HYDROMETEOROLOGICAL REPORT NO. 45

Probable Maximum and TVA Precipitation for Tennessee River Basins up to 3,000 Square Miles in Area and Durations to 72 Hours

U.S. DEPARTMENT OF COMMERCE
ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION
WEATHER BUREAU
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HYDROMETEOROLOGICAL REPORTS

*No. 1. Maximum possible precipitation over the Ompompanoosuc Basin above Union Village, Vt. 1943.
*No. 2. Maximum possible precipitation over the Ohio River Basin above Pittsburgh, Pa. 1942.
*No. 3. Maximum possible precipitation over the Sacramento Basin of California. 1943.
*No. 4. Maximum possible precipitation over the Panama Canal Basin. 1943.
*No. 5. Thunderstorm rainfall. 1947.
*No. 6. A preliminary report on the probable occurrence of excessive precipitation over Fort Supply Basin, Okla. 1938.
*No. 7. Worst probable meteorological condition on Mill Creek, Butler and Hamilton Counties, Ohio. 1937. (Unpublished.) Supplement, 1938.
*No. 8. A hydrometeorological analysis of possible maximum precipitation over St. Francis River Basin above Wappapello, Mo. 1938.
*No. 9. A report on the possible occurrence of maximum precipitation over White River Basin above Mud Mountain Dam site, Wash. 1939.
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*No. 16. A preliminary report on the maximum possible precipitation over the Potomac and Rappahannock River Basins. 1943.
*No. 17. Maximum possible precipitation over the Pecos Basin of New Mexico. 1944. (Unpublished.)
*No. 18. Tentative estimates of maximum possible flood-producing meteorological conditions in the Columbia River Basin. 1945.
*No. 19. Preliminary report on depth-duration-frequency characteristics of precipitation over the Muskingum Basin for 1- to 9-week periods. 1945.
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*No. 25A. Representative 12-hour dewpoints in major United States storms east of the Continental Divide. 2d edition. 1949.
*No. 26. Analysis of winds over Lake Okeechobee during tropical storm of August 26–27, 1949. 1951.
*No. 27. Estimate of maximum possible precipitation, Rio Grande Basin, Fort Quitman to Zapata. 1951.
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*No. 29. Seasonal variation of the standard project storm for areas of 200 and 1,000 square miles east of 105th meridian. 1953.
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No. 38. Meteorology of flood-producing storms in the Ohio River Basin. 1961.
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No. 40. Probable maximum precipitation, Susquehanna River drainage above Harrisburg, Pa. 1965.
No. 41. Probable maximum and TVA precipitation over the Tennessee River Basin above Chattanooga. 1965.
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No. 43. Probable maximum precipitation, Northwest States. 1966.
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ADDENDUM

to

Hydrometeorological Report No. 45

PROBABLE MAXIMUM AND TVA PRECIPITATION FOR TENNESSEE RIVER BASINS UP TO 3,000 SQUARE MILES IN AREA AND DURATIONS TO 72 HOURS

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FIGURES

ADDENDUM

TO

HYDROMETEOROLOGICAL REPORT NO. 45

PROBABLE MAXIMUM AND TVA PRECIPITATION FOR TENNESSEE RIVER BASINS UP TO 3,000 SQUARE MILES IN AREA AND DURATIONS TO 72 HOURS

Introduction

Users of Hydrometeorological Report No. 45, "Probable Maximum and TVA Precipitation for Tennessee River Basins up to 3,000 Square Miles in Area and Durations to 72 Hours," (HMR 45) have indicated the need for guidance in handling problems involving the two separate generalized procedures in the report. One procedure is for basin sizes up to 100 sq mi, while the other is for basin sizes from 100 to 3,000 sq mi. The application of these methods gives some answers differing by more than 10 percent at the 100-sq-mi interface. This Addendum provides modifications to the procedures for determining specific basin estimates from the large basins generalized criteria that minimize these differences. In addition, guidance is provided for reconciling differences that may still exist.

The modifications to the generalized procedure are summarized in figures A1 and A2. Figure A1 shows the percentage increase to apply in the large-area generalized approach based on the degree and amount of terrain augmentation of thunderstorm rainfall over areas of 100 sq mi. Figure A2 provides for reducing the percentage as the influence of thunderstorm activity decreases with increasing size of basin.

This Addendum also gives revisions to some of the figures in HMR 45. None of these revisions are major. The generalized sheltering adjustments for the eastern half of the Tennessee River Watershed (figs. 2-17 and 2-20) have been combined and some slight increase in the sheltering effect over the western half of this region indicated. The depth-duration relations of figures 2-34 to 2-37 have been extended to cover a wider range of precipitation values. These curves are unchanged except for some minor smoothing between the old curves and their extensions. Changes in the nomogram for isohyet labels in the pattern storms result from a change in concept. In HMR 45, a pattern storm is recommended for the first three 6-hr increments. In this Addendum, a pattern storm is recommended only for the first 6-hr increment. *

Finally, stepwise procedures for computing PMP and TVA precipitation estimates are given, taking into account the modifications developed in this Addendum and the revisions in the figures of HMR 45. These stepwise procedures also clarify some ambiguous wording of HMR 45.

Computations of PMP for 100 sq mi were made using the small-basin procedure and the modified large-basin procedure for a network of grid points covering the Tennessee River Watershed. Differences were found to be within acceptable limits.

Differences in Estimates at 100-Sq-Mi Interface

Problem

In the procedure for basins up to 100 sq mi, PMP and TVA precipitation estimates are developed from consideration of the thunderstorm mechanism. In the developed criteria, rough topography gives small-area thunderstorm rainfall 20 percent greater than that over smooth (essentially level) terrain. This 20 percent difference is shown for the 6-hr duration in figures 2-14 and 2-15 of HMR 45. The 20-percent orographic factor is not related to additional lifting by slopes. Rather, the terrain increases the rainfall by "triggering" and "fixing" effects. The thunderstorm itself provides adequate vertical motion.

The generalized procedure in HMR 45 for basins larger than 100 sq mi is based on synoptic situations with inflow of moisture in wider bands than those involving concentrated thunderstorm rainfall. In such storms, increases in rain due to additional lifting caused by slopes and decreases due to sheltering in lee areas are important. Although all the eastern mountainous region (hatched area of fig. 3-21 in HMR 45) is classified as rough, the total orographic effects in this region may be more (where there is forced ascent from ground slopes) or less (where sheltering decreases moisture supply) than the basic 20-percent increase that results from a rough terrain classification in the procedure for small basins.

Special evaluation of the orographic effects was made in HMR 45 for specific basins, many of them outside the hatched area of figure 3-21; for example, the Clinch River drainage in the eastern half and the Duck River drainage in the western half of the Tennessee River Watershed. This Addendum does not attempt to duplicate the specific adjustments made in the precipitation estimates for these basins. The overall smoothed results of these and other specific basin estimates are the basis for the relation shown in figure 3-22 of HMR 45.

Solution

From the earlier discussion, it can be seen that the adopted procedures of HMR 45 made up of the thunderstorm type for small basins and of the more general storm type for large basins may lead to differences in estimates at the interface of 100 sq mi, since thunderstorm augmentation was not specifically evaluated in the large basin procedure in HMR 45. The large-basin procedure has been modified in this Addendum to minimize these differences. Figure A1 gives adjustments to be applied to the large-basin estimates for 100-sq-mi basins (maximum adjustment is 20 percent when basin is all rough). Figure A2 modifies the adjustment from figure A1 for basins larger than 100 sq mi. For the region west of 85°, 50 percent of the computed adjustments are used.

The logic of applying these adjustments is that the roughness factor (from "fixing" and "triggering" of thunderstorm activity over small basins) is applicable in a modified form (decreasing effect) for basins larger than 100 sq mi. For large basins with a significant inflow from an optimum direction, it is not realistic to assume that all rough areas will be effective in promoting thunderstorm fixing and triggering. The adopted decrease in the orographic effects associated with thunderstorm rainfall with increasing area size, figure A2, is applied to values determined from figure A1. One reads from figure A2 the adjustment that applies to the percentage increase determined from figure A1 for the size of the basin under consideration. Note that adjustments for basins greater than 500 sq mi remain constant at 25 percent of the adjustment determined in figure A1 for 100-sq-mi areas. For an all rough 500-sq-mi basin, this only amounts to an increase of 5 percent, a modest adjustment.

Use of the adjustments, figures A1 and A2, for all basins of 100 sq mi or more except for those in the mountainous east (hatched area of figure 3-21 of HMR 45) is as follows. First locate the basin on figure 2-22A or 2-22B of HMR 45. Then determine the percent of the basin in each of the three terrain categories (rough, intermediate, and smooth) and compute the percentage increases based on these percents (fig. A1) and the modification for the area size (fig. A2). For convenience, the criteria for terrain classification are shown in figure A1. For basins west of 85°, one-half of the computed adjustments are used.

As an example, suppose a 200-sq-mi basin in the eastern half of the Tennessee River Watershed (other than the hatched area of fig. 3-21 in HMR 45) has 20 percent of its area classified rough (rainfall greater than 17.0 in.), 50 percent intermediate (rainfall between and including 16.0 and 17.0 in.), and 30 percent smooth (rainfall less than 16.0 in.). A combined adjustment is then obtained from figure A1, considering the percent of the basin in rough and intermediate terrain. In our example, this amounts to 9 percent (4 percent for the 20 percent rough portion of the basin plus an additional 5 percent for the 50 percent intermediate portion of the basin). Therefore, the nonorographic basin PMP and TVA precipitation values are increased 9 percent for the roughness of the basin topography. This 9 percent would apply unadjusted if the basin were 100 sq mi. The reduction to this orographic increase for basin size is obtained from figure A2. The percent increase obtained from figure A1 is multiplied by the percent from figure A2 for the area of the basin. In our example, this would be 64 percent (200-sq-mi basin) times 9 percent to give an increase of 5.8 percent.

In the mountainous east, the entire region is classified as rough. Additionally, other orographic effects are incorporated into the 6-hr 5-sq-mi PMP index map. To evaluate the effects of thunderstorm "triggering" and "fixing" and the other orographic effects appropriate to basins larger than 100 sq mi, first, the blanket 20 percent adjustment must be removed. Then, the appropriate adjustment for the effects of thunderstorms over large basins can be incorporated as explained in the preceding paragraph.

We believe the use of figures A1 and A2 and other suggestions in this Addendum will minimize the need for the subjective modifications for orography suggested in HMR 45. For example, on page 83 of HMR 45, it states, "These values should be increased slightly in the rougher regions of the Cumberland Plateau . . . ." Also, on page 83, the user was advised to blend chapter II estimates for small basins with those derived by chapter III for larger basins. On page 89, it is pointed out that, except for basins up to "a few tens of square miles," the user needs to consider orography in a more detailed manner, as was done in each case for the specific basin estimates made in the report.

Application of modifications in this Addendum for large basins may still result in differences between the large- and small-basin estimates. Our recommendations on how they should be reconciled can be illustrated by the following two hypothetical, but realistically possible, situations. Suppose numerous project sites are involved on the same tributary with the basin sizes ranging from 50 to 500 sq mi, thus embracing the 100-sq-mi interface.

One possibility is that the larger basin estimate, when extrapolated by the larger basin depth-area relation to 100 sq mi, has a smaller value than does the estimate from use of the smaller basin procedure when its estimate is extrapolated by the appropriate small-basin depth-area relation to an area of 100 sq mi. In such a situation, we recommend the small-basin estimate be accepted and that a depth-area curve (for the appropriate duration) be blended into the large-basin depth-area curve at an area of 500 sq mi or less. This is accomplished by extending smoothly the small-basin depth-area curve beyond 100 sq mi and then gradually changing its curvature until it smoothly joins the large-basin depth-area curve at around 500 sq mi.

Another possibility is that a subbasin less than 100 sq mi in area (say, 96 sq mi) has an estimated PMP less than, say, a 104-sq-mi basin that includes the 96-sq-mi drainage. For such a situation, we recommend that the basin estimate for the larger basin be accepted. To obtain the "corrected" estimate for the smaller basin, extend the large-basin estimate to 100 sq mi by smoothing into the appropriate small-basin depth-area relation (fig. 2-23 of HMR 45) to obtain values for smaller areas.

The examples just cited involve the problem of consistent relationships for basins near the 100-sq-mi interface. Another problem that still exists and that cannot be fully resolved by the Addendum procedures concerns differences that result between estimates from a generalized procedure and estimates where special attention was given to particular basins. Generalized procedures have the important advantage of providing consistency. Individual estimates, on the other hand, enable one to devote attention to details that must be smoothed over in the generalized approach. It is impossible to make results from generalized procedures completely consistent with estimates prepared for a specific basin. If it is more important to have complete consistency, the results from the generalized procedure must be used for all basins at the sacrifice of some accuracy for those basins for which individual estimates have been prepared. The alternate solution would be to make detailed studies for all specific basins of concern.

Revision of Figures in HMR 45

Introduction

Studies of HMR 45 were originally planned to cover estimates only for a certain number of specific large basins. During the course of the studies, requirements were expanded. Thus, the report did not cover the entire range of basin sizes without some extrapolation in some of the figures by the user. In the Addendum, a number of the figures from HMR 45 have been extended or amended to provide for more complete generalization. These have the same figure numbers as those in the report, except that they are preceded by letter "A."

Combined Figures 2-17 and 2-20

Figures 2-17 (broad-scale sheltering for mountainous east) and 2-20 (moisture index for remainder of eastern half of the Tennessee River Watershed) have been combined and are presented in this Addendum as figure A3. What was formerly called the 100-percent line in HMR 45 (fig. 2-17) is now labeled as the zero adjustment curve of figure A3. North of the 10-percent line, the adjustment remains constant at 10 percent. Figure A3 eliminates some small discontinuities between the "sheltering effect" shown in figure 2-17 and the moisture lines shown in figure 2-20.

Extended Depth-Duration Relations

Figures A2-34 to A2-37 (numbered to coincide with HMR 45 numbering) extend depth-duration relations to include a wider range of PMP and TVA precipitation values. The extensions to HMR 45 figures avoid unrealistic depth-duration ratios, such as 1- to 3-hr rain ratios greater than 0.73 and 1- to 6-hr rain ratios greater than 0.60. To meet such criteria, the previous assumption of constant 1-hr depth used in HMR 45 was modified to give lower 1- and 3-hr values for smaller 6-hr depths.

The limiting 1- to 3-hr and 1- to 6-hr ratios in the previous paragraph are not to be interpreted as rigid upper limits. However, in developing variable depth-duration ratios for TVA precipitation in HMR 45, the rainfall data from both in and near the Tennessee River Watershed and applicable data from more distant places suggested a spectrum of ratios with the approximate limits indicated.

Extended Within-Basin Rain Distribution

Relations of figure 3-24, HMR 45, were extended to include within-basin distribution of rainfall for areas as small as 100 sq mi. The revised figure is numbered A3-24. In reevaluating within-basin distribution, the decision was made to use uniform distribution of rainfall for all 6-hr rain increments beyond the maximum 6-hr increment.

Revised Stepwise Procedure for Obtaining Rainfall Estimates

Large Basins Except in Hatched Area of Figure 3-21, HMR 45

The stepwise procedure for western and central Tennessee River Watersheds (HMR 45, pages 102-104) has been expanded to include the revised figures and modifications. The procedure that follows is applicable to all of the Tennessee River Watershed, except the hatched mountainous area outlined in figure 3-21 of HMR 45. The procedure is set up for computation of TVA precipitation. PMP is mentioned only where it adds to clarity.

Step A. Scale 6-, 12-, 18-, 24-, 48-, and 72-hr precipitation depths at basin size from figure 3-12 (fig. 3-11 for PMP). These are non-orographic precipitation values applicable to Knoxville Airport.

Step B. Read percent at center of basin from figure 3-13 or 3-14. Multiply values of step A by this percent. This adjusts the Knoxville Airport values for basin location.

Step C. Construct a smooth depth-duration curve from the values of step B in order to read smooth values for all cumulative 6-hr durations. This provides unadjusted enveloping depth-duration values for the basin.

Step D. Locate basin on figure 2-22A or 2-22B. If all of basin has a 6-hr 5-sq-mi TVA precipitation of less than 16.0 in. (all of basin classifies as smooth), go to step I.

Step E. Providing basin is not all smooth, determine the percent of basin, from figure 2-22A or 2-22B, that has TVA precipitation between and including 16.0 and 17.0 in. (intermediate classification) and greater than 17.0 in. (rough classification). Using these percentages, obtain adjustments from figure A1. The percent of the basin with less than 16.0 in. (smooth classification) needs no adjustment. The sum of required adjustments is used if the basin is east of 85°. If the basin is west of 85°, one-half of the computed adjustment is used. If basin area is larger than 100 sq mi, go to step F. Otherwise go to step G.

Step F. If basin area is larger than 100 sq mi, go to figure A2 using basin size and obtain percent to apply to the step E value.

Step G. Add 100 to the adjustment percent from either step E (basin is 100-sq-mi area) or F (for basins larger than 100 sq mi) and multiply by the values of step C.

Step H. For TVA precipitation, use figures A2-34 to A2-36, as appropriate. These give appropriate depth-duration values based upon critical storm duration. If smoother incremental values are required, again plot a depth-duration curve and read smoothed values.

Step I. Place the standard isohyetal pattern (HMR 45, fig. 3-23) in position that best fits the basin.

Step J. Obtain labels for isohyets for first 6-hr period by entering figure A3-24 with basin size and reading off ratios.

Step K. Multiply the 6-hr TVA precipitation from step C or G by the respective ratios from step J, obtaining the isohyetal labels for 6-hr TVA precipitation.

Step L. For the remaining 6-hr increments, use step C or G values directly as uniform depths throughout the basin.

Step M. Arrange the 6-hr increments with a time distribution as specified in HMR 45, page 102.

Step N. The maximum 3-hr increment can be obtained by using the ratios of 3-hr to 6-hr increments of figure 3-27.

Large Basins in the Mountainous East (i.e., Hatched Area of Figure 3-21)

Users have experienced some difficulty in applying the stepwise procedure for the mountainous east as outlined in HMR 45 on pages 104 to 107. The procedure has been rewritten to provide greater clarity. In addition, an actual, rather than a hypothetical, basin is used in the following example. The basin selected is the 295-sq-mi Little Tennessee River Watershed above Franklin, N.C., centered at 35°05'N latitude, 83°23'W longitude. Steps A to R in the following listing are for PMP computations; the remaining steps are for computation of TVA precipitation. Table A3-4 (numbered to coincide with HMR 45 numbering) lists major steps and computed values.

Some additional explanation of the rather lengthy step D seems advisable. In step D, the groundwork is laid for obtaining a total orographic value for the basin, which is corrected for basin size by the Addendum procedures. This basin-size adjusted orographic value is later used, by comparison with a non-orographic value, to obtain a net orographic effect (step F).

All of the mountainous east (hatched area of fig. 3-21 of HMR 45) is classified as rough and therefore a plus 20-percent roughness factor was used in preparing the basic charts. Figures 2-21B and 2-22B indicated some values that are of a magnitude less than rough. This is because the mountainous east values are made up of other orographic factors (in addition to roughness), such as upslope and downslope effects. Thus, the division by 1.20 temporarily removes the thunderstorm orographic component.

In order to further clarify the stepwise procedure that follows, a schematic diagram of the procedure is shown in figure A4.

Step A. Scale 6-, 12-, 18-, 24-, 48-, and 72-hr precipitation depths at basin size from figure 3-11. These are non-orographic values appropriate to Knoxville Airport (line A).

Step B. Read percent at center of basin from figure 3-14 (line B). This is the adjustment to Knoxville Airport values for basin location.

Step C. Multiply values of line A by line B. This gives the non-orographic geographically adjusted PMP values (line C).

Note: The first three steps provide non-orographic PMP for the basin. The next six steps develop the orographic adjustment appropriate to this basin.

Step D. Lay out the basin on figure 2-21B and determine the basin average 6-hr 5-sq-mi PMP. This value (32.2 in.) needs to be adjusted by use of figures A1 and A2. Since basins in the hatched area of figure 3-21, including the 295-sq-mi basin under consideration, are all 100 percent rough, there is a small-basin orographic factor, from figure A1, of plus 20 percent. Therefore, dividing the 32.2 in. by 1.20 gives 26.8, which removes all the thunderstorm-induced orographic effect at a basin size of 100 sq mi so that the appropriate thunderstorm-induced orographic adjustment for the size of the basin can now be obtained. Figure A2 is now used to obtain the adjustment for the size of the basin; in this case, 295 sq mi. From figure A2 for a 295-sq-mi basin, the adjustment is 42 percent of the total 20 percent (for the all rough basin), or 8.4 percent. Multiplying the 26.8 in. by 1.084 gives 29.1 in. (line D).

Note: This may be illustrated by the following symbolic equations:

$$PI_{6/5} = P_{6/5}\,(R_5)\,(O_I)\,(S_h)$$

$PI_{6/5}$ = PMP from 6-hr 5-sq-mi index chart (fig. 2-21B)

$P_{6/5}$ = PMP from thunderstorm for smooth terrain

R_5 = Adjustment for thunderstorm-induced orographic effect for rough-terrain basin ranging from 5 to 100 sq mi in area

O_I = Other orographic intensification

S_h = Sheltering effects

Dividing $PI_{6/5}$ by R_5 $\left(\frac{PI_{6/5}}{R_5}\right)$ removes the effect of the small-basin roughness adjustment. There is a roughness adjustment appropriate for basins larger than 100 sq mi. This can be evaluated by the following step:

$$\left(\frac{PI_{6/5}}{R_5}\right) \times R_{(A1,A2)}$$

where:

$R_{(A1,A2)}$ is the thunderstorm effect for larger basins developed in this Addendum and determined from figures A1 and A2.

Step E. This step introduces sheltering effect of the mountains into our non-orographic 6-hr 5-sq-mi PMP (the latter determined from figure 2-15 of HMR 45). The smooth 6-hr 5-sq-mi PMP for the basin is needed in order to evaluate total orographic effects in the basin. To obtain the smooth basin value, reduce 25.0 in. (the smooth 6-hr 5-sq-mi value at the southern edge of the Tennessee River Watershed or at the 0-percent correction line of figure A3) by the percentage reduction from figure A3. The percentage reduction from figure A3 is 2 percent. The adjusted value is therefore 24.5 in. (25.0 in. times 98 percent). List this smooth 6-hr 5-sq-mi PMP adjusted for sheltering on line E.

Note: We have developed $PI_{NO\ 6/5} = P_{6/5}\ (S_h)$, where $PI_{NO\ 6/5}$ is non-orographic 6-hr 5-sq-mi PMP adjusted for sheltering effects of the mountains and $P_{6/5}$ and S_h are as defined in the previous note. The difference between the values developed in steps D and E is solely the result of the net orographic effects in the eastern mountainous region.

Step F. Divide the value on line D by the value on line E and put result on line F in table A3-4. This is the orographic factor (or the percent orographic increase) for the project basin yet to be adjusted for optimum moisture inflow direction.

Step G. Using figure 3-21, determine the percentage of the basin that has a common optimum wind direction. In other words, whatever direction controls most of the basin, then, the percent of the basin controlled by this (optimum) direction is the desired percent. This is 70 percent (line G).

Step H. Enter figure 3-22 with the percentage from line G and read the corresponding orographic factor percentage. This is .95 (line H).

Step I. Multiply line F by line H to get the net orographic factor. This is 1.13 (line I).

Step J. List the products of line C and the net orographic adjustment factor (line I) on line J. These values are the accumulated orographic PMP values for the given basin.

Step K. Construct a smooth depth-duration curve from the values of line J. Read desired increments. Tabulate on line K.

Note: The following steps, L to R, giving the areal and time distributions of PMP, are not shown in table A3-4.

Step L. Place the standard isohyetal pattern, HMR 45, figure 3-23, in position that best fits basin. Modify shapes of isohyets for topographic influences as described on page 97 in text of HMR 45.

Step M. Enter figure A3-24 with area of basin and read out ratios for area of basin that apply to the isohyets.

Step N. Multiply 6-hr PMP from line J by the respective ratios of step M, obtaining tentative isohyetal labels. Determine average 6-hr precipitation within the basin using these tentative labels. The objective is to secure labels that place the appropriate PMP volume in the basin.

Step O. Take ratio of basin average precipitation from step N to 6-hr value on line J. Multiply tentative isohyetal labels (step M) by this ratio. This gives final isohyetal labels for first (maximum) 6-hr PMP.

Step P. The remaining 6-hr increments are used as uniform depth over the basin or are distributed in proportion to the mean annual precipitation chart, figure 3-15, HMR 45.

Step Q. Arrange 6-hr increments in a critical chronological sequence following the suggestions on page 102.

Step R. The maximum 3-hr PMP increment can be obtained by entering figure 3-27 with the maximum 6-hr increment.

Note: Steps S to W (also shown on table A3-4) demonstrate computations of TVA precipitation values for the 72-hr TVA storm and the 24-hr TVA storm. The steps follow:

Step S. Determine the 72-hr TVA precipitation by multiplying the 72-hr PMP of line K by 0.6. This is 20.5 (line S).

Step T. Obtain a set of depth-duration values by entering figure A2-36 with 20.5 in. on the vertical scale and read incremental TVA precipitation values. List values on line T.

Step U. List durations to 24 hr for 24-hr TVA storm computation (line U).

Step V. Determine the 24-hr TVA precipitation by multiplying the 24-hr PMP of line K (27.8) by 0.6. This is 16.7 (line V).

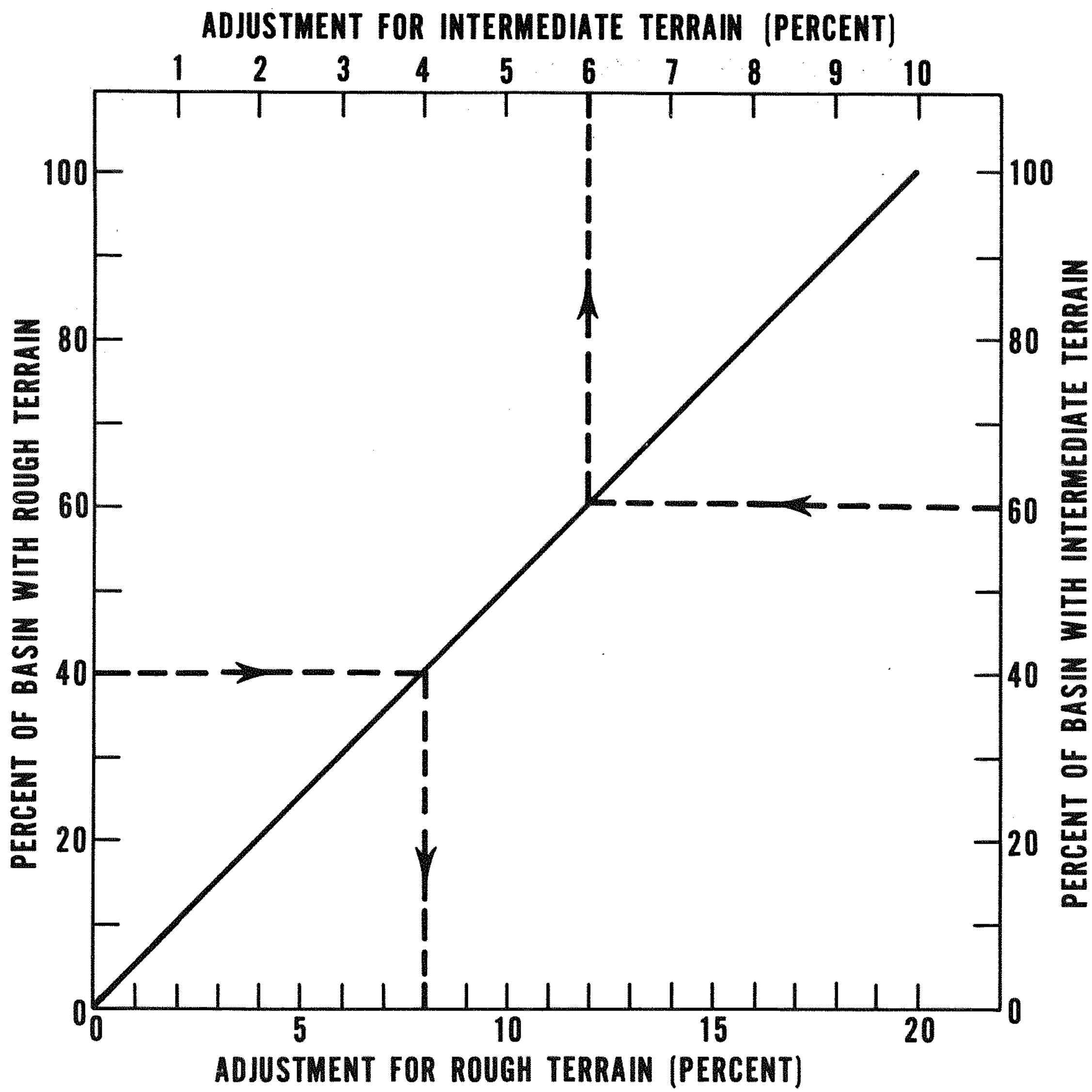
Step W. Obtain a set of depth-duration values by entering figure A2-35 (part B) with 16.7 in. on the vertical scale and read incremental TVA precipitation values. List values on line W.

Table A3-4.--Sample computation of PMP and TVA precipitation estimates for the 295-sq-mi Little Tennessee River Basin above Franklin, North Carolina

		Duration (hr)							
Line	Item and Source	6	12	18	24	36	48	60	72
A	Unadjusted PMP (fig. 3-11)(in.)	16.8	20.0	22.2	23.9		27.3		29.4
B	Adjustment for location (fig. 3-14)	1.03	1.03	1.03	1.03		1.03		1.03
C	Basin PMP, unadjusted for terrain (line A x line B)	17.3	20.6	22.9	24.6		28.1		30.3
D	Adjusted 6-hr 5-sq-mi PMP (fig. 2-21B)	29.1							
E	Non-orographic basin 6-hr 5-sq-mi PMP = 25.0 in. (PMP at southern edge of TVA area). 25.0 in. minus 2 percent (generalized sheltering from figure A3)	24.5							
F	Orographic factor (line D ÷ line E)	1.19	1.19	1.19	1.19		1.19		1.19
G	Percent of basin exposed to optimum wind direction (fig. 3-21)	70	70	70	70		70		70
H	Orographic factor percentage (fig. 3-22)	.95	.95	.95	.95		.95		.95
I	Line F x line H	1.13	1.13	1.13	1.13		1.13		1.13
J	Basin PMP = (line C x line I)	19.5	23.3	25.9	27.8		31.8		34.2
K	Basin PMP "smoothed" durationally (in.)	19.5	23.3	25.9	27.8		31.8		34.2
	72-hr TVA Storm								
S	72-hr TVA precipitation (line K x 0.60)	-	-	-	-		-	-	20.5
T	Precipitation in 72-hr TVA storm (fig. A2-36) (in.)	8.1	11.6	14.1	15.8	17.8	19.8	19.7	20.5

24-hr TVA Storm

Line	Item and Source									
U	Duration (hr)	1	2	3	4	5	6	12	18	24
V	24-hr TVA precipitation (line K x 0.60)	-	-	-	-	-	-	-	-	16.7
W	Precipitation in 24-hr TVA storm (fig. A2-35 Part B) (in.)	4.4	5.9	7.1	7.9	8.7	9.4	12.6	15.1	16.7



TOPOGRAPHIC CLASSIFICATION

CLASS	TVA* PRECIPITATION (IN)
ROUGH	> 17.0
INTERMEDIATE	16.0-17.0
SMOOTH	< 16.0

*HMR NO. 45 FIG. 2-22A AND B

Figure A1.--Adjustments for terrain roughness, 100-sq-mi basins.

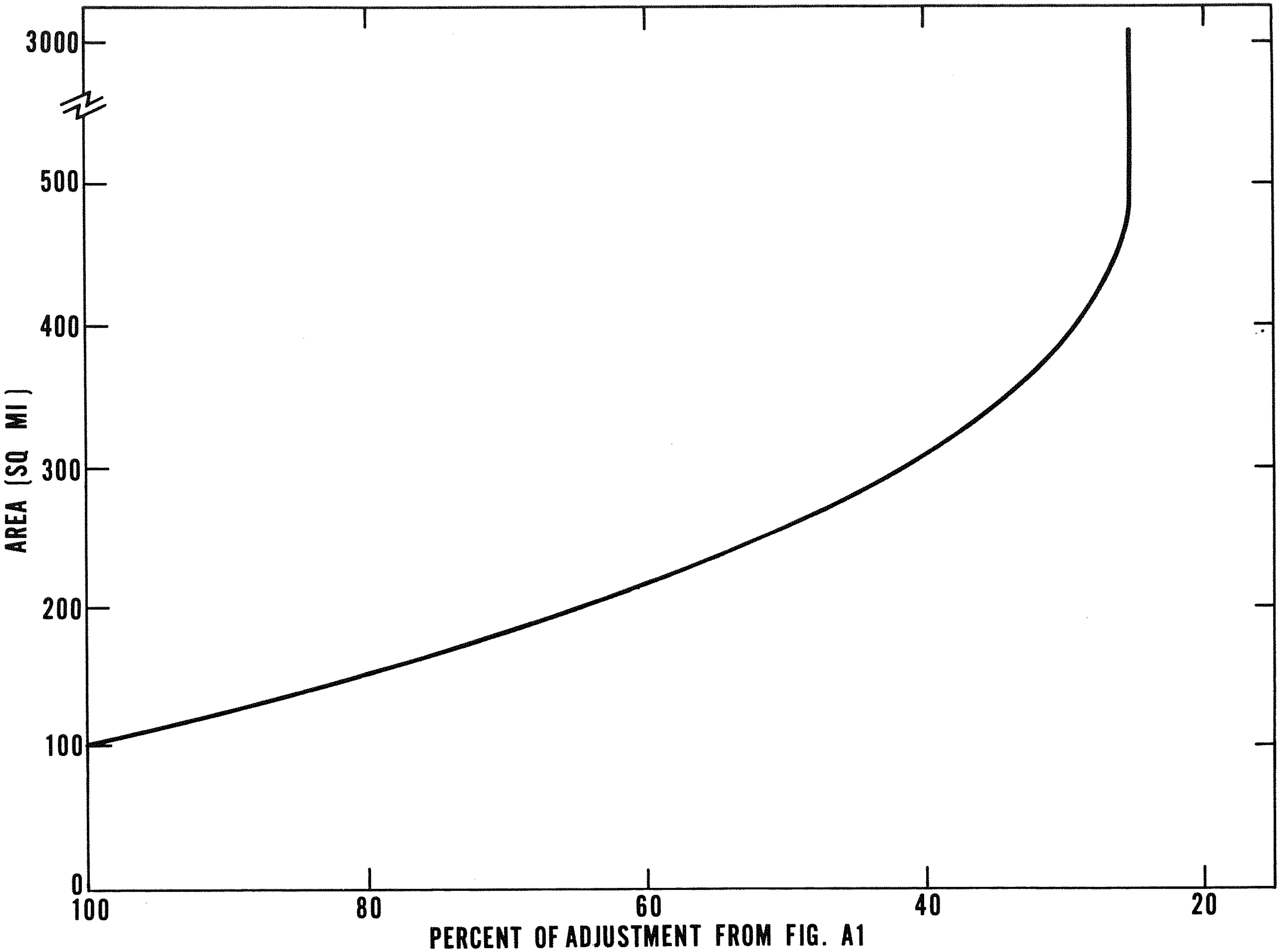


Figure A2.--Variation of terrain roughness adjustment (fig. A1) with basin size.

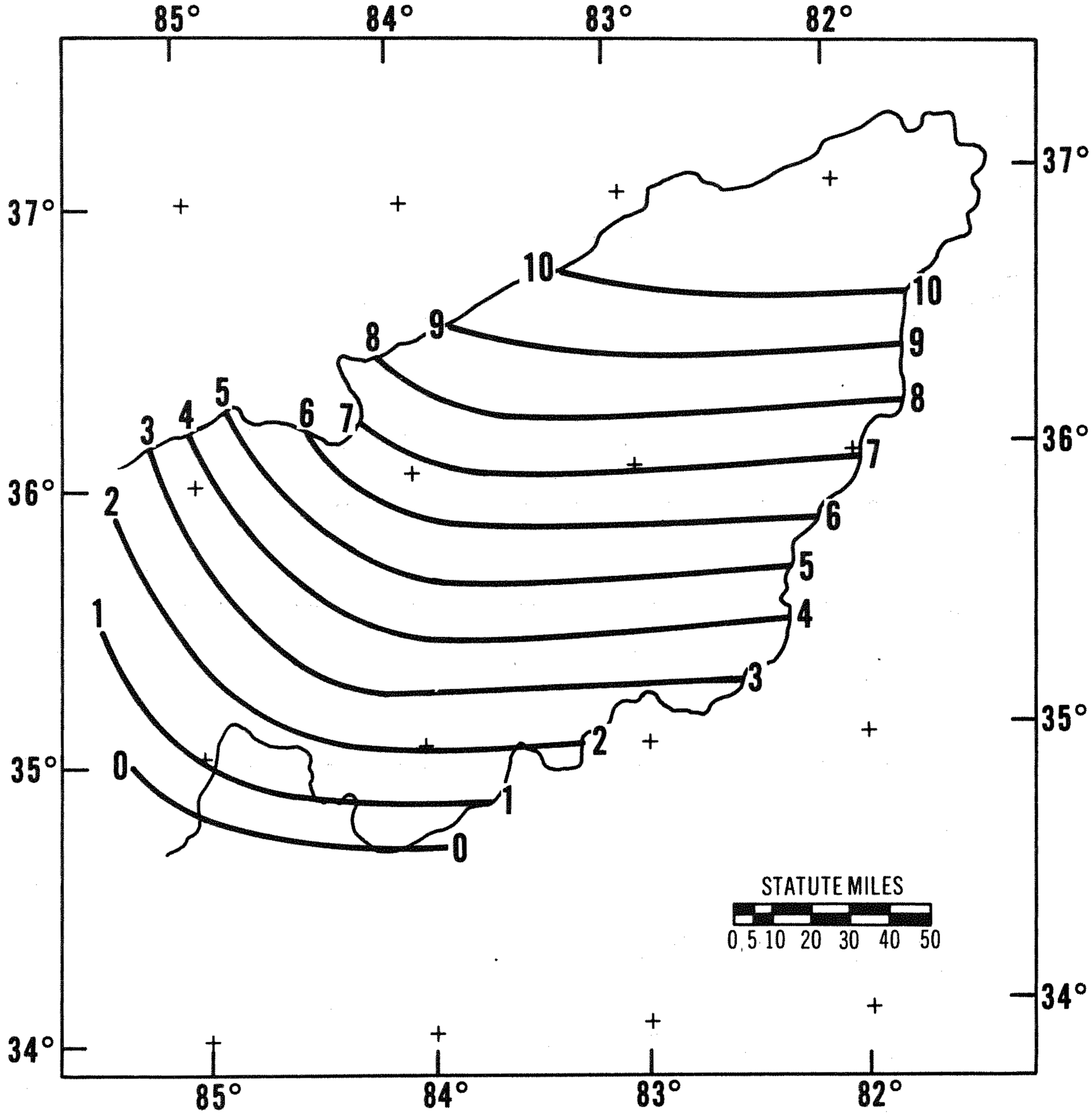


Figure A3.--Generalized adjustment for terrain sheltering in the eastern half of the Tennessee River Drainage Basin (percent reduction in PMP and TVA precipitation).

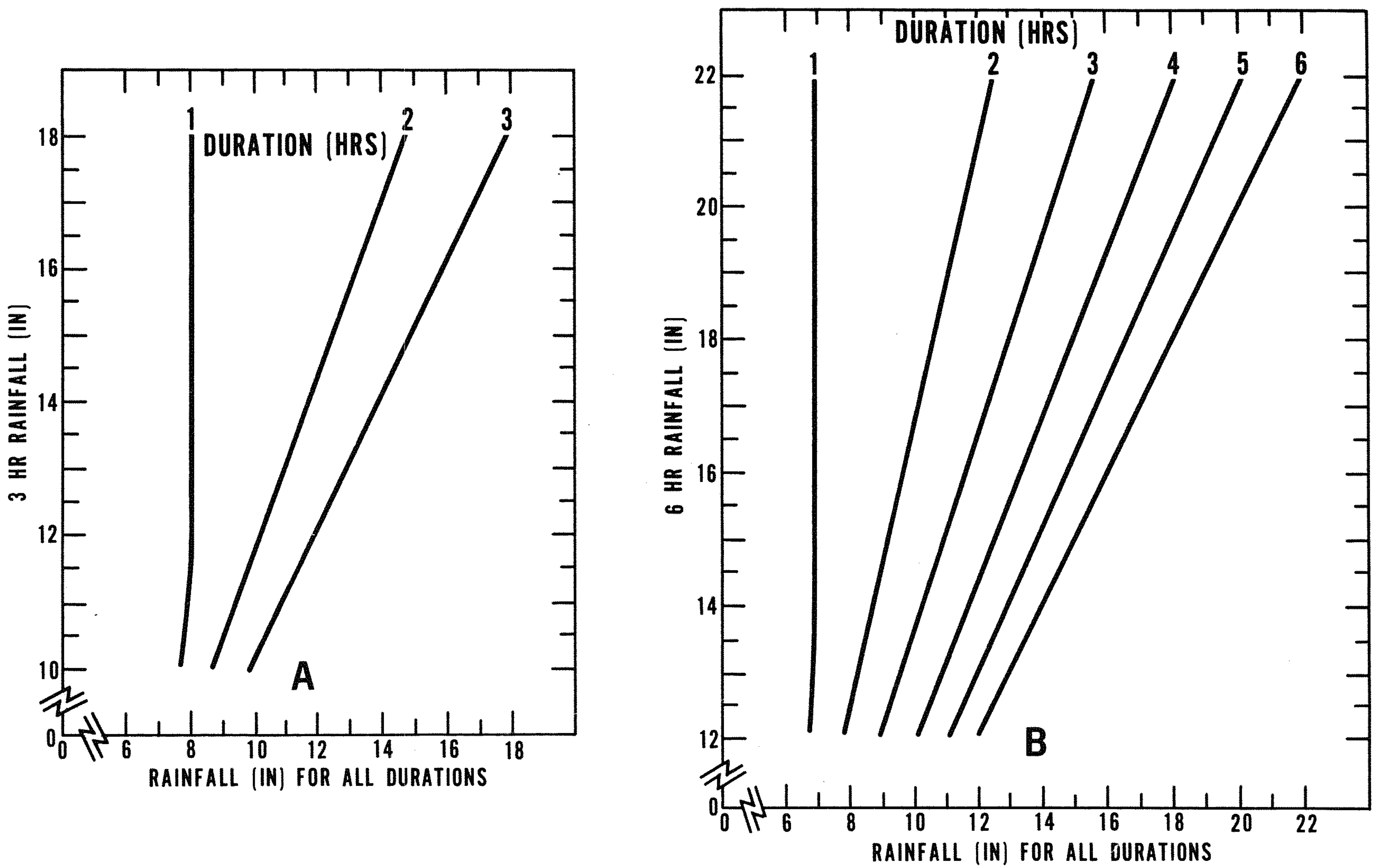


Figure A2-34.--Depth-duration relations for (A) 3-hr TVA precipitation storm and (B) 6-hr TVA precipitation storm.

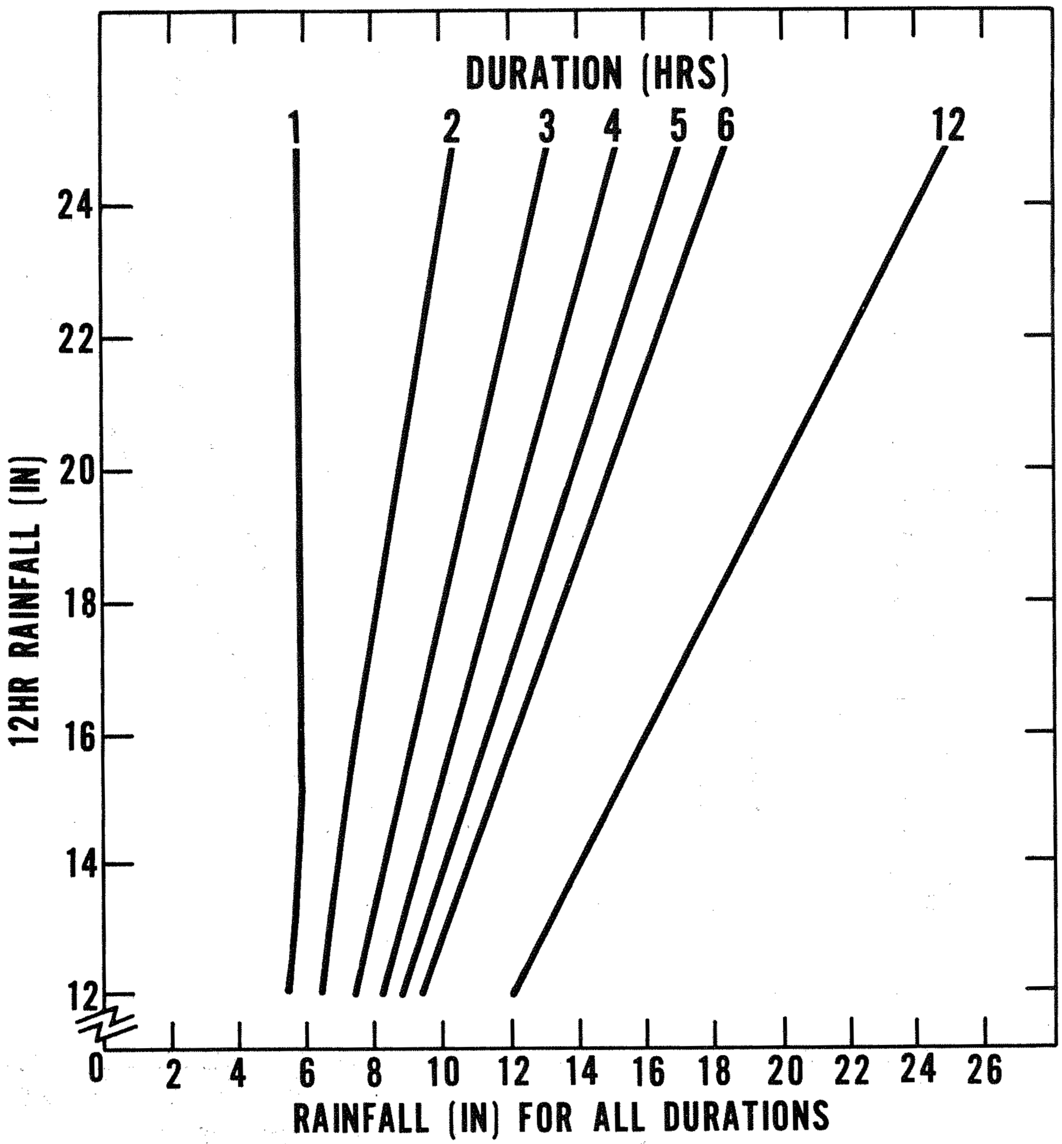


Figure A2-35.--(Part A) Depth-duration relations for 12-hr TVA precipitation storm.

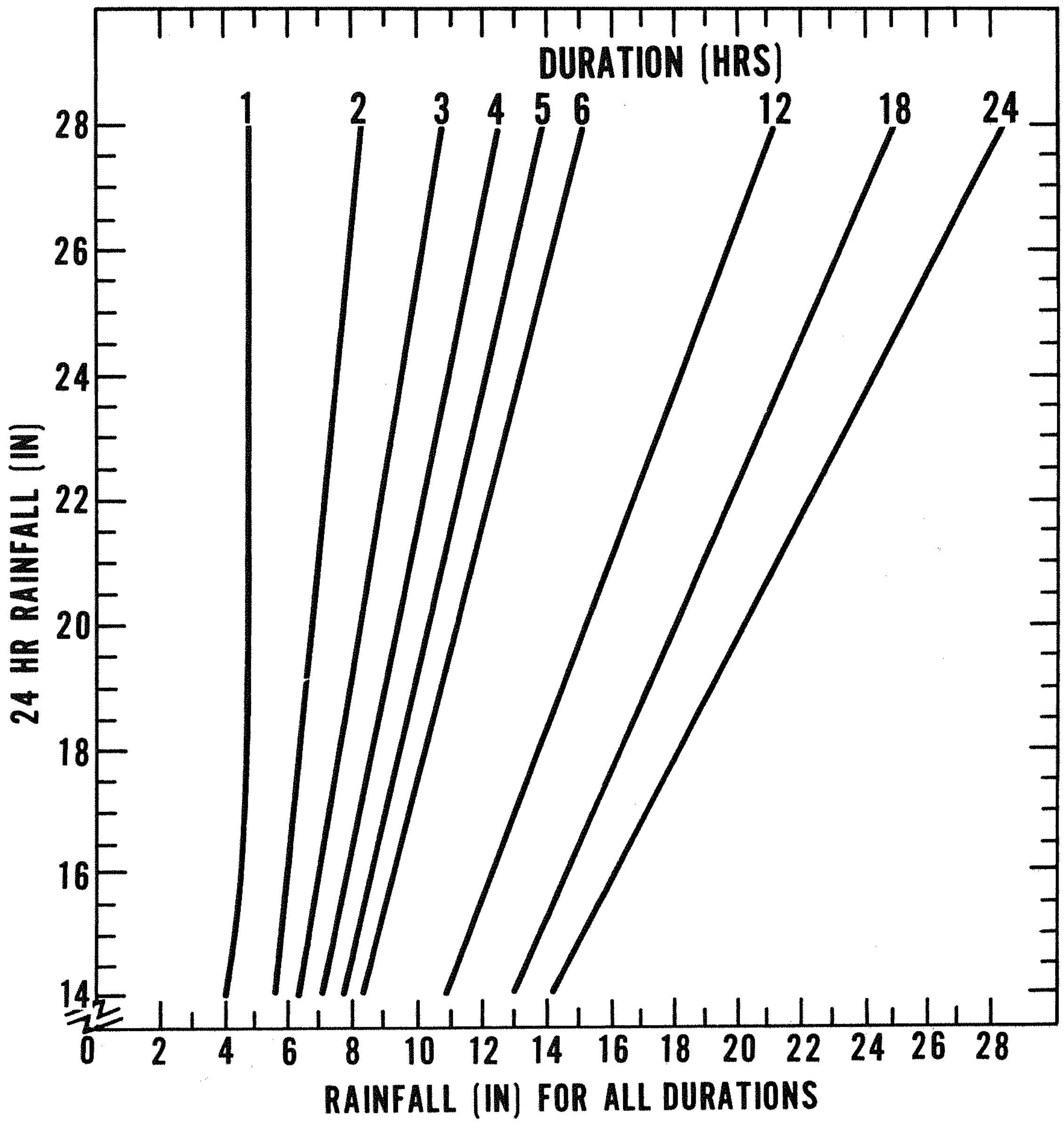


Figure A2-35.--(Part B) Depth-duration relations for 24-hr TVA precipitation storm.

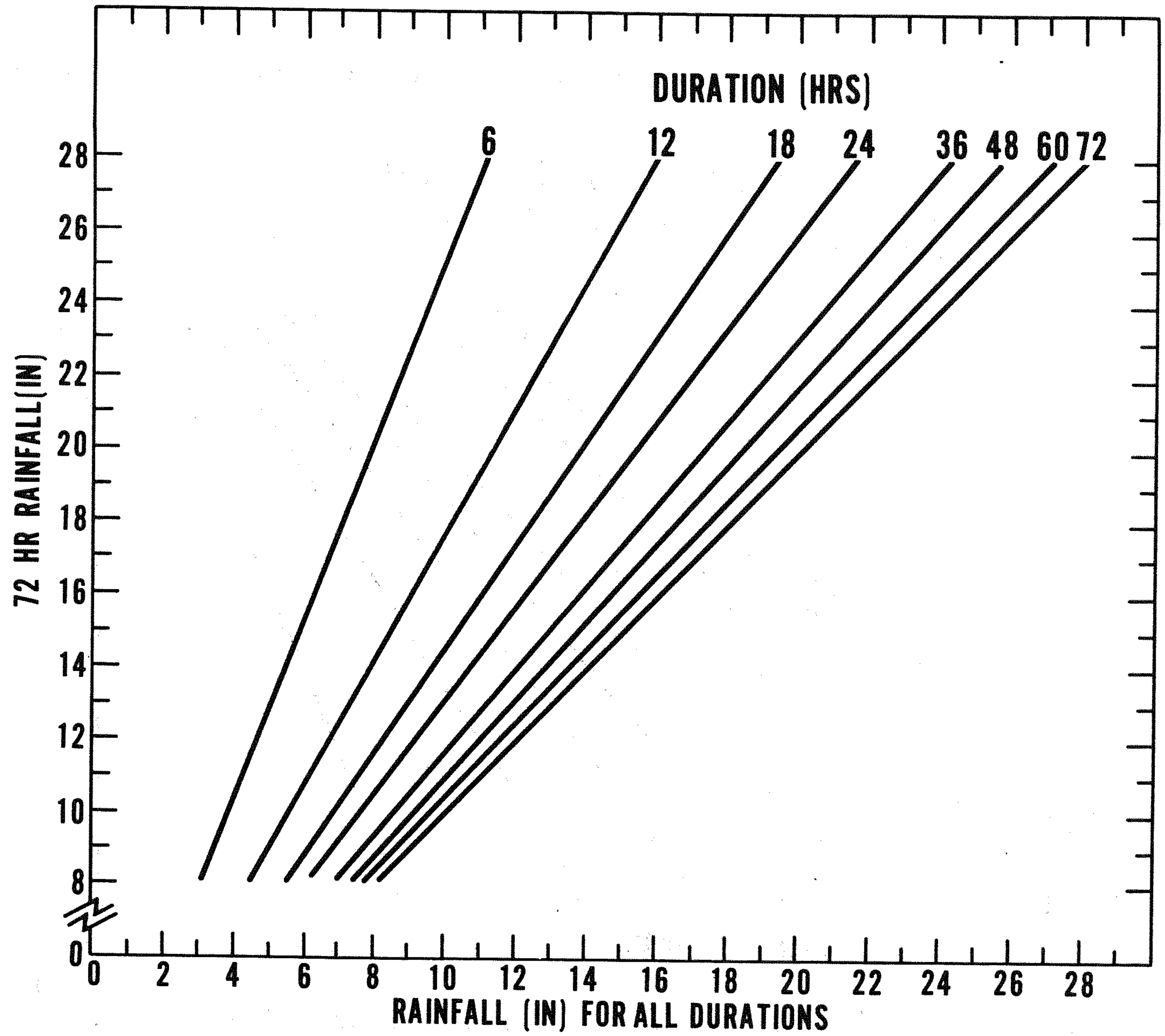


Figure A2-36.--Depth-duration relations for 72-hr TVA precipitation storm.

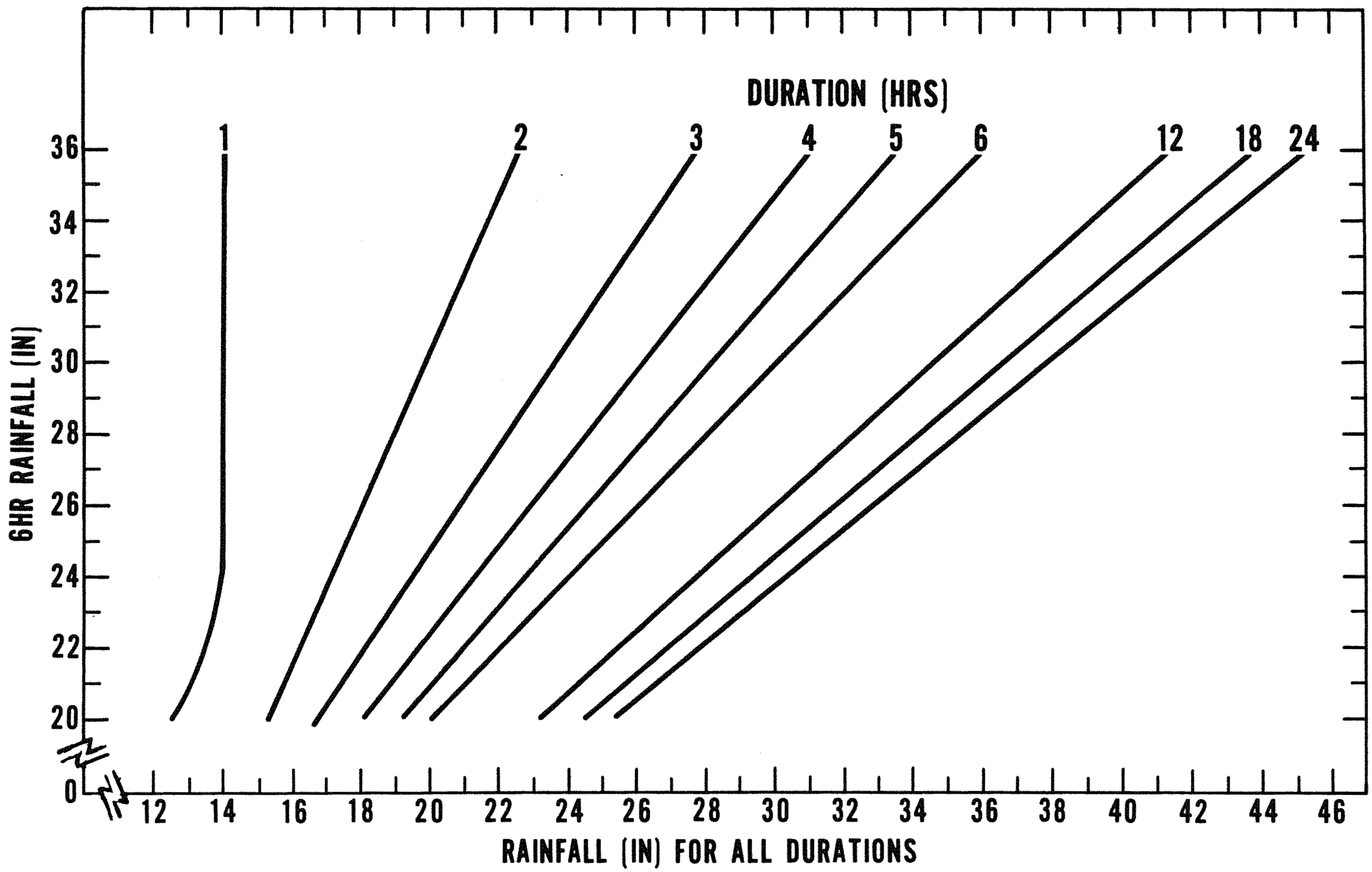


Figure A2-37.--Depth-duration relations for 24-hr PMP storm.

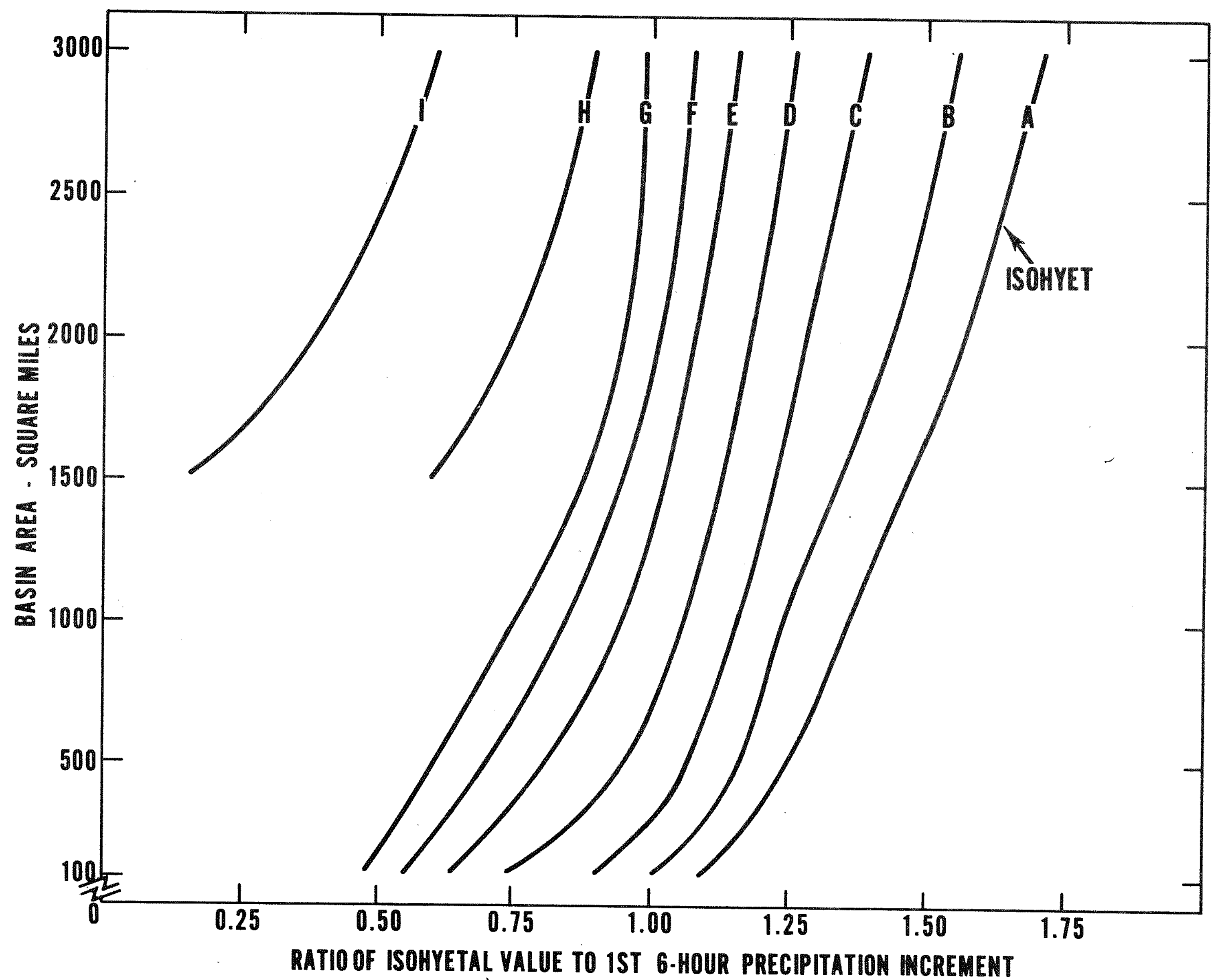


Figure A3-24.--Nomogram for isohyet values in pattern storms - 1st 6-hr increment.

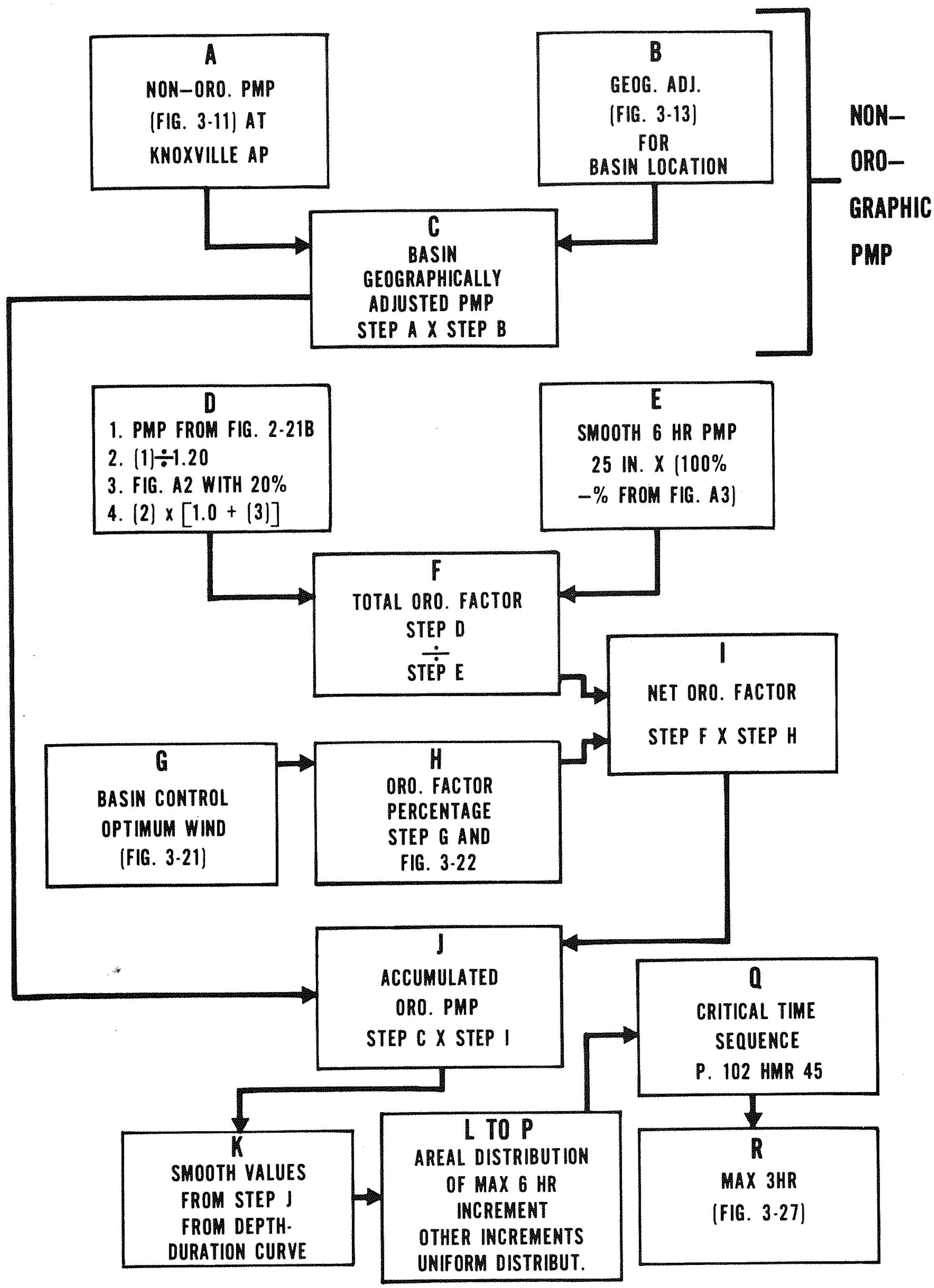


Figure A4.--Schematic diagram illustrating step-wise procedure for mountainous east.

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HYDROMETEOROLOGICAL REPORT NO. 45

Probable Maximum and TVA Precipitation for Tennessee River Basins up to 3,000 Square Miles in Area and Durations to 72 Hours

Prepared by
Francis K. Schwarz and Norbert F. Helfert
Hydrometeorological Branch, Office of Hydrology

for

The Tennessee Valley Authority
(Contract TV-23942A)

Silver Spring, Md.
May 1969

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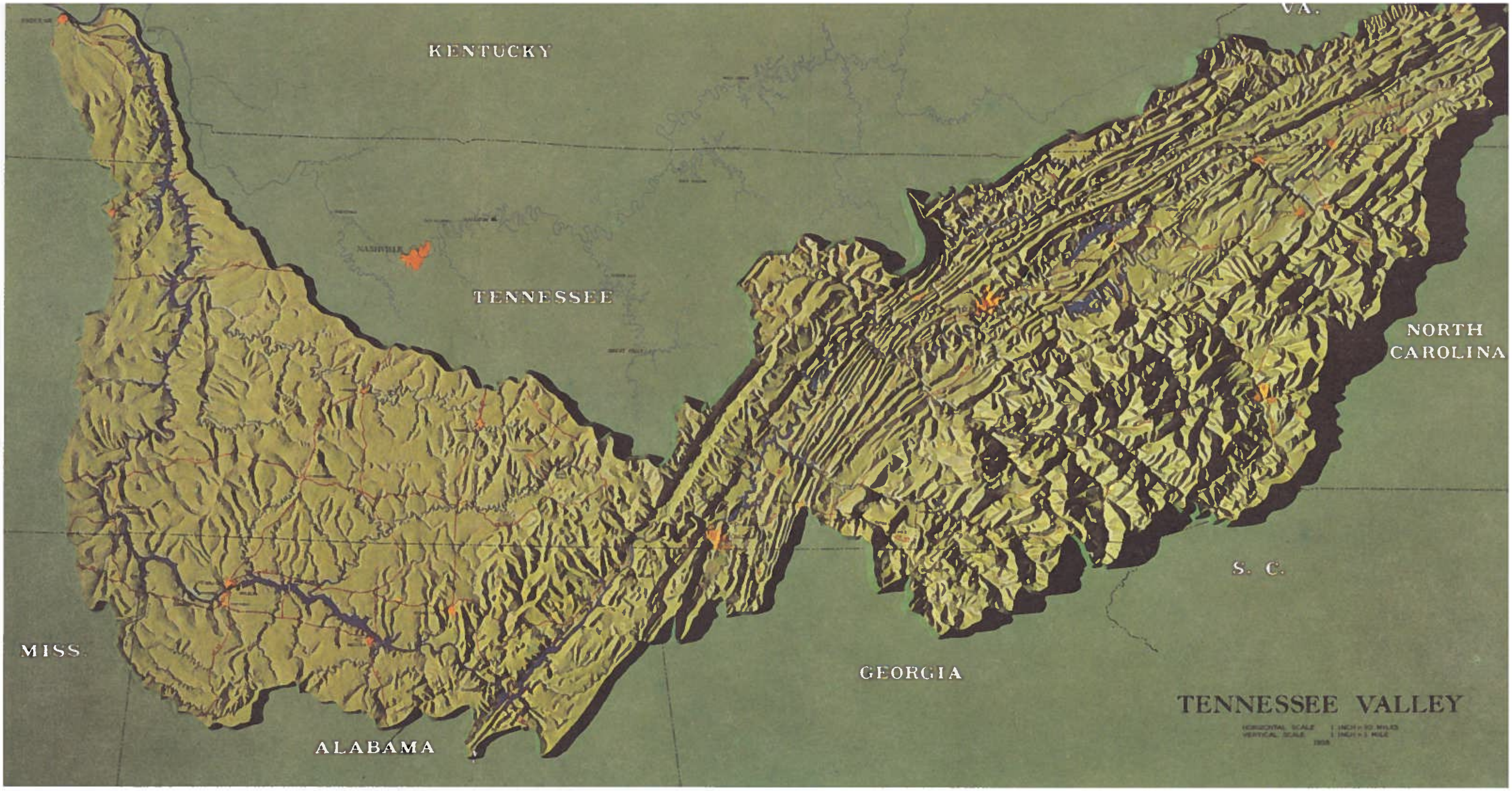
551.5	Meteorology
.509	Weather forecasting
.509.324.2	Precipitation forecasting
.577	Precipitation
.577.37	Maximum precipitation
.579	Hydrometeorology
.579.4	Fluctuations of surface water (caused by precipitation)
627.8	Dams
(76)	U.S. South Central States

TABLE OF CONTENTS

FIGURES

TABLES



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Chapter I

INTRODUCTION

Purpose of report

Generalized estimates of extreme precipitation are necessary for consistent spillway design for projects within any given region. The Tennessee Valley Authority is giving increased emphasis to this approach. Toward this end the present report provides generalized estimates of 1- to 72-hr. precipitation extremes for basins ranging in size from a few square miles to about 3000 square miles. Antecedent rainfall criteria are provided also for use as indices to soil moisture conditions and existing streamflows at the beginning of the critical rainfalls. The detailed probable maximum precipitation estimates of this report supersede within the Tennessee River watershed previous generalized estimates published in Hydrometeorological Report No. 33 [1-1].

Basins larger than 3000 square miles are not covered in this report. Thus a need for generalized estimates for larger basins to supplement those of Hydrometeorological Report No. 41, "Probable Maximum and TVA Precipitation over the Tennessee River Basin above Chattanooga," (HMR 41) [1-2] remains.

Authorization

The authorization for this study is an agreement between the Tennessee Valley Authority and the U. S. Weather Bureau. Excerpts from the agreement are found in appendix A.

Scope

Two categories of extreme precipitation, namely probable maximum precipitation (PMP) and a standardized, less extreme rainfall called "TVA precipitation," are covered in this report.

A discussion of the concept of PMP and some of the practical problems of estimating PMP are discussed in HMR 41 [1-2]. A more detailed discussion may be found in Weather Bureau Technical Memorandum HYDRO-5 [1-3].

The definition of PMP used in the present report is the same as that used in HMR 41, namely, "the rainfall depth (for a particular size basin) that approaches the upper limit (for a specified duration) that the present climate can produce." The large sampling of extreme storms experienced in the United States has provided a few storms assumed to have produced precipitation from water vapor in the atmosphere with optimum efficiency. In such cases, nature can be looked upon as performing all the necessary integrating of rain-producing factors except for some slight upward adjustment for moisture charge. Such rare storms are transposed to adjoining regions. In the present report, the general level of the small basins PMP is controlled by such a storm--the Smethport, Pa., storm of July 17-18, 1942--which dumped over 30 inches of rain in less than 6 hours.

Like the PMP, the TVA precipitation concept is preserved from HMR 41 in the present report. Basically, the TVA storm is defined as one resulting from transposition and adjustment, but without maximization, to the Tennessee Valley of outstanding storms which have occurred elsewhere. Some of the most extreme events are undercut. It is the level of expected rainfall used to define the "TVA" maximum flood. In this report, in order to make the TVA precipitation estimates agree with actual storm experience, a variable depth-duration concept is introduced, which, for example, determines that, at the TVA level of precipitation, there is little chance that the maximum 72-hr. storm event also includes the maximum 6-hr. rainfall event.

