COMMUNITY SELF-HELP RIVER FORECAST PROCEDURES

by

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INTRODUCTION

Many communities with flood problems cannot be adequately provided with flood forecasts under the normal National Weather Service river forecast organization. The normal forecast service provides for collection by National Weather Service offices of river and rainfall reports that exceed criteria conditions at 6-hour intervals (7 AM, 1 PM, 7 PM, and, hopefully at 1 AM). These reports are relayed to a River Forecast Center where the forecasts are prepared. The river forecasts are then sent to Weather Service Forecast Offices for dissemination to the public. In order for this procedure to work effectively, the time delay from the end of rainfall to crest stage at the forecast point must be more than 12 hours. For shorter time delays a different type of organization is required.

Two methods have been developed for furnishing flood warnings for streams where normal procedures are too slow to provide adequate forecasts. One method is the use of self-help river forecast procedures by community representatives. The other method is the use of a flash flood alarm system developed by the National Weather Service. This paper will be primarily concerned with the development and use of self-help river forecast procedures but flash flood alarm systems will also be briefly described.

The self-help concept requires the collection of rainfall reports at frequent intervals from the drainage area above the river gage by a community representative. The representative prepares crest stage forecasts from simplified procedures provided by the National Weather Service and is also responsible for providing the forecast to the community agency that warns the public.

DEVELOPMENT OF SELF-HELP FORECAST PROCEDURES

The Southeast River Forecast Center prepares self-help forecast procedures in the form of a set of flood warning tables. The table number indicates the soil moisture conditions at the beginning of the rainfall period. These tables will be described later.

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Development of the self-help flood warning tables requires: (1) a method of computing storm runoff from rainfall; (2) an assumed distribution of rainfall during the storm; (3) a method of converting the storm runoff volume into a hydrograph of discharge versus time; and (4) a stage-discharge relation for changing the forecast peak discharge to crest stage.

Computation of Storm Runoff - Although any type of rainfall-runoff relation can be used in developing flood warning tables, the Southeast River Forecast Center uses a relationship between rainfall excess, rainfall, and storm runoff as shown in Figures 1 and 2. (Storm runoff volume is converted to inches of depth over the drainage area.) This type of relationship was developed in 1960 when computer facilities were not available and forecast relations had to be relatively simple for manual use. We have access at the present time to a large computer and are now changing our forecast procedures to the more sophisticated National Weather Service hydrologic model. However, since a complete changeover will require a number of years and our flood warning tables were developed from our present system, a brief description of this system will be given. A more complete explanation was given by Fox (1) at Clemson University in 1965.

In developing or using a rainfall-runoff relation, continuous computations to determine soil moisture conditions must be made. The Southeast River Forecast Center uses a soil moisture deficiency accounting system for computing soil moisture conditions. Soil moisture deficiency is defined as the moisture required to bring the soil moisture to field capacity. The system assumes that no appreciable storm runoff occurs from pervious areas (except for runoff near streams where groundwater is near the surface) until the soil moisture deficiency is satisfied. Although this assumption might appear questionable, it has provided accurate forecast results for more than 15 years of operational forecasting in the southeastern United States. Using this "threshold" concept, the following equation can be used to compute soil moisture deficiency for each rainfall station:

$$d_e = d_b - R + E \qquad (1)$$

where d_e is the soil moisture deficiency at the end of the computational period (usually 24 hours), d_b is the deficiency at the beginning of the period, R is rainfall (or melted snow) and E is evapotranspiration. The parameter d_e is set to zero for use in future computations when a negative value is computed. A computed negative value for d_e represents rainfall in excess of that required to bring the soil moisture to field capacity and is the rainfall excess shown in Figures 1 and 2.

Use of equation (1) requires a determination of the parameters R and E and a beginning value of deficiency (d_b). The rainfall (R) is the measurement at the rain gage and d_b can be assumed as zero if computations are begun after a rainfall period that produced substantial runoff. The evapotranspiration (E) can be determined from computations of potential evapotranspiration and a relationship between soil moisture deficiency and the ratio of actual to potential evapotranspiration. According to Thornthwaite (2), potential evapotranspiration can be defined as the "water loss which will occur if at no time there is a deficiency of water in the soil for the use of vegetation." The numerous techniques for computing potential evapotranspiration are discussed in hydrology books such as Linsley, Kohler, and Paulhus (3). The Southeast River Forecast Center uses 85% of lake evaporation as computed in Kohler et al (4) for potential evapotranspiration. After computing potential values, actual evapotranspiration can be determined from the relations shown on Figure 3. Separate computations are made for forest and non-forest due to the greater root depth of forest vegetation.

As previously indicated, computed negative values for d_e represent rainfall excess. These values are accumulated during the storm and accumulated rainfall and rainfall excess values are used to compute storm runoff from the type of runoff relations shown in Figures 1 and 2. These runoff relations were developed from average basin rainfall, rainfall excess, and storm runoff values for past rainfall periods. Storm runoff was determined by the method of hydrograph separation shown in Figure 4. The horizontal spacing between rainfall lines represents storm runoff from impervious areas (such as roads, streets, housetops, etc.), water surfaces, and from areas near perennial streams where the ground remains near saturation. The percentage of impervious surfaces over the drainage area above the river gage on Peachtree Creek in Atlanta, Georgia is about 35% but the additional effect of runoff from water surfaces and areas near streams causes 40% of the rainfall to become storm runoff even when the soil moisture deficiency for pervious areas is not satisfied. In contrast to the runoff relation for the highly urbanized drainage area of Peachtree Creek in Atlanta, the runoff relation for the drainage area of Sowashee Creek above Meridian, Miss. (Figure 2) shows only 5% of rainfall as storm runoff when the moisture deficiency for pervious areas is not satisfied.

<u>Assumed Distribution of Rainfall for Storm Period</u> - Since it would not be feasible to use all possible rainfall distributions for computing flood warning tables, an assumed distribution must be used that will provide reasonable forecasts for all actual distributions. As shown on Figure 10, the actual rainfall in the last period of time is used. Prior to the last time period, the rainfall is assumed to be evenly distributed with time. For example, if the total storm rainfall in Figure 10 is 7.0 inches, the storm duration is 18 hours, and 3.0 inches of rainfall occurred in the last 6 hours, then it was assumed that 2.0 inches of rainfall occurred in each of the two 6-hour periods prior to the last 6 hours. Obviously, this simplified rainfall distribution will not be completely suitable for all storms, but it does seem to provide reasonably accurate crest stage forecasts.

<u>Time Distribution of Storm Runoff Volume Using Unit Hydrograph</u> - After developing a storm runoff relation, the next step in the

computation of flood warning tables is the development of a method of distributing the storm runoff volume with time at the forecast point. If hourly rainfall data and continuous streamflow data are available, a unit hydrograph for the desired time period can be determined from past records. As introduced by L. K. Sherman (5) in 1932, the unit hydrograph theory assumes that all storm hydrographs for a given duration of rainfall should have the same time base and, if the time and areal distribution of the storms are similar, the ordinates of each hydrograph are proportional to its volume of storm runoff (Figure 5). The unit hydrograph is the hydrograph resulting from 1.00 inch of runoff. When using the unit hydrograph for forecasting, the storm runoff is computed from the runoff relation by time intervals corresponding to the unit hydrograph time period. Storm hydrographs resulting from the runoff in each time interval are computed by multiplying the storm runoff by each ordinate of the unit hydrograph. The resulting hydrographs are successively lagged (according to the time period) and added together to obtain the storm hydrograph. For example, if a time period of 12 hours is used, each 12-hour ordinate of the hydrograph resulting from the first 12-hour runoff amount would be computed from the unit hydrograph; the hydrograph for the next 12-hour runoff amount would then be computed, lagged 12 hours, and this lagged hydrograph added to the first hydrograph (Figure 6). This procedure would be continued until rainfall ceases. Estimated base flow is added to the storm hydrograph to obtain the total forecast hydrograph.

Time Distribution of Storm Runoff Volume Using Time-of-Travel-Zones - The unit hydrograph cannot be determined directly in some cases due to lack of hourly rainfall and/or streamflow data. In other instances a curvilinear relationship between basin storage and discharge at the gaging station invalidates the unit hydrograph method. We have found that storage routing of inflow hydrographs derived from time-of-travel zones as described by Linsley, Kohler and Paulhus (3) provides the most accurate solution (Figure 7) for both of these situations. Time-of-travel zones can be determined from inspection of observed discharge hydrographs (Figure 8), the time interval between the end of heavy rainfall and crest stage, or relations between stream slope and time-of-travel as determined from nearby, similar basins. Time-of-travel (isochrone) lines cannot be considered as true time-of-travel values to the outflow point, even for zero storage effects. The lines should only be considered as defining a set of zones which, when used with runoff relations and combined with storage routing, will reproduce the outflow hydrograph.

Use of time-of-travel zones requires a runoff relation. If data are not available from the actual basin, a relation from a nearby, similar basin can be used. Also, a procedure is needed for routing the inflow hydrograph determined from the runoff relation and the time-of-travel zones. There are many types of streamflow routing procedures that can be developed from the continuity storage equation:

$$\Delta S/t = \overline{I} - \overline{O} \qquad (2)$$

where ΔS is the change in storage, $\bar{I}$ is the average inflow and $\bar{O}$ is the average outflow during the time period (t). If t is in hours and S is in units of (t/24) CFS - day, t can be eliminated from the equation.

