NOAA HYDROMETEOROLOGICAL REPORT NO. 52

Application of Probable Maximum Precipitation Estimates - United States East of the 105th Meridian

U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF THE ARMY
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WASHINGTON, D.C.
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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 (Unpublished.)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.
*No. 10. Maximum possible rainfall over the Arkansas River Basin above Caddoa, Colo. 1939. Supplement, 1939.
*No. 11. A preliminary report on the maximum possible precipitation over the Dorena, Cottage Grove, and Fern Ridge Basins in the Willamette Basin, Oreg. 1939.
*No. 12. Maximum possible precipitation over the Red River Basin above Denison, Tex. 1939.
*No. 13. A report on the maximum possible precipitation over Cherry Creek Basin in Colorado. 1940.
*No. 14. The frequency of flood-producing rainfall over the Pajaro River Basin in California. 1940.
*No. 15. A report on depth-frequency relations of thunderstorm rainfall on the Sevier Basin, Utah. 1941.
*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 (Unpublished.)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.
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*No. 20. An estimate of maximum possible flood-producing meteorological conditions in the Missouri River Basin above Garrison Dam site. 1945.
*No. 21. A hydrometeorological study of the Los Angeles area. 1939.
*No. 21A. Preliminary report on maximum possible precipation, Los Angeles area, California. 1944.
*No. 21B. Revised report on maximum possible precipitation, Los Angeles area, California. 1945.
*No. 22. An estimate of maximum possible flood-producing meteorological conditions in the Missouri River Basin between Garrison and Fort Randall. 1946.
*No. 23. Generalized estimates of maximum possible precipitation over the United States east of the 105th meridian, for areas of 10,200, and 500 square miles. 1947.
*No. 24. Maximum possible precipitation over the San Joaquin Basin, California. 1947.
*No. 25. Representative 12-hour dewpoints in major United States storms east of the Continental Divide. 1947.
*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.
*No. 28. Generalized estimate of maximum possible precipitation over New England and New York. 1952.
*No. 29. Seasonal variation of the standard project storm for areas of 200 and 1,000 square miles east of 105th meridian. 1953.
*No. 30. Meteorology of floods at St. Louis. 1953. (Unpublished.)
*No. 31. Analysis and synthesis of hurricane wind patterns over Lake Okeechobee, Florida. 1954.
*No. 32. Characteristics of United States hurricanes pertinent to levee design for Lake Okeechobee, Florida. 1954.
No. 33. Seasonal variation of the probable maximum precipitation east of the 105th meridian for areas from 10 to 1,000 square miles and durations of 6, 12, 24, and 48 hours. 1956.
No. 34. Meteorology of flood-producing storms in the Mississippi River Basin. 1956.
No. 35. Meteorology of hypothetical flood sequences in the Mississippi River Basin. 1959.
*No. 36. Interim report--probable maximum precipitation in California. 1961. Also available is a supplement, dated October 1969.
No. 37. Meteorology of hydrologically critical storms in California. 1962.
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No. 43. Probable maximum precipitation, Northwest States. 1966.
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Application of Probable Maximum Precipitation Estimates - United States East of the 105th Meridian

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APPLICATION OF PROBABLE MAXIMUM PRECIPITATION ESTIMATES - UNITED STATES EAST OF THE 105TH MERIDIAN

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ABSTRACT--This study provides a stepwise approach to the temporal and spatial distribution of probable maximum precipitation (PMP) estimates derived from Hydrometeorological Report No. 51, "Probable Maximum Precipitation Estimates - United States East of the 105th Meridian." Included are discussions of the shape and orientation of isohyetal patterns for major rainfalls of record. An elliptical isohyetal pattern with a ratio of major to minor axes of 2.5 to 1 is recommended, and a procedure is outlined for obtaining appropriate isohyet values. A procedure is given to determine PMP values for durations less than 6 hours. Example applications have been worked through to serve as guidance in the use of this procedure.

1. INTRODUCTION

1.1 Background

Generalized estimates of all-season probable maximum precipitation (PMP) applicable to drainages of the United States east of the 105th meridian are provided in Hydrometeorological Report No. 51 (Schreiner and Riedel 1978). Hereinafter, that report will be referred to as HMR No. 51, and references to other reports in this series will be similarly abbreviated.

The terminology in HMR No. 51 has not always been precise, particularly where PMP estimates are referred to as being for drainages from 10 to 20,000 mi^2. It is important to realize that the term drainages as used in that report is a rather loose interpretation when the more precise term is areas. The term drainage or drainage area in the present report will apply to a specific drainage only. HMR No. 51 provides storm-area PMP estimates for a specific range of area sizes (10 to 20,000 mi^2) and durations (6 to 72 hr).

1.2 Objective

The objective of this report is to aid the user in adapting or applying PMP estimates from HMR No. 51 to a specific drainage. This report recommends a procedure for the application of PMP estimates to a drainage for which both the temporal and spatial distributions are needed. This information is necessary for the determination of peak discharge and can be useful in estimating the maximum volume in evaluations of the probable maximum flood (PMF).

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1.3 Definitions

Probable Maximum Precipitation (PMP). Theoretically the greatest depth of precipitation for a given duration that is physically possible over a given size storm area at a particular geographical location at a certain time of the year. (This definition is a 1982 revision to that used previously (American Meteorological Society 1959) and results from mutual agreement among the National Weather Service, the U.S. Army Corps of Engineers, and the Bureau of Reclamation.)

PMP Storm Pattern. The isohyetal pattern that encloses the PMP area plus the isohyets of residual precipitation outside the PMP portion of the pattern.

Storm-centered area-averaged PMP. The values obtained from HMR No. 51 corresponding to the area of the PMP portion of the PMP storm pattern. In this report all references to PMP estimates or to incremental PMP infer storm-area averaged PMP.

Drainage-averaged PMP. After the PMP storm pattern has been distributed across a specific drainage and the computational procedure of this report applied, we obtain drainage-averaged PMP estimates. These values include that portion of the PMP storm pattern that occur over the drainage, both PMP and residual.

Temporal Distribution. The order in which 6-hr incremental amounts are arranged in a 3-day sequence (72 hr). This report includes information regarding determination of hourly and smaller units within the maximum 6-hr increment, but does not discuss the distribution of units less than 6-hr.

Spatial Distribution. The value of fixed isohyets in the idealized pattern storm for each 6-hr increment and shorter durations within the maximum 6-hr increment of PMP when area-averaged PMP is to be distributed.

Total Storm Area and Total Storm Distribution. The largest area size and longest duration for which depth-area-duration data are available in the records of major storm rainfall.

Standard Areas. The specific area sizes for which PMP estimates are available from the generalized maps in HMR No. 51, i.e., 10-, 200-, 1,000-, 5,000-, 10,000-, and 20,000-mi^2 areas.

Standard Isohyet Area Sizes. In this report, the standard isohyet area sizes are are those enclosed by the isohyets of the recommended pattern, i.e., 10, 25, 50, 100, 175, 300, 450, 700, 1,000, 1,500, 2,150, 3,000, 4,500, 6,500, 10,000, 15,000, 25,000, 40,000, and 60,000 mi^2.

Residual Precipitation. The precipitation that occurs outside the area of the PMP pattern placed on the drainage, regardless of the area size of the drainage. Because of the irregular shape of the drainage, or because of the choice of a PMP pattern smaller in area than the area of the drainage, the residual precipitation can fall within the drainage. A particular advantage in the consideration of residual precipitation, is that of allowing for the determination of concurrent precipitation, i.e., the precipitation falling on an adjacent drainage as compared to that for which the PMP pattern has been applied.

Isohyetal Orientation. The orientation (direction from north) of the major axis through the elliptical pattern of PMP. The term is used in this study also to define the orientation of precipitation patterns of major storms when approximated by elliptical patterns of best fit.

Within/Without-Storm Depth-Area Relations. This relation evolves from the concept that the depth-area relation for area-averaged PMP represents an envelopment of maximized rainfall from various storms each effective for a different area size(s). The within-storm depth-area relation represents the areal variation of precipitation within a storm that gives PMP for a particular area size. This can also be stated as the storm that results in PMP for one area size may not give PMP for any other area size. Except for the area size that gives PMP, the within-storm depth-area relation will give depths less than PMP for smaller area sizes. This concept is illustrated in the schematic diagram shown in figure 1. In this figure, precipitation for areas in the PMP storm outside the area size of the PMP pattern describes a without-storm depth-area relation. The precipitation described by the without-storm relations is the residual precipitation defined elsewhere in this report.

1.4 Summary of Procedures and Methods of this Report

All procedures described in this study are based on information derived from major storms of record, and are applicable to nonorographic regions of the eastern United States.

The temporal distributions provided allow some flexibility in determining the hydrologically most critical sequence of incremental PMP. The procedure used to determine the temporal distributions has been used in some other Hydrometeorological Branch reports (Riedel 1973, and Schwarz 1973 for example), and is described in chapter 2.

We have surveyed major storm isohyetal patterns for statistics on pattern shape, and have adopted an elliptical shape having a 2.5 to 1 ratio of major to minor axes as representative of a precipitation pattern. This elliptical shape has been adopted for PMP and is applied to all 6-hr incremental patterns. The discussion of the shape of the isohyetal patterns is found in chapter 3.

Another aspect of this study is a generalized approach to adjustments for pattern orientation to fit the drainage when inconsistent with the orientation determined for the PMP isohyetal pattern. Outlined in chapter 4 is an empirical method that allows up to 15 percent reduction to storm-centered area-averaged PMP for drainage areas larger than 3,000 mi^2 which differ by more than 40 degrees from the orientation consistent with PMP-producing storms.

In determining spatial distribution a basic assumption is that rainfall depths for areas smaller and larger than the total area for which PMP is needed over a particular drainage, are less than PMP. (See within/without-storm depth-area definitions.) This assumption, for areas smaller than the PMP, has been commonly made in some other studies by this branch (Riedel 1973, Riedel, et al. 1969, and others), and results in what has been referred to in those reports as within-storm or within-drainage depth-area-duration (D.A.D) relations. Application of a similar assumption to areas larger than that for the PMP is a consideration unique to the present study and introduces the concept of residual precipitation.

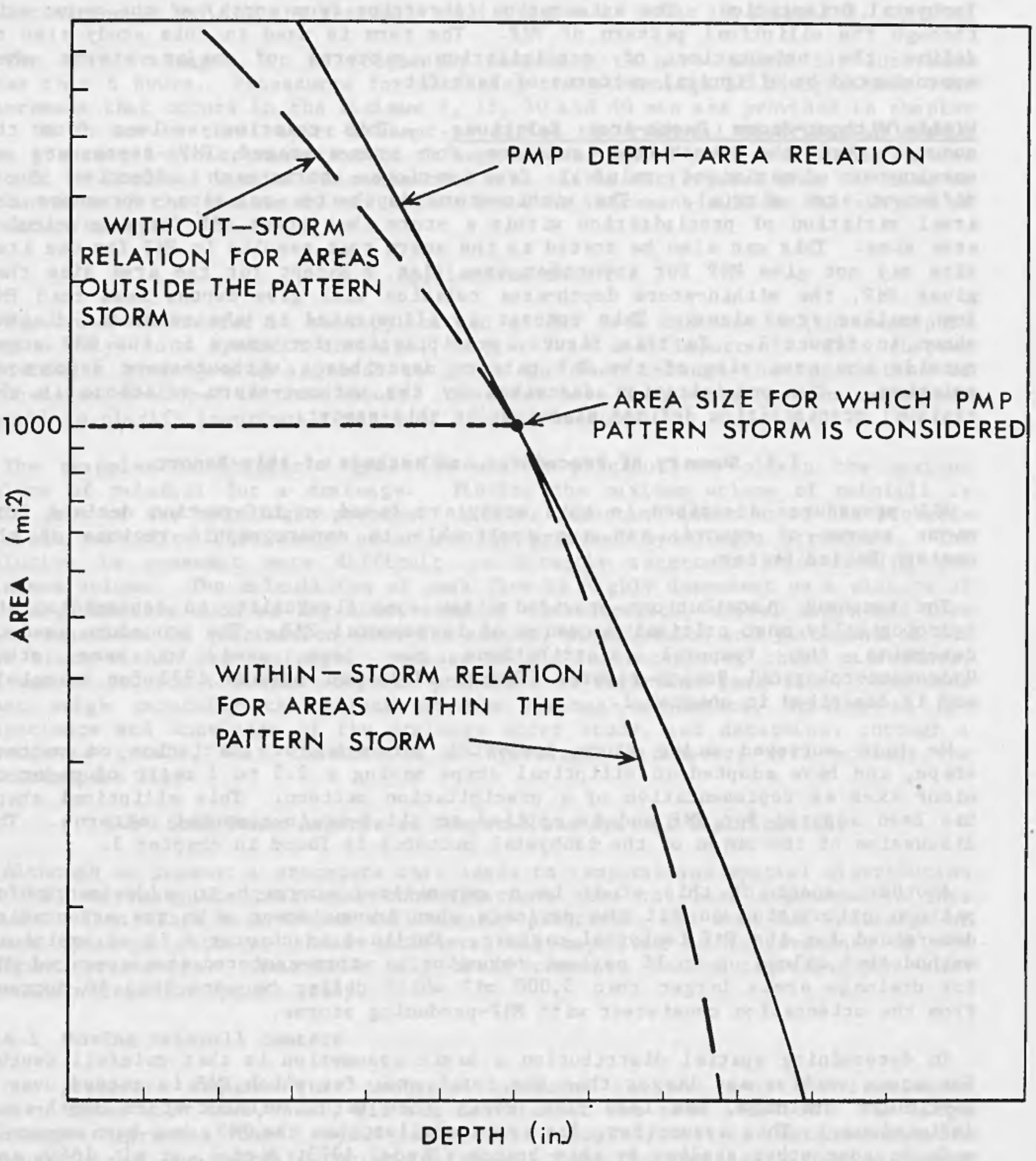

Figure 1.—Schematic diagram showing the relation between depth-area curve for PMP and the within/without-storm relations for PMP at 1,000 mi^2.

(See sec. 1.3 definitions.) Discussion of the procedure to obtain the spatial distribution of PMP and the residual precipitation is given in chapter 5.

For many drainages, it is frequently necessary to have values for durations less than 6 hours. Procedures for obtaining the percentage of the greatest 6-hr increment that occurs in the maximum 5, 15, 30 and 60 min are provided in chapter 6. We do not in this report attempt to define the temporal distribution within the greatest 6-hr increment except to suggest that the 5-, 15- and 30-min values should be included within the maximum 60 min. It is anticipated that the time of occurrence of the maximum 60 min within the 6-hr increment will be the subject of a future study.

1.5 Application to PMP

For those interested in the application of PMP from HMR No. 51 (nonorographic region only) to a specific drainage, chapter 7 is most important. This chapter provides a step-by-step approach to guide the user through the application of procedures developed in this report. Examples have been worked out in sufficient detail to clarify important aspects of these procedures.

The examples in chapter 7 give the user a procedure to obtain the maximum volume of rainfall for a drainage. Finding the maximum volume of rainfall is only part of the hydrologic problem. Another important question is the probable maximum peak flow that could occur at the proposed hydrologic structure. The solution is somewhat more difficult to directly ascertain than finding the maximum volume. The calculation of peak flow is highly dependent on a mixture of basin parameters such as lag time, time of concentration, travel time, and loss rate functions in combination with the amount, distribution and placement of the PMP storm within the drainage. Because of the interaction of these parameters, we cannot provide a simple stepwise procedure to determine peak flow. The user must weigh carefully the effect of the various parameters, drawing on his experience and knowledge of the drainage under study, and determine, through a series of trials, what combination of hydrologic parameters will produce the maximum peak flow.

1.6 Some Other Aspects of Temporal and Spatial Distributions

Although we present a procedure that leads to temporal and spatial distribution of PMP, we recognize that some considerations have not been discussed in this study. When storm data become sufficiently plentiful, and when our knowledge of storm dynamics permits, these considerations may lead to improvements in the current procedures. Meanwhile only brief comments follow regarding two such considerations for future study.

1.6.1 Moving rainfall centers

Our procedure assumes that isohyetal patterns for all 6-hr PMP increments remain fixed with time, i.e., all are centered at the same location. For large drainages (greater than 10,000 mi^2, for example), it is meteorologically reasonable for the rainfall center to travel across the drainage with time during the storm. It is conceivable that such movement could result in a higher flood peak if the direction and speed of movement coincides with downstream progression of the flood crest.

It was decided jointly by the Corps of Engineers and the Hydrometeorological Branch that the present report would not cover application of moving centers. Generalization of moving centers would require analysis of observational data such as incremental storm isohyetal patterns that are presently not available. It is anticipated that a future study will cover moving centers.

1.6.2 Distributions from an actual storm

Use of elliptical patterns for spatial distribution permits simplicity in generalized depth-area relations and in determining isohyet values. It also helps maintain consistency in results among drainages, area sizes, and durations. Such consistency is also maintained by the recommended temporal distributions. An alternate but unrecommended procedure is to adopt the distributions of a record storm precipitation that occurred on the drainage or within a homogeneous region including the drainage.

The isohyetal pattern from an actual storm might "fit" a drainage better than an elliptical pattern, and multiplying the isohyets by percent of PMP (say for 6 hours for the drainage, divided by the drainage depth from the storm pattern after it is located on the drainage) will give isohyet values for PMP. Such isohyets, however, quite possibly could give greater than PMP depths for smaller areas within the drainage.

The temporal distribution of such a storm could also be used for PMP. Again, however, there could very likely be problems. The most intense three 6-hr rain increments in a 72-hr storm may be widely separated in a time sequence of incremental rainfall (mass curve). Thus, 12- or 18-hr PMP could not be obtained unless rain bursts somehow were brought together. However, such arrangement is often done as a maximization step and PMP depths from HMR No. 51 used. These modifications would be towards the generalized criteria of the present study in which there are no results that are inconsistent or irreconcilable.

Paulhus and Gilman (1953) published a technique for using an actual pattern for distributing PMP. The referenced paper describes a "sliding" technique for obtaining the spatial distribution of PMP that has its greatest merit in applications in the more orographic regions (stippled zones in HMR No. 51) covered by this study, such as the Appalachians and along the western border to the region, where site-specific studies are recommended. However, we advise caution in application of this technique directly as Paulhus and Gilman have proposed, in that it is possible to obtain PMP for a much smaller area size than that for the drainage to which it is applied. Since this disagrees with our within-storm concept, we therefore suggest adherence to the following modifications to the technique presented by Paulhus and Gilman, if it is used:

a. Use a set of depth-area relations (from HMR No. 51) which, when "slid over" the depth-area relations for the storm, will give PMP for an area size within 10 percent of the area of the drainage of concern.

b. It is desirable that PMP (from HMR No. 51) be obtained for at least the hydrologically critical duration.

c. For other durations between 6 and 72 hours, stay within 15 percent of PMP as specified in HMR No. 51. For additional information regarding application of this technique, the reader is referred to the Paulhus and Gilman paper.

1.7 Other Meteorological Considerations

Other aspects of extreme rainfall criteria can be important to determinations of peak flow. Some of these aspects are described here.

1.7.1 PMP for smaller areas within the total drainage.

Our previous studies have concentrated on defining PMP for the total drainage area. In fact, in the present study we recommend spatial distributions resulting in somewhat less than PMP for smaller as well as larger areas than the PMP pattern. The question can naturally be asked, does PMP for a smaller area size than the storm area size that is applicable to the entire drainage, which when centered over a portion of the drainage (experiencing more intense rainfall than that for the entire drainage), result in a more critical peak flow? There is a possibility that PMP covering only a subportion of the drainage could provide a hydrologically more critical peak discharge, and the hydrologist should consider such a possibility. The depth of rainfall to use over the remaining portion of the drainage would need to be specified. (See discussion on residual precipitation in sections 3.5.3 and 5.2.5.)

1.7.2 Rains for extended periods

Especially for large drainages, rainfalls for durations longer than 3 days could be important in defining critical volumes for hydrologic design. As examples, the Hydrometeorological Branch, working with Corps of Engineers hydrologists, has evaluated the meteorology of hypothetical sequences of record storms transposed in space and recommended how close together such storms can follow each other (Myers 1959, and Schwarz 1961). Similar studies may be needed for other large drainage projects. Sufficiently severe assumptions, however, relative to how full reservoirs are prior to the PMF and the antecedent soil conditions, could obviate the need for such studies.

1.8 Report Preparation

Preparation of this report began in 1977 as follow on studies to HMR No. 51. Initial discussions with the Corps of Engineers outlined the scope of the project. As indicated in a previous section, certain problems were left to be considered in later studies. The basic studies were undertaken when all the authors were affiliated with the National Weather Service (NWS). These studies were completed after one of the authors, L. Schreiner, transferred to the Bureau of Reclamation (USBR). Several of the concepts and procedures included in this report evolved after Mr. Schreiner's transfer, as a collaborative effort of the three authors and other meteorologists affiliated with both the NWS and the USBR.

2. TEMPORAL DISTRIBUTION

2.1 Introduction

When applying PMP to determine the flood hydrograph, it is necessary to specify how the rain falls with time, that is, in what order various rain increments are arranged with time from the beginning of the storm. Such a rainfall sequence in an actual storm is given by what is called a mass curve of rainfall, or the accumulated rainfall plotted against time from the storm beginning. Mass curves observed in severe storms show a great variety of sequences of rain increments.

Table 1.—Major storms from HMR No. 51 used in this study

Storm center location	Date	Storm assignment number	Lat.		Long.		Total storm duration (hr)	Total storm area size (mi^2)	Orient. of pattern (°)
			(°)	(')	(°)	(')			
1. Jefferson, OH (T)#	9/10-13/1878	OR 9-19	41	45	80	46	84	90,000	190
2. Wellsboro, PA	5/30-6/1/1889	SA 1-1	41	45	77	17	60	82,000	200
3. Greeley, NE	6/4-7/1896	MR 4-3	41	33	98	32	78	84,000	205
4. Lambert, MN	7/18-22/1897	UMV 1-2	47	47	95	55	102	80,000	230
5. Jewell, MD	7/26-29/1897	NA 1-7B	38	46	76	34	96	32,000	205
6. Hearne, TX (T)	6/27-7/1/1899	GM 3-4	30	52	96	37	108	78,000	170
7. Eutaw, AL	4/15-18/00	LMV 2-5	32	47	87	50	84	75,000	230
8. Paterson, NJ (T)	10/7-11/03	GL 4-9	40	55	74	10	96	35,000	170
9. Medford, WI	6/3-8/05	GL 2-12	45	08	90	20	120	67,000	205
10. Bonaparte, IA	6/9-10/05	UMV 2-5	40	42	91	48	12	20,000	285
11. Warrick, MT	6/6-8/06	MR 5-13	48	04	109	39	54	40,000	250
12. Knickerbocker, TX	8/4-6/06	GM 3-14	31	17	100	48	48	24,600	235
13. Meeker, OK	10/19-24/08	SW 1-11	35	30	96	54	126	80,000	200
14. Beaulieu, MN	7/18-23/09	UMV 1-11A	47	21	95	48	108	5,000	285
15. Merryville, LA	3/24-28/14	LMV 3-19	30	46	93	32	96	125,000	200
16. Cooper, MI	8/31-9/1/14	GL 2-16	42	25	85	35	6	1,200	300
17. Altapass, NC (T)	7/15-17/16	SA 2-9	35	53	82	01	108	37,000	155
18. Meek, NM (T)	9/15-17/19	GM 5-15B	33	41	105	11	54	75,000	200
19. Springbrook, MT	6/17-21/21	MR 4-21	47	18	105	35	108	52,600	240
20. Thrall, TX (T)	9/8-10/21	GM 4-12	30	35	97	18	48	12,500	210
21. Savageton, WY	9/27-10/1/23	MR 4-23	43	52	105	47	108	95,000	230
22. Boyden, IA	9/17-19/26	MR 4-24	43	12	96	00	54	63,000	240
23. Kinsman Notch, NH (T)	11/2-4/27	NA 1-17	44	03	71	45	60	60,000	220
24. Elba, AL	3/11-16/29	LMV 2-20	31	25	86	04	114	100,000	250
25. St. Fish Htchy., TX	6/30-7/2/32	GM 5-1	30	10	99	21	42	30,000	205
26. Scituate, RI (T)	9/16-17/32	NA 1-20A	41	47	71	30	48	10,000	200
27. Ripogenus Dam, ME (T)	9/16-17/32	NA 1-20B	45	53	69	15	30	10,000	200
28. Cheyenne, OK	4/3-4/34	SW 2-11	35	37	99	40	18	2,200	230
29. Simmesport, LA	5/16-20/35	LMV 4-21	30	59	91	48	102	75,000	235
30. Hale , CO	5/30-31/35	MR 3-28A	39	36	102	08	24	6,300*	235

Table 1.—Major storms from HMR No. 51 used in this study - Continued

	Storm center location	Date	Storm assignment number	Lat.		Long.		Total storm duration (hr)	Total storm area size (mi^2)	Orient. of pattern (°)
				(°)	(')	(°)	(')			
31.	Woodward Rch., TX	5/31/35	GM 5-20	29	20	99	18	10	7,000	210
32.	Hector, NY	7/6-10/35	NA 1-27	42	30	76	53	90	38,500	255
33.	Snyder, TX	6/19-20/39	--	32	44	100	55	6	2,000	285
34.	Grant Twnshp., NE	6/3-4/40	MR 4-5	42	01	96	53	20	20,000	210
35.	Ewan, NJ (T)	9/1/40	NA 2-4	39	42	75	12	12	2,000	205
36.	Hallett, OK	9/2-6/40	SW 2-18	36	15	96	36	90	20,000	160
37.	Hayward, WI	8/28-31/41	UMV 1-22	46	00	91	28	78	60,000	270
38.	Smethport, PA	7/17-18/42	OR 9-23	41	50	78	25	24	4,300	145
39.	Big Meadows, VA (T)	10/11-17/42	SA 1-28A	38	31	78	26	156	25,000	200
40.	Warner, OK	5/6-12/43	SW 2-20	35	29	95	18	144	212,000	225
41.	Stanton, NE	6/10-13/44	MR 6-15	41	52	97	03	78	16,000	260
42.	Collinsville, IL	8/12-16/46	MR 7-2B	38	40	89	59	114	20,400	260
43.	Del Rio, TX	6/23-24/48	--	29	22	100	37	<24	10,000	180
44.	Yankeetown, FL (T)	9/3-7/50	SA 5-8	29	03	82	42	96	43,500	205
45.	Council Grove, KS	7/9-13/51	MR 10-2	38	40	96	30	108	57,000	280
46.	Ritter, IA	6/7/53	MR 10-8	43	15	95	48	20	10,000	220
47.	Vic Pierce, TX (T)	6/23-28/54	SW 3-22	30	22	101	23	120	27,900	140
48.	Bolton, Ont., Can. (T)	10/14-15/54	ONT 10-54	43	52	79	48	78	20,000	190
49.	Westfield, MA (T)	8/17-20/55	NA 2-22A	42	07	72	45	72	35,000	230
50.	St. Pierre Baptiste, Que., Can.	8/3-4/57	QUE 8-57	46	12	71	35	18	7,000	285
51.	Sombreretillo, Mex. (T)	9/19-24/67	SW 3-24	26	18	99	55	126	60,000	220
52.	Tyro, VA (T)	8/19-20/69	NA 2-23	37	49	79	00	48	15,000	270
53.	Zerbe, PA (T)	6/19-23/72	NA 2-24A	40	37	76	32	96	130,000	200

#(T) = Precipitation associated with tropical cyclone

* = Area of combined centers of precipitation with Elbert, CO 39°13'N, 104°32'W, generally referred to as Cherry Ck.

Certain sequences result in more critical flow (higher peak) than others. We leave the determination of criticality to the hydrologist, but recognize that the mass curve or temporal distribution selected for PMP is important.

PMP estimates can be obtained in HMR No. 51 for 6-, 12-, 24-, 48- and 72-hr durations. A plot of these depths against duration joined by a smooth curve defines PMP for all durations between 6 and 72 hours. In many applications, definition of PMP by 6-hr time increments is sufficient. Thus, PMP values for 6, 12, 18, 24, ..., 72 hr can be read from such a smooth curve. Successive subtraction of the PMP for each of these durations from that of the duration 6-hr longer gives 6-hr increments of PMP. We have shown in HMR No. 51 that, in general, allowing PMP for all durations (6 to 72 hr) to occur in a single storm is not an undue maximization.

2.2 Observed Sequences of 6-hr Increments in Major Storms

We considered the sequences of 6-hr rain increments of the more important storms east of the 105th meridian as guidance for recommending sequences for PMP. These storms, 53 of which are given in the appendix of HMR No. 51, are listed in table 1 and represent a primary data base for this study. Table 1 includes information on storm location, duration, areal extent, and the orientation of the isohyetal pattern (refer to chapter 4).

To obtain information on the chronological sequence of 6-hr increments of precipitation, we referred to storm data summarized for most major storms listed in table 1 (not available for the 2 storms of 9/16-17/1932, and those of 6/19-20/1939, 6/23-24/1948, 10/14-15/1954, and 8/3-4/1957). For the 47 remaining storms, these data are contained in what we refer to as Part 2 storm study files in which point data are grouped to obtain chronological sequences of areally averaged depths. A search was made through these storms for cases in which depths were given for both 100- and 10,000-mi^2 approximate areas for the storm center with maximum precipitation. The storms were further limited to those for which 6-hr incremental depths occurred over a period of more than 48 hr, to assure us that we were considering representative 3-day storms.

Table 2 lists the 28 storms that met these conditions, and separates them by storm type--tropical and nontropical. The remaining 19 storms had rainfall durations or areas that failed to meet our threshold. It should be pointed out that the limitations for 48-hr sequences from the Part 2 data do not necessarily agree with the listing of total-storm duration given in table 1. For example, the Greeley, Nebraska (6/4-7/1896) storm in table 1 is considered to have a total storm duration of 78 hr (U.S. Army Corps of Engineers 1945-). This same storm for the 100- and 10,000-mi^2 approximate areas in the maximum storm rainfall center provides sequences of depths only up to about 24 hr ($\sim$100 mi^2) and 36-hr ($\sim$10,000 mi^2).

A rainfall was considered tropical if it occurred within 200 miles of a storm track contained in Neumann, et al. (1978), and if the rain occurred within 2 days prior to passage of the storm. Other storm rainfalls were also designated tropical if they occurred within 500 miles beyond and within 2 days after the last reported position of a tropical cyclone track in Neumann. In such cases, the assumption made was that moisture from the tropical cyclone continued to move

Table 2.—Major storms from table 1 used in study of temporal distributions

Location	Date	Storm assignment number
TROPICAL		
Jefferson, OH	9/10-13/1878	OR 9-19
Hearne, TX	6/27-7/1/1899	GM 3-4
Paterson, NJ	10/7-11/1903	GL 4-9
Altapass, NC	7/15-17/1916	SA 2-9
Big Meadows, VA	10/11-17/1942	SA 1-28A
Yankeetown, FL	9/3-7/1950	SA 5-8
Vic Pierce, TX	6/23-28/1954	SW 3-22
Westfield, MA	8/17-20/1955	NA 2-22A
Sombreretillo, Mex.	9/19-24/1967	SW 3-24
Zerbe, PA	6/19-23/1972	NA 2-24A
NONTROPICAL		
Lambert, MN	7/18-22/1897	UMV 1-2
Jewell, MD	7/26-29/1897	NA 1-7B
Eutaw, AL	4/15-18/1900	LMV 2-5
Medford, WI	6/3-8/1905	GL 2-12
Warrick, MT	6/6-8/1906	MR 5-13
Meeker, OK	10/19-24/1908	SW 1-11
Merryville, LA	3/24-28/1914	LMV 3-19
Springbrook, MT	6/17-21/1921	MR 4-21
Thrall, TX	9/8-10/1921	GM 4-12
Savageton, WY	9/27-10/1/1923	MR 4-23
Elba, AL	3/11-16/1929	LMV 2-20
Simmesport, LA	5/16-20/1935	LMV 4-21
Hector, NY	7/6-10/1935	NA 1-27
Hayward, WI	8/28-31/1941	UMV 1-22
Warner, OK	5/6-12/1943	SW 2-20
Stanton, NE	6/10-13/1944	MR 6-15
Collinsville, IL	8/12-16/1946	MR 7-2B
Council Grove, KS	7/9-13/1951	MR 10-2

beyond the dissipated circulation system and possibly combined with frontal or orographic mechanisms to produce the observed extreme rain. Such probably was the case with the Big Meadows, Virginia (10/11-17/1942) rain listed in table 2. A further check was made of daily weather maps to determine if any of these rains may have been associated with tropical disturbances of less intensity than covered in Neumann, et al. The Hearne, Texas (6/27-7/1/1899) rain, as an important example, is believed to have resulted from extreme moisture associated with one of these weaker systems located off the Texas Gulf Coast, and which moved rapidly inland. More discussion on meteorological factors in extreme rainfalls is given in chapter 4.

While the sample of storms in table 2 is too small to set quantitative differences, we wish to see if qualitative differences appear. Figure 2, as an example, shows sequences of 6-hr increments for 5 of the storms in table 2. (Two of the five are tropical.) In this figure, the 100-mi^2 results are shown as solid lines and the 10,000-mi^2 results as dashed lines. Incremental amounts are expressed as a percentage of the 72-hr rainfall.

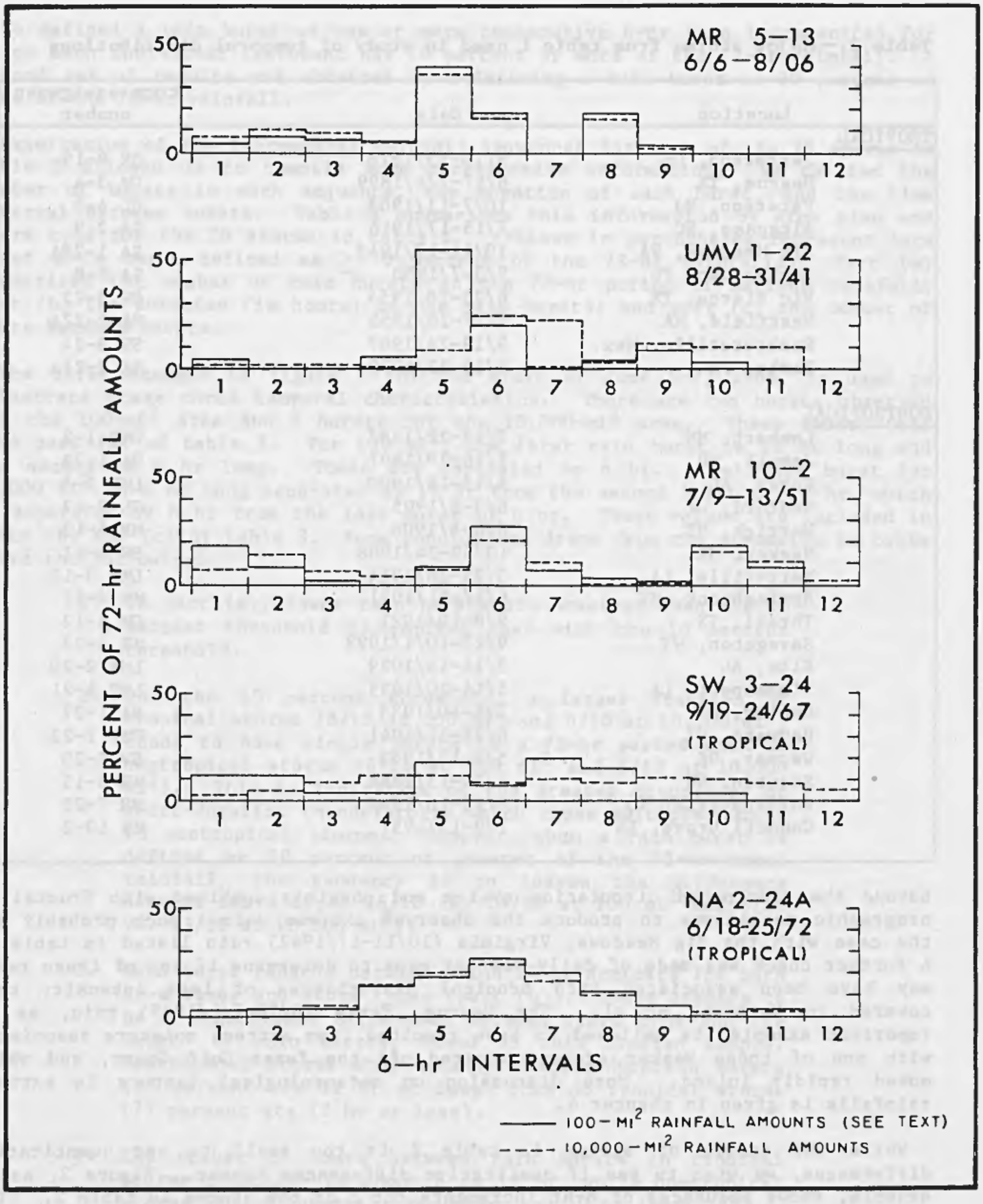

Figure 2.—Examples of temporal sequences of 6-hr precipitation in major storms.

We defined a rain burst as one or more consecutive 6-hr rain increment(s) for which each individual increment has 10 percent or more of the 72-hr rainfall. A second set of results was obtained by redefining a rain burst as 20 percent or more of the 72-hr rainfall.

Examination of the incremental rainfall sequences for each of the 28 storms in table 2 allowed us to compile some constructive information. We tallied the number of bursts in each sequence, the duration of each burst, and the time interval between bursts. Table 3 summarizes this information by area size and storm type for the 28 storms in table 2. (Values in parentheses represent data based on a burst defined as $\geq$ 20 percent of the 72-hr rainfall.) Part (a) summarizes the number of rain bursts in the 72-hr period of maximum rainfall; part (b) the duration (in hours) of the rain bursts; and part (c) the number of hours between bursts.

The first example in figure 2 for the storm of June 6-8, 1906, is used to illustrate these three temporal characteristics. There are two bursts observed for the 100-mi^2 area and 3 bursts for the 10,000-mi^2 area. These counts went into part (a) of table 3. For 100 mi^2, the first rain burst is 12 hr long and the second is 6 hr long. These are separated by 6 hr. The first burst for 10,000 mi^2 is 6 hr long separated by 12 hr from the second burst of 12 hr, which is separated by 6 hr from the last burst of 6 hr. These values are included in parts (b) and (c) of table 3. Some conclusions drawn from the summaries in table 3 are the following:

1. In part (a), fewer rain bursts are observed when the 20 percent threshold is applied than with the 10 percent threshold.

2. For the 10 percent threshold, a larger fraction of tropical storms (8/10 at 100 mi^2 and 6/10 at 10,000 mi^2) tends to have single bursts in a 72-hr period than do nontropical storms (6/18 at 100 mi^2 and 6/18 at 10,000 mi^2). This is indicative of the greater occurrence of short-duration thunderstorms which cause multiple bursts in nontropical storms. However, when a rain burst is defined as 20 percent or greater of the 72-hr total rainfall, the tendency is to lessen the difference between storm types (6/10 vs. 14/18 at 100 mi^2 and 6/10 vs. 13/18 at 10,000 mi^2).

3. Rain burst lengths between 6 and 24 hr dominate for both area sizes and storm types (part (b)). There appears to be a significant difference between storm type and the length of rain bursts, based on this limited sample. Nontropical storms show notably shorter-duration bursts (89 percent are 12 hr or less) than do tropical storms (77 percent are 12 hr or less).

4. The number of hours between rain bursts in tropical storms typically is about 6 to 12 hr, while nontropical storms showed intervals between 6 and 30 hr (part (c)).

Table 3.—Summary of rain burst characteristics of 28 major rainfalls listed in table 2

Part (a); Number of bursts

	Number of rain bursts in a 72-hr period									
	0		1		2		3		Total	
Area (mi^2)	T	NT	T	NT	T	NT	T	NT	T	NT
	Number of Storms									
100	0(2)	0(0)	8(6)	6(14)	0(2)	7(4)	2(0)	5(0)	10	18
10,000	0(4)	0(1)	6(6)	6(13)	3(0)	7(4)	1(0)	5(0)	10	18

Part (b); Duration of bursts

	Duration of rain bursts (hr)													
	6		12		18		24		30		36		Total	
Area (mi^2)	T	NT	T	NT	T	NT	T	NT	T	NT	T	NT	T	NT
	Number of bursts													
100	3(7)	19(14)	3(3)	12(8)	3(0)	4(0)	3(0)	0(0)	2(0)	0(0)	0(0)	0(0)	14(10)	35(22)
10,000	3(2)	14(14)	5(3)	13(7)	0(0)	7(0)	4(1)	0(0)	2(0)	0(0)	1(0)	1(0)	15(6)	35(21)

Part (c); Duration of intervals

	Number of hours between rain bursts (length of intervals)													
	6		12		18		24		30		36		Total	
Area (mi^2)	T	NT	T	NT	T	NT	T	NT	T	NT	T	NT	T	NT
	Number of intervals													
100	2(2)	6(0)	2(0)	5(0)	0(0)	3(3)	0(0)	1(0)	0(0)	2(1)	0(0)	0(0)	4(2)	17(4)
10,000	4(0)	5(1)	1(0)	7(0)	0(0)	4(2)	0(0)	0(0)	0(0)	1(1)	0(0)	0(0)	5(0)	17(4)

T - tropical, NT - nontropical

( ) - Values in parentheses are for results when definition for rain burst is increased from $\geq$ 10% to $\geq$ 20% of the 72-hr total rain (see text).

2.3 Recommended Sequences for PMP Increments

While the 28-storm sample shows some evidence for rain burst sequences to differ depending on the storm type, table 3 suggests the difference may be in part due to the choice of threshold value. Furthermore, differentiation by storm type would necessitate delineating regions of control on PMP. This is not recommended since anomalies in major rains related to storm type occur. An example of this is one of the most extreme rain events for large areas along the gulf coast, the Elba, Alabama storm of 3/11-16/1929. This was a nontropical storm. Another reason for not distinguishing time sequences for PMP by storm type is that the PMP in coastal regions may be produced by a complex weather situation that is a mixture of both tropical and nontropical influences. Therefore, one standard set of temporal sequences, independent of storm type, is recommended for the PMP increments determined as described in section 2.1.

The limited sample of storms in table 2 was further examined for guidance on how to arrange the increments of PMP. Almost any arrangement could be found in these data. The Warner, Oklahoma, (9/6-12/1943) storm showed the six greatest 6-hr increments to be consecutive in the middle of the 72-hr rain sequence, while the Council Grove, Kansas (7/9-13/1951) storm showed daily bursts of 12 hr with lesser rains between.

To get PMP for all durations within a 72-hr storm requires that the 6-hr increments be arranged with a single peak (fig. 3). We chose a 24-hr period as including most rain bursts in major storms, and set this as the length of rain bursts for the PMP, giving three 24-hr periods in a 72-hr period. Based on results from examination of the 28-storm sample, guidance follows for arranging 6-hr increments of PMP within a 72-hr period. To obtain PMP for all durations:

A. Arrange the individual 6-hr increments such that they decrease progressively to either side of the greatest 6-hr increment. This implies that the lowest 6-hr increment will be at either the beginning or the end of the sequence.

B. Place the four greatest 6-hr increments at any position in the sequence except within the first 24-hr period of the storm sequence. Our study of major storms (exeeding 48-hr durations) shows maximum rainfall rarely occurs at the beginning of the sequence.

3. ISOHYETAL PATTERN

3.1 Introduction

There are two important considerations relative to the isohyetal pattern used for PMP rainfalls. The first is the shape of the pattern and how it is to be represented. The second is the number and magnitude of isohyets within the pattern.

This chapter deals with the selection of the pattern shape and the number of isohyets considered to represent the shape. The magnitude of the individual isohyets will be determined from the procedure described in chapter 5, Isohyet Values. In addition to establishing the shape of the isohyetal pattern for

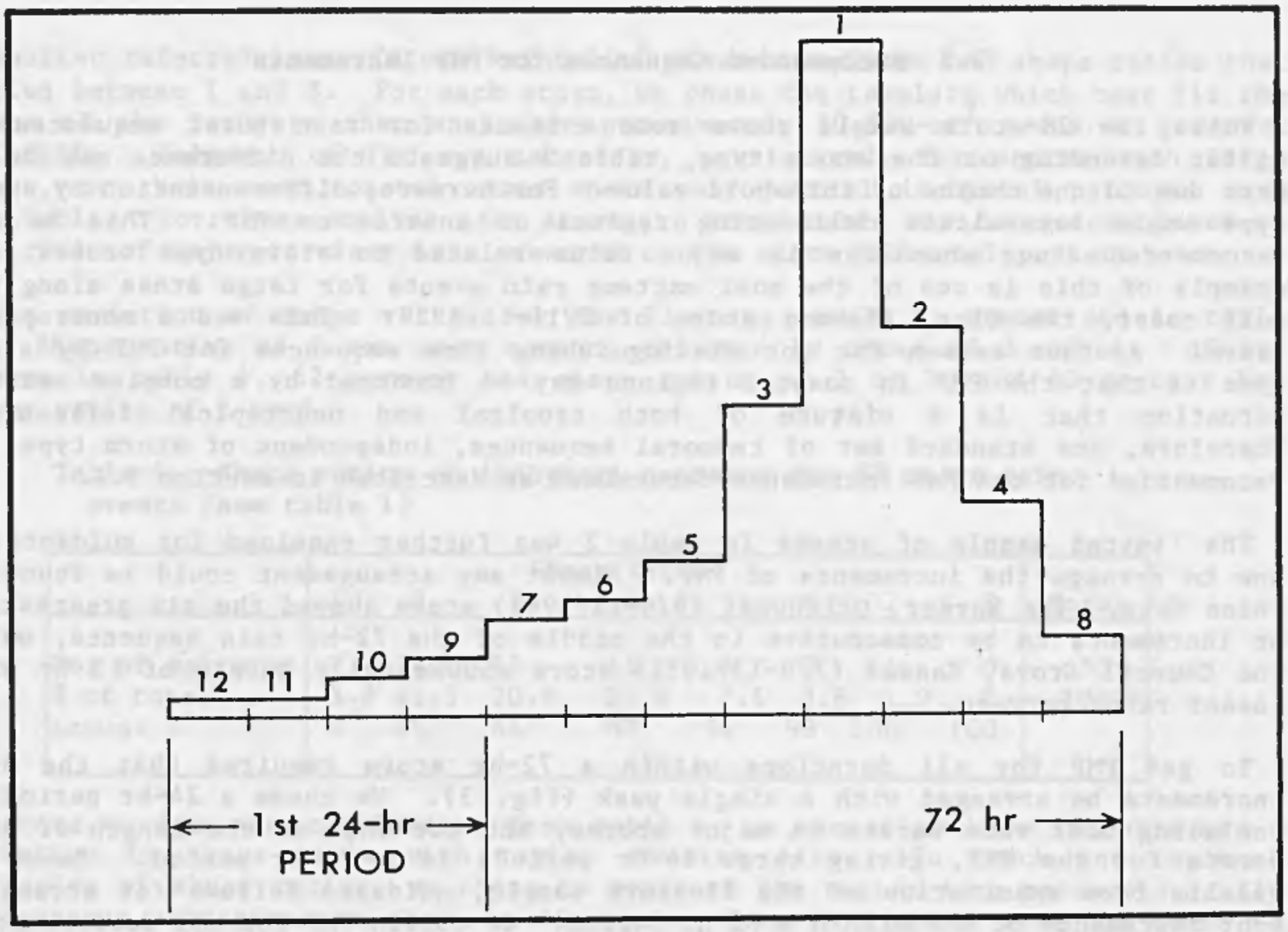

Figure 3.—Schematic example of one temporal sequence allowed for 6-hr increments of PMP. See text for restrictions placed on allowed sequences.

distributing area-averaged PMP over a drainage for the three greatest increments, it should be emphasized that this shape applies as well to the remaining 6-hr increments of PMP for distribution of residual precipitation and other adjustments.

3.2 Isohyetal Shape

To understand more about the shape of isohyetal patterns, we considered those for the 53 major rainfalls listed in table 1. It was apparent from this sample of storms as well as from our experience with other samples that the most representative shape for all such storms is that of an ellipse. Actual storm patterns in general are extended in one or more directions, primarily as a result of storm movement, and one finds that an ellipse having a particular ratio of major to minor axis can be fit to the portion of heaviest precipitation in most storms. Therefore, one question we posed was, what was the most representative ratio of axes for the major storms in our sample. Also of interest was to learn the variation of pattern shape with area size and with region.

To determine the shape ratio (i.e., the ratio of the major to minor axis) for the storms in our sample, we developed a number of elliptical templates that were scaled to contain 20,000 mi^2, relative to the small isohyetal maps portrayed in "Storm Rainfall in the United States" (U.S. Army Corps of Engineers 1945-), hereafter referred to as "Storm Rainfall." These templates had shape ratios that varied between 1 and 8. For each storm, we chose the template which best fit the shape of the isohyets that enclosed approximately 20,000-mi^2 areas of greatest rainfall. Judgment of fit was necessary, particularly for storms with large areas, or those near coastal zones where only partial isohyetal patterns were available. For those smaller area storms, a shape ratio was determined based on the ratio of major to minor axis measured on the storm isohyetal pattern.

The variation of shape ratios for the 53-storm sample is summarized in table 4. Shape ratios of 2 are most common, followed by those of 3 and 4. Of the storms in table 4, 62 percent had shape ratios of 2 or 3, and 83 percent had shape ratios of 2 to 4.

Table 4.--Shape ratios of isohyetal patterns for 53 major rain events (see table 1)

	Shape Ratio								
	1	2	3	4	5	6	7	8	Total
No. of patterns	2	22	11	11	4	2	1	0	53
% of total	3.8	41.5	20.8	20.8	7.5	3.8	1.9	0	100
Accum. %	4	45	66	87	94	98	100	100	

Before we draw any conclusions from table 4, we wanted to know if there was a variation in shape ratio with region or area size. To check the regional variation of shape ratios, we chose to separate the region into meteorologically homogeneous subregions as shown in figure 4. These subregions were not meant to represent the entire region of homogeneity but to be sufficiently independent portions of such broadscale subregions among which one might expect to find differences in shape ratios. These regions, shown in figure 4, contained 33 (62%) of the 53 storms.

Table 5 shows the distribution of shape ratios within each of the six subregions, and although the number of storms in each is small, the percent of total shown at the bottom of the table is somewhat similar to that for the entire sample given in table 4. The number of storms in table 5 is too small to be significant, but distinguishable regional differences are not apparent, all tending to support shape ratios of 2 or 3.

Table 5.--Shape ratios for six subregions

	Shape Ratio								Total no. of storms
Subregions	1	2	3	4	5	6	7	8	
	% of storms in region								
Atlantic Coast	20	40	0	20	20	0	0	0	5
Appalachians	20	40	20	0	20	0	0	0	5
Gulf Coast	0	56	22	11	11	0	0	0	9
Central Plains	0	67	0	17	17	0	0	0	6
North Plains	0	0	50	0	0	25	25	0	4
Rocky Mt. Slopes	0	50	25	25	0	0	0	0	4
% of total	6	45	18	12	12	3	3	0	33 99

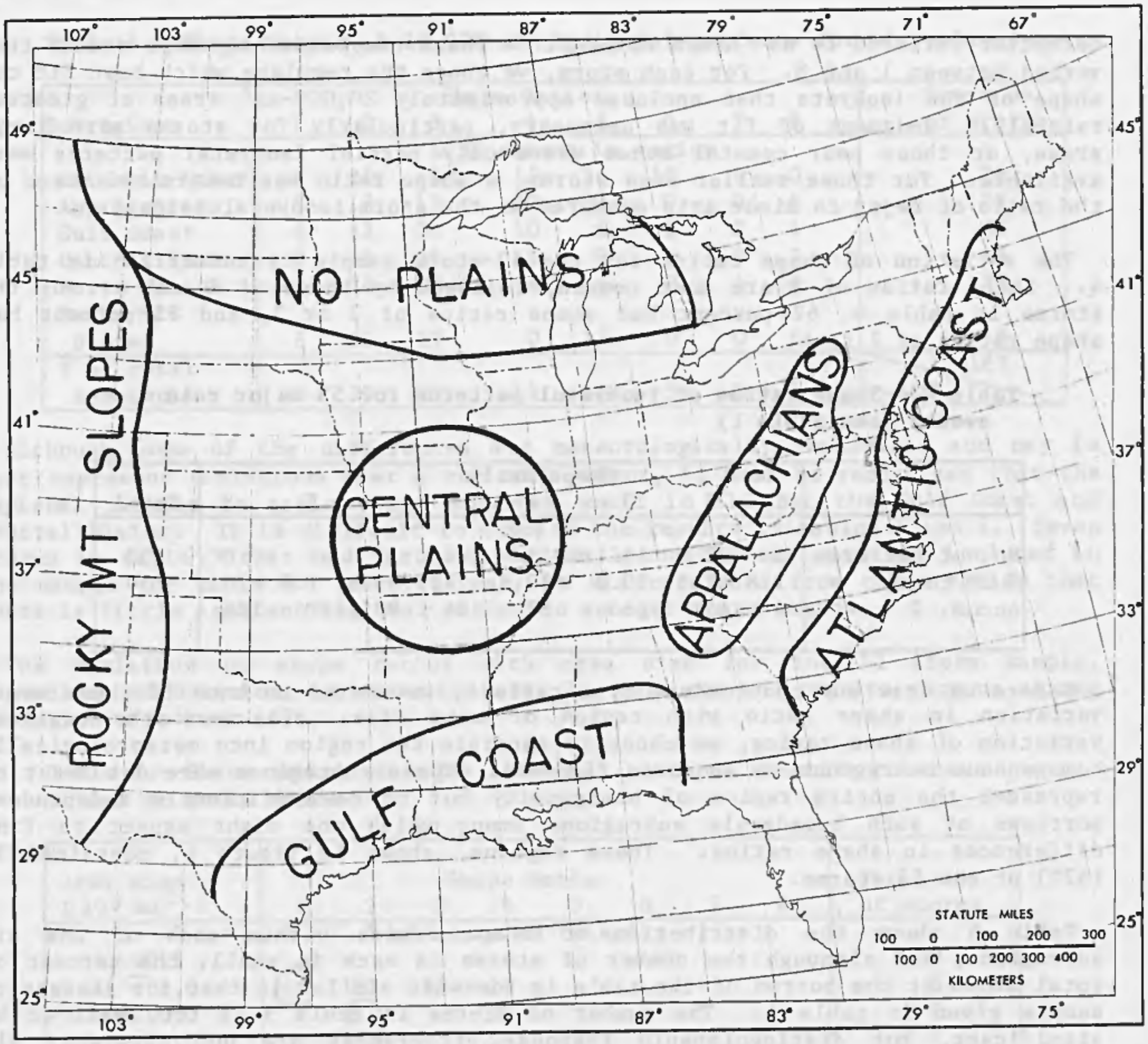

Figure 4.—Homogeneous topographic/climatologic subregions used in study of regional variation of isohyetal patterns.

The appendix contains a discussion of a larger sample of storms, 183 of which occurred in these same six subregions. Results from these storms are shown in table 6. Information from table 6 indicates that the Atlantic Coast and North Plains regions have the greatest percentage (16) of storms with shape ratios greater than 5. The North Plains also has the greatest percentage (16) of approximately circular patterns. The Appalachians show the greatest percentage of storms with shape ratios of 4 and 5. This may be a reflection of an orographic effect of the mountains combined with the northeastward movement of storms along the east coast. These results are not typical of all orographic regions, for shape ratios of 2 predominate on the Rocky Mountain Slopes. This is meteorologically reasonable since many large storms in this region result from nearly stationary weather systems over or near the east face of the mountains.

Table 6.--Shape ratios of 20,000-mi^2 isohyetal patterns for six subregions

Subregions	Shape Ratio 1	2	3	4	5	6	7	8	Total no. of storms
	% of storms in region								
Atlantic Coast	4	31	19	15	15	12	4	0	26
Appalachians	4	17	13	30	30	0	0	4	23
Gulf Coast	6	42	28	10	6	2	2	4	50
Central Plains	2	26	35	16	9	9	0	2	43
North Plains	16	28	28	8	4	8	4	4	25
Rocky Mt. Slopes	6	56	19	0	13	0	0	6	16
% of total subsample	6	33	25	14	12	5	2	3	183 100

Although some of the differences are meteorologically reasonable and may in fact represent variations over a regional extent, it must be recognized that the regional samples in table 6 are somewhat small in all but the Gulf Coast and Central Plains. It is difficult to compare the results in tables 5 and 6. Seven storms in table 5 that had particularly small total areas were not included in the sample for table 6. Nevertheless, it was concluded from these tables that there is little apparent regional variation amongst shape ratios.

The variation of shape ratios with area size for the 53 storm sample, regardless of duration, is shown in table 7. Here too the results show no strong variation with area size.

Table 7.--Shape ratios of major isohyetal patterns relative to area size of total storm

Area size (10^3 mi^2)	Shape Ratio 1	2	3	4	5	6	7	8	Total no. of storms
	% of storm in category								
$\leq$0.3									0
0.31 - 5.0	40	20	20	20					5
5.1 - 10.0		67		33					3
10.1 - 20.0		57		28	14				7
20.1 - 30.0	12	50	12	25					8
30.1 - 40.0		50		33	17				6
40.1 - 50.0		50		50					2
50.1 - 70.0		22	33	11		22	11		9
70.1 - 90.0		28	43		28				7
$\geq$ 90.0		33	50	17					6
% of total	6	40	21	21	8	4	2	0	53

In table 7, the larger values in each row have been circled. In this sample, there appears to be a tendency for larger percentages of storms to be circular at the smaller area size. In the same manner, there is a tendency for shape ratios to increase from 2 for areas between 5,000 mi^2 and 50,000 mi^2 to 3 for larger areas. Although these results are perhaps handicapped by the small size of the sample, somewhat similar results were obtained from the larger sample of storms discussed in the appendix.

3.3 Summary of Analysis

The following conclusions were drawn from analysis of shape ratios of major storm isohyetal patterns.

1. Approximately 60 percent of our sample of major storms had shape ratios between 2 and 3.
2. No strong regional variation of shape ratios was apparent, although some meteorologically reasonable trends could be obtained from the data.
3. No strong relation was found between shape ratio and total-storm area size, but there was some evidence that lower shape ratios occur with the smaller area sizes.

3.4 Recommended Isohyetal Pattern for PMP

Since a majority of the storms considered in this study had shape ratios of 2 and 3, we recommend an idealized (elliptical) isohyetal pattern with a ratio of major to minor axis of 2.5 to 1 for distribution of all 6-hr increments of precipitation over drainages in the nonstippled zones east of the 105th meridian (see figs. 18-47 of HMR No. 51). The choice of a single shape ratio for the entire region east of the 105th meridian simplifies the procedure for determining the hydrologically most critical pattern placement on a drainage, does not violate the data, and tends to be in the direction of the small-area patterns observed in major storms of record.

A recommended pattern is given in figure 5, drawn to a scale of 1 to 1,000,000. This pattern contains 14 isohyets (A through N), that we think would provide reasonable coverage of drainage areas up to about 3,000 mi^2. Since it would be cumbersome to include a pattern drawn to 1:1,000,000 scale with isohyets enclosing the largest suggested area, we have limited figure 5 to only 6,500 mi^2. All discussion of figure 5 implies a pattern of 19 isohyets extending from A to S and covers an area of 60,000-mi^2. It is necessary to provide patterns larger than 20,000 mi^2 (the limit of PMP given in HMR No. 51) in order to cover a narrow drainage with isohyets, particularly if the pattern and the drainage have different axial orientations, or if you want to consider non-basin centered placements. The 10-mi^2 isohyet is taken to be the same as point rainfall.

If it is desired to apply figure 5 to some other scale or to add larger isohyets to the pattern, and suitable templates are not available, table 8 aids the reproduction of figure 5 and gives the length in miles of the semi-minor and semi-major axes of an ellipse along with selected radials that enclose the suggested areas for a shape ratio of 2.5. For example, to obtain a 2,150-mi^2 ellipse, the minor axis is twice the value of 16.545 given in table 8, or 33.09 mi. The major axis is then 82.725 mi. The information in table 8 is sufficient to obtain isohyets that enclose areas for which HMR No. 51 is applicable.

The procedure in chapter 7 for determining isohyet values suggests that at times it may be necessary to consider isohyets supplementary to those specified in figure 5. To aid in construction of any additional isohyets, we provide the

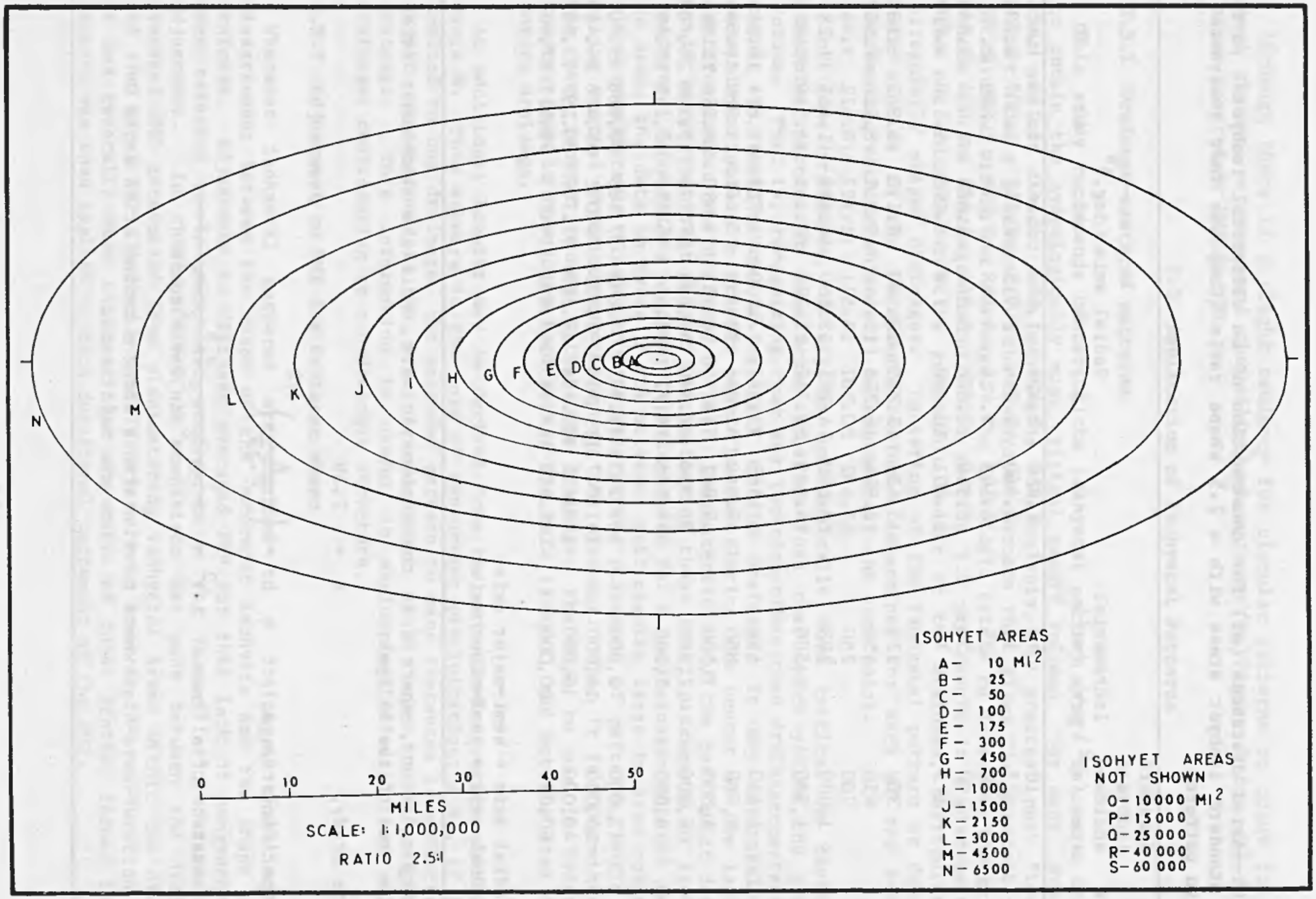

Figure 5.--Standard isohyetal pattern recommended for spatial distribution of PMP east of the 105th meridian (scale 1:1,000,000).

Table 8.--Axial distances (mi) for construction of an elliptical isohyetal pattern for standard isohyet areas with a 2.5 shape ratio (Complete four quadrants to obtain pattern)

Isohyet label	Standard isohyets enclosed area (mi^2)	Incremental area (mi^2)	Radial axis (deg.)* 0	15	30	45	60	90
A	10	10	2.820	2.426	1.854	1.481	1.269	1.128
B	25	15	4.460	3.836	2.933	2.342	2.007	1.784
C	50	25	6.308	5.426	4.148	3.313	2.839	2.523
D	100	50	8.920	7.672	5.866	4.685	4.014	3.568
E	175	75	11.801	10.150	7.758	6.198	5.310	4.720
F	300	125	15.451	13.289	10.160	8.115	6.953	6.180
G	450	150	18.924	16.276	12.444	9.939	8.516	7.569
H	700	250	23.602	20.301	15.521	12.397	10.622	9.441
I	1,000	300	28.209	24.263	18.550	14.816	12.965	11.284
J	1,500	500	34.549	29.717	22.720	18.146	15.549	13.820
K	2,150	650	41.363	35.577	27.200	21.725	18.614	16.545
L	3,000	850	48.860	42.026	32.130	25.662	21.989	19.544
M	4,500	1,500	59.841	51.470	39.351	31.430	26.930	23.936
N	6,500	2,000	71.920	61.860	47.294	37.774	32.366	28.768
O	10,000	3,500	89.206	76.728	58.661	46.853	40.145	35.682
P	15,000	5,000	109.225	93.973	71.846	57.383	49.168	43.702
Q	25,000	10,000	141.047	121.318	92.752	74.082	63.476	56.419
R	40,000	15,000	178.412	153.456	17.323	93.707	80.292	71.365
S	60,000	20,000	218.510	187.945	143.691	114.767	98.337	87.404

* 0° radial axis = semi-major axis
90° radial axis = semi-minor axis

following relations, where a is the semi-major axis, b is the semi-minor axis, and A is area of the ellipse.