Organization of report

Chapter II describes the development of 24-hr. generalized estimates for basins up to 100 square miles. Generalized procedures for estimating 72-hr. precipitation for basins up to 3000 square miles are the subject of chapter III. In chapter IV, the procedures are used, with innovations as required, to provide specific estimates for 28 basins. Finally, chapter V is devoted to the development of antecedent precipitation criteria.

Broad-scale topographic features of the Tennessee River watershed

The Tennessee River watershed (frontispiece and fig. 1-1) can be divided into four topographic regions: the Western Basin, the Cumberland Plateau, the Great Valley and the Appalachian Mountains. The Western Basin is relatively low, with rolling hills. The Cumberland Plateau is not a flat plateau, but characterized by irregular highlands and ridges which are particularly steep along the edge. The characteristics of the Great Valley are parallel ridges running from southwest to northeast. The southern Appalachian Mountains are characterized by the Blue Ridge Mountains, which border the region on the south and east, and by the Great Smoky Mountains which run from southwest through northeast on the western border of the southern Appalachians.

With regard to broad-scale controls on storm rainfall, the Blue Ridge and Great Smoky Mountains shelter the interior of the southern Appalachian and the Great Valley areas from storms moving from the south and east. The Cumberland Plateau shelters the Great Valley and western slopes of the southern Appalachians from storms moving from the west. The Western Basin is relatively free from any broad-scale sheltering.

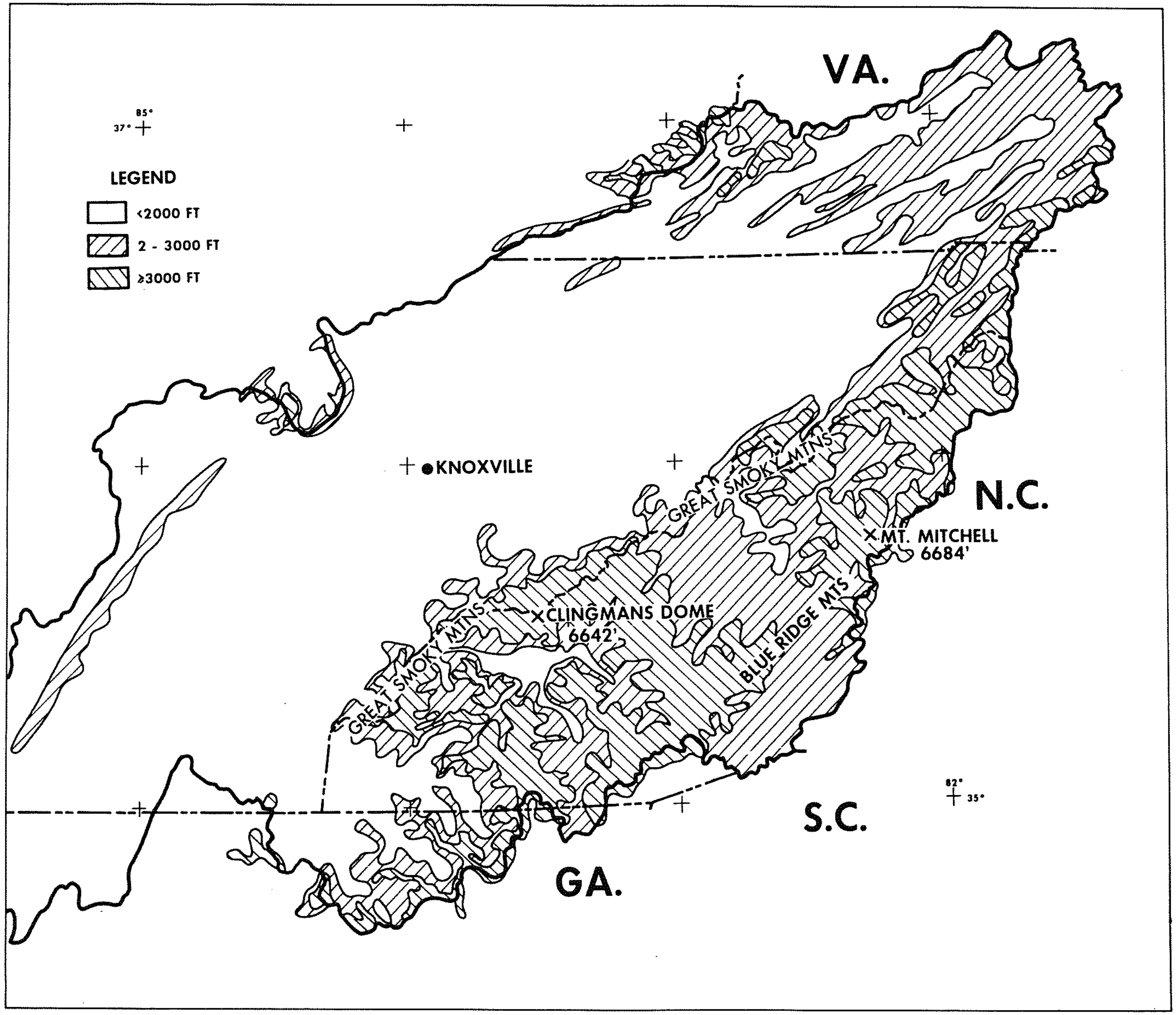


Figure 1-1. Topography of the mountainous eastern portion of the Tennessee River watershed

Chapter II

SUMMER PMP AND TVA PRECIPITATION FOR SMALL BASINS

A. DEVELOPMENT OF PMP STORM TYPE

Introduction

In section A of this chapter the type of storm which will produce the small-area PMP in the Tennessee River watershed is established. It will be shown that the PMP type differs in important ways from a "typical" thunderstorm situation.

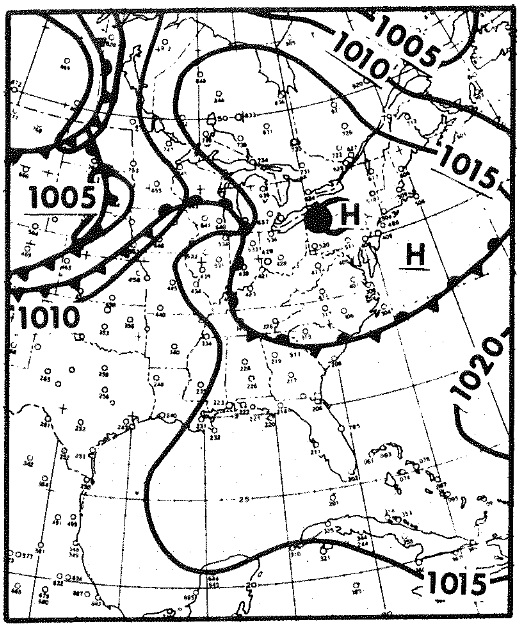
The typical summer thunderstorm lasts only a short time--not so with the PMP type. The typical summer thunderstorm is quite restricted in area. In the PMP type larger areas may be involved with more thunderstorm activity. The typical summer thunderstorm occurs in the afternoon or evening. The PMP-type thunderstorm lasts through the nighttime hours.

Only a very few storms have yet been observed anywhere in the United States that clearly resemble the PMP type. The best example resembling the PMP type is the Smethport, Pa. storm of July 17-18, 1942. Surface weather maps for this storm are shown in figure 2-1. Characteristics of this outstanding storm are important to establishing the PMP type for the Tennessee River watershed. Additional insight into the probable characteristics of the PMP type comes from examination of intense short duration storms and some major large-area long-duration storms, and from the climatology of thunderstorms including their diurnal and other characteristics.

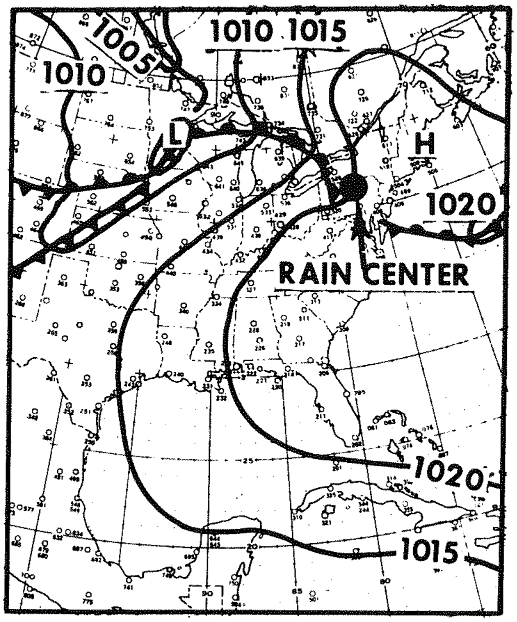
Intense rains in and near the Tennessee River watershed

The dates, location and other information regarding intense rains in or near the Tennessee River watershed are shown in table 2-1. The basic information on these storms was provided by the TVA [2-1]. Bucket surveys provided most of these outstanding rainfall values. Regularly reporting rainfall stations rarely catch such outstanding rains. The TVA has long recognized that the average spacing of rain gauges fails to sample most extreme summer storms. Its engineers have made many field investigations immediately following the occurrence of severe storms to obtain "bucket" rainfall measurements [2-2], and there is a fairly complete record of such storms dating back to 1933.

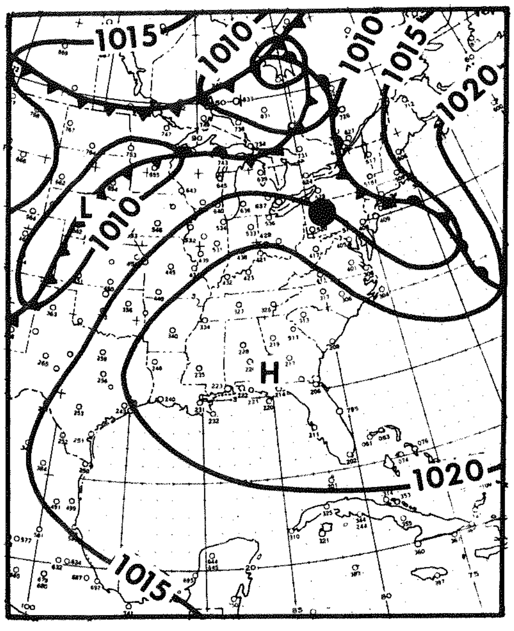
The meteorology of the intense storms of table 2-1 was investigated by studying the surface, and where available, upper-air weather maps. The weather maps of these storms showed no consistent pattern in relation to



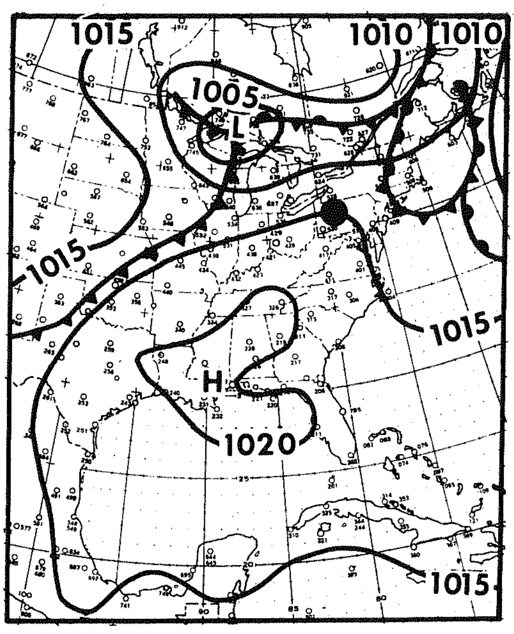
July 16, 1942 Sea Level 1230GMT



July 17, 1942 Sea Level 1230GMT



July 18, 1942 Sea Level 1230GMT



July 19, 1942 Sea Level 1230GMT

Figure 2-1. Surface weather maps for the Smethport, Pa. storm of July 16-19, 1942

Table 2-1. Intense Small-Area Storms In Or Near Tennessee River Watershed

Date	Approximate Location* Lat. (N)	Long. (W)	Index No.	Dew Point (°F)	Duration (hr.)	Area (sq.mi.)	Depth (in.)
June 13, 1924	36°18'	82°16'	0		3.5	Point	12
June 3, 1937	35°49'	82°30'	1	70	1.5	4	6.25
June 3, 1937	36°02'	83°56'	2		0.5	4	1.8
July 30, 1937	36°15'	83°05'	2		2	4.3	5
June 2, 1937	36°16'	85°46'	3	70	0.3-0.4	0.35	5.5
May 22, 1938	35°57'	85°02'	4	70	2	Point	11
June 18, 1938	35°27'	86°48'	5	70	3	30	9
July 7, 1938	35°05'	82°50'	6	75	1	4	6
July 8, 1938	35°14'	86°06'	7	75	0.75	22	6
August 4, 1938	35°46'	83°26'	7a	74	3-4	27	11
June 9, 1939	37°12'	80°48'	8	69	4	25	10
April 30, 1940	35°47'	88°22'	9		1	6	1.73
June 7, 1940	35°14'	88°24'	10		1	0.125	3.5
June 18, 1940	36°27'	84°05'	11		0.75	7	4.5
July 8, 1940	36°22'	83°03'	12		1	1.5	4.5
July 11, 1941	35°11'	86°47'	13		2	15	6
July 13, 1941	36°10'	82°24'	14		2	7.45	4
August 6, 1943	35°05'	85°04'	15		0.75	Point	3
May 15, 1946	35°08'	85°17'	16		1.5	Point	6
May 15, 1946	35°08'	85°17'	16	65	3	6.21	6.7
June 28, 1947	36°04'	82°50'	17		3.5	Point	5.4
July 28, 1947	35°45'	83°15'	18		3	Point	5.82
June 4, 1949	35°55'	85°28'	19	65	2	Point	9.5
July 16, 1949	36°14'	83°20'	20		1.75	Point	4.5
July 19, 1949	35°22'	83°13'	21	72	1	0.98	5.5
July 28, 1951	35°38'	83°00'	22		0.75	Point	6.0
July 28, 1951	36°04'	82°50'	23		0.5	Point	3.2
July 25, 1951	35°06'	84°39'	24		2	8	5.6
Sept. 1, 1951	35°33'	83°10'	25	75	1	Point	6.5
Sept. 1, 1951	35°43'	83°31'	26	75	1	Point	6.5±
June 5, 1952	34°58'	83°55'	27		1	2	4.18
June 13, 1952	35°41'	85°48'	28	73	3	Point	10.5
June 13, 1952	35°09'	84°11'	29		6	Point	7.8
July 6, 1953	36°54'	81°19'	30		2	5	4
July 18, 1953	35°02'	85°12'	31		2	Point	5.2
June 13, 1954	36°36'	82°11'	32		0.92	50.2	3.05
Aug. 8-9, 1954	35°07'	85°36'	33	73	3±	30±	10±
March 21, 1955	35°06'	87°26'	34		0.2	Point	0.83
Sept. 6, 1957	35°46'	82°25'	35		2	3.56	5.5
June 21, 1956	37°06'	83°43'	36	71	3	Point	11.7
June 30, 1956	35°36'	83°01'	37	70	1	Point	10-12
Nov. 18-19, 1957	35°42'	81°55'	38	69	2.0	200	9
July 23, 1958	35°52'	84°31'	39		0.6	Point	2.05
July 24, 1958	35°51	84°41'	39		2.5	Point	2.75
August 12, 1958	35°48'	82°40'	40		1.5	Point	3.2
June 9, 1959	35°38'	88°11'	41		1	10.6	2.06
Aug. 25, 1959	35°02'	85°12'	42		1	Point	2.37
June 16, 1960	35°32'	87°01'	43		3	Point	12.2
July 26, 1960	34°33'	84°04'	44	74	3	Point	12.5
August 10, 1960	35°51'	84°41'	45		1.5	11.7	3.45
August 10, 1960	35°56'	84°19'	46	73	3.3	Point	9
June 12, 1961	36°02'	82°06'	47	70	2.5	3.49	8.5
July 23, 1963	34°27'	86°56'	48		1.5	4	7
April 28, 1964	35°11'	84°49'	50		1	1	4
July 24, 1965	36°36'	83°43'	51		4	Point	11
July 24, 1965	36°14'	84°17'	52		3	10	12

*In most cases, of nearest community.

causes of the heavy rains. About half of the storms involved surface fronts separating contrasting air masses. Some showed strong low-level inflow of moisture (May 15, 1946 and July 19, 1949), while others had weak moisture inflow (e.g., June 4, 1949).

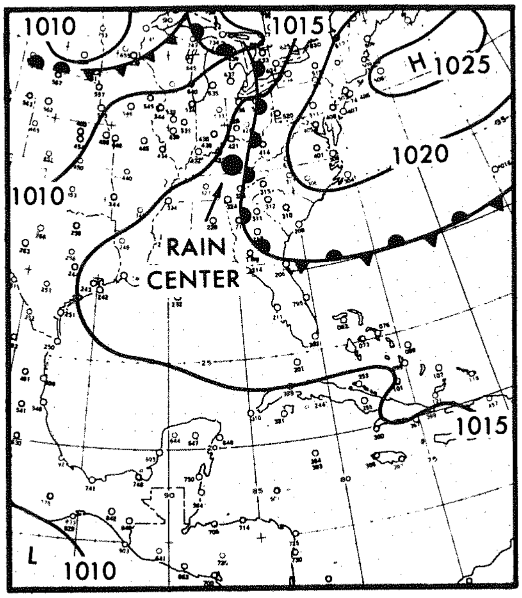
Figures 2-2 and 2-3 show weather maps for some of the more important TVA storms. The June 30, 1956 storm (fig. 2-3) reportedly produced 10 to 12 inches of rain in about 1 hour. This estimate was based on runoff computations. The precipitation fell mostly between noon and 1 p.m. on June 30. A weak warm front at the surface and a minor trough of low pressure at 500 mb. seem to have been contributing factors. A similar intense storm involving more surface inflow was that of June 21, 1956, near Manchester, Ky., (fig. 2-2). This storm produced nearly 12 inches of rain in 3 hours (table 2-1).

Regardless of the weather factors operating, a common feature of most extreme rains in and near the Tennessee River watershed, like similar rains elsewhere, is the degree of organization and geographic "fixing" of convective activity. Huff and Changnon reported such a feature in a 1961 investigation [2-3] of severe rainstorms in Illinois. A more recent paper [2-4] discusses two more recent Illinois storms, reemphasizing the importance of a succession of convective cells reaching their greatest intensity over the same general area. These Illinois storms, in lasting about 4 hours, come a little closer to representing the PMP type for a maximum 24-hr. rain in the Tennessee Valley than did most of the TVA storms which had shorter durations.

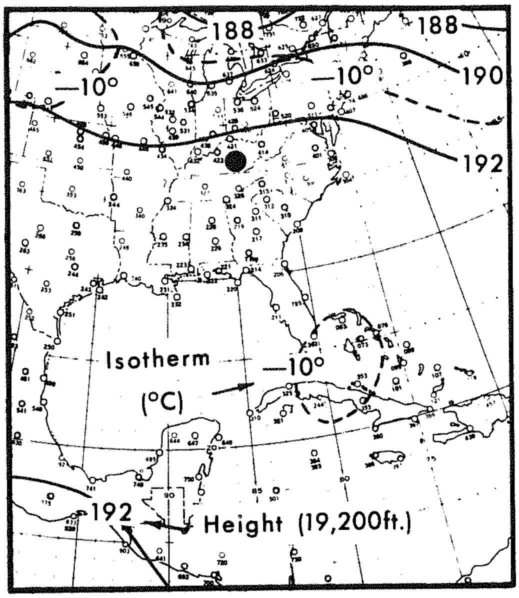
One does not always find fronts or other easily identifiable causes of intense rains whether in the Tennessee River watershed or elsewhere. A discussion [2-5] of a wintertime occurrence of such organized convection within a warm-air mass, concluded that "convective organization is the difference between little rain in one region and 10 inches in another." Only slight triggering mechanisms are necessary to release the air's convective instability. Such triggering disturbances, when they exist aloft, are not always detectable in the synoptic upper-air analyses because of the sparse upper-air network.

Orographic considerations. Approximate elevations were determined for most of the storms. Elevations ranged from 700 feet to over 4000 feet. A unique rainfall-elevation relationship was not evident. This lack of relationship supports a procedure that does not overemphasize the role of orography in short-duration rains.

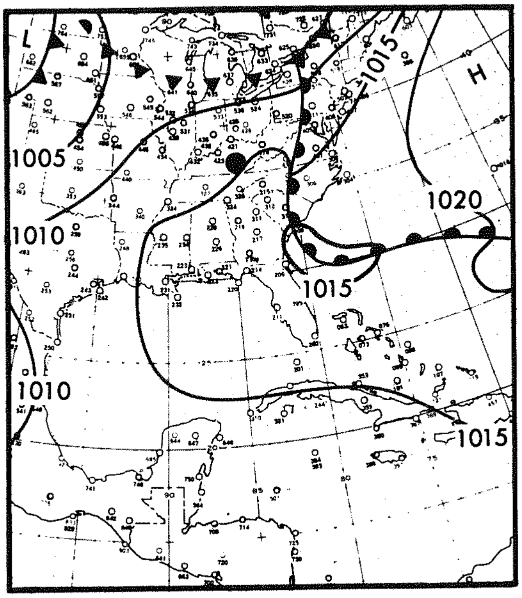
In addition to no correlation with orography no important geographical pattern was discernible in the data of table 2-1. Some of the more important values of table 2-1 are plotted in figures 2-4 and 2-5. Also



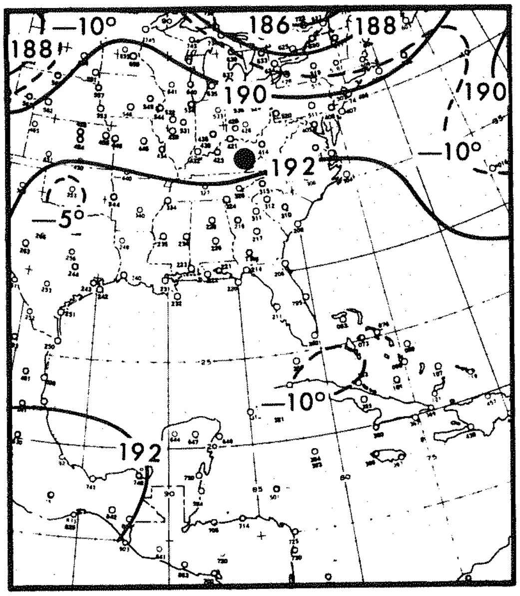
June 20, 1956 Sea Level 1230GMT



June 20, 1956 500 MB 1500GMT

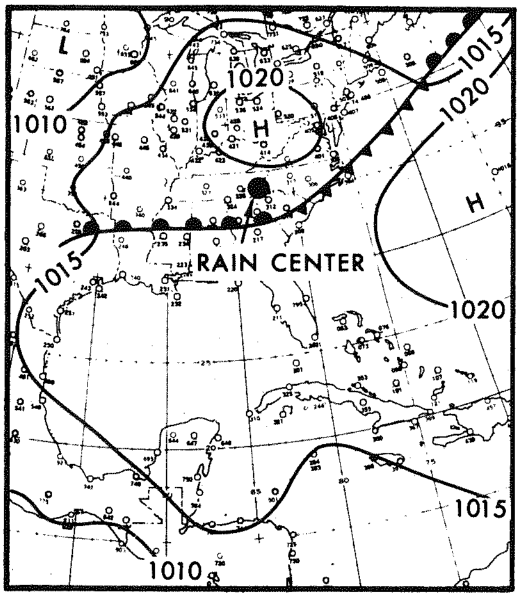


June 21, 1956 Sea Level 1230GMT

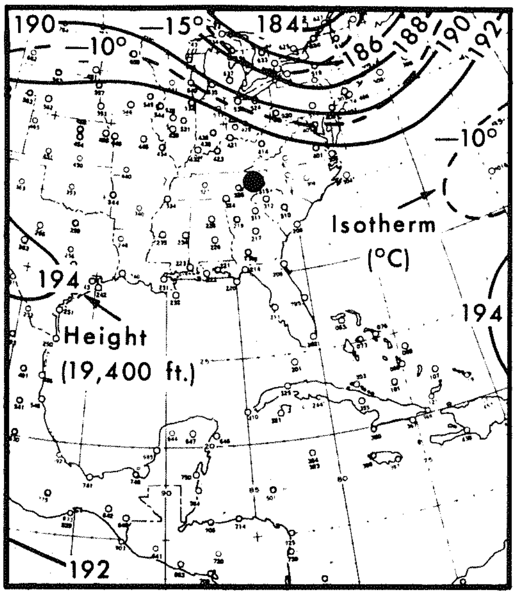


June 21, 1956 500 MB 1500GMT

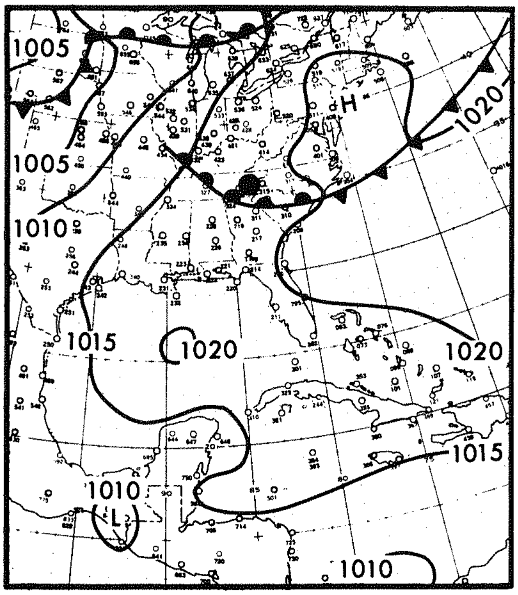
Figure 2-2. Surface and upper-air weather maps for storm of June 20-21, 1956



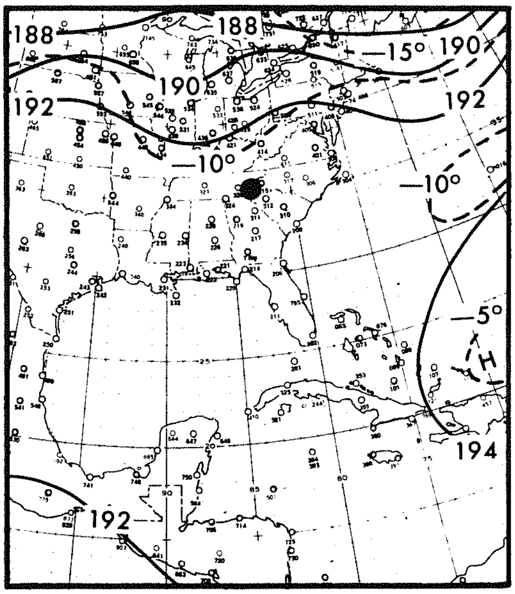
June 29, 1956 Sea Level 1230GMT



June 29, 1956 500 MB 1500GMT



June 30, 1956 Sea Level 1230GMT



June 30, 1956 500 MB 1500GMT

Figure 2-3. Surface and upper-air weather maps for storm of June 29-30, 1956

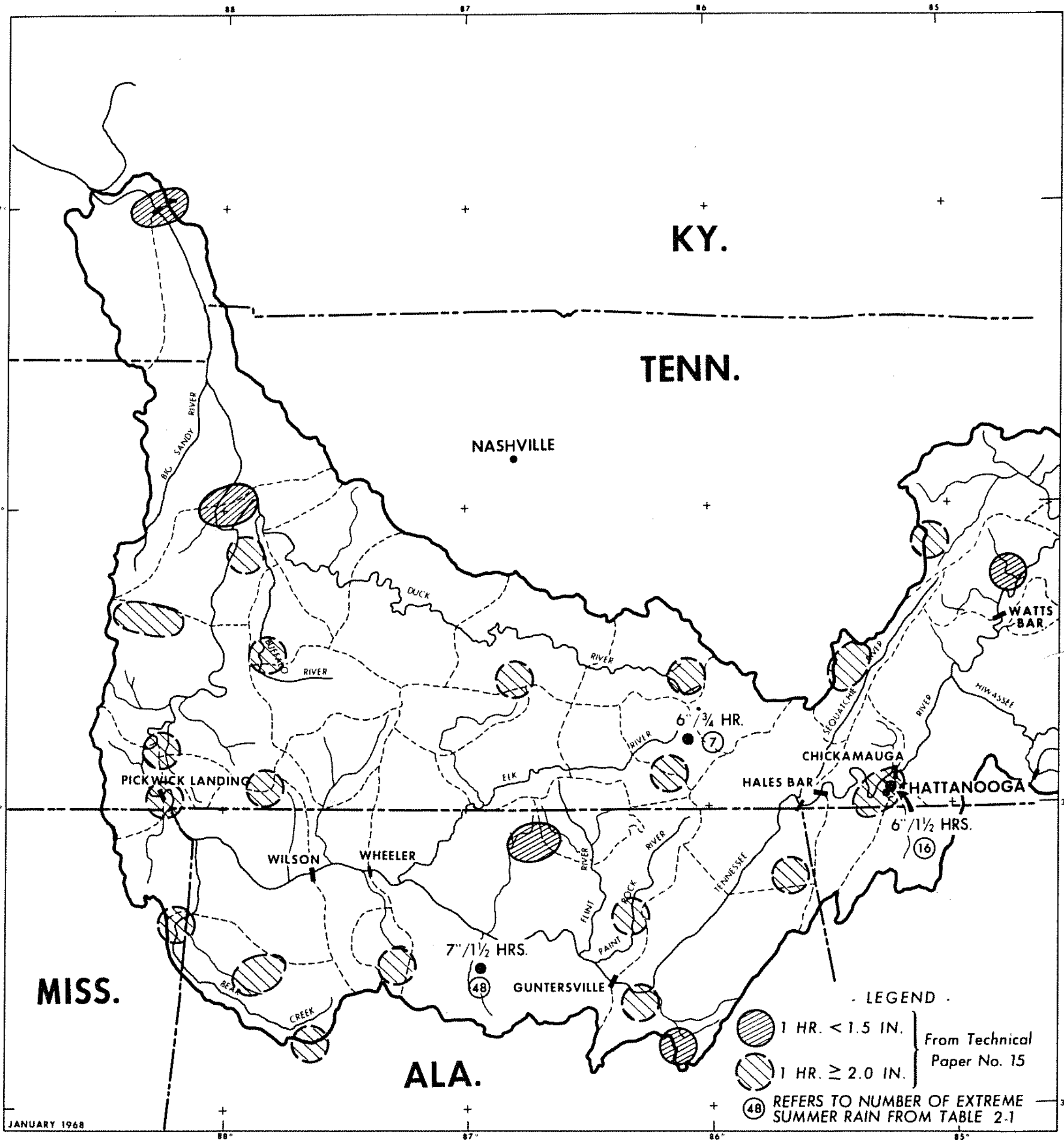


Figure 2-4. Maximum observed 1-hour rains over western Tennessee River watershed

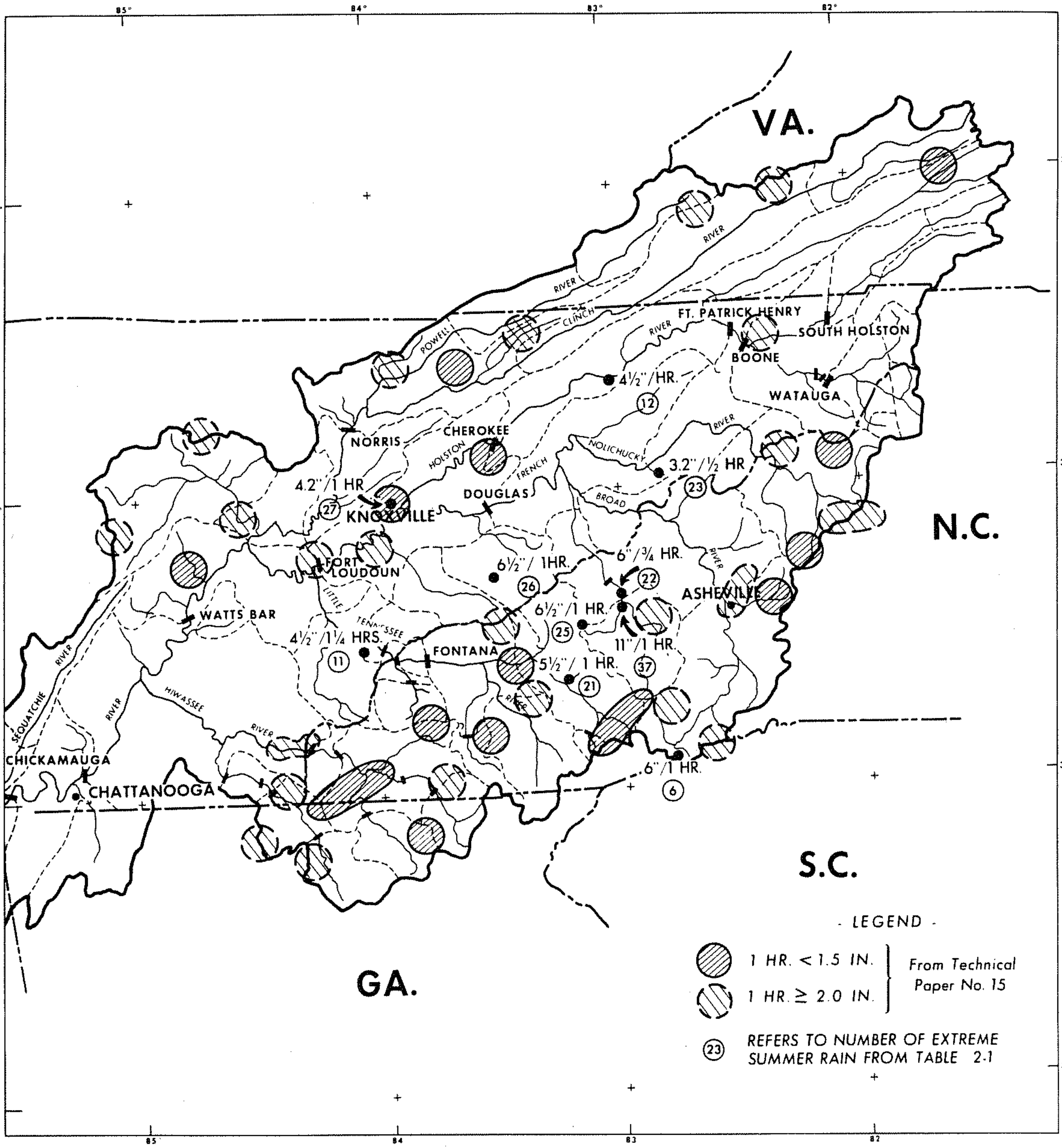


Figure 2-5. Maximum observed 1-hour rains over eastern Tennessee River watershed

shown on these figures are areas of maximum 1-hr. rains based upon regular reporting stations. In order to reveal any possible regional differences, the amounts are categorized into those exceeding 2 inches an hour and those less than 1-1/2 inches an hour. No clear-cut regional preferences are evident. Such data support a procedure that does not allow either topographic or regional difference in 1-hr. PMP or TVA precipitation.

As stated in the introduction most observed intense rains fail to approximate the PMP type in that they last only a short period. For this reason, lower magnitude rains that do last longer than a few hours can tell more about orographic effects than can the higher magnitude short-duration rains. Such data were investigated.

Maximum 24-hr. rains over the eastern, more mountainous portion of the Tennessee River watershed were plotted and analyzed for two rainfall categories. The categories were 24-hr. rains in excess of 8 inches and those less than 4 inches. On this basis, generalized areas were outlined as shown in figure 2-6. The effects of upslope and broad-scale sheltering are clearly indicated. These effects are discussed more thoroughly later in the chapter.

Intense short-duration rains throughout the United States

Intense small-area short-duration storms were abstracted from over 600 storm studies for the United States [2-6]. The pertinent storms for assessing intense small-area rains were all cases of 6-hr. 10-sq. mi. rainfall of 10 inches or more (table 2-2). Particular attention was given to those cases exceeding 15 inches in 6 hours, except where smaller values involved a large moisture adjustment. In addition, all cases of storms of duration shorter than 6 hours, listed in [2-6], were summarized. The locations of some of the more important of the maximum values of table 2-2 are shown in figure 2-7. Observed and moisture-maximized values are shown.

Again, as with the intense storms in the Tennessee River watershed, no single clearly defined synoptic type emerges. Suffice it to say the Smethport, Pa. storm of July 17-18, 1942, with its characteristics of lasting through the night and being part of a larger area of thunderstorms while concentrating the rain over a fixed area, single it out as most clearly depicting the PMP type.

Clues from larger area storms

Since storms like the Smethport storm are such a rarity we are forced to turn to storms producing less phenomenal rainfall totals in order to further characterize the PMP type. The criterion used for selecting summer (or summer-type) storms which produced large volumes of rainfall in or near the Tennessee River watershed was the number of stations which simultaneously recorded maximum 24-hr. rains. Weather Bureau Technical

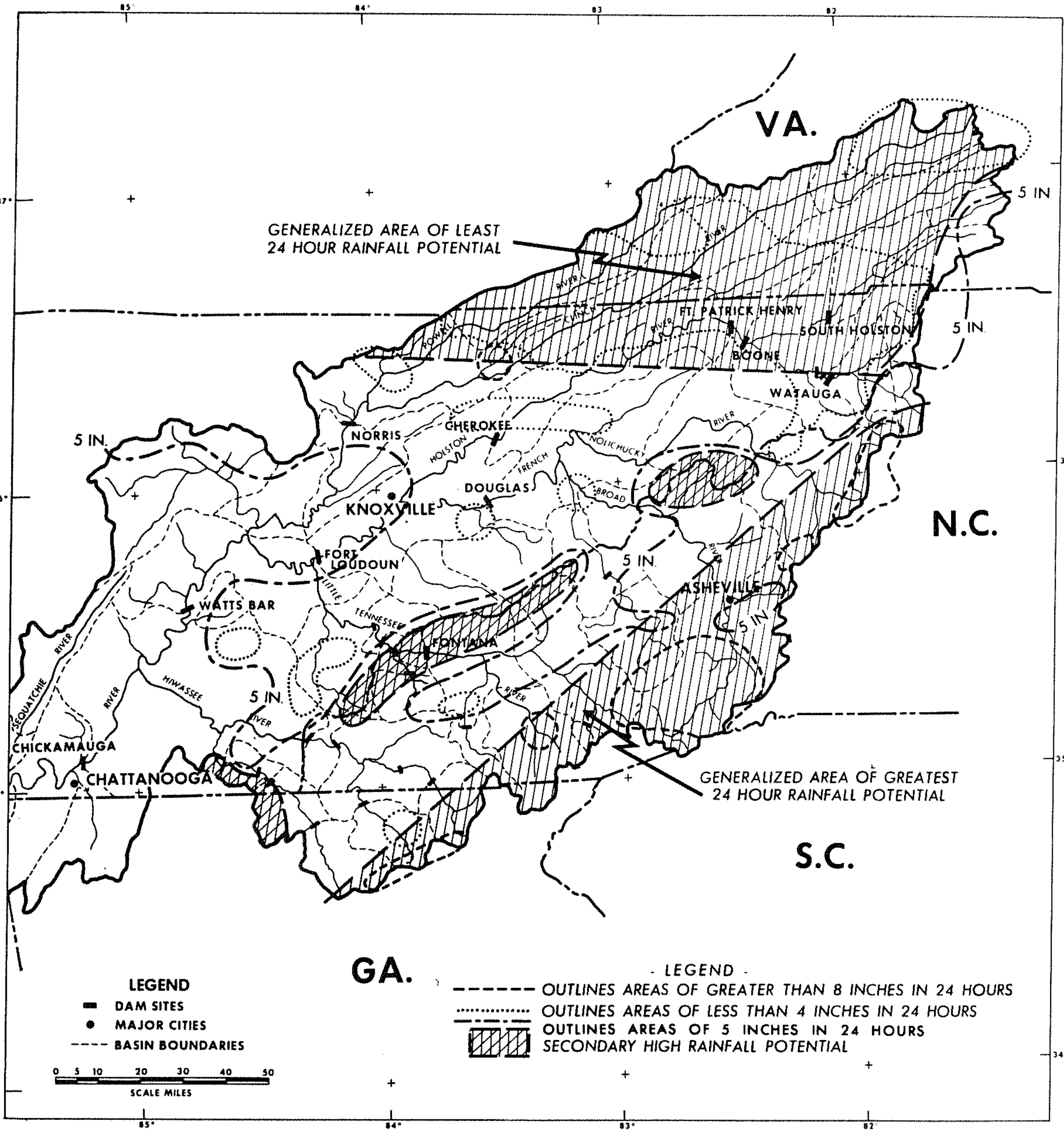


Figure 2-6. Areas of greatest and least 24-hr. rainfall potential based on station rainfall data

Table 2-2. U. S. Rainfall Occurrences Equaling or Exceeding 10 Inches in 6 Hours*

Date	Observed Amount (in.) 6-hr. 10-sq.mi.		Moisture Maximization (percent)
June 13-17, 1886	11.5	Alexandria, La.	+16
June 23-27, 1891	10.4	Larabee, Iowa	+22
June 4-7, 1896	12.0	Greenley, Nebr.	0
July 26-29, 1897	13.0	Jewell, Md.	+48
June 12-13, 1907	6.2 (3 hrs.)	Fort Meade, S. Dak.	+28
July 18-23, 1909	10.5	Ironwood, Mich.	0
July 18-23, 1909	10.5	Beaulieu, Minn.	+34
Aug. 28-31, 1911	14.9	St. George, Ga.	+21
Aug. 31-Sept. 1, 1914	12.6	Cooper, Mich.	+55
Aug. 1-3, 1915	12.9	St. Petersburg, Fla.	+16
Sept. 28-30, 1915	10.1	Franklinton, La.	+16
July 5-10, 1916	15.9	Bonifay, Fla.	+10
June 2-6, 1921	10.4	Pueblo, Colo.	0
June 17-21, 1921	10.5	Springbrook, Mont.	+28
Sept. 8-10, 1921	22.4	Thrall (Taylor), Tex.	+ 5
July 9-12, 1922	10.8	Grant City, Mo.	+34
Oct. 4-11, 1924	13.6	New Smyrna, Fla.	+21
Sept. 11-16, 1926	13.4	Neosho Falls, Kans.	+34
Sept. 17-19, 1926	18.4	Boyden, Iowa	+34
April 12-16, 1927	13.8	Jeff.-Plaq. Drain. Dist., La.	+22
March 11-16, 1929	14.0	Elba, Ala.	+34
May 25-30, 1929	11.3	Henly, Tex.	+10
June 30-July 2, 1932	13.3	State Fish Hatchery, Tex.	+16
Aug. 30-Sept. 5, 1932	10.0	Fairfield, Tex.	+10
April 3-4, 1934	17.3	Cheyenne, Okla.	+48
May 2-7, 1935	10.6	Melville, La.	+22
May 16-20, 1935	13.8	Simmesport, La.	+28
May 30-31, 1935	20.6	N.E. of Colorado Springs, Colo.	+48
June 27-July 4, 1936	14.0	Bebe, Tex.	0
Sept. 14-18, 1936	16.0	Broome, Tex.	+ 5
May 30-31, 1938	10.0	Sharon Springs, Kans.	+28
July 19-25, 1938	11.5	Eldorado, Tex.	+16
Aug. 12-15, 1938	10.9	Koll, La.	+10
May 25, 1939	8.2	Lebanon, Va.	+22
June 19-20, 1939	18.8	Snyder, Tex.	+48
July 4-5, 1939	18.6 (3 hrs.)	Simpson P. O., Ky.	+16
July 4-5, 1939	20.0	Simpson P. O., Ky.	+16
Aug. 21, 1939	9.5	Baldwin, Maine	+10
June 3-4, 1940	13.0	Grant Township, Nebr.	0
June 28-30, 1940	11.0	Engle, Tex.	+ 5
Sept. 1, 1940	20.1	Ewan, N. J.	+34
Sept. 2-6, 1940	18.4	Hallett, Okla.	+41
May 22, 1941	6.5 (3 hrs.)	Plainville, Ill.	0
Oct. 17-22, 1941	12.9	Trenton, Fla.	+16
April 14-17, 1942	13.1	Green Acres City, Fla.	+48
July 17-18, 1942	24.7	Smethport, Pa.	+10
May 12-20, 1943	15.9	Near Mounds, Okla.	+28
June 5-7, 1943	14.2	Silver Lake, Tex.	0
July 27-29, 1943	10.7	Devers, Tex.	+10
Aug. 4-5, 1943	11.1	Glenville, W. Va.	+16
June 10-13, 1944	13.4	Stanton, Nebr.	+41
July 9, 1945	9.1 (4 hrs.)	Easton, Pa.	+71
Aug. 26-29, 1945	10.1	Hockley, Tex.	0
Aug. 12-15, 1946	10.6	Cole Camp, Mo.	+21
Sept. 26-27, 1946	15.8	San Antonio, Tex.	+ 8
June 18-23, 1947	11.5	Holt, Mo.	+16
Aug. 27-28, 1947	13.8	Wickes, Ark.	0
Aug. 24-27, 1947	10.9	Dallas, Tex.	+28
June 23-24, 1948	13.2	Del Rio, Tex.	+21
Sept. 3-7, 1950	16.0	Yankeetown, Fla.	+10

*A few cases of storms less than 6 hours duration are included.

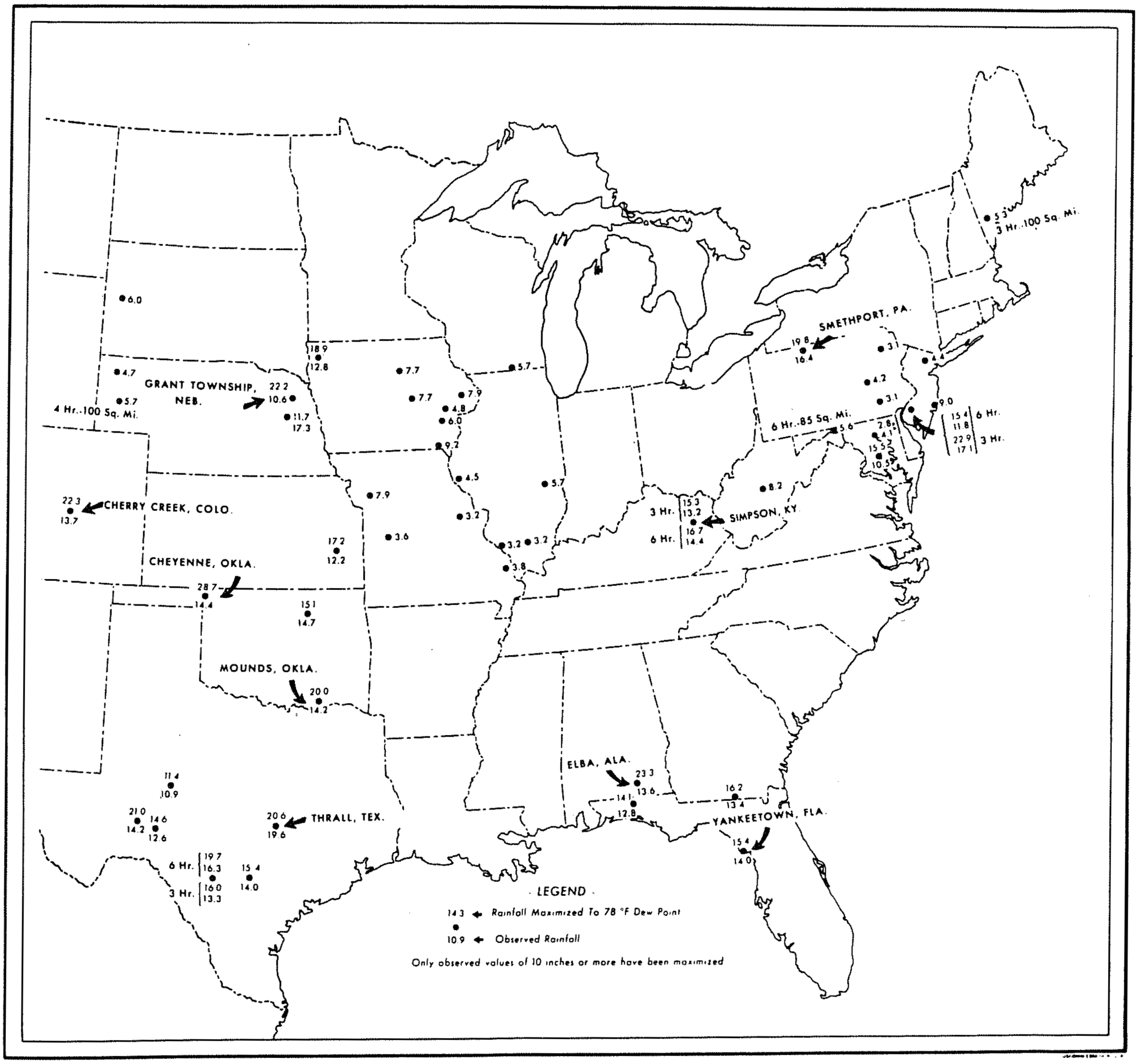


Figure 2-7. Maximum 6-hr. 100-sq. mi. rainfall values from "Storm Rainfall in the United States" [2-6]

Paper No. 16 [2-7] provides a convenient summary of such data. From a survey involving several hundred stations six storms were defined. These are listed in table 2-3, showing the storm period and the number of stations recording their maximum 24-hr. rains.

Table 2-3. Storms Producing Maximum 24-Hour Rains at Stations in and Near the Tennessee River Watershed

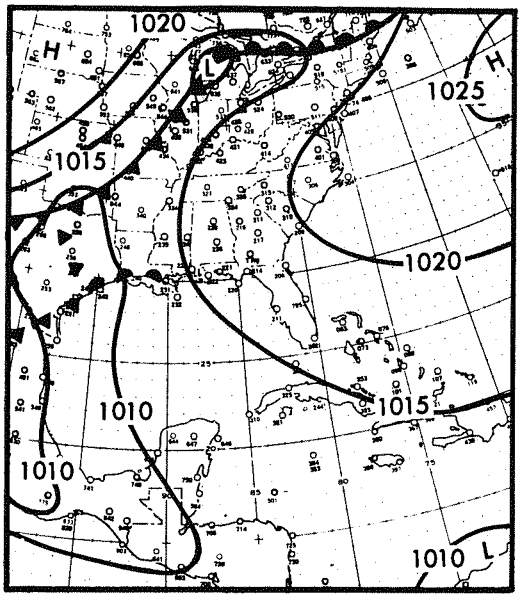
Storm Date	No. of Stations
September 29-30, 1944	28
August 13-14, 1940	16
August 29-30, 1940	16
June 27-29, 1947	5
June 15-16, 1949	11
October 30-31, 1949	7

These storms, and some discussed in chapter III, show that maximum 24-hr. rains often are not isolated events, though most of the more intense ones are (table 2-1). The problem is to postulate what can occur for a 24-hr. period over a small basin. Weather maps for two of the storms in table 2-3 are shown in figures 2-8 and 2-9.

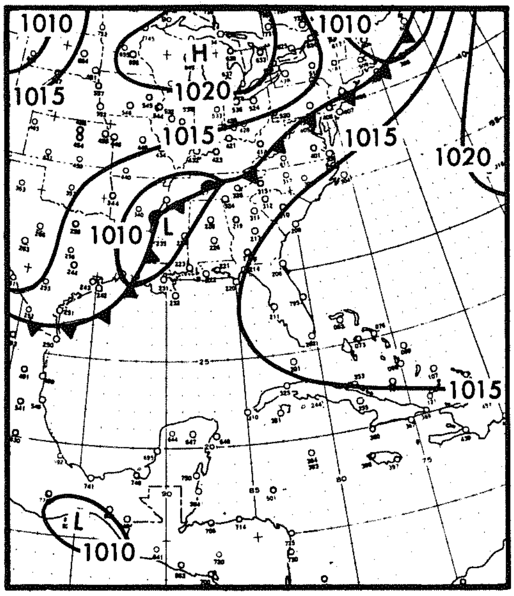
The fact that most of the above storms are not in the midsummer period is significant. They are close enough to midsummer to draw upon high moisture values yet close enough to the cooler seasons to utilize more efficient rain-enhancing mechanisms (such as the convergence with significant fronts, etc.). Since rain-enhanced mechanisms are more frequent in the vicinity of the Tennessee River watershed in the transition seasons it is at these times that one is more apt to find a greater number of storms that have the "longer-lasting" characteristic of the summer PMP type. Thunderstorms are involved in these transition season storms but their rain-producing capabilities are somewhat limited by not being able to draw upon moisture values as high as what is possible in midsummer.

An example of a late-fall storm which produced intense rainfall values is that of November 18, 1957 [2-8]. This storm produced 9 inches in two hours [2-1] over 200 square miles (table 2-1). The moisture charge, instability and air inflow rate in this case were similar to those in other heavy rain-producing situations. A slowing down in the movement of a squall line apparently resulted in an unusual concentration of heavy rain by prolonging the rainfall in a fixed area. Such a storm, though a late-season one, embodies features of the PMP type since intense thunderstorm-produced rains are part of a longer-lasting and larger rainfall area.

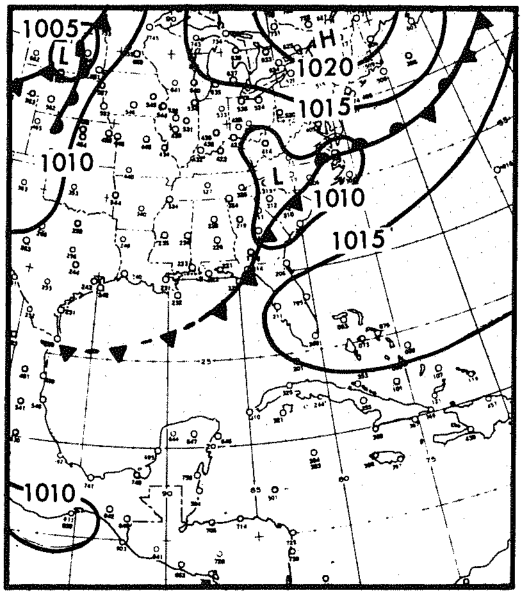
The Tennessee River watershed lies far enough north that mechanisms of rain production such as squall lines common in the transitional season



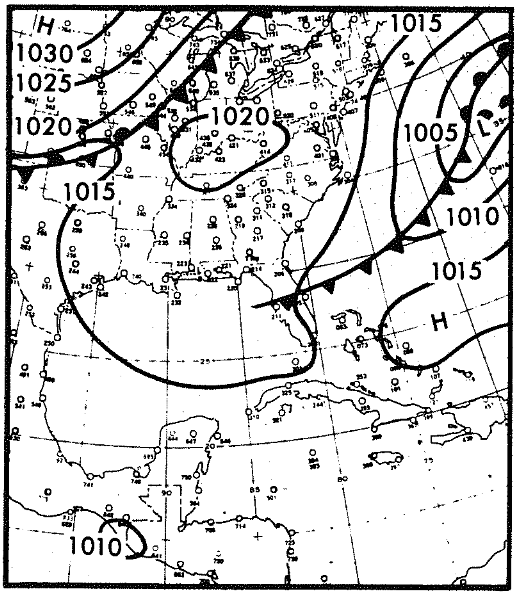
Sept. 28, 1944 Sea Level 1230GMT



Sept. 29, 1944 Sea Level 1230GMT

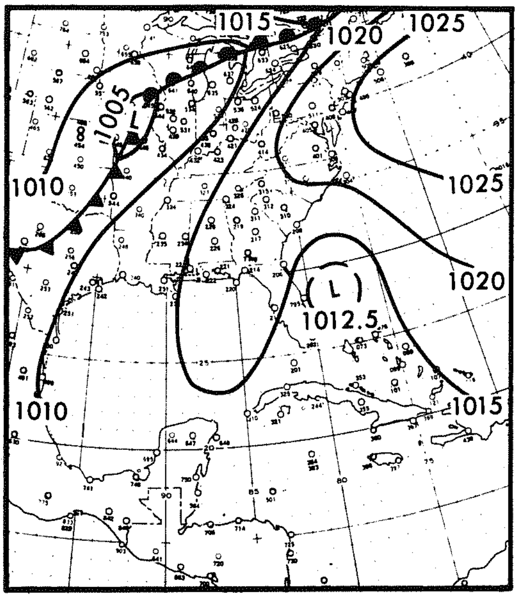


Sept. 30, 1944 Sea Level 1230GMT

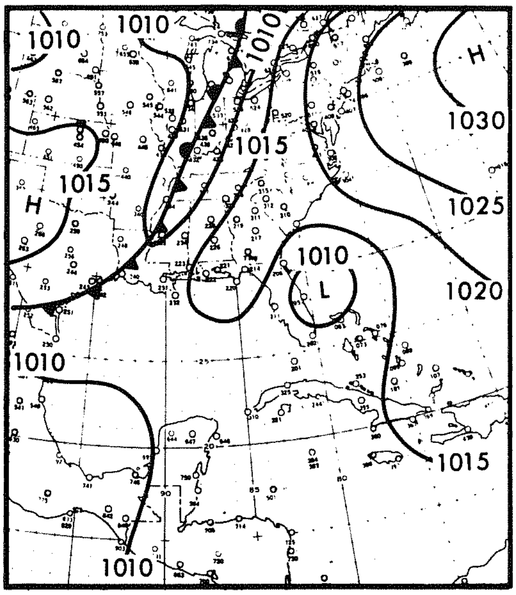


Oct. 1, 1944 Sea Level 1230GMT

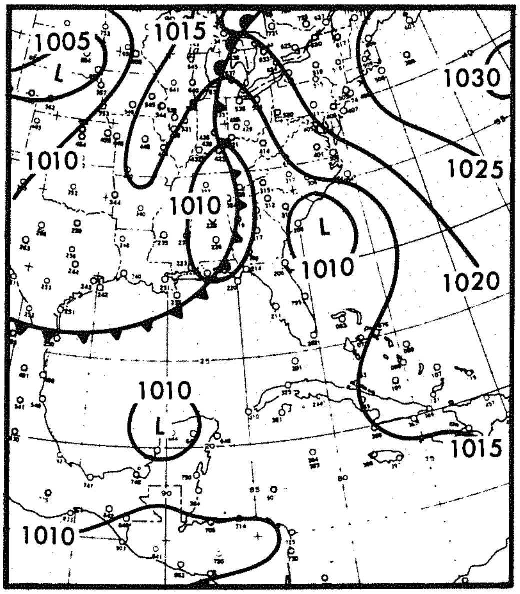
Figure 2-8. Surface weather maps for storm of September 28-October 1, 1944



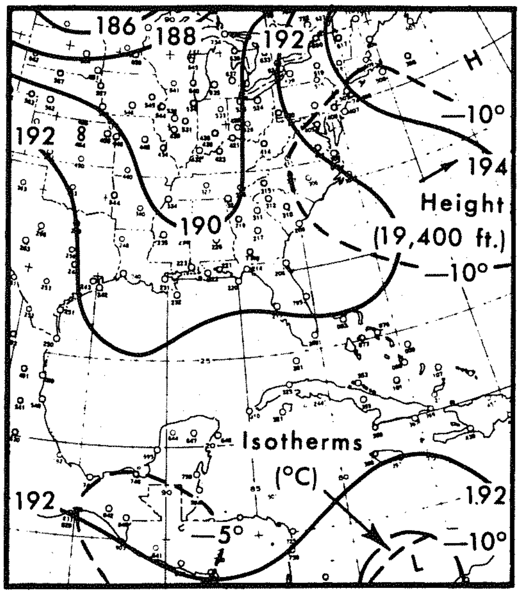
June 14, 1949 Sea Level 1230 GMT



June 15, 1949 Sea Level 1230 GMT



June 16, 1949 Sea Level 1230 GMT



June 16, 1949 500 MB 0300 GMT

Figure 2-9. Surface and upper-air weather maps for storm of June 14-16, 1949

are also possible (although much less frequent) in the midsummer months. When one or more of such "mechanisms" operates in summer over a geographically fixed area, with moisture near maximum a Smethport type PMP storm is the result.

Thunderstorm climatology and the diurnal character of thunderstorm rainfall

The PMP thunderstorm day is envisioned as continued repetition of thunderstorms throughout a 24-hr. period. Such a situation requires a continued transport of high moisture into the area of thunderstorm activity. For the Tennessee Basin, this would generally require winds with a southern component since the moisture source is the Gulf of Mexico. For some areas, such as the westward-facing slopes of the Smokies in Virginia, a more indirect influx of Gulf of Mexico moisture by-passing the mountains and then turning to come from a westerly direction would provide the most effective utilization of existing ground slopes.

A summation of thunderstorm statistics for typical stations in the basin helps to clarify certain characteristics of the PMP type of thunderstorm situation. Consideration of only summer data on thunderstorms can be misleading. Figure 2-10 shows the monthly variation of thunderstorm days at Tennessee stations. Figure 2-11 shows the average daily amount of rainfall on days with thunderstorms. The less frequent cooler-season storms which show more average daily rain, are in one sense more typical of the PMP type since the cooler-season thunderstorms occur in longer duration rain situations.

Diurnal variation of thunderstorms as related to the PMP type. Most thunderstorms in the Eastern United States occur in the afternoon or evening. However this diurnal variation does not necessarily apply to the PMP type. Most afternoon thunderstorms last an hour or less, and even the extreme ones observed generally last less than three hours. Recent studies [2-9, 2-10, 2-11] emphasize the complexity of the diurnal variation problem as related to extreme thunderstorm rainfall.

Most observed Tennessee River watershed summer thunderstorms (like those summarized in figs. 2-10 and 2-11) are of the "insolation," short-lived type. One trend that can be found in the Tennessee River watershed thunderstorm data is the decrease in importance of the "insolation" factor as the intensity and longevity of the thunderstorm increase. This can be seen by use of thunderstorm statistics at a typical station.

Chattanooga thunderstorm diurnal characteristics. The hourly distribution of precipitation for Chattanooga was summarized for all thunderstorm days in the March-October season during the 10-yr. period 1955-1964. A threshold of one-half inch of rain was required for making the data meaningful. Figure 2-12A summarizes the average hourly rainfall for all cases with a daily total of one-half inch or more while figure 2-12B does so for

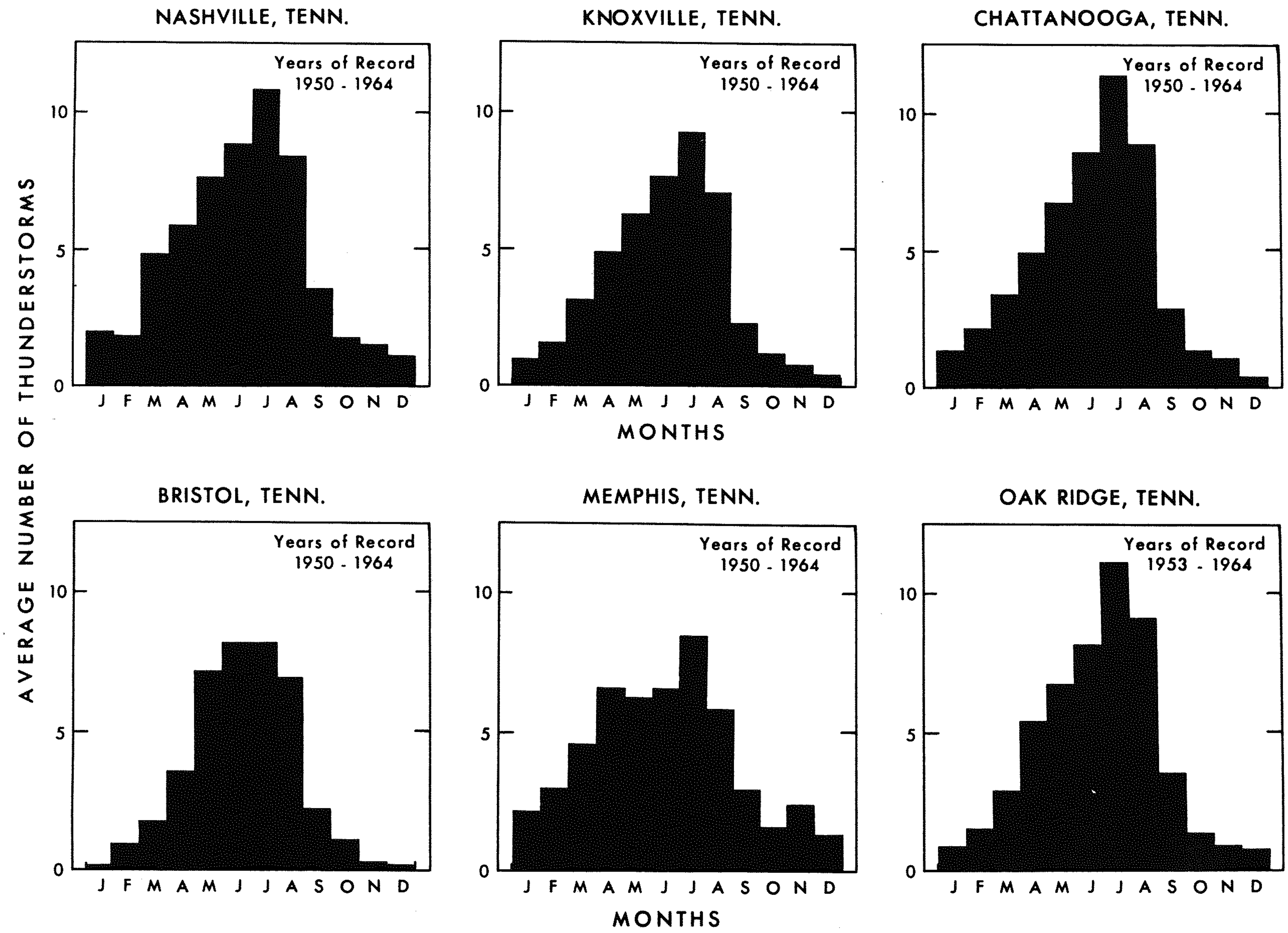


Figure 2-10. Monthly variation of thunderstorms at Tennessee stations

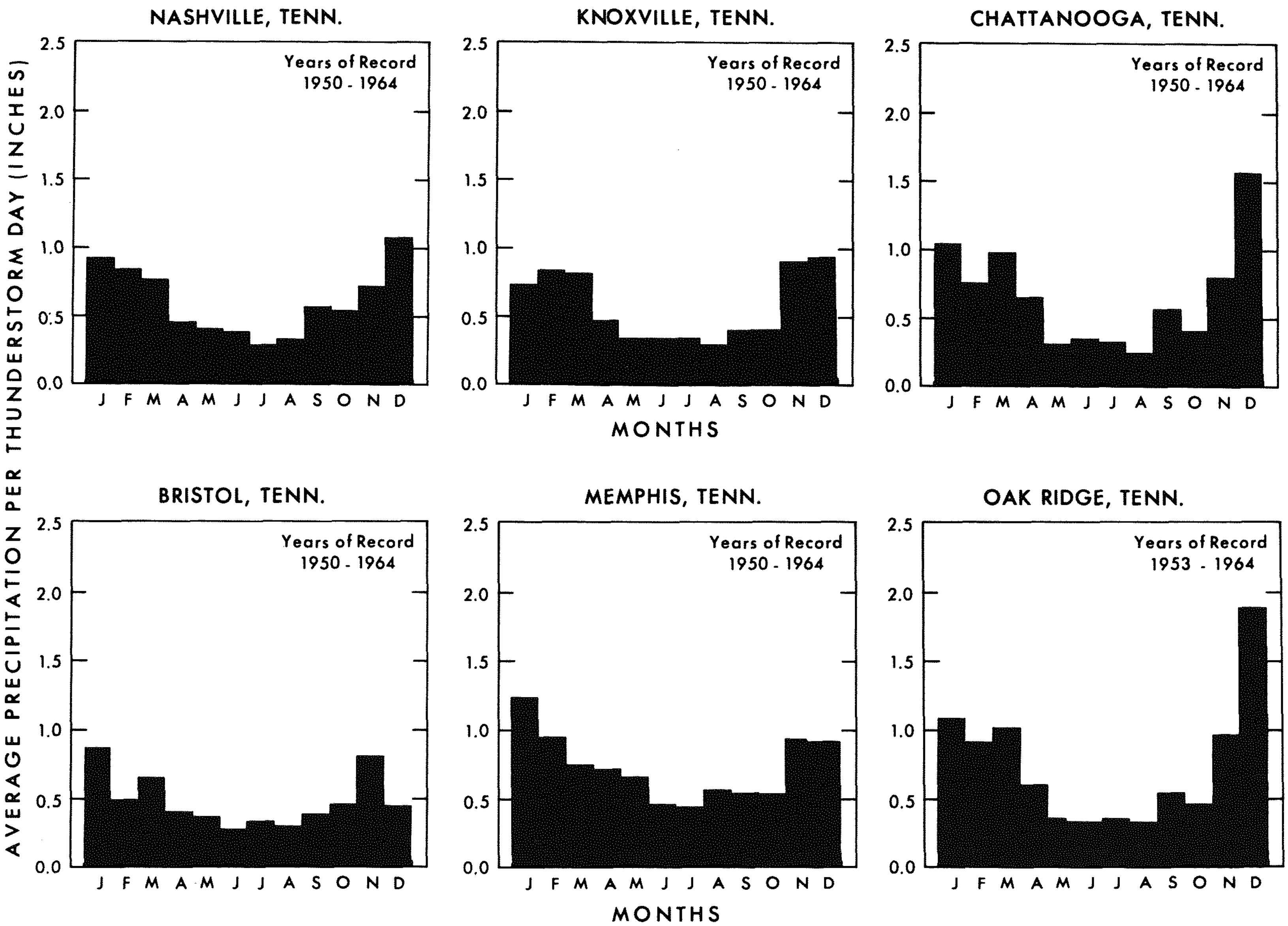


Figure 2-11. Monthly variation of average daily precipitation on days with thunderstorms

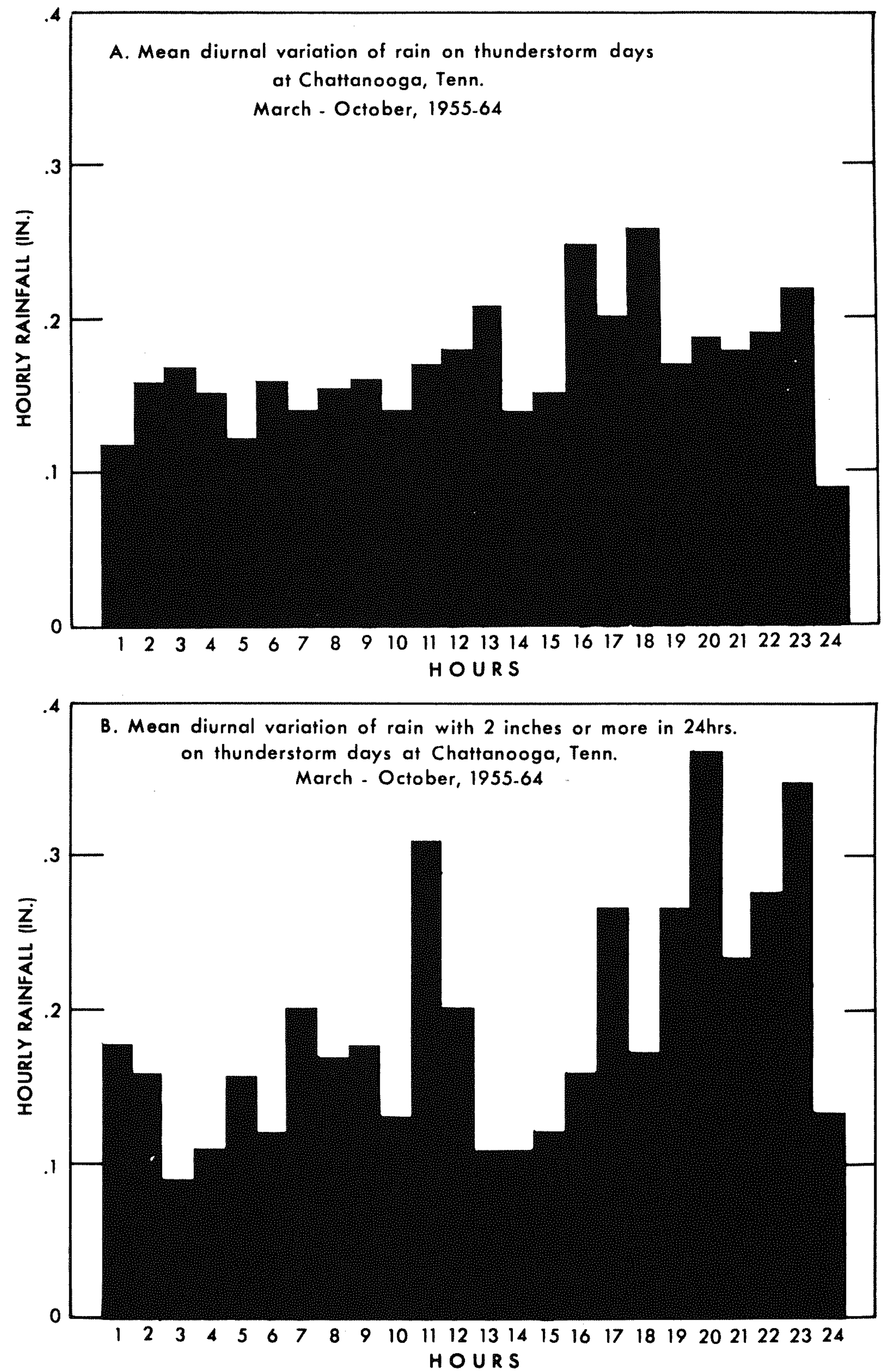


Figure 2-12. Diurnal variation of thunderstorm rainfall at Chattanooga on days with (A) one-half inch or more (B) two inches or more

cases with daily rainfall amounts of 2 or more inches. A decreased effect of the diurnal heating factor is suggested as the heavier rainfall cases are considered. (See average thunderstorm rain intensity for the hours of 8 to 12 p.m. local time in fig. 2-12B.) This trend away from the importance of insolation as the thunderstorm intensity increases becomes more evident as one considers the most extreme occurrences.