If subscripts 1 and 2 are used for the beginning and ending, respectively, of the routing time period and the time period is sufficiently short that the average of beginning and ending values represents the average inflows and outflows during the period, then equation (2) can be rewritten as follows:

$$\bar{I} + S_1 - O_1/2 = S_2 + O_2/2 \qquad (3)$$

The Southeast River Forecast Center uses this routing equation since the same computer program can be used for linear and non-linear storage-outflow relations. Solution of equation (3) requires a relationship between O and S + O/2. This can be obtained from the storage equation:

$$S = KO \qquad (4)$$

where K is either a storage constant (linear routing) or a function of outflow (non-linear routing). For routing inflows from time-of-travel zones, the value of K can be obtained from hydrographs for the forecast gage or from nearby, similar basins by use of the following equation:

$$K = 1/(-\ln K_r) \qquad (5)$$

where $\ln K_r$ is the natural logarithm of the storm discharge recession factor (O_2/O_1). K_r and K can vary with discharge or can be constants. The unit of K is the time period for K_r. For example, if the recession factor is obtained from 6-hour intervals of outflow, K will be in units of 6 hours.

In developing the O versus S + O/2 relation, storage (S) can be determined directly from equation (4) if K is a constant. When K varies with outflow, storage is obtained by accumulating incremental values from the equation:

$$\Delta S = \bar{K}(O_2 - O_1) \qquad (6)$$

where ΔS is the change in storage and $\bar{K}$ is the average K value between discharges O_1 and O_2. For a constant K, the Muskingum type of routing (with X = 0) as described in Linsley, Kohler, and Paulhus (3) is easier for manual computations.

Reference is made to hydrology textbooks such as Linsley, Kohler, and Paulhus (6) for solution of equation (3) or variations of this equation, using a relationship between O and S + O/2. Equation (3) is usually called a reservoir-routing type of equation.

Streamflow routing from an upstream to a downstream gage usually requires a relationship between inflow and lag with the upstream hydrograph being lagged before the storage routing. Lag is already incorporated in the inflow time-of-travel zones and only storage routing is normally used for these cases.

If K is a constant in equation (4), a unit hydrograph can be computed from the time-of-travel zones by putting a runoff volume of one inch in each time of travel zone, lag the volumes according to the time-of-travel, and then rout the resulting hydrograph.

Stage-Discharge Relation - Since peak discharges rather than crest stages are obtained from the forecast procedure, a relation between stage and discharge (Figure 9) is required for determining the crest stages. If the forecast point is a U. S. Geological Survey gaging station, the stage-discharge relation is available from that agency. Otherwise, the relation must be determined by correlating forecast peak discharges with observed crest stages.

EXPLANATION OF SELF-HELP FLOOD WARNING TABLES

The Southeast River Forecast Center uses flood warning tables as self-help forecast procedures for community representatives. A set of six numbered tables are prepared with the table number indicating the initial soil moisture conditions. Tables 1 and 6 denote the wettest and driest initial conditions, respectively. The intervening tables indicate initial soil conditions between these two extremes. Figures 10 and 11 show tables 1 and 6 for Sowashee Creek at Meridian, Mississippi. Since these two tables show the full range of possible forecast crest stages, tables 2 through 5 are not needed for explanatory purposes although these four additional tables are part of the set of six flood warning tables for this forecast point. Since a National Weather Service Office is located at Meridian and is open 24 hours a day, that office instead of a community representative prepares the crest stage forecast from the tables and disseminates the forecast.

The Southeast River Forecast Center issues daily the correct table number to use for the locations where flood warning tables are in use. Since loss of communication is a possibility, the tables in some cases are used as back-up procedures by Weather Service offices for gages regularly forecast by the River Forecast Center. The table numbers are designated according to the average soil moisture deficiency over the basin at the beginning of the rainfall period. Using soil moisture deficiency values to the nearest tenth of an inch, the table limits are as follows:

Table No.	Soil Moisture Deficiency in Inches
1	0.0 to 0.5
2	0.6 to 1.0
3	1.1 to 2.0
4	2.1 to 3.0
5	3.1 to 4.0
6	4.1 to 6.0

Soil moisture deficiency values are computed daily by the Southeast River Forecast Center for 740 rainfall stations and weighted averages are computed for the basins that use flood warning tables.

As an example of use of the tables, assume that the ground is wet over the Sowashee Creek drainage and flood warning table 1 in Figure 10 is being used. Assume that the rainfall in the last 6 hours ending at 6 AM is 2.0 inches, duration of storm is 24 hours, and total storm rainfall is 5.0 inches. The forecast crest stage from Figure 10 would be 19.6 feet. The forecast crest stage would be issued at 19 to 20 feet occurring in the afternoon.

The previous example of rainfall distribution can be used to show computations for one crest stage in Figure 10. A six-hour unit hydrograph was used to compute discharges for Sowashee Creek at Meridian. Computations for one crest stage are shown in Table 1.

DISCUSSION OF FORECAST ACCURACY

A number of observed and forecast crest stages are listed in Table 2 and plotted on Fig. 12. In most cases, all available past rainfall reports were used in computing the forecast crest stages. The forecast that was issued at the time of the flood might have been different due to some rainfall data not being available at that time. However, the community representatives for the Virginia stations indicated that the listed crest stage forecasts were those determined at the time of the floods.

Generally, the forecast crest stages agree reasonably well with observed values but are not too accurate in some cases. However, forecasts using a unit hydrograph and the actual rainfall time distribution also show large errors at times. For example, using the 6-hour unit hydrograph and observed rainfall distribution, a forecast crest stage of 21.8 feet is obtained for the flood of December, 1973 on Sowashee Creek at Meridian, Mississippi. This forecast is more accurate than that obtained from the tables since the rainfall distribution was considerably different from that assumed for the tables, but is still 1.7 feet higher than the observed crest stage. Lack of sufficient rainfall reports is the main problem in forecasting for small areas. For example, the only rainfall station in the Sowashee Creek area is located near Russell, Mississippi. For actual forecasting, the Meridian Airport observations are sometimes the only available rainfall reports and this gage is located more than 4 miles outside the drainage area. Extreme variations in rainfall, that are not properly represented by rainfall reports, can cause large errors in crest forecasts for small drainage areas. The same rainfall variations over larger areas are not normally as critical due to the greater dampening effect of storage for the larger drainage areas.

The present self-help flood warning tables need some revision for use in rainfall periods that last for a number of days. The total storm rainfall period should be limited to the time base of the unit hydrograph with lower (wetter) table numbers being used when the rainfall duration exceeds the time base of the unit hydrograph. For this type of situation a wetter table than table 1 in Figure 10 might be needed. The present tables seem to work satisfactorily for the storms tested but probably would not work too well on extremely long storms. For example, the rainfall in October, 1970 over the Rio de La Plata above Proyecto La Plata, Puerto Rico lasted five days and caused a number of crest stages. We do not have hourly rainfall data for checking forecasts for this flood but it seems obvious that the last crest stage forecast would be much too high if rainfall for the entire five days is used for total storm rainfall. We plan to revise the tables so that reliable crest forecasts can be made for the extremely long storms.

FLASH FLOOD ALARM SYSTEMS

The Flash Flood Alarm System (FFAS) offers another means of warning inhabitants in flash flood areas. The FFAS (Figure 13) is composed of three stations: a river station, intermediate station, and an alarm station. The river station senses the critical water level and activates the alarm when this level is reached. It consists of an enclosed float switch (sensor) which is installed at the critical water level, and a weather-proofed box containing a battery, signal transmitter and interconnecting circuitry. The intermediate station provides power to the river station and couples the river station's signal output, by means of a pair of telephone lines, to the alarm station. The intermediate station is located at a point where both AC power and telephone service are available and is connected to the river station by a pair of wires which may be up to 12 miles in length. The alarm station, which is located in a firehouse, police station, or some other appropriate location in the community with 7-day, 24-hour-a-day staffing, receives a continuous input from the river station. Indicator lamps and/or an alarm provide information when the critical water level is exceeded and indicate the operational status of the system. The community is responsible for disseminating the warnings.

The Flash Flood Alarm System (FFAS) does not provide information on the magnitude of the flood and provides less warning time than the tables since the river stage must respond significantly before the alarm goes off. A combination of the FFAS and Flood Warning Tables provides the most effective warning system.

SUMMARY AND CONCLUSIONS

The National Weather Service has difficulty in providing adequate flood forecasts when the time delay from end of rainfall to crest stage is less than 12 hours. Self-help river forecast procedures enable community representatives to provide flood warnings in short time delay situations. The Southeast River Forecast Center develops self-help procedures in the form of flood warning tables. Six tables are prepared with the table number indicating soil moisture conditions at the beginning of the rainfall period. The tables are developed at the present time by means of simplified relations that include a soil moisture accounting procedure, rainfall-storm runoff relations, and unit hydrographs (or time-of-travel zones). The more sophisticated National Weather Service hydrologic model will be used in the future.

Table numbers are determined daily for the forecast points where flood warning tables are used. The self-help tables provide satisfactory forecast accuracy when sufficient rainfall reports are available from the drainage area above the river gage. The most effective flood forecast organization for small drainage areas is a combination of a flash flood alarm system and crest stage forecasts from flood warning tables.

REFERENCES

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3. Linsley, R. K., Kohler, M. A., and Paulhus, J.L.H., "Hydrology for Engineers", Second Edition, McGraw-Hill Book Co., New York, 1975.

4. Kohler, M. A., Nordenson, T. J., and Fox, W. E., "Evaporation from Pans and Lakes", U. S. Weather Bureau Research Paper No. 38, 1955.

5. Sherman, L. K., "Streamflow from Rainfall by the Unit-Graph Method", Engineering News Record, Vol. 108, pp. 501-505, 1932.

