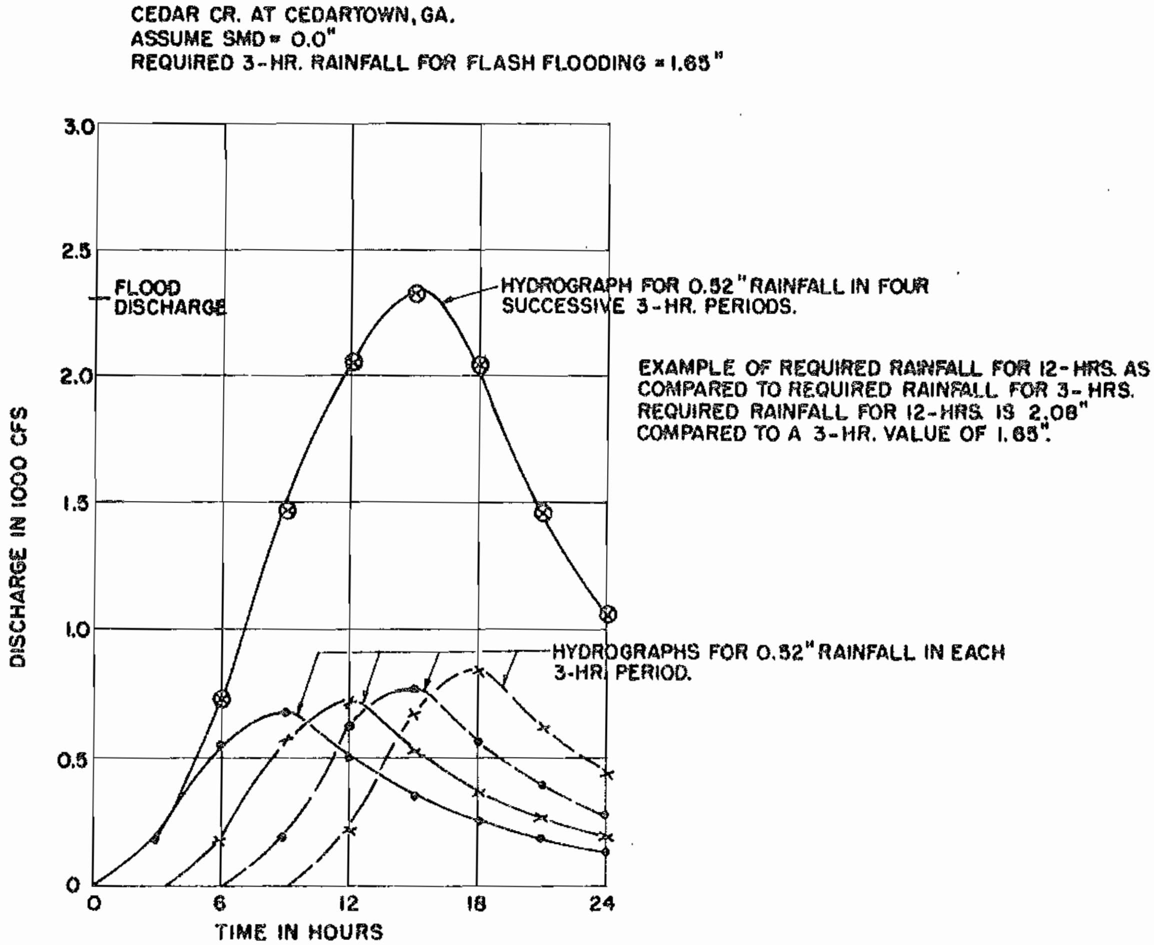

Fig. 6

Fig. 6 shows required rainfall for 3 and 12 hours, again assuming that the rain is evenly distributed with time. A total 12-hour rainfall of 2.08" is required with 0.52" in each 3-hour period. In this example the difference in the required 3 and 12-hour amounts is 0.43". Use of the initial 3-hour required rainfall of 1.65" in the last 3 hours, instead of the actual value of 0.52", would cause an error of 1.13". *As indicated from Figs. 5 and 6, the error from use of the initial 3-hour value increases with rainfall duration.*

An example of rainfall-runoff and unit hydrograph computations is shown in Table 1. These computations were used in preparing the example shown in Fig. 5. A trial and error type of solution is used in determining the required rainfall for durations in excess of 3 hours. The planned computer program will expedite these computations.