Diurnal characteristics of extreme U. S. rains. The Tennessee River watershed storm of June 13, 1924 (table 2-1) began after 6 p.m. and lasted into the early morning hours. That of July 26, 1960, at Grizzle Creek, Ga., occurred mostly between 10 p.m. and 1 a.m. Study of the "granddaddy" of all thunderstorm situations, the Smethport, Pa., storm of July 17-18, 1942, indicates that most rain in this storm occurred between midnight and noon. Thus, the usual diurnal characteristics are lost in the really big summer thunderstorms. Mechanisms contributing to the fixing and prolonging of the rain assume more importance in such storms so that diurnal heating effect is overwhelmed.

A study was made of the hours of occurrence of 60 intense rainstorms listed in table 2-2. Although many of these rains started as showers in the afternoon the modal time was from 1 to 2 a.m. Since this sample included storms from the Plains States, where nocturnal thunderstorms are common [2-12], a separate evaluation was made using only cases east of the Mississippi. Results were similar, with 2 to 4 a.m. being the modal time of rainfall occurrences. These extreme rains more nearly represent the PMP type in terms of the loss of afternoon diurnal control. A convergence mechanism that overwhelms insolation and other influences predominates in the more extreme rains and in the PMP storm especially.

Conclusions on diurnal characteristics. We conclude from the discussion above that the diurnal characteristics common to many thunderstorms both in and outside the Tennessee River watershed does not need to be adhered to in the PMP situation. In the PMP case the rainfall will extend through and perhaps maximize during the nighttime hours.

In the procedure that follows in this and subsequent chapters allowance is partially made for the more characteristic abbreviated thunderstorm by allowing a TVA level thunderstorm to prevail for as short as three hours.

Joining of thunderstorms as related to PMP type

Eyewitnesses typically describe extreme rain situations in terms of two or more clouds (storms) "coming together." Table 2-4 compiled from TVA storm-survey files, summarizes a group of such eyewitness accounts of storms which have occurred in Tennessee and nearby states. The phenomenon, which has also been observed by radar, must occur rather frequently judging from the reported observance of such occurrences. Such observations are not necessarily restricted to daylight hours since the frequency of lightning in extreme rainfall occurrences permits such observations at night.

Table 2-4. Storms in the Tennessee River Watershed with Eyewitness Accounts of 2 Storms Meeting or Coming Together

Location	(Coordinates)		Date	Description
Saltville, Va.	36°53'	81°46'	7/5/36	"...two storms came together and one man said he thought---three storm clouds...all came together at the same time"
Lebanon, Va.	36°54'	82°05'	5/25/39	"...two storm clouds approached from opposite directions, one from the SW and the other from the NE..."
Speer Ferry, Va.	36°39'	82°45'	7/17/36	"...apparently two clouds met, one approaching from the North and the other from the West"
Hayesville (nr.), N.C.	35°05'	82°50'	7/7/38*	"...observed the approach and meeting of two rain clouds, one from the NW and one from the east"
Winchester Springs (nr.) Tenn.	35°14'	86°06'	7/8/38	"...rain came from two clouds, one approaching from the east and one from the west, which met just north of his house"
Adamsville, Tenn.	35°14'	88°24'	6/7/40	"...rain came from two clouds one moving in from the SW and one from the NW"
Rogersville, Ala.	36°22'	83°03'	7/8/40	"...heavy rain lasted about 1 hr. and resulted from the meeting of two clouds, one moving from the SW and one from the SE"
Sparta (nr.), Tenn.	35°55'	85°28'	6/4/49	"The clouds appeared to meet (from east and west) at the top of Little Chatnut mountain..."
Bulls Gap (nr.), Tenn.	36°15'	83°05'	7/30/37	"...described the storm as the meeting of 3 or 4 clouds from as many directions"
Dillard, Ga.	34°58'	83°55'	6/5/52	"...2 storms, one approaching from ... the SW ... and the other from ... the NE, converged ... just south of Dillard"
Grizzle Creek, Ga.	34°33'	84°04'	7/26/60	"Two clouds moved in from two different directions and met over this area and "the bottom dropped out"

*Rainfall values for this and following storms may be found in table 2-1.

Outstanding storms in other parts of the country have been similarly described by eyewitnesses. For example, eyewitnesses of a storm near Morgan, Utah, on August 16, 1958, that reportedly produced 7 inches of rain in an hour, stated that two clouds appeared to meet right over a valley. Another example is quoted from observers notes from a Campo, Calif., storm of August 12, 1891, in which an estimated 11-1/2 inches occurred in 80 minutes; "... and then another cloud came up and the one that had passed over drew back and the two came together and it poured down whole water nearby." Finally, the observer had this to say about a Catskill, N. Y., storm of July 26, 1819, which dumped 18 inches of rain in 7-1/2 hours:

> "about half past 5 another dense and black cloud accompanied by a fresh wind arose from the southwest. About the same time or immediately after, a very thick and dark cloud rose up rapidly from the northeast. They met immediately over the town."

Eyewitnesses of the outstanding Smethport, Pa., storm also spoke of stupendous masses of clouds approaching the area from several directions.

Two things were noted about these accounts. First, they usually refer to thunderstorm occurrences in areas that have hills and valleys in close proximity. Second, they concern thunderstorm situations that produced unusually heavy rains.

One may conjecture on the meaning of such eyewitness accounts in connection with outstanding cloudbursts. It is possible that the nearly simultaneous occurrence on nearby slopes of two separate thunderstorms sets the stage. With the two gravity-aided cold outflows (racing downhill), the resulting convergence sets off a new and more vigorous convective development as the two outflows approach or intermingle. The new thunderstorm development "takes over," and the surrounding inflow entrains the remnants of the initial thunderstorms into the new development. The new thunderstorm would presumably be extremely efficient since it would entrain into itself not only moist air (minimizing evaporation losses) but also residual, previously formed raindrops. This makes possible local rainfall rates of a magnitude exceeding rates computed by the usual theories which relate the convergence of water vapor to precipitation.

The discussion above has some bearing on the adoption of a storm like the Smethport, Pa. storm as the PMP-type for the Tennessee River watershed. The question arises as to whether such a storm is possible to the fullest extent throughout the Tennessee River watershed. Since it has been observed that the observances of the "clouds-coming-together" phenomenon is characteristically reported in areas with hills and valleys in close proximity, it apparently would not be realistic to postulate the occurrence of the Smethport, Pa. type storm unadjusted in very flat regions. A geographical distinction is made therefore in applying the PMP type storm (section B).

Conclusions on PMP-type thunderstorm for the Tennessee River watershed

The discussions in section A of this chapter suggest the following conclusions:

1. In summer, the small-area PMP storm situation, unlike nearly all extreme summer rains observed to date in the Tennessee River watershed and elsewhere in the United States will involve a continuation of thunderstorms, fixed geographically, throughout a 24-hr. period.

2. The summer PMP type thunderstorm will likely depart from the usual diurnal characteristics of thunderstorms in and near the Tennessee River watershed. The role of diurnal heating will be minimized as the maximum rainfall rates may occur during the nighttime hours as in the important Smethport, Pa. storm.

3. The summer PMP type thunderstorm will be capable of producing more rainfall in some geographical areas (e.g., slopes and valleys in close proximity) than in others (e.g., very flat areas with no nearby slopes).

4. The summer PMP type thunderstorm for short durations of an hour or less will show little, if any, orographic variations. However, for longer durations orographic effects are suggested.

B. DERIVATION OF PMP AND TVA PRECIPITATION VALUES

Introduction

This section discusses the determination of the magnitude of summer PMP and TVA precipitation over small basins. In conforming to the definitions adopted in chapter I the rarest known storms with moisture maximization are guides to defining the PMP level, while the TVA precipitation level is based on storms as observed without moisture maximization and with undercutting of the most extreme events. Maps were derived, based primarily on the transposition of storms, of 6-hr. 5-sq. mi. PMP and TVA precipitation. Depth-area and depth-duration relations were developed for use with these maps to give the extreme precipitation values for other durations up to 24 hours and basin sizes up to 100 square miles. For the TVA level of precipitation, a family of variable depth-duration curves is provided, an innovation in studies of this kind. An important aspect of the study is the evaluation of topographic factors and their influence on rainfall.

Data

The basic storm information used to determine the short-duration PMP and TVA precipitation are the 56 outstanding storms that occurred in or near the Tennessee River watershed (table 2-1) and the storms which occurred elsewhere in the country given in table 2-2. The most important of the storms outside the Tennessee River watershed was the Smethport, Pa. storm of July 17-18, 1942.

Topographic classification

Topography is known to play an important role in rainfall in the Tennessee River watershed. The problems are to develop a meaningful broad-scale classification system that could be related to the occurrence of intense storms.

One means of assessing orographic factors is on-site inspection. Early in the study the authors joined with TVA personnel on a flight over the sites of a number of the outstanding rainfall occurrences. In addition a number of the sites were inspected on the ground.

Another means is from inspection of topographic maps. The Tennessee Valley Basin has been completely mapped to a scale of 1/24,000 on 7-1/2 minute quadrangles, with 20-foot contours.

From both the field and topographic map inspection the decision was made that PMP and TVA estimates should be developed for three classifications of topographic settings. These were "smooth," typified by the area around Columbia, Tenn.; "rough," typified by most of the Cumberland Plateau; and "intermediate," of which the area around Knoxville is an example.

Each quadrangle map in the Tennessee River watershed was classified "smooth," "intermediate," or "rough," in accordance with the following rules:

"Smooth," if there are few elevation differences of 50 ft. in 1/4 mile.

"Intermediate," where elevation differences from 50 to 150 ft. within 1/4 mile are frequent.

"Rough," if there are general areas with elevation differences exceeding 150 ft. within 1/4 mile.

Single isolated mountains or hills did not warrant a rough classification. In areas of narrowing "V"-shaped valleys elevation differences of less than 150 feet admitted a rough classification, based on the idea that this type of land form favors convergence of the air and lifting. For extensive mountain chains or ridges the rough classification was carried out 3 miles or so away from the mountain.

Under this classification all of the eastern mountainous part of the Tennessee River watershed is "rough." For the western part of the watershed the classifications of the individual quadrangles were noted on a master map of the basin, and a single map constructed dividing the region into the 3 topographic classes by smoothing.

Topographic effects in the eastern Blue Ridge-Appalachian region

Although the eastern portion of the Tennessee River watershed was classified as "rough" this did not adequately explain the variations in rain potential across the region. In some places mountains extend in elevation up to 6000 feet above mean sea level. Large valleys are sheltered by mountains.

This contrast between high mountains and large sheltered valleys required additional consideration besides "roughness" in order to fully assess the orographic effects on intense summer rains.

As an aid to delineating orographic effects a map of 100-year return period daily rains was constructed. This was done using all rainfall stations with 15 or more years of record.

After some experimentation the following concepts evolved and were adopted.

First upslope: This is defined as a mountain slope facing the lowlands in a direction east through southwest with no intervening mountains between the slope and the Gulf of Mexico or the Atlantic. In general, total summer precipitation on first upslope areas is around twice that of sheltered areas.

Secondary upslope: A secondary upslope is high and steep enough to increase precipitation, but is partially shielded upwind (toward moisture source) by a lower mountain range, with an elevation difference between the crests of at least 1500 feet. Total summer precipitation on secondary slopes is 30 to 50 percent greater than that of sheltered areas.

Sheltered areas: These are defined as valleys having upwind barriers from southeast through southwest of 2000 feet elevation above sea level or higher.

Depression: The elevation difference between the crest of a barrier and a point within a sheltered area is the "depression" at that point.

Adopted values. The following guides are adopted for topographic influence on PMP and TVA precipitation in the eastern portion of the basin.

Precipitation increase of 10 percent per 1000 feet from sea level up to 2500 feet on first upslopes with no further increase above 2500 feet. Precipitation increase of 5 percent per 1000 feet from sea level on secondary upslopes at all elevations.

Five percent decrease per 1000 feet of depression in sheltered areas.

A map showing these topographic categories is shown in figure 2-13. Some smoothing has been done by judgment based on both inspection of topographic maps and rainfall behavior. For example, some portions of the Ocoee Basin while technically "sheltered" by the above definition, according to the rainfall experience are effectively "first upslope."

Broad-scale sheltering effects

A broad-scale decrease in rainfall potential from south-to-north is depicted later (fig. 2-17) as a latitudinal gradient.

Normalized rainfall indices, such as 2-yr. 24-hr. precipitation suggest such a broad-scale sheltering effect increasing northward as interference to moisture inflow by the mountains increases. The suggested decrease amounts to about 10 percent from the Ocoee Basin northeastward to the South Holston Basin.

TVA depth-duration curves for 5 square miles

Following the concept of "TVA precipitation" expressed in the introduction to this report, the TVA storm for small basins is based on depth-duration curves of observed extreme point rainfalls. The 18 heaviest rainfalls from the list of Tennessee River watershed storms (table 2-1) are plotted in figure 2-14, with the storms identified by number. Added to the plot are the Simpson, Ky. storm of July 1939 and the Glenville, W. Va. storm of August 1943. The topographic classification of the site of each storm is indicated.

Enveloping depth-duration curves for "rough" topography and "smooth" topography were constructed applying the following concepts and principles.

a. Over areas of a few square miles and durations of about one hour, maximum precipitation rates depend on the extreme upward velocities that may exist in thunderstorms. These velocities are related to the dynamics of the thunderstorm itself and are so great that topographic effects are negligible. Thus the same maximum rates may be expected over various terrain categories within the same air mass.

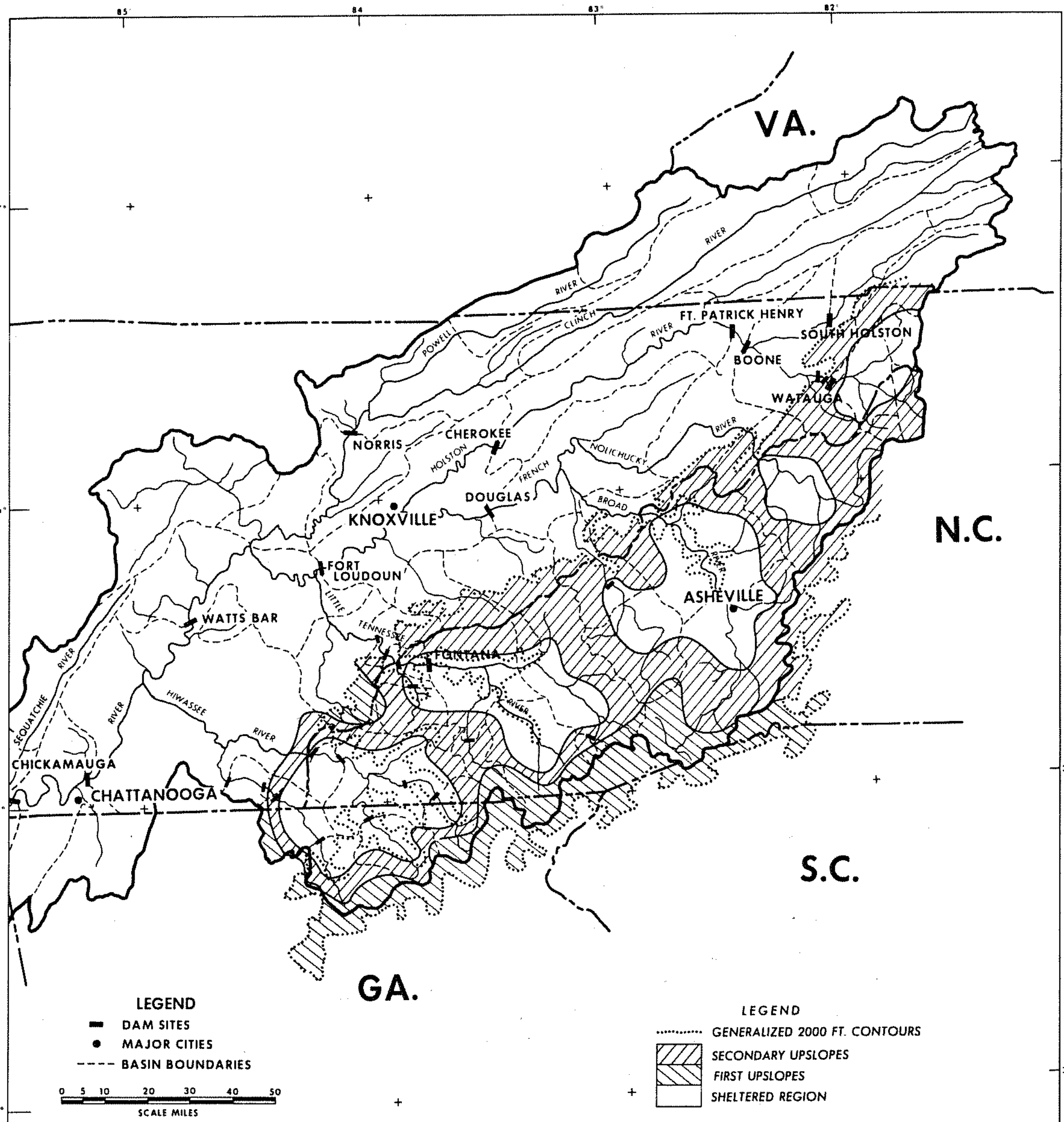


Figure 2-13. Topographic classifications of the mountainous eastern portion of the Tennessee River watershed

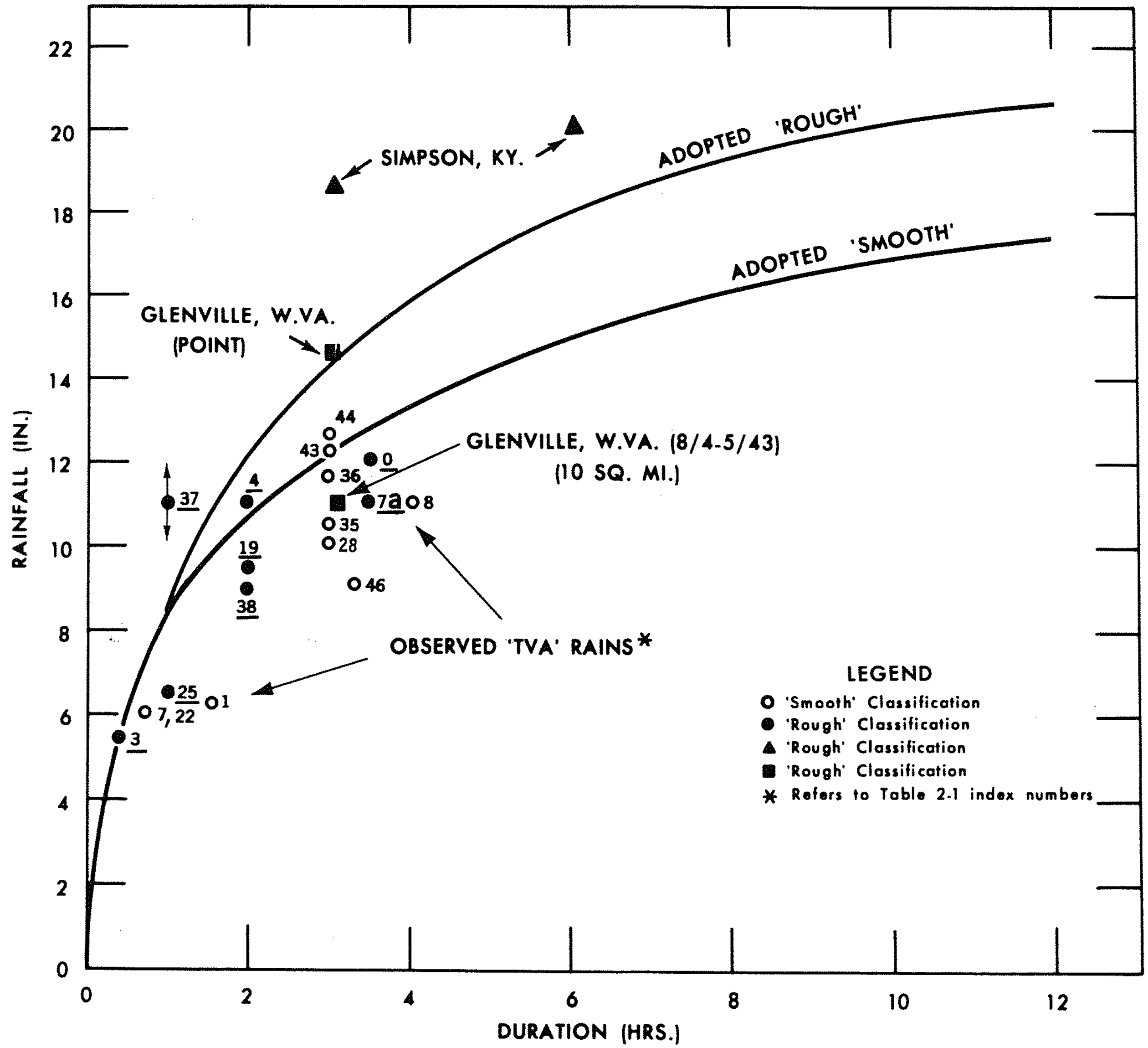


Figure 2-14. Adopted 5-sq. mi. TVA precipitation with supporting data

b. Beyond the minimum duration of about one hour, terrain roughness becomes increasingly important to the maximum convective rainfall rate. There are three influences. First, slopes and roughnesses of the terrain accentuate upward velocities in the air. Secondly, an intense thunderstorm tends to remain at one location longer over a topographically favorable site than over more uniformed terrain where it would drift more randomly with the wind or propogate laterally by its own dynamics. Finally, for longer durations, the probability of continued rain after an intense thunderstorm is enhanced by favorable topography.

c. The TVA level of intense precipitation corresponds to the largest values that have been observed in the region (without moisture maximization) except that spectacular events which are extreme "outliers" are undercut. Thus the depth-duration curve labeled "rough" envelops the rainfall values at rough sites, except that the storm at Simpson, Ky. is undercut as is storm No. 37. The latter is a somewhat vague measurement. The Simpson, Ky. storm is transposable to at least some parts of the Tennessee River watershed.

d. Experience with appropriate storms throughout the country is useful in shaping the depth-duration curves. The enveloping depth-duration curves are extended from 3 hours to 24 hours (only 12 hours shown in figure) by ratio to the PMP curves (adopted curve-fig. 2-16) described in a later paragraph.

e. Point values of rainfall detected in rain gauges and other containers are likely to be less than true maximum point intensities. The enveloping curves constructed as described are arbitrarily considered to apply to averages over an area of 5 square miles, the smallest basin size assigned in the study.

PMP depth-duration curves for 5 square miles

The practice in deriving estimates of probable maximum precipitation in the Central and Eastern United States is to maximize appropriate outstanding observed storms for moisture and either transpose them with moisture adjustment to the basin and envelop the transposed values or envelop the moisture-maximized values regionally on a map. An example is figure 5-3 of HMR 41 [1-2]. For this study the direct transposition method was used with allowance for regional variations in thunderstorm intensity by omitting the moisture maximization for the June 1947 Holt, Mo. storm. The largest U. S. rainfalls of six hours duration and less from table 2-2 treated in this manner are plotted in figure 2-15, along with 12-hr. values for some of the storms. Durational envelopes are constructed with the following considerations in mind.

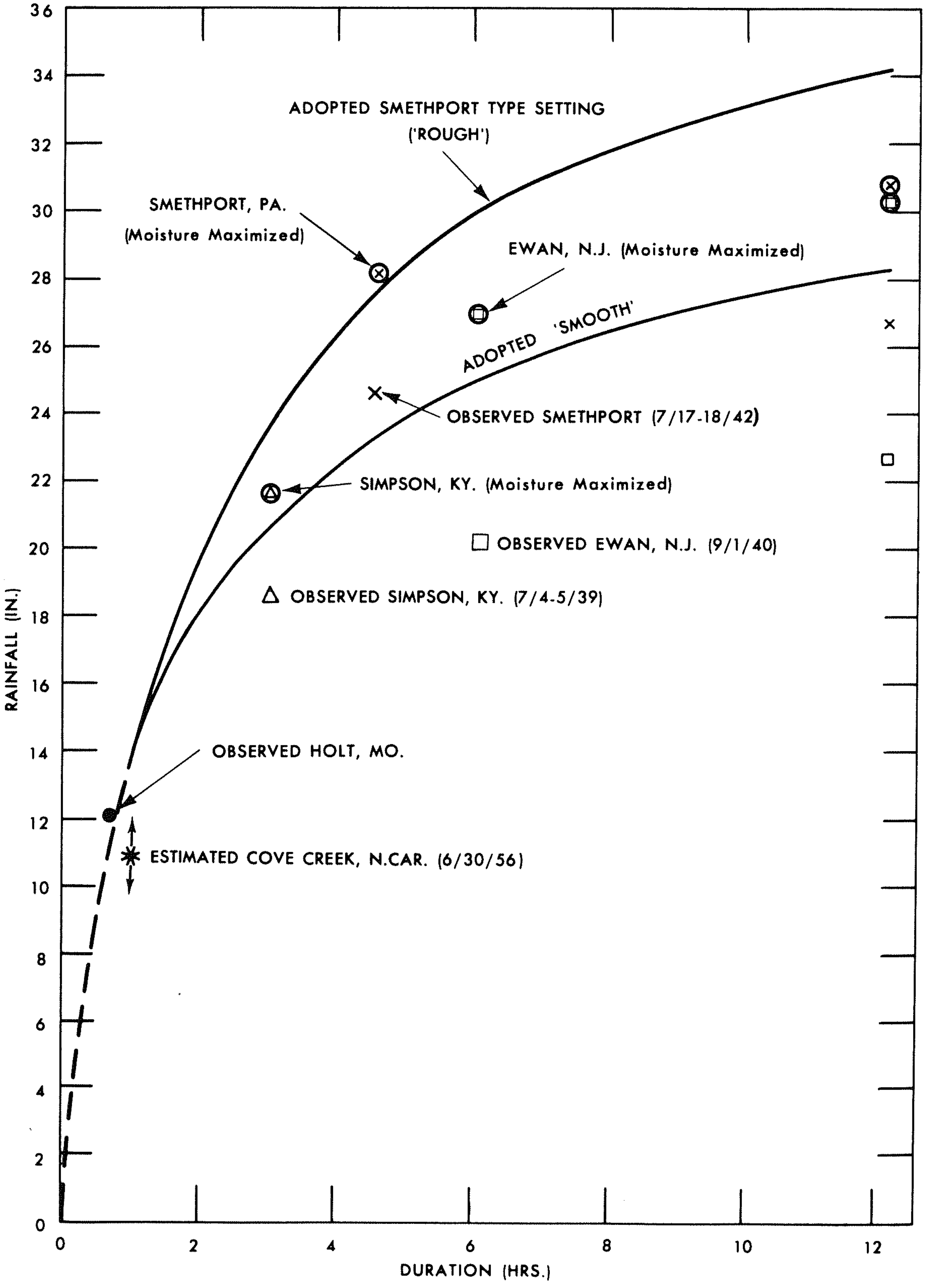


Figure 2-15. Adopted 5-sq. mi. PMP with supporting data

a. The Smethport, Pa. storm of July 1942, the Simpson, Ky. storm, and other storms not shown because they fall below the enveloping curve, were moisture maximized to 78°F. The site of both the Smethport storm and Simpson storm is "rough," and the basic enveloping curve of figure 2-15 therefore applies to "rough" sites in the Tennessee River watershed.

b. The short-duration Holt, Mo. storm of June 1947 was not moisture-maximized on the basis that thunderstorms reach more extreme intensities in the Midwest than over the Tennessee River watershed. Tornado frequencies, thunderstorm frequencies, and statistically-determined 30-minute and one-hour 50-yr. rainfalls [2-13] and general experience support this view.

c. The ratio of "smooth" to "rough" site storm intensity is considered to be the same for TVA and PMP storms at any given duration. There are insufficient storm data to derive the PMP "smooth" values directly. Consequently the "smooth" curve of figure 2-15 is derived by maintaining the same relative separation between "smooth" and "rough" as found for the TVA storm on figure 2-14.

d. When extending PMP depth-duration curves to longer durations, it is customary to use as a guide the ratio of longer duration to shorter duration precipitation in observed large storms of an appropriate type (HMR 41, p. 82, HMR 43, p. 45, [2-14]). The ratios adopted for PMP are generally larger than the mean of a sample of storm depth-duration relationships, but below the envelope of such data; this takes into account the fact that the PMP necessarily involves continuation of precipitation at the same location to a greater extent than found in most observed storms, as explained in section A of this chapter.

A collection of durational ratio data is shown in figure 2-16 together with the adopted PMP ratio curve to 24 hours. Among the data shown are durational ratios of 100-year point rainfalls in the Tennessee River watershed, taken from Weather Bureau Technical Paper No. 40 [2-13].

The adopted depth-duration ratios are patterned rather closely after the Smethport storm. Some maximization is allowed in line with the synoptic features of the Smethport storm. The continued influx of moist air could have resulted in a more critical continuation of the rainfall in this storm.

Adjustment for moisture gradient and latitudinal gradient

An adjustment for moisture was developed for all of the Tennessee River watershed except the mountainous eastern section. Here a "latitudinal gradient chart" (fig. 2-17) was developed instead. The latitudinal gradient

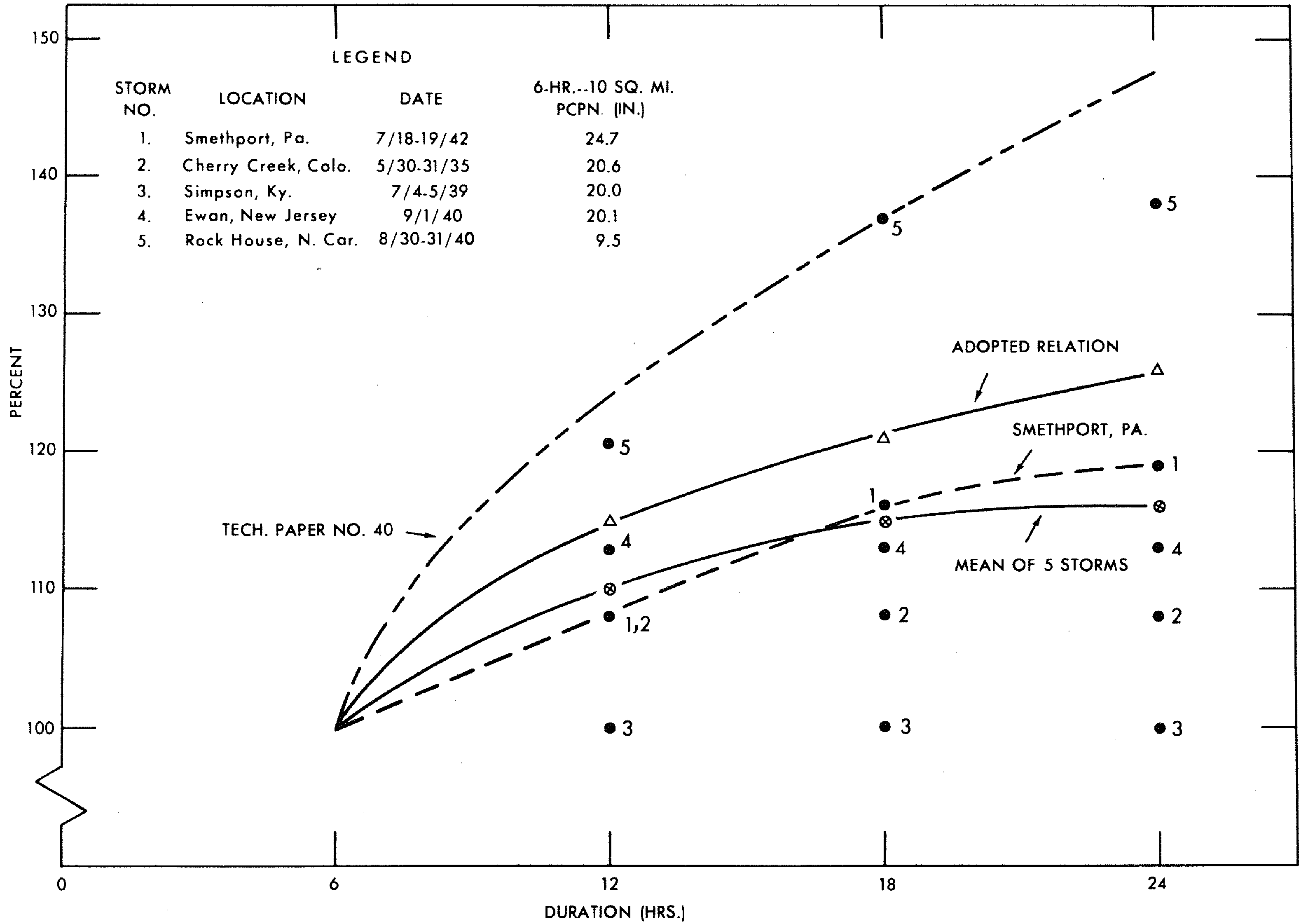


Figure 2-16. Adopted small basins PMP depth-duration curve with supporting data

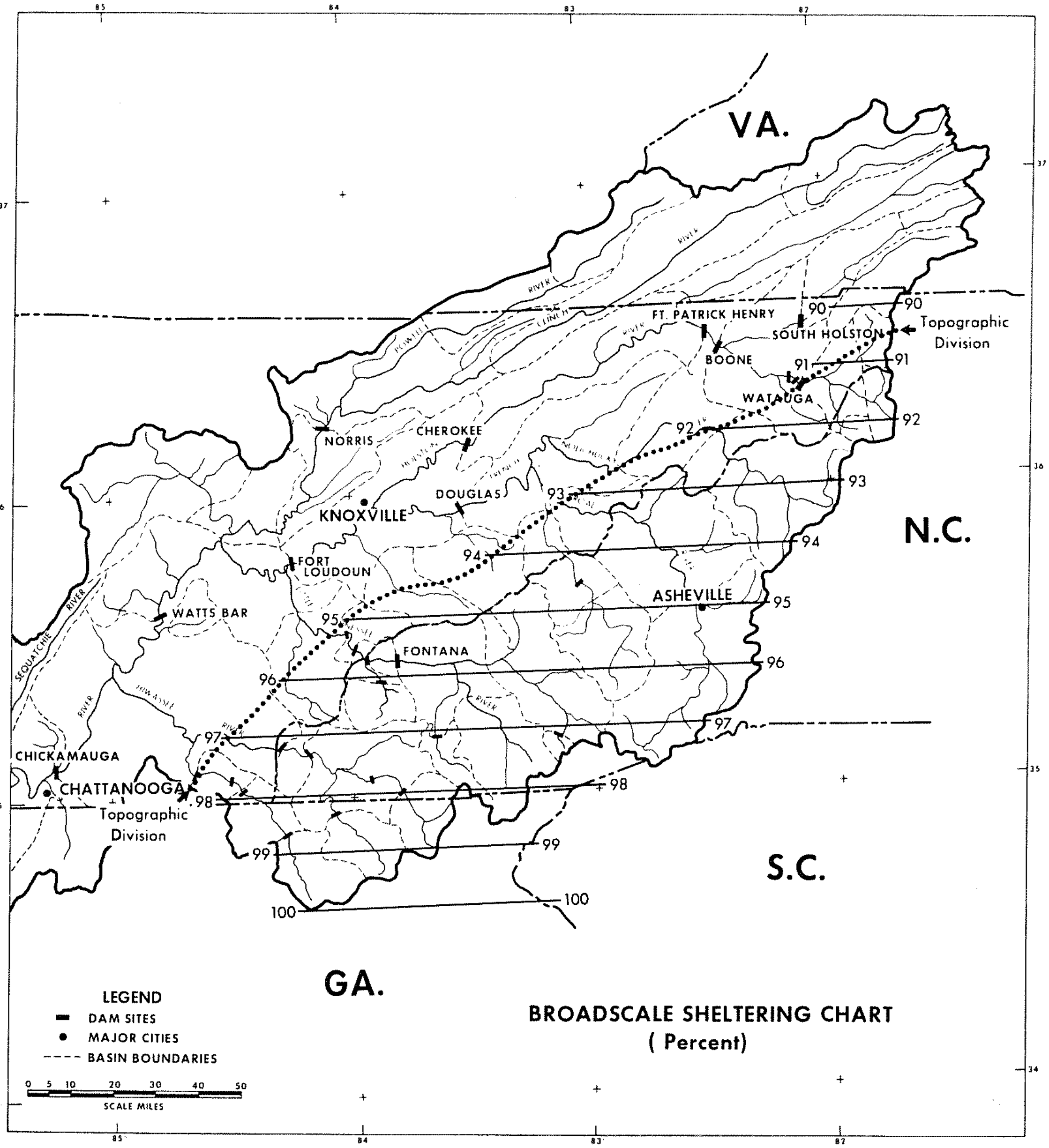


Figure 2-17. Broad-scale sheltering by mountainous complex of eastern Tennessee River watershed

chart, based on observed rainfall gradients due primarily to sheltering by mountains, also implicitly incorporates moisture effects. While rain gradients satisfactorily defined the latitudinal gradient in the mountainous east, an assessment of moisture parameters was required to define the moisture gradient over the remainder of the basin.

The moisture adjustment charts (figs. 2-19 and 2-20) were made from an assessment of mean and extreme dew points. Dodd's charts [2-15] provided the information on mean dew points, while 12-hr. maximum persisting dew points developed in the Hydrometeorological Branch [2-16] provided the source of maximum dew points. These dew point sources were supplemented by a survey of high dew point situations affecting the Tennessee area during the period of 1956-1965. From several situations, an outstanding period from July 26, 1956 to August 6, 1956, was selected for analysis. Mean dew points for stations in and around Tennessee were averaged for this period. The result is shown in figure 2-18. All station dew points were moist-adiabatically reduced to 1000 mb. before being plotted and analyzed. This 12-day period consisted of recurring high dew points and is considered representative of a persisting high dew point situation that precedes and accompanies an extreme summer rainfall occurrence.

The various analyses support a regional dew point gradient of about 2°F., from the southwestern to the northeastern portion of the basin. This corresponds to a difference in rainfall of 10 percent, based on the usual model for convective rain during extreme storms [2-17, 1-3 (p. 14)]. Figure 2-19 shows the moisture index lines in percent for the western portion of the basin, while figure 2-20 covers the central part.

The moisture adjustment percentage lines of figure 2-20 for the central portion of the Tennessee River watershed and the latitudinal gradient percentage line of figure 2-17 for the east have similar but not identical values at their boundary, as they derive from different concepts. This discontinuity is taken care of by smoothing in the final precipitation index maps, figures 2-21b and 2-22b. A single percentage map without discontinuities, while esthetically pleasing, would have little additional practical significance and therefore was not constructed.

Six-hour 5-square mile precipitation index maps

The charts and concepts discussed above were used to develop 6-hr. 5-sq. mi. index maps of PMP (fig. 2-21) and TVA precipitation (fig. 2-22). Large working copies of the index maps are available.

PMP. Six-hour PMP values from figure 2-15 of 25, 27.5 (by interpolation), and 30 inches, respectively, were assigned to smooth, intermediate and rough terrain categories, and multiplied by the moisture adjustment percents of figures 2-19 and 2-20.

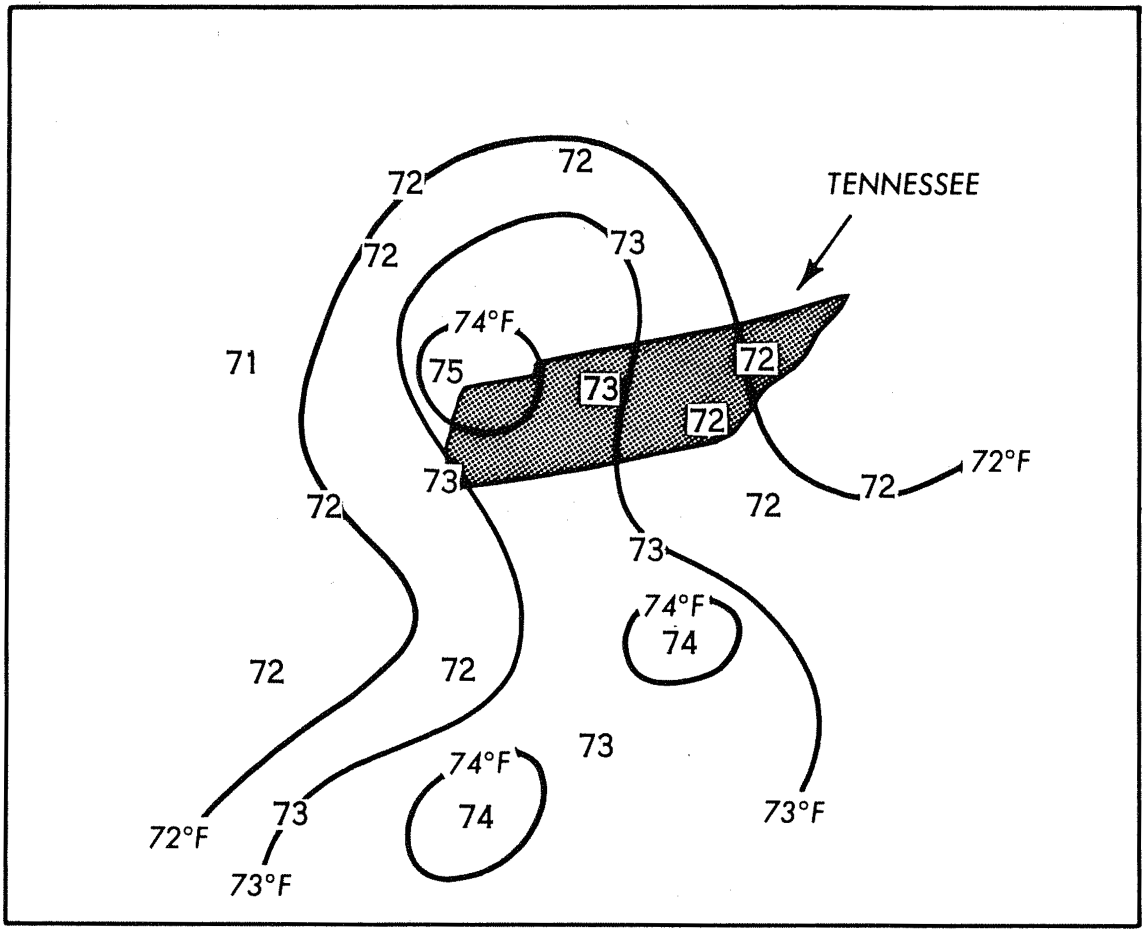


Figure 2-18. Mean dew points for high moisture inflow situation of July 25-August 6, 1956

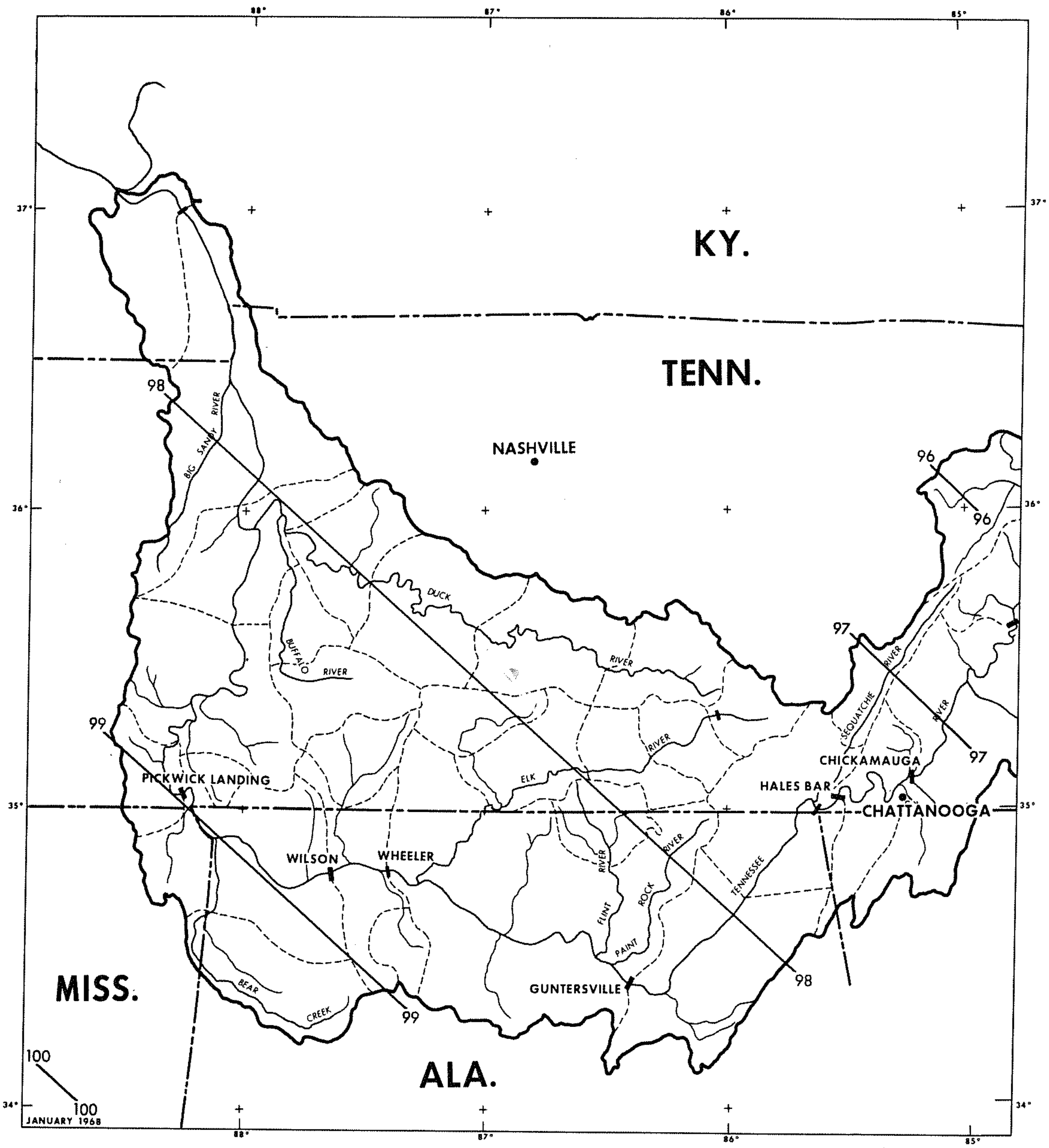


Figure 2-19. Moisture index chart - western half of Tennessee River watershed

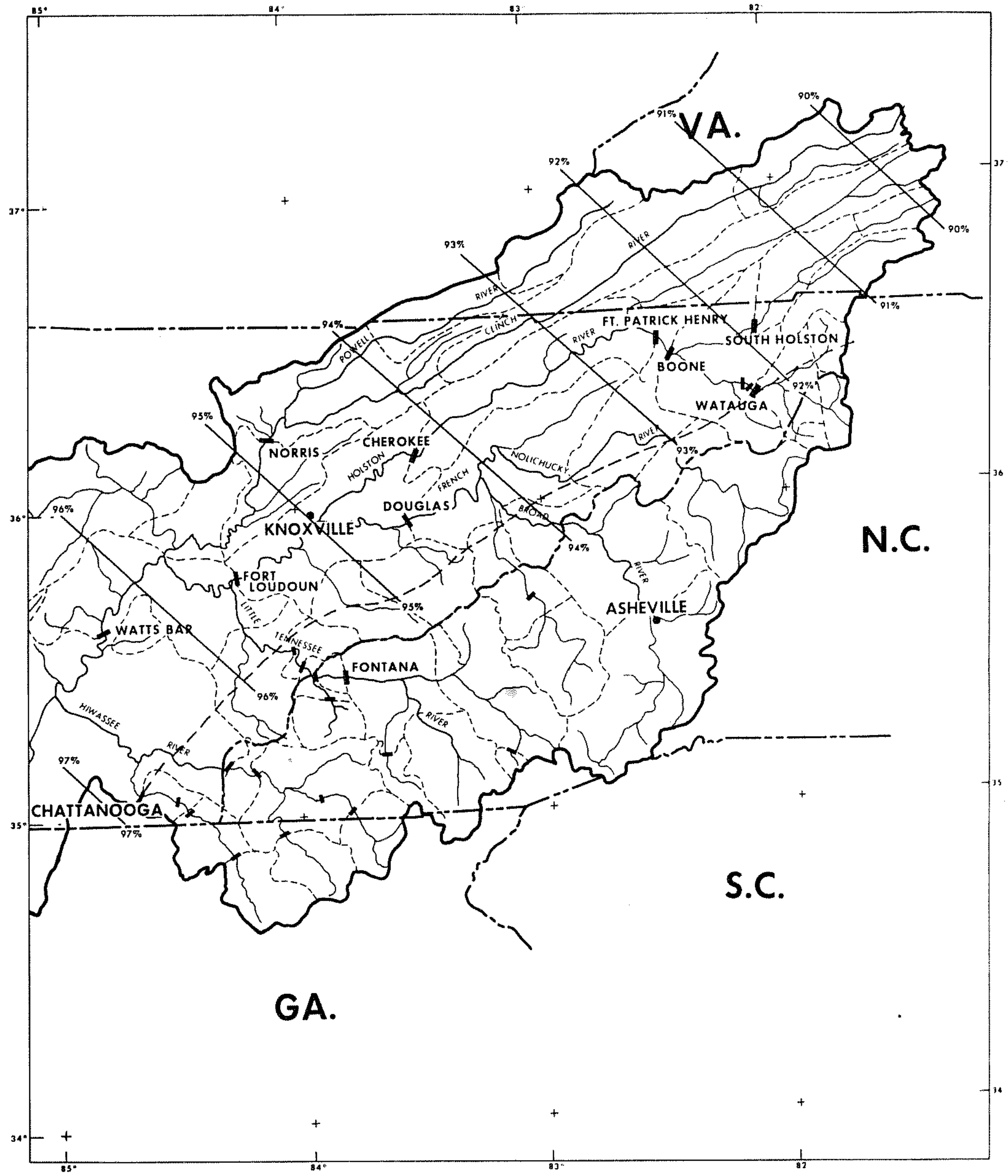


Figure 2-20. Moisture index chart - eastern half of Tennessee River watershed

Isohyets of 6-hr. PMP were constructed, placing the steepest gradient in the vicinity of the most important changes in elevation. These gradients may appear artificial, but the approach used nevertheless provides a reasonable placement of the maximum gradient, i.e., near the edges of the Cumberland Plateau.

In the mountainous east (classified rough), a basic 6-hr. "rough" PMP value of 30 inches was assigned the southern edge of the basin (i.e., the 100-percent line of fig. 2-17). This was progressively reduced to the north by means of the percentage lines of figure 2-17. The topographic adjustments, such as for the "first upslope" (fig. 2-13) previously discussed were applied to the reduced values. With some smoothing the basic PMP index charts, figures 2-21a and b, resulted.

TVA. The TVA 6-hr. index charts, figures 2-22a and b, are developed in an identical manner, starting with basic values from figure 2-14 of 15, 16.5, and 18 inches for 5 sq. mi. over "smooth," "intermediate," and "rough" surfaces and also 18 inches ("rough" classification) at the 100-percent line of figure 2-17.

Depth-area relations

Basic 5-sq. mi. PMP and TVA precipitation are adjusted for size of basin up to 100 square miles. The adopted reduction factors are shown in figure 2-23.

Depth-area relations in a variety of extreme storms were summarized for consideration in selecting the adopted relations. A key duration was 3 hours--the duration of many of the extreme Tennessee River watershed storms. The intense Tennessee River watershed storms used in the depth-area relations are listed in table 2-5.

Table 2-5. Intense TVA Summer Storms Used in Depth-Area Determinations

Date	General Storm Location	Amount (in.)	Duration (hr.)
6/13/24	Carter County, Tenn.	12	3-1/2
5/22/38	Crossville, Tenn.	11	2
6/18/38	Lewisburg, Tenn.	9	3
7/8/38	Winchester Springs, Tenn.	6	3/4
8/4/38	Pittman Center, Tenn.	11	3-1/2
6/9/39	Richlands, Va.	10	4
6/28/47	Greenville, Tenn.	5.4	3-1/2
8/8/54	Sequatchie County, Tenn.	10	3
11/18/57	Spring City, Tenn.	9	2
6/16/60	Columbia, Tenn.	12.2	3
8/10/60	Rockwood, Tenn.	3.45	1-1/2

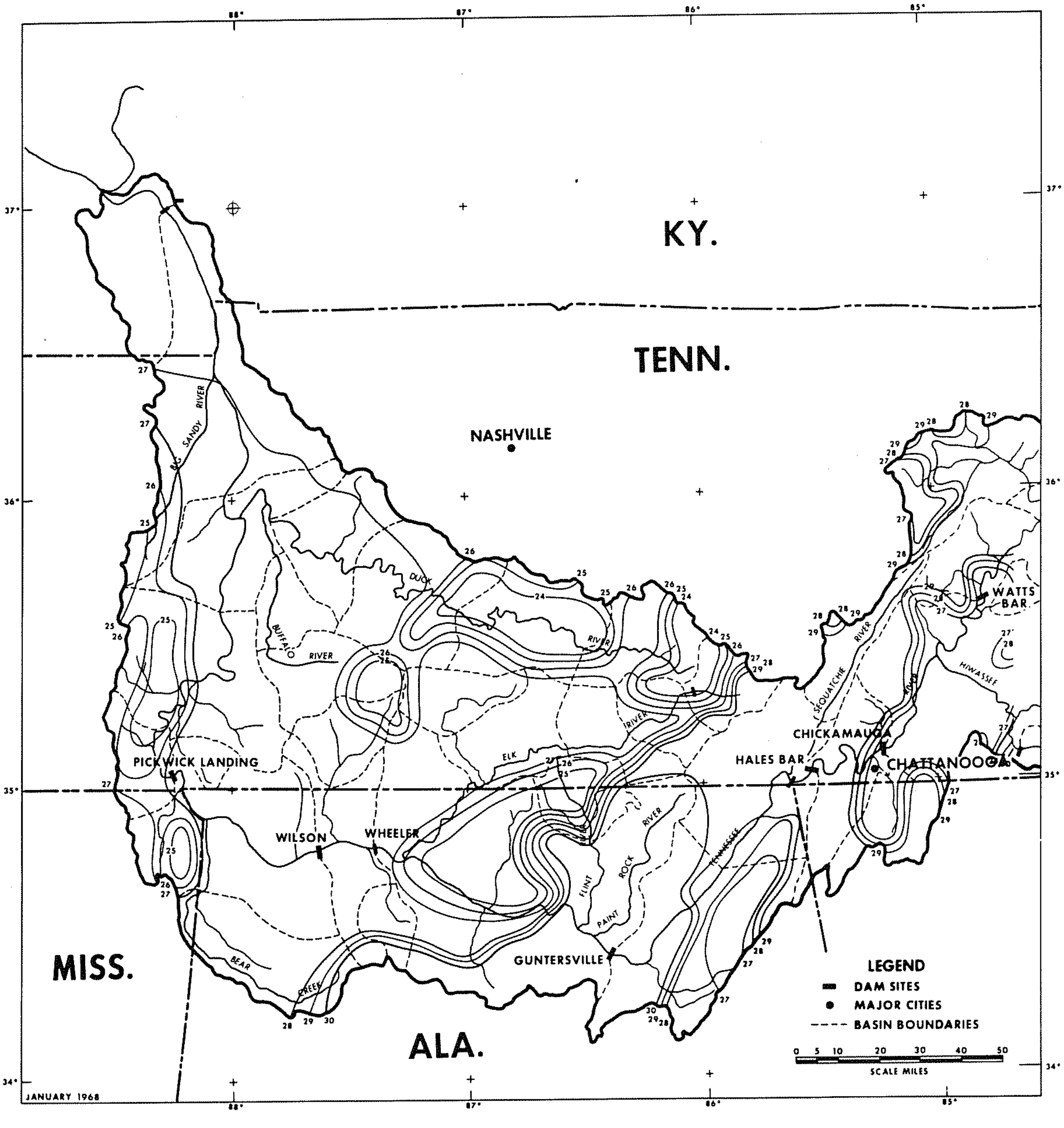


Figure 2-21A. 6-hr. 5-sq. mi PMP (in.) - western half Tennessee River watershed

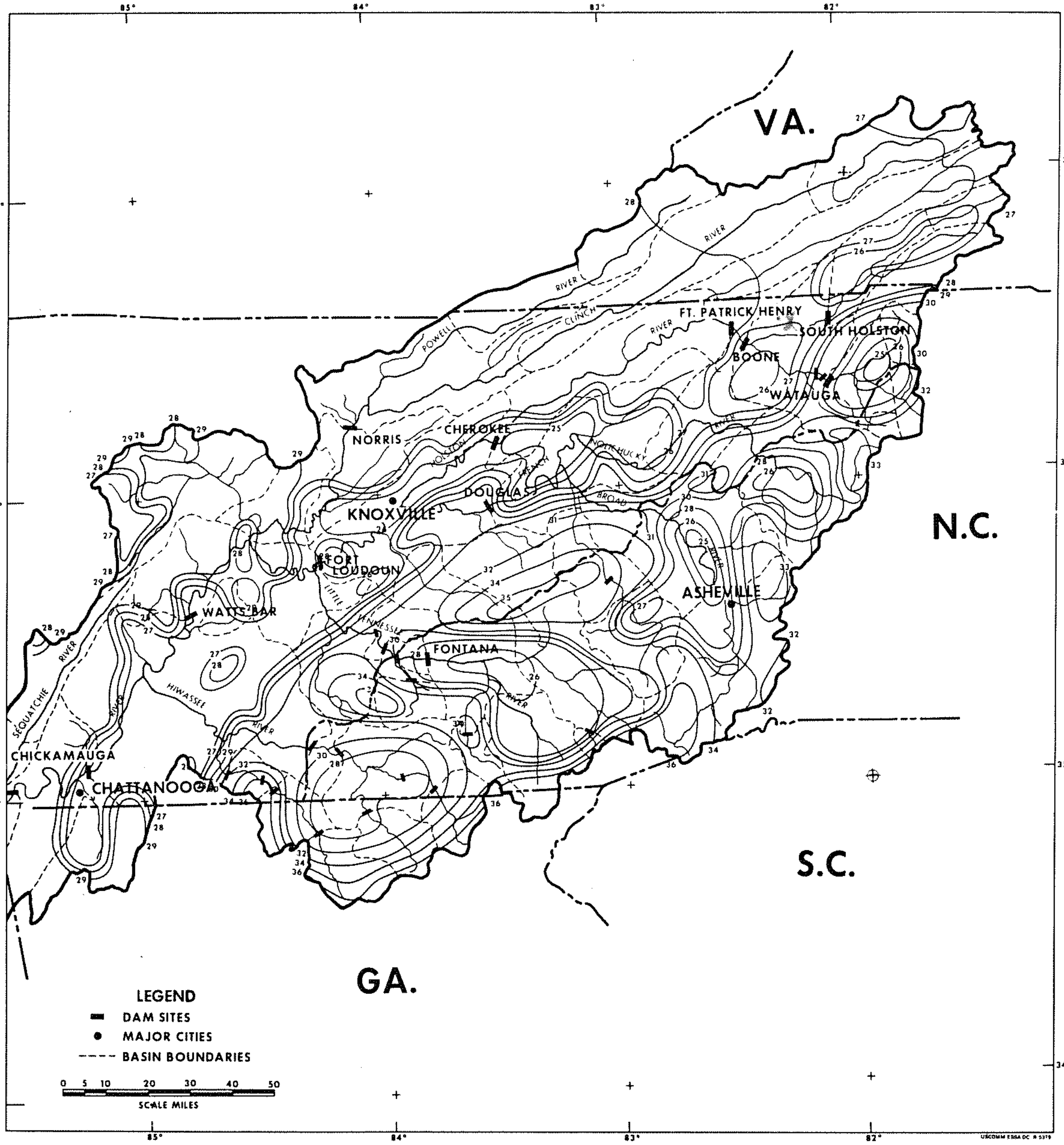


Figure 2-21B. 6-hr. 5-sq. mi. PMP (in.) - eastern half Tennessee River watershed

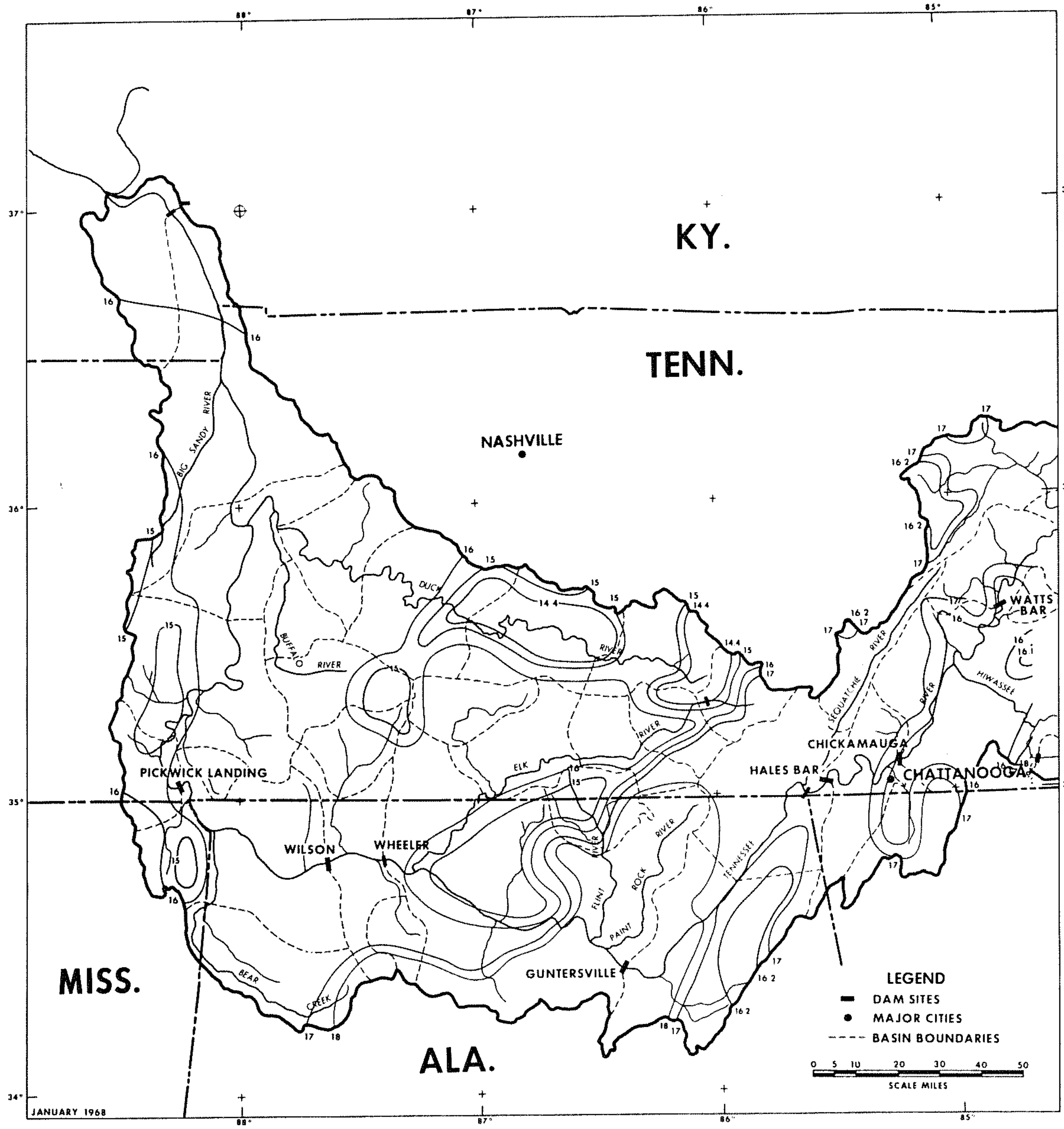


Figure 2-22A. 6-hr. 5-sq. mi. TVA precipitation (in.) - western half Tennessee River watershed

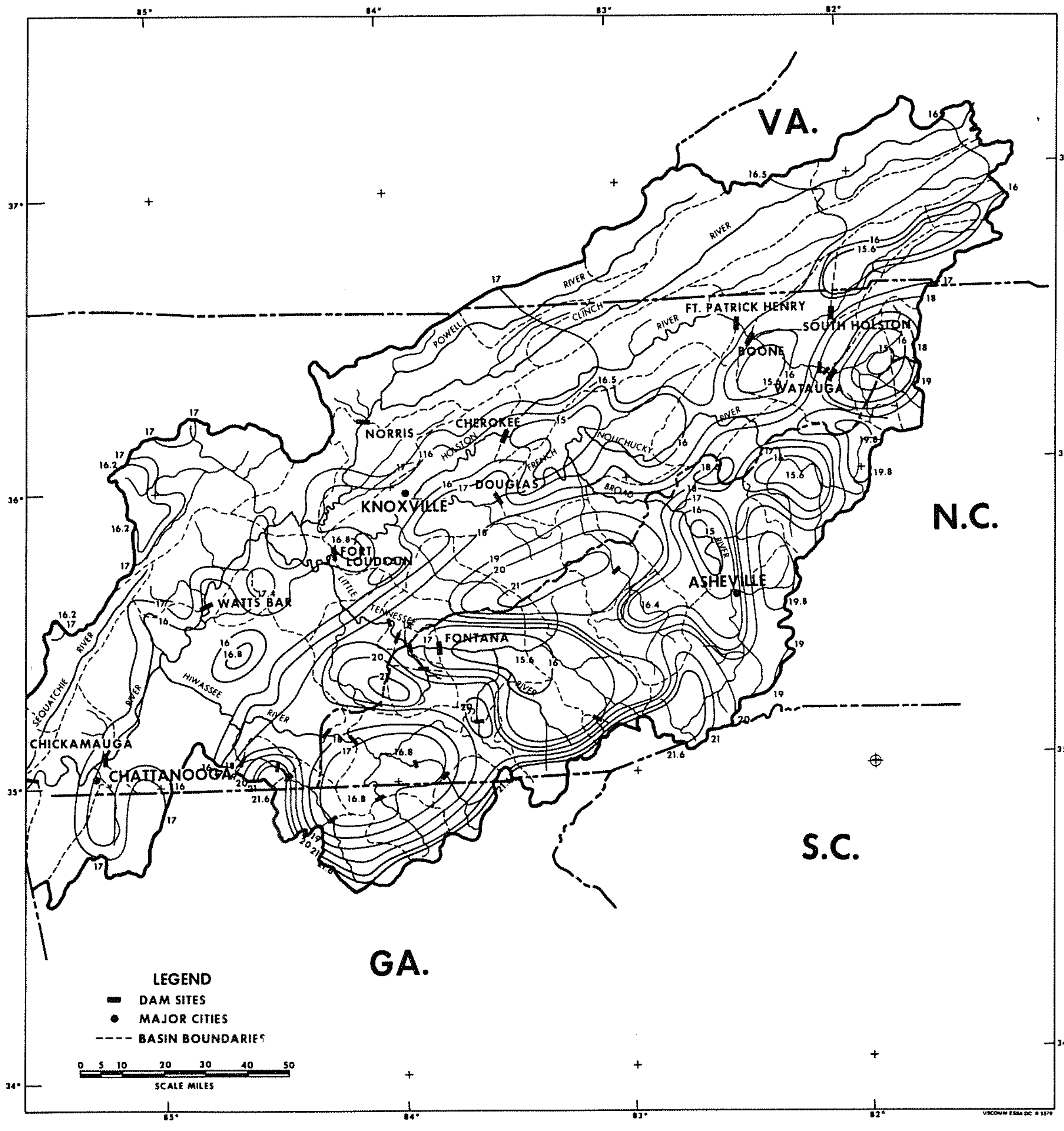


Figure 2-22B. 6-hr. 5-sq. mi. TVA precipitation (in.) - eastern half Tennessee River watershed

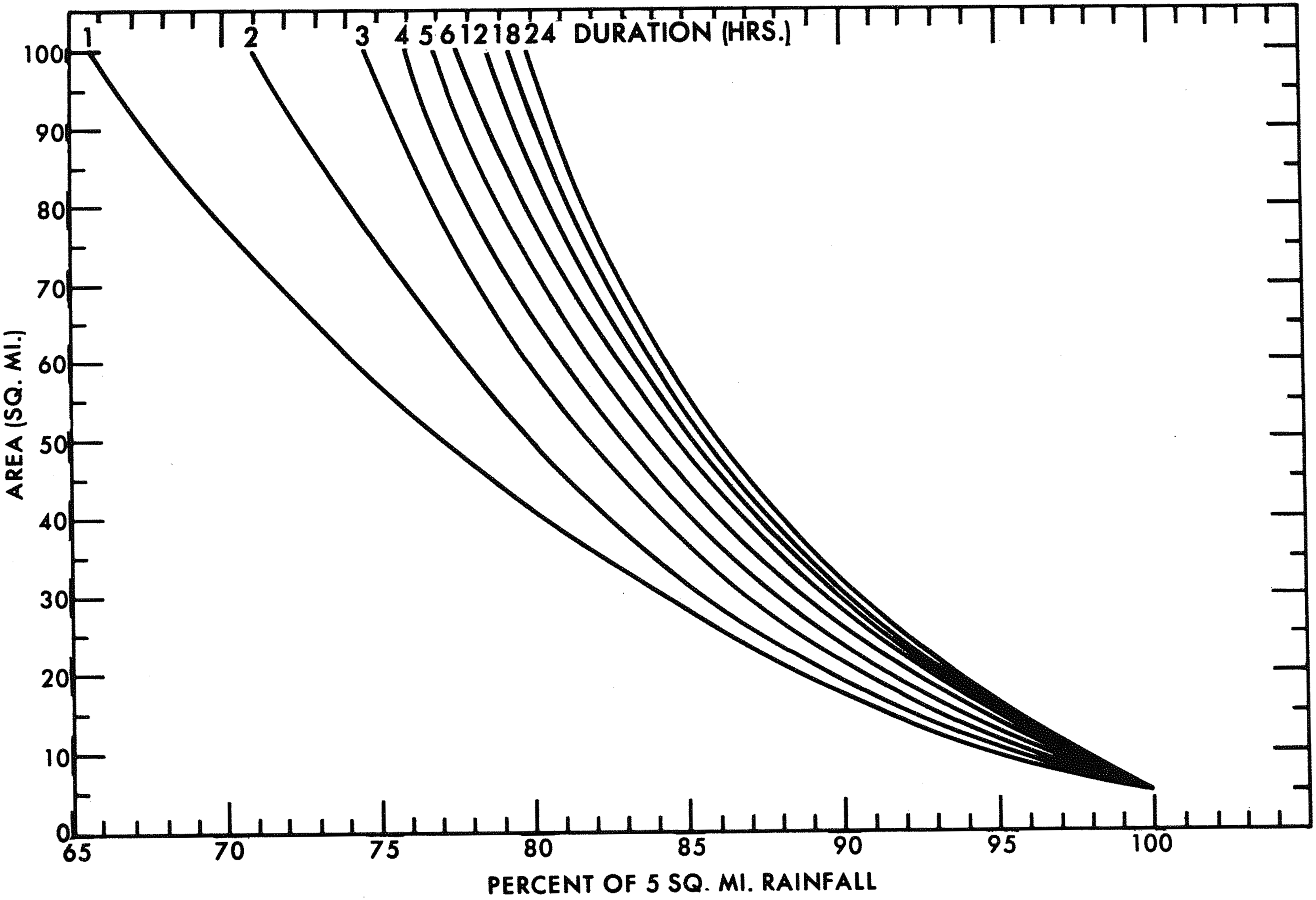


Figure 2-23. Depth-area relations for small basin estimates

Figures 2-24 and 2-25 show the depth-area curves for the TVA storms of table 2-5 compared to the adopted curve for a duration of 3 hours. The approximate duration of the rainfall is indicated on the figures for each storm shown.

Figure 2-26 shows the adopted 3-hr. depth-area curve along with similar curves from a few of the most significant storms outside the basin, including the Smethport, Pa. storm. The adopted 3-hr. curve from HMR 39 [2-18] is also shown, since this was derived from an assessment of outstanding thunderstorm occurrences.

Variable depth-duration criteria for TVA precipitation, index value 16.5 inches

Storm events show considerably different depth-duration characteristics. In large-area general storms, for example, the ratio of 24-hr. to 6-hr. precipitation is larger than in intense small-area thunderstorms. Such observed relations are preserved in the TVA precipitation criteria. Desired is a depth-duration curve characteristic of a storm of a given duration. Thus, if for a particular basin a 12-hr. storm is critical, the 3-hr. rain to be used in this 12-hr. storm is not the extreme 3-hr. but rather a maximum 3-hr. rainfall increment characteristic of a 12-hr. storm.

Depth-duration data for 3-, 6-, 24- and 72-hr. storms were compiled from "Storm Rainfall in the United States" [2-6] and other sources [2-13] and [2-14]. Figures 2-27 and 2-28 show adopted TVA depth-duration curves based on these data for storm durations of 3 to 72 hours.

Any of these curves applies directly to any basin where the TVA 6-hr. precipitation for 5-sq. mi. (fig. 2-22) is 16.5 inches ("intermediate" classification). Treatment of the full range of index values is covered in a subsequent paragraph.

The appropriate TVA depth-duration curve for a particular basin is the one that leads to most critical flow as determined by hydrologic trial. The short-duration curves provide higher peak intensities, the longer duration curves larger total volume. It is valid to interpolate between the curves for intermediate storm durations. The curves indicate no rain for three hours after the 3-hr. storm, no rain for six hours after the 6-hr. storm, etc. Depth-duration values are undefined beyond this period.