6. Linsley, R. K., Kohler, M. A., and Paulhus, J.L.H., "Applied Hydrology", McGraw-Hill Book Co., New York, 1949.

TABLE 1

COMPUTATION OF ONE CREST STAGE FOR MERIDIAN

FLOOD WARNING TABLES

Storm Runoff Computations

6-Hour Rainfall	Sum of Rainfall	Sum of Rainfall Excess 1/	Sum of Storm Runoff	6-Hr. Values of Storm Runoff
1.0	1.0	0.8	0.5	0.5
1.0	2.0	1.8	1.2	0.7
1.0	3.0	2.8	2.0	0.8
2.0	5.0	4.8	3.7	1.7

Unit Hydrograph Computations

Unit Hydrograph	0.3	1.1	1.8	1.2	0.8	0.3	0.1	

Discharges in 1000 CFS

Time in Hours	6	12	18	24	30	36	42	48
Runoff								
0.5	0.2	0.6	0.9	0.6	0.4	0.2	0.1	
0.7		0.2	0.8	1.3	0.8	0.6	0.2	0.1
0.8			0.2	0.9	1.4	1.0	0.6	0.2
1.7				0.5	1.9	3.1	2.0	1.4
Groundwater	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Forecast Hydrograph	0.3	0.9	2.0	3.4	4.6	5.0	3.0	1.8

Forecast Peak Discharge = 5,000 CFS

Forecast Crest Stage = 19.9 Ft. (From Figure 9). Difference between this value and the table value of 19.6 ft. is due to rounding off errors.

1/ Soil Moisture deficiency of 0.2 inch is used in computations for flood warning table 1.

TABLE 2

COMPARISON OF FORECAST AND OBSERVED CREST STAGES 1/

River Station	Flood Stage	Ending Date of Rainfall	Forecast Crest Stage	Observed Crest Stage	Forecast Minus Observed
Peachtree Creek at Atlanta, Ga.	13	9/17/71	13.8	13.8	0
		6/06/73	16.6	15.6	+1.0
		8/08/74	16.4	16.8	-0.4
		3/13/75	19.9	19.4	+0.5
		1/26/76	19.2	17.4	+1.8
		3/16/76	20.5	20.3	+0.2
Sowashee Creek at Meridian, Miss. 2/	15	4/06/64	22.0	21.0	+1.0
		7/30/71	19.9	17.2	+2.7
		3/31/73	19.1	19.6	-0.5
		12/26/73	22.5	20.1	+2.4
		4/13/74	21.0	21.5	-0.5
		6/06/74	17.2	17.5	-0.3
French Broad River at Rosman, N. C.	8	9/29/64	13.7	13.3	+0.4
		10/04/64	13.5	15.0	-1.5
		6/04/67	11.3	10.6	+0.7
		6/15/69	10.5	9.5	+1.0
		5/03/72	10.3	10.0	+0.3
		5/28/73	12.3	13.1	-0.8
		9/23/75	10.3	10.2	+0.1
		10/17/75	12.7	12.2	+0.5
Rio de La Plata at Proyecto La Plata, Puerto Rico 2/	-	9/06/60	29.2	30.6	-1.4
		8/27/61	31.8	32.2	-0.4
		8/15/73	15.6	15.3	+0.3
		10/11/73	12.5	12.8	-0.3

1/ Stages are in feet above gage datum. Forecast crest stages were obtained from flood warning tables.

2/ These stations are outside the area covered by the Southeast River Forecast Center but we were asked to prepare flood warning tables. Rio de La Plata was used to test the accuracy of the tables in tropical regions.

TABLE 2 (Cont'd)

COMPARISON OF FORECAST AND OBSERVED CREST STAGES 1/

River Station	Flood Stage	Ending Date of Rainfall	Forecast Crest Stage	Observed Crest Stage	Forecast Minus Observed
Guest River at	7	1/11/74	7.6	8.2	-0.6
Norton, Va. 2/		3/30/75	7.5	8.3	-0.8
Clinch River at	16	1/11/75	13.1	13.1	0
Cleveland,		3/14/75	16.8	17.3	-0.5
Va. 2/		3/30/75	18.8	19.0	-0.2
Town Creek at	21	3/11/73	23.3	23.4	-0.1
Tupelo, Ms.		3/16/73	28.0	27.1	+0.9
		11/28/73	24.8	24.7	+0.1
		3/21/74	22.6	22.8	-0.2
		5/16/74	24.4	24.5	-0.1
		5/23/74	23.7	24.2	-0.5
		6/1/74	23.6	22.1	+1.5

1/ Stages are in feet above gage datum. Forecast crest stages were obtained from flood warning tables.

2/ These stations are outside the area covered by the Southeast River Forecast Center but we were asked to prepare flood warning tables.

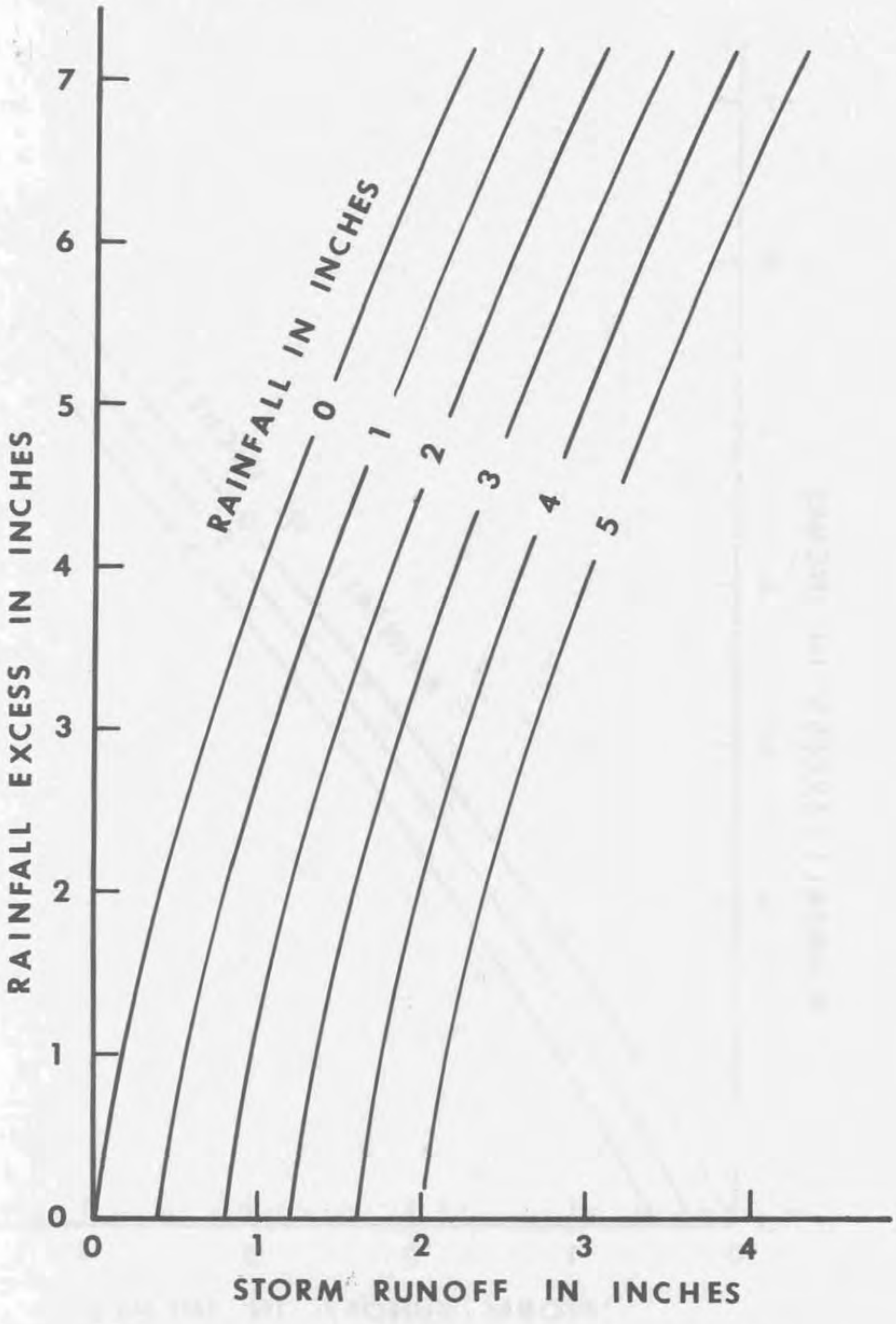

Figure 1.--Relationship Between Rainfall Excess, Rainfall, and Storm Runoff for Peachtree Creek at Atlanta, Ga.

