HYDROMETEOROLOGICAL REPORT NO. 51

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
CORPS OF ENGINEERS

Washington, D.C.
June 1978

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 (Unpublished.)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 (Unpublished.)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.
*No. 19. Preliminary report on depth-duration-frequency characteristics of precipitation over the Muskingum Basin for 1- to 9-week periods. 1945.
*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.
No. 38. Meteorology of flood-producing storms in the Ohio River Basin. 1961.
No. 39. Probable maximum precipitation in the Hawaiian Islands. 1963.
No. 40 Probable maximum precipitation, Susquehanna River drainage above Harrisburg, Pa. 1965.
No. 41. Probable maximum and TVA precipitation over the Tennessee River Basin above Chattanooga. 1965.
No. 42. Meteorological conditions for the probable maximum flood on the Yukon River above Rampart, Alaska. 1966.
No. 43. Probable maximum precipitation, Northwest States. 1966.
No. 44. Probable maximum precipitation over South Platte River, Colorado, and Minnesota River, Minnesota. 1969.

*Out of print.

(Continued on inside back cover)

U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

U.S. DEPARTMENT OF THE ARMY
CORPS OF ENGINEERS

HYDROMETEOROLOGICAL REPORT NO. 51

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

Prepared by
Louis C. Schreiner and John T. Riedel
Hydrometeorological Branch
Office of Hydrology
National Weather Service

WASHINGTON, D.C.
June 1978

Reprinted August 1980

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

CONTENTS

		Page
Abstract		1
1.	Introduction	1
1.1.	Background	1
1.2.	Assignment	1
1.3.	Definition of PMP	2
1.4.	Scope	2
1.4.1.	Generalized vs. individual drainage estimates	2
1.4.2.	Stippled regions on PMP maps	3
1.5.	Application of drainage PMP values	3
2.	Approach to generalized PMP	3
2.1.	Introduction	3
2.2.	Basic data	4
2.2.1.	Sources	4
2.2.2.	Variation in rainfall data with duration and area size	6
2.2.3.	Point rainfall vs. 10-mi^2 (26-km^2) average rainfall	7
2.3.	Moisture maximization	7
2.3.1.	Definition - concept	7
2.3.2.	Atmospheric moisture	8
2.3.3.	Representative storm dew point	8
2.3.4.	Maximum dew point	9
2.3.5.	Moisture adjustment	9
2.3.6.	Elevation and barrier considerations	9
2.4.	Transposition	10
2.4.1.	Definition	10
2.4.2.	Transposition limits	10
2.4.3.	Transposition adjustment	11
2.4.4.	Distance-from-coast adjustment for tropical storm rainfall	11
2.4.5.	Large-area rainfall adjustment in the gentle upslope region	11
2.4.6.	Example of storm adjustments	14
3.	Details of analysis	16
3.1.	Minimum envelopes	16
3.2.	Special problems	26
3.2.1.	Introduction	26
3.2.2.	Adjustments greater than 50 percent	28
3.2.3.	Colorado storm May 30-31, 1935	28
3.2.4.	Smethport, Pa. storm July 17-18, 1942	28
3.2.5.	Yankeetown, Fla. storm September 3-7, 1950	29
3.3.	Consistency checks	30
3.3.1.	Introduction	30
3.3.2.	Variation of incremental PMP with area size	31
3.3.3.	Consistency in depth-area-duration relations	32

Page

3.3.4. Cross section checks 32
3.3.5. Rainfall difference check 32
3.3.6. Rainfall ratio check 32
3.3.7. PMP maps 38

4. Evaluation of generalized PMP charts 38
4.1. Degree of envelopment 38
4.2. Use of PMP for all durations in one PMP storm 40
4.2.1. Introduction 40
4.2.2. Storm commonality test 40

5. Use of PMP charts 42

Acknowledgments 43

References 44

Appendix -- Maximum observed areal precipitation for important storms 78

TABLES

1. Number of analyzed storms, east of the 105th meridian, with areal rainfall depths for indicated area sizes and durations 6

2. Example of computations of moisture maximization and transposition adjustments 17

3. Example of total storm adjustments 18

4. Storms that give moisture maximized rainfall within 10 percent of PMP for at least one area size and duration 39

5. Exceptions to "storm commonality" 42

FIGURES

1. Location of storms 5

2. Distance-from-coast adjustment for transposing tropical storm rainfall 12

3. Gentle upslope region 13

4. Example of data used for storm adjustments 15

Page

5. Envelopment of 24-hr observed storm rainfall (in.) in place of occurrence for 10,000 mi^2 (25,900 km^2).................... 20

6. Envelopment of 24-hr moisture maximized storm rainfall (in.) in place of occurrence for 10,000 mi^2 (25,900 km^2)........... 21

7. Envelopment of greatest average monthly precipitation (in.) for State climatic divisions (1931-60)........................ 22

8. Envelopment of greatest average weekly precipitation (in.) for State climatic divisions (1906-35)........................ 24

9. Envelopment of the greatest 24-hr station precipitation (in.) within each State climatic division (through 1970)........... 25

10. Example of minimum smooth envelope of moisture maximized rainfall, in place and transposed............................ 27

11. Adopted transposition adjustment along the Atlantic coast for the Yankeetown, Fla. storm, September 3-7, 1950.............. 31

12. Example of depth-duration smoothing............................ 33

13. Example of depth-area smoothing................................ 34

14. Example of cross-section smoothing--constant duration.......... 35

15. Example of cross-section smoothing--constant area.............. 36

16. Example of checks of durational differences in PMP............ 37

17. Regions for storm commonality tests............................ 41

18. All-season PMP (in.) for 6 hr 10 mi^2 (26 km^2).................. 48

19. All-season PMP (in.) for 12 hr 10 mi^2 (26 km^2)................. 49

20. All-season PMP (in.) for 24 hr 10 mi^2 (26 km^2)................. 50

21. All-season PMP (in.) for 48 hr 10 mi^2 (26 km^2)................. 51

22. All-season PMP (in.) for 72 hr 10 mi^2 (26 km^2)................. 52

23. All-season PMP (in.) for 6 hr 200 mi^2 (518 km^2)................ 53

24. All-season PMP (in.) for 12 hr 200 mi^2 (518 km^2)............... 54

25. All-season PMP (in.) for 24 hr 200 mi^2 (518 km^2)............... 55

Page

26. All-season PMP (in.) for 48 hr 200 mi^2 (518 km^2).............. 56

27. All-season PMP (in.) for 72 hr 200 mi^2 (518 km^2).............. 57

28. All-season PMP (in.) for 6 hr 1,000 mi^2 (2,590 km^2)............ 58

29. All-season PMP (in.) for 12 hr 1,000 mi^2 (2,590 km^2)........... 59

30. All-season PMP (in.) for 24 hr 1,000 mi^2 (2,590 km^2)........... 60

31. All-season PMP (in.) for 48 hr 1,000 mi^2 (2,590 km^2)........... 61

32. All-season PMP (in.) for 72 hr 1,000 mi^2 (2,590 km^2)........... 62

33. All-season PMP (in.) for 6 hr 5,000 mi^2 (12,950 km^2)........... 63

34. All-season PMP (in.) for 12 hr 5,000 mi^2 (12,950 km^2).......... 64

35. All-season PMP (in.) for 24 hr 5,000 mi^2 (12,950 km^2).......... 65

36. All-season PMP (in.) for 48 hr 5,000 mi^2 (12,950 km^2).......... 66

37. All-season PMP (in.) for 72 hr 5,000 mi^2 (12,950 km^2).......... 67

38. All-season PMP (in.) for 6 hr 10,000 mi^2 (25,900 km^2).......... 68

39. All-season PMP (in.) for 12 hr 10,000 mi^2 (25,900 km^2)......... 69

40. All-season PMP (in.) for 24 hr 10,000 mi^2 (25,900 km^2)......... 70

41. All-season PMP (in.) for 48 hr 10,000 mi^2 (25,900 km^2)......... 71

42. All-season PMP (in.) for 72 hr 10,000 mi^2 (25,900 km^2)......... 72

43. All-season PMP (in.) for 6 hr 20,000 mi^2 (51,800 km^2).......... 73

44. All-season PMP (in.) for 12 hr 20,000 mi^2 (51,800 km^2)......... 74

45. All-season PMP (in.) for 24 hr 20,000 mi^2 (51,800 km^2)......... 75

46. All-season PMP (in.) for 48 hr 20,000 mi^2 (51,800 km^2)......... 76

47. All-season PMP (in.) for 72 hr 20,000 mi^2 (51,800 km^2)......... 77

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

Louis C. Schreiner and John T. Riedel
Office of Hydrology
NOAA, National Weather Service, Silver Spring, Md.

ABSTRACT. Generalized estimates of Probable Maximum Precipitation, the greatest rainfall rates for specified durations theoretically possible, are presented for the United States east of the 105th meridian. They are all-season estimates, that is, the greatest for any time of year, for drainages from 10 to 20,000 mi^2 (26 to 51,800 km^2) for durations of 6 to 72 hours. Details of the procedures and methods used for developing these estimates are described.

1. INTRODUCTION

1.1 Background

Generalized charts setting the level of all-season Probable Maximum Precipitation (PMP) for drainages up to 1,000 mi^2 (2,590 km^2), covering the United States east of the 105th meridian, have been available since 1947 (U.S. Weather Bureau 1947) and the seasonal variation since 1956 (Riedel et al. 1956). These studies have been used extensively by the Corps of Engineers, other Federal agencies, State and local governments, private engineers and meteorologists. Because of increased interest in projects involving large drainages, it was found necessary to extend estimates to areas greater than 1,000 mi^2 (2,590 km^2). At the same time, it was necessary to revise the small area, less than 1,000 mi^2 (2,590 km^2) study in order to appropriately consider all important historical storms; for example, the Yankeetown, Fla. storm of September 3-7, 1950. The areal depths for this storm were not available when the 1956 study was prepared.

1.2 Assignment

Discussions concerning the need for the generalized PMP charts for large areas were held at a meeting with representatives of the Office of the Chief, Corps of Engineers, at Phoenix, Ariz., May 17-20, 1971. Authorization for the revision of the previous small-area study and coordination of the results with the extension to larger areas stemmed from a meeting with representatives of the Office of the Chief, Corps of Engineers at Silver Spring, Md., September 19, 1974.

1.3 Definition of PMP

PMP is defined as "the theoretically greatest depth of precipitation for a given duration that is physically possible over a particular drainage area at a certain time of year," (American Meteorological Society 1959). In consideration of our limited knowledge of the complicated processes and interrelationships in storms, PMP values are identified as estimates.

Another definition of PMP more operational in concept is "the steps followed by hydrometeorologists in arriving at the answers supplied to engineers for hydrological design purposes" (WMO 1973). This definition leads to answers deemed adequate by competent meteorologists and engineers and judged as meeting the requirements of a design criterion.

1.4 Scope

This study can be used to determine drainage average all-season PMP for any drainage from 10 to 20,000 mi^2 (26 to 51,800 km^2) in area for durations of 6 to 72 hours in the United States east of the 105th meridian. In northern portions of the region, all-season PMP may not yield the probable maximum flood. Critical spring soil conditions with snow on the ground, in combination with spring season PMP values, may yield greater flood peaks.

1.4.1 Generalized vs. Individual Drainage Estimates

The PMP values of this study are termed generalized estimates. By this we mean isolines of PMP are given on a map allowing determination of average PMP for any drainage.

Through the years, the Hydrometeorological Branch has determined PMP estimates for individual drainages. This was done: (a) if generalized PMP studies were not available, (b) for drainages larger in size than covered by available generalized PMP studies, or (c) for drainages such as in the Appalachians, where detailed studies indicated orographic effects would yield PMP estimates significantly different from those determined from available generalized PMP charts. Some of the more substantive studies have been published. The more recent ones cover drainages of the Red River of the North and Souris River (Riedel 1973), the Colorado and Minnesota Rivers (Riedel et al. 1969), the Tennessee River (Schwarz 1965, and Schwarz and Helfert 1969) and the Susquehanna River (Goodyear and Riedel 1965). These and other unpublished individual drainage PMP estimates made by the Hydrometeorological Branch may take precedence over estimates obtained from generalized PMP studies of this report because the individual drainage studies take into account orographic features that are smoothed out in this study. On the other hand, due to passage of time, individual drainage studies will not necessarily include recent storm data and advances in meteorological concepts. It is not practical to evaluate all the individual drainage PMP estimates at this time. We suggest a decision be made on a case-by-case basis as needed.

1.4.2 Stippled Regions on PMP Maps

The generalized PMP maps (figs. 18-47) are stippled in two regions, (a) the Appalachian Mountains extending from Georgia to Maine and (b) a strip between the 103rd and 105th meridian. This stippling outlines areas within which the generalized PMP estimates might be deficient because detailed terrain effects have not been evaluated.

In developing the maps of PMP, it was sometimes necessary to transpose storms to and from higher terrain. Determination of storm transposition limits (section 2.4.2) took into account topography homogeneity in a general sense, thereby avoiding major topographic considerations. However, regional analysis required definition across mountains such as the Appalachians. For such regions, the assumption was made that the reduced height of the column of moisture available for processing (section 2.3.2) at higher elevations is compensated by intensification from steeper terrain slopes.

In contrast to the use of these simplifying assumptions, studies of PMP covering portions of the Western States (U.S. Weather Bureau 1961, 1966, and Hansen et al. 1977) and the Tennessee River drainage (Schwarz and Helfert 1969) do take into account detailed terrain effects. A laminar flow orographic precipitation computation model, useful in some regions where cool-season precipitation is of greatest concern, gives detailed definition for some of the Western States. For the Tennessee River drainage, nonorographic PMP was adjusted for terrain effects by consideration of numerous different rainfall criteria, taking into account meteorological aspects of critical storms of record.

We expect future studies of the Hydrometeorological Branch will involve detailed generalized studies covering the stippled regions. Until these studies are completed, we suggest that major projects within the stippled regions be considered on a case-by-case basis as the need arises.

1.5 Application of Drainage PMP Values

The results of this study are drainage average PMP depths for the designated durations (6 to 72 hours) without specifying a time sequence for occurrence of 6-hr incremental PMP values. A companion report (Hansen and Schreiner) to this study covers methods for spatially distributing the most important 6-hr PMP increments. It also gives meteorological reasonable time sequences of the 6-hr PMP increments from the beginning of the PMP storm. Additionally, shape and orientation of isohyetal patterns are discussed.

2. APPROACH TO GENERALIZED PMP

2.1 Introduction

The basic approach used in developing PMP estimates has been described in numerous publications (WMO 1973, Wiesner 1970, WMO 1969a, Paulhus and Gilman 1953, and U.S. Weather Bureau 1960). The first reference contains the most comprehensive discussion. For nonorographic regions, the approach may be briefly summarized by three operations on observed areal storm precipitation: moisture maximization, transposition, and envelopment.

Moisture maximization consists of increasing the storm precipitation to a value that is consistent with the maximum moisture in the atmosphere for the storm location and month of occurrence.

Transposition means relocating storm precipitation within a region that is homogeneous relative to terrain and meteorological features important to the particular storm rainfall. Transposition greatly increases the available data for evaluating the rainfall potential for a drainage.

Envelopment is smoothly interpolating between the maxima from a group of values for different durations and/or areas. Such smooth enveloping curves in many cases may give greater values for some durations or area sizes than obtained from only moisture maximization and transposition. In addition, envelopment over a region entails smooth geographic variation of moisture maximized and transposed rainfall values obtained from numerous storms. Such smoothing compensates for the random occurrence of large rainfalls, in that a drainage may not have experienced equally efficient precipitation mechanisms for all pertinent durations and sizes of areas. Envelopment also gives regionally consistent mapped values; unless differences can be explained meteorologically or topographically, anomalies should be avoided. Methods of envelopment applied in this report are explained in section 3.

2.2 Basic Data

2.2.1 Sources

The basic data for this study are maximum observed areal precipitation depths for various durations. These data are developed by a standardized depth-area-duration (D-A-D) analysis of point precipitation amounts. The procedure used for D-A-D analysis can be found in several publications (WMO 1969b and U.S. Weather Bureau 1946).

For the United States, over 500 storms have been so analyzed, and the pertinent data, that is, the maximum areal depths, have been published (Corps of Engineers, U.S. Army 1945-). Canada has made similar analysis for over 400 storms (Atmospheric Environment Service 1961-). Some of the Canadian storms were useful in the present study. Storm rainfalls from these sources were augmented by unofficial storm D-A-D values developed by the Hydrometeorological Branch or found in the literature (Shipe and Riedel 1976).

The appendix chronologically lists observed rainfall depths for the important storms of this study. These were most influential in setting the level of PMP for at least one combination of area size and duration. Figure 1 shows the locations of these storms along with other storms discussed in the text. Storms mentioned in the text, listed in the appendix, or shown in various figures are identified by a storm index number. In the text, this number is in parenthesis following reference to the storm. For storms

Storm Index No.	Storm Assignment No.	Date
1	OR 9-19	9/10-13/1878
2	SA 1-1	5/30-6/1/1889
3	MR 4-3	6/4-7/1896
4	UMV 1-2	7/18-22/1897
6	NA 1-7B	7/26-29/1897
7	GM 3-4	6/27-7/1/1899
8	LMV 2-5	4/15-18/1900
11	GL 4-9	10/7-11/1903
13	GL 2-12	6/3-8/1905
14	UMV 2-5	6/9-10/1905
16	MR 5-13	6/6-8/1906
17	GM 3-14	8/4-6/1906
20	SW 1-11	10/19-24/1908
22	UMV 1-11A	7/18-23/1909
26	LMV 3-19	3/24-28/1914
29	GL 2-16	8/31-9/1/1914
31	SA 2-9	7/13-17/1916
33	GM 5-15B	9/15-17/1919
36	MR 4-21	6/17-21/1921
37	GM 4-12	9/8-10/1921
38	MR 4-23	9/27-10/1/1923
42	MR 4-24	9/17-19/1926
44	NA 1-17	11/2-4/1927
47	LMV 2-20	3/11-16/1929
49	GM 5-1	6/30-7/2/1932
50	NA 1-20A	9/16-17/1932
51	NA 1-20B	9/16-17/1932
53	SW 2-11	4/3-4/1934
54	LMV 4-21	5/16-20/1935
55	MR 3-28A	5/30-31/1935
56	- -	5/30-31/1935
57	GM 5-20	5/31/1935
59	NA 1-27	7/6-10/1935
65	- -	6/19-20/1939
67	MR 4-5	6/3-4/1940
68	NA 2-4	9/1/1940
69	SW 2-18	9/2-6/1940
71	UMV 1-22	8/28-31/1941
74	OR 9-23	7/17-18/1942
76	SA 1-28A	10/11-17/1942
77	SW 2-20	5/6-12/1943
78	MR 6-15	6/10-13/1944
80	MR 7-2B	8/12-16/1946
82	- -	6/23-24/1948
85	SA 5-8	9/3-7/1950
86	MR 10-2	7/9-13/1951
87	MR 10-8	6/7/1953
88	SW 3-22	6/23-28/1954
90	ONT 10-54	10/14-15/1954
91	NA 2-22A	8/17-20/1955
93	QUE 8-57	8/3-4/1957
96	SW 3-23	6/13-20/1965
97	SW 3-24	9/19-24/1967
99	NA 2-23	8/19-20/1969
100	NA 2-24A	6/19-23/1972

Figure 1.--Location of storms. [*Storms of appendix (section 2.2.1), others mentioned in text (sections 2.4.5 and 3.2.3), and those within 10 percent of PMP (section 4.1)*]

shown in figures or listed in the appendix, a storm assignment number is also given. This number is either assigned by the Corps of Engineers (for U.S. storms) or the Atmospheric Environment Service (for Canadian storms). Those storms without a storm assignment number refer to unofficial rainfall data accumulated by the Hydrometeorological Branch.

2.2.2 Variation in Rainfall Data with Duration and Area Size

Table 1 shows the number of United States storms east of the 105th meridian, for which areal rainfall depths have been analyzed for listed area sizes and durations.

Table 1.--Number of analyzed storms east of the 105th meridian, with areal rainfall depths for indicated area sizes and durations.

Area		Duration (hr)				
mi^2	(km^2)	6	12	24	48	72
10	(26)	496	482	456	356	187
200	(518)	521	508	483	376	201
1,000	(2,590)	567	555	533	419	234
5,000	(12,950)	528	526	517	417	262
10,000	(25,900)	489	489	486	406	263
20,000	(51,800)	396	396	396	351	242

One would expect a decrease in basic data with increasing area size and increasing duration. With respect to duration, it is easy to show that the storms that last 6 or 12 hours are much more numerous than storms that last beyond 12 hours. Similarly, we know that many storms cover only a small area, e.g., summer thunderstorms.

There are several reasons why table 1 does not fully show this variation. There has been more need for maximum precipitation criteria over small areas, i.e., drainages less than 1,000 mi^2 (2,590 km^2); therefore, analysis of storms covering these areas has been emphasized. In the construction of table 1, a storm was not counted if the rainfall ceased to increase with increasing duration. Often for large-area storms, the small-area precipitation is concentrated in a shorter duration than the total storm period. This permits more values to be listed for large areas and long durations.

Another reason for the variation shown in table is that a special effort was made to augment basic data for areas of 1,000 mi^2 (2,590 km^2) and larger, particularly in regions with few analyzed storms. In the effort to obtain additional storm data, short-cut procedures were used, such as using only recording raingages for determining the time variation of rainfall. If recording raingages are well spaced, the results are quite similar to those obtained by standard procedures (WMO 1969b and U.S. Weather Bureau 1946). A few of these additional storms were important in setting the general level of PMP.

2.2.3 Point Rainfall vs. 10-mi^2 (26-km^2) Average Rainfall

This study estimates PMP for drainage sizes down to 10 mi^2 (26 km^2). The basic data (Corps of Engineers, U.S. Army 1945-) often use point rainfall as 10-mi^2 (26-km^2) rainfall in D-A-D analyses. This is done in order to at least partially compensate for the slim chance of "catching" the most intense rainfall in any storm. The question may then be raised as to whether PMP for areas less than 10 mi^2 (26 km^2) would be greater than the 10-mi^2 (26-km^2) values of this report. This is answered by the fact that with few exceptions the critical values establishing the PMP magnitude for 10 mi^2 came from 10-mi^2 (26-km^2) average rainfalls rather than single station amounts. This indicates that PMP for areas smaller than 10 mi^2 (26 km^2) would be greater than the 10-mi^2 (26-km^2) values in this report.

2.3 Moisture Maximization

2.3.1 Definition - Concept

Moisture maximization refers to the process of increasing storm rainfall depths for the storm location and season, for higher atmospheric moisture than was available in the actual storm.

Significant precipitation results from lifting moist air. Processes causing this lifting, associated with horizontal convergence, have been described in numerous texts. Various attempts at developing a model that will reproduce extreme rainfalls are hampered by the lack of sufficient data within storms to adequately check the magnitudes of horizontal convergence, vertical motion, and other parameters. Since measurements of these parameters during severe storms are not readily obtainable, the solution has been to use extreme record storm rainfalls as an indirect measure of parameters, other than moisture, that are important to such events.

We thus adjust storms of record to the equivalent of what would have occurred with maximum moisture and make the following assumption: The sample of extreme storms is sufficiently large so that near optimum "mechanism" (or efficiency) has occurred. By "mechanism" is meant a combined measure of all the important parameters to rainfall production, except moisture. The assumption thus circumvents a quantitative evaluation of "mechanism" and results in increasing storm rainfall occurring with assumed near optimum "mechanism" by an adjustment for maximum moisture.

In our use of the term mechanism, we do not include lifting by terrain. For PMP studies in the Western States, augmentation or depletion by terrain is taken in account (U.S. Weather Bureau 1966, and Hansen et al. 1977). Over most of the region of the present study the terrain effect is small. Sections 1.4.2 and 2.4.5 discuss how the more important terrain features were considered.

2.3.2 Atmospheric Moisture

The best measure of atmospheric moisture can be obtained from radiosonde observations. Soundings, giving the variation of moisture with height, are available for about 100 stations in the United States for 20 years. However, radiosonde data alone cannot be used for several reasons. First, many extreme storms occurred before the radiosonde network was established. Second, the radiosonde network is much too sparse to detect narrow tongues of moisture (Schwarz 1967) that are important to many storms. The solution is to use surface dew points, which are observed at many stations, as indices to atmospheric moisture. A saturated pseudo-adiabatic atmosphere is assumed, tied to surface dew points, which fixes the moisture and its distribution with height in the atmosphere. Tests have shown that the moisture thus computed is an adequate approximation to atmospheric moisture in major storms or for high dew point situations (Miller 1963).

Two dew points are required for moisture maximization. One is the dew point representative of moisture inflow during the storm. The other is the maximum dew point for the same location and time of year as the storm. Both storm and maximum dew points are reduced pseudo-adiabatically to 1000 mb (100 kPa) in order to normalize for differences in station elevations.

The measure of atmospheric moisture used is precipitable water (w_p). This is the depth of water vapor condensed into liquid in a column of air of unit cross section. For a saturated pseudo-adiabatic atmosphere, tables have been prepared (U.S. Weather Bureau 1951) giving w_p values based on 1000-mb (100-kPa) dew points.

Both storm and maximum dew points are usually taken as the highest value persisting for 12 hours. Instantaneous extreme dew point measurements may not be representative of inflow moisture over a significant time period. Also, taken over a duration, the effect of possible erroneous instantaneous dew point values is reduced.

The depth of precipitable water to use for adjustments was considered (U.S. Weather Bureau 1947) in a convergence storm model. Formation of cumulus clouds suggested division of the model into 3 layers; the lower inflow layer, the center with vertical motion, and the upper or outflow layer. It was found that the moisture adjustment did not change appreciably when various different proportional heights were assumed for these 3 layers. It was also determined that the height of the model [whether 400 or 200 mb (40 or 20 kPa)] did not materially change the moisture adjustment. Tests also indicated that the moisture adjustment is basically the same whether total w_p or effective w_p is used. The effective w_p is the inflow layer w_p minus the outflow layer w_p.

2.3.3 Representative Storm Dew Point

Dew points are selected in the warm moist air flowing into the storm. Both distance and direction of the dew points from the rainfall center are recorded. An average dew point value from several stations is considered to give the best estimate. Care must be used to ensure that dew point observations are taken only within the moist tongue involved in the heavy precipitation (Schwarz 1967). The time sequence of dew points from each station is reduced to 1000 mb (100 kPa) before averaging. After averaging, the highest persisting 12-hr value is selected.

2.3.4 Maximum Dew Point

Maximum dew points are generally the highest dew points observed for a given location and time of year. These dew points are based on seasonal and regional envelopes of maximum observed surface dew points that have persisted for 12 hours, reduced to 1000 mb (100 kPa) at many stations (Environmental Data Service 1968).

We adjust the storm to the maximum dew point 15 days from the storm date into the warmer season except for cases accompanied by unusually cold air judged to be dynamically significant to the rainfalls. Moisture maximization adjustments are increased by up to 10 percent due to the 15-day transposition.

2.3.5 Moisture Adjustment

Moisture maximization is accomplished by multiplying observed rainfall by the moisture adjustment, which is the ratio of w_p for the maximum 1000-mb (100-kPa) 12-hr persisting dew point to the w_p for the storm 1000-mb (100-kPa) 12-hr persisting dew point. This maximization expressed mathematically is:

$$P \times \frac{w_p \text{ Maximum}}{w_p \text{ Storm}} = \text{moisture-adjusted rainfall}$$

where P = observed rainfall

w_p = precipitable water. Maximum refers to enveloping highest observed w_p and Storm refers to storm w_p. (Both dew points are for the same location.)

2.3.6 Elevation and Barrier Considerations

Where there is a significant mountain barrier between the moisture source and rain location, or the rain occurs at a high elevation, a refinement to the moisture adjustment is usually applied. In such cases, mean elevation of the barrier ridge, or elevation of the rainfall rather than the 1000-mb (100-kPa) surface, is used as the base of the column of moisture. Section 2.4.5 discusses refinements to the moisture adjustment applied to large-area storms transposed in the gentle upslope region. Section 1.4.2 discussed the extent of orographic considerations used in this study. The location of representative storm dew points (usually toward a coast and at lower elevations) and restrictions to storm transposition (section 2.4.2) generally eliminated the need for using elevations in the moisture adjustment.

2.4 Transposition

2.4.1 Definition

Transposition means relocating isohyetal patterns of storm precipitation within a region that is homogeneous relative to terrain and meteorological features important to the particular storm rainfall under concern.

2.4.2 Transposition Limits

Topography is one of the more important controls on limits to storm transposition. If observed rainfall patterns show correspondence with underlying terrain features, or indicate triggering of rainfall by slopes, transposition should be limited to areas of similar terrain. Identification of broadscale meteorological features is important, e.g., surface and upper air high and low pressure centers that are associated with the storm, and how they interact to produce the rainfall. Also useful in determining transposition limits are storm isohyetal charts, weather maps, storm tracks and rainfalls of record for the type of storm under consideration, and topographic charts.

The more important guidelines to storm transposition for this study were:

a. Transposition was not permitted across the generalized Appalachian Mountain ridge.

b. Tropical storm rainfall centers were not transposed farther away from nor closer to the coast without an additional adjustment (section 2.4.4).

c. In regions of large elevation differences, transpositions were restricted to a narrow elevation band (usually within 1000 ft (305 m) of the elevation of the storm center).

d. Eastward limits to transposition of storms located in Central United States were the first major western upslopes of the Appalachians.

e. Westward transposition limits of storms located in Central United States were related to elevation. This varied from storm-to-storm but in most cases the 3000- or 4000-ft (915- or 1220-m) contour.

f. Southern limits to transposition were generally not defined since other storms located farther south usually provided higher rainfall values.

g. Northward limits were not defined if they extended beyond the Canadian border (the limits of the study region).

2.4.3 Transposition Adjustment

The transposition adjustment applied to relocated rainfall values is the ratio of w_p for the maximum 12-hr persisting dew point for the transposed location to that of the storm in place. The maximum dew point is for the same distance and direction from the transposed location as the storm representative dew point is from the storm location (section 2.3.3).

2.4.4 Distance-From-Coast Adjustment for Tropical Storm Rainfall

The general decrease in tropical storm rainfall with distance inland is well known. It is attributed to the difficulty of maintaining the same rainfall intensity as distance from the moisture source increases, and the deterioration of the tropical circulation with increasing distance inland. The usual transposition methods (section 2.4.3) provide little or no decrease in tropical storm rainfall when such storms are transposed farther inland. This is because the maximum 1000-mb (100-kPa) 12-hr persisting dew point charts (Environmental Data Service 1968) for the tropical storm season show little or no variation for up to approximately 550 mi (885 km) inland from the gulf coast. Therefore, an adjustment for distance from the coast was determined specifically for tropical storms when they were transposed inland.

A study (Schwarz 1965) developed a relation showing the decrease in tropical rainfall with distance [coast to 300 n.mi. (556 km)] inland. The relation was based on both observed and moisture-maximized tropical rainfall data for several area sizes and durations. Figure 2 shows this variation along with its extension for distances farther inland (solid line). The extension used additional data of the same type as used by Schwarz. Another relation derived from the same type of data (Schoner 1968) is shown by the dashed line. We have adopted Schwarz's relation with the extension for use in the present study. It shows no decrease in rainfall for the first 50 n.mi. (93 km) inland from the gulf coast, a smooth decrease to 80 percent at 205 n.mi. (380 km) inland, and 55 percent at 400 n.mi. (740 km) inland.

We applied the adjustment for distance from the coast to tropical storm rainfall (all area sizes and durations) transposed within the region where the maximum persisting 12-hr 1000-mb (100-kPa) dew point temperature charts (Environmental Data Service 1968) indicate no variation. When transposing rainfalls nearer to the coast, the values are increased. In the same way, they are decreased when transposed farther inland.

2.4.5 Large-Area Rainfall Adjustment in the Gentle Upslope Region

This report did not apply an elevation adjustment when transposing storms within limited differences in elevation (section 2.3.6). However, in the gently rising terrain west of the Mississippi River to the generalized initial steep slopes in the western portion of the study region (fig. 3) patterns of tentative PMP were not consistent with patterns in the guidance material discussed in section 3.1. The guidance material indicated a greater decrease in areal rainfall toward the west in the gentle upslope region.

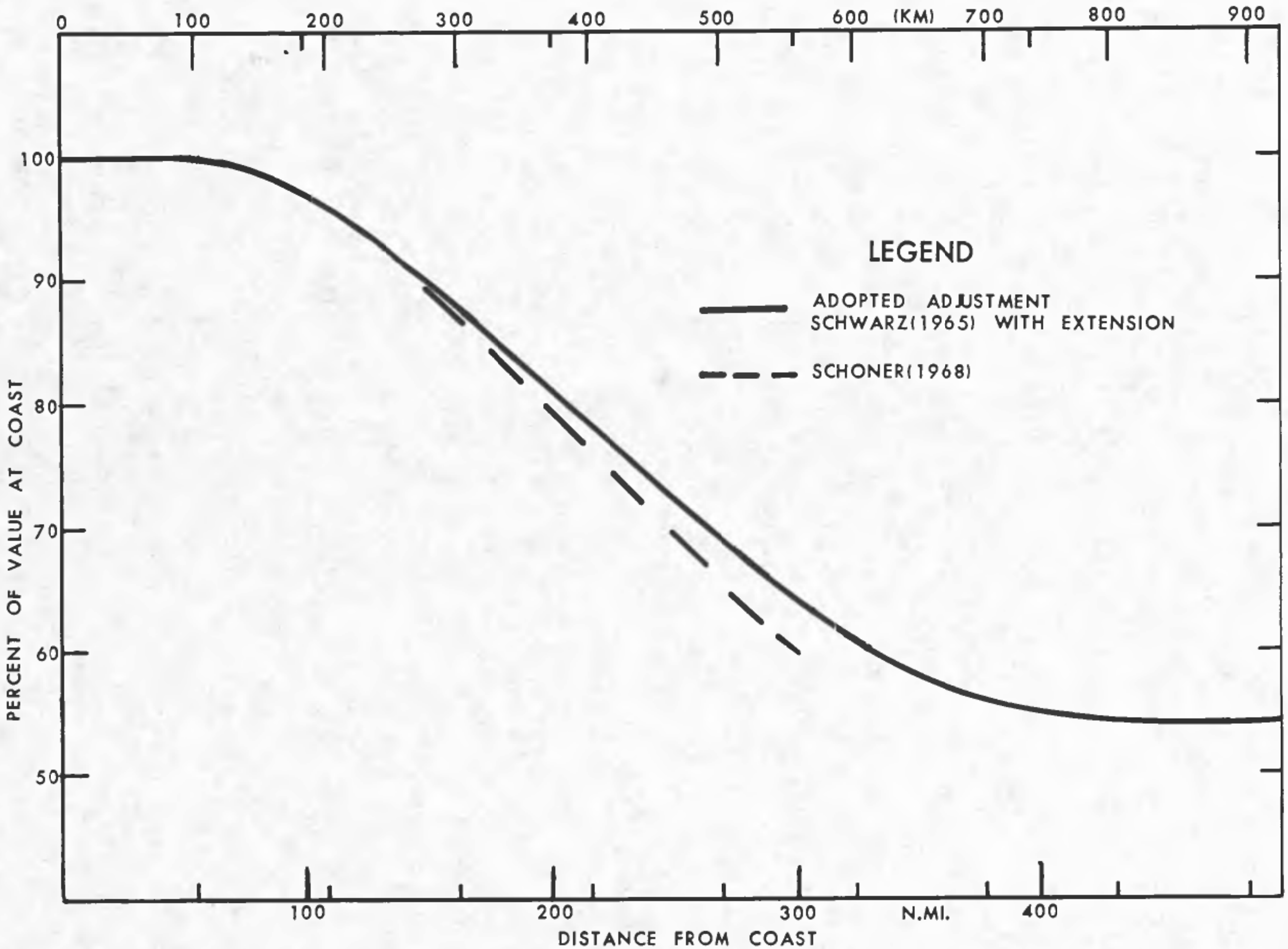


Figure 2.--Distance-from-coast adjustment for transposing tropical storm rainfall.