For this study, $a = 2.5b$

For a specific area, A, $b = \left(\frac{A}{2.5\pi} \right)^{1/2}$

Radial equation of ellipse, $r^2 = \frac{a^2 b^2}{a^2 \sin^2 0 + b^2 \cos^2 0}$

where r = distance along a radial at an angle 0 to the major axis.

Although there is a slight tendency for circular patterns to occur for small area storms, we recommend the elliptical pattern in figure 5 for all drainage areas covered by HMR No. 51.

3.5 Application of Isohyetal Patterns

3.5.1 Drainage-centered patterns

This study recommends centering the isohyetal pattern (fig. 5) over a drainage to obtain the hydrologically most critical runoff volume. For many drainages that are not divided into sub-basins for analysis, the greatest peak flow will result from a placement of the isohyetal pattern that gives the greatest volume of rainfall within the drainage. The hydrologic trials to determine the greatest volume in the drainage discussed in section 5.3 may result in a placement that does not coincide with the geographic center of the drainage, particularly in irregularly shaped drainages. Centering of the isohyetal pattern as described here applies to the incremental volumes determined for each of the 6-hr PMP increments, each of which will be centered at the same point.

For some drainages, it may be hydrologically more critical to center the isohyetal pattern at some other location than that which yields the greatest volume. That is, recognizing that any location other than drainage-centered may result in less volume of rainfall in the drainage, it may nevertheless be possible to obtain a greater peak flow by placing the center of the isohyetal patterns nearer the drainage outlet. Characteristics of the particular drainage would be an important factor in considering these trial placements of isohyetal patterns. Should this secondary consideration for a nondrainage-centered pattern be used, the data in table 8 are believed sufficiently large in area covered to allow considerable flexibility in alternative placement of patterns, while still giving spatial distribution throughout the drainage. When it is determined that the zero isohyet occurs within the drainage, the area to use in hydrologic computations is that contained within the zero isohyet, and not the area of the entire drainage.

An additional benefit may be derived from the extent of coverage provided in table 8. This appears in the form of concurrent precipitation; i.e., if PMP is applied to one drainage, the extended pattern in many instances is sufficient to permit estimation of the precipitation that could occur on a neighboring drainage. This information is useful in evaluating effects from multiple drainages contributing to a hydrologic structure.

3.5.2 Adjustment to PMP for drainage shape

Whenever isohyetal patterns are applied to a drainage, there will be disagreement between the shape of the outermost isohyets and the shape of the drainage. Adjustment to drainage averaged PMP for this lack of congruency has been referred to in some past studies as a "fit factor" or a "basin shape" adjustment. In those studies, a comparison was made between the drainage-averaged PMP determined from planimetering isohyetal areas within the drainage and the total PMP (generally for 72 hr) derived from depth-area-duration data. It has generally been the case that the ratio of these depths, termed the fit factor, was then applied to each durational increment of the PMP.

Since we have established that there is a pattern shape assigned to each 6-hr increment, we can reasonably expect that there will be some reduction to the volume precipitation determined from the isohyetal pattern when the pattern is "fit" to an irregularly shaped drainage. Comparison of the drainage-averaged volume of precipitation and that from the depth-area curve derived from HMR 51 for a 6-hr period is indicative of the percentage reduction due to the drainage shape. The largest reduction occurs in the first 6-hr period and decreases with each succeeding 6-hr period.

3.5.3 Pattern applicable to PMP

When the isohyetal pattern in figure 5 is applied to a drainage, both drawn to the same scale, one might ask whether it is necessary to use all the isohyets given, since the outermost isohyet encloses 60,000 mi^2, well above the area size for which PMP is given. The answer to this question depends upon the shape of the drainage. It is only necessary to use as many of the isohyets of figure 5 as needed to cover the contributing portion of the drainage. If one has a perfectly elliptical drainage of 2,150 mi^2 with a shape ratio of 2.5, then it is only necessary to evaluate isohyets A through K in the pattern in figure 5. Since almost all drainages are highly irregular in shape, the K isohyet is unlikely to provide total coverage for a drainage of this size, and for an extremely long 2,150-mi^2 drainage, even though one is applying the 2,150-mi^2 PMP, it may be necessary to evaluate the M, N or larger isohyets.

At this point in our discussion, we note that figure 5 is applied only to the three greatest 6-hr increments of PMP (18-hr PMP). For the nine remaining 6-hr increments of PMP in the 3-day storm, we recommend a uniform distribution of PMP throughout the area of PMP. This means that for each of the three greatest increments, the magnitude of PMP is such that it is reasonable to expect it to be spatially distributed according to the isohyets in figure 5. However, the magnitudes of the increments of PMP decrease rapidly after the greatest 6-hr amount, and by the fourth 6-hr period are reduced to a level at which we assume they can be approximated by constant values over the PMP portion of the pattern for the fourth through 12th 6-hr periods.

Since most drainages have irregular shapes and as we have already discussed earlier in this section, the pattern shape in figure 5 will not fit when placed over the drainage. Therefore, there will be portions of the drainage that may for some unusually shaped drainages be uncovered by the pattern for a particular area size of PMP. (Chapter 5 discusses how to determine what area pattern to place on a drainage.) We are faced with the problem of what precipitation to expect outside the area of the PMP pattern. The solution lies in the concept of residual precipitation.

Residual precipitation is the precipitation that occurs outside the PMP area size pattern. For example, if we find the pattern area size that gives the maximum volume of PMP in the drainage is 2,150 mi^2, then for the 3 greatest 6-hr increments, apply figure 5, where the K isohyet encloses the PMP area. The isohyets inside and outside of K represent values that will give areal average depths somewhat less than PMP. In this example, the isohyets outside of K determine the residual precipitation. It should also be emphasized that residual precipitation is that outside the area of the PMP pattern, and not necessarily outside the drainage.

Now, for the fourth through 12th 6-hr periods we have assumed a constant value approximates the respective 6-hr increment of PMP through the area size of PMP. Therefore, for these increments, there would be no A through J isohyets in the patterns applied. But, there would remain isohyets outside the isohyet for the area size of the PMP (outside K in the above example), and thus there is a residual precipitation pattern assigned to each of the fourth through 12th 6-hr increments of PMP, in addition to the patterns for the three greatest 6-hr increments. (See discussion in section 5.2.5 and fig. 21.)

Although the concept of residual precipitation and its application and representation in isohyetal patterns is new, and perhaps confusing at this point, further discussion in chapter 5 and the examples in chapter 7 should be helpful.

4. ISOHYETAL ORIENTATION

4.1. Introduction

The subject of isohyetal orientation arises quite naturally from discussion of placing isohyetal patterns over a drainage, since the orientation of a PMP pattern and that of the drainage over which it is placed may be entirely different. Guidance is needed on how well these orientations match for the PMP storm. It is assumed, though perhaps not always true, that the greatest volume of rainfall within a drainage results when the isohyetal pattern and the drainage are similarly oriented.

An objective of this section, therefore, is to determine whether there are meteorological restrictions or preferences for certain orientations. We are also interested in determining if there are any regional variations or constraints on orientations due to terrain or other factors.

As in the previous chapter, we rely on major observed storm rainfalls and apply the results to adjust the isohyetal orientation of the 6-hr PMP increments. (See section 5.2.1.)

Since 6-hr incremental isohyetal patterns are available only for a very few storms, we assume that the orientation of isohyets for the 6-hr incremental patterns of rainfall is the same as that for the total storm. Limited support for this assumption is found in the few incremental isohyetal patterns given in a study of Mississippi River basin storms by Lott and Myers (1956). For 10 of the 18 storms studied by Lott and Myers, 6-hr isohyetal patterns were determined. The orientations of the 6-hr isohyetal increments for these 10 storms vary from the total-storm orientations by no more than 40°.

4.2 Data

The sample of isohyetal patterns from the 53 major storms in table 1 were considered for the study of isohyetal orientations.

4.2.1 Average orientations

In this chapter, reference is sometimes made to the average of several orientations. It is believed important to remark here on how these averages were obtained, because averages of angular measure do not follow that of simple arithmetic averages. First, recognizing that every orientation line (or axis) is

Problem: Obtain an average of three orientation lines given below. If the lines are designated as #1 = 020° or 200°, #2 = 150° or 330°, and #3 = 165° or 345°, then if we average 020°, 150° and 165°, we get 112°, which is seen to represent a false average.

Solution: Choose values to average from ends of the lines (quadrants) that give the minimum range. Here the range of 200° minus 150°, or 380° minus 330°, is the minimum (50° range). Thus, the representative average is 172°, or 352° respectively.

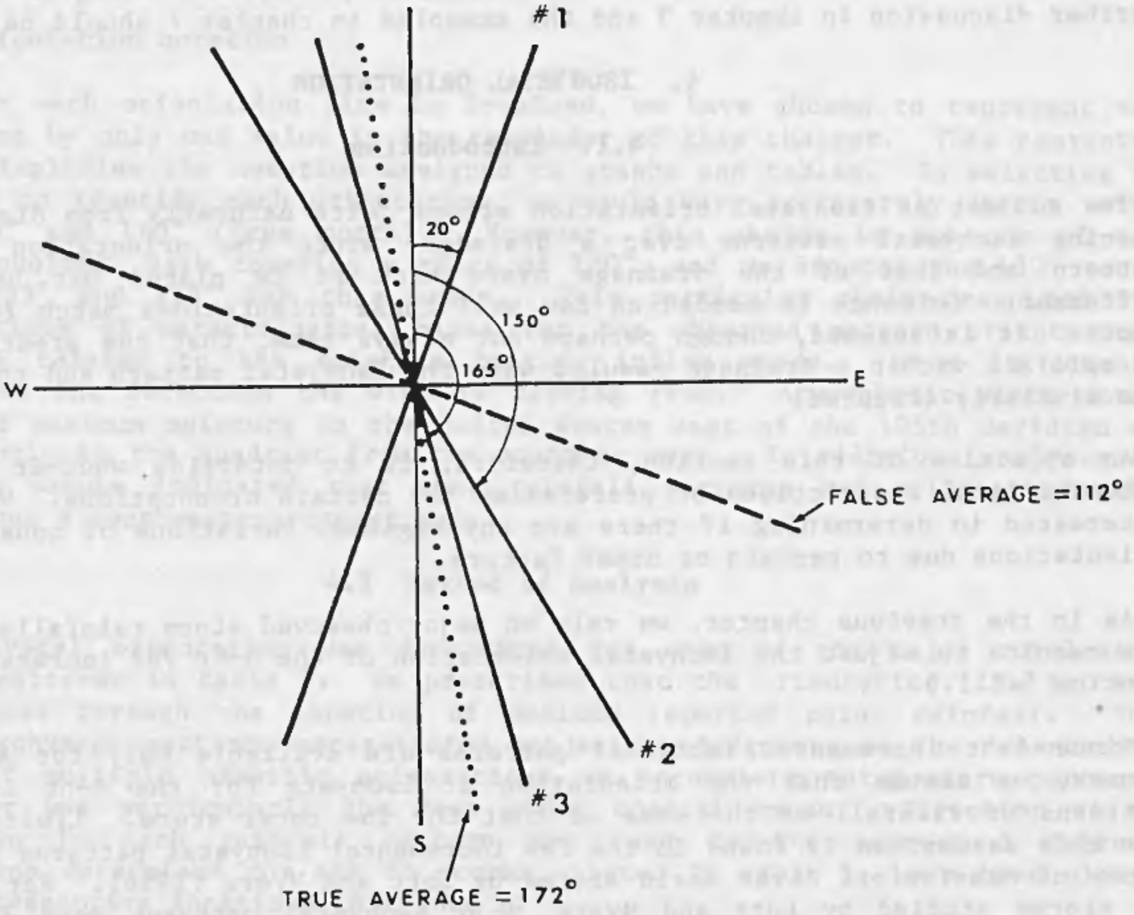

Figure 6.--Schematic example of problem in averaging isohyetal orientations.

2-valued, we obtain different averages relative to which value is chosen to represent a particular orientation. Therefore, a rule must be developed, when averaging such values, on which of the 2 values to use so that everyone obtains a comparable and representative result. The rule we applied was to use those values that would give a minimum range for all the values to be averaged. This procedure will be illustrated by the following example. Average the three orientation lines in figure 6 (#1 is 020° - 200°, #2 is 150° - 330°, and #3 is 165° - 345°). (Three orientations are considered here only to keep the problem simple; the procedure is the same regardless of the number of orientations to be averaged). If one chose to average the three smallest values (reading from north) of 20°, 150° and 165°, the result would be 112° given by the dashed line in figure 6. This is an unrepresentative average when compared to the three solid lines in this figure. We say the range of those 3 values is 145° (165° minus 020°). However, following the rule to obtain a minimum range, consider the three values of 150°, 165° and 200° (representing the same three orientations, but reading the other end of the 020° - 200° line). We get a range of 50° (i.e., 200° minus 150°), and similarly a 50° range is obtained for the set of other ends to these same 3 lines (380° minus 330°). Since 50° is the least difference we can obtain from any set of directions, for these 3 particular lines, the correct values to average are either 150°, 165° and 200° or, 020° + 360°, 330° and 345°, for which the average orientation is 172° or 352°, respectively shown by the dotted line in figure 6.

4.2.2 Orientation notation

Although each orientation line is 2-valued, we have chosen to represent each orientation by only one value in the remainder of this chapter. This convention greatly simplifies the notation assigned to graphs and tables. In selecting the one value to identify each orientation, we could have arbitrarily chosen values between 0° and 180° (from north). However, this choice is but one of many possible choices, each covering a range of 180°, and we adopted the 180° sector between 135° and 315° for this study. This particular choice resulted from considerations of meteorological bases for the observed pattern orientations, which are related to the moisture bearing inflow winds. Wind is commonly reported as the direction the wind is blowing from. Atmospheric winds during periods of maximum moisture in the United States east of the 105th meridian are predominantly in the quadrant from the south to west. In addition, analysis for our storm sample indicated that most rainfall patterns had orientations that varied about a southwest-northeast axis.

4.3 Method of Analysis

An isohyetal orientation was determined for each of the major total-storm rainfall patterns in table 1. We prescribed that the orientation line for each pattern pass through the location of maximum reported point rainfall. Some complex isohyetal patterns necessitated subjective judgments on the orientation, because of multiple possible orientations or incomplete total-storm patterns. The latter was particularly the case along coastal zones. Direction of the orientation in each rainfall pattern was read to the nearest 5 degrees. Orientations determined for the 53 storms, listed in table 1, have been plotted at their respective locations in figure 7.

4.4 Analysis

The amount of variation in orientations given in table 1 and figure 7 gave rise to the question, whether it was possible to generalize these orientations into a consistent pattern over the entire study region.

4.4.1 Regional variation

The same six subregions used to study shape ratios were used to determine regionally averaged orientations. Averages of the orientation for the major storms in each subregion are given in table 9. The range of orientations for storms considered in each subregion is also indicated.

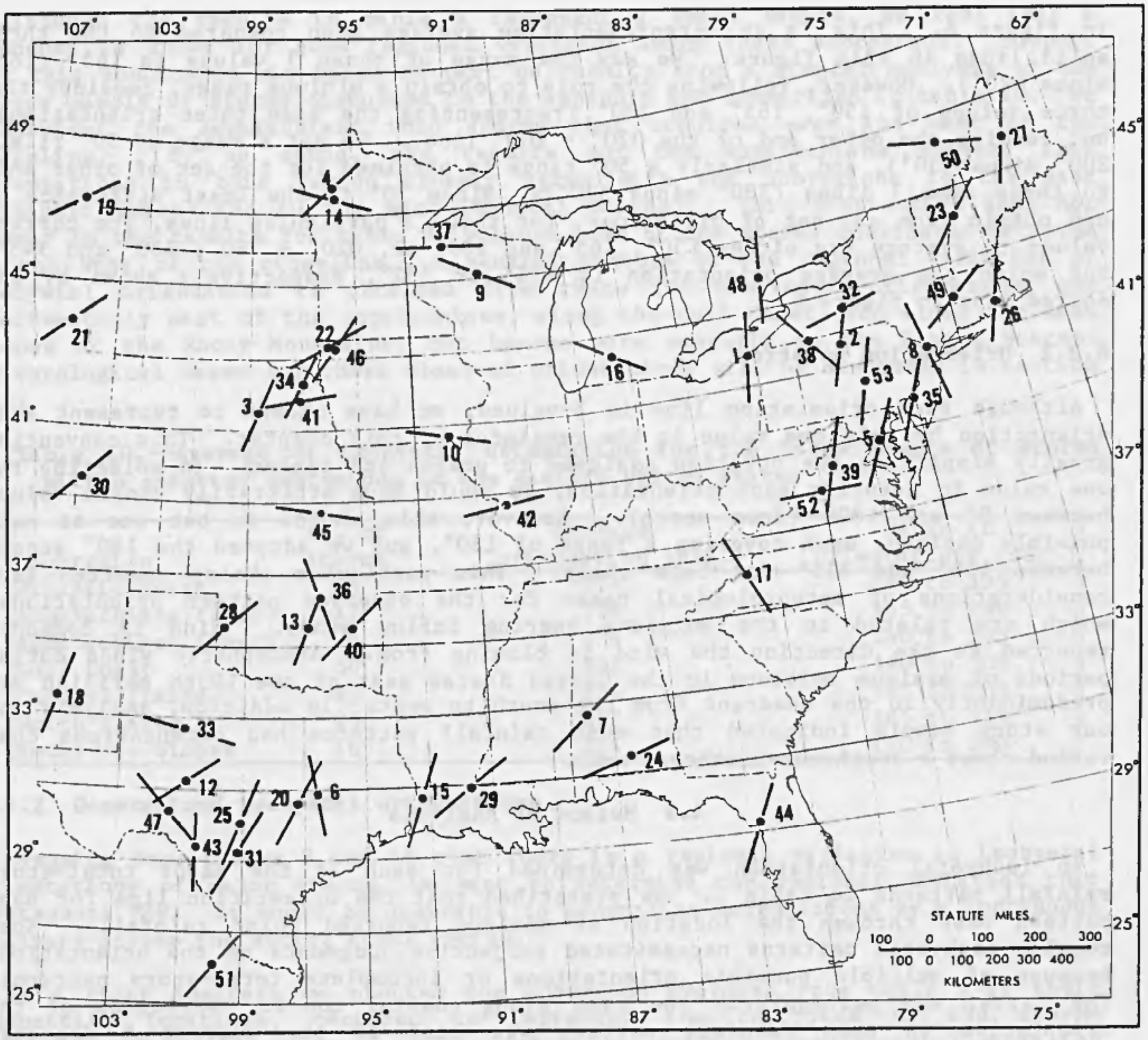

Figure 7.—Location and orientation of precipitation pattern for 53 major storms listed in HMR No. 51. Identification numbers refer to table 1.

Table 9.—Averages of isohyetal orientations for major storms within selected subregions of the eastern United States (storms contained in appendix of HMR No. 51)

Subregion	No. of Storms	Average orientation (deg)	Range in orientations (deg)
Atlantic Coast	5	202	170 to 230
Appalachians	5	194	145 to 270
Gulf Coast	9	214	170 to 290
Central Plains	6	235	160 to 285
North Plains	4	270	230 to 295
Rocky Mt. Slopes	4	224	200 to 240

Although the results in table 9 represent a small sample, we feel that a tendency is shown for some regional variation among these subregions. Support for this conclusion was based in part on results from a similar analysis of the larger sample of storms discussed in the appendix and summarized in table 10. We subdivided the Appalachians into storms that occurred east and west of the ridgeline. By so doing, the results for the Appalachians suggest that orientations in this region closely agree with the subregions to the east (Atlantic Coast) and to the west (Central Plains). This distinction does not appear in the results for table 9, because none of the storms considered occurred to the west of the ridgeline. A general picture of the regional variation of isohyetal orientation is obtained from these two samples: orientations are southwesterly east of the Appalachians, along the Gulf Coast, and along the east slopes of the Rocky Mountains, but become more westerly in the Plains States. Meteorological bases for those observed orientations will be discussed in section 4.5.

Table 10.--Average of isohyetal orientation for the large sample of storms within selected subregions in the eastern United States

Subregion	No. of storms	Average orientation (deg.)	Range in orientations (deg.)
Atlantic coast	26	204	140 to 305
Appalachians (East)	17	204	155 to 240
Appalachians (West)	6	278	240 to 305
Gulf Coast	50	235	140 to 300
Central Plains	43	256	195 to 300
North Plains	25	257	185 to 310
Rocky Mt. Slopes	16	214	170 to 290

4.4.2 Generalized isohyetal orientations

Assuming from tables 9 and 10 that there is a regional variation in isohyetal orientations of major storms, we want to determine the regional variation that represents PMP. It would be desirable to generalize orientations by a continuous analysis across the entire study region.

As a first approach we plotted the subregion averages from table 9 at their respective locations, centered to represent the centroids of the storms averaged. From this basis, a rough pattern was drawn to show regional variation (not shown here). It was felt that although a general pattern could be obtained in this manner, drawing to five data points for so large a region was less than desirable.

A decision was made to consider a number of major storms distributed throughout the region and develop the generalized pattern from their orientations. Storms were selected from table 1 according to the following conditions:

1. No other major storm in table 1 occurred within a radius of 100 miles of the storm chosen. When two or more storms were within 100 miles of one another, only the storm with the larger 24-hr 1,000-mi^2 depth was considered.

2. No storm was selected whose total storm duration was less than 24 hr, as they were believed to represent local storms for which almost any orientation is believed possible.

With this guidance, 25 storms (roughly one-half the storms in table 1) were selected. In addition, to the 25 major storms from table 1, six storms were selected from "Storm Rainfall" (U.S. Army Corps of Engineers 1945-) to fill in portions of the region not represented by storms in table 1. These storms also met the selection criteria noted above.

The 31 storms were plotted at their respective locations as shown in figure 8. Through considerable trials, a generalized pattern was drawn which attempted to match as many of the storm orientations as possible and yet maintain some internal consistency regarding gradients and smoothness. Also shown in figure 8 is the result of this analysis.

In making the analysis shown in this figure, we attempted to control the variation from observed orientation whenever possible. Table 11 lists the 31 differences. It is apparent that some large variations occur, e.g., 72° at Smethport, Pennsylvania. For the most part, variations are considerably less, as summarized by 10° categories in table 12. Two-thirds of the analysed orientations are within 30° of the observed orientations, while nearly 94% are within 50°.

Although there are some portions of the region (e.g., eastern Great Lakes) that show rather large variation from the analysis, a decision was made not to complicate the analysis further by creating regional anomalies. Therefore, the analysis shown in figure 8 was adopted to represent the pattern of orientations for our data, and we further assumed that this pattern applied to the most favorable conditions for PMP. For drainages that lie outside the region covered by the analysis (for example in northern Michigan), use the orientation of the nearest isopleth.

4.4.3 Variation of PMP with pattern orientation applied to drainage

In application of PMP to specific drainage, figure 8 is used to determine the orientation of the isohyetal pattern most likely to be conducive to a PMP type event. It is unrealistic to expect that figure 8 is without error and that PMP at any location is restricted to only one orientation. For these reasons we recognize that it is more reasonable that PMP occur through a range of orientations centered on the value read from figure 8. Following this line of reasoning, we also expect that for precipitation orientations that do not fall within the optimum range, the magnitude of PMP would be somewhat less.

4.4.3.1 Range of full PMP. The range of full PMP (100% PMP) is that range of orientations, centered on the value read from figure 8, for which there is no reduction to the amounts read from HMR No. 51 for orientation. Our concept of PMP is that the conditions resulting in a PMP-type event are somewhat restricted, and we believe that the range of full PMP should also be limited. However, to gain support for this limitation, we again referred to our sample of major storms and, from the summary of orientations in table 12, we chose a range of ±40° (representing about 85 percent of the variation in our sample) to assign to PMP. Therefore, whenever the pattern best fitted to the drainage for which PMP is being determined has an orientation that falls within 40° of the orientation obtained for that location (from fig. 8), full PMP is used.

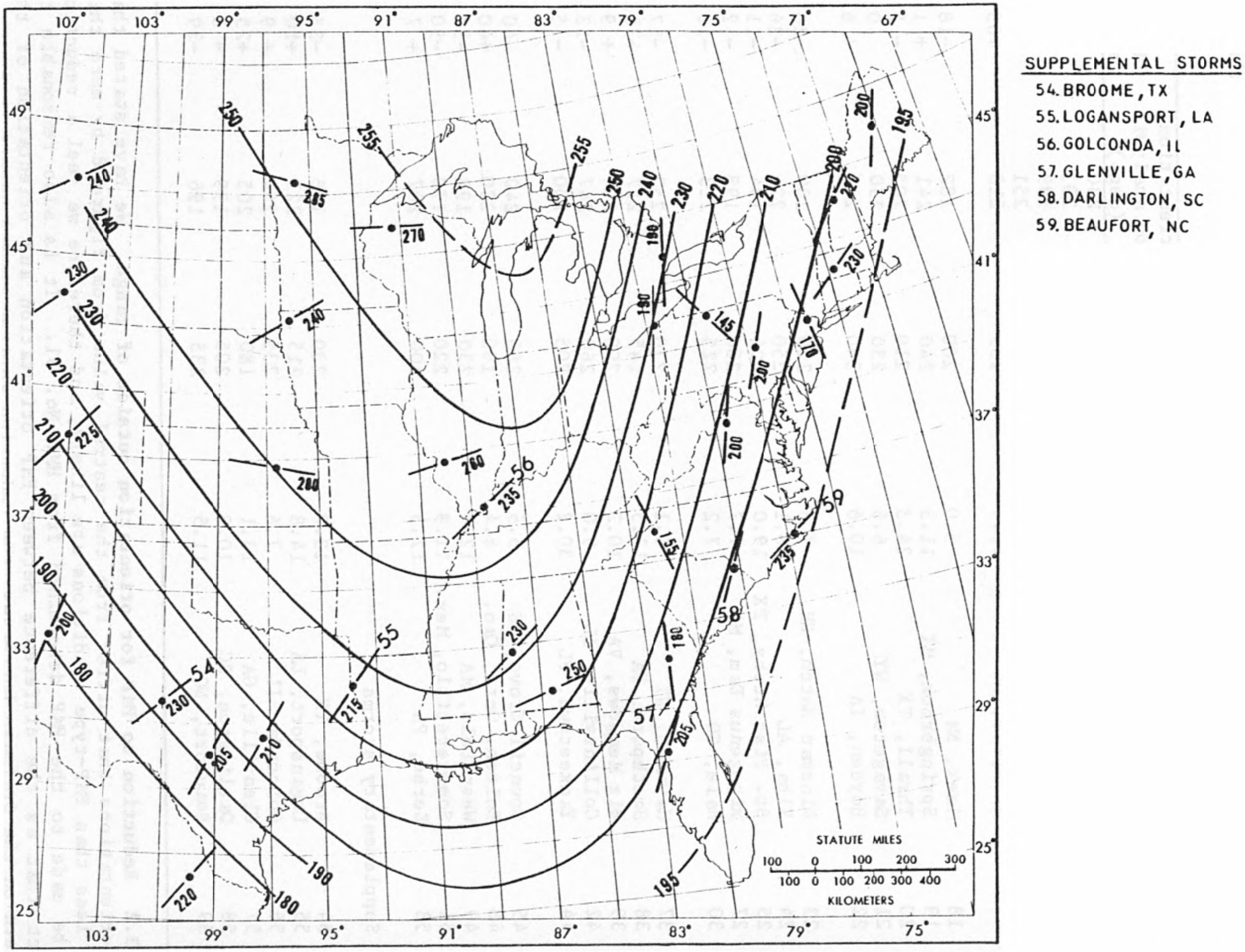

Figure 8.--Analysis of isohyetal orientations for selected major storms adopted as recommended orientation for PMP within ± 40°. Addition of 6 major storms not in figure 7 have been identified numerically above station locations and in the margin.

Table 11.—Major storm orientations relative to generalized analysis including summary information

Storm index no. from table 1	Name	24-hr 1000-mi^2 depth (in.)	Observed orientation (deg.)	Orientation from analysis (deg.)	Differences
1	Jefferson, OH	11.0	190	230	+40
7	Eutaw, AL	11.3	230	231	+ 1
8	Paterson, NJ	10.9	170	199	+29
14	Beaulieu, MN	10.0	285	251	-34
17	Altapass, NC	15.0	155	218	+63
18	Meek, NM	5.0	200	182	-18
19	Springbrook, MT	11.3	240	241	+ 1
20	Thrall, TX	24.3	210	205	- 5
21	Savageton, WY	6.6	230	230	0
22	Boyden, IA	10.6	240	246	+ 6
23	Kinsman Notch, NH	7.8	220	200	-20
24	Elba, AL	16.1	250	224	-26
25	St. Fish Htchy, TX	19.0	205	194	-11
27	Ripogenus Dam, ME	7.7	200	198	- 2
30	Hale, CO	7.2	225	213	-12
37	Hayward, WI	9.1	270	253	-17
38	Smethport, PA	13.3	145	217	+72
39	Big Meadows, VA	10.3	200	209	+ 9
42	Collinsville, IL	9.0	260	247	-13
44	Yankeetown, FL	30.2	205	200	- 5
45	Council Grove, KS	6.6	280	240	-40
48	Bolton, Ont., Can.	6.4	190	230	+40
49	Westfield, MA	12.4	230	198	-32
51	Sombreretillo, Mex.	11.9	220	170	-50
53	Zerbe, PA	12.3	200	207	+ 7
Supplementary storms					
54	Broome, TX	13.8	230	195	-35
55	Logansport, LA	14.8	215	225	+10
56	Golconda, IL	7.4	235	244	+ 9
57	Glenville, GA	13.1	180	205	+25
58	Darlington, SC	10.8	205	199	- 6
59	Beaufort, NC	11.5	235	196	-39

4.4.3.2 Reduction to PMP for orientation outside of range. We have stated that for orientations that differ from the central value from figure 8 by more than 40°, less than PMP-type conditions are likely, and therefore we feel a reduction can be made to the PMP determined from HMR No. 51. It is also reasonable to expect that as the difference between PMP orientation and orientation of the pattern on the drainage increases, the reduction applied to PMP should increase.

Table 12.—Frequency of various difference categories between observed and preferred orientations

Categ. (deg.)	-50 to -41	-40 to -31	-30 to -21	-20 to -11	-10 to -1	0 to 9	10 to 19
Freq.	1	5	1	6	4	7	1
%	3	16	3	19	13	23	3

Categ. (deg.)	20 to 29	30 to 39	40 to 49	50 to 59	60 to 69	70 to 79	Total
Freq.	2	-	2	-	1	1	31
%	6	-	6	-	3	3	98

Range	Frequency	Cum. %
±10°	11	35.5
±20°	18	58.1
±30°	21	67.7
±40°	26	83.9
±50°	29	93.5
±60°	29	93.5
±70°	30	96.8
±80°	31	100.0

Because we anticipated there could be a regional variation, we considered the subregions in figure 4. Our sample in table 1 of major storms within these subregions is too small to be useful, and we relied on the increased sample described in the appendix. Within each subregion, storms were ranked according to magnitude of 72-hr 20,000-mi^2 depth, and then converted to percent of the maximum depth occurring in each region. We plotted the percent of maximum rainfall vs. orientation for each storm by geographic region. An enveloping curve drawn on these graphs provided guidance on the range of orientations that should be permitted without reduction and on the appropriate reduction for greater variations. The data for the Gulf Coast region are shown in figure 9, as an example of these plots.

In figure 9, the Hearne, Texas (6/27-7/1/1899) storm gave the maximum depth, and the Elba, Alabama (3/11-16/1929) storm was the second greatest at about 80 percent of the Hearne depth. We remind the reader that since orientation is a form of circular measure, the left-hand end of the scale in figure 9 is identical with the right-hand end of the scale.

Considering each of the subregional distributions, of which figure 9 is an example, we developed a model based essentially on envelopment of subordinate depth storms. The model shows that 100 percent of PMP applies within ± 40° of the central value as indicated in section 4.4.3.1. Maximum reduction to PMP is limited to 15 percent applicable to orientation differences of ± 65° or more. This model is given in figure 10, in which the adjustment factor (100% minus the percentage reduction) to PMP is read from the right-hand axis for differences of orientation from the central value obtained from figure 8 (represented by the 0 value on the left of the model).

4.4.3.3 Variation due to area size. It appears reasonable that no reduction should be applied to storms on the scale of a single thunderstorm cell (or

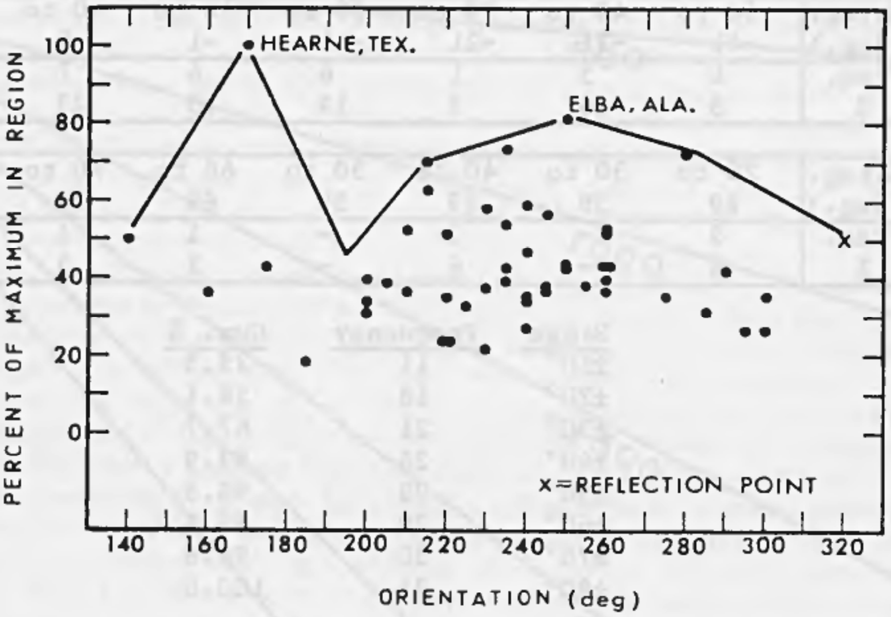

Figure 9.—Distribution of isohyetal orientations for 50 major storms (from sample listed in the appendix) that occurred in the gulf coast subregion.

possibly a complex cell). Such a system is expected to have equal intensity at any orientation. An area size of 300 mi^2 was chosen as the smallest storm area for which a reduction should be applied. A rational argument can also be developed to say that if we limit reduction of PMP for orientation to storm area sizes of 300 mi^2 and larger, it is unreasonable to expect that a discontinuity occurs at 300 mi^2. On this basis, there should also be some limit at which the maximum reduction of 15% applies. Between these limits, a reduction between 0 and 15% applies. Although we have no data to support our decision, we chose to set a limit of 3,000 mi^2 (ten times the lower limit of 300 mi^2) as the area above which 15% reduction is possible.

To use figure 10 for pattern areas greater than 300 mi^2 consider the diagonal lines provided for guidance. These lines have been drawn for every 500 mi^2 up to 3,000 mi^2, and intermediate 100-mi^2 areas are indicated by the dots along the right margin. By connecting the vertex in the upper left with the appropriate dot on the right, the user can determine the adjustment factor corresponding to the orientation difference noted along the abscissa. As an example, for a 1,000-mi^2 isohyetal pattern whose orientation differs by 57° from that determined from figure 8, the adjustment factor read from figure 10 is 97.3%. Note for orientation differences of 65° or larger, the adjustment factor is that given by the scale along the right margin for the respective areas.

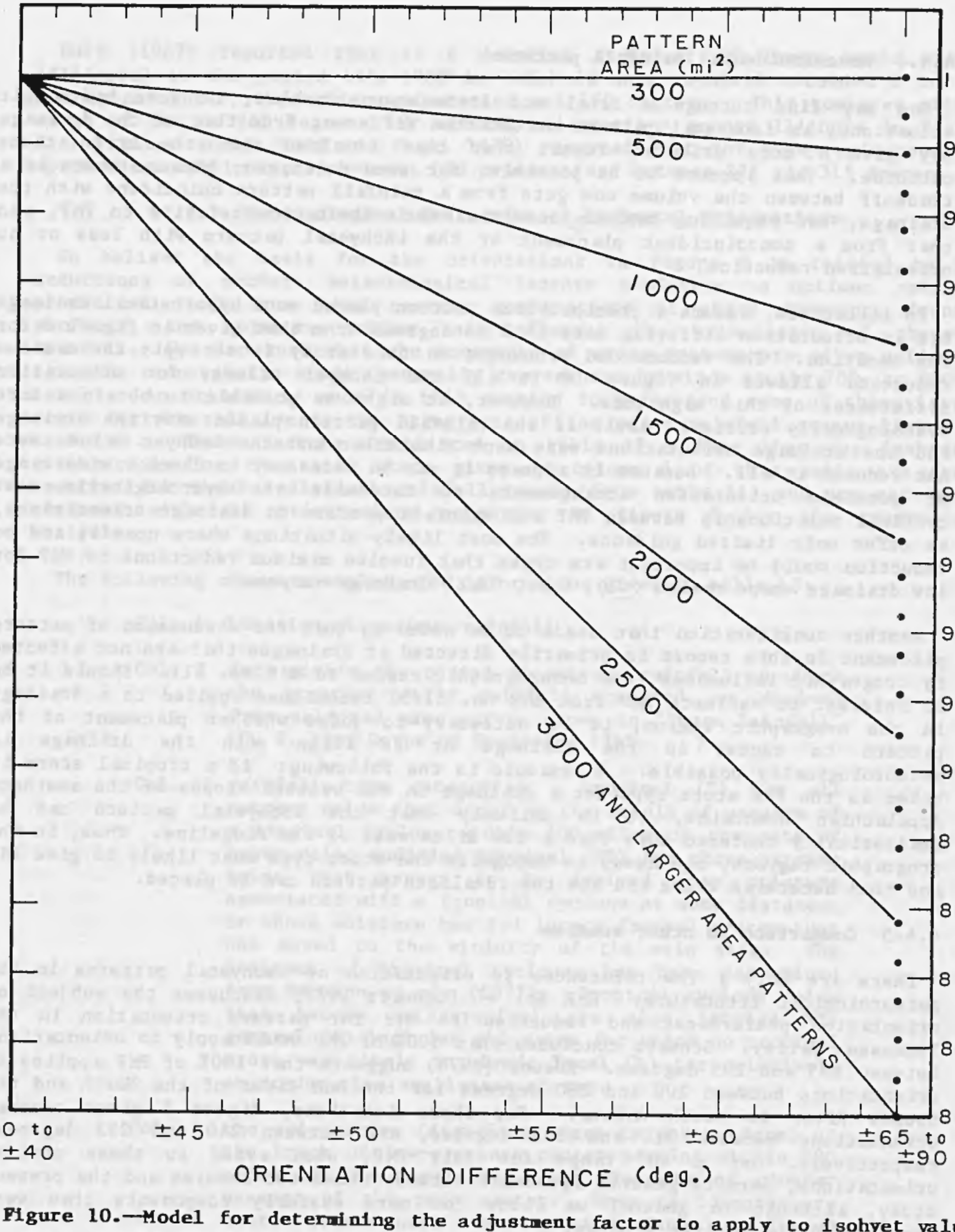

Figure 10.--Model for determining the adjustment factor to apply to isohyet values as a result of placing the pattern in figure 5 at an orientation differing from that given in figure 8 by more than 40°, for a specific location.

4.4.4 Noncoincidental rainfall pattern

One may find through a trial and error approach that, in some hydrologic situations, an isohyetal pattern orientation different from that of the drainage may give a more critical result than that obtained when the orientations coincide. This appears to be possible, for some drainages, because there is a tradeoff between the volume one gets from a rainfall pattern coincident with the drainage, but requiring maximum reduction for orientation relative to PMP, and that from a noncoincident placement of the isohyetal pattern with less or no orientation reduction.

To illustrate, assume a precipitation pattern placed on a hypothetical drainage has an orientation differing more than 65 degrees from that given in figure 8 for the location. The recommended procedure in this study is to apply the maximum reduction allowed in figure 10 to all the isohyet values, for orientation differences of this magnitude. However, it might be possible to obtain a more hydrologically critical result if the rainfall pattern placed over the drainage and the drainage orientations were kept dissimilar and the isohyet values were not reduced at all. Because it appears it may be necessary to check a wide range of possible orientation arrangements to determine the hydrologically most critical relationship between PMP and rainfall pattern on drainage orientations, we offer only limited guidance. The most likely situations where non-fit and no reduction would be important are those that involve maximum reductions to PMP for low drainage shape ratios (≤2), i.e., "fat" drainage shapes.

Another consideration that needs to be noted is that the discussion of pattern placement in this report is primarily directed at drainages that are not affected by orographic influences (the nonorographic region in HMR No. 51). Should it be of interest to estimate PMP from HMR No. 51/52 techniques applied to a drainage in the orographic region, it is necessary to judge whether placement of the pattern to center in the drainage or to align with the drainage is meteorologically possible. An example is the following: if a tropical storm is taken as the PMP storm type for a drainage on the western slopes of the southern Appalachian Mountains, it is unlikely that the isohyetal pattern can be realistically centered more than a few miles west of the ridgeline. Thus, in the orographic regions, one needs to recognize the storm type most likely to give PMP and then determine where and how the idealized pattern can be placed.

4.4.5 Comparison to other studies

There are only a few references to orientation of isohyetal patterns in the meteorological literature. HMR No. 47 (Schwarz 1973) discusses the subject of orientation preferences and reduction to PMP for pattern orientation in the Tennessee Valley. Schwarz concludes that 100% of PMP would apply to orientations between 195 and 205 degrees. Riedel (1973) suggests that 100% of PMP applies to orientations between 200 and 280 degrees for the Red River of the North and the Souris River in North Dakota. For these locations, figure 8 gives central orientations between 210 and 245 degrees, and between 240 and 255 degrees, respectively. Our ± 40° range for full PMP, when added to these central orientations, permits general agreement between these two studies and the present study, although in general we allow for more westerly components than were reported in the earlier studies.

Huff (1967) reported that in a detailed study of 10 large scale storms (Illinois) in the period 1951-1960 in which 12-hour rainfall exceeded 8 in. at the storm center, the median orientation was 270 degrees. This compares with a range of 245 to 255 degrees for central orientations across Illinois in figure 8. A later study (Huff and Vogel 1976) reported that for heavy rainstorms in northeastern Illinois, 84 percent had orientations between 236 and 315 degrees.

4.5 Meteorological Evaluation of Isohyetal Orientations

We believe the basis for the orientations in figure 8 is related to the occurrence of certain meteorological factors conducive to optimum rainfall production. We know that certain combinations of storm movement, frontal surfaces, and moisture inflow can influence the orientation of observed rainfall. We also know that the movements of storm systems are often guided by the mean tropospheric winds (generally represented by winds at the 700- to 500-mb level). An attempt is made in this section to understand some of these large-scale factors relative to the occurrence of the major rainfall events listed in table 11. These factors are listed in table 13. Note that the isohyetal orientations for the total storm given in column 6 of this table are those observed for these individual rainfall cases (from table 11) and are not to be confused with the orientations appearing in figure 8 for the generalized analysis.

The following comments explain the information given in table 13:

Col. 1	location of maximum rainfall
Col. 2	date within the period of extreme rainfall on which the greatest daily rainfall occurred, as derived from selected mass curves shown in "Storm Rainfall" (U. S. Army Corps of Engineers 1945-)
Col. 3	rainfall type categories: **tropical** (T) for all extreme rains that occur as the result of passage of a tropical cyclone within 200 miles of the site of heavy rain; **modified tropical** (MT) for those extreme rains that appear to be derived from moisture associated with a tropical cyclone at some distance, or whose moisture has fed into a frontal system that has moved to the vicinity of the rain site. The presence of tropical cyclones has been determined from Neumann et al. (1977). Tropical cyclone rains that become extratropical are also labeled MT; **general** (G) includes all rains for which no tropical storm was likely involved; **local** (L) for relatively short-duration small-area storms.
Col. 4	the orientation (direction storm is moving from) of the track of low-pressure center passing within 200 miles of the heavy rain, for the date of closest passage of the rain center. When no low-pressure center passes near the rain site, "none" is listed in table 13.

Table 13.—Meteorological factors pertinent to isohyetal orientation for major storms used to develop regional analysis (fig. 8)

		Column			
1	2	3	4	5	6
Storm center	Date of max. daily rain	Type of rain-storm	Orient. of storm track	Orient. of front. surface	Observed orient. of iso. pat.
1. Jefferson, OH	9/13/1878	MT	190	135	190
2. Eutaw, AL	4/16/00	G	none	210	230
3. Paterson, NJ	10/09/03	MT	100	180	170
14. Beaulieu, MN	7/19/09	G	none	none	285
17. Altapass, NC	7/16/16	MT*1	none	none	155
18. Meek, NM	9/16/19	MT*2	none	none	200
19. Springbrook, Mt.	6/19/21	G	260	200	240
20. Thrall, TX	9/09/21	MT*3	none	none	210
21. Savageton, WY	9/28/23	G	none	none	230
22. Boyden, IA	9/17/26	G	none	210	240
23. Kinsman Notch, NH	11/04/27	MT*4	none	180	220
24. Elba, AL	3/14/29	G	none	210	250
25. St. Fish Htchy.,TX	7/01/32	G	none	240	205
27. Ripogenus Dam, ME	9/17/32	MT	185	160	200
30. Hale, CO	5/31/35	L	none	090	225
37. Hayward, WI	8/30/41	G	none	250	270
38. Smethport, PA	7/18/42	L	none	190	145
39. Big Meadowns, VA	10/15/42	MT*5	none	none	200
42. Collinsville, IL	8/16/46	G	none	260	260
44. Yankeetown, FL	9/05/50	T	180*8	none	205
45. Council Grove, KS	7/11/51	G	none	250	280
48. Bolton, Ont. Can.	10/16/54	MT	200	200	190
49. Westfield, MA	8/18/55	MT	175	none	230
51. Sombreretillo, Mex.	9/21/67	T	020	none	220
53. Zerbe, PA	6/22/72	MT	150	220	200
54. Broome, TX	9/17/36	MT*6	none	none	230
55. Logansport, LA	7/23/33	T	240	245	215
56. Golconda, IL	10/05/10	G	none	235	235
57. Glenville, GA	9/27/29	MT*7	230*7	none	180
58. Darlington, SC	9/18/28	T	230	220	205
59. Beaufort, NC	9/15/24	MT	240	210	235

LEGEND

T - Tropical
MT - Modified Tropical
G - General
L - Local

*1 - Trop. cycl. dissipated in central Georgia on 14th
2 - Hurricane dissipated in southwestern Texas on 15th
3 - Hurricane dissipated on Texas-Mexico border on 8th
4 - Tropical cyclone headed north @ 36°N, 80°W. mid-day 3rd
5 - Tropical cyclone dissipated in eastern North Carolina on 12th
6 - Tropical cyclone dissipated near Del Rio, TX on 14th
7 - Hurricane at Key West on 27th, track given for 30th
8 - Storm looping on 4-5th

Col. 5 the orientation (only one end of the 2-ended line given) of the frontal surface if the front is within 100 miles of the rain center (from United States Daily Weather Maps) for the date of greatest daily rainfall. When no frontal surface appears near rain site, "none" is listed in table 13.

Col. 6 the orientation of observed rainfall pattern for the total storm from table 11

Eighteen of the 31 rains in table 13 come from tropical or modified tropical storms. A logical question is whether the orientation of the rainfall pattern is the same as the orientation of the storm track. Eleven of the thirteen rainfalls that have storm track information show agreement within 50 degrees between the storm track and rainfall orientations.

Some of the modified tropical cyclone rains showed that maximum rainfall occurred where tropical moisture interacted with a frontal surface generally approaching from the west or northwest. This kind of interaction and the complexity involved in ascertaining the cause for the particular isohyetal orientation is illustrated in the case of the Zerbe, Pa. storm (6/19-23/72). Figure 11 shows a cold front through the Great Lakes at 1200 GMT on the 21st that moved eastward and became stationary through western New England by 1200 GMT on the 22nd. The track of the tropical cyclone center is shown by 6-hr positions. After 1200 GMT on the 22nd, the storm center appears to be attracted toward the approaching frontal trough position and recurves inland through Pennsylvania. The orientation (approx. 200°) of the total-storm isohyetal pattern is plotted in figure 11 for comparison. Although the front appears to be dissipating with the approach of the tropical cyclone, the orientation of the total-storm rainfall would suggest that the effect of the frontal surface as a mechanism for heavy rainfall release was important. Thunderstorms along the frontal surface may have moved in a northeasterly direction (200°), steered by the upper-level winds. Since all of these features are in motion, it is likely that the orientation of the isohyetal pattern is the composite result of several interactions. One additional factor that has not been discussed is the effect of the Appalachian Mountains. The ridges comprising these mountains also have a northeast-southwest orientation. We are unable to say at this time how the interaction between moisture flows and these terrain features contribute to the overall orientation of the precipitation pattern.

The Springbrook (6/17-21/21) and Savageton (9/27-10/1/23) storms were associated with nontropical low-pressure centers to the south of the respective rainfall maxima, around which moist air drawn from gulf latitudes encountered strong convergence to release convective energy.

Reviewing the results given in table 13, one may ask, what meteorological feature provides the source of precipitation for those storms that show "none" in columns 4 and 5. To answer this question requires studies beyond the scope of this discussion, but in many instances we believe the precipitation was caused by horizontal convergence of very moist air. This convergence in most instances was due to meteorological conditions, while in others it may have been enhanced by terrain features.

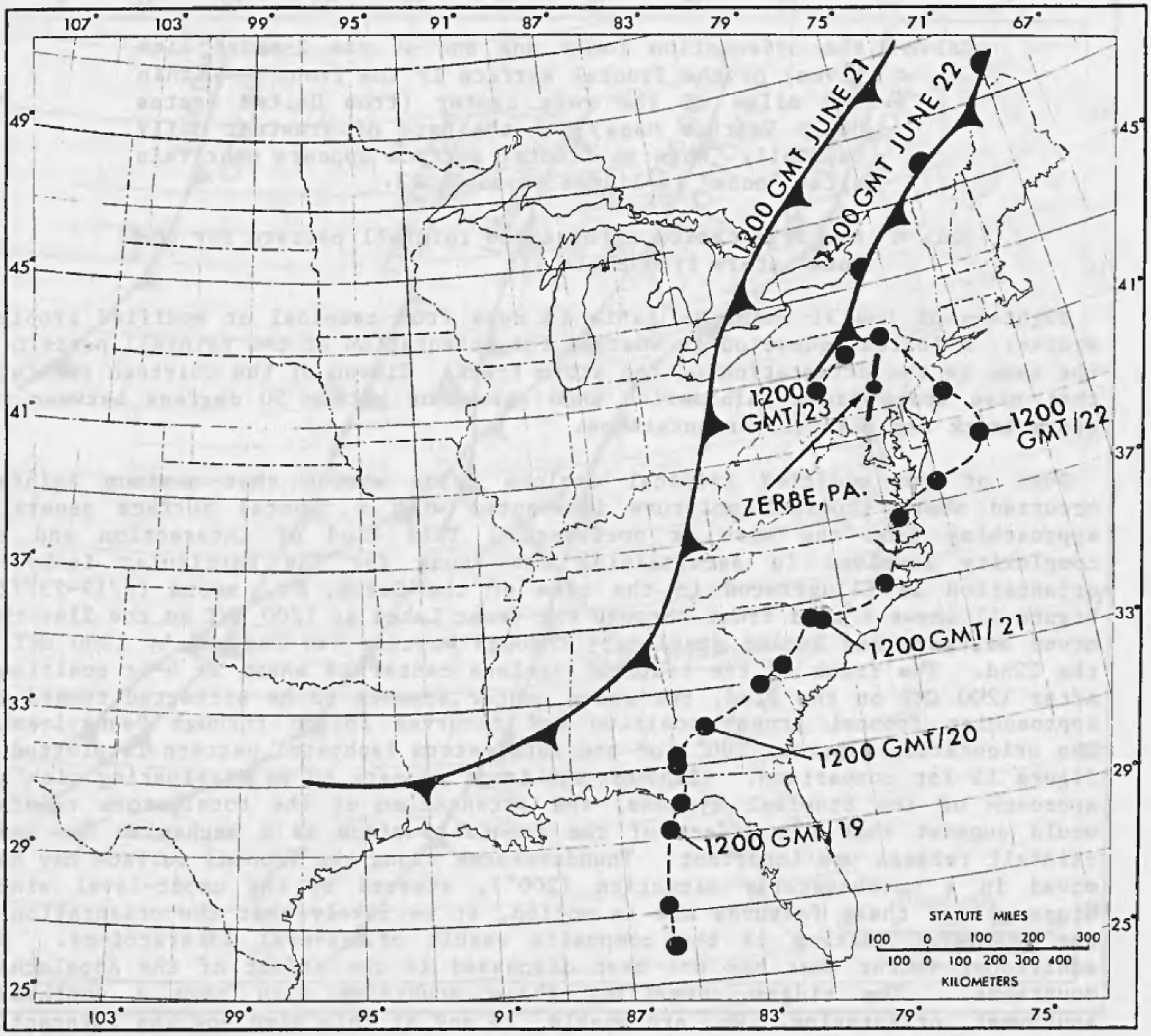

Figure 11.—Track of hurricane Agnes (6/19-22/72) showing frontal positions and orientation of the greatest 20,000-mi^2 precipitation area centered at Zerbe, PA.

The Golconda, Illinois, storm (10/3-6/10) is representative of most of the other major storms in table 13 in which the isohyetal orientation can be more closely related to the orientation of the frontal surface. For this storm figure 12 shows a weak and dissipating cold front (A) approaching Golconda from the west on the 3rd and 4th. Farther west on the 4th a second cold front (B) is passing through the Dakotas and moves rapidly eastward to a position southwest-northeast through the Great Lakes on the 5th. Twenty-four hours later this second front has passed eastward of Golconda. Prior to its passage, strong southerly surface winds bring moist tropical air northward through the Mississippi Valley. It is presumed that this moist air upon meeting the frontal surface, is lifted to a level at which convective lifting takes over. Thunderstorms, or local storms, triggered along the frontal surface produce the observed rainfall orientation.

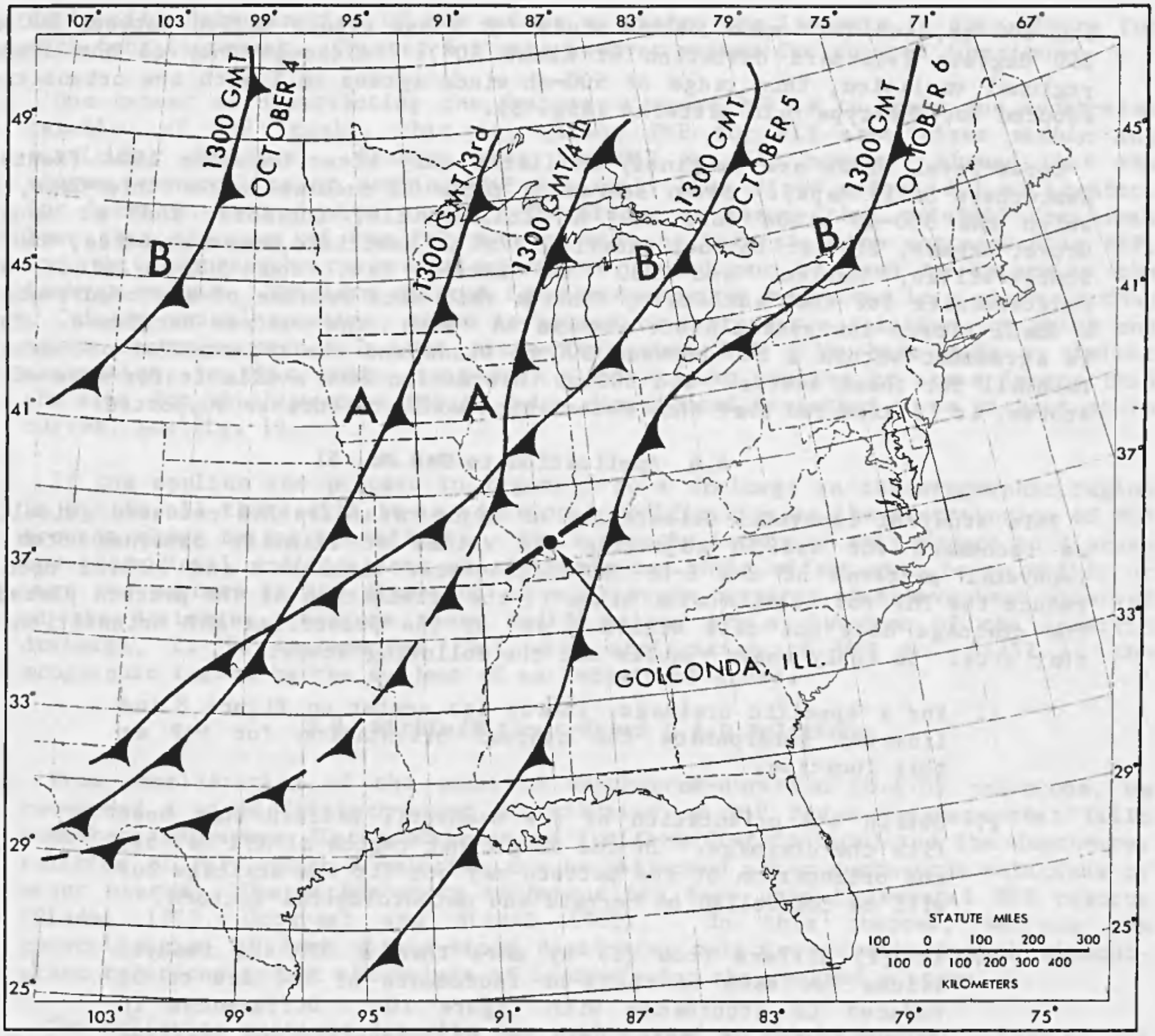

Figure 12.—Frontal positions and orientation of the greatest 20,000-mi^2 precipitation area centered at Golconda, IL (10/3-6/10).

Almost all of the 31 major storms listed in table 13 included thunderstorm-type bursts of heavy rain. Tendencies for these short-duration bursts are evident in major portions of the mass curves (not shown here) for each storm. Thunderstorms imbedded within widespread rain patterns are common to major rainfalls in the study region. Since thunderstorms are involved, we speculate that the isohyetal pattern orientations probably are controlled to some degree by the upper-level flows (see Newton and Katz 1958, for example).

Maddox et al. (1973) studied the synoptic scale aspects of 151 flash floods, 113 of which occurred east of the 105th meridian. (One-third of these had maximum precipitation amounts equal to or exeeding 10 in.) Their results showed that the winds aloft tend to parallel the frontal zone during these events. They also showed that 500-mb winds were representative of the winds aloft between 700 and 200 mb, and that mean 500-mb winds for these events varied between 220 and 250 degrees (standard deviation of about 30°). Although they do not discuss regional variation, this range of 500-mb winds agrees well with the orientations adopted for PMP-type rain patterns (fig. 8).

Upper-level winds are routinely available only after December 1944 (Northern Hemisphere Daily Maps). Seven storms in table 12 occurred after this date, for which the 500-mb winds were 280° at Collinsville, Illinois, 260° at Council Grove, Kansas, 210° at Bolton, Ontario, 215° at Westfield, Massachusetts, 020° at Sombreretillo, Mexico, and 220° at Zerbe, Pa., the 500-mb winds were indeterminate for the Yankeetown, Florida rain site because of the occurrence of a small closed low system aloft associated with the surface hurricane. There is agreement within ± 20° between 500-mb winds and the orientation of heaviest rainfall for these storms. Had 500-mb information been available for more of the storms, it is expected that this association would be further supported.

4.6 Application to HMR No. 51

This study of isohyetal orientation of major rainfalls has produced guidelines we recommend for use in adjusting the volume of rainfall obtained from the isohyetal patterns of the 6-hr PMP increments. Figures 8 and 10 are used to reduce the PMP for certain area sizes if the orientation of the pattern placed on the drainage does not fall within ± 40° of the prescribed PMP orientation for that site. To apply these results use the following steps:

1. For a specific drainage, locate its center on figure 8 and linearly interpolate the central orientation for PMP at that location.
2. Obtain the orientation of the isohyetal pattern that best fits the drainage. In the orographic region of HMR No. 51, the orientation of the pattern may not fit the drainage but will be controlled by terrain and meteorological factors.
3. If (1) differs from (2) by more than ± 40° the isohyet values for each of the 6-hr increments of PMP are to be reduced in accordance with figure 10. Differences in orientations of more than ± 65° require the maximum reduction. The reduction that is applicable, however, is a function of the storm pattern area size with no reduction if 300 mi^2 or less, and a maximum of 15% if 3,000 mi^2 or more.

5. ISOHYET VALUES

5.1 Introduction

When considering the spatial distribution of rainfall over a drainage, a question that needs to be answered is how concentrated the rain should be. Keep in mind that the concentration or distribution of the drainage-average PMP does not change the total rain volume for idealized elliptically shaped drainages. For this report, the spatial distribution is set by the values of isohyets in the isohyetal pattern. Part of this question has been answered in chapter 3, where we developed an idealized pattern shown in figure 5. This chapter, therefore, deals with determination of the values to assign the isohyets in that figure for each 6-hr increment. Chapter 6 treats isohyet values for shorter durations.

One manner of distributing the drainage-average PMP is to apply the depth-area relation of PMP itself, that is, giving PMP for all area sizes within any particular drainage. Studies made for HMR No. 51, however, showed that the storms, controlling or setting PMP for small area sizes, often did not control for large areas and vice versa. Therefore, we assume that rainfall for areas less than the area of the PMP pattern will be less than the corresponding PMP, and that the depth-area relation of PMP should not be used to determine the isohyet values. The term adopted for the depth-area relations in a storm is thus a "within-storm" relation, since it serves to represent a relation for which one storm controls over all area sizes less than PMP. We have made a similar assumption, in this study, that such a curve also applies to areas larger than the area for which average PMP is being distributed (referred to as without-storm curves, see fig. 1).

If one applies the pattern in figure 5 to a drainage in the orographic region in HMR No. 51 there will be an additional modification to the distribution of PMP brought about by terrain effects. It is not the intent of this report to discuss how these local modifications are derived, but their effect will be to modify or warp the pattern in the direction of major storm patterns that have been observed on the drainage. Because these modifications are a function of the specific drainage, it is recommended that each application of HMR No. 51/52 in the orographic region be the subject of an individual study.

5.2 Within/Without-Storm D.A.D Relations

From consideration of the possible depth-area-duration (D.A.D) relations, we recommend a within/without-storm distribution of PMP for a drainage that falls somewhere between a flat average value (uniform distribution) and the depth-area relation of PMP. Such a relation can be patterned after depth-area relations of major storms. The within-storm technique has been used in several HMR reports (Riedel 1973, Goodyear and Riedel 1965). In this chapter, we use the generalization of such within-storm depth-area relations combined with without-storm relations to set the values of isohyets for the adopted pattern.

The following sections describe the method used to obtain isohyet values at one location and explain how we generalized the procedure throughout the region. Since the method is somewhat complex, it is necessary to present a more detailed description of its development.

To begin this discussion several questions are posed: a.) For which 6-hr PMP increments do we need isohyetal values?, b.) How are within/without-storm depth-area relations for 6-hr PMP increments in (a) determined?, c.) How are isohyetal profiles for a 6-hr incremental PMP used to obtain isohyet values?, and d.) How can we generalize (c) to provide isohyet values for areas between 10 and 20,000 mi^2 anywhere within the study region?

5.2.1 PMP increments for which isohyet values are required

Record storm rainfalls show a wide variation in D.A.D relations. They all indicate a sharp decrease with area size for the maximum 6-hr rainfall. The remaining 6 hr rainfall increments may vary from showing a decrease, an increase, or no change with increasing area size. This mixture may be due in part to a storm with a complex combination of both high and low rainfall centers with maximum depths controlled by several centers. However, for internal consistency no increase in incremental PMP values with increasing area size was allowed in HMR No. 51. If it were, it would designate a low rather than a high rainfall center, or a doughnut type configuration.

We have let the D.A.D relations of PMP in HMR No. 51 set the number of increments for which areal variation is required. These show that most spatial variation occurs in the largest 6-hr increment, and practically none, if any, occurs after the third greatest 6-hr increment. This is to say, as an example, that the fourth greatest 6-hr incremental PMP determined by subtracting 18-hr PMP from 24-hr PMP varies only slightly, if at all, with area size. Therefore, we recommend distributing incremental PMP for only the three greatest 6-hr PMP increments. The remaining nine 6-hr PMP increments are used as storm pattern averages, that is, as uniform depths over the pattern area used for distributing PMP.

5.2.2 Isohyet values for the greatest 6-hr PMP increment

Since we need to obtain all isohyet values for only the three greatest 6-hr PMP increments, we have chosen to discuss each increment separately. The procedure we followed began with consideration of the depth-area-duration relations taken from major storms in table 1; we used these data to develop within/without-storm curves which we then converted to isohyetal profiles. Finally, we generalized these profiles in developing a set of nomograms that give isohyet values for any area size.

5.2.2.1 Depth-area relations. We chose to consider depth-area data only for those storms in table 1 that provided moisture maximized transposed depths within 10 percent of PMP for 6 hr. This condition reduced our sample to the 29 storms in table 14. Next, depth-area data for these storms, taken from the appendix of HMR No. 51, were used to form all available ratios of depths. For example, for 10 mi^2, divide the 10-, 200-, 1,000-, 5,000-, 10,000-, and 20,000-mi^2 depths by the 10-mi^2 depth. Then form all the ratios for 200 mi^2 and so on to the 20,000-mi^2 ratios. Those within/without-storm average ratios, since they are individually done for each storm, are thus given as a percent of the respective standard area size value.