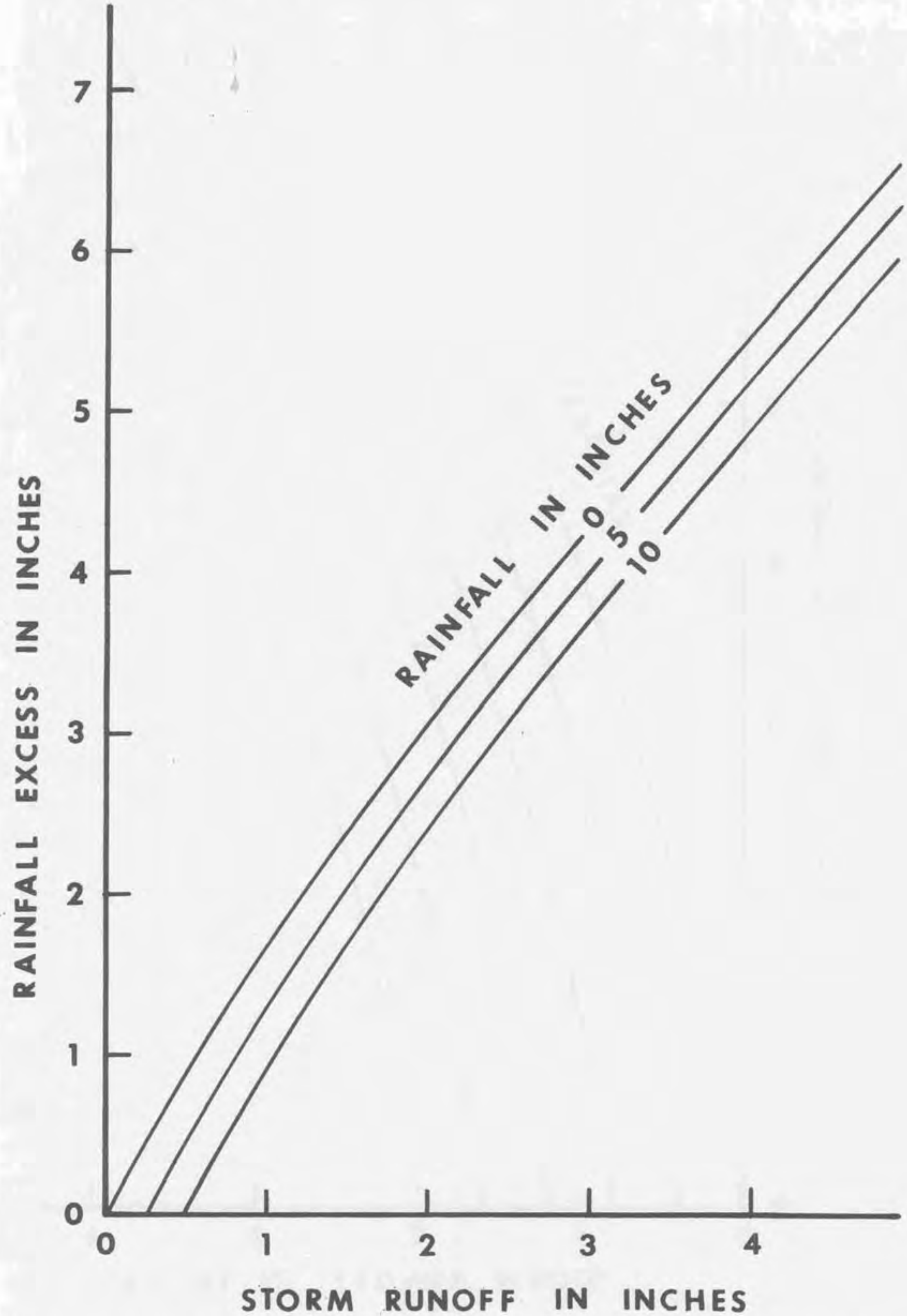

Figure 2.--Relationship Between Rainfall Excess, Rainfall, and Storm Runoff For Sowashee Creek at Meridian, Miss.

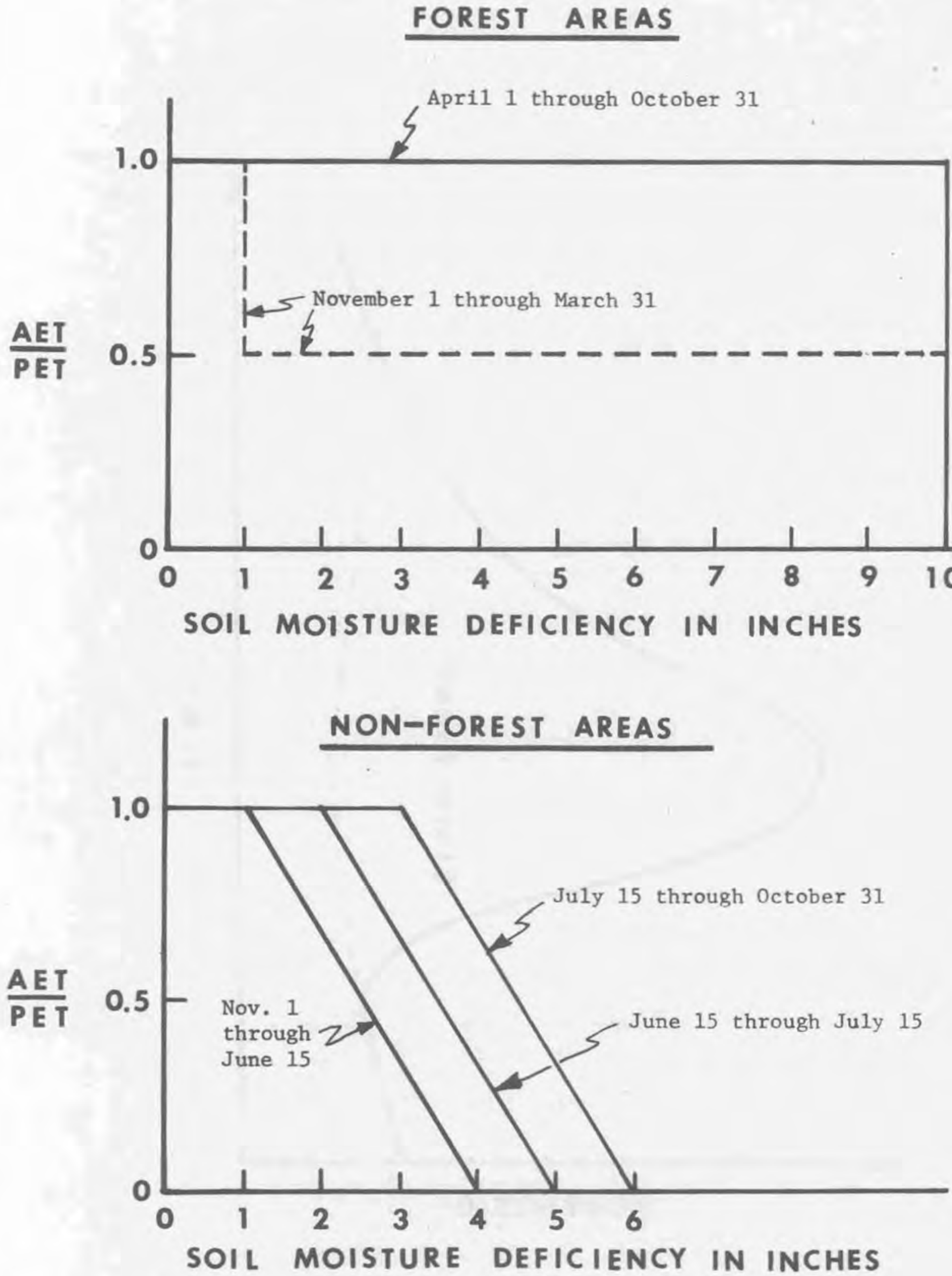

Figure 3.--Relationship Between Actual Evapotranspiration, Potential Evapotranspiration, and Soil Moisture Deficiency