Fig. 7 shows rainfall required for flash flooding (average for 7 or 12 forecast points) versus rainfall duration in hours. Rainfall was assumed to be evenly distributed with respect to time. Separate lines are shown for forecast points draining in less than 12 hours and more than 24 hours; and for wet, medium and extremely dry soil moisture conditions. One-hour values could be determined only for the 7 forecast points where the storm runoff drains in less than 12 hou

Table 1

COMPUTATION OF HYDROGRAPHS PLOTTED ON FIGURE 5

Storm Runoff Computations

3-Hour Rainfall	Sum of Rainfall	Sum of [1] Rainfall Excess	Sum of [2] Storm Runoff	3-Hr Values of Storm Runoff
0.92	0.92	0.92	0.45	0.45
0.92	1.84	1.84	0.94	0.49

Unit Hydrograph Computations

Discharges in 1000 CFS

Ordinates for Unit Hydrograph	0.7	2.2	2.8	2.0	1.4	1.0	0.8	0.6	0.4	0.3	0.2	
Time in Hours	3	6	9	12	15	18	21	24	27	30	33	
Runoff												
0.45	0.3	1.0	1.3	0.9	0.6	0.4	0.4	0.3	0.2	0.1	0.1	
0.49		0.3	1.1	1.4	1.0	0.7	0.5	0.4	0.3	0.2	0.1	0.1
Computed Hydrograph	0.3	1.4	2.4	2.3	1.6	1.1	0.9	0.7	0.5	0.3	0.2	

Groundwater flow is assumed to be zero for these computations. The computed hydrograph is slightly different from the plotted values on Figure 5 due to use of unit graph ordinates in CFS when computing the plotted values.

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[1] Soil moisture deficiency of 0.0" is assumed and sum of rainfall excess is the same as the sum of rainfall.

[2] The runoff relation in Figure 2 is used to compute storm runoff. Storm runoff must be computed for pervious and impervious areas and the two values are added together.