Table 14.--Major storms from table 1 used in depth-area study (index numbers refer to listing in table 1)

1\. Jefferson, OH
2\. Wellsboro, PA
3\. Greeley, NE
6\. Hearne. TX
7\. Eutaw, AL
8\. Paterson, NJ
10\. Bonaparte, IA
12\. Knickerbocker, TX
13\. Meeker, OK
14\. Beaulieu, MN
15\. Merryville, LA
16\. Boyden, IA
23\. Kinsman Notch, NH
24\. Elba, AL
27\. Ripogenus Dam, ME
28\. Cheyenne, OK
29\. Simmesport, LA
30\. Hale, CO
34\. Grant Township, NE
35\. Ewan, NJ
36\. Hallett, OK
38\. Smethport, PA
40\. Warner, OK
44\. Yankeetown, FL
45\. Council Grove, KS
46\. Ritter, IA
47\. Vic Pierce, TX
51\. Sombreretillo, Mex.
53\. Zerbe, PA

Because of the relatively small sample of storms, we chose not to consider any regional variation that may exist in these storm ratios. This conclusion is believed justified at this time, however, future study should investigate regional variation in depth-area relations.

The ratios obtained for the 29 storms were then averaged and the average was plotted against area size. Since some storms are relatively small in area size while others are much larger than 20,000 mi^2, not all 29 storms have all the depth data needed to complete all ratios, and the larger area averages are made from fewer and fewer storms. The plotted data are smoothed into a consistent set of curves as shown in figure 13. The solid lines represent within-storm averages for areas less than that of the PMP, and the dashed lines represent without-storm averages for areas greater than the area for PMP, the residual precipitation. Because of our assumption of no regional variation, figure 13 applies to the entire region.

Now, by applying the curves in figure 13 to the storm area averaged PMP in HMR No. 51 at a specific location, we obtain a set of curves of the form shown in figure 14. The solid curve connects the 6-hr PMP for various area sizes (in parentheses). The short-dashed lines are the within-storm curves for areas less than the PMP area, and the long-dashed lines are the without-storm curves for areas larger than the PMP area. It is the long-dashed curves covering the residual or without-storm precipitation that are unique to this study. To use figure 14, if one considers PMP for a particular area size, say 1,000 mi^2, enter the figure on the ordinate at 1,000 mi^2, and move horizontally to the solid line to obtain the value of PMP at this location, 15.5 in. To determine the corresponding precipitation during this PMP storm for any smaller (larger) area size in that 1,000-mi^2 PMP pattern, follow the short-dashed (long-dashed) curves from the point of PMP. In this figure, we have treated the juncture of within- and without-storm curves as a discontinuity, although a tangential approach to the point of PMP may be more realistic. We assume that this decision has little affect on our procedure and on the results obtained. If the PMP is for some area size other than the standard areas shown, then interpolation is necessary, using the indicated curves as guidance.

5.2.2.2 Isohyetal profile. Figure 14 gives a plot of the within/without-storm precipitation relative to area size. In the application of our idealized elliptical pattern, we need to know the value of the isohyet that encloses the specified areas. That is, if we drew a radial from the center of the pattern to the outermost isohyet, it would intersect all the intermediate enclosed isohyets. If we then plotted the value of the isohyet against the enclosed area of that isohyet, we could draw a curve through all the points of intersection and obtain a profile of isohyet values for a particular pattern area of PMP. A different distribution pattern of PMP would give a different isohyetal profile.

For 37°N, 89°W, we have converted the within/without-storm curves in figure 14 to the corresponding isohyetal profiles shown in figure 15. The curves in figure 15 were computed by reversing the process generally followed for deriving D.A.D curves from an isohyetal profile. This process has been briefly outlined in the "Manual for Estimation of Probable Maximum Precipitation" (World Meteorological Organization 1973). A necessary assumption for this conversion procedure is that of equivalent radius. That is, since the radius of an ellipse varies with the angle between a particular radius and the axis, different profiles would be obtained, depending upon which radial is chosen. To avoid this problem, we approximate the elliptical pattern by a circular pattern of equivalent areas and

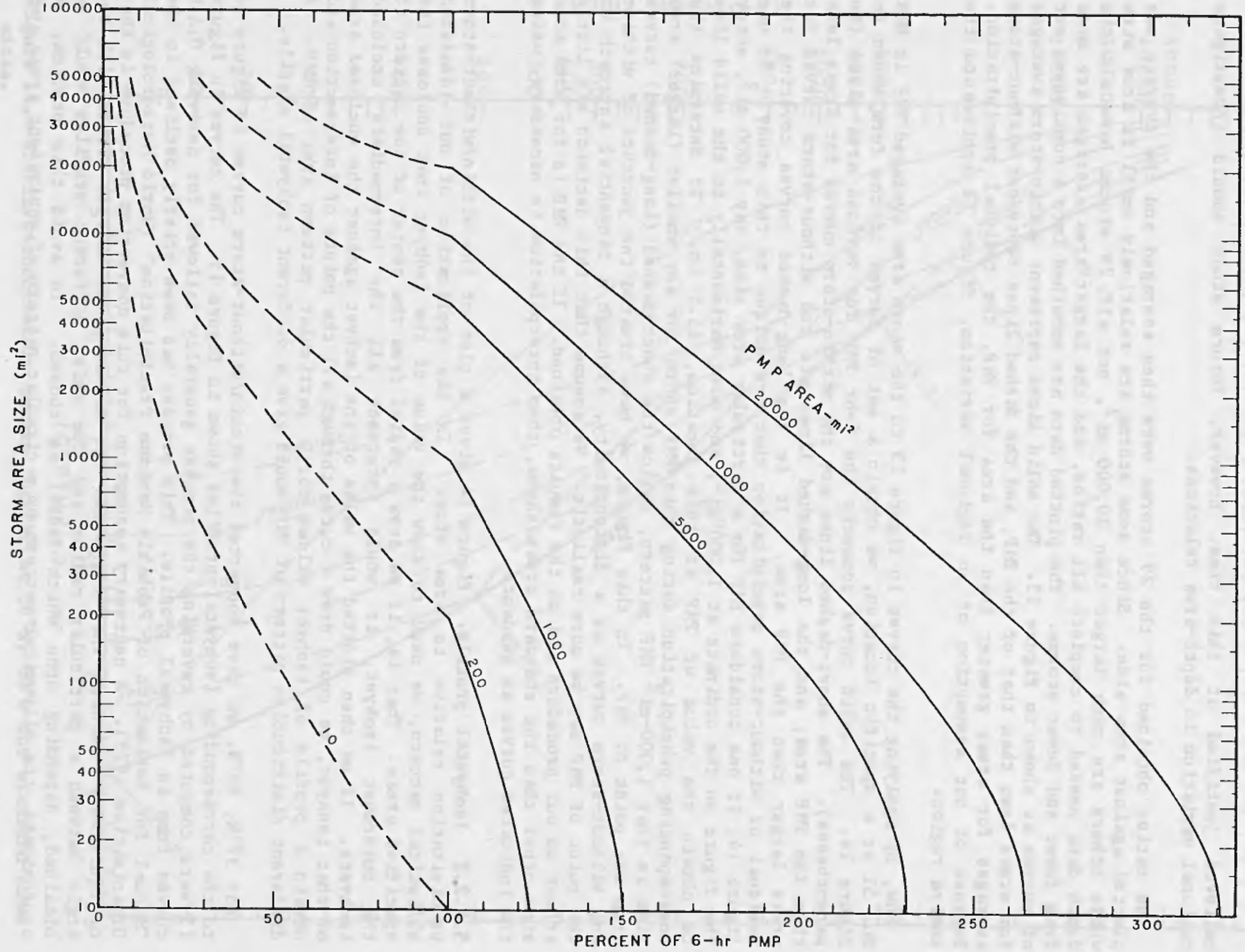

Figure 13.—6-hr within/without-storm average curves for standard area sizes.

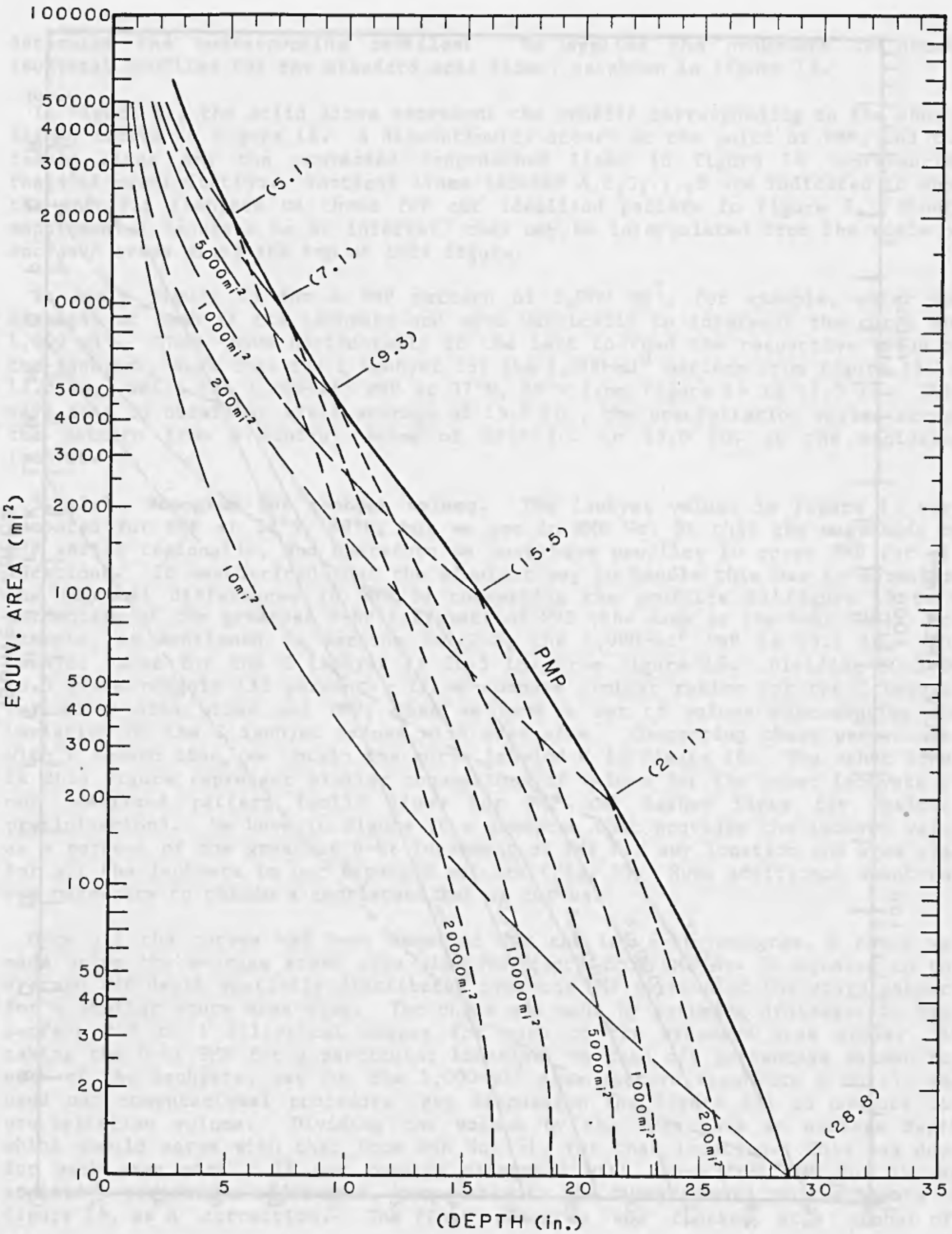

Figure 14.—Within/without-storm curves for PMP at 37°N, 89°W for standard area sizes.

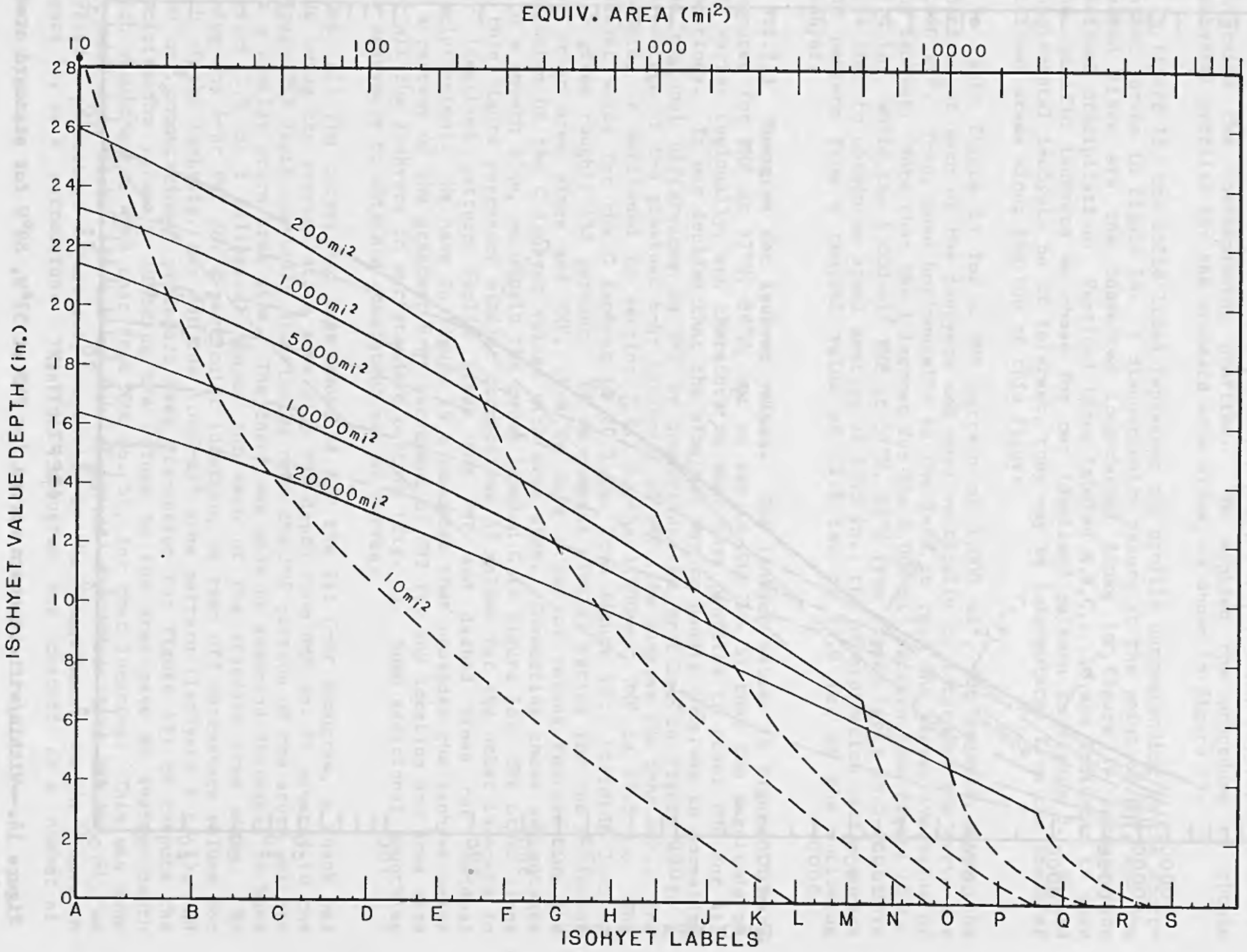

Figure 15.—Isohyetal profiles for standard area sizes at 37°N, 89°W.

determine the corresponding profiles. We applied the procedure to obtain isohyetal profiles for the standard area sizes, as shown in figure 15.

In figure 15, the solid lines represent the profile corresponding to the short-dashed curves in figure 14. A discontinuity occurs at the point of PMP, and the dashed lines are the converted long-dashed lines in figure 14 representing residual precipitation. Vertical lines labeled A,B,C,...,S are indicated to show the specific isohyets we chose for our idealized pattern in figure 5. Should supplemental isohyets be of interest, they may be interpolated from the scale of enclosed areas along the top of this figure.

To apply figure 15 for a PMP pattern of 1,000 mi^2, for example, enter the abscissa at each of the isohyets and move vertically to intersect the curve for 1,000 mi^2. Then, move horizontally to the left to read the respective value of the isohyet. Note that the I isohyet for the 1,000-mi^2 pattern from figure 15 is 13.0 in., while the 1,000-mi^2 PMP at 37°N, 89°W from figure 14 is 15.5 in. This says that to obtain an areal average of 15.5 in., the precipitation varies across the pattern from a central value of 23.3 in. to 13.0 in. at the enclosing isohyet.

5.2.2.3 Nomogram for isohyet values. The isohyet values in figure 15 were computed for PMP at 37°N, 89°W, but we see in HMR No. 51 that the magnitude of PMP varies regionally, and therefore we must have profiles to cover PMP for all locations. It was decided that the simplest way to handle this was to normalize the regional differences in PMP by converting the profiles in figure 15 to a percentage of the greatest 6-hr increment of PMP (the same as the 6-hr PMP). For example, as mentioned in section 5.2.2.2, the 1,000-mi^2 PMP is 15.5 in. The isohyet value for the C isohyet is 20.5 in. from figure 15. Dividing 20.5 by 15.5 gives roughly 132 percent. If we compute similar ratios for the C isohyet for other area sizes and PMP, then we have a set of values representing the variation of the C isohyet values with area size. Connecting these percentages with a smooth line, we obtain the curve labeled C in figure 16. The other lines in this figure represent similar connections of values for the other isohyets in our idealized pattern (solid lines for PMP and dashed lines for residual precipitation). We have in figure 16 a nomogram that provides the isohyet value as a percent of the greatest 6-hr increment of PMP for any location and area size for all the isohyets in our standard pattern (fig. 5). Some additional smoothing was necessary to obtain a consistent set of curves.

Once all the curves had been smoothed for the 1st 6-hr nomogram, a check was made using the average storm area size PMP depth from HMR No. 51 equated to the average PMP depth spatially distributed over the PMP portion of the storm pattern for a similar storm area size. The check was made by assuming drainages to have perfect 2.5 to 1 elliptical shapes for each of the standard area sizes. By taking the 6-hr PMP for a particular location, we read off percentage values for each of the isohyets, say for the 1,000-mi^2 area pattern (isohyets A to I), and used our computational procedure (see discussion for figure 43) to compute the precipitation volume. Dividing the volume by the area gave an average depth which should agree with that from HMR No. 51, for that location. This was done for each area size. If our results disagreed with those from HMR No. 51, we applied a percentage adjustment, comparable to the disagreement, to the points in figure 16, as a correction. The final nomogram was checked at a number of regional locations to verify that all variations from average PMP in HMR No. 51 were less than 2%.

In figure 16, the cusps represent the discontinuity points in figure 15, and although there is a question whether first-order discontinuities occur in an actual precipitation pattern, and while actual discontinuities in rainfall patterns may not exist in the regions of moderate or heavy rainfall, these are regions where the gradients of rainfall change rapidly. Our capability to represent such changes are limited and we have chosen to show them as a cusp. The discontinuities in figure 16 indicate that the gradient of the respective isohyet value variation with area size changes at that point.

To use the nomogram in figure 16 for distributing the 1,000-mi^2 PMP, one enters the figure at 1,000 mi^2 on the ordinate and reads from right to left at the points of intersection with the respective curves. That is, values of approximately 149, 140, 131,..., 82 percent are obtained for isohyets A, B, C,...,I contained within the 1,000-mi^2 ellipse, and 60, 44, 32, 21, 12, and 5 percent are obtained for the isohyets of residual precipitation (J to O) outside the 1,000-mi^2 ellipse.

5.2.3 Isohyet values for the second greatest 6-hr PMP increment

Section 5.2.2 describes the development of the procedure to obtain isohyet values for the greatest 6-hr PMP increment. We wish to follow a similar procedure to obtain isohyet values for the second greatest 6-hr PMP increment. To do this, however, we need to return to our data base of storms in table 1 and find the set of storms whose 12-hr moisture maximized and transposed rainfall came within 10 percent of the 12-hr PMP. The 12-hr depth-area data for these storms were used to compute ratios at all the available area sizes. Again, the ratios were averaged and these average ratios plotted against area size to get the 12-hr within/without-storm curves shown in figure 17. Then we converted the curves in figure 17 to depths relative to the 12-hr PMP at 37°N, 89°W (not shown). The computational procedure (World Meteorological Organization 1973) was used again to obtain 12-hr isohyetal profile curves (not shown). At this point, we subtracted the 6-hr isohyetal profile data from the 12-hr profile data to get profiles for the 2nd 6-hr increment (not shown). Then, reading depths for the standard isohyets chosen in figure 5 and converting these into a percentage of the 2nd 6-hr increment of PMP, we developed the 2nd 6-hr nomogram shown in figure 18.

Once again, a check was made for accuracy as represented by the average PMP data from HMR No. 51, and appropriate adjustments and smoothing made where needed. The set of solid curves in figure 18, representing isohyets within the PMP area, tends to have shifted closer to the 100 percent value. This is expected, because as we mentioned earlier, by the fourth increment little to no areal distribution was evident in our study computations; i.e., a value of 100 percent of the incremental PMP applies throughout the PMP portion of the pattern storm (this does not include residual precipitation).

5.2.4 Isohyet values for the third greatest 6-hr PMP increment

We used the observation of converging values discussed in section 5.2.3 to obtain isohyet values for the third greatest 6-hr PMP increment, rather than repeat the complex procedure followed for the greatest and second greatest

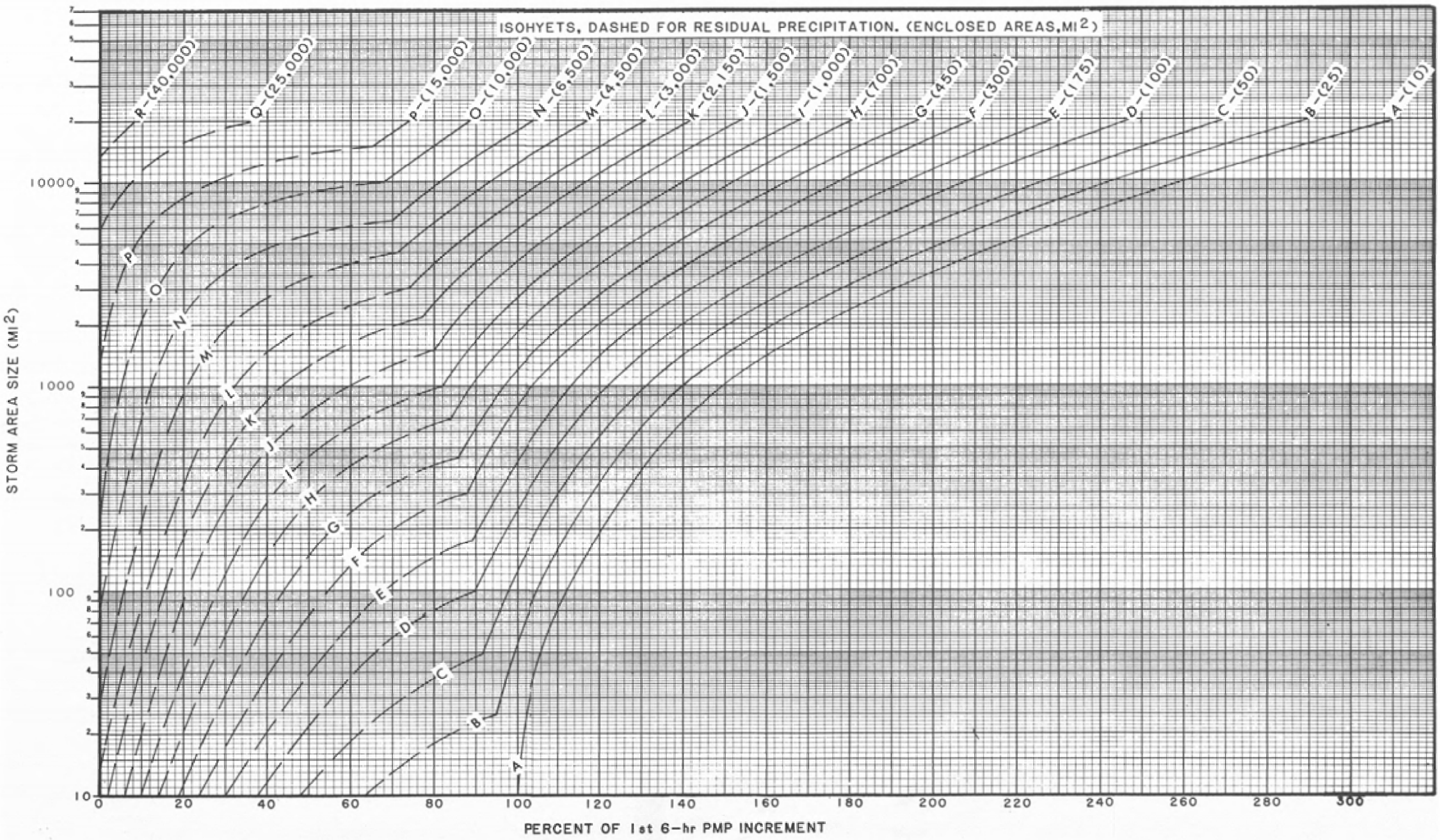

Figure 16.—Nomogram for the 1st 6-hr PMP increment and for standard isohyet area sizes between 10 and 40,000 mi^2.

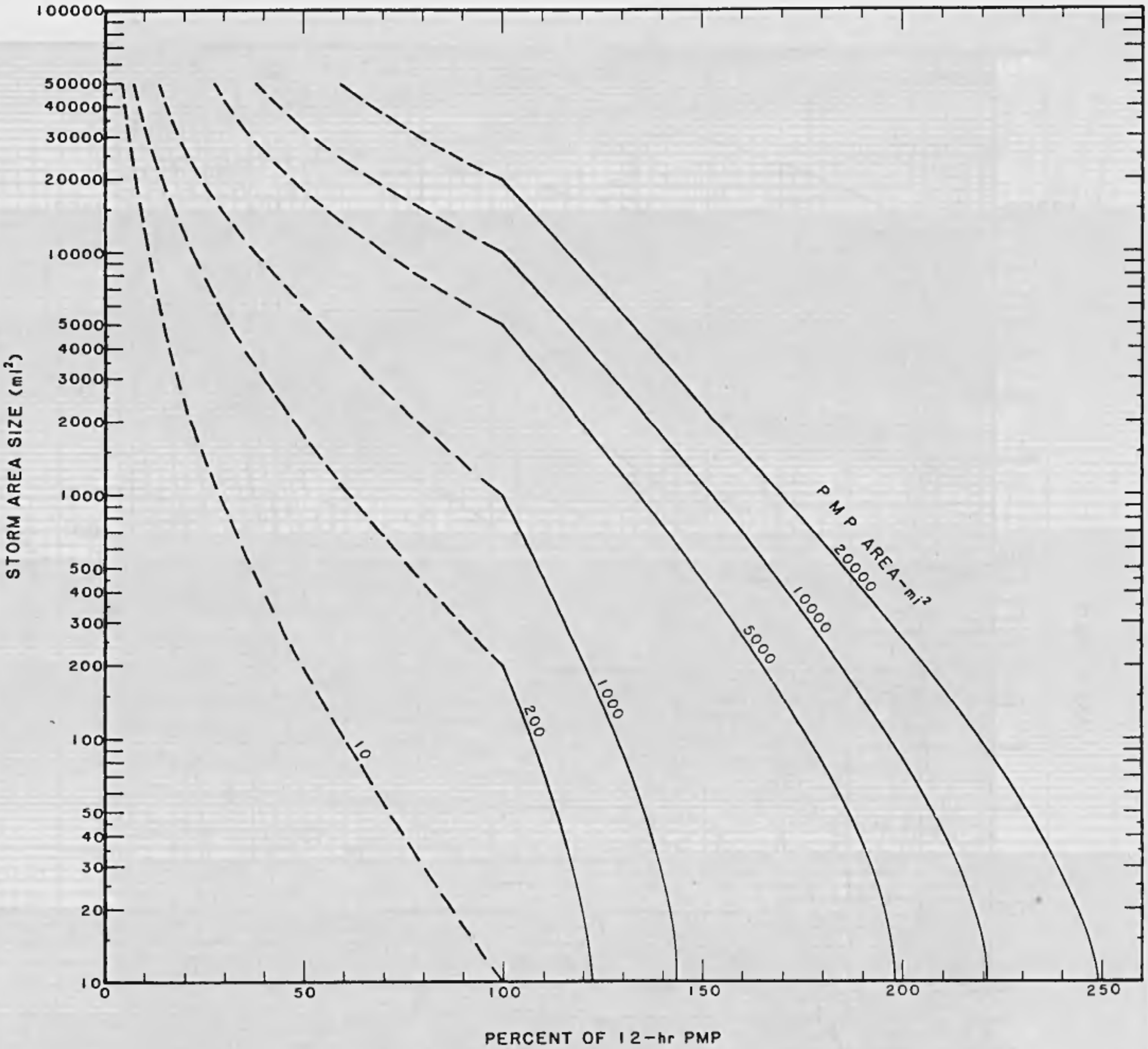

Figure 17.—12-hr within/without-storm curves for standard area sizes.

increments. Therefore, we plotted the values of the first and second greatest 6-hr PMP increments for each isohyet from the respective nomograms (figs. 16 and 18) and connected them with a smooth curve to a value of 100 percent used to represent the fourth increment. From these simple curves, we then interpolated the percents for the third 6-hr PMP increment. One advantage of this procedure was that it guaranteed consistency between results.

The results of this interpolative scheme are shown in figure 19 in percent of the third greatest 6-hr PMP increment. In this figure, we see that the respective curves for PMP (solid lines) are very near to 100 percent. Note the difference in scale of the abscissa between PMP curves and residual precipitation curves, made to facilitate their use. These curves were also checked for

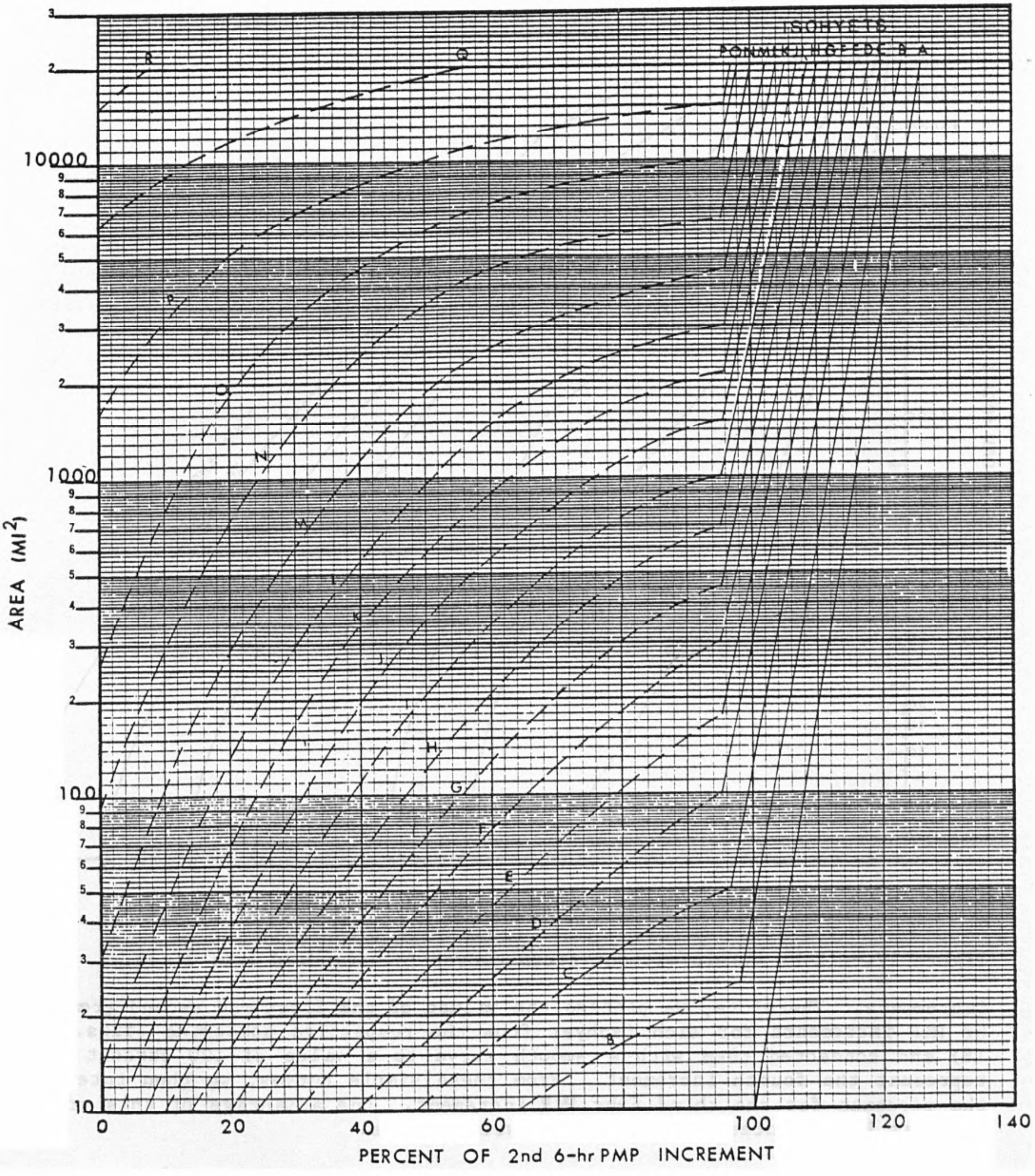

Figure 18.—Nomogram for the 2nd 6-hr PMP increment and for standard isohyet area sizes between 10 and 40,000 mi^2.

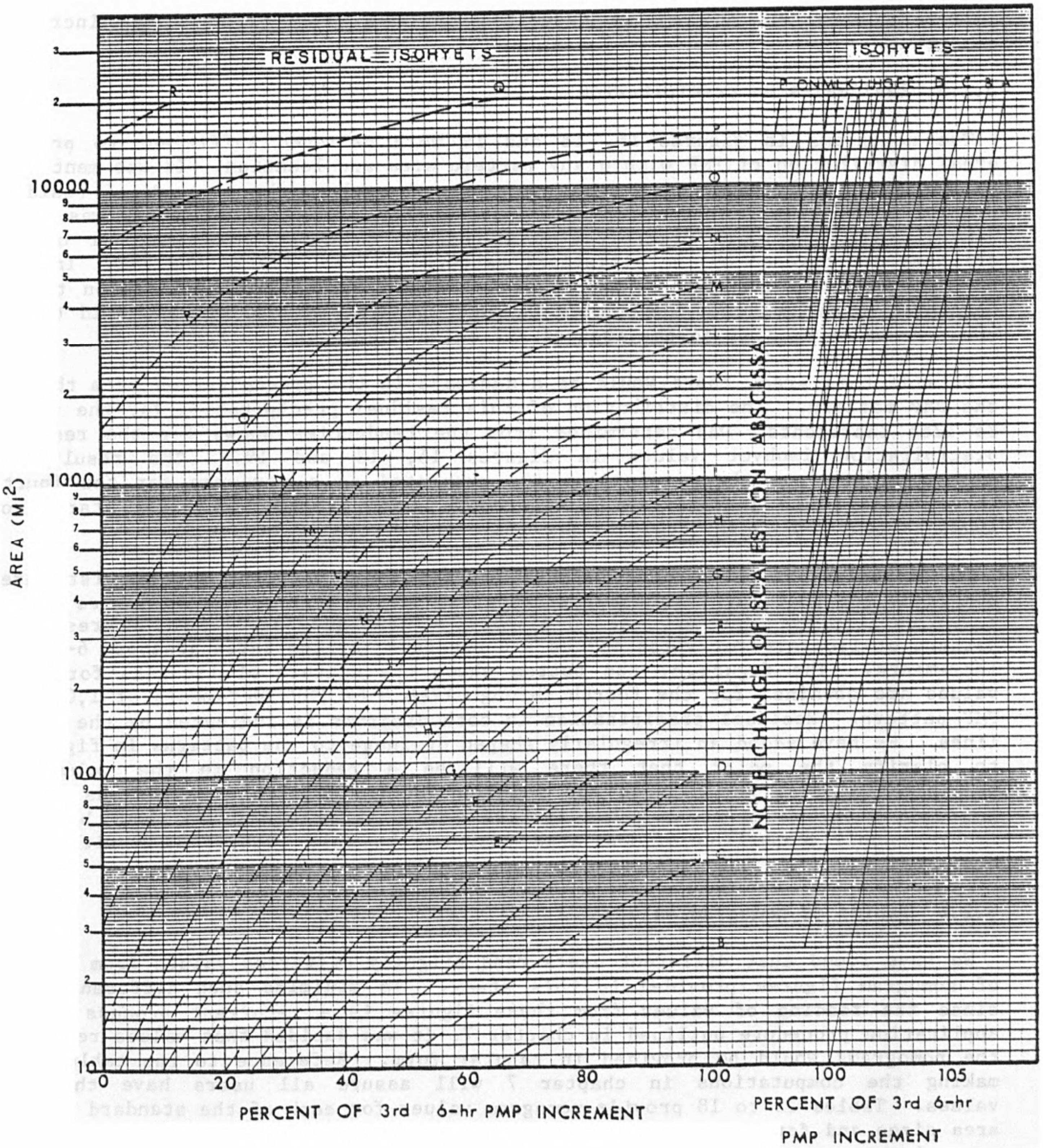

Figure 19.—Nomogram for the 3rd 6-hr PMP increment and for standard isohyet area sizes between 10 and 40,000 mi^2.

agreement with HMR No. 51 as described for the previous two 6-hr increment nomograms.

5.2.5 Residual-area precipitation

The nomograms in figures 16, 18 and 19 were believed sufficient to provide areal distribution of PMP within any pattern area and location. It was mentioned in section 3.5.3, that it was necessary to introduce the concept of residual precipitation, i.e., that which fell outside the area for which PMP was being distributed. Residual precipitation is needed to cover the remainder of the drainage not covered by the elliptical pattern for the area of the PMP. In each of the nomograms the dashed curves give isohyet values for application to the uncovered drainage. For the fourth through 12th increments, we have said that a constant value applies to the area of PMP being considered.

Outside this area, there would be a decrease in the precipitation from that of the PMP pattern. The distribution of this residual precipitation for the fourth to 12th increments was determined from the tendencies shown for the residual precipitation isohyet values in figures 16, 18 and 19. The results of extrapolation from these relations are presented as a nomogram for the fourth through 12th 6-hr increments, in figure 20. Note these curves all start from 100%, as compared to the residual precipitation curves in figure 19.

To emphasize the difference between precipitation patterns for the 1st three nomograms and that for figure 20, we show two schematic diagrams in figure 21 for a PMP pattern of 1,000 mi^2, as an example. The figure at the top represents a pattern of isohyets for which values are obtained for the three greatest 6-hr PMP increments. The figure at the bottom shows the pattern of isohyets for which values are obtained for the fourth through 12th 6-hr PMP increments of 1,000-mi^2 PMP pattern. Residual precipitation in both diagrams is indicated by the dashed lines. We have added an irregularly shaped drainage to the patterns in figure 21 to clarify the point that there will be a reduction in the volume of precipitation that occurs even for the fourth through 12th 6-hr periods. That is, even though a constant value applies across the drainage as shown by the I isohyet, only a portion of the area enclosed by this isohyet lies within the drainage.

5.2.6 Tables of nomogram values

We have found that different users read slightly different values from the set of nomogram figures provided in this study. To minimize such differences and since the reading of values from these figures is a recurrent process in the application procedure outlined in chapter 7, it was decided that values read from the nomograms would be provided in tabular form. Reference to the tables when making the computations in chapter 7 will assure all users have the same values. Tables 15 to 18 provide nomogram values for each of the standard isohyet area sizes and for an intermediate area size between each of the standard isohyet area sizes.

Note that, although these tables are useful for all computations, it may still be necessary to refer to the nomograms on occasion. One such ocassion would be when one wishes to distribute PMP over an area size other than one of the

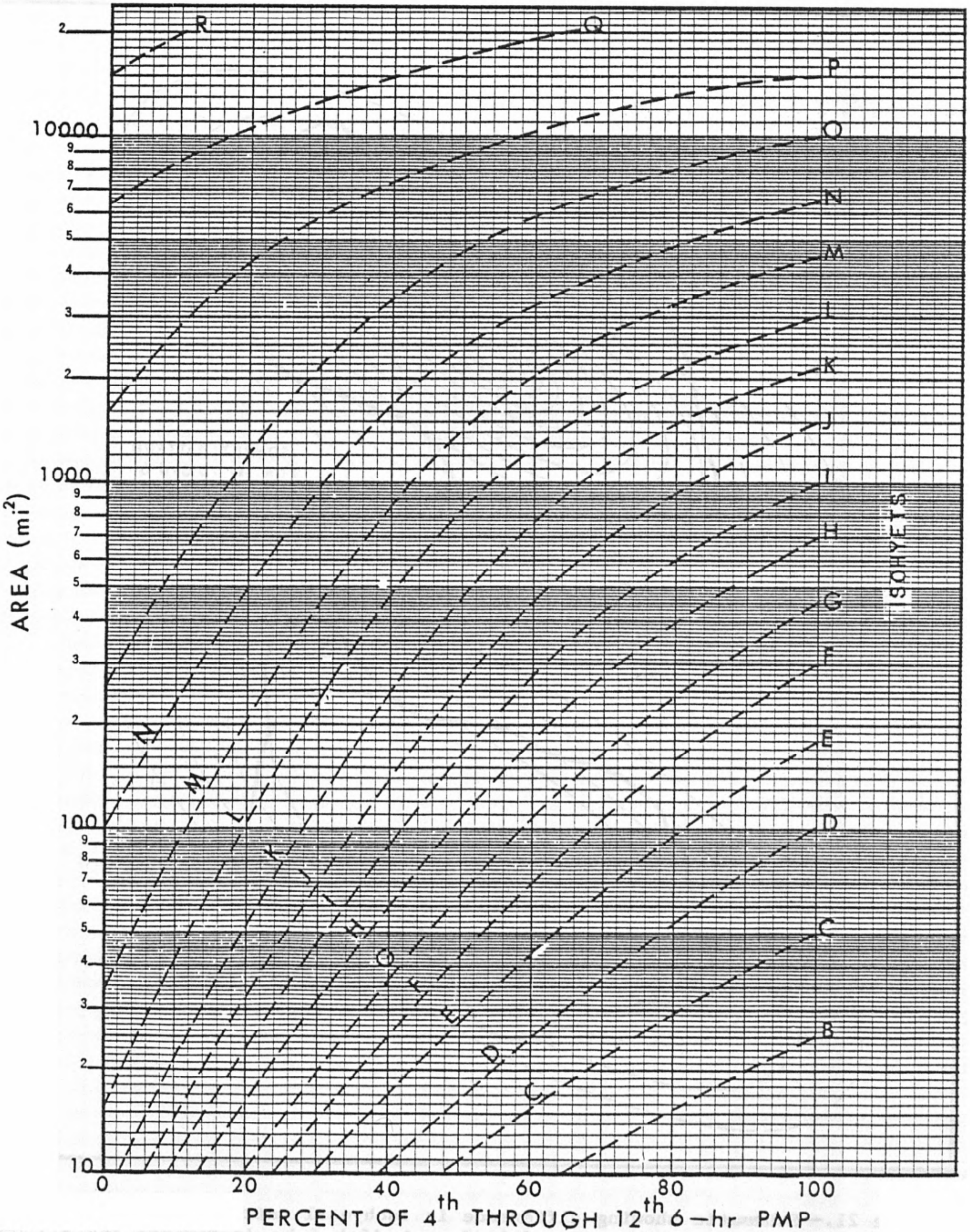

Figure 20.—Nomograms for the 4th through 12th 6-hr PMP increments and for standard isohyet area sizes between 10 and 40,000 mi^2.

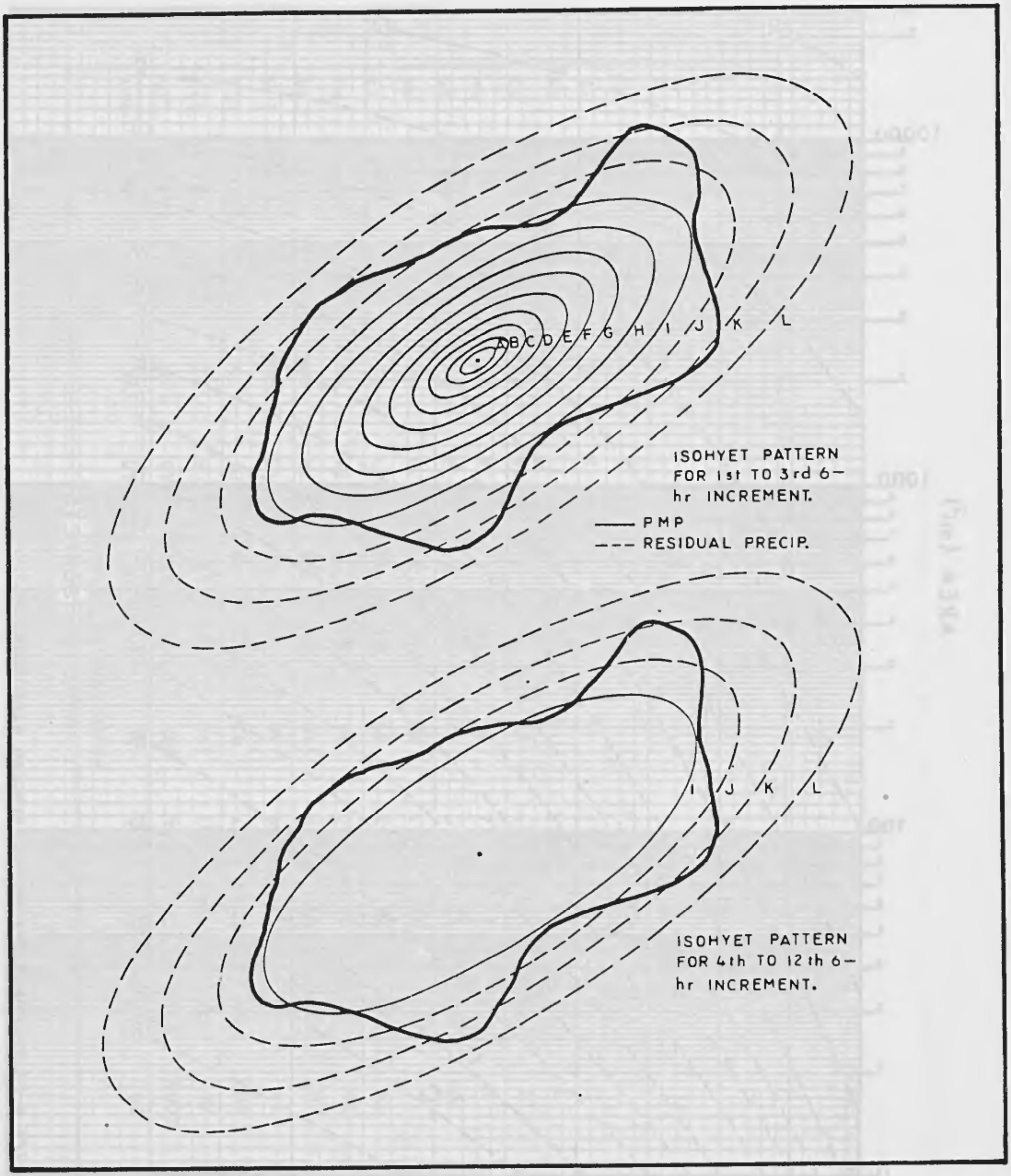

Figure 21.—Schematic showing difference in isohyetal patterns for 3 greatest 6-hr PMP increments and that for 4th through 12th 6-hr increments for a 1,000-mi^2 storm.

Table 15.—1st 6-hr nomogram values at selected area sizes

	Storm Area (mi^2) size											
Isohyet	10	17	25	35	50	75	100	140	175	220	300	360
A	100*	101	102	104	106	109	112	116	119	122	126	129
B	64	78	95*	97	99	102	105	108	111	114	118	121
C	48	58	67	77	92*	95	98	101	103	106	110	113
D	38	46	52	59	66	77	90*	93	96	99	103	105
E	30	37	43	48	54	62	68	78	89*	92	96	98
F	24	30	34	39	44	50	55	61	66	73	88*	90
G	19	24	28	32	35	40	44	49	53	58	65	73
H	14	19	22	25	28	32	35	39	42	46	51	56
I	10	14	17	19	22	26	28	32	34	37	42	45
J	6	9	12	14	16	19	21	24	26	28	32	35
K	2	5	7	9	11	14	16	18	20	22	25	27
L	0	1	3	5	7	9	11	13	15	17	19	21
M		0	0	1	3	5	6	8	9	10	12	13
N				0	0	0	1	2	3	4	6	7
O							0	0	0	0	1	2
P											0	0

*Indicates cusp.

Table 15.--1st 6-hr nomogram values at selected area sizes - Continued

Isohyet	Storm area (mi^2) size										
	450	560	700	850	1000	1200	1500	1800	2150	2600	3000	3800
A	132	136	140	145	149	155	162	169	176	184	191	203
B	124	128	132	136	140	145	152	158	165	172	179	189
C	116	120	124	128	131	136	142	147	154	160	166	176
D	108	111	115	119	122	126	132	137	142	148	154	163
E	101	104	107	110	113	116	122	126	131	137	142	150
F	93	95	98	101	104	107	112	117	122	127	132	140
G	86*	89	92	94	97	100	105	108	113	118	122	130
H	63	72	84*	87	89	92	96	99	103	108	112	119
I	50	56	63	72	82*	85	88	91	95	99	102	108
J	38	43	48	54	60	68	80*	83	86	89	92	98
K	30	33	36	40	44	49	56	64	77*	80	83	89
L	23	25	27	30	32	35	41	46	52	62	74*	79
M	15	16	18	19	21	23	26	29	33	38	44	56
N	8	9	10	11	12	14	16	18	20	22	25	31
O	3	3	4	4	5	6	7	8	9	11	13	15
P	0	0	0	0	0	0	0	1	2	3	4	6
Q								0	0	0	0	0

*Indicates cusp

Table 15.—1st 6-hr nomogram values at selected area sizes - Continued

Isohyet	Storm area (mi^2) size								
	4500	5500	6500	8000	10000	12000	15000	18000	20000
A	212	223	233	247	262	274	290	304	312
B	198	209	218	230	243	255	271	283	291
C	184	194	203	214	227	238	253	264	271
D	170	180	187	198	209	219	232	242	248
E	157	166	174	183	194	203	214	224	229
F	146	153	160	169	178	186	196	205	210
G	135	142	148	157	166	174	183	192	197
H	124	131	137	144	152	159	168	176	181
I	113	119	125	132	140	147	156	164	168
J	103	108	113	120	128	135	143	150	154
K	93	98	103	110	117	123	131	138	142
L	83	88	93	99	107	113	120	127	131
M	71*	76	81	87	93	99	106	113	117
N	37	48	70*	75	82	87	94	101	104
O	19	23	29	40	68*	73	80	86	89
P	8	10	13	18	26	38	65*	71	74
Q	0	0	1	3	7	11	18	28	36
R			0	0	0	0	2	6	8
S							0	0	0

*Indicates cusp

Table 16.—2nd 6-hr nomogram values at selected area sizes

	Storm area (mi^2) size											
Isohyet	10	17	25	35	50	75	100	140	175	220	300	360
A	100*	102	103	104	105.5	107	108	109	110	110.5	111.5	112
B	64	81.5	98*	99	100.5	102	103	104	105	106	107	108
C	48	61	72	82	96.5*	98	99	100.5	101.5	102.5	103.5	104
D	39	50	59	66.5	76	86	95*	96.5	97.5	98.5	100	101
E	30	40	48	54.5	62.5	72	79	88	95*	96	97.5	98.5
F	24	32	39	44.5	51	59.5	65	73	79	85	95*	96
G	20	27	32.5	37.5	43.5	50	55	62	66.5	72	80	85
H	14	20.5	26	30.5	36	42	47	52.5	56.5	61	67.5	72
I	10	15.5	20	24	29	34.5	38.5	43.5	47	51	57	61
J	7	12	15.5	19	23	27.5	31	35	38.5	42	47	50
K	3	7	10.5	13.5	17	21	24	27.5	30	33	37.5	40.5
L	0	1.5	5	7.5	11	14.5	17	20.5	23	26	30	33
M		0	0	1	4	7	9	12	14.5	17	20.5	23
N				0	0	0	1	3.5	5	7.5	10	12
O							0	0	0	0	1	3
P											0	0

*Indicates cusp

Table 16.--2nd 6-hr nomogram values at selected area sizes - Continued

	Storm area (mi^2) size										
Isohyet	450	560	700	850	1000	1200	1500	1800	2150	2600	3000	380
A	113	114	114.5	115	116	116.5	117	118	118.5	119	119.5	120.5
B	109	109.5	110	111	112	112.5	113	114	114.5	115.5	116	117
C	105	106	107	107.5	108.5	109	110	110.5	111	112	112.5	113.5
D	102	102.5	104	104.5	105	106	107	108	108.5	109.5	110	111
E	99.5	100.5	101	102	103	104	105	105.5	106.5	107	108	109
F	97	98	99	100	101	102	103	104	104.5	105.5	106	107
G	95*	96	97	98	99	99.5	100.5	101.5	102	103	104	105
H	77.5	85	95*	96	97	97.5	99	99.5	100	101	102	103
I	66	71.5	78	85	95*	96	97	98	99	99.5	100.5	101.5
J	54.5	60	65.5	71	76	82.5	95.5*	96	97	98	99	100
K	44.5	49	54	58.5	63	68	75.5	83	96*	96.5	97	98
L	36.5	40	44	48	51	55	60.5	66	73	83	96*	97
M	25.5	28.5	32	35	38	41	45	49.5	54	60.5	67	81
N	14	17	19.5	22	24	27	31	34	37.5	41.5	45	52.5
O	4.5	6.5	9	11	12.5	14.5	17	19.5	22	25.5	28.5	34
P	0	0	0	0	0	0	0	1.5	4	7	9	13.5
Q								0	0	0	0	0

*Indicates cusp

Table 16.—2nd 6-hr nomogram values at selected area sizes - Continued

Isohyet	Storm area (mi^2) size 4500	5500	6500	8000	10000	12000	15000	18000	20000
A	121	122	122	123	124	124.5	125	126	126
B	117	118	119	120	120.5	121	122	122.5	123
C	114	115	115.5	116.5	117	118	119	119.5	120
D	112	112.5	113	114	115	116	117	118	118
E	109.5	110.5	111	112	113	114	115	116	116
F	108	108.5	109	110	111	112	113	113.5	114
G	105.5	106.5	107	108	109	110	111	112	112
H	103.5	104.5	105	106	107	108	109	110	110
I	102	103	104	104.5	105.5	106.5	107	108	108.5
J	100.5	101.5	102	103	104	105	106	106.5	107
K	99	100	100.5	101.5	102.5	103	104	105	105
L	97.5	98.5	99	100	101	102	102.5	103.5	104
M	96*	97	97.5	98.5	99	100	101	102	102
N	59	72.5	95.5*	96	97	98	99	99.5	100
O	39	46	52.5	66	95*	96	97	97.5	98
P	17	22	27.5	37	50	64	96*	96.5	97
Q	0	0	1	6	14	21	34	47	55
R		0		0	0	0	0	4.5	7
S									0

*Indicates cusp

Table 17.—3rd 6-hr nomogram values at selected area sizes

	Storm area (mi^2) size											
Isohyet	10	17	25	35	50	75	100	140	175	220	300	360
A	100*	100.6	101	101.3	101.6	102	102.3	102.6	102.8	103.1	103.4	103.6
B	65	83.5	99*	99.4	99.8	100.3	100.7	101	101.3	101.5	101.9	102.1
C	48	63	74.5	85.5	98.5*	99	99.3	99.7	100	100.3	100.7	100.9
D	39	51	60.5	69	78.5	90	98.6*	99	99.2	99.5	99.8	100.1
E	30	40	48.5	55.5	63	73.5	81.5	92	98.8*	99	99.3	99.5
F	24	33	40	46.5	53.5	61.5	68	76.5	83	89	99.0*	99.2
G	20	28	34	39.5	46	53	59	66	71	77	86	92
H	14	21	27	32.5	37.5	44	49	55	59.5	64	72	76.5
I	10	16.5	21.5	26.5	31.5	37.5	42	47.5	51	55.5	62	66
J	6.5	12.5	17	21	26	31.5	35.5	40.5	44	47.5	53	56
K	3	7.5	11.5	15	19.5	24.5	28	32.5	35	38.5	43	46
L	0	1.5	5	8.5	12	16.5	20	24	26.5	29.5	33.5	36
M		0	0	1	4	8.5	11.5	15	18	20.5	24.5	27
N				0	0	0	1	4.5	7	10	14	16
O							0	0	0	0	2	4
P											0	0

*Indicates cusp

Table 17.—3rd 6-hr nomogram values at selected area sizes - Continued

Isohyet	Storm area (mi^2) size											
	450	560	700	850	1000	1200	1500	1800	2150	2600	3000	3800
A	103.8	104	104.2	104.4	104.6	104.7	105	105.2	105.3	105.5	105.7	105.8
B	102.4	102.7	102.9	103.2	103.3	103.5	103.8	104	104.2	104.4	104.6	104.8
C	101.2	101.5	101.7	102	102.3	102.5	102.7	102.9	103.2	103.4	103.5	103.8
D	100.3	100.6	100.8	101.1	101.3	101.5	101.7	102	102	102.4	102.5	102.8
E	99.8	100	100.2	100.4	100.6	100.8	101	101.2	101.3	101.5	101.7	101.9
F	99.5	99.7	99.9	100.1	100.3	100.4	100.7	100.8	101	101.2	101.3	101.5
G	99.2*	99.4	99.6	99.7	99.9	100	100.3	100.4	100.6	100.7	100.9	101.1
H	84	91	99.2*	99.4	99.6	99.7	100	100.1	100.3	100.4	100.5	100.7
I	71	77.5	85	92	99.3*	99.5	99.7	99.8	100	100.1	100.2	100.5
J	60	64.5	70.5	76.5	82.5	89.5	99.4*	99.5	99.7	99.8	99.9	100.1
K	50	54	58.5	62.5	67	72.5	81	89	99.5*	99.5	99.6	99.8
L	39.5	43	47	50.5	54	58.5	65.5	72.5	80.5	90.5	99.3*	99.5
M	30	33	37	40	43	46.5	51.5	56.5	61	69	76	88.5
N	19	22.5	25.5	28.5	31	34	38	42	46.5	52	57	67
O	7	10	13	15.5	17.5	20.5	24	27	30.5	34	37.5	43.5
P	0	0	0	0	0	0	0	2.5	5.5	9	12	16.5
Q									0	0	0	0

*Indicates cusp

Table 17.—3rd 6-hr nomogram values at selected area sizes - Continued

	Storm area (mi^2) size								
Isohyet	4500	5500	6500	8000	10000	12000	15000	18000	20000
A	106	106.2	106.4	106.6	106.8	107	107.2	107.4	107.5
B	105	105.3	105.5	105.7	106	106.2	106.5	106.7	106.8
C	104	104.3	104.5	104.8	105	105.3	105.5	105.8	105.9
D	103.1	103.2	103.5	103.7	104	104.2	104.4	104.6	104.7
E	102.1	102.3	102.5	102.7	102.8	103	103.3	103.5	103.6
F	101.7	101.8	102	102.2	102.4	102.6	102.8	103	103
G	101.2	101.4	101.5	101.7	101.9	102.1	102.3	102.4	102.5
H	100.9	101.1	101.2	101.4	101.6	101.8	102	102.2	102.2
I	100.6	100.8	100.9	101.1	101.3	101.5	101.7	101.8	101.9
J	100.2	100.4	100.5	100.7	100.9	101	101.2	101.3	101.4
K	99.9	100	100.2	100.3	100.5	100.7	100.8	101	101.1
L	99.6	99.7	99.8	100	100.2	100.3	100.5	100.6	100.7
M	99.3*	99.4	99.5	99.6	99.8	99.9	100.1	100.2	100.2
N	76	88	98.9*	99	99.2	99.3	99.5	99.6	99.7
O	49	57	65	79	98.7*	98.8	99	99.1	99.2
P	21	27.5	34.5	44.5	59	71.5	98*	98.7	98.2
Q	0	0	1	8	18	27.5	42	54.5	66
R			0	0	0	0	1	7.5	12
S							0	0	0

*Indicates cusp

Table 18.—4th to 12th 6-hr nomogram values at selected area sizes

Isohyet	Storm area (mi^2) size											
	10	17	25	35	50	75	100	140	175	220	300	360
A	100											
B	65	83.5	100									
C	48	62.5	74.5	86	100							
D	39	50.5	60.5	68.5	78.5	89.5	100					
E	30	40	48.5	55	63	73	81.5	91	100			
F	24	33	40	46	53.5	61.5	68	76.5	83	89	100	
G	20	27.5	34	39	46	53	59	65.5	71	77	86	91.5
H	14	21	27	31.5	37.5	44	49	55	58.5	64	72	77
I	10	16	21.5	26	31.5	37	42	47.5	51	55	62	65.5
J	6.5	12	17	21	26	31	35.5	40	44	47	53	55.5
K	3	7.5	11.5	15	19.5	24	28	32	35	38.5	43	46
L	0	0.5	5	8.5	12	16	20	23.5	26.5	29	33.5	36
M		0	0	0.5	4	8.5	11.5	15	18	20.5	24.5	27
N				0	0	0	1	4	7	9.5	14	16
O							0	0	0	0	2	4
P											0	0

Table 18.—4th to 12th- 6-hr nomogram values at selected area sizes - Continued

Isohyet	Storm area (mi^2) size										
	450	560	700	850	1000	1200	1500	1800	2150	2600	3000	3800
A												
B												
C												
D												
E												
F												
G	100											
H	84	91	100									
I	71	77.5	85	92	100							
J	60	64.5	70.5	77	82.5	89.5	100					
K	50	53.5	58.5	62	67	72	81	89	100			
L	39.5	43	47	50.5	54	58.5	65.5	72.5	80.5	90	100	
M	30	33	37	40	43	46.5	51.5	56	61	69	76	88.5
N	19	22	25.5	28	31	33.5	38	41.5	46.5	51.5	57	67
O	7	9.5	13	15	17.5	20	24	26.5	30.5	33.5	37.5	43.5
P	0	0	0	0	0	0	0	2.5	5.5	9	12	17
Q							0	0	0	0	0	

Table 18.--4th to 12th 6-hr-nomogram values at selected area sizes - Continued

Isohyet	Storm area (mi^2) size								
	4500	5500	6500	8000	10000	12000	15000	18000	20000
A									
B									
C									
D									
E									
F									
G									
H									
I									
J									
K									
L									
M	100								
N	76	88	100						
O	49	56.5	65	79	100				
P	21	27	34.5	44	59	71	100		
Q	0	0	1	8	18	27	42	54	66
R			0	0	0	0	1	7	12
S							0	0	0

standard isohyet area sizes, for which it is then necessary to construct supplemental isohyet(s). This construction is discussed in chapter 7.

5.3 Area of Pattern Applied to Drainage

Up to this point in our discussion we have not indicated specifically how we select the area size of the PMP to distribute across a particular drainage. In previous PMP studies, we have assumed that the maximum peak discharge and the maximum volume of precipitation in the drainage were represented by a basin-centered pattern for PMP equivalent to the area of the drainage. This assumption was necessary because we do not have sufficient information to determine what the hydrologically most critical condition is for peak discharge. Obviously, as precipitation patterns are moved to centering positions closer to the drainage outlet, greater peaks may occur but volume probably will be reduced.

In the present study, we have chosen to base our selection of PMP pattern on maximizing the volume of precipitation within the drainage. This eliminates the assumption used in other Hydrometeorological Reports that PMP be based on an area equal to the drainage area. Maximum volume is a function of pattern centering, of basin irregularity of shape, and of the area size of PMP distributed over the drainage. Of these, we have control over the pattern centering when we recommend that all patterns be centered to place as many complete isohyets within the drainage as possible. The irregularity of the drainage is fixed, and we are left with the area of the PMP pattern as a variable. However, the process of maximizing volume for various area sizes results in a procedure involving a series of trials.

To obtain the area that maximizes precipitation within the drainage, we propose that the user start by selecting an area size in the vicinity of that for the drainage. It is convenient to choose areas that match those for the isohyets in our idealized pattern (700, 1,500, 6,500 mi^2, etc.). Compute the volume of precipitation for each of the 3 greatest 6-hr increments of PMP at the area size chosen and obtain the total volume. Then, choose additional areas on either side of the initial choice, and evaluate the volume corresponding to each of these. By this trial process, and by plotting the results as area size (selected) vs. volume (computed), we can approximate the area size at which the volume reaches a maximum. (This may require drawing supplemental isohyets.)

This procedure will be better demonstrated by the examples presented in chapter 7. It will be found that, as experience is gained in the application of patterns to variously shaped drainages, one can do a better job at the initial selection of area sizes.

5.4 Multiple Rainfall Centers

In general, we recommend a single-centered isohyetal pattern for distributing PMP. From major storms of record we note that as the size of the rainfall pattern increases, the number of rainfall centers increases. This observation has led to the following considerations.