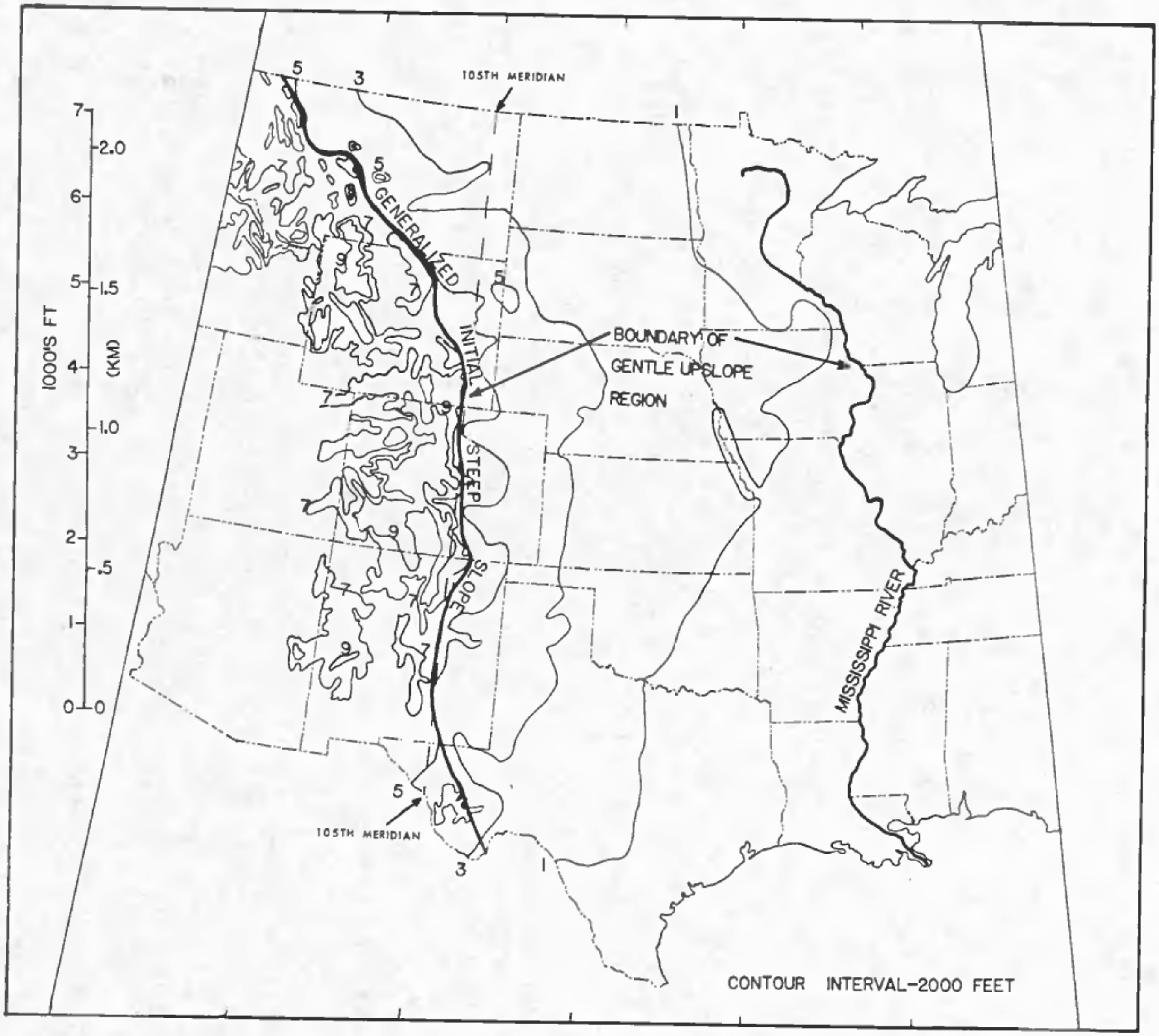


Figure 3.--Gentle upslope region.

Storm Rainfall (Corps of Engineers, U.S. Army 1945-) in the gentle upslope region was analyzed regionally. In this analysis the data were stratified and adjusted to eliminate variations due to distance from the moisture source and moisture availability in the record storms. The results showed a significant decrease toward the west in both the extremes of record and the averages of the three greatest values. Stratification of the rainfall by area size showed a decided trend toward greater decrease for large-area rainfall than for small.

The greater decrease for large-area rainfall can be the result of several factors. For small areas, a narrow band of inflowing moisture from the Gulf of Mexico can be important to extreme rainfalls. The intense center of the June 14-17, 1965 storm (No. 96) was associated with such a moisture band (Schwarz 1967). For larger areas, the broader and more persistent moisture bands are much more difficult to maintain, particularly into higher elevations of the gentle upslope region. Another factor of importance is the scattering of small hills and ridges throughout the region. These stimulate local rainfalls that are important to small-area storms. The decrease in available moisture with increasing elevation in the gentle upslope region is thus more important for large-area rainfalls.

With the evidence from rainfall data of various kinds and meteorological analyses within the gentle upslope region, we decreased large-area rainfalls when transposing to higher elevations and increased them when transposing to lower elevations. Storm depths for 1,000 mi^2 (2,590 km^2) or less were not adjusted.

The adjustment is based on the variation in precipitable water with height in the atmosphere for the maximum 12-hr persisting dew point in the storm location and in the transposed location. The adjustment ranges between 6 and 10 percent per 1,000 ft (305 m) change in elevation, depending on the elevation of the storm and the maximum dew point. This adjustment was applied to rainfall for all area sizes greater than 1,000 mi^2 (2,590 km^2). Any discontinuity introduced in PMP at 1,000 mi^2 (2,590 km^2) was eliminated by the various consistency checks (see section 3.3).

There are a number of major large-area storms in the gentle upslope region with limits of transposition east of the Mississippi River - beyond the boundaries of the gentle upslope region. In calculating the adjusted rainfall for the eastward transposition of these storms, the adjustment for gentle upslope was not applied. In all such cases the small change in elevation would have altered the total storm adjustment by less than 4 percent.

2.4.6 Example of Storm Adjustments

The rainfall of the May 6-12, 1943 storm (No. 77), centered at Warner, Okla., is used to demonstrate computation of storm adjustments.

The representative storm dew point (section 2.3.3) is located 225 mi (362 km) south-southeast of the rain center. Figure 4 depicts the areas enclosed by the 3- and 9-in. (76- and 229-mm) isohyets, the storm's

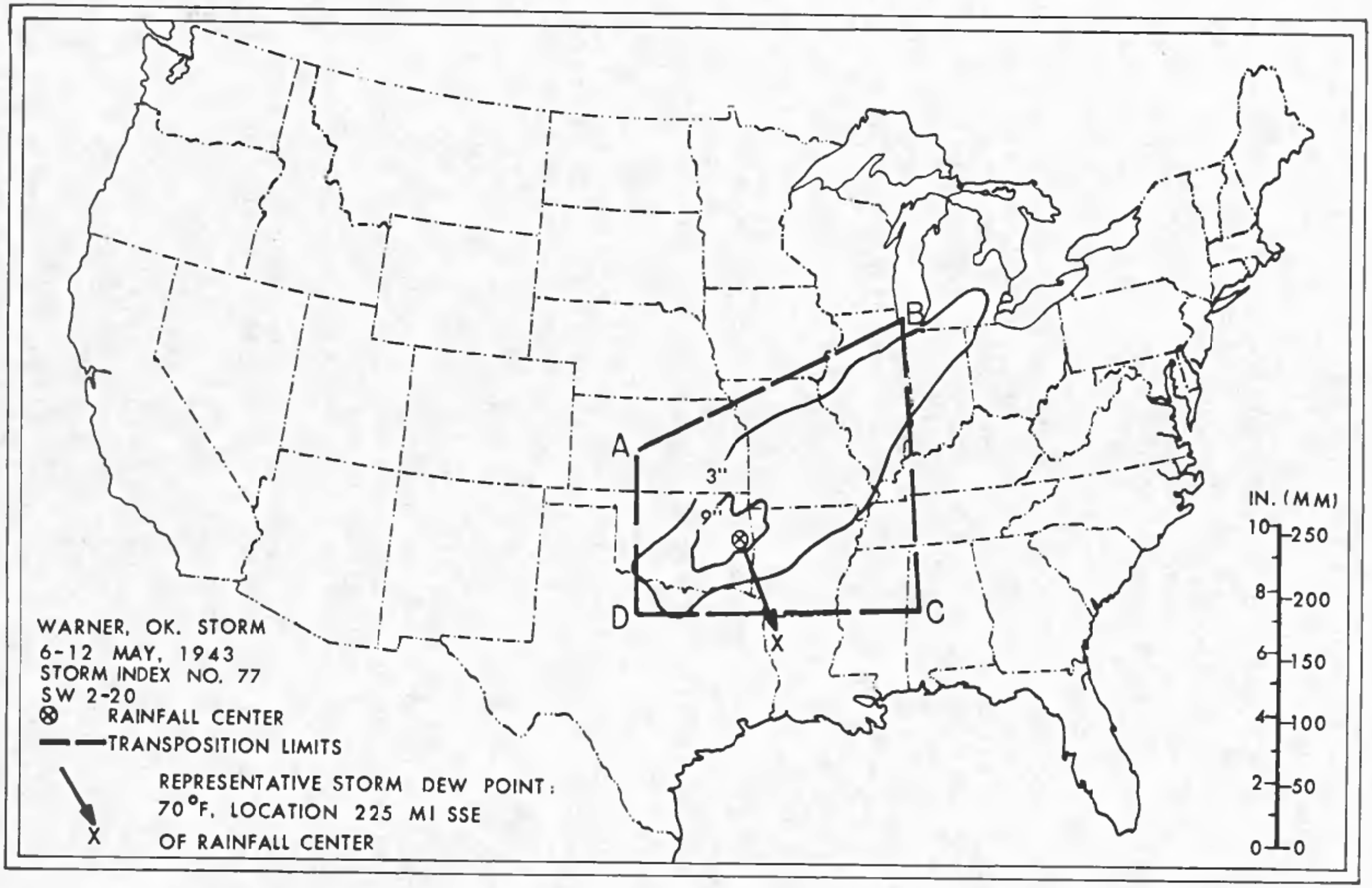


Figure 4.--Example of data used for storm adjustments. [*May 6-12, 1943 storm, Warner, Okla.*]

transposition limits (dashed lines), and the location of the representative storm dew point. As with all major storms, the adjusted rainfall was computed when transposed to the most distance points, in this case A, B, C, and D. Table 2 lists required data and computations necessary for calculating the moisture maximization and transposition adjustments. Table 3 lists additional data and computations for the gentle upslope adjustment.

In our example, we will compute the adjusted storm rainfall for 20,000 mi^2 (51,800 km^2) and a duration of 24 hours where the storm occurred (in place) and for points A, B, C, and D. From the appendix, the observed storm depth is 6.1 in. (155 mm).

The first step is to find the maximum 1000-mb (100-kPa) 12-hr persisting dew point (section 2.3.4) at the given distance and direction from each location (in place, A, B, C, and D). The storm dew point occurred on the 10th of May. Introducing the 15-day transposition into the warm season (section 2.3.4), the maximum 1000-mb (100-kPa) 12-hr persisting dew points (Environmental Data Service 1968) for May 25 are 77, 75, 73, 78, and 76°F (25.0, 23.9, 22.8, 25.6 and 24.4°C), respectively, for the storm in place and for the points A, B, C, and D (table 2, col. 1). The corresponding precipitable water (w_p) values up to 200 mb (20 kPa) (U.S. Weather Bureau 1951) are shown in table 2, col. 2.

The second step is to compute adjustment factors for maximum moisture and transposition (table 2, col. 3a and b). The product of these factors, all that is required for most storms, is shown in table 2, col. 4.

The next step is to consider adjustment for gentle upslope (section 2.4.5). Two of the transposed locations -- A and D -- are in this region. From a generalized topographic map, the elevation of the rainfall center and that of location D are approximately the same (table 3, col. 2); thus, no further adjustment is required for D. Location A is 1,000 ft (305 m) higher than the storm center in place. The increased elevation at A gives a downward adjustment of 8 percent per 1,000 ft (305 m) accounting for the loss of available w_p between 1,000 and 2,000 ft (305 and 610 m) for this maximum w_p. The total storm adjustment for location A is the product of the adjustment factor (col. 1) and gentle upslope factor (col. 3) shown in table 3. Multiplication of the appropriate factors by the storm's observed depth results in the adjusted depths shown in table 3, col. 4.

Were this a tropical storm then an alternate to the dew point transposition adjustment may apply. The alternate, an adjustment for distance-from-coast is described in section 2.4.4.

3. DETAILS OF ANALYSIS

3.1 Minimum Envelopes

All available storm rainfall values that could possibly give highest or near highest values were adjusted and transposed. A total of 30 maps were then prepared showing these highest values, either from adjusted storms in

Table 2.--Example of computations of moisture maximization and transposition adjustments. [Warner, Okla. storm, May 6-12, 1943 (51,800 km²) 24 hours]

Location	(1) Maximum dew point °F	(°C)	(2) w_p 1000 mb (100 kPa) to 200 mb (20 kPa) in.	(mm)	(3) Adjustments (a) (moisture max.)	(3) Adjustments (b) (transposition)	(4) Max. moist. and trans. adjustment factor (col. 3a x col. 3b)
in place	77	(25.0)	3.191	(81.05)	$\frac{w_p\ (\text{max.})}{w_p\ (\text{storm}^{\dagger})} = \frac{3.191}{2.268}$	-----	1.41
A*	75	(23.9)	2.896	(73.56)	$\frac{w_p\ (\text{max.})}{w_p\ (\text{storm})} = \frac{3.191}{2.268}$	$\frac{w_p\ (\text{max.A})}{w_p\ (\text{max.})} = \frac{2.896}{3.191}$	1.28
B	73	(22.8)	2.626	(66.70)	$\frac{w_p\ (\text{max.})}{w_p\ (\text{storm})} = \frac{3.191}{2.268}$	$\frac{w_p\ (\text{max.B})}{w_p\ (\text{max.})} = \frac{2.626}{3.191}$	1.16
C	78	(25.6)	3.349	(85.06)	$\frac{w_p\ (\text{max.})}{w_p\ (\text{storm})} = \frac{3.191}{2.268}$	$\frac{w_p\ (\text{max.C})}{w_p\ (\text{max.})} = \frac{3.349}{3.191}$	1.48
D	76	(24.4)	3.041	(77.24)	$\frac{w_p\ (\text{max.})}{w_p\ (\text{storm})} = \frac{3.191}{2.268}$	$\frac{w_p\ (\text{max.D})}{w_p\ (\text{max.})} = \frac{3.041}{3.191}$	1.34

* Points to which storm was transposed (see fig. 4).

† Storm dew point is 70°F (21.1°C); w_p = 2.268 in. (57.61 mm).

Table 3.--Example of total storm adjustments. [*Warner, Okla., storm, May 6-12, 1943 for 20,000 mi^2 (51,800 km^2) 24 hours*]

Location	(1) Adjustment factor (for moisture maximization and transposition, from table 2, col. 4)	(2) Elevation in gentle upslope region ft	(m)	(3) Gentle upslope adjustment factor	(4) Adjusted 20,000 mi^2 (51,800 km^2) 24-hr depth† in.	(mm)
in place	1.41	1,000	(305)	none	8.6	(218)
A	1.28	2,000	(610)	0.92	7.2	(183)
B#	1.16	—		--	7.1	(180)
C#	1.48	—		--	9.0	(229)
D	1.34	1,000	(305)	none	8.2	(208)

† Observed depth for 20,000 mi^2 (51,800 km^2) and 24 hours = 6.1 in. (155 mm).

Beyond gentle upslope region.

place or transposed to their outer limits, for 10, 200, 1,000, 5,000, 10,000, and 20,000 mi^2 (26, 518, 2,590, 12,950, 25,900, and 51,800 km^2) for durations of 6, 12, 24, 48, and 72 hours.

Less detailed maps and analyses were prepared for 50,000-mi^2 (129,500-km^2) areas to incorporate the influence of possible extreme values for this area size on areas $\leq$ 20,000 mi^2 (51,800 km^2). Similarly, rainfall values out to 96 hours were considered to take into account the effects of these extremes on rainfalls for durations of $\leq$ 72 hours.

Smooth minimum enveloping isohyets were drawn to the data on each map. These envelopes introduced some regional smoothing. Guidance in determining the general shape and gradients of the analysis came from evaluating numerous other kinds of rainfall data, as follows:

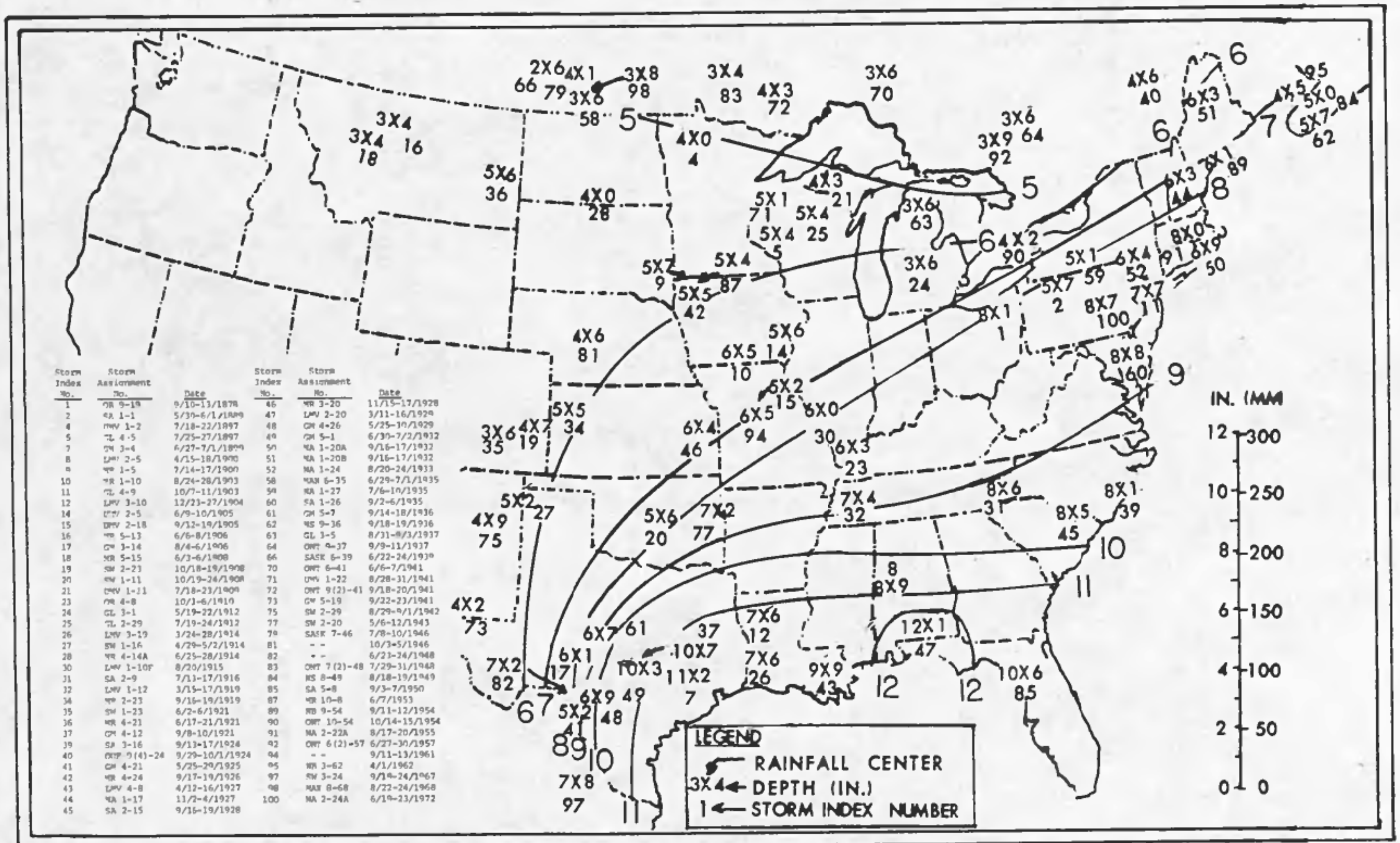
a. Regional patterns of storms plotted in place. For selected areas and durations covered by this report, two sets of maps were developed showing the smooth envelopment of highest areal rainfalls where they occurred. One set was based on observed values and the other on moisture maximized values. Without storm transposition, these maps come close to representing regional variations and gradients of actual storms. The magnitude of PMP must still be determined after storm transposition.

Figures 5 and 6 are examples of data and analyses of observed and moisture maximized rainfall respectively for 10,000-mi^2 (25,900-km^2) areas for 24-hr duration. Storms are identified in tables on both figures. (Many of these storms do not appear in the appendix since transposition of storms give far greater depths.) Figure 5 shows a steep rainfall gradient in central Texas. A similar gradient was maintained in the final product. The trend for higher moisture maximized values (fig. 6) in the Northern Plains States relative to values to the east and west was also maintained in the PMP.

b. Greatest monthly precipitation. Useful guidance, especially appropriate for the larger areas and longer durations, came from a map showing the one greatest average monthly rainfall of record for the period 1931-60 for each State climatic division (U.S. Weather Bureau 1963). These averages are the average of station precipitation within each division for each month of record. The highest of the 360 averages for each division were plotted on a map and analyzed. The data, rounded to the nearest inch for convenience, and the analysis are shown in figure 7.

The smooth analysis takes into account moisture sources and does not allow extreme variation in gradients. The orographically increased 12-in. (305-mm) rainfall for the Black Hills, South Dakota area has been undercut. Some noteworthy features of the map are:

1. Some of the greatest depths along the east slopes of the Appalachians are approximately of the same magnitude as those along the Atlantic coast.



Storm Index No.	Storm Assignment No.	Date	Storm Index No.	Storm Assignment No.	Date
1	OR 9-19	9/10-13/1878	46	MR 3-20	11/15-17/1928
2	SA 1-1	5/30-6/1/1889	47	LMV 2-20	3/11-16/1929
4	UMV 1-2	7/18-22/1897	48	GM 4-26	5/25-30/1929
5	GL 4-5	7/25-27/1897	49	GM 5-1	6/30-7/2/1932
7	SW 3-4	6/27-7/1/1899	50	NA 1-20A	9/16-17/1932
8	LMV 2-5	4/15-18/1900	51	NA 1-20B	9/16-17/1932
9	MR 1-5	7/14-17/1900	52	NA 1-24	8/20-24/1933
10	MR 1-10	8/24-28/1903	58	MAN 6-35	6/29-7/1/1935
11	GL 4-9	10/7-11/1903	59	NA 1-27	7/6-10/1935
12	LMV 3-10	12/23-27/1904	60	SA 1-26	9/2-6/1935
14	UMV 2-5	6/9-10/1905	61	GM 5-7	9/14-18/1936
15	UMV 2-18	9/12-19/1905	62	MS 9-36	9/18-19/1936
16	MR 5-13	6/6-8/1906	63	GL 3-5	8/31-9/3/1937
17	GM 3-14	8/4-6/1906	64	ONT 9-37	9/9-11/1937
18	MR 5-15	6/3-6/1908	66	SASK 6-39	6/22-24/1939
19	SW 2-23	10/18-19/1908	70	ONT 6-41	6/6-7/1941
20	SW 1-11	10/19-24/1908	71	UMV 1-22	8/28-31/1941
21	UMV 1-11	7/18-23/1909	72	ONT 9(2)-41	9/18-20/1941
23	OR 4-8	10/1-6/1910	73	GM 5-19	9/22-23/1941
24	GL 3-1	5/19-22/1912	75	SW 2-29	8/29-9/1/1942
25	GL 2-29	7/19-24/1912	77	SW 2-20	5/6-12/1943
26	LMV 3-19	3/24-28/1914	79	SASK 7-46	7/8-10/1946
27	SW 1-16	4/29-5/2/1914	81	- -	10/3-5/1946
28	MR 4-14A	6/25-28/1914	82	- -	6/23-24/1948
30	LMV 1-10F	8/20/1915	83	ONT 7(2)-48	7/29-31/1948
31	SA 2-9	7/13-17/1916	84	MS 8-49	8/18-19/1949
32	LMV 1-12	3/15-17/1919	85	SA 5-8	9/3-7/1950
34	MR 2-23	9/16-19/1919	87	MR 10-8	6/7/1953
35	SW 1-23	6/2-6/1921	89	NB 9-54	9/11-12/1954
36	MR 4-21	6/17-21/1921	90	ONT 10-54	10/14-15/1954
37	GM 4-12	9/8-10/1921	91	NA 2-22A	8/17-20/1955
39	SA 3-16	9/13-17/1924	92	ONT 6(2)-57	6/27-30/1957
40	ONT 9(4)-24	9/29-10/1/1924	94	- -	9/11-13/1961
41	GM 4-21	5/25-29/1925	95	MR 3-62	4/1/1962
42	MR 4-24	9/17-19/1926	97	SW 3-24	9/19-24/1967
43	LMV 4-8	4/12-16/1927	98	MAN 8-68	8/22-24/1968
44	NA 1-17	11/2-4/1927	100	NA 2-24A	6/19-23/1972
45	SA 2-15	9/16-19/1928			

Figure 5.--Envelopment of 24-hr observed storm rainfall (in.) in place of occurrence for 10,000 mi²
(25,900 km²).

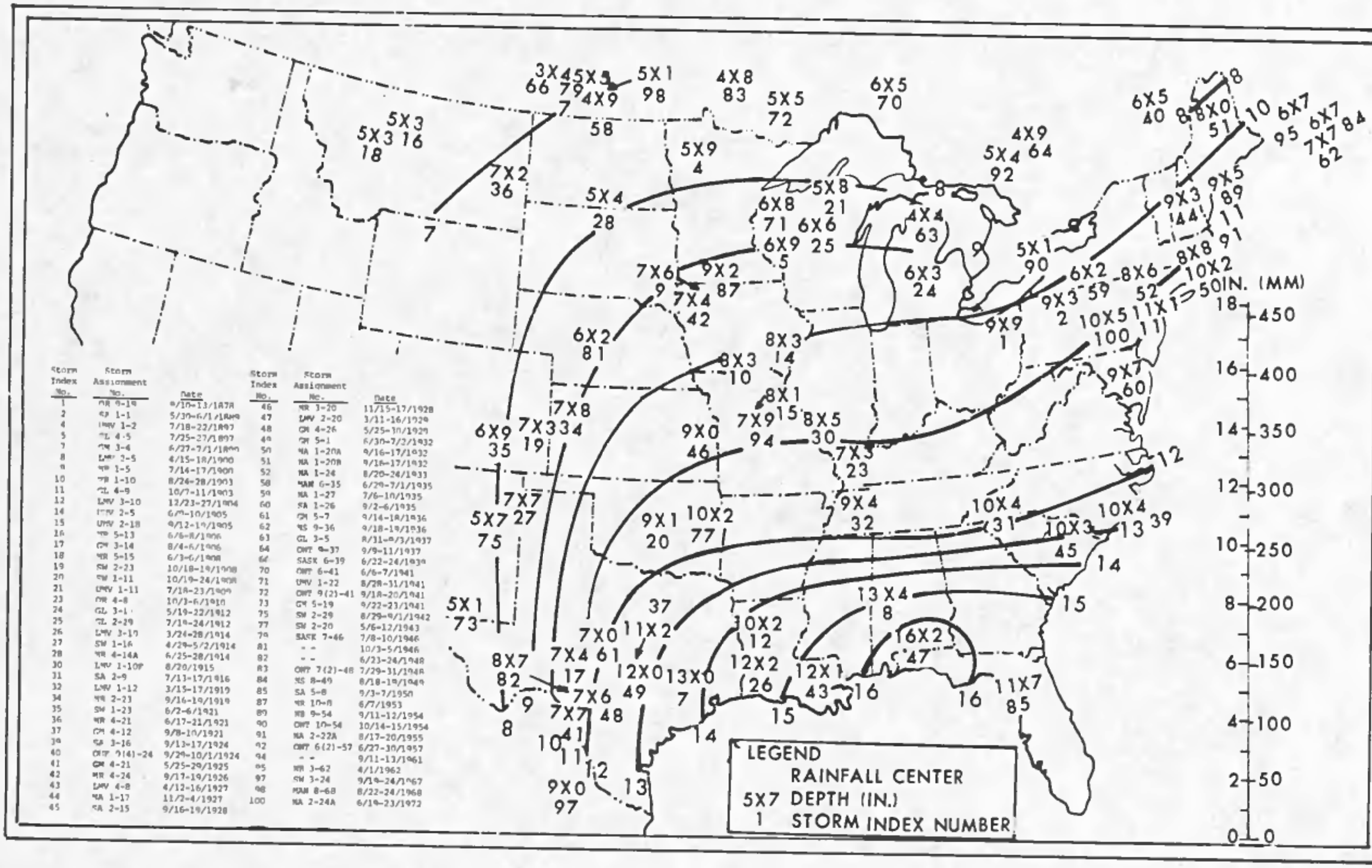


Figure 6.--Envelopment of 24-hr moisture maximized storm rainfall (in.) in place of occurrence for 10,000 mi^2 (25,900 km^2).

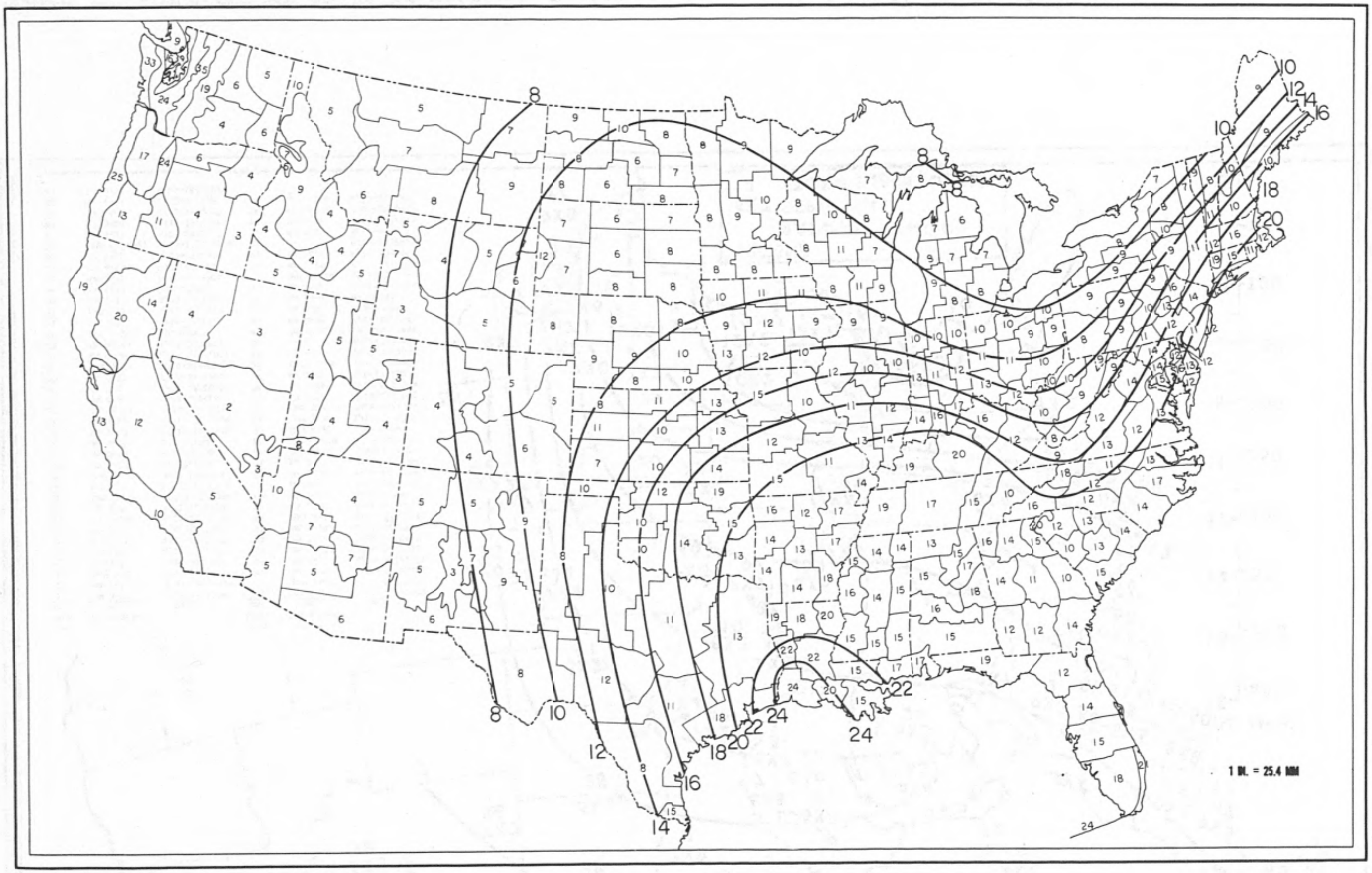


Figure 7.--Envelopment of greatest average monthly precipitation (in.) for State climatic divisions (1931-60).

2. Lower values south of Lake Erie extend southward along the west slopes of the Appalachians.

3. Highest rainfall values are found in the lower Mississippi River Valley.

4. There is a decrease approaching the Continental Divide.

5. There is little difference in values along the entire east coast.

There are some limitations to these mapped greatest monthly values as guidance to regional variation of PMP. The size of the State climatic divisions varies from about 500 to 36,000 mi^2 (1,295 to 93,200 km^2), averaging approximately 10,000 mi^2 (25,900 km^2). All other factors being equal, such as storm centering, etc., the larger the division, the lower the rainfall depth. Additionally, monthly totals may not be representative of 3-day totals.

c. Greatest weekly rainfall. Another guide to regional patterns of PMP, similar to the greatest monthly rainfall averages, is the greatest weekly rainfall averages for climatic divisions. These averages were extracted from tabulation of the average precipitation over each division for each week of the period 1906-35 (McDonald 1944). Similar weekly averages are not readily available for recent years. The climatic divisions for this data set are different from those showing monthly precipitation. The weekly climatic divisions vary in size from 5,000 to 65,000 mi^2 (12,950 to 168,300 km^2) averaging about 20,000 mi^2 (51,800 km^2).

Figure 8 shows these highest average rainfalls for each climatic division. As in the monthly analysis, rainfall for the division including the Black Hills has been undercut. The enveloping lines have many of the same features as the highest monthly precipitation map: A trough of low values in the Great Lakes region, isolines oriented north-south near the Continental Divide, and a region of higher values extending into the Northern Plains. Maximum depths occur along the gulf coast in the states of Mississippi, Alabama, and Florida. The large areas and long durations detract from use of these data but to a lesser degree than the monthly data.

d. Maximum 1-day station rainfall. Another guide to regional PMP isohyets, especially useful for the small areas and short durations, is from maximum 1-day station rainfalls of record (Jennings 1952). These have been updated through 1970. Figure 9 shows the highest recorded station value for each State climatic division. The shape of enveloping lines drawn to these data (fig. 9) gave clues to the location of tight or loose rainfall gradients. Some features of note: An extension or bulge to the northwest into Montana, a dip in the Great Lakes region relative to values to the east and west, and similar magnitudes in the envelopment along the coast from southern Texas through Florida.