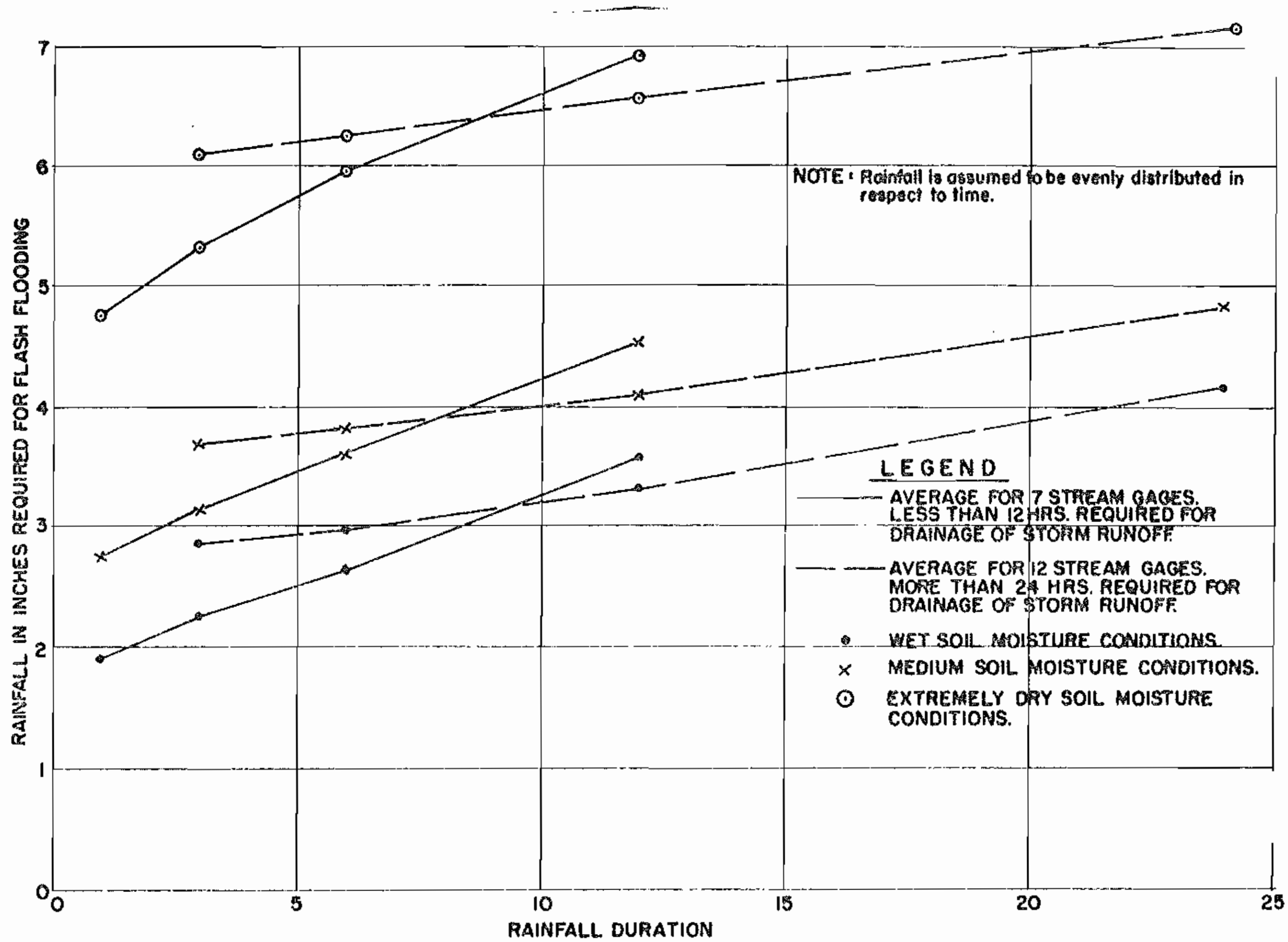

Fig. 7

The lines on Fig. 7 show approximately the same slope for wet, medium and dry soil moisture conditions. This indicates that an arithmetical correction is a feasible method of adjusting the advisory value of the required 3-hour flash flood rainfall. Correction values were computed and plotted on the graph in Fig. 8 which shows the average correction to 3-hour rainfall versus rainfall duration. The data are shown separately for the 7 stream gauges with fast drainage and the 12 stream gauges where the water drains more slowly. The data show very little difference between wet, medium, and extremely dry soil moisture conditions, but do show a considerable difference between the two sets of stream gauges.

The average values used in Fig. 8 do not indicate the magnitude of error for individual forecast points. This is shown in Fig. 9 which illustrates the correction for each rainfall duration and soil moisture condition for all of the 19 flash flood points. The widest variation in the data is shown for a duration of 12 hours where data from all 19 stream gauges were used. (57 points were available for plotting at the 12-hour duration since there are 3 soil