5.4.1 Development of a multicentered isohyetal pattern

A consideration when discussing the numbers of centers in an isohyetal pattern is how the end product (the flood peak) varies with the number of rainfall

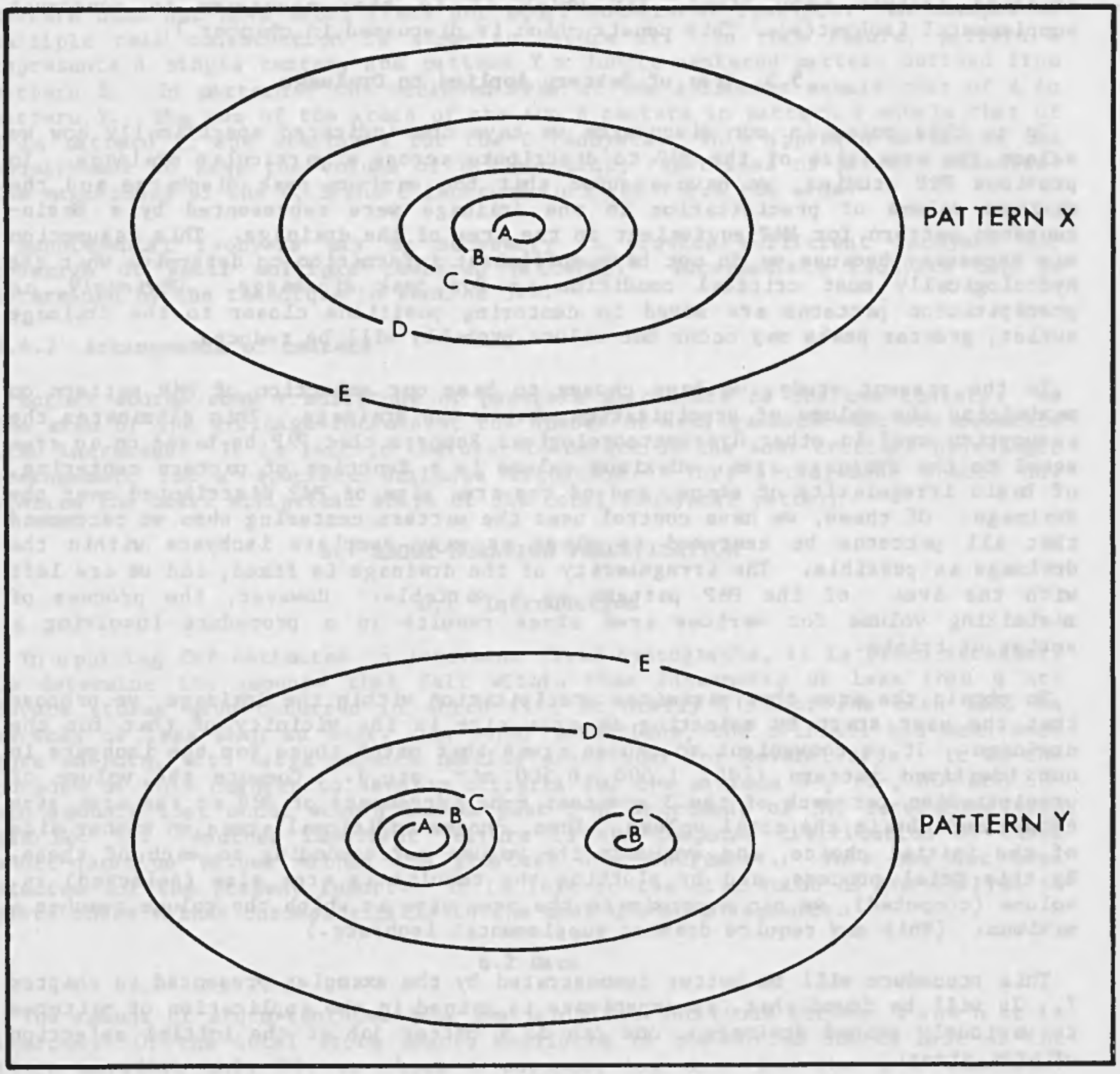

Figure 22.—Schematic showing an example of multiple centered isohyetal pattern (PMP portion only).

centers. In general, all else being equal, the more centers used, the lower the peak discharge. If multiple centers are to be considered, we therefore recommend a limit of two.

The process for deriving these centers within an elliptical pattern is based on the standard isohyets and their values for a single-centered pattern as determined from the nomograms described in sections 5.2.2 to 5.2.5. The multiple centers need not have equal areas nor equal numbers of isohyets. An example of multiple cell construction is shown in figure 22. In this figure, pattern X represents a single center, and pattern Y a double-centered pattern derived from pattern X. In pattern Y the enclosed area of the A isohyet equals that of A in pattern X. The sum of the areas of the two B centers in pattern Y equals that of B in pattern X, and similarly for the C isohyets. This approach satisfies the requirement to keep the volume of PMP constant, regardless of pattern selected. The magnitudes of the A, B and C isohyets in X and Y are the same.

Supplemental isohyets may be necessary to provide sufficient isohyets for coverage of small multiple centered patterns. Intermediate isohyets can be determined by the technique in section 3.4.

5.4.2 Arrangement of centers

Actual storms show a multitude of possible placements of the two centers. As the size of the drainage increases, the number of arrangements that are possible also increases. It is left to the user to determine the most critical hydrologic arrangement for a specific drainage situation. This arrangement should not violate the basic elliptical shape of the total isohyetal pattern.

6. SHORT-DURATION PRECIPITATION

6.1 Introduction

In applying PMP estimates to determine flood hydrographs, it is often necessary to determine the amounts that fell within time increments of less than 6 hr. Severe storms have occurred in which all, or nearly all, of the rain fell in periods of less than an hour. In other situations, the rainfall has been much more uniform, with large amounts falling every hour for several days. It is the purpose of this chapter to develop criteria for the maximum 5-, 15-, 30- and 60-min amounts that occur within the largest 6-hr increment of PMP determined from HMR No. 51. Another important feature is the temporal distribution of these short-duration values within the greatest 6-hr increment. This has not been studied for the present report. It is left to the discretion of the analyst to place these values chronologically in the most critical sequence.

6.2 Data

The amount of storm-centered data available for durations between 1 and 6 hr is limited. Of the total storm sample available in the United States east of the 105th meridian only 29, or about 6 percent, had data for the 1-hr duration. These storms are listed in table 19 and provide a basis for much of the analysis in this chapter. For many storms, data are insufficient to define an accurate isohyetal pattern near the storm center. In these cases the value for the largest observation, or the innermost isohyet drawn, is assumed to represent the average depth over a 10-mi^2 area. Of our storm sample, 12 had sufficient data to define the areal distribution to the nearest square mile. These storms are identified by an asterisk in table 19.

Many of the storms in table 19 did not last more than a few hours. Since the information in HMR No. 51 is restricted to areas of 10 mi^2, or larger, it was necessary to define a relationship between point and 10-mi^2 values for 6 and 12

Table 19.—Storms used in analysis of 1-hr storm-area averaged PMP values

Location of storm center						
Nearest station	Lat. (°)	(')	Long. (°)	(')	Date	Storm assignment number+
Baltimore, MD	39	17	79	37	7/12/1903	SA 1-6
Bonaparte (nr), IA	40	42	91	48	6/9-10/1905	UMV 2-5
Cambridge, OH	40	02	81	36	7/16/1914	OR 2-16
Gordon, PA	40	45	76	20	8/21-22/1915	SA 1-7
Oakdale, NE	42	04	97	58	7/16-17/1920	MR 4-18
Lancaster, PA	40	03	76	17	8/18/1920	SA 1-8
Baltimore, MD	39	17	76	37	10/9-10/1922	SA 1-9
Harrisburg, PA	40	13	76	51	8/8/1925	SA 1-10
Toledo, IA	42	00	92	34	8/1-2/1929	UMV 2-17
Lakeville, PA	42	27	75	16	7/24/1933	SA 1-11
Woodward Ranch, TX	29	20	99	18	5/31/1935	GM 5-20
Elm Grove, WV*	40	03	80	40	7/10/1937	OR 9-15
Pickwick, TN	35	05	88	14	8/21-25/1937	OR 3-25
Winchester Spr., TN*	35	12	86	12	7/8/1938	--
Lucas Garrison, MO*	38	45	90	23	8/25/1939	UMV 3-19
Washington, D.C.	38	54	77	03	7/23/1940	--
Ewan, NJ*	39	42	75	12	9/1/1940	NA 2-4
Plainville, IL*	39	48	91	11	5/22/1941	UMV 2-19
Iowa City, IA*	41	38	91	33	9/8/1942	UMV 2-21
Gering (nr), NE*	41	49	103	41	6/17-18/1947	MR 7-16
Holt, MO	39	27	94	20	6/22-23/1947	MR 8-20C
St. Louis, MO*	38	36	90	18	7/5/1948	UMV 3-27
Marsland (nr), NE*	42	36	103	06	7/27-28/1951	MR 10-7
Kelso, MO	37	12	89	33	8/11-12/1952	UMV 3-30
Ritter, IA	43	15	95	48	6/7/1953	MR 10-8
Tulsa, OK*	36	11	95	54	7/25/1963	--
--*	35	22	98	18	9/20-21/1965	--
Glen Ullin, ND*	47	21	101	19	6/24/1966	--
Greeley (nr), NE	41	33	98	32	8/12-13/1966	--

+These numbers are assigned by the Corps of Engineers (indexed to major drainages) and are given in "Storm Rainfall" (U. S. Army Corps of Engineers 1945-). Storms without index numbers are from less complete storm studies maintained in the Hydrometeorological Branch.

*Storms for which an isohyetal pattern was developed that permitted determination of areal values for 1 mi^2 and larger.

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hr. For this purpose another storm sample was selected that consisted of all storms in "Storm Rainfall" (U. S. Army Corps of Engineers 1945-) for which adequate data were available to define depth-area relations between 1 and 10 mi^2. These 54 storms are listed in table 20.

Table 20.--Storms used to define 1- to 10-mi^2 area ratios for 6 and 12 hr

Location of storm center						
	Lat.		Long.			Storm assignment
Nearest station	(°)	(')	(°)	(')	Date	number+
Constableville, NY	43	44	74	46	7/1-5/1890	GL 1-2
S. Canisteo, NY	42	15	77	33	9/8-13/1890	GL 4-1
Blanchard, IA	40	31	95	13	7/6-7/1898	MR 1-3A
Girardville, PA	40	48	76	17	8/3-5/1898	SA 1-4
Friesburg, NJ	39	35	75	25	9/12-15/1904	NA 1-9
Bonaparte (nr), IA	40	42	91	48	6/9-10/1905	UMV 2-5
Arkadelphia, AR	34	07	93	03	6/28-7/2/1905	MR 1-16B
Elk, NM	32	56	105	17	7/21-25/1905	GM 3-13
LaFayette, LA	30	14	91	59	5/7-10/1907	LMV 3-12
Sugarland, TX	29	36	95	38	5/28-31/1907	LMV 3-13
Ardmore, OK	34	12	97	08	7/12-15/1927	SW 2-5
Cheltenham, MD	38	44	76	51	8/10-13/1928	NA 1-18
Algiers, LA	29	56	90	03	9/5-9/1929	LMV 4-13
Meeker, OK	35	30	96	54	6/2-6/1932	SW 2-7
Tribune, KS	38	28	101	46	6/2-6/1932	SW 2-7A
St. Fish Htchry., TX*	30	10	99	21	6/30-7/2/1932	GM 5-1
Elka Park, NY	42	10	74	14	10/4-6/1932	NA 1-21
Peekamoose, NY	41	56	74	23	8/20-24/1933	NA 1-24A
York, PA	39	55	76	45	8/20-24/1933	NA 1-24B
Cheyenne (nr), OK*	35	37	99	40	4/3-4/1934	SW 2-11
Cherry Ck., CO*#	39	13	104	32	5/30-31/1935	MR 3-28A
Keene, OH	40	16	81	52	8/6-7/1935	OR 9-11
Bentonville, AR	36	22	94	13	9/6-10/1937	SA 2-15A
Cherokee, OK	36	45	98	22	9/6-10/1937	SW 2-15B
New Orleans, LA	29	57	90	04	9/30-10/4/1937	LMV 4-22A
Woodworth, LA	31	08	92	29	9/30-10/4/1937	LMV 4-22B
Loveland (nr), CO	40	23	105	04	8/30-9/4/1938	MV 5-8
Miller Island, LA*	29	45	92	10	8/6-9/1940	LMV 4-24
Ewan, NJ	39	42	75	12	9/1/40	NA 2-4
Hallett, OK*	36	15	96	36	9/2-6/1940	SW 2-18
Larchmont, NY	40	55	73	46	7/26-28/1942	NA 2-7
Charlottesville, VA	38	02	78	30	8/7-10/1942	NA 2-8
Warner, OK	35	29	95	18	5/6-12/1943	SW 2-20
Mounds (nr), OK*	35	52	96	04	5/12-20/1943	SW 2-21
Pierce (nr), NE	42	12	97	32	5/10-12/1944	MR 6-13
Stanton (nr), NE*	41	52	97	03	6/10-13/1944	MR 6-15
Turkey Ridge St., SD	43	16	97	08	6/10-13/1944	MR 6-15A
New Brunswick, NJ	40	29	74	27	9/12-15/1944	NA 2-16
Cedar Grove, NJ	40	52	74	13	7/22-23/1945	NA 2-17
Jerome, IA	40	43	93	02	7/16-17/1946	MR 7-9

Table 20.--Storms used to define 1- to 10-mi^2 area ratios for 6 and 12 hr - Continued

Location of storm center						
	Lat.		Long.			Storm assignment
Nearest station	(°)	(')	(°)	(')	Date	number+
Collinsville, IL	38	40	89	59	8/12-16/1946	MR 7-2B
Holt (nr), MO	39	27	94	20	6/18-23/1947	MR 8-20
Wickes, AR*	34	14	94	20	8/27-28/1947	SW 3-7A
Dallas, TX	32	51	96	51	8/24-27/1947	SW 3-7B
Mifflin, WI	42	52	90	21	7/15-16/1950	UMV 3-28
Dumont (nr), IA	42	44	92	59	6/25-26/1951	UMV 3-29
Council Gr. (nr), KS	38	40	96	30	7/9-13 /1951	MR 10-2
Vic Pierce, TX*	30	22	101	23	6/23-28/1954	SW 3-22
New Bern, NC	35	07	77	03	8/10-15/1955	NA 2-21B
Slide Mtn., NY	42	01	74	25	8/11-15/1955	NA 2-21A
Big Meadows, VA	38	31	78	26	8/15-19/1955	NA 2-22B
Westfield, MA	42	07	72	45	8/17-20/1955	NA 2-22A
Big Elk Mdw. Res., CO	40	16	105	25	5/4-8/1969	--
Broomfield (nr), CO	39	55	105	06	5/5-6/1973	--

\+ - See note for table 19.

\# - Westernmost center of two large nearly equal amounts, generally known as Cherry Ck. The easternmost center is at Hale CO, 39° 36'N, 102° 08'W (see table 1).

* - Storms with larger 6- and 12-hr values used in depth-area development.

Data for durations less than 1 hr are not available from the storm studies prepared for "Storm Rainfall" (U. S. Army Corps of Engineers 1945-). For these durations maximum annual values were used. These values were determined from excessive precipitation tables of "Climatological Data" (National Weather Service 1914-).

6.3 1-hr PMP

Since maximum 1-hr data are relatively scarce, it has been necessary to resort to indirect methods to develop the 1-hr PMP. The primary tool was the development of depth-duration ratios for point or 1-mi^2 precipitation. These were used to develop 1-mi^2 1-hr PMP maps. Depth-area ratios developed from storm values were used to develop maps for other area sizes.

6.3.1 Depth-duration ratios

The first step in this procedure is to develop depth-duration ratios for durations from 5 min to 12 hr along meridians at 2° intervals starting at 69°W. Depth-duration curves were prepared for each 2° of latitude from 29°N. For 6- and 12-hr durations, the 10-mi^2 values from HMR No. 51 were used. Values for the 2- and 3-hr durations were obtained for the 100-yr recurrence interval from Weather Bureau Technical Paper No. 40 (Hershfield 1961). For the shorter durations, 5, 10, 15, 30 and 60 min, the 100-yr amounts were determined from NOAA Technical Memorandum NWS 35 (Frederick et al. 1977). Along the 105th meridian, however, all rainfall-frequency values were determined from NOAA Atlas 2 (Miller et al. 1973).

All values were expressed as a percent of the 6-hr 10-mi^2 amount, and a smooth set of curves was developed for each meridian. These curves (not shown) indicate that the ratio between amounts for durations less than 6 hr and the 6-hr amount decreased from north to south. This variation was consistent along all meridians. The same trend can be seen by examining 6- to 24-hr ratios in PMP values of HMR No. 51. Although considerable scatter is present when 1- to 6-, 2- to 6-, or 3- to 6-hr ratios in major storms are examined, a trend toward increasing ratios with latitude can also be detected. After constructing a smooth family of curves along the meridian, the 1-hr pt. to 6-hr 10-mi^2 ratios were plotted and regionally smoothed (fig. 23). This smoothing step required changes of less than 2 percent from the values determined from the sets of curves.

6.3.2 1-hr 1-mi^2 PMP

The ratio map of figure 23 was used to compute 1-hr 1-mi^2 PMP values over a 2° grid from the 6-hr 10-mi^2 PMP amounts shown in HMR No. 51. These values were plotted and isohyets drawn as shown in figure 24. The 1-hr data used to develop the 1- to 6-hr ratios were based upon single station observations, and the resulting maps can be considered "point" values. We have developed a convention for this report that they should be considered applicable to 1 mi^2. We do not recommend any increase in these values for smaller areas.

Though the paucity of data prevents development of the 1-hr 1-mi^2 PMP by traditional methods, an important step in evaluating the reasonableness of the PMP values developed is to compare the limited data available with the derived map. Table 21 shows the important 1-hr values used in this comparison. In most cases, 1-hr values are not obtainable directly from the observations of the most extreme rainfall in the storm and must be estimated by indirect methods. The technique used for each storm is indicated in the remarks column.

These maximum observed amounts together with the moisture maximized values are shown in figure 25. There are only a few storms that provide controlling or near controlling values: a) Smethport, Pennsylvania; b) Glen Ullin, North Dakota; c) Buffalo Gap, Saskatchewan; and d) Simpson P.O., Kentucky. The moisture maximized amount for Buffalo Gap of 16.3 in. exceeds the value interpolated from figure 24 of 14.4 in. for the northern Great Plains, the region within which it could be transposed. However, the moisture maximization factor for this storm is 155 percent. Since this moisture maximized value is not supported by the values for other storms in the region, we have adopted the convention of limiting the adjustment factor to 150 percent.

The Buffalo Gap observation is based upon a D.A.D. analysis of the results of a bucket survey. Figure 24 "undercuts" the moisture maximized transposed value by about 1 in. and is about 4 in. larger than the observed precipitation value. Considering all the uncertainties involved, we feel this is a reasonable estimate of the 1-mi^2 1-hr PMP for this region, and that it is comparable to practices followed in HMR No. 51. (See section 4.1 of that report.)

In figure 25, the moisture adjustment factor used for the Cherry Ck. storm is 122 percent. (This percent was also used for the Hale center of the same storm listed in HMR No. 51.) Recently, the dew point for this storm was reevaluated

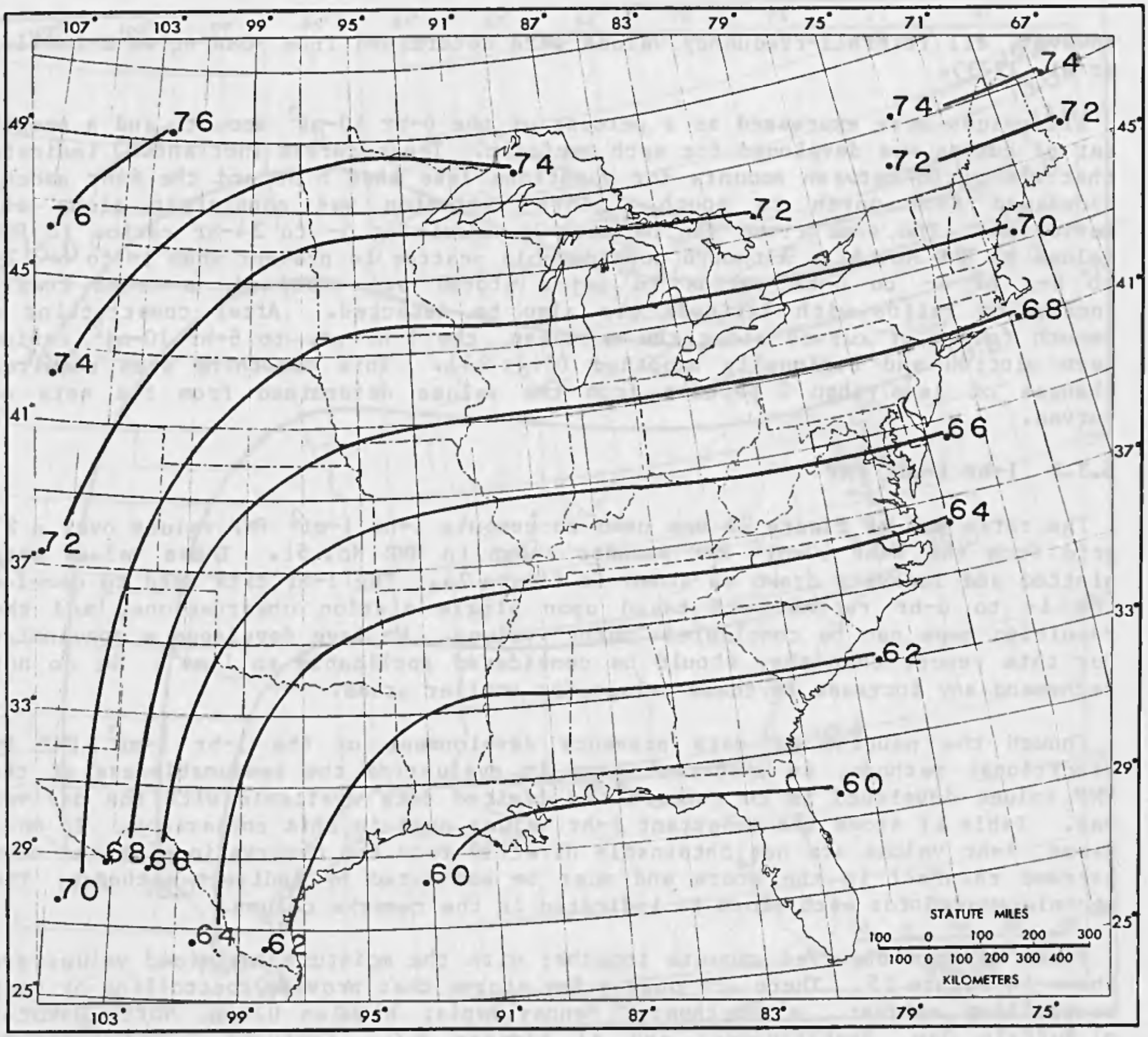

Figure 23.—1-hr pt. to 6-hr 10-mi^2 ratio of precipitation based on major storms used in HMR No. 51 and rainfall frequency studies.

and resulted in a revised moisture adjustment factor of 141 percent. Applying this new adjustment factor to the 1-hr value for the storm gives a maximized value of 15.5 in., which more closely supports the 16.7 in. value interpolated from figure 24.

The moisture adjusted values show little support for the values shown in the southern portion of the 1-hr 1-mi^2 PMP map. The next step in the traditional method for developing PMP values would be transposition of the maximized amounts within regions of meteorological homogeneity for each extreme storm of record. Figure 26 shows the transposition limits for the Smethport, Pennsylvania storm of July 17-18, 1942, the moisture maximized value at the storm location, and the moisture maximized transposed value for the southwestern extreme of the

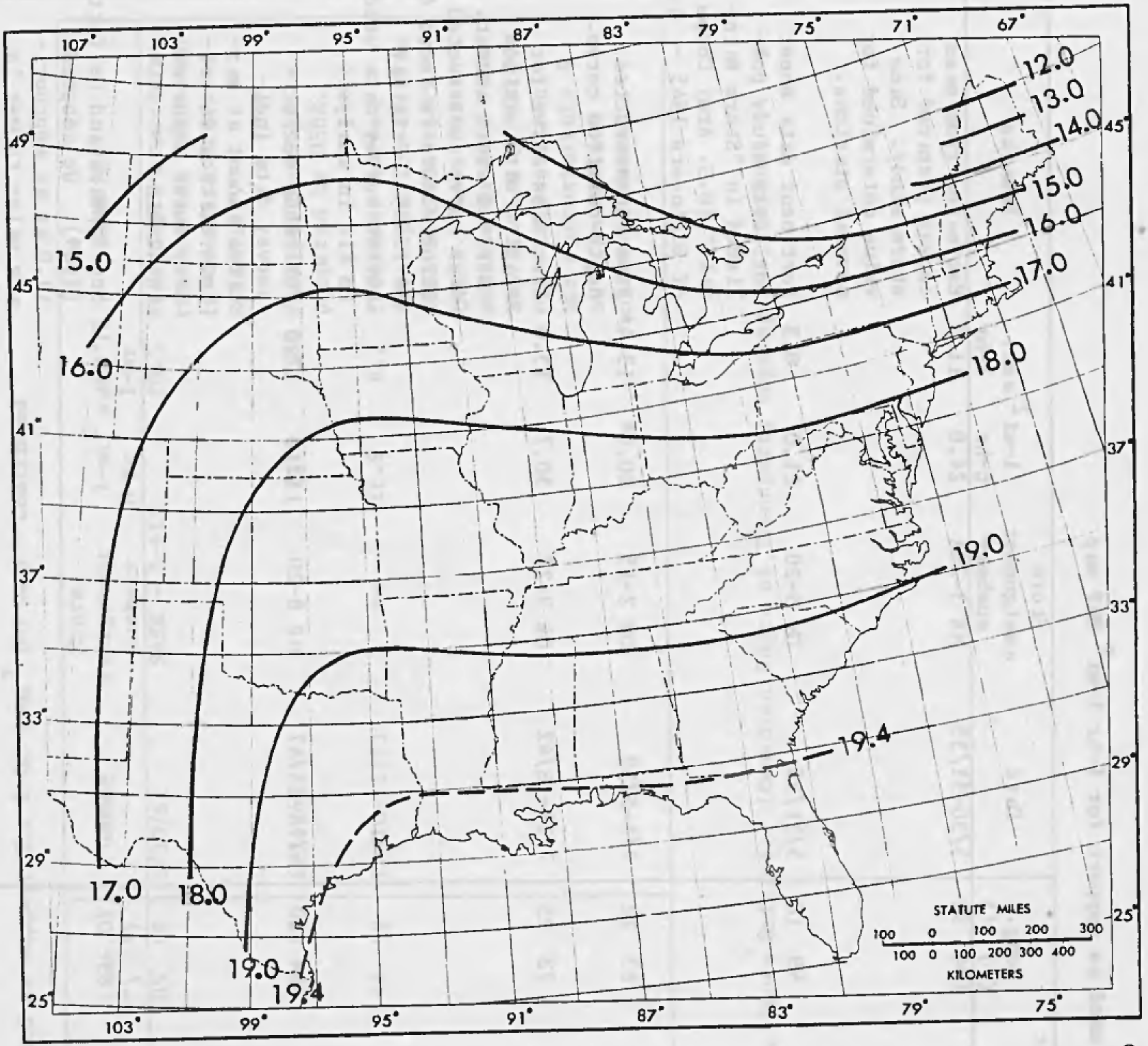

Figure 24.—1-hr 1-mi^2 PMP analysis based on figure 23 and 6-hr 10-mi^2 precipitation from HMR No. 51.

transposition limits. Comparison of this 18.3-in. value with the 1-hr 1-mi^2 PMP from figure 24 shows a difference of 0.6 in. We consider this a reasonable envelopment of a moisture maximized transposed amount.

6.3.3 Depth-area ratios

Preparation of 1-hr PMP values over the range of area sizes of interest required development of depth-area reduction ratios. A primary basis for such reduction ratios is the list in table 19 of 12 extreme storms (those noted by asterisks) for which point or 1-mi^2 data are available at 1 hr. A problem with the data from these 12 storms is the limited area of most storms. Nearly 60 percent have an areal extent of less than 240 mi^2, while one fourth of them

Table 21.—Extreme 1-hr amounts used as support for 1-hr 1-mi^2 PMP map

Location of storm center					Date	Storm assignment number+	1-mi^2 amt.		Remarks
Nearest station	Lat. (°)	(')	Long. (°)	(')			6-hr	1-hr	
Elbert, CO (Cherry Ck.)#	39	13	104	32	5/30-31/35	MR 3-28A	24.0	11.0	Estimated from mass curves prepared for storm study. Same value determined for several stations.
Woodward Ranch, TX	29	20	99	18	5/31/35	GM 5-20	21.0	9.3	Pertinent data sheet for storm study published in "Storm Rainfall" (U.S. Army Corps of Engineers 1945 -).
Simpson P.O., KY	38	13	83	22	7/4-5/39	OR 2-15	20.0*	13.4*	From reconstructed depth-duration curve.
Smethport, PA	41	50	78	25	7/17-18/42	OR 9-23	30.7	15.0	From mass curve for station with maximum observed storm amount. Mass curve constructed using recorders about 4 mi away. Original bucket survey data used to aid in analysis.
Holt, MO	39	27	94	20	6/18-23/47	MR 8-20	12.0	12.0	Published bucket survey data indicates amount at maximum station in primary burst occurred in 42 min.
Cove Creek, NC	35	36	83	01	6/30/56	--		10.12	See Schwarz and Helfert (1969). We adopted 11.0 as an appropriate value to use in these comparisons.

Table 21.—Extreme 1-hr amounts used as support for 1-hr 1-mi^2 PMP map - Continued

Location of storm center					Date	Storm assignment number+	1-mi^2 amt.		Remarks
	Lat.		Long.						
Nearest station	(°)	(')	(°)	(')			6-hr	1-hr	
Buffalo Gap, Saskatchewan, Can.	49	07	105	18	5/30/61	SASK - 5-61†		10.5	From depth-area-duration curves published in Canadian Storm Rainfall†.
Glen Ullin, ND	47	21	101	19	6/24/66	--	12.16	7.89	From pertinent data prepared by USBR.
Enid, OK	36	25	97	52	10/10-11/73	--	16.9	6.7	From mass curve developed for station with maximum storm total. Mass curve modeled on data from NWS station at Enid, OK. Enid station was approximately 6 mi from maximum observed amount.

* 10-mi^2 amount

\+ See table 19

† Assignment number from "Canadian Storm Rainfall" (Canadian Dept. of Transport; ongoing publication)

\# See note for table 20

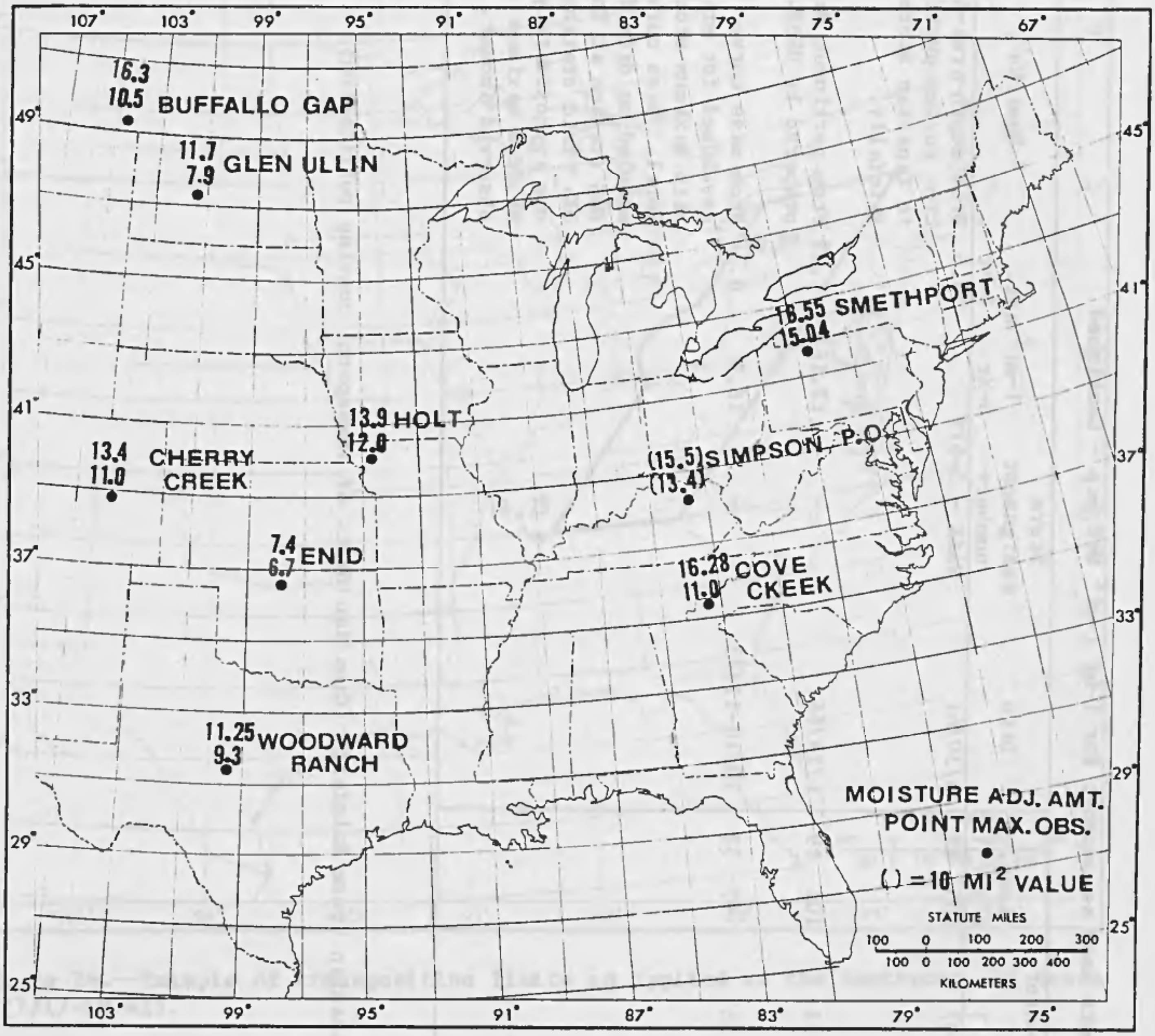

Figure 25.—Maximized observed 1-hr point amounts and moisture maximized values from major storms listed in table 21.

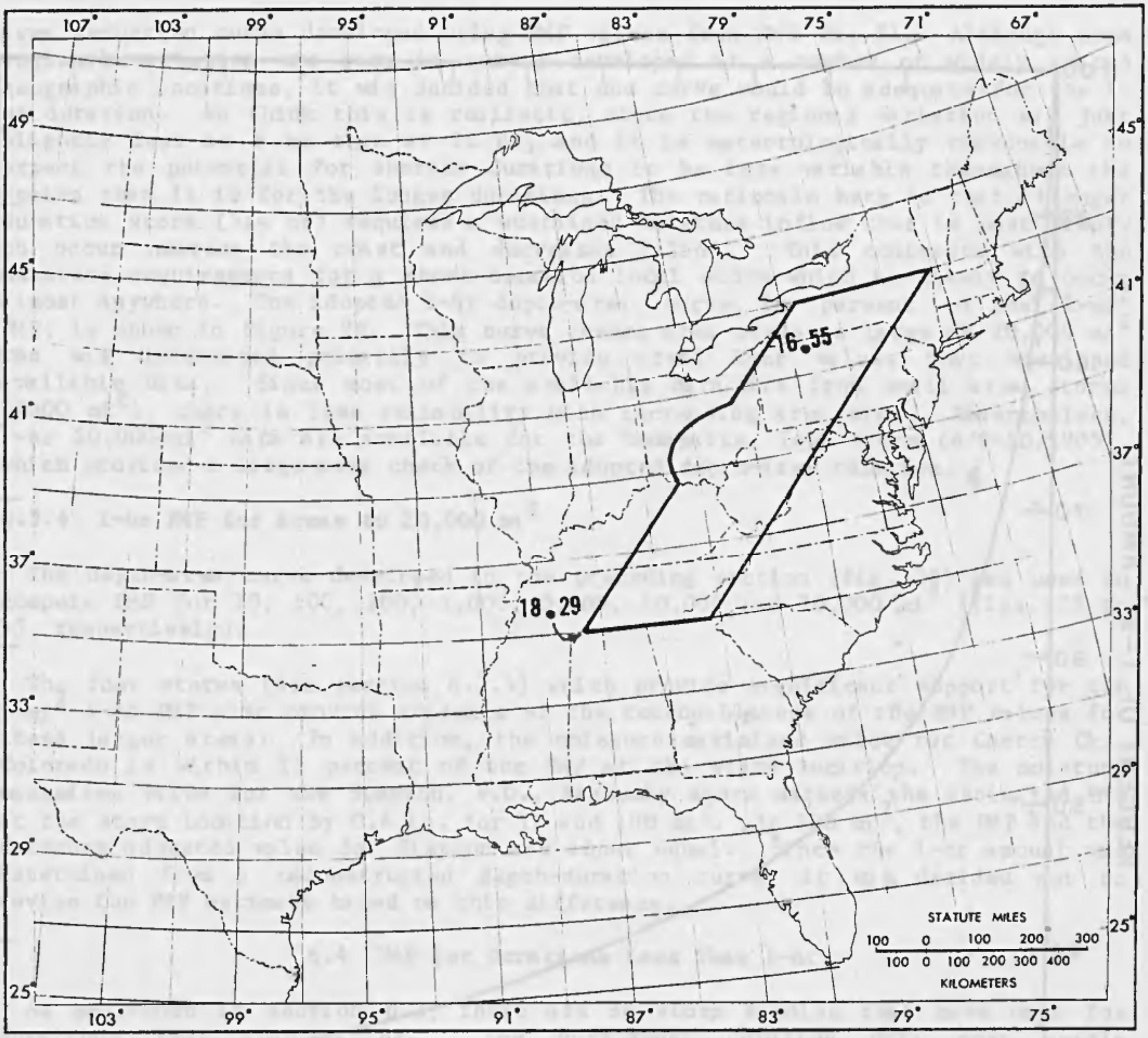

Figure 26.—Example of transposition limits as applied to the Smethport, PA storm (7/17-18/42).

enclose an area less than 100 mi^2. It was decided to develop an average depth-area curve for the 1-hr duration from these 12 storms and similar curves for the 6- and 12-hr durations from these storms and 9 additional storms from the 54 storms for which maximum point or 1-mi^2 amounts were available (table 20). The curves for the 6- and 12-hr durations were used as an aid in shaping the 1-hr curve for the larger area sizes. Figure 27 shows the data for these 12 storms for the areas of 600 mi^2 and less and the curve of best fit for the data. Similar curves (not shown) were drawn for the 6- and 12-hr durations.

The depth-area relations implicit in the set of PMP values derived from the maps of HMR No. 51 represent enveloping values from a combination of storms. We therefore adjusted our family of curves to be compatible with an average depth-

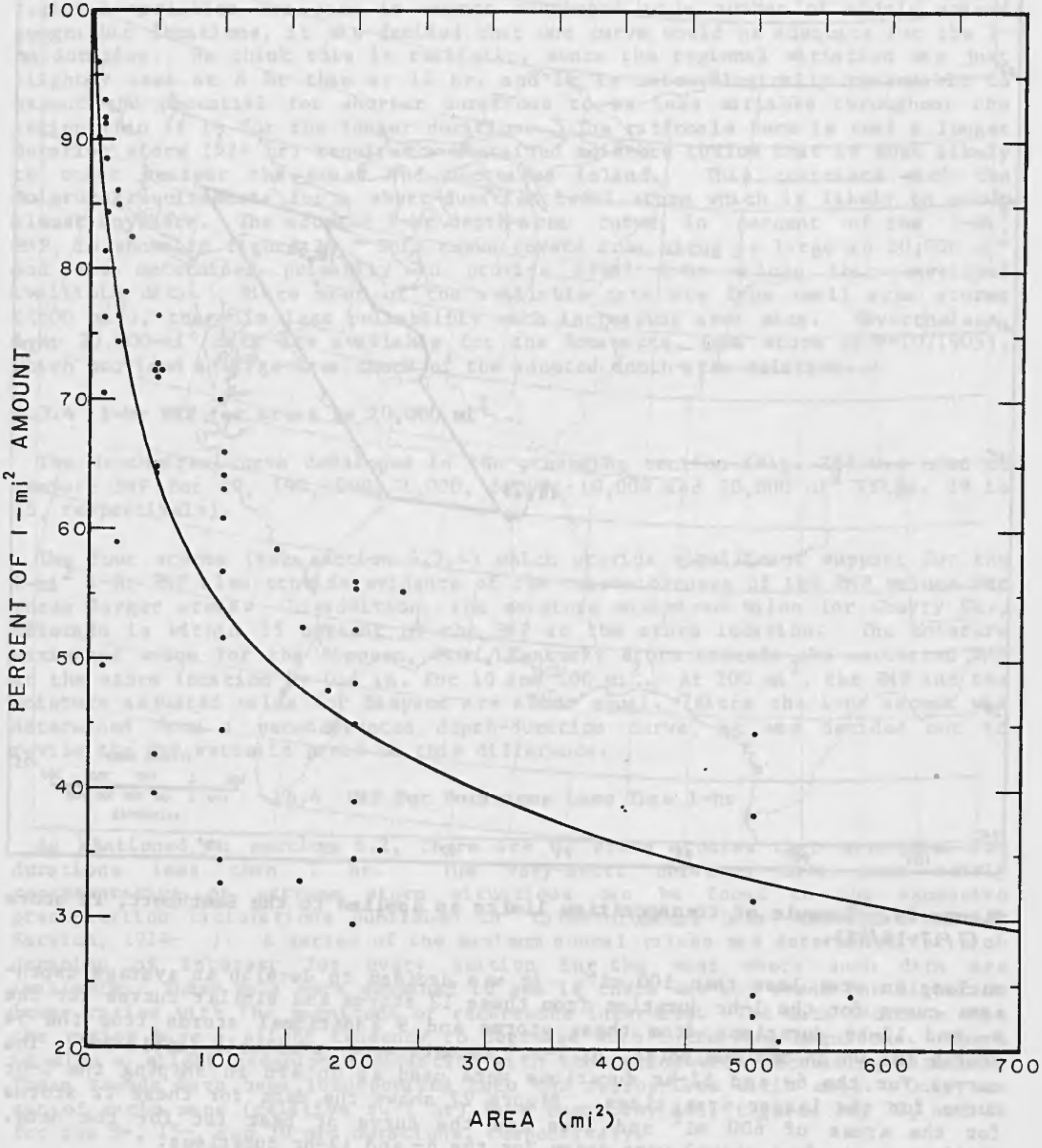

Figure 27.—Depth-area data plotted as percent of maximum 1-hr 1-mi^2 amount for storms where the maximum 1-hr 1-mi^2 amount was determined from a dense network of observations or bucket survey amounts.

area reduction curve developed using PMP values from HMR No. 51. Although some regional variation was seen in curves developed at a number of widely spaced geographic locations, it was decided that one curve would be adequate for the 1-hr duration. We think this is realistic, since the regional variation was just slightly less at 6 hr than at 12 hr, and it is meteorologically reasonable to expect the potential for shorter durations to be less variable throughout the region than it is for the longer durations. The rationale here is that a longer duration storm (>24 hr) requires a sustained moisture inflow that is most likely to occur nearest the coast and decreases inland. This contrasts with the moisture requirements for a short-duration local storm which is likely to occur almost anywhere. The adopted 1-hr depth-area curve, in percent of the 1-mi^2 PMP, is shown in figure 28. This curve covers area sizes as large as 20,000 mi^2 and was determined primarily to provide areal 1-hr values that enveloped available data. Since most of the available data are from small area storms (<500 mi^2), there is less reliability with increasing area size. Nevertheless, 1-hr 20,000-mi^2 data are available for the Bonaparte, Iowa storm (6/9-10/1905), which provided a large-area check of the adopted depth-area relation.

6.3.4 1-hr PMP for areas to 20,000 mi^2

The depth-area curve developed in the preceding section (fig. 28) was used to compute PMP for 10, 100, 200, 1,000, 5,000, 10,000 and 20,000 mi^2 (figs. 29 to 35, respectively).

The four storms (see section 6.3.4) which provide significant support for the 1-mi^2 1-hr PMP also provide evidence of the reasonableness of the PMP values for these larger areas. In addition, the moisture maximized value for Cherry Ck., Colorado is within 15 percent of the PMP at the storm location. The moisture maximized value for the Simpson, P.O., Kentucky storm exceeds the estimated PMP at the storm location by 0.4 in. for 10 and 100 mi^2. At 200 mi^2, the PMP and the moisture adjusted value for Simpson are about equal. Since the 1-hr amount was determined from a reconstructed depth-duration curve, it was decided not to revise the PMP estimate based on this difference.

6.4 PMP for Durations Less Than 1-hr

As mentioned in section 6.2, there are no storm studies that have data for durations less than 1 hr. The very-short duration data most nearly representative of extreme storm situations can be found in the excessive precipitation tablulations published in "Climatological Data" (National Weather Service, 1914-). A series of the maximum annual values was determined for each duration of interest for every station in the east where such data are available. These data were examined to see if there was any trend for higher or lower ratios with the magnitude or recurrence intervals. The data indicate that the ratios have a slight tendency to decrease with increasing magnitude. There is also a slight geographic variation with the ratios with decreasing latitude. These trends have been incorporated into the appropriate ratio maps. Only one set of ratio maps (relative to 1 hr) have been provided, figures 36, 37, and 38 for the 5-, 15-, and 30-min durations, respectively.

Since there are no data from which to develop areal corrections, we apply the same ratio for all areas. It is for this reason that we feel values for these shorter durations should be be limited only to area sizes of 200 mi^2 or less.

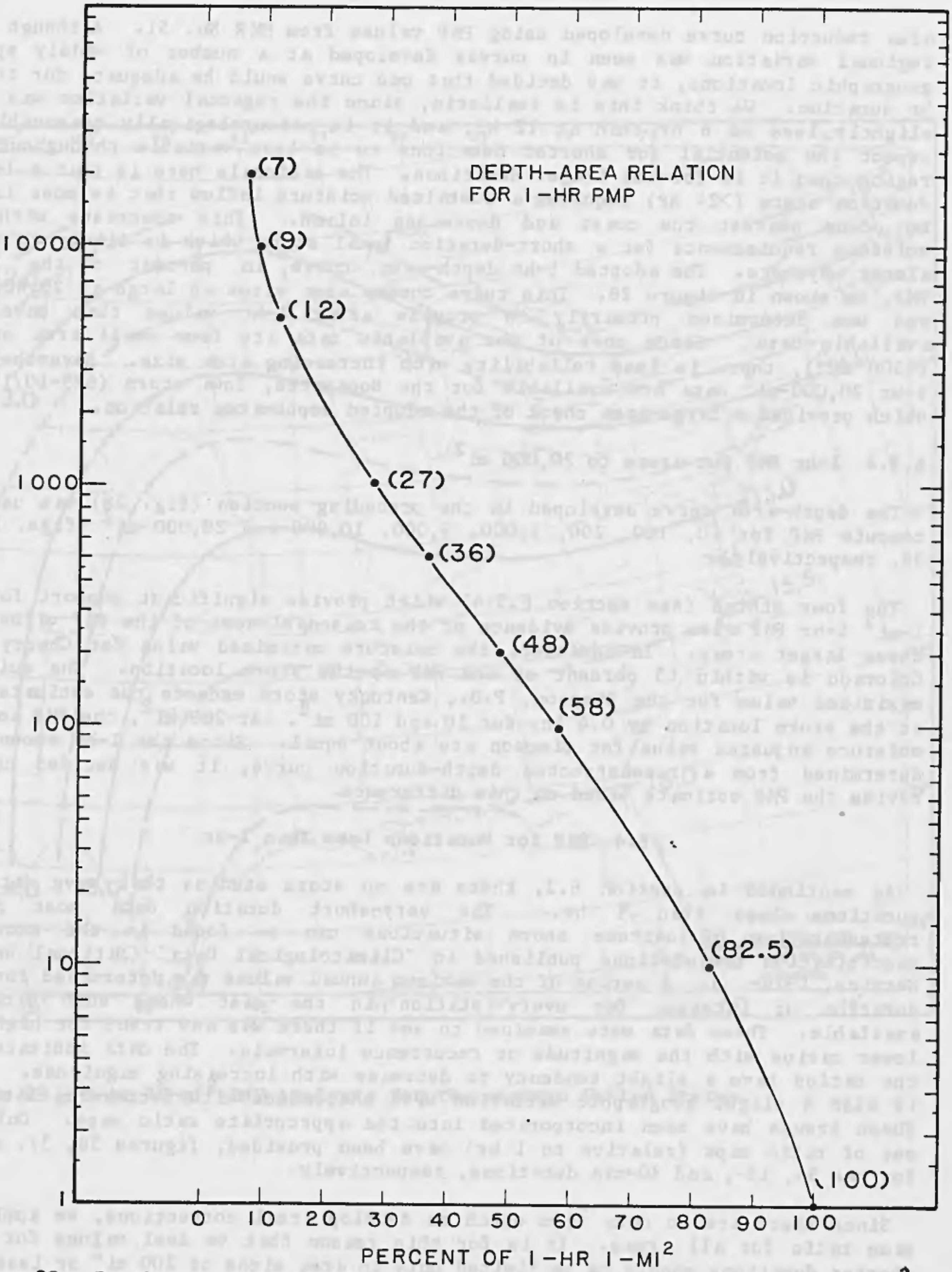

Figure 28.—Depth-area relation for 1-hr PMP in percent of maximum point (1-mi^2) amount.

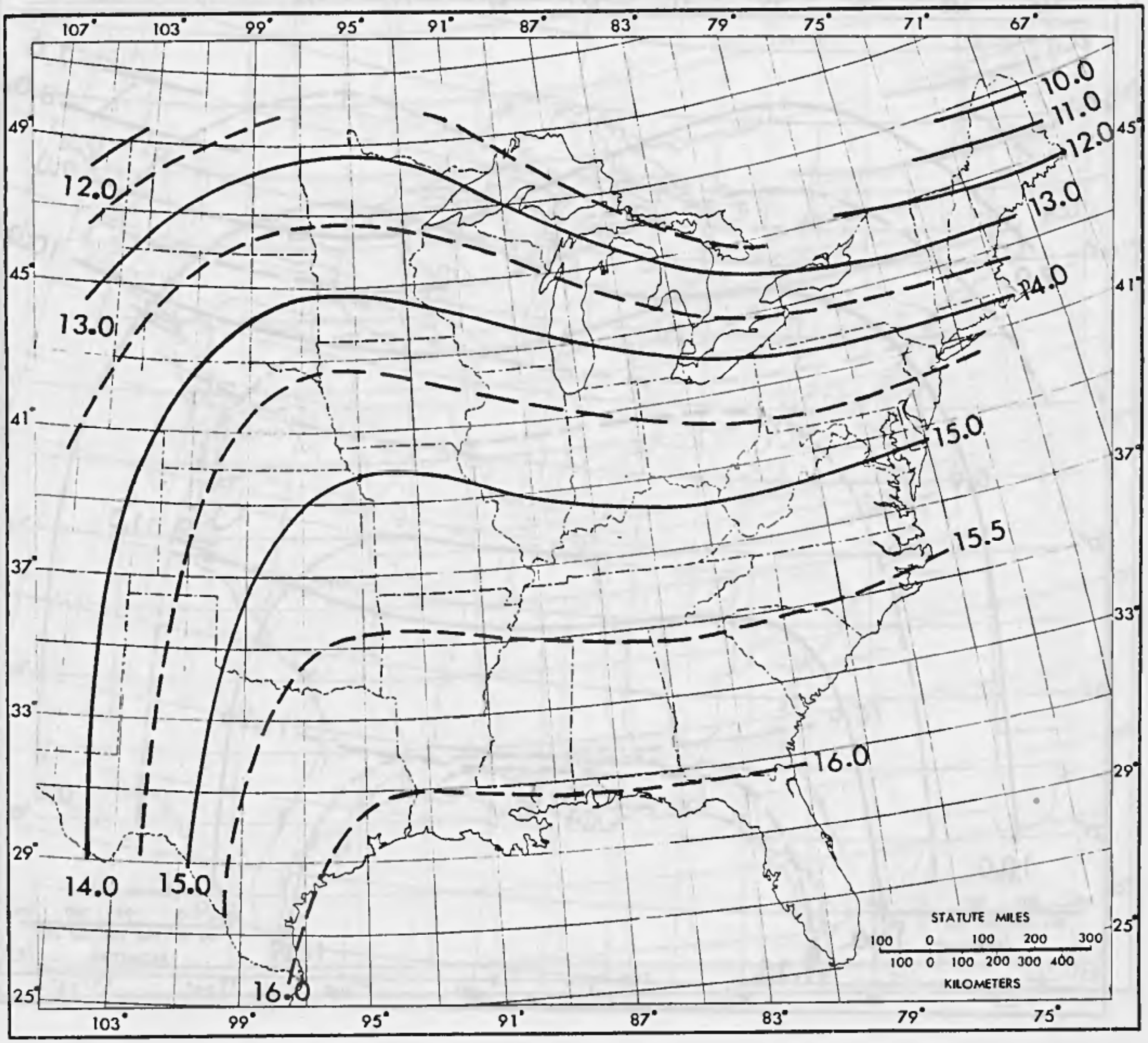

Figure 29.—1-hr 10-mi^2 PMP analysis for the eastern United States.

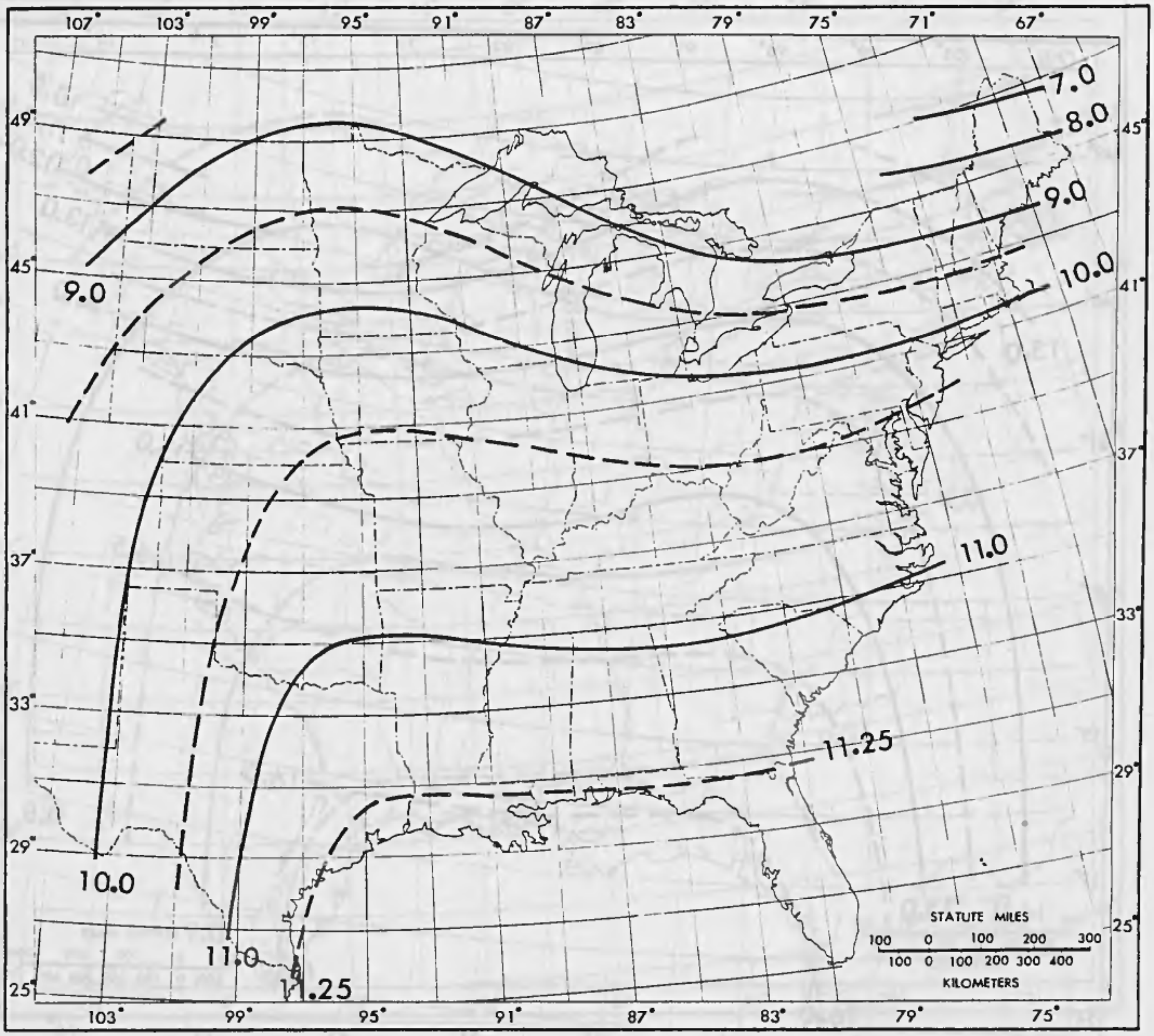

Figure 30.—1-hr 100-mi^2 PMP analysis for the eastern United States.

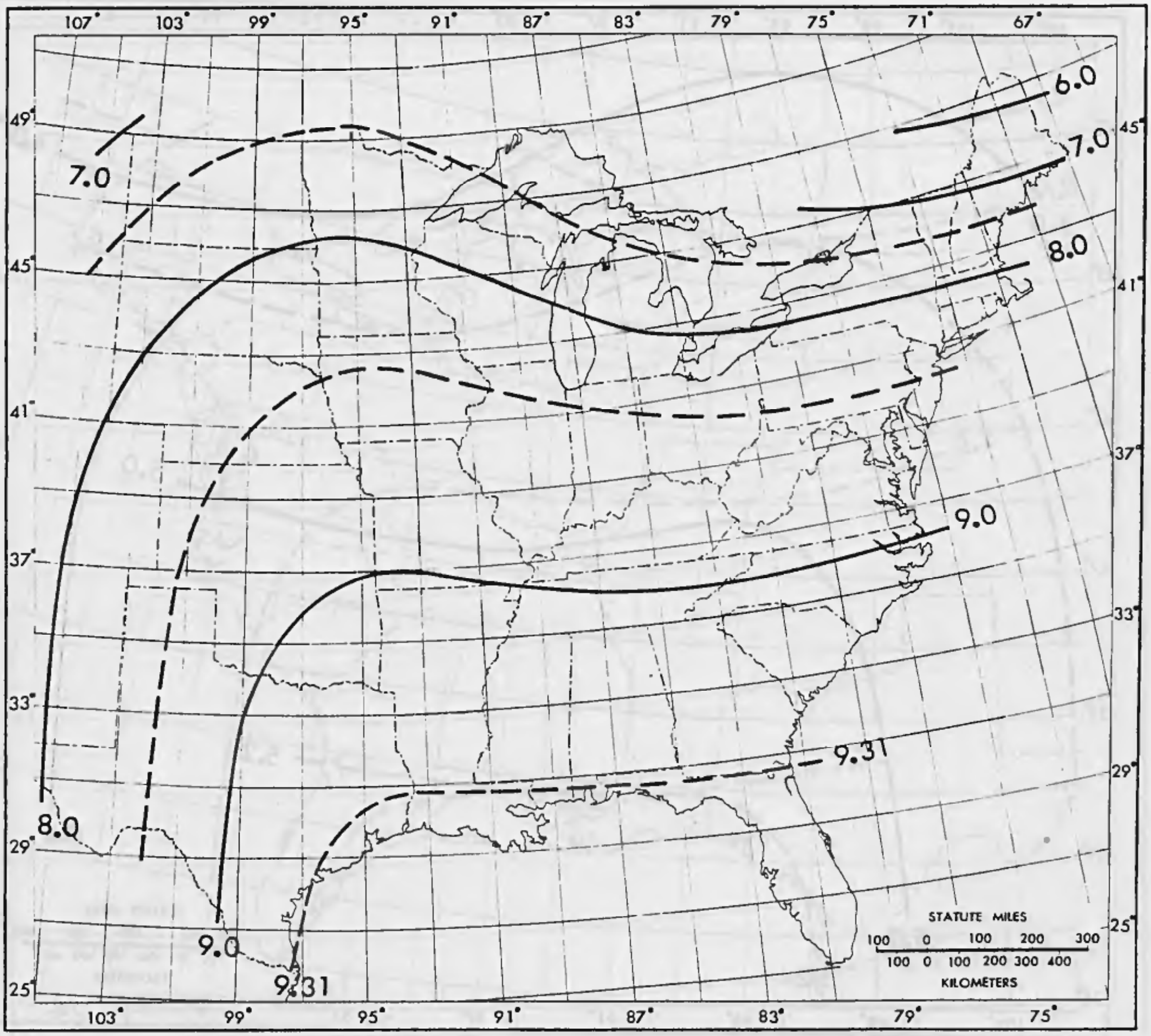

Figure 31.—1-hr 200-mi^2 PMP analysis for the eastern United States.

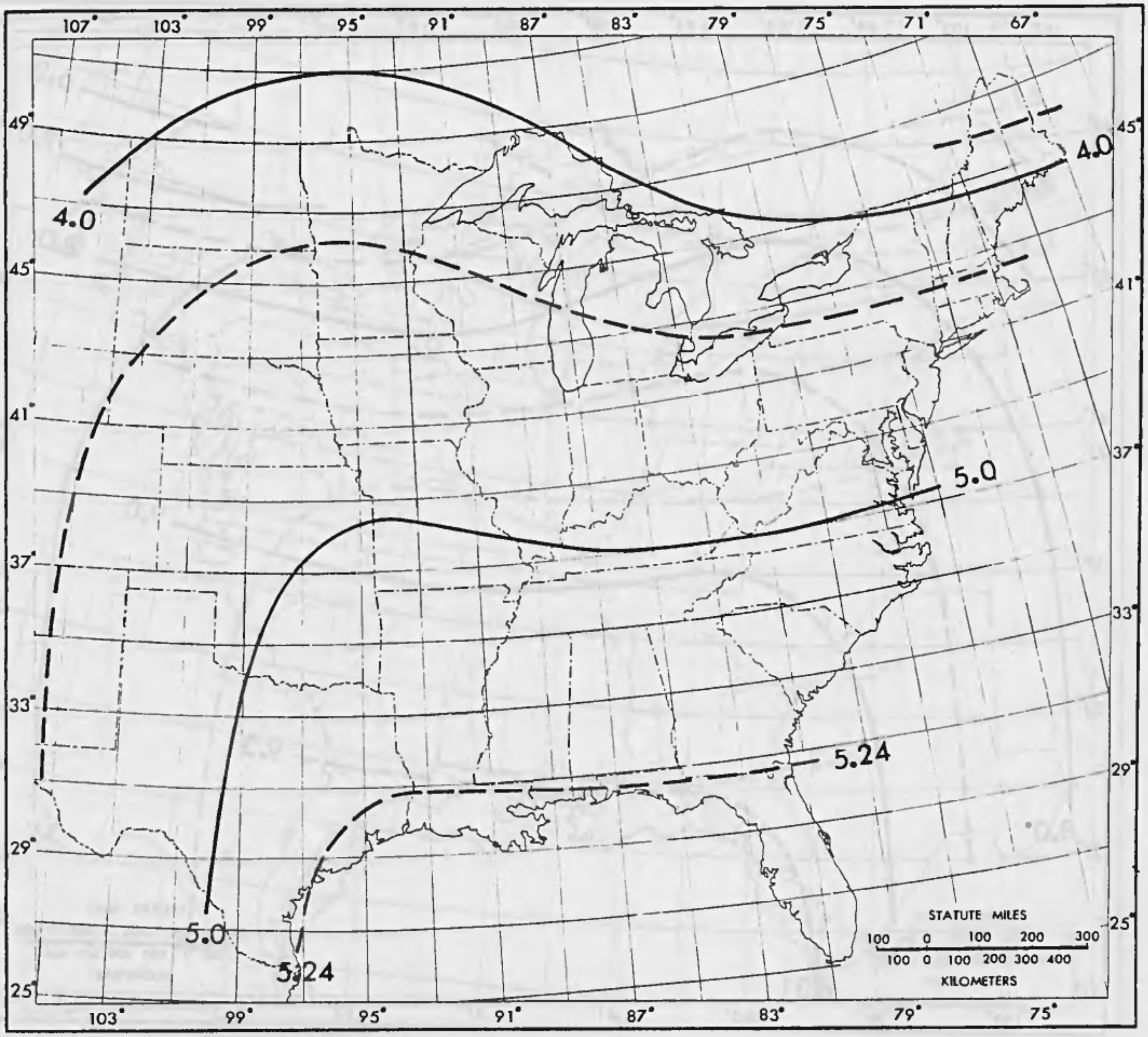

Figure 32.—1-hr 1,000-mi^2 PMP analysis for the eastern United States.

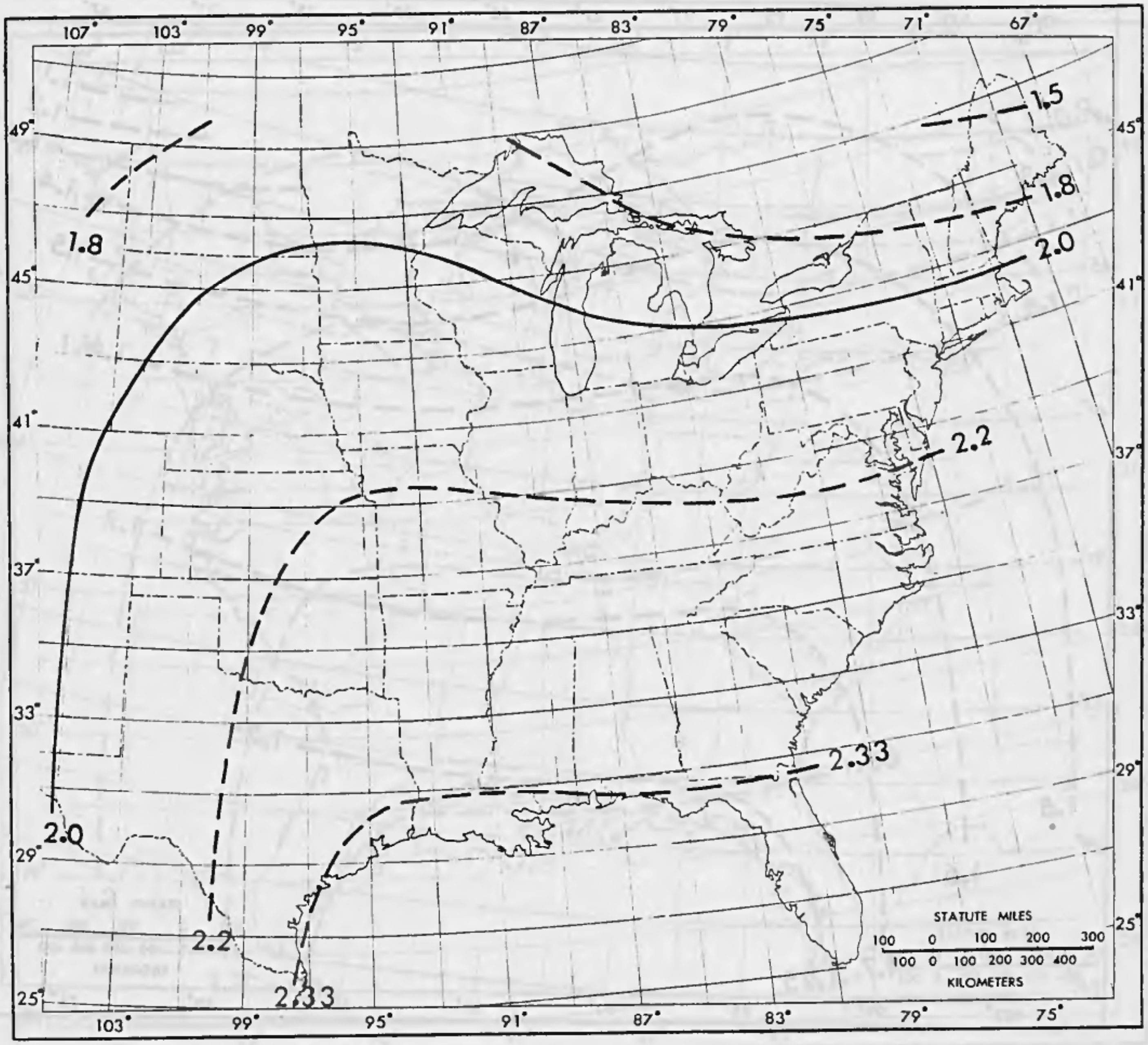

Figure 33.—1-hr 5,000-mi^2 PMP analysis for the eastern United States.