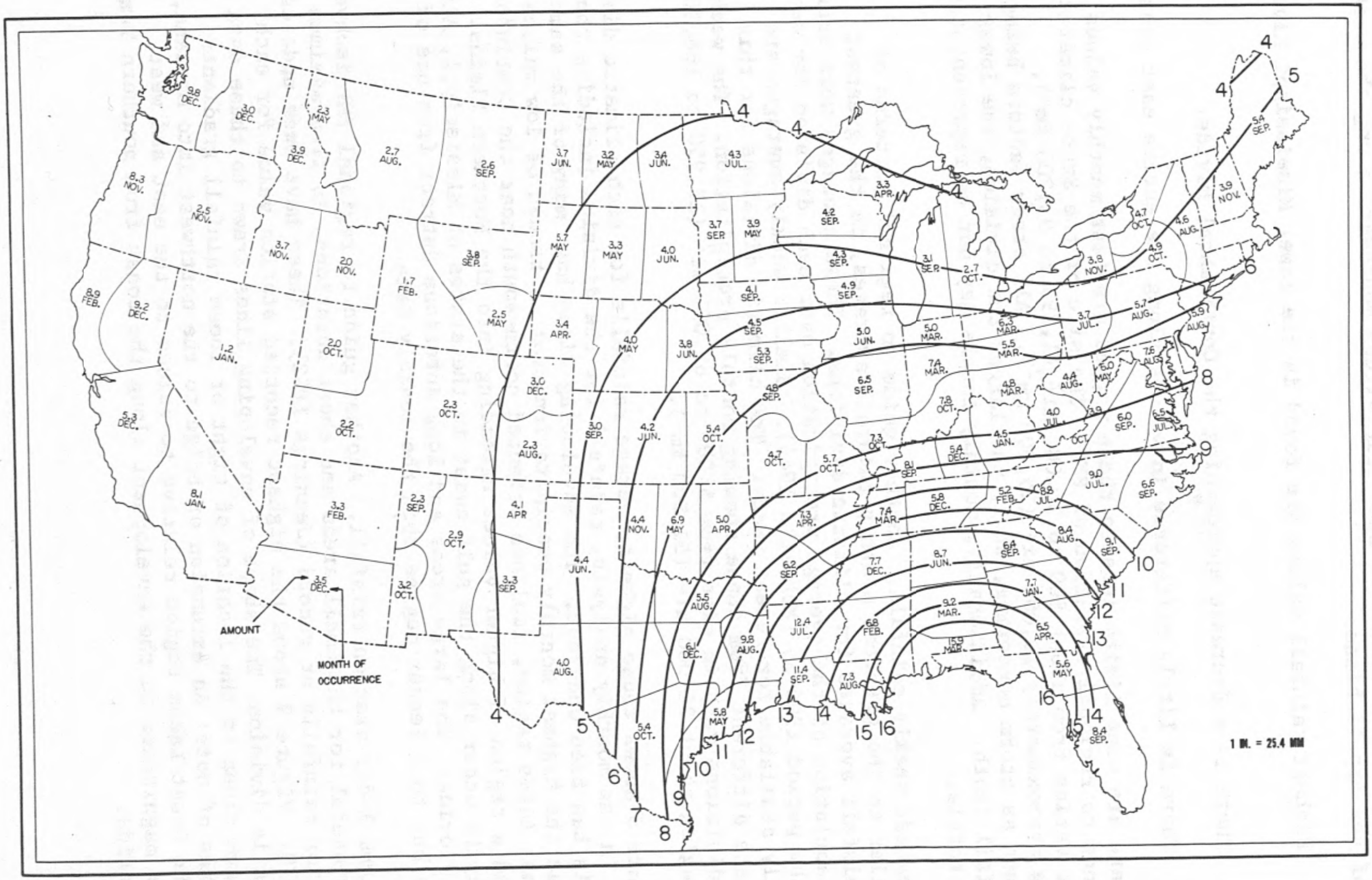


Figure 8.--Envelopment of greatest average weekly precipitation (in.) for State climatic divisions (1906-35).

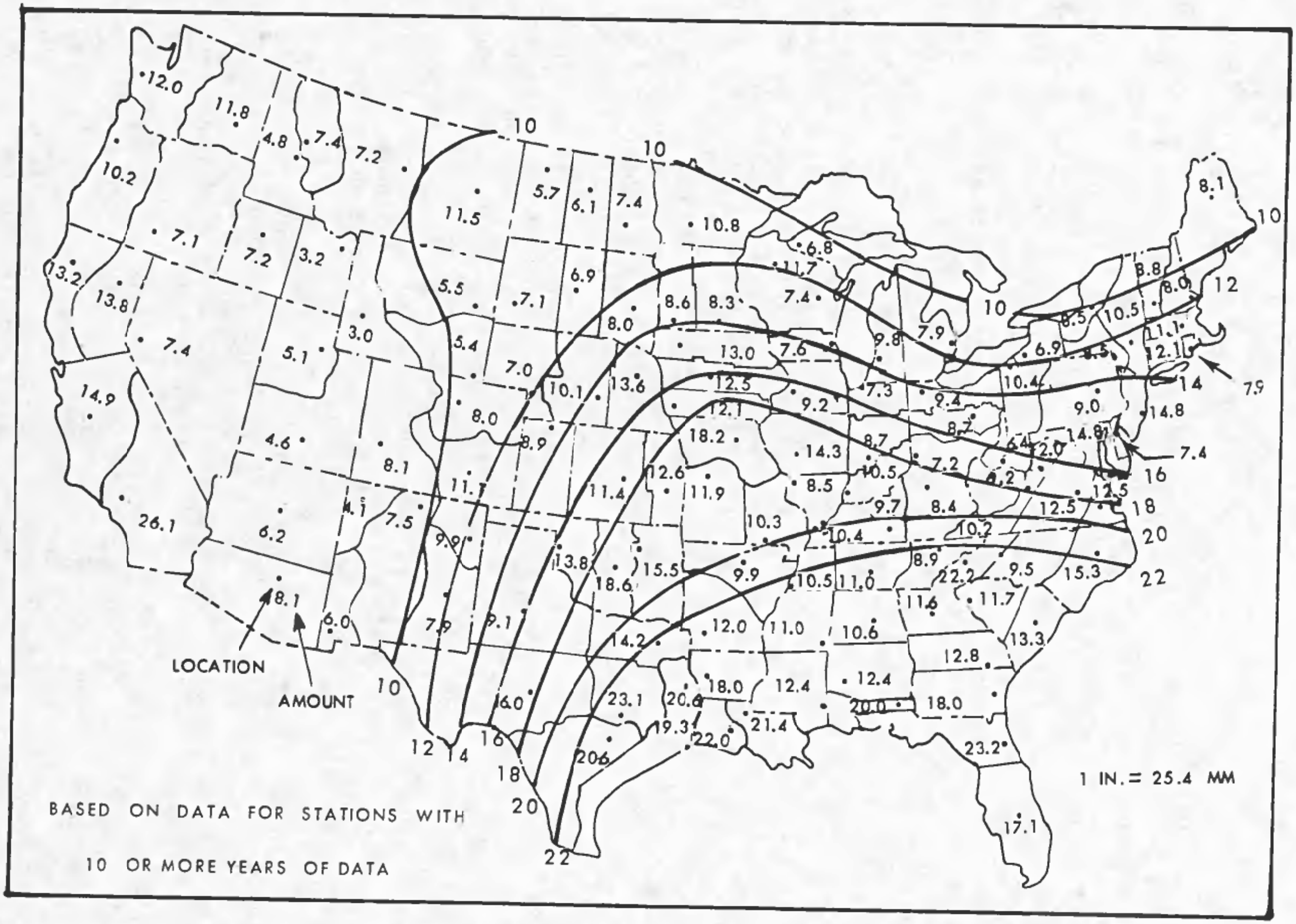


Figure 9.--Envelopment of the greatest 24-hr station precipitation (in.) within each State climatic division (through 1970).

Another map (not shown) was developed of maximum observed 24-hr station rainfall amounts (Corps of Engineers, U.S. Army 1945-). These data include supplementary rainfall data from surveys after major storms that are often several times greater than amounts measured at nearest regular reporting stations. The general shape and gradients of isohyets for that map were not greatly different from those shown on figure 9, with the exception that the enveloping isohyets near the eastern seaboard paralleled the coast.

e. Maximum persisting dew points. Regional distribution of maximum persisting 12-hr dew points (Environmental Data Service 1968) is an important index to rainfall potential. Use of these charts (not shown) for storm transposition already to some extent incorporates their variation. Many of the features of the dew point charts can be seen in the resulting PMP maps. Examples are the east-west gradients in values near the western boundary of the study area, higher values bulging towards the northwest into the Northern Plains, southwest-northeast orientation of isolines along the Atlantic coast, and a dip or lowering of values near the Great Lakes.

f. Station 100-yr precipitation. Maps of station 100-yr 24-hr precipitation (Hershfield 1961) and 100-yr 48-hr precipitation (Miller 1964) were inspected for useful clues to the regional variation for small area rainfall. Frequencies are perhaps better than maximum 1-day rainfalls in that differences due to varying lengths of record from station to station are normalized. High 100-yr return-period precipitation centers show up along the Appalachians. Other features of the frequency map are isolines paralleling the Gulf of Mexico and Atlantic coasts, almost north-south orientation of isolines near the eastern slopes of the Continental Divide, and lower values in the Great Lakes region as compared to those to the east and west.

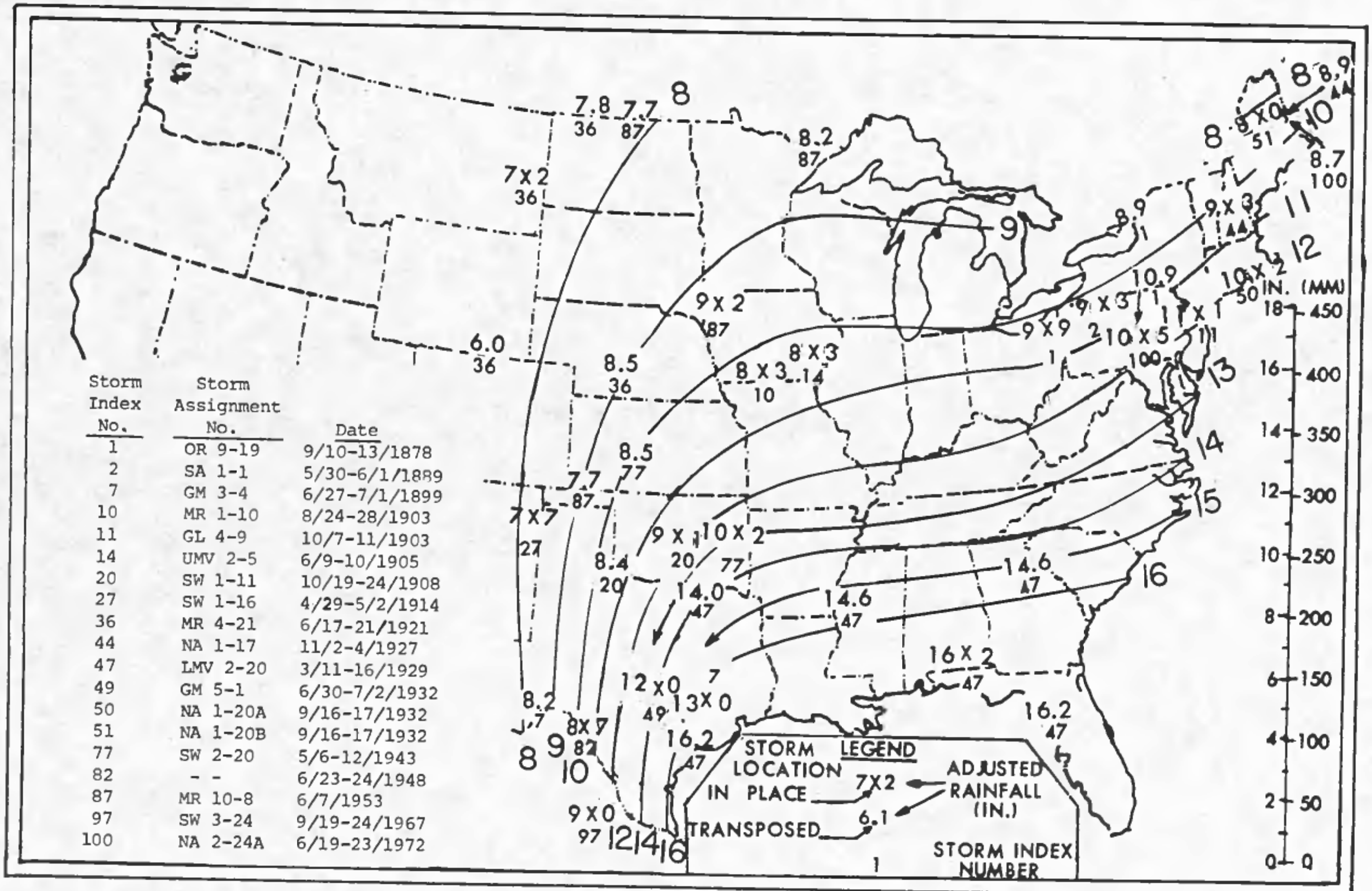
g. Regional patterns of other indices. Because thunderstorms, hail, and tornadoes are often associated with major rainfalls, patterns of the occurrences of these phenomena can serve as indices to regional variation of PMP. Regional distributions of these weather phenomena (U.S. Weather Bureau 1969) show several important features, such as maximum occurrence in Oklahoma, a moderately reduced occurrence along the northern Appalachians, and lines of equal occurrences generally parallel to the Rio Grande in Texas. Regional patterns of cloud heights as determined from radar echoes east of the Continental Divide for the period 1962-67 (Grantham and Kantor 1968) support isolines generally parallel to the Continental Divide.

Using these indices, a regionally smooth set of minimum envelopes were drawn to the adjusted rainfall data. Figure 10 is an example for 24 hours 10,000 mi^2 (25,900 km^2). Values shown, identified by storm index numbers, are moisture maximized rainfall depths in place or at their critical transposed locations.

3.2 Special Problems

3.2.1 Introduction

The analyses of minimum envelopes necessarily required some departures to seemingly objective procedures discussed in previous sections. Such



Storm Index No.	Storm Assignment No.	Date
1	OR 9-19	9/10-13/1878
2	SA 1-1	5/30-6/1/1889
7	GM 3-4	6/27-7/1/1899
10	MR 1-10	8/24-28/1903
11	GL 4-9	10/7-11/1903
14	UMV 2-5	6/9-10/1905
20	SW 1-11	10/19-24/1908
27	SW 1-16	4/29-5/2/1914
36	MR 4-21	6/17-21/1921
44	NA 1-17	11/2-4/1927
47	LMV 2-20	3/11-16/1929
49	GM 5-1	6/30-7/2/1932
50	NA 1-20A	9/16-17/1932
51	NA 1-20B	9/16-17/1932
77	SW 2-20	5/6-12/1943
82	- -	6/23-24/1948
87	MR 10-8	6/7/1953
97	SW 3-24	9/19-24/1967
100	NA 2-24A	6/19-23/1972

Figure 10.--*Example of minimum smooth envelope of moisture maximized rainfall, in place and transposed. [24 hr/10,000 mi^2 (25,900 km^2) in inches]*

departures were necessary to avoid undue emphasis and/or reliance on individual storm values obtained by storm transposition and storm adjustment. These departures involved decisions on "how far" (with respect to transposition) and "how much" (with respect to maximization) that can only be answered by storm experience and meteorological judgment. The most outstanding departures from the objective procedures are explained in this section.

3.2.2 Adjustments Greater Than 50 Percent

The relations among various meteorological parameters that contribute to heavy rainfalls are not yet fully understood nor measured.

Extreme increases in one parameter, say moisture, could well counteract other important factors; therefore, total storm adjustments that increased rainfalls by more than 50 percent were given further attention. If a storm had an adjustment giving an increase greater than 50 percent, but its adjusted depth was supported quite closely by surrounding storm depths with only moderate adjustments, the high adjusted value was accepted. If a high adjustment (greater than 50 percent) gave an amount that stood out among all other storms in a region, this depth was undercut. Undercutting was limited to a value obtained by multiplying the observed depth by 150 percent.

The moisture adjustments for the storms listed in the appendix give a measure of how important this constraint is to the study. Eight of the 53 storms have moisture adjustments greater than 150 percent, ranging from 155 to 189 percent. Six of these high adjustments give rainfall depths that are supported by other storms in the general region with adjustments less than 150 percent. The two exceptions, storm index numbers 8 and 26, have adjustments of 163 and 189 percent, respectively. For storm No. 8, the most critical depth was at 20,000 mi^2 (51,800 km^2) for 12 hours. We used an adjustment of 150 percent giving 8.5 in. (216 mm) and analyzed for this depth. For storm No. 26, the most critical depth was at 10,000 mi^2 (25,900 km^2) for 6 hours. We accepted a value of 7.5 in. (190 mm) which was supported by other storm depths. The 7.5 in. (190 mm) is 160 percent of the observed depth.

3.2.3 Colorado Storm, May 30-31, 1935

This storm produced two intense rainfall centers (fig. 1), one at Cherry Creek, Colo. (No. 55) and the other at Hale, Colo. (No. 56). The Cherry Creek depths were not used since it is near very steep slopes that could have increased the rainfall. Only the areal average rainfall surrounding the Hale center was used. The record-breaking cold air mass associated with this storm could not reasonably occur 15 days later into the warm season. Therefore, the normal procedure of adjusting storms 15 days into the warm season (section 2.3.4) was not applied.

3.2.4 Smethport,Pa. Storm, July 17-18, 1942

The in-place moisture maximized rainfall values for the Smethport, Pa. storm (No. 74) of July 17-18, 1942 (fig. 1), were slightly undercut for 6, 12, and 24-hr durations for 10-mi^2 (26-km^2) areas. The greatest undercutting

(7 percent) was for 6 hours. The slight undercutting avoids excessive envelopment of all other data in a large region surrounding the Smethport location.

3.2.5 Yankeetown, Fla. Storm, September 3-7, 1950

The last exception deals with the rainfall associated with the Yankeetown, Fla. storm (No. 85) of September 3-7, 1950. Inland transposition of this storm incorporates the distance-from-coast adjustment already discussed. This storm is important because it provides the greatest observed rainfall depths in the United States for areas from 10 to 2,000 mi^2 (26 to 5,180 km^2) and durations from 18 to 72 hours.

The outstanding rains of the Yankeetown storm have been attributed to the looping track of the hurricane just off the western coast of Florida, causing the downpour to be concentrated in space. Looping has been observed in many tropical storms along the Atlantic and gulf coasts, summarized by Cry (1965) and updated. For the period 1901-76, 58 storm tracks show looping or points of recurvature (the latter having an equivalent effect as looping in concentrating rainfall if the storm is moving slowly) over water or land surfaces within 60 n.mi. (111 km) of the coast from Brownsville, Tex., to Eastport, Maine. It is assumed that if other major rain-producing tropical storms had looped or recurved while crossing the coast, the resulting areal rainfall would have been more concentrated.

A partial check of this assumption was made by computing hypothetical areal rainfall depths for two major gulf coast tropical storms (Hurricane Carla, September 10-13, 1961, and the hurricane of August 6-9, 1940) assuming they had looped near the coast. The forward speed of each storm was reduced to the speed of the Yankeetown storm. Assuming the rainfalls in these storms were then closely associated with the storm tracks, recomputation of rain depths gave values of approximately the same magnitude as the Yankeetown storm.

It can be hypothesized that the Yankeetown rainfall (centered near latitude 29°N on the west coast of Florida) was enhanced because air trajectories from both the Gulf of Mexico and the Atlantic Ocean allowed greater transport of moisture into the storm than would be possible along other sections of the gulf coast. To check this hypothesis, the moisture inflow associated with Easy (the storm giving the Yankeetown rainfall) was compared with that of two other tropical storms, Carla (September 1961) and Beulah (September 1967). These were large rain producers near the coast of Texas.

Lacking psychrometric data over the water surface, the portion of the tropical storms that extended over land during the period of heavy rainfall were examined. Dew points were compared, both at the surface and 850-mb (85-kPa) level, at equal distances from the centers of each hurricane. Both Carla and Beulah recorded approximately the same or higher dew points than those found in Easy. The rate of drying in Easy as the moist air from the Atlantic Ocean flowed westward over land was approximately the same as that in the westward flow of moist air from the Gulf of Mexico for Carla and Beulah. Because of these considerations, it was decided to transpose the Yankeetown rainfall along the entire gulf coast of the United States.

The northward transposition limits of Yankeetown along the Atlantic coast has been set as Cape Hatteras, N.C. Remaining is the problem of determining the adjustment for transposition to this point. If no downward adjustment is used, there would be either a large over-envelopment of all other storm rainfall data along the coast or an extreme gradient to the north of Cape Hatteras. The standard transposition adjustment based on maximum dew points extended over the ocean surface (U.S. Weather Bureau 1952) would give no decrease to Cape Hatteras since the 78°F (25.6°C) value (the highest maximum dew point considered) is located north of this point.

As an alternate, the variation in sea-surface temperatures was used. These temperatures, with some overland modification, set upper limits to the amount of water vapor the atmosphere can hold. Both the mean and 95th percentile sea-surface temperatures (U.S. Naval Oceanographic Office 1967) were analyzed for September, the month of the Yankeetown storm. The temperatures were averaged within 400-mi (644-km) diameter circles off the coast from 29° to 38° N latitude. This size circle covers an area considered representative of the area from which a large tropical cyclone could process moisture in 24 hours (Gilman and Peterson 1958). The average temperature determined the precipitable water (w_p) assuming saturation and a pseudo-adiabatic lapse rate through the atmosphere. Figure 11 shows the relation between latitude and w_p in percent of the w_p value at 29°N latitude. A relation based on the average of the w_p for the mean temperature and the 95th percentile temperature was the basis for adjustment of the Yankeetown storm. This gives a 15-percent reduction for transposition to Cape Hatteras. Transpositions farther to the north using this relation gives values that are consistent with other adjusted storm depths.

The latitudinal adjustment for Yankeetown was also applied to the transposition of all tropical storms located near the Atlantic coast south of Cape Hatteras, N.C. None of these storms, so adjusted, affected the minimum envelopes.

3.3 Consistency Checks

3.3.1 Introduction

The minimum PMP maps (fig. 10) were checked for consistency. Anomalies to smooth regional patterns of PMP were eliminated unless there was a meteorological explanation. Consistency in depth duration and depth areal relations at various locations in the study region was maintained. The checks usually resulted in raising the minimum PMP values, although envelopment was minimized.

For the checks, a 2-by-2 degree latitude and longitude grid (154 points) was established. Values were read for each grid point from the minimum PMP maps. Computer techniques aided in processing the large volume of data.

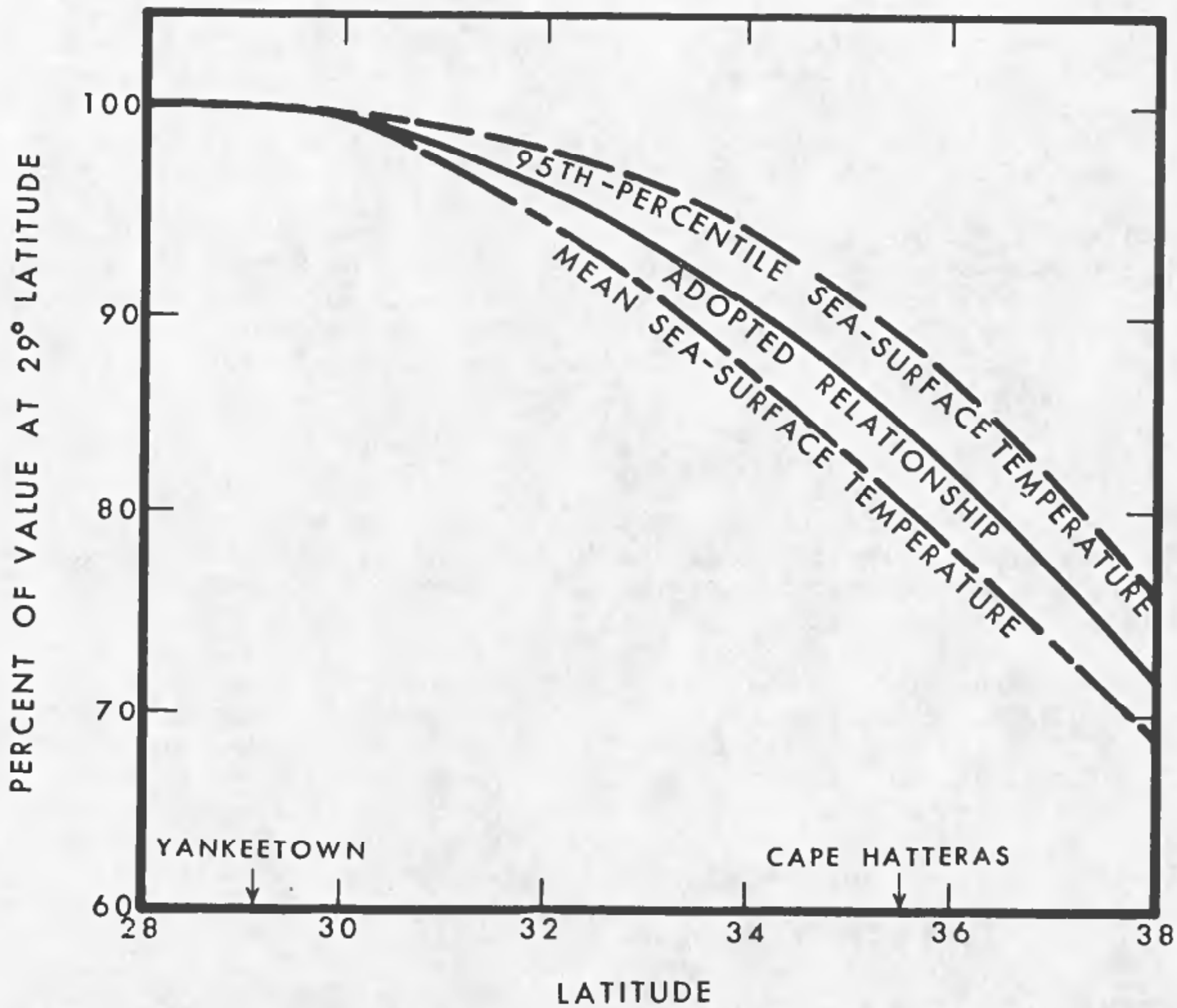


Figure 11.--Adopted transposition adjustment along the Atlantic coast for the Yankeetown, Fla. storm, September 3-7, 1950.

3.3.2 Variation of Incremental PMP with Area Size

A constraint in this study was to maintain the same or lesser incremental PMP with increasing area size. For example, the incremental PMP from 12- to 18-hr duration (PMP for 18 hr minus PMP for 12 hr) could not increase with increasing area size. Individual storm depth-area-duration (D-A-D) relations can and do show increasing incremental rainfall with increasing area size. This is so because control of the D-A-D curves of rainfall can come from several different centers for, say, the 12- and 18-hr maximum areal rainfall depths. Accepted application of PMP to a drainage has been through use of incremental PMP isohyets. Such isohyets would not have internal consistency if incremental PMP increases with increasing area size.

3.3.3 Consistency in Depth-Area-Duration Relations

Depth-area-duration (D-A-D) plots of PMP, with area and with duration as the third parameter, were made for each of the 154 grid points and then smoothed. Figure 12 is an example of depth-duration smoothing and figure 13 an example of depth-area smoothing. These examples show the final values after all adjustments were applied. For these plots, depth was expressed in percent of the rainfall for 10 mi^2 (26 km^2) for 72 hours.

Analyses of the 308 D-A-D plots flagged inconsistencies such as incremental PMP increasing with increasing area size or incremental PMP for a certain area size not decreasing with duration. They also ensured smooth envelopes of D-A-D rainfall values. Such smoothness takes into account the strong probability that nature has not provided maximum depths for the entire range of areas and durations covered by this report.

3.3.4 Cross Section Checks

Another check was made on the gradients of PMP along cross sections of the study region. Gradients established by use of guidance material (section 3.1) and the just described D-A-D smoothing did not necessarily correct regional inconsistencies.

Six north-south and five east-west cross sections of PMP depths were made running along the 103°, 97°, 91°, 85°, 79° and 71° longitude and the 47°, 43°, 39°, 35°, and 31° latitude lines. Two types of plots were made. In the first set, durations were held constant allowing checks on consistency of areal rainfall magnitudes. An example of this type is given in figure 14. In the second type, areas were held constant while durational values were checked. An example of these cross sections is figure 15.

3.3.5 Rainfall Difference Check

Another check was on the differences in PMP between standard durations and between standard area sizes. At each of the 154 grid points, the difference between 24-hr PMP and the 6-hr PMP and the difference between the 72-hr PMP and the 24-hr PMP were computed for each of three area sizes [10, 1,000, and 20,000 mi^2 (26, 2,590, and 51,800 km^2)]. Likewise areal differences in PMP [10-mi^2 (26-km^2) PMP minus 1,000-mi^2 (2,590-km^2) PMP and 1,000-mi^2 (2,590-km^2) PMP minus 20,000-mi^2 (51,800-km^2) PMP] were computed for each of three durations (6, 24, and 72 hours). Mapped values of these differences were analyzed and PMP maps modified when inconsistent differences occurred from one location to another. An example of final differences between 24- and 6-hr values for 20,000 mi^2 (51,800 km^2) is shown in figure 16.

3.3.6 Rainfall Ratio Check

We also maintained consistency in regional trends of durational rainfall ratios (6/24 and 24/72 hour) for areas of 10, 200, 1,000, 5,000, 10,000, and 20,000 mi^2 (26, 518, 2,590, 12,950, 25,900, and 51,800 km^2). Similarly, we maintained consistency in regional trends of areal rainfall ratios

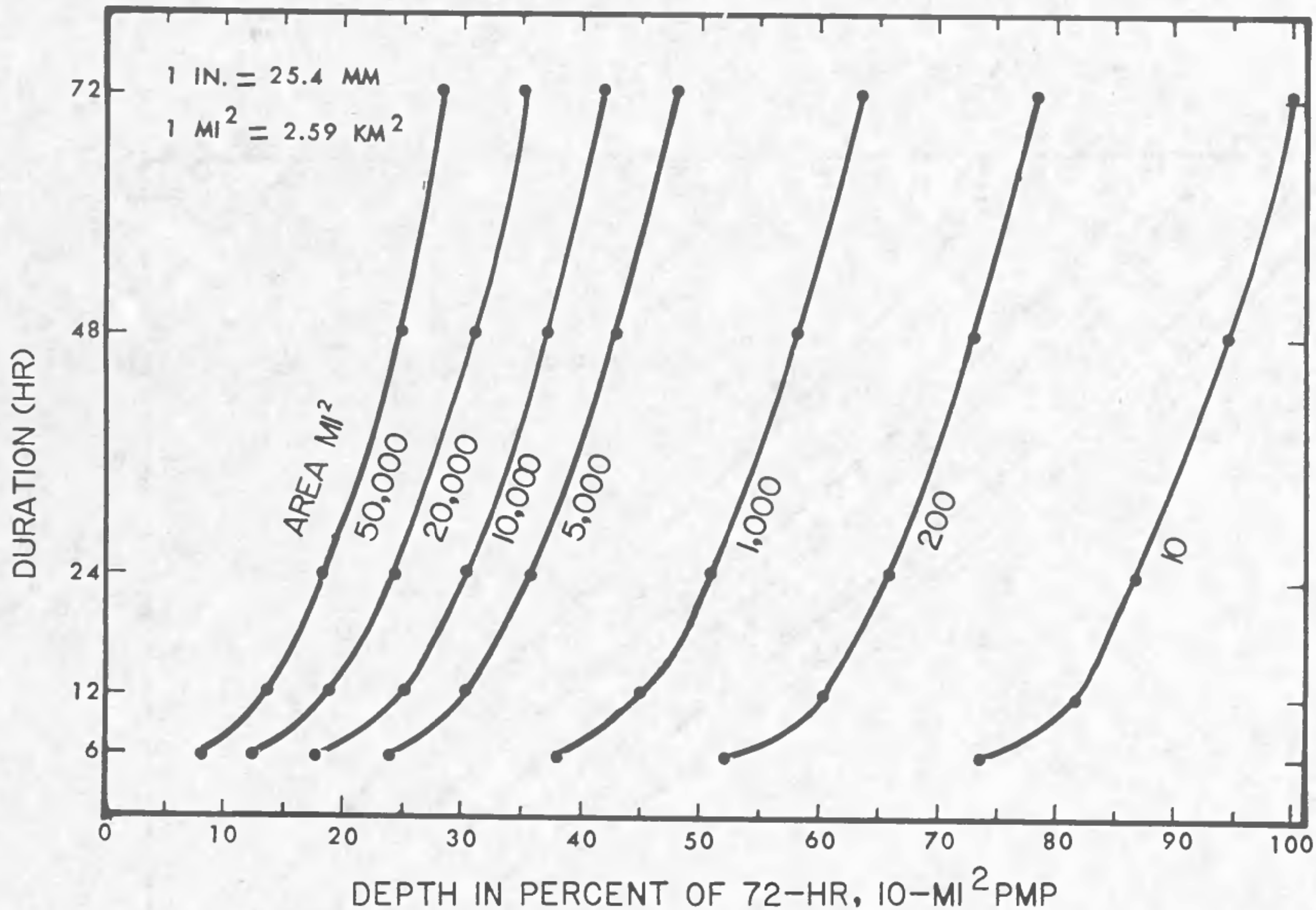


Figure 12.--Example of depth-duration smoothing. [*Grid point 39°N, 89°W*]

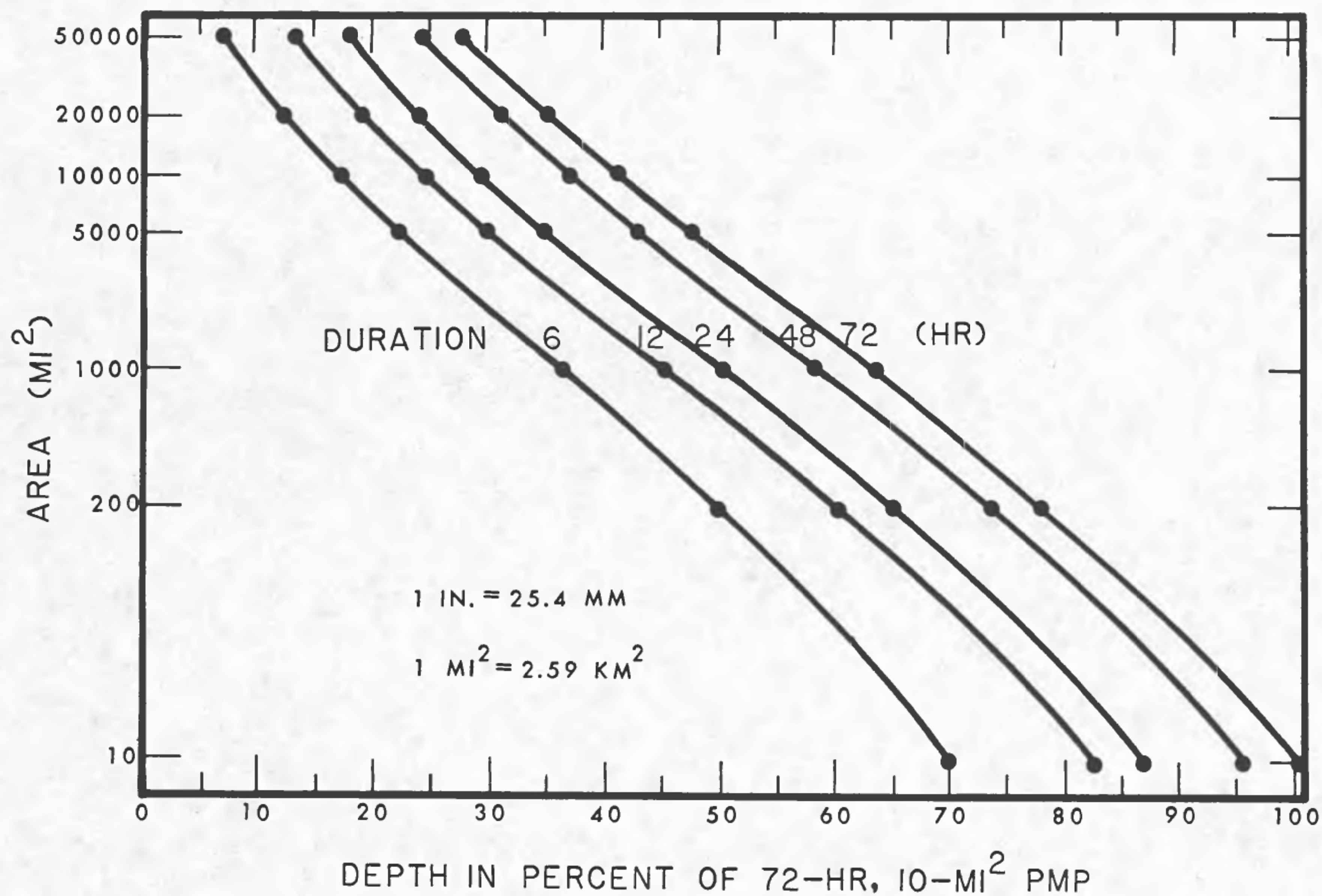


Figure 13.--Example of depth-area smoothing. [*Grid point 39°N, 89°W*]