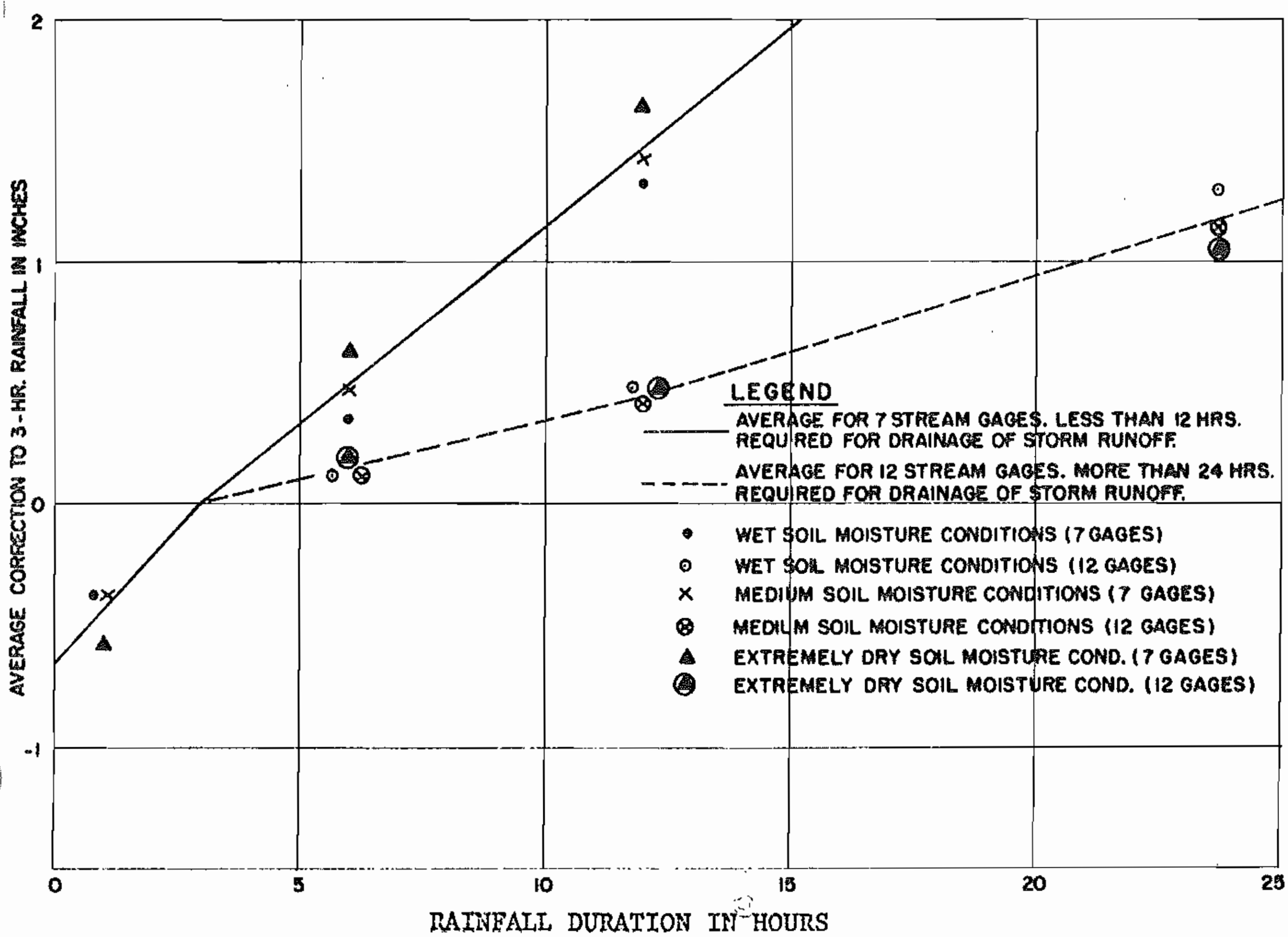

Fig. 8

moisture conditions for each gauge.) The data for the 24-hour duration shows only the points for the 12 stream gauges that require more than 24 hours for drainage of storm runoff.

It should be pointed out that even required rainfall values for a period of 3 hours vary widely within each forecast zone. The variation is due to differences in runoff characteristics, height of overflow banks, channel storage conditions, and variable soil moisture conditions throughout the zone. (The single value issued by the Southeast River Forecast Center for each zone is not an average value; our method of computation selects a value closer to the minimum values.) Even with uniformly wet soil moisture conditions, a variation from 1.5" to 4.2" for required 3-hour rainfall is shown for flash flood points in one of the forecast zones in Georgia. With variable soil moisture conditions during the summer, the variation could be even greater. However, this particular zone shows an unusual degree of variation for required 3-hour rainfall.