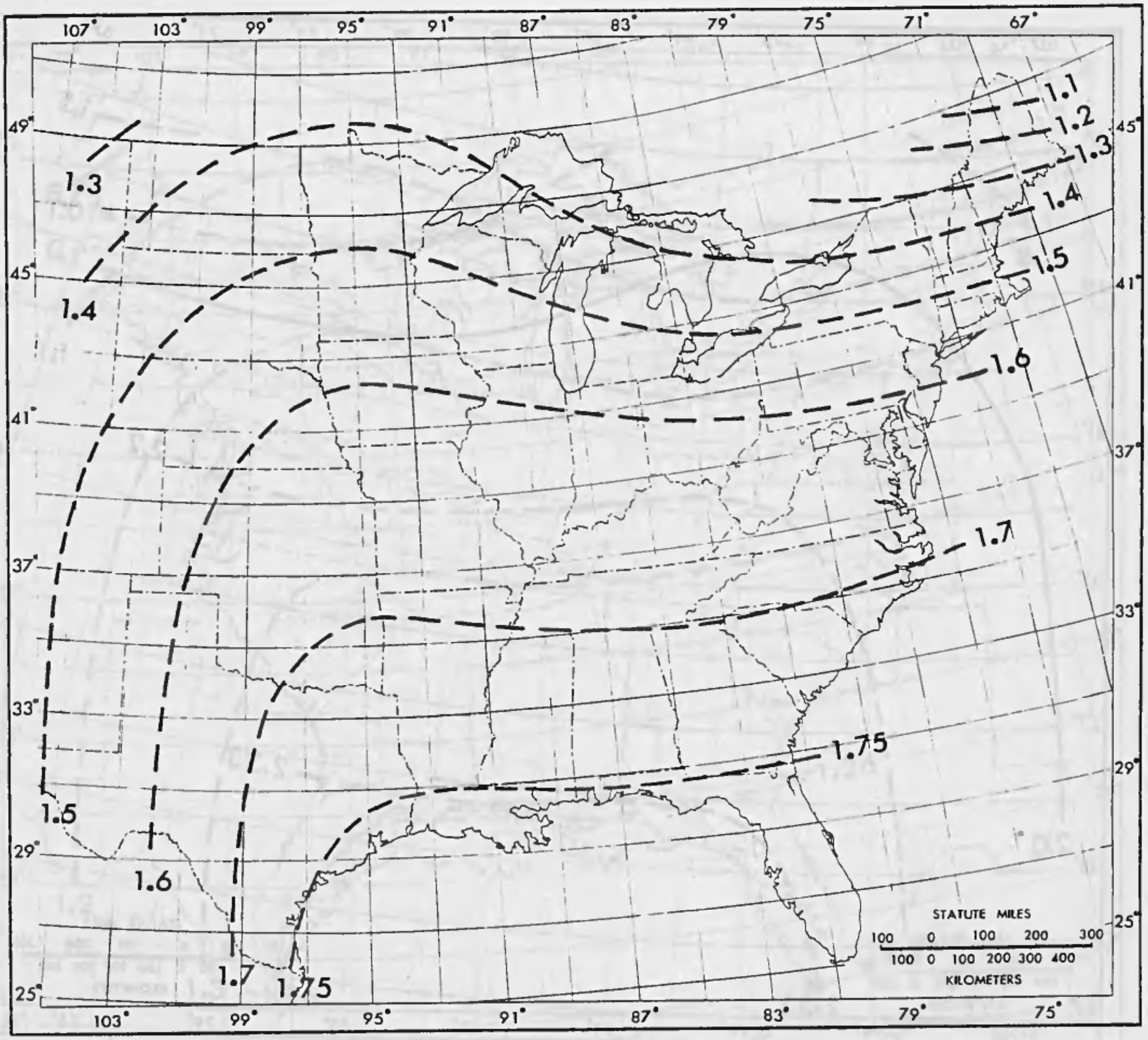

Figure 34.—1-hr 10,000-mi^2 PMP analysis for the eastern United States.

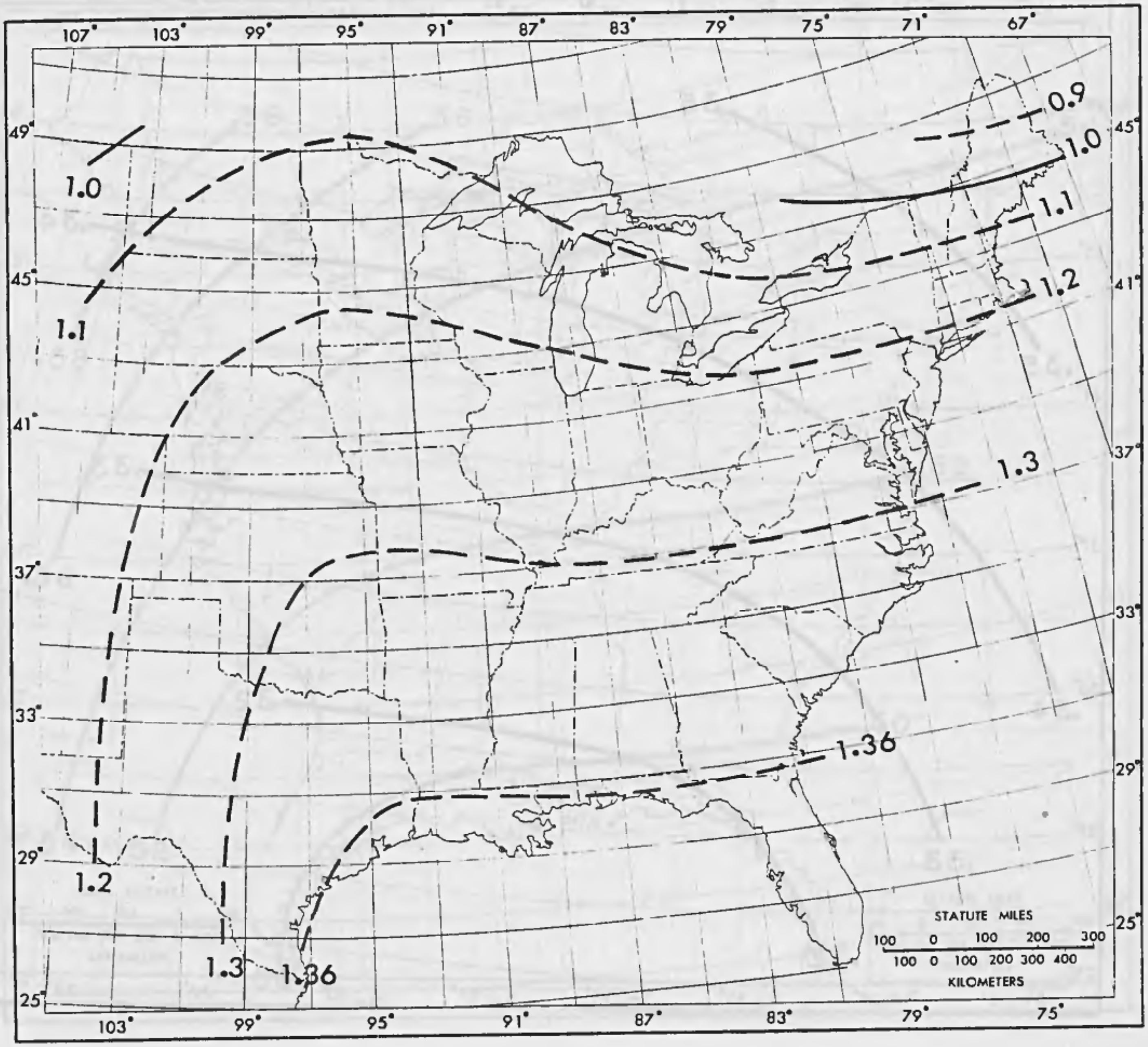

Figure 35.—1-hr 20,000-mi^2 PMP analysis for the eastern United States.

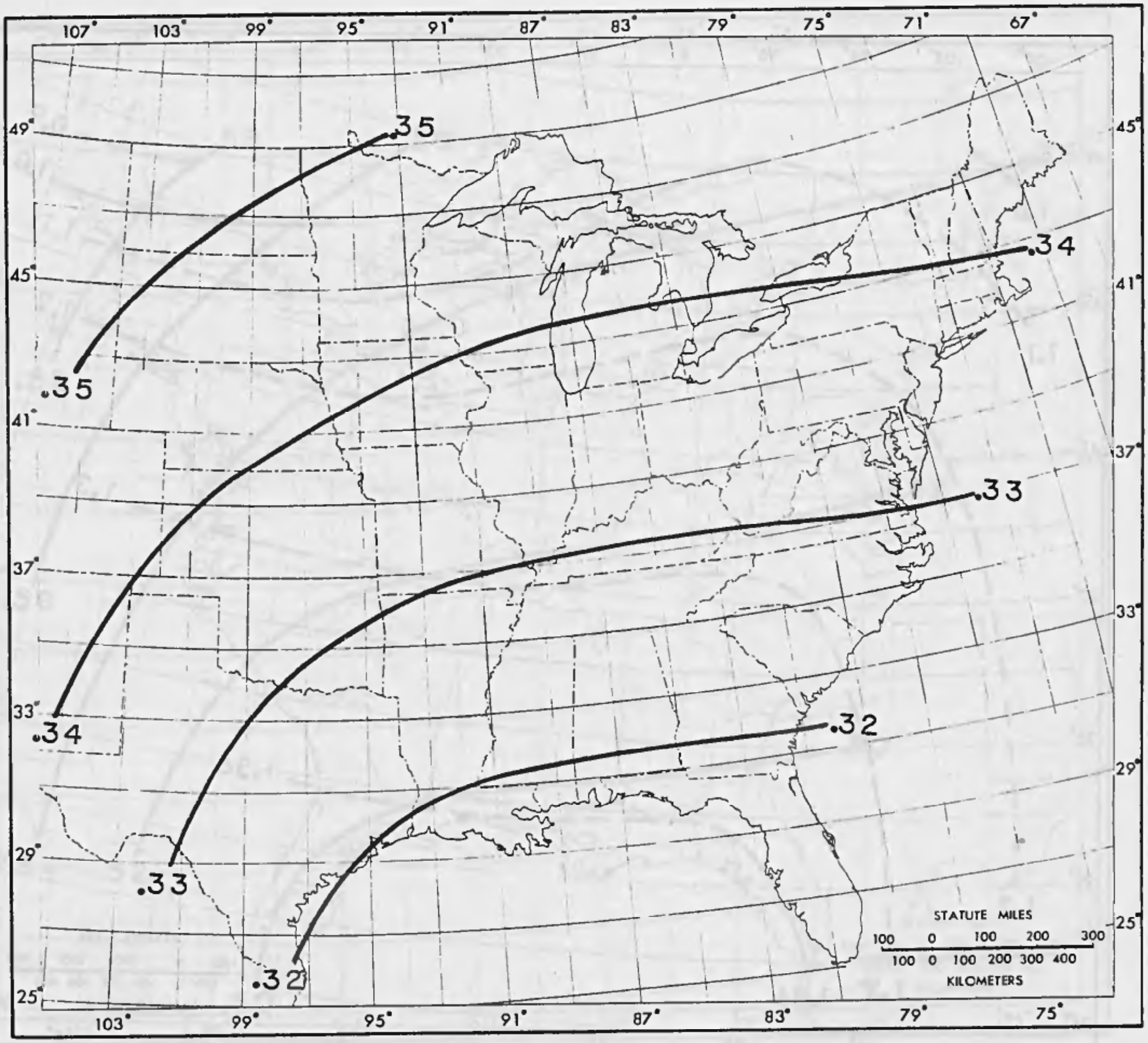

Figure 36.—Ratio analysis of 5- to 60-min precipitation used to obtain 5-min PMP. (Applicable to area sizes < 200 mi^2.)

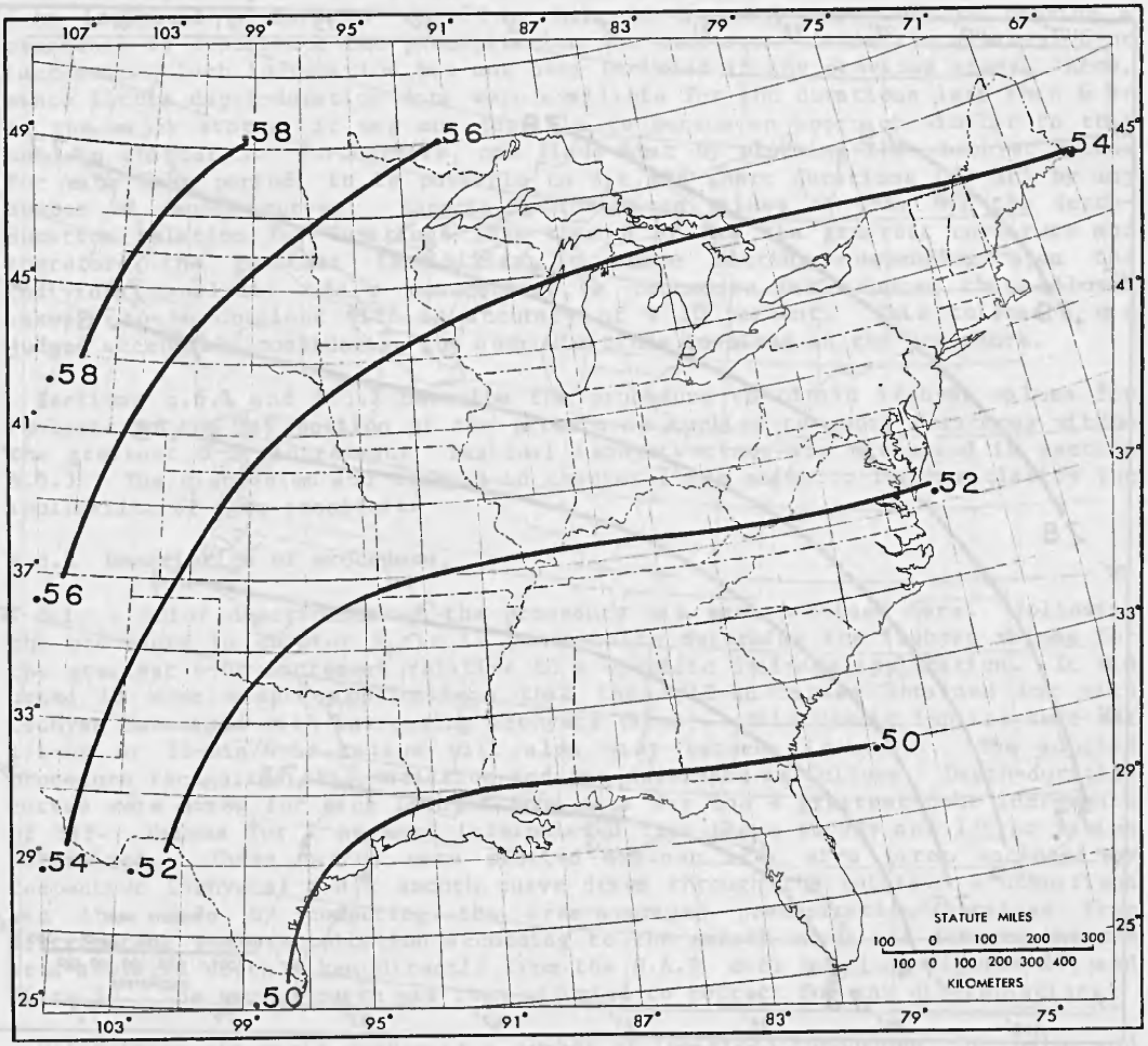

Figure 37.—Ratio analysis of 15- to 60-min precipitation used to obtain 15-min PMP. (Applicable to area sizes < 200 mi^2.)

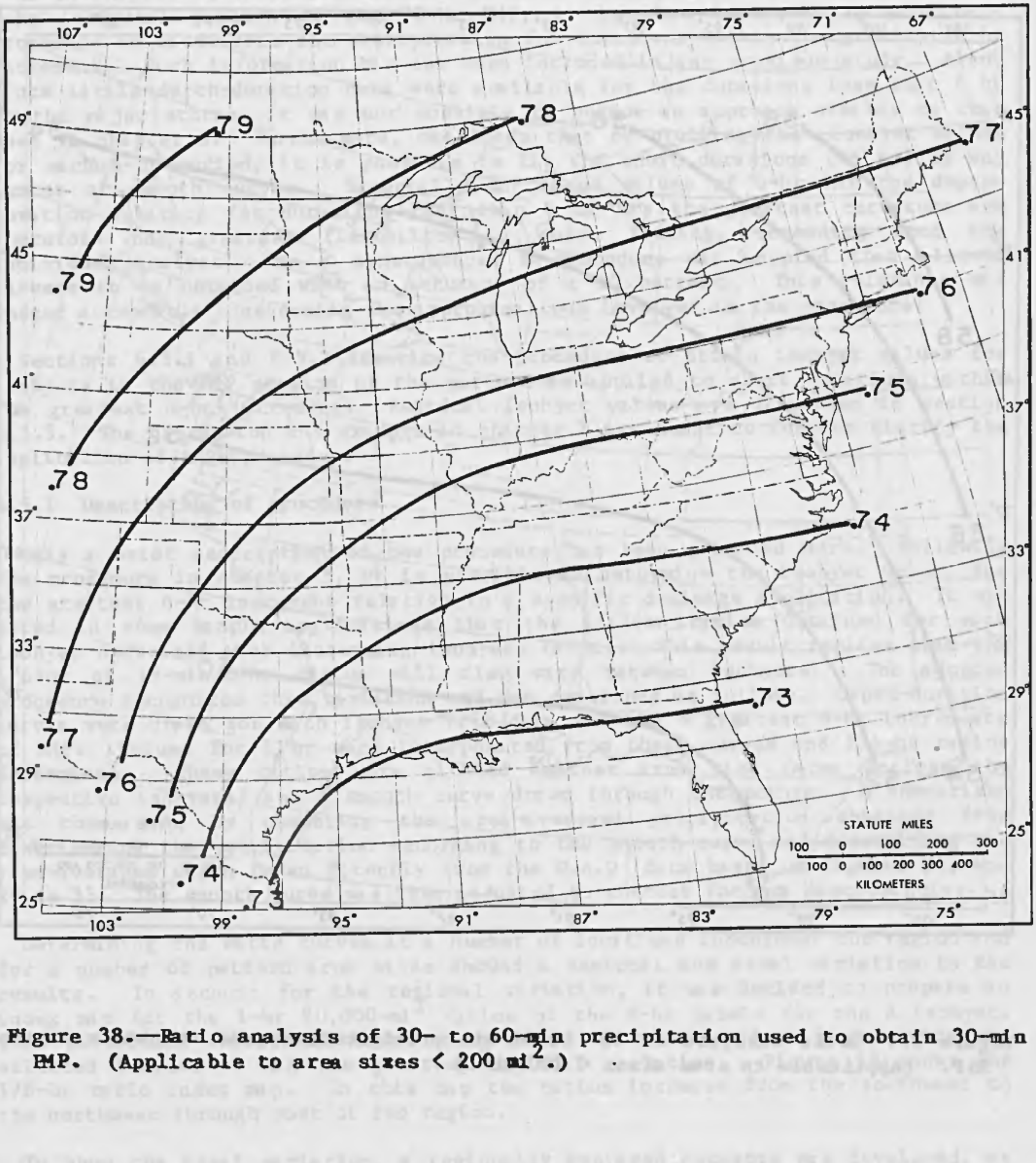

Figure 38.—Ratio analysis of 30- to 60-min precipitation used to obtain 30-min PMP. (Applicable to area sizes < 200 mi^2.)

6.5 Isohyet Values for Durations Less Than 1-hr

As in chapter 5, where a procedure was given to compute isohyet values for each 6-hr isohyetal pattern of the 72-hr PMP, it is also important to provide a procedure to distribute the precipitation for durations within the greatest 6-hr increment. Such information has not been included in any previous study. Also, since little depth-duration data were available for the durations less than 6 hr in the major storms, it was not possible to pursue an approach similar to that used in chapter 5. Furthermore, one finds that by plotting the isohyet values for each 6-hr period, it is possible to fit the short durations (<6 hr) by any number of smooth curves. Especially for large values of 6-hr PMP the depth-duration relation for durations less than 6 hr has the greatest curvature and therefore the greatest flexibility in curve fitting, depending upon the individual analyst. As a consequence, a procedure was adopted that allowed answers to be obtained with an accuracy of ± 10 percent. This tolerance was judged acceptable considering the approximations involved in the procedure.

Sections 6.5.1 and 6.5.2 describe the procedure to obtain isohyet values for isohyets in the PMP portion of the pattern as applied to short durations within the greatest 6-hr increment. Residual isohyet values are discussed in section 6.5.3. The discussion and example in chapter 7 are meant to further clarify the application of this procedure.

6.5.1 Description of procedure

Only a brief description of the procedure has been provided here. Following the procedure in chapter 5, it is possible to determine the isohyet values for the greatest 6-hr increment relative to a specific drainage application. It was noted in some sample applications that the 6/12-hr ratios obtained for each isohyet decreased with increasing isohyets (area). This result implies that the 1/6-hr or 15-min/6-hr ratios will also vary between isohyets. The adopted procedure recognizes this variation and was developed as follows. Depth-duration curves were drawn for each isohyet from data for the 4 greatest 6-hr increments of PMP. Values for 1 hr were interpolated from these curves and 1/6-hr ratios determined. These ratios were plotted against area size (area enclosed by respective isohyets) and a smooth curve drawn through the points. A comparison was then made by computing the area-averaged precipitation obtained from distributing the precipitation according to the smooth curve and determining the area-averaged depth taken directly from the D.A.D data based on figures 24, and 29 to 35. The smooth curve was then adjusted to correct for any discrepancies.

Determining the ratio curves at a number of locations throughout the region and for a number of pattern area sizes showed a regional and areal variation in the results. To account for the regional variation, it was decided to prepare an index map for the 1-hr 20,000-mi^2 ratios of the 6-hr labels for the A isohyet. This particular choice was based on a number of trials and this area size was selected because it had the greatest regional variation. Figure 39 shows the 1/6-hr ratio index map. In this map the ratios increase from the southeast to the northwest through most of the region.

To show the areal variation, a regionally averaged nomogram was developed, as shown in figure 40. The abscissa is based on a scale of percent of the corresponding 6-hr isohyet value. It was necessary to omit every other isohyet (B, D, F, H) from these nomograms for clarity, but simple interpolation will

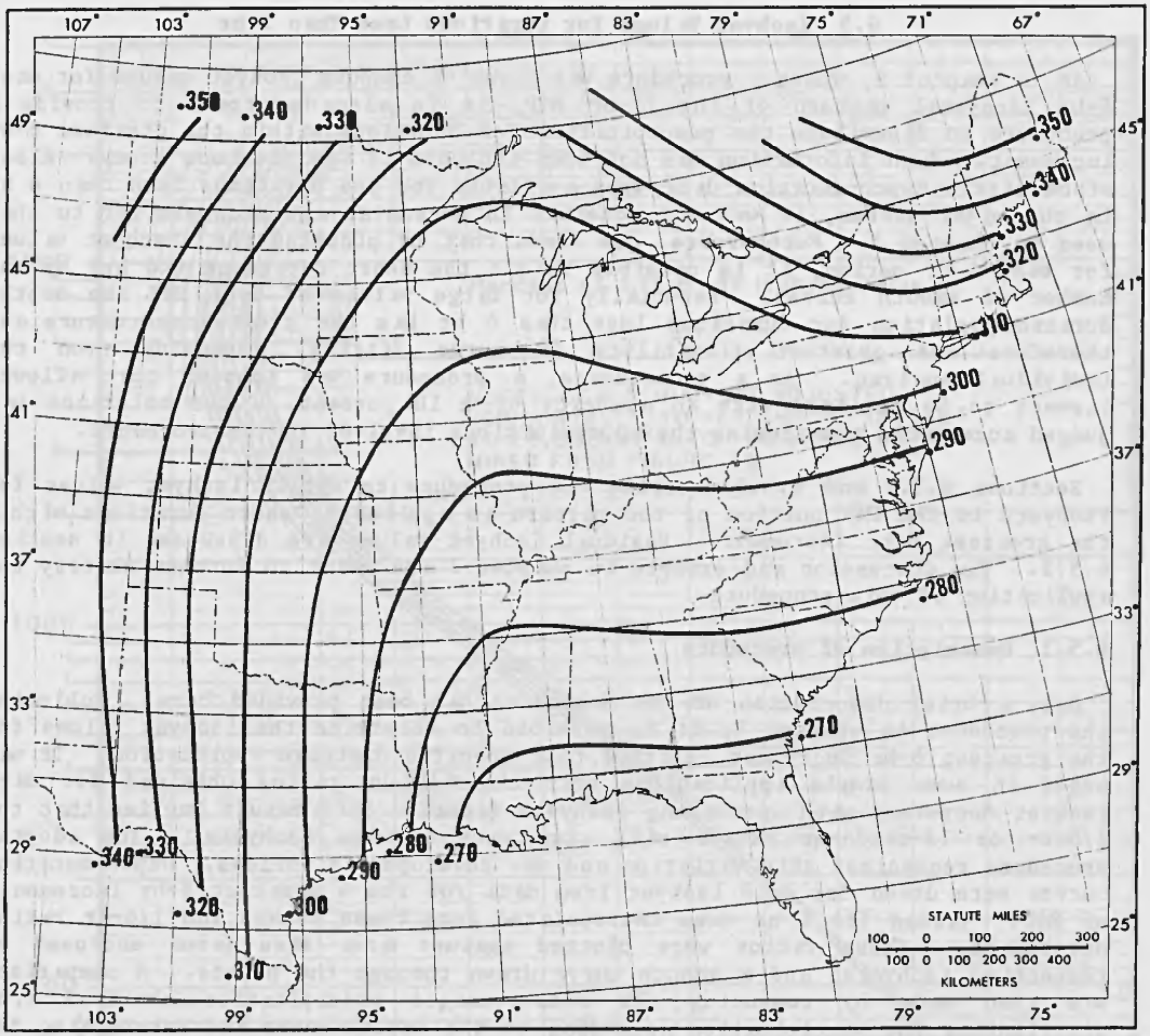

Figure 39.—Index map for 1- to 6-hr ratios for 20,000-mi^2 "A" isohyet.

provide values for the missing isohyets. The nomogram does not include information for the residual isohyets.

6.5.2 Application of nomogram for short duration isohyets

The use of the relations in figure 40 is simple. One locates the center of the drainage being considered (for which 6-hr isohyet values have been determined as directed in chapter 5) on figure 39 and interpolates the 1/6-hr ratio. This ratio then represents the label of the 1-hr 20,000-mi^2 A isohyet on the nomogram in figure 40. The user must then make a copy of the scale provided with the nomogram and place the scale on the nomogram to correspond to the value determined from the index map. Having adjusted the scale, all isohyet values

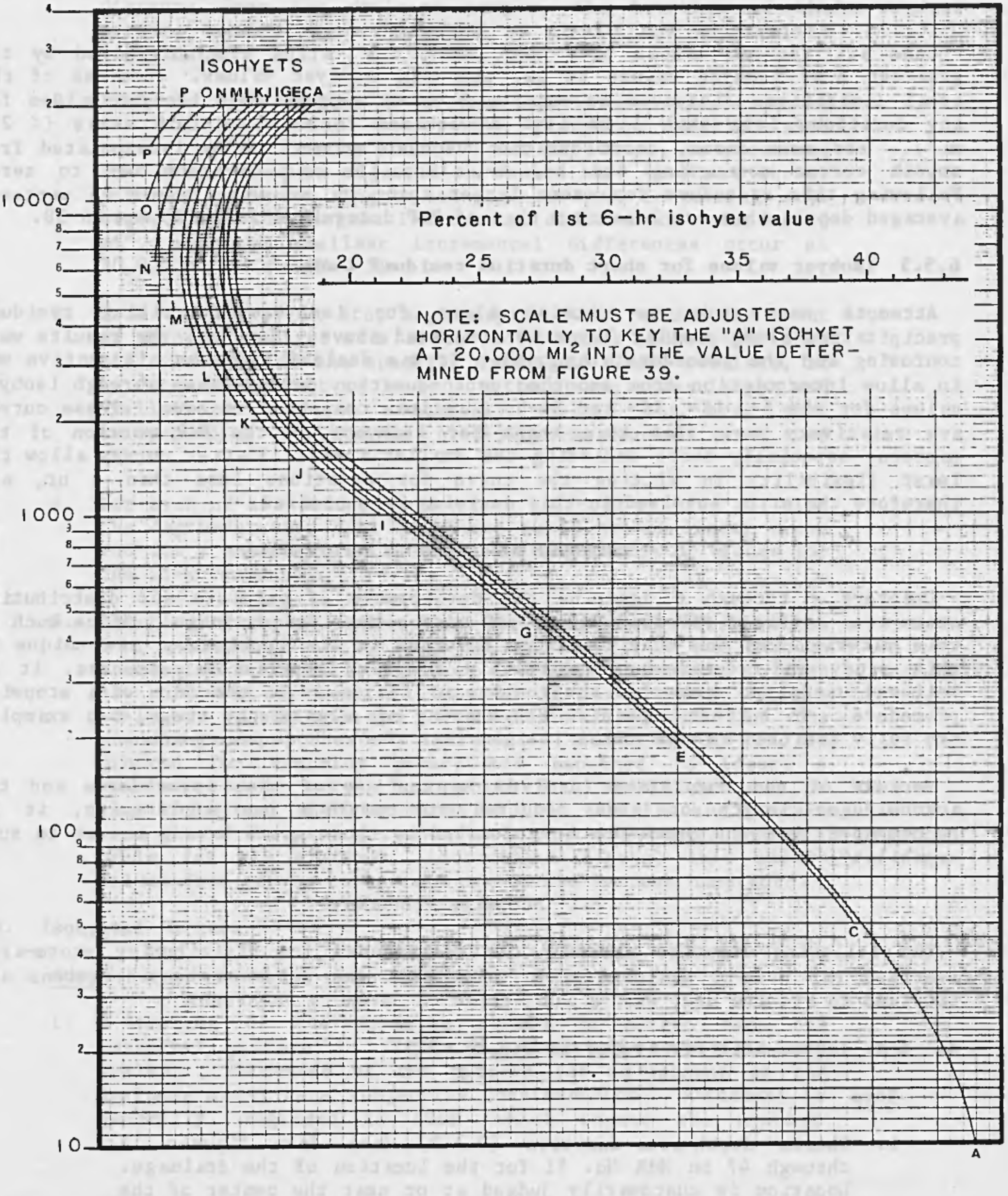

Figure 40.—Regionally-averaged nomogram for 1-hr isohyet values in percent of 1st 6-hr isohyet values.

may be read directly from the nomogram as percents of the corresponding 6-hr isohyet values.

Once all isohyet values have been read, the ratios are multiplied by the greatest 6-hr isohyet values to get the 1-hr isohyet values. Because of the areal limitations discussed in section 6.4, we suggest that isohyet values for any durations less than 1 hr also be limited to small pattern areas (< 200 mi^2). For such cases, short duration isohyet values can be interpolated from smooth curves connecting the 1-, 6-, 12-, 18- and 24-hr values to zero. Following this procedure for areas larger than 200 mi^2 will result in pattern-averaged depths that are less than that of PMP determined from figures 36-38.

6.5.3 Isohyet values for short duration residual isohyets

Attempts were made to obtain values for isohyets describing residual precipitation along similar lines as discussed above. However, the results were confusing and the procedure abandoned. It was decided that the alternative was to allow interpolation from smoothed depth-duration curves drawn through isohyet values for the 6-, 12-, 18- and 24-hr durations connected to zero. These curves are relatively more flat than those for isohyets in the PMP portion of the pattern, especially those enclosing the smaller areas. Flatter curves allow the least flexibility in fitting the curve for durations less than 6 hr, and therefore the error involved in this decision is minimized.

7. PROCEDURE AND EXAMPLE APPLICATION

Chapters 2 through 6 describe the development of guidance for distributing storm-area averaged PMP from HMR No. 51 over a specific drainage. Since much of this material and the considerations involved in its application are unique to this study and represent a relatively complex computational process, it is believed useful to summarize the results of the study in the form of a stepwise procedure. To further emphasize the meaning of each of the steps, two examples are fully detailed as additional insight into the methods recommended.

Because of the complexity involved in the use of these procedures and the acknowledged length of time required to complete one application, it is recommended that the procedure be automated by those users having access to such capability.

7.1 Stepwise Procedure

The following stepwise procedure is recommended for distributing storm-area averaged PMP over a drainage. In addition, some guidance considerations are provided to aid the user when a subjective decision is required.

A. 6-Hr Incremental PMP (refer to HMR No. 51)

Step

1. Obtain depth-area-duration (D.A.D) data from figures 18 through 47 in HMR No. 51 for the location of the drainage. Location is customarily judged at or near the center of the drainage. For particularly large drainages in which isohyetal pattern placements may be made at considerable

distance from the drainage center, the location of the pattern center should be used to obtain the appropriate D.A.D data.

2. Plot the data in step A1 on semi-logarithmic paper (area on the log scale) and join points of common duration with curves. When drawing a smooth set of curves, we recommend that the curves be adjusted to assure that they are either parallel or show slight convergence with increasing area size; i.e., the largest incremental differences occur at 10 mi^2, and the smallest incremental differences occur at 20,000 mi^2 in HMR No. 51.

3. From the curves in step A2, read off D.A.D values for a set of standard isohyet area sizes* both larger and smaller than the area size of the specific drainage. Where possible, it is recommended that at least 4 pattern area sizes larger and smaller be used to adequately enclose the area size corresponding to maximum precipitation volume (see step C11).

4. For each of the pattern area sizes selected in step A3, plot the depth-duration data (at least to 48 hr) on linear paper and fit a smooth curve to enable interpolation of values for the 18-hr duration.

5. Obtain incremental differences for each of the first three 6-hr periods (0 to 6, 6 to 12, and 12 to 18 hr) through successive subtraction for each area size considered in step A4. Because of possible inaccuracies in reading the map analyses, plotting, and drawing for the data in the preceding steps, the 6-hr incremental values should also be plotted (on semi-log paper) and smoothed to insure a consistent data set. Incremental data should decrease or remain constant with increases in both duration and pattern area size. In drawing these final smoothing curves choose a scale for the abscissa (incremental depths) that allows values from curves to be read off to the nearest hundredth.

B. Isohyetal Pattern

Step

1. A tracing of the drainage should be placed over the isohyetal pattern in figure 5, drawn at comparable map scales. Placement of the pattern (or adjustment of the drainage axis) is a subjective consideration. Placement is generally regarded as that which inputs the maximum

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*The standard isohyet area sizes are those of: 10, 25, 50, 100, 175, 300, 450, 700, 1,000, 1,500, 2,150, 3,000, 4,500, 6,500, 10,000, 15,000, 25,000, 40,000, and 60,000 mi^2.

precipitation to the drainage. In most cases this consideration is met by drainage-centering the isohyetal pattern, that is, the isohyetal and drainage patterns have approximately the same center and axial orientation (see section 4.4.4 for exception). Judgment is guided by trying to place the greatest number of whole isohyets completely within the drainage, since the isohyets that enclose smaller area sizes contain proportionately higher rain amounts. This guidance is subject to consideration of the relative orientations preferred for PMP-type patterns discussed in the following steps.

2. Determine the orientation (to nearest whole degree) of the pattern when placed on the drainage, in terms of degrees from north. If this orientation does not fall between 135° and 315°, add 180° so that it does.

3. Determine the orientation preferred for PMP conditions from figure 8 at the location of the pattern center. If the difference between orientations from step B3 and B2 is less than 40 degrees, then for the isohyetal pattern as placed over the drainage there is no reduction factor to consider. If the orientation differences exceed 40 degrees, then a decision must be made whether the pattern is to be placed at some angle to the drainage at which no reduction to isohyet values is required, or aligned with the drainage and a reduction made to the isohyet values. A truly objective decision on the orientation of the pattern yielding maximum volume would require numerous applications. As guidance, the area size of the drainage, the shape of the drainage, and the differences in orientations (preferred PMP and pattern placed on the drainage) have the greatest bearing on the volume of precipitation determined. Only the experience gained from numerous trials will enable the user to reduce the effort involved in making these decisions. An illustration of the effects of alternative placements is demonstrated in the examples.

4. Skip this step if no adjustment for orientation is needed. Having settled on a placement of the isohyetal pattern, determine the appropriate adjustment factors due to orientation for the isohyets involved from the model shown in figure 10 (read to tenths of percent). Note that the amount of reduction is dependent upon area size (only pattern areas larger than 300 mi^2 need to be reduced) and the difference between orientations. Multiply the adjustment factor times the corresponding 6-hr incremental amounts from step A5 for each pattern area size to obtain incremental values reduced as a result of pattern orientation.

C. Maximum Precipitation Volume

Determine the maximum volume of precipitation for the three largest 6-hr incremental periods resulting from placement of the pattern over the drainage. To do this, it is necessary to obtain the value to be assigned to each isohyet in the pattern that occurs over the drainage during each period. Guidance for this determination is given in the following steps related to the format presented in figure 41. It is suggested that an ample number of copies of this figure be reproduced to serve in the computation procedure.

Step

Start by determining the maximum volume for the 1st 6-hr incremental period.

1. Fill in the name of the drainage, drainage area, date of computation, and increment (either 1st, 2nd or 3rd) in the appropriate boxes at top of form (fig. 41).

2. Put the area size (mi^2) from step A3 for which the first computation is made under the heading at the upper left of form.

3. Column I contains a list of isohyet labels. Use only as many isohyets as needed to cover the drainage.

4. For the area size in step C2, list in column II the corresponding percentages read from table 15 or the nomogram in figure 16 (first 6-hr period) for those isohyets needed to cover the drainage; use table 16 or figure 18 and table 17 or figure 19 for the 2nd and 3rd 6-hr periods, respectively, when determining step C10.

5. Under the heading amount (Amt.) in column III place the value from step B4 corresponding to area size and increment of computation. Multiply each of the percentages in column II by the Amt. at the head of column III to fill column III.

6. Column IV represents the average depth between adjacent isohyets. The average depth of the "A" isohyet is taken to be the value from column III. The average depth between all other isohyets which are totally enclosed by the drainage is the arithmetic average of paired values in column III. For incomplete isohyets covering the drainage, it is necessary to make a weighted estimate of the average depth if a portion of the drainage extends beyond a particular isohyet. The average depth for the extended portion of the drainage may be taken as 0.5 to 1.0 times the difference between the enclosing isohyets plus the lower isohyet. The weighting relation is given by:

$$F\ (X-Y) + Y$$

where X and Y are adjacent isohyet values, $X \geq Y$, and the weight factor, F, may be between 0.5 and 1.0. If only a small portion of the drainage extends beyond X, then the

Figure 41.—Example of computation sheet showing typical format.

Increment: __________

Drainage: ____________________ Area: ________ Date: __________

Area size	I Iso.	II Nomo.	III Amt.	IV Avg. depth	V ΔA	VI ΔV	Area size	I Iso.	II Nomo.	III Amt.	IV Avg. depth	V ΔA	VI ΔV
	A							A					
	B							B					
	C							C					
	D							D					
	E							E					
	F							F					
	G							G					
	H							H					
	I							I					
	J							J					
	K							K					
	L							L					
	M							M					
	N							N					
	O							O					
	P							P					
					Sum =							Sum =	

Area size			Amt.				Area size			Amt.			
	A							A					
	B							B					
	C							C					
	D							D					
	E							E					
	F							F					
	G							G					
	H							H					
	I							I					
	J							J					
	K							K					
	L							L					
	M							M					
	N							N					
	O							O					
	P							P					
					Sum =							Sum =	

Area size			Amt.				Area size			Amt.			
	A							A					
	B							B					
	C							C					
	D							D					
	E							E					
	G							G					
	H							H					
	I							I					
	J							J					
	K							K					
	L							L					
	M							M					
	N							N					
	O							O					
	P							P					
					Sum =							Sum =	

weight factor may be taken closer to 1.0, and if the drainage extends nearly to Y, then a weight factor close to 0.5 is appropriate.

7. Column V lists the incremental areas between adjacent isohyets. For the isohyets enclosed by the drainage, the incremental area can be obtained from table 8. For all other isohyets it will be necessary to planimeter the area of the drainage enclosed by each isohyet and make the appropriate successive subtractions. The sum of all the incremental areas in column V should equal the area of the drainage. If the computation in step 5 results in the zero isohyet's crossing the drainage, the appropriate total area is that contained within the zero isohyet, and not the total drainage area.

8. Column VI gives the incremental volume obtained by multiplying values in column IV times those in column V. The incremental volumes are summed to obtain the total volume of precipitation in the drainage for the specified pattern area size in the 6-hr period.

9. Steps C2 to C8 are repeated for all the other pattern area sizes selected in step A3.

10. The largest of the volumes obtained in steps C8 and C9 represents the preliminary maximum volume for the 1st 6-hr incremental period and specifies the pattern area to which such volume relates. The area of maximum volume can be used as guidance in choosing pattern areas to compute volumes for the 2nd and 3rd 6-hr incremental period. Presumably, this guidance narrows in on the range of pattern area sizes considered and possibly reduces in some degree the number of computations. Compute the 2nd and 3rd 6-hr incremental volumes by repeating steps C1 to C9, using the appropriate tables or nomograms.

11. Sum the volumes from steps C8 to C10 at corresponding area sizes and plot the results in terms of volume vs. area size (semi-log plot). Connect the points to determine the area size for the precipitation pattern that gives the maximum 18-hr volume in the drainage.

12. It is recommended, although not always necessary, that the user repeat steps C2 through C11 for one or two supplemental area sizes (area sizes other than those of the standard isohyetal pattern) on either side of the area size of maximum volume in step C11. This provides a check on the possibility that the maximum volume occurs between two of the standard isohyet area sizes. To make this check, an isohyet needs to be drawn for each supplemental area size in the standard isohyetal pattern and positioned on the drainage so that the corresponding incremental areas between isohyets can be determined (planimetered). In addition, supplemental cusp points need to be determined in figures

16, 18 and 19 for each of the area sizes considered. To find the appropriate cusp position, enter the ordinate at the supplemental area size, and move horizontally to intersect a line between the two most adjacent cusps. This intermediate point will be the percentage for the supplemental isohyet when reading the other isohyet percentages in step C4; otherwise follow the computational procedure outlined.

13. The largest 18-hr volume obtained from either step C11 or C12 then determines the final pattern area size of maximum volume for the pattern placement chosen in step B1.

D. Distribution of Storm-Area Averaged PMP over the Drainage

Step

1. For the pattern area size for PMP determined in step C13, use the data in step A3 to extend the appropriate depth-duration curve in step A4 to 72-hr, and read off values from the smoothed curve for each 6 hr (6 to 72 hr).

2. Obtain 6-hr incremental amounts for data in step D1 for the 4th through 12th 6-hr periods in accordance with step A5, and follow procedural steps B1 to B4 to adjust these incremental values for isohyetal orientation, if needed.

3. Steps D1 and D2 give incremental average depths for each of the 12 6-hr periods in the 72-hr storm. To obtain the values for the isohyets that cover the drainage, multiply the 1st 6-hr incremental depth by the 1st 6-hr percentages obtained from table 15 or the nomogram (fig. 16) for the area size determined in step C13. Then multiply the 2nd 6-hr incremental depth by the 2nd 6-hr percentages from table 16 or the nomogram (fig. 18) for the same area size, and similarly for the 3rd 6-hr increment (table 17 or fig. 19). Finally, multiply each remaining 6-hr incremental depth by the 4th through 12th percentages in table 18 or the nomogram (fig. 20). As a result of this step, a matrix of the following form can be completed (to the extent of whichever isohyets cover the drainage).

	6-hr periods											
Isohyet (in.)	1	2	3	4	5	6	7	8	9	10	11	12
A												
B												
C					Isohyet Values (in.)							
etc.												

4. To obtain incremental average depths for the drainage, compute the incremental volumes for the area size of the PMP

pattern determined in step C10. Divide each incremental volume by the drainage area (that portion covered by precipitation).

5. Should it be of interest to determine the isohyetal values for durations less than 6 hr within the greatest 6-hr increment, the procedure discussed in section 6.3 gives the following steps.

   a. Interpolate the 1/6-hr ratio at the drainage location from figure 39.

   b. Adjust an overlay of the scale given in figure 40 along the abscissa of the figure such that the 20,000-mi^2 "A" isohyet equals the ratio read in step D5a.

   c. At the area size for the PMP pattern found in step C10, read from the nomogram (fig. 40) percentages of the 6-hr isohyet values. These isohyets cover only the PMP portion of the pattern.

   d. Multiply the ratio in step D5c by the corresponding 6-hr isohyet values in step D3 to obtain 1-hr isohyet values.

   e. Plot the values from step D5d along with the 6-, 12-, 18-, and 24-hr isohyet values for each isohyet from step D3. Draw a smooth curve of best fit through points for each isohyet to include the origin.

   f. Read off isohyet values for any other intermediate duration of interest. Note that the values interpolated from these smooth curves, 5-, 15-, and 30-min durations, will result in somewhat lower drainage-averaged PMP estimates than obtained from figures 36-38.

   g. To obtain isohyet values for any isohyet of residual precipitation in the PMP pattern, plot the 6-, 12-, 18- and 24-hr isohyet values from step D3 and fit a smooth curve through the points to include the origin. Read off isohyet values for any intermediate duration. (Note in step D5f is also valid for 1-hr values in this step.)

E. Temporal Distribution

In the matrix in step D3, storm-area averaged PMP has been distributed according to increasing 6-hr period. The discussion in chapter 2 provides guidance on distributing these incremental periods with time. A number of distributions are possible, with the choice being left to the user, depending on which is most appropriate for the drainage under study. Whatever distribution is selected must be applied to all isohyets. An example of one possible distribution is reordering the 6-hr incremental periods in step D3 as follows:

6-hr periods

1	2	3	4	5	6	7	8	9	10	11	12
11	10	8	5	1	2	3	4	6	7	9	12

F. Subdrainages

Should it be necessary to determine the areal distribution of PMP across subdrainages of a particular drainage, consider the following steps:

Step

1. With the pattern placed across the entire drainage as given in step B1, and incremental isohyet values as determined in step D3 and/or D5, planimeter the incremental areas contained between isohyets within each subdrainage.
2. Follow the computational procedure outlined in steps C5 to C8 to obtain the incremental subdrainage volumes for 6-hr periods 1 through 12.
3. The subdrainage volumes divided by the subdrainage areas yield the average depths across the subdrainage for each 6-hr increment.

   Note: If the subdrainage is crossed by the zero isohyet, the appropriate area for consideration is the subdrainage area inside the zero isohyet, not that of the total subdrainage.
4. If it is hydrologically critical to rearrange the temporal sequence of the incremental amounts determined in step F3 for a particular subdrainage, then it is necessary that the same arrangement be applied to all other subdrainages. This requirement is important and must be observed without exception. Demonstration of a subdrainage application is given in example 2a.

7.2 Example No. 1a

The first example demonstrates the computational procedure, and shows the affect on maximum volume determination that results from consideration of orientation of the isohyetal pattern.

The drainage used in this example is that of the Leon River in Texas above Belton Reservoir (approximately 3,660 mi^2) shown in figure 42, drawn to a scale of 1:1,000,000. Drainage center is about 31°45'N, 98°15'W.

The following steps correspond to those outlined in section 7.1 leading to determination of the area size of the isohyetal pattern that gives maximum volume, from which we then assign isohyet values.

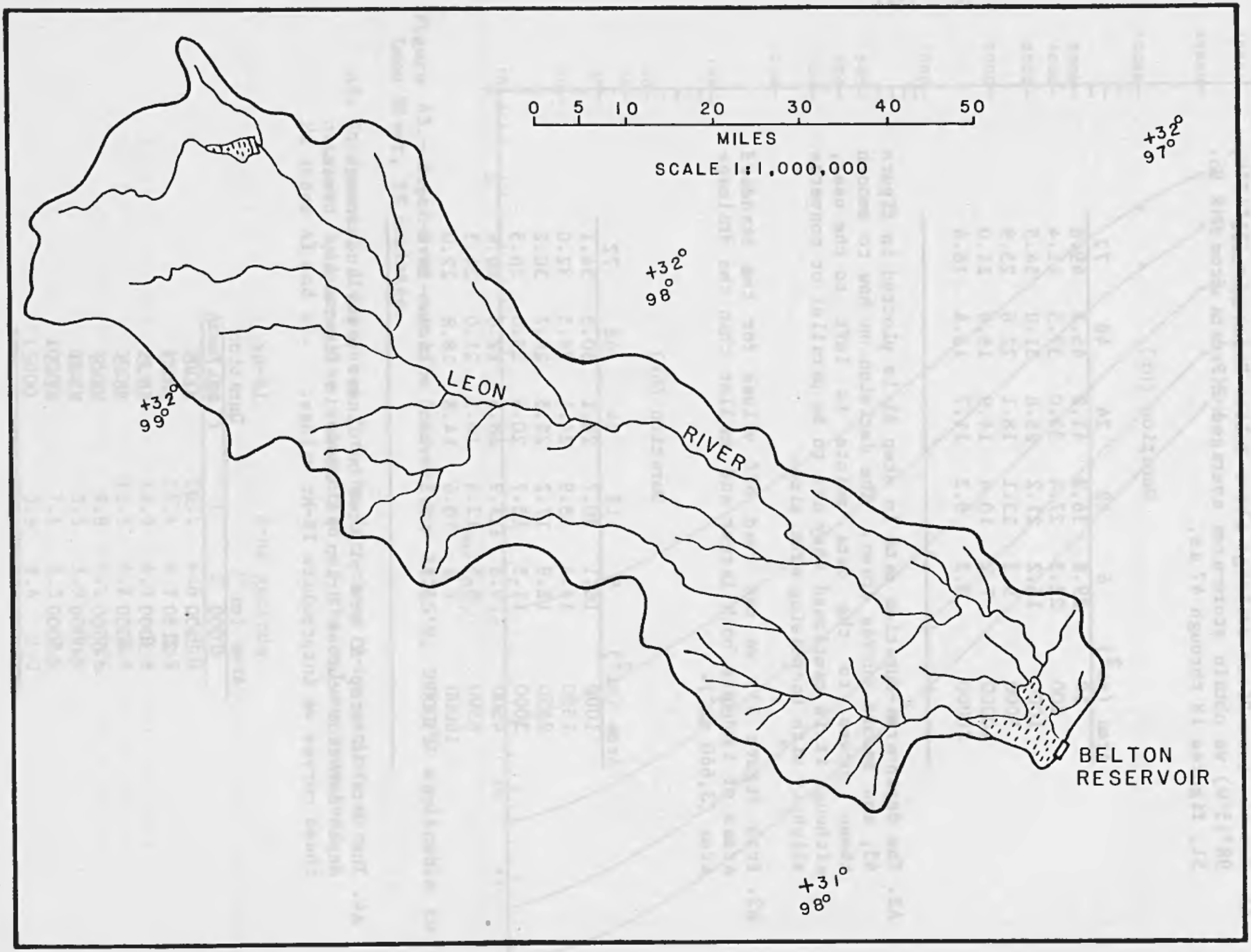

Figure 42.—Leon River, TX (3,660 mi^2) above Belton Reservoir showing drainage.

Step

A1. For the Leon River drainage above Belton Reservoir (31°45°N, 98°15'W) we obtain storm-area averaged PMP data from HMR No. 51, figures 18 through 47 as,

	Duration (hr)				
Area (mi^2)	6	12	24	48	72
10	29.8	36.2	41.8	46.7	49.8
200	22.3	27.4	33.0	37.5	41.4
1000	16.2	21.2	26.8	31.0	34.5
5000	9.3	13.1	18.1	22.6	25.9
10000	7.2	10.4	14.9	18.8	21.0
20000	5.2	8.2	11.7	15.4	18.4

A2. The depth-area-duration data in step A1 is plotted in figure 43, and smooth curves drawn. The decision on how to smooth these curves to the data points is left to the user, although it is cautioned they are to be parallel or converge slightly with increasing area size.

A3. From figure 43, we can read off values for the standard areas of isohyets both larger and smaller than the drainage area (3,660 mi^2).

	Duration (hr)				
Area (mi^2)	6	12	24	48	72
1000	16.1	20.7	26.1	30.5	34.1
1500	14.4	18.9	24.1	28.5	32.0
2150	12.9	17.2	22.3	26.7	30.2
3000	11.5	15.7	20.6	25.0	28.5
4500	9.8	13.9	18.6	22.8	26.4
6500	8.5	12.4	16.7	21.0	24.3
10000	7.1	10.6	14.8	18.8	22.0
15000	5.9	9.3	13.0	16.8	20.0

A4. The data in step A3 are plotted on linear paper and smooth depth-duration curves drawn as shown in figure 44. From these curves we interpolate 18-hr values:

Area (mi^2)	18-hr Duration
1000	23.7
1500	21.8
2150	20.0
3000	18.5
4500	16.5
6500	14.8
10000	13.0
15000	11.3

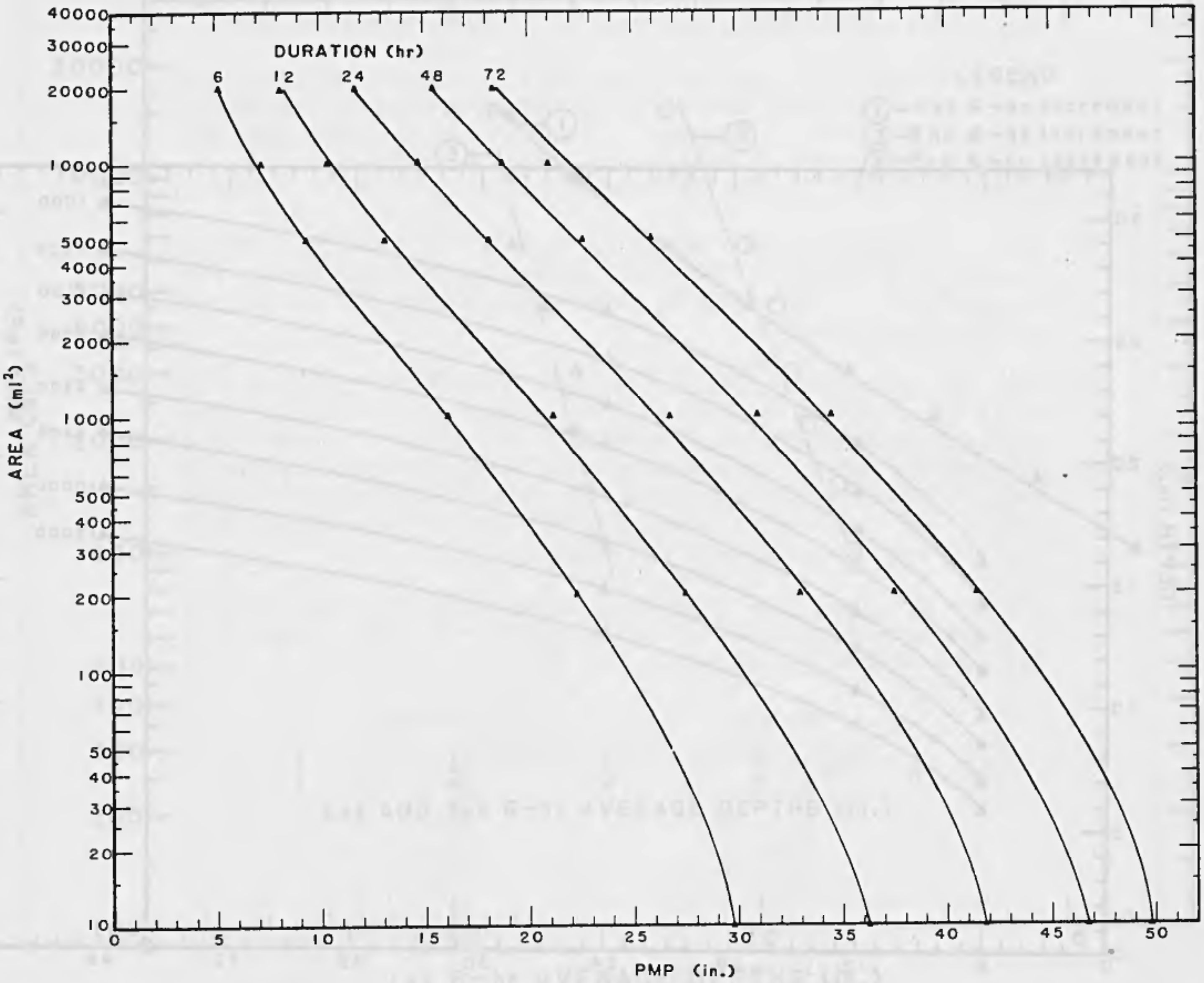

Figure 43.—Depth-area-duration curves for 31°45'N, 98°15'W applicable to the Leon River, TX drainage.

A5. Incremental differences for the 1st three 6-hr periods are obtained by successive subtraction of the values contained in steps A3 and A4.

	6-hr periods		
Area (mi^2)	1	2	3
1000	16.1	4.6	3.0
1500	14.4	4.5	2.9
2150	12.9	4.3	2.8
3000	11.5	4.2	2.8
4500	9.8	4.1	2.6
6500	8.5	3.9	2.4
10000	7.1	3.5	2.4
15000	5.9	3.4	2.0

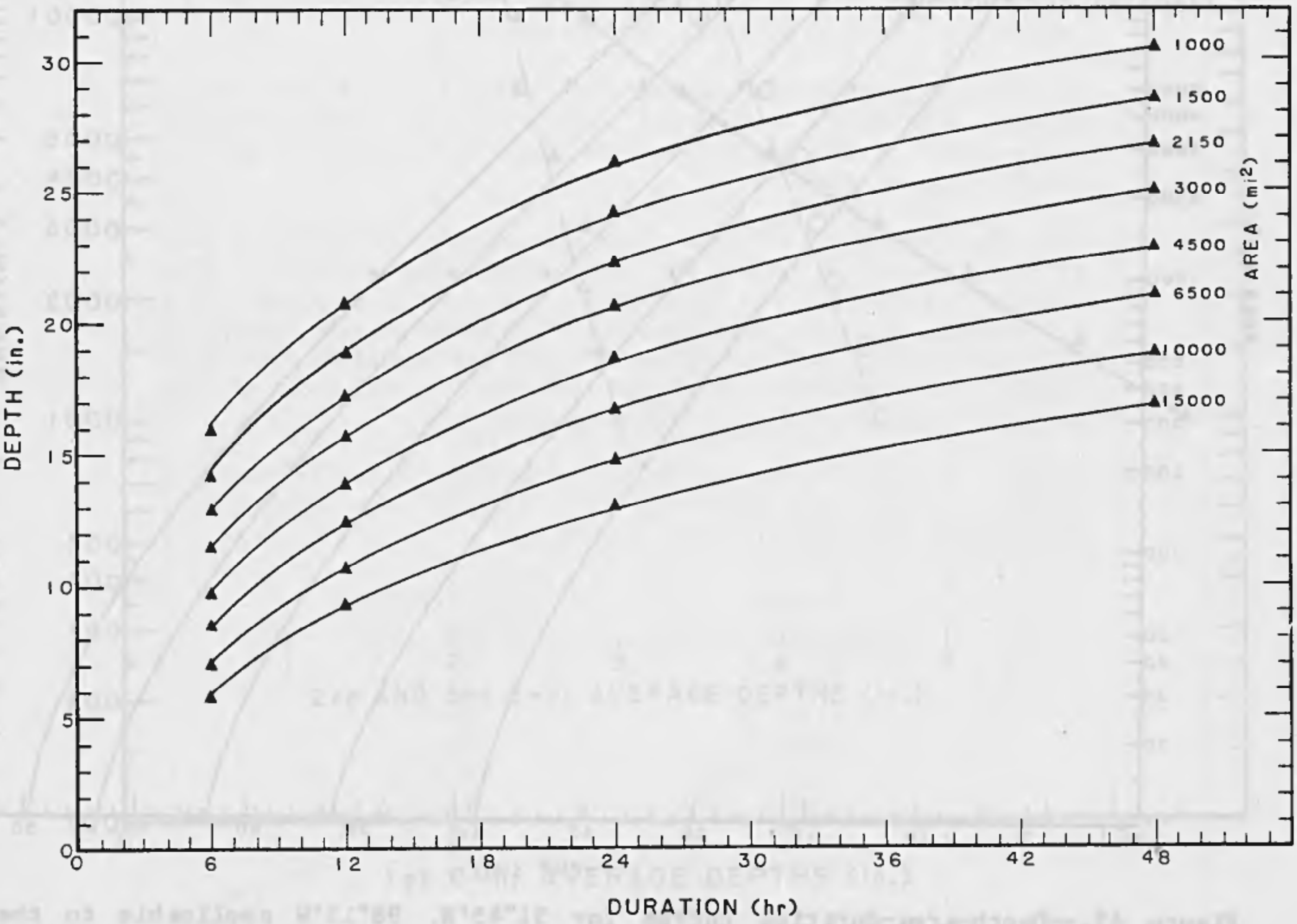

Figure 44.—Depth-duration curves for selected area sizes at 31°45'N, 98°15'W.

Plotting each set of 6-hr values against area and fitting the points by smooth lines as shown in figure 45 gives the following set of incremental data (read to hundredths).

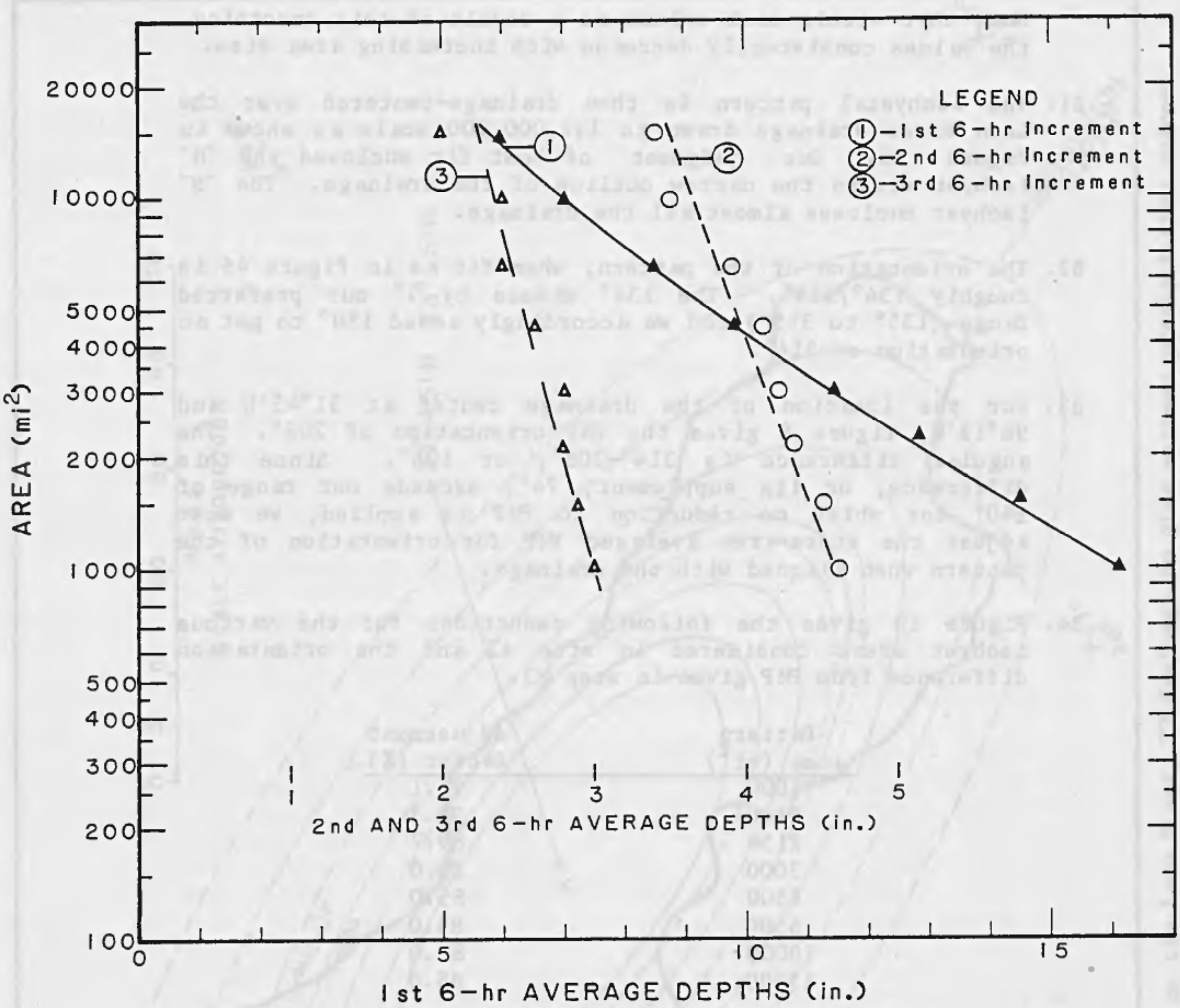

Figure 45.—Smoothing curves for 6-hr incremental values at selected area sizes for Leon River, TX drainage.