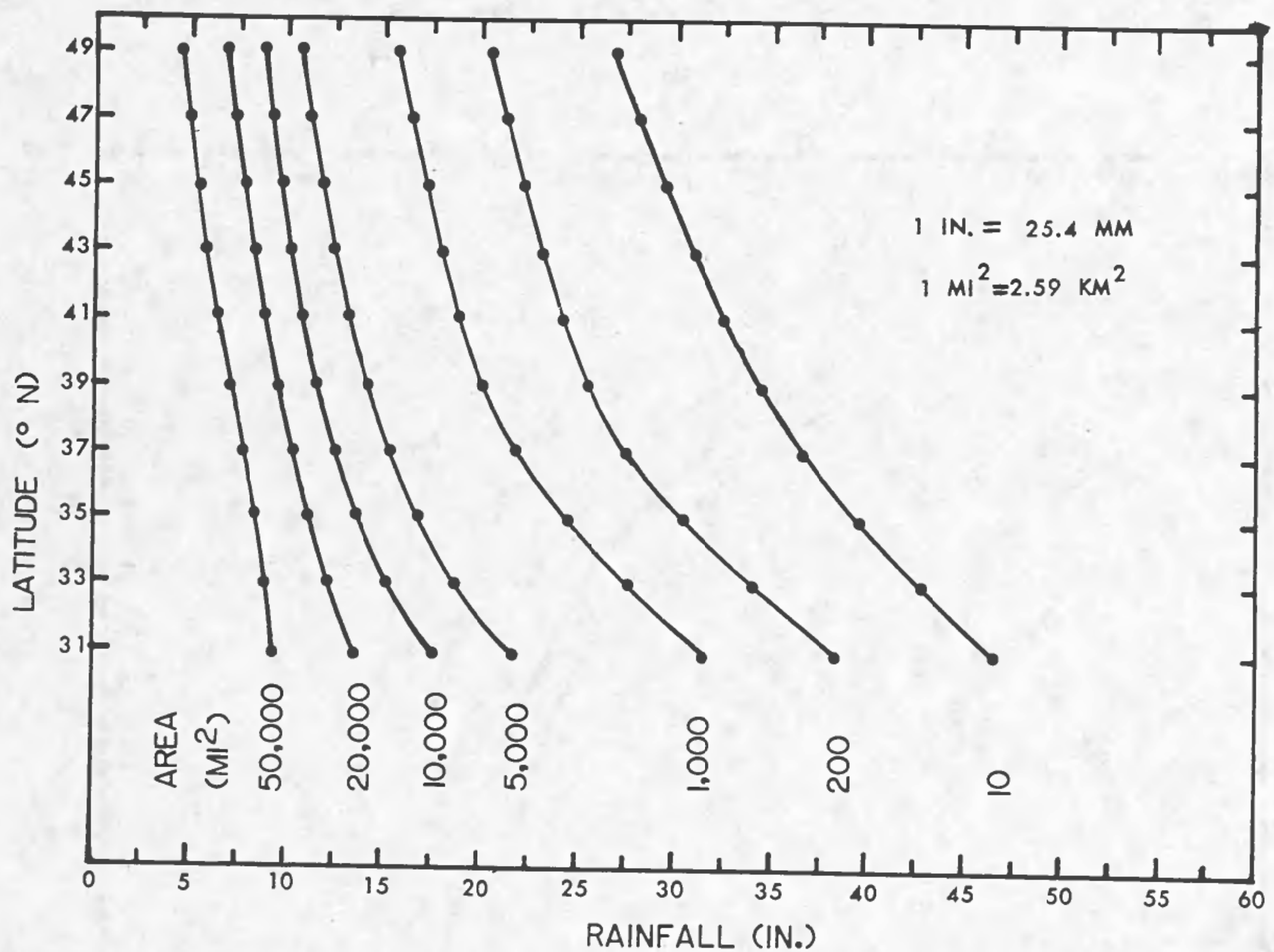


Figure 14.--Example of cross-section smoothing--constant duration. [Depth vs. latitude along 91°W longitude for 24 hr]

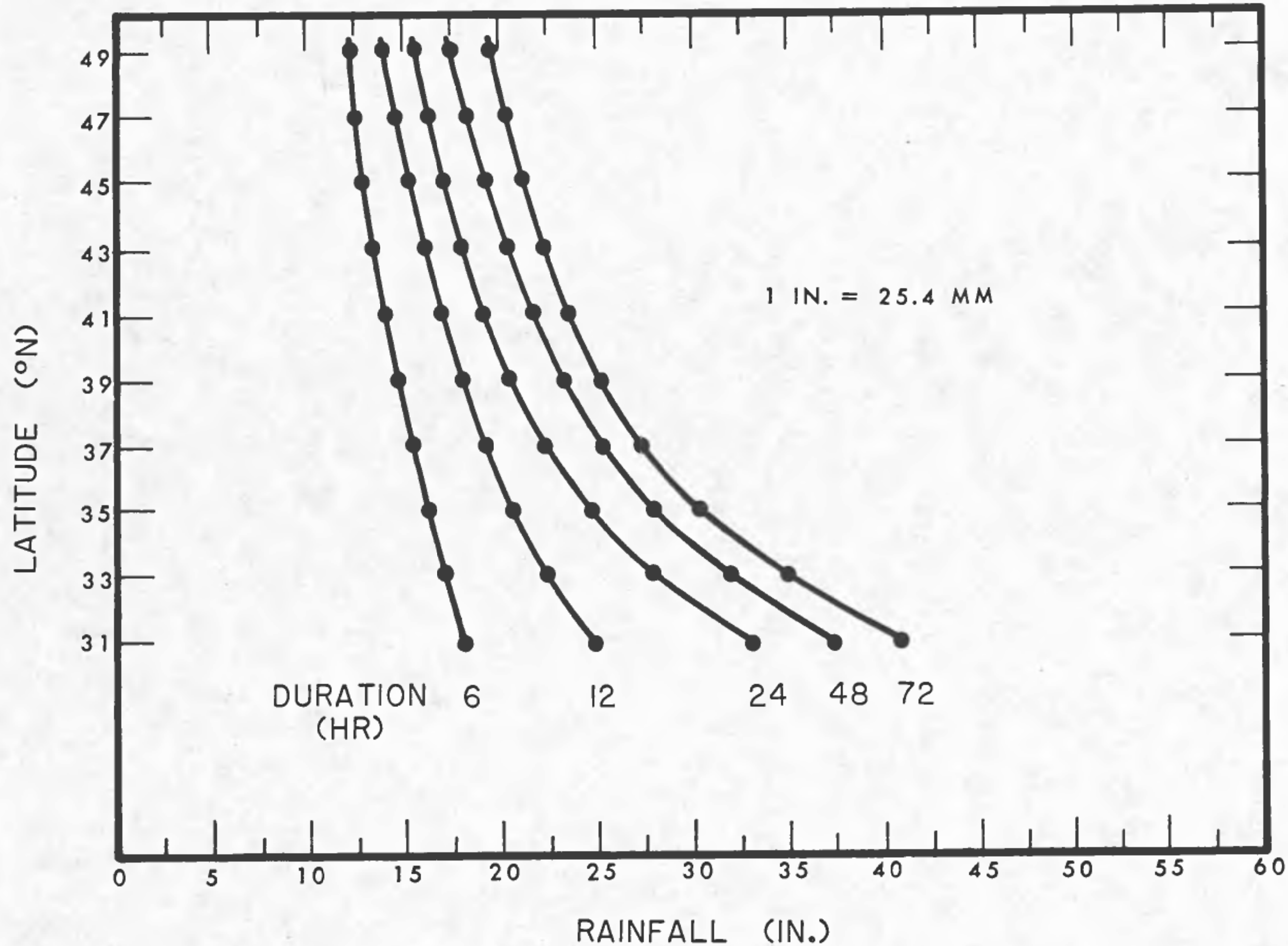


Figure 15.--Example of cross-section smoothing--constant area. [Depth vs. latitude along 91°W longitude for 1,000 mi^2 (2,590 km^2)]

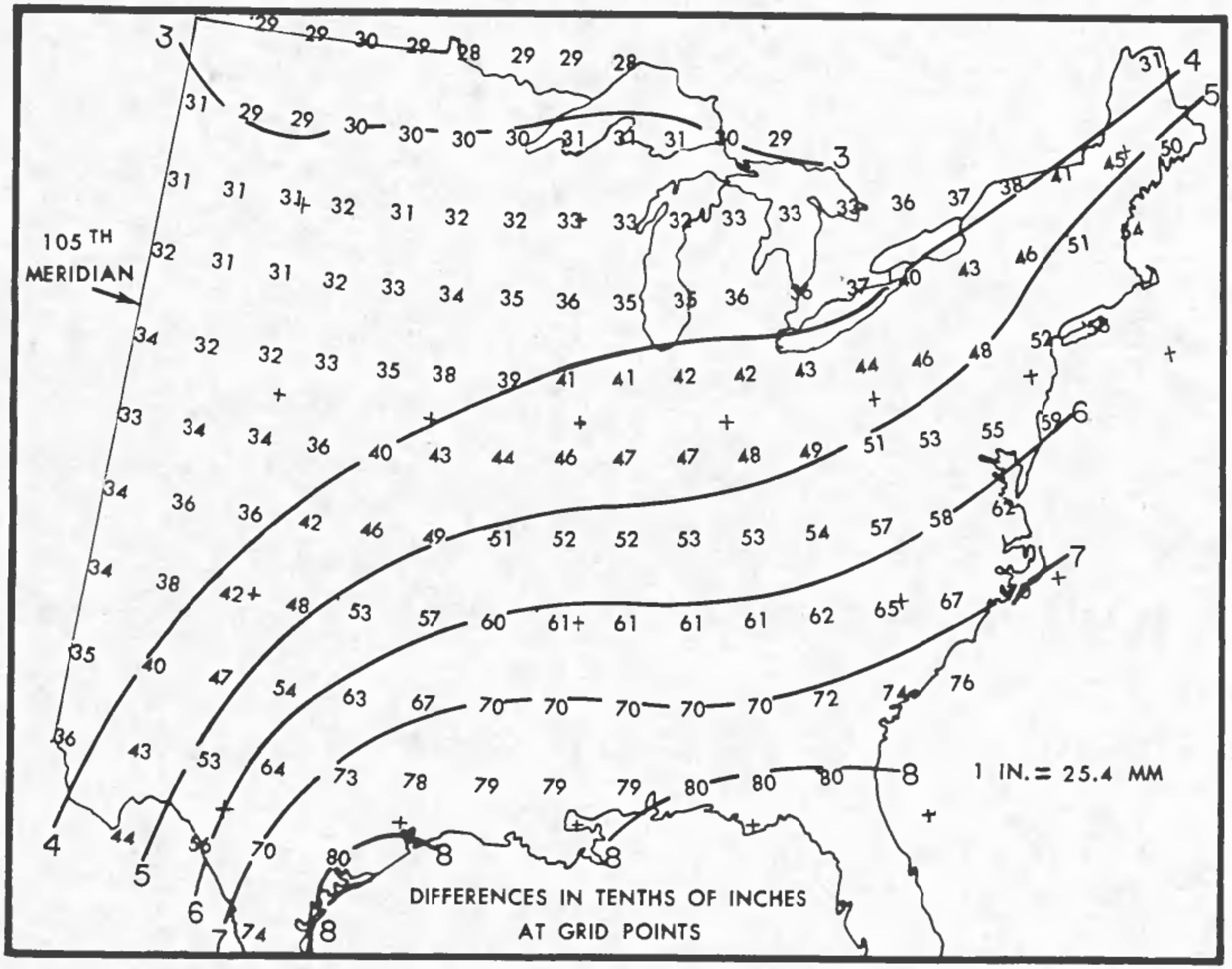


Figure 16.--Example of checks of durational difference in PMP. [24-hr PMP minus 6-hr PMP (in.) for 20,000 mi² (51,800 km²)]

[20,000/1,000, 20,000/10, 10,000/10, and 1,000/10 mi^2 (51,800/2,590, 51,800/26, 25,900/26, and 2,590/26 km^2)] for durations of 6, 24, and 72 hours. These ratios were allowed to vary from region to region; however, smooth transitions were maintained.

3.3.7 PMP Maps

Modifications made for any one of the consistency checks (sections 3.3.2 to 3.3.6) necessarily required replotting and reanalysis of PMP. The resulting PMP maps covering durations of 6, 12, 24, 48, and 72 hours for areas of 10, 200, 1,000, 5,000, 10,000, and 20,000 mi^2 (26, 518, 2,590, 12,950, 25,900, and 51,800 km^2) are given in figures 18 through 47.

4. EVALUATION OF GENERALIZED PMP CHARTS

4.1 Degree of Envelopment

Evaluation of how much effect storm transposition and modifications due to consistency checks have on the PMP estimates is of interest. For such an evaluation, the magnitudes of moisture maximized storm depths where they occurred (in place) were compared with the PMP estimates for these locations. The comparison of in-place values rather than transposed values circumvents the judgmental decisions on storm transpositions and adjustments.

Table 4 lists the storms that have in-place moisture maximized rainfalls within 10 percent of PMP. Observed maximum areal average rainfall depths for these storms are found in the appendix. Only the most critical rainfall depth (for the duration and area coming closest to PMP) was used in the table. The table also gives the moisture adjustment for each storm.[1]

Table 4 shows that four storms give in-place moisture maximized rainfall greater than PMP. Three of these storms (Nos. 2, 51, and 77) were undercut by $\leq$ 2 percent. The moisture maximized depth for the storm (No. 2) of May 30-June 1, 1889 [20,000 mi^2 (51,800 km^2) for 48 hours] of 11.4 in. (290 mm) was undercut by 0.2 in. (5 mm). Similarly for the storm (No. 51) of September 16-17, 1932, the depth [10,000 mi^2 (25,900 km^2) for 12 hours] of 7.0 in. (178 mm) was undercut by 0.1 in. (2.5 mm), and the depth for the storm (No. 77) of May 6-12, 1943 [20,000 mi^2 (51,800 km^2) for 48 hours] of 14.1 in. (358 mm) was undercut by 0.1 in. (2.5 mm). Because of smoothing and other constraints to PMP, increasing the values for these area sizes and durations by only 0.1 or 0.2 in. (2.5 or 5 mm) means much more significant envelopment at other areas and durations. This is particularly so with regard to the constraint on incremental PMP with respect to increasing area size (section 3.3.2).

---

[1] The cases with moisture adjustments greater than 150% are supported by rainfalls in other nearby storms with adjustments less than 150% (section 3.2.2).

Table 4.--Storms that give moisture maximized rainfall within 10 percent of PMP for at least one area size and duration.

Storm Index No. (see fig.1)	Storm Assignment No.	Date	In-place Moisture Adj. (%)	Ratio: Moist. Max. Rainfall*/PMP
74	OR9-23	7/17-18/1942	110	1.07
2	SA1-1	5/30-6/1/1889	163	1.02
51	NA1-20B	9/16-17/1932	127	1.01
77	SW2-20	5/6-12/1943	141	1.01
88	SW3-22	6/23-28/1954	116	1.00
3	MR4-3	6/4-7/1896	155	1.00
47	LMV2-20	3/11-16/1929	134	1.00
85	SA5-8	9/3-7/1950	110	1.00
14	UMV2-5	6/9-10/1905	148	.99
7	GM3-4	6/27-7/1/1899	116	.98
87	MR10-8	6/7/1953	171	.98
42	MR4-24	9/17-19/1926	134	.98
22	UMV1-11A	7/18-23/1909	134	.98
68	NA2-4	9/1/1940	122	.98
97	SW3-24	9/19-24/1967	116	.97
69	SW2-18	9/2-6/1940	141	.97
54	LMV4-21	5/16-20/1935	128	.97
8	LMV2-5	4/15-18/1900	150	.97
1	OR9-19	9/10-13/1878	122	.97
100	NA2-24A	6/19-23/1972	121	.97
20	SW1-11	10/19-24/1908	163	.95
53	SW2-11	4/3-4/1934	149	.94
11	GL4-9	10/7-11/1903	144	.94
56	--	5/30-31/1935	122	.93
26	LMV3-19	3/24-28/1914	150	.93
44	NA1-17	11/2-4/1927	148	.93
65	--	6/19-20/1939	128	.92
86	MR10-2	7/9-13/1951	128	.91
17	GM3-14	8/4-6/1906	121	.91
67	MR4-5	6/3-4/1940	163	.90

*For the standard area size and standard duration giving the highest ratio.

Of more concern was the undercutting of the July 17-18, 1942 storm (No. 74) centered at Smethport, Pa. This storm's in-place moisture maximized 10-mi^2 (26-km^2) 6-hr depth of 27.2 in. (690 mm) is undercut by 7 percent. Without this undercutting there would be excessive envelopment in a large region surrounding the Smethport location for numerous area sizes and durations.

Figure 1 identifies the 30 storms listed in table 4. One of these storms (No. 97) is centered outside the study region. This storm is included because it produced important large-area rainfalls that extended into the United States. Considering deficiencies in the total storm sample, the distribution of the 30 storms indicates reasonably comparable PMP over the study region. In our judgment, these comparisons indicate that envelopment and smoothing steps did not raise the PMP values excessively.

4.2 Use of PMP for all Durations in one PMP Storm

4.2.1 Introduction

In application of the all-season PMP values, a concern is whether PMP for all durations for any given area size can occur in one PMP storm. It is possible that the storms controlling at short durations could be different in type or season than those controlling at long durations. If this should be the case, use of PMP values for all durations in one PMP storm would be unrealistic. A test was made to determine if such cross season or different storm type control exists for a given area size. We labeled this test "storm commonality."

4.2.2 Storm Commonality Test

A clearcut solution of the problem would be to type each storm used in the report. The difficulty with this approach is that whatever typing system is used, many storms would not easily fit into distinct types. This is particularly so because we are dealing with extreme events that are difficult to categorize just because they are rare.

Storm rainfall data were surveyed to see if within seven regions the greatest or near greatest depths for three durations (6, 24, and 72 hours) came from the same storm. Each standard area size [10, 200, 1,000, 10,000, and 20,000 mi^2 (26, 518, 2,590, 25,900, and 51,800 km^2)] was considered separately.

Boundaries for the seven regions are shown in figure 17. For each zone and area size, all the moisture maximized rainfall depths that came within 15 percent of the greatest depth for each duration were determined. If among these data a common storm showed up for all three durations, we assumed "storm commonality" was fulfilled.

Of 35 cases (7 regions and 5 area sizes), 26 met the commonality requirement. The nine exceptions are listed in table 5.

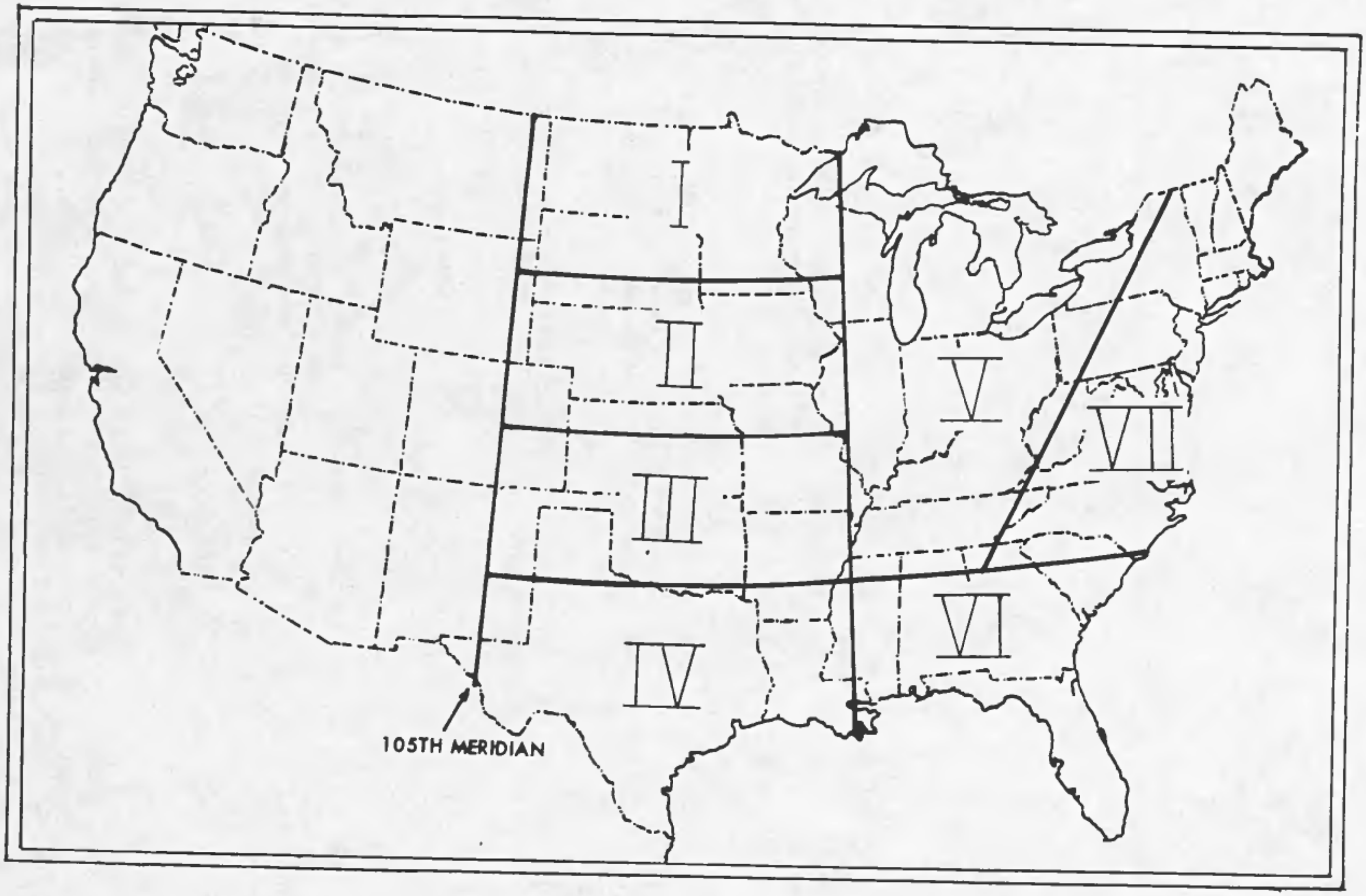


Figure 17.--Regions for storm commonality test.

Table 5.--Exceptions to "storm commonality"

Region	Area Size mi^2 (km^2)
I	10; 200 (26; 518)
III	1,000 (2,590)
IV	200; 10,000; 20,000 (518; 25,900; 51,800)
VI	200 (518)
VII	200; 1,000 (518; 2,590)

Examination of these nine exceptions showed that seven of them would meet the commonality requirement if values from different storms, still within 15 percent of the greatest value but definitively of the same storm type, were allowed to be combined.

The two remaining exceptions are in zone IV for 10,000 and 20,000 mi^2 (25,900 and 51,800 km^2). For 10,000 mi^2 (25,900 km^2) we obtain storm commonality if the criteria lowered to 19 percent of the greatest moisture maximized depth. For 20,000 mi^2 (51,800 km^2) storm commonality was obtained if 23 percent of the greatest depth were allowed.

In the test for "storm commonality", our storm sample for some area sizes and zones of necessity must deal with storms of less than PMP magnitude. The thresholds set for the data samples were arbitrary; however, if full transposition of the storms were allowed (section 2.4), the thresholds used could have been much more stringent and still show "storm commonality".

We conclude there is not undue maximization in the region covered by this study to assume PMP for all durations can be used in one PMP storm for any drainage size.

5. USE OF PMP CHARTS

The set of PMP maps of this report are given in figures 18 through 47. Generalized PMP estimates for any drainage in the United States, east of 105 degrees longitude, for drainages between 10 and 20,000 mi^2 (26 and 51,800 km^2) and for durations from 6 to 72 hours can be determined by following these steps:

a. Determine the geographic location and size of the drainage under study.

b. From the PMP maps (figures 18 through 47) record the average PMP depths for the basin location. (See section 1.4.2 concerning estimates located in stippled areas.) It is not necessary to use each PMP map, but we recommend that PMP values from at least four of the six area sizes closest to the basin size be considered. For these areas, tabulate PMP values for all durations, 6, 12, 24, 48, and 72 hours. Example: If the drainage covers

11,300 mi^2 (29,250 km^2) tabulate PMP for 1,000, 5,000, 10,000, and 20,000 mi^2 (2,590, 12,950, 25,900, 51,800 km^2) for 6, 12, 24, 48, and 72 hours.

c. Plot the PMP depths on semilog paper (depth vs. area). Draw smooth duration curves through the plotted data points (as in fig. 13, except that the depths should be plotted directly in inches).

d. From the depth-area-duration graph of step c, determine the PMP depths at the basin size for each duration.

e. Plot these basin area PMP values on linear graph paper (depth vs. duration). Draw a smooth curve connecting these points. Interpolate along this curve to obtain PMP depths for other durations, if required.

NOTE: To determine PMP for a basin located in one of the Gulf Coast States south of the last PMP isoline shown (for example, a basin in Florida), use the PMP values given by the southernmost isolines.

ACKNOWLEDGMENTS

The authors express their appreciation to Mr. John F. Miller, Chief of the Water Management Information Division, Office of Hydrology, NWS, and Dr. Vance A. Myers, Chief, Special Studies Branch, for their guidance, comments and editorial review of the manuscript. We appreciate the large amount of technical assistance from Miriam McCarty, Marion Choate, Wallace Brewer, Ray Evans, Roxanne Johnson and Teresa Johnson, and we thank Virginia Hostler, Cora Ludwig, and Clara Brown for typing the report.

REFERENCES

American Meteorological Society, 1959: *Glossary of Meteorology*. Boston, Mass., 638 pp.

Atmospheric Environment Service, 1961-: *Storm Rainfall in Canada*, Downsview, Ontario, Canada.

Corps of Engineers, U.S. Army, 1945-: *Storm Rainfall in the United States*, Washington, D.C.

Cry, George W., 1965: Tropical cyclones of the North Atlantic Ocean, tracks and frequencies of hurricanes and tropical storms, 1871-1963. *Technical Paper* No. 55, Weather Bureau, U.S. Department of Commerce, Washington, D.C., 148 pp.

Environmental Data Service, 1968: Maximum persisting 12-hour 1000-mb dew points (°F) monthly and of record. *Climatic Atlas of the United States*, Environmental Science Services Administration, U.S. Department of Commerce, Washington, D.C., pp. 59-60.

Gilman, Charles S., and Peterson, Kendall R., 1958: Northern floods of 1955: Meteorology of the floods. *Journal of the Hydraulics Division*, Vol. 84, No. HY3, pp. 1661-1 to 1661-37.

Goodyear, Hugo V., and Riedel, John T., 1965: Probable maximum precipitation Susquehanna River drainage above Harrisburg, Pennsylvania. *Hydrometeorological Report* No. 40, Weather Bureau, U.S. Department of Commerce, Washington, D.C., 70 pp.

Grantham, Donald D., and Kantor, Arthur J., 1968: Climatological distributions and range effects on height detection of high altitude radar echoes. *Proceedings of the Thirteenth Radar Meteorological Conference*, 20-23 August 1968, McGill University, Montreal, Canada, American Meteorological Society, Boston, Mass., pp. 298-303.

Hansen, E.M., Schwarz, Francis K., and Riedel, John T., 1977: Probable maximum precipitation estimates, Colorado River and Great Basin drainages. *Hydrometeorological Report* No. 49, National Weather Service, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Silver Spring, Md., 161 pp.

Hansen, E.M., and Schreiner, Louis C.,: Application of probable maximum precipitation estimates, United States east of the 105th meridian. *Hydrometeorological Report* No. 52, National Weather Service, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Silver Spring, Md. (in preparation).

Hershfield, David M., 1961: Rainfall frequency atlas of the United States for durations from 30 minutes to 24 hours and return periods from 1 to 100 years. *Technical Paper* No. 40, Weather Bureau, U.S. Department of Commerce, Washington, D.C., 115 pp.

Jennings, Arthur H., 1952: Maximum 24-hour precipitation in the United States. *Technical Paper* No. 16, Weather Bureau, U.S. Department of Commerce, Washington, D.C., 284 pp.

McDonald, Willard F., 1944: *Average Precipitation in the United States for the Period 1906 to 1935 Inclusive*. Weather Bureau, U.S. Department of Commerce, Washington, D.C., 69 pp.

Miller, John F., 1963: Probable maximum precipitation and rainfall-frequency data for Alaska. *Technical Paper* No. 47, Weather Bureau, U.S. Department of Commerce, Washington, D.C., 69 pp.

Miller, John F., 1964: Two- to ten-day precipitation for return periods of 2 to 100 years in the contiguous United States. *Technical Paper* No. 49, Weather Bureau, U.S. Department of Commerce, Washington, D.C., 29 pp.

Paulhus, Joseph L.H., and Gilman, Charles S., 1953: Evaluation of probable maximum precipitation. *Transactions of the American Geophysical Union*, Vol. 34, No. 5, Washington, D.C., pp. 701-708.

Riedel, John T., Appleby, James F., and Schloemer, Robert W., 1956: Seasonal variation of the probable maximum precipitation east of the 105th meridian for areas from 10 to 1000 square miles and durations of 6, 12, 24, and 48 hours. *Hydrometeorological Report* No. 33, Weather Bureau, U.S. Department of Commerce, Washington, D.C., 58 pp.

Riedel, John T., Schwarz, Francis K., and Weaver, Robert L., 1969: Probable maximum precipitation over South Platte River, Colorado, and Minnesota River, Minnesota. *Hydrometeorological Report* No. 44, Weather Bureau, Environmental Science Services Administration, U.S. Department of Commerce, Washington, D.C., 114 pp.

Riedel, John T., 1973: Probable maximum precipitation and snowmelt criteria for Red River of the North above Pembina, and Souris River above Minot, North Dakota. *Hydrometeorological Report* No. 48, National Weather Service, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Silver Spring, Md., 69 pp.

Schoner, Robert W., 1968: Climatological regime of rainfall associated with hurricanes after landfall. *ESSA Technical Memorandum* WBTM-ER-29, Weather Bureau, Environmental Science Services Administration, U.S. Department of Commerce, Garden City, N.Y., 25 pp.

Schwarz, Francis K., 1965: Probable maximum and TVA precipitation over the Tennessee River basin above Chattanooga. *Hydrometeorological Report* NO. 41, Weather Bureau, U.S. Department of Commerce, Washington, D.C., 148 pp.

Schwarz, Francis K., 1967: The role of persistence, instability, and moisture in the intense rainstorms in eastern Colorado, June 14-17, 1965. *ESSA Technical Memorandum* WBTM HYDRO-3, Weather Bureau, Environmental Science Services Administration, U.S. Department of Commerce, Washington, D.C., 21 pp.

Schwarz, Francis K., and Helfert, Norbert F., 1969: Probable maximum and TVA precipitation for Tennessee River basins up to 3000 square miles in area and durations to 72 hours. *Hydrometeorological Report* No. 45, Weather Bureau, Environmental Science Services Administration, U.S. Department of Commerce, Silver Spring, Md., 166 pp.

Shipe, Albert P., and Riedel, John T., 1976: Greatest known areal storm rainfall depths for the contiguous United States. *NOAA Technical Memorandum* NWS HYDRO-33, National Weather Service, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Silver Spring, Md., 174 pp.

U.S. Naval Oceanographic Office, 1967: Oceanographic Atlas of the North Atlantic Ocean, Section 2, physical properties. *Publication No. 700*, Oceanographic Office, Department of the Navy, Washington, D.C., 300 pp.

U.S. Weather Bureau, 1946: Manual for depth-area-duration analysis of storm precipitation. *Cooperative Studies Technical Paper* No. 1, U.S. Department of Commerce, Washington, D.C., 82 pp.

U.S. Weather Bureau, 1947: Generalized estimates of maximum possible precipitation over the United States east of the 105th meridian, for areas of 10, 200, and 500 square miles. *Hydrometeorological Report* No. 23, U.S. Department of Commerce, Washington, D.C., 77 pp.

U.S. Weather Bureau, 1951: Tables of precipitable water and other factors for a saturated pseudo-adiabatic atmosphere. *Technical Paper* No. 14, U.S. Department of Commerce, Washington, D.C., 27 pp.

U.S. Weather Bureau, 1952: Generalized estimates of maximum possible precipitation over New England and New York. *Hydrometeorological Report* No. 28, U.S. Department of Commerce, Washington, D.C., 14 pp.

U.S. Weather Bureau, 1960: Generalized estimates of probable maximum precipitation for the United States west of the 105th meridian for areas to 400 square miles and durations to 24 hours. *Technical Paper* No. 38, U.S. Department of Commerce, Washington, D.C., 66 pp.

U.S. Weather Bureau, 1961: Interim report probable maximum precipitation in California. *Hydrometeorological Report* No. 36, U.S. Department of Commerce, Washington, D.C. 202 pp.

U.S. Weather Bureau, 1963: Decennial census of United States climate - monthly average for state climatic divisions, 1931-1960. *Climatography of the United States* No. 85, U.S. Department of Commerce, Washington, D.C.

U.S. Weather Bureau, 1966: Probable maximum precipitation, northwest states. *Hydrometeorological Report* No. 43, Environmental Science Services Administration, U.S. Department of Commerce, Washington, D.C., 228 pp.

U.S. Weather Bureau, 1969: Severe local storm occurrences, 1955-1967. *ESSA Technical Memorandum* WBTM FCST 12, Environmental Science Services Administration, U.S. Department of Commerce, Silver Spring, Md., 77 pp.

Wiesner, Clarence J., 1970: *Hydrometeorology*. Chapman and Hall LTD., London, England, 232 pp.

World Meteorological Organization, 1969a: Estimation of maximum floods. *WMO* No. 233, TP 126, *Technical Note* No. 98, Geneva, Switzerland, 288 pp.

World Meteorological Organization, 1969b: Manual for depth-area-duration analysis of storm precipitation. *WMO* No. 129, Geneva, Switzerland, 114 pp.