Figures 2-29 to 2-31 repeat the depth-duration curves with some of the supporting data.

A comparison of extreme 1-hr. and 24-hr. rain occurrences demonstrates the reasonableness of not specifying that a single enveloping depth-duration relation be used in TVA precipitation application. A summary of annual maximum 1-hr. and 24-hr. rains at Tennessee Basin stations is shown in figures 2-32 and 2-33, which show that the probability of the maximum 1-hr.

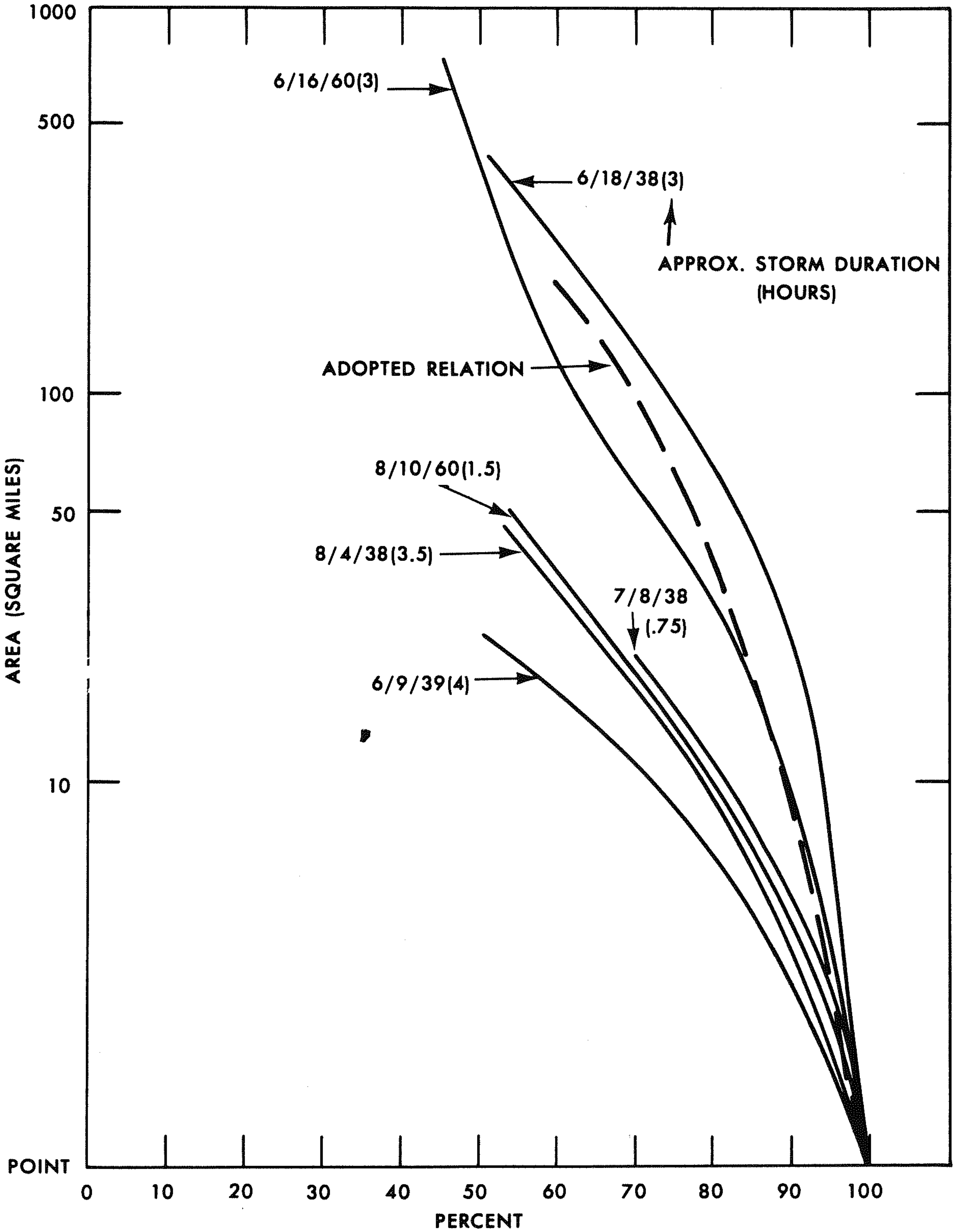


Figure 2-24. Adopted 3-hr. depth-area curve compared with Tennessee River watershed intense storm data (1)

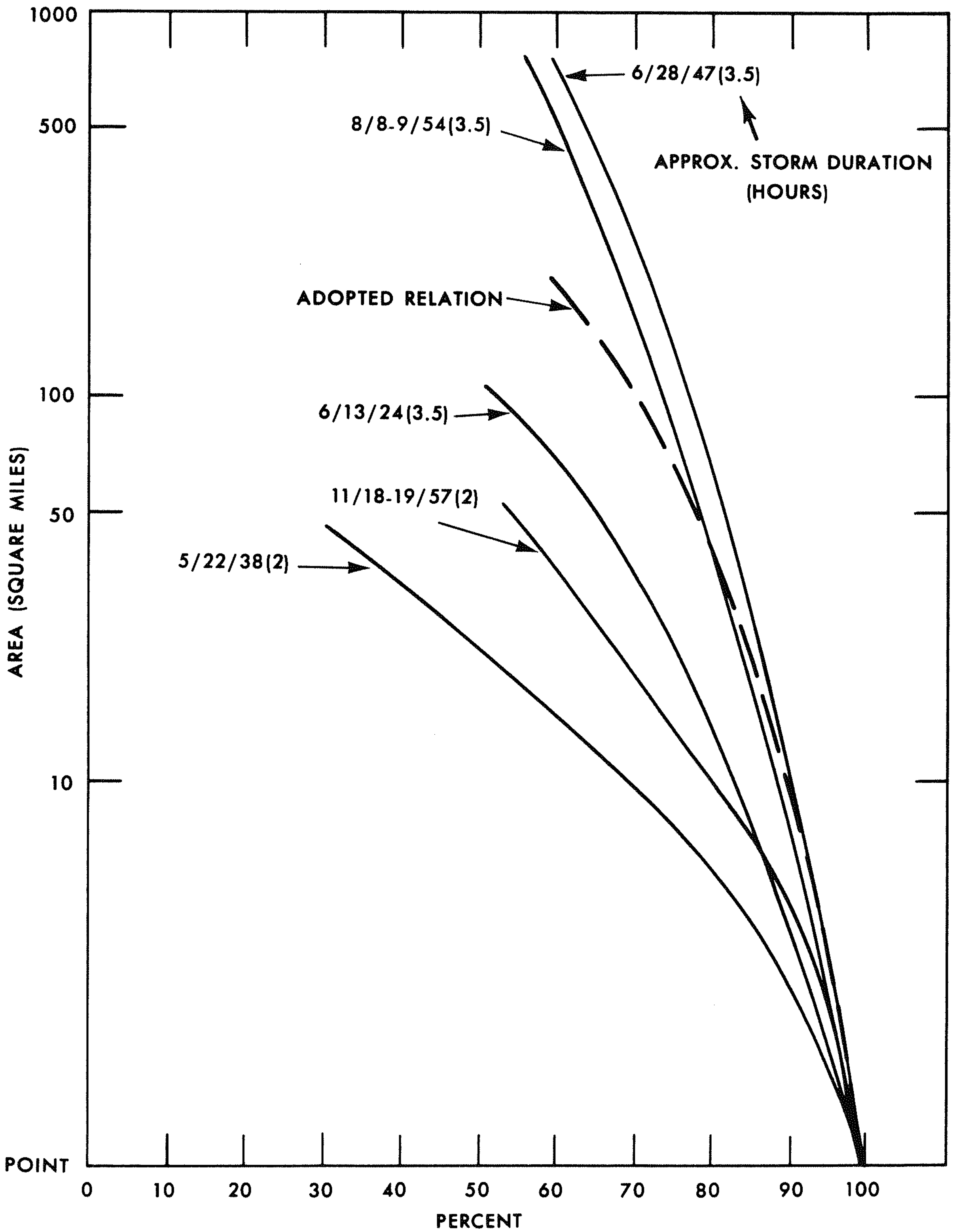


Figure 2-25. Adopted 3-hr. depth-area curve compared with Tennessee River watershed intense storm data (2)

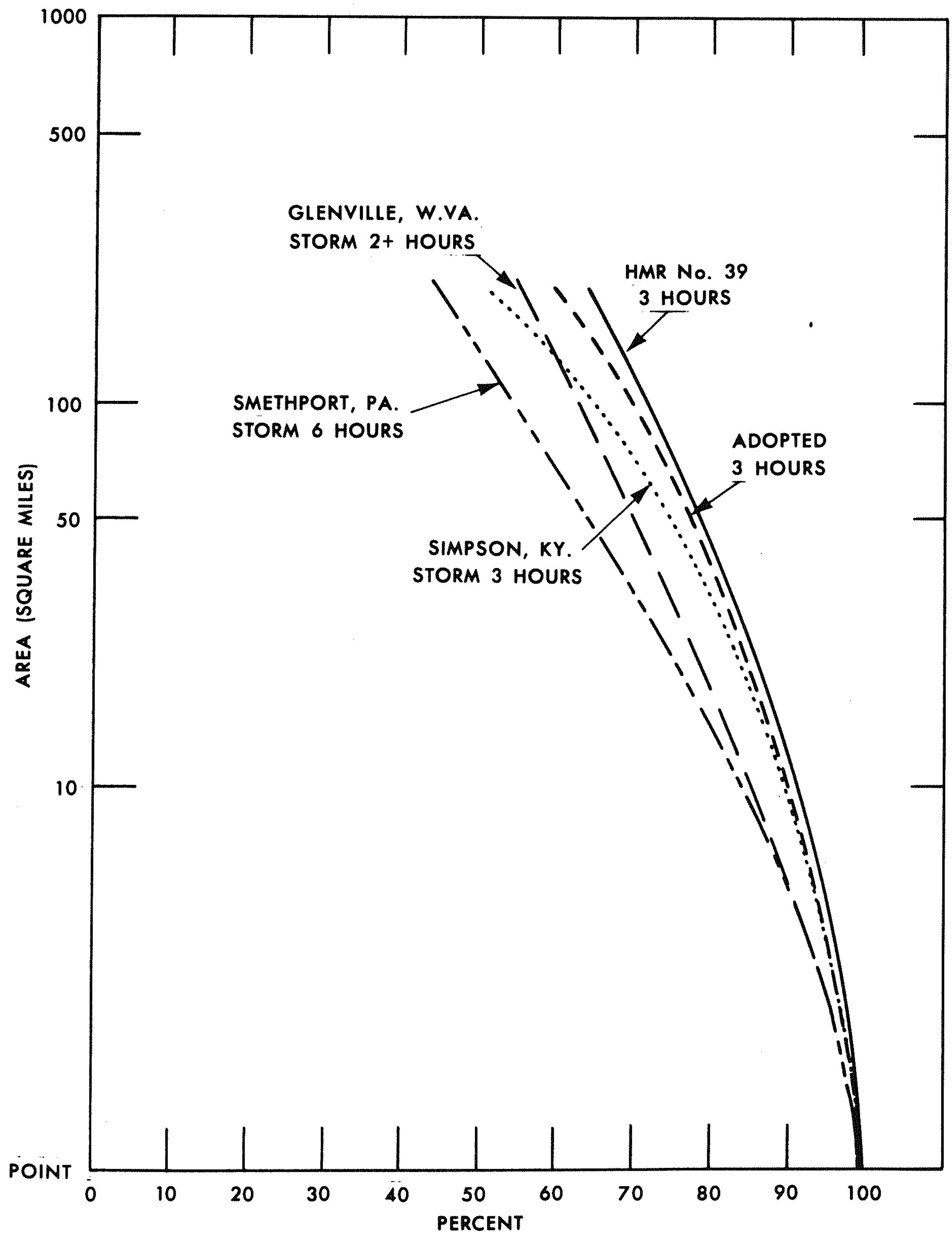


Figure 2-26. Adopted 3-hr. depth-area curve compared with data from other storms and reports

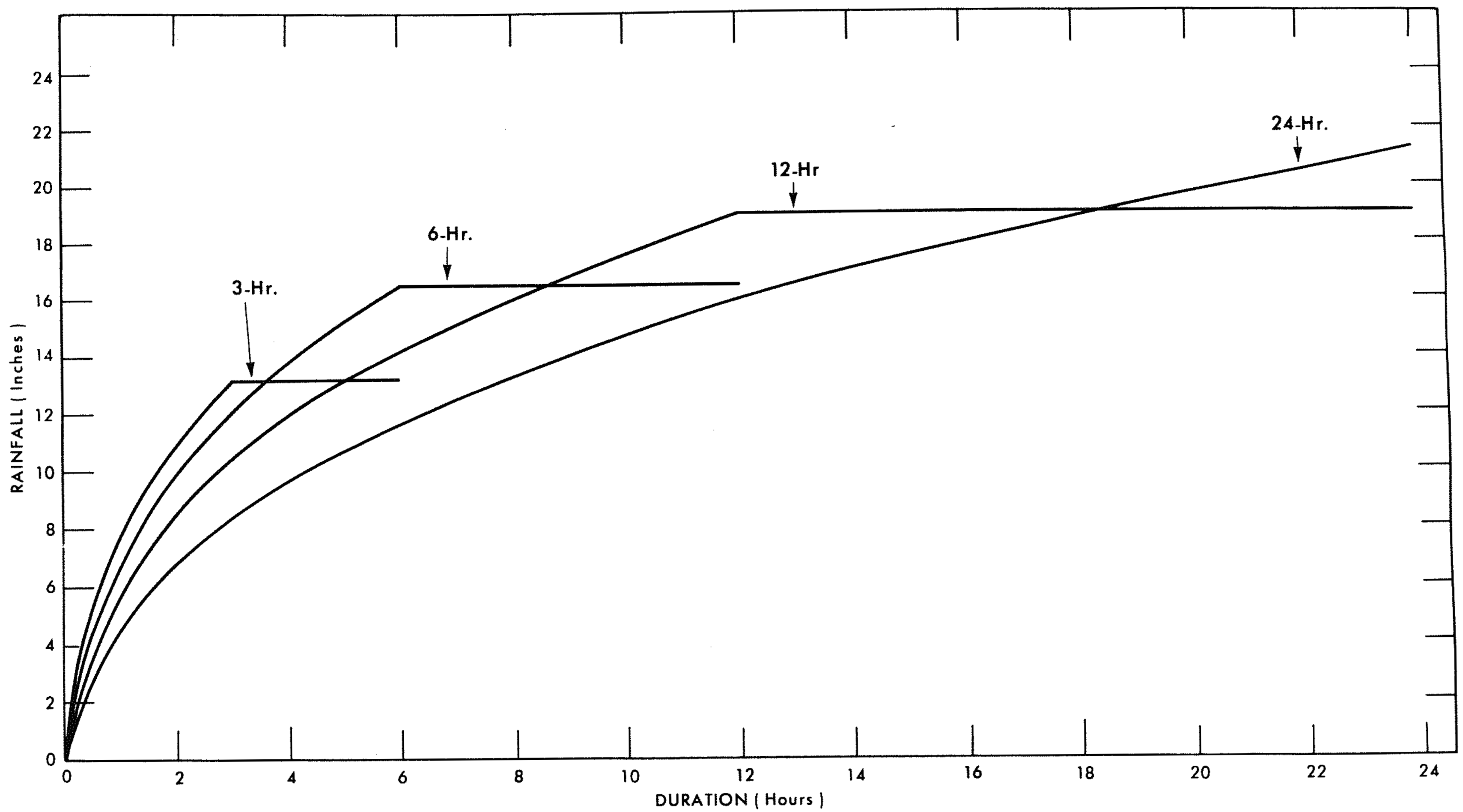


Figure 2-27. Depth-duration curves for 3-, 6-, 12-, and 24-hr. TVA storm ("intermediate" classification)

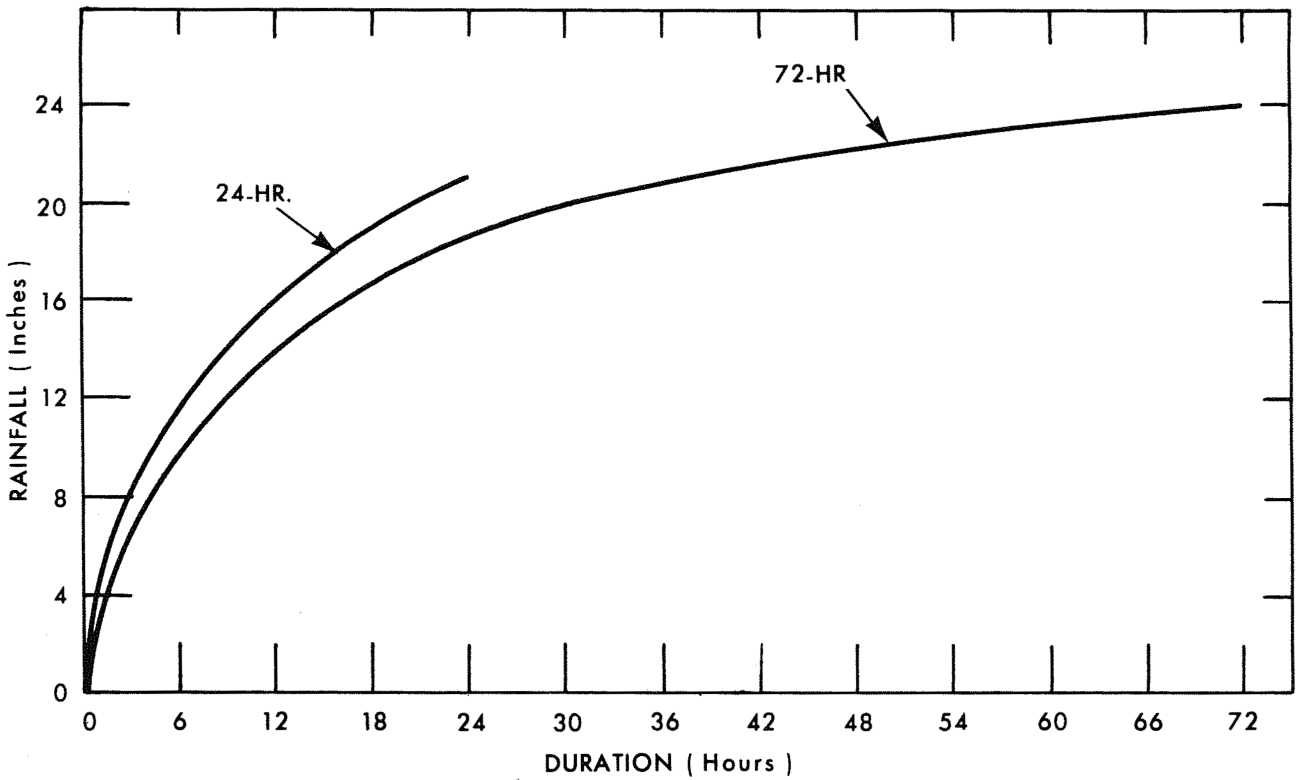


Figure 2-28. Depth-duration curves for 24- and 72-hr. TVA storm ("intermediate" classification)

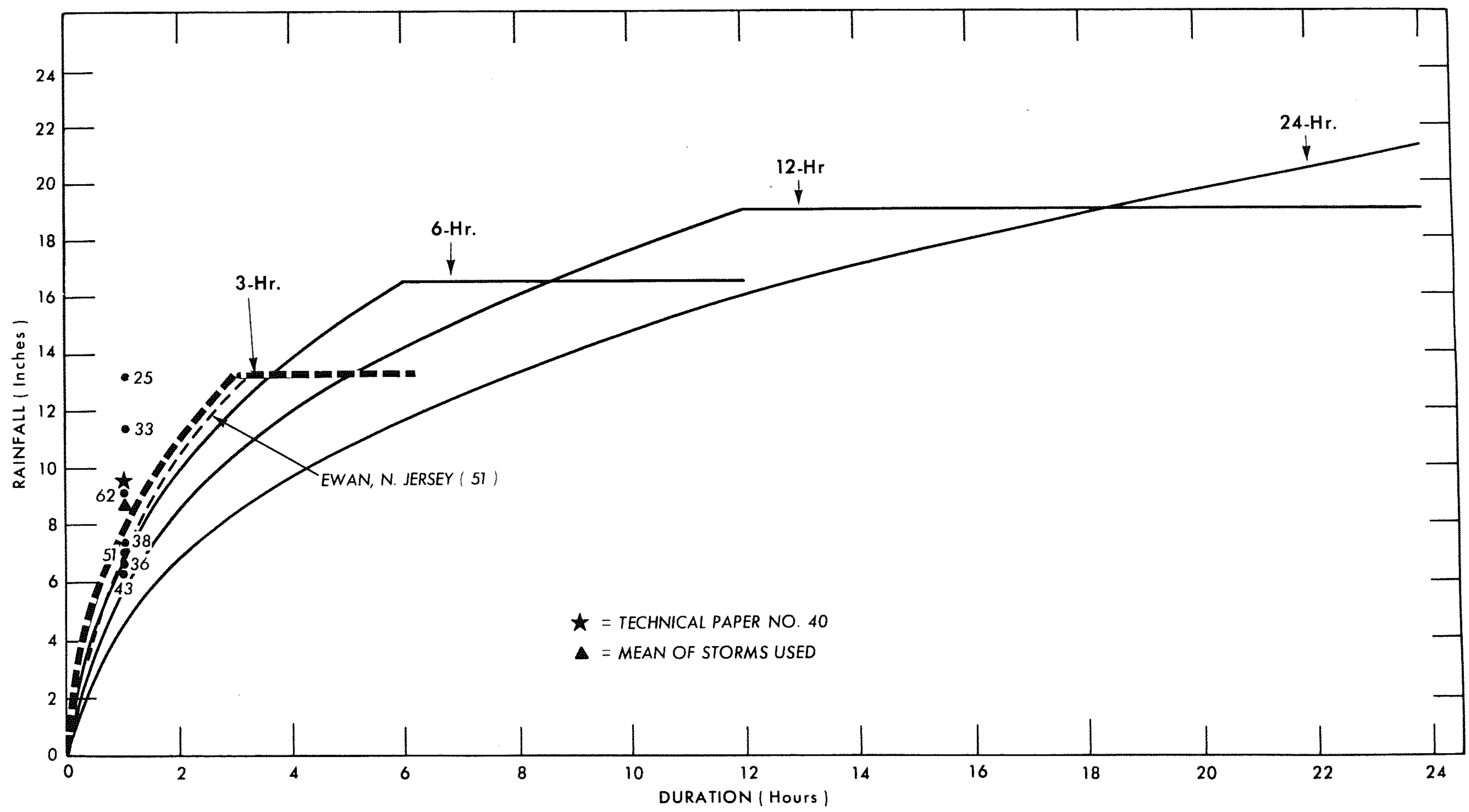


Figure 2-29. Curves of figure 2-27 with supporting data for 3 hours

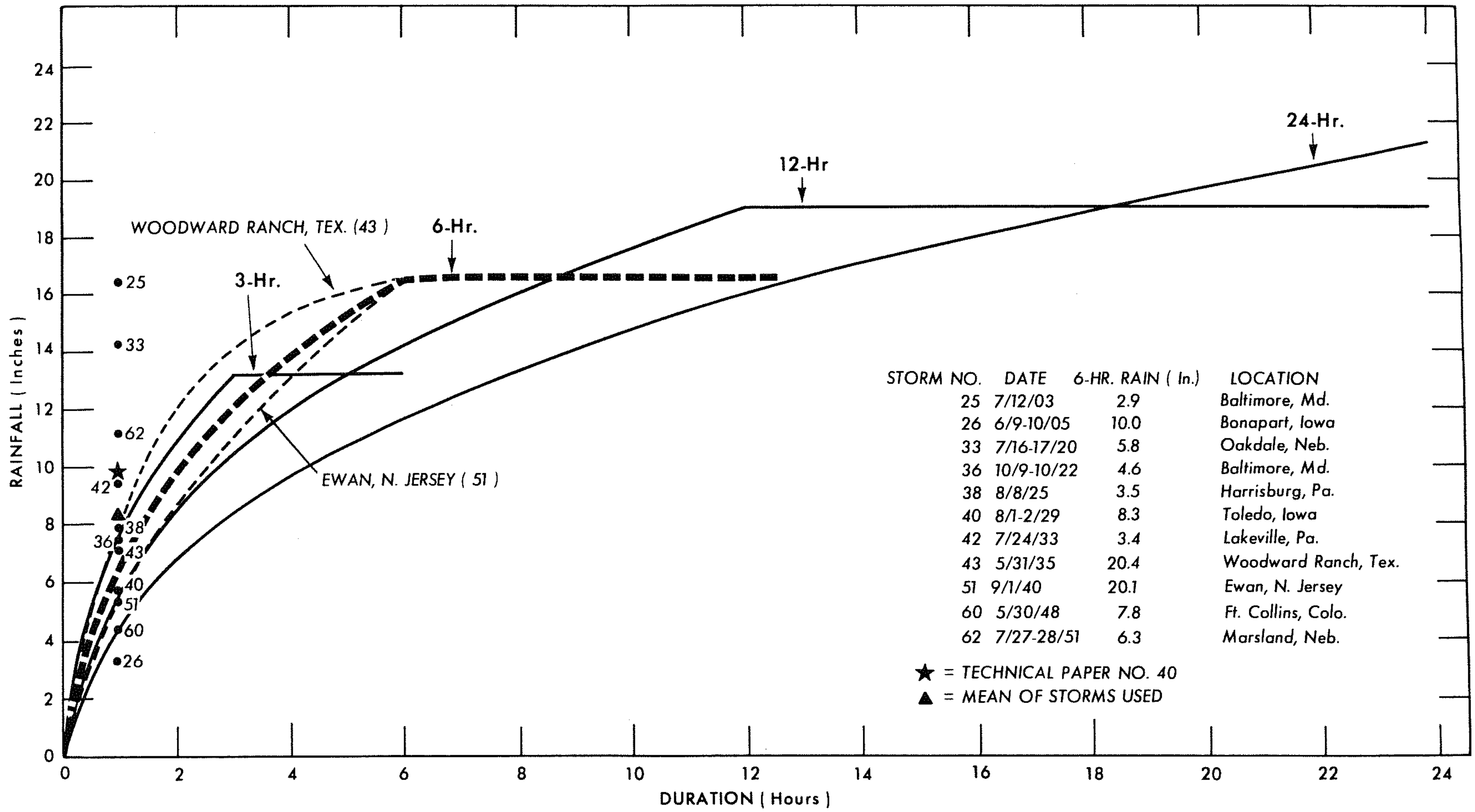


Figure 2-30. Curves of figure 2-27 with supporting data for 6 hours

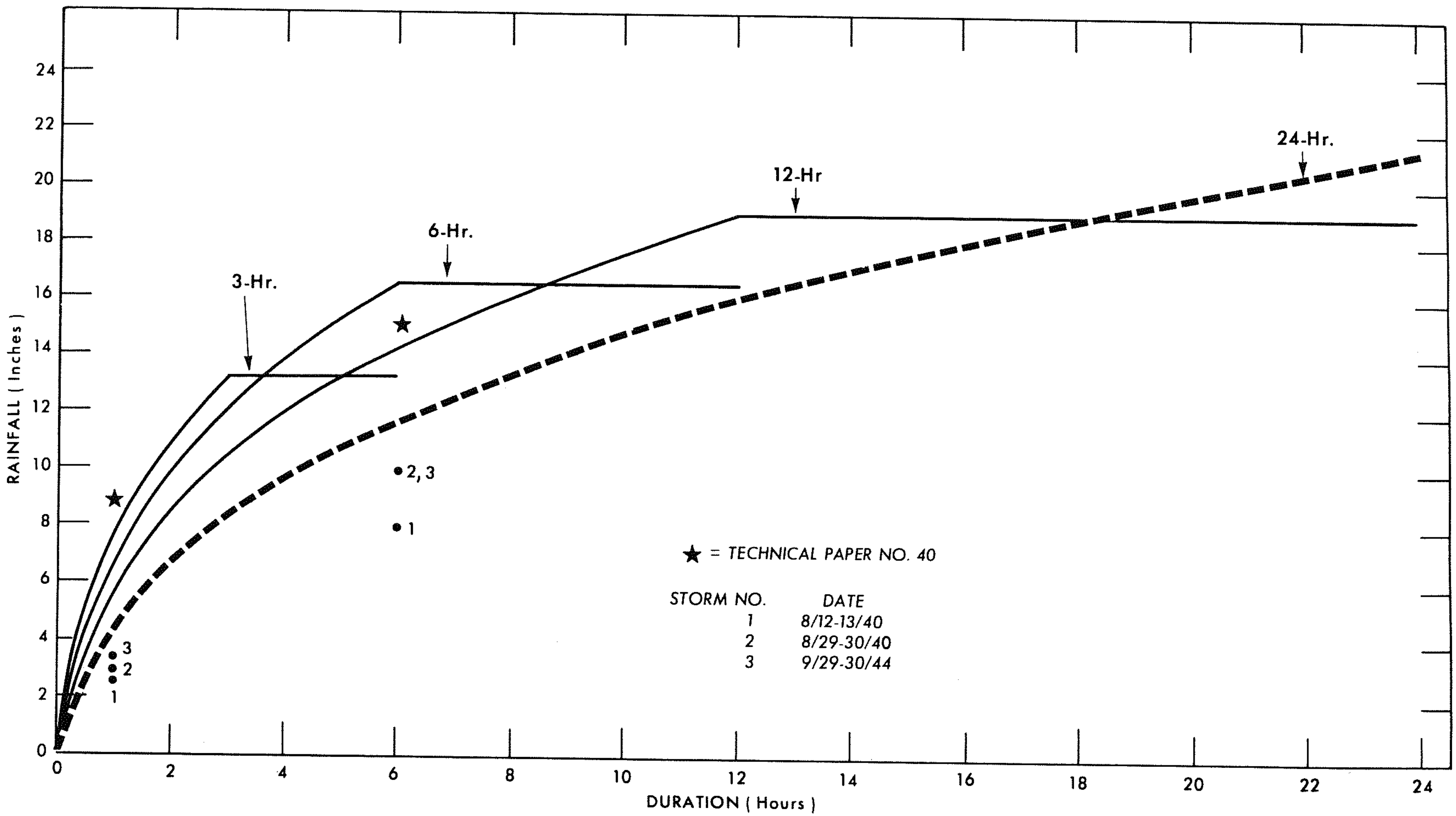


Figure 2-31. Curves of figure 2-27 with supporting data for 24 hours

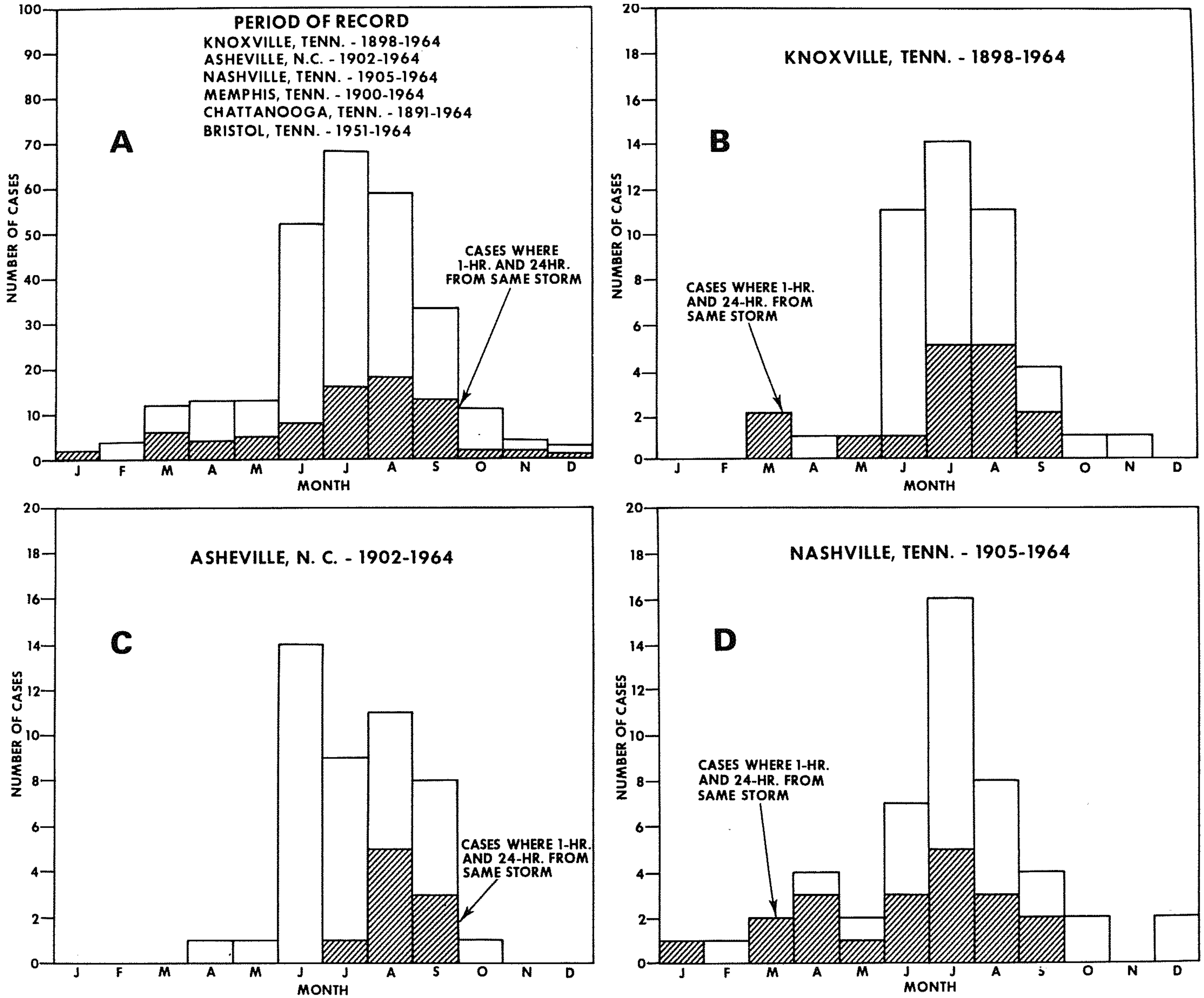


Figure 2-32. Frequency distribution of annual maximum 1-hr. rains (A) all stations, (B) Knoxville, (C) Asheville and (D) Nashville

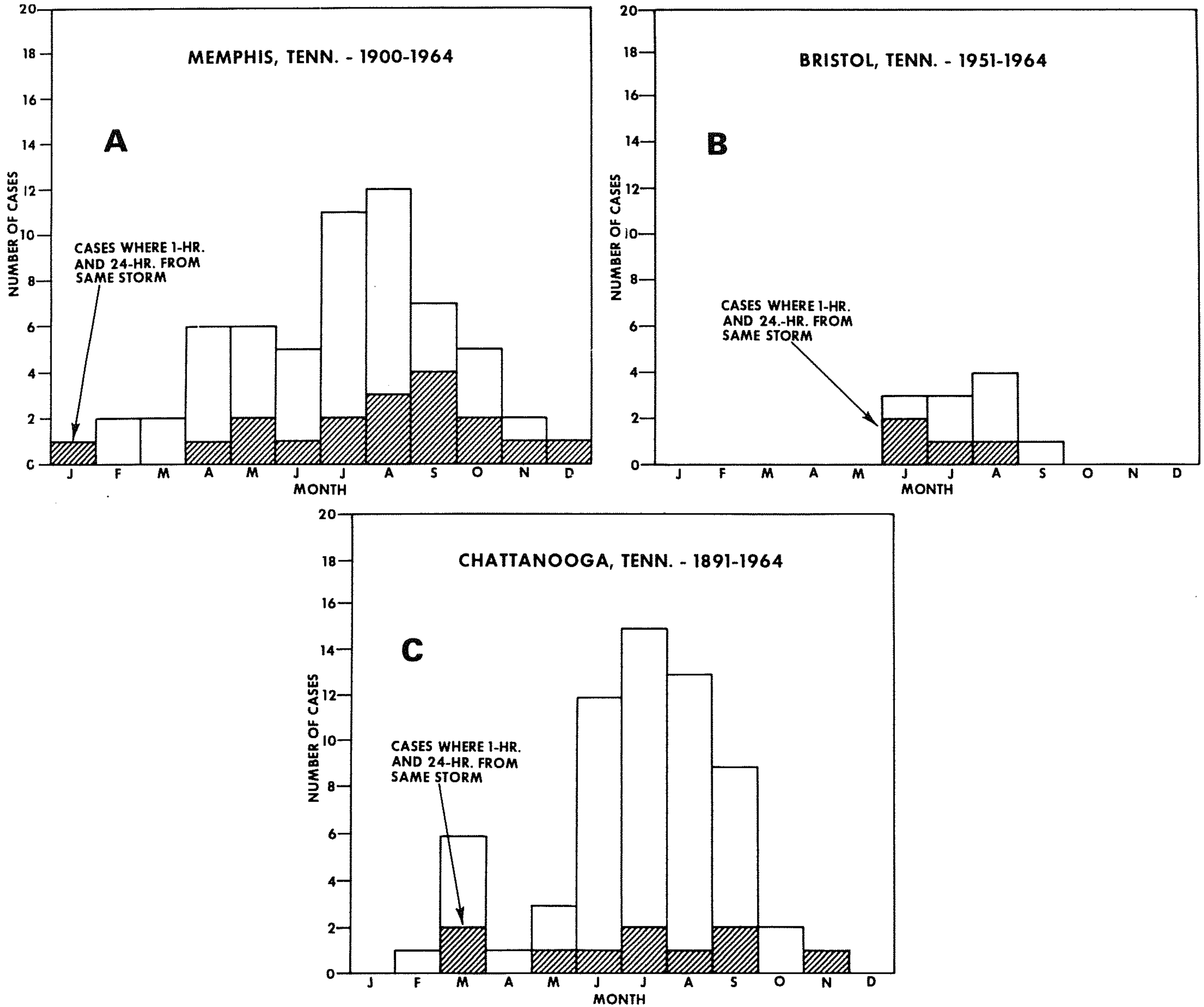


Figure 2-33. Frequency distribution of annual maximum 1-hr. rains (A) Memphis, (B) Bristol, and (C) Chattanooga

and the maximum 24-hr. rains coming from the same storm is small. Such an occurrence is therefore appropriately assigned only to the rare "PMP" event, while a variable set of depth-duration criteria is suitable for the "TVA" event. Table 2-8, in the example of section C, provides factors for obtaining 3-, 12- and 24-hr. TVA storm rainfall values based upon the 6-hr. index values (fig. 2-22) being equal to 100 percent.

TVA depth-duration relations, index value other than 16.5 inches

As indicated previously, one-hour TVA (or PMP) precipitation is controlled by atmospheric dynamics and is independent of all but the most prominent topographic features. With increasing duration, the magnitude of the rainfall is more topography-dependent, as shown by the separation of the "smooth" and "rough" curves in figures 2-14 and 2-15. This variation requires that the depth-duration relation be not only a function of storm duration, as discussed in preceding paragraphs, but also a function of index value (from fig. 2-22). The requisite set of depth-duration curves, derived by interpolations from previous figures, is found in figures 2-34a to 2-36.

Depth-duration criteria for PMP

For time distribution of the probable maximum storm, a procedure is followed allowing greater maximization than for the TVA storm. Rainfall during one time period does not necessarily preclude rain during a succeeding period. Following the procedure of HMR 33 [1-1] and other studies of PMP, a PMP storm is subdivided into durational increments in accordance with the enveloping depth-duration curve, such as figure 2-15. For example, the 3-hr. PMP is followed in the next three hours by the difference between 6-hr. PMP and 3-hr. PMP. The PMP depth-duration nomogram is shown in figure 2-37.

Time distribution of rainfall

Previous sections have dealt with magnitudes of time increments of TVA and PMP storms. This section specifies the arrangement of these increments into a sequence.

Extreme storms in Tennessee have generally been one-burst affairs in which little or insignificant rain follows the extreme 3-hr. rainfall. Storm experience, in general, points to the occurrence of a 24-hr. rainfall in bursts. With this in mind, the following guidelines are suggested for time distribution of the PMP and TVA rainfall.

Six-hour rainfall increments in 24-hr. storm. Arrange the four increments with the second highest next to the highest, the third highest adjacent to these and the fourth highest at either end. This still allows various arrangements, and the critical one is that which would yield most critical flow.

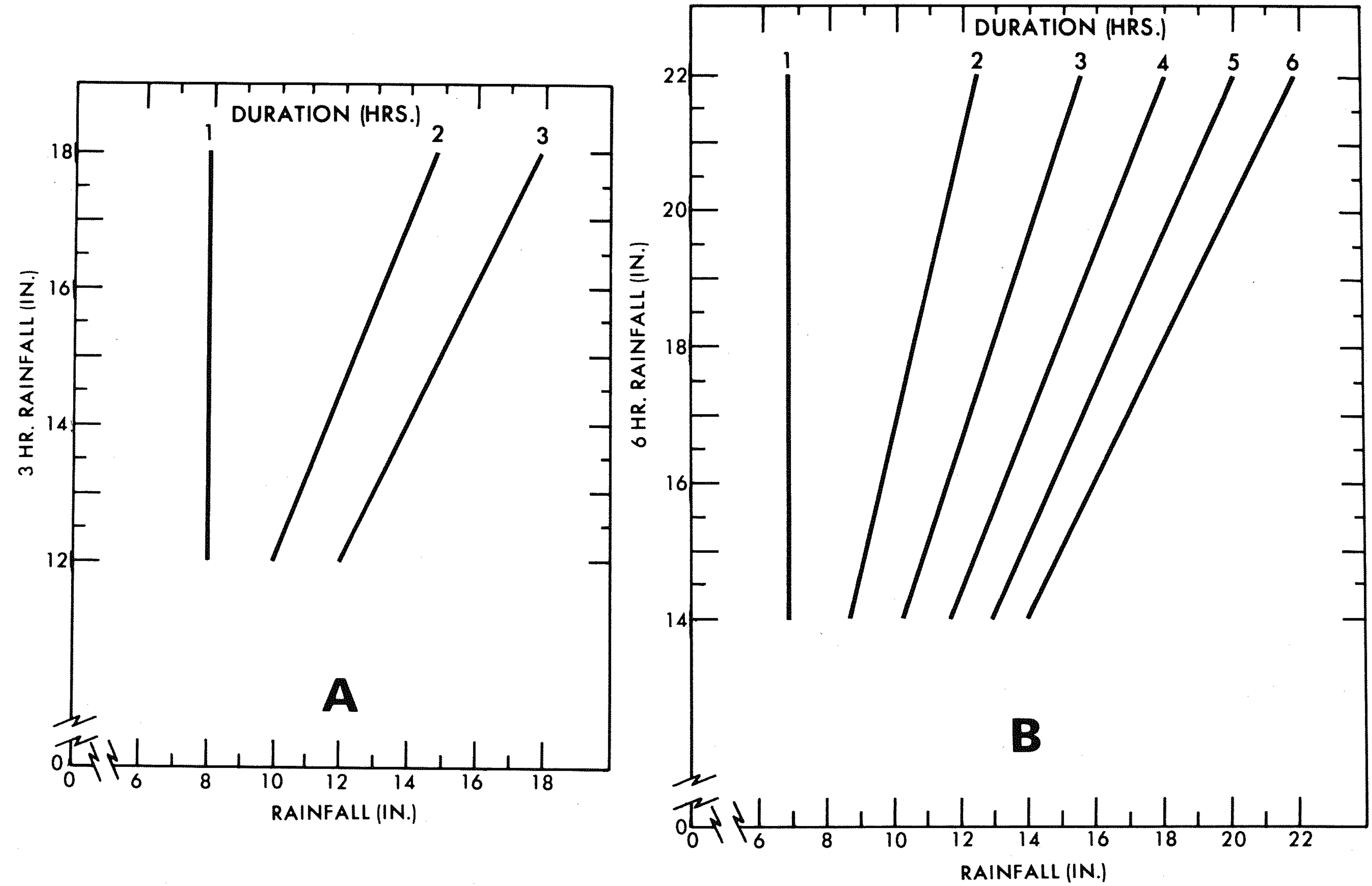


Figure 2-34. Depth-duration relations for (A) 3-hr. TVA precipitation storm and (B) 6-hr. TVA precipitation storm

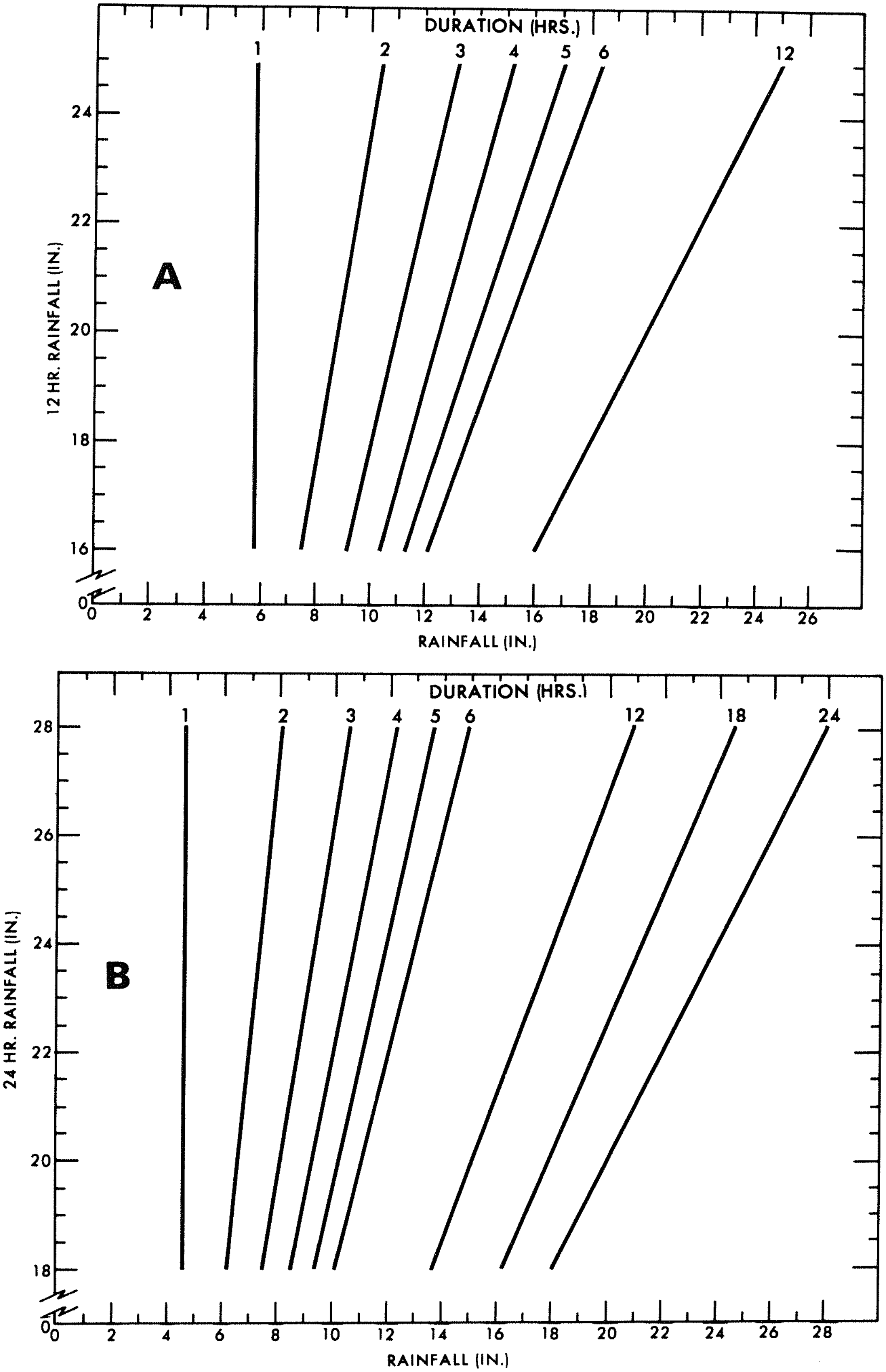


Figure 2-35. Depth-duration relations for (A) 12-hr. TVA precipitation storm and (B) 24-hr. TVA precipitation storm

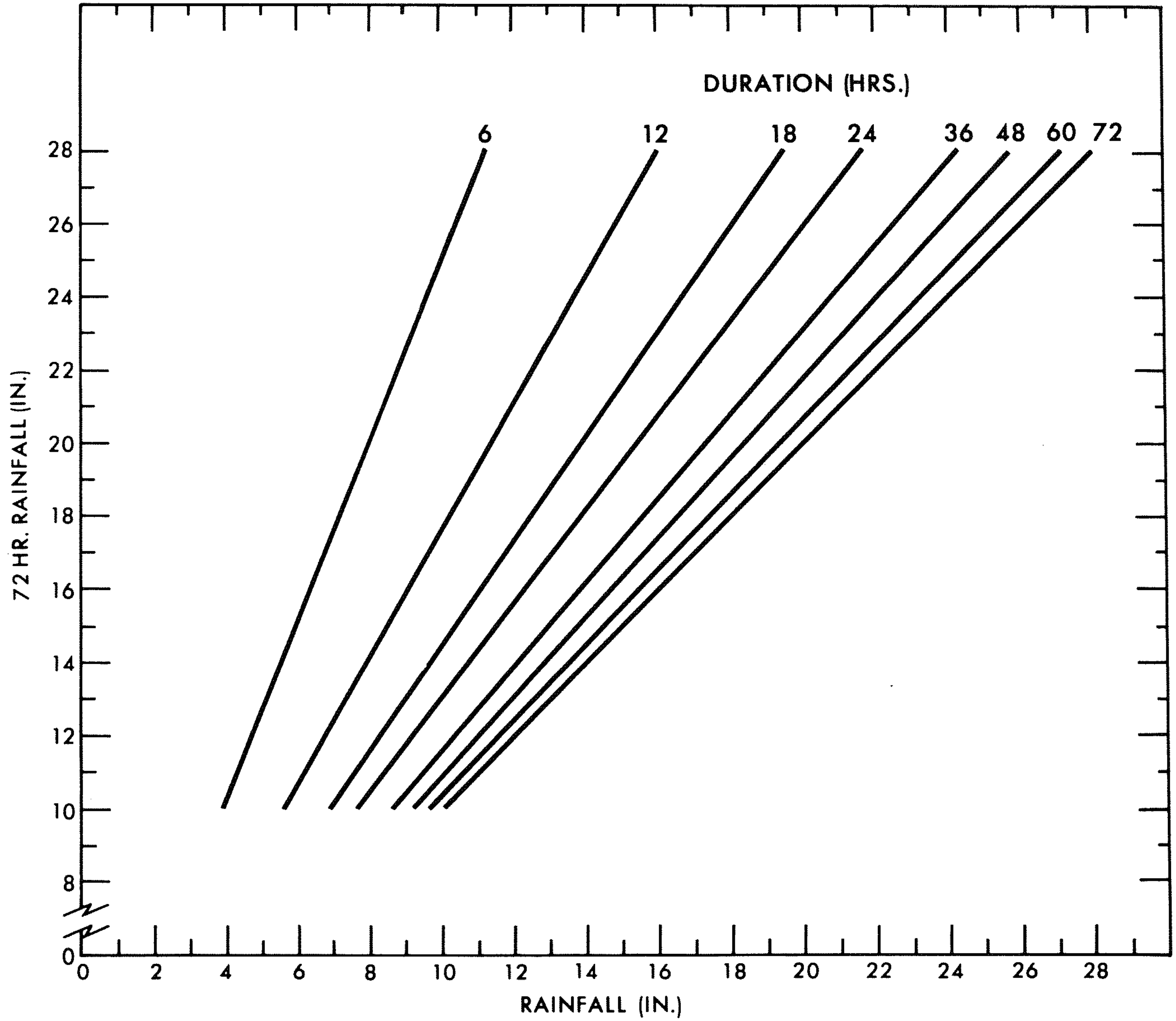


Figure 2-36. Depth-duration relations for 72-hr. TVA precipitation storm

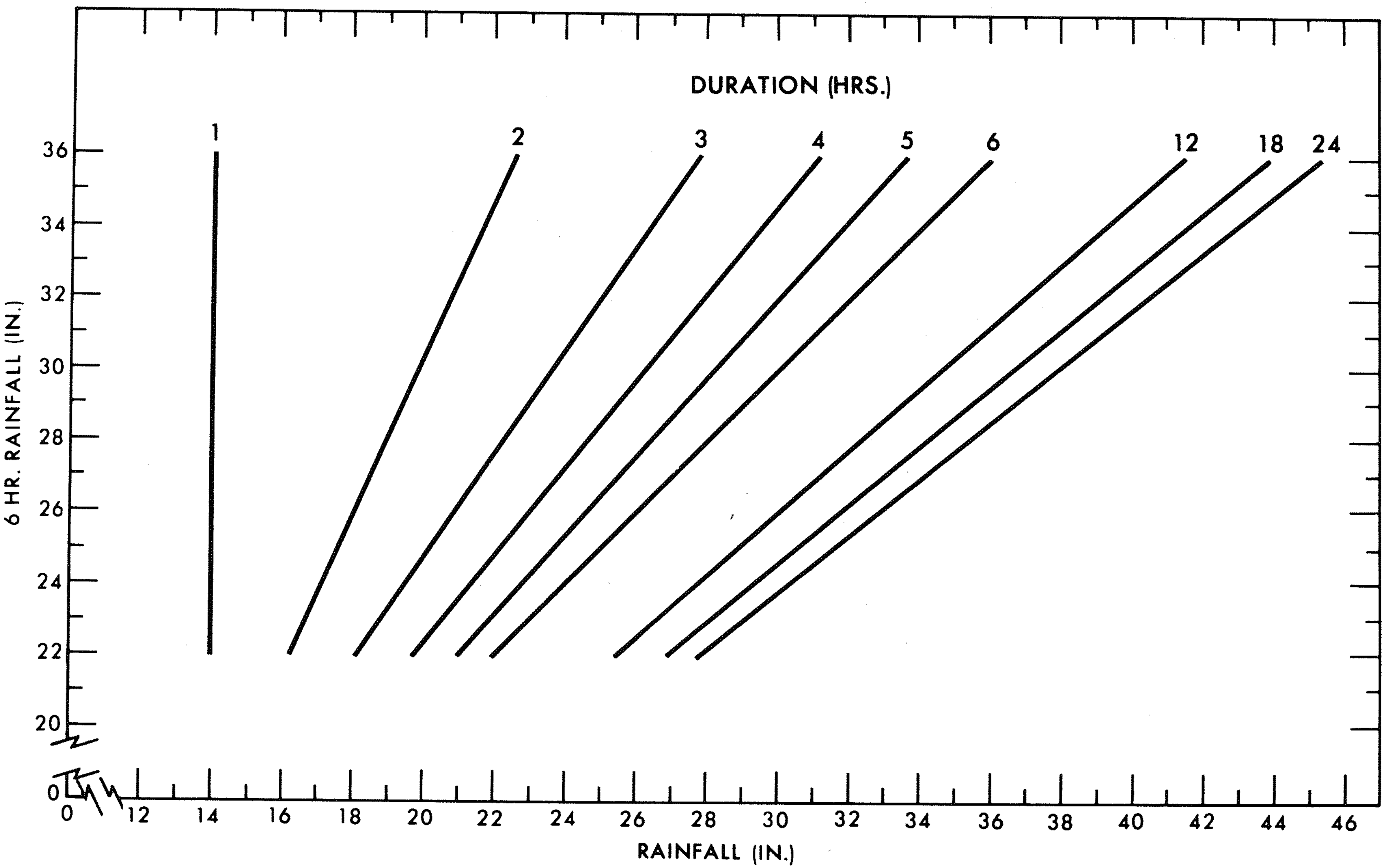


Figure 2-37. Depth-duration relations for 24-hr. PMP storm

<u>One-hour increments in maximum 6-hr. rainfall</u>. Any arrangement of 1-hr. increments is acceptable so long as it keeps the highest two-hourly amounts adjoined, the highest three-hourly amounts adjoined, etc.

C. EXAMPLE OF PROCEDURE FOR SMALL BASINS

Introduction

A hypothetical 50-sq. mi. basin in the orographically controlled upper Hiwassee drainage is assumed. First, the estimate of PMP to 24 hours is calculated. This is followed by estimates of TVA precipitation for storm durations of 3 and 12 hours. Ordinarily, if the hydrologic characteristics of a basin are well known, non-critical durations may be omitted.

PMP estimate

1. Outline the hypothetical basin on figure 2-21 and, using grid or other means, determine mean 6-hr. 5-sq. mi. PMP for basin. Let us assume the 6-hr. amount turns out to be 31.8 inches.

2. Going to figure 2-37 with 31.8 inches on the left scale, 5-sq. mi. PMP values are read for durations of 1 to 24 hours and tabulated in second column of table 2-6.

3. Figure 2-23 is now used to reduce the cumulative precipitation values of step 2 to values appropriate to the 50-sq. mi. hypothetical basin. The reduction factors and computations to obtain incremental 50-sq. mi. values are shown in table 2-6. The cumulative 50-sq. mi. values in the fourth column result from a multiplication of preceding two columns.

Table 2-6. Computation of Incremental Basin PMP

Duration (hr.)	5-Sq. Mi. Precip. (in.)	Area Reduction (%)	Cumulative 50-sq. mi. Precip. (in.)	Basin PMP Increments (in.)
1	14.0	77.2	10.8	10.8
2	20.7	79.9	16.5	5.7
3	24.9	81.9	20.4	3.9
4	27.7	83.0	23.0	2.6
5	29.8	83.8	25.0	2.0
6	31.8	84.7	26.9	1.9
12	36.7	85.2	31.2	4.3
18	38.9	85.7	33.3	2.1
24	40.1	86.1	34.5	1.2

4. Plot the incremental basin PMP values from the last column of table 2-6 against duration and make any slight corrections needed by constructing a smooth depth-duration curve.

5. Choose a time sequence of PMP increments in accordance with the "time-distribution" instructions given prior to the examples in this chapter. A sample selection is:

   a. Sequence of hourly amounts in maximum 6-hr. rainfall: 6, 5, 4, 3, 1, 2 where 1 refers to highest hourly amount.

   b. Sequence of 6-hourly amounts: 4, 2, 1, 3 where 1 now refers to maximum 6-hr. increment.

6. Arrange the PMP increments of step 4 or 5 as shown in table 2-7.

Table 2-7. Time Distribution of PMP Increments

Hours from beginning of storm	PMP increments (in.)
1-6	1.2
7-12	4.3
13	1.9
14	2.0
15	2.6
16	3.9
17	10.8
18	5.7
19-24	2.1

TVA precipitation estimates

1. Following step 1 of the PMP procedure, determine mean 6-hr. 5-sq.mi. TVA precipitation by using the TVA precipitation index map, figure 2-22. For our hypothetical Hiwassee 50-sq. mi. basin, the mean 5-sq. mi. 6-hr. TVA index precipitation is 19.1 inches.

Factors for adjusting 6-hr. 5-sq. mi. TVA depths are shown in table 2-8.

Table 2-8. Factors For Adjusting 6-Hr. 5-Sq. Mi. TVA Depths To Other Durations

Storm Duration (hr.)	Factor
3	0.80
6	1.00
12	1.15
24	1.29

2. The initial interest is in the 3-hr. TVA precipitation values. Going into figures 2-34 with 15.3 inches on the left scale, 5-sq. mi. TVA precipitation values are read for durations of 1 to 3 hours and tabulated as second column in table 2-9.

Table 2-9. 3-Hour TVA Storm Values For Hypothetical Hiwassee Basin

Duration (hr.)	5-sq. mi. Precip. (in.)	Area Reduction (%)	Cumulative 50-sq. mi. Precip. (in.)	Basin TVA Pcpn. Increments (in.)
1	8.0	77.2	6.2	6.2
2	12.7	79.9	10.2	4.0
3	15.3	81.9	12.5	2.3

3. Obtain area-reduction factors. Since PMP and TVA precipitation area-reduction factors are the same, the factors need not be read again from figure 2-23 but rather taken directly from table 2-6, which for the first 3 hours are as shown in the third column of table 2-9. These factors yield the area-reduced incremental values shown in the last column of table 2-9.

4. Plot the incremental basin TVA precipitation values from table 2-9 against duration and make any slight corrections needed by constructing a smooth depth-duration curve.

5. Choose a time sequence in accordance with the time-distribution instructions at the end of section B of this chapter. For example, the following sequence is acceptable: 2.3, 6.2 and 4.0 inches.

6. The same general procedure is followed to obtain a sequence of TVA rainfall for other storm durations. This is illustrated by completing the example for the 12-hr. TVA precipitation.

To obtain 12-hr. 5-sq. mi. TVA precipitation values, the 19.1-inch basin index value has been multiplied by a factor of 1.15 from table 2-8 to give a 12-hr. value of 22.0 inches.

7. Figure 2-35a is used with the 22.0 inches to obtain 5-sq. mi. TVA precipitation values for the 12-hr. storm (table 2-10).

Table 2-10. 12-Hour TVA Storm Values For Hypothetical Hiwassee Basin

Duration (hr.)	5-sq. mi. Precip. (in.)	Area Reduction (%)	Cumulative 50-sq. mi. Precip. (in.)	Basin TVA Pcpn. Increments (in.)
1	5.8	77.2	4.5	4.5
2	9.4	79.9	7.5	3.0
3	11.9	81.9	9.8	2.3
4	13.6	83.0	11.3	1.5
5	15.2	83.8	12.7	1.4
6	16.3	84.7	13.8	1.1
12	22.0	85.2	18.7	4.9

8. Obtain area-reduction factors already tabulated in table 2-6 or from figure 2-23. Application of these factors to the 5-sq. mi. values yields the cumulative values in the fourth column of table 2-10. Successive subtraction results in the desired incremental values shown in the last column.

9. These incremental values are plotted and checked for smoothness and adjustments made as required.

10. A time sequence is chosen in accordance with the time-distribution instructions given prior to the examples in this chapter. A sample selection is:

a. Sequence of hourly amounts maximum 6-hr. rainfall: 6, 5, 4 3, 1, 2 where 1 refers to highest hourly amount.

b. Sequence of 6-hr. amounts: 2, 1, where 1 refers to maximum 6-hr. increment.

11. Arrange TVA precipitation increments of steps 10a and 10b as shown in table 2-11.

Table 2-11. Time Distribution of TVA Precipitation Increments

Hours from beginning of storm		TVA Precipitation increments (in.)
1-6		4.9
7-12	7	1.1
	8	1.4
	9	1.5
	10	2.3
	11	4.5
	12	3.0

In a similar manner, TVA rainfall values are determined for as many storm durations as necessary. If durations other than for 3, 6, 12 and 24 hours are required, smooth curves may be constructed as necessary to obtain interpolated values. The most critical sequence of the several permitted by the meteorological guidelines is determined on the basis of computed hydrographs.

Chapter III

GENERALIZED PROCEDURE FOR 100- TO 3000-SQUARE MILE BASIN ESTIMATES

Introduction

Chapter II provides a means of obtaining estimates for basins up to 100 square miles in area. Chapter III presents a generalized procedure for obtaining estimates for drainages from 100 to 3000 square miles.

The chapter is divided into three sections. Section A describes meteorological characteristics of pertinent storms. Section B discusses the derivation of a generalized procedure, while Section C gives a stepwise example of the preparation of a basin estimate.

Because the eastern portion of the basin is more mountainous than the west and therefore exerts a more complicated control on precipitation, the procedures for obtaining generalized estimates differ in the east and the west.

A. STORM CHARACTERISTICS

Introduction

In chapter II of this report the PMP type warm-season small area thunderstorm situation was described. In HMR 41 /1-2/ the winter-type PMP-producer for basins of 8000 square miles and larger was the main concern. Here we are concerned with the type or types of situations that will provide PMP and TVA precipitation values over intermediate-size basins of up to 3000 square miles.

A variety of specific rain-producing mechanisms may be involved in the PMP or TVA precipitation over a 3-day period. A decadent tropical storm or hurricane may or may not be involved.

Summer control of maximum U. S. rainfall

Maximum observed rainfall near the Gulf Coast occurs in summer for areas up to at least 2000 square miles. The maximum observed values from "Storm Rainfall" /2-6/ are listed in table 3-1.

Table 3-1. Maximum Observed U. S. Rainfall (in.)

Area (sq. mi.)	Duration (hr.) 6	12	18	24	36	48	72
200	17.9	25.6	31.4	34.2	36.7	37.7	39.2
500	15.4	24.6	29.7	32.7	35.0	36.0	37.3
1000	13.4	22.6	27.4	30.2	32.9	33.7	34.9
2000	11.2	17.7	22.5	24.8	27.3	28.4	29.7

All the above values except those for 6 hours were from the Yankeetown, Fla., hurricane "Easy" of September 3-7, 1950. The 6-hr. values were from the Thrall, Tex., storm of September 8-10, 1921.

A hurricane like the Altapass, N. C. storm of July 1916, may best typify the PMP storm for the mountainous eastern portion of the Tennessee watershed. The western two-thirds of the Tennessee watershed may also be influenced by decadent tropical storms or hurricanes. Figures 3-1 and 3-2, reproduced from HMR 41 /1-2, figs. 3-20 and 3-21/ show some typical tracks of past tropical storms. However, the distance of the Tennessee watershed from the ocean source increases the chance of a more complex weather situation than a decadent tropical storm alone being the cause of the 3-day PMP or TVA precipitation. The record-breaking rains in the Tennessee Basin mountains in late September and early October 1964 were produced by a storm which will demonstrate this point.

September 28-October 4, 1964 "storm"

This recent "storm" that affected the mountainous eastern portion of the Tennessee Basin demonstrates a combination of types that gave heavy total precipitation over 6 days. Separate types of events produced about equally heavy 24-hr. rains at the same location within this storm period. The first of the two storms dumped its rain on September 28-29, while the remnants of hurricane Hilda added more rain on October 4-5. Figures 3-3 through 3-8 are presented to help clarify the narrative discussion.

The TVA has published a fairly comprehensive account of the floods of September and October 1964 /3-1/. A few of the highlights of the associated storm events as listed at the beginning of the TVA report are repeated here:

1. The most significant rain was "along the crest of the Blue Ridge in western North Carolina and northern Georgia."

2. Rosman, N. C. established new rainfall records with a total accumulation from September 28-October 4, of 35.4 inches.

3. The second half of the storm period produced "floods in the upper French Broad River Basin" that "were the highest since 1916 on most

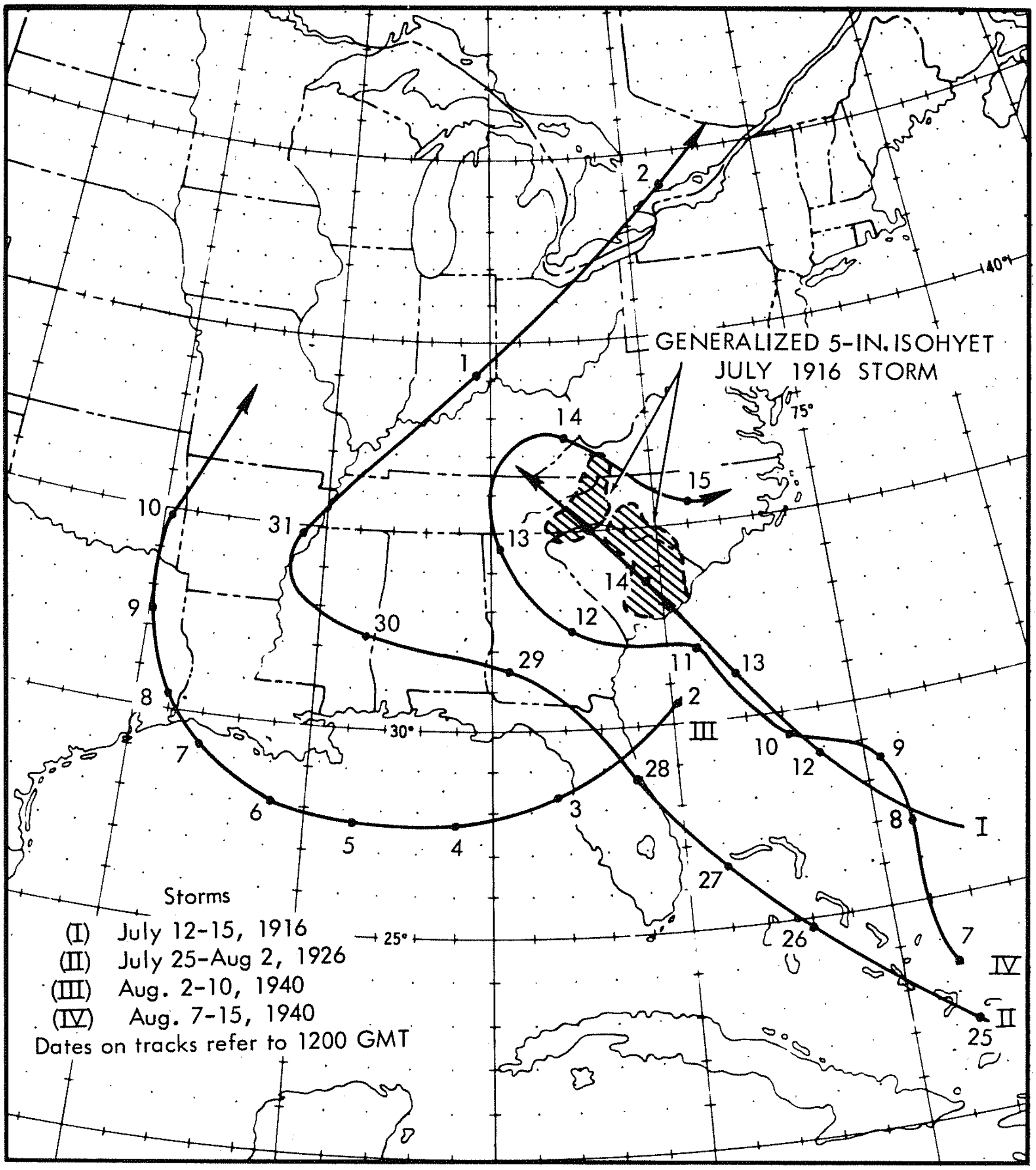


Figure 3-1. Hurricane tracks from the Atlantic

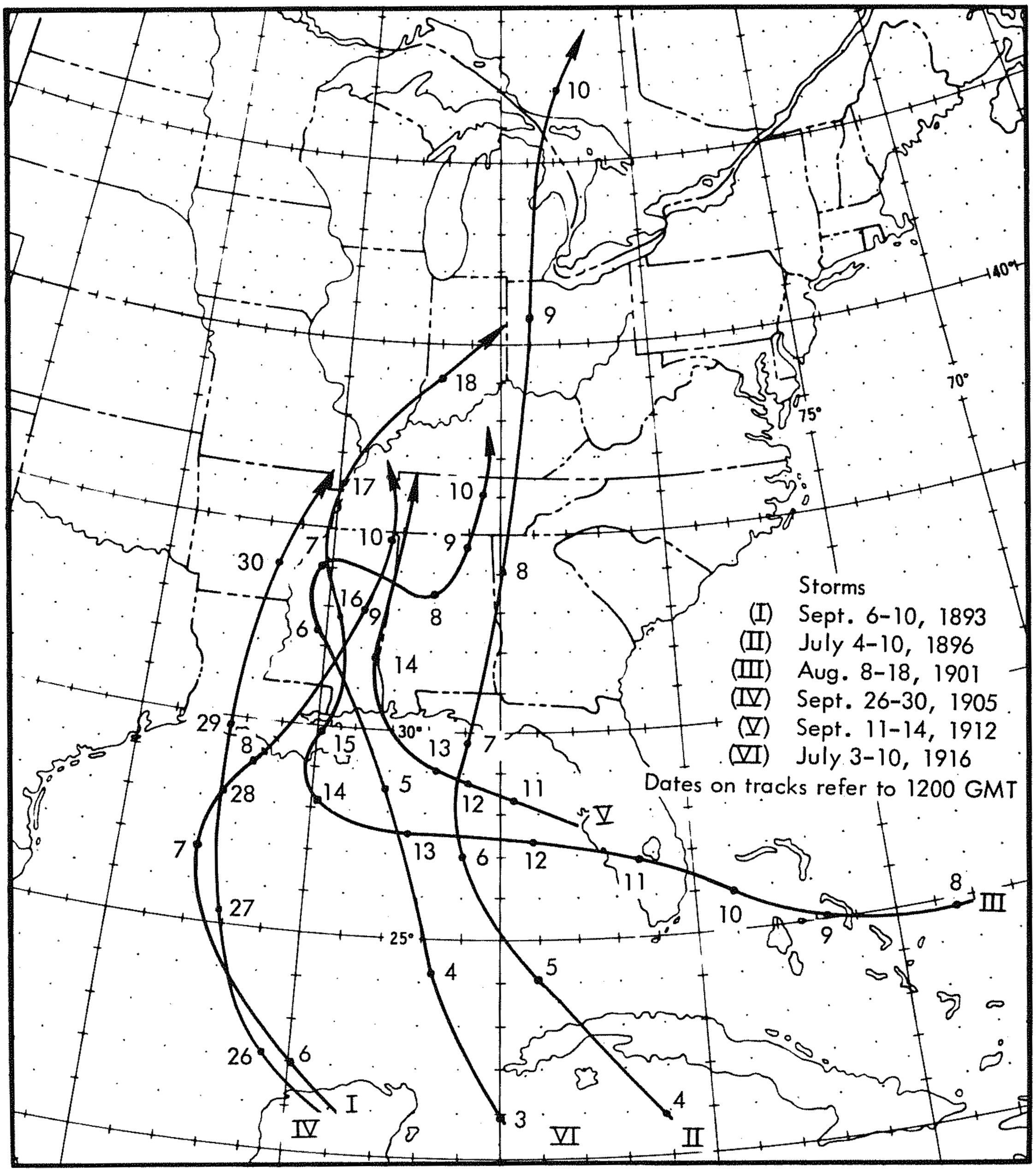


Figure 3-2. Hurricane tracks from the south

streams." Also, "on the upper Little Tennessee River the flood exceeded the highest previously known flood."