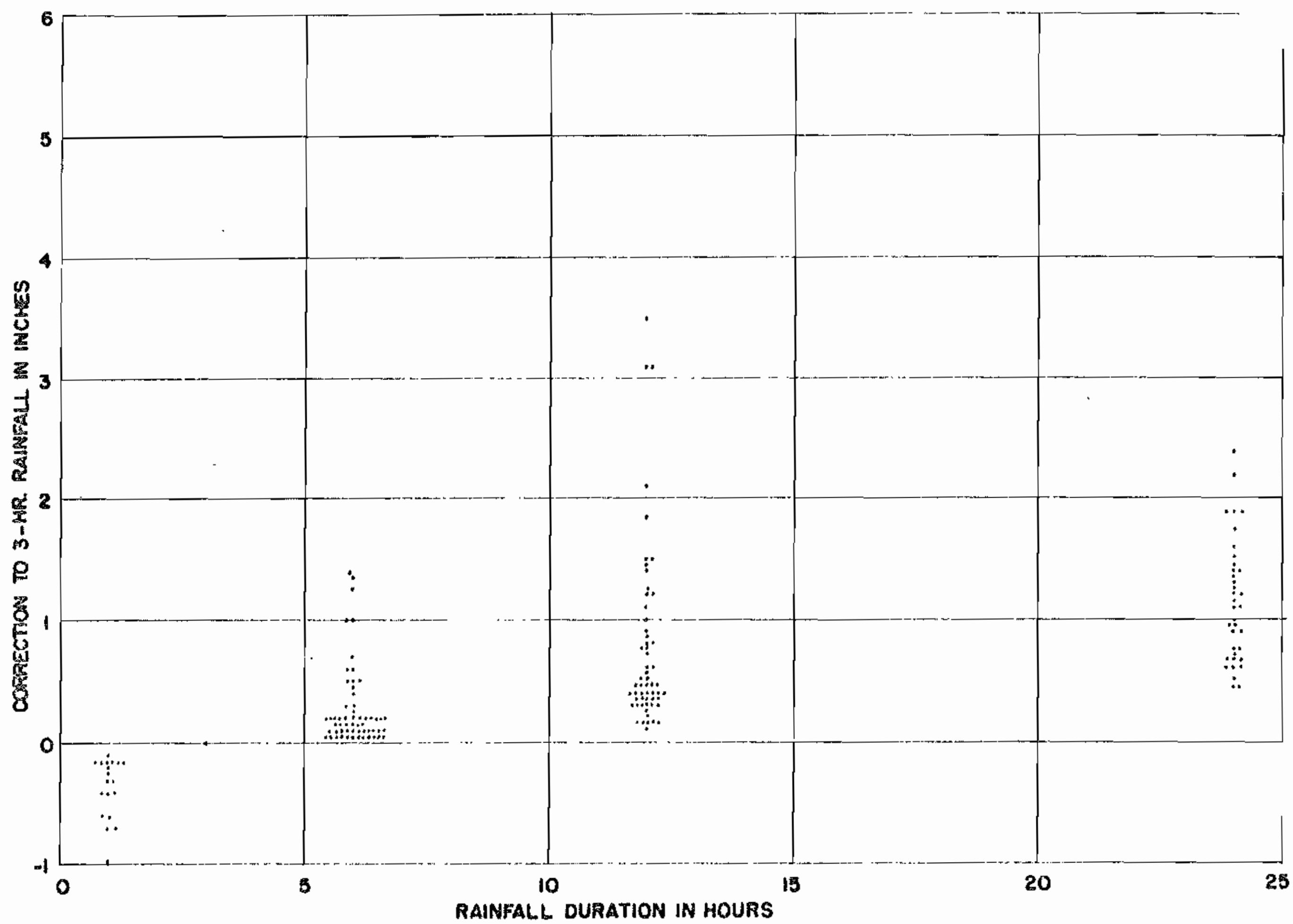

Fig. 9

Even though rainfall guidance values can be highly variable over a zone and cannot be accurately expressed by a single value, some means is needed for defining the required rainfall for flash flooding for durations other than 3 hours. It is not practical to revise the required 3-hour rainfall value every 3 hours since we do not receive the data necessary to make this revision. Also, if complete accuracy is to be achieved, the varying effects of previous rainfall would require separate 3-hour values for each small basin. This is obviously not practical and, therefore, a simple method for adjusting the initial 3-hour advisory values would seem to be a feasible solution.