World Meteorological Organization, 1973: Manual for estimation of probable maximum precipitation. *WMO* No. 332, *Operational Hydrology Report* No. 1, Geneva, Switzerland, 190 pp.

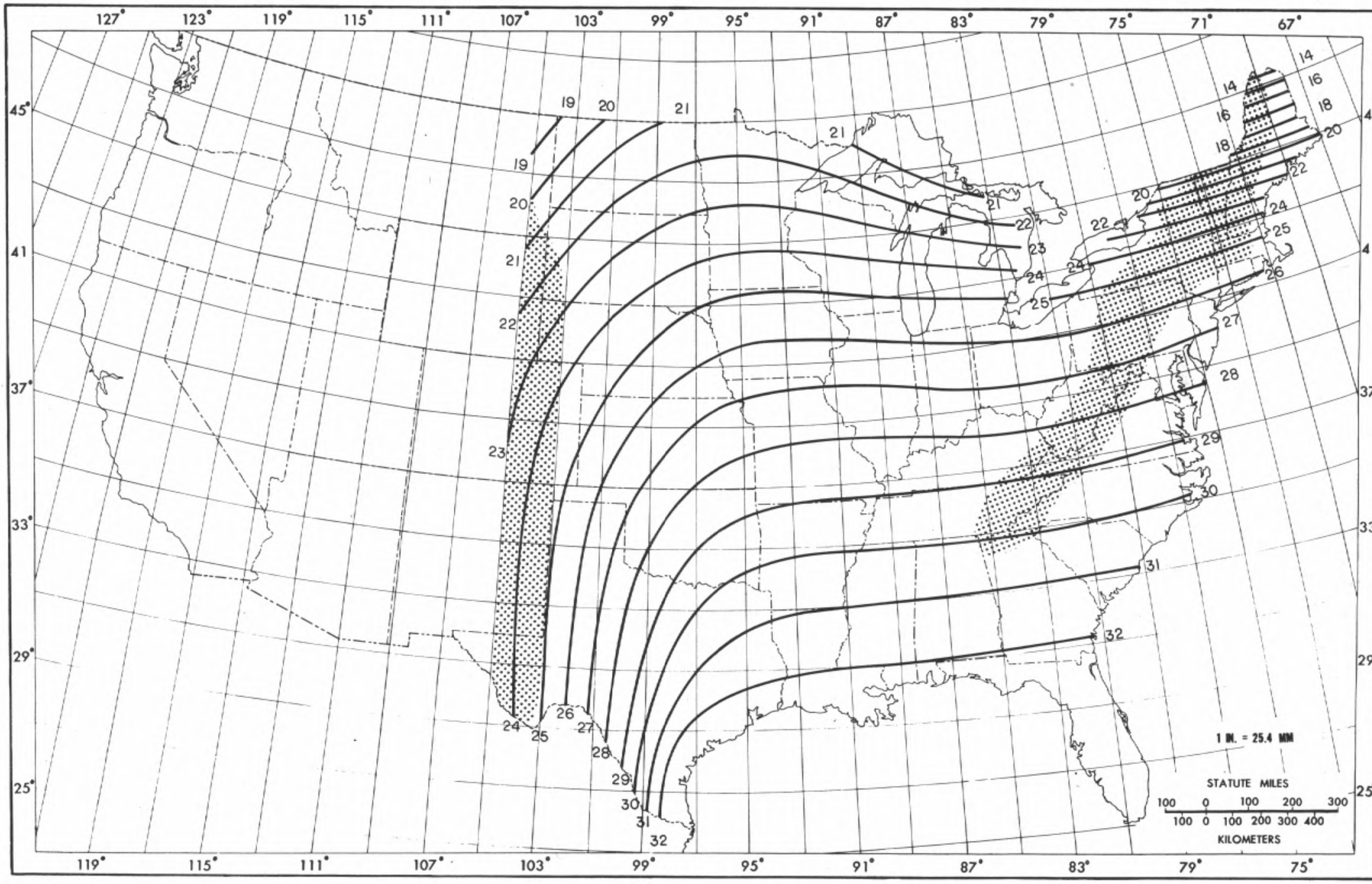


Figure 18.--All-season PMP (in.) for 6 hr 10 mi^2 (26 km^2).

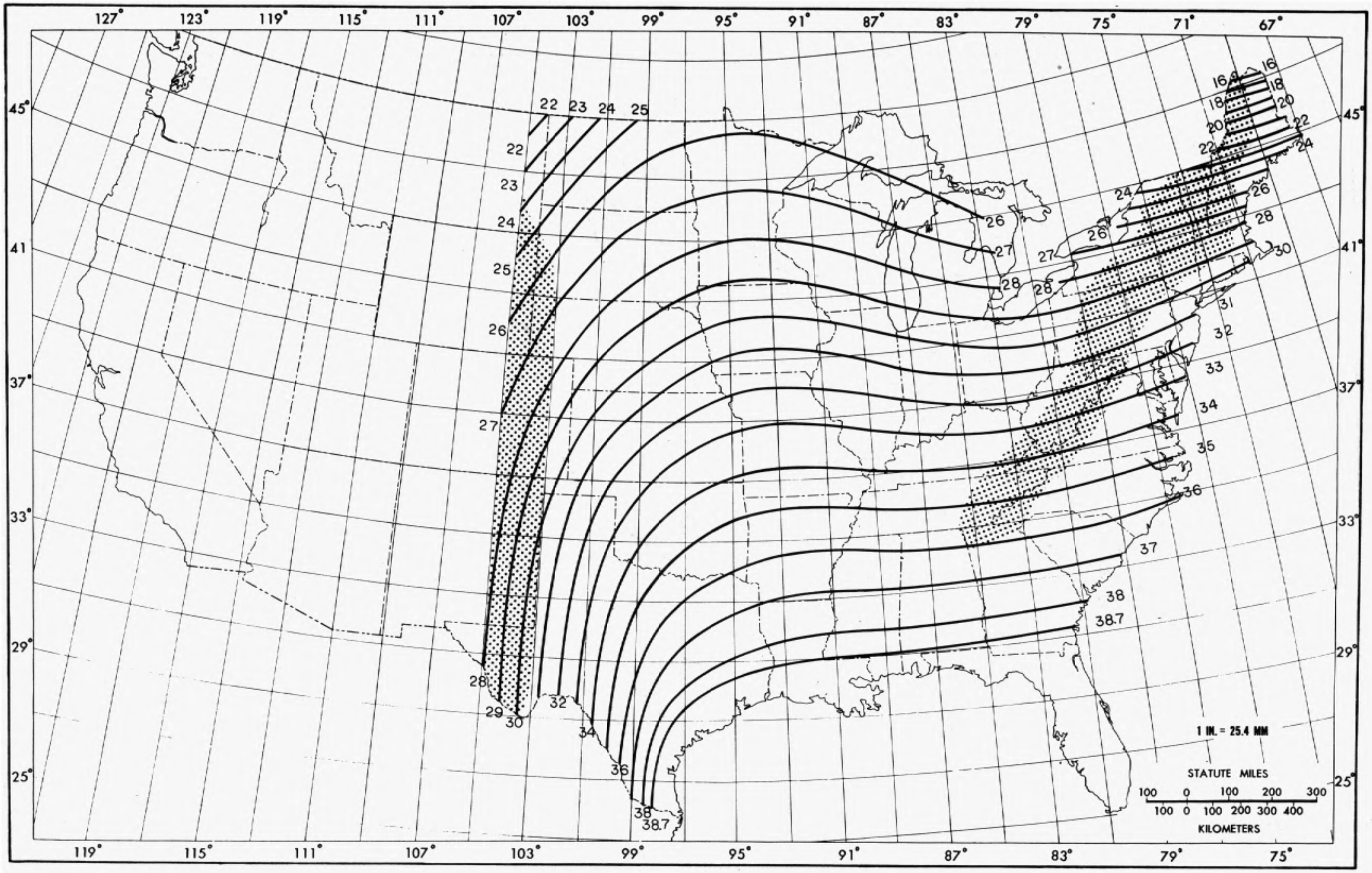


Figure 19.--All-season PMP (in.) for 12 hr 10 mi^2 (26 km^2).

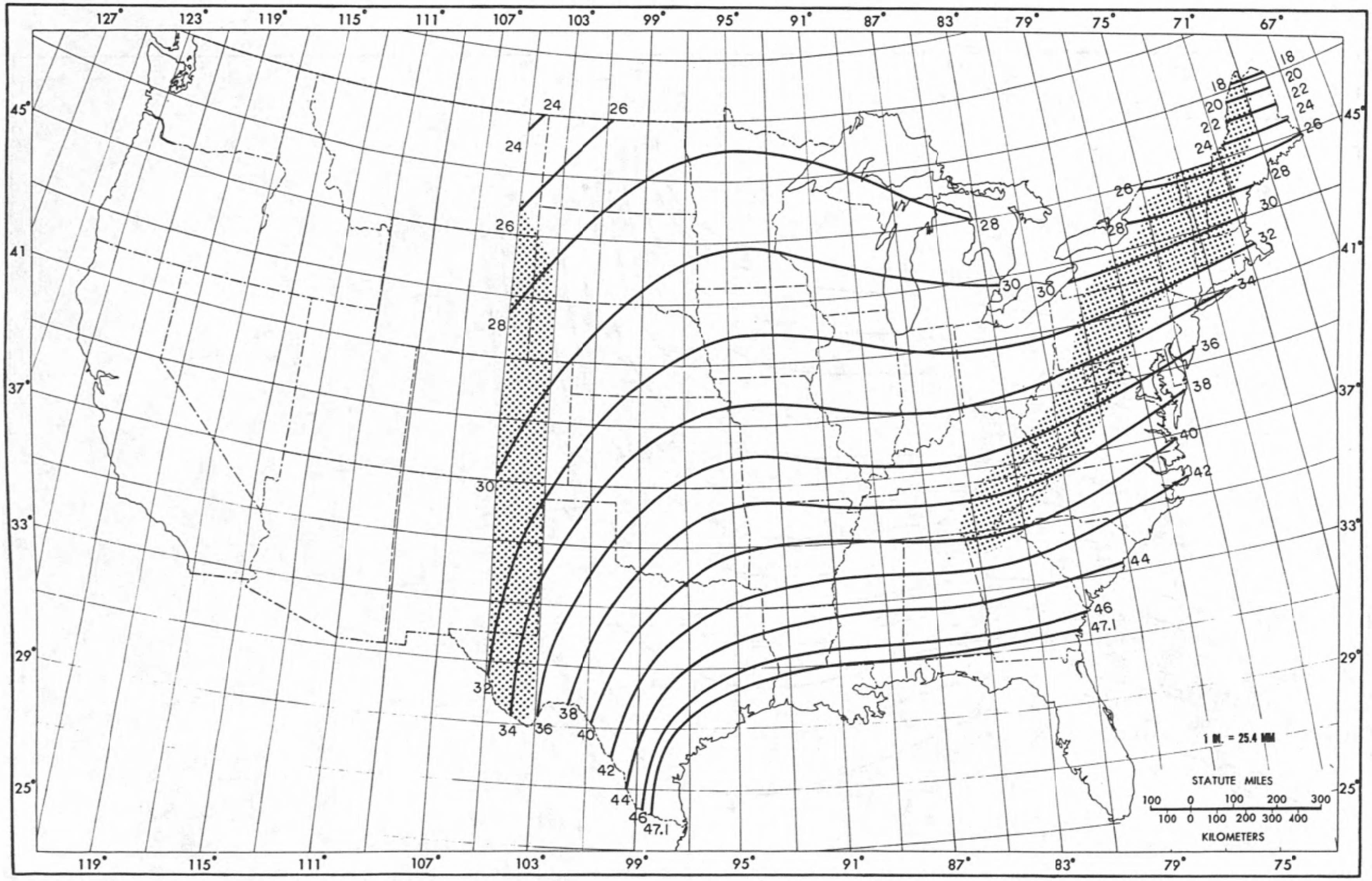


Figure 20.--All-season PMP (in.) for 24 hr 10 mi^2 (26 km^2).

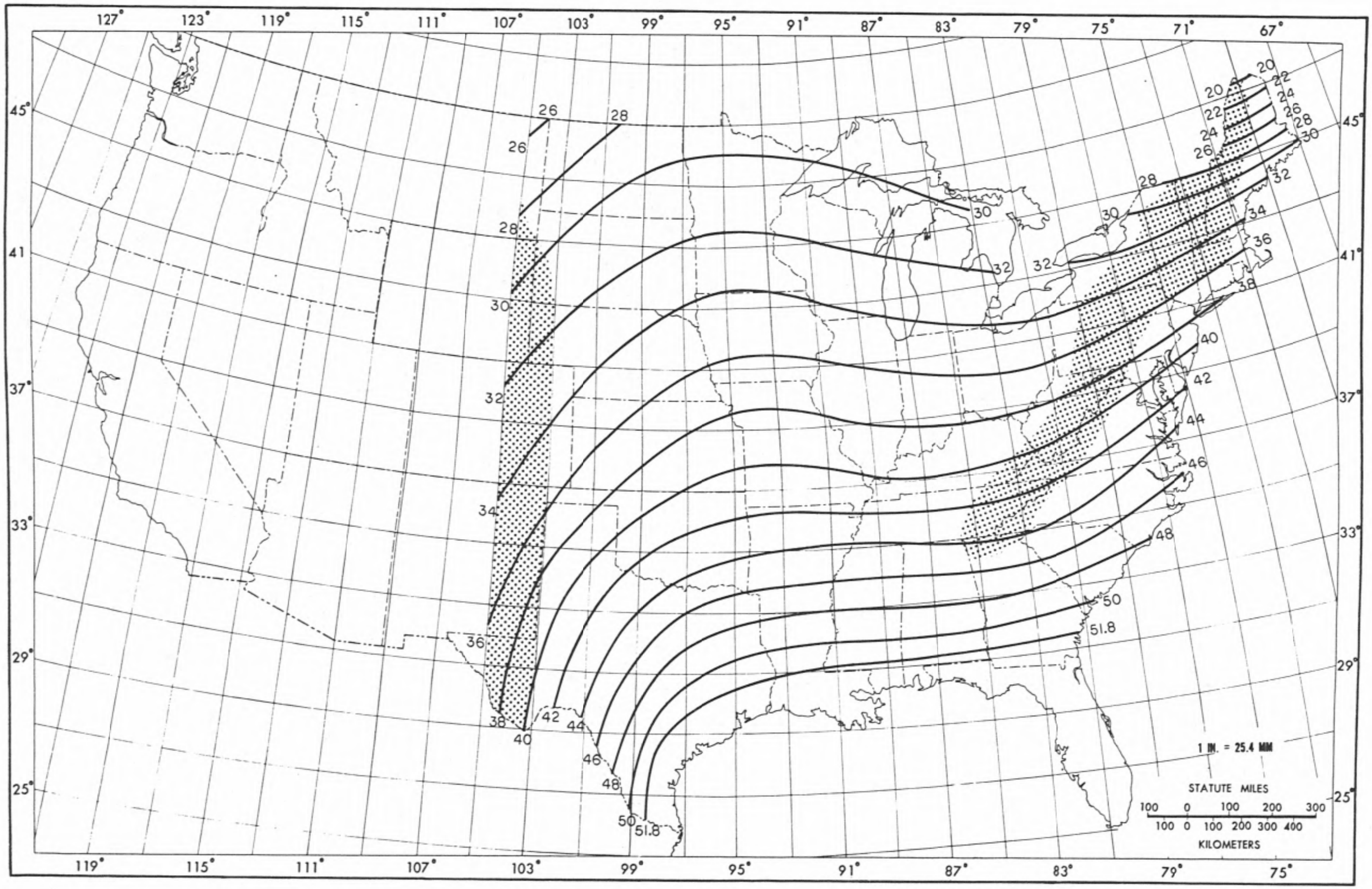


Figure 21.--All-season PMP (in.) for 48 hr 10 mi^2 (26 km^2).

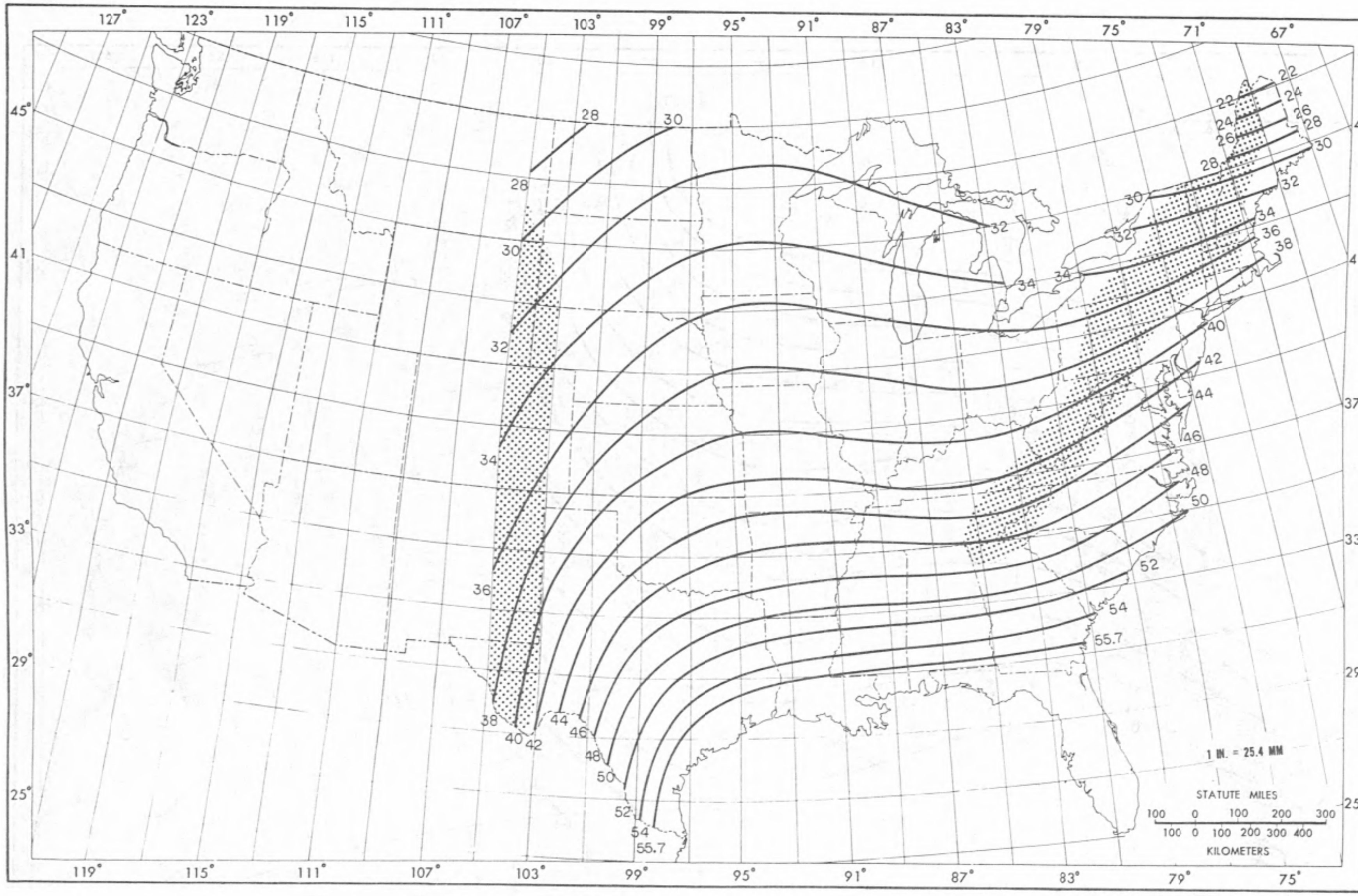


Figure 22.--All-season PMP (in.) for 72 hr 10 mi^2 (26 km^2).

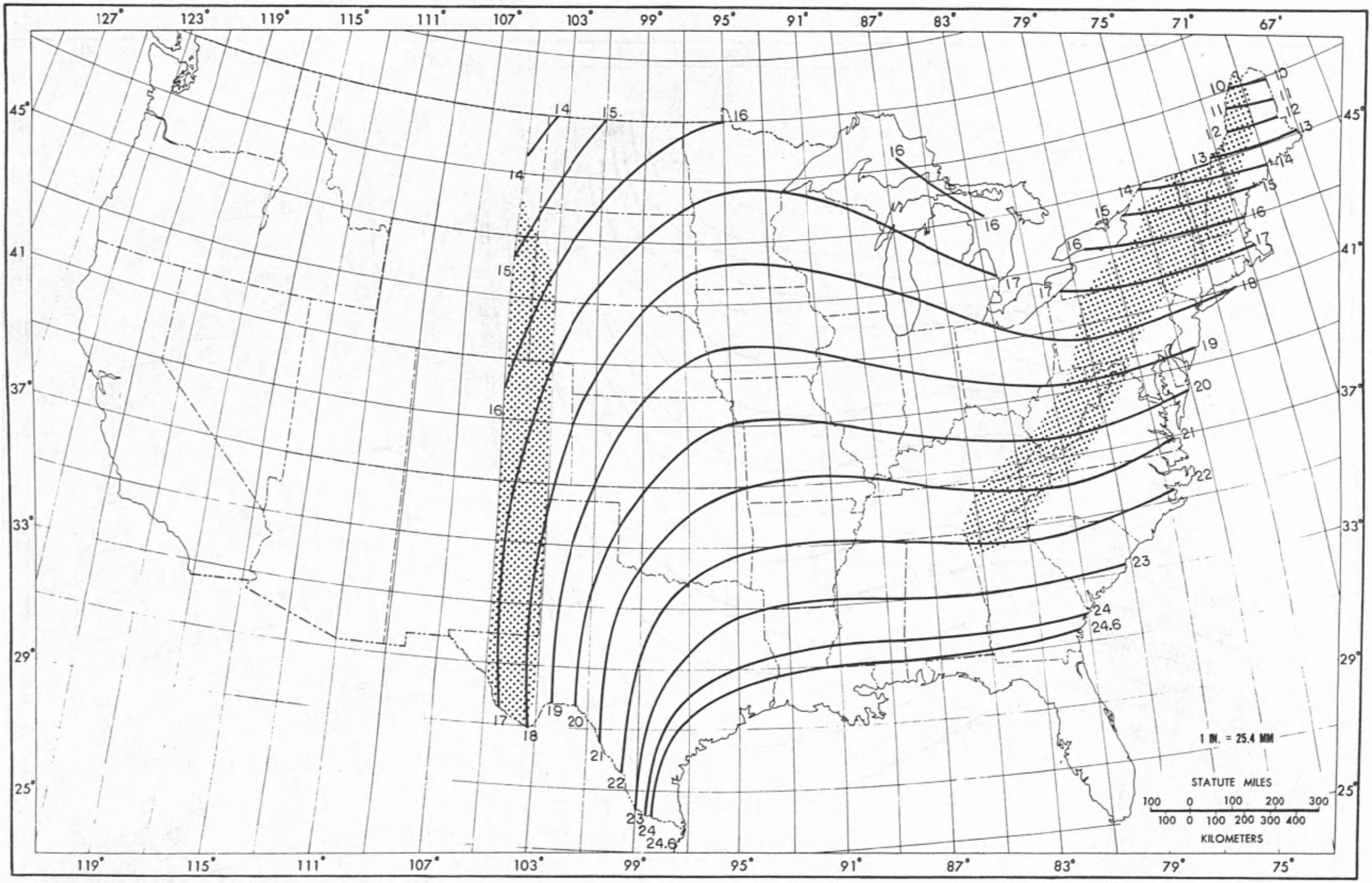


Figure 23.--All-season PMP (in.) for 6 hr 200 mi^2 (518 km^2).

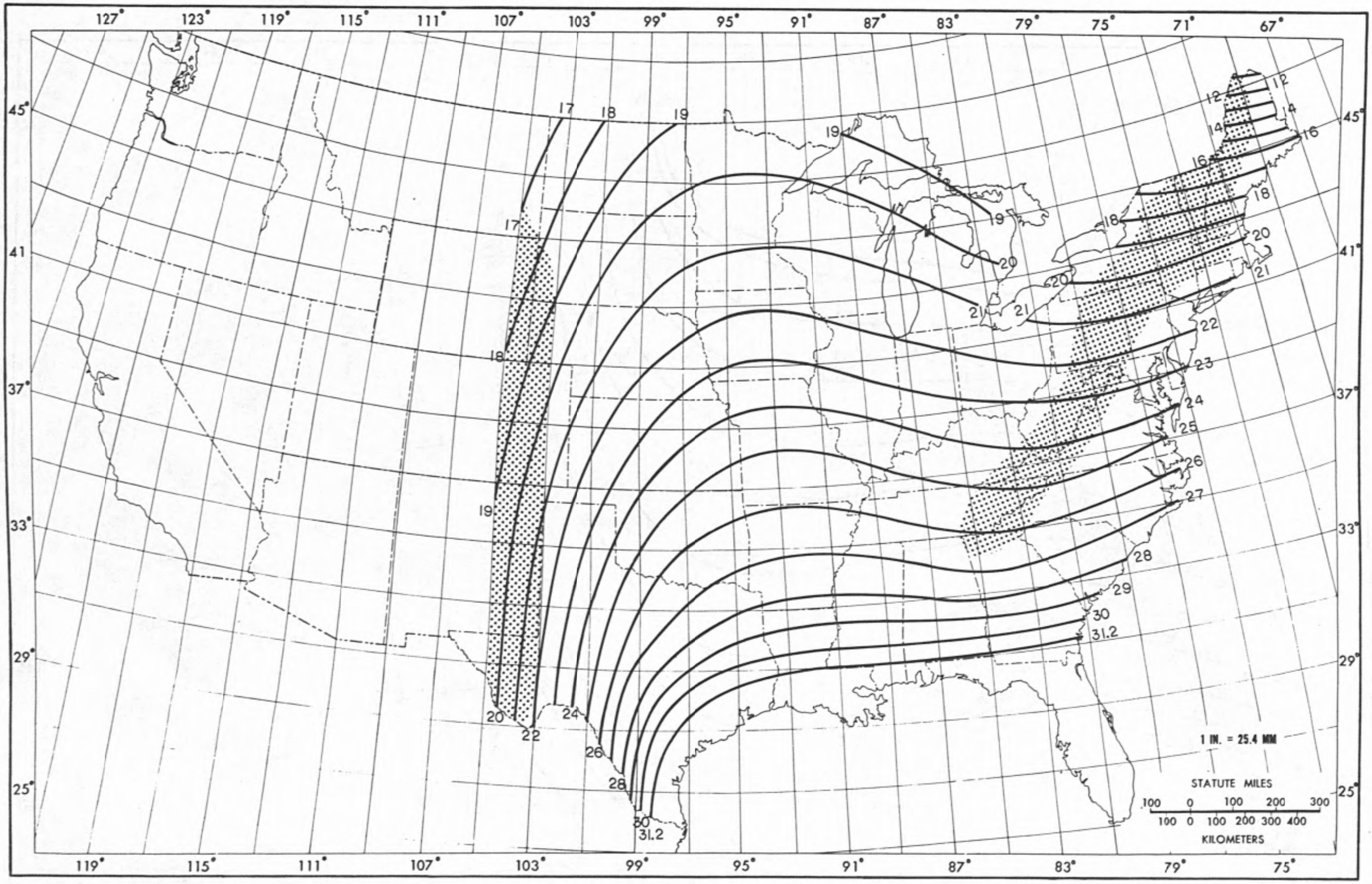


Figure 24.--All-season PMP (in.) for 12 hr 200 mi^2 (518 km^2).

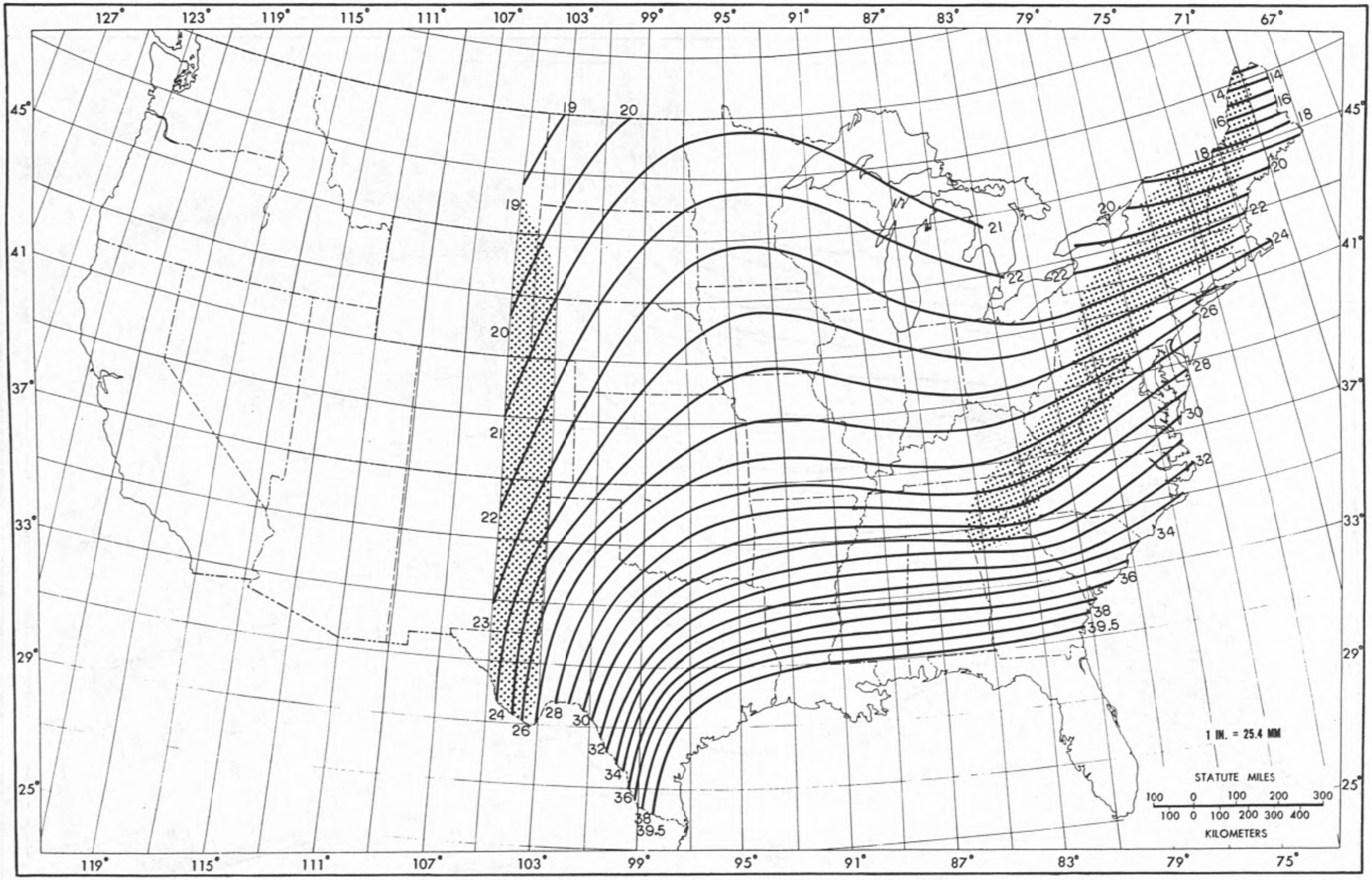


Figure 25.--All-season PMP (in.) for 24 hr 200 mi^2 (518 km^2).

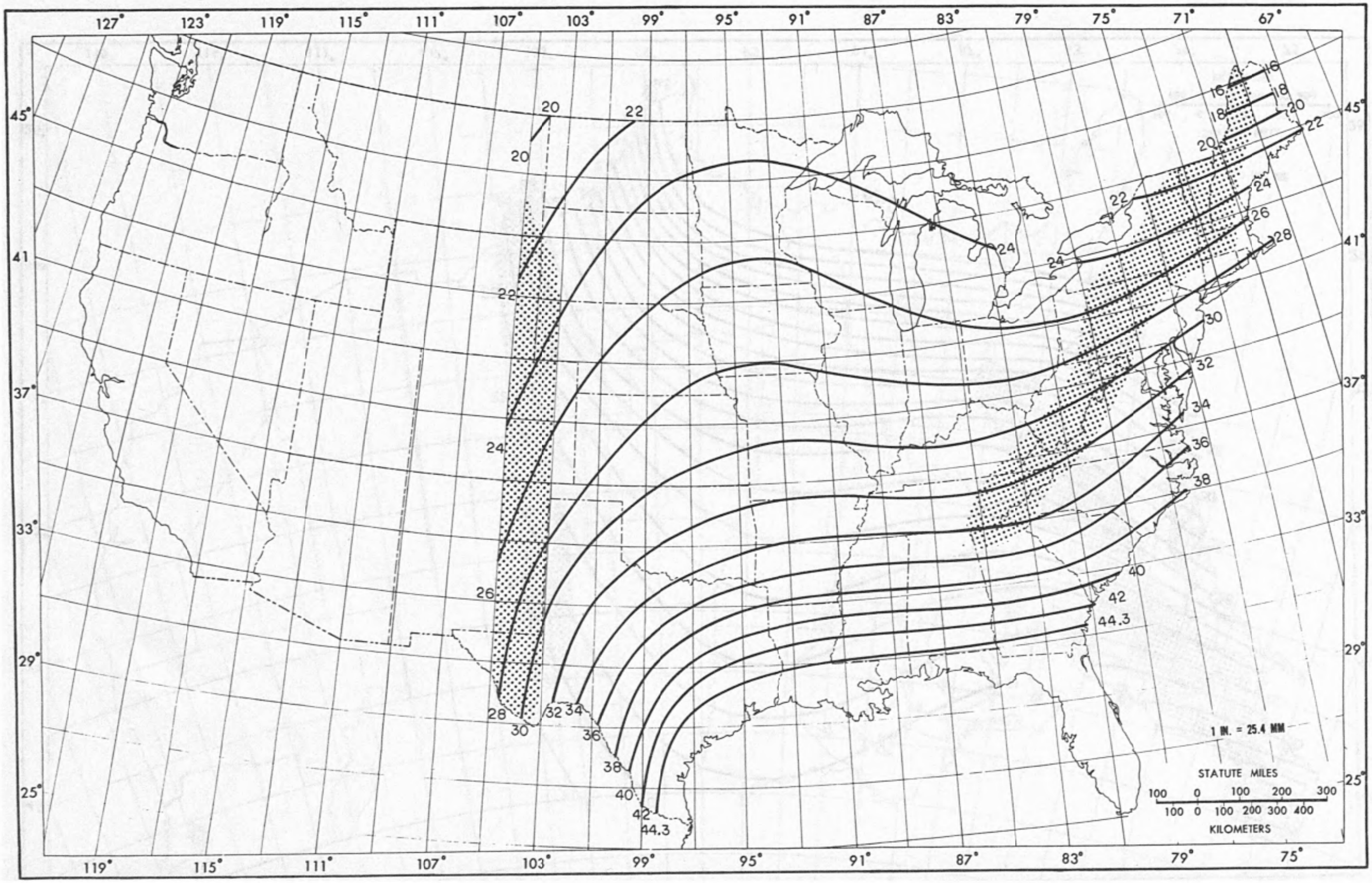


Figure 26.--All-season PMP (in.) for 48 hr 200 mi^2 (518 km^2).