A high volume of non-orographic rainfall was made possible in the September 28-29 storm by a large low-level transport of moisture into an area of strong low-level convergence associated with an inverted-V trough and a quasi-stationary front. This type is a classic producer of heavy rain throughout the Central United States. Added to this low-level convergence mechanism was an orographic upslope influence as evidenced by the primary rain center near Rosman, N. C. (fig. 4-9).

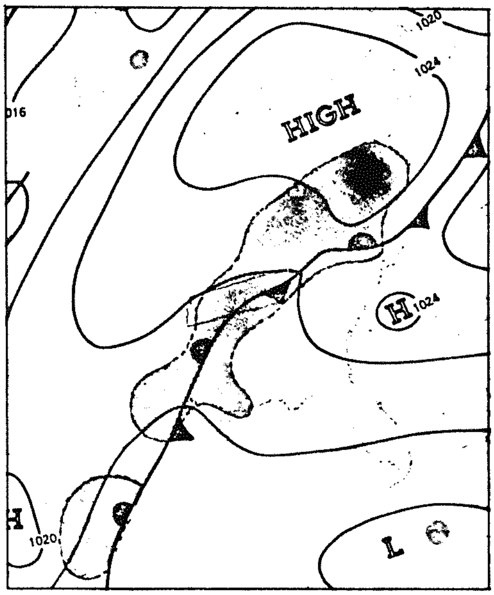
The 500-mb. charts (figs. 3-3 and 3-4) show a trough in the westerlies which did not extend its influence close to the hurricane. This synoptic picture permitted the hurricane to continue at a rather slow rate. Had a major trough entered the area the hurricane would have likely turned to a northeasterly course and increased its speed so that its rain would not have fallen over the same area as the prior heavy rain. Such a "fixing" of the broad-scale synoptic features is extremely important for heavy rains to repeat over approximately the same area. See, for example, the discussion on pages 3-4 of HMR 38 [3-2].

That the persisting, or geographically fixed, influx of very moist air was an important feature of the repeating heavy rains of September 28-October 4, is demonstrated by figures 3-7 and 3-8. Highlighted on figure 3-7 is the pronounced 850-mb. tongue of moisture extending toward the eastern border of Tennessee. Figure 3-8 shows that the most unstable region (Showalter Index [3-3]) centered from northern Alabama into eastern Tennessee in conjunction with persisting high values of precipitable water. (A stability of index of zero represents a marked degree of instability since this is an average for the whole storm period.) The precipitable water values in figure 3-8 are also for the period September 28-October 4 so their magnitude must be judged accordingly. Figure 3-9 provides a basis for judgment, giving the climatological assessment of precipitable water values at an atmospheric sounding station south of the Tennessee Basin. The 12-hr. persisting dew point data on figure 3-9 are from charts developed in the Hydrometeorological Branch and published in the National Climatic Atlas [2-16]. Their precipitable water equivalent is based on an assumed saturated atmosphere. The 100-yr. values of precipitable water, as well as the maximum precipitable water of record (in fig. 3-9), are derived from twice-a-day precipitable water measurements for Montgomery, Ala., for the period 1949-1965.

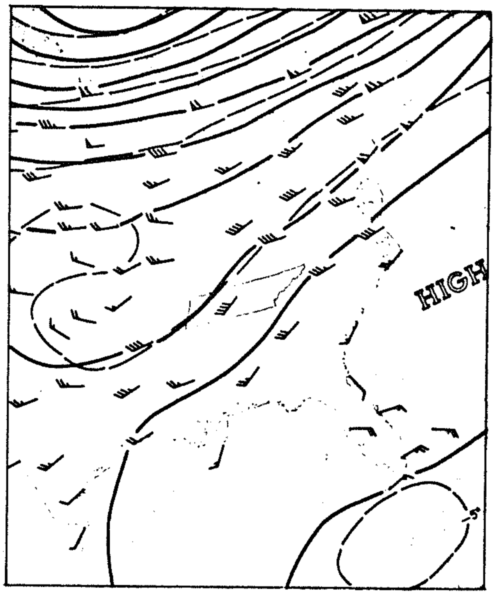
For a portion of the 1964 storm period, surface dew points of 74°F. were observed near the Gulf Coast, while on October 2, Burrwood, La. observed a precipitable water value of 2.34 inches [3-4].

Conclusions

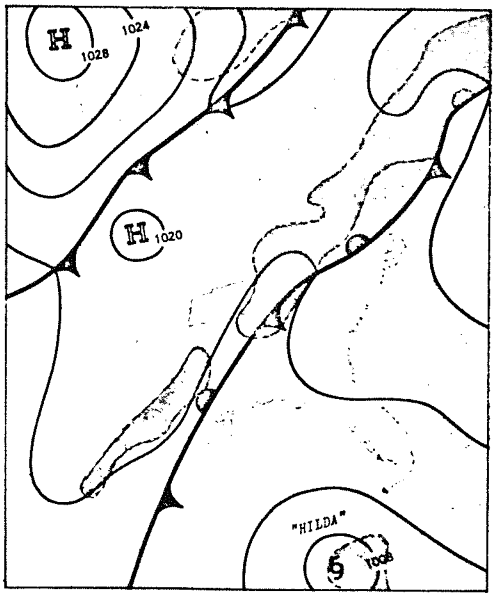
We are concerned in this chapter with storm durations to three days. Although the slow-moving decadent tropical storm or hurricane may play a



SEPT. 28, 1964 Surface 1800GMT



SEPT. 28, 1964 500mb 0000GMT



SEPT. 29, 1964 Surface 1800GMT

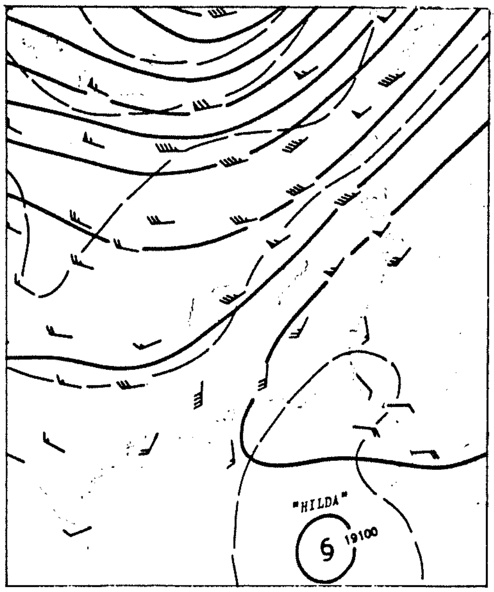


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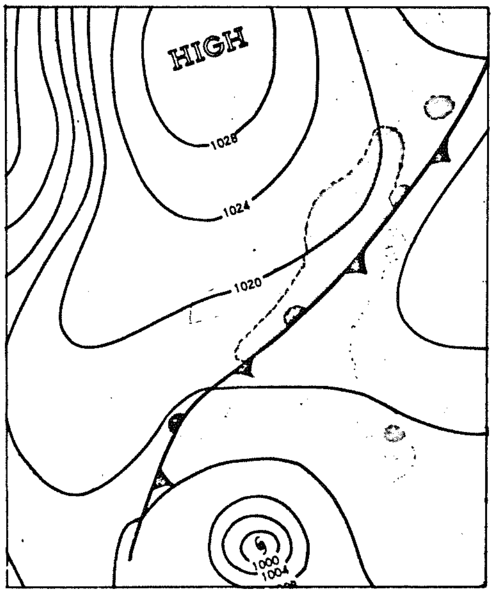
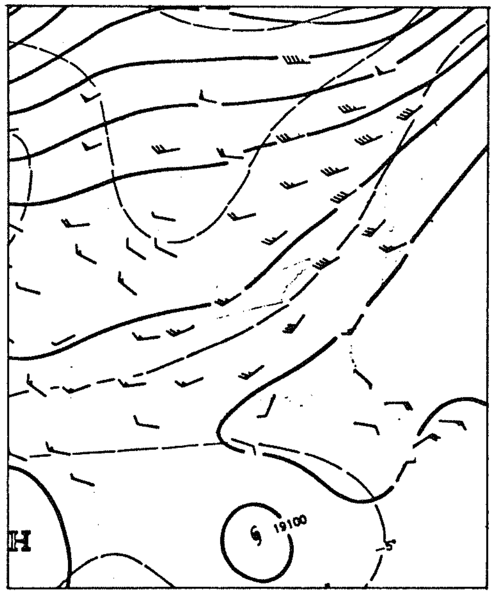
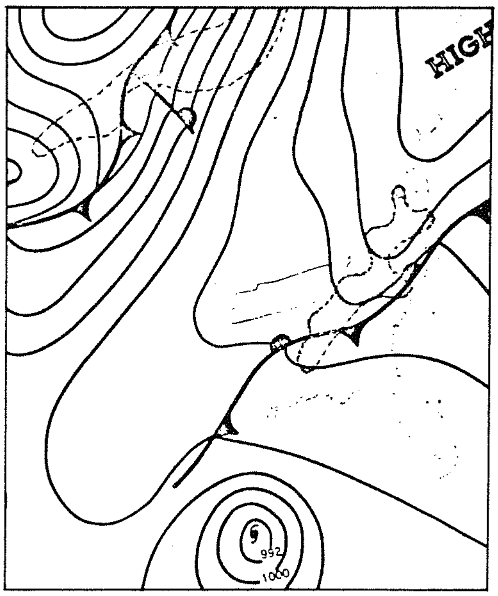
Figure 3-3. Surface and upper-air weather maps for September 28-29, 1964



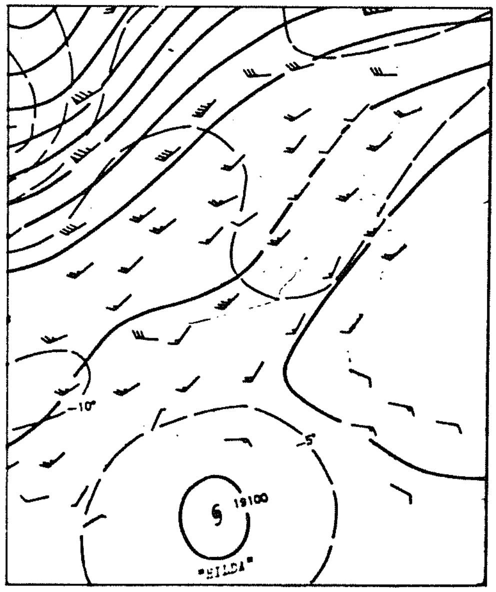
Sept. 30, 1964 Surface 1800GMT



Sept. 30, 1964 500mb 0000GMT

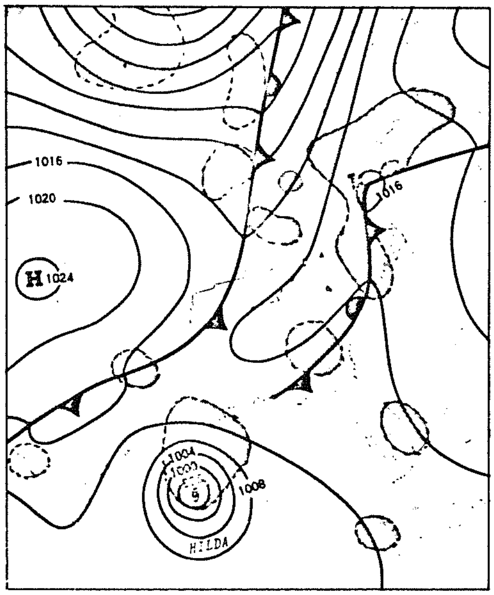


Oct. 1, 1964 Surface 1800GMT

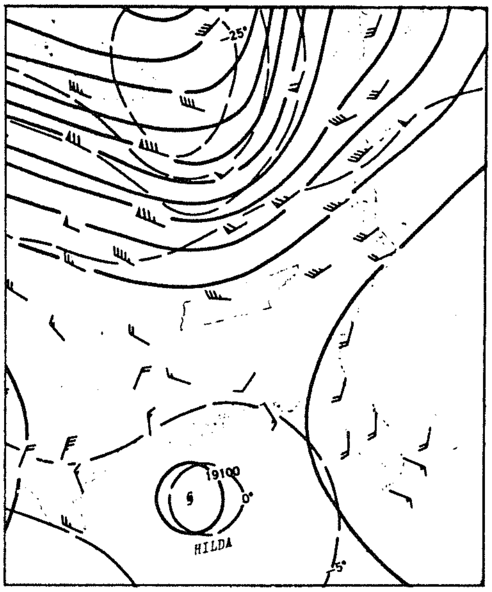


Oct. 1, 1964 500mb 0000GMT

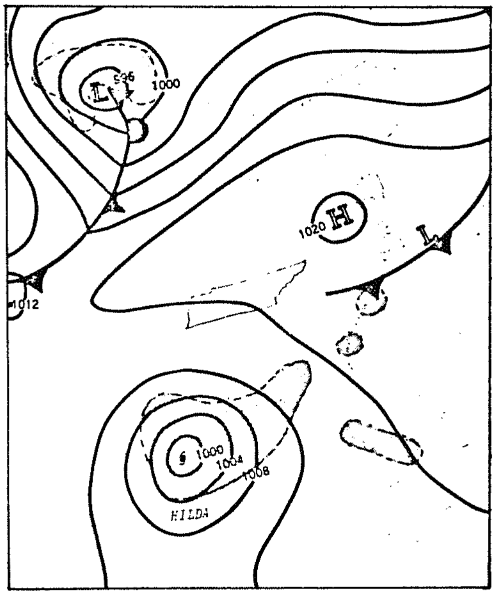
Figure 3-4. Surface and upper-air weather maps for September 30-October 1, 1964



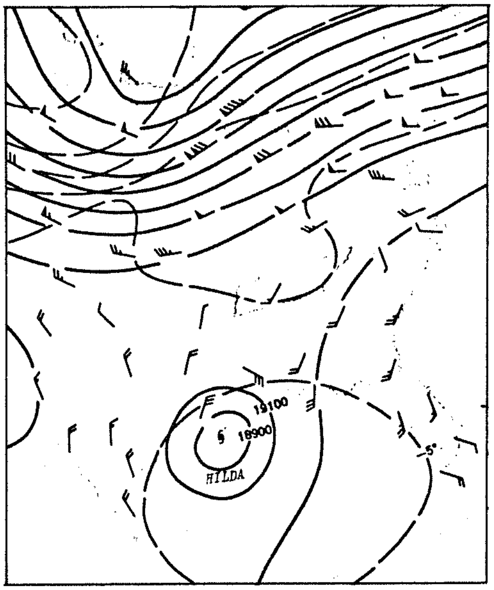
Oct. 2, 1964 Surface 1800GMT



Oct. 2, 1964 500mb 0000GMT

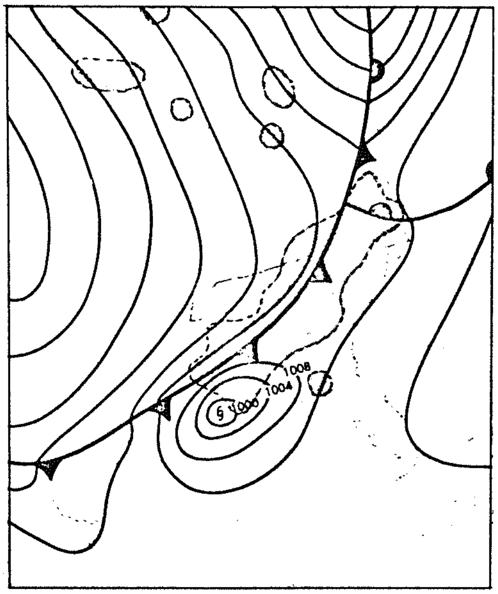


Oct. 3, 1964 Surface 1800GMT

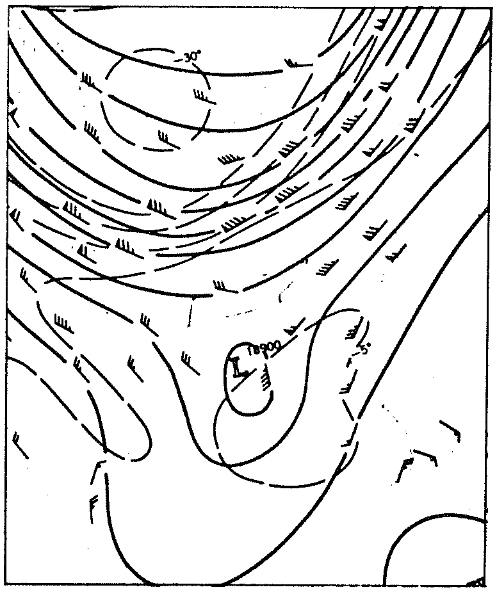


Oct. 3, 1964 500mb 0000GMT

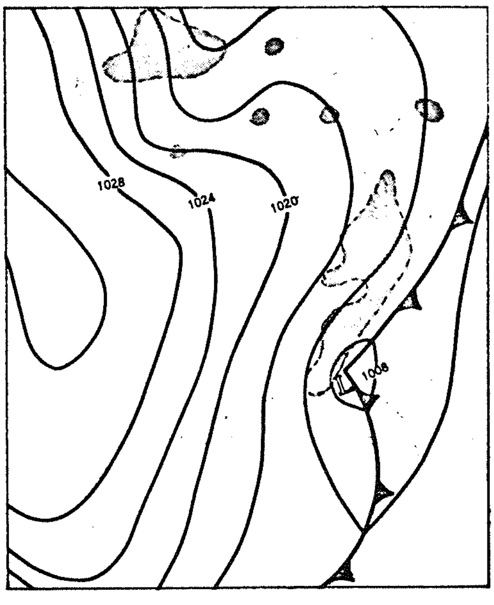
Figure 3-5. Surface and upper-air weather maps for October 2-3, 1964



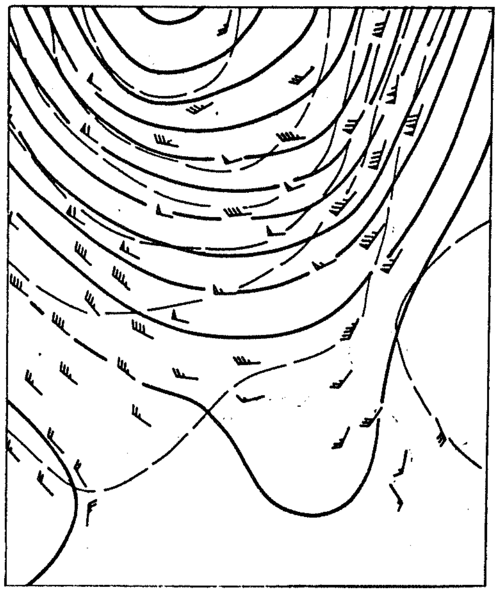
Oct. 4, 1964 Surface 1800GMT



Oct. 4, 1964 500mb 0000GMT



Oct. 5, 1964 Surface 1800GMT



Oct. 5, 1964 500mb 0000GMT

Figure 3-6. Surface and upper-air weather maps for October 4-5, 1964

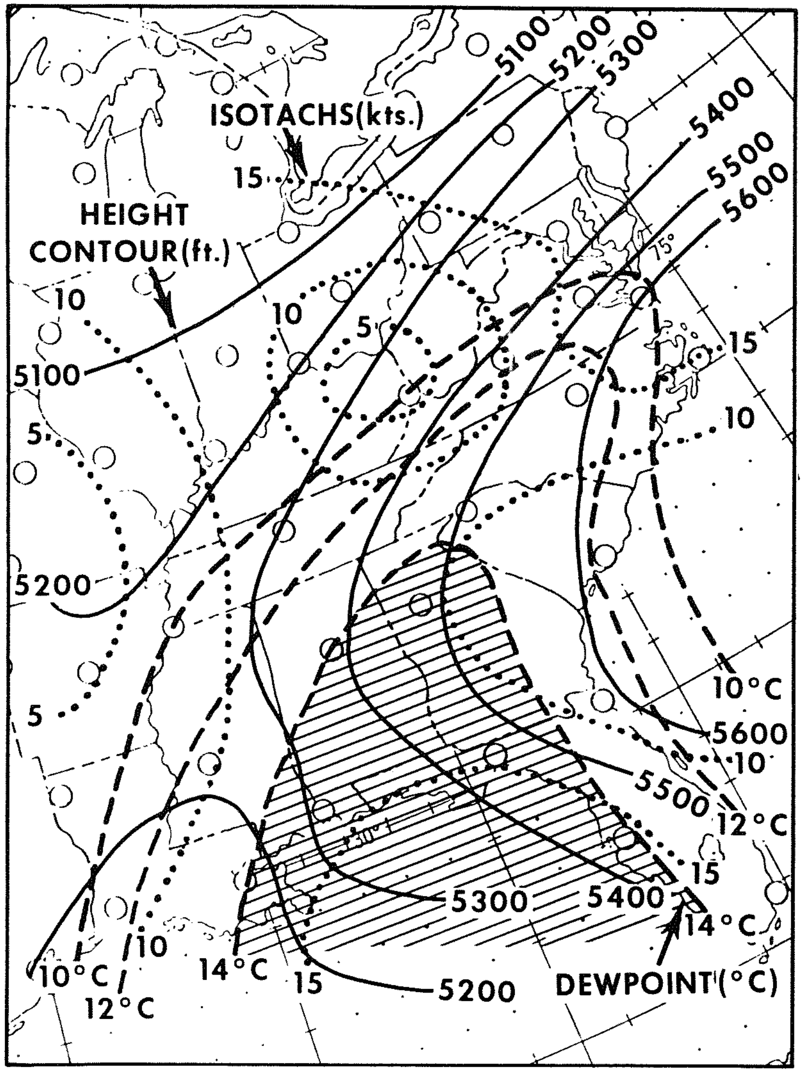


Figure 3-7. Composite 850-mb. (≈5000 ft.) chart for September 28-October 4, 1964

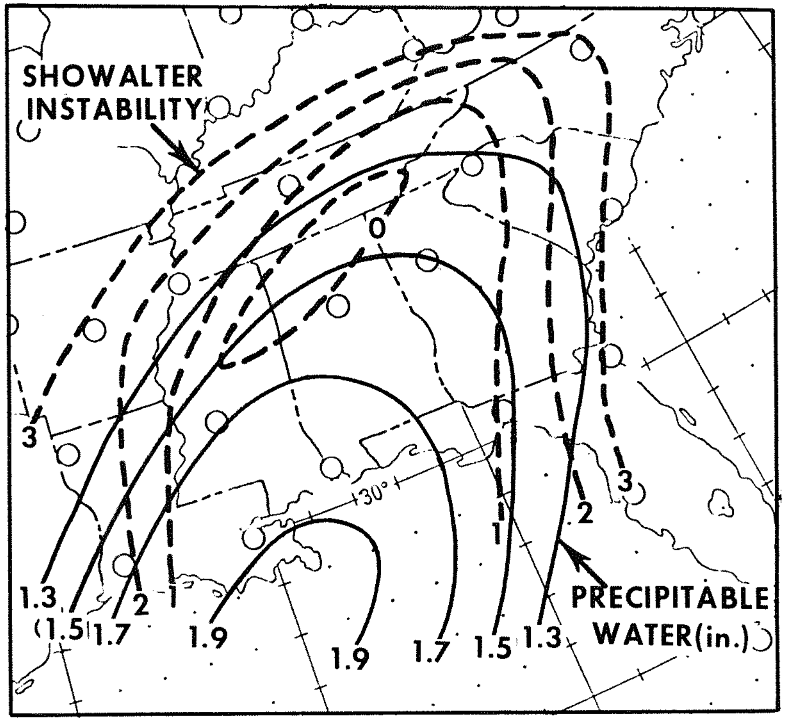


Figure 3-8. Composite moisture-instability chart for September 28-October 4, 1964

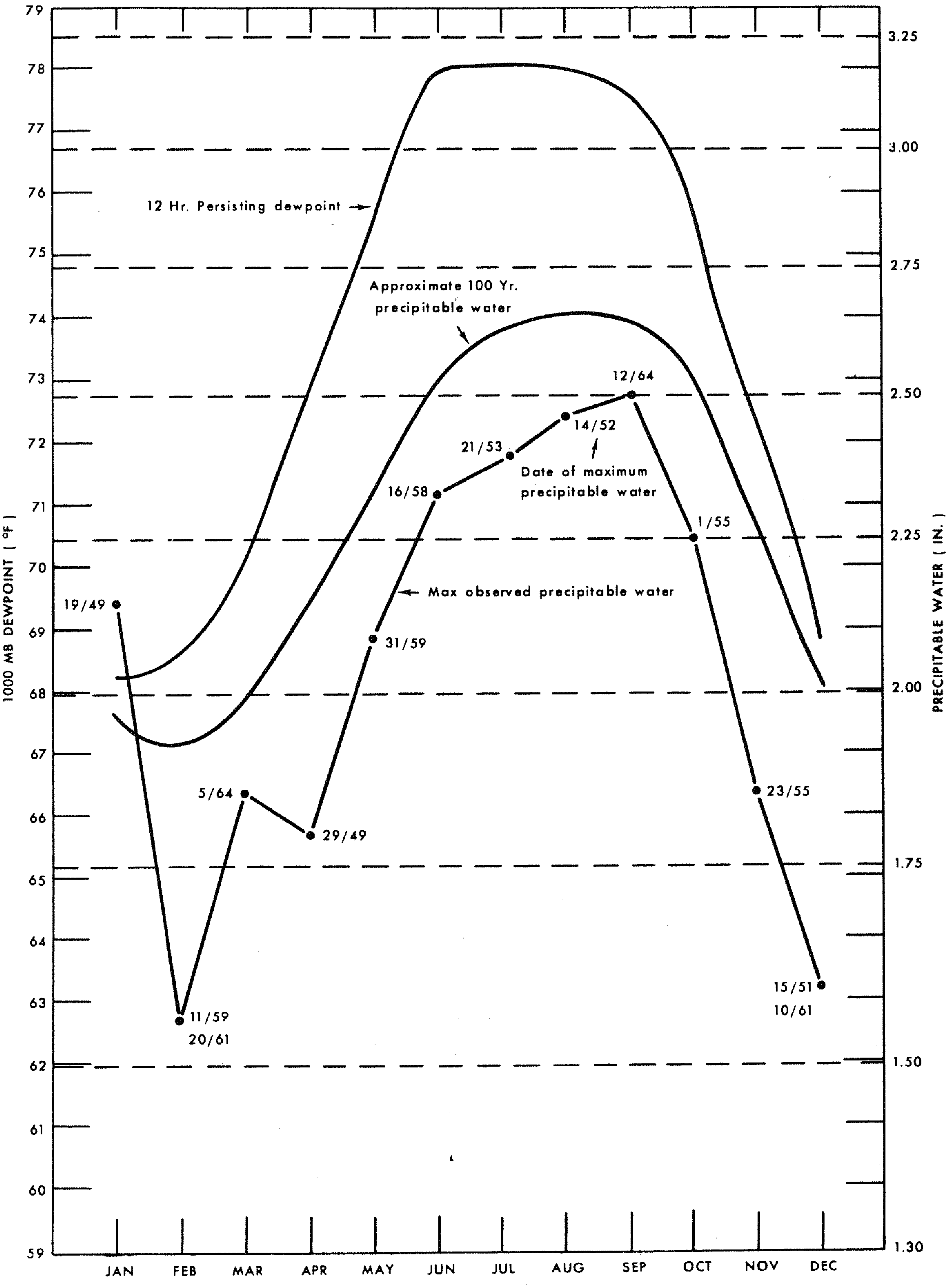


Figure 3-9. Seasonal variation of maximum moisture, Montgomery, Ala.

role in providing the maximum rainfall, other types of weather situations will likely be involved, either in combination with a decadent hurricane as in October 1964 or without the involvement of any tropical storm.

Regardless of weather type, features that will play a role are:

1. High values of moisture for the season of occurrence.
2. Geographical "fixing" of repeating rain events.
3. Thunderstorm involvement.

B. GENERALIZED TVA AND PMP VALUES FOR 100 TO 3000 SQUARE MILES 6 TO 72 HOURS

PMP depth-area-duration values

Estimates of probable maximum precipitation for basins in this size range in the Central and Eastern United States are generally based on moisture maximization, transposition, and envelopment of storm values, /1-1/; /1-3/. This was the method in Hydrometeorological Report No. 41 for estimating basic non-orographic PMP values for areas of 8000 and 21,000 square miles above Chattanooga. In that study moisture maximized values for selected basin sizes and durations were plotted on maps at the various storm locations and enveloping isohyets constructed, thus applying an implicit envelopment and transposition. Figure 5-3 in Hydrometeorological Report No. 41 is an example of this for cool-season type storms for 10,000 square miles in 24 hours.

The same technique is used here; maps like figure 5-3 cited above were constructed for a number of basin sizes and durations, with the isohyets not only enveloping the data on each chart but also showing smooth progressions with varying duration and basin size. As an example, the chart for 20[illegible] square miles and 24 hours is reproduced in figure 3-10; the basic data are listed in table 3-2. (This map includes storms at all seasons while figure 5-3 of HMR 41 is only for the cool season).

Scaling values from the set of maps like figures 3-10, at the location of Knoxville, leads to an array of basic PMP depth-area-duration values, figure 3-11. These values are blended into small area criteria of chapter II.

In figure 3-11, midwestern intense storms, particularly at Bonaparte, Iowa in June 1905 and at Hallett, Okla. in September 1940, have the biggest influence on the 6-hr. values. Hurricanes exercise the most influence at intermediate durations; these include both the Gulf of Mexico hurricanes and the Jefferson, Ohio storm of September 1878, a hurricane that crossed northwestward across the Appalachian Chain. The spring cool-season storm centered at Elba, Ala. has the most influence on large areas and long durations e.g., 5000 square miles and 72 hours.

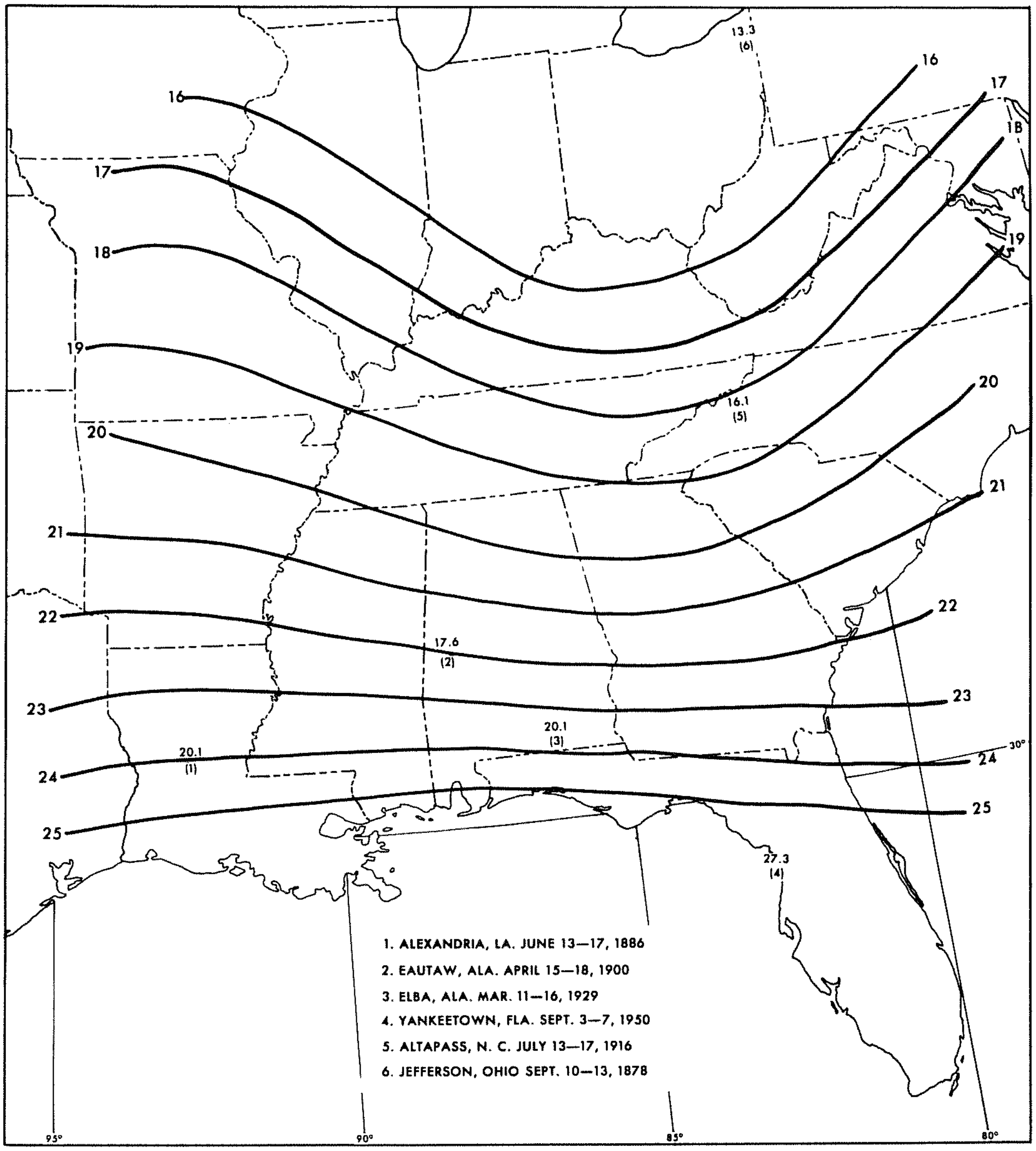


Figure 3-10. 24-Hr. 2000-sq. mi. PMP (inches)

Table 3-2. Maximum Observed and Moisture-Maximized Storm Rainfall for 24 Hours Over 2000 Square Miles

Date	Storm Center	Obs. Amt. (in.)	Moist.-Max. Amt. in Place (in.)
9/10-13/1878	Jefferson, Ohio	10.4	13.3
6/13-17/1886	Alexandria, La.	17.3	20.1
6/27-7/1/1899	Hearne, Tex.	19.0	22.0
4/15-18/1900	Eautaw, Ala.	10.8	17.6
10/7-11/1903	Cortland, N. Y.	10.2	16.6
8/28-31/1911	St. George, Ga.	11.3	13.7
3/24-28/1914	Merryville, La.	10.1	18.3
9/28-30/1915	Franklinton, La.	11.4	13.2
7/5-10/1916	Bonifay, Fla.	14.6	16.1
7/13-17/1916	Altapass, N. C.	13.3	16.1
9/8-10/1921	Thrall, Tex.	20.6	21.6
9/13-17/1924	Beaufort, N. C.	10.7	13.7
10/4-11/1924	New Smyrna, Fla.	11.9	14.4
4/12-16/1927	Louisiana	13.3	16.2
6/1-5/1928	Thomasville, Ala.	10.9	14.0
9/16-19/1928	Darlington, S. C.	10.3	12.5
3/11-16/1929	Elba, Ala.	15.0	20.1
9/23-28/1929	Washington, Ga.	12.1	14.6
6/30-7/2/1932	State Fish Hatchery, Tex.	16.9	19.6
8/30-9/5/1932	Fairfield, Tex.	12.8	14.1
7/22-27/1933	Logansport, La.	13.0	14.3
12/5-8/1935	Satsuma, Tex.	11.9	18.6
6/27-7/4/1936	Bebe, Tex.	12.2	12.2
9/14-18/1936	Broome, Tex.	11.6	12.2
8/6-9/1940	Miller Is., La.	16.7	18.4
9/2-6/1940	Hallett, Okla.	10.7	15.1
10/17-22/1941	Trenton, Fla.	15.2	17.6
7/17-18/1942	Smethport, Pa.	10.2	11.2
9/3-7/1950	Yankeetown, Fla.	24.8	27.3
6/23-28/1954	Pierce, Tex.	14.7	17.1

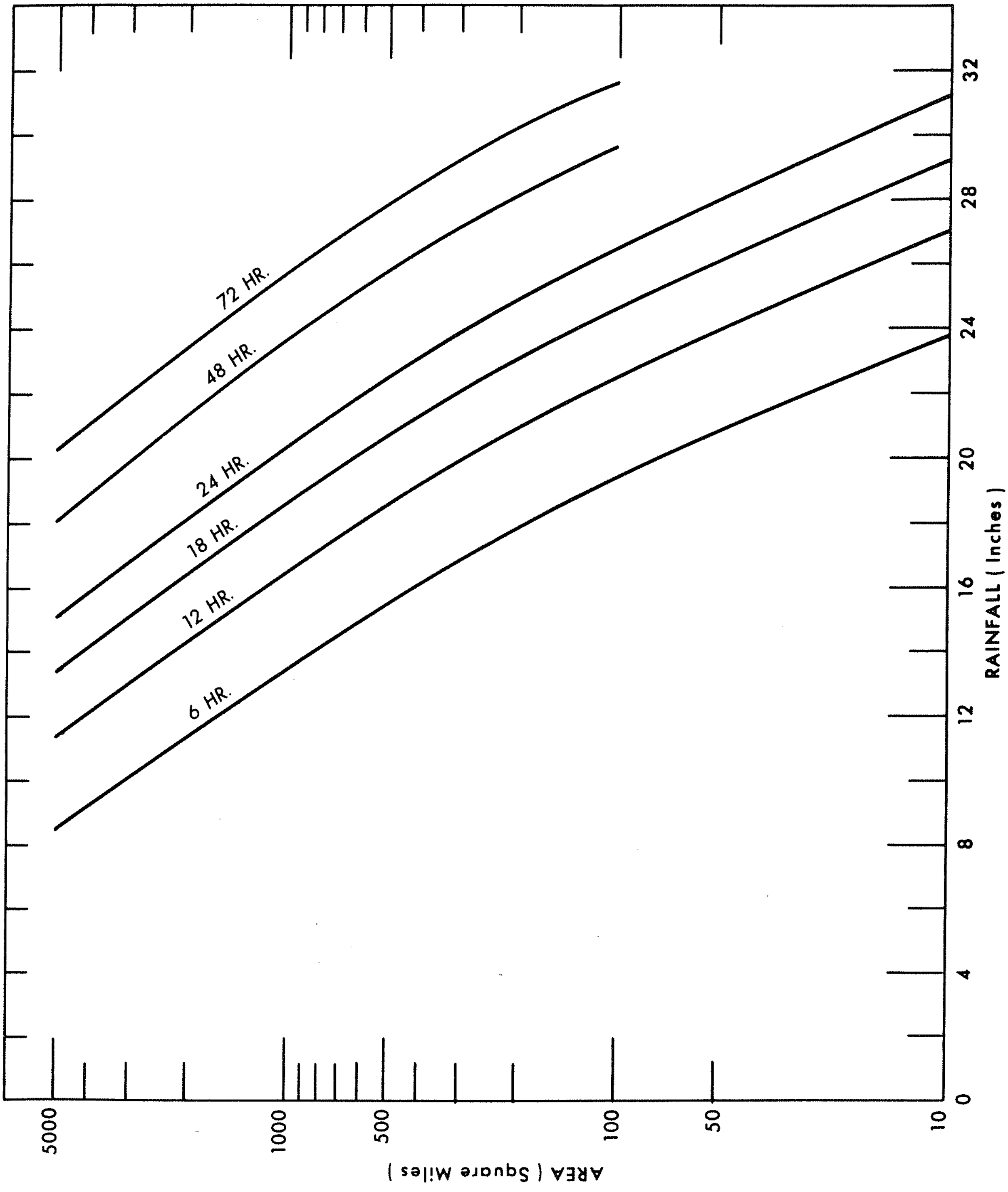


Figure 3-11. Depth-duration-area curves for PMP at Knoxville

TVA depth-area-duration values

Figure 3-12 shows the basic TVA depth-area-duration values for the location of Knoxville. These were derived in a manner analogous to the PMP values of figure 3-11, with omission of the moisture maximization step and with some undercutting of storm values at some distance from the Tennessee Basin. Adjusted depths in the July 1916 hurricane are plotted on the diagram for comparison.

Basin-wide-variation of basic non-orographic PMP and TVA depth-area-duration values

The 24-hr. 1000-sq. mi. isohyets (not shown) of the set like figure 3-10 are converted to percentage of values at Knoxville Airport, figures 3-13 and 3-14. The gradients of PMP and TVA precipitation for the basin sizes and durations that are the subject of this chapter are sufficiently the same over the Tennessee Valley that figures 3-10 and 3-11 can be used as index charts for the full range of sizes and durations. Multiplication of the depth-area-duration values of figures 3-11 and 3-12 by the percentages of 3-13 and 3-14 yield non-orographic values at various positions in the basin. Adjustments for orographic influences in the mountainous eastern portion of the basin are described below.

No specific orographic adjustments are developed for the less mountainous central and western portions of the basin. Unadjusted values apply to "smooth" and "intermediate" regions. These values should be increased slightly in the rougher regions of the Cumberland Plateau in the 100-500 sq. mi. basin size range. This can be accomplished by extrapolating from chapter II less-than-100-sq. mi. values and blending into chapter III values at larger areas.

Indices of orographic influence on PMP and TVA precipitation

Four indicators of the orographic influence on precipitation in the eastern part of the basin were developed for use with the generalized procedure and also with the specific basin estimates of chapter IV:

Mean annual non-orographic and orographic precipitation. Figure 3-15 is a mean annual precipitation chart for the eastern portion of the basin adopted from one developed by the TVA /3-5/. To indicate the influence of orography on the mean annual values, a hypothetical mean annual non-orographic precipitation chart is needed. Such a chart is shown in figure 3-16 and is derived by extrapolating mean annual precipitation values from surrounding areas beyond the immediate influence of the Appalachian Chain. The orientation of the isohyets agrees fairly well with that of the generalized PMP percentile lines of figure 3-14. Comparison of figure 3-15 and 3-16 provides one measure of the generalized orographic effect in a particular basin.

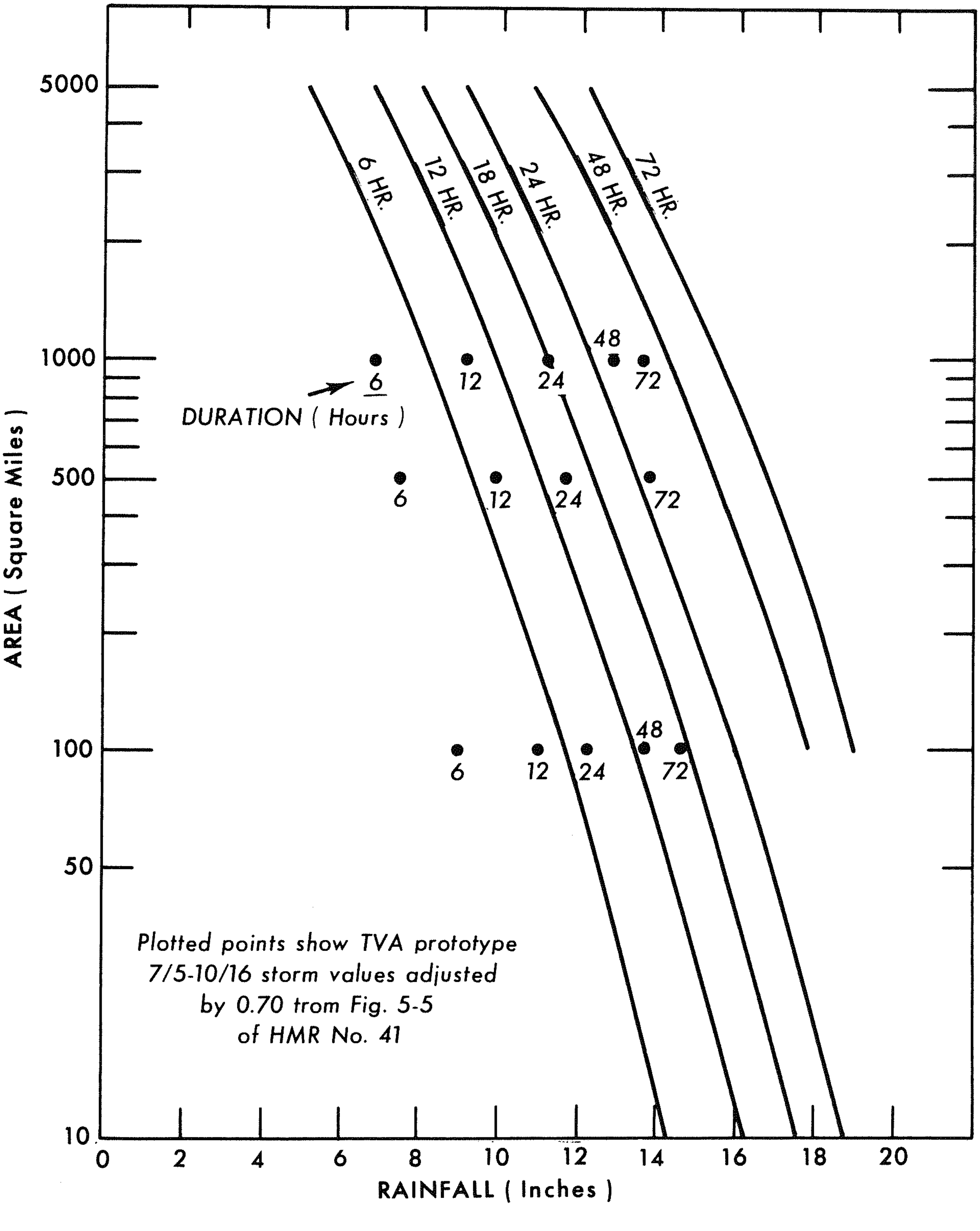


Figure 3-12. Depth-duration-area curves for TVA precipitation at Knoxville

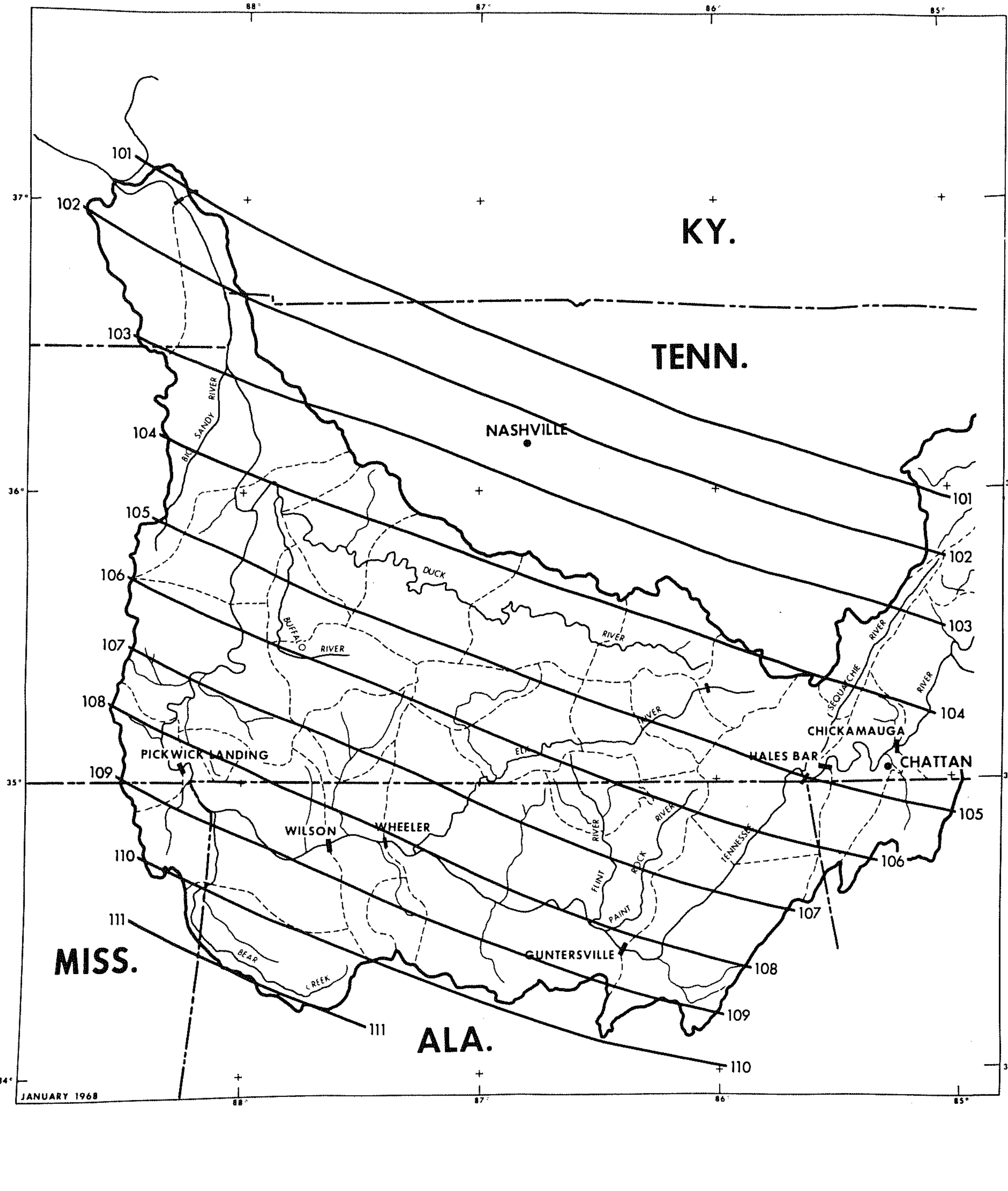


Figure 3-13. 24-Hr. 1000-sq. mi. PMP percentiles of Knoxville for western portion of Tennessee River watershed

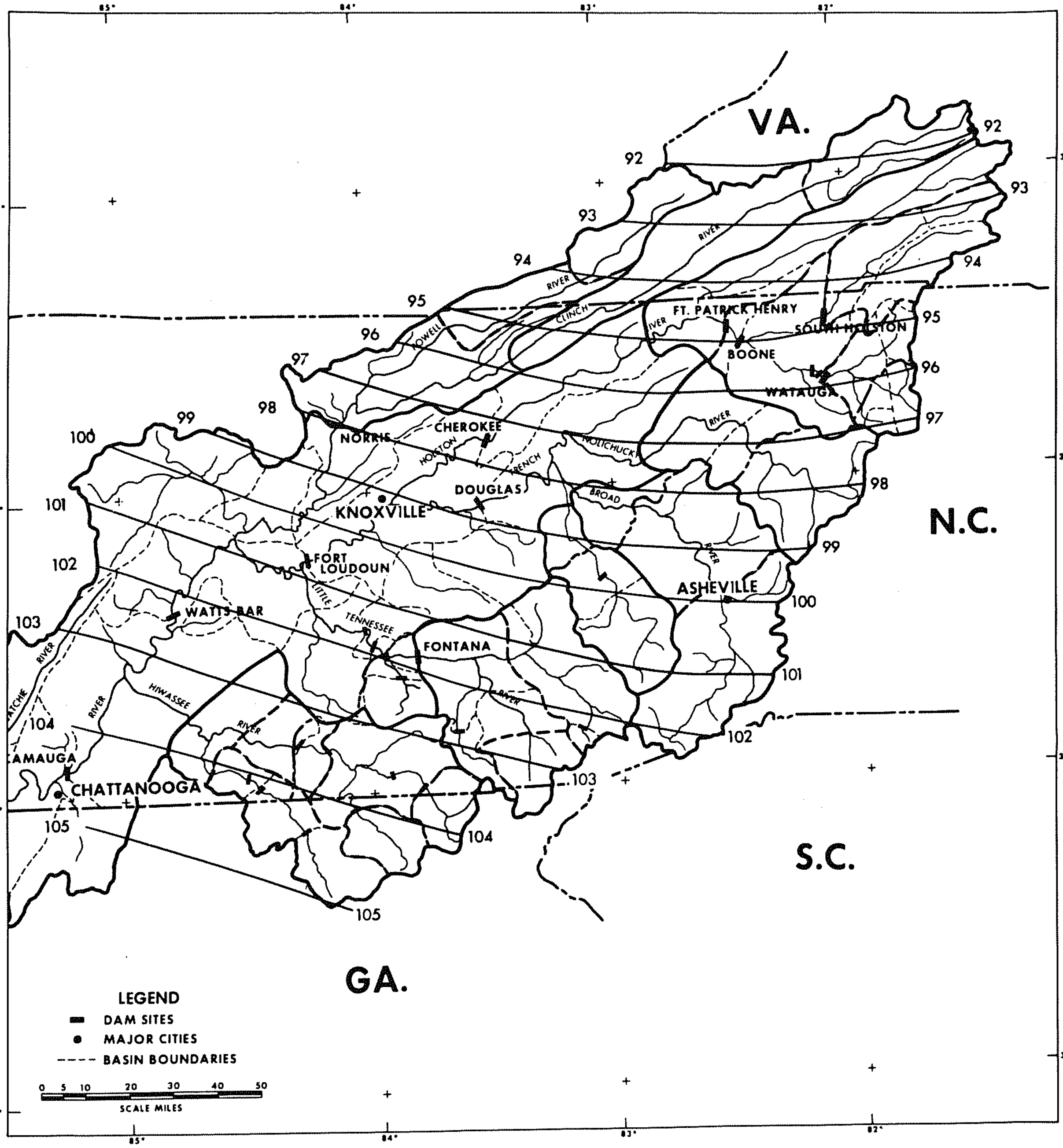


Figure 3-14. 24-Hr. 1000-sq. mi. PMP percentiles of Knoxville for eastern portion of Tennessee River watershed

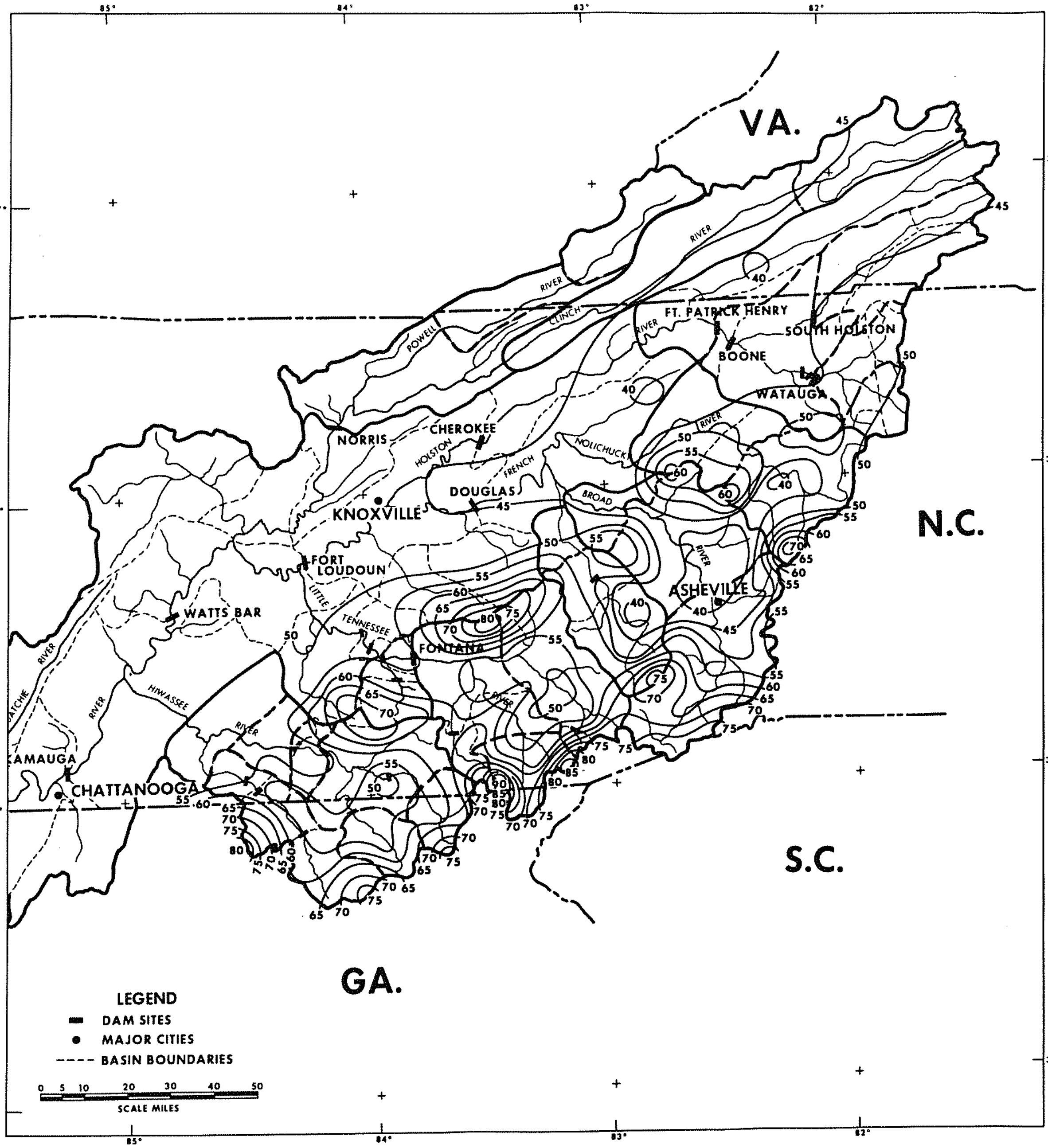


Figure 3-15. Mean annual precipitation for the eastern Tennessee River watershed (inches)

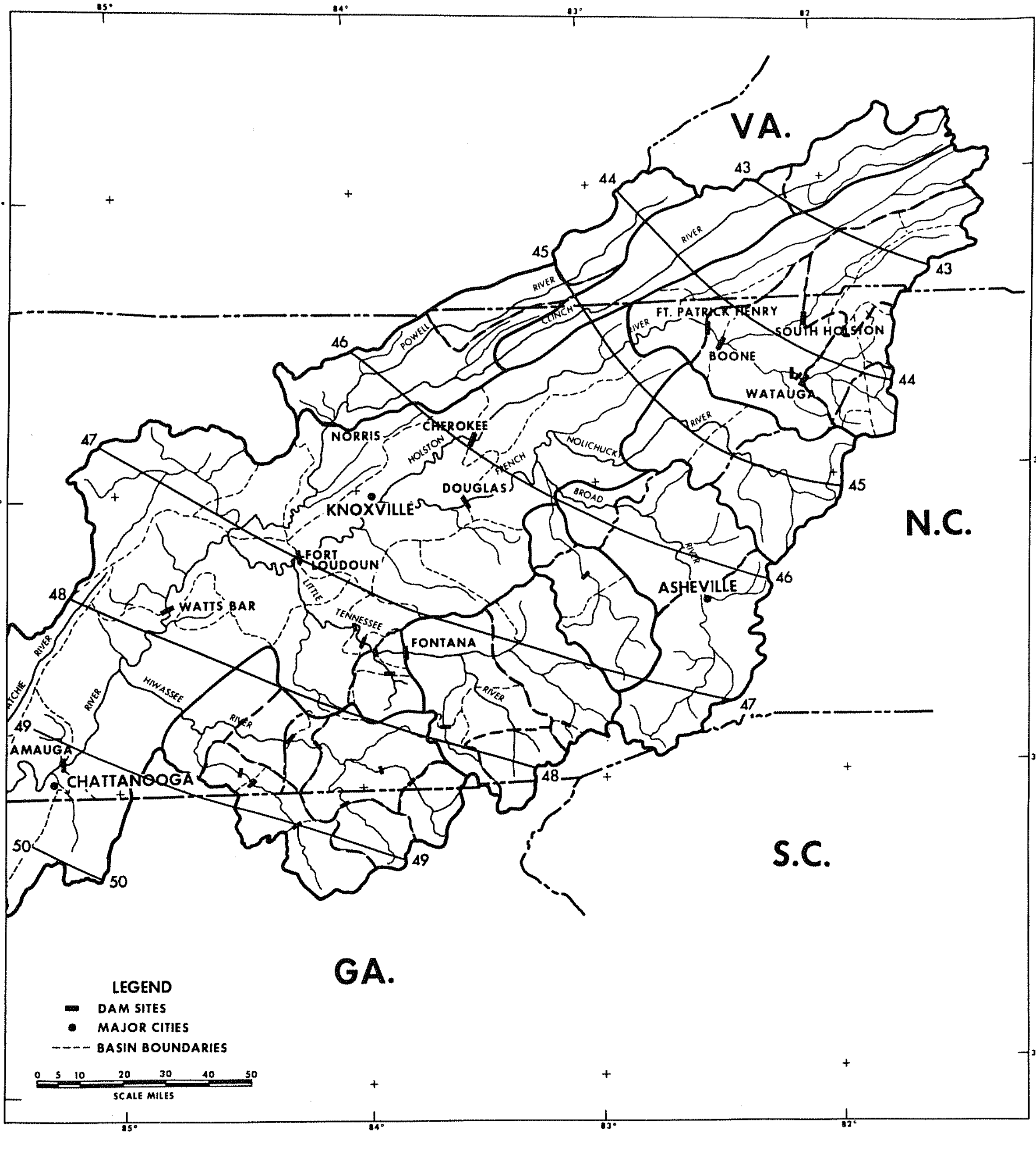


Figure 3-16. Mean annual precipitation (non-orographic) for the eastern Tennessee River watershed (inches)

2-yr. 24-hr. precipitation charts. To derive a 2-yr. 24-hr. precipitation chart, frequency analysis was made of the annual maximum 24-hr. rains for almost 600 stations in and near the Tennessee Basin with 15 years or more of record. Figure 3-17 shows that a 15-yr. record tends to yield results not greatly different from those from a 60-yr. record. An analysis of the 2-yr. 24-hr. values in the eastern portion of the basin is shown in figure 3-18.

Extreme monthly rains in subbasins. Monthly precipitation averages over subbasins, published routinely in "Precipitation in the Tennessee Valley" /3-6/, were also used for evaluating orographic effects. Naturally, subbasins with strongest orographic effects will tend to show highest monthly averages. Figure 3-19 depicts, for the eastern portion of the Tennessee River watershed, the average of the three highest monthly precipitation values during 1955-1965; the months contributing these values are listed in table 3-3. The frequency of October 1964 in the tabulations is emphasized by underlining. The highest individual monthly values are shown in figure 3-20 with the dominance of certain stormy months in contributing these values over certain areas indicated.

Small basin PMP. Another indicator of orographic influence, which to a certain extent makes use of the other indicators, is the 5-sq. mi. 6-hr. PMP (fig. 2-21b) vs. the "smooth" value that would be calculated at the position in the absence of terrain features. This is used as a specific index relation in the generalized procedure to be described.

Optimum wind direction. Over a small basin--a few ten's of square miles--it is presumed that the wind direction most favorable for unobstructed inflow of moist air and for accentuation of lift by ground slope prevails during the PMP or TVA storm. In larger basins, the optimum direction for precipitation may differ from one portion of the basin to another because of varying orientation of principal slopes. The wind direction most critical for the basin as a whole is defined as the direction that is "optimum" over the largest fraction of the basin. A procedure is applied whereby the orographic intensification factor is related to the fraction of the basin for which the overall critical wind direction is also the local optimum. Figure 3-21 showing the optimum moisture inflow direction for local areas is used for this.

Orographic adjustment procedure

Non-orographic PMP and TVA depth-area-duration values are adjusted upward in the mountainous east by a factor depending on the difference between the PMP index chart for 6 hours and 5 square miles and the corresponding calculated non-orographic PMP. The ratio of largest fraction of the basin that has the same optimum wind direction to the total basin area is scaled from figure 3-21 and the orographic intensification factor is related to this ratio by figure 3-22. Figure 3-22 was developed empirically after a number of specific basin estimates were made in the mountainous east (chapter IV). For exact procedures using figure 3-22 see the stepwise outline in section C.