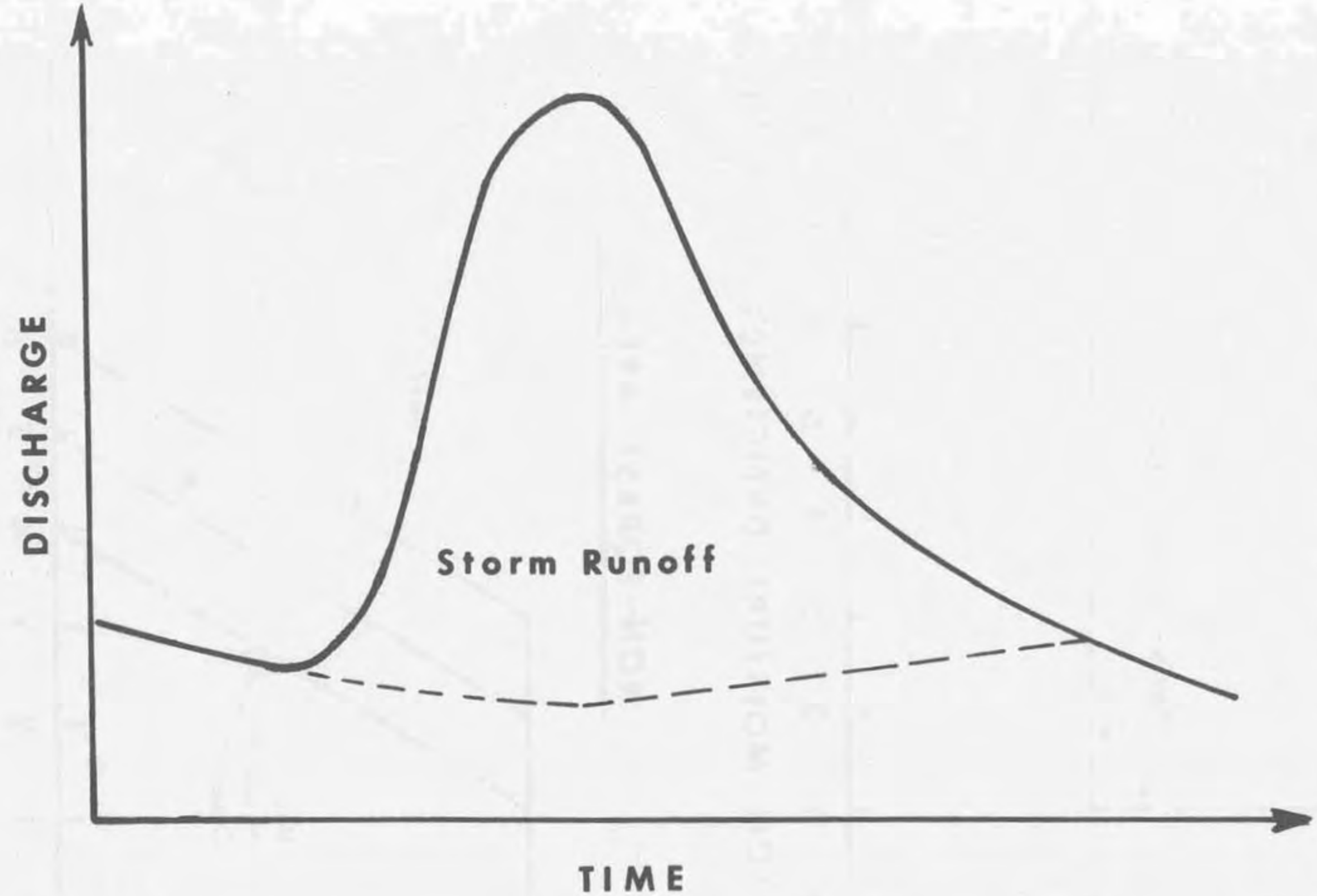

Figure 4.—Method of Hydrograph Separation

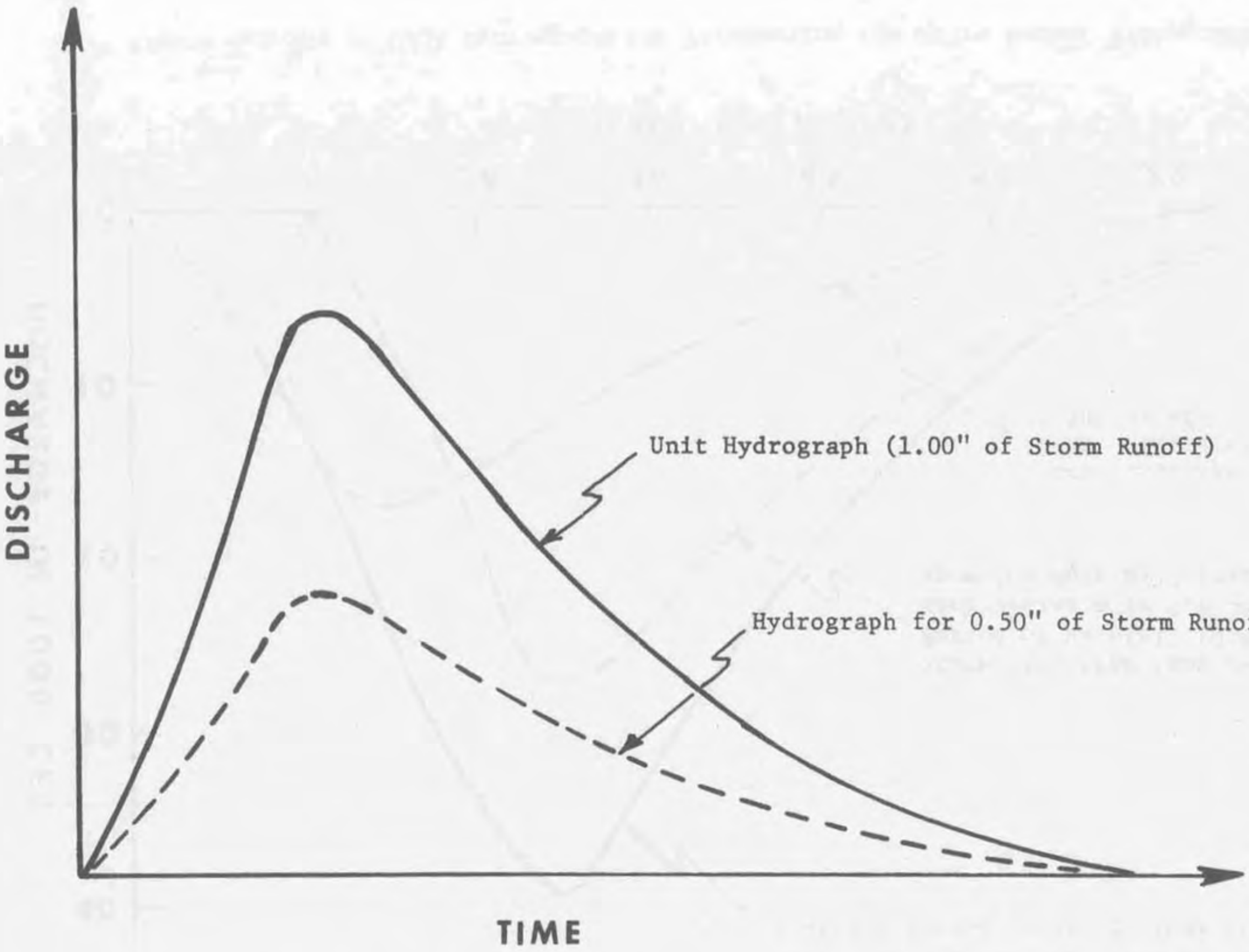

Figure 5.--Unit Hydrograph

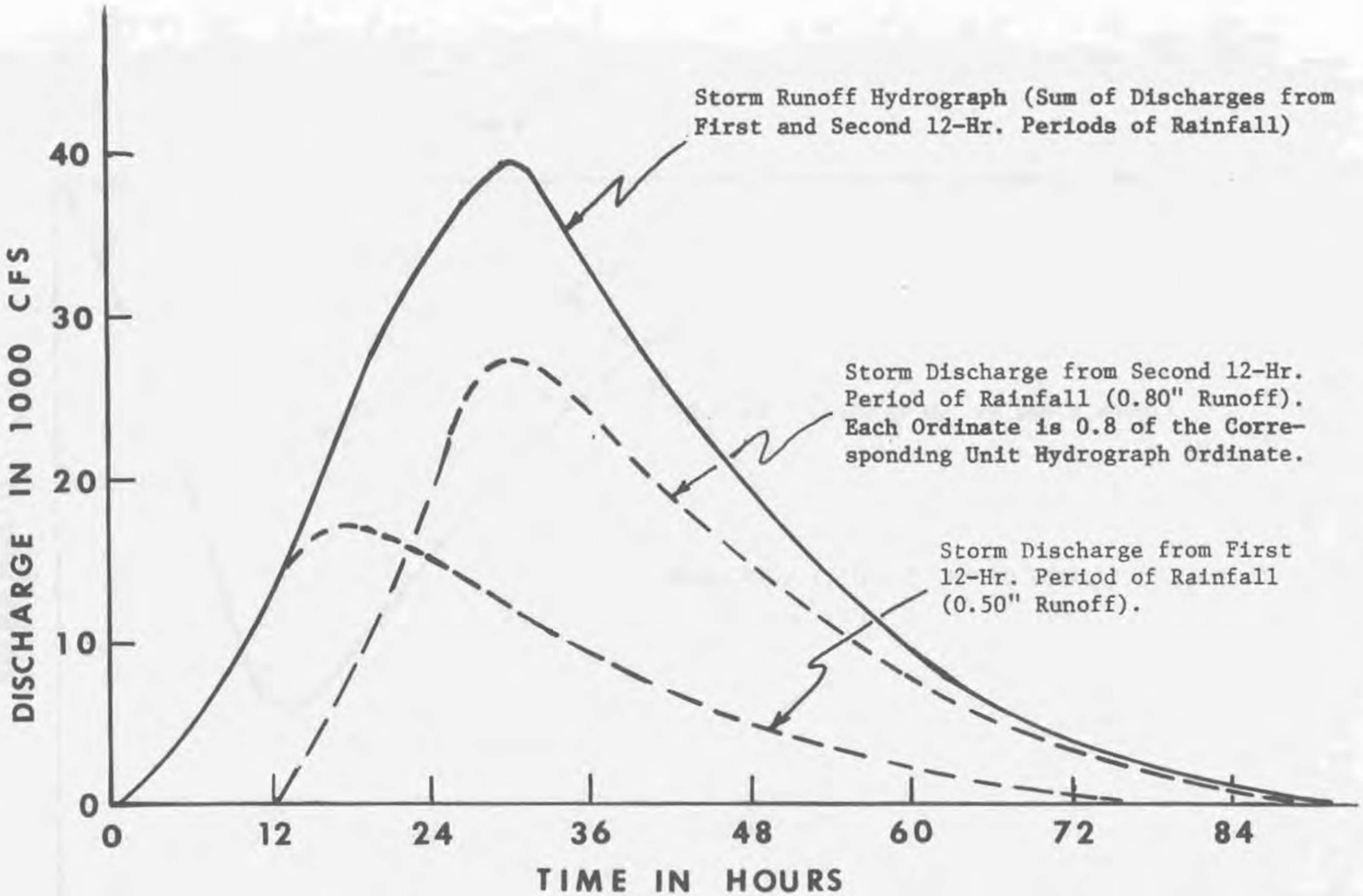

Figure 6.--Use of Unit Hydrograph for Forecasting the Storm Runoff Hydrograph

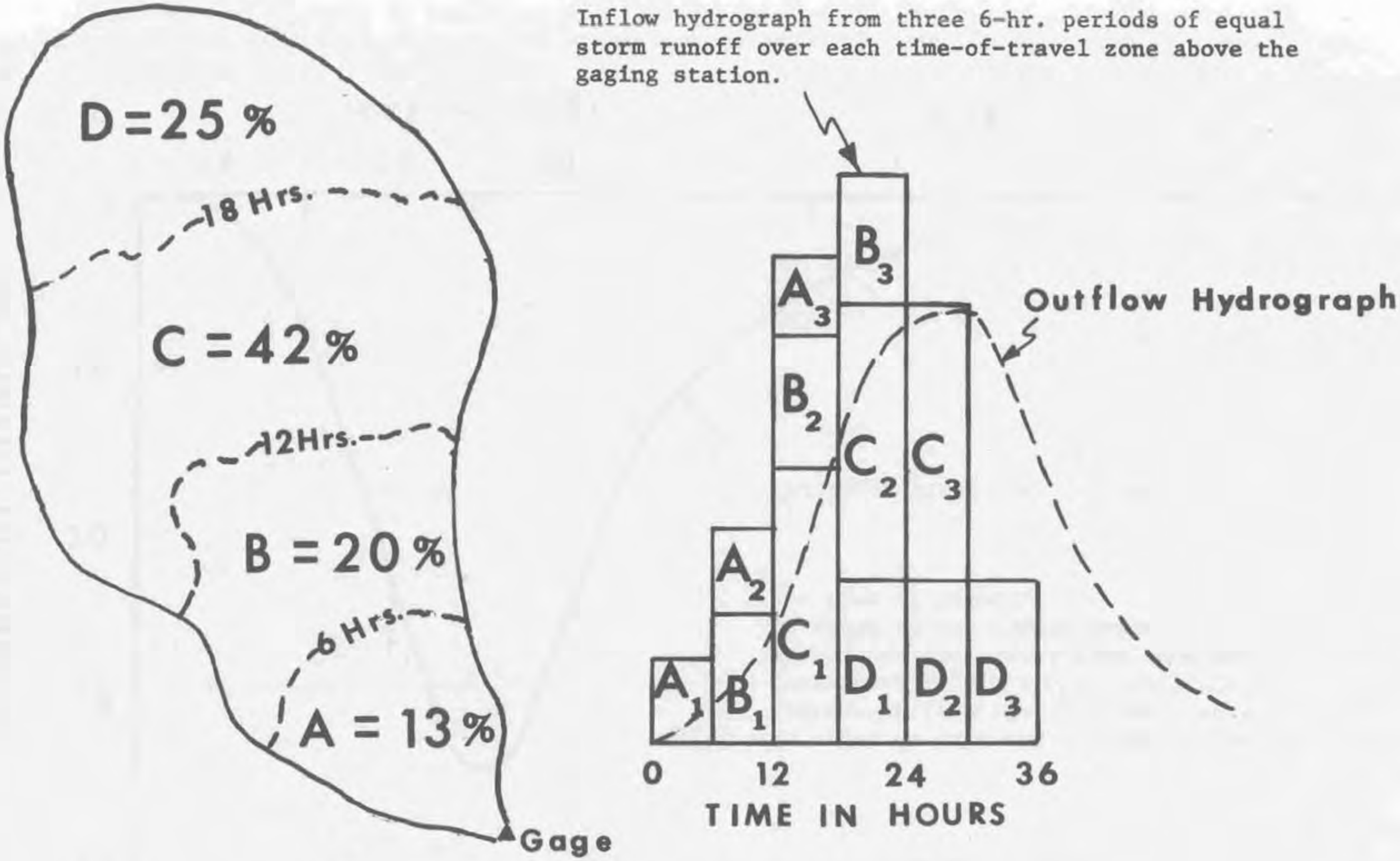