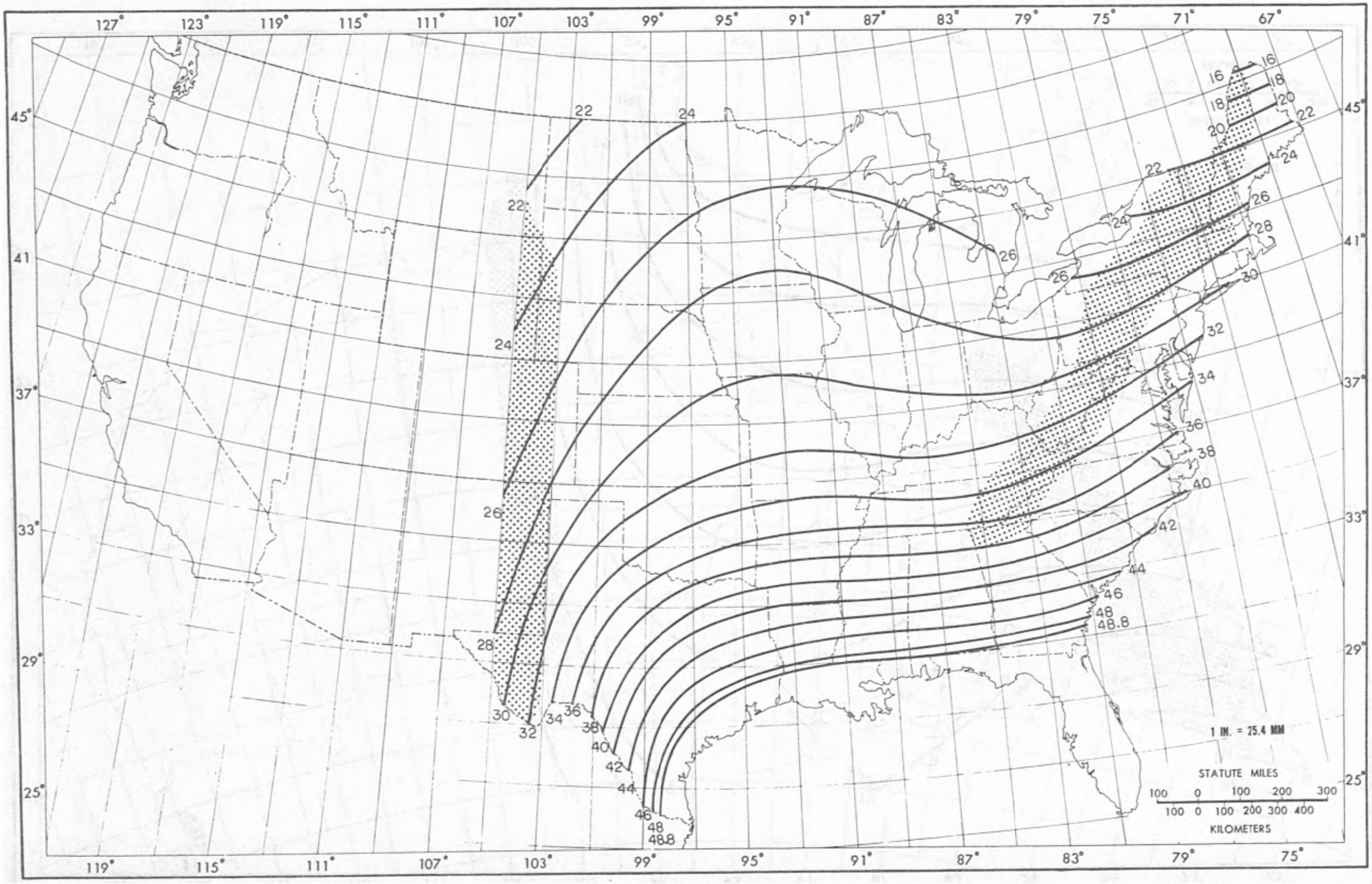


Figure 27.--All-season PMP (in.) for 72 hr 200 mi^2 (518 km^2).

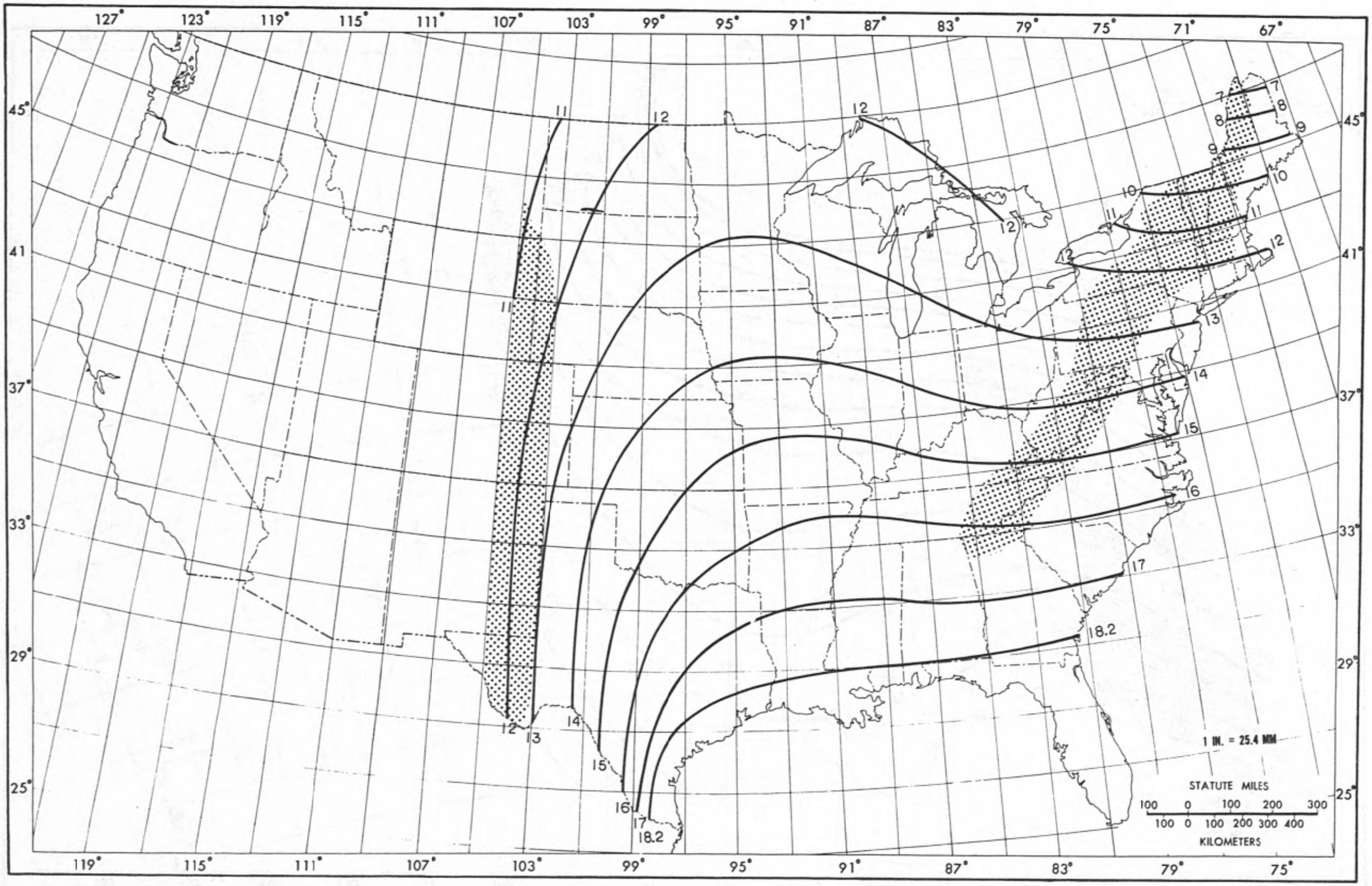


Figure 28.--All-season PMP (in.) for 6 hr 1,000 mi^2 (2,590 km^2).

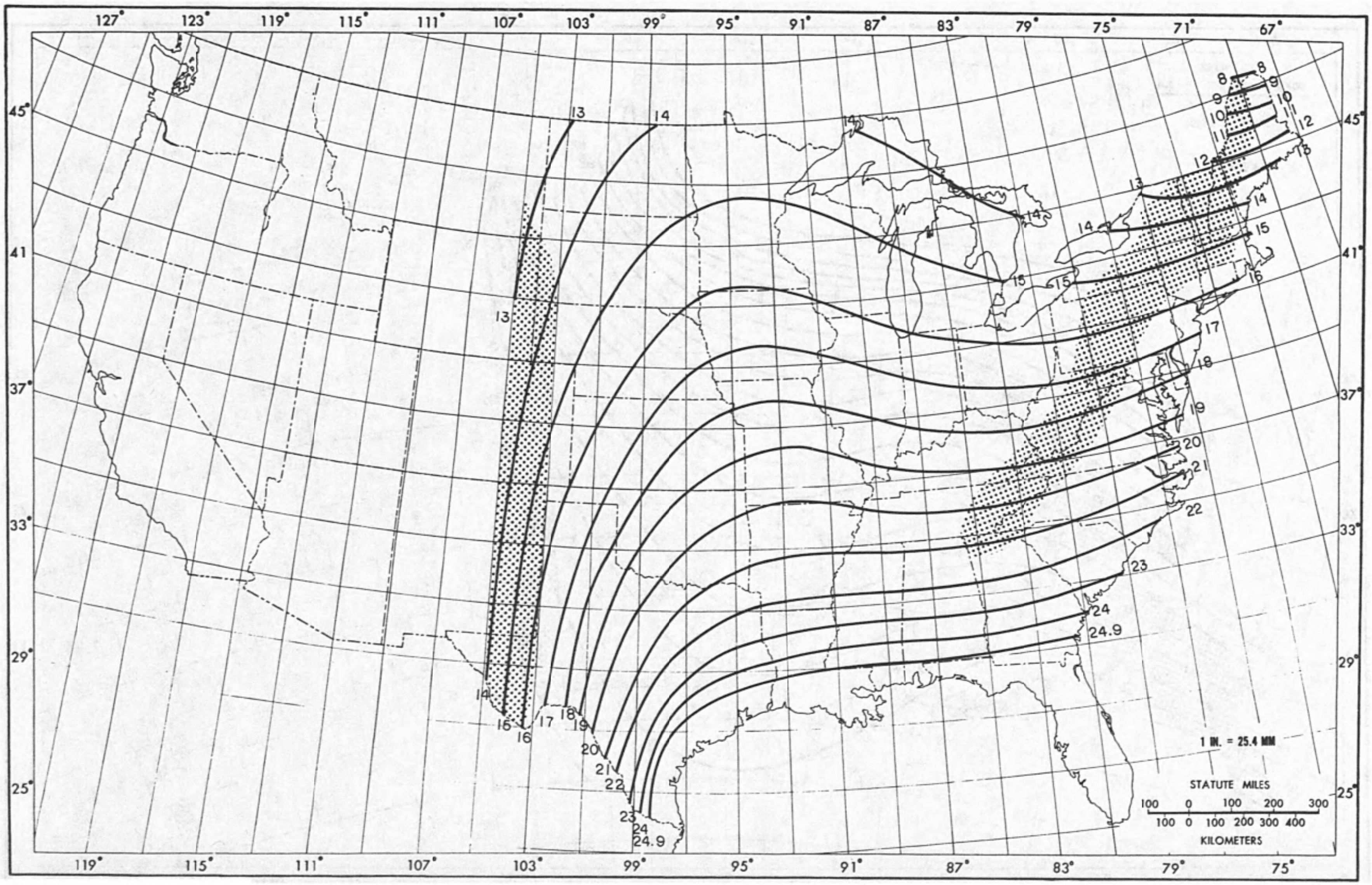


Figure 29.--All-season PMP (in.) for 12 hr 1,000 mi^2 (2,590 km^2).

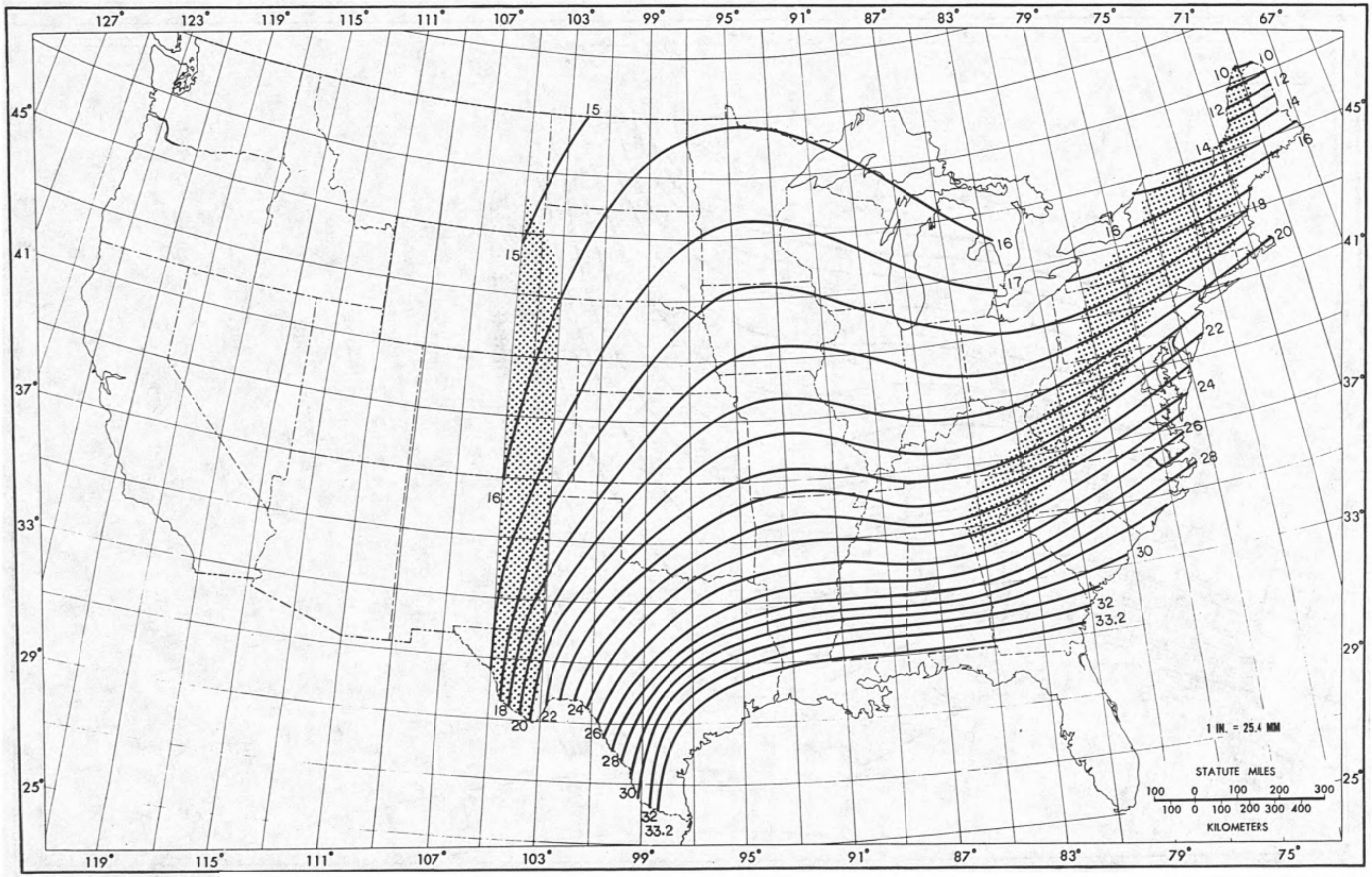


Figure 30.--All-season PMP (in.) for 24 hr 1,000 mi^2 (2,590 km^2).

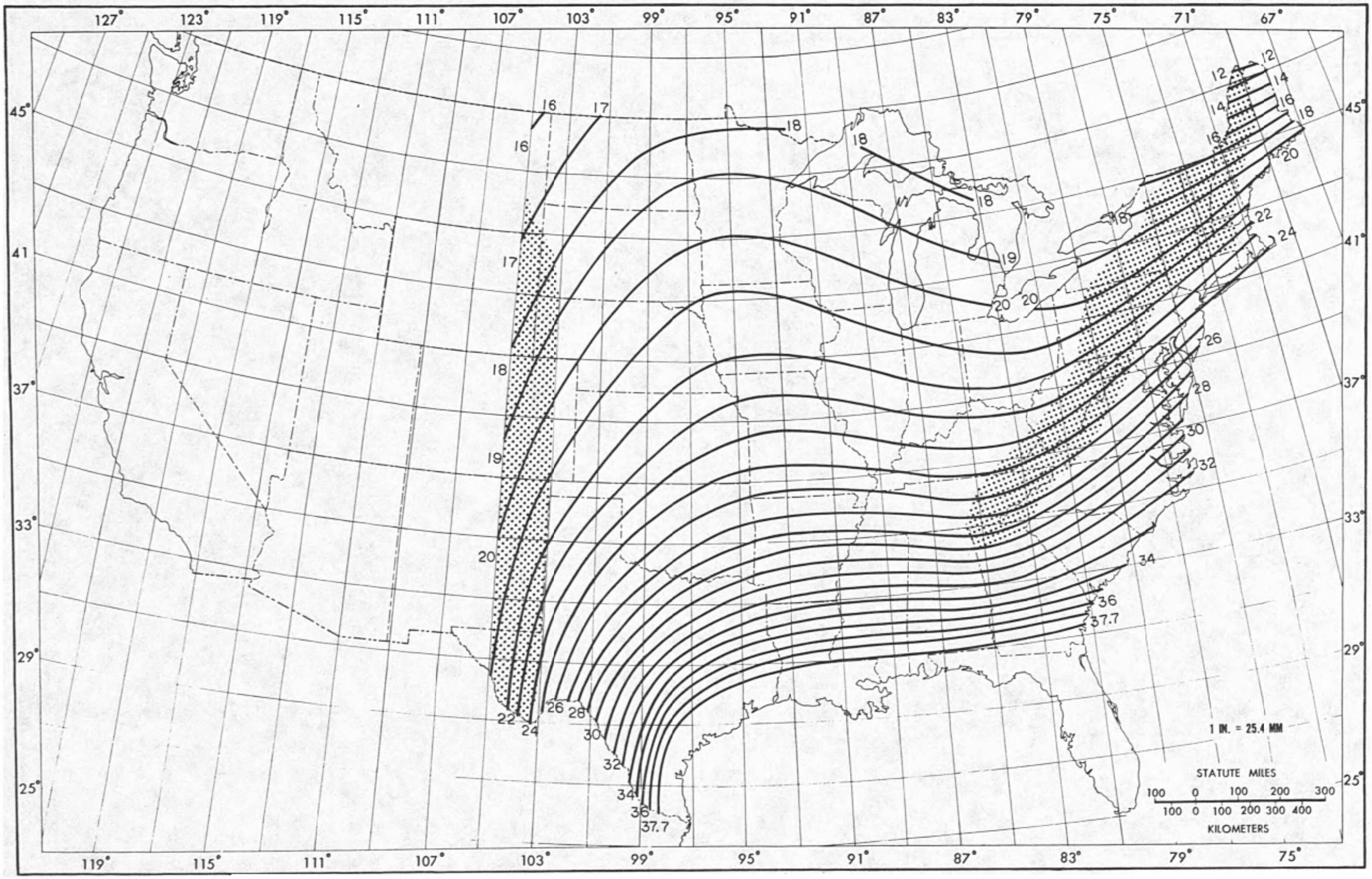


Figure 31.--All-season PMP (in.) for 48 hr 1,000 mi^2 (2,590 km^2).

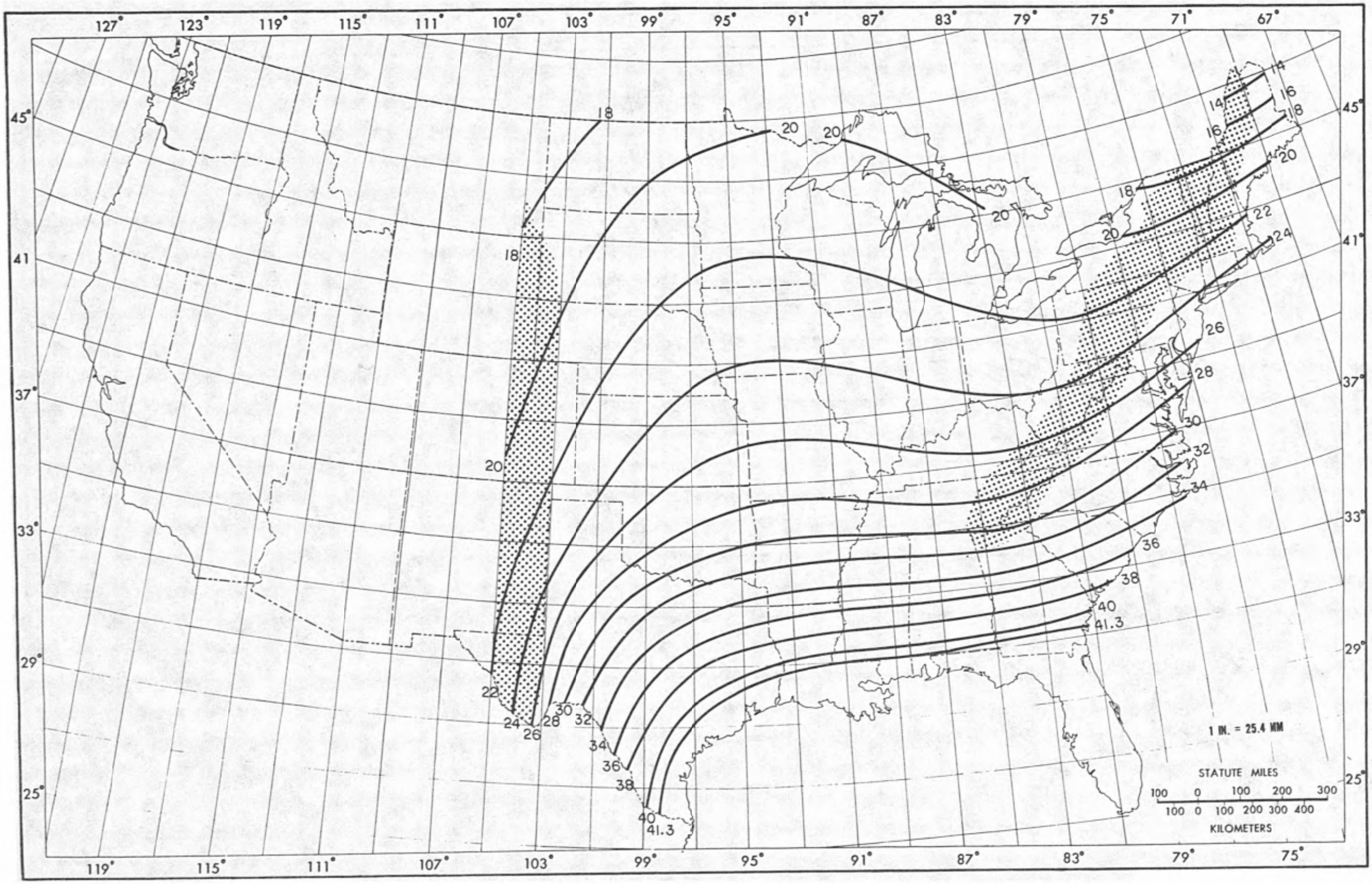


Figure 32.--All-season PMP (in.) for 72 hr 1,000 mi^2 (2,590 km^2).

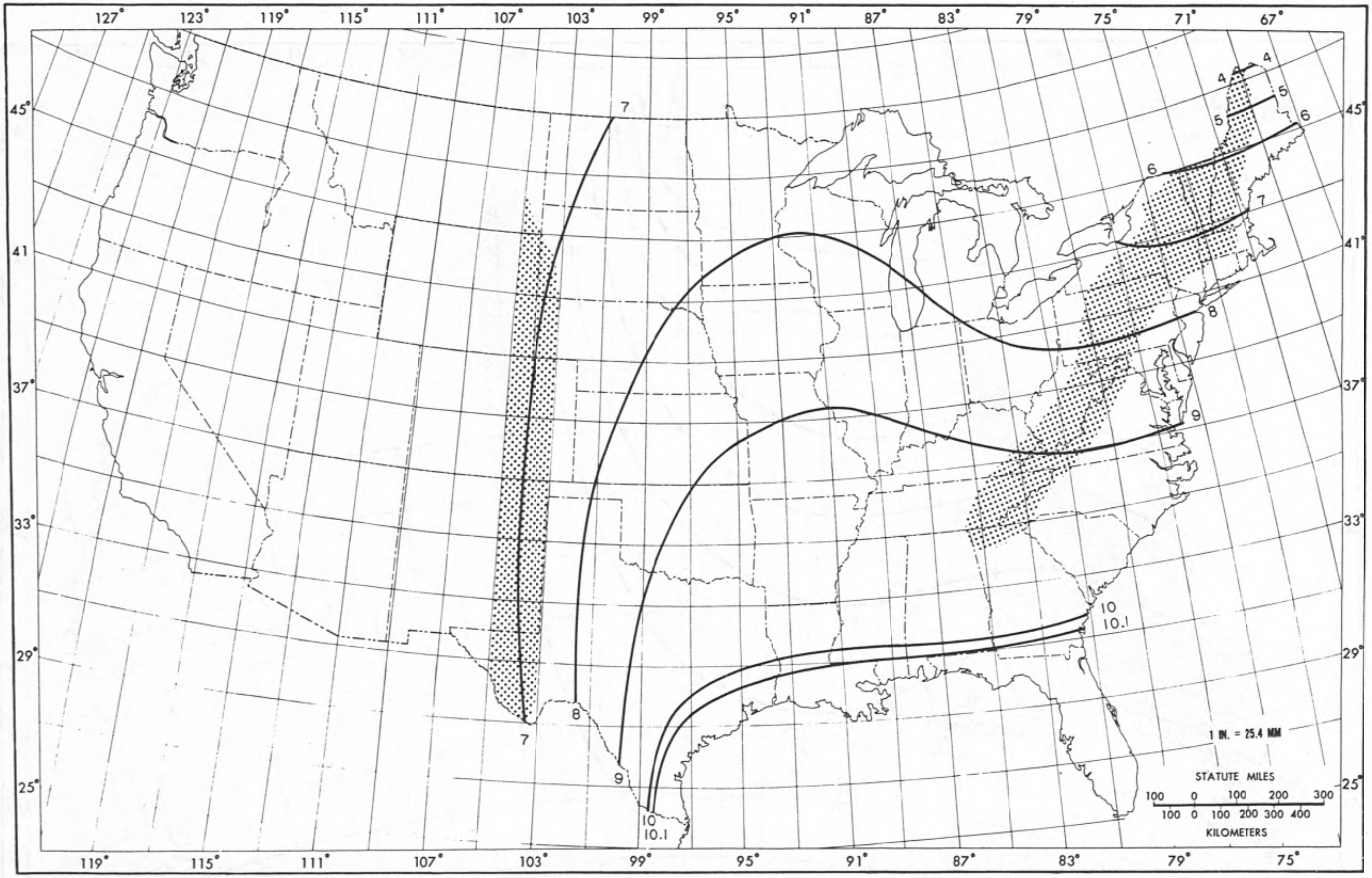


Figure 33.--All-season PMP (in.) for 6 hr 5,000 mi^2 (12,950 km^2).

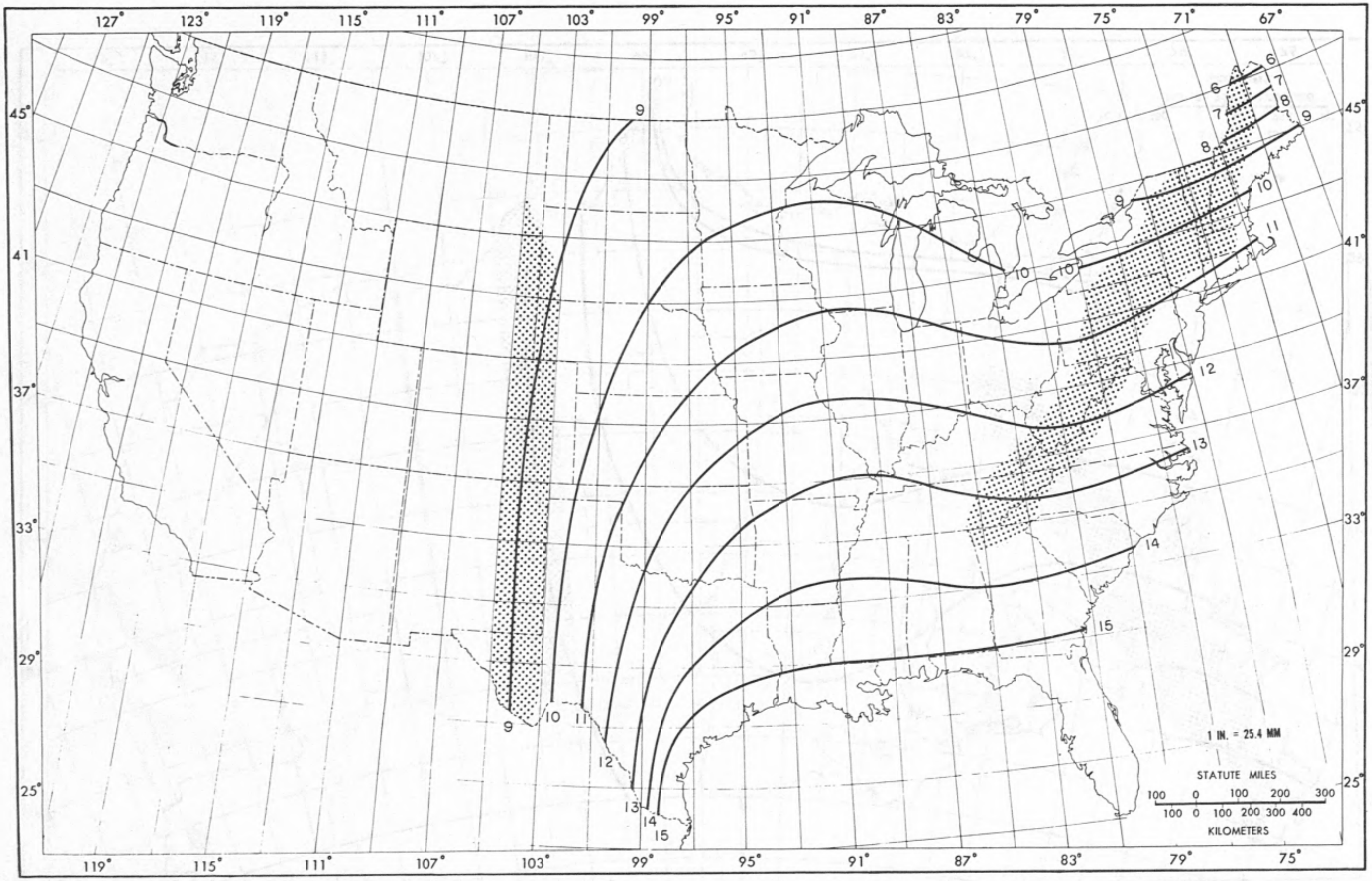


Figure 34.--All-season PMP (in.) for 12 hr 5,000 mi^2 (12,950 km^2).

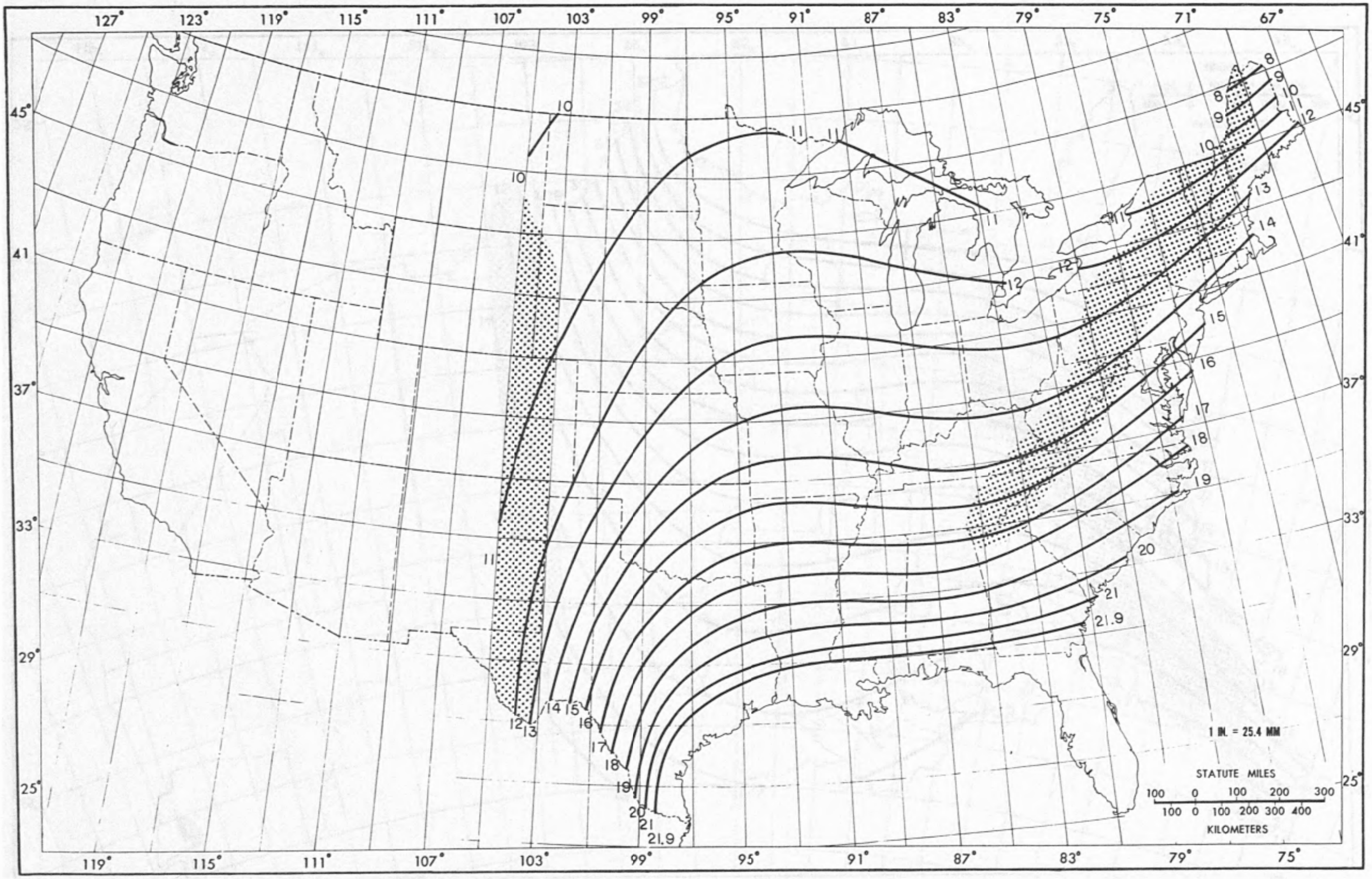


Figure 35.--All-season PMP (in.) for 24 hr 5,000 mi^2 (12,950 km^2).