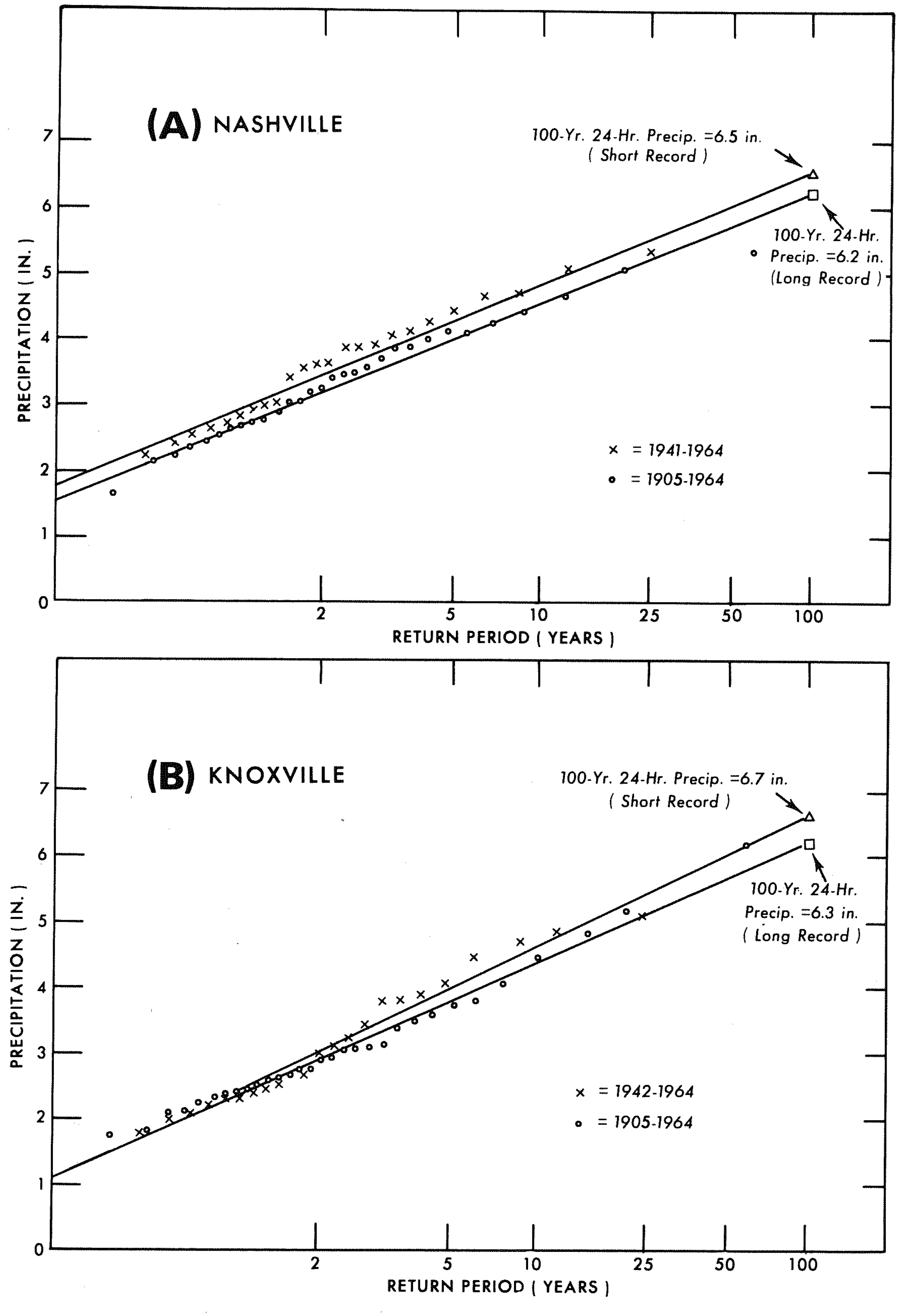


Figure 3-17. Rainfall-frequency curves for (A) Nashville and (B) Knoxville

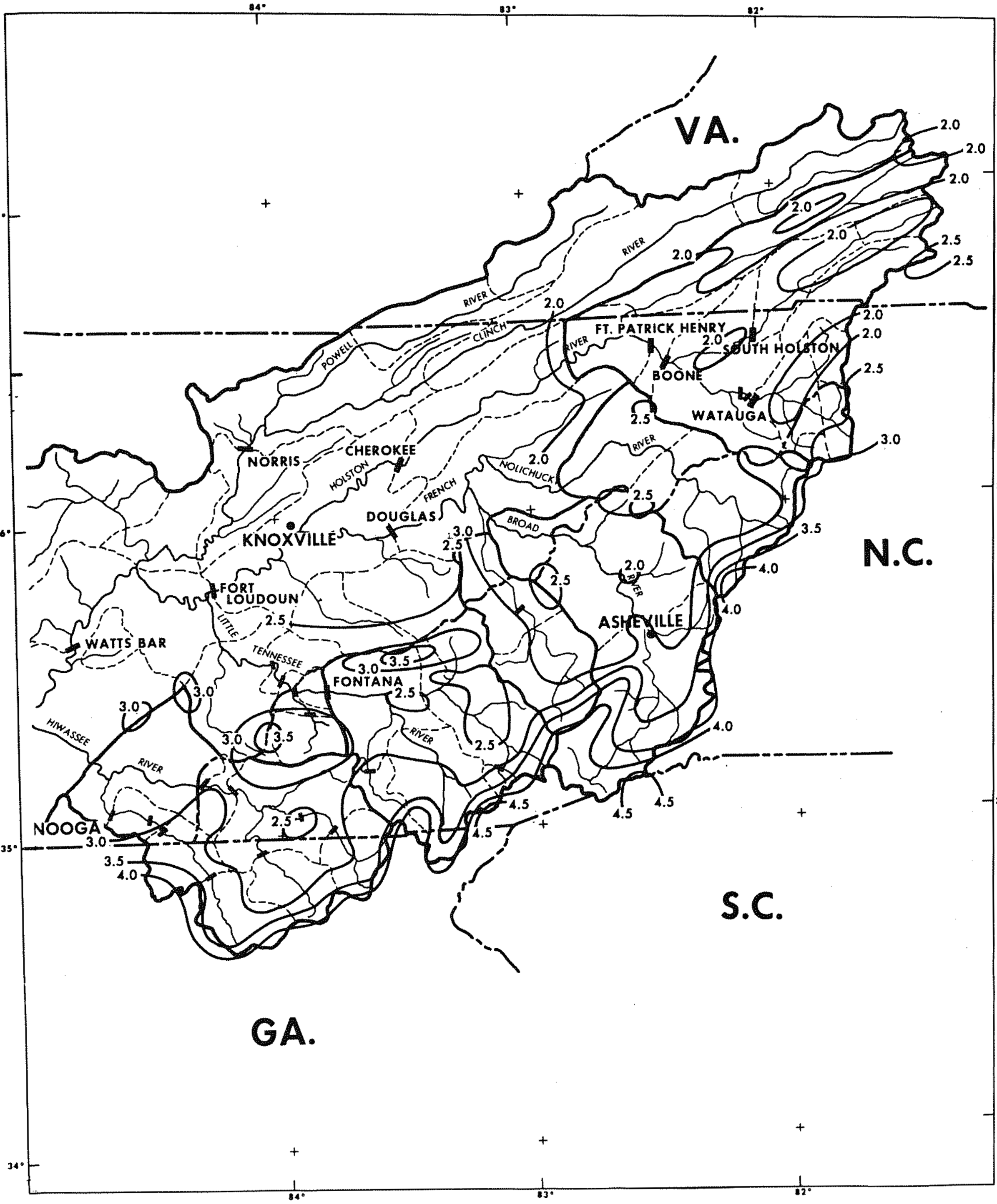


Figure 3-18. 2-Year 24-hr. precipitation (inches)

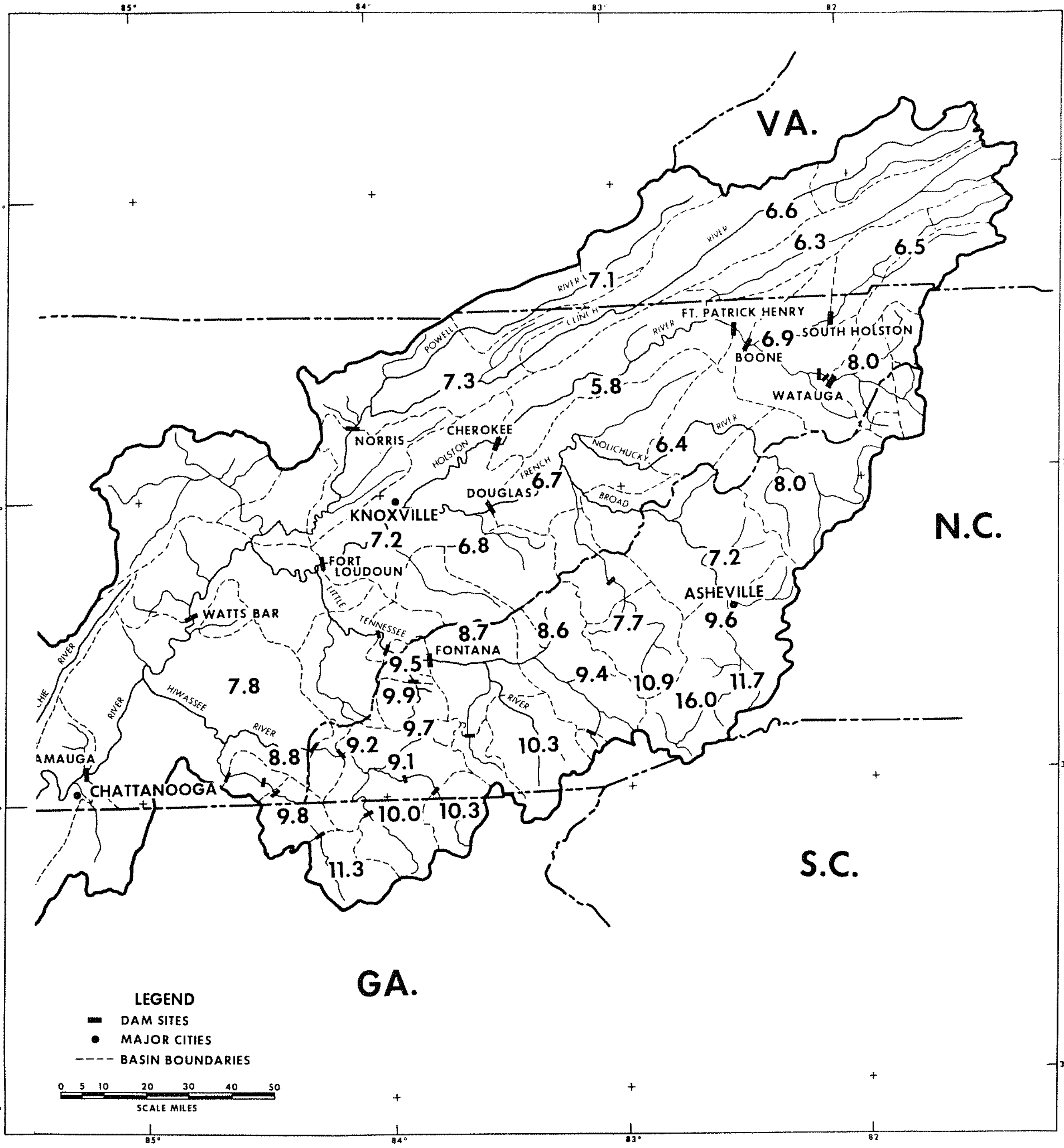


Figure 3-19. Average of highest three months (table 3-3) of subbasin precipitation (inches)

Table 3-3. Dates of Highest Monthly Precipitation Over Mountainous Eastern Zones

(1955-1965)

TVA Zone	Drainage	Highest	2d Highest	3d Highest
40	Hiwassee	Sept. 1937	July 1963	July 1958
41	Ocoee	July 1958	Sept. 1957	Oct. 1964
46	Toccoa	July 1958	Oct. 1964	June 1961
48	Hiwassee	July 1958	Aug. 1964	Aug. 1960
49	Hiwassee	July 1958	Aug. 1960	July 1963
52	Nottely	Oct. 1964	July 1958	June 1963
53A	Hiwassee	July 1958	Oct. 1964	Aug. 1960
54A	Hiwassee	Oct. 1964	Oct. 1959	July 1958
55	Valley	July 1958	July 1963	June 1957
62	Clinch	Sept. 1957	June 1960	July 1965
63	Powell	Sept. 1957	July 1956	June 1957
65	Clinch	Sept. 1957	July 1956	July 1958
67	Tennessee	Sept. 1957	July 1963	July 1958
69	Little Tennessee	July 1963	June 1957	July 1958
70	Little Tennessee	Aug. 1964	July 1963	June 1957
71	Cheoah	July 1963	June 1957	July 1958
72A	Little Tennessee	Aug. 1964	July 1963	July 1958
73	Tuckasegee	July 1958	Aug. 1964	Aug. 1960
74	Tuckasegee	Oct. 1964	Oct. 1959	Aug. 1964
75	Little Tennessee	Oct. 1964	July 1958	Oct. 1959
78	Nantahala	July 1958	Oct. 1964	Oct. 1959
84	French Broad	Aug. 1964	July 1956	June 1957
87	Holston	July 1958	July 1956	Oct. 1959
88	Holston	Sept. 1957	July 1958	June 1957
89	Holston	June 1957	July 1956	July 1958
92	Holston	July 1958	July 1956	Aug. 1957
93	Watauga	July 1956	Aug. 1961	June 1957
99	French Broad	Aug. 1964	July 1958	June 1957
101	Pigeon	Aug. 1964	Oct. 1964	July 1958
105	Pigeon	Sept. 1959	Sept. 1957	Oct. 1964
106	French Broad	Aug. 1964	July 1956	June 1957
110	French Broad	Aug. 1961	Oct. 1964	Sept. 1959
114	French Broad	Aug. 1961	Oct. 1964	Sept. 1959
117	French Broad	Aug. 1961	Oct. 1964	June 1957
120	Nolichucky	July 1956	Aug. 1964	July 1965
121	Nolichucky	Aug. 1961	June 1957	Sept. 1957

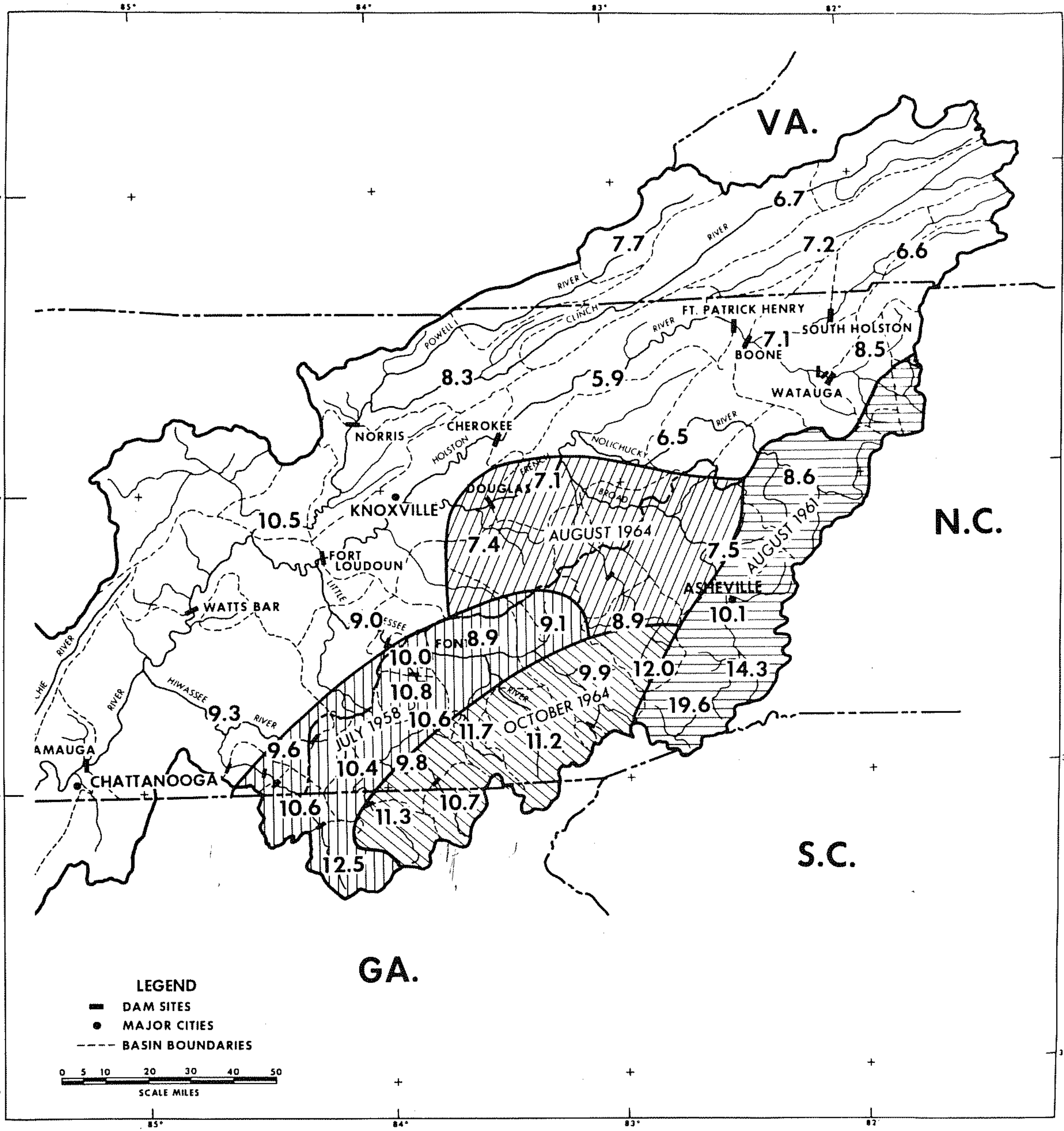


Figure 3-20. Highest month (table 3-3) subbasin amount (inches). Hatched areas show limits of control by specific months

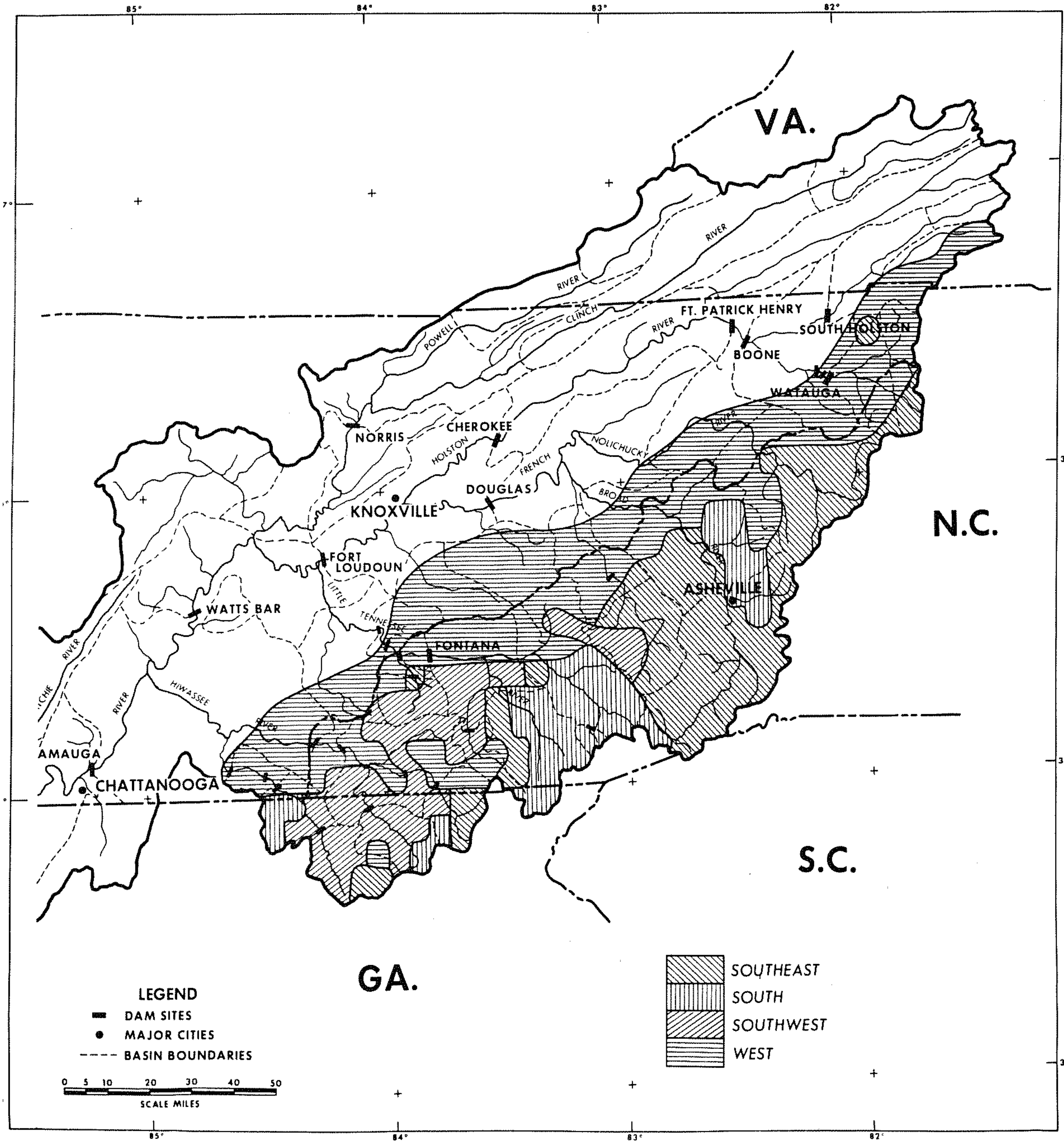


Figure 3-21. Areas controlled by specific wind directions

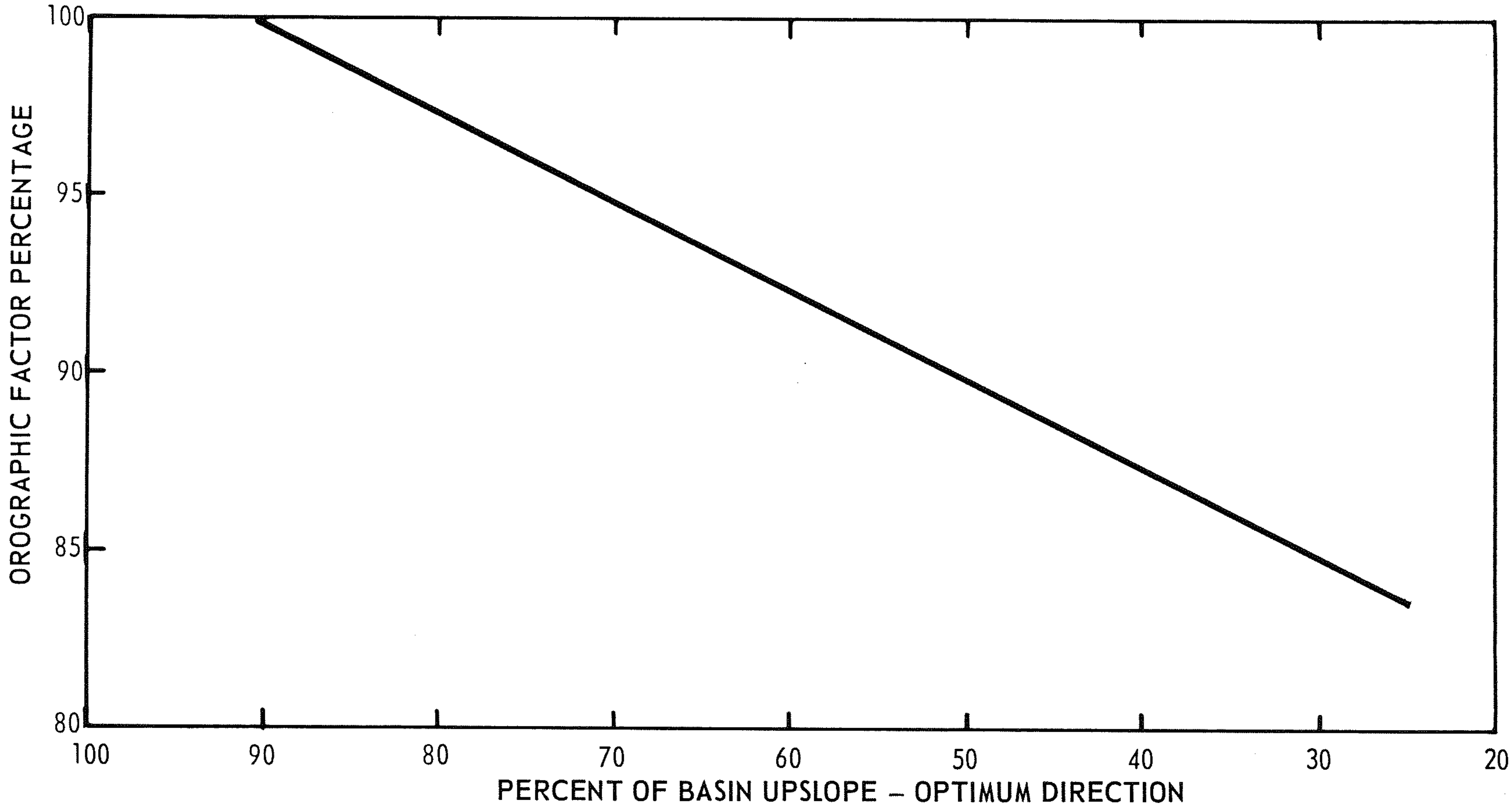


Figure 3-22. Orographic adjustment chart

Areal distribution

The relationships up to this point define the volume of PMP or TVA precipitation within a specified size of area, for various durations. Here we take up the question of the distribution of this volume within the basin.

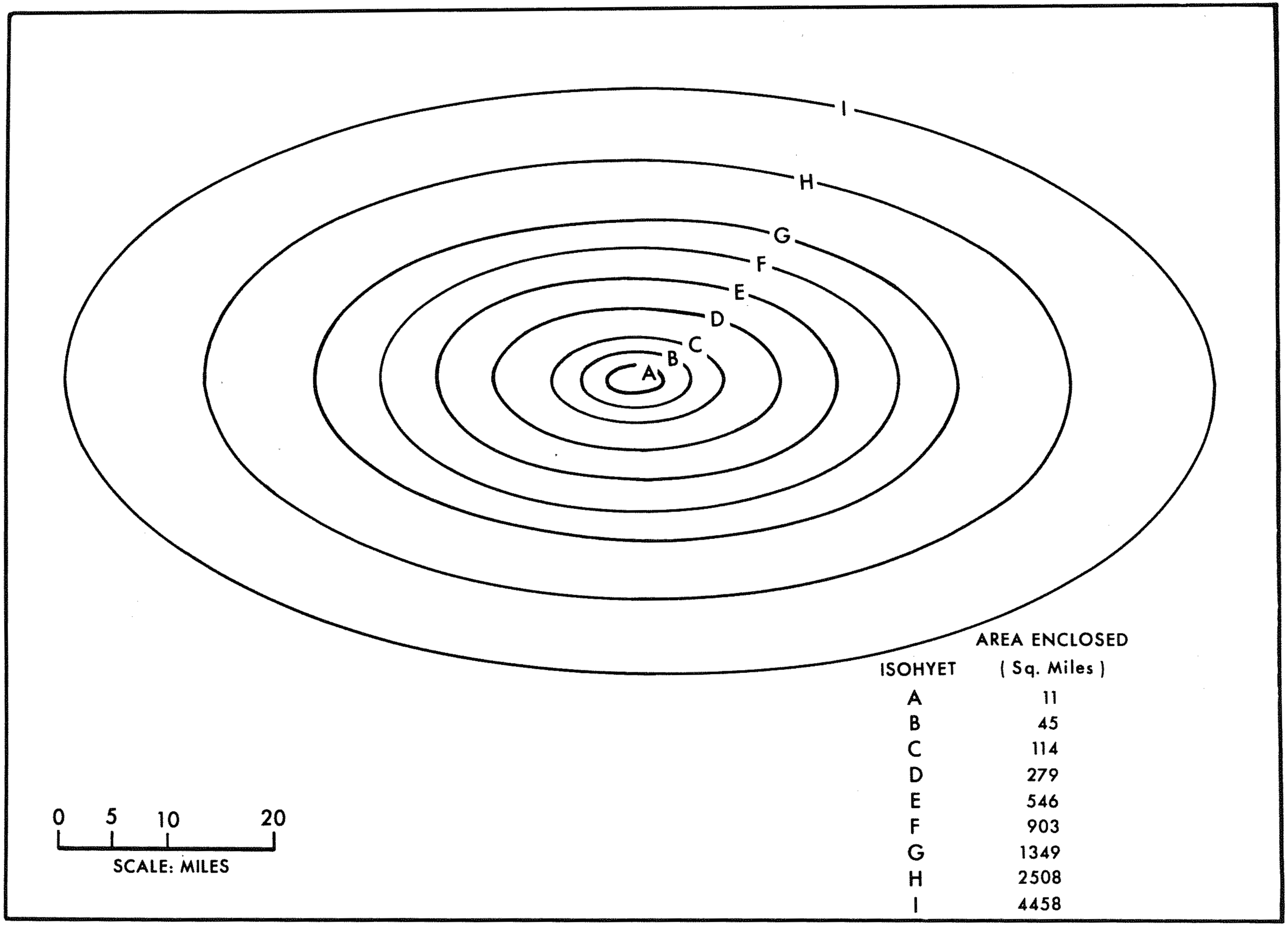
West. The elliptical isohyetal pattern of figure 3-23 represents typical concentrations and is recommended for all western basins. The pattern is aligned with the orientation that most closely fits the basin. Isohyetal labels for the first, second and third 6-hr. increments (that is, heaviest three 6-hr. increments) of a PMP or TVA storm can be obtained from figures 3-24 through 3-26. These relationships were developed from nomograms for isohyet values in pattern storms from figures 16b, 16c, and 16d of HMR 40 /3-7/.

The intent of these nomograms is to give the prescribed PMP or TVA 6-hr. volume within an ellipse equal in area to the basin under investigation. The noncoincidence of this ellipse with the basin outlined leads to a "basin-shape factor," that is, a slight reduction of the volume of rain within the basin because of lack of exact coincidence of the storm pattern with the basin.

Uniform distribution of precipitation without pattern is recommended for the 4th and subsequent 6-hr. volumes, as in HMR 40 /3-7/.

East. Basins in the mountainous east require an areal distribution of precipitation that retains the fixed orographic control. It is not possible to set forth a concise set of objective rules for modifying isohyetal patterns to fit all the complicated possibilities. The user should proceed as follows. Align the standard pattern of figure 3-23 along the basin. Modify the isohyets to show heavier precipitation on favorable slopes and, perhaps, also modify some isohyets downward in shielded locations or along desiccating downslopes. For guides in this modification use the 2-yr. 24-hr. precipitation map (fig. 3-18), and other maps in this chapter illustrating orographic influences, selected storms (see table 3-3 for possible dates), and a topographic chart.

The isohyetal labels from figures 3-24 to 3-26 are then applied tentatively to modified isohyets for the 1st, 2d, and 3d 6-hr. increments of PMP or TVA precipitation. The basin volume rainfall is calculated from these tentative values, and compared with total basin volume rainfall by 6-hr. increments that have already been determined by geographical and topographical (fig. 3-22) modification of the basic depth-area-duration values. The tentative isohyetal labels are then multiplied by the ratio of the two values, thus adjusting the isohyetal labels to the required basin volume. (In this procedure there is no reduction for basin-shape factor. The particularized treatment of each basin is thought to make this inappropriate). For the 4th and subsequent 6-hr. PMP and TVA increments, uniform distribution, while not strictly realistic, will in general give adequate



ISOHYET	AREA ENCLOSED (Sq. Miles)
A	11
B	45
C	114
D	279
E	546
F	903
G	1349
H	2508
I	4458

Figure 3-23. Generalized pattern storm

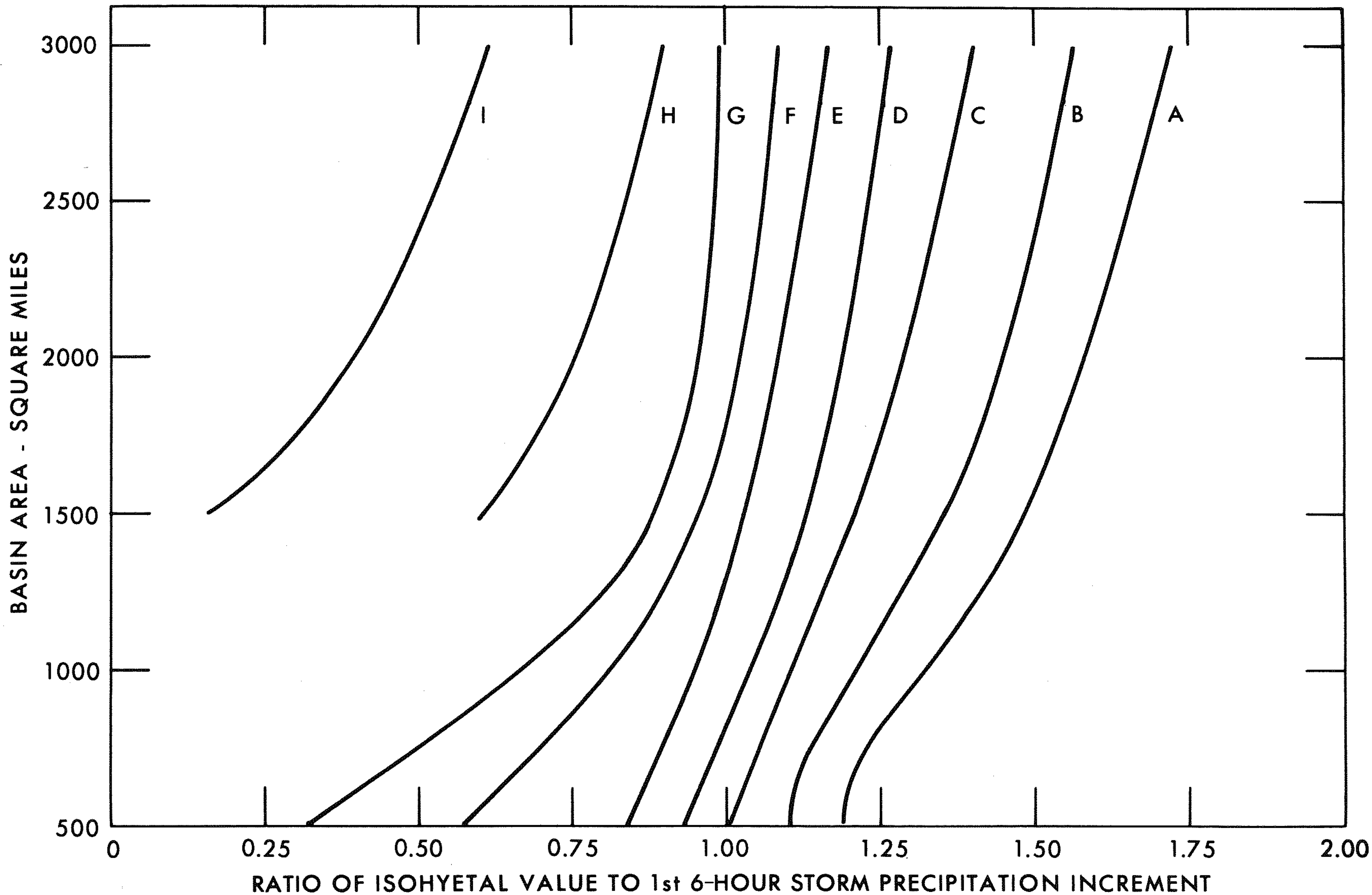


Figure 3-24. Nomogram for isohyet values in pattern storms - 1st 6-hr. increment

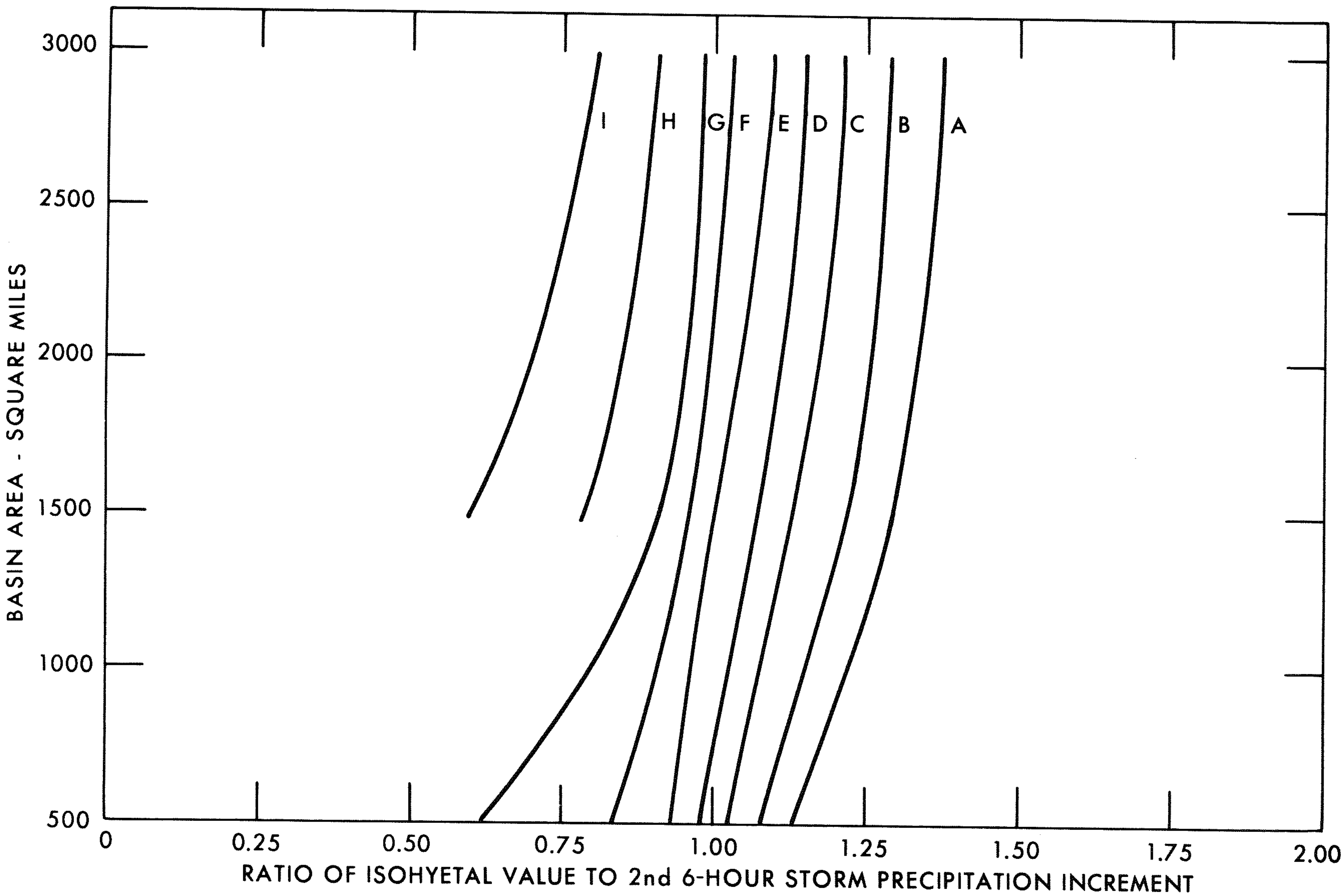


Figure 3-25. Nomogram for isohyet values in pattern storms - 2d 6-hr. increment

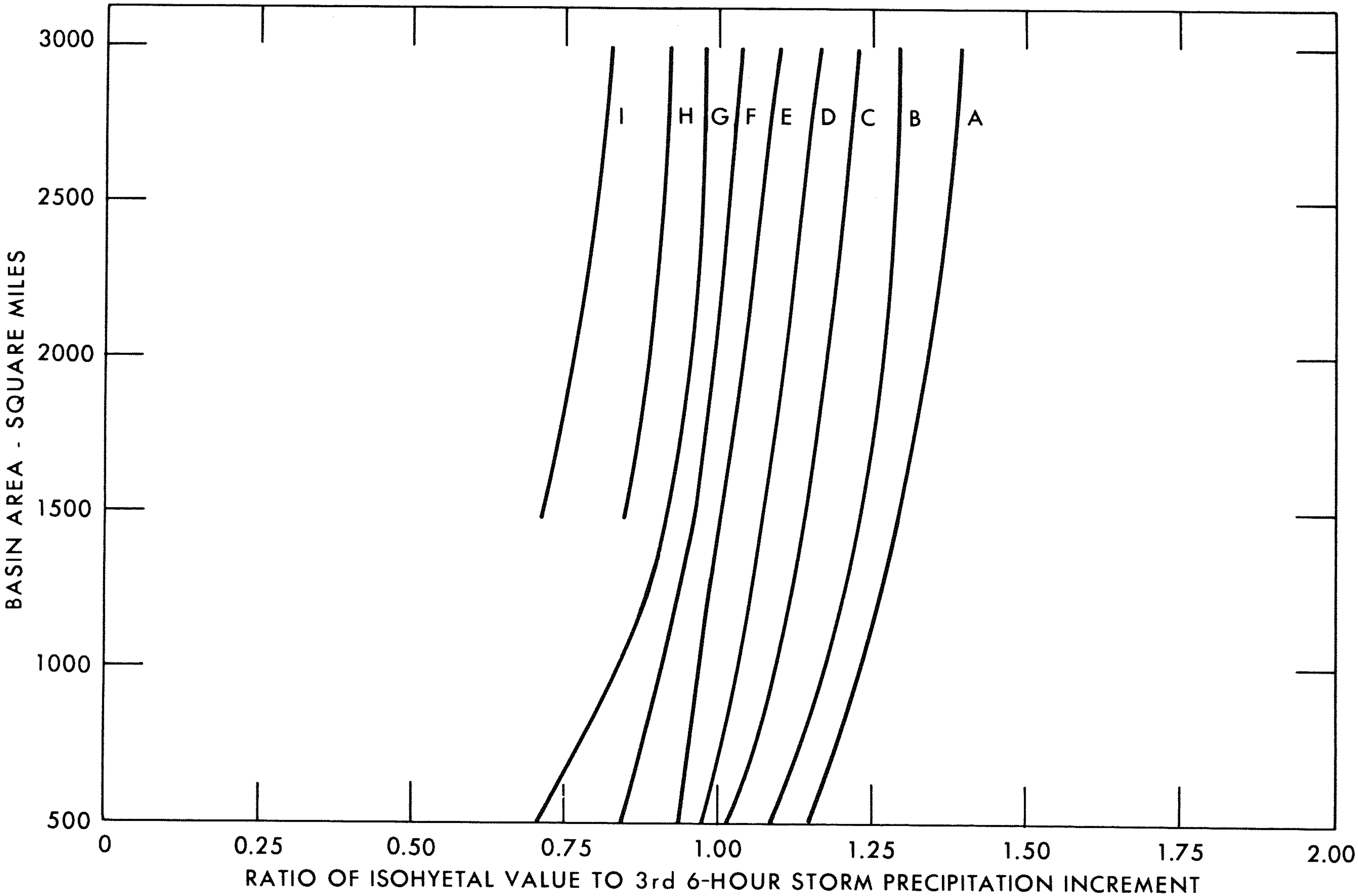


Figure 3-26. Nomogram for isohyet values in pattern storms - 3d 6-hr. increment

hydrograph definition. If desired, these increments could be distributed in proportion to the mean annual chart (fig. 3-15) without reference to the elliptical pattern.

Time distribution

In arranging 6-hr. PMP or TVA increments in a chronological sequence, the user should adhere to the rules below:

1. Group the four heaviest 6-hr. increments of the 72-hr. storm in a 24-hr. sequence, the middle four increments in a 24-hr. sequence, and the smallest four increments in a 24-hr. sequence.

2. Arrange the three 24-hr. sequences with the second highest 24-hr. period next to the highest with the third at either end. Any of the possible combinations of the three 24-hr. periods is acceptable with the exception of placing the lightest 24-hr. period in the middle.

3. The 6-hr. increments are to be arranged within a 24-hr. period such that the highest two and the highest three 6-hr. increments are adjoined.

C. EXAMPLE OF PMP AND TVA PRECIPITATION ESTIMATES FOR A BASIN BETWEEN 100 AND 3000 SQUARE MILES

Western and central Tennessee watershed

The required charts for the PMP computations are:

1. An outline of the basin.
2. Figure 3-11 or 3-12 depth-area-duration values for probable maximum or TVA precipitation at Knoxville.
3. Figure 3-13 and 3-14, 24-hr. 1000-sq. mi. PMP and TVA percentages of values at Knoxville.
4. Figure 3-23, generalized pattern storm.
5. Figure 3-24 to 3-26, nomograms for isohyetal values in pattern storm for 1st, 2d and 3d 6-hr. increments.
6. Figure 3-27, areal relationship between maximum 3-hr. PMP increment and 6-hr. PMP increment.

Steps

Step A. Scale 6-, 12-, 18-, 24-, 48-, and 72-hr. values at basin size from figure 3-11 (for PMP) or figure 3-12 (for TVA storm).

Step B. Read percent at center of basin from figure 3-13. Multiply values of step A by this percent.

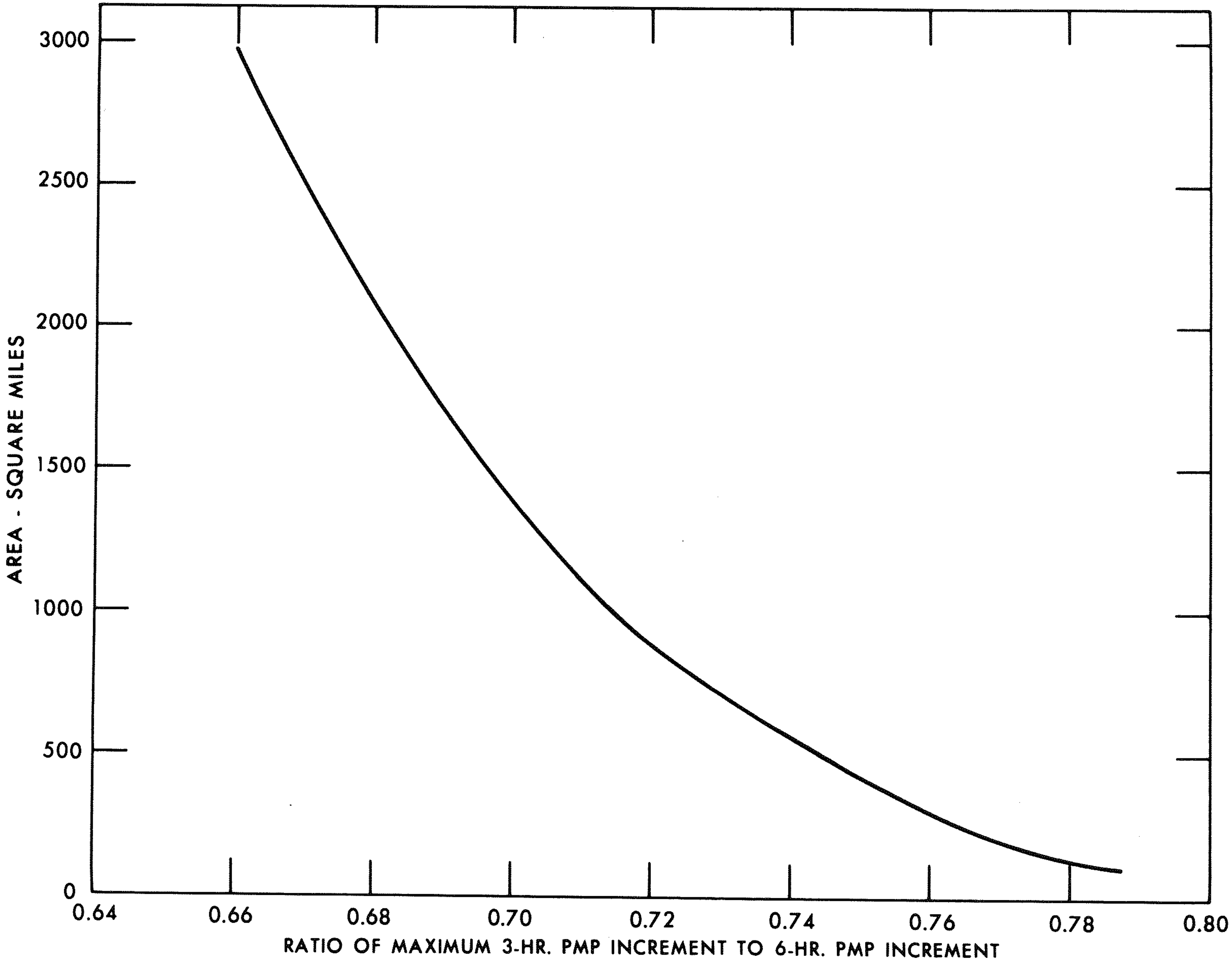


Figure 3-27. Areal relationships between maximum 3-hr. PMP increment and 6-hr. PMP increment

Step C. Construct smooth depth-duration curve from the values of step B. By subtraction, read off 6-hr. increments to 72 hours.

Step D. Place standard isohyetal pattern, figure 3-23, in position that best fits basin.

Step E. Obtain labels for isohyets for 1st 6-hr. period by entering figure 3-24 with basin size and reading off ratios. Multiply step C values for 1st 6 hours by these ratios. Similarly treat 2d and 3d 6-hr. periods with ratios from figures 3-25 and 3-26.

Step F. For remaining 6-hr. periods, use step C values directly as uniform depths throughout the basin.

Step G. Arrange the 6-hr. increments in a chronological sequence as specified earlier in the text.

Mountainous east

The required charts are:

1. An outline of the basin.
2. Figure 3-11 or 3-12 depth-area-duration values for probable maximum or TVA precipitation at Knoxville.
3. Figures 2-21b and 2-22b, 6-hr. 5-sq. mi. PMP and TVA precipitation.
4. Figure 3-21, areas controlled by particular wind directions.
5. Figure 3-22, orographic adjustment graph.
6. Figure 3-23, generalized pattern storm.
7. Figures 3-24 through 3-26, nomograms for isohyetal values in pattern storms during 1st, 2d and 3d 6-hr. increments.
8. Figure 3-27, areal relationship between maximum 3-hr. PMP increment and 6-hr. PMP increment.

PMP

The calculations for a hypothetical basin are depicted in table 3-4.

Step A. Determine the basin area. Using this area read from figure 3-11 the nonadjusted PMP values for durations from 6 hours to 72 hours. Record on line A of table 3-4.

Step B. Determine the location adjustment factor for the center of the basin from figure 3-14. Record this value on line B.

Step C. Multiply line A by line B, giving the geographically adjusted PMP values.

Step D. Lay out the basin outline on figure 2-21b and determine the average 6-hr. 5-sq. mi. PMP from the figure. Record this value on line D.

Table 3-4. Sample Computation of PMP and TVA Precipitation Estimates For Hypothetical Basin in Mountainous Eastern Region

Line	Item and Source	6	12	18	24	36	48	60	72	
		(Duration hr.)								
A	Unadjusted PMP (fig. 3-11)	16.1	19.2	21.3	23.2		25.3		28.5	
B	Adjustment for location (fig. 3-14)	0.99	0.99	0.99	0.99		0.99		0.99	
C	Basin PMP, unadjusted for terrain (line A x line B)	15.9	19.0	21.1	23.0		25.0		28.2	
D	6-hr. 5-sq. mi. PMP (fig. 2-21B)	28.0	28.0	28.0	28.0		28.0		28.0	
E	Non-orographic 6-hr. 5-sq. mi. PMP = 25.0 in. (PMP) at southern edge of TVA area x 0.94 Broad-scale sheltering factor (fig. 2-17 and 2-20) 23.5 in. (smooth 6-hr. 5-sq. mi. at Knoxville) x 0.99	23.5	23.5	23.5	23.5		23.5		23.5	
F	Orographic factor (line D ÷ line E)	1.19	1.19	1.19	1.19		1.19		1.19	
G	Percent of basin exposed to optimum wind direction (fig. 3-21)	47	47	47	47		47		47	
H	Orographic factor percentage (fig. 3-22)	.88	.88	.88	.88		.88		.88	
I	Line F x line H	1.05	1.05	1.05	1.05		1.05		1.05	
J	Basin PMP (line C x line I)	16.8	20.0	22.2	24.2		27.3		29.7	
					72-hr. TVA Storm					
S	72-hr. TVA precipitation (line J x 0.60)	-	-	-	-	-	-	-	17.8	
T	Precipitation in 72-hr. TVA storm (fig. 2-36)	7.1	10.1	12.4	13.7	15.4	16.4	17.3	17.8	
					24-hr. TVA Storm					
U	Duration (hr.)	1	2	3	4	5	6	12	18	24
V	24-hr. TVA precipitation (line J x 0.60)	-	-	-	-	-	-	-	-	14.5
W	Precipitation in 24-hr. TVA storm (fig. 2-35	3.3	4.9	6.0	6.8	7.5	8.1	11.0	13.0	14.5

Step E. To obtain the required "smooth" hypothetical 6-hr. 5-sq. mi. PMP at the center of the basin proceed as follows. The latitudinal gradient of 5-sq. mi. PMP is very nearly the same as of 24-hr. 1000-sq. mi. PMP. Use tne percentage factor at the center of the basin from figure 3-14 read in step B. Multiply 23.5 inches (the "smooth" 6-hr. 5-sq. mi. PMP at Knoxville)* by this percentage and record on line E.

Step F. Divide the value on line D by the value on line E. Record this value on line F. This is the unadjusted orographic factor.

Step G. Using figure 3-21, determine the percent of the basin which has a common optimum wind direction. Record this value on line G.

Step H. Enter figure 3-22 with the percent from line G and read out the corresponding "orographic factor percentage." Record on line H.

Step I. Multiply line F by line H and record on line I. This is the net orographic factor.

Step J. List the products of line C and the net orographic adjustment factor (line I) on line J. These values are the accumulated orographic PMP values for the given basin.

Step K. Plot the values of line J as a depth-duration curve, construct a smooth curve, and read off 6-hr. (or other desired) increments. Record on line K. (The remaining steps are not shown in table 3-4).

Step L. Align isohyetal pattern of figure 3-23 on basin. Modify shapes of isohyets for topographic influences as described in text.

Step M. Enter figure 3-24 with area of basin and read out ratios that apply to the isohyets.

Step N. Multiply 6-hr. PMP from line J by the respective ratios, obtaining tentative isohyetal labels. Determine average precipitation within the basin using these tentative labels in the placement selected in step L.

Step O. Take ratio of basin average precipitation from step N to computed 6-hr. value on line J. Multiply tentative isohyetal labels (step M) by this ratio. This gives final isohyetal labels for heaviest 6 hours of PMP.

*The 23.5 inches is equal to 25.0 inches ("smooth" value at 100 percent line of figure 2-17) times 0.94 which is adjustment for Knoxville based on figures 2-17 and 2-20.

Step P. Repeat the above adjustment process for the 2d and 3d 6-hr. increments, reading ratios from figure 3-25 and 3-26 and adjusted to calculated 6-hr. increments on line K. The remaining 6-hr. increments are used as uniform depths over the basin or are distributed in proportion to the mean annual precipitation chart, figure 3-15.

Step Q. Arrange 6-hr. increments in a critical chronological sequence, following the principles designated at the end of section B of this chapter.

Step R. The maximum 3-hr. increments can be obtained by using the maximum 6-hr. increment in figure 3-27.

Steps for TVA precipitation

The steps to calculate the TVA precipitation are the same as for the PMP except that TVA index charts and depth-duration are substituted for PMP index charts. See bottom of table 3-4 for example when PMP has already been computed.

Chapter IV

SPECIFIC BASIN ESTIMATES FOR PMP AND TVA PRECIPITATION

Introduction

The material in this chapter includes PMP and TVA precipitation estimates for 28 specific basins with areas greater than 100 square miles. Figure 4-1 shows the 23 of these that are in the eastern part of the basin. Discussions of the estimates are grouped geographically. A description of the related topography can be found in chapter I.

Non-orographic PMP and TVA values are derived for each basin by the procedure of chapter III. Special considerations are then applied to each basin to derive the orographic adjustment to these values. Most of the text of this chapter is devoted to explaining these adjustments. The single generalized procedure of chapter III would yield orographic adjustments close to but not identical with those worked out here for each basin.

Finally, a topographically adjusted isohyetal pattern is derived for each basin. The principal guide to topographic variations for this is the 2-yr. 24-hr. precipitation analysis of figure 3-18. These patterns apply primarily to the heaviest three 6-hr. periods of the storm. Uniform rain depth is recommended for the lighter 4th thru 12th periods of the 72-hr. storm.

A. HIWASSEE RIVER DRAINAGE

Adopted values

Subbasins 1, 2, 3, 4, 5, 6 and 6A of the Hiwassee River drainage are shown in figure 4-1. They range in size from 189 square miles to 2189 square miles. PMP and TVA precipitation estimates for the seven subbasins are shown in table 4-1 (A) by average depths for the indicated durations.

Orographic intensification was incorporated in the final values. This was estimated primarily by comparing 6-hr. 5-sq. mi. PMP with "non-orographic" 6-hr. 5-sq. mi. PMP, and mean annual precipitation with the mean annual "non-orographic" precipitation (table 4-2). The basis for these comparisons is given in chapter III.

A 10-percent orographic increase was used over subbasin 1, the Hiwassee River drainage above Charleston and subbasin 2, the Hiwassee River drainage above Austral. This is less than the comparative ratios mentioned above (table 4-2) and allows for the fact that the northeast and central interior of the subbasins are, in general, sheltered.

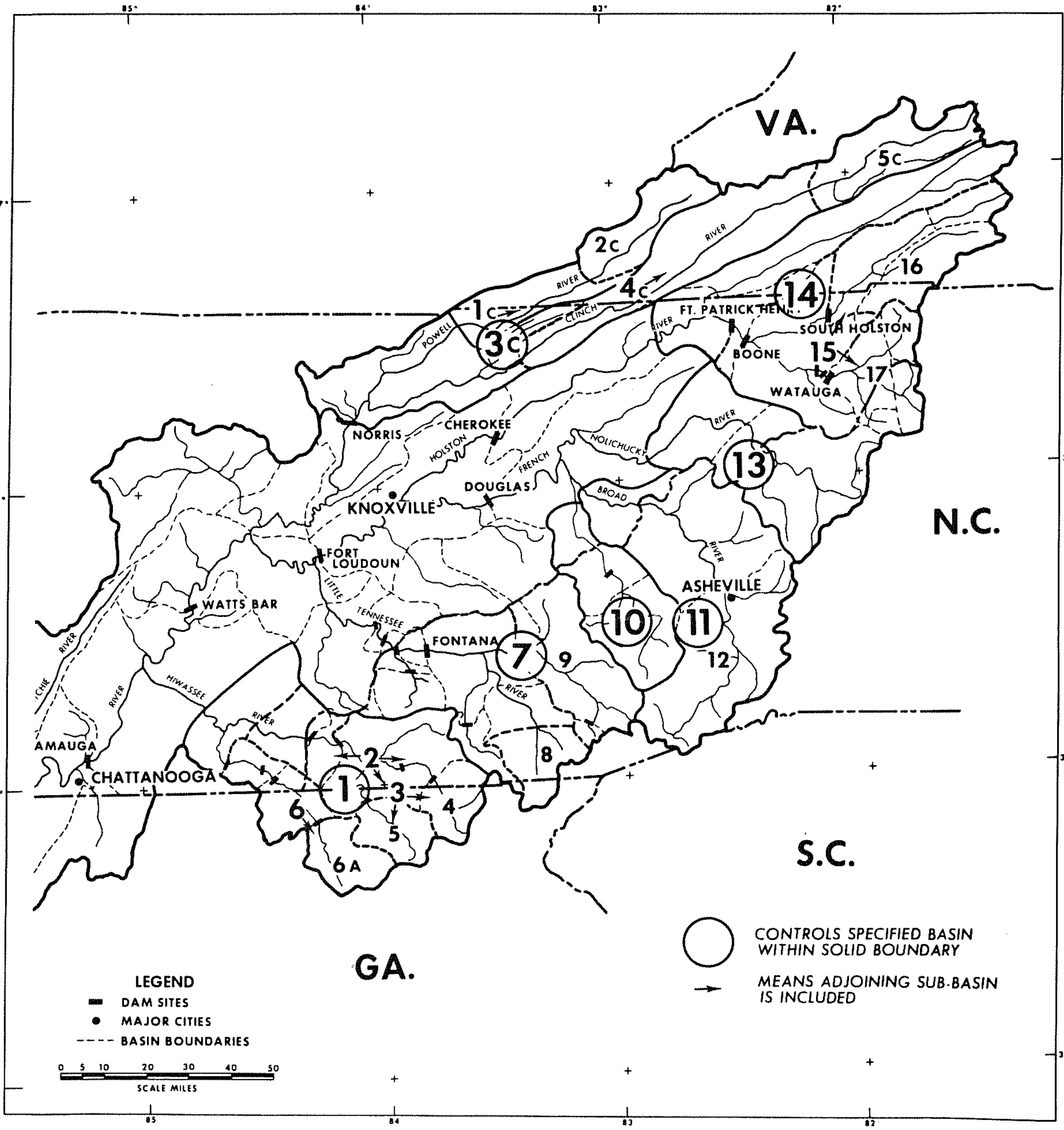


Figure 4-1. Subbasin locations

Table 4-1. Accumulated PMP and TVA Precipitation (in.)

A. Hiwassee River Drainages

Subbasin	Precip. Type	Duration (hr.) 6	12	18	24	30	36	42	48	54	60	66	72
Hiwassee R. above Charleston, Tenn.	PMP	12.8	16.0	18.5	20.2	21.4	22.4	23.3	24.0	24.7	25.3	25.9	26.4
(Subbasin 1, fig. 4-2) 2189 sq.mi.	72-hr. TVA	6.2	9.0	11.0	12.2	13.0	13.6	14.1	14.6	15.0	15.3	15.6	15.8
Hiwassee R. above Austral, Tenn.	PMP	14.7	18.2	20.7	22.6	23.7	24.6	25.4	26.2	26.9	27.5	28.1	28.6
(Subbasin 2, fig. 4-2) 1228 sq. mi.	72-hr. TVA	6.8	9.8	11.9	13.3	14.1	14.8	15.4	15.9	16.3	16.7	17.0	17.2
Hiwassee R. above Hiwassee Dam, Tenn.	PMP	15.5	18.9	21.4	23.3	24.4	25.4	26.3	27.0	27.7	28.3	28.9	29.4
(Subbasin 3, fig. 4-3) 968 sq. mi.	72-hr. TVA	7.0	10.0	12.2	13.6	14.5	15.2	15.8	16.2	16.6	17.0	17.3	17.6
Hiwassee R. above Chatuge Dam, N. C.	PMP	24.4	28.4	31.4	33.8	35.3	36.4	37.4	38.3	39.0	39.7	40.4	41.0
(Subbasin 4, fig. 4-3) 189 sq. mi.	24-hr. TVA	11.2	15.2	18.0	20.3								
	72-hr. TVA	9.8	14.0	17.1	19.0	20.3	21.3	22.0	22.6	23.2	23.8	24.2	24.6
Nottely R. above Nottely Dam, Ga.	PMP	23.0	27.2	29.9	32.3	33.7	34.8	35.8	36.6	37.3	38.0	38.6	39.2
(Subbasin 5, fig. 4-3) 214 sq. mi.	24-hr. TVA	10.8	14.7	17.4	19.4								
	72-hr. TVA	9.4	13.4	16.3	18.1	19.3	20.3	21.0	21.6	22.2	22.7	23.2	23.5
Ocoee R. above Ocoee Dam #1, Tenn.	PMP	18.8	22.6	25.2	27.5	28.8	29.9	30.8	31.6	32.4	33.1	33.7	34.3
(Subbasin 6, fig. 4-3) 595 sq. mi.	72-hr. TVA	11.3	13.6	15.1	16.5	17.3	17.9	18.5	19.0	19.4	19.8	20.2	20.6
Toccoa R. above Blue Ridge Dam, Ga.	PMP	23.0	27.2	29.9	32.3	33.7	34.8	35.8	36.6	37.4	38.1	38.7	39.3
(Subbasin 6A, fig. 4-3) 232 sq. mi.	24-hr. TVA	10.8	14.7	17.4	19.4								
	72-hr. TVA	9.4	13.5	16.4	18.2	19.4	20.4	21.1	21.7	22.3	22.8	23.3	23.6

B. Little Tennessee River Drainages

Subbasin	Precip. Type	6	12	18	24	30	36	42	48	54	60	66	72
Little Tennessee R. above Fontana Dam, N. C.	PMP	13.6	16.9	19.2	21.2	22.3	23.2	24.0	24.6	25.2	25.7	26.2	26.6
(Subbasin 7, fig. 4-6) 1571 sq. mi.	72-hr. TVA	6.3	9.0	11.0	12.2	13.0	13.7	14.2	14.6	15.0	15.4	15.7	15.9
Little Tennessee R. above Franklin, N. C.	PMP	22.6	26.7	29.8	32.0	33.4	34.6	35.6	36.4	37.2	37.9	38.6	39.2
(Subbasin 8, fig. 4-6) 295 sq. mi.	24-hr. TVA	10.8	14.8	17.5	19.2								
	72-hr. TVA	9.4	13.5	16.4	18.2	19.4	20.4	21.1	21.7	22.3	22.8	23.2	23.6
Tuckasegee R. above Bryson City, N. C.	PMP	16.3	19.6	22.2	24.0	25.2	26.2	27.1	27.8	28.4	29.0	29.5	30.0
(Subbasin 9, fig. 4-6) 655 sq. mi.	72-hr. TVA	7.2	10.2	12.5	13.9	14.8	15.5	16.1	16.6	17.0	17.4	17.7	18.0

C. Pigeon and French Broad River Drainages

Subbasin	Precip. Type	6	12	18	24	30	36	42	48	54	60	66	72
Pigeon R. above Newport, Tenn.	PMP	16.0	19.2	21.6	22.6	24.7	25.6	26.4	27.2	27.8	28.4	29.0	29.5
(Subbasin 10, fig. 4-8) 666 sq. mi.	72-hr. TVA	7.0	10.1	12.2	13.6	14.5	15.3	15.8	16.3	16.8	17.2	17.5	17.7

Table 4-1.--Continued

C. Pigeon and French Broad River Drainages

Subbasin	Precip. Type	Duration (hr.) 6	12	18	24	30	36	42	48	54	60	66	72
French Broad R. above Newport, Tenn.	PMP	12.8	16.0	18.4	20.2	21.4	22.2	23.0	23.7	24.3	24.9	25.5	26.0
(Subbasin 11, fig. 4-8) 1858 sq. mi.	72-hr. TVA	6.2	8.8	10.8	12.0	12.7	13.4	13.9	14.3	14.7	15.0	15.3	15.6
French Broad R. above Asheville, N. C.	PMP	15.8	19.3	21.8	23.8	25.0	26.0	26.9	27.6	28.3	28.9	29.5	30.0
(Subbasin 12, fig. 4-12) 945 sq. mi.	72-hr. TVA	7.2	10.2	12.5	13.9	14.8	15.5	16.0	16.5	17.0	17.4	17.7	18.0

D. Holston and Nolichucky River Drainages

Subbasin	Precip. Type	6	12	18	24	30	36	42	48	54	60	66	72
Nolichucky R. above Nolichucky Dam, Tenn.	PMP	13.9	17.1	19.4	21.2	22.3	23.2	24.0	24.8	25.4	26.0	26.5	27.0
(Subbasin 13, fig. 4-14) 1183 sq. mi.	72-hr. TVA	6.4	9.2	11.2	12.4	13.2	13.9	14.4	14.9	15.3	15.6	15.9	16.2
Holston R. above Surgoinsville, Tenn.	PMP	9.7	12.5	14.5	16.1	17.3	18.3	19.1	19.9	20.4	20.7	20.9	21.0
(Subbasin 14, fig. 4-15) 2874 sq. mi.	72-hr. TVA	5.0	7.1	8.7	9.7	10.3	10.8	11.2	11.6	11.9	12.2	12.4	12.6
Holston R. above Fort Patrick Henry, Tenn.	PMP	11.0	13.7	15.7	17.4	18.3	19.1	19.8	20.4	20.9	21.4	21.9	22.3
(Subbasin 15, fig. 4-16) 1903 sq. mi.	72-hr. TVA	5.2	7.6	9.2	10.3	11.0	11.5	12.0	12.3	12.6	12.9	13.2	13.4
Holston R. above South Holston Dam, Tenn.	PMP	14.0	17.2	19.3	21.0	22.1	23.0	23.8	24.4	25.0	25.5	26.0	26.4
(Subbasin 16, fig. 4-17) 703 sq. mi.	72-hr. TVA	6.2	9.0	11.0	12.2	13.0	13.6	14.2	14.6	15.0	15.3	15.6	15.8
Watauga R. above Watauga Dam, Tenn.	PMP	17.2	20.6	22.9	24.8	26.0	27.1	27.9	28.6	29.3	29.9	30.4	30.9
(Subbasin 17, fig. 4-17) 468 sq. mi.	72-hr. TVA	7.4	10.6	12.8	14.3	15.2	16.0	16.6	17.1	17.5	17.9	18.2	18.5

E. Clinch River Drainages

Subbasin	Precip. Type	6	12	18	24	30	36	42	48	54	60	66	72
Powell R. above Arthur, Tenn.	PMP	12.9	15.6	17.6	19.1	20.0	20.8	21.4	22.0	22.5	23.0	23.4	23.8
(Subbasin 1C, fig. 4-1) 685 sq. mi.	72-hr. TVA	5.6	8.1	9.9	11.0	11.8	12.3	12.8	13.2	13.5	13.8	14.1	14.3
Powell R. above Jonesville, Tenn.	PMP	14.2	16.7	18.7	20.2	21.1	21.9	22.6	23.1	23.6	24.1	24.5	24.9
(Subbasin 2C, fig. 4-1) 319 sq. mi.	72-hr. TVA	5.9	8.4	10.3	11.5	12.3	12.9	13.4	13.8	14.1	14.4	14.7	14.9
Clinch R. above Norris Dam, Tenn.	PMP	9.0	11.8	13.5	15.1	16.0	16.7	17.4	17.9	18.4	18.9	19.4	19.8
(Subbasin 3C, fig. 4-1) 2912 sq. mi.	72-hr. TVA	4.6	6.7	8.2	9.1	9.8	10.2	10.5	10.8	11.1	11.4	11.7	11.9
Clinch R. above Tazewell, Tenn.	PMP	10.8	13.5	15.4	17.0	17.7	18.3	18.9	19.5	20.1	20.6	21.1	21.6
(Subbasin 4C, fig. 4-1) 1474 sq. mi.	72-hr. TVA	5.1	7.3	8.9	9.9	10.6	11.1	11.5	11.9	12.2	12.5	12.7	12.9
Clinch R. above Cleveland, Tenn.	PMP	12.9	15.5	17.3	18.8	19.8	20.6	21.2	21.7	22.2	22.6	23.0	23.4
(Subbasin 5C, fig. 4-1) 528 sq. mi.	72-hr. TVA	5.5	8.0	9.7	10.8	11.5	12.0	12.5	12.9	13.3	13.6	13.8	14.0

Table 4-1.--Continued

F. Western Basins

Subbasin	Precip. Type	Duration (hr.) 6	12	18	24	30	36	42	48	54	60	66	72
Duck R. Drainage	PMP	14.4	18.1	19.8	21.1	22.1	22.9	23.6	24.3	24.9	25.4	25.8	26.2
1208 sq. mi. (fig. 4-18)	72-hr. TVA	8.9	11.2	12.4	13.1	13.7	14.2	14.6	15.0	15.4	15.7	16.0	16.2
Emory R. Drainage	PMP	15.9	19.9	21.8	23.2	24.3	25.2	26.0	26.7	27.4	28.0	28.4	28.8
798 sq. mi. (fig. 4-18)	72-hr. TVA	9.9	12.3	13.5	14.4	15.1	15.6	16.1	16.6	17.0	17.3	17.6	17.8
Obed R. Drainage	PMP	17.0	21.3	23.4	24.9	26.0	27.0	27.8	28.6	29.4	30.0	30.4	30.8
518 sq. mi. (fig. 4-18)	72-hr. TVA	10.5	13.2	14.5	15.4	16.1	16.7	17.2	17.7	18.2	18.6	18.9	19.1
Caney Fork Drainage	PMP	13.0	16.7	19.1	20.8	21.8	22.6	23.4	24.0	24.5	25.0	25.5	25.9
1640 sq. mi. (fig. 4-19)	72-hr. TVA	8.0	10.3	11.8	12.9	13.5	14.1	14.5	14.9	15.2	15.5	15.8	16.0

Over subbasin 3, the Hiwassee River drainage above Hiwassee Dam, a 15-percent orographic increase was applied. Although both the mean annual precipitation and the 6-hr. 5-sq. mi. PMP orographic factor indicate greater increases, the limitation on moisture due to barriers over a major portion of the subbasin suggested a lesser orographic adjustment.

In the case of subbasin 4, the Hiwassee River drainage above Chatuge Dam, a 30-percent orographic increase was used. A 25-percent orographic increase was used over both subbasin 5, the Nottely River drainage above Nottely Dam and subbasin 6A, the Toccoa River drainage above Blue Ridge Dam. These adjustments are supported by the 6-hr. 5-sq. mi. estimates and the ratios of the mean annual precipitation to the mean "non-orographic" precipitation (table 4-2). A 25-percent orographic increase in PMP and TVA precipitation is justified on the basis of the topography, moisture source, and winds favoring major storms similar to those for subbasin 6A. Therefore, an orographic adjustment over subbasin 5 equal to that for subbasin 6A is adopted. The fact that southeast winds could influence subbasins 4, 5 and 6A during a rainstorm provides additional support for the orographic adjustments used.

A 20-percent orographic increase was applied over subbasin 6, the Ocoee River drainage above Ocoee Dam #1. This adjustment, which is smaller than both the mean annual precipitation and the 6-hr. 5-sq. mi. PMP orographic factors indicated, was used because the orographic effect is coincident with the upslope and spillover areas which comprise at least half of the subbasin.

Areal distribution

The adopted isohyetal patterns for subbasins 1, 2, 3, 4, 5, 6, and 6A are shown in figures 4-2 and 4-3. The 2-yr. 24-hr. precipitation analysis shown in figure 3-18 is the basis for the adopted patterns. The isohyetal patterns for subbasins 1, 2, and 3, are also supported by the isohyetal pattern of the storm of July 10-11, 1948 (fig. 4-4). The storms of August 13, 1940 [4-1] and August 20-24, 1967 (fig. 4-5) support the isohyetal patterns for subbasins 4, 5, and 6A. The isohyetal pattern of the storm of August 20-24, 1967, also supports the adopted isohyetal pattern for subbasin 6. The adopted isohyetal patterns have been shifted slightly east and northeastward because the postulated south-to-southwest inflow wind for maximum rains in these subbasins tends to shift the rain center towards the northeast. Isohyetal labels are given in table 4-3.

Maximum 3-hour increment. The maximum 3-hr. increment is obtained by multiplying the maximum 6-hr. increment by 0.67 for subbasin 1; 0.72 for subbasins 2 and 3; 0.77 for subbasins 4, 5, and 6A; and 0.74 for subbasin 6 (fig. 3-27).