	6-hr periods		
Area (mi²)	1	2	3
1000	16.10	4.60	3.01
1500	14.35	4.42	2.89
2150	12.82	4.27	2.79
3000	11.40	4.14	2.70
4500	9.80	3.96	2.58
6500	8.50	3.82	2.48
10000	7.05	3.66	2.36
15000	5.80	3.50	2.25

Note that within each column as a result of this smoothing, the values consistently decrease with increasing area size.

B1. The isohyetal pattern is then drainage-centered over the Leon River drainage drawn to 1:1,000,000 scale as shown in figure 46. Our judgment of best fit enclosed the "H" isohyet within the narrow outline of the drainage. The "N" isohyet encloses almost all the drainage.

B2. The orientation of the pattern, when fit as in figure 46 is roughly 134°/314°. The 134° misses by 1° our preferred range (135° to 315°) and we accordingly added 180° to get an orientation of 314°.

B3. For the location of the drainage center at 31°45'N and 98°15'W, figure 8 gives the PMP orientation of 208°. The angular difference is 314°-208°, or 106°. Since this difference, or its supplement, 74°, exceeds our range of ±40° for which no reduction to PMP is applied, we must adjust the storm-area averaged PMP for orientation of the pattern when aligned with the drainage.

B4. Figure 10 gives the following reductions for the various isohyet areas considered in step A3 and the orientation difference from PMP given in step B3.

Pattern area (mi^2)	Adjustment factor (%)
1000	96.1
1500	93.3
2150	89.7
3000	85.0
4500	85.0
6500	85.0
10000	85.0
15000	85.0

Multiply each of the final smoothed 6-hr incremental values in step A5 by the adjustment factors of step B4 to get the adjusted incremental values,

	6-hr periods		
Pattern area (mi^2)	1	2	3
1000	15.47	4.42	2.89
1500	13.39	4.12	2.70
2150	11.50	3.83	2.50
3000	9.69	3.52	2.30
4500	8.33	3.37	2.19
6500	7.22	3.25	2.11
10000	5.99	3.11	2.01
15000	4.93	2.98	1.91

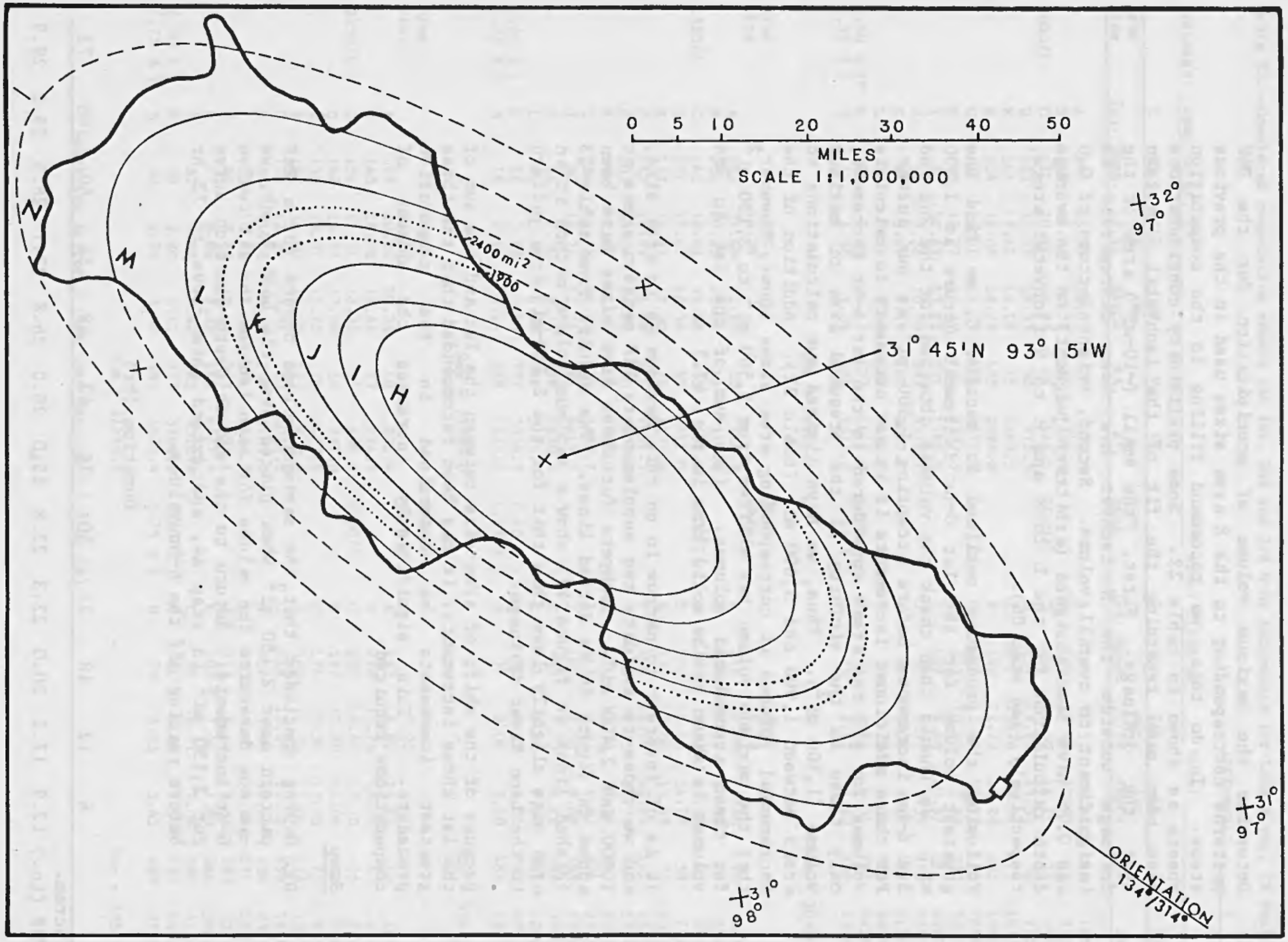

Figure 46.—Isohyetal pattern placed on the Leon River, TX drainage to give maximum precipitation volume.

C. Determine the maximum volume of precipitation for the PMP patterns corresponding to the 8 area sizes used in the previous steps. To do this, we recommend filling in the computation sheets as shown in table 22. Some preliminary considerations have been made regarding the fit of the isohyetal pattern over the drainage. First, the small (~10-mi^2) area of the drainage outside the N isohyet has been disregarded as insignificant to overall volume. Second, weight factors of 0.6 and 0.75 have been assigned (arbitrary judgment) to the average depth calculation for the L to M and M to N isohyetal areas, respectively (see step C6).

Following the procedure outlined in section C, we find the greatest volume for the 1st 6-hr increment occurs at 1,500 mi^2. We should then check the volumes obtained for the 2nd and 3rd 6-hr increments before accepting 1,500 mi^2 as our answer. For these additional increments it is not necessary to calculate volumes for all the areas considered in the 1st 6-hr increment, only those in the vicinity of the presumed area of maximum volume (1,500 mi^2). Thus, we have limited our calculations to areas between 1,000 and 3,000 mi^2 (table 22). Addition of the incremental volumes at corresponding area sizes shows, however, that the maximum volume has shifted from 1,500 mi^2 to 2,150 mi^2 for these accumulated volumes. (The sum of the 1st to 3rd volumes is shown by the solid line in fig. 47.)

It is of interest to narrow in on this maximum as to area size, and we chose to evaluate two supplementary PMP pattern areas at 1,900 and 2,400 mi^2. Isohyets for these area sizes have been added to figure 46 as dotted lines. The results from table 23 (dashed lines in figure 47) show a maximum volume occurs at an area size slightly less than that for the 2,150-mi^2 area pattern in the Leon River drainage.

Because of the shift of area size between the 1st and the sum of the 1st three increments, it has been recommended that the three greatest increments be determined in the computation procedure. This significantly increases the number of computations required.

<u>Step</u>

D1. Having concluded that the maximum volume occurs for a PMP pattern near 2,150 mi^2 when placed over the Leon River, we can now determine the values for each isohyet for all twelve 6-hr increments. Return to the smooth depth-duration curve for 2,150 mi^2 in step A4, and extend this curve to 72 hr before reading off the 6-hr values.

	Duration (hr)											
	6	12	18	24	30	36	42	48	54	60	66	72
Increm. PMP (in.)	12.9	17.2	20.0	22.3	23.8	25.0	26.0	26.8	27.7	28.5	29.2	29.9

Table 22.—Completed computation sheets for 1st, 2nd and 3rd 6-hr increments for Leon River, TX drainage

Increment: 1

Drainage: Leon River, TX   Area: 3,660 mi^2 Date:

	I	II	III	IV	V	VI
Area size	Iso.	Nomo.	Amt. 15.47	Avg. depth	ΔA	ΔV
	A	149	23.05	23.05	10	230.5
	B	140	21.66	22.36	15	335.4
1000/1	C	131	20.27	20.97	25	524.2
	D	122	18.87	19.57	50	978.5
	E	113	17.48	18.18	75	1363.5
	F	104	16.09	16.79	125	2098.8
	G	97	15.01	15.55	150	2332.5
	H	89	13.77	14.39	250	3597.5
	I	82	12.69	13.23	271	3585.3
	J	60	9.28	10.99	393	4319.1
	K	44	6.81	7.69	488	3752.7
	L	32	4.95	5.88	582	3422.2
(.60 X)*	M	21	3.25	4.27	737	3146.9
(.75 X)	N	12	1.85	3.09	489	1511.0

Sum = 31198.1

Area size			Amt. 13.39			
	A	162	21.69	21.69	10	216.9
	B	152	20.35	21.02	15	315.8
1500/1	C	142	19.01	19.68	25	492.0
	D	132	17.67	18.34	50	917.0
	E	122	16.33	17.00	75	1275.0
	F	112	14.99	15.66	125	1957.5
	G	105	14.06	14.52	150	2178.0
	H	96	12.85	13.46	250	3365.0
	I	88	11.78	12.32	271	3338.7
	J	80	10.71	11.24	393	4417.3
	K	56	7.50	9.10	488	4440.8
	L	41	5.49	6.50	582	3783.0
(.60 X)	M	26	3.48	4.69	737	3456.5
(.75 X)	N	16	2.14	3.14	489	1535.5

Sum = 31689.0

Area size			Amt. 11.50			
	A	176	20.24	20.24	10	202.4
	B	165	18.98	19.61	15	294.2
2150/1	C	154	17.71	18.35	25	458.6
	D	142	16.33	17.02	50	851.0
	E	131	15.07	15.70	75	1177.5
	F	122	14.03	14.55	125	1818.8
	G	113	12.99	13.51	150	2026.5
	H	103	11.58	12.42	250	3105.0
	I	95	10.93	11.39	271	3086.7
	J	86	9.89	10.41	393	4091.1
	K	77	8.86	9.38	488	4577.4
	L	52	5.98	7.42	582	4318.4
(.60 X)	M	33	3.80	5.11	737	3766.1
(.75 X)	N	20	2.30	3.42	489	1672.4

Sum = 31446.3

	I	II	III	IV	V	VI
Area size	Iso.	Nomo.	Amt. 9.69	Avg. depth	ΔA	ΔV
	A	191	18.51	18.51	10	185.1
	B	179	17.93	17.93	15	258.9
3000/1	C	166	16.09	16.72	25	418.0
	D	154	14.92	15.51	50	775.5
	E	142	13.76	14.34	75	1075.5
	F	132	12.79	13.28	125	1660.0
	G	122	11.82	12.31	150	1846.5
	H	112	10.85	11.34	250	2835.0
	I	102	9.88	10.37	271	2810.3
	J	92	8.91	9.39	393	3690.3
	K	83	8.04	8.48	488	4138.2
	L	74	7.17	7.61	582	4429.0
(.60 X)	M	44	4.26	6.01	737	4428.4
(.75 X)	N	25	2.42	3.80	489	1858.2

Sum = 30418.9

Area size			Amt. 8.33			
	A	212	17.66	17.66	10	176.6
	B	198	16.49	17.08	15	256.1
4500/1	C	184	15.33	15.91	25	397.8
	D	170	14.16	14.75	50	737.5
	E	157	13.08	13.62	75	1021.5
	F	146	12.16	12.62	125	1577.5
	G	135	11.25	11.71	150	1756.5
	H	124	10.33	10.79	250	2697.5
	I	113	9.41	9.87	271	2674.8
	J	103	8.58	9.00	393	3537.0
	K	93	7.75	8.16	488	3982.1
	L	83	6.91	7.33	582	4266.1
(.60 X)	M	71	5.91	6.51	737	4797.9
(.75 X)	N	37	3.08	5.20	489	2542.8

Sum = 30421.7

Area size			Amt. 7.22			
	A	233	16.82	16.82	10	168.2
	B	218	15.74	16.28	15	244.2
6500/1	C	203	14.66	15.20	25	380.0
	D	187	13.50	14.08	50	704.0
	E	174	12.56	13.03	75	977.3
	F	160	11.55	12.06	125	1507.5
	G	148	10.69	11.12	150	1668.0
	H	137	9.89	10.29	250	2572.5
	I	125	9.03	9.46	271	2563.7
	J	113	8.16	8.59	393	3375.9
	K	103	7.44	7.80	488	3806.4
	L	93	6.71	7.08	582	4120.6
(.60 X)	M	81	5.85	6.37	737	4694.7
(.75 X)	N	70	5.05	5.65	489	2762.8

Sum = 29545.7

* Weighting factor F (see text Section 7.1 Step C6)

Table 22.—Completed computation sheets for 1st, 2nd and 3rd 6-hr increments for Leon River, TX drainage – Continued

Increment: 1,2

Drainage: Leon River, TX Area: 3,660 mi^2 Date:

	I	II	III	IV	V	VI
Area size	Iso.	Nomo.	Amt. 5.99	Avg. depth	ΔA	ΔV
	A	262	15.69	15.69	10	156.9
	B	243	14.56	15.12	15	226.8
10000/1	C	227	13.60	14.08	25	352.0
	D	209	12.52	13.06	50	653.0
	E	194	11.62	12.07	75	905.2
	F	178	10.66	11.14	125	1392.5
	G	166	9.94	10.30	150	1545.0
	H	152	9.10	9.52	250	2380.0
	I	140	8.39	8.74	271	2368.5
	J	128	7.67	8.03	393	3155.8
	K	117	7.01	7.34	488	3581.9
	L	107	6.41	6.71	582	3905.2
(.60 X)	M	93	5.57	6.07	737	4473.6
(.75 X)	N	82	4.91	5.40	489	2640.6
						Sum = 27737.0
Area size			Amt. 4.42			
	A	116	5.13	5.13	10	51.3
	B	112	4.95	5.04	15	75.6
1000/2	C	108.5	4.80	4.88	25	121.9
	D	105	4.64	4.72	50	236.0
	E	103	4.55	4.60	75	345.0
	F	101	4.46	4.51	125	563.8
	G	99	4.38	4.42	150	663.0
	H	97	4.29	4.34	250	1085.0
	I	95	4.20	4.25	271	1151.8
	J	76	3.36	3.78	393	1485.5
	K	63	2.78	3.07	488	1498.2
	L	51	2.25	2.52	582	1466.6
(.60 X)	M	38	1.68	2.02	737	1488.7
(.75 X)	N	24	1.06	1.52	489	743.3
						Sum = 10975.7
Area size			Amt. 3.83			
	A	118.5	4.54	4.54	10	45.4
	B	114.5	4.39	4.47	15	67.0
2150/2	C	110.5	4.25	4.32	25	108.0
	D	108.5	4.16	4.21	50	210.5
	E	106.5	4.08	4.12	75	309.0
	F	104.5	4.00	4.04	125	505.0
	G	102	3.91	3.96	150	594.0
	H	100	3.83	3.96	250	967.5
	I	99	3.79	3.81	271	1032.5
	J	97	3.72	3.76	393	1477.7
	K	96	3.68	3.70	488	1805.6
	L	73	2.80	3.24	582	1885.7
(.60 X)	M	54	2.07	2.62	737	1930.9
(.75 X)	N	37.5	1.44	1.91	489	934.0
						Sum = 11872.8

	I	II	III	IV	V	VI
Area size	Iso.	Nomo.	Amt. 4.93	Avg. depth	ΔA	ΔV
	A	290	14.30	14.30	10	143.0
	B	271	13.36	13.83	15	207.4
15000/1	C	253	12.47	12.92	25	323.0
	D	232	11.44	11.96	50	598.0
	E	214	10.55	11.00	75	825.0
	F	196	9.66	10.10	125	1262.5
	G	183	9.02	9.34	150	1411.0
	H	168	8.28	8.65	250	2162.5
	I	156	7.69	7.98	271	2162.6
	J	143	7.05	7.37	393	2896.4
	K	131	6.46	6.76	488	3298.9
	L	120	5.92	6.19	582	3602.6
(.60 X)	M	106	5.22	5.64	737	4156.7
(.75 X)	N	94	4.63	5.07	489	2479.2
						Sum = 25518.8
Area size			Amt. 4.12			
	A	117	4.82	4.82	10	48.2
	B	113	4.66	4.74	15	71.1
1500/2	C	110	4.53	4.60	25	114.9
	D	107	4.41	4.47	50	223.5
	E	105	4.33	4.37	75	327.8
	F	103	4.24	4.29	125	535.6
	G	100.5	4.14	4.19	150	628.5
	H	99	4.08	4.11	250	1027.5
	I	97	4.00	4.04	271	1094.8
	J	95.5	3.93	3.97	393	1560.2
	K	75.5	3.11	3.52	488	1717.8
	L	605	2.49	2.80	582	1629.6
(.60 X)	M	45	1.85	2.23	737	1643.5
(.75 X)	N	31	1.28	1.71	489	836.2
						Sum = 11459.2
Area size			Amt. 3.52			
	A	119.5	4.21	4.21	10	42.1
	B	116	4.08	4.15	15	62.2
3000/2	C	112.5	3.96	4.02	25	100.5
	D	110	3.87	3.92	50	196.0
	E	108	3.80	3.84	75	288.0
	F	106	3.77	3.77	125	471.2
	G	104	3.66	3.70	150	555.0
	H	102	3.59	3.63	250	907.5
	I	100.5	3.54	3.56	271	964.8
	J	99	3.48	3.51	393	1379.4
	K	97	3.41	3.45	488	1683.6
	L	96	3.38	3.40	582	1978.8
(.60 X)	M	67	2.36	2.97	737	2188.9
(.75 X)	N	45	1.58	2.17	489	1061.1
						Sum = 11879.1

Table 22.—Completed computation sheets for 1st, 2nd and 3rd 6-hr increments for Leon River, TX drainage – Continued

Increment: 3

Drainage: Leon River, TX　Area: 3,660 mi^2　Date: ______

	I	II	III	IV	V	VI		I	II	III	IV	V	VI
Area size	Iso.	Nomo.	Amt. 2.89	Avg. depth	ΔA	ΔV	Area size	Iso.	Nomo.	Amt. 2.70	Avg. depth	ΔA	ΔV
	A	104.6	3.02	3.02	10	30.2		A	105	2.84	2.84	10	28.4
	B	103.3	2.98	3.00	15	45.0		B	103.8	2.80	2.82	15	42.3
1000/3	C	102.3	2.96	2.97	25	74.2	1500/3	C	102.7	2.77	2.785	25	69.6
	D	101.3	2.93	2.945	50	147.2		D	101.7	2.74	2.755	50	137.8
	E	100.6	2.91	2.92	75	219.0		E	101	2.73	2.735	75	205.1
	F	100.3	2.90	2.905	125	393.1		F	100.7	2.72	2.725	125	340.6
	G	99.9	2.89	2.895	150	434.2		G	100.3	2.71	2.715	150	407.2
	H	99.6	2.88	2.885	250	721.2		H	100	2.70	2.705	250	676.2
	I	99.3	2.87	2.875	271	779.1		I	99.7	2.69	2.695	271	730.3
	J	82.5	2.38	2.70	393	1061.1		J	99.4	2.68	2.685	393	1055.2
	K	67	1.94	2.16	488	1054.1		K	81	2.19	2.44	488	1190.7
	L	54	1.56	1.75	582	1018.5		L	65.5	1.77	1.98	582	1152.4
(.60 X)	M	43	1.24	1.43	737	1053.9	(.60 X)	M	51.5	1.39	1.62	737	1193.9
(.75 X)	N	31	.90	1.16	489	567.2	(.75 X)	N	38	1.03	1.30	489	635.7
					Sum =	7598.0						Sum =	7865.4
Area size			Amt. 2.50				Area size			Amt. 2.30			
	A	105.3	2.63	2.63	10	26.3		A	105.7	2.43	2.43	10	24.3
	B	104.2	2.60	2.615	15	39.2		B	104.6	2.41	2.42	15	36.3
2150/3	C	103.2	2.58	2.59	25	64.8	3000/3	C	103.5	2.38	2.40	25	60.0
	D	102	2.55	2.565	50	128.2		D	102.5	2.36	2.37	50	118.5
	E	101.3	2.53	2.54	75	190.5		E	101.7	2.34	2.35	75	176.3
	F	101	2.52	2.525	125	315.6		F	101.3	2.33	2.345	125	293.1
	G	100.6	2.52	2.52	150	378.0		G	100.9	2.32	2.335	150	350.2
	H	100.3	2.51	2.515	250	628.8		H	100.5	2.31	2.315	250	578.8
	I	100	2.50	2.505	271	678.8		I	100.2	2.30	2.305	271	624.6
	J	99.7	2.49	2.495	393	980.5		J	99.9	2.30	2.30	393	903.9
	K	99.5	2.49	2.49	488	1215.1		K	99.6	2.29	2.295	488	1120.0
	L	80.5	2.01	2.25	582	1309.5		L	99.3	2.28	2.285	582	1329.9
(.60 X)	M	61	1.52	1.81	737	1334.0	(.60 X)	M	76	1.75	2.07	737	1525.6
(.75 X)	N	46.5	1.16	1.43	489	699.3	(.75 X)	N	57	1.31	1.64	489	802.0
					Sum =	7988.6						Sum =	7943.5

Table 23.—Completed computation sheet for the 1st to 3rd 6-hr increments for supplemental isohyets on the Leon River, TX drainage

Increment: 1 to 3

Drainage: Leon River, TX　Area: 3,660 mi^2　Date: ______

	I	II	III	IV	V	VI
Area size	Iso.	Nomo.	Amt. 12.12	Avg. depth	ΔA	ΔV
	A	171	20.72	20.72	10	207.2
	B	160	19.39	20.06	15	300.9
1900/1	C	149	18.06	18.72	25	468.0
	D	138	16.73	17.40	50	870.0
	E	128	14.51	16.12	75	1209.0
	F	118	14.30	14.90	125	1862.5
	G	110	13.33	13.82	150	2073.0
	H	100	12.12	12.72	250	3180.0
	I	93	11.27	11.70	271	3170.7
	J	84	10.18	10.72	393	4213.0
	-	78	9.45	9.82	345	3387.9
	K	68	8.24	8.84	143	1264.1
	L	48	5.82	7.03	582	4091.5
(.60 X)	M	30	3.64	4.95	737	3548.2
(.75 X)	N	18	2.18	3.28	489	1603.9
						Sum = 31449.9
Area size			Amt. 3.93			
	A	118	4.64	4.64	10	46.4
	B	116	4.56	4.60	15	69.0
1900/2	C	111	4.36	4.46	25	111.5
	D	108	4.24	4.30	50	215.0
	E	106	4.16	4.20	75	315.0
	F	104	4.09	4.125	125	515.6
	G	102	4.01	4.05	150	607.5
	H	100	3.93	4.97	250	1242.5
	I	98	3.85	3.89	271	1054.2
	J	96.5	3.79	3.82	393	1501.3
	-	95.5	3.75	3.77	345	1300.6
	K	86	3.38	3.57	143	510.5
	L	68	2.67	3.03	582	1763.5
(.60 X)	M	50.5	1.98	2.39	737	1761.4
(.75 X)	N	37	1.48	1.86	489	909.5
						Sum = 11923.5
Area size			Amt. 2.56			
	A	105.2	2.69	2.69	10	26.9
	B	104.1	2.66	2.675	15	40.1
1900/3	C	103	2.64	2.65	25	66.2
	D	102	2.61	2.625	50	131.2
	E	101.2	2.59	2.06	75	195.0
	F	100.8	2.58	2.585	125	323.1
	G	100.5	2.57	2.575	150	386.2
	H	100.2	2.56	2.565	250	641.2
	I	99.8	2.55	2.555	271	692.4
	J	99.6	2.55	2.55	393	1000.2
	-	99.4	2.54	2.545	345	878.0
	K	92	2.36	2.45	143	350.4
	L	75	1.92	2.14	582	1245.5
(.60 X)	M	58	1.48	1.74	737	1285.3
(.75 X)	N	43	1.10	1.39	489	679.7
						Sum = 7940.5

	I	II	III	IV	V	VI
Area size	Iso.	Nomo.	Amt. 10.86	Avg. depth	ΔA	ΔV
	A	181	19.66	19.66	10	196.6
	B	169	18.35	19.00	15	285.0
2400/1	C	158	17.16	17.76	25	444.0
	D	146	15.86	16.51	50	825.5
	E	134	14.55	15.20	75	1140.0
	F	125	13.58	14.06	125	1757.5
	G	116	12.60	13.09	150	1963.5
	H	106	11.51	12.06	250	3015.0
	I	97	10.53	11.02	271	2986.4
	J	88	9.56	10.04	393	3945.7
	K	79	8.98	9.07	488	4426.2
	-	76	8.25	8.42	211	1776.6
	L	58	6.30	7.28	371	2700.9
(.60 X)	M	36	3.91	5.34	737	3935.6
(.75 X)	N	21	2.28	3.50	489	1711.5
						Sum = 31110.0
Area size			Amt. 3.73			
	A	119	4.44	4.44	10	44.4
	B	115	4.29	4.36	15	65.4
2400/2	C	112	4.18	4.24	25	106.0
	D	109	4.06	4.12	50	206.0
	E	107	3.99	4.025	75	301.9
	F	105	3.92	3.955	125	494.4
	G	103	3.84	3.88	150	582.0
	H	101	3.77	3.805	250	951.2
	I	99	3.69	3.73	271	1010.8
	J	97.5	3.64	3.665	393	1440.3
	K	96.5	3.60	3.62	488	1766.6
	-	96	3.58	3.59	211	757.5
	L	78	2.91	3.25	371	1205.8
(.60 X)	M	57.5	2.14	2.60	737	1916.2
(.75 X)	N	40	1.49	1.98	489	968.2
						Sum = 11816.7
Area size			Amt. 2.43			
	A	105.4	2.56	2.56	10	25.6
	B	104.3	2.53	2.545	15	38.2
2400/3	C	103.3	2.51	2.52	25	63.0
	D	102.3	2.48	2.495	50	124.8
	E	101.5	2.47	2.475	75	185.6
	F	101.0	2.45	2.46	125	307.5
	G	100.7	2.45	2.45	150	367.5
	H	100.3	2.44	2.445	250	611.2
	I	100.0	2.43	2.435	271	659.9
	J	99.8	2.42	2.425	393	953.0
	K	99.4	2.42	2.42	488	1181.0
	-	99.3	2.41	2.415	211	509.6
	L	86	2.09	2.25	371	834.8
(.60 X)	M	66	1.60	1.89	737	1392.9
(.75 X)	N	49.5	1.20	1.50	489	733.5
						Sum = 7988.1

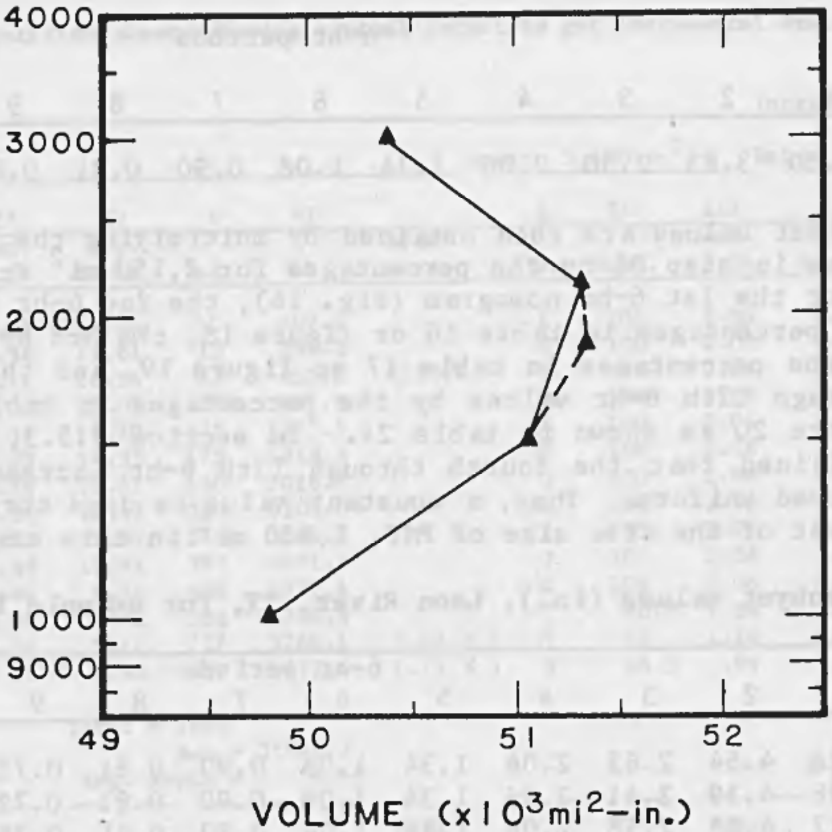

Figure 47.—Volume vs. area curve for 1st three 6-hr increments for Leon River, TX drainage.

D2. Successively subtract the 6-hr values in step D1.

	6-hr periods											
	1	2	3	4	5	6	7	8	9	10	11	12
Increm. PMP (in.)	12.9	4.3	2.8	2.3	1.5	1.2	1.0	0.8	0.9	0.8	0.7	0.7

We read slightly different values (read to hundreths) in smoothed data from figure 45 for the 1st three 6-hr increments, which we substitute here, for consistency.

Note that to assure a series of decreasing values it was necessary to reverse the values for the 8th and 9th increment. This does not cause any problem for our computations.

	6-hr periods											
	1	2	3	4	5	6	7	8	9	10	11	12
Increm. PMP (in.)	12.82	4.27	2.79	2.30	1.50	1.20	1.00	0.90	0.80	0.80	0.70	0.70

Multiply each of these 6-hr incremental PMP by 89.7% to reduce them for orientation.

	6-hr periods											
	1	2	3	4	5	6	7	8	9	10	11	12
Adj. PMP (in.)	11.50	3.83	2.50	2.06	1.34	1.08	0.90	0.81	0.72	0.72	0.63	0.63

D3. Isohyet values are then obtained by multiplying the 1st 6-hr value in step D2 by the percentages for 2,150 mi^2 from table 15 or the 1st 6-hr nomogram (fig. 16), the 2nd 6-hr value by the percentages in table 16 or figure 18, the 3rd 6-hr value by the percentages in table 17 or figure 19, and the fourth through 12th 6-hr values by the percentages in table 18 or figure 20 as shown in table 24. In section 3.5.3, we have explained that the fourth through 12th 6-hr increments are assumed uniform. Thus, a constant value is used through the extent of the area size of PMP, 2,150 mi^2 in this example.

Table 24.—Isohyet values (in.), Leon River, TX, for example 1a

	6-hr periods											
Isohyet	1	2	3	4	5	6	7	8	9	10	11	12
A	20.24	4.54	2.63	2.06	1.34	1.08	0.90	0.81	0.72	0.72	0.63	0.63
B	18.98	4.39	2.61	2.06	1.34	1.08	0.90	0.81	0.72	0.72	0.63	0.63
C	17.17	4.25	2.58	2.06	1.34	1.08	0.90	0.81	0.72	0.72	0.63	0.63
D	16.33	4.16	2.56	2.06	1.34	1.08	0.90	0.81	0.72	0.72	0.63	0.63
E	15.07	4.08	2.53	2.06	1.34	1.08	0.90	0.81	0.72	0.72	0.63	0.63
F	14.03	4.00	2.53	2.06	1.34	1.08	0.90	0.81	0.72	0.72	0.63	0.63
G	12.99	3.91	2.52	2.06	1.34	1.08	0.90	0.81	0.72	0.72	0.63	0.63
H	11.85	3.83	2.51	2.06	1.34	1.08	0.90	0.81	0.72	0.72	0.63	0.63
I	10.93	3.77	2.50	2.06	1.34	1.08	0.90	0.81	0.72	0.72	0.63	0.63
J	9.89	3.72	2.49	2.06	1.34	1.08	0.90	0.81	0.72	0.72	0.63	0.63
K	8.86	3.68	2.48	2.06	1.34	1.08	0.90	0.81	0.72	0.72	0.63	0.63
L	5.98	2.80	2.03	1.66	1.08	0.87	0.72	0.65	0.58	0.58	0.51	0.51
M	3.80	2.07	1.55	1.26	0.82	0.66	0.55	0.49	0.44	0.44	0.38	0.38
N	2.30	1.44	1.16	0.96	0.62	0.50	0.42	0.38	0.33	0.33	0.29	0.29

Note: The results shown in this matrix emphasize the fact that for the fourth through 12th 6-hr period the distribution of PMP is uniform across the PMP portion of the pattern (A through K) for each increment. However, isohyets L to N represent residual precipitation for the 2,150-mi^2 pattern and these isohyets are assigned decreasing values.

D4. The values in table 24 represent the incremental isohyetal values for the Leon River drainage with the 2,150-mi^2 PMP pattern placed as shown in figure 46. To obtain incremental average depths (PMP) for this drainage it is necessary to compute the incremental volumes as determined from the tabulated isohyetal values according to the procedures described for figure 41, and then divide each incremental volume by the drainage area. This results in the following incremental average depths. (See computations in table 25.)

Table 25.—Completed computation sheets showing typical format to get incremental drainage-average depths, Leon River, TX

Increment: 1 to 6

Drainage: Leon River, TX Area: 3,660 mi^2 Date: ____

Area size	I Iso.	II Nomo.	III Amt. 11.50	IV Avg. depth	V ΔA	VI ΔV
	A		20.24	20.24	10	202.4
	B		18.98	19.61	15	294.2
2150/1	C		17.71	18.35	25	458.8
	D		16.33	17.02	50	851.0
	E		15.07	15.70	75	1177.5
	F		14.03	14.55	175	1818.8
	G		12.99	13.51	150	2026.5
	H		11.85	12.42	250	3105.0
	I		10.93	11.39	271	3086.7
	J		9.89	10.41	393	4091.1
	K		8.86	9.38	488	4577.4
	L		5.98	7.42	582	4318.4
(.60 X)	M		3.80	5.11	737	3766.1
(.75 X)	N		2.30	3.42	489	1672.4

Total = 3660

Sum = 31446.3

Avg. depth = 8.59

Area size			Amt. 3.83			
	A				10	45.4
	B				15	67.0
2150/2	C				25	108.0
	D				50	210.5
	E				75	309.0
	F				125	505.0
	G				150	594.0
	H				250	967.5
	I				271	1032.5
	J				393	1477.7
	K				488	1805.6
	L				582	1887.5
(.60 X)	M				737	1930.9
(.75 X)	N				489	934.0

Sum = 11872.8

Avg. depth = 3.24

Area size			Amt. 2.50			
	A				10	26.3
	B				15	39.2
2150/3	C				25	64.8
	D				50	128.2
	E				75	190.5
	F				125	315.6
	G				150	378.0
	H				250	628.8
	I				271	678.8
	J				393	980.5
	K				488	1215.1
	L				582	1309.5
(.60 X)	M				737	1334.0
(.75 X)	N				489	699.3

Sum = 7988.6

Avg. depth = 2.18

Area size	I Iso.	II Nomo.	III Amt. 2.06	IV Avg. depth	V ΔA	VI ΔV
	A	100	2.06	2.06	10	20.6
	B	100	2.06	2.06	15	30.9
2150/4	C	100	2.06	2.06	25	51.5
	D	100	2.06	2.06	50	103.0
	E	100	2.06	2.06	75	154.5
	F	100	2.06	2.06	125	257.5
	G	100	2.06	2.06	150	309.0
	H	100	2.06	2.06	250	515.0
	I	100	2.06	2.06	271	558.3
	J	100	2.06	2.06	393	809.6
	K	100	2.06	2.06	488	1005.3
	L	80.5	1.66	1.86	582	1082.5
(.60 X)	M	61	1.26	1.46	737	1076.0
(.75 X)	N	46.5	.96	1.11	489	542.8

Sum = 6516.5

Avg. depth = 1.78

Area size			Amt. 1.34			
	A	100	1.34	1.34	10	13.4
	B	100	1.34	1.34	15	20.1
2150/5	C	100	1.34	1.34	25	33.5
	D	100	1.34	1.34	50	67.0
	E	100	1.34	1.34	75	100.5
	F	100	1.34	1.34	125	167.5
	G	100	1.34	1.34	150	201.0
	H	100	1.34	1.34	250	335.0
	I	100	1.34	1.34	271	363.1
	J	100	1.34	1.34	393	526.6
	K	100	1.34	1.34	488	653.9
	L	80.5	1.08	1.21	582	704.2
(.60 X)	M	61	0.82	0.95	737	700.2
(.75 X)	N	46.5	0.62	0.72	489	352.1

Sum = 4238.1

Avg. depth = 1.16

Area size			Amt. 1.08			
	A	100	1.08	1.08	10	10.8
	B	100	1.08	1.08	15	16.2
2150/6	C	100	1.08	1.08	25	27.0
	D	100	1.08	1.08	50	54.0
	E	100	1.08	1.08	75	81.0
	F	100	1.08	1.08	125	135.0
	G	100	1.08	1.08	150	162.0
	H	100	1.08	1.08	250	270.0
	I	100	1.08	1.08	271	292.7
	J	100	1.08	1.08	393	424.4
	K	100	1.08	1.08	488	527.0
	L	80.5	0.87	0.98	582	570.4
(.60 X)	M	61	0.66	0.77	737	567.5
(.75 X)	N	46.5	0.50	0.58	489	283.6

Sum = 3421.6

Avg. depth = 0.93

Table 25.—Completed computation sheets showing typical format to get incremental drainage-averaged depths, Leon River, TX. - Continued

Increment: 7 to 12

Drainage: Leon River, TX Area: 3,660 mi^2 Date:

Area size	I Iso.	II Nomo.	III Amt. 0.90	IV Avg. depth	V ΔA	VI ΔV
	A	100	0.90	0.90	10	9
	B	100	0.90	0.90	15	13.5
2150/7	C	100	0.90	0.90	25	22.5
	D	100	0.90	0.90	50	45.0
	E	100	0.90	0.90	75	67.5
	F	100	0.90	0.90	125	112.5
	G	100	0.90	0.90	150	135.0
	H	100	0.90	0.90	250	225.0
	I	100	0.90	0.90	271	243.9
	J	100	0.90	0.90	393	353.7
	K	100	0.90	0.90	488	439.2
	L	80.5	0.72	0.81	582	471.4
(.60 X)	M	61	0.55	0.64	737	471.7
(.75 X)	N	46.5	0.42	0.49	489	239.6

Sum = 2849.5
Avg. depth = 0.78

Area size			Amt. 0.81			
	A	100	0.81	0.81	10	8.1
	B	100	0.81	0.81	15	12.2
2150/8	C	100	0.81	0.81	25	20.3
	D	100	0.81	0.81	50	40.5
	E	100	0.81	0.81	75	60.8
	F	100	0.81	0.81	125	101.3
	G	100	0.81	0.81	150	121.5
	H	100	0.81	0.81	250	202.5
	I	100	0.81	0.81	271	219.5
	J	100	0.81	0.81	393	318.3
	K	100	0.81	0.81	488	395.3
	L	80.5	0.65	0.73	582	424.9
(.60 X)	M	61	0.49	0.57	737	420.1
(.75 X)	N	46.5	0.38	0.44	489	215.2

Sum = 2560.4
Avg. depth = 0.70

Area size			Amt. 0.72			
	A	100	0.72	0.72	10	7.2
	B	100	0.72	0.72	15	10.8
2150/9	C	100	0.72	0.72	25	18.0
	D	100	0.72	0.72	50	36.0
	E	100	0.72	0.72	75	54.0
	F	100	0.72	0.72	125	90.0
	G	100	0.72	0.72	150	108.0
	H	100	0.72	0.72	250	180.0
	I	100	0.72	0.72	271	195.1
	J	100	0.72	0.72	393	282.9
	K	100	0.72	0.72	488	351.4
	L	80.5	0.58	0.65	582	378.3
(.60 X)	M	61	0.44	0.51	737	375.9
(.75 X)	N	46.5	0.33	0.39	489	190.7

Sum = 2278.3
Avg. depth = 0.62

Area size	I Iso.	II Nomo.	III Amt. 0.72	IV Avg. depth	V ΔA	VI ΔV
	A	100	0.72	0.72	10	7.2
	B	100	0.72	0.72	15	10.8
2150/10	C	100	0.72	0.72	25	18.0
	D	100	0.72	0.72	50	36.0
	E	100	0.72	0.72	75	54.0
	F	100	0.72	0.72	125	90.0
	G	100	0.72	0.72	150	108.0
	H	100	0.72	0.72	250	180.0
	I	100	0.72	0.72	271	195.1
	J	100	0.72	0.72	393	282.9
	K	100	0.72	0.72	488	351.4
	L	80.5	0.58	0.65	582	378.3
(.60 X)	M	61	0.44	0.51	737	375.9
(.75 X)	N	46.5	0.33	0.39	489	190.7

Sum = 2278.3
Avg. depth = 0.62

Area size			Amt. 0.63			
	A	100	0.63	0.63	10	6.3
	B	100	0.63	0.63	15	9.5
2150/11	C	100	0.63	0.63	25	15.8
	D	100	0.63	0.63	50	31.5
	E	100	0.63	0.63	75	47.3
	F	100	0.63	0.63	125	78.8
	G	100	0.63	0.63	150	94.5
	H	100	0.63	0.63	250	157.5
	I	100	0.63	0.63	271	170.7
	J	100	0.63	0.63	393	247.6
	K	100	0.63	0.63	488	307.4
	L	80.5	0.51	0.57	582	331.7
(.60 X)	M	61	0.38	0.45	737	331.7
(.75 X)	N	46.5	0.29	0.34	489	166.3

Sum = 1996.6
Avg. depth = 0.54

Area size			Amt. 0.63			
	A	100	0.63	0.63	10	6.3
	B	100	0.63	0.63	15	9.5
2150/12	C	100	0.63	0.63	25	15.8
	D	100	0.63	0.63	50	31.5
	E	100	0.63	0.63	75	47.3
	F	100	0.63	0.63	125	78.8
	G	100	0.63	0.63	150	94.5
	H	100	0.63	0.63	250	157.5
	I	100	0.63	0.63	271	170.7
	J	100	0.63	0.63	393	247.6
	K	100	0.63	0.63	488	307.4
	L	80.5	0.51	0.57	582	331.7
(.60 X)	M	61	0.38	0.45	737	331.7
(.75 X)	N	46.5	0.29	0.34	489	166.3

Sum = 1996.6
Avg. depth = 0.54

	6-hr periods											
	1	2	3	4	5	6	7	8	9	10	11	12
Avg. PMP (in.)	8.59	3.24	2.18	1.78	1.16	0.93	0.78	0.70	0.62	0.62	0.54	0.54

These give a 72-hr total drainage-averaged PMP of 21.68 in., which can be compared to 27.4 in. for 3,660 mi^2 (from fig. 43), or a 21 percent reduction from HMR No. 51. The reduction is due to orientation and basin shape factors.

D5. a. At 31°45'N, 98°15'W, we read a 1/6-hr ratio of 0.306 from figure 39.

b. We adjust the scale for the nomogram in figure 40 such that the abscissa for the 20,000-mi^2 "A" isohyet reads 0.306.

c. With the scale set as in step D5b, we read ratios for the following isohyets.

Isohyet	1/6-hr ratio
A	.299
B	.298*
C	.297
D	.295*
E	.293
F	.2915*
G	.290
H	.2875*
I	.285
J	.282
K	.279

*interpolated isohyet on nomogram

d. Multiply the ratios in step D5c by the corresponding values from table 24 (1st 6-hr period only) to get the 1-hr isohyet values.

Isohyet	1-hr isohyet values
A	6.05
B	5.66
C	5.10
D	4.82
E	4.42
F	4.09
G	3.77
H	3.73
I	3.12
J	2.78
K	2.47

e. Plot the values in step D5d and those for the 4 greatest increments from table 24 and draw a smooth curve of best fit through these points with the origin as the starting point as shown in figure 48.

f. From figure 48, we can read isohyet values for any other duration less than 6 hr (see note in procedure step 7D5f).

g. The 4 greatest 6-hr incremental isohyet values for the M isohyet have also been plotted on figure 48 as an example of residual precipitation. It is apparent that this curve is flatter than those for the PMP portion of the pattern. Lesser errors are therefore likely in interpolating short duration isohyet values for residual precipitation than for those within the PMP area. (Note in procedure step 7D5f applies here and to 1-hr values for residual precipitation.)

7.3 Example 1b

As a comparison to the results of example 1a, we will now evaluate the maximum volume for the Leon River, Texas drainage when no adjustment for orientation is applied. In step B3, we obtained the orientation for PMP from figure 8 as 208° for 31°45'N, 98°15'W. Figure 10 indicates that within 40° of PMP orientation, no reduction need be applied to isohyets values. Subtracting 40° from 208°, we get an orientation of 168°. Thus, if we place the isohyetal pattern at an orientation of 168° on the Leon River drainage, as shown in figure 49, no adjustment is necessary. We must planimeter the areas between each of the incomplete isohyets, and then refer to step C in the procedure.

C. Complete the computational process of figure 41 for the area sizes considered in example 1a. We have omitted the 1,000- and 15,000-mi^2 areas based on the outcome of example 1a. Note that the nomogram percentages will be the same as those used in example 1a, but the amount heading column III is now unadjusted for orientation; i.e., smoothed values from figure 45.

Table 26 presents completed computations for this example. The preliminary maximum volume for the first 6-hr increment appears to occur between 6,500 and 10,000 mi^2. To check on this outcome, the 15,000-mi^2 area pattern volume was determined and was found to be significantly less than that at 10,000 mi^2. Computation of the 2nd and 3rd 6-hr increments for the standard isohyet areas between 4,500 and 15,000 mi^2 resulted in 18-hr volumes ranging between 45,000 and 49,000 mi^2-in.

Note that by not adjusting the isohyets for orientation, the PMP pattern area of maximum volume has greatly increased from 2,150 mi^2 in example 1a to 10,000 mi^2 in this example, but the total volume as decreased. This occurs because some of the larger isohyets become more effective as the isohyet values increase with increasing area, and combine with proportionately larger incremental areas. At the same time the volume contributed by the isohyets enclosing smaller areas has been markedly reduced.

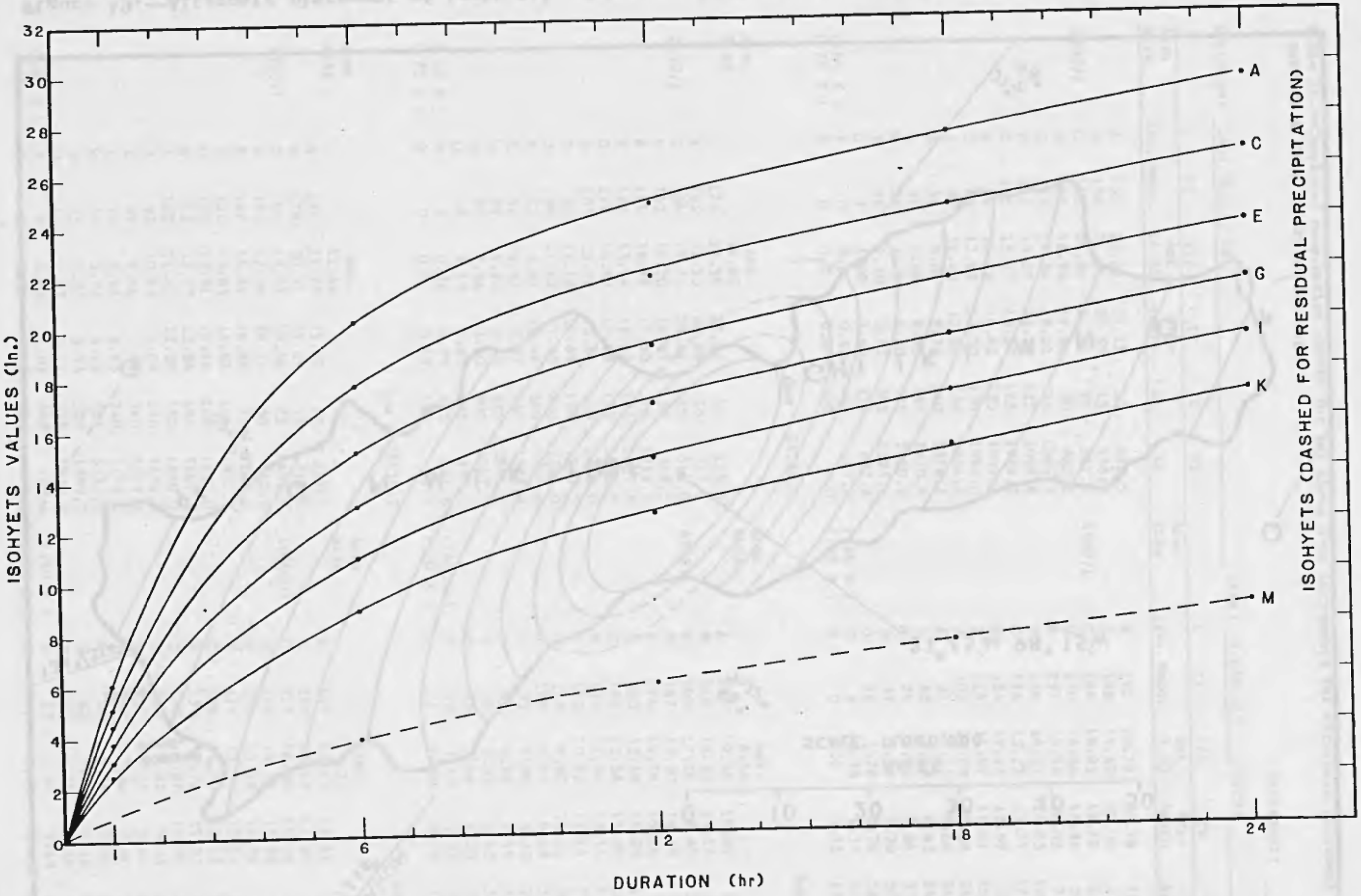

Figure 48.--Smoothed durational curves used to interpolate short-duration isohyet values for the Leon River, TX drainage.

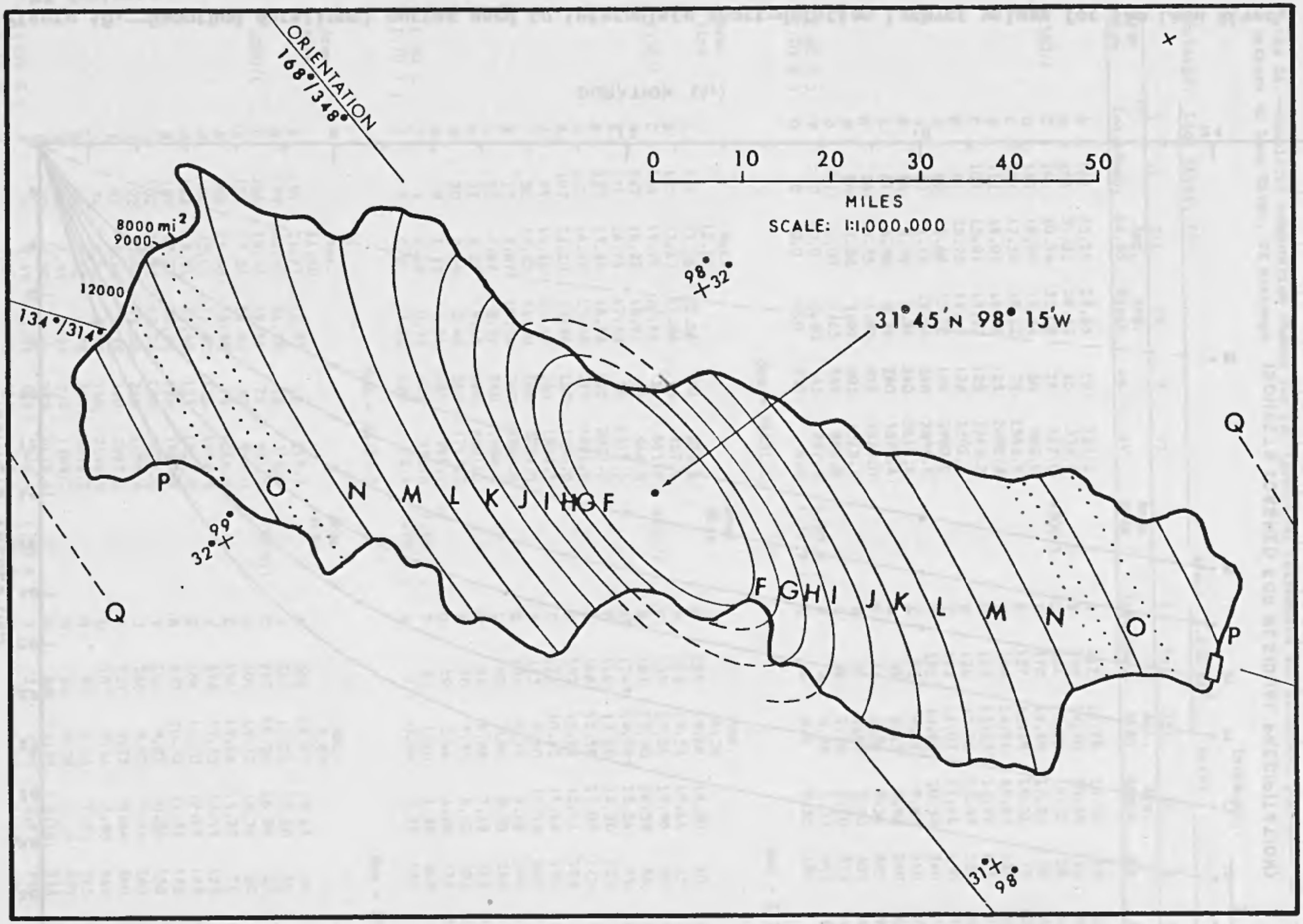

Figure 49.--Alternate placement of isohyetal pattern on Leon River, TX drainage such that no adjustment is applicable for orientation.

Table 26.—Completed computation sheets for 1st three 6-hr increments for alternate placement of pattern on Leon River, TX drainage

Increment: 1

Drainage: Leon River, TX   Area: 3,660 mi^2 Date:

	I	II	III	IV	V	VI
Area size	Iso.	Nomo.	Amt. 14.35	Avg. depth	ΔA	ΔV
	A	162	23.25	23.25	10	232.5
	B	152	21.81	22.53	15	338.0
1500/1	C	142	20.34	21.08	25	527.0
	D	132	18.94	19.64	50	982.0
	E	122	17.54	18.22	75	1366.5
	F	112	16.07	16.79	125	2098.8
	G	105	15.07	15.57	125	1946.2
	H	96	13.78	14.42	125	1802.5
	I	88	12.68	13.20	150	1980.0
	J	80	11.48	12.06	240	2894.4
	K	56	8.04	9.76	340	3318.4
	L	41	5.88	6.96	240	1670.4
	M	26	3.73	4.80	525	2520.0
	N	16	2.30	3.02	505	1525.1
	O	7	1.00	1.65	535	882.8
(.60 X)	P	0	0.0	0.60	445	267.0
(.70 X)	Q	0	0.0	0.0	130	0.0

Sum = 24251.6

	I	II	III	IV	V	VI
Area size	Iso.	Nomo.	Amt. 9.80	Avg. depth	ΔA	ΔV
	A	212	20.78	20.78	10	207.8
	B	198	19.40	20.09	15	301.4
4500/1	C	184	18.03	18.72	25	468.0
	D	170	16.66	17.34	50	867.0
	E	157	15.39	16.02	75	1201.5
	F	146	14.31	14.85	125	1856.2
	G	135	13.23	13.77	125	1721.2
	H	124	12.15	12.69	125	1586.2
	I	113	11.07	11.61	150	1741.5
	J	103	10.09	10.58	240	2539.2
	K	93	9.11	9.60	340	3264.0
	L	83	8.13	8.62	240	2068.8
	M	71	6.96	7.54	525	3958.5
	N	37	3.63	5.30	505	2676.5
	O	18	1.76	2.70	535	1444.5
(.60 X)	P	8	0.78	1.37	445	609.6
(.70 X)	Q	0	0.0	0.55	130	71.5

Sum = 26583.4

Area Size			Amt. 12.82			
	A	176	22.56	22.56	10	225.6
	B	165	21.15	21.86	15	327.9
2150/1	C	154	19.74	20.44	25	511.0
	D	142	18.20	18.97	50	948.5
	E	131	16.79	17.50	75	1312.5
	F	122	15.64	16.22	125	2027.5
	G	113	14.49	15.06	125	1882.5
	H	103	13.20	13.84	125	1730.0
	I	95	12.18	12.69	150	1903.5
	J	86	11.02	11.60	240	2784.0
	K	77	9.87	10.44	340	3549.6
	L	52	6.67	8.27	240	1984.8
	M	33	4.23	5.45	525	2861.2
	N	20	2.56	3.40	505	1717.0
	O	9	1.15	1.86	535	995.1
(.60 X)	P	2	0.26	0.79	445	351.6
(.70 X)	Q	0	0.0	0.18	130	23.4

Sum = 25135.7

Area Size			Amt. 8.50			
	A	233	19.80	19.80	10	198.0
	B	218	18.53	19.16	15	287.5
6500/1	C	203	17.26	17.90	25	447.4
	D	187	15.90	16.58	50	829.0
	E	174	14.79	15.34	75	1150.5
	F	160	13.60	14.20	125	1775.0
	G	148	12.58	13.09	125	1636.2
	H	137	11.64	12.11	125	1513.8
	I	125	10.62	11.14	150	1671.0
	J	113	9.60	10.11	240	2426.4
	K	103	8.76	9.18	340	3121.2
	L	93	7.90	8.33	240	1999.2
	M	81	6.88	7.39	525	3879.8
	N	70	5.95	6.42	505	3242.1
	O	29	2.46	4.20	535	2247.0
(.60 X)	P	13	1.10	1.92	445	854.4
(.70 X)	Q	1	0.08	0.79	130	102.7

Sum = 27381.2

Area size			Amt. 11.40			
	A	191	21.77	21.77	10	217.7
	B	179	20.41	21.09	15	316.4
3000/1	C	166	18.92	19.66	25	491.5
	D	154	17.56	18.24	50	912.0
	E	142	16.89	16.88	75	1266.0
	F	132	15.05	15.62	125	1952.5
	G	122	13.91	14.48	125	1810.0
	H	112	12.77	13.34	125	1667.5
	I	102	11.63	12.20	150	1830.0
	J	92	10.49	11.06	240	2654.4
	K	83	9.46	9.98	340	3393.2
	L	74	8.44	8.95	240	2148.0
	M	44	5.02	6.73	525	3533.2
	N	25	2.85	3.94	505	1989.7
	O	12	1.37	2.11	535	1128.8
(.60 X)	P	4	0.46	1.01	445	449.4
(.70 X)	Q	0	0.0	0.32	130	41.6

Sum = 25808.3

Area size			Amt. 7.05			
	A	262	18.47	18.47	10	184.7
	B	243	17.13	17.80	15	267.0
10000/1	C	227	16.00	16.56	25	414.1
	D	209	14.73	15.36	50	768.0
	E	194	13.68	14.20	75	1065.0
	F	178	12.55	13.11	125	1638.8
	G	166	11.70	12.12	125	1515.6
	H	152	10.72	11.21	125	1401.2
	I	140	9.87	10.30	150	1544.2
	J	128	9.02	9.44	240	2265.6
	K	117	8.25	8.64	340	2937.6
	L	107	7.54	7.90	340	1894.8
	M	93	6.56	7.05	525	3701.2
	N	82	5.78	6.16	505	3110.8
	O	68	4.79	5.28	535	2824.8
(.60 X)	P	27	1.90	3.63	445	1615.4
(.70 X)	Q	7	0.49	1.48	130	192.4

Sum = 27341.2

Table 26.—Completed computation sheets for 1st three 6-hr increments for alternate placement of pattern on Leon River, TX drainage - Continued

Increment: 1 to 3

Drainage: Leon River, TX Area: 3,660 mi^2 Date:

	I	II	III	IV	V	VI
Area size	Iso.	Nomo.	Amt. 5.80	Avg. depth	ΔA	ΔV
	A	290	16.82	16.82	10	168.2
	B	271	15.72	16.26	15	243.9
15000/1	C	253	14.67	15.20	25	379.9
	D	232	13.46	14.06	50	703.0
	E	214	12.41	12.94	75	970.5
	F	196	11.37	11.89	125	1486.2
	G	183	10.61	10.99	125	1373.8
	H	168	9.74	10.18	125	1272.5
	I	156	9.05	9.40	150	1410.0
	J	143	8.29	8.67	240	2080.8
	K	131	7.60	7.94	340	2699.6
	L	120	6.99	7.30	240	1752.0
	M	106	6.21	6.60	525	3465.0
	N	94	5.45	5.83	505	2944.2
	O	80	4.64	5.04	535	2696.4
(.60 X)	P	65	3.77	4.29	445	1909.0
(.70 X)	Q	18	1.04	2.95	130	383.5

Sum = 25938.5

	I	II	III	IV	V	VI
Area size	Iso.	Nomo.	Amt. 3.66	Avg. depth	ΔA	ΔV
	A	122	4.54	4.54	10	45.0
	B	120.5	4.41	4.48	15	67.2
10000/2	C	117	4.28	4.34	25	108.5
	D	115	4.21	4.245	59	212.2
	E	113	4.14	4.175	75	313.1
	F	111	4.06	4.10	125	512.5
	G	109	3.99	4.025	125	503.1
	H	107	3.92	3.96	125	494.4
	I	105.5	3.86	3.89	150	583.5
	J	104	3.81	3.84	240	920.5
	K	102.5	3.75	3.78	340	1285.2
	L	101	3.70	3.72	240	894.0
	M	99	3.62	3.66	525	1921.5
	N	97	3.55	3.58	505	1810.4
	O	95	3.48	3.52	535	1880.5
(.60 X)	P	50	1.83	2.82	445	1254.9
(.70 X)	Q	14	.51	1.43	130	185.9

Sum = 12992.4

Area size			Amt. 3.96			
	A	121	4.79	4.79	10	47.9
	B	117	4.63	4.71	15	70.6
4500/2	C	114	4.51	4.57	25	142.2
	D	112	4.44	4.48	50	224.0
	E	109.5	4.34	4.39	75	329.2
	F	108	4.28	4.31	125	538.8
	G	105.5	4.18	4.23	125	528.8
	H	103.5	4.10	4.14	125	517.5
	I	102	4.04	4.07	150	610.5
	J	100.5	4.00	4.02	240	964.8
	K	99	3.92	3.96	340	1346.4
	L	97.5	3.86	3.89	240	933.6
	M	96	3.80	3.83	525	2010.8
	N	59	2.34	3.07	505	1550.4
	O	39	1.54	1.94	535	1037.9
(.60 X)	P	17	0.67	1.19	445	529.6
(.70 X)	Q	00	0.00	0.47	130	61.1

Sum = 11416.1

Area size			Amt. 3.50			
	A	125	4.38	4.38	10	43.8
	B	122	4.27	4.33	15	64.9
15000/2	C	119	4.17	4.22	25	105.5
	D	117	4.10	4.14	50	207.0
	E	115	4.03	4.07	75	305.0
	F	113	3.96	4.00	125	500.0
	G	111	3.89	3.93	125	491.2
	H	109	3.82	3.86	125	482.5
	I	107	3.75	3.79	150	568.5
	J	106	3.71	3.73	240	895.2
	K	104	3.64	3.68	340	1251.2
	L	102.5	3.59	3.62	240	868.8
	M	101	3.54	3.57	525	1874.2
	N	99	3.47	3.51	505	1772.6
	O	97	3.40	3.44	535	1840.4
(.60 X)	P	96	3.36	3.38	445	1504.1
(.70 X)	Q	34	1.19	2.71	130	332.3

Sum = 13127.4

Area size			Amt. 3.82			
	A	122	4.66	4.66	10	46.6
	B	119	4.54	4.60	15	69.0
6500/2	C	115.5	4.41	4.48	25	112.0
	D	113	4.32	4.36	50	218.0
	E	111	4.24	4.28	75	321.0
	F	109	4.16	4.20	125	525.0
	G	107	4.08	4.12	125	515.0
	H	105	4.01	4.045	125	505.6
	I	104	3.97	3.99	150	598.5
	J	102	3.90	3.94	240	945.6
	K	100.5	3.84	3.87	340	1315.8
	L	99	3.78	3.81	240	914.4
	M	97.5	3.72	3.75	525	1968.8
	N	95.5	3.65	3.68	505	1858.4
	O	52.5	2.02	2.82	535	1508.7
(.60 X)	P	27.5	1.07	1.64	445	729.8
(.70 X)	Q	1.0	0.04	0.76	130	98.8

Sum = 12251.0

Area size			Amt. 2.58			
	A	106	2.73	2.73	10	27.3
	B	105	2.72	2.72	15	40.8
4500/3	C	104	2.68	2.695	25	67.4
	D	103.1	2.66	2.67	50	133.5
	E	102.1	2.63	2.645	75	198.4
	F	101.7	2.62	2.625	125	328.1
	G	101.2	2.61	2.615	125	326.9
	H	100.9	2.60	2.605	125	325.6
	I	100.6	2.60	2.60	150	390.0
	J	100.2	2.59	2.595	240	622.8
	K	99.9	2.58	2.585	340	878.9
	L	99.6	2.57	2.575	240	618.0
	M	99.3	2.56	2.565	525	1346.6
	N	76	1.96	2.26	505	1141.3
(.60 X)	O	49	1.26	1.61	535	861.4
(.70 X)	P	21	0.54	0.97	445	431.6
	Q	0	0.00	0.38	130	49.4