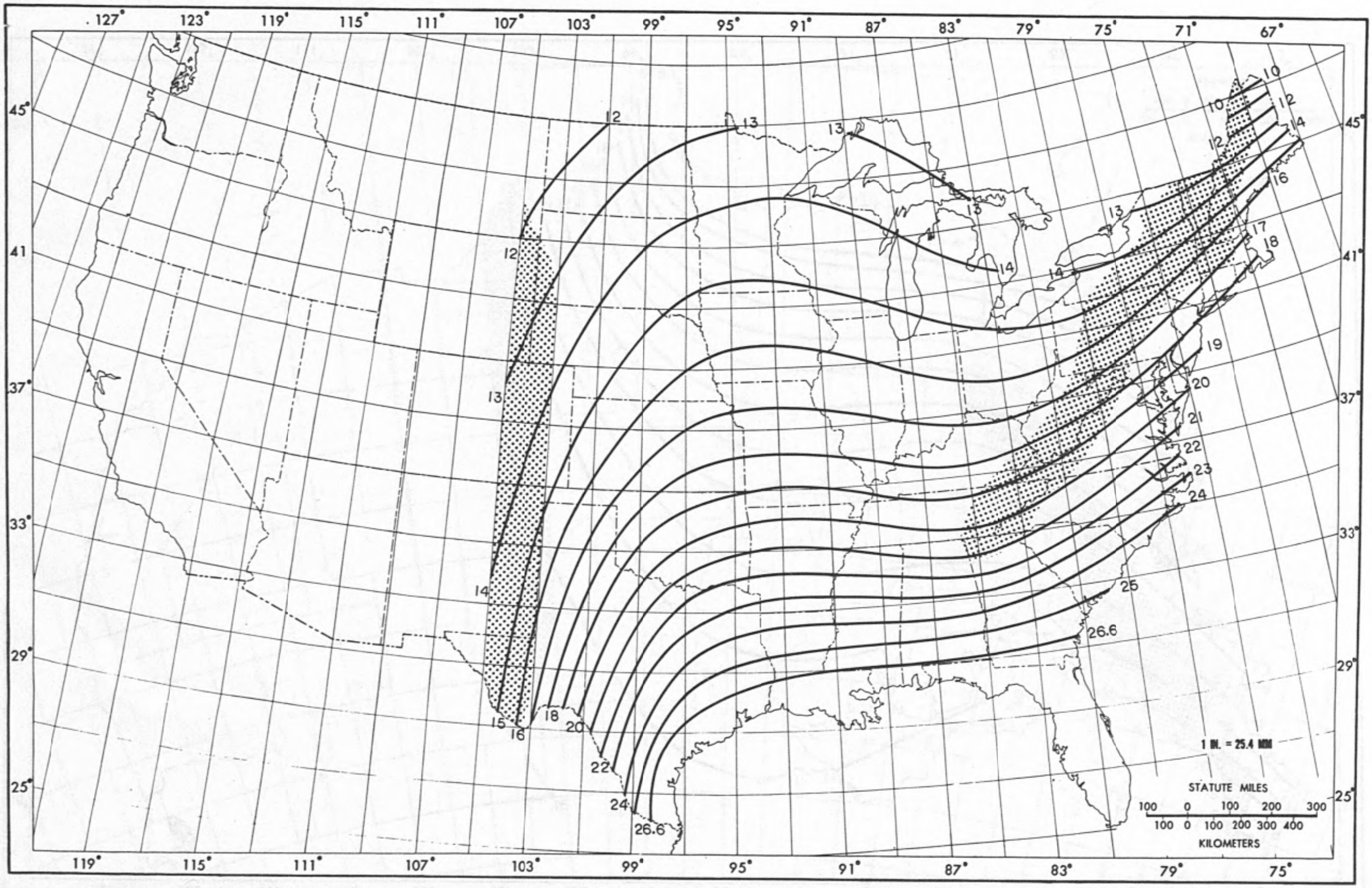


Figure 36.--All-season PMP (in.) for 48 hr 5,000 mi^2 (12,950 km^2).

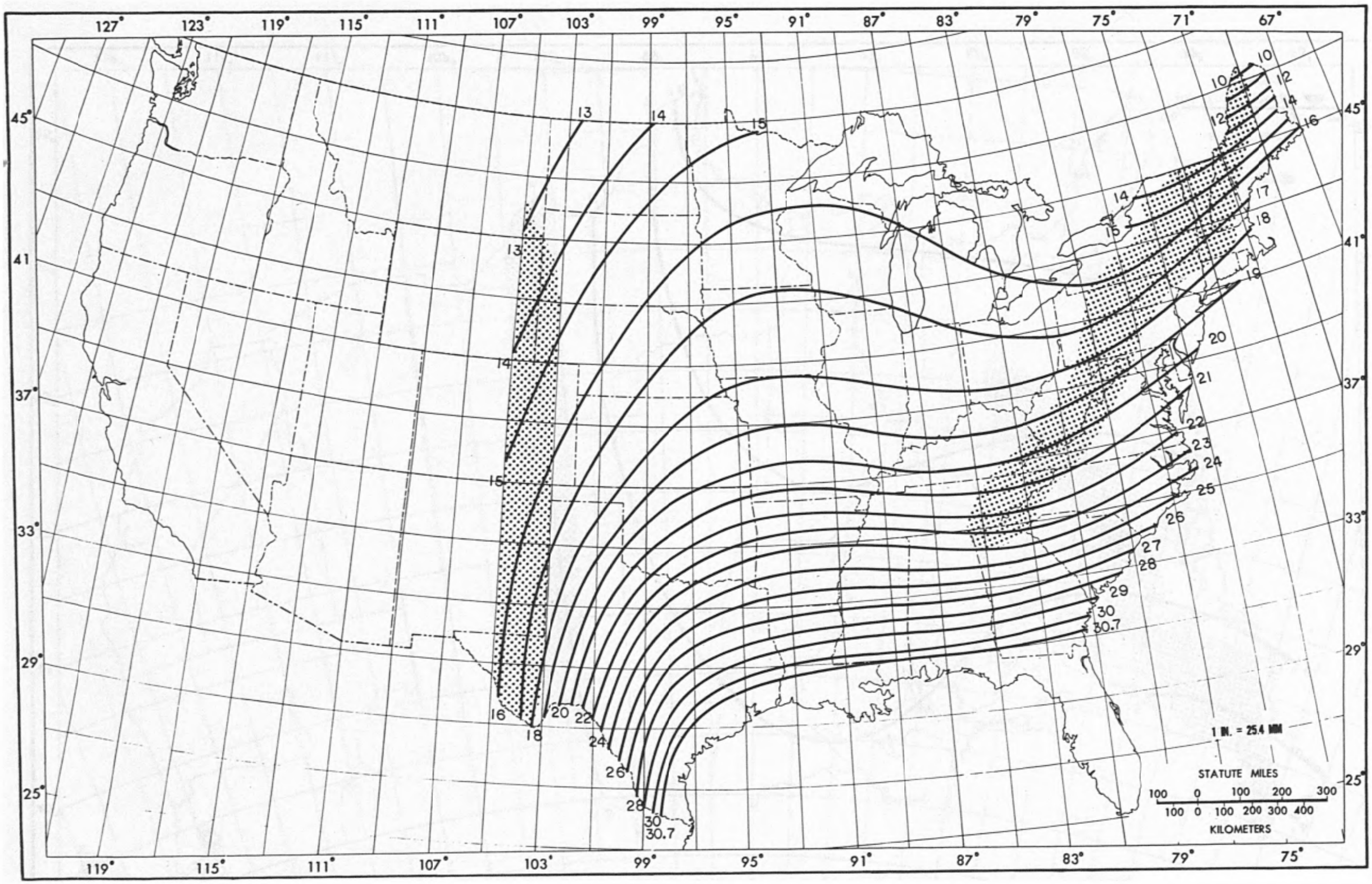


Figure 37.--All-season PMP (in.) for 72 hr 5,000 mi^2 (12,950 km^2).

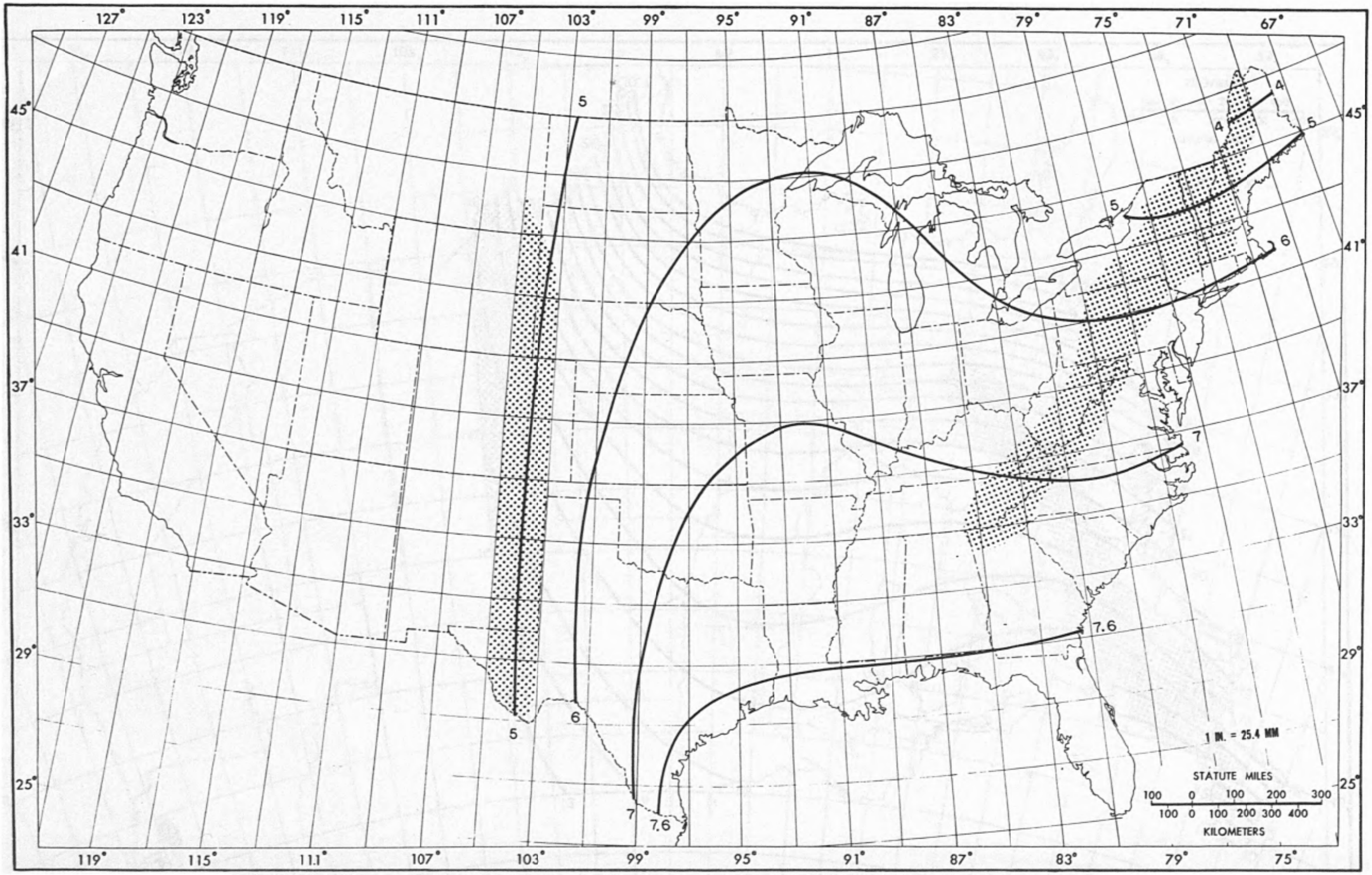


Figure 38.--All-season PMP (in.) for 6 hr 10,000 mi^2 (25,900 km^2).

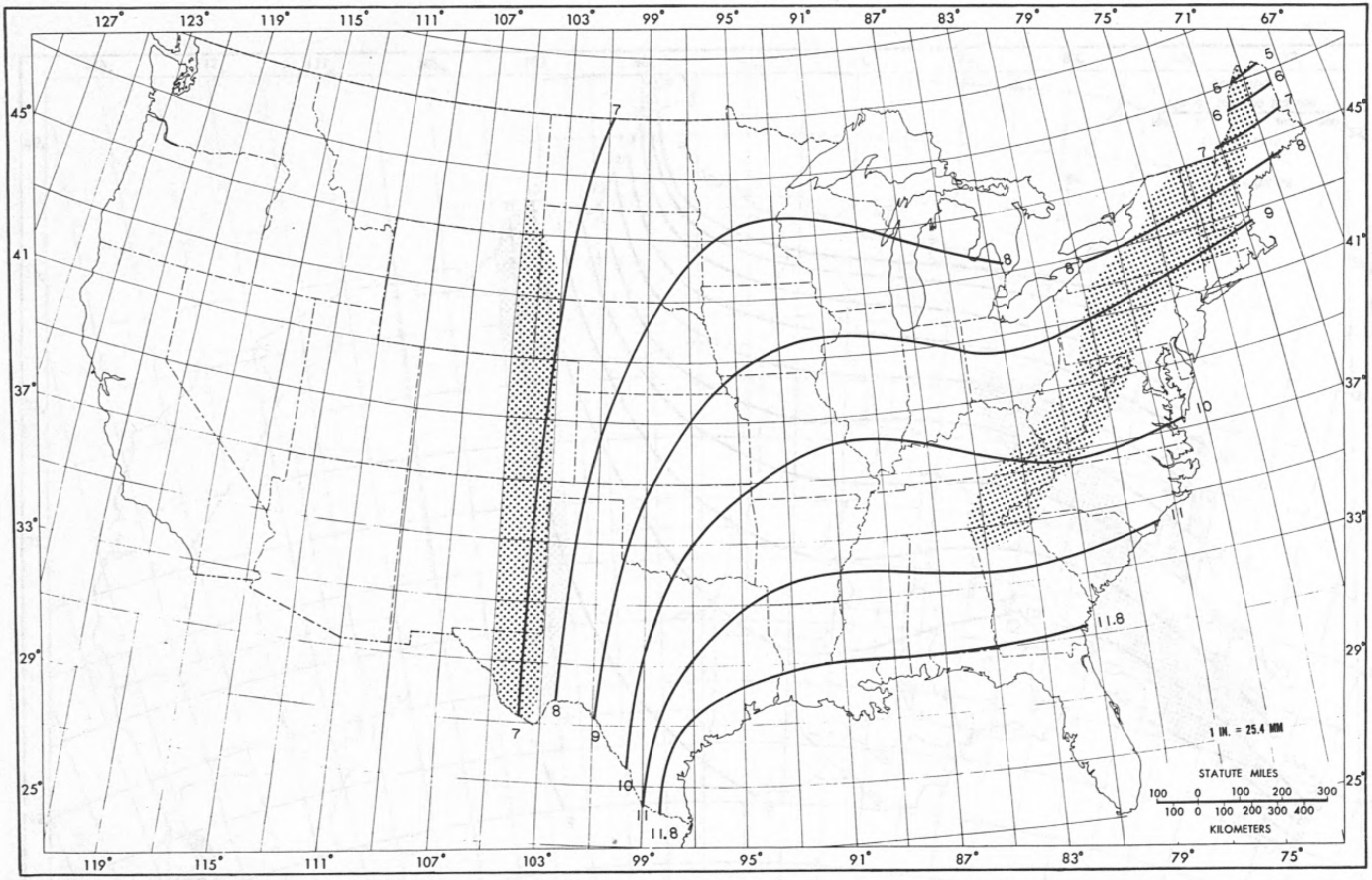


Figure 39.--All-season PMP (in.) for 12 hr 10,000 mi^2 (25,900 km^2).

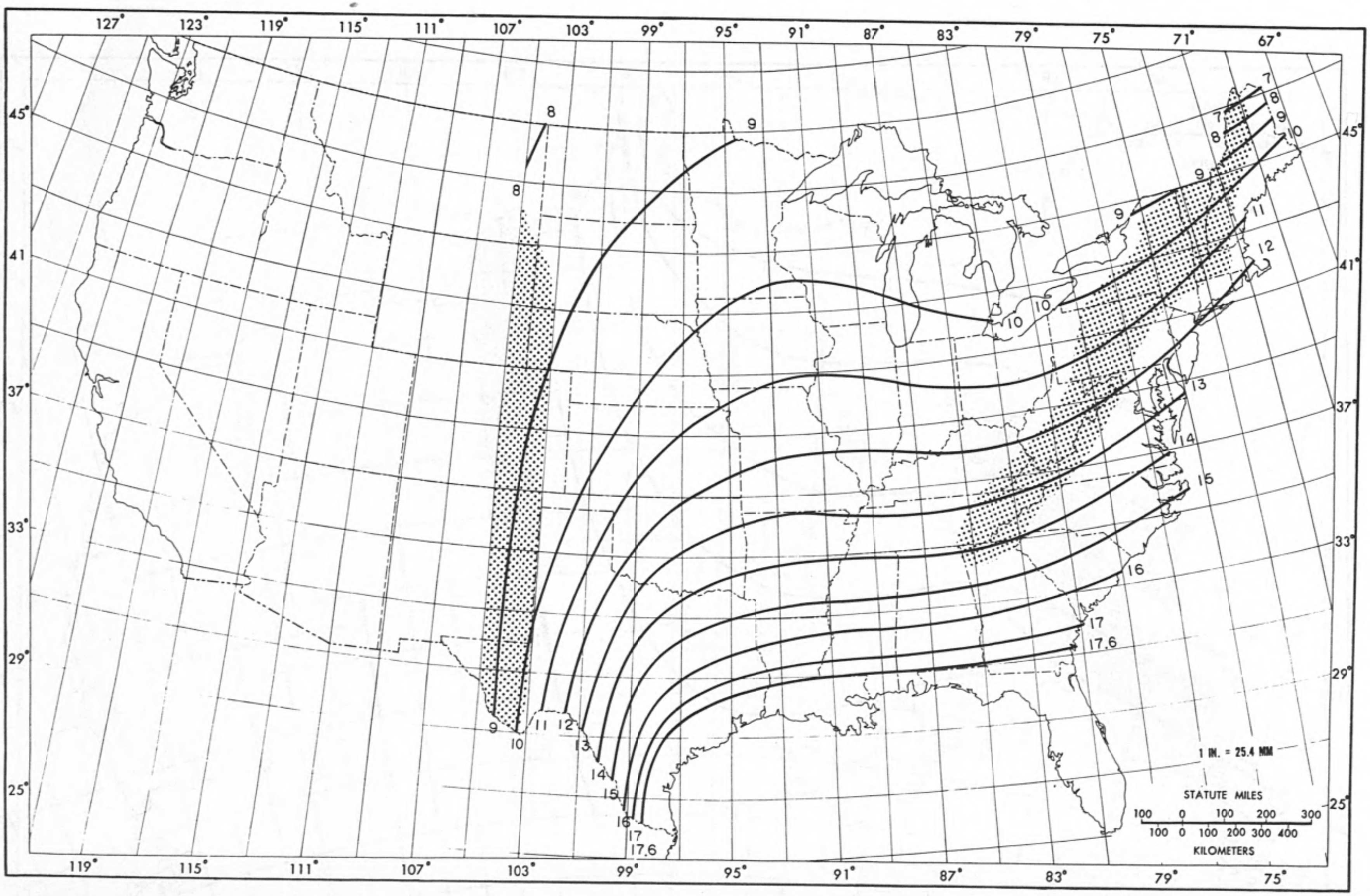


Figure 40.--All-season PMP (in.) for 24 hr 10,000 mi^2 (25,900 km^2).

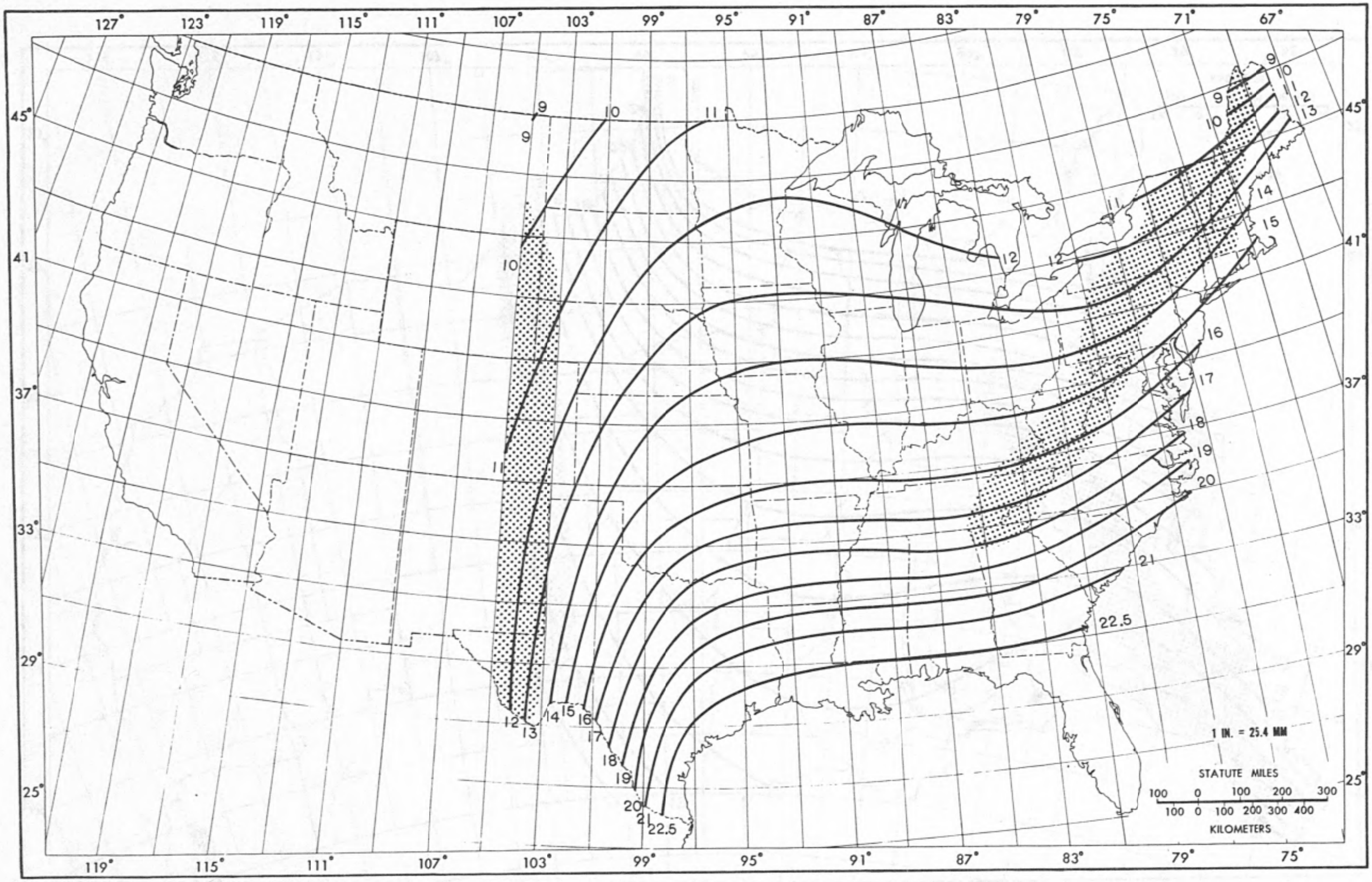


Figure 41.--All-season PMP (in.) for 48 hr 10,000 mi^2 (25,900 km^2).

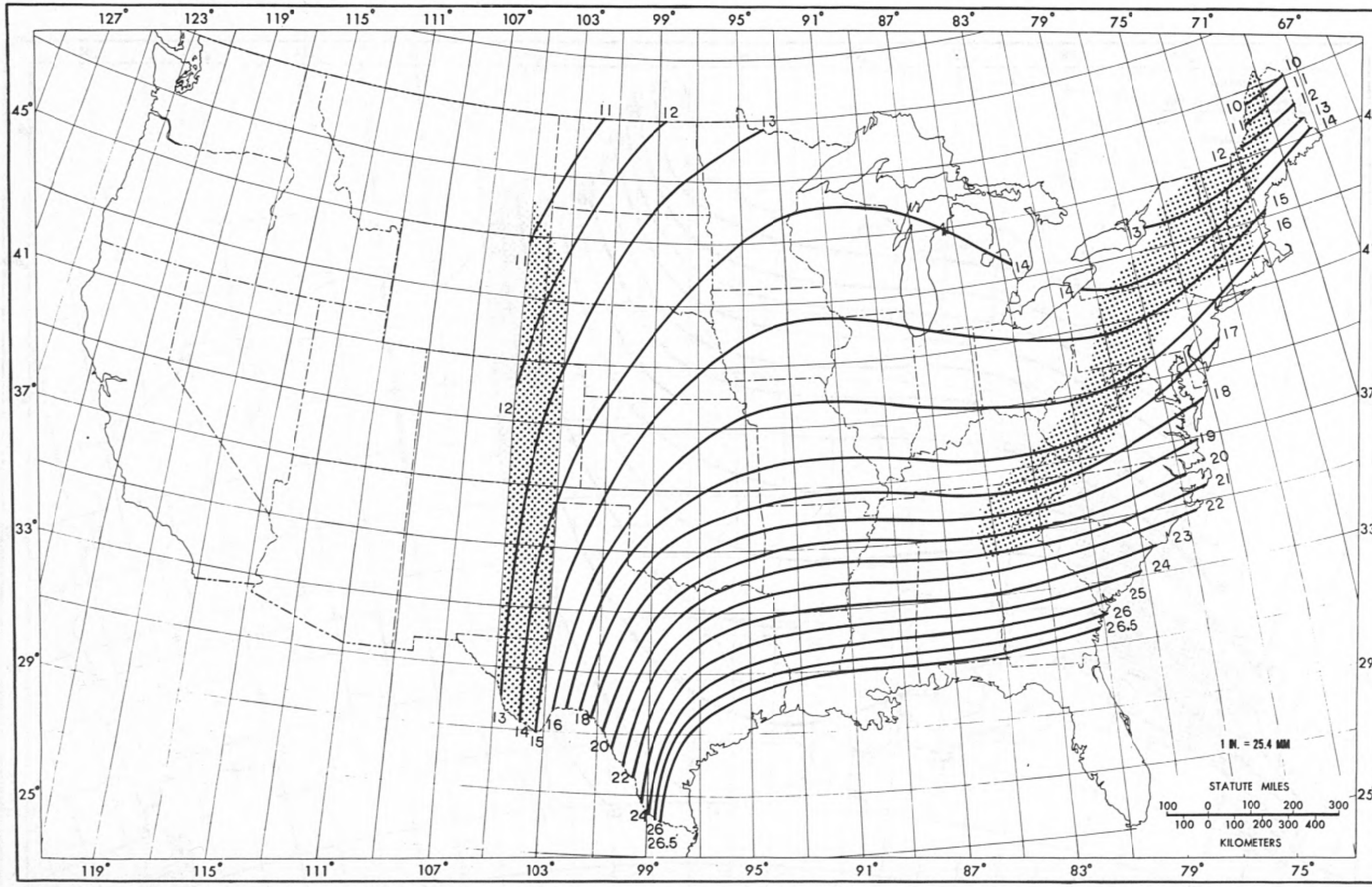


Figure 42.--All-season PMP (in.) for 72 hr 10,000 mi^2 (25,900 km^2).

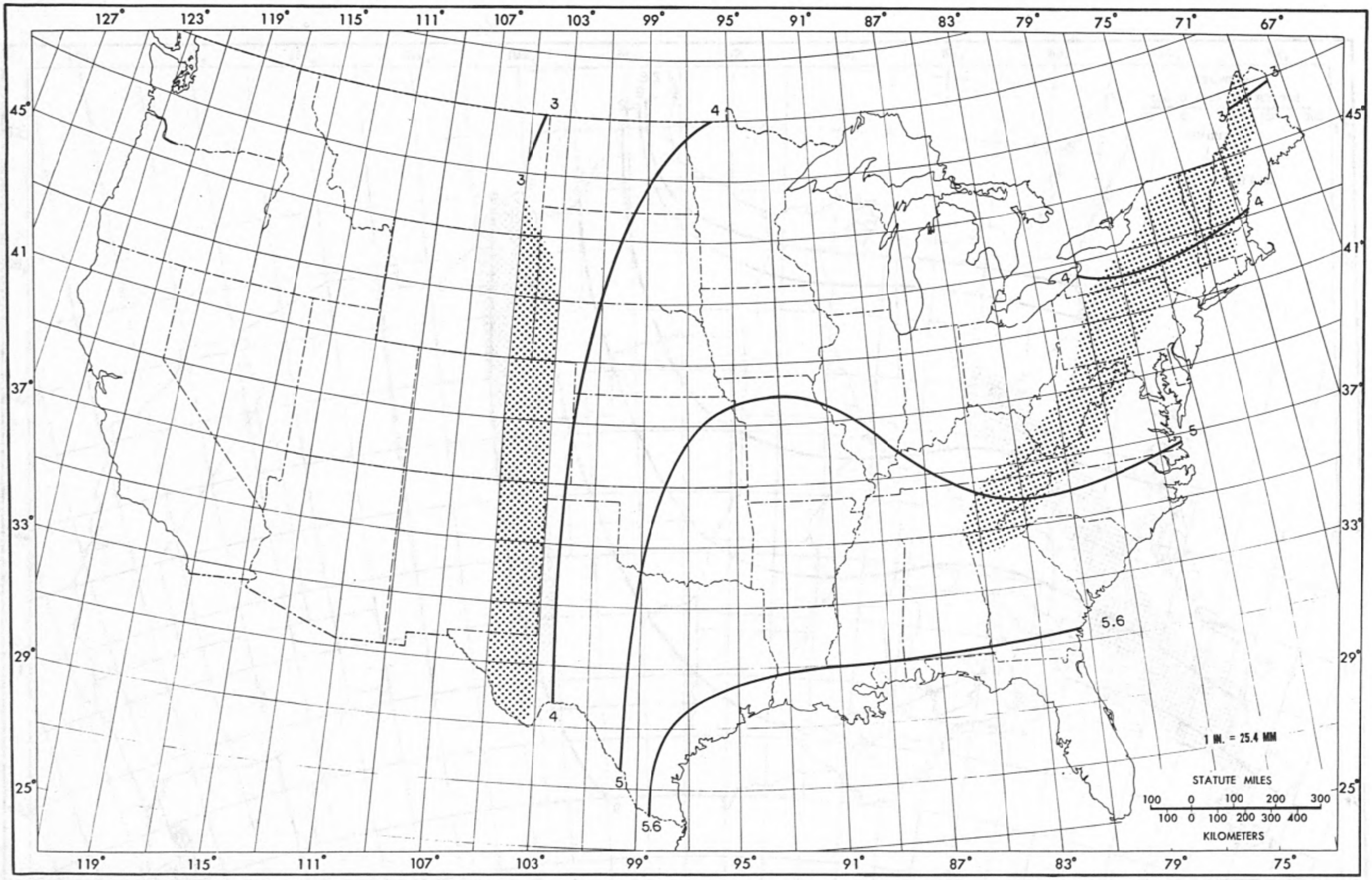


Figure 43.--All-season PMP (in.) for 6 hr 20,000 mi^2 (51,800 km^2).

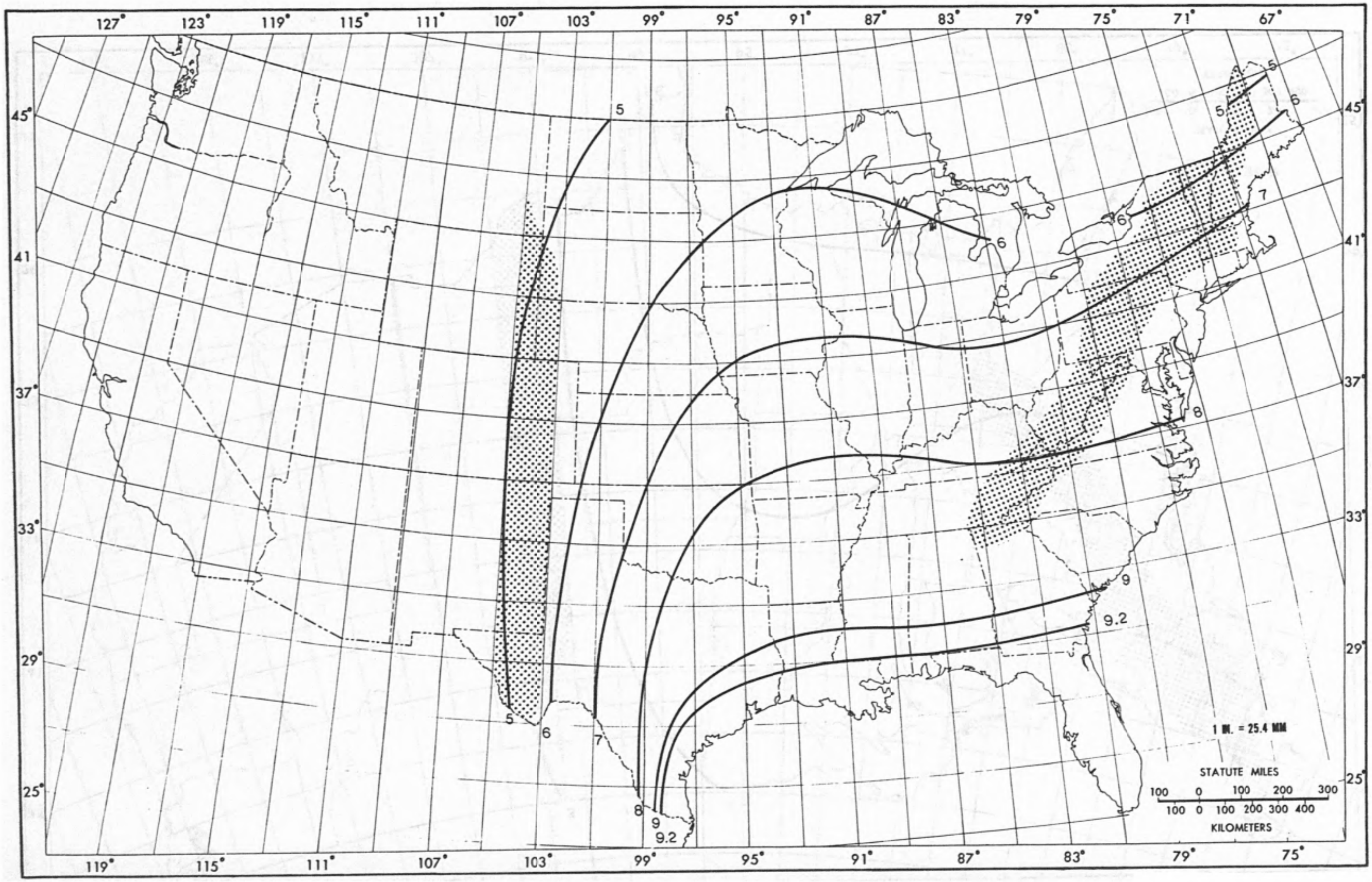


Figure 44.--All-season PMP (in.) for 12 hr 20,000 mi^2 (51,800 km^2).