Table 4-2. Factors Used in Estimating PMP and TVA Precipitation

A. Hiwassee River Drainages

Item No.	Item							
1	Subbasin Number	1	2	3	4	5	6	6A
2	Basin-size adjustment factor (fig. 3-11)	0.88	0.97	1.00	1.34	1.32	1.11	1.30
3	6-hr. 5-sq. mi. PMP orographic increase (percent) (fig. 2-22B, etc.)	29	23	30	35	30	32	32
4	Average mean annual precipitation (in.) (fig. 3-15)	57.4	58.3	59.5	63.2	57.5	61.7	61.0
5	Average annual non-orographic precipitation (in.) (fig. 3-16)	48.6	48.5	48.5	48.5	48.9	49.1	49.2
6	Ratio of item (4) to item (5)	1.18	1.20	1.23	1.30	1.18	1.26	1.24
7	Orographic increase applied (percent)	10	10	15	30	25	20	25

B. Little Tennessee River Drainages

1	Subbasin Number	7	8	9
2	Basin-size adjustment factor (fig. 3-11)	0.90	1.25	1.09
3	6-hr. 5-sq. mi. PMP orographic increase (percent) (fig. 2-22B, etc.)	30	41	25
4	Average mean annual precipitation (in.) (fig. 3-15)	61.5	67.8	58.9
5	Average annual non-orographic precipitation (in.) (fig. 3-16)	47.4	48.0	47.1
6	Ratio of item (4) to item (5)	1.30	1.37	1.25
7	Orographic increase applied (percent)	10	30	10

C. Pigeon and French Broad River Drainages

1	Subbasin Number	10	11	12
2	Basin-size adjustment factor (fig. 3-11)	1.08	0.86	1.01
3	6-hr. 5-sq. mi. PMP orographic increase (percent) (fig. 2-22B, etc.)	35	30	33
4	Average mean annual precipitation (in.) (fig. 3-15)	53.1	50.9	61.0
5	Average annual non-orographic precipitation (in.) (fig. 3-16)	46.5	46.2	46.8
6	Ratio of item (4) to item (5)	1.14	1.10	1.30
7	Orographic increase applied (percent)	10	10	15

D. Nolichucky and Holston River Drainages

1	Subbasin Number	13	14	15	16	17
2	Basin-size adjustment factor (fig. 3-11)	0.96	0.84	0.90	0.94	1.18
3	6-hr. 5-sq. mi. PMP orographic increase (percent) (fig. 2-22B, etc.)	+27	+22	+24	+20	+27
4	Average mean annual precipitation (in.) (fig. 3-15)	48.8	46.0	45.4	45.0	47.0
5	Average annual non-orographic precipitation (in.) (fig. 3-16)	45.0	43.5	43.7	43.0	44.0
6	Ratio of item (4) to item (5)	1.09	1.06	1.04	1.05	1.07
7	Orographic increase applied (percent)	10	0	0	5	15

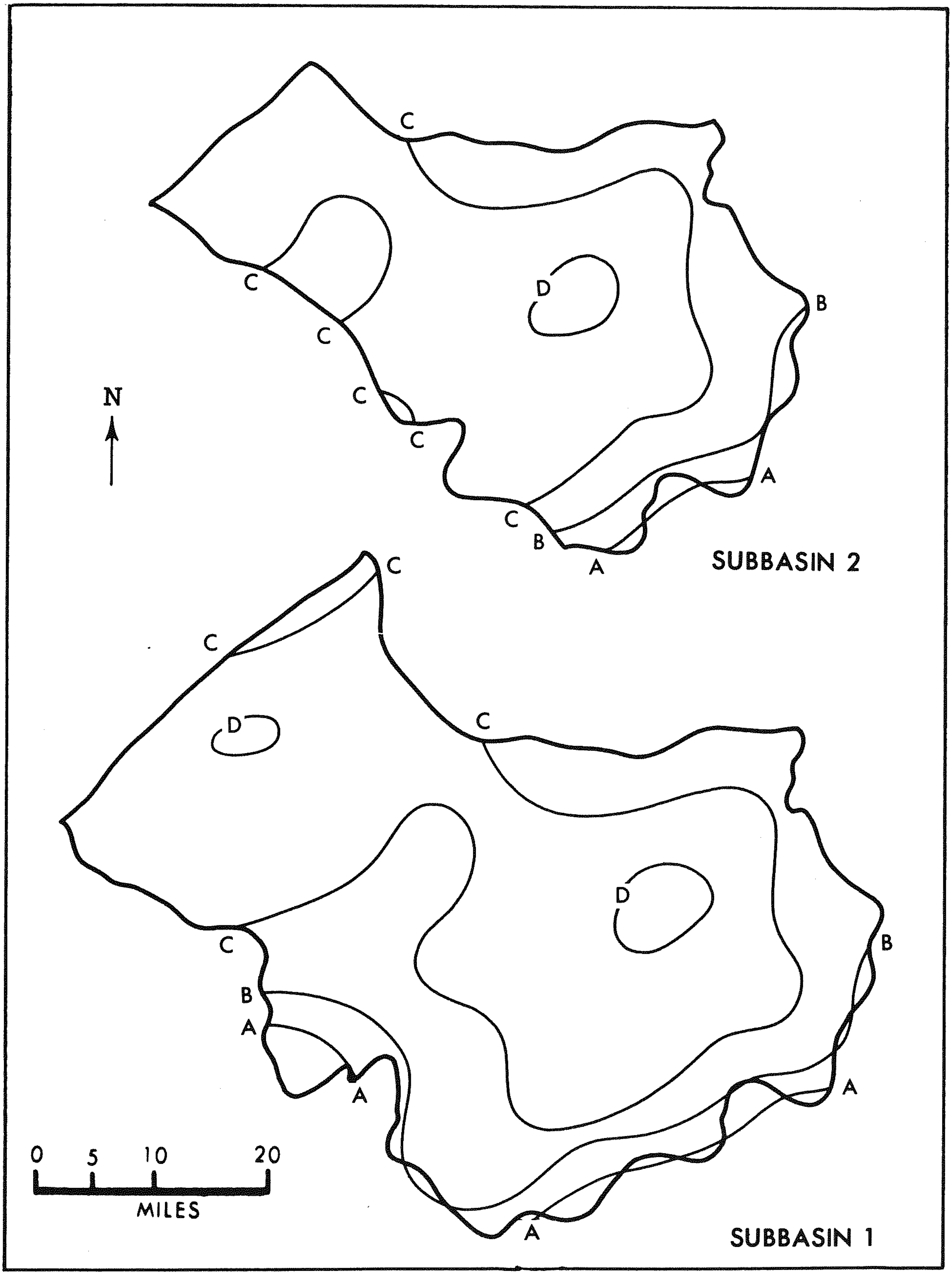


Figure 4-2. Isohyetal patterns for subbasins 1 and 2, Hiwassee River

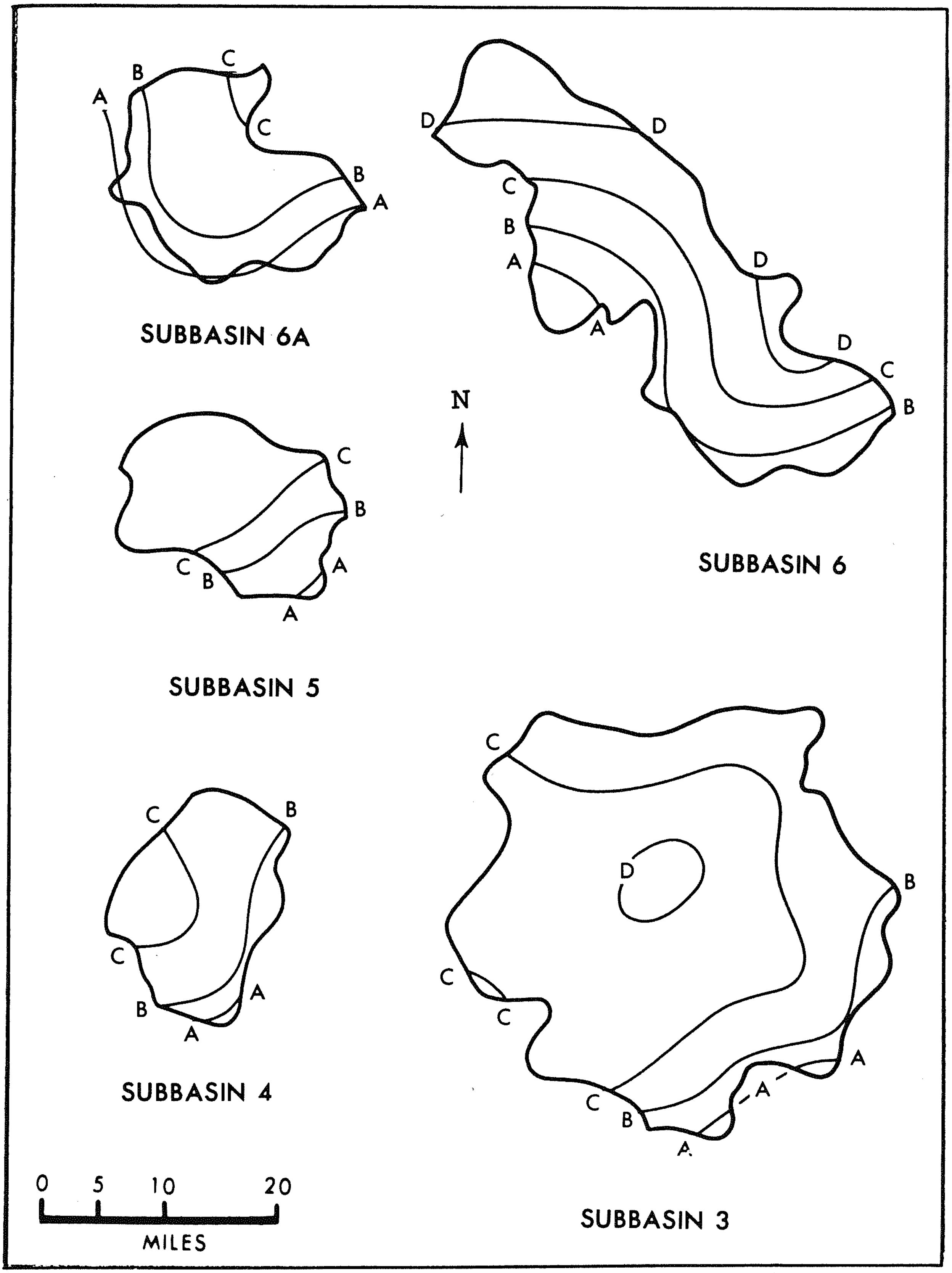


Figure 4-3. Isohyetal patterns for subbasins 3, 4, 5, 6 and 6A, Hiwassee River

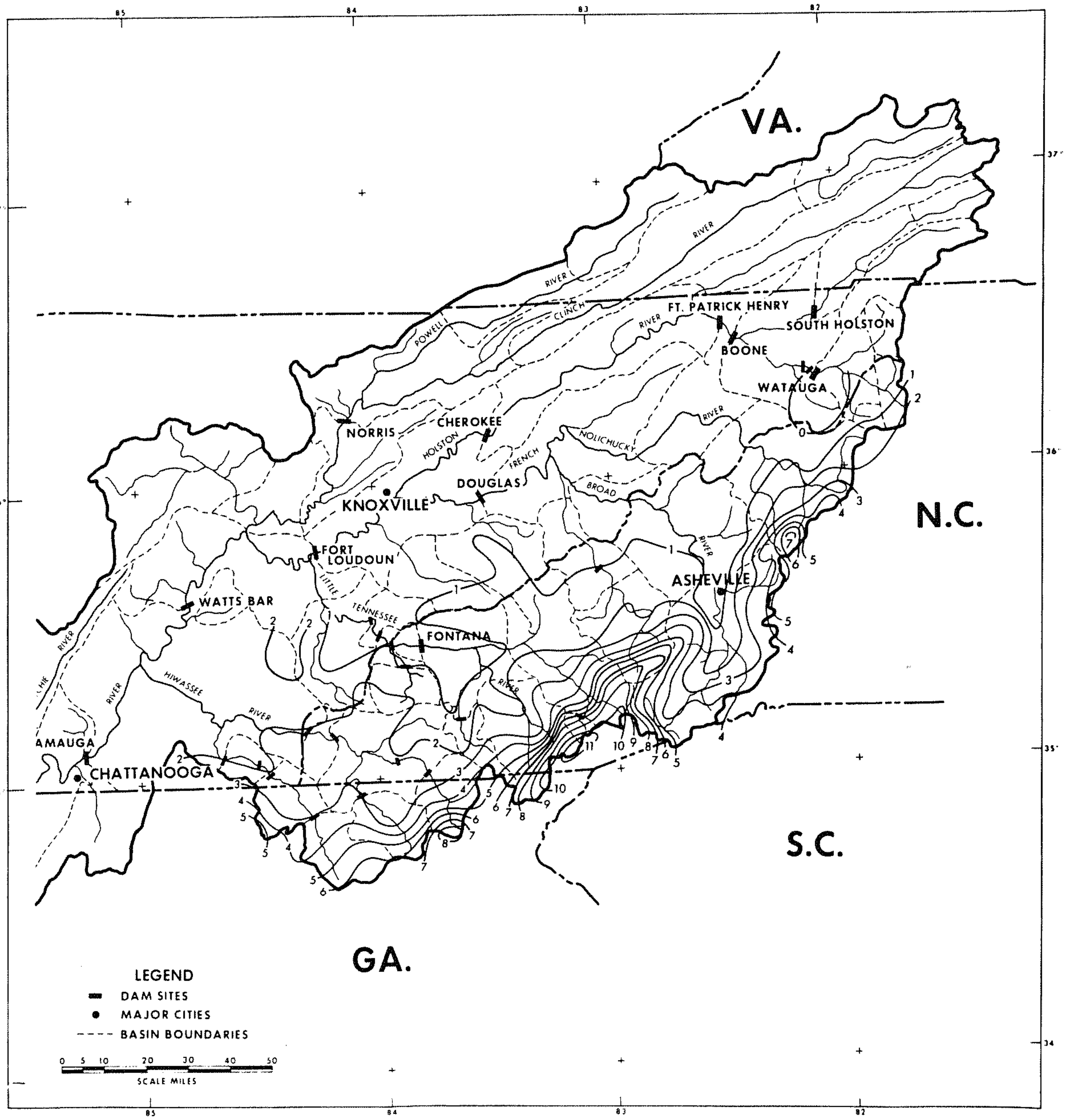


Figure 4-4. Isohyetal map for storm of July 10-11, 1948 (inches)

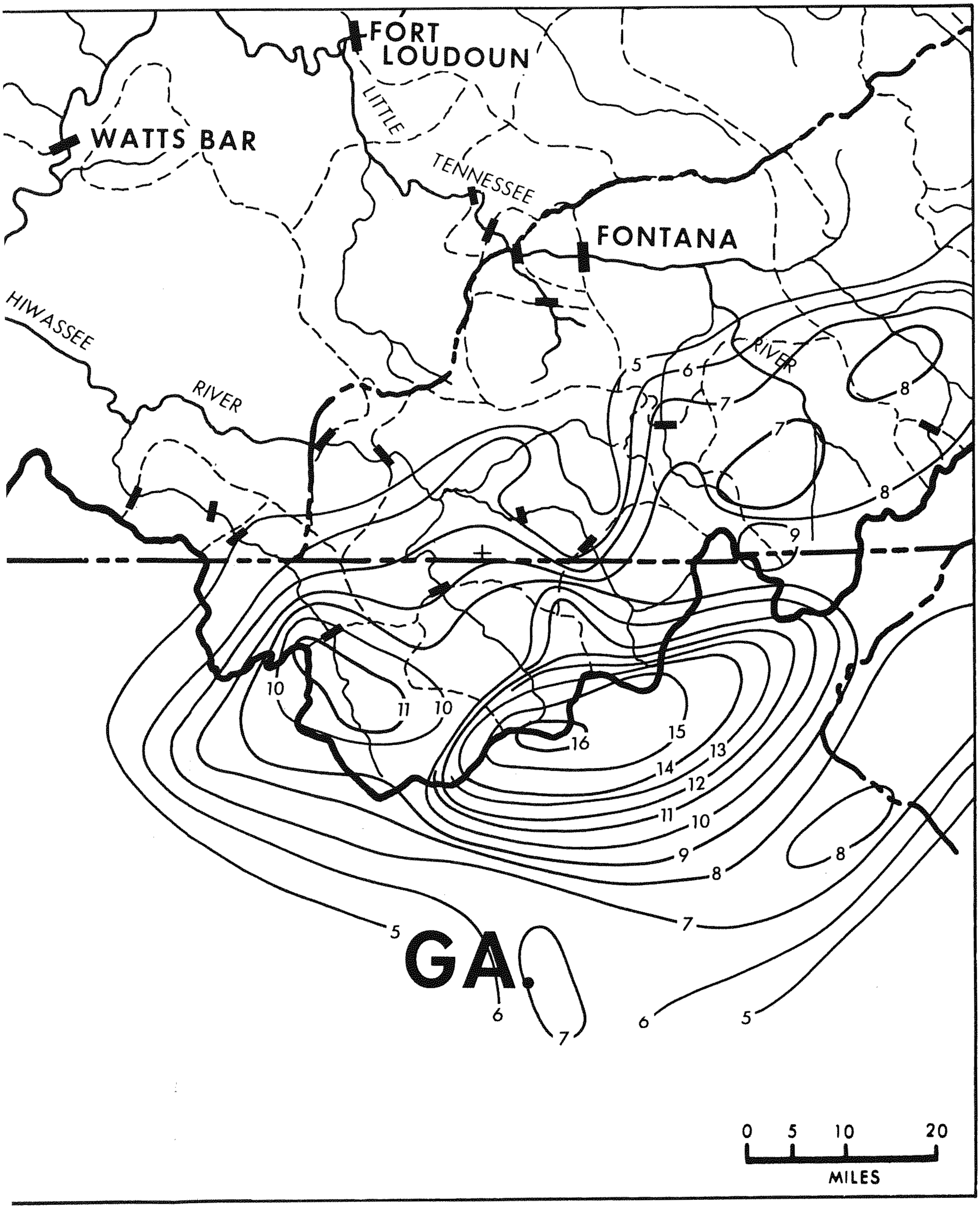


Figure 4-5. Isohyetal map for storm of August 20-24, 1967 (inches)

B. LITTLE TENNESSEE RIVER DRAINAGE

Adopted values

Probable maximum and TVA precipitation estimates for subbasins 7, 8, and 9 (fig. 4-1) are given in table 4-1 (B) by average depths over the area for the indicated durations.

Data applying to the orographic intensification factor similar to the Hiwassee are given in table 4-2 (B). For subbasin 7, the Little Tennessee River drainage above Fontana Dam, and subbasin 9, the Tuckasegee River drainage above Franklin, 10-percent orographic increases were used. This allows for half or more of each basin being "sheltered" during a general rainstorm. A 30-percent orographic increase was used over subbasin 8, the Little Tennessee River drainage above Franklin, which has minimum sheltering effects.

The "sheltering" effects that determined the orographic factors applied are dependent on the type of storm and basin size, in line with the concepts of the "areas controlled by particular wind directions" (fig. 3-21).

Areal distribution

The adopted isohyetal patterns are shown in figure 4-6. The mean annual precipitation for each of the subbasins is very similar to the 2-yr. 24-hr. analysis. These are the principal guides to the isohyetal patterns. The rainfall patterns of the storms of July 19-24, 1938 (fig. 4-7) and July 10-11, 1948 (fig. 4-4) provide additional support to the adopted isohyetal patterns. Isohyetal values associated with isohyetal patterns are given in table 4-3.

Maximum 3-hour increment. The maximum 3-hr. increment is obtained by multiplying the maximum 6-hr. increment by 0.75 for subbasins 8 and 9 and by 0.70 for subbasin 7 (fig. 3-27).

C. PIGEON AND FRENCH BROAD RIVER DRAINAGES

Adopted values

Subbasins 10, 11 and 12 are shown in figure 4-1. The eastern foothills of the Appalachians produce storm rainfall spillover over the subbasins immediately adjacent to the foothills but produce rainfall sheltering effects for remaining basin areas. The southern and eastern slopes of the New Found Mountains, separating subbasins 10 and 11, are of secondary importance in determining rain distribution in severe storms.

Probable maximum and TVA precipitation estimates for the three subbasins are shown in table 4-1 (C) by average depths for the indicated

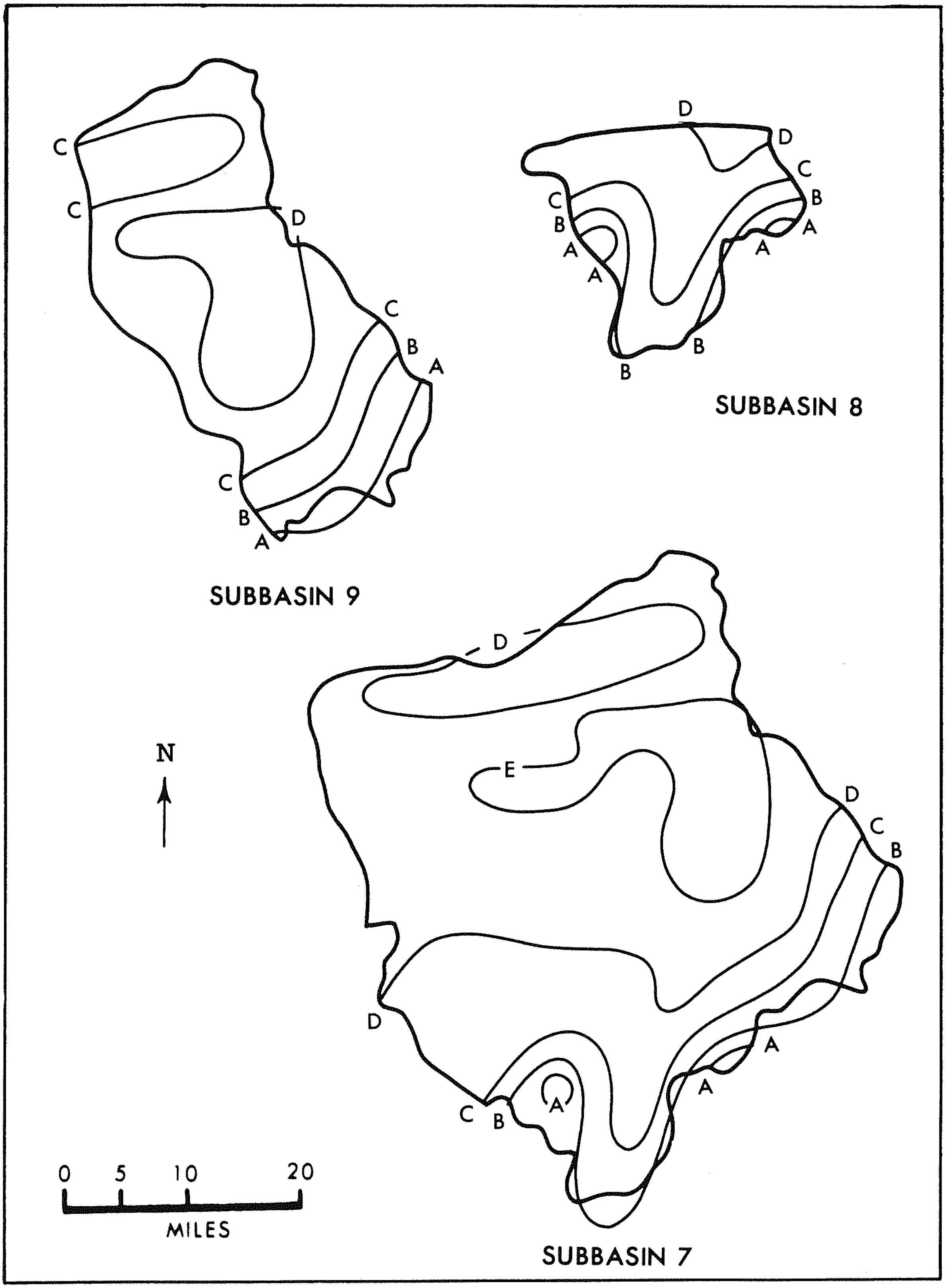


Figure 4-6. Isohyetal patterns for subbasins 7, 8, and 9, Little Tennessee River

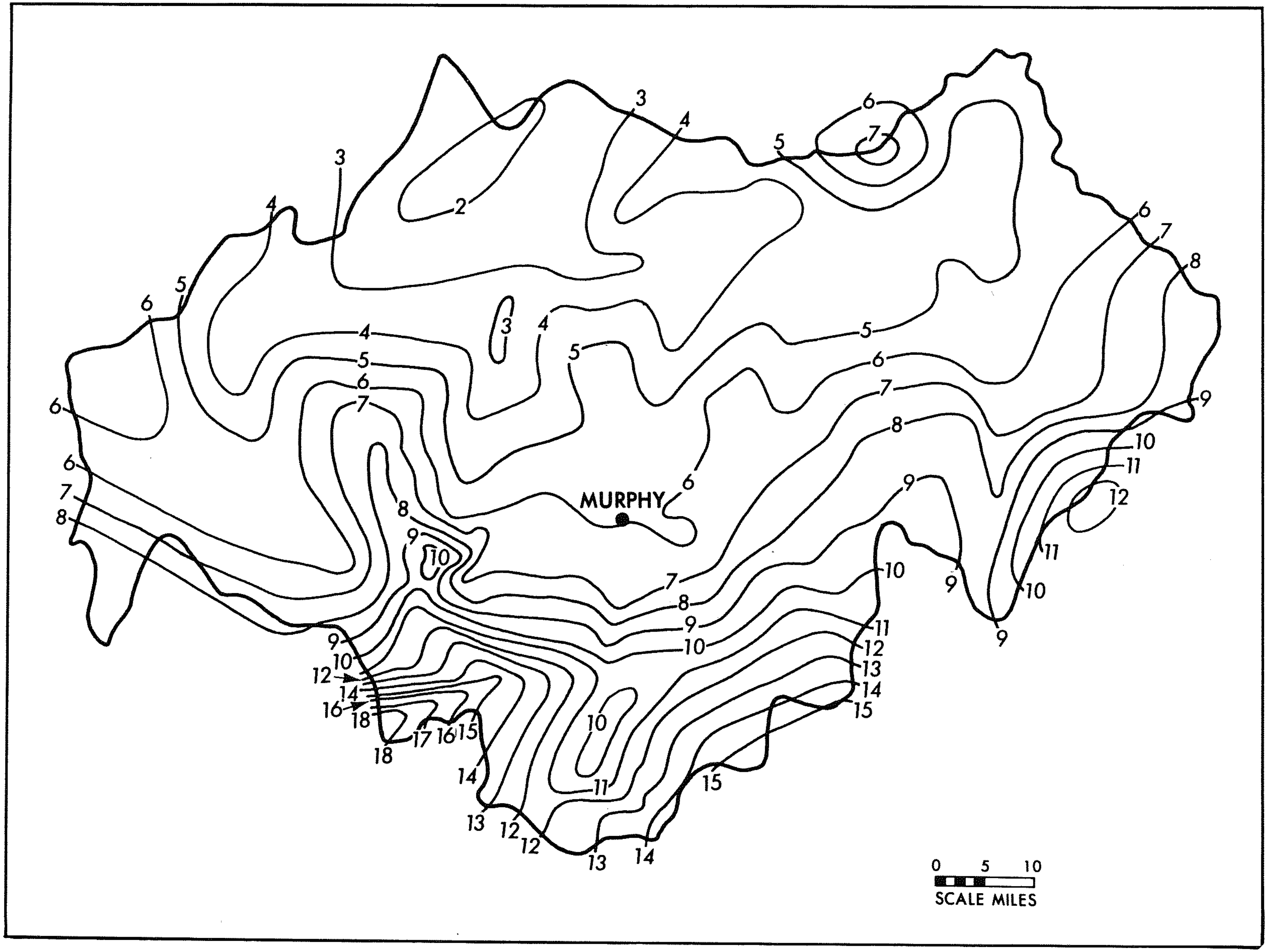


Figure 4-7. Isohyetal map for storm of July 19-24, 1938 (inches) Hiwassee and Little Tennessee River

Table 4-3. Isohyet Labels (in.) for PMP and TVA Precipitation Patterns

A. Hiwassee River Drainages

Subbasin	Iso-hyet	Area Enclosed (sq.mi.)	PMP 1st 6 hr.	PMP 2nd 6 hr.	PMP 3rd 6 hr.	PMP * 4-12th 6 hr.	24-hr. TVA 1st 6 hr.	24-hr. TVA 2nd 6 hr.	24-hr. TVA 3rd 6 hr.	24-hr. TVA 4th 6 hr.	72-hr. TVA 1st 6 hr.	72-hr. TVA 2nd 6 hr.	72-hr. TVA 3rd 6 hr.	72-hr. TVA * 4-12th 6 hr.
Hiwassee River above Charleston, Tenn. (Subbasin 1, fig. 4-2) 2189 sq. mi.	A	75	17.1	3.8	2.7	UAD					8.3	3.3	2.2	UAD
	B	258	14.9	3.5	2.6	UAD					7.2	3.1	2.1	UAD
	C	972	12.7	3.2	2.5	UAD					6.2	2.8	2.0	UAD
	D	2130	10.7	2.8	2.3	UAD					5.2	2.5	1.8	UAD
Hiwassee River above Austral, Tenn. (Subbasin 2, fig. 4-2) 1228 sq. mi.	A	15	19.5	4.4	2.7	UAD					9.0	3.8	2.3	UAD
	B	80	17.0	4.0	2.6	UAD					7.9	3.4	2.2	UAD
	C	497	14.6	3.6	2.5	UAD					6.8	3.1	2.1	UAD
	D	1188	12.2	3.2	2.3	UAD					5.7	2.7	1.9	UAD
Hiwassee River above Hiwassee Dam, Tenn. (Subbasin 3, fig. 4-3) 968 sq. mi.	A	15	20.3	4.0	3.0	UAD					9.2	3.5	2.6	UAD
	B	80	17.9	3.7	2.8	UAD					8.1	3.2	2.5	UAD
	C	416	15.5	3.4	2.6	UAD					7.0	3.0	2.3	UAD
	D	928	13.1	3.1	2.4	UAD					5.9	2.7	2.1	UAD
Hiwassee River above Chatuga Dam, N. C. (Subbasin 4, fig. 4-3) 189 sq. mi.	A	5	29.9	4.1	3.1	UAD	13.6	4.1	3.0	2.3	12.0	4.3	3.4	UAD
	B	42	25.9	4.0	3.0	UAD	11.8	4.0	2.8	2.3	10.4	4.2	3.2	UAD
	C	143	21.9	4.0	2.9	UAD	9.9	4.0	2.7	2.3	8.8	4.1	3.0	UAD
Nottely River above Nottely Dam, Ga. (Subbasin 5, fig. 4-3) 214 sq. mi.	A	5	28.2	4.4	3.1	UAD	13.3	4.1	2.8	2.0	11.6	4.2	3.0	UAD
	B	38	25.0	4.3	2.8	UAD	11.8	4.0	2.7	2.0	10.2	4.1	2.9	UAD
	C	81	21.8	4.2	2.7	UAD	10.2	3.9	2.7	2.0	8.9	4.0	2.9	UAD
Ocoee River above Ocoee Dam #1, Tenn. (Subbasin 6, fig. 4-3) 595 sq. mi.	A	23	23.4	4.2	2.8	UAD					14.0	2.5	1.7	UAD
	B	122	20.9	4.0	2.7	UAD					12.5	2.4	1.6	UAD
	C	303	18.4	3.8	2.6	UAD					11.0	2.3	1.5	UAD
	D	496	15.9	3.7	2.4	UAD					9.5	2.2	1.4	UAD
Toccoa River above Blue Ridge Dam, Ga. (Subbasin 6A, fig. 4-3) 232 sq. mi.	A	17	27.0	4.3	2.8	UAD	12.7	4.1	2.8	2.0	11.8	4.3	3.0	UAD
	B	93	23.0	4.2	2.7	UAD	10.8	3.9	2.7	2.0	9.5	4.1	2.9	UAD
	C	211	20.0	4.1	2.7	UAD	9.4	3.7	2.6	2.0	8.3	4.0	2.9	UAD

*UAD - Uniform areal distribution.

Table 4-3.--Continued

B. Little Tennessee River Drainages

Subbasin	Iso-hyet	Area Enclosed (sq.mi.)	PMP 1st 6 hr.	PMP 2nd 6 hr.	PMP 3rd 6 hr.	PMP * 4-12th 6 hr.	24-hr. TVA 1st 6 hr.	24-hr. TVA 2nd 6 hr.	24-hr. TVA 3rd 6 hr.	24-hr. TVA 4th 6 hr.	72-hr. TVA 1st 6 hr.	72-hr. TVA 2nd 6 hr.	72-hr. TVA 3rd 6 hr.	72-hr. TVA * 4-12th 6 hr.
Little Tennessee River above Fontana Dam, N. C. (Subbasin 7, fig. 4-6) 1571 sq. mi.	A	11	20.1	4.4	2.9	UAD					9.3	3.6	2.5	UAD
	B	77	17.9	4.0	2.7	UAD					8.3	3.3	2.3	UAD
	C	198	15.7	3.6	2.5	UAD					7.3	2.9	2.2	UAD
	D	643	13.5	3.2	2.3	UAD					6.3	2.6	2.0	UAD
	E	1406	11.3	2.8	2.2	UAD					5.2	2.3	1.9	UAD
Little Tennessee River above Franklin, N. C. (Subbasin 8, fig. 4-6) 295 sq. mi.	A	12	28.9	4.6	2.7	UAD	13.8	4.5	2.9	1.7	12.0	4.6	3.1	UAD
	B	42	25.7	4.3	2.6	UAD	12.3	4.2	2.8	1.7	10.7	4.3	3.0	UAD
	C	119	22.5	4.0	2.5	UAD	10.8	3.9	2.7	1.7	9.4	4.0	2.9	UAD
	D	277	19.3	3.7	2.4	UAD	9.2	3.6	2.6	1.7	8.0	3.7	2.8	UAD
Tuckasegee River above Bryson City, N. C. (Subbasin 9, fig. 4-6) 655 sq. mi.	A	31	22.3	4.2	3.1	UAD					9.9	3.9	1.7	UAD
	B	78	19.5	3.8	2.9	UAD					8.6	3.5	1.6	UAD
	C	209	16.7	3.4	2.7	UAD					7.8	3.1	1.5	UAD
	D	503	13.9	3.0	2.5	UAD					6.1	2.7	1.4	UAD

C. Pigeon and French Broad River Drainages

Subbasin	Iso-hyet	Area Enclosed (sq.mi.)	PMP 1st 6 hr.	PMP 2nd 6 hr.	PMP 3rd 6 hr.	PMP * 4-12th 6 hr.	24-hr. TVA 1st 6 hr.	24-hr. TVA 2nd 6 hr.	24-hr. TVA 3rd 6 hr.	24-hr. TVA 4th 6 hr.	72-hr. TVA 1st 6 hr.	72-hr. TVA 2nd 6 hr.	72-hr. TVA 3rd 6 hr.	72-hr. TVA * 4-12th 6 hr.
Pigeon River above Newport, Tenn. (Subbasin 10, fig. 4-8) 666 sq. mi.	A	15	20.0	4.2	2.9	UAD					8.6	4.0	2.7	UAD
	B	40	19.1	4.0	2.7	UAD					8.2	3.8	2.6	UAD
	C	71	18.2	3.7	2.6	UAD					7.8	3.6	2.4	UAD
	D	102	17.3	3.5	2.5	UAD					7.4	3.4	2.3	UAD
	E	148	16.4	3.2	2.4	UAD					7.0	3.2	2.2	UAD
	F	382	15.5	3.0	2.3	UAD					6.6	3.0	2.1	UAD
	G	635	14.6	2.9	2.2	UAD					6.2	2.8	2.0	UAD
French Broad River above Newport, Tenn. (Subbasin 11, fig. 4-8) 1858 sq. mi.	A	22	16.5	4.1	2.9	UAD					8.0	3.4	2.4	UAD
	B	119	15.5	3.8	2.7	UAD					7.5	3.2	2.3	UAD
	C	211	14.5	3.6	2.6	UAD					7.0	3.0	2.2	UAD
	D	395	13.5	3.4	2.5	UAD					6.6	2.8	2.1	UAD
	E	762	12.5	3.2	2.4	UAD					6.2	2.6	2.0	UAD
	F	1545	11.5	3.1	2.3	UAD					5.7	2.5	2.0	UAD

*UAD - Uniform areal distribution .

Table 4-3.--Continued

Pigeon and French Broad River Drainages

Subbasin	Isohyet	Area Enclosed (sq.mi.)	PMP 1st 6 hr.	PMP 2nd 6 hr.	PMP 3rd 6 hr.	PMP * 4-12th 6 hr.	24-hr. TVA 1st 6 hr.	24-hr. TVA 2nd 6 hr.	24-hr. TVA 3rd 6 hr.	24-hr. TVA 4th 6 hr.	72-hr. TVA 1st 6 hr.	72-hr. TVA 2nd 6 hr.	72-hr. TVA 3rd 6 hr.	72-hr. TVA * 4-12th 6 hr.
French Broad River above Asheville, N.C.	A	40	19.2	4.1	3.0	UAD					8.7	3.6	2.6	UAD
(Subbasin 12, fig. 4-12) 945 sq. mi.	B	114	17.9	3.8	2.8	UAD					8.1	3.3	2.4	UAD
	C	248	16.6	3.6	2.6	UAD					7.6	3.1	2.3	UAD
	D	510	15.3	3.4	2.4	UAD					7.0	2.9	2.0	UAD
	E	891	14.0	3.2	2.2	UAD					6.4	2.7	1.9	UAD
	F	1355	11.4	2.3	1.5	UAD					5.1	2.0	1.3	UAD
	G	1839	8.6	1.9	1.2	UAD					4.0	1.6	1.0	UAD

D. Holston and Nolichucky River Drainages

Subbasin	Isohyet	Area Enclosed (sq.mi.)	PMP 1st 6 hr.	PMP 2nd 6 hr.	PMP 3rd 6 hr.	PMP * 4-12th 6 hr.	24-hr. TVA 1st 6 hr.	24-hr. TVA 2nd 6 hr.	24-hr. TVA 3rd 6 hr.	24-hr. TVA 4th 6 hr.	72-hr. TVA 1st 6 hr.	72-hr. TVA 2nd 6 hr.	72-hr. TVA 3rd 6 hr.	72-hr. TVA * 4-12th 6 hr.
Nolichucky River above Nolichucky Dam, Tenn.	A	22	23.1	4.2	2.6	UAD					10.7	3.7	2.3	UAD
(Subbasin 13, fig. 4-14) 1183 sq. mi.	B	44	20.1	3.9	2.5	UAD					9.3	3.4	2.2	UAD
	C	82	17.1	3.6	2.4	UAD					7.9	3.1	2.1	UAD
	D	391	14.1	3.3	2.3	UAD					6.5	2.9	2.0	UAD
	E	1128	11.1	3.0	2.2	UAD					5.1	2.6	1.9	UAD
Holston River above Surgoinsville, Tenn.	A	11	12.5	3.5	2.5	UAD					6.4	2.9	2.0	UAD
(Subbasin 14, fig. 4-15) 2874 sq. mi.	B	72	11.3	3.2	2.3	UAD					5.8	2.6	1.8	UAD
	C	842	10.1	2.9	2.1	UAD					5.2	2.4	1.7	UAD
	D	1911	8.0	2.3	1.6	UAD					4.1	1.9	1.3	UAD
Holston River above Fort Patrick Henry, Tenn.	A	11	13.4	3.3	2.2	UAD					6.3	2.9	1.8	UAD
(Subbasin 15, fig. 4-16) 1903 sq. mi.	B	72	12.2	3.0	2.1	UAD					5.8	2.7	1.7	UAD
	C	914	11.0	2.7	2.0	UAD					5.4	2.4	1.6	UAD
	D	1792	8.8	2.2	1.9	UAD					4.2	2.0	1.4	UAD
Holston River above South Holston Dam, Tenn.	A	16	16.5	3.6	2.4	UAD					7.3	3.4	2.3	UAD
(Subbasin 16, fig. 4-17) 703 sq. mi.	B	320	14.1	3.2	2.2	UAD					6.2	3.0	2.1	UAD
	C	682	10.5	2.5	1.8	UAD					4.7	2.3	1.7	UAD
Watauga River above Watauga Dam, Tenn.	A	7	28.6	4.5	2.5	UAD					12.3	4.2	2.4	UAD
(Subbasin 17, fig. 4-17) 468 sq. mi.	B	86	22.6	3.9	2.4	UAD					9.3	3.7	2.3	UAD
	C	303	16.6	3.3	2.3	UAD					7.1	3.1	2.2	UAD

*UAD - Uniform areal distribution.

Table 4-3.--Continued

E. Clinch River Drainages

Subbasin	Isohyet	Area Enclosed (sq.mi.)	PMP 1st 6 hr.	PMP 2nd 6 hr.	PMP 3rd 6 hr.	PMP * 4-12th 6 hr.	24-hr. TVA 1st 6 hr.	24-hr. TVA 2nd 6 hr.	24-hr. TVA 3rd 6 hr.	24-hr. TVA 4th 6 hr.	72-hr. TVA 1st 6 hr.	72-hr. TVA 2nd 6 hr.	72-hr. TVA 3rd 6 hr.	72-hr. TVA * 4-12th 6 hr.
Powell River above Arthur, Tenn.	A	11	15.6	3.1	2.4	UAD					6.8	2.9	2.2	UAD
(Subbasin 1C, fig. 3-27) 685 sq. mi.	B	45	14.5	3.0	2.3	UAD					6.3	2.8	2.1	UAD
	C	114	13.4	2.8	2.1	UAD					5.8	2.6	1.9	UAD
	D	279	12.5	2.7	2.0	UAD					5.4	2.5	1.8	UAD
	E	546	11.6	2.5	1.9	UAD					5.1	2.3	1.7	UAD
	F	903	8.5	2.3	1.8	UAD					3.7	2.2	1.6	UAD
	G	1349	5.5	2.0	1.5	UAD					2.4	2.0	1.4	UAD
Clinch River above Norris Dam, Tenn.	A	11	15.5	3.7	2.4	UAD					7.9	2.9	2.0	UAD
(Subbasin 3C, fig. 3-27) 2912 sq. mi.	B	45	14.1	3.5	2.3	UAD					7.2	2.7	1.9	UAD
	C	114	12.5	3.3	2.2	UAD					6.4	2.5	1.8	UAD
	D	279	11.5	3.1	2.0	UAD					5.8	2.4	1.7	UAD
	E	546	10.5	2.9	1.9	UAD					5.4	2.3	1.6	UAD
	F	903	9.8	2.8	1.8	UAD					5.0	2.2	1.5	UAD
	G	1349	8.9	2.6	1.7	UAD					4.5	2.1	1.5	UAD
	H	2508	7.6	2.4	1.6	UAD					3.5	1.9	1.4	UAD
	I	4458	5.5	2.2	1.5	UAD					2.8	1.7	1.2	UAD
Clinch River above Tazewell, Tenn.	A	11	15.9	3.5	2.5	UAD					7.5	2.8	2.1	UAD
(Subbasin 4C, fig. 3-27) 1474 sq. mi.	B	45	14.5	3.3	2.3	UAD					6.9	2.7	1.9	UAD
	C	114	13.0	3.1	2.1	UAD					6.2	2.5	1.8	UAD
	D	279	12.1	2.9	2.0	UAD					5.7	2.3	1.7	UAD
	E	546	11.1	2.7	1.9	UAD					5.3	2.2	1.6	UAD
	F	903	10.2	2.6	1.8	UAD					4.8	2.1	1.5	UAD
	G	1349	8.9	2.5	1.7	UAD					4.2	2.0	1.5	UAD
	H	2508	6.5	2.1	1.6	UAD					3.3	1.7	1.3	UAD
Clinch River above Cleveland, Tenn.	A	11	15.1	3.0	2.1	UAD					6.4	2.9	2.0	UAD
(Subbasin 5C, fig. 3-27) 528 sq. mi.	B	45	14.3	2.8	2.0	UAD					6.1	2.7	1.9	UAD
	C	114	13.0	2.7	1.9	UAD					5.6	2.6	1.8	UAD
	D	279	12.1	2.6	1.8	UAD					5.2	2.5	1.7	UAD
	E	546	10.7	2.4	1.7	UAD					4.6	2.4	1.6	UAD
	F	903	7.7	2.0	1.5	UAD					3.3	2.1	1.4	UAD
	G	1349	4.6	1.6	1.3	UAD					2.0	1.6	1.2	UAD

*UAD - Uniform areal distribution.

Table 4-3.--Continued

F. Specific Estimates for Western Basins

			PMP				24-hr. TVA				72-hr. TVA			
Subbasin	Iso-hyet	Area Enclosed (sq. mi.)	1st 6 hr.	2nd 6 hr.	* 3rd 6 hr.	* 4-12th 6 hr.	1st 6 hr.	2nd 6 hr.	3rd 6 hr.	4th 6 hr.	1st 6 hr.	2nd 6 hr.	* 3rd 6 hr.	* 4-12th 6 hr.
Duck River above Columbia, Tenn.	A	11	20.2	4.7	2.1	UAD					12.6	2.9	1.3	UAD
1208 sq. mi. (fig. 3-27)	B	45	18.6	4.4	2.0	UAD					11.5	2.7	1.2	UAD
	C	114	17.2	4.2	1.9	UAD					10.6	2.6	1.2	UAD
	D	279	15.8	3.9	1.8	UAD					9.8	2.4	1.1	UAD
	E	546	14.4	3.6	1.7	UAD					8.9	2.2	1.1	UAD
	F	903	13.0	3.5	1.6	UAD					8.1	2.2	1.0	UAD
	G	1349	11.2	3.3	1.5	UAD					6.9	2.0	0.9	UAD
Emory River above Harriman, Tenn.	A	11	20.1	4.8	2.3	UAD					12.4	3.0	1.4	UAD
798 sq. mi. (fig. 3-27)	B	45	18.8	4.5	2.2	UAD					11.6	2.8	1.4	UAD
	C	114	17.2	4.3	2.1	UAD					10.7	2.7	1.3	UAD
	D	279	16.7	4.2	2.0	UAD					10.3	2.6	1.2	UAD
	E	546	14.4	3.8	1.8	UAD					8.9	2.4	1.1	UAD
	F	903	12.5	3.6	1.7	UAD					7.7	2.2	1.1	UAD
	G	1349	8.8	3.2	1.4	UAD					5.4	2.0	0.9	UAD
Obed River above Nemo, Tenn.	A	11	20.0	4.9	2.4	UAD					12.4	3.0	1.5	UAD
518 sq. mi. (fig. 3-27)	B	45	18.8	4.7	2.3	UAD					11.7	2.9	1.4	UAD
	C	114	17.9	4.6	2.2	UAD					11.1	2.8	1.4	UAD
	D	279	16.2	4.2	2.1	UAD					10.0	2.6	1.3	UAD
	E	546	14.7	4.0	2.0	UAD					9.1	2.5	1.2	UAD
	F	903	10.2	3.6	1.8	UAD					6.3	2.2	1.1	UAD
	G	1349	6.3	2.5	1.3	UAD					3.9	1.6	0.8	UAD
Caney Fork above Great Falls, Tenn.	A	11	19.4	4.9	UAD	UAD					12.0	3.0	UAD	UAD
1640 sq. mi. (fig. 3-27)	B	45	17.5	4.5	UAD	UAD					10.8	2.8	UAD	UAD
	C	114	16.2	4.3	UAD	UAD					10.0	2.7	UAD	UAD
	D	279	14.9	4.0	UAD	UAD					9.2	2.5	UAD	UAD
	E	546	13.4	3.7	UAD	UAD					8.3	2.3	UAD	UAD
	F	903	12.4	3.6	UAD	UAD					7.7	2.2	UAD	UAD
	G	1349	11.1	3.4	UAD	UAD					6.9	2.1	UAD	UAD
	H	2508	8.0	2.9	UAD	UAD					4.9	1.8	UAD	UAD

*UAD - Uniform areal distribution.

durations. A 10-percent orographic increase was used over subbasin 10, the Pigeon River drainage above Newport. This is supported by the ratio of the mean annual precipitation to the mean annual "non-orographic" precipitation. Although the average orographic adjustment used in the 6-hr. 5-sq. mi. estimates was 35 percent, this increase cannot be applied over the entire area of subbasin 10, which is sheltered by relatively high mountain barriers.

Over subbasin 11, the French Broad River drainage above Newport, a 10-percent orographic increase was used. This is supported by the limitation of barriers on moisture over the entire 1858 square miles of subbasin 11. A 15-percent orographic increase was used over subbasin 12, the French Broad River drainage above Asheville. Here the mean annual precipitation and 6-hr. 5-sq. mi. PMP orographic factors are 1.33 and 1.30 respectively; but a smaller adjustment was used because the orographic effect is restricted mostly to upslope areas, which comprise less than half of the subbasin.

Areal distribution

The adopted isohyetal patterns based on the usual considerations are shown in figure 4-8. The isohyetal patterns of the storms of September 28-30, 1964 (fig. 4-9) and October 4-5, 1964 (fig. 4-10) were also considered for subbasin 10 and the Altapass, N. C. storm of July 13-17, 1916 (fig. 4-11) and the Upper French Broad River storm of August 1940 /4-1/ for subbasin 11.

The isohyetal pattern of the storm of July 13-17, 1916 is the basis for the adopted isohyetal pattern for subbasin 12 (fig. 4-12). Other heavy rainfalls, such as in the storms of September 28-30, 1964, (fig. 4-9), October 4-5, 1964 (fig. 4-10), and August 24-25, 1961 (fig. 4-13), have centers at different points in the southern half of the subbasin. Therefore, trials utilizing various positions of the storm pattern are suggested for determining the most critical flow at Asheville. The pattern may be moved along the line (X-X') such that isohyet A of figure 4-12 remains within the portion Y_1 to Y_2. The adopted isohyetal pattern may be rotated about point "P", 15 degrees in either direction from line $X\text{-}X^1$. A basin-shape factor is implicitly involved in this procedure. Isohyetal labels are given in table 4-3.

Maximum 3-hour increment. The maximum 3-hr. increment is obtained by multiplying the maximum 6-hr. increment by a factor from figure 3-27. The factor for subbasins 11 and 12 is 0.70, and for subbasin 10 is 0.74.

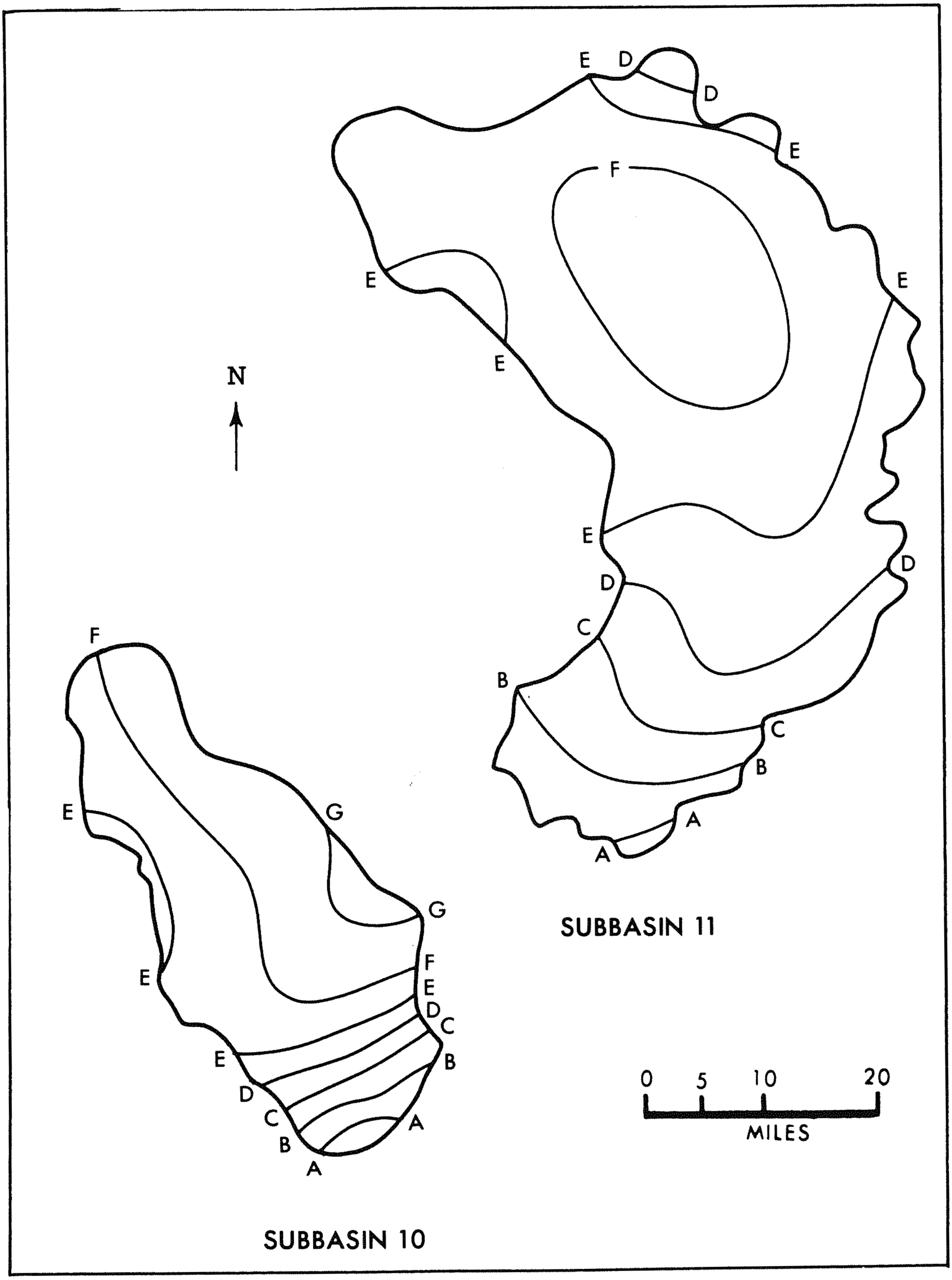


Figure 4-8. Isohyetal patterns for subbasins 10 and 11, Pigeon and French Broad Rivers

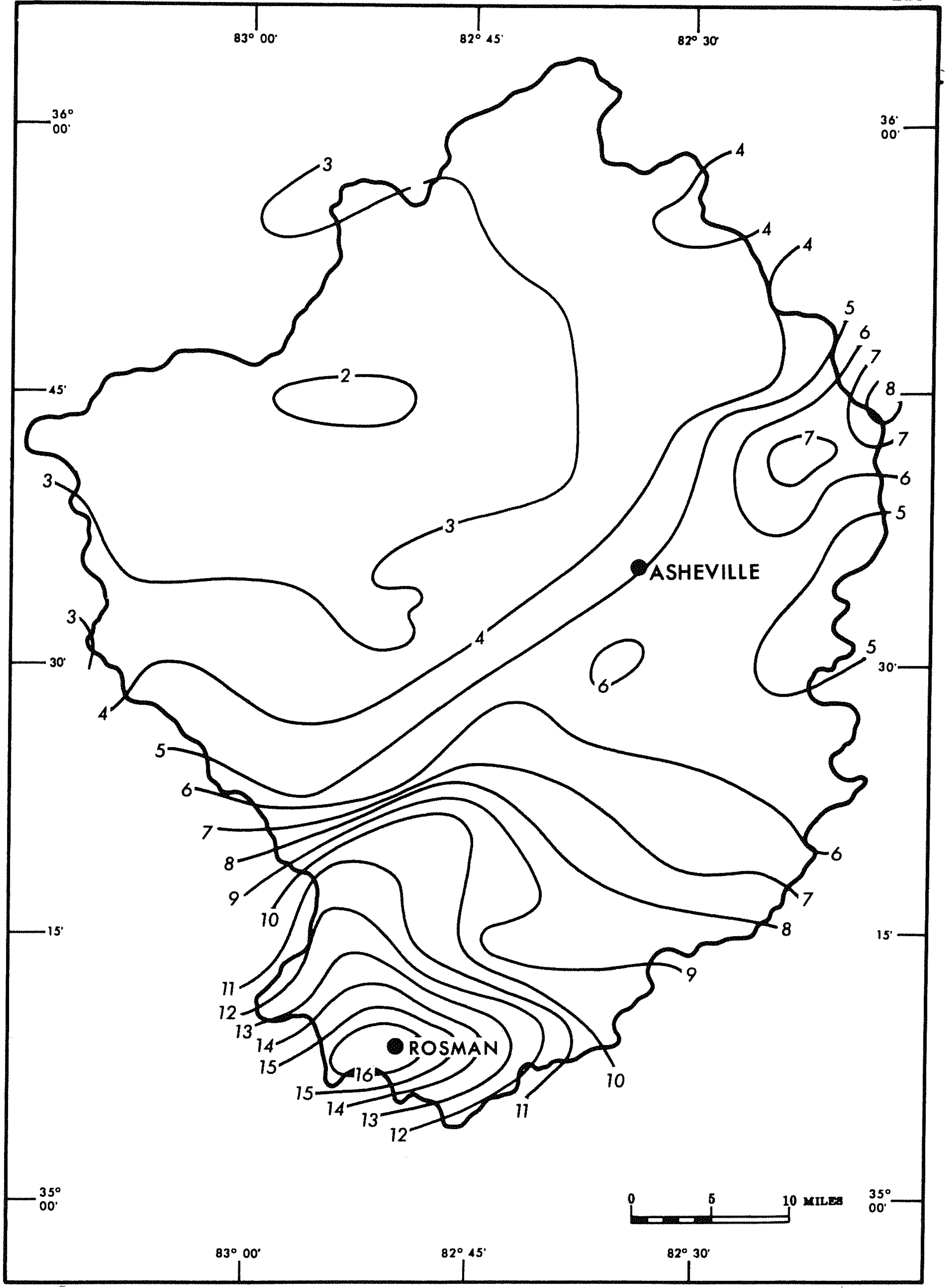


Figure 4-9. Isohyetal map for storm of September 28-30, 1964 (inches)

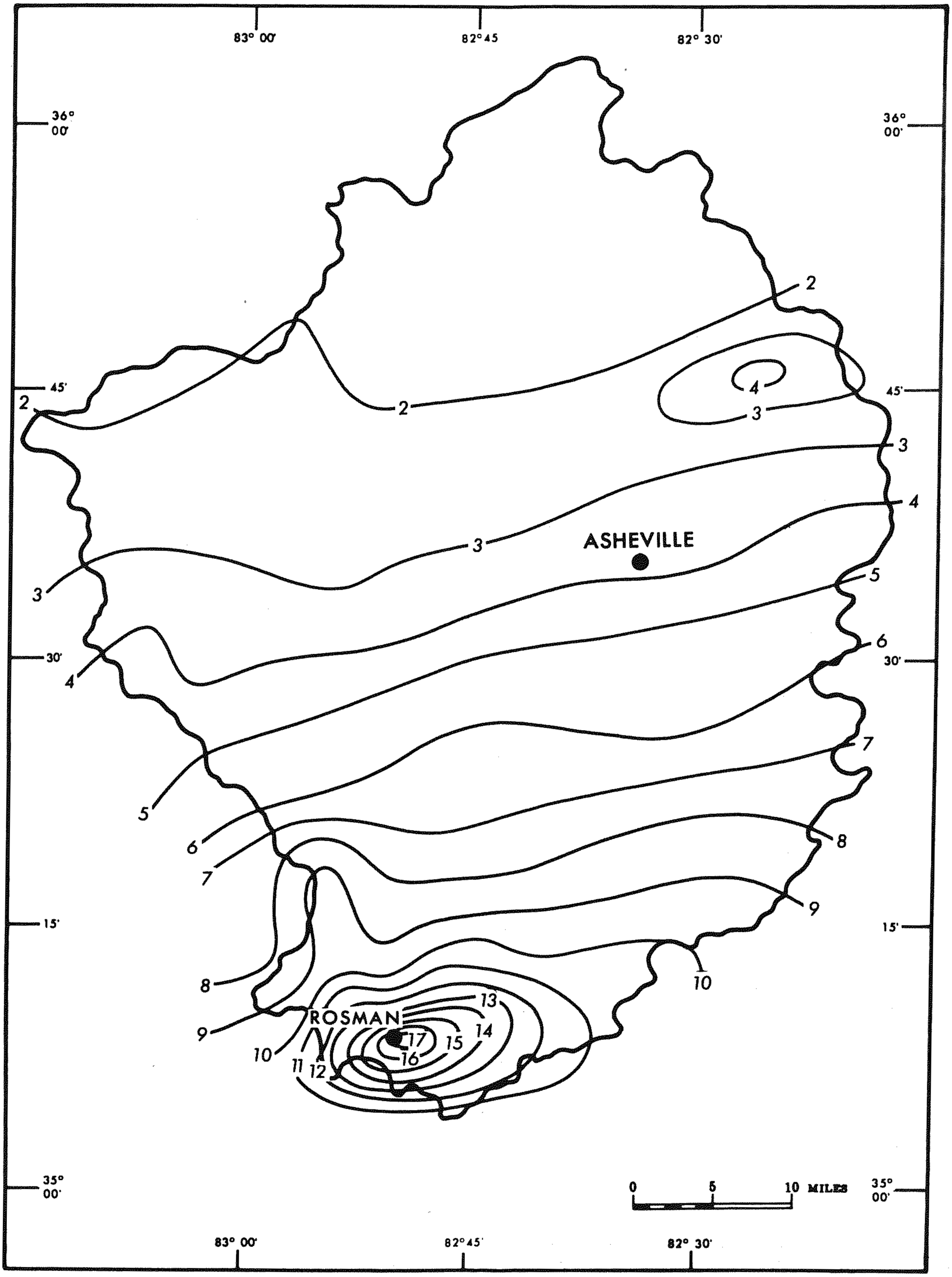


Figure 4-10. Isohyetal map for storm of October 4-5, 1964 (inches)

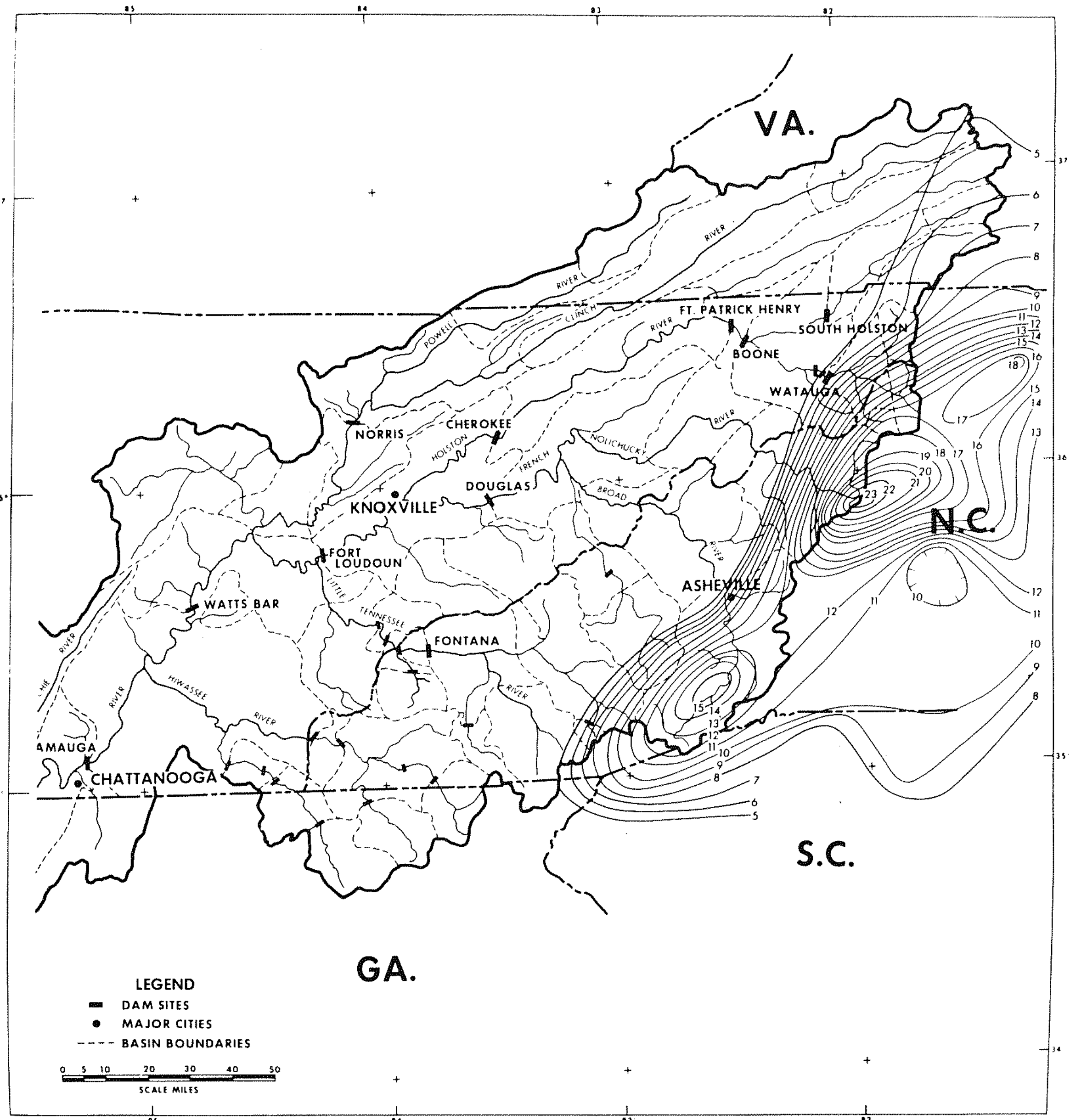


Figure 4-11. Isohyetal map for Altapass storm of July 13-17, 1916 (inches)

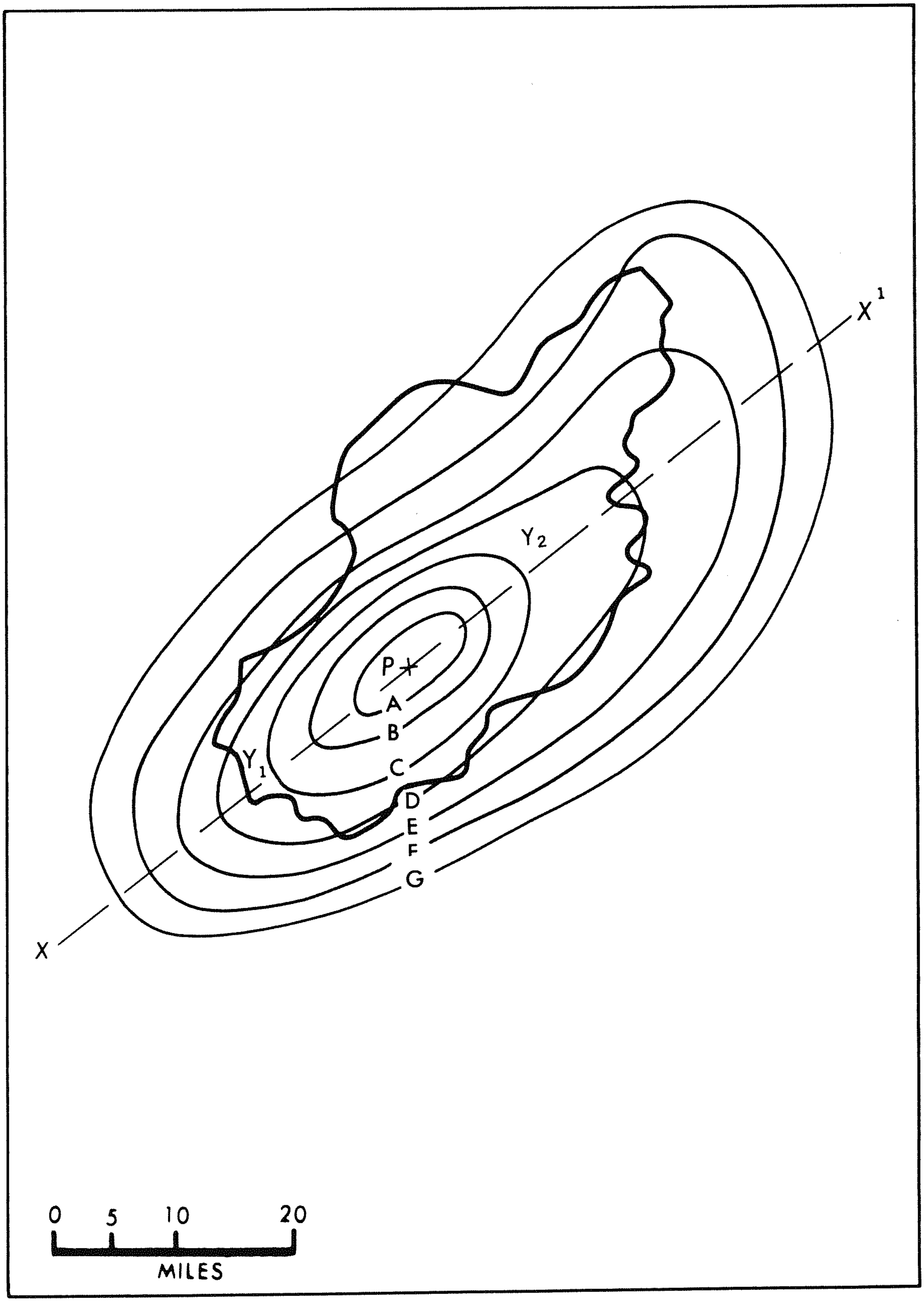


Figure 4-12. Isohyetal pattern for subbasin 12, French Broad River

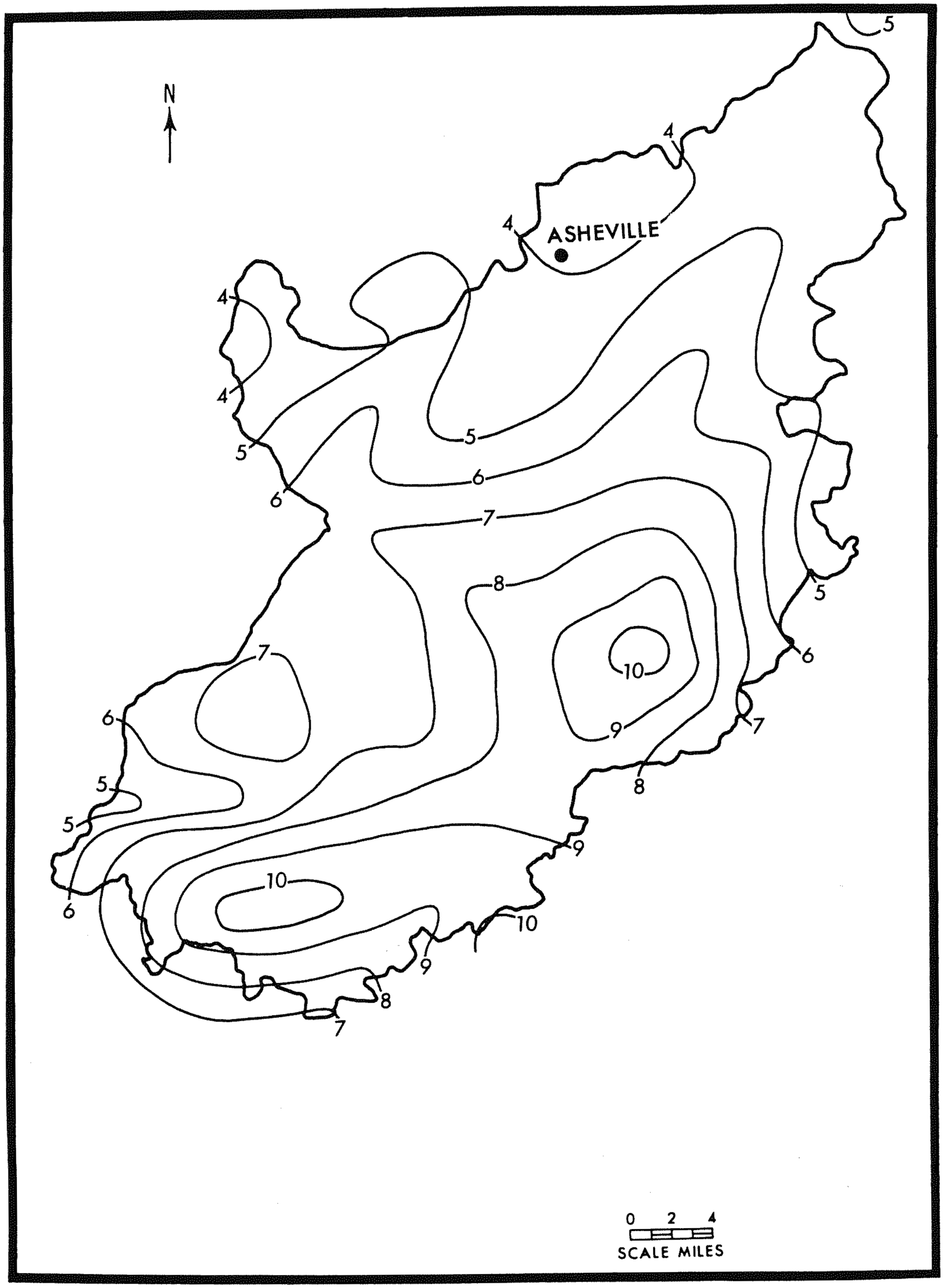


Figure 4-13. Isohyetal map for storm of August 24-25, 1961 (inches), Upper French Broad River Basin

D. HOLSTON AND NOLICHUCHY RIVER DRAINAGES

Adopted values

Subbasins 13 through 17 are shown in figure 4-1. The windward slopes of the Great Smoky and Blue Ridge Mountains and the subbasin areas immediately adjacent to them experience orographic rainfall. The Great Smokies shelter the interior of the Nolichucky subbasin and the central and western interiors of the Holston River drainage.

Probable maximum and TVA precipitation estimates for the subbasins are shown in table 4-1 (D) by average depths for the indicated durations.

A 10-percent orographic increase was applied over subbasin 13, the Nolichucky River drainage above Nolichucky Dam, and a 15-percent orographic increase was applied over subbasin 17, the Watauga River drainage above Watauga Dam. The 6-hr. 5-sq. mi. PMP factors are higher than this. But these higher values cannot be applied over the entire area of subbasin 13, because the northeast and central interior portions are, in general, sheltered. Likewise, the higher values cannot be applied over the entire area of subbasin 17, because the central interior is sheltered.

No orographic increase was used for subbasins 14 and 15 because sheltering by the Great Smoky and Blue Ridge Mountains in the central and western portions of the basins is assumed to compensate for spillover into the eastern sections. Spillover into subbasin 16 from the crests of the Blue Ridge Mountains is considered somewhat more important than sheltering effects leading to an estimated 5-percent orographic increase.

Areal distribution

The adopted isohyetal patterns are shown in figures 4-14 through 4-17. For subbasin 13 the isohyetal pattern of the storm of July 13-17, 1916 (fig. 4-11) supports the adopted isohyetal pattern. The adopted patterns for subbasins 13 and 17 have been adjusted by consideration of wind barrier limitations. A postulated south to southeast inflow wind for optimum rain in these subbasins tends to place more rain east of the Smoky Mountains in subbasin 13 than west of them. In the case of subbasin 17, the postulated south to southeast inflow wind tends to place spillover rain just west of the ridge of the Blue Ridge Mountains.