One method might be the adjustment of the 3-hour advisory values to values required for longer durations. The following corrections could be used in the Southeast River Forecast Center area:

Rainfall Duration	Correction to 3-Hour Rainfall
1 hour	-0.5"
3 hours	0"
12 hours	+0.5"
24 hours	+1.2

Values for other durations can be interpolated from these values. The proposed ǀlue for 12 hours is too low for the smallest basins but will be applicable to the /erage size of a flash flood basin.

Table 2. Proposed Equations for Correcting Advisory Values of 3-Hour Rainfall Required for Flooding on Small Streams.

$$CR = IR3 + \frac{DUR + TP - 3}{18} - OR$$

12 Slow-Draining Streams
(Avg Drainage Area = 70 sqmi)

$$CR = IR3 + \frac{DUR + TP - 3}{6} - OR$$

7 Fast-Draining Streams
(Avg Drainage Area = 3 sqmi)

$$CR = IR3 + \frac{0.9(DUR + TP) - 3}{(AREA)^{2/3}} - OR$$

GENERAL EQUATION

CR = Required rainfall for next time period (TP)
TP = Next time period in hours
IR3 = Initial 3-hour required rainfall in inches on advisory
DUR = Duration of rainfall in hours since advisory time
OR = Observed or estimated rainfall in inches since advisory time
AREA = Drainage area in square miles

gative values of CR indicate that flooding has or soon will occur. Required rainfall (evenly distributed with time) for any time period can be determined prior to rainfall by computing CR with TP set to the desired time period and with DUR and OR = 0. For example, required rainfall in 1 hour might be desired for small, fast-draining areas.

Another method of adjusting the advisory value of 3-hour required rainfall is the computation of the required rainfall for the next time period. Table 2 shows equations for making this computation. Three hours would usually be used for the next time period (TP) but any period could be used. In the case of fast-draining streams, a time period of 1 hour would be more appropriate and could be determined from the equation for fast-draining streams. The equations in Table 2 are derived from Fig. 8. For an average basin the data appear to fit the General Equation but results for individual basins can vary considerably. This is due to the fact that the time required for drainage of water from the basin is dependent not only on drainage area but also on terrain and stream configurations. In SERFC's flash flood advisory, limits of 5" for the 3-hour required rainfall for flash flooding in non-urban areas and 3" for urban areas are used. These limiting values will still be used, when applicable, in determining the corrected required rainfall. The computed 1-hour required rainfall could possible be negative and in this case a small positive rainfall value should be used.

3 SUMMARY

Twelve of the flash flood basins used in this study are in the Piedmont area of the southeastern United States, six are in mountainous areas and one is in the coastal plain. Other groups of basins would likely give somewhat different results. Other RFCs should make a similar analysis to see if results are significantly different. In a future study the SERFC plans a more comprehensive analysis with a larger number of additional basins. At the present time RFCs assume no significant channel flow from previous rainfall when computing the required 3-hour rainfall for the flash flood advisory. In the future these computations will have to include the effect of channel flow from previous rainfall in order to reflect correct values of required 3-hour rainfall on the morning advisory.

The ultimate solution to the problem of changing values of rainfall required for flash flooding would be the ability to forecast the discharge and stage hydrograph at any point on any stream at any time. Since we do not currently have this capability, the proposed methods of correcting the advisory value of the required 3-hour rainfall would appear to provide the best solution at the present time.