Figure 7.--Derivation of inflow and outflow hydrographs from time-of-travel zones.

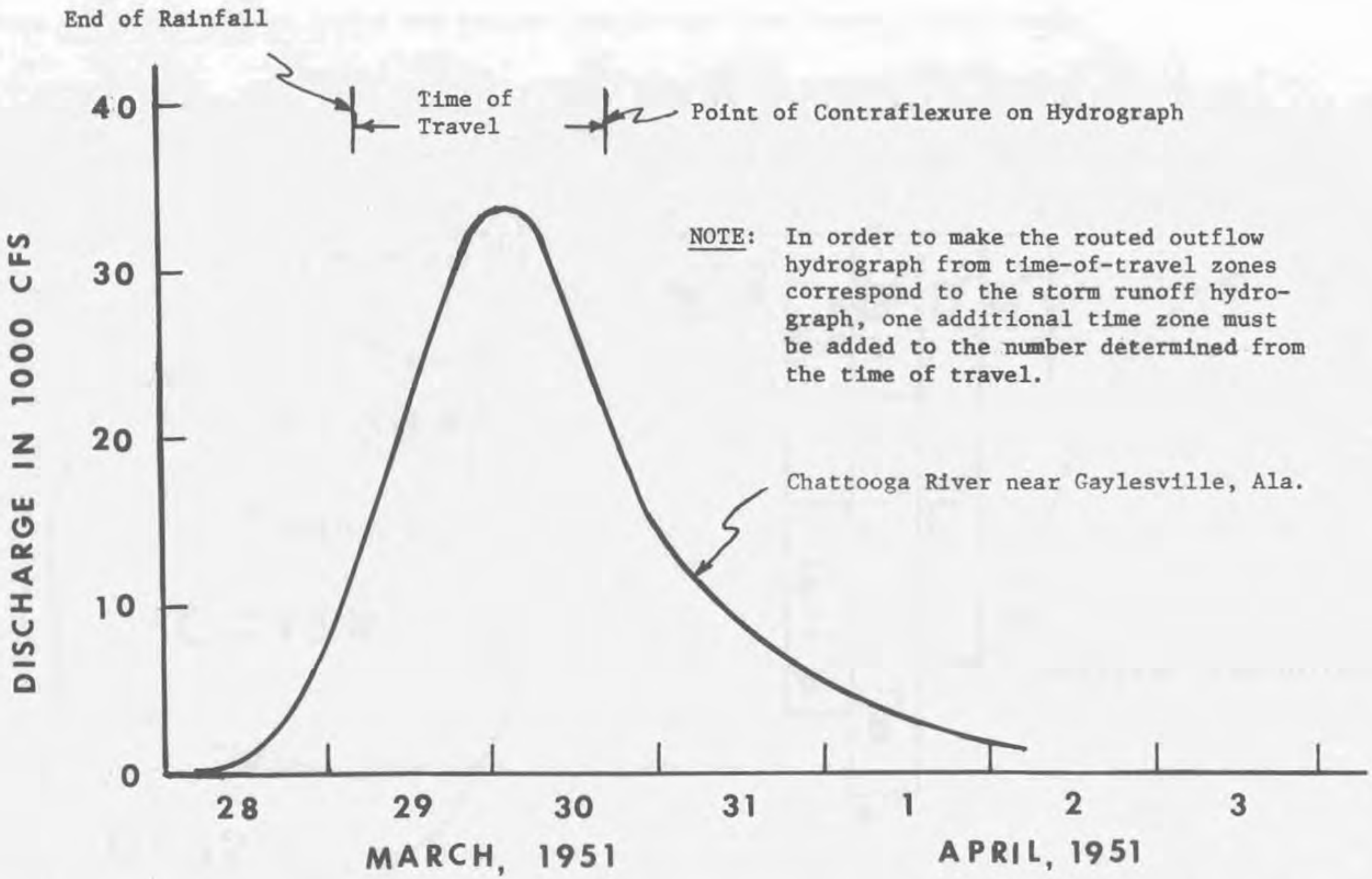

Figure 8.--Discharge Hydrograph for Chattooga River near Gaylesville, Ala. Showing Time of Travel from Upstream End of Basin to Gaylesville

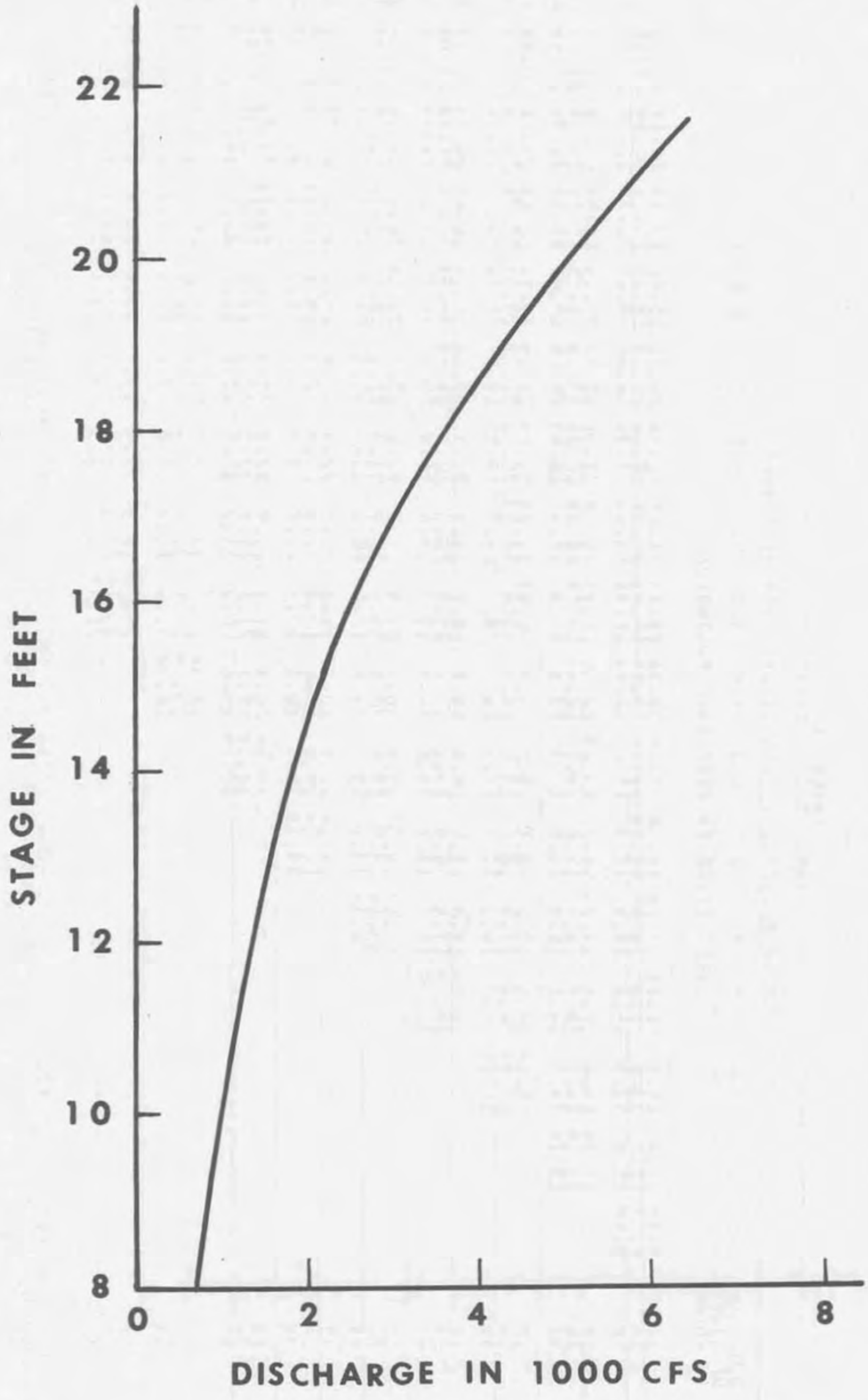

Figure 9.--Stage-Discharge Relation for Sowashee Cr. at Meridian, Mississippi.