Sum = 7788.0

Table 26.—Completed computation sheets for 1st three 6-hr increments for alternate placement of pattern on Leon River, TX drainage - Continued

Increment: 3, 1

Drainage: Leon River, TX Area: 3,660 mi^2 Date:

	I	II	III	IV	V	VI
Area size	Iso.	Nomo.	Amt. 2.48	Avg. depth	ΔA	ΔV
	A	106.4	2.64	2.64	10	26.4
	B	105.5	2.62	2.63	15	39.4
6500/3	C	104.5	2.59	2.605	25	65.1
	D	103.5	2.57	2.58	50	129.0
	E	102.5	2.54	2.555	75	191.6
	F	102	2.53	2.535	125	316.9
	G	101.5	2.52	2.525	125	315.6
	H	101.2	2.51	2.515	125	314.4
	I	100.9	2.50	2.505	150	375.8
	J	100.5	2.49	2.495	240	598.8
	K	100.2	2.48	2.485	340	844.9
	L	99.8	2.48	2.48	240	595.2
	M	99.5	2.47	2.475	525	1299.4
	N	98.9	2.45	2.46	505	1242.3
	O	65	1.60	2.02	535	1080.7
(.60 X)	P	34.5	0.86	1.30	445	578.5
(.70 X)	Q	1	0.02	0.61	130	79.3

Sum = 8093.3

Area size			Amt. 2.36			
	A	106.8	2.52	2.52	10	25.2
	B	106	2.50	2.51	15	37.6
10000/3	C	105	2.48	2.49	25	62.2
	D	104	2.45	2.465	50	123.2
	E	102.8	2.43	2.44	75	183.0
	F	102.4	2.42	2.425	125	303.1
	G	101.9	2.41	2.415	125	301.9
	H	101.6	2.40	2.405	125	300.6
	I	101.3	2.39	2.395	150	359.2
	J	100.9	2.38	2.385	240	572.4
	K	100.5	2.37	2.375	340	807.5
	L	100.2	2.36	2.365	240	567.6
	M	99.8	2.36	2.36	525	1239.0
	N	99.2	2.34	2.35	505	1186.8
	O	98.7	2.33	2.335	535	1249.2
(.60 X)	P	59	1.37	1.95	445	867.8
(.70 X)	Q	18	0.42	1.08	130	140.4

Sum = 8326.7

Area size			Amt. 2.25			
	A	107.2	2.41	2.41	10	24.1
	B	106.5	2.40	2.405	15	36.1
15000/3	C	105.5	2.37	2.385	25	59.6
	D	104.4	2.35	2.36	50	118.0
	E	103.3	2.32	2.335	75	175.1
	F	102.8	2.31	2.315	125	289.4
	G	102.3	2.30	2.305	125	288.5
	H	102	2.30	2.30	125	287.5
	I	101.7	2.29	2.295	150	344.2
	J	101.2	2.28	2.285	240	548.4
	K	100.8	2.27	2.275	340	773.5
	L	100.5	2.26	2.265	240	543.6
	M	100.1	2.25	2.255	525	1183.9
	N	99.5	2.24	2.245	505	1133.7
	O	99	2.23	2.235	535	1195.7
	P	78	2.21	2.22	445	987.9
(.60 X)	Q	42	0.95	1.83	130	237.9
(.70 X)						

Sum = 8226.7

	I	II	III	IV	V	VI
Area size	Iso.	Nomo.	Amt. 7.70	Avg. depth	ΔA	ΔV
	A	247	18.98	18.98	10	189.8
	B	230	17.71	18.34	15	275.1
8000/1	C	214	16.48	17.10	25	427.5
	D	198	15.17	15.82	50	791.0
	E	183	14.09	14.63	75	1097.2
	F	169	12.97	13.53	125	1691.2
	G	157	12.01	12.49	125	1561.2
	H	144	11.09	11.55	125	1443.8
	I	132	10.16	10.62	150	1593.0
	J	120	9.28	9.72	240	2332.8
	K	110	8.43	8.86	340	3012.4
	L	99	7.62	8.02	240	1924.8
	M	87	6.70	7.16	525	3759.0
	N	75	5.81	6.26	505	3161.3
	-	69	5.31	5.56	320	1779.7
	O	40	3.08	4.20	215	903.0
(.60 X)	P	18	1.39	2.40	445	1068.0
(.70 X)	Q	4	0.31	1.07	130	139.1

Sum = 27149.6

Area size			Amt. 7.35			
	A	254	18.67	18.67	10	186.7
	B	237	17.42	18.04	15	270.6
9000/1	C	221	16.24	16.83	25	420.8
	D	203	14.92	15.58	50	779.0
	E	189	13.89	14.40	75	1080.0
	F	174	12.79	13.34	125	1667.5
	G	161	11.83	12.31	125	1538.8
	H	148	10.88	11.36	125	1420.0
	I	136	10.00	10.44	150	1566.0
	J	124	9.15	9.58	240	2299.2
	K	113	8.30	8.72	340	2964.8
	L	103	7.57	7.94	240	1905.6
	M	90	6.65	7.11	525	3732.8
	N	78	5.77	6.21	505	3136.0
	-	68	5.00	5.38	435	2340.3
	O	51	3.75	4.38	100	438.0
(.60 X)	P	22	1.62	2.90	445	1290.5
(.70 X)	Q	5	0.37	1.24	130	161.2

Sum = 27197.8

Area size			Amt. 6.40			
	A	274	17.54	17.54	10	175.4
	B	255	16.32	16.93	15	254.0
12000/1	C	238	15.23	15.78	25	394.5
	D	219	14.02	14.62	50	731.0
	E	203	12.99	13.50	75	1012.5
	F	186	11.90	12.44	125	1555.0
	G	174	11.14	11.52	125	1440.0
	H	159	10.18	10.66	125	1332.5
	I	147	9.41	9.80	150	1470.0
	J	135	8.64	9.02	240	2164.8
	K	123	7.87	8.26	340	2808.5
	L	113	7.23	7.55	240	1812.0
	M	99	6.34	6.78	525	3559.5
	N	87	5.57	5.96	505	3009.8
	O	73	4.67	5.12	535	2739.2
	-	67	4.29	4.48	220	985.6
(.60 X)	P	38	2.43	3.55	225	798.8
(.70 X)	Q	11	0.70	1.86	130	241.8

Sum = 26484.8

Table 26.—Completed computation sheets for 1st three 6-hr increments for alternate placement of pattern on Leon River, TX drainage - Continued

Increment: 2 to 3

Drainage: Leon River, TX Area: 3,660 mi^2 Date: ____

I		II	III	IV	V	VI
Area size	Iso.	Nomo.	Amt. 3.75	Avg. depth	ΔA	ΔV
	A	123	4.61	4.61	10	46.1
	B	120	4.50	4.56	15	68.4
8000/2	C	116.5	4.37	4.44	25	110.9
	D	114	4.28	4.32	50	216.0
	E	112	4.20	4.24	75	318.0
	F	100	4.12	4.16	125	520.0
	G	108	4.05	4.085	125	510.6
	H	106	3.98	4.015	125	501.9
	I	104.5	3.92	3.95	150	492.5
	J	103	3.86	3.89	240	933.6
	K	101.5	3.81	3.835	340	1303.9
	L	100	3.75	3.78	240	907.2
	M	98.5	3.69	3.72	525	1953.0
	N	96	3.60	3.63	505	1833.2
	-	95	3.56	3.58	320	1145.6
	O	66	2.48	3.02	215	649.3
(.60 X)	P	37	1.39	2.04	445	907.8
(.70 X)	Q	6	0.22	1.04	130	135.2

Sum = 12653.2

Area size			Amt. 3.70			
	A	123.5	4.57	4.57	10	45.7
	B	120	4.44	4.50	15	67.5
9000/2	C	117	4.33	4.38	25	109.5
	D	115	4.26	4.30	50	215.0
	E	113	4.18	4.24	75	318.0
	F	110.5	4.09	4.135	125	516.9
	G	108.5	4.01	4.05	125	506.2
	H	106.5	3.94	3.975	125	496.9
	I	104.5	3.87	3.905	150	585.8
	J	103.5	3.83	3.85	240	924.0
	K	102	3.77	3.80	340	1292.0
	L	100.5	3.72	3.745	240	898.8
	M	99	3.66	3.69	525	1937.2
	N	97	3.59	3.625	505	1830.6
	-	95	3.52	3.56	435	1548.6
	O	79	2.92	3.22	100	322.0
(.60 X)	P	43	1.59	2.39	445	1063.6
(.70 X)	Q	10	0.37	1.22	130	158.6

Sum = 12836.9

Area size			Amt. 3.58			
	A	124.5	4.46	4.46	10	44.6
	B	121	4.33	4.40	15	66.0
12000/2	C	118	4.22	4.28	25	107.0
	D	116	4.15	4.18	50	209.0
	E	114	4.08	4.12	75	309.0
	F	112	4.01	4.04	125	505.0
	G	110	3.94	3.98	125	497.5
	H	108	3.87	3.90	125	487.5
	I	106.5	3.81	3.84	150	576.0
	J	105	3.76	3.78	240	907.2
	K	103	3.69	3.72	340	1264.8
	L	102	3.65	3.67	240	880.8
	M	100	3.58	3.62	525	1900.5
	N	98	3.50	3.54	505	1787.7
	O	96	3.44	3.47	535	1856.4
	-	95	3.40	3.42	220	752.4
(.60 X)	P	64	2.29	2.96	225	666.0
(.70 X)	Q	21	0.75	1.83	130	237.9

Sum = 13055.3

I		II	III	IV	V	VI
Area size	Iso.	Nomo.	Amt. 2.41	Avg. depth	ΔA	ΔV
	A	106.6	2.57	2.57	10	25.7
	B	105.7	2.55	2.56	15	38.4
8000/3	C	104.8	2.52	2.535	25	63.4
	D	103.7	2.50	2.51	50	125.5
	E	102.7	2.48	2.49	75	186.8
	F	102.2	2.46	2.47	125	308.8
	G	101.7	2.45	2.455	125	306.9
	H	101.4	2.44	2.445	125	305.6
	I	101.1	2.44	2.44	150	366.0
	J	100.7	2.43	2.435	240	584.4
	K	100.3	2.42	2.425	340	824.5
	L	100	2.41	2.415	240	579.6
	M	99.6	2.40	2.405	525	1262.6
	N	99	2.38	2.39	505	1207.0
	-	99	2.38	2.38	320	761.6
	O	79	1.90	2.14	215	460.1
(.60 X)	P	45	1.08	1.57	445	698.6
(.70 X)	Q	8	0.19	0.81	130	105.3

Sum = 8210.8

Area size			Amt. 2.37			
	A	106.7	2.53	2.53	10	25.3
	B	105.8	2.51	2.52	15	37.8
9000/3	C	104.9	2.49	2.50	25	62.5
	D	103.8	2.46	2.475	50	123.8
	E	102.7	2.43	2.445	75	183.4
	F	102.3	2.42	2.425	125	303.1
	G	101.8	2.41	2.415	125	301.9
	H	101.5	2.40	2.405	125	300.6
	I	101.2	2.40	2.40	150	360.0
	J	100.8	2.39	2.395	240	574.8
	K	100.5	2.38	2.385	340	810.9
	L	100	2.37	2.375	240	570.0
	M	99.7	2.36	2.365	525	1241.6
	N	99.1	2.35	2.355	505	1189.3
	-	99	2.35	2.35	435	1022.2
	O	88	2.08	2.215	100	221.5
(.60 X)	P	52	1.23	1.74	445	774.3
(.70 X)	Q	12	0.28	0.94	130	122.2

Sum = 8225.2

Area size			Amt. 2.30			
	A	107	2.46	2.46	10	24.6
	B	106.2	2.44	2.45	15	36.8
12000/3	C	105.3	2.42	2.43	25	60.8
	D	104.2	2.40	2.41	50	120.5
	E	103.0	2.37	2.385	75	178.9
	F	102.6	2.36	2.365	125	295.6
	G	102.1	2.35	2.355	125	294.4
	H	101.8	2.34	2.345	125	293.1
	I	101.5	2.33	2.335	150	350.2
	J	101	2.32	2.325	240	558.0
	K	100.7	2.32	2.32	340	788.8
	L	100.3	2.31	2.315	240	555.6
	M	99.9	2.30	2.305	525	1210.1
	N	99.3	2.28	2.29	505	1156.4
	O	98.8	2.27	2.275	535	1217.1
	-	98.3	2.26	2.265	220	498.3
(.60 X)	P	71.5	1.64	2.01	225	452.2
(.70 X)	Q	27.5	0.63	1.34	130	174.2

Sum = 8265.6

In view of this result, and considering the elongated shape of the drainage, greater volume might have been obtained had the pattern in figure 49 been centered at one of the fatter parts of the drainage. By doing so, it appears possible that the H isohyet could be totally enclosed in the drainage when compared with the F isohyet as placed in figure 49. However, there would be proportionately lower volumes contributed from the rest of the drainage.

We will not carry this example beyond this point, as to do so would repeat the procedure demonstrated in example 1a. The objective of this example has been to show that, particularly for a long drainage, alignment of the isohyetal pattern (isohyets reduced for orientation) with the drainage axis will generally give greater volume than will a non-aligned pattern of unreduced isohyets.

7.4 Example No. 2a

The second example describes the effect of a drainage-centered pattern vs. a pattern placement that may be considered for obtaining peak discharge. Also considered in this example will be the evaluation of subdrainages.

For this example we chose the Ouachita River, Arkansas, above Rennel Dam, a drainage encompassing about 1,600 mi^2. The drainage outline drawn to a map scale of 1:1,000,000 is shown in figure 50 and includes four typical subdrainages. The areas within the four subdrainages are:

		Area (mi^2)
1.	Above Pine Ridge	300
2.	Between Pine Ridge and Washita	278
3.	Between Washita and Blakely Mt. Dam	604
4.	Between Blakely Mt. Dam and Rennel Dam	418

As in example 1a we will concern ourselves with determining the storm area size of the PMP pattern that provides the maximum volume within the entire 1,600 mi^2 drainage.

The following steps correspond to those outlined in section 7.1.

Step

A1. The drainage center for the Ouachita River above Rennel Dam is roughly 34°36'N, 93°27'W. At this location, the following table of values is obtained from figures 18 through 42 of HMR No. 51.

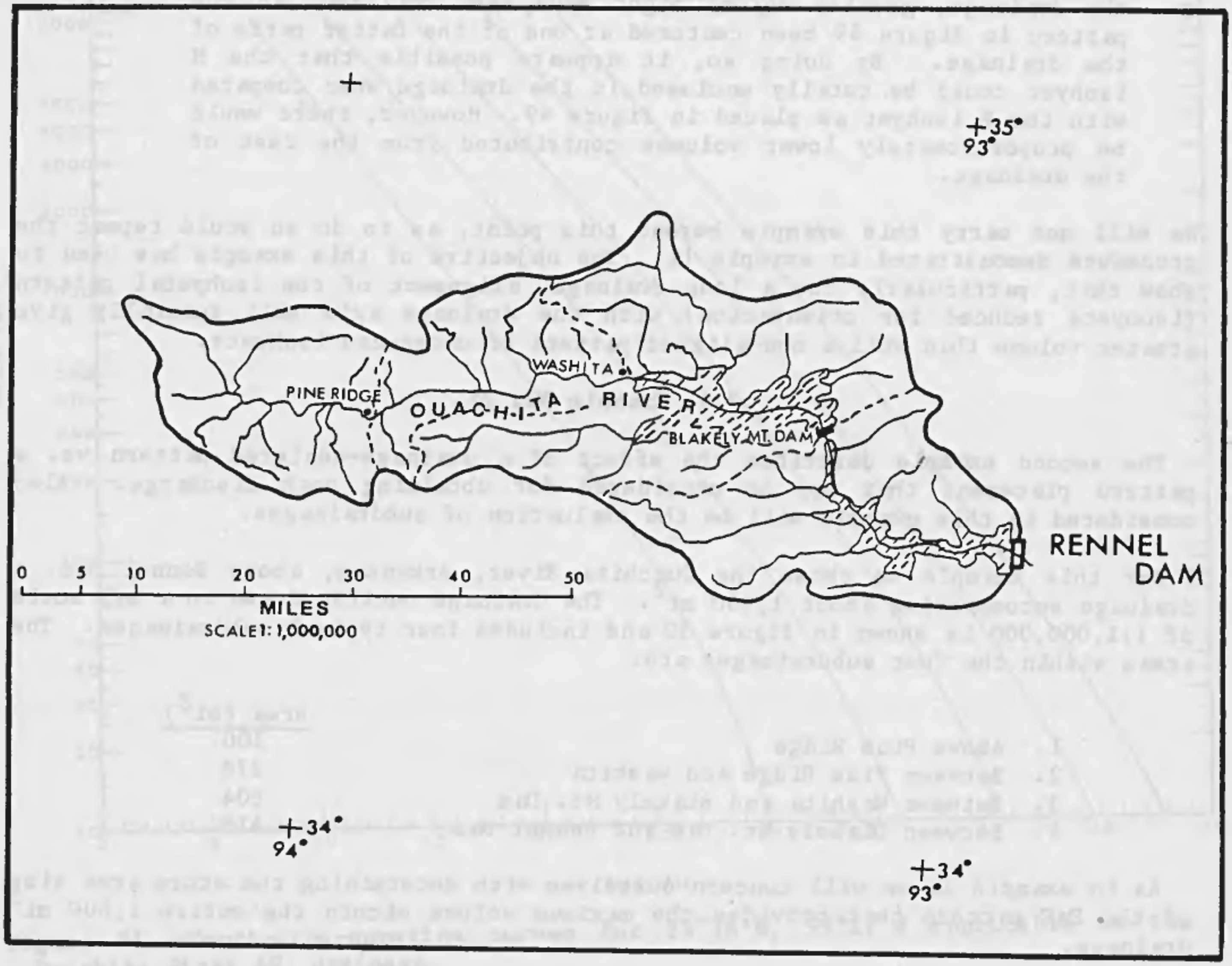

Figure 50.—Ouachita River, AR (1,600 mi^2) above Rennel Dam showing drainage.

	Duration (hr)				
Area (mi^2)	6	12	24	48	72
10	30.0	35.9	40.6	44.6	47.1
200	22.2	27.0	31.2	34.7	37.7
1000	16.3	21.0	25.3	29.0	31.2
5000	9.5	13.5	17.7	21.6	24.2
10000	7.3	10.7	14.0	18.0	20.8

A2. The storm-area averaged PMP depths in step A1 are plotted in figure 51 and smooth curves drawn. Notice that to obtain a consistent set of curves, it has not been possible to draw through all the data points.

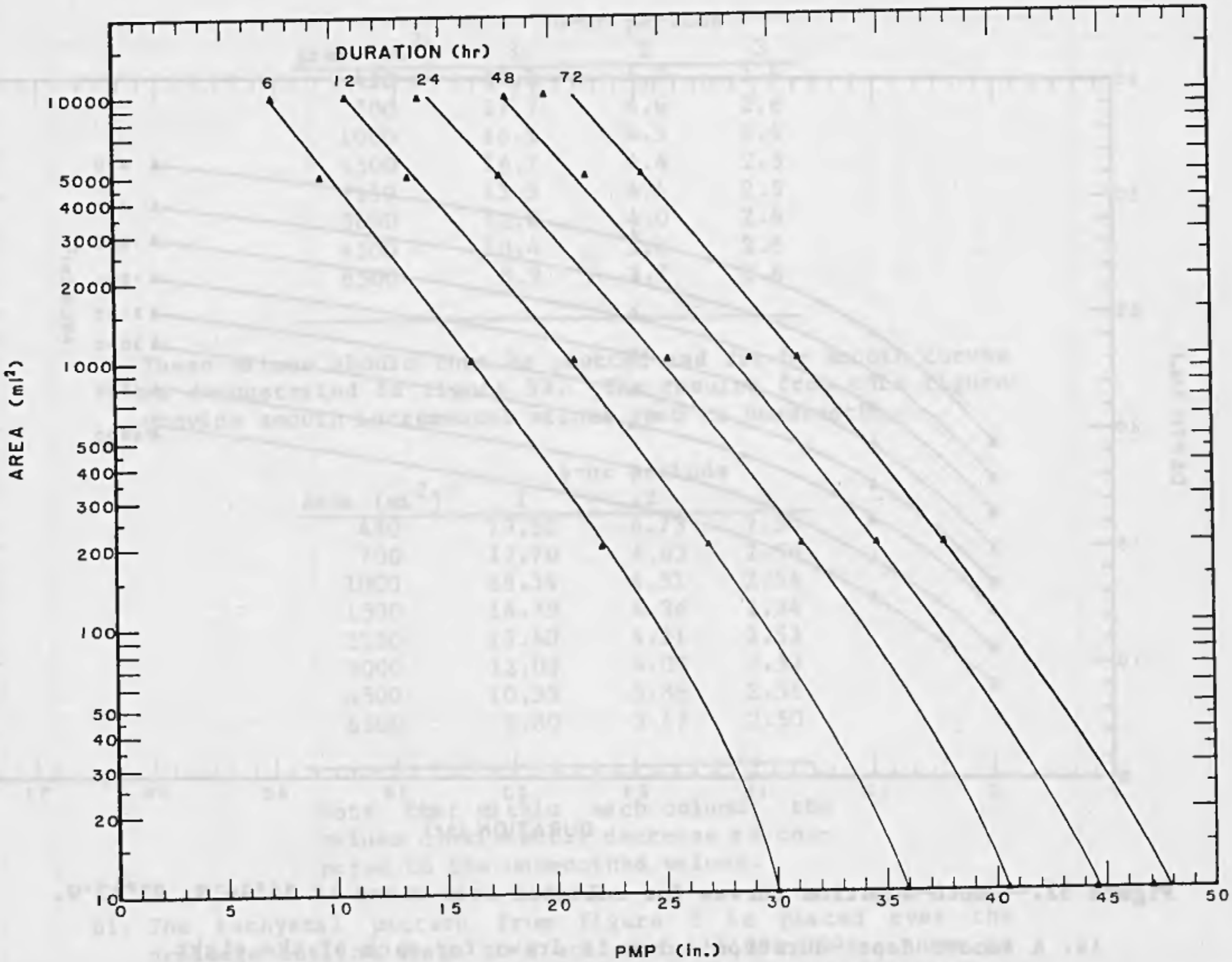

Figure 51.—Depth-area-duration curves for 34°36'N, 93°27'W applicable to the Ouachita River AR, drainage.

A3. From figure 51 we read off the data for at least 4 standard isohyet area sizes larger and smaller than the area of the drainage. We have chosen the areas in the following table.

	Duration (hr)				
Area (mi^2)	6	12	24	48	72
450	19.3	24.0	28.2	31.2	34.3
700	17.7	22.3	26.3	29.5	32.6
1000	16.3	20.8	24.9	28.0	31.1
1500	14.7	19.1	23.1	26.4	29.4
2150	13.3	17.5	21.5	24.8	27.8
3000	12.0	16.0	20.0	23.4	26.4
4500	10.4	14.2	18.2	21.5	24.6
6500	8.9	12.6	16.5	19.8	23.0

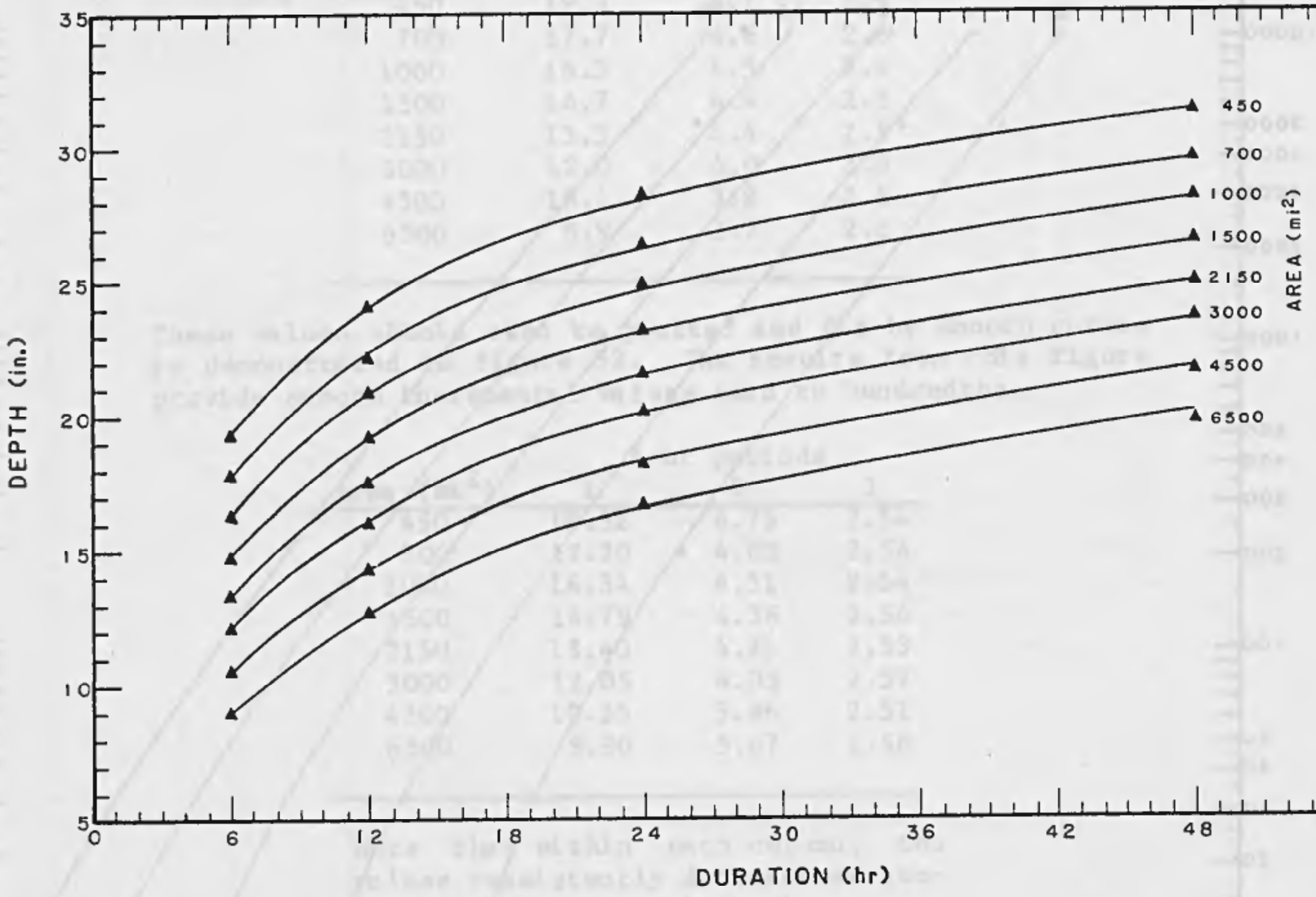

Figure 52.—Depth-duration curves for selected area sizes at 34°36'N, 93°27'W.

A4. A smooth depth-duration curve is drawn for each of the eight area sizes listed in step A3, as shown in figure 52. From these curves, values are interpolated for 18-hr durations.

Area (mi^2)	18-hr Duration
450	26.5
700	24.9
1000	23.2
1500	21.6
2150	20.0
3000	18.6
4500	16.8
6500	15.2

A5. Incremental differences are obtained for the 1st three 6-hr periods through subtraction of successive 6-hr values.

Area (mi^2)	6-hr periods 1	2	3
450	19.3	4.7	2.5
700	17.7	4.6	2.6
1000	16.3	4.5	2.4
1500	14.7	4.4	2.5
2150	13.3	4.4	2.5
3000	12.0	4.0	2.6
4500	10.4	3.8	2.6
6500	8.9	3.7	2.6

These values should then be plotted and fit by smooth curves as demonstrated in figure 53. The results from this figure provide smooth incremental values read to hundredths.

Area (mi^2)	6-hr periods 1	2	3
450	19.32	4.73	2.54
700	17.70	4.63	2.54
1000	16.34	4.51	2.54
1500	14.79	4.36	2.54
2150	13.40	4.21	2.53
3000	12.05	4.05	2.52
4500	10.35	3.86	2.51
6500	8.80	3.67	2.50

Note that within each column, the values consistently decrease as compared to the unsmoothed values.

B1. The isohyetal pattern from figure 5 is placed over the drainage outline drawn to a scale of 1:1,000,000 as shown in figure 54. It was judged that the best fit of the isohyetal pattern was to enclose the H isohyet by the drainage outline.

B2. For the isohyetal pattern placement in figure 54, the orientation is 095°. Since this orientation does not fall between the specified range of 135° and 315°, we add 180° to get an orientation of 275° (effectively the other end of the orientation line).

B3. From figure 8, the orientation for PMP at 34°36'N, 93°27'W is about 235°. The difference between the orientation of the pattern laid over the drainage and that of PMP from figure 8 is 40°. On the basis of the model shown in figure 10, no adjustment need be made to the values in step A5.

B4. This step is skipped as no reduction is required.

C. Now we can determine the maximum volume for PMP isohyetal pattern areas given in step A5. This computation is performed using the form provided in figure 41 and is completed for the

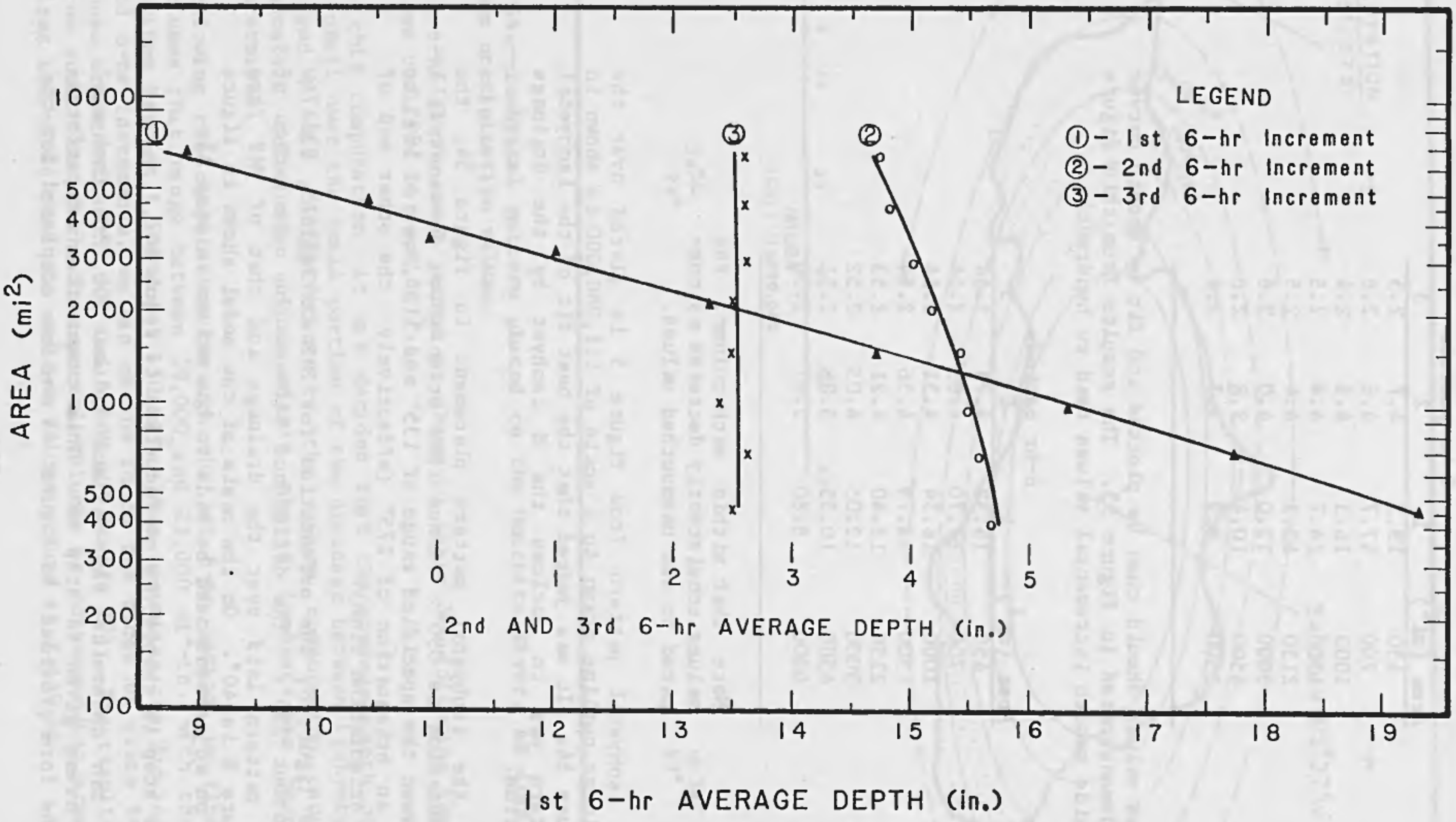

Figure 53.--Smoothing curves for 6-hr incremental values at selected area sizes for Ouachita River, AR drainage.

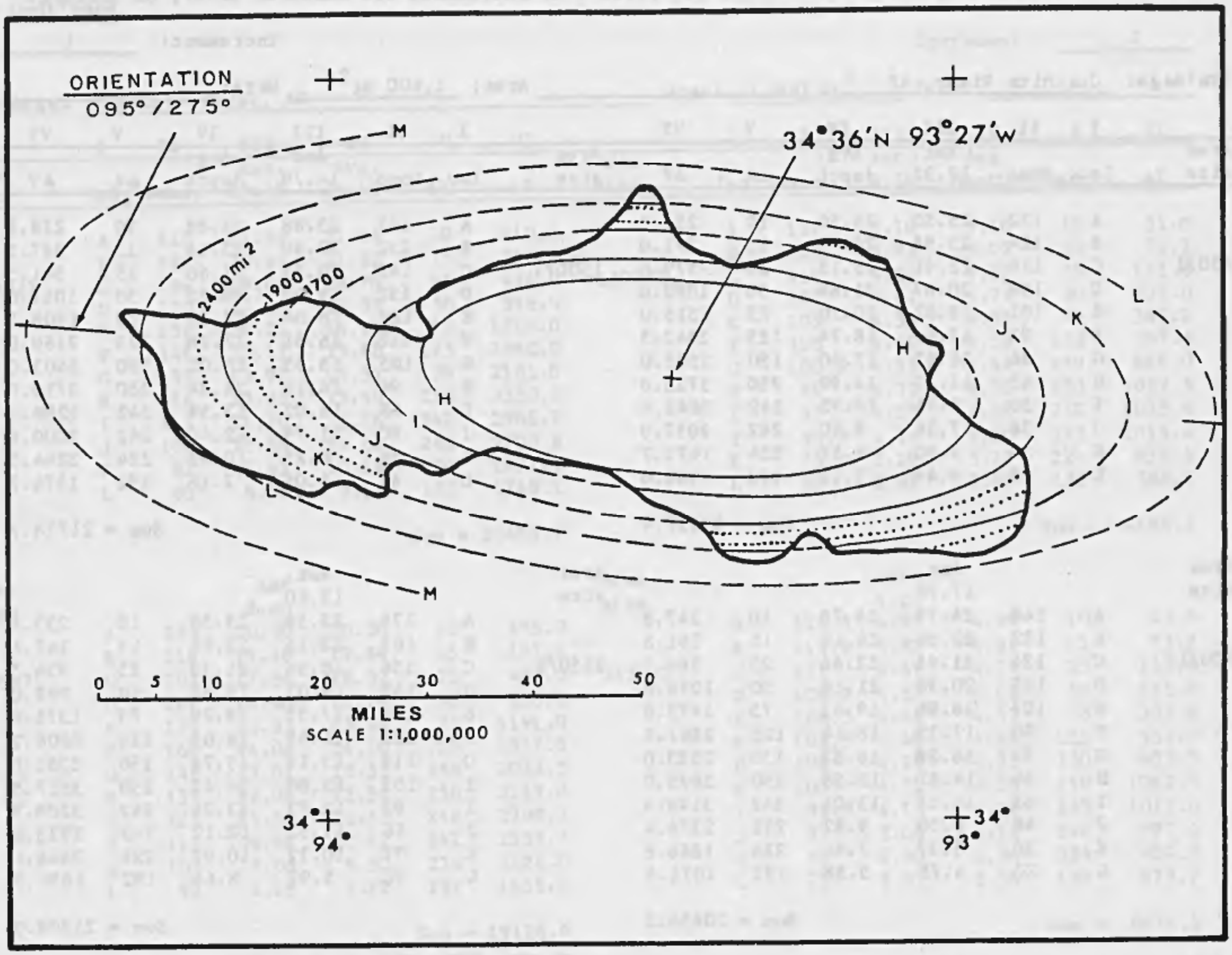

Figure 54.—Isohyetal pattern placed on the Ouachita River, AR drainage to give maximum precipitation volume.

1st 6-hr incremental period as shown in table 27, following the steps outlined in section 7.1c.

In this computation, it was decided that the average depth of rainfall over the small portion of the drainage between isohyets L and M was insignificant to the volume computation, and therefore only the volume within the L isohyet has been determined.

Following the computation through the 1st 6-hr period, we find volumes that range between 19,000 and 22,000 mi^2-in. with the maximum between 1,500 and 2,150 mi^2. When computing the 2nd and 3rd 6-hr increments, we can narrow in on the range of areas to those areas between 1,000 and 4,500 mi^2 (table 27). The results from summation of the incremental volumes at corresponding area sizes indicates that the maximum volume occurs at 2,150 mi^2.

Table 27.—Completed computation sheets for 1st three 6-hr increments for Ouachita River, AR drainage

Increment: 1

Drainage: Ouachita River, AR Area: 1,600 mi^2 Date: ____

Area size	I Iso.	II Nomo.	III Amt. 19.32	IV Avg. depth	V ΔA	VI ΔV	Area size	I Iso.	II Nomo.	III Amt. 14.79	IV Avg. depth	V ΔA	VI ΔV
	A	132	25.50	25.50	10	255.0		A	162	23.88	23.88	10	238.8
	B	124	23.96	24.73	15	371.0		B	152	22.40	23.14	15	347.1
450/1	C	116	22.41	23.18	25	579.6	1500/1	C	142	20.93	21.66	25	541.5
	D	108	20.87	21.64	50	1082.0		D	132	19.52	20.22	50	1011.0
	E	101	19.52	20.20	75	1515.0		E	122	18.04	18.78	75	1408.5
	F	93	17.97	18.74	125	2342.5		F	112	16.51	17.28	125	2160.0
	G	86	16.62	17.30	150	2593.0		G	105	15.53	16.02	150	2403.0
	H	63	12.17	14.90	250	3725.0		H	96	14.15	24.84	250	3710.0
	I	50	9.66	10.92	242	2642.6		I	88	13.02	13.59	242	3288.8
	J	38	7.34	8.50	242	2057.0		J	80	11.79	12.40	242	3000.8
	K	30	5.80	6.57	224	1471.7		K	56	8.25	10.02	224	2244.5
	L	23	4.44	5.12	192	983.0		L	41	6.06	7.16	192	1374.7
						Sum = 19617.4							Sum = 21728.7
Area size			Amt. 17.70				Area size			Amt. 13.40			
	A	140	24.78	24.78	10	247.8		A	176	23.58	23.58	10	235.8
	B	132	23.36	24.12	15	361.8		B	165	22.11	22.84	15	342.6
700/1	C	124	21.95	22.66	25	566.5	2150/1	C	154	20.64	21.38	25	534.5
	D	115	20.36	21.16	50	1058.0		D	142	19.03	19.84	50	992.0
	E	107	18.94	19.65	75	1473.8		E	131	17.55	18.29	75	1371.8
	F	98	17.35	18.14	125	2267.5		F	122	16.35	16.05	125	2006.2
	G	92	16.28	16.82	150	2523.0		G	113	15.14	15.74	150	2361.0
	H	84	14.87	15.58	250	3895.0		H	103	13.80	14.47	250	3617.5
	I	63	11.15	13.01	242	3148.4		I	95	12.73	13.26	242	3208.9
	J	48	8.50	9.82	242	2376.4		J	86	11.52	12.12	242	2933.0
	K	36	6.37	7.44	224	1666.6		K	77	10.32	10.92	224	2446.1
	L	27	4.78	5.58	192	1071.4		L	52	5.97	8.64	192	1658.9
						Sum = 20656.2							Sum = 21708.3
Area size			Amt. 16.34				Area size			Amt. 12.05			
	A	149	24.35	24.35	10	243.5		A	191	23.02	23.02	10	230.2
	B	140	22.88	23.58	15	353.7		B	179	21.57	22.30	15	334.5
1000/1	C	131	21.41	22.12	25	553.0	3000/1	C	166	20.00	20.78	25	519.5
	D	122	19.93	20.67	50	1033.5		D	154	18.56	19.28	50	964.0
	E	113	18.46	19.20	75	1440.0		E	142	17.11	17.84	75	1338.0
	F	104	16.99	17.72	125	2215.0		F	132	15.91	16.51	125	2063.8
	G	97	15.85	16.42	150	2463.0		G	122	14.70	15.30	150	2295.0
	H	89	14.54	15.20	250	3800.0		H	112	13.50	14.10	250	3525.0
	I	82	13.40	13.97	242	3380.7		I	102	12.29	12.90	242	3121.8
	J	60	9.80	11.60	242	2807.2		J	92	11.09	11.69	242	2829.0
	K.	44	7.19	8.50	224	1904.0		K	83	9.88	10.48	224	2347.5
	L	32	5.23	6.21	192	1192.3		L	74	8.92	9.40	192	1804.8
						Sum = 21385.9							Sum = 21373.1

Table 27.—Completed computation sheets for 1st three 6-hr increments for Ouachita River, AR drainage - Continued

Increment: 1, 2

Drainage: Ouachita River, AR Area: 1,600 mi^2 Date: ____

Area size	I Iso.	II Nomo.	III Amt. 10.35	IV Avg. depth	V ΔA	VI ΔV	Area size	I Iso.	II Nomo.	III Amt. 4.36	IV Avg. depth	V ΔA	VI ΔV
	A	212	21.94	21.94	10	219.4		A	117	5.10	5.10	10	51.0
	B	198	20.49	21.22	15	318.3		B	113	4.93	5.02	15	74.2
4500/1	C	184	19.04	19.76	25	494.0	1500/2	C	110	4.80	4.87	25	121.8
	D	170	17.60	18.32	50	916.0		D	107	4.67	4.74	50	237.0
	E	157	16.25	16.92	75	1269.0		E	105	4.58	4.63	75	347.2
	F	146	15.11	15.68	125	1960.0		F	103	4.49	4.54	125	567.5
	G	135	13.97	14.54	150	2181.0		G	100.5	4.38	4.44	150	666.0
	H	124	12.83	13.40	250	3350.0		H	99	4.32	4.35	250	1087.5
	I	113	11.70	12.26	242	2966.9		I	97	4.23	4.28	242	1035.8
	J	103	10.66	11.18	242	2705.6		J	95.5	4.16	4.20	242	1016.4
	K	93	9.63	10.14	224	2271.4		K	75.5	3.29	3.73	224	835.5
	L	83	8.59	9.11	192	1749.1		L	60	2.62	2.96	192	568.3
					Sum =	20409.7						Sum =	6608.2
Area size			Amt. 8.80				Area size			Amt. 4.21			
	A	233	20.50	20.50	10	205.0		A	118.5	4.99	4.99	10	49.9
	B	218	19.18	19.84	15	297.6		B	114.5	4.82	4.91	15	73.7
6500/1	C	203	17.86	18.52	25	463.0	2150/2	C	111	4.67	4.75	25	118.8
	D	187	16.46	17.16	50	858.0		D	108.5	4.57	4.62	50	231.0
	E	174	15.31	15.88	75	1191.0		E	106.5	4.48	4.53	75	339.8
	F	160	14.08	14.70	125	1837.5		F	104.5	4.40	4.44	125	555.0
	G	148	13.02	13.55	150	2032.5		G	102	4.29	4.35	150	652.5
	H	137	12.06	12.54	250	3135.0		H	100	4.21	4.25	250	1062.5
	I	125	11.00	11.53	242	2790.3		I	98.5	4.15	4.18	242	1011.6
	J	113	9.94	10.47	242	2533.7		J	97	3.08	4.12	242	997.0
	K	103	9.06	9.50	224	2128.0		K	95	4.00	4.04	224	904.9
	L	93	8.18	8.62	192	1655.0		L	73	3.07	3.54	192	679.7
					Sum =	19126.6						Sum =	6676.4
Area size			Amt. 4.51				Area size			Amt. 4.05			
	A	116	5.23	5.23	10	52.3		A	119.5	4.84	4.84	10	48.4
	B	112	5.05	5.14	15	77.1		B	116	4.70	4.77	15	71.6
1000/2	C	108.5	4.89	4.97	25	124.3	3000/2	C	112.5	4.56	4.63	25	115.8
	D	105	4.74	4.82	50	241.0		D	110	4.46	4.51	50	225.5
	E	103	4.65	4.70	75	352.5		E	108	4.37	4.42	75	331.5
	F	101	4.56	4.61	125	576.2		F	106	4.29	4.33	125	541.3
	G	99	4.46	4.51	150	676.5		G	104	4.21	4.25	150	637.5
	H	97	4.37	4.42	250	1105.0		H	102	4.13	4.17	250	1042.5
	I	95	4.28	4.33	242	1047.9		I	100	4.05	4.09	242	989.8
	J	76	3.43	3.86	242	934.1		J	99	4.01	4.03	242	975.3
	K	63	2.48	3.14	224	703.4		K	97	3.93	3.97	224	889.3
	L	51	2.30	2.57	192	493.4		L	96	3.89	3.91	192	750.7
					Sum =	6383.7						Sum =	6619.2

Table 27.—Completed computation sheets for 1st three 6-hr increments for Ouachita River, AR drainage - Continued

Increment: 2, 3

Drainage: Ouachita River, AR Area: 1,600 mi^2 Date:

	I	II	III	IV	V	VI
Area size	Iso.	Nomo.	Amt. 3.86	Avg. depth	ΔA	ΔV
	A	121	4.67	4.67	10	46.7
	B	117	4.52	4.60	15	68.9
4500/2	C	114	4.40	4.46	25	111.5
	D	112	4.32	4.36	50	218.0
	E	109.5	4.23	4.28	75	321.0
	F	108	4.17	4.20	125	525.0
	G	105.5	4.07	4.12	150	618.0
	H	103.5	4.00	4.04	250	1010.0
	I	102	3.94	3.97	242	960.7
	J	100.5	3.88	3.91	242	946.2
	K	99	3.82	3.85	224	862.4
	L	97.5	3.76	3.79	192	727.7
					Sum =	6416.1

Area size			Amt. 2.54			
	A	104.6	2.66	2.66	10	26.6
	B	103.3	2.62	2.64	15	39.6
1000/3	C	102.3	2.60	2.61	25	65.3
	D	101.3	2.57	2.59	50	129.5
	E	100.6	2.56	2.57	75	192.8
	F	100.3	2.55	2.56	125	320.0
	G	99.9	2.54	2.55	150	382.5
	H	99.6	2.53	2.54	250	635.0
	I	99.3	2.52	2.53	242	612.3
	J	82.5	2.10	2.31	242	559.0
	K	67	1.70	1.90	224	425.6
	L	54	1.37	1.54	192	295.7
					Sum =	3683.9

Area size			Amt. 2.54			
	A	105	2.67	2.67	10	26.7
	B	103.8	2.64	2.66	15	39.8
1500/3	C	102.7	2.61	2.63	25	65.8
	D	101.7	2.58	2.60	50	130.0
	E	101.0	2.57	2.58	75	193.5
	F	100.7	2.56	2.57	125	321.2
	G	100.3	2.55	2.56	150	384.0
	H	100	2.54	2.55	250	637.5
	I	99.7	2.53	2.535	242	613.5
	J	99.4	2.52	2.525	242	611.0
	K	81	2.06	2.29	224	513.0
	L	65.5	1.66	1.86	192	357.1
					Sum =	3893.1

	I	II	III	IV	V	VI
Area size	Iso.	Nomo.	Amt. 2.53	Avg. depth	ΔA	ΔV
	A	105.3	2.66	2.66	10	26.6
	B	104.2	2.64	2.65	15	39.8
2150/3	C	103.2	2.61	2.625	25	65.6
	D	102	2.58	2.595	50	129.8
	E	101.3	2.56	2.57	75	192.8
	F	101	2.56	2.56	125	320.0
	G	100.6	2.54	2.55	150	382.5
	H	100.3	2.54	2.54	250	635.0
	I	100	2.52	2.53	242	612.3
	J	99.7	2.52	2.52	242	609.8
	K	99.5	2.52	2.525	224	565.6
	L	80.5	2.04	2.28	192	437.8
					Sum =	4017.6

Area size			Amt. 2.51			
	A	105.7	2.65	2.65	10	26.5
	B	104.6	2.63	2.64	15	39.6
3000/3	C	103.5	2.60	2.62	25	65.4
	D	102.5	2.57	2.59	50	129.5
	E	101.7	2.55	2.56	75	192.0
	F	101.3	2.54	2.55	125	318.8
	G	100.9	2.53	2.54	150	381.0
	H	100.5	2.52	2.53	250	632.5
	I	100.2	2.52	2.52	242	609.8
	J	99.9	2.51	2.52	242	609.8
	K	99.6	2.50	2.51	224	562.2
	L	99.2	2.49	2.50	192	480.0
					Sum =	4046.8

Area size			Amt. 2.51			
	A	106	2.66	2.66	10	26.6
	B	105	2.64	2.65	15	39.8
4500/3	C	104	2.61	2.63	25	65.8
	D	103.1	2.59	2.60	50	130.0
	E	102.1	2.56	2.58	75	193.5
	F	101.7	2.55	2.56	125	320.0
	G	101.2	2.54	2.55	150	382.5
	H	100.9	2.53	2.54	250	635.0
	I	100.6	2.53	2.53	242	612.3
	J	100.2	2.52	2.53	242	612.3
	K	99.9	2.51	2.52	224	564.5
	L	99.6	2.50	2.51	192	481.9
					Sum =	4064.2

Table 27.—Completed computation sheets for 1st three 6-hr increments for Ouachita River, AR drainage - Continued

Increment: 1, 2

Drainage: Ouachita River, AR Area: 1,600 mi^2 Date: ______

	I	II	III	IV	V	VI
Area size	Iso.	Nomo.	Amt. 14.30	Avg. depth	ΔA	ΔV
	A	167	23.88	23.88	10	238.8
	B	156	22.31	23.10	15	346.4
1700/1	C	145	20.74	21.52	25	538.1
	D	135	19.30	20.02	50	1001.0
	E	125	17.88	18.59	75	1394.2
	F	116	16.59	17.24	125	2155.0
	G	107	15.30	15.94	150	2391.0
	H	98	14.01	14.52	250	3630.0
	I	91	13.01	13.51	242	3269.4
	J	82	11.73	12.37	242	2993.5
	–	79	11.30	11.52	87	1002.2
	K	62	8.87	10.08	137	1381.0
	L	44	6.29	7.58	192	1455.4
					Sum =	21796.0
Area size			Amt. 13.85			
	A	171	23.68	23.68	10	236.8
	B	160	22.16	22.92	15	343.8
1900/1	C	149	20.64	21.40	25	535.0
	D	138	19.11	19.88	50	994.0
	E	128	17.73	18.42	75	1381.5
	F	118	16.34	17.03	125	2128.8
	G	110	15.24	15.79	150	2368.5
	H	100	13.85	14.54	250	3635.0
	I	93	12.88	13.36	242	3233.1
	J	84	11.63	12.26	242	2966.9
	–	78	10.80	11.22	144	1615.7
	K	68	9.42	10.11	80	808.8
	L	48	6.65	8.04	192	1543.7
					Sum =	21791.6
Area size			Amt. 12.94			
	A	181	23.42	23.42	10	234.2
	B	169	21.87	22.64	15	339.6
2400/1	C	158	20.44	21.16	25	528.9
	D	146	18.89	19.66	50	983.0
	E	134	17.34	18.12	75	1359.0
	F	125	16.18	16.76	125	2095.0
	G	116	15.01	15.60	150	2340.0
	H	106	13.72	14.36	250	3590.0
	I	97	12.55	13.14	242	3179.9
	J	88	11.39	11.97	242	2896.7
	K	79	10.22	10.77	224	2412.5
	–	76	9.83	10.80	70	756.0
	L	58	7.50	8.67	122	1057.7
					Sum =	21772.5

	I	II	III	IV	V	VI
Area size	Iso.	Nomo.	Amt. 4.30	Avg. depth	ΔA	ΔV
	A	117.5	5.05	5.05	10	50.5
	B	114	4.90	4.98	15	74.6
1700/2	C	110.5	4.75	4.83	25	120.8
	D	107.5	4.62	4.69	50	234.5
	E	105	4.52	4.57	75	342.8
	F	103.5	4.45	4.49	125	561.2
	G	101	4.34	4.40	150	660.0
	H	99	4.26	4.30	250	1075.0
	I	97	4.17	4.22	242	1021.2
	J	96	4.13	4.15	242	1004.3
	–	95.5	4.10	4.12	87	358.4
	K	80	3.44	3.77	137	516.5
	L	64	2.74	3.07	192	589.4
					Sum =	6609.2
Area size			Amt. 4.25			
	A	118	5.02	5.02	10	50.2
	B	116	4.93	4.98	15	74.6
1900/2	C	111	4.72	4.83	25	120.8
	D	108	4.59	4.66	50	233.0
	E	106	4.51	4.5	75	341.3
	F	104	4.42	4.47	125	558.8
	G	102	4.34	4.38	150	657.0
	H	100	4.25	4.30	250	1075.0
	I	98	4.17	4.21	242	1018.8
	J	96.6	4.10	4.14	242	1001.9
	–	95.5	4.06	4.08	144	587.5
	K	86	3.66	3.86	80	308.8
	L	68	2.87	3.28	192	629.8
					Sum =	6657.5
Area size			Amt. 4.15			
	A	119	4.94	4.94	10	49.4
	B	115	4.77	4.86	15	72.8
2400/2	C	112	4.65	4.71	25	117.8
	D	109	4.52	4.59	50	229.3
	E	107	4.44	4.48	75	336.0
	F	105	4.36	4.40	125	550.0
	G	103	4.27	4.32	150	647.3
	H	101	4.19	4.23	250	1057.5
	I	99	4.11	4.15	242	1004.3
	J	97.5	4.05	4.08	242	987.4
	K	96.5	4.00	4.025	224	901.6
	–	96	3.98	3.99	70	279.3
	L	78	3.24	3.61	122	440.4
					Sum =	6613.1

Table 27.—Completed computation sheets for 1st three 6-hr increments for Ouachita River, AR drainage - Continued

Increment: 3

Drainage: Ouachita River, AR   Area: 1,600 mi^2 Date:

Area size	I Iso.	II Nomo.	III Amt. 2.54	IV Avg. depth	V ΔA	VI ΔV	Area size	I Iso.	II Nomo.	III Amt.	IV Avg. depth	V ΔA	VI ΔV
	A	105.1	2.67	2.67	10	26.7							
	B	104	2.64	2.66	15	39.8							
1700/3	C	102.8	2.61	2.63	25	65.8							
	D	101.9	2.59	2.60	50	130.0							
	E	101.1	2.57	2.58	75	193.5							
	F	100.7	2.56	2.57	125	321.2							
	G	100.4	2.55	2.56	150	384.0							
	H	100	2.54	2.55	250	637.5							
	I	99.7	2.53	2.54	242	614.7							
	J	99.5	2.53	2.53	242	612.3							
	–	99.3	2.52	2.525	87	219.7							
	K	86	2.18	2.35	137	322.0							
	L	70	1.78	1.98	192	380.2							
					Sum =	3947.4							

Area size			Amt. 2.53			
	A	105.2	2.66	2.66	10	26.6
	B	104.1	2.63	2.65	15	39.7
1900/3	C	103	2.61	2.62	25	65.5
	D	102	2.58	2.60	50	130.0
	E	101.2	2.56	2.57	75	192.8
	F	100.8	2.55	2.56	125	320.0
	G	100.5	2.54	2.55	150	382.5
	H	100.2	2.54	2.54	250	635.0
	I	99.8	2.52	2.53	242	612.3
	J	99.6	2.52	2.52	242	609.8
	–	99.4	2.51	2.525	144	363.4
	K	92	2.33	2.42	80	193.6
	L	75	1.90	2.12	192	407.0
					Sum =	3978.2

Area size			Amt. 2.52			
	A	105.4	2.66	2.66	10	26.6
	B	104.3	2.63	2.65	15	39.7
2400/3	C	103.3	2.60	2.62	25	65.4
	D	102.3	2.58	2.59	50	129.5
	E	101.5	2.56	2.57	75	192.8
	F	101	2.55	2.56	125	320.0
	G	100.7	2.54	2.55	150	382.5
	H	100.3	2.53	2.54	250	635.0
	I	100	2.52	2.53	242	612.3
	J	99.8	2.51	2.52	242	609.8
	K	99.4	2.50	2.51	224	562.2
	–	99.3	2.50	2.50	70	175.0
	L	86	2.17	2.34	122	285.5
					Sum =	4036.3

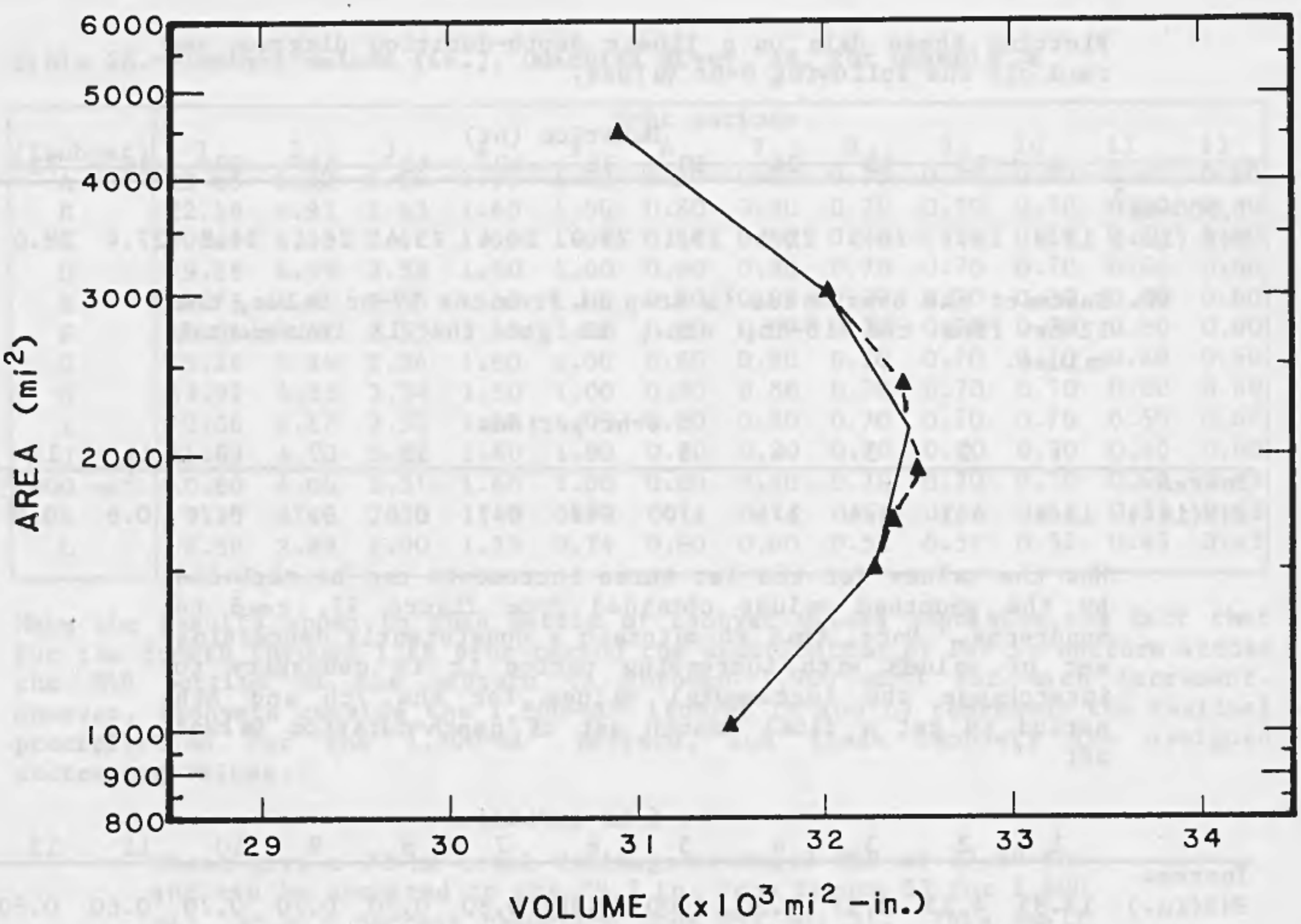

Figure 55.—Volume vs. area curve for 1st three 6-hr increments for Ouachita River, AR drainage.

As recommended in the procedure, we should compute volumes for supplemental area sizes on either side of 2,150 mi^2. We chose 1,700, 1,900 and 2,400 mi^2 (see table 27 for computations). Supplemental isohyets for these three area sizes have been added to figure 54 as the dotted isohyets. The additional computations result in the conclusion that the 1,900-mi^2 area pattern provides the greatest volume (about 32,400 mi^2-in.). (See the dashed line in figure 55.)

Step

D1. For an area size of 1,900 mi^2, it is necessary to return to figure 51 and read off depth-duration values as follows:

	Duration (hr)				
	6	12	24	48	72
1,900 mi^2					
PMP (in.)	13.8	18.1	22.1	25.4	28.1

Plotting these data on a linear depth-duration diagram, we read off the following 6-hr values.

	Duration (hr)											
	6	12	18	24	30	36	42	48	54	60	66	72
1,900-mi^2 PMP (in.)	13.8	18.1	20.5	22.1	23.1	23.9	24.6	25.4	26.1	26.8	27.4	28.0

D2. Subtract the 6-hr value in step D1 from the 12-hr value, the 12-hr from the 18-hr, etc., to get the 12 incremental values.

	6-hr periods											
	1	2	3	4	5	6	7	8	9	10	11	12
Increm. PMP(in.)	13.8	4.3	2.4	1.6	1.0	0.8	0.7	0.8	0.7	0.7	0.6	0.6

Now the values for the 1st three increments can be replaced by the smoothed values obtained from figure 53, read to hundreths. Note, that to maintain a consistently decreasing set of values with increasing period it is necessary to interchange the incremental values for the 7th and 8th period to get a final smooth set of depth-duration values of:

	6-hr periods											
	1	2	3	4	5	6	7	8	9	10	11	12
Increm. PMP(in.)	13.85	4.25	2.53	1.60	1.00	0.80	0.80	0.70	0.70	0.70	0.60	0.60

D3. Form the matrix of isohyet values shown in table 28 by multiplying the 1st 6-hr value in step D2 times the isohyet percentages for 1,900 mi^2 from the 1st 6-hr nomogram (fig. 16), the 2nd 6-hr value in step D2 times the percentages for 1,900 mi^2 from figure 18, etc., and each of the fourth through 12th 6-hr values times the percentages from figure 20.

D4. Incremental average depths for the Ouachita River drainage with the 1,900-mi^2 PMP storm pattern placed as shown in figure 54 can be obtained using the incremental isohyetal labels in step D3 and the 6-hr incremental depths from step D2, as was done for example 1a. These results (computations shown in table 29) are,

	6-hr periods											
	1	2	3	4	5	6	7	8	9	10	11	12
Drainage avg. PMP (in.)	13.62	4.16	2.49	1.55	0.98	0.78	0.78	0.68	0.68	0.68	0.59	0.59

Table 28.—Isohyet values (in.), Ouachita River, AR, for example 2a

	6-hr periods											
(Isohyet)	1	2	3	4	5	6	7	8	9	10	11	12
A	23.68	5.02	2.66	1.60	1.00	0.80	0.80	0.70	0.70	0.70	0.60	0.60
B	22.16	4.93	2.63	1.60	1.00	0.80	0.80	0.70	0.70	0.70	0.60	0.60
C	20.64	4.72	2.61	1.60	1.00	0.80	0.80	0.70	0.70	0.70	0.60	0.60
D	19.18	4.59	2.58	1.60	1.00	0.80	0.80	0.70	0.70	0.70	0.60	0.60
E	17.73	4.51	2.56	1.60	1.00	0.80	0.80	0.70	0.70	0.70	0.60	0.60
F	16.41	4.42	2.55	1.60	1.00	0.80	0.80	0.70	0.70	0.70	0.60	0.60
G	15.24	4.34	2.54	1.60	1.00	0.80	0.80	0.70	0.70	0.70	0.60	0.60
H	13.92	4.25	2.54	1.60	1.00	0.80	0.80	0.70	0.70	0.70	0.60	0.60
I	12.88	4.17	2.52	1.60	1.00	0.80	0.80	0.70	0.70	0.70	0.60	0.60
J	11.63	4.10	2.52	1.60	1.00	0.80	0.80	0.70	0.70	0.70	0.60	0.60
1900 mi^2	10.80	4.06	2.51	1.60	1.00	0.80	0.80	0.70	0.70	0.70	0.60	0.65
K	9.35	3.66	2.33	1.47	0.92	0.74	0.74	0.64	0.64	0.64	0.55	0.55
L	6.58	2.89	1.90	1.19	0.74	0.60	0.60	0.52	0.52	0.52	0.45	0.45

Note the results shown in this matrix of isohyet values emphasize the fact that for the fourth through 12th 6-hr period the distribution of PMP is uniform across the PMP portion of the pattern (A through 1,900 mi^2) for each increment. However, isohyets outside the 1,900-mi^2 isohyet (K and L) represent the residual precipitation for the 1,900-mi^2 pattern, and these isohyets are assigned decreasing values.

These give a 72-hr total drainage-averaged PMP of 27.59 in. and can be compared to the 29.2 in. from figure 51 for 1,600 mi^2, or a 6 percent reduction from HMR No. 51. This small reduction is in part caused by the fact that no adjustment was made for orientation and the fact that the basin shape is relatively elliptical.

D5. In this example, isohyetal values for durations less than 6 hr were not required. If they were needed, they would be computed at this point.

E. Temporal Distribution

The isohyet values listed in the matrix of step D3 may be reordered according to the limitations given in section 2.3. Remember that if reordering is done, it must be done consistently for all isohyets covering the drainage.