The adopted patterns for subbasins 14, 15 and 16 are based on a smooth 2-yr. 24-hr. analysis and a postulated southeast inflow wind for optimum rain over these subbasins. A broad-scale sheltering factor of minus 10 percent was applied to the westernmost isohyetal label for each subbasin. This becomes just a token adjustment for subbasins 15 and 16 but represents an additional appreciable adjustment for subbasin 14, where broad-scale sheltering is an important factor. It recognizes that the situation enhancing rainfall over the slopes in the eastern portion of the basin cannot

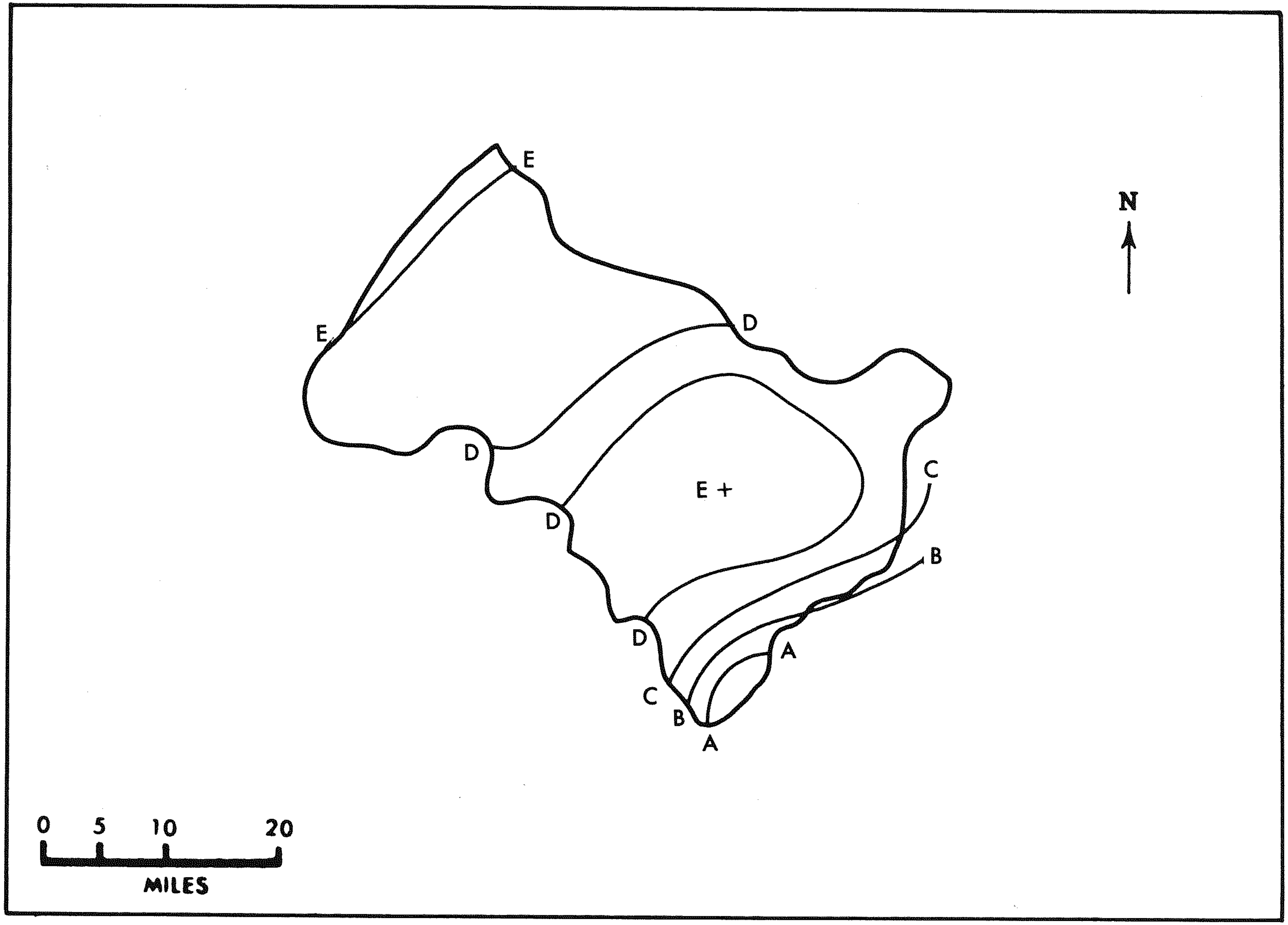


Figure 4-14. Isohyetal pattern for subbasin 13

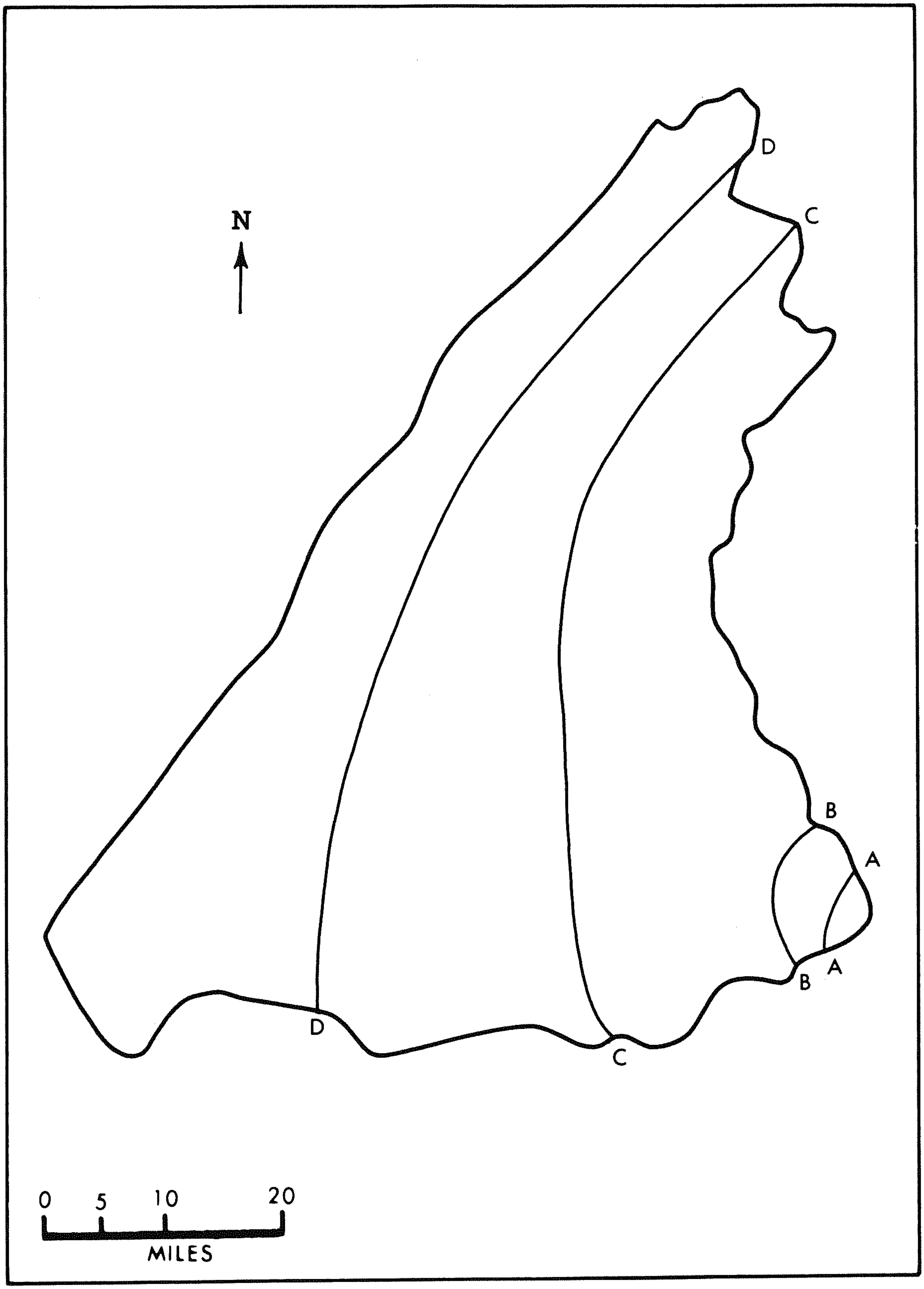


Figure 4-15. Isohyetal pattern for subbasin 14

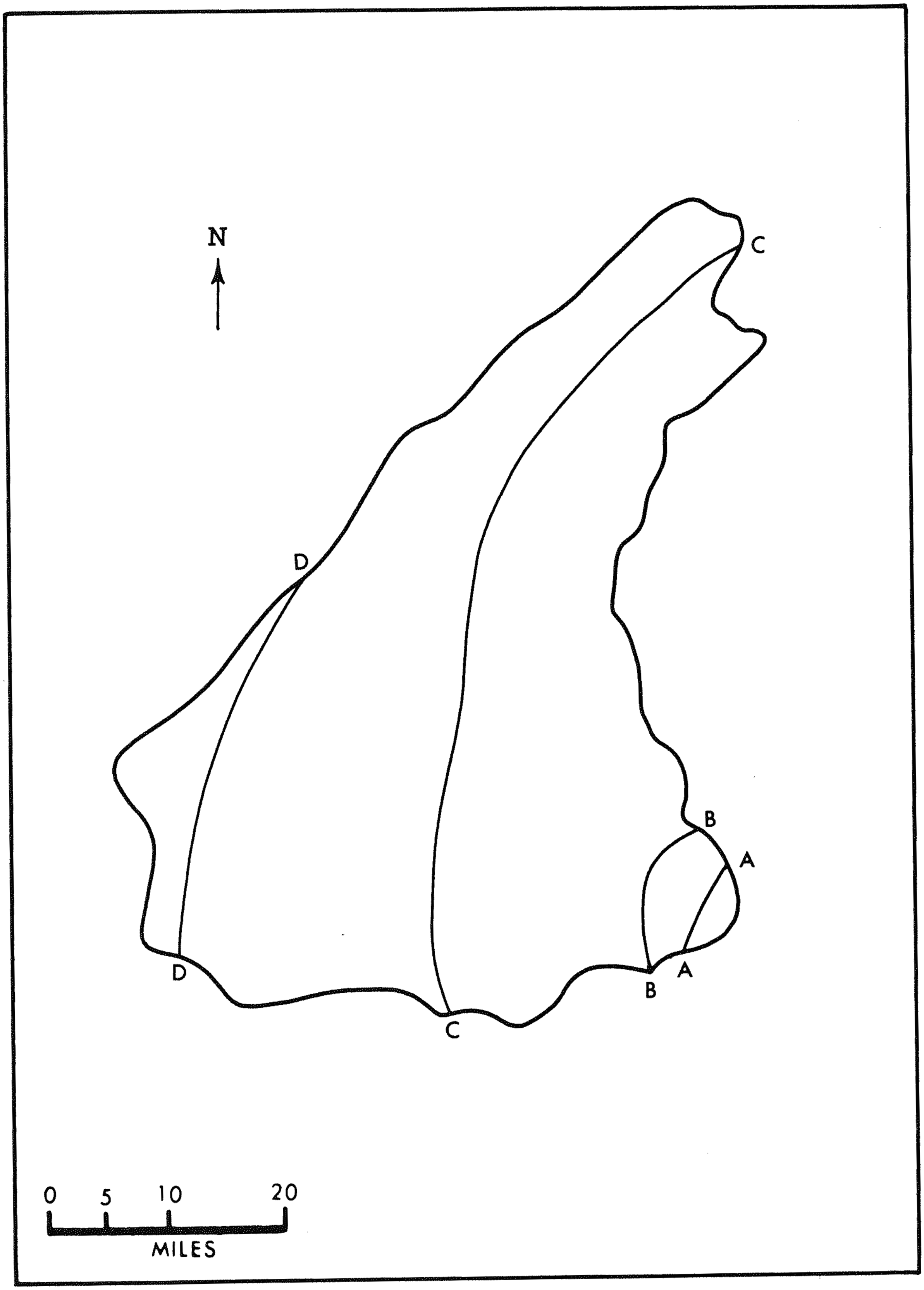


Figure 4-16. Isohyetal pattern for subbasin 15

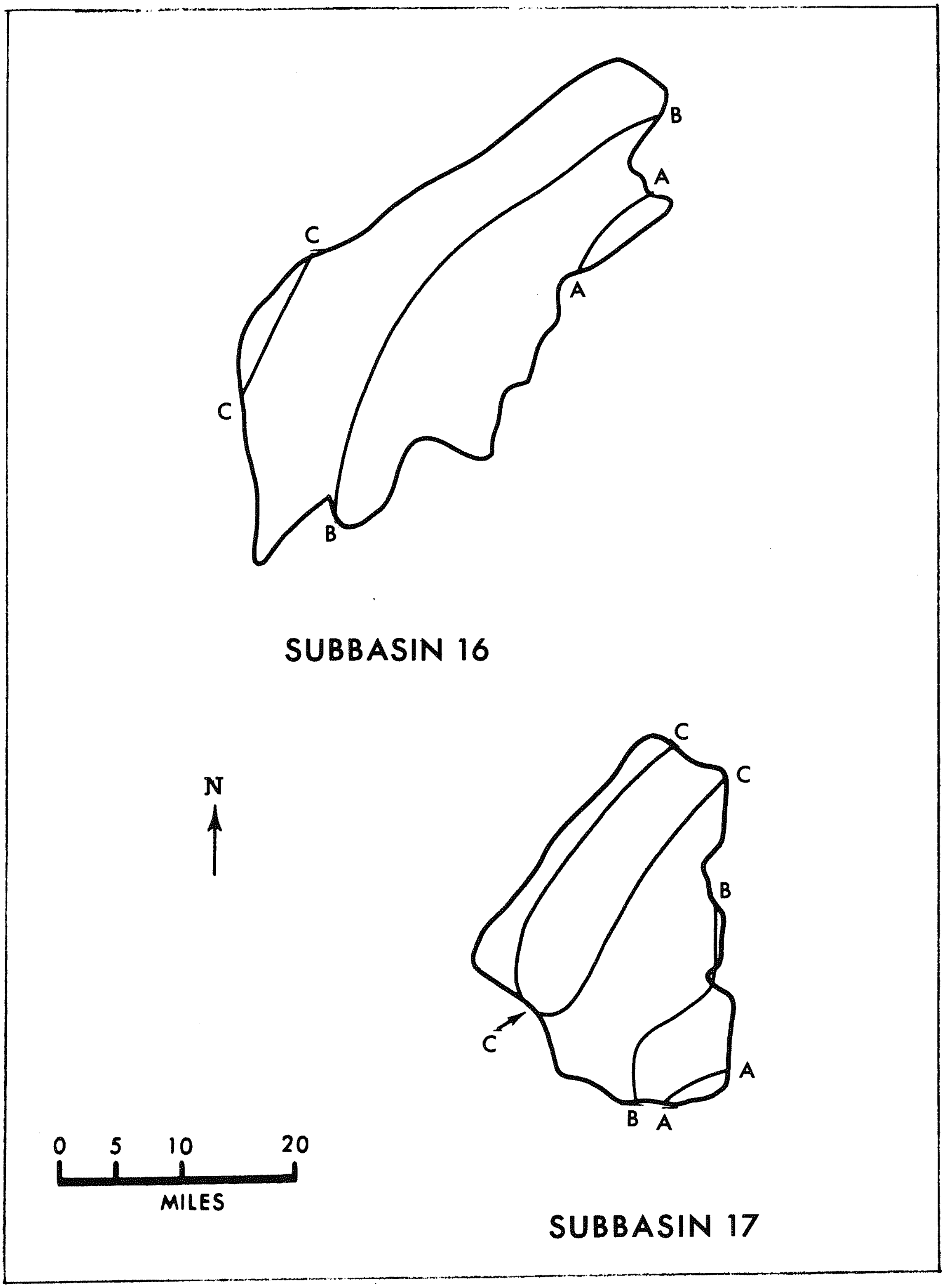


Figure 4-17. Isohyetal pattern for subbasins 16 and 17

simultaneously produce a similar effect in the western portion of the basin. Isohyetal values are given in table 4-3.

Maximum 3-hour increment. The maximum 3-hr. increment is obtained by multiplying the maximum 6-hr. increment by 0.71 for subbasin 13, by 0.66 for subbasin 14, by 0.69 for subbasin 15, by 0.74 for subbasin 16 and by 0.75 for subbasin 17 (fig. 3-27).

E. CLINCH RIVER DRAINAGE

Adopted values

Subbasins 1C, 2C, 3C, 4C and 5C of the Clinch River drainage are shown in figure 4-1. The ridges within the drainage are relatively low and generally parallel the direction of inflow of moisture during extreme storms. Therefore topographic effects within the basin are minimal or compensating and were not applied in determining rainfall volume or distribution. The broad-scale sheltering effects of the Great Smoky Mountains and Cumberland Plateau result in a net reduction of rainfall volume compared to more favorably exposed areas.

Probable maximum and TVA precipitation estimates for the five subbasins are shown in table 4-1 (E) by average depths for the indicated durations. The adjustment factors from 1000 square miles to subbasin areas for both PMP and TVA precipitation are: 1.05 for subbasin 1C; 1.16 for subbasin 2C; 0.83 for subbasin 3C; 0.94 for subbasin 4C and 1.09 for subbasin 5C.

A minus 5-percent sheltering adjustment was applied over subbasins 1C, 3C and 4C, and a minus 8 percent over subbasins 2C and 5C. These adjustments are for broad-scale sheltering by the Great Smoky Mountains and Cumberland Plateau.

Areal distribution

An elliptical isohyetal pattern (fig. 3-23) is provided for rainfall distribution. Within-basin depth-area relations were determined in accordance with generalized procedures described in Hydrometeorological Report No. 40 /3-7/. Isohyetal values given in table 4-3 are for the first three 6-hr. periods of the 72-hr. storm. For the 4th through 12th 6-hr. periods, uniform areal distribution is recommended. The major axis of the elliptical pattern should coincide with the major axis of the basin index study. Uniform areal distribution is recommended over subbasin 2C for all rain periods.

Maximum 3-hour increment. The maximum 3-hr. increment is obtained by multiplying the maximum 6-hr. increment by 0.74 for subbasins 1C, 2C and 5C, by 0.66 for subbasin 3C and by 0.72 for subbasin 4C.

F. SPECIFIC ESTIMATES FOR WESTERN BASINS

Adopted values

The PMP and TVA precipitation estimates for the western basins were adopted prior to the development of the generalized procedure for obtaining estimates for basin areas from 100 square miles to 3000 square miles. Therefore, these estimates will be comparable but not identical to those that can be obtained by using the generalized procedure. The western basins for which estimates are given are shown in figures 4-18, 4-19 and 4-20.

PMP and TVA precipitation estimates for the 1208-sq. mi. Duck River drainage above Columbia, Tenn., the 798-sq. mi. Emory River drainage above Harriman, Tenn., the 518-sq. mi. Obed River drainage above Nemo, Tenn., and the 1640-sq. mi. Caney Fork River drainage above Great Falls, Tenn., are given in table 4-1 (F). The given values are for average depths over the basin area for the indicated durations.

Transposition and adjustment of storms is the basis of the adopted values. The adopted values are consistent with other estimates made for similar basins in nearby states. For the PMP, the storms are moisture maximized and liberally transposed. TVA values are based on observed storm values not maximized for moisture and subjected to more restricted transposition of storms.

Areal distribution

An elliptical isohyetal pattern (fig. 3-23) is recommended for areal distribution. Within-basin depth-area relations were determined in accordance with generalized procedures described in Hydrometeorological Report No. 40 /3-7/. This procedure gives labels for isohyets for successive 6-hr. periods such that the appropriate depth-area relations are maintained. Table 4-3 lists the isohyet labels for the first three 6-hr. periods of the 72-hr. storm. Uniform areal distribution is recommended for the 4th through 12th 6-hr. period (3d through 12th 6-hr. period for the Caney Fork drainage). The isohyetal pattern should be centered over the basin in question, with the major axis coincidental with the major axis of the basin.

Estimates for the Duck River drainage above Normandy site, Tennessee

Probable maximum and TVA precipitation estimates for the 196-sq. mi. drainage above Normandy site, Tenn., are given in table 4-4.

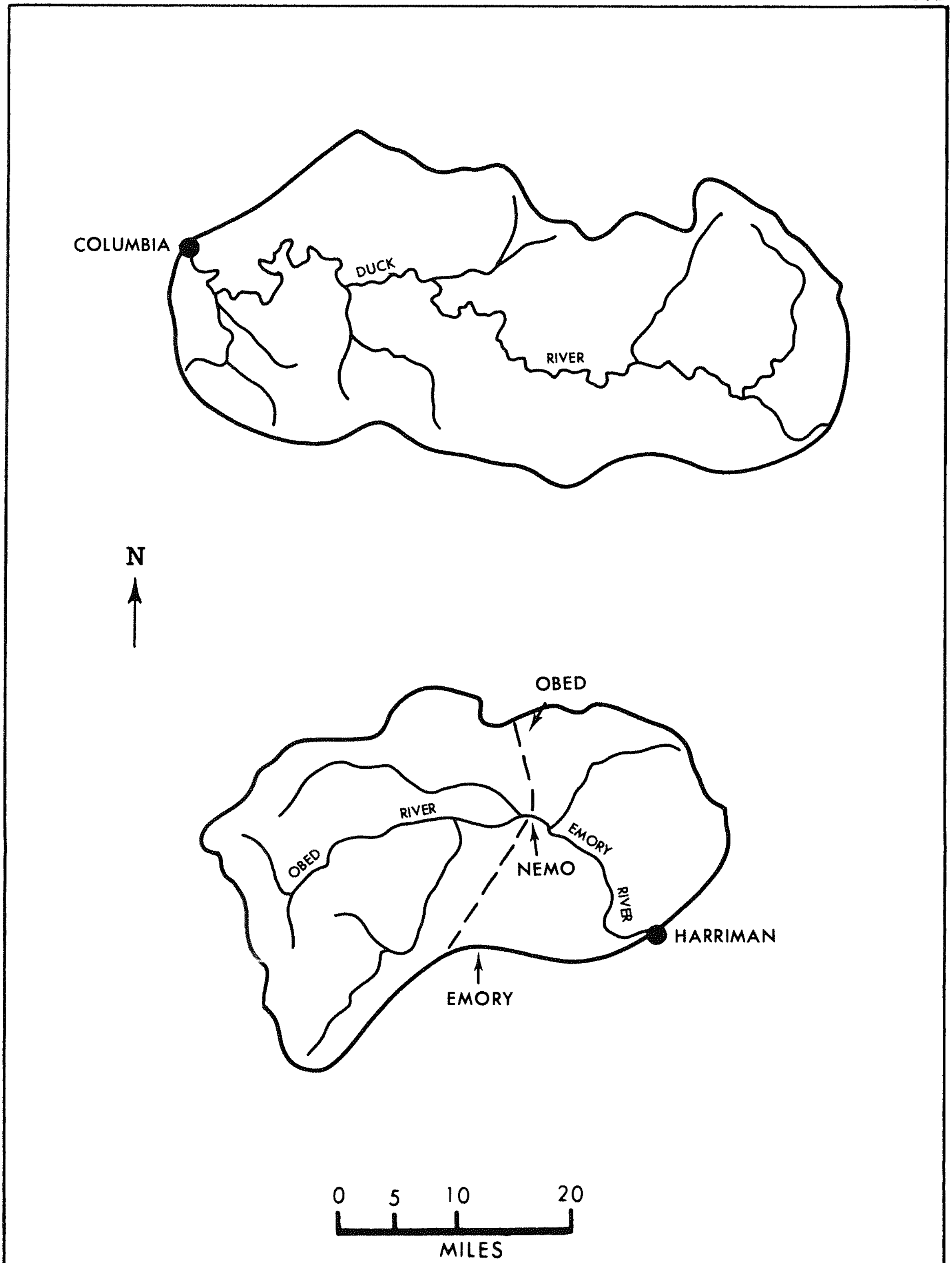


Figure 4-18. Duck River drainage above Columbia, Obed River drainage above Nemo and Emory River drainage above Harriman, Tenn.

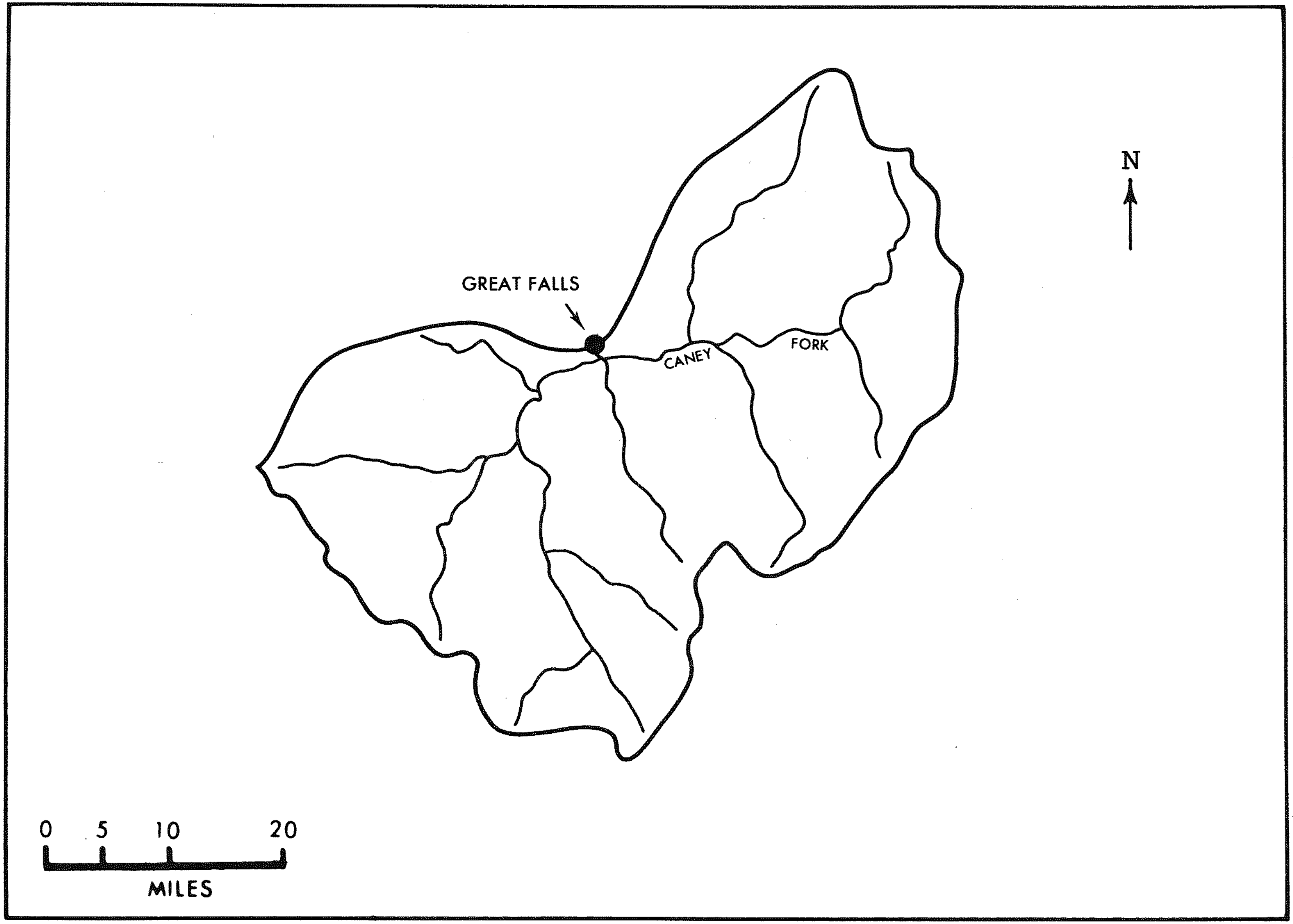


Figure 4-19. Caney River drainage above Great Falls, Tenn.

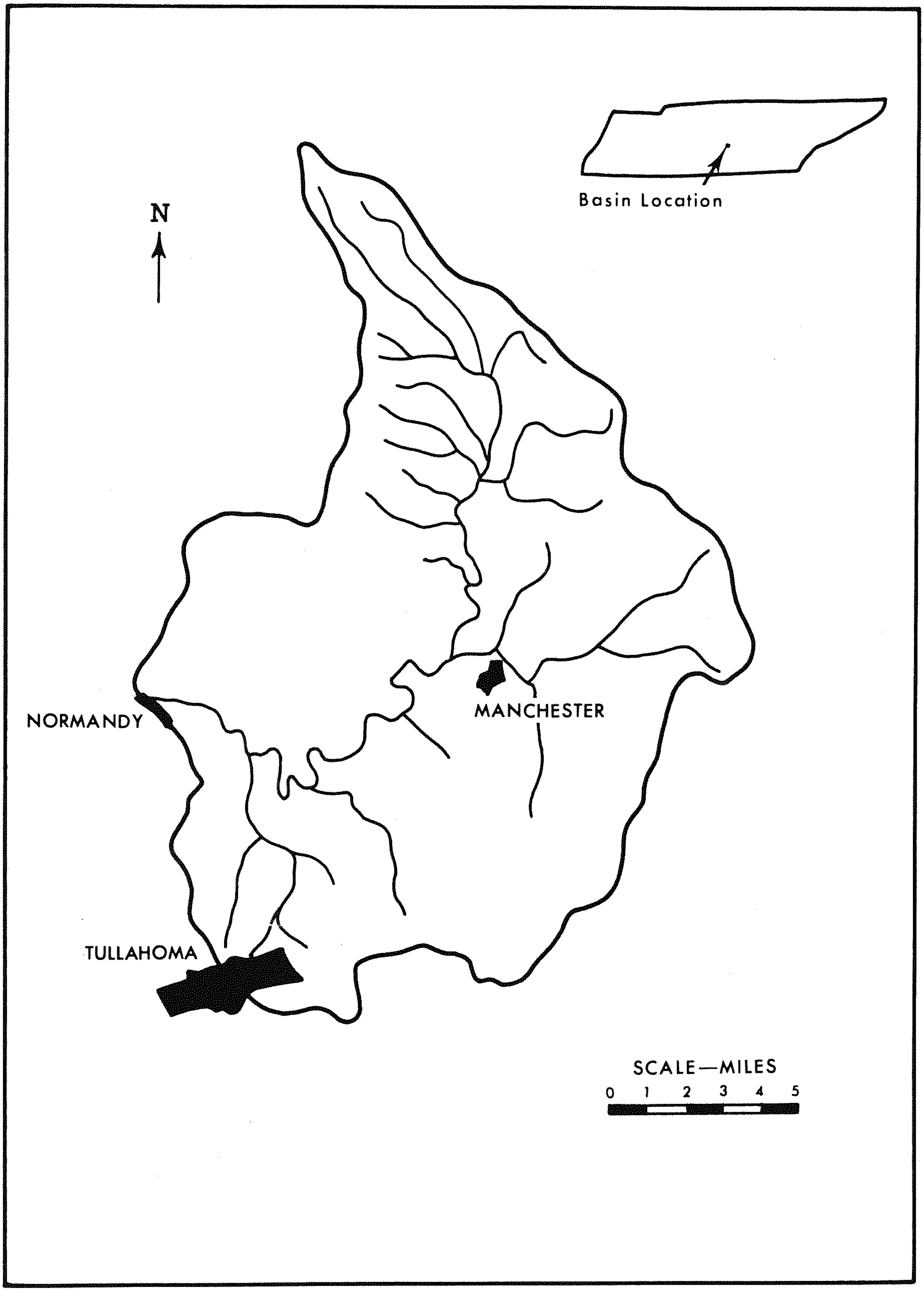


Figure 4-20. Duck River drainage above Normandy Site, Tenn.

Table 4-4. Accumulated PMP and TVA Precipitation (in.), Duck River Drainage above Normandy site, Tenn. (196 sq. mi.)

	Duration (hr.)								
Precip. Type	1	2	3	4	5	6	12	18	24
24-hr. PMP	8.2	11.1	13.5	15.2	16.5	17.6	20.9	22.6	24.0
3-hr. TVA	4.7	6.4	8.0						
6-hr. TVA	4.3	5.9	7.3	8.6	9.7	10.6			
12-hr. TVA	3.4	5.1	6.5	7.6	8.4	9.1	12.5		
24-hr. TVA	2.7	4.1	5.4	6.3	7.1	7.7	10.7	12.9	14.7
	Duration (hr.)								
	6	12	18	24	36	48	60	72	
72-hr. PMP	17.6	20.9	22.6	24.0	25.9	27.2	28.2	29.1	
72-hr. TVA	6.9	9.9	12.0	13.4	15.0	16.0	16.8	17.4	

The method as described in the small basins estimate (chapter II) was used for the 24-hr. storm estimates. A basic 6-hr. 5-sq. mi. PMP value of 24.7 inches was used. Generalized depth-area-duration curves were used to preserve consistency between the estimates in table 4-4 and the previous western basins estimates and were used to determine values between 24-hr. and 72-hr. durations in table 4-4.

Uniform areal distribution is recommended because of the relatively small size of the basin.

Time distribution applicable to all estimates

Six-hour increments of PMP and TVA precipitation are obtained by taking differences in tables of accumulated PMP and TVA precipitation values. The user may exercise his judgment in arranging these increments in a critical sequence, in accordance with rules given in section B of chapter III under "time distribution."

Chapter V

ANTECEDENT RAINFALL

Introduction

Antecedent rains are important in determining the size of a flood that occurs on a particular basin. Hydrometeorological Report No. 41 /1-2/ develops antecedent rainfall criteria for large-size basins above Chattanooga. Here our concern is with antecedent rainfall both for small basins less than 100 square miles, and for intermediate-size basins ranging up to 2000 to 3000 square miles. For small basins, antecedent rainfall is applied to maximum 24-hr. rains, while for the intermediate-size basins, conditions prior to 3-day maximum rains are required.

The antecedent rainfall amounts, at the TVA precipitation level, are intended to be conditions that normally occur and are selected with the intent that their use does not change the probability of the total event. Thus, if a 3-day antecedent rain is added to a 3-day TVA rain with three intervening rainless days, the intention is that the probability of the 9-day event is about the same as that of the 3-day TVA precipitation event. When adopting antecedent conditions for the PMP storm, the condition of equal probability is relaxed.

It will be demonstrated later that some prior rainfall within a few days of a large storm is commonly experienced.

The study of antecedent rainfall was broken into two separate studies: (A) rainfall antecedent to 24-hr. intense small-basin storms, and (B) rainfall antecedent to 3-day PMP and 3-day TVA precipitation for larger basins.

Antecedent criteria presented in this chapter are intended to cover all basins encountered in application of the generalized procedure of chapter III. For simplicity of application and to avoid compounding of probabilities, the antecedent rainfall should be uniformly distributed over the basin.

A. CONDITIONS ANTECEDING MAXIMUM 24-HOUR RAINFALL

Data. From the months of June through October for the period 1937-1965, daily rainfalls of over 5 inches and over 7 inches were selected from over 600 stations in the Tennessee River watershed. Of the 168 cases exceeding 5 inches, June had the lowest number of cases with 17 and September the highest with 45. The rains during the 5 days prior to the day of maximum rainfall were summarized both for cases exceeding 5 inches and for the smaller number of cases exceeding 7 inches.

Another set of data consisted of high daily rains within two exceptionally rainy months in the Tennessee River watershed, August 1901 and July 1916. In these two months all stations with daily rainfall of 4 inches or more were summarized, and the rainfall for each of the 5 antecedent days tabulated. There were 53 cases meeting the 4-inch or more criteria.

A third set of data are the rains antecedent to extremely intense summer rainfalls in and near the Tennessee River watershed. These are perhaps the best indicators for setting rains antecedent to maximum 24-hr. values. One problem, however, is that the most intense rains usually turn up as a result of bucket surveys and are therefore at locations where the rains for previous days are not reported. However, for 10 such rains the average antecedent rainfall could be estimated from nearby regularly reporting stations.

In addition to the 3 sets of data above, frequency analyses were made of daily rains at 4 stations for the months of May through September using 20 years of data.

Analyses. Of the 10 intense Tennessee River watershed rains for which antecedent conditions could be evaluated, most were preceded by 2 to 3 days of showery conditions. This appeared to be part of the process of building up to the extreme rain. Antecedent rainfall did not appear to favor significantly any one of the 3 days more than the other two. The average of the daily antecedent rainfall was 0.26 inch on each of the 3 days.

Figure 5-1 shows the results of analyses of the moderately heavy rain situations from the 1937-1965 survey and the two rainy months. Median and upper 10-percentile values resulting from a statistical analysis of each are given. At the median level of the 7-inch threshold data, the amount of first-day antecedent rainfall did not differ significantly from that of the 5-inch threshold data. However, for the rarer event (upper 10-percentile) the first-day antecedent rainfall decreased considerably for the 7-inch threshold compared to the 5-inch.

The 53 cases of daily rainfall greater than or equal to 4 inches in August 1901 and July 1916 are referred to as "rainy months" data in figure 5-1. These have antecedent rains comparable to the previous set except at the upper 10-percentile point on the first antecedent day.

The question of dependence of rainfall events can be resolved in part by comparing median rainfall for all days with the median on days prior to large storms. A frequency analysis of a 20-year daily rainfall record (1941-60) was made at four stations for the months of May through September. Figures 5-2 through 5-4 summarize expected daily rainfalls at three of the stations, Asheville, Chattanooga, and Memphis for various probability levels. The maximum for the 1941-1960 period is also shown. There is a 50 percent probability of no rain for all three stations. The median rainfall one day prior to large daily amounts is 0.25 inch (fig. 5-1). This comparison shows that there is some association of rain one day with the next.

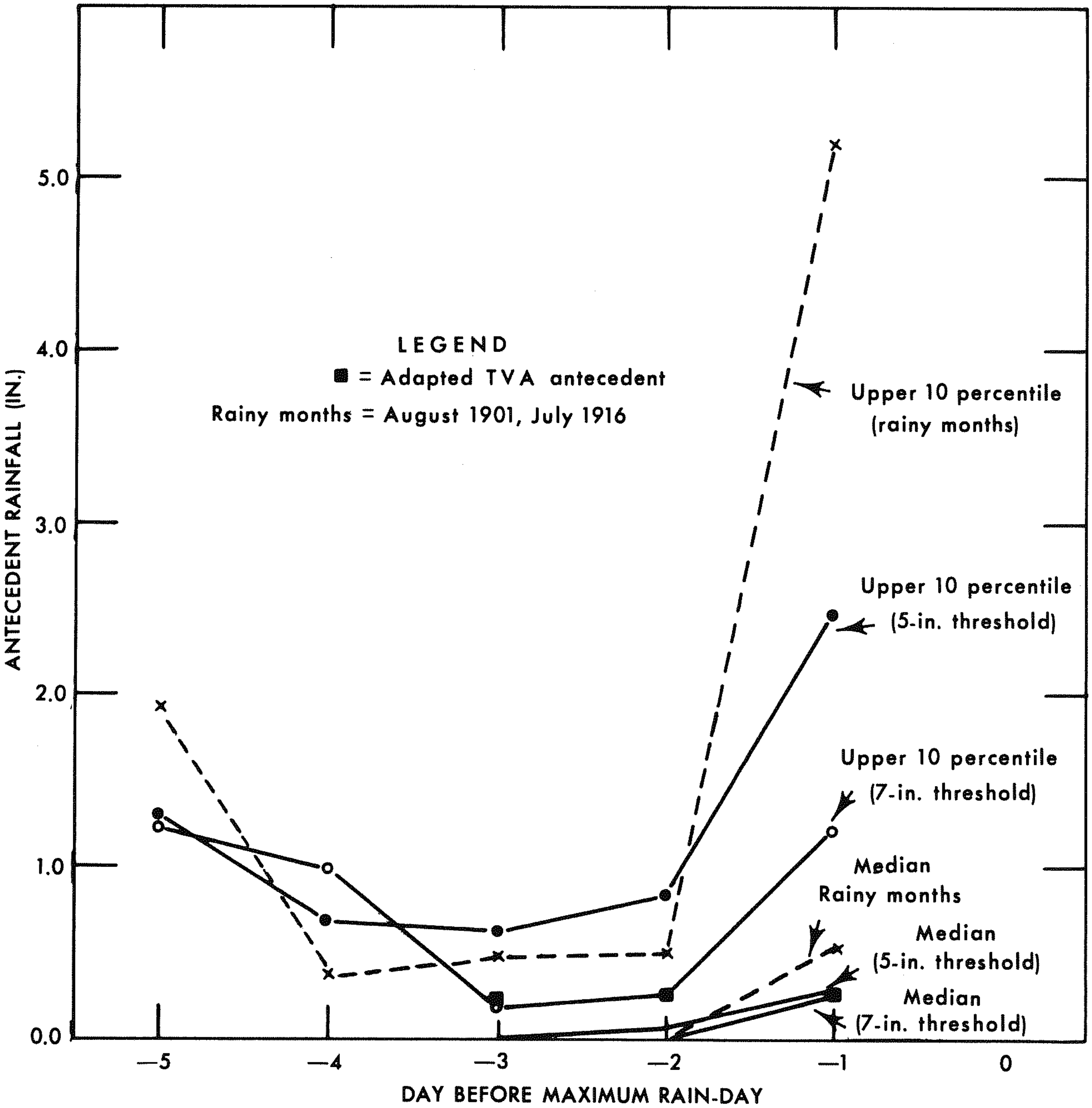


Figure 5-1. Antecedent rainfall of moderately heavy rain situations from 1937-1965

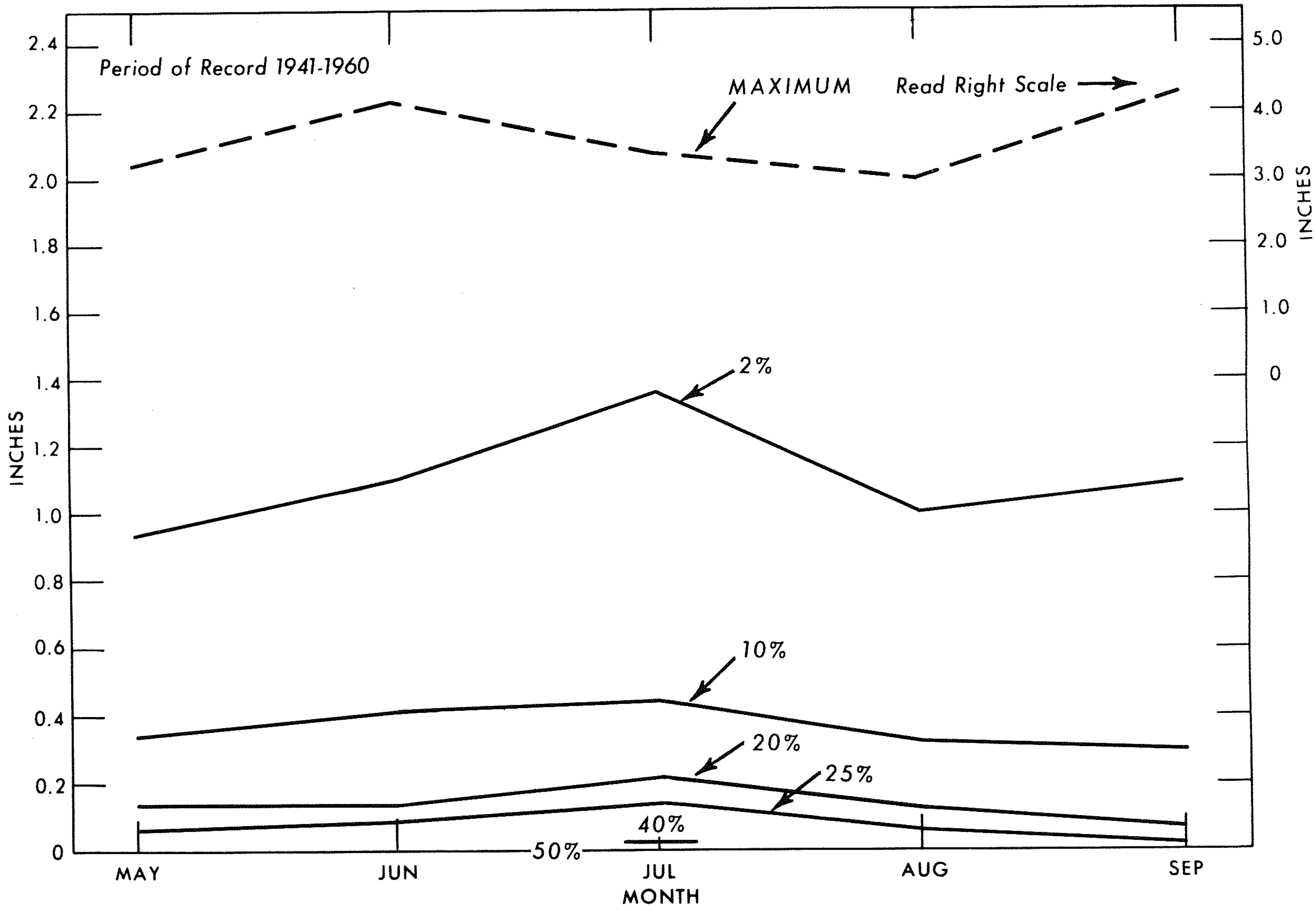


Figure 5-2. Percent chance of daily rainfall at Asheville, N. C.

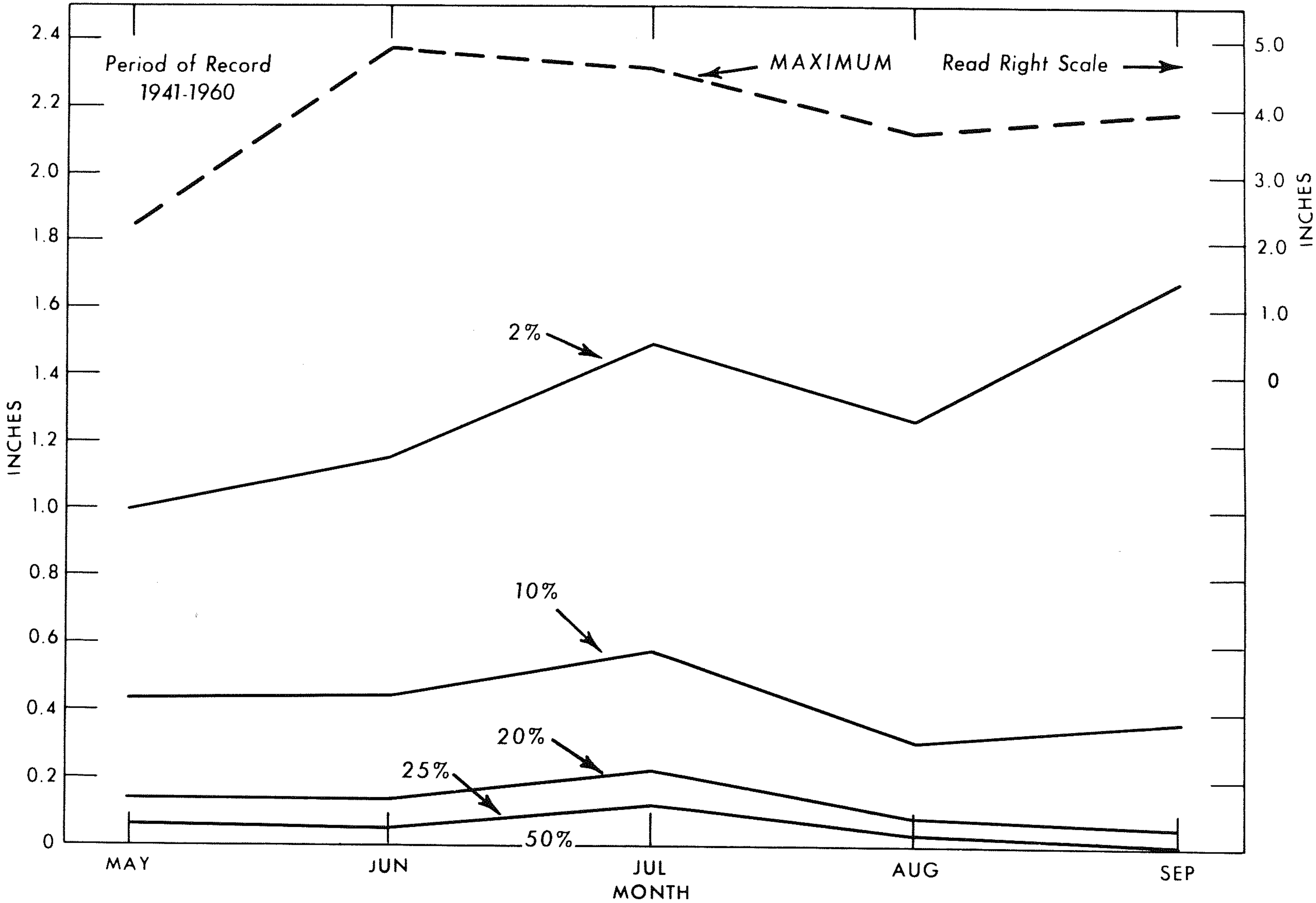


Figure 5-3. Percent chance of daily rainfall at Chattanooga, Tenn.

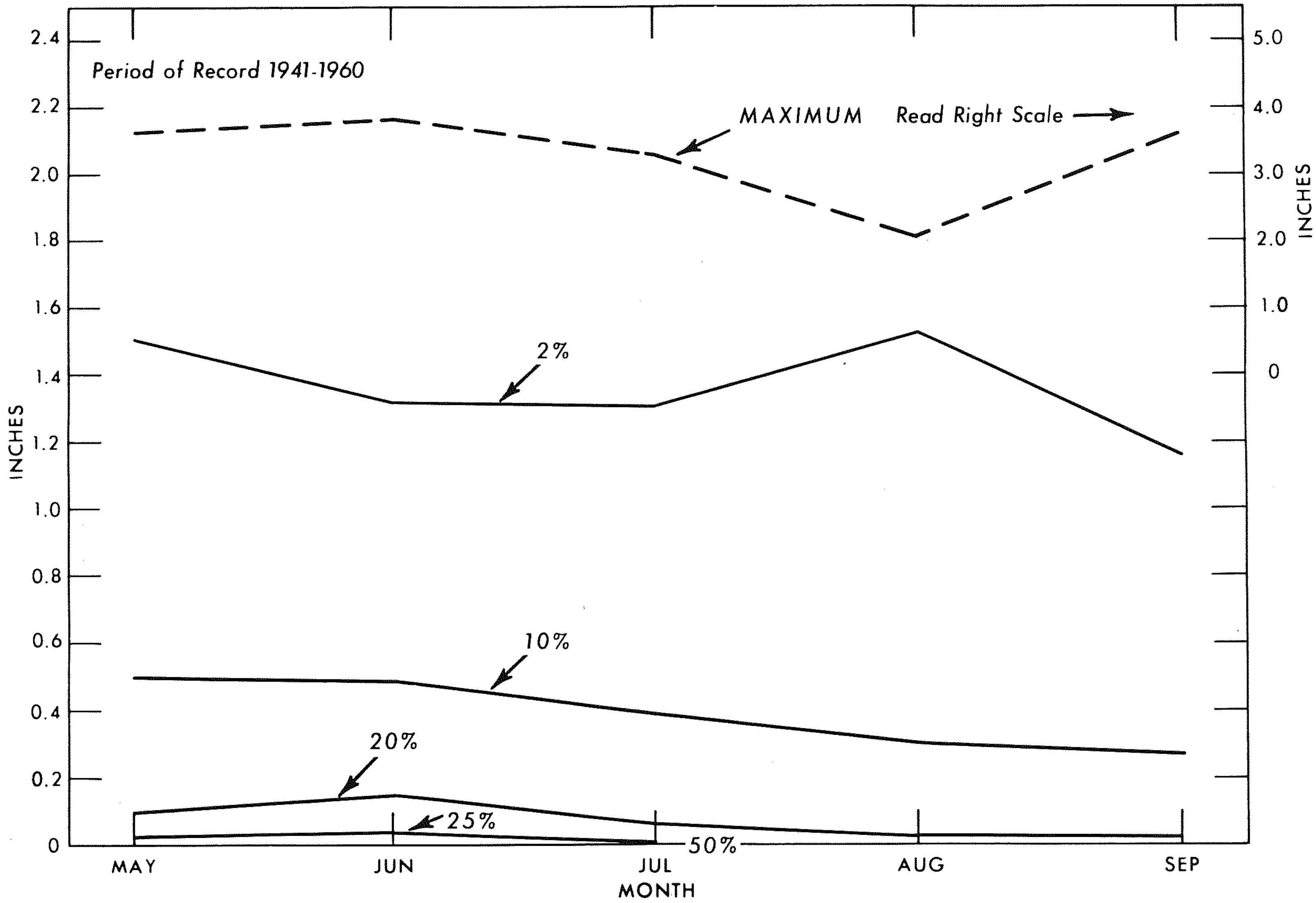


Figure 5-4. Percent chance of daily rainfall at Memphis, Tenn.

The interdependence is strong at the 10 percentile level. Table 5-1 lists the upper 10-percentile values from all daily rainfalls at four stations. The May through September average of the upper ten percentile is 0.45 inch, significantly different from the 10-percentile first-day antecedent value of 1.2- and 2.5-inch for the 7- and 5-inch thresholds, respectively.

The analysis discussed above supports the conclusion that rainfall prior to the TVA 24-hr. storm will tend to exceed the normal. One reason for this, physically, is persistence of a broad-scale synoptic situation favorable for heavy rains. This results in the influx of high moisture into the area so that some shower activity is likely to precede a heavy rain situation.

Table 5-1. Upper Ten Percentile of Average Daily Rainfall (in.) (1941-1960)

Station	May	June	July	August	September
Asheville	.34	.41	.44	.32	.29
Chattanooga	.43	.44	.57	.30	.36
Memphis	.50	.49	.39	.30	.27
Tray Mtn.	.72	.51	.90	.54	.64
Mean	.50	.46	.56	.36	.39

May-September mean 0.45

Adopted values antecedent to maximum 24-hr. rain

Antecedent rainfall of 0.25 inch for each of two antecedent days preceding the 24-hr. TVA rainfall is recommended for application to all small basin estimates. Such magnitudes are supported both by the conditions preceding extreme summer short-duration rainfalls in the Tennessee River watershed and the median antecedent conditions resulting from the greater quantity of less extreme but still large rainfall amounts.

For PMP storms where there is less concern about making the event less probable more extreme antecedent possibilities are appropriate. An assessment of the highest observed storm rainfall amounts for durations of 48 and 72 hours provides guidance in selecting antecedent rainfall to go with 24-hr. PMP over small basins. Hydrometeorological Report No. 33 /1-1/ provides such guidance.

A smooth extension of the data in HMR 33 to 72 hours, combined with a 2 to 1 apportioning of antecedent vs. subsequent (following the precedent of HMR 41) results in an adopted 10 percent increment for the first day antecedent to the 24-hr. PMP and 2 percent for the second antecedent day. These incremental percentages are to be applied to the 24-hr. PMP for the range of basin sizes of 5 to 100 square miles.

B. CONDITIONS ANTECEDING MAXIMUM 3-DAY RAINFALL

Introduction

For basins with drainage areas of several hundred to several thousand square miles, sequences of recurring rainfall become increasingly important. With the broad-scale meteorological controls remaining relatively fixed, storms may readily repeat over approximately the same area. For very large basins, the January 1937 rainfall in the Tennessee River and Ohio River watersheds is an outstanding example of such an event /3-2/. For more moderate-size basins in the mountainous eastern portion of the Tennessee River watershed /2-2/, the repeating, hurricane-associated rainfall in July 1916 provides an excellent example.

The intent in this section is to develop antecedent rainfall criteria applicable to maximum 3-day rains at both the PMP and TVA precipitation levels.

Rainless interval

Previous investigations by the Hydrometeorological Branch /1-2/, /3-2/, /5-1/ have established that an interval of about 3 days between heavy flood-producing storms that cover sizable areas is common enough that it is an appropriate criterion here. A 3-day rainless interval is adopted preceding both the PMP and TVA maximum 3-day rain. The relative rarity of the total rainfall event for PMP vs. TVA rainfall is handled by changing the magnitude of the antecedent rainfall rather than using a varying rainless interval.

HMR 41 /1-2/ is concerned with very large basins. Here our concern is with more moderate-size basins. Certain conclusions from HMR 41 are applicable to such basins. However, additional data need to be evaluated to adjust the results to the basins covered by the present report.

Data sources

Long-duration (10- to 13-day) rains were compared in magnitude to their maximum 3-day and 1-day rains. Several sources of rainfall data were used to form these ratios including: (1) hypothetical storm sequences in previous Hydrometeorological Reports /1-2/, /3-2/, /5-2/; (2) maximum rainfalls and rainfall-frequency data for selected durations /2-13/, /5-3/; (3) important summer storms giving heavy rains over sizable areas and; (4) rainfall anteceding maximum flood-producing storms of 30 basins in the Tennessee River watershed.

Storms of January 1937. The record-breaking storm of January 1937 provides some information on long duration rain characteristics over fixed areas. The 3-day rains /2-6/ and 11- to 3-day and 15- to 3-day rain ratios in this storm are listed in table 5-2.

Table 5-2. Durational Rain Ratios in January 1937 Storm

Area (sq. mi.)	3-Day Rain (in.)	11- to 3-Day Ratio	15- to 3-Day Ratio
500	11.0	1.85	1.95
1000	10.7	1.90	1.99
2000	10.3	1.96	2.08
5000	9.6	1.94	2.08

Storms of May 1943. An outstanding sequence of spring storms is provided by the Warner, Okla. (May 6-12, 1943) and the Mounds, Okla. (May 12-20, 1943) storms /2-6/. The intense rain centers in these storms were less than 200 miles apart. To assume regional coincidence is a maximizing factor of undetermined degree. Nevertheless, it is instructive to make a comparison of ratios for these warm season storms to those for the Ohio Valley winter storm of January 1937. Table 5-3 shows the rain ratios.

Table 5-3. Durational Rain ratios in Two May 1943 Storms

Area (sq. mi.)	3-Day Rain (in.)	11- to 3-Day Ratio	15- to 3-Day Ratio
500	19.4	1.76	1.76
1000	18.0	1.82	1.82
2000	16.5	1.83	1.83
5000	14.4	1.86	1.87

Station 10-day rains. Maximum 10-day rains at Asheville, Memphis, Birmingham and Louisville provided additional data used to help evaluate antecedent rains. From the total period of record, 42 cases of 10-day rains in excess of 5 inches were found and summarized according to the magnitude of the 3-day rain. Table 5-4 shows this summary.

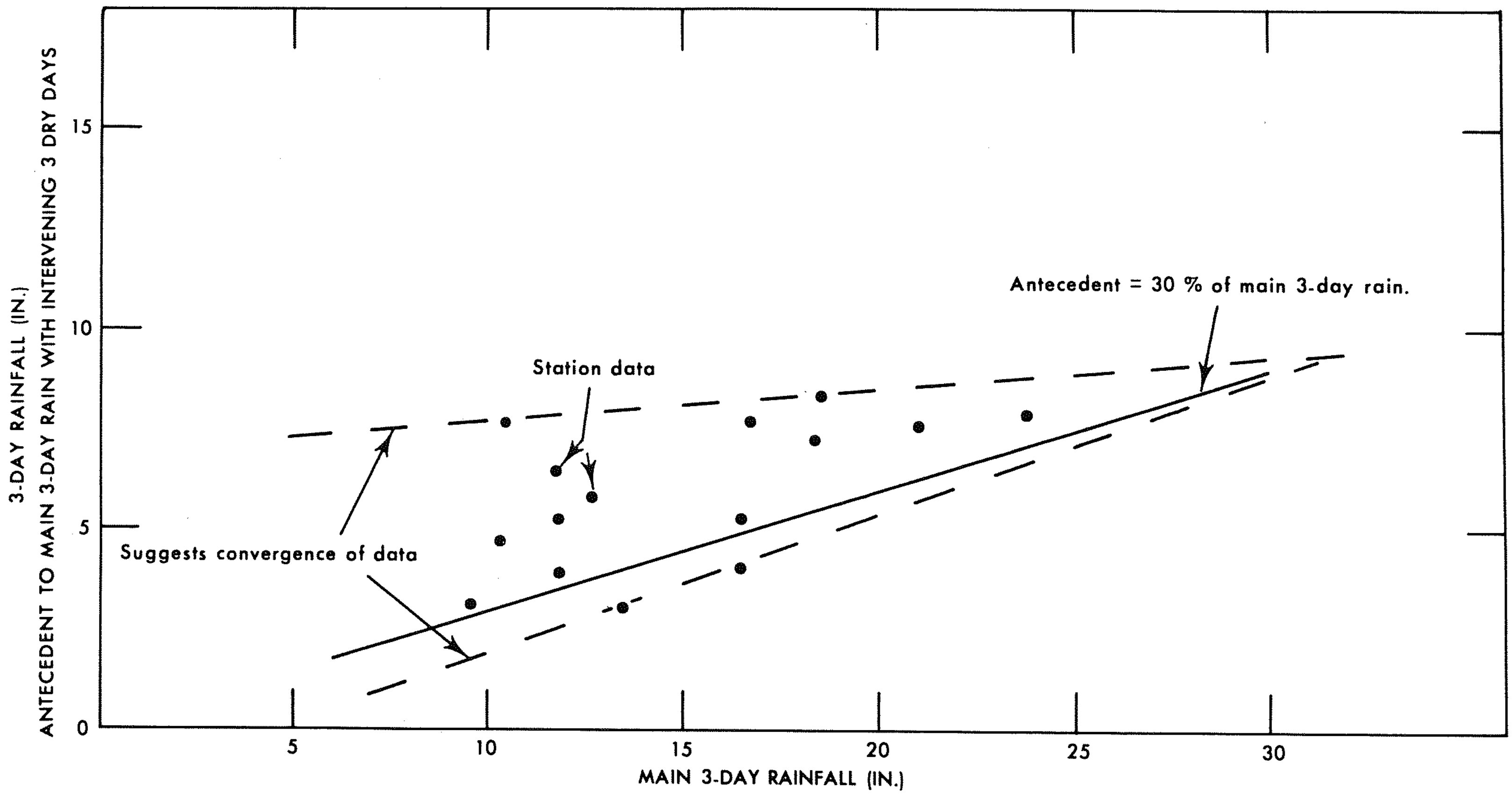


Figure 5-5. Antecedent rainfall preceding Altapass storm of July 13-17, 1916

Table 5-4. Comparison of Highest 3-Day Rains Within Maximum 10-Day Rains

Maximum 3-Day Rain (in.)	Number of Cases	10-Day Rains Minus 3-Day Rain	
		Average (in.)	Range (in.)
3-4	12	2.2	1.5 - 3.3
4-5	10	1.8	0.9 - 2.5
5-6	12	1.6	0.0 - 6.1
>6	8	1.8	0.0 - 3.1

Discussion of data

In assessing the significance of the ratios in table 5-2, the magnitude of the 3-day rainfall should be kept in mind. Although large, these values fall considerably short of the magnitude of PMP values of this report for summer rainfall. The resulting ratios therefore should be considered as too high for application to summertime 3-day PMP and for 3-day TVA precipitation.

The ratios in table 5-3 mean more than those of table 5-2 for PMP events because of the larger 3-day rains. However, an average ratio of about 1.8 is of centers which did not coincide. It is important to make allowance for geographical separation particularly for TVA precipitation where increased compounding of probabilities is not desired.

Regarding the data in table 5-4, interestingly, the largest incremental increase in rain from 3 to 10 days (3.1 in.) for 3-day rains greater than 6 inches was associated with the largest 3-day rain (12.3 inches observed at Birmingham, Ala. in July 1916). This July 1916 storm is singled out as the storm type for the summertime TVA precipitation producer in the Tennessee River watershed [HMR 41, p. 47].

The 10- to 3-day ratio in the July 1916 storm was 1.25 at Birmingham. Among the cases in table 5-4 with 3-day rains in excess of 6 inches was a Birmingham case in October 1918 with a 10- to 3-day ratio of 1.44. These ratios are to be compared to a mean statistically-determined ratio of 1.30 [2-13, 5-3].

The outstanding July 1916 rain at Birmingham was due primarily to a decadent tropical storm that moved northward from the Gulf of Mexico. Farther north in Tennessee and North Carolina, this storm was followed by heavy rains from the Altapass, N. C., hurricane. The occurrence of these two successive storms provides excellent data for assessing antecedent rain capabilities for Tennessee basins. Data were summarized for stations where the Altapass storm produced 3-day rainfall amounts of 10 inches or more. Fifteen stations in North Carolina met this criterion. Antecedent 3-day amounts (preceding 3 intervening "dry" days) were plotted vs. the primary (Altapass storm) amounts. These are shown in figure 5-5 indicating that a 30 percent 3-day antecedent rain with three intervening dry days is realistic. The data suggest a convergence toward this value for high rainfall intensity although this possibly is due to the smaller amount of data in the high 3-day rainfall category.

The average station daily rainfall during the three days between heavy rains was only 0.17 inch. The adopted 3-day rainless interval is based on such rather insignificant 3-day rain amounts.

An additional check was based on data for the October 1964 storm, which centered in the headwaters of the French Broad watershed. In this storm low-level convergence in a frontal zone was associated with considerable rain followed by additional large rain amounts from the remnants of hurricane Hilda. This sequence comprised two heavy rains separated by three relatively rainless days. The synoptics of this storm are covered in chapter III.

Tennessee Valley Authority antecedent rainfall study

A separate study of antecedent rainfall associated with flood situations in the Tennessee River watershed was done by the Tennessee Valley Authority /5-4/. Most of the following paragraphs come directly from the TVA report.

The study was confined to the 41,900-sq. mi. Tennessee River watershed. The data evaluated consisted of rainstorms which produced the ten largest floods of record at 47 gauged watersheds. The largest flood was defined by its peak discharge. The watersheds studied were selected from those having long stream gaging records with particular interest in areas from 100 to 3000 square miles where 3-day storm events are likely to control. Within time and data limitations the watersheds were selected so as to define possible variations with watershed area and geographic location. Drainage areas varied from 13 to 2557 square miles with 28 of the 47 investigated being in the 100- to 1000-sq. mi. range.

The basin rainfall which produced a flood and the antecedent rainfall were estimated initially by taking an unweighted average of a selected sample of rain gauges located within or near the watershed. When expanding the initial study Thiessen weighting of all pertinent precipitation data were used to estimate basin rainfall for all added storms. At the same time a selected number of the original storm estimates were reevaluated using all precipitation data and Thiessen weights. Rainfall for 160 of the 459 floods analyzed was computed using Thiessen weights. Although Thiessen weighted estimates of basin rainfall differed somewhat from the unweighted average estimates, the differences were small and did not affect significantly the results for the purposes of this study.

Storm events were divided into three categories: (1) storms of 3 or less days duration with no antecedent rainfall, (2) storms of 6 to 10 days duration with no distinct break, and (3) storms of 3 or less days duration with a distinct period and an antecedent storm. Figure 5-6 shows a typical

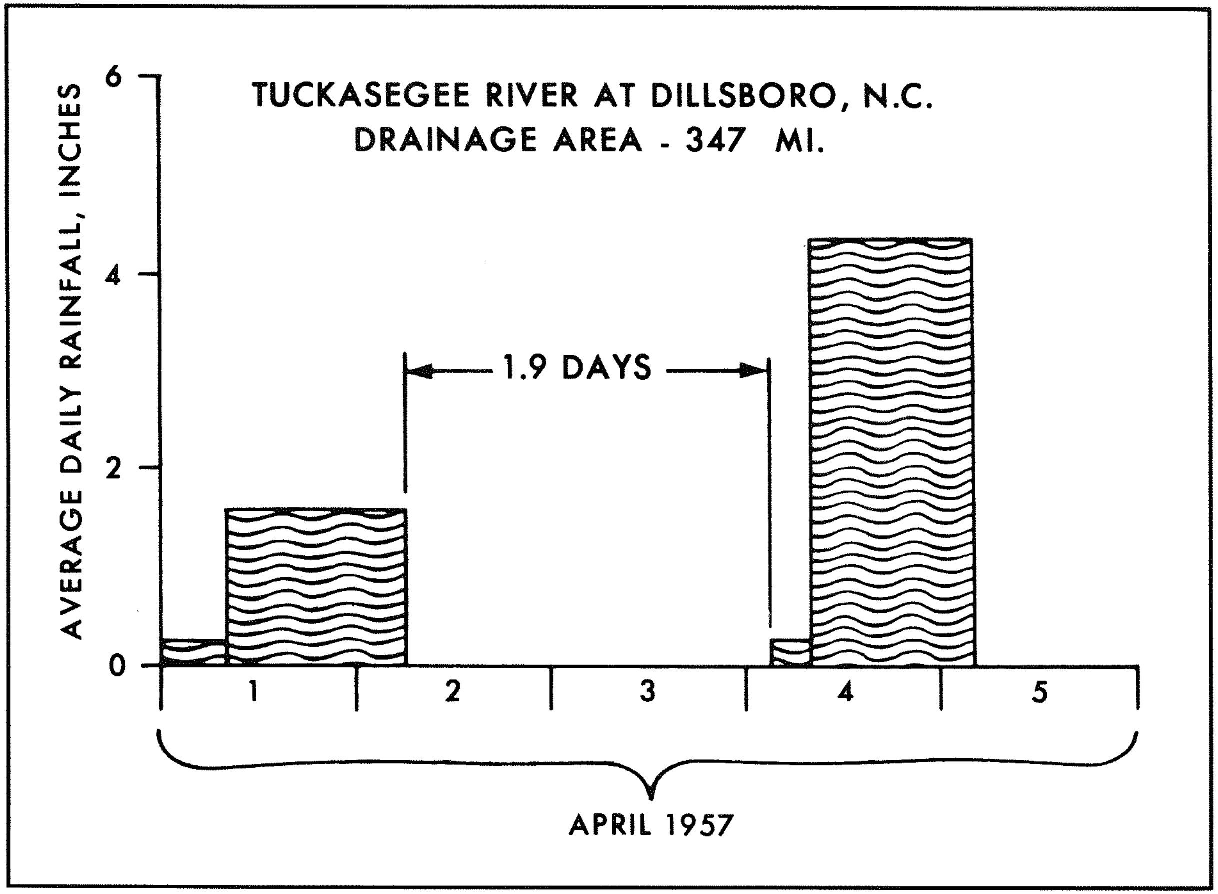


Figure 5-6. Example of storm with antecedent rain

example of a short storm with a distinct antecedent storm. Those events with distinct antecedent storms were analyzed to determine the average length of dry interval between storms and amount of antecedent rainfall expressed as a percentage of the main storm rainfall.

Tables 5-5 and 5-6 summarize the data for the 47 watersheds. Table 5-5 lists data for all watersheds west of the Appalachian Divide and table 5-6 for those to the east. This breakdown was made because of the marked difference in the season of maximum flood occurrences. In the "eastern" basins, 48 percent of all the floods and 70 percent of the highest two floods occurred in the "summer" months of May through October. In the "western" section, only 10 percent of the floods studied occurred in the summer.

In the 22 "eastern" watersheds, 73 percent of the floods were produced by storms with antecedent rainfall. The median antecedent rainfall was 30.5 percent of the main storm. In the 25 "western" watersheds 77 percent of the floods were produced by storms with antecedent rainfall. The average dry interval between storms was 2.8 days, and the median antecedent rainfall was 21.7 percent of the main storm.

Table 5-7 shows the results when the data are stratified by season and by flood and storm magnitude. The seasonal and magnitude stratification of data shows that there is some reduction in antecedent storm rainfall for the larger floods and for the summer floods when antecedent rainfall is expressed as a percentage of the main storm.

This TVA study of flood-producing basin rainfall supports the inclusion of antecedent rainfall with the PMP - and TVA precipitation - level storms and also supports use of a 3-day rainless period between storms.

Conclusions

Based on the analysis of the data discussed above and the independent TVA study, antecedent rainfall of 15 percent of the main storm is considered reasonable for TVA storm events while a 30 percent value is in line with the PMP concept.

Table 5-5

Antecedent Storm Data - Western Watersheds

Location of Watershed	Drainage Area, Sq. Mi.	Years of Record	Number of Floods Studied	Percent in Each Case: Without Antecedent Rain	Percent in Each Case: No Break	Percent in Each Case: With Antecedent Rain	Antecedent Storm: Average Dry Interval, Days	Antecedent Storm: Median Depth, Percent*
North Potato Cr. nr Ducktown, Tenn.	13	33	9	22	11	67	3.7	8.4
Chambers Cr. opposite Kendrick, Miss.	21.1	20	9	11	11	78	2.9	25.0
Chestuee Cr. at Zion Hill, Tenn.	37.8	18	10	0	20	80	2.7	17.4
Duck River below Manchester, Tenn.	107	33	8	0	25	75	2.4	18.1
Sewee Cr. nr Decatur, Tenn.	117	33	10	0	20	80	3.1	17.6
Limestone Cr. nr Athens, Ala.	119	28	10	10	10	80	2.6	27.7
MF Holston River at Sevenmile Ford, Va.	132	26	9	0	22	78	2.4	50.2
Toccoa River nr Dial, Georgia	177	55	10	20	10	70	3.7	5.1
Piney River at Vernon, Tenn.	193	42	10	10	30	60	2.7	48.8
Little River nr Maryville, Tenn.	269	17	9	0	22	78	2.8	28.5
Powell River nr Jonesville, Va.	319	36	10	10	0	90	2.4	23.4
Flint River nr Chase, Ala.	342	37	10	20	10	70	2.6	29.1
Shoal Creek at Iron City, Tenn.	348	42	9	11	0	89	2.6	42.1
Sequatchie River at Whitwell, Tenn.	384	47	9	0	22	78	2.7	10.6
Duck River nr Shelbyville, Tenn.	481	33	10	10	20	70	2.9	30.5
Clinch River at Cleveland, Va.	528	47	10	0	0	100	3.0	38.3
NF Holston River nr Gate City, Va.	672	36	10	10	10	80	2.6	15.6
Powell River nr Arthur, Tenn.	685	48	10	10	0	90	2.4	20.9
Emory River at Oakdale, Tenn.	764	40	10	0	20	80	3.7	18.8
Nolichucky River at Embreeville, Tenn.	805	47	10	0	20	80	3.0	32.6
Elk River above Fayetteville, Tenn.	827	33	10	0	30	70	3.3	14.0
Duck River at Columbia, Tenn.	1208	47	10	0	30	70	2.2	20.5
Clinch River above Tazewell, Tenn.	1474	48	10	10	0	90	2.2	31.3
Elk River nr Prospect, Tenn.	1784	49	10	0	40	60	2.7	12.3
Duck River above Hurricane Mills, Tenn.	2557	42	10	0	40	60	2.9	23.7

*Percent of principal storm

Table 5-6

Antecedent Storm Data - Eastern Watersheds

Location of Watershed	Drainage Area, Sq. Mi.	Years of Record	Number of Floods Studied	Percent in Each Case: Without Antecedent Rain	Percent in Each Case: No Break	Percent in Each Case: With Antecedent Rain	Antecedent Storm: Average Dry Interval, Days	Antecedent Storm: Median Depth, Percent*
Allen Creek nr Hazelwood, N. C.	14.4	18	10	10	10	80	3.6	26.1
WF Pigeon River above Lake Logan, N. C.	27.6	13	10	10	30	60	2.6	34.0
Davidson River nr Brevard, N. C.	40.4	47	10	30	0	70	2.9	25.7
Clear Creek nr Hendersonville, N. C.	42.2	10	10	0	10	90	3.1	43.3
Scott Creek above Sylva, N. C.	50.7	26	9	11	22	67	2.7	26.5
South Toe River at Newdale, N. C.	60.8	18	9	11	11	78	4.4	21.9
Cane Creek at Fletcher, N. C.	63.1	16	10	20	0	80	2.8	37.3
Jonathan Creek nr Cove Creek, N. C.	65.3	37	10	10	20	70	3.3	15.7
Mills River nr Mills River, N. C.	66.7	33	10	10	20	70	3.1	30.5
French Broad River at Rosman, N. C.	67.9	29	10	10	10	80	3.2	29.0
Hominy Creek at Candler, N. C.	79.8	25	10	30	0	70	2.7	27.6
Watauga River nr Sugar Grove, N. C.	90.8	28	10	20	10	70	2.9	43.9
North Toe River at Altapass, N. C.	104	24	9	0	0	100	3.0	40.2
Mud Creek at Naples, N. C.	109	17	10	10	0	90	3.2	45.0
Big Laurel Creek nr Stackhouse, N. C.	126	33	10	20	10	70	3.4	17.0
Swannanoa River at Biltmore, N. C.	130	33	10	20	20	60	3.5	45.3
Pigeon River at Canton, N. C.	133	39	10	30	10	60	2.3	39.4
Cane River nr Sioux, N. C.	157	33	10	10	10	80	3.5	23.7
Ivy River nr Marshall, N. C.	158	33	10	10	10	80	2.8	23.3
Tuckasegee River at Dillsboro, N. C.	347	39	10	10	30	60	2.1	19.7
Pigeon River nr Hepco, N. C.	350	40	10	10	20	70	3.2	8.9
French Broad River at Asheville, N. C.	945	72	10	10	30	60	2.6	26.6

*Percent of principal storm

Table 5-7

Summary of Antecedent Storm Analysis

Floods Analyzed	Total Units Studied: Watersheds	Total Units Studied: Floods	Percentage of Floods With Antecedent Rain	Antecedent Storm: Average Dry Interval, Days	Antecedent Storm: Median Depth, Percent*
Western Watersheds					
All	25	242	77	2.8	21.7
Summer	13	25	72	3.3	15.8
Winter	25	217	78	2.7	22.6
Largest	25	25	84	3.0	25.0
Largest two	25	50	84	3.0	28.5
With 7 inches or more rainfall	-	11	92	2.9	19.5
Eastern Watersheds					
All	22	217	73	3.0	30.5
Summer	22	104	64	3.2	20.3
Winter	22	113	82	2.8	38.5
Largest	22	22	68	2.9	15.5
Largest two	22	44	73	3.3	13.9
With 7 inches or more rainfall	-	26	69	2.6	10
With 10 inches or more rainfall	-	5	100	3.3	6.6

*Percent of principal storm

ATTACHMENT A

TVA STORM STUDIES REQUEST

The following excerpts are taken from the letter of agreement between the TVA and ESSA dated January 6, 1966.

"This is to request that the U. S. Weather Bureau conduct for TVA special storm studies for the Tennessee River Basin under terms of our memorandum of agreement (contract No. TV-23942A) dated January 22, 1963, and as provided for in item b on page 5 of the work plan dated May 26, 1965, for fiscal year 1966.

The nature and scope of the storm studies to be made by the Bureau for TVA were discussed by Donald W. Newton, Head, Flood Hydrology Section, with Vance A. Myers, Head, Hydrometeorological Branch... At the conference it was agreed that....

1. The Bureau's Hydrometeorological Branch will conduct studies to establish generalized criteria and procedures for estimating probable maximum and TVA's maximum probable storm rainfall within meteorological homogeneous subunits of the Tennessee River watershed. Studies will proceed by units as jointly agreed upon so as to fit best TVA's program and to assure efficient study completion.

2. The study will start as soon as proper staffing can be accomplished and will proceed until completed. The time required for the study is expected to be about 2-1/2 years...

3. The Bureau will furnish TVA results of the studies as each subunit is completed and a summary report within 6 months after completion of the studies. In the event it is decided to publish the results of these studies, the cost of publication will be covered by a supplemental agreement."

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