FLOOD WARNING TABLE
SOWASHEE CREEK AT MERIDIAN MISS.
FLOOD STAGE - 15.0 FT.

TABLE 1
(SMD 0.0 - 0.5)

RAINFALL IN LAST 6 HOURS	DURATION OF STORM IN HOURS	TOTAL STORM RAINFALL IN INCHES OVER DRAINAGE AREA																
		1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	7.0	8.0	10.0	12.0	16.0	20.0
		CREST STAGE IN FEET (SEE FOOTNOTE)																
1.0	12	9.9*	12.4	14.3	15.7$	17.1$	18.3$	19.4$	20.3$	21.1$	21.8$	22.6$	24.2$	25.4$	27.1$	28.8$	30.9$	32.4$
	24	9.9*	12.2	13.6	14.8	16.0$	17.1$	18.1$	18.9$	19.6$	20.3$	20.8$	22.0$	23.2$	25.3$	26.6$	29.1$	30.7$
	48	9.9*	11.7	12.3	13.5	14.5	15.3	15.8	16.4$	16.9$	17.4$	17.9$	18.8$	19.8$	21.3$	22.9$	25.5$	27.2$
1.5	12		13.1*	14.8	16.1	17.2	18.2	19.0$	20.0$	20.8$	21.5$	22.3$	23.9$	25.2$	26.9$	28.6$	30.8$	32.3$
	24		13.1*	14.7	15.7	16.6	17.4	18.1	18.8$	19.5$	20.2$	20.8$	21.9$	23.1$	25.3$	26.5$	29.1$	30.7$
	48		13.1*	14.4	15.1	15.9	16.5	16.9	17.3	17.6	17.9	18.2$	19.0$	19.8$	21.1$	22.7$	25.4$	27.1$
2.0	12			15.2*	16.5	17.6	18.4	19.2	19.9	20.5$	21.2$	22.0$	23.6$	25.1$	26.8$	28.5$	30.8$	32.2$
	24			15.2*	16.4	17.2	18.0	18.6	19.1	19.6	20.1$	20.7$	21.8$	23.0$	25.2$	26.5$	29.0$	30.7$
	48			15.2*	16.2	16.8	17.3	17.9	18.2	18.5	18.7	19.0	19.5	20.1$	21.3$	22.7$	25.3$	26.9$
2.5	12				16.7*	17.9	18.7	19.5	20.2	20.7	21.2	21.7	23.3$	24.9$	26.6$	28.3$	30.7$	32.2$
	24				16.7*	17.8	18.5	19.1	19.6	20.1	20.5	20.8	21.8$	22.9$	25.2$	26.4$	29.0$	30.6$
	48				16.7*	17.7	18.1	18.5	18.9	19.3	19.6	19.8	20.2	20.7	21.6$	22.9$	25.2$	26.8$
3.0	12					18.1*	19.0	19.7	20.4	20.9	21.5	22.0	23.1	24.6$	26.4$	28.1$	30.6$	32.1$
	24					18.1*	18.9	19.5	20.1	20.5	20.9	21.3	22.1	22.9	25.1$	26.4$	28.9$	30.6$
	48					18.1*	18.8	19.2	19.6	20.0	20.2	20.4	20.9	21.3	22.1	23.1$	25.3$	26.7$
3.5	12						19.1*	20.0	20.6	21.1	21.7	22.3	23.4	24.5	26.3$	28.0$	30.6$	32.0$
	24						19.1*	19.9	20.4	20.8	21.3	21.7	22.5	23.3	25.1$	26.3$	28.9$	30.6$
	48						19.1*	19.6	20.1	20.4	20.7	21.0	21.5	21.9	22.8	23.7	25.4$	26.8$
4.0	12							20.1*	20.8	21.3	21.9	22.5	23.6	24.8	26.1$	27.8$	30.5$	31.9$
	24							20.1*	20.7	21.2	21.6	22.0	22.9	23.7	25.2	26.3$	28.8$	30.6$
	48							20.1*	20.6	20.9	21.2	21.5	22.1	22.5	23.4	24.4	25.5$	26.9$
4.5	12								20.9*	21.5	22.1	22.7	23.9	25.0	26.2	27.7$	30.4$	31.9$
	24								20.9*	21.5	21.9	22.4	23.3	24.2	25.4	26.3	28.8$	30.5$
	48								20.9*	21.4	21.7	22.0	22.6	23.1	24.1	25.0	25.8	27.0$
5.0	12									21.7*	22.3	22.9	24.1	25.1	26.3	27.5	30.4$	31.8$
	24									21.7*	22.3	22.7	23.7	24.6	25.6	26.5	28.7$	30.5$
	48									21.7*	22.2	22.5	23.2	23.7	24.7	25.3	26.2	27.1$

THE CREST STAGE NORMALLY OCCURS ABOUT 8 TO 12 HOURS AFTER THE END OF HEAVY RAINFALL. WHEN ISSUING THE CREST STAGE FORECAST, ROUND OFF TO THE NEAREST WHOLE FOOT. COMPUTE THE FORECAST FROM THE DURATION(AND THE RAINFALL FOR THAT DURATION WHICH GIVES THE HIGHEST CREST STAGE. THIS MAY BE LESS RAINFALL AND DURATION THAN THE STORM TOTAL RAINFALL AND DURATION. IF THE RAINFALL EXCEEDS 5.0 INCHES IN THE LAST 6 HOURS, USE 5.0 INCHES AND THE STORM RAINFALL AND DURATION THAT WILL GIVE THE HIGHEST CREST STAGE.

* RAINFALL DURATION FOR THESE CREST STAGE VALUES IS 6 HOURS.

$ DUE TO PREVIOUS HEAVY RAINFALL, THE CREST STAGE SHOULD OCCUR AT LEAST 6 HOURS EARLIER THAN NORMAL AND MAY HAVE ALREADY OCCURRED.

Figure 10 - Table 1 of flood warning tables for Sowashee Creek at Meridian, Miss.

FLOOD WARNING TABLE
SOWASHEE CREEK AT MERIDIAN MISS.
FLOOD STAGE = 15.0 FT.

TABLE 6
(SMD 4.1 — 6.0)

RAINFALL IN LAST 6 HOURS	DURATION OF STORM IN HOURS	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	7.0	8.0	10.0	12.0	16.0	20.0
		TOTAL STORM RAINFALL IN INCHES OVER DRAINAGE AREA — CREST STAGE IN FEET (SEE FOOTNOTE)																
1.0	12	3.8*	4.1	4.4	4.7$	5.2$	5.6$	6.0$	6.3$	7.4$	10.8	13.5	16.3$	18.7$	22.1$	25.1$	28.5$	30.8$
	24	3.8*	4.0	4.2	4.4$	4.7$	5.0$	5.3$	5.5$	6.8	10.3	12.9	16.0$	18.4$	21.4$	24.0$	27.1$	29.7$
	48	3.8*	3.9	4.0	4.1	4.1	4.2	4.3$	4.5$	6.3	9.7	12.3	15.2	17.3$	19.9$	21.5$	25.0$	26.7$
1.5	12		4.2*	4.5	4.8	5.1	5.4$	5.8$	6.2$	7.5	10.9	14.0	16.4	18.4	21.8$	25.0$	28.3$	30.7$
	24		4.2*	4.4	4.6	4.8	4.9	5.2$	5.5$	7.0	10.4	13.4	16.2	18.2	21.2$	23.9$	27.1$	29.7$
	48		4.2*	4.3	4.4	4.5	4.6	4.6	4.7	6.5	9.9	12.9	16.0	17.7	20.0$	21.5$	24.7$	26.6$
2.0	12			4.6*	4.9	5.2	5.5	5.8	6.0$	7.5	11.0	14.0	16.8	18.7	21.5$	24.7$	28.2$	30.6$
	24			4.6*	4.8	5.0	5.2	5.4	5.5	7.1	10.5	13.6	16.6	18.5	21.1$	23.7$	27.0$	29.6$
	48			4.6*	4.7	4.8	4.9	5.0	5.0	6.7	10.1	13.1	16.4	18.2	20.0$	21.6$	24.5$	26.4$
2.5	12				5.1*	5.3	5.6	5.9	6.1	7.6	11.0	14.0	17.0	18.9	21.4	24.4$	28.0$	30.6$
	24				5.1*	5.2	5.4	5.6	5.8	7.3	10.7	13.7	16.8	18.8	21.2	23.6$	26.9$	29.6$
	48				5.1*	5.1	5.2	5.3	5.4	7.0	10.3	13.3	16.6	18.6	20.5	21.7$	24.7$	26.3$
3.0	12					5.5*	5.8	6.0	6.2	7.7	11.1	14.1	17.0	19.2	21.7	24.1$	27.8$	30.5$
	24					5.5*	5.7	5.8	6.0	7.5	10.8	13.8	16.6	19.0	21.5	23.4$	26.9$	29.5$
	48					5.5*	5.6	5.6	5.7	7.2	10.5	13.5	16.7	18.9	21.0	22.2	24.9$	26.3$
3.5	12						5.9*	6.1	6.3	7.8	11.2	14.1	17.0	19.3	21.9	24.1	27.7$	30.4$
	24						5.9*	6.0	6.2	7.6	11.0	14.0	16.9	19.2	21.7	23.7	26.8$	29.5$
	48						5.9*	6.0	6.0	7.4	10.7	13.7	16.7	19.0	21.4	22.7	25.0$	26.4$
4.0	12							6.2*	6.4	7.9	11.3	14.2	17.0	19.3	22.1	24.4	27.5$	30.4$
	24							6.2*	6.3	7.8	11.1	14.0	16.9	19.2	21.9	24.1	26.7$	29.4$
	48							6.2*	6.3	7.7	10.9	13.9	16.8	19.1	21.7	23.3	25.2	26.5$
4.5	12								6.5*	8.0	11.4	14.2	17.1	19.3	22.3	24.6	27.4$	30.3$
	24								6.5*	8.0	11.2	14.1	17.0	19.2	22.2	24.4	26.7	29.3$
	48								6.5*	7.9	11.1	14.0	16.9	19.1	22.0	23.7	25.5	26.6$
5.0	12									8.1*	11.4	14.3	17.1	19.4	22.5	24.9	27.3	30.2$
	24									8.1*	11.4	14.2	17.0	19.3	22.4	24.7	26.9	29.3$
	48									8.1*	11.3	14.1	16.9	19.2	22.3	24.2	25.8	26.7