F. Subdrainage Average Depths

Figure 56 shows the four subdrainages within the Ouachita River Drainage (above Rennel Dam) covered by the isohyetal pattern. It is often of interest to determine the incremental average depths of precipitation applied to each subdrainage. For this example we will demonstrate the steps to determine average depth

Table 29.—Completed computation sheets showing typical format to get incremental drainage-average depths, Ouachita River, AR .

Increment: 1 to 7

Drainage: Ouachita River, AR Area: 1,600 mi^2 Date:

Area size	I Iso.	II Nomo.	III Amt. 13.85	IV Avg. depth	V A	VI V
	A				10	236.8
	B				15	343.8
1900/1	C				25	535.0
	D				50	994.0
	E				75	1381.5
	F				125	2128.4
	G				150	2368.5
	H				250	3635.0
	I				242	3233.1
	J				242	2966.9
	-				144	1615.7
	K				80	808.8
	L				192	1543.7

Total = 1600

Sum = 21791.6

Avg. depth = 13.62

Area size			Amt. 4.25			
	A				10	50.2
	B				15	74.6
1900/2	C				25	120.8
	D				50	233.0
	E				75	341.3
	F				125	558.8
	G				150	657.0
	H				250	1075.0
	I				242	1018.8
	J				242	1001.9
	-				144	587.5
	K				80	308.8
	L				192	629.8

Sum = 6657.5

Avg. depth = 4.16

Area size			Amt. 2.53			
	A				10	26.6
	B				15	39.7
1900/3	C				25	65.5
	D				50	130.0
	E				75	192.8
	F				125	320.0
	G				150	382.5
	H				250	635.0
	I				242	612.3
	J				242	609.8
	-				144	363.4
	K				80	193.6
	L				192	407.0

Sum = 3978.2

Avg. depth = 2.49

Area size	I Iso.	II Nomo.	III Amt. 1.60	IV Avg. depth	V A	VI V
	A	100	1.60	1.60	10	16.0
	B	100	1.60	1.60	15	24.0
1900/4	C	100	1.60	1.60	25	40.0
	D	100	1.60	1.60	50	80.0
	E	100	1.60	1.60	75	120.0
	F	100	1.60	1.60	125	200.0
	G	100	1.60	1.60	150	240.0
	H	100	1.60	1.60	250	400.0
	I	100	1.60	1.60	242	387.2
	J	100	1.60	1.60	242	387.2
	-	100	1.60	1.60	144	230.4
	K	92	1.35	1.48	80	118.4
	L	74.5	1.19	1.27	192	243.8

Sum = 2487.0

Avg. depth = 1.55

Area size			Amt. 1.00			
	A	100	1.00	1.00	10	10.0
	B	100	1.00	1.00	15	15.0
1900/5	C	100	1.00	1.00	25	25.0
	D	100	1.00	1.00	50	50.0
	E	100	1.00	1.00	75	75.0
	F	100	1.00	1.00	125	125.0
	G	100	1.00	1.00	150	150.0
	H	100	1.00	1.00	250	250.0
	I	100	1.00	1.00	242	242.0
	J	100	1.00	1.00	242	242.0
	-	100	1.00	1.00	144	144.0
	K	92	0.92	0.96	80	76.8
	L	74.5	0.74	0.83	192	159.4

Sum = 1564.2

Avg. depth = .98

Area size			Amt. 0.80			
	A	100	0.80	0.80	10	8.0
	B	100	0.80	0.80	15	12.0
1900/6,7	C	100	0.80	0.80	25	20.0
	D	100	0.80	0.80	50	40.0
	E	100	0.80	0.80	75	60.0
	F	100	0.80	0.80	125	100.0
	G	100	0.80	0.80	150	120.0
	H	100	0.80	0.80	250	200.0
	I	100	0.80	0.80	242	193.6
	J	100	0.80	0.80	242	193.6
	-	100	0.80	0.80	144	115.2
	K	92	0.74	0.77	80	61.6
	L	74.5	0.60	0.67	192	128.6

Sum = 1252.6

Avg. depth = .78

Table 29.–Completed computation sheets showing typical format to get incremental drainage-average depths, Ouachita River, AR – Continued

Increment: 8 to 12

Drainage: Ouachita River, AR

Area: 1,600 mi^2

Date:

Area size	I Iso.	II Nomo.	III Amt. 0.70	IV Avg. depth	V ΔA	VI ΔV	Area size	I Iso.	II Nomo.	III Amt.	IV Avg. depth	V ΔA	VI ΔV
	A	100	0.70	0.70	10	7.0							
	B	100	0.70	0.70	15	10.5							
1900/8,9,10	C	100	0.70	0.70	25	17.5							
	D	100	0.70	0.70	50	35.0							
	E	100	0.70	0.70	75	52.5							
	F	100	0.70	0.70	125	87.5							
	G	100	0.70	0.70	150	105.0							
	H	100	0.70	0.70	250	175.0							
	I	100	0.70	0.70	242	169.4							
	J	100	0.70	0.70	242	169.4							
	–	100	0.70	0.70	144	100.8							
	K	92	0.64	0.67	80	53.6							
	L	74.5	0.52	0.58	192	111.4							

Sum = 1094.6

Avg. depth = .68

Area size			Amt.			
		100	0.60			
	A	100	0.60	0.60	10	6.0
	B	100	0.60	0.60	15	9.0
1900/11,12	C	100	0.60	0.60	25	15.0
	D	100	6.60	0.60	50	30.0
	E	100	0.60	0.60	75	45.0
	F	100	0.60	0.60	125	75.0
	G	100	0.60	0.60	150	90.0
	H	100	0.60	0.60	250	150.0
	I	100	0.60	0.60	242	145.2
	J	100	0.60	0.60	242	145.2
	–	100	0.60	0.60	144	86.4
	K	92	0.55	0.58	80	46.4
	L	74.5	0.45	0.50	192	96.0

Sum = 939.2

Avg. depth = .59

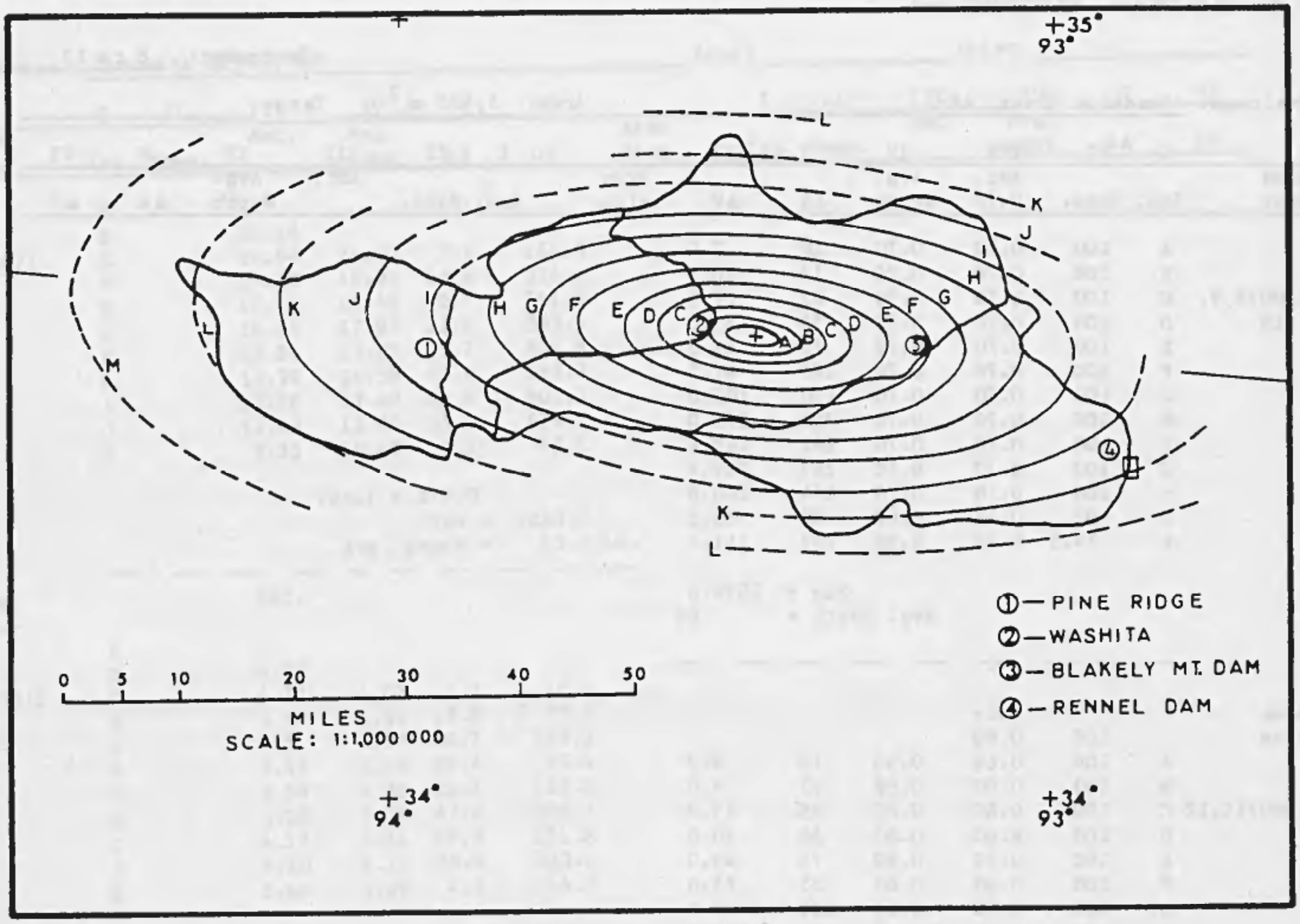

Figure 56.—Isohyetal pattern placed on the Ouachita River, AR drainage relative to subdrainages.

over the subdrainage between Pine Ridge and Washita (278 mi^2). From figure 56 we see that this subdrainage is covered by isohyets B through K.

Step

F1. Planimeter the areas between isohyets for each isohyet that crosses the subdrainage to obtain the areas used in column V of the computation sheet shown in table 30.

F2. Use the isohyet values in step D3 to fill in column III in table 30. Follow the computational procedure outlined in steps C5 to C8 to obtain the subdrainage incremental volumes. Note that for the fourth through 12th 6-hr periods it is not necessary to formally compute the volumes, since the subregion is not covered by residual precipitation, and

Table 30.—Completed computation sheet for determining average depths for 1st three 6-hr increments over subdrainage between Blakely Mt. Dam and Washita, AR

Increment: 1 to 3

Drainage: Ouachita River, AR

Area:

Date:

Area Size	I Iso.	II Nomo.	III Amt.	IV Avg. depth	V ΔA	VI ΔV	Area size	I Iso.	II Nomo.	III Amt.	IV Avg. depth	V ΔA	VI ΔV
	A												
	B		22.16										
1900/1	C		20.64	21.40	7.7	164.8							
	D		19.18	19.91	15.8	314.6							
	E		17.73	18.46	40.7	751.3							
	F		16.41	17.07	21.4	365.3							
	G		15.24	15.82	25.7	406.6							
	H		13.92	14.58	47.0	685.3							
	I		12.88	13.40	59.8	801.3							
	J		11.63	12.22	55.6	679.4							
	K		9.35	10.49	4.3	45.1							
				Total =	278.0								
				Sum =		4213.7							
				Avg. depth =		15.2 in.							

Area size			Amt.			
	A					
	B		4.93			
1900/2	C		4.72	4.82	7.7	37.4
	D		4.59	4.66	15.8	73.6
	E		4.51	4.55	40.7	185.2
	F		4.42	4.46	21.4	95.4
	G		4.34	4.38	25.7	112.6
	H		4.25	4.30	47.0	202.1
	I		4.17	4.21	59.8	251.8
	J		4.10	4.14	55.6	230.2
	K		3.66	3.88	4.3	16.7
					Sum =	1205.0
					Avg. depth =	4.3 in.

Area size			Amt.			
	A					
	B		2.63			
1900/3	C		2.61	2.62	7.7	20.2
	D		2.58	2.595	15.8	41.0
	E		2.56	7.57	40.7	104.6
	F		2.55	2.555	21.4	54.7
	G		2.54	2.545	25.7	65.4
	H		2.54	2.54	47.0	119.4
	I		2.52	2.53	59.8	151.3
	J		2.52	2.52	55.6	140.1
	K		2.33	2.42	4.3	10.4
					Sum =	707.1
					Avg. depth =	2.5 in.

thus the average depths for these increments will be the same as the incremental PMP amounts.

F3. The average depths for the subdrainage between Pine Ridge and Washita are thus,

	6-hr periods											
	1	2	3	4	5	6	7	8	9	10	11	12
Subdrainage. avg. depth (in.)	15.2	4.3	2.5	1.6	0.9	0.8	0.8	0.8	0.8	0.8	0.8	0.7

7.5 Example No. 2b

In this example we want to suggest that a placement of the isohyetal pattern closer to the outlet may be advantageous to bring about a greater peak discharge, however, the result is a lower volume than the drainage-centered placement considered in example 2a. Figure 57 shows the displacement of our standard pattern toward the drainage outlet. One might judge that a somewhat better placement is possible than that shown. However, for the purpose of illustration, it was believed necessary not to change the original orientation in order to show that any reduction in volume was due to difference other than orientation.

For this example, it is not necessary to start over by obtaining new values from HMR NO. 51.* Therefore, we can proceed directly to the computation of volume previously determined in table 27, and it is only necessary to change the incremental areas as a result of planimetering figure 57. The computations for the 1st three 6-hr increments for the standard isohyetal areas as recomputed in table 31 are shown to be roughly 10 percent lower than those for the drainage-centered placement (fig. 54).

In table 31, we find that unlike the result from example 2a, the area of PMP determined by maximum volume in the drainage has increased from 1,900 mi^2 to the vicinity of 3,000 mi^2. This result implies a less intense storm has been considered. Although not shown, a reduction in volume would also have occurred had we applied the same isohyet values from table 28 to the pattern shown in figure 57. These results support our claim that a placement that may be advantageous to obtaining a maximum peak discharge in general will give less than maximum volume.

Although relocation of a PMP storm pattern closer to the drainage outlet results in a a smaller drainage volume, one should consider the impact of concentrating a more intense storm pattern near the dam. A more intense storm here means a PMP storm pattern area less than that giving the maximum volume of precipitation in the drainage, but which contains greater central depths. For the example storm shown in figure 54, we might consider a PMP storm pattern for 450 mi^2 or 1,000 mi^2 and compute the peak discharge. Since we do not have sufficient information to compute the peak discharge, it is left to the user to make such tests. From these tests the user can determine whether other more

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*The user may need to redetermine these if the pattern is moved a significant distance.

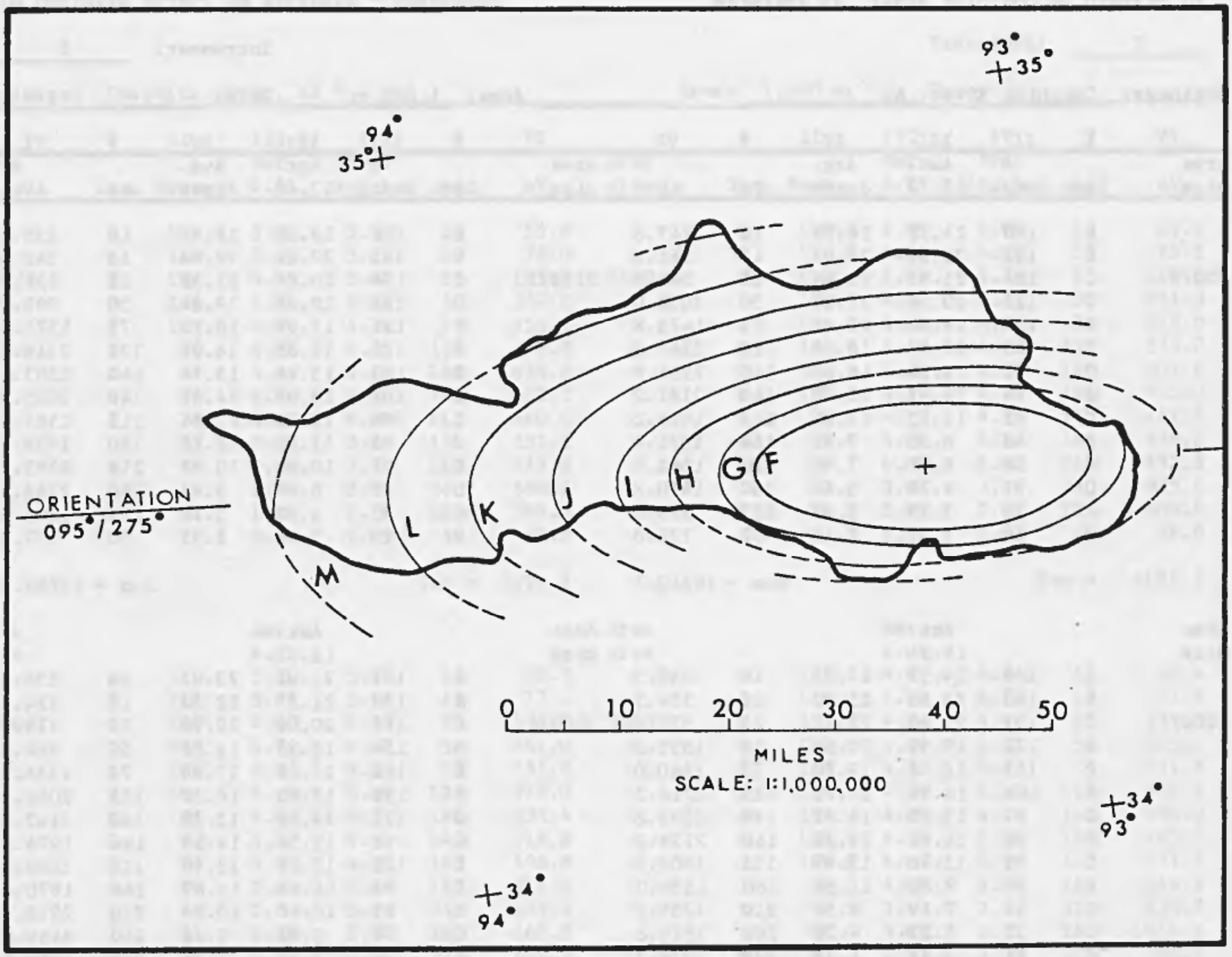

Figure 57.—Alternate placement of isohyetal pattern on Ouachita River, AR drainage typical of determination of peak discharge.

intense storms or pattern repositions will yield more critical peak flows. It should be noted again that drainage-averaged depths from any PMP pattern smaller than that which gives maximum volume in the drainage, will be less than drainage-averaged PMP.

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Table 31.--Completed computation sheets for 1st three 6-hr increments for alternate placement of pattern on Ouachita River, AR drainage

Increment: 1

Drainage: Ouachita River, AR Area: 1,600 mi^2 Date:

	I	II	III	IV	V	VI		I	II	III	IV	V	VI
Area size	Iso.	Nomo.	Amt. 17.70	Avg. depth	ΔA	ΔV	Area size	Iso.	Nomo.	Amt. 13.40	Avg. depth	ΔA	ΔV
	A	140	24.78	24.78	10	247.8		A	176	23.58	23.58	10	235.8
	B	132	23.36	24.07	15	361.0		B	165	22.11	22.84	15	342.6
700/1	C	124	21.95	22.66	25	566.5	2150/1	C	154	20.64	21.38	25	534.5
	D	115	20.36	21.16	50	1058.0		D	142	19.03	19.84	50	992.0
	E	107	18.94	19.65	75	1473.8		E	131	17.55	18.29	75	1371.8
	F	98	17.35	18.14	125	2267.5		F	122	16.35	16.95	125	2118.8
	G	92	16.28	16.82	140	2354.8		G	113	15.14	15.74	140	2203.6
	H	84	14.87	15.58	140	2181.2		H	103	13.80	14.47	140	2025.8
	I	63	11.15	13.01	115	1496.2		I	95	12.73	13.26	115	1524.9
	J	48	8.50	9.82	160	1571.2		J	86	11.52	12.12	160	1939.2
	K	36	6.37	7.44	210	1562.4		K	77	10.32	10.92	210	2293.2
	L	27	4.78	5.58	260	1450.8		L	52	6.97	8.64	260	2246.4
	M	18	3.19	3.98	225	895.5		M	33	4.42	5.70	225	1282.5
	N	10	1.77	2.48	50	124.0		N	20	2.68	3.55	50	177.5
						Sum = 16310.7							Sum = 19288.6
Area size			Amt. 16.34				Area size			Amt. 12.05			
	A	149	24.35	24.35	10	243.5		A	191	23.02	23.02	10	230.2
	B	140	22.88	23.62	15	354.3		B	179	21.57	22.30	15	334.5
1000/1	C	131	21.40	22.14	25	553.5	3000/1	C	166	20.00	20.78	25	519.5
	D	122	19.93	20.66	50	1033.0		D	154	18.56	19.28	50	964.0
	E	113	18.46	19.20	75	1440.0		E	142	17.11	17.84	75	1338.0
	F	104	16.99	17.73	125	2216.2		F	132	15.90	16.50	125	2062.5
	G	97	15.85	16.42	140	2298.8		G	122	14.70	15.30	140	2142.0
	H	89	14.54	15.20	140	2128.0		H	112	13.50	14.10	140	1974.0
	I	82	13.40	13.97	115	1606.6		I	102	12.29	12.90	115	1483.5
	J	60	9.80	11.60	160	1856.0		J	92	11.09	11.69	160	1870.4
	K	44	7.19	8.50	210	1785.0		K	83	10.00	10.54	210	2213.4
	L	32	5.23	6.21	260	1614.6		L	74	8.92	9.46	260	2459.6
	M	21	3.43	4.33	225	974.2		M	44	5.02	6.97	225	1568.2
	N	12	1.96	2.70	50	135.0		N	25	3.01	4.02	50	201.0
						Sum = 18238.7							Sum = 19360.8
Area size			Amt. 14.79				Area size			Amt. 10.35			
	A	162	23.96	23.96	10	239.6		A	212	21.94	21.94	10	219.4
	B	152	22.48	23.22	15	348.3		B	198	20.49	21.22	15	318.3
1500/1	C	142	21.00	21.74	25	543.5	4500/1	C	184	19.04	19.76	25	494.0
	D	132	19.52	20.26	50	1013.0		D	170	17.60	18.32	50	916.0
	E	122	18.04	18.78	75	1408.5		E	157	16.25	16.92	75	1269.0
	F	112	16.56	17.30	125	2162.5		F	146	15.11	15.68	125	1960.0
	G	105	15.53	16.04	140	2245.6		G	135	13.97	14.54	140	2035.6
	H	96	14.20	14.86	140	2080.4		H	124	12.83	13.40	140	1876.0
	I	88	13.02	13.61	115	1565.2		I	113	11.70	12.26	115	1409.9
	J	80	11.83	12.42	160	1987.2		J	103	10.66	11.18	160	1788.8
	K	56	8.28	10.06	210	2112.6		K	93	9.62	10.14	210	2129.4
	L	41	6.06	7.17	260	1864.2		L	83	8.59	9.10	260	2366.0
	M	26	3.84	4.95	225	1113.8		M	71	7.35	7.97	225	1793.2
	N	16	2.37	3.10	50	155.0		N	37	3.83	5.59	50	279.5
						Sum = 18839.4							Sum = 18855.1

Table 31.--Completed computation sheets for 1st three 6-hr increments for alternate placement of pattern on Ouachita River, AR drainage - Continued

Increment: 2

Drainage: Ouachita River, AR Area: 1,600 mi^2 Date:

Area size	I Iso.	II Nomo.	III Amt. 4.63	IV Avg. depth	V ΔA	VI ΔV
	A	114.5	5.30	5.30	10	53.0
	B	110	5.09	5.20	15	78.0
700/2	C	107	4.95	5.02	25	125.5
	D	104	4.81	4.88	50	244.0
	E	101	4.68	4.74	75	355.0
	F	99	4.58	4.63	125	578.8
	G	97	4.49	4.54	140	635.6
	H	95	4.40	4.445	140	622.3
	I	78	3.61	4.005	115	460.6
	J	65.5	3.03	3.32	160	531.2
	K	54	2.50	2.76	210	579.6
	L	44	2.04	2.27	260	590.2
	M	32	1.48	1.76	225	396.0
	N	19.5	0.90	1.19	50	59.5
					Sum =	5309.3
Area size			Amt. 4.51			
	A	116	5.23	5.23	10	52.3
	B	112	5.05	5.14	15	77.1
1000/2	C	108.5	4.89	4.97	25	124.2
	D	105	4.74	4.82	50	241.0
	E	103	4.64	4.69	75	351.8
	F	101	4.56	4.60	125	575.0
	G	99	4.46	4.51	140	631.4
	H	97	4.37	4.42	140	618.8
	I	95	4.28	4.32	165	496.8
	J	76	3.43	3.86	160	617.6
	K	63	2.84	3.14	210	659.4
	L	51	2.30	2.57	260	668.2
	M	38	1.71	2.01	225	452.2
	N	24	1.08	1.40	50	70.0
					Sum =	5635.8
Area size			Amt. 4.36			
	A	117	5.10	5.10	10	51.0
	B	113	4.93	5.02	15	75.0
1500/2	C	110	4.80	4.86	25	121.5
	D	107	4.66	4.73	50	236.5
	E	105	4.58	4.62	75	346.5
	F	103	4.49	4.54	125	567.5
	G	100.5	4.38	4.44	140	621.6
	H	99	4.32	4.35	140	609.0
	I	97	4.23	4.28	115	492.2
	J	95.5	4.16	4.20	160	672.0
	K	75.5	3.29	3.72	210	781.2
	L	60.5	2.64	2.96	260	769.6
	M	45	1.96	2.30	225	517.5
	N	31	1.35	1.66	50	83.0
					Sum =	5944.1

Area size	I Iso.	II Nomo.	III Amt. 4.21	IV Avg. depth	V ΔA	VI ΔV
	A	118.5	4.99	4.99	10	49.9
	B	114.5	4.82	4.90	15	73.5
2150/2	C	111	4.67	4.74	25	118.5
	D	108.5	4.57	4.62	50	231.0
	E	106.5	4.48	4.52	75	339.0
	F	104.5	4.40	4.44	125	555.0
	G	102	4.29	4.34	140	607.6
	H	100	4.21	4.25	140	595.0
	I	99	4.17	4.19	115	481.8
	J	97	4.08	4.12	160	659.2
	K	96	4.04	4.06	210	852.6
	L	73	3.07	3.56	260	925.6
	M	54	2.27	2.67	225	600.8
	N	37.5	1.58	1.92	50	96.0
					Sum =	6185.5
Area size			Amt. 4.05			
	A	119.5	4.84	4.84	10	48.4
	B	116	4.70	4.77	15	71.6
3000/2	C	112.5	4.56	4.64	25	115.0
	D	110	4.46	4.51	50	225.0
	E	108	4.37	4.42	75	331.5
	F	106	4.29	4.33	125	541.2
	G	104	4.21	4.25	140	595.0
	H	102	4.13	4.17	140	483.8
	I	100.5	4.07	4.10	115	471.5
	J	99	4.01	4.04	160	646.5
	K	97	3.93	3.97	210	833.7
	L	96	3.89	3.91	260	1016.6
	M	67	2.71	3.30	225	742.5
	N	45	1.82	2.26	50	113.0
					Sum =	6336.7
Area size			Amt. 3.86			
	A	121	4.67	4.67	10	46.7
	B	117	4.52	4.60	15	69.0
4500/2	C	114	4.40	4.46	25	111.5
	D	112	4.32	4.36	50	218.0
	E	109.5	4.23	4.28	75	321.0
	F	108	4.17	4.20	125	525.0
	G	105.5	4.07	4.12	140	576.8
	H	103.5	4.00	4.04	140	565.6
	I	102	3.94	3.97	115	456.6
	J	100.5	3.88	3.91	160	625.6
	K	99	3.82	2.85	210	808.5
	L	97.5	3.76	3.79	260	985.4
	M	96	3.71	3.74	225	841.5
	N	59	2.28	3.00	50	150.0
					Sum =	6301.2

Table 31.--Completed computation sheets for 1st three 6-hr increments for alternate placement of pattern on Ouachita River, AR drainage - Continued

Increment: 3

Drainage: Ouachita River, AR   Area: 1,600 mi^2 Date:

Area size	I Iso.	II Nomo.	III Amt. 2.54	IV Avg. depth	V ΔA	VI ΔV
	A	104.2	2.65	2.65	10	26.5
	B	102.9	2.61	2.63	15	39.3
700/3	C	101.7	2.58	2.595	25	64.9
	D	100.8	2.56	2.57	50	128.5
	E	100.2	2.54	2.55	75	191.2
	F	99.9	2.54	2.54	125	317.5
	G	99.6	2.53	2.535	140	354.9
	H	99.2	2.52	2.525	140	353.5
	I	85	2.16	2.34	115	269.1
	J	70.5	1.79	1.98	160	316.8
	K	58.5	1.48	1.64	210	344.4
	L	47	1.19	1.34	260	348.4
	M	37	0.94	1.06	225	238.5
	N	25.5	0.65	0.80	50	40.0
					Sum =	3033.5

Area size			Amt. 2.54			
	A	104.6	2.66	2.66	10	26.6
	B	103.3	2.62	2.64	15	39.6
1000/2	C	102.3	2.60	2.61	25	65.2
	D	101.3	2.57	2.585	50	129.2
	E	100.6	2.56	2.565	75	192.4
	F	100.3	2.55	2.555	125	319.4
	G	99.9	2.54	2.545	140	356.3
	H	99.6	2.53	2.535	140	354.9
	I	99.3	2.52	2.525	115	290.4
	J	82.5	2.10	2.31	160	369.6
	K	67	1.70	1.90	210	399.0
	L	54	1.73	1.16	260	301.6
	M	43	1.09	1.23	225	276.8
	N	31	0.79	0.94	50	47.0
					Sum =	3168.0

Area size			Amt. 2.54			
	A	105	2.67	2.67	10	26.7
	B	103.8	2.64	2.655	15	39.8
1500/3	C	102.7	2.61	2.625	25	65.6
	D	101.7	2.58	2.595	50	129.8
	E	101	2.56	2.57	75	192.8
	F	100.7	2.56	2.56	125	320.0
	G	100.3	2.55	2.555	140	357.7
	H	100	2.54	2.545	140	356.3
	I	99.7	2.53	2.535	115	291.5
	J	99.4	2.52	2.525	160	404.0
	K	81	2.06	2.29	210	480.9
	L	65.5	1.66	1.86	260	483.6
	M	51.5	1.31	1.48	225	333.0
	N	38	0.96	1.14	50	57.0
					Sum =	3548.7

Area size	I Iso.	II Nomo.	III Amt. 2.53	IV Avg. depth	V ΔA	VI ΔV
	A	105.3	2.66	2.66	10	26.6
	B	104.2	2.64	2.65	15	39.8
2150/3	C	103.2	2.61	2.625	25	65.6
	D	102	2.58	2.595	50	129.8
	E	101.3	2.56	2.57	75	192.8
	F	101	2.56	2.56	125	320.0
	G	100.6	2.54	2.55	140	357.0
	H	100.3	2.54	2.54	140	355.6
	I	100	2.53	2.535	115	291.5
	J	99.7	2.52	2.525	160	404.0
	K	95.5	2.42	2.47	210	518.7
	L	80.5	2.04	2.23	260	579.8
	M	61	1.54	1.79	225	402.8
	N	46.5	1.18	1.36	50	68.0
					Sum =	3752.0

Area size			Amt. 2.52			
	A	105.7	2.66	2.66	10	26.6
	B	104.6	2.64	2.65	15	39.8
3000/3	C	103.5	2.61	2.625	25	65.6
	D	102.5	2.58	2.595	50	129.8
	E	101.7	2.56	2.57	75	192.8
	F	101.3	2.55	2.555	125	319.4
	G	100.9	2.54	2.545	140	356.3
	H	100.5	2.53	2.535	140	354.9
	I	100.2	2.52	2.525	115	290.4
	J	99.9	2.52	2.52	160	403.2
	K	99.6	2.51	2.515	210	528.2
	L	99.3	2.50	2.505	260	651.3
	M	76	1.92	2.21	225	497.2
	N	57	1.44	1.68	50	84.0
					Sum =	3939.5

Area size			Amt. 2.51			
	A	106	2.66	2.66	10	26.6
	B	105	2.64	2.65	15	39.8
4500/3	C	104	2.61	2.625	25	65.6
	D	103.1	2.59	2.60	50	130.0
	E	102.1	2.56	2.575	75	193.0
	F	101.7	2.55	2.555	125	319.4
	G	101.2	2.54	2.545	140	356.3
	H	100.9	2.53	2.535	140	354.9
	I	100.6	2.52	2.525	115	290.4
	J	100.2	2.52	2.52	160	403.2
	K	99.9	2.51	2.515	210	528.2
	L	99.6	2.50	2.505	260	651.3
	M	99.3	2.49	2.495	225	591.4
	N	76	1.91	2.20	50	110.0
					Sum =	4030.2

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APPENDIX

The 53 storms listed in the Appendix to HMR 51 were chosen as the sample of storms to be used initially in this study. However, in the study of storm shapes and orientations it was found that this sample was particularly small when questions of regional variation, regional averages, or statistical distributions were considered. For this reason a subordinate storm sample was created to provide additional guidance in some of these discussions.

The subordinate sample of storms was derived from the major storms listed in "Storm Rainfall" (U.S. Army Corps of Engineers 1945-). This file includes storms from as early as the 1870's and is continually updated as new storms are studied. Some additional storm data are available from other agencies and from storms studied by the Hydrometeorological Branch. We concentrated on the 253 storms whose areas were 10,000 mi^2 or larger and whose durations were 60 hr or longer, since we believe the larger/longer storms were more useful in pointing up possible differences. We also imposed a controlling factor in our storm selection, that only storms whose 72-hr depth was 90 percent or more of the total-storm depth (20,000 mi^2, 72 hr) would be used, because we wanted storms that basically represented extreme 3-day rains. These are listed in table A.1.

The distribution of the 253 storms according to area and duration classes is shown in table A.2.

The regional distribution of this sample is shown in figure A.1, which includes the orientation of the respective rainfall patterns. One feature shown in this figure is that even in this sample of 253 storms, there are local regions for which no storms satisfying the areal and durational criteria of our sample occur. That is not to say that storms of these magnitudes have not occurred in these regions, but rather that we have no records of such storms.

The distribution of the 253 storms relative to area size and shape ratio classes is given in table A.3. These results can be compared to those in table 7 for the 53 storm sample.

Table A.1.--253 Major storms (listed in Storm Rainfall, $\geq$ 10,000 mi^2 and $\geq$ 60 hr; 72 hr $\geq$ 90% total storm amount at 20,000 mi^2, arranged in chronological order)

Date	Station nearest center	Lat.		Long.		Tot. st. dur. (hr)	Tot. st. area (mi^2)	1000-mi^2 24-hr amt. (in.)
		(°)	(')	(°)	(')			
9/10-13/1878	Jefferson, OH	41	45	80	46	84	90,000	11.0
9/20-24/82	Paterson, NJ	40	55	74	10	108	40,000	7.9
7/27-31/87	Union Pt., GA	33	37	83	04	114	100,000	9.0
9/8-12/88	Greenwood, SC	34	12	82	10	120	120,000	8.4
5/30-6/1/89	Wellsboro, PA	41	45	77	17	60	82,000	8.3
3/5-9/91	Kosciusko, MS	33	05	89	35	114	185,000	7.2
6/23-27/91	Larrabee, IA	42	52	95	30	96	30,000	9.3
7/24-28/92	Minneapolis, MN	45	04	93	18	108	20,000	6.4
5/25-29/93	Marianna, AR	34	44	90	49	96	175,000	7.7
8/26-28/93	Manning, SC	33	41	80	12	66	54,000	11.1
9/6-10/93	Franklin, LA	29	47	91	30	114	40,000	10.4
3/17-20/94	Washington, AR	33	48	93	40	72	112,000	6.0
5/17-22/94	Bridgeton, NJ	39	26	75	14	120	57,000	5.1
5/29-31/94	Ward District, CO	40	04	105	32	60	25,300	4.6
8/3-6/94	Folkland, NC	35	34	77	38	96	72,800	6.4
12/16-20/95	Phillipsburg, MO	37	34	92	47	96	110,000	6.5
6/4-7/96	Greeley, NE	41	33	98	32	78	84,000	9.2
7/6-8/96	Greenwood, SC	34	11	82	09	66	118,000	6.0
9/27-30/96	Bloomery, WV	39	23	78	22	66	50,000	6.8
7/12-14/97	Southington, CT	41	39	72	53	60	44,000	6.7
7/18-22/97	Lambert, MN	47	47	95	55	102	80,000	5.8
7/25-27/97	Butternut, WI	46	00	90	30	66	15,000	8.6
7/26-29/97	Jewell, MD	38	46	76	34	96	32,000	6.2
12/31-1/3/97	Pine Bluff, AR	34	12	92	00	78	118,000	5.7
12/1-4/97	Jackson, MS	32	17	90	11	96	70,000	6.6
5/2-6/98	Norman, OK	35	13	97	28	84	68,000	6.0
6/2-6/98	Pine River Dam, MN	46	41	94	07	102	30,000	5.7
8/26-29/98	St. Andrews Bay, FL	30	10	85	42	96	64,000	7.0
8/30-9/3/98	Port Royal, SC	32	23	80	42	120	42,000	9.6
9/28-10/1/98	Pensacola, FL	30	25	87	13	84	75,500	8.1
10/2-4/98	Highlands, NC	35	02	83	12	66	60,000	5.9
6/27-7/1/99	Hearne, TX	30	52	96	37	108	78,000	21.1
12/8-11/99	Port Gibson, MS	31	58	90	59	66	30,000	7.3
4/15-18/1900	Eutaw, AL	32	47	87	50	84	75,000	11.3
7/14-17/00	Primghar, IA	43	05	95	38	78	100,000	9.1
9/7-11/00	Elk Point, SD	42	41	96	40	102	50,000	6.1
10/27-30/00	La Crosse, WI	43	48	91	15	78	15,200	6.7
5/18-22/01	Lumberton, NC	34	32	79	00	108	79,600	6.2
7/1-6/01	New Folden, MN	48	22	96	20	108	50,000	6.1
3/25-29/02	Ripley, MS	34	42	88	57	114	100,000	8.6

Table A.1 - 253 Major storms (listed in Storm Rainfall, $\geq$ 10,000 mi^2 and $\geq$ 60 hr; 72 hr $\geq$ 90% total storm amount at 20,000 mi^2, arranged in chronological order) - Continued

Date	Station nearest center	Lat. (°)	(')	Long. (°)	(')	Tot. st. dur. (hr)	Tot. st. area (mi^2)	1000-mi^2 24-hr amt. (in.)
9/20-24/02	Wakeeney, KS	39	01	99	53	108	81,600	5.3
9/24-27/02	Colora, MD	39	40	76	06	72	40,000	5.6
8/24-28/03	Woodburn, IA	40	57	93	35	96	59,000	10.3
9/7-10/03	Burlington, KS	38	12	95	45	72	40,900	5.7
9/28-10/1/03	Gainesville, TX	33	37	97	08	90	50,000	7.5
10/7-11/03	Paterson, NJ	40	55	74	10	96	35,000	10.9
5/1-3/04	Boxelder, CO	40	59	105	11	66	21,200	3.4
6/1-5/04	Hartshorne, OK	34	51	95	33	84	66,000	7.2
6/2-5/04	Spearfish, SD	44	29	103	47	78	12,300	3.4
9/12-15/04	Friesburg, NJ	39	35	75	25	66	35,000	6.7
9/26-30/04	Rociada, NM	35	52	105	27	90	70,000	5.4
2/10-13/05	Putman, GA	32	14	84	25	72	80,000	5.8
6/3-8/05	Medford, WI	45	08	90	20	120	67,000	7.0
7/18-21/05	Hartshorne, OK	34	51	95	33	84	100,000	6.8
10/16-19/05	New Haven, MO	38	38	91	13	69	26,000	6.6
8/21-25/06	Hartington, NE	42	37	97	16	96	33,900	4.7
8/22-26/06	Warsaw, MO	38	15	93	21	102	24,300	6.6
5/7-10/07	Lafayette, LA	30	14	91	59	96	49,000	9.0
5/28-31/07	Sugarland, TX	29	36	95	38	90	80,000	8.7
7/13-16/07	Nemaha, NE	40	20	95	41	96	40,000	7.9
5/21-25/08	Chatanooga, OK	34	25	98	39	108	175,000	6.1
7/28-31/08	New Bern, NC	35	07	77	03	72	29,000	5.9
8/23-28/08	Vade Mecum, NC	36	26	80	28	120	69,600	9.5
9/16-20/08	Cameron, LA	29	45	93	20	102	22,000	10.1
10/19-24/08	Meeker, OK	35	30	96	54	126	80,000	8.6
5/24-28/09	Shoccoa, MS	32	39	89	53	114	70,000	7.2
7/4-7/09	Bethany, MO	40	15	94	02	66	27,000	7.3
7/18-23/09	Ironwood, MI	46	27	90	11	108	50,000	10.0
9/6-9/09	Topeka, KS	39	04	95	37	78	39,000	6.9
9/19-22/09	St. Francisville, LA	30	46	91	22	66	31,000	10.2
6/6-11/10	Boonville, MO	38	58	92	45	120	70,000	2.9
10/3-6/10	Golconda, IL	37	22	88	29	90	70,000	7.4
2/16-18/11	Woodward (nr), OK	36	27	99	23	60	44,400	4.5
4/12-15/11	Benton, AR	34	33	92	37	60	75,000	4.9
8/28-31/11	St. George, GA	30	30	82	02	84	39,000	13.5
4/11-14/12	Arnegard, ND	47	48	103	25	90	10,700	2.0
5/19-22/12	Gladwin, MI	43	59	84	29	72	37,156	4.6
6/14-18/12	Johnstown, PA	40	20	78	55	120	50,000	4.0
9/22-25/12	Emmitsburg, Md	39	41	77	21	72	40,000	4.6
9/22-25/12	Camden, SC	34	15	80	37	72	16,000	5.5

Table A.1 - 253 Major storms (listed in Storm Rainfall, $\geq$ 10,000 mi^2 and $\geq$ 60 hr; 72 hr $\geq$ 90% total storm amount at 20,000 mi^2, arranged in chronological order) - Continued

Date	Station nearest center	Lat. (°)	(')	Long. (°)	(')	Tot. st. dur. (hr)	Tot. st. area (mi^2)	1000-mi^2 24-hr amt. (in.)
7/12-15/13	Toboso, OH	40	03	82	13	84	17,000	5.9
12/1-5/13	San Marcos (nr), TX	29	52	97	57	96	70,000	9.3
3/24-28/14	Merryville, LA	30	46	93	32	96	125,000	10.7
4/24-28/14	Merryville, LA	30	46	93	32	96	100,000	8.1
4/29-5/2/14	Clayton, NM	36	20	103	06	66	36,500	7.9
6/25-28/14	Hazelton, ND	46	29	100	17	90	66,000	6.8
6/25-28/14	Morris, MN	45	35	95	55	60	45,000	4.7
2/12-14/15	Onida, SD	44	42	100	04	60	50,000	3.1
6/2-7/15	Henrietta, TX	33	48	98	12	138	60,000	4.7
9/6-9/15	Moran, KS	37	56	95	10	96	24,000	7.6
5/14-19/16	York, NY	42	52	77	52	120	21,400	3.8
7/13-17/16	New Ulm, MN	44	19	94	28	96	30,000	5.6
7/15-17/16	Altapass, NC	35	53	82	01	108	37,000	15.0
9/10-12/16	Cunningham, KS	37	39	98	24	60	44,000	4.4
9/14-16/17	Hatteras, NC	35	15	75	40	60	25,000	6.5
3/12-15/18	Holcomb, WV	38	15	80	34	66	17,200	4.0
5/9-13/18	Mountain Home, AR	36	20	92	30	78	70,000	5.7
8/19-22/18	Mayville, ND	47	30	97	19	78	24,000	4.8
10/24-27/18	Tryon, NC	35	13	82	14	72	17,200	7.1
10/26-31/18	Highlands, NC	35	02	83	12	120	107,000	6.7
11/6-8/18	Neosha, MO	36	52	94	22	72	34,500	4.5
3/14-16/19	Atchison, KS	39	34	95	07	60	33,000	5.0
6/22-24/19	Clinton, IL	40	08	88	58	66	20,000	5.1
8/25-29/19	Warrensburg, MO	38	46	93	44	102	19,900	9.3
9/16-19/19	Bruning, NE	40	20	97	34	66	58,350	7.4
10/7-12/19	Anahugo, TX	29	47	94	40	120	60,000	8.1
10/25-28/19	Steelville, MO	37	59	91	22	60	84,000	6.8
12/6-10/19	Selma, AL	32	25	87	02	90	116,000	7.5
1/21-24/20	Pontotoc, MS	34	15	89	00	84	100,000	2.8
2/3-6/20	Runnymede, VA	37	01	76	39	60	20,000	-
5/9-12/20	Vale, SD	44	37	103	24	78	54,000	3.8
6/15-18/20	W. Newton, PA	40	13	79	36	84	30,000	3.8
9/6-9/20	Memphis, TN	35	09	90	03	66	24,000	3.7
3/11-14/21	Magnolia, MS	31	06	90	28	72	42,000	10.1
6/2-6/21	Pueblo (nr), CO	38	27	105	04	114	144,000	7.8
6/17-21/21	Springbrook, MT	47	18	105	35	108	52,600	11.3
10/29-11/2/21	Marion, NC	35	41	82	01	96	24,000	4.6
11/16-19/21	Searcy, AR	35	15	91	44	78	130,000	7.4
2/19-23/22	West Branch, MI	44	19	84	17	114	35,000	3.5
4/24-27/22	Weatherford, TX	32	45	97	48	66	65,700	7.6

Table A.1 – 253 Major storms (listed in Storm Rainfall, $\geq$ 10,000 mi^2 and $\geq$ 60 hr; 72 hr $\geq$ 90% total storm amount at 20,000 mi^2, arranged in chronological order) – Continued

Date	Station nearest center	Lat. (°)	(')	Long. (°)	(')	Tot. st. dur. (hr)	Tot. st. area (mi^2)	1000-mi^2 24-hr amt. (in.)
6/8-11/22	Wrightstown, WI	44	20	88	12	84	45,000	6.1
6/9-12/22	Syracuse (nr), NY	43	04	76	16	84	20,000	4.2
7/9-12/22	Grant City, MO	40	29	94	25	78	113,500	9.3
9/27-10/1/23	Savageton, WY	43	52	105	47	108	95,000	6.6
7/11-14/24	Fort Scott, KS	37	51	94	42	72	35,000	5.6
8/3-6/24	West Bend, WI	43	25	88	11	90	50,000	6.7
9/13-17/24	Beaufort, NC	34	44	76	39	96	100,000	11.5
12/4-8/24	Brownsville, KY	37	13	86	15	108	32,400	6.2
5/27-29/25	Eagle Pass, TX	28	43	100	30	60	47,100	7.1
6/1-3/25	St. Joseph, MO	39	46	94	55	66	64,000	4.9
9/23-26/25	Freeman Springs, AR	35	40	93	06	90	75,000	3.9
3/20-22/26	St. Francisville, LA	30	46	91	22	66	28,200	5.9
8/23-26/26	Donaldsonville, LA	30	06	90	58	72	50,000	11.5
9/2-5/26	Columbus, KS	37	15	94	52	78	50,000	5.9
9/17-21/26	Bay Minette, AL	30	53	87	47	120	35,700	13.7
9/25-30/26	Eufaula, OK	35	17	95	35	108	40,000	6.6
2/11-14/27	Clinton, LA	30	52	91	00	72	50,000	7.0
3/17-20/27	Tuscumbia, MO	38	15	92	27	60	32,000	4.2
4/12-16/27	Jefferson, LA	29	40	90	05	108	250,000	14.7
5/5-9/27	Belvidere, SD	43	50	101	16	108	150,000	3.7
5/20-23/27	Kaplan, LA	30	01	92	19	72	12,500	8.1
7/12-15/27	Ardmore, OK	34	12	97	08	96	33,000	8.6
8/11-14/27	Bison, KS	38	31	99	12	72	34,000	6.6
11/2-4/27	Kinsman Notch, NH	44	03	71	45	60	60,000	7.8
5/14-16/28	Woodville, MS	31	06	91	18	60	34,000	8.0
6/12-17/28	Crystal Sprngs, MS	31	59	90	26	108	20,000	8.6
6/28-30/28	Clinton, TN	36	06	84	08	66	70,000	7.7
7/5-8/28	Berthold, ND	48	20	101	46	72	20,000	5.8
7/18-21/28	Mt. Ayr, IA	40	43	94	14	84	19,500	3.8
8/9-13/28	Settle, NC	36	01	80	46	96	24,000	7.0
8/10-13/28	Cheltenham, MD	38	44	76	51	66	35,000	8.8
8/13-17/28	Caesars Head, SC	35	07	82	38	102	77,300	9.4
9/4-7/28	Marion, SC	34	11	79	23	72	19,600	4.9
9/16-19/28	Darlington, SC	34	17	79	02	96	100,000	10.8
11/15-17/28	Lebo, KS	37	55	95	26	60	60,000	8.1
3/11-16/29	Elba, AL	31	25	86	04	114	100,000	16.1
7/16-18/29	Woodville, MS	31	09	91	18	66	24,000	5.4
9/20-23/29	Gallinas (nr), NM	35	09	105	39	72	17,000	2.6
9/23-28/29	Glenville, GA	31	56	81	56	120	70,000	13.1
9/29-10/3/29	Vernon, FL	30	38	85	43	84	103,000	9.3

Table A.1 – 253 Major storms (listed in Storm Rainfall, $\geq$ 10,000 mi^2 and $\geq$ 60 hr; 72 hr $\geq$ 90% total storm amount at 20,000 mi^2, arranged in chronological order) – Continued

Date	Station nearest center	Lat. (°)	Lat. (')	Long. (°)	Long. (')	Tot. st. dur. (hr)	Tot. st. area (mi^2)	1000-mi^2 24-hr amt. (in.)
1/6-11/30	Arkadelphia, AR	34	07	93	03	114	70,000	5.4
5/15-19/30	Camden, AR	33	36	92	49	108	116,000	7.3
6/12-15/30	Washington, IA	41	17	91	41	63	70,000	7.7
10/9-12/30	Porter, NM	35	12	103	17	60	27,700	7.2
7/20-25/31	Conklingville, NY	43	19	73	56	120	17,000	3.1
6/2-6/32	Meeker, OK	35	30	96	54	84	70,000	8.7
7/3-8/32	Clay, WV	38	28	81	05	120	36,000	5.6
7/31-8/3/32	Lexington, KY	38	02	84	36	72	23,300	5.8
9/5-7/32	Abilene, TX	32	26	99	41	60	20,400	4.5
10/4-6/32	Elka Park, NY	42	10	74	14	66	60,000	7.4
10/4-7/32	Elka Park, NY	42	10	74	14	96	29,000	6.9
10/14-18/32	Tuscaloosa, AL	33	14	87	37	90	70,000	6.8
10/15-18/32	Rocky Mount, NC	37	00	79	54	72	50,000	7.4
12/21-24/32	Sulphur, OK	34	30	96	58	66	100,000	6.7
4/11-14/33	Durham, NH	43	08	70	56	60	20,000	5.0
7/22-27/33	Logansport, LA	31	58	94	00	126	100,000	14.8
8/20-24/33	Peekamoose, NY	41	56	74	23	108	66,000	8.2
2/27-3/4/34	De Ridder, LA	30	50	93	16	126	200,000	7.2
6/6-8/34	Akron, IA	42	49	96	33	66	53,400	5.2
9/4-9/34	Beaufort, NC	34	44	76	39	108	19,000	7.3
11/19-21/34	Millry, AL	31	38	88	19	66	130,000	9.0
11/28-12/1/34	Southport, NC	33	55	78	01	84	90,000	6.4
1/18-21/35	Hernando, MS	34	50	90	00	84	98,500	7.9
5/2-7/35	Melville, LA	30	41	91	44	126	133,000	11.1
5/16-20/35	Simmesport, LA	30	59	91	48	102	75,000	10.4
7/6-10/35	Hector, NY	42	30	76	53	90	38,500	8.6
9/2-6/35	Easton, MD	38	46	76	01	114	48,469	10.8
12/5-8/35	Satsuma (nr), TX	29	54	96	37	60	56,500	13.9
7/29-8/2/36	Blountstown, FL	30	26	85	02	120	100,000	6.7
9/14-18/36	Broome, TX	31	47	100	50	96	70,000	13.8
9/25-28/36	Hillsboro, TX	32	01	97	08	90	157,000	9.9
4/24-28/37	Clear Springs, MD	39	40	77	54	114	20,000	6.1
5/26-30/37	Ragland, NM	34	49	103	44	84	37,000	3.3
6/11-13/37	Circle, MT	47	30	105	34	60	62,000	4.0
8/31-9/3/37	Wolverine, MI	45	17	84	37	72	19,000	7.0
9/6-10/37	Bentonville, AR	36	22	94	13	84	42,750	6.1
9/30-10/4/37	New Orleans, LA	29	57	90	04	114	20,000	11.3
10/17-20/37	Caesars Head, SC	35	07	82	38	72	15,000	6.1
3/28-31/38	Ford's Ferry, KY	37	28	88	06	84	25,000	6.0
4/5-9/38	Lock No. 2, AL	32	08	88	02	108	95,000	7.9

Table A.1 - 253 Major storms (listed in Storm Rainfall, $\geq$ 10,000 mi^2 and $\geq$ 60 hr; 72 hr $\geq$ 90% total storm amount at 20,000 mi^2, arranged in chronological order) - Continued

Date	Station nearest center	Lat.		Long.		Tot. st. dur. (hr)	Tot. st. area (mi^2)	1000-mi^2 24-hr amt. (in.)
		(°)	(')	(°)	(')			
6/26-28/38	Odessa, DE	39	28	75	40	60	10,500	5.3
8/12-15/38	Koll, LA	30	20	92	45	90	34,000	12.0
8/30-9/4/38	Loveland (nr), CO	40	23	105	04	126	21,500	3.1
9/17-22/38	Buck, CT	41	40	72	40	120	67,000	7.7
3/9-12/39	Charleston, IL	39	29	88	11	72	70,000	3.9
8/6-9/40	Miller Island, LA	29	45	92	10	84	36,200	18.4
9/2-6/40	Hallett, OK	36	15	96	36	90	20,000	13.6
11/22-25/40	Hempstead, TX	30	08	96	08	78	78,000	14.2
5/26-31/41	Jennings, LA	30	13	92	39	120	54,000	5.6
8/28-31/41	Hayward, WI	46	00	91	28	78	60,000	9.1
9/20-23/41	McColleum Ranch, NM	32	10	104	44	78	38,000	6.3
10/17-22/41	Trenton, FL	29	48	82	57	138	25,000	18.2
10/18-22/41	Lindsborg, KS	38	34	97	40	96	16,000	7.9
4/17-21/42	Kenton (nr), OK	36	55	102	58	102	54,500	3.1
5/19-23/42	Carbondale, PA	40	48	76	08	96	12,000	5.0
6/23-26/42	Clifton Hill, MO	39	25	92	42	72	35,000	6.9
7/2-6/42	Spring Branch, TX	29	55	98	25	96	52,800	6.9
8/7-10/42	Charlottesville, VA	38	02	78	30	96	24,500	5.3
8/29-9/1/42	Rancho Grande, NM	34	56	105	06	84	35,600	6.8
10/11-17/42	Big Meadows, VA	38	31	78	26	156	25,000	9.1
12/27-30/42	Ashville, AL	33	51	86	20	79	30,950	9.7
1/16-19/43	River Falls, AL	31	21	86	32	66	40,000	8.7
5/6-12/43	Warner, OK	35	29	95	18	144	212,000	11.1
5/12-20/43	Mounds (nr), OK	35	52	96	03	192	200,000	8.5
7/27-29/43	Devers, TX	30	02	94	35	60	33,000	13.7
6/10-13/44	Stanton, NE	41	52	97	03	78	16,000	9.3
6/2-5/44	Colony, WY	44	56	104	12	72	36,000	3.4
9/12-15/44	New Brunswick, NJ	40	29	74	27	96	50,000	5.6
8/26-29/45	Hockley, TX	30	02	95	51	72	34,000	13.4
5/25-28/46	Renovo, PA	41	20	77	45	78	16,800	4.7
8/12-15/46	Cole Camp (nr), MO	38	29	93	13	78	45,000	8.3
8/12-16/46	Collinsville, IL	38	40	89	59	114	20,400	9.0
5/25-30/47	Plattsmouth, NE	41	01	95	53	132	300,000	-
6/2-7/47	Browning (nr), MO	40	03	93	06	120	306,000	4.8
6/10-13/47	Earlham, IA	41	28	94	07	78	300,000	-
6/18-23/47	Holt (nr), MO	39	27	94	20	120	306,000	5.6
6/23-26/47	Annapolis, MD.	37	22	90	42	66	306,000	2.3
6/26-30/47	Lathrop, MO	39	33	94	20	96	306,000	4.1
8/10-13/47	Plentywood, MT	48	45	104	30	72	64,329	3.9
8/24-27/47	Dallas, TX	32	51	96	51	72	30,000	9.3

Table A.1 - 253 Major storms (listed in Storm Rainfall, $\geq$ 10,000 mi^2 and $\geq$ 60 hr; 72 hr $\geq$ 90% total storm amount at 20,000 mi^2, arranged in chronological order) - Continued

Date	Station nearest center	Lat. (°)	(')	Long. (°)	(')	Tot. st. dur. (hr)	Tot. st. area (mi^2)	1000-mi^2 24-hr amt. (in.)
4/22-25/50	Monmouth (nr), IL	40	55	90	43	60	20,000	4.6
9/3-7/50	Yankeetown, FL	29	03	82	42	96	43,500	30.2
8/9-13/51	Council Grove, KS	38	40	96	30	108	57,000	6.6
6/23-28/54	Vic Pierce, TX	30	22	101	23	120	27,900	18.4
8/10-15/55	New Bern, NC	35	07	77	03	126	69,000	8.9
8/11-15/55	Slide Mt., NY	42	01	42	25	120	81,000	6.0
8/15-19/55	Big Meadows, VA	38	31	78	26	96	50,000	5.5
8/17-20/55	Westfield, MA	42	07	72	45	72	35,000	12.4
5/18-21/60	New Prague, MN	44	35	93	35	85	10,000	4.4
9/10-13/61	Bay City, TX	28	58	95	57	90	100,000	9.6
9/11-13/61	Shelbina, MO	39	41	92	03	60	121,000	7.1
3/2-5/66	Courtenay (nr), ND	47	14	98	35	72	35,000	3.1
6/19-23/72	Zerbe, PA	40	37	76	32	96	130,000	12.3

Table A.2.--Distribution of 253 major storms by duration and area size classes

Area (10^3 mi^2)	10- <20	20- <30	30- <40	40- <50	50- <60	60- <70	70- <80	80- <90	90- <100	100- <120	120- <140	140- <160	160- <180	189- <200	200- <300	≥300	Total
Dur. (hr)																	
60	1	7	4	5	2	3	2	2	.	.	1	.	.	.	.	.	27
66	2	7	5	1	4	4	1	.	.	2	1	.	.	.	.	1	28
72	10	3	10	4	3	1	1	1	.	1	.	.	.	.	.	.	34
78	4	1	3	1	2	1	2	1	.	3	1	.	.	.	.	1	20
84	2	2	5	2	.	2	3	.	3	3	.	.	.	.	.	.	22
90	1	1	2	.	2	1	4	1	.	2	.	1	.	.	.	.	15
96	1	5	6	3	3	1	4	.	.	4	2	.	1	.	.	1	31
102	1	2	1	.	2	.	2	1	.	1	.	.	.	.	.	.	10
108	1	2	2	2	4	1	2	1	2	1	.	1	1	.	1	.	21
114	.	3	1	2	.	.	2	.	.	3	.	1	.	1	.	.	13
120	1	2	2	1	3	4	2	1	.	1	1	.	.	.	.	2	20
126	.	1	.	.	.	1	.	1	.	1	1	.	.	.	1	.	6
132	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	1
138	.	.	.	.	.	1	.	.	.	.	.	.	.	1	.	.	2
144	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1.	.	1
≥150	.	1	.	.	.	.	.	.	.	.	.	.	.	.	1	.	2
Total	24	37	41	21	25	20	25	9	5	22	7	3	2	2	4	6	253

Table A.3.--Shape ratios of 253 major storm isohyetal patterns relative to area size classes

Area size category (10^3 mi^2)	Shape ratio								Total no. of storms
	1	2	3	4	5	6	7	8	
	% of total storms in category								
10 to < 20	17	33	29	8	4	4	4		24
20 to < 30	8	25	36	11	11	3		6	36
30 to < 40	2	41	22	17	12	5			41
40 to < 50		24	33	19	19		5		21
50 to < 60	8	38	8	15	19	8	4		26
60 to < 75	6	28	25	19	6	11	3	3	36
75 to <100		22	22	26	17	9	4		23
100 to <125	9	17	30	26	4	4	9		23
≥ 125	4	35	39	4	17				23
									Total 253

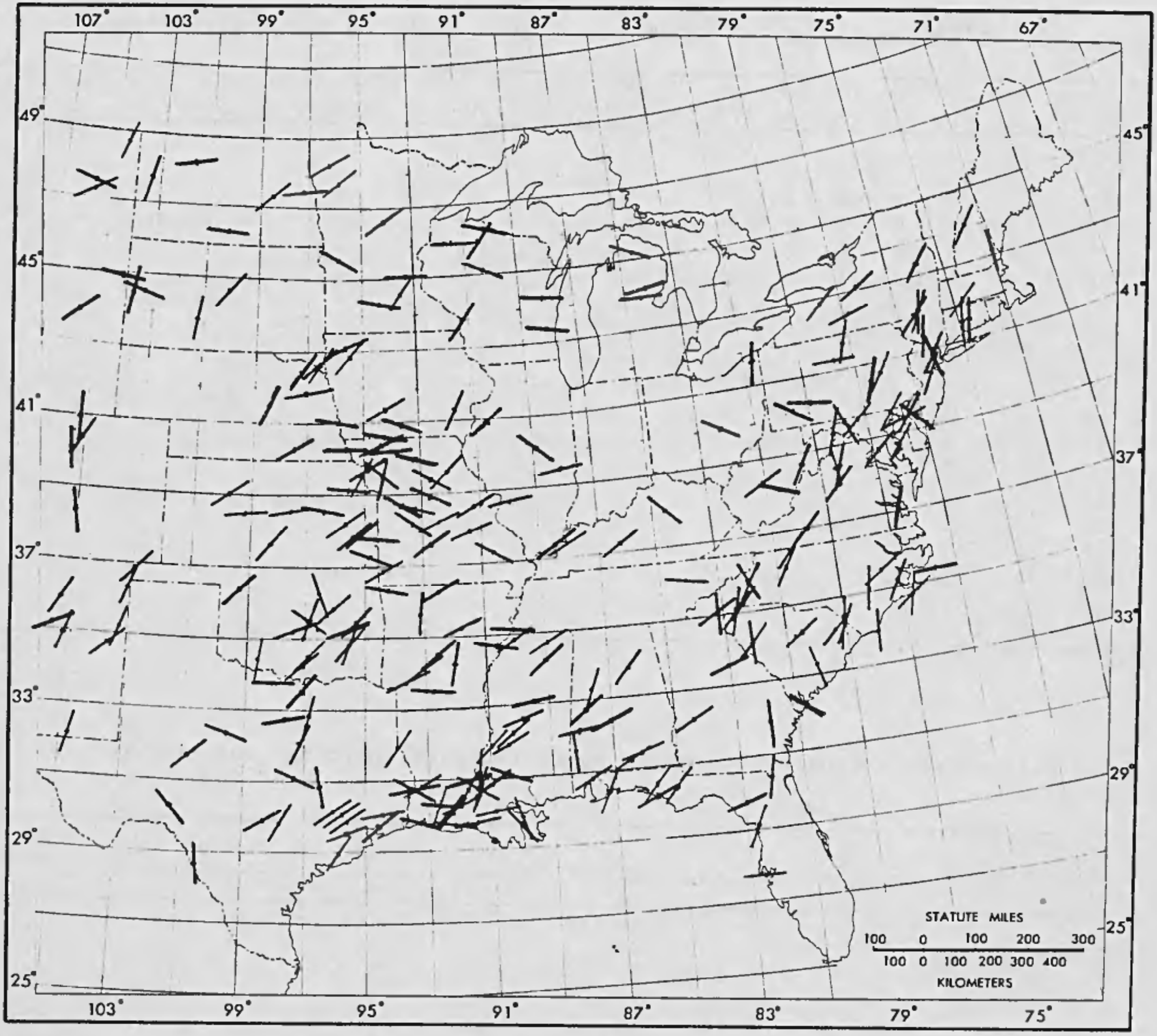

Figure A.1.—Regional distribution of 253 major storms listed in table A1 showing orientation of total-storm precipitation patterns.

(Continued from inside front cover)

No. 45. Probable maximum and TVA precipitation for Tennessee River Basins up to 3,000 square miles in area and durations to 72 hours. 1969.
No. 46. Probable maximum precipitation, Mekong River Basin. 1970.
No. 47. Meteorological criteria for extreme floods for four basins in the Tennessee and Cumberland River Watersheds. 1973.
No. 48. Probable Maximum Precipitation and Snowmelt Criteria For Red River of the North Above Pembina, and Souris River Above Minot, North Dakota. 1973.
No. 49. Probable Maximum Precipitation Estimates, Colorado River and Great Basin Drainages. 1977.
No. 50. The Meteorology of Important Rainstorms in the Colorado River and Great Basin Drainages. 1982 (PB82 185414)
No. 51. Probable Maximum Precipitation Estimates, United States East of 105th Meridian. 1978. (PB287925)
No. 52. Application of Probable Maximum Precipitation Estimates--United States East of the 105th Meridian. 1982.
No. 53. Seasonal Variation of 10-Square-Mile Probable Maximum Precipitation Estimates, United States East of the 105th Meridian. 1980. (NUREG/CR-1486)