THE CREST STAGE NORMALLY OCCURS ABOUT 8 TO 12 HOURS AFTER THE END OF HEAVY RAINFALL. WHEN ISSUING THE CREST STAGE FORECAST, ROUND OFF TO THE NEAREST WHOLE FOOT. COMPUTE THE FORECAST FROM THE DURATION(AND THE RAINFALL FOR THAT DURATION WHICH GIVES THE HIGHEST CREST STAGE. THIS MAY BE LESS RAINFALL AND DURATION THAN THE STORM TOTAL RAINFALL AND DURATION. IF THE RAINFALL EXCEEDS 5.0 INCHES IN THE LAST 6 HOURS, USE 5.0 INCHES AND THE STORM RAINFALL AND DURATION THAT WILL GIVE THE HIGHEST CREST STAGE.

* RAINFALL DURATION FOR THESE CREST STAGE VALUES IS 6 HOURS.

$ DUE TO PREVIOUS HEAVY RAINFALL, THE CREST STAGE SHOULD OCCUR AT LEAST 6 HOURS EARLIER THAN NORMAL AND MAY HAVE ALREADY OCCURRED.

Figure 11 - Table 6 of flood warning tables for Sowashee Creek at Meridian, Miss.

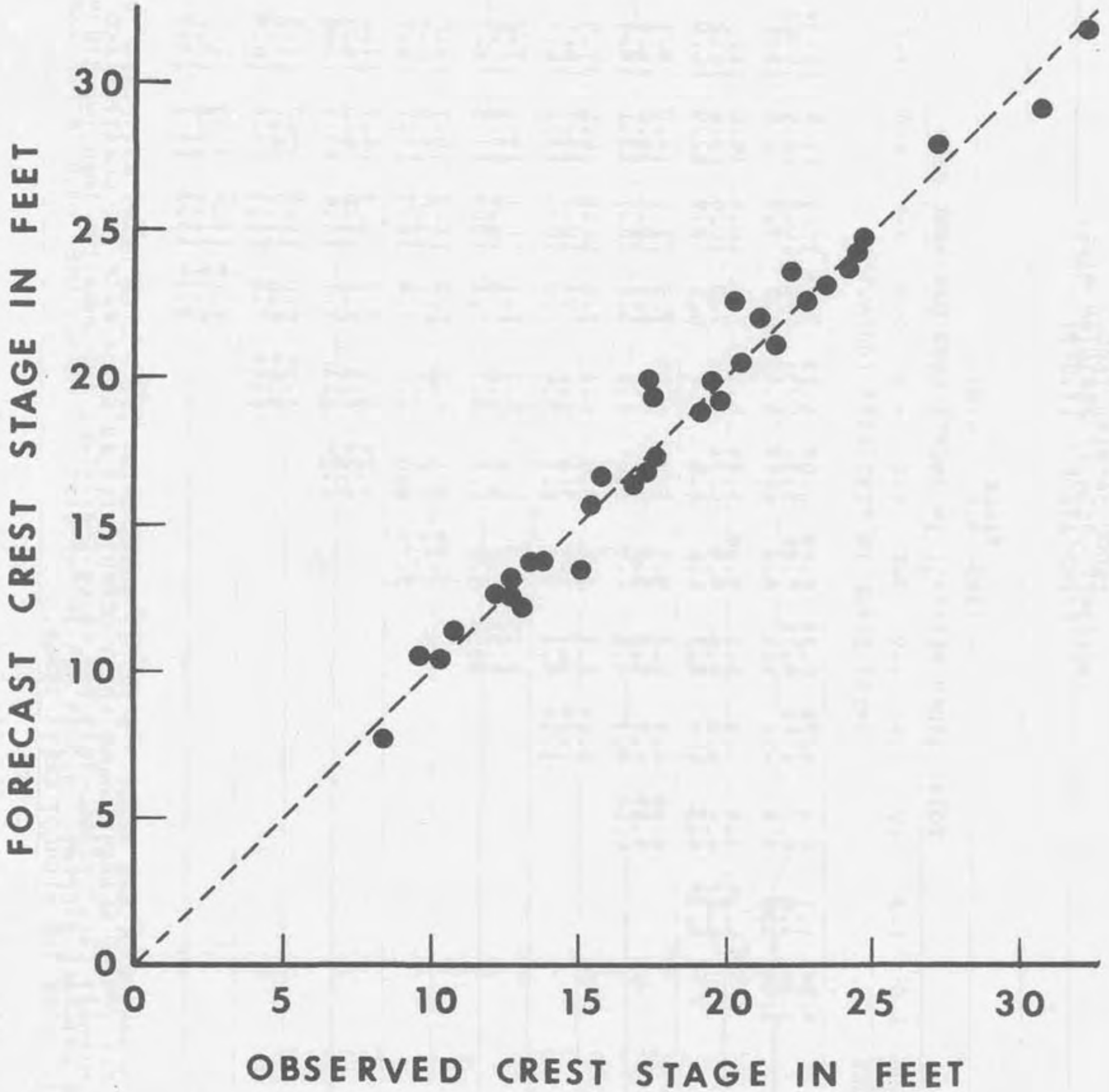

Figure 12.--Comparison of Forecast and Observed Crest Stages

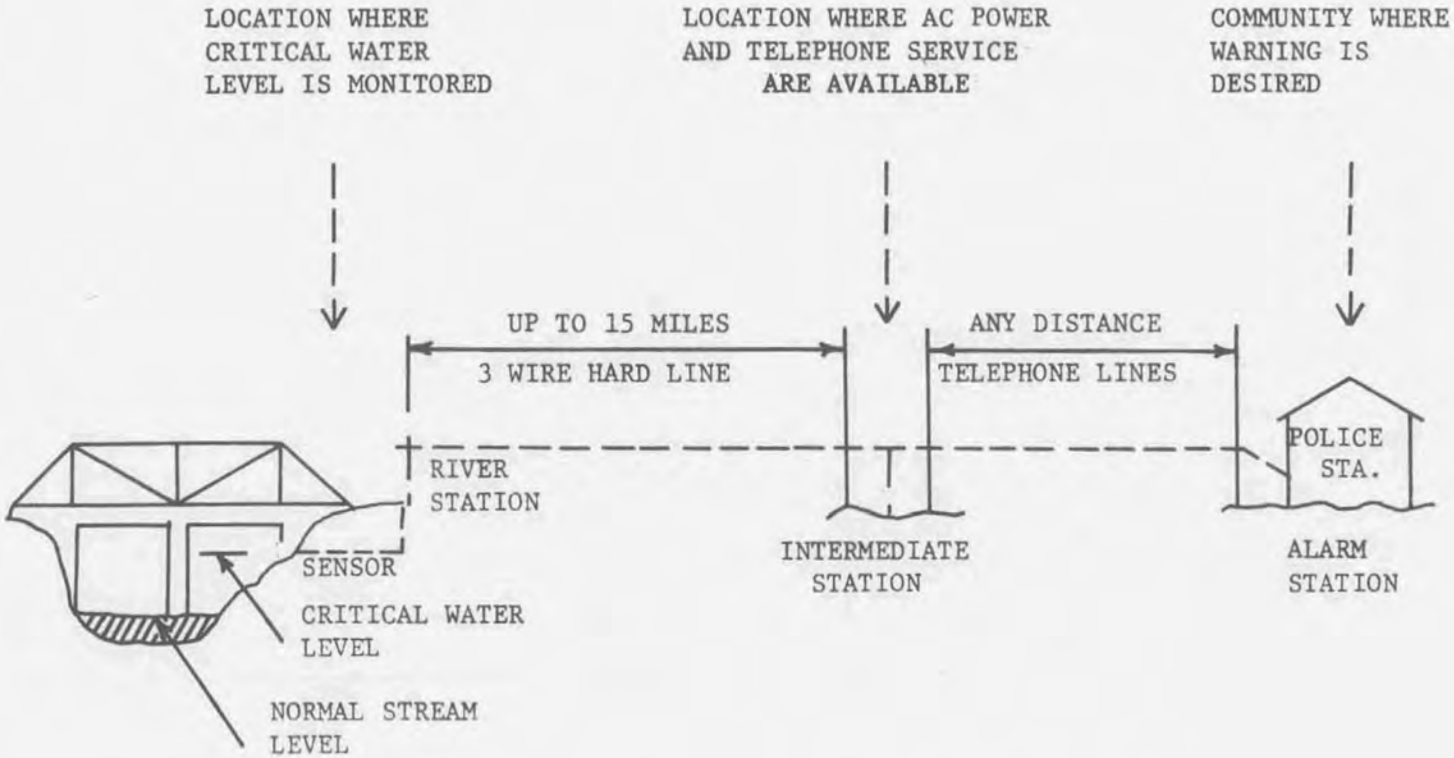

Figure 13.--Typical Flash Flood Alarm System