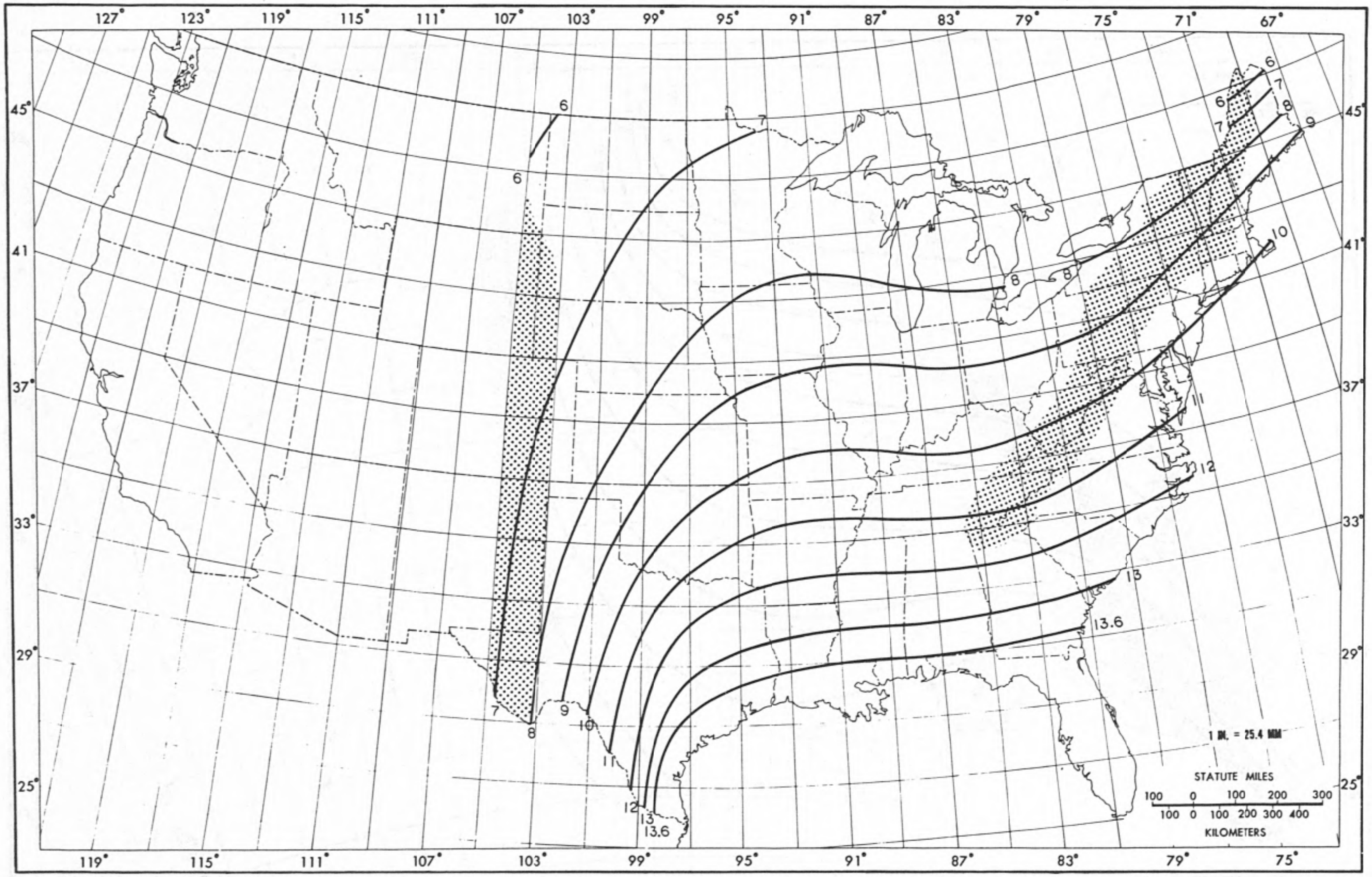


Figure 45.--All-season PMP (in.) for 24 hr 20,000 mi^2 (51,800 km^2).

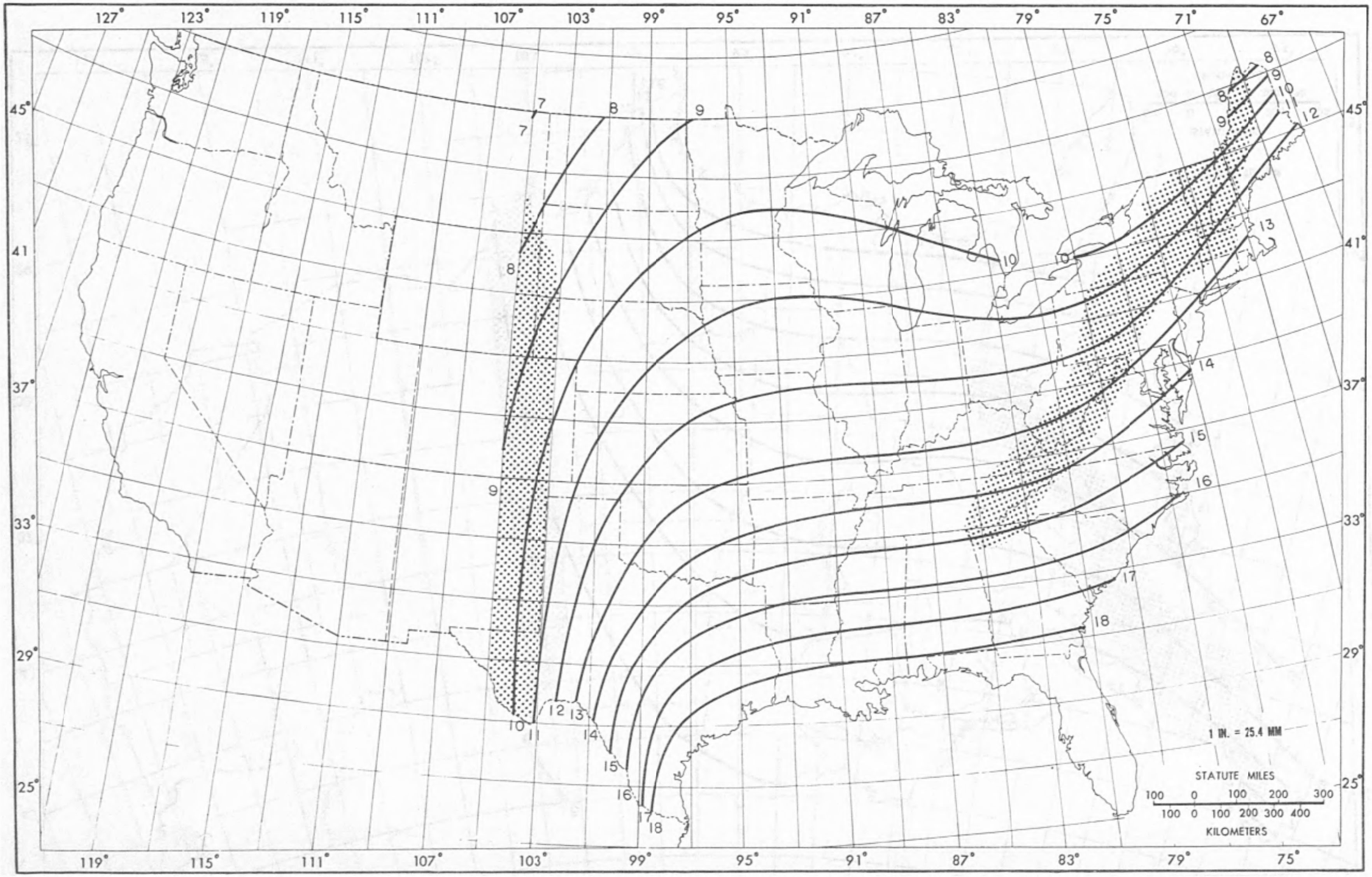


Figure 46.--All-season PMP (in.) for 48 hr 20,000 mi^2 (51,800 km^2).

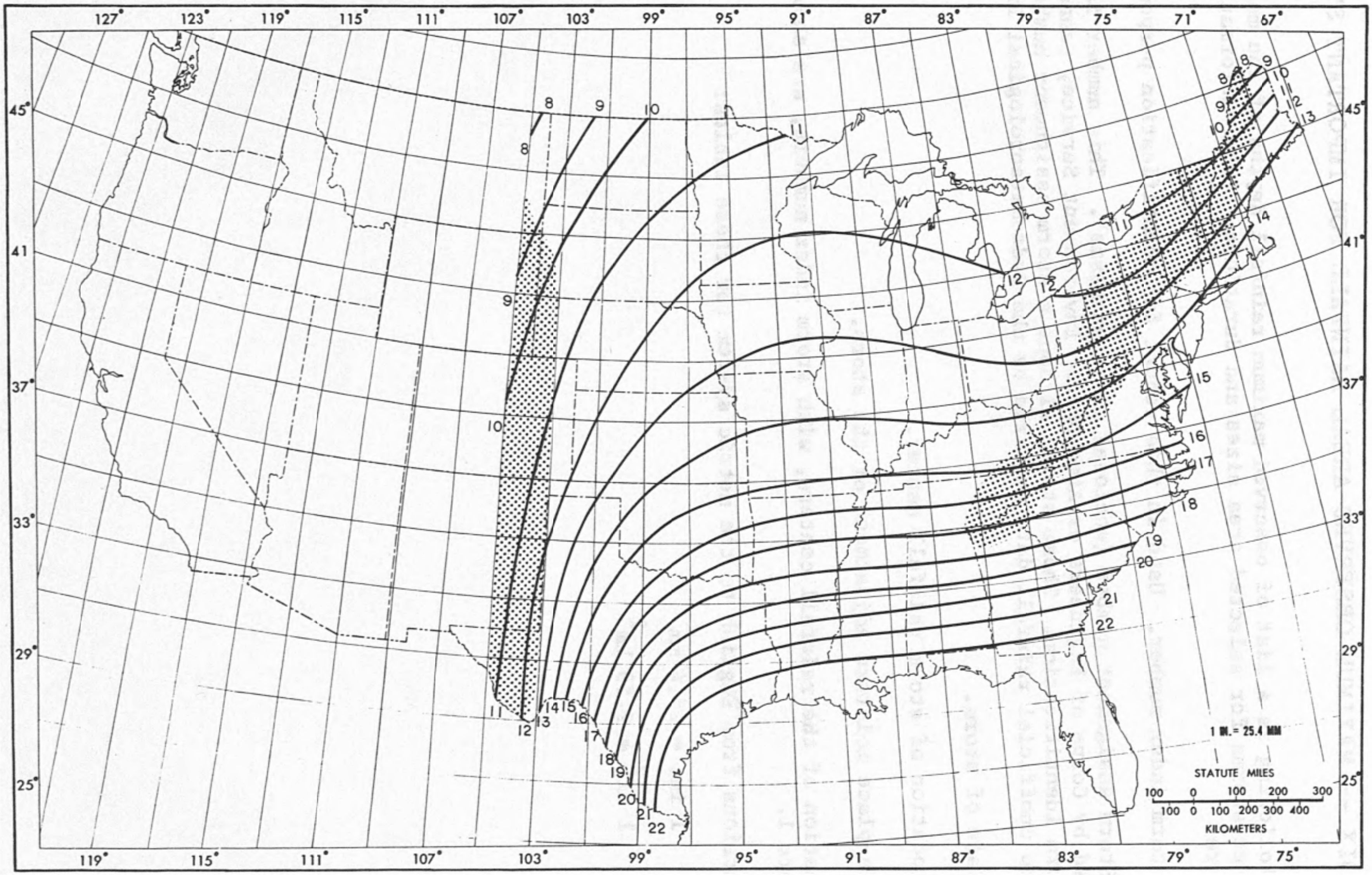


Figure 47.--All-season PMP (in.) for 72 hr 20,000 mi^2 (51,800 km^2).

APPENDIX -- MAXIMUM OBSERVED AREAL RAINFALL FOR IMPORTANT STORMS

The following is a list of observed maximum rainfall depths of the most important storms for selected area sizes and durations. Other information shown are:

a. Storm index number. Used in this report for identification purposes.

b. Storm assignment number (enclosed in parenthesis). This number is assigned by Corps of Engineers or Atmospheric Environment Service, Canada, for storm identification. Those storms without a storm assignment number refer to unofficial rainfall data acquired by the Hydrometeorological Branch.

c. Date of storm.

d. Location of storm rainfall center.

e. In-place moisture adjustment of the storm.

The location of the rainfall centers, with storm index numbers, are shown in figure 1.

Conversions from English to the metric system for these tables:

1 in. = 25.4 mm

1 mi^2 = 2.59 km^2

APPENDIX - - IMPORTANT STORMS

STORM INDEX NO. 1 (OR 9-19) DATE 9/10-13/1878
RAINFALL CENTER JEFFERSON,OH MOIST.ADJ.=122

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

AREA SQ.MI.	6	12	18	24	30	36	48	60	66
	DURATION OF RAINFALL IN HOURS								
10	5.9	11.2	11.7	12.2	13.0	13.4	14.3	14.9	15.0
100	5.8	10.9	11.6	12.1	12.7	13.2	14.1	14.6	14.7
200	5.8	10.8	11.4	11.9	12.5	12.9	13.9	14.4	14.5
1000	5.3	10.1	10.6	11.0	11.7	12.1	12.9	13.4	13.5
5000	4.1	8.0	8.8	9.2	9.9	10.3	10.9	11.3	11.3
10000	3.5	6.8	7.5	8.1	8.8	9.0	9.7	9.9	10.0
20000	2.8	5.4	6.1	6.7	7.2	7.5	8.1	8.4	8.4
50000	1.9	3.5	4.1	4.6	4.9	5.2	5.8	6.1	6.1

STORM INDEX NO. 2 (SA 1-1) DATE 5/30-6/1/1889
RAINFALL CENTER WELLSBORO,PA MOIST.ADJ.=163

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

AREA SQ.MI.	6	12	18	24	30	36	48
	DURATION OF RAINFALL IN HOURS						
10	7.4	8.6	9.1	9.2	9.2	9.7	9.8
100	7.2	8.3	8.9	9.0	9.0	9.5	9.6
200	7.1	8.2	8.7	8.8	8.8	9.3	9.4
1000	6.7	7.7	8.2	8.3	8.3	8.7	8.8
5000	3.9	4.9	6.4	6.8	7.5	8.0	8.1
10000	2.8	4.0	5.0	5.7	7.0	7.6	7.7
20000	2.1	3.2	4.0	4.7	6.3	6.8	7.0
50000	1.4	2.4	3.1	3.6	4.8	5.4	5.6

STORM INDEX NO. 3 (MR 4-3) DATE 6/4-7/1896
RAINFALL CENTER GREELEY,NB MOIST.ADJ.=155

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

AREA SQ.MI.	6	12	18	24	30	36	48	60	72
	DURATION OF RAINFALL IN HOURS								
10	12.0	12.0	12.2	12.3	12.3	12.3	12.3	12.3	12.3
100	11.6	11.6	11.6	11.8	11.8	11.8	11.8	11.8	11.8
200	11.2	11.2	11.2	11.5	11.5	11.5	11.5	11.5	11.5
1000	8.7	8.9	9.0	9.2	9.4	9.4	9.4	9.4	9.4
5000	4.0	4.3	4.9	5.1	5.2	5.3	5.3	5.3	5.3
10000	2.4	2.8	3.7	4.0	4.1	4.2	4.2	4.4	4.5
20000	1.3	1.8	2.6	3.0	3.1	3.2	3.2	3.7	3.8
50000	.6	1.1	1.7	2.1	2.3	2.4	2.5	3.1	3.3

STORM INDEX NO. 4 (UMV 1-2) DATE 7/18-22/1897
RAINFALL CENTER LAMBERT,MN MOIST.ADJ.=148

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

AREA SQ.MI.	6	12	18	24	30	36	48	60	72	96
	DURATION OF RAINFALL IN HOURS									
10	3.2	5.2	6.2	6.5	6.5	6.5	6.9	8.0	8.0	8.2
100	3.1	4.8	6.0	6.3	6.3	6.3	6.8	7.9	7.9	8.2
200	3.0	4.6	5.9	6.2	6.2	6.2	6.7	7.8	7.8	8.1
1000	2.7	4.2	5.5	5.8	5.8	5.8	6.3	7.3	7.3	7.3
5000	2.3	3.4	4.3	4.5	4.7	4.7	5.2	6.1	6.2	6.4
10000	1.9	3.0	3.8	4.0	4.2	4.2	4.5	5.4	5.5	5.7
20000	1.7	2.8	3.5	3.7	3.8	3.8	4.2	4.8	5.0	5.3
50000	1.3	2.3	2.9	3.1	3.3	3.4	3.7	3.9	4.1	4.6

STORM INDEX NO. 6 (NA 1-7B) DATE 7/26-29/1897
RAINFALL CENTER JEWELL,MD MOIST.ADJ.=141

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

AREA SQ.MI.	6	12	18	24	30	36	48	60
	DURATION OF RAINFALL IN HOURS							
10	13.0	14.5	14.7	14.7	14.7	14.7	15.8	15.8
100	10.5	11.7	11.9	11.9	11.9	11.9	12.8	12.8
200	9.4	10.5	10.6	10.6	10.6	10.6	11.5	11.5
1000	5.5	6.0	6.2	6.2	6.2	6.2	7.0	7.0
5000	2.3	2.7	3.0	3.1	3.2	3.2	3.6	3.7

STORM INDEX NO. 7 (GM 3-4) DATE 6/27-7/1/1899
RAINFALL CENTER HEARNE,TX MOIST.ADJ.=116

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

AREA SQ.MI.	6	12	18	24	30	36	48	60	72	96
	DURATION OF RAINFALL IN HOURS									
10	6.9	12.6	18.6	24.1	26.4	29.0	30.8	34.0	34.5	34.5
100	6.3	12.1	18.1	23.3	25.7	28.2	30.0	32.8	33.6	33.6
200	6.2	11.8	17.8	23.0	25.3	27.8	29.5	32.2	33.1	33.1
1000	5.5	10.8	16.3	21.1	23.1	25.6	27.1	29.7	30.4	30.5
5000	4.2	7.8	11.4	14.7	16.4	18.7	20.7	23.6	24.4	25.1
10000	3.5	6.0	8.7	11.2	13.1	15.1	17.4	20.5	21.3	22.1
20000	2.8	4.5	6.3	8.2	9.7	11.6	13.8	16.5	17.6	18.6
50000	1.9	2.7	3.7	4.8	5.6	6.9	8.5	9.9	11.0	12.0

APPENDIX - - IMPORTANT STORMS

STORM INDEX NO. 8 (LMV 2-5) DATE 4/15-18/1900
RAINFALL CENTER EUTAW,AL MOIST.ADJ.=163*

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

AREA	DURATION OF RAINFALL IN HOURS							
SQ.MI.	6	12	18	24	30	36	48	60
10	7.6	9.9	12.2	12.6	13.7	13.9	13.9	13.9
100	6.7	9.8	11.9	12.4	13.4	13.6	13.6	13.7
200	6.4	9.7	11.7	12.2	13.2	13.4	13.4	13.5
1000	5.5	9.1	10.8	11.3	12.3	12.6	12.7	12.8
5000	4.3	7.5	9.0	9.9	10.7	11.7	11.7	11.8
10000	3.7	6.6	8.0	8.9	9.8	10.3	11.0	11.1
20000	3.1	5.7	6.9	7.8	8.5	9.1	9.9	10.2
50000	2.2	4.2	5.1	5.9	6.6	7.1	7.8	8.3

*Moisture adj. limited to 150 percent for this study (see section 3.2.2).

STORM INDEX NO. 14 (UMV 2-5) DATE 6/9-10/1905
RAINFALL CENTER BONAPART,IA MOIST.ADJ.=148

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

AREA	DURATION OF RAINFALL IN HOURS	
SQ.MI.	6	12
10	10.0	12.0
100	9.2	11.5
200	8.9	11.3
1000	8.0	10.0
5000	5.8	7.3
10000	4.4	5.6
20000	3.0	3.9

STORM INDEX NO. 11 (GL 4-9) DATE 10/7-11/1903
RAINFALL CENTER PATTERSON,NJ MOIST.ADJ.=144

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

AREA	DURATION OF RAINFALL IN HOURS									
SQ.MI.	6	12	18	24	30	36	48	60	72	96
10	5.4	8.0	11.7	13.7	14.5	14.9	15.0	15.0	15.0	15.5
100	5.0	7.3	10.9	12.8	13.5	13.8	14.0	14.0	14.4	14.5
200	4.7	7.1	10.4	12.4	13.1	13.4	13.5	13.5	13.9	14.0
1000	3.7	6.4	8.9	10.9	11.7	12.0	12.1	12.1	12.4	12.5
5000	2.6	4.9	6.9	9.0	9.6	9.7	9.9	9.9	10.2	10.2
10000	2.1	4.1	5.8	7.7	8.3	8.5	8.7	8.7	8.9	9.0
20000	1.7	3.2	4.5	6.1	6.7	7.1	7.4	7.4	7.6	7.7

STORM INDEX NO. 16 (MR 5-13) DATE 6/6-8/1906
RAINFALL CENTER WARRICK,MT MOIST.ADJ.=156

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

AREA	DURATION OF RAINFALL IN HOURS							
SQ.MI.	6	12	18	24	30	36	48	54
10	6.0	7.8	8.4	10.2	10.9	11.6	13.1	13.3
100	5.0	7.1	7.6	9.2	9.7	10.5	11.8	12.2
200	4.6	6.6	7.1	8.7	9.2	9.9	11.2	11.5
1000	3.5	5.0	5.4	6.7	7.1	7.6	8.7	8.9
5000	2.1	3.0	3.2	4.2	4.4	4.9	5.7	5.9
10000	1.7	2.5	2.7	3.4	3.8	4.2	5.0	5.2
20000	1.5	2.2	2.5	2.9	3.5	3.7	4.2	4.3

STORM INDEX NO. 13 (GL 2-12) DATE 6/3-8/1905
RAINFALL CENTER MEDFORD,WI MOIST.ADJ.=141

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

AREA	DURATION OF RAINFALL IN HOURS									
SQ.MI.	6	12	18	24	30	36	48	60	72	96
10	7.2	8.4	8.5	8.9	9.1	9.9	10.5	11.2	11.2	11.2
100	6.8	8.1	8.3	8.5	8.7	9.6	10.1	10.7	10.7	10.7
200	6.6	7.8	8.0	8.2	8.5	9.2	9.9	10.5	10.5	10.5
1000	5.4	6.2	6.4	7.0	7.6	8.0	8.7	9.3	9.3	9.3
5000	3.8	4.5	4.8	5.5	6.1	6.5	7.0	7.6	7.7	7.8
10000	3.1	3.8	4.0	4.8	5.4	5.8	6.2	6.9	7.0	7.1
20000	2.4	3.0	3.3	4.1	4.8	5.1	5.3	6.1	6.2	6.3
50000	1.5	2.1	2.4	2.9	3.5	3.6	4.0	4.5	4.7	4.8

STORM INDEX NO. 17 (GM 3-14) DATE 8/4-6/1906
RAINFALL CENTER KNICKERBOCKER,TX MOIST.ADJ.=121

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

AREA	DURATION OF RAINFALL IN HOURS						
SQ.MI.	6	12	18	24	30	36	48
10	7.8	7.9	7.9	8.6	9.0	9.0	9.0
100	7.6	7.9	7.9	8.6	9.0	9.0	9.0
200	7.5	7.9	7.9	8.6	9.0	9.0	9.0
1000	7.0	7.8	7.8	8.3	9.0	9.0	9.0
5000	5.8	6.6	7.1	8.2	8.2	8.2	8.2
10000	4.8	5.5	5.5	6.1	7.0	7.0	7.1
20000	3.3	3.9	4.0	4.3	5.3	5.3	5.5

APPENDIX - - IMPORTANT STORMS

STORM INDEX NO. 20 (SW 1-11) DATE 10/19-24/1908
RAINFALL CENTER MEEKER,OK MOIST.ADJ.=163

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

AREA SQ.MI.	DURATION OF RAINFALL IN HOURS 6	12	18	24	30	36	48	60	72	90
10	9.4	10.0	10.0	11.4	11.8	12.0	14.5	14.9	15.2	15.8
100	8.2	9.3	9.4	10.3	11.3	11.5	13.6	14.4	14.9	15.4
1000	6.3	7.5	7.7	8.6	9.9	10.2	12.7	13.3	13.7	14.0
5000	4.4	5.4	5.7	6.6	7.6	8.2	10.5	11.3	11.7	12.1
10000	3.5	4.5	4.8	5.6	6.4	7.1	9.2	10.0	10.6	11.0
20000	2.7	3.6	3.9	4.6	5.3	5.9	7.7	8.6	9.0	9.6
50000	1.6	2.4	2.8	3.4	3.8	4.3	5.6	6.2	6.6	7.2

STORM INDEX NO. 29 (GL 2-16) DATE 8/31-9/1/1914
RAINFALL CENTER COOPER,MI MOIST.ADJ.=155

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

AREA SQ.MI.	DURATION OF RAINFALL IN HOURS 6
10	12.6
100	11.3
200	10.0
1000	5.7

STORM INDEX NO. 22 (UMV 1-11A) DATE 7/18-23/1909
RAINFALL CENTER BEAULIEU,MN MOIST.ADJ.=134

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

AREA SQ.MI.	DURATION OF RAINFALL IN HOURS 6	12	18	24	30	36	48	60	72	96
10	10.5	10.7	10.8	11.5	11.7	11.8	11.8	12.0	12.1	12.1
100	10.3	10.5	10.7	11.3	11.5	11.7	11.7	12.0	12.0	12.0
200	10.1	10.4	10.5	11.1	11.3	11.5	11.5	11.8	11.8	11.8
1000	9.2	9.6	9.7	10.0	10.4	10.6	10.6	10.8	10.9	10.9
5000	4.8	5.9	6.0	6.1	6.7	7.0	7.2	7.9	8.0	8.1

STORM INDEX NO. 31 (SA 2-9) DATE 7/13-17/1916
RAINFALL CENTER ALTAPASS,NC MOIST. ADJ.=121

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

AREA SQ.MI.	DURATION OF RAINFALL IN HOURS 6	12	18	24	30	36	48	60	72	96
10	8.0	12.6	17.0	22.2	22.9	23.0	23.2	23.7	23.7	23.8
100	7.2	12.0	15.6	19.3	20.8	21.1	21.7	22.1	22.1	22.2
200	6.9	11.7	15.0	18.3	19.9	20.3	20.9	21.3	21.4	21.4
1000	5.9	10.4	12.9	15.0	16.7	17.3	18.1	18.4	18.6	18.7
5000	3.9	7.4	9.3	10.9	12.0	12.6	13.4	13.6	13.8	14.0
10000	3.0	5.5	7.2	8.6	9.4	9.9	10.6	10.8	11.0	11.2
20000	2.1	3.8	5.0	5.9	6.6	7.3	8.0	8.2	8.4	8.6

STORM INDEX NO. 26 (LMV 3-19) DATE 3/24-28/1914
RAINFALL CENTER MERRYVILLE,LA MOIST.ADJ.=189*

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

AREA SQ.MI.	DURATION OF RAINFALL IN HOURS 6	12	18	24	30	36	48	60	72	96
10	8.3	12.0	12.4	12.6	12.6	12.6	12.9	12.9	12.9	12.9
100	8.0	11.0	11.7	11.9	12.0	12.0	12.2	12.3	12.3	12.3
200	7.8	10.6	11.4	11.6	11.7	11.7	11.9	12.0	12.0	12.0
1000	7.2	9.7	10.5	10.7	10.8	10.8	11.0	11.2	11.2	11.2
5000	6.1	7.9	8.7	9.0	9.1	9.1	9.3	9.5	9.6	9.6
10000	4.7	6.1	7.1	7.6	7.8	7.8	8.1	8.4	8.6	8.7
20000	2.9	3.7	4.5	4.9	5.1	5.3	6.4	7.2	7.5	7.6
50000	2.0	2.6	3.2	3.8	4.1	4.2	4.9	5.6	5.8	6.0

*Moisture adj. limited to 160 percent for this study (see section 3.2.2).

STORM INDEX NO. 33 (GM 5-15B) DATE 9/15-17/1919
RAINFALL CENTER MEEK,NM MOIST.ADJ.=134

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

AREA SQ.MI.	DURATION OF RAINFALL IN HOURS 6	12	18	24	30	36	48	54
10	3.8	4.5	6.2	7.4	8.5	9.1	9.5	9.5
100	3.2	4.2	5.1	6.4	7.3	7.9	8.3	8.3
200	3.0	4.1	4.7	6.0	6.9	7.5	7.9	7.9
1000	2.5	3.4	4.0	5.0	5.8	6.5	6.9	9.6
5000	1.9	2.7	3.2	4.0	4.8	5.3	5.9	6.0
10000	1.6	2.4	2.9	3.6	4.3	4.8	5.5	5.6
20000	1.3	2.0	2.5	3.1	3.8	4.3	5.1	5.2
50000	.9	1.6	2.1	2.6	3.2	3.7	4.6	4.7

APPENDIX - - IMPORTANT STORMS

STORM INDEX NO. 36 (MR 4-21) DATE 6/17-21/1921
RAINFALL CENTER SPRINGBROOK,MT MOIST.ADJ.=128

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

AREA	DURATION OF RAINFALL IN HOURS									
SQ.MI.	6	12	18	24	30	36	48	60	72	96
10	10.5	11.7	12.9	13.3	13.4	13.4	14.2	14.5	14.6	14.9
100	8.5	11.1	12.6	13.0	13.3	13.3	14.1	14.2	14.4	14.9
200	8.3	10.8	12.3	12.7	13.0	13.0	13.8	13.9	14.2	14.6
1000	7.4	9.6	10.8	11.3	11.5	11.5	12.1	12.3	12.5	12.8
5000	4.9	6.2	7.3	7.7	8.0	8.0	9.0	9.3	9.5	9.8
10000	3.0	4.3	5.1	5.6	5.8	5.8	7.3	7.6	7.7	7.9
20000	1.6	2.7	3.4	3.9	4.1	4.2	5.2	5.5	5.8	6.0

STORM INDEX NO. 37 (GM 4-12) DATE 9/8-10/1921
RAINFALL CENTER THRALL,TX MOIST.ADJ.=105

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

AREA	DURATION OF RAINFALL IN HOURS						
SQ.MI.	6	12	18	24	30	36	48
10	22.4	29.8	35.0	36.5	37.2	37.6	37.6
100	19.6	26.2	30.7	31.9	32.6	32.9	32.9
200	17.9	24.3	28.7	29.7	30.4	30.7	30.8
1000	13.4	18.8	22.9	24.0	24.6	24.9	25.1
5000	8.1	11.1	14.1	15.0	15.9	16.2	16.3
10000	5.6	7.7	9.7	10.7	11.8	12.1	12.2

STORM INDEX NO. 38 (MR 4-23) DATE 9/27-10/1/1923
RAINFALL CENTER SAVAGETON,WY MOIST.ADJ.=141

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

AREA	DURATION OF RAINFALL IN HOURS									
SQ.MI.	6	12	18	24	30	36	48	60	72	96
10	6.0	9.1	9.3	9.5	13.0	16.5	16.9	16.9	16.9	16.9
100	5.1	8.4	8.7	9.0	12.2	15.5	15.9	15.9	15.9	15.9
200	4.9	8.0	8.4	8.6	11.7	14.8	15.2	15.2	15.2	15.2
1000	3.7	6.2	6.4	6.6	9.0	11.4	11.6	11.7	11.8	12.0
5000	2.2	3.6	3.8	4.0	5.6	7.0	7.2	7.4	7.6	8.1
10000	1.6	2.5	2.7	3.0	4.2	5.3	5.7	6.1	6.3	6.9
20000	1.2	1.8	2.1	2.5	3.2	3.9	4.7	5.1	5.5	6.0
50000	.8	1.5	1.8	2.1	2.7	3.1	3.7	4.0	4.3	4.7

STORM INDEX NO. 42 (MR 4-24) DATE 9/17-19/1926
RAINFALL CENTER BOYDEN,IA MOIST.ADJ.=134

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

AREA	DURATION OF RAINFALL IN HOURS						
SQ.MI.	6	12	18	24	30	36	48
10	15.1	20.7	21.7	21.7	21.7	21.7	21.7
100	12.8	17.1	17.8	17.8	17.8	17.8	17.8
200	11.7	15.8	16.6	16.6	16.6	16.6	16.6
1000	7.5	10.1	10.4	10.6	10.6	10.6	10.6
5000	4.1	6.3	6.4	6.6	6.6	6.6	6.6
10000	3.0	5.2	5.4	5.5	5.6	5.6	5.6
20000	2.1	4.1	4.3	4.4	4.6	4.8	4.9
50000	1.4	2.7	2.9	3.0	3.2	3.6	3.8

STORM INDEX NO. 44 (NA 1-17) DATE 11/2-4/1927
RAINFALL CENTER KINSMAN NOTCH,NH MOIST.ADJ.=148

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

AREA	DURATION OF RAINFALL IN HOURS						
SQ.MI.	6	12	18	24	30	36	48
10	7.8	10.8	11.7	12.0	12.8	13.7	14.0
100	5.8	8.3	8.8	9.2	9.5	10.1	10.3
200	5.7	8.2	8.6	8.8	9.0	10.0	10.2
1000	4.8	7.3	7.7	7.8	8.2	8.8	8.9
5000	2.7	4.8	6.1	6.7	7.2	7.7	7.9
10000	2.3	4.0	5.5	6.3	6.7	7.0	7.3
20000	2.0	3.5	4.7	5.3	5.8	6.2	6.4
50000	1.6	2.8	3.6	4.1	4.5	4.9	5.1

STORM INDEX NO. 47 (LMV 2-20) DATE 3/ 11-16/1929
RAINFALL CENTER ELBA,AL MOIST.ADJ.=134

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

AREA	DURATION OF RAINFALL IN HOURS									
SQ.MI.	6	12	18	24	30	36	48	60	72	96
10	14.0	15.4	19.5	20.0	21.4	23.8	27.4	28.0	29.6	29.6
100	13.6	14.9	18.9	19.3	20.7	22.9	26.1	26.6	28.4	28.4
200	13.1	14.4	18.3	18.6	20.0	22.2	25.5	26.0	27.6	27.6
1000	10.2	11.8	15.4	16.1	17.0	18.6	22.1	22.9	24.4	24.6
5000	7.1	8.6	12.2	13.5	13.9	14.8	17.3	18.1	19.4	19.7
10000	5.6	7.2	10.1	12.1	12.5	13.1	15.2	15.9	17.1	17.5
20000	3.8	5.4	7.9	9.6	10.1	11.0	12.5	13.3	14.3	14.7
50000	2.5	3.6	5.3	6.3	7.1	7.9	8.9	9.7	10.5	10.8

APPENDIX - - IMPORTANT STORMS

STORM INDEX NO. 49 (GM 5-1) DATE 6/30-7/2/1932
RAINFALL CENTER STATE FISH HATCHERY,TX MOIST.ADJ.=116

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

AREA SQ.MI.	DURATION OF RAINFALL IN HOURS 6	12	18	24	30	36	42
10	13.3	19.5	30.0	31.7	32.9	33.6	33.7
100	11.2	15.8	23.7	25.8	26.8	27.5	27.7
200	10.3	14.3	21.2	23.8	24.9	25.5	25.7
1000	7.7	10.5	15.5	19.0	20.2	20.7	20.9
5000	4.8	6.8	9.8	13.5	14.9	15.3	15.6
10000	3.6	5.2	7.4	10.3	11.3	11.6	11.8
20000	2.4	3.6	4.9	7.0	7.7	7.9	8.1

STORM INDEX NO. 50 (NA 1-20A) DATE 9/16-17/1932
RAINFALL CENTER SCITUATE,RI MOIST.ADJ.=148

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

AREA SQ.MI.	DURATION OF RAINFALL IN HOURS 6	12	18	24	30	36	48
10	7.0	10.2	11.9	12.2	12.2	12.2	12.2
200	6.8	10.2	11.1	11.6	11.6	11.6	11.6
1000	5.8	8.6	9.5	10.2	10.2	10.2	10.2
5000	4.0	6.5	7.3	7.9	8.1	8.2	8.2
10000	3.2	5.5	6.5	6.9	7.2	7.4	7.5

STORM INDEX NO. 51 (NA 1-20B) DATE 9/16-17/1932
RAINFALL CENTER RIPOGENUS DAM,ME MOIST.ADJ.=127

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

AREA SQ.MI.	DURATION OF RAINFALL IN HOURS 6	12	18	24	30
10	7.7	8.1	8.4	8.6	8.7
100	6.9	8.0	8.3	8.5	8.6
200	6.5	7.8	8.1	8.3	8.5
1000	5.2	7.2	7.5	7.7	7.9
5000	3.6	6.1	6.4	6.7	6.9
10000	3.0	5.5	5.9	6.3	6.5

STORM INDEX NO. 53 (SW 2-11) DATE 4/3-4/1934
RAINFALL CENTER CHEYENNE,OK MOIST.ADJ.=149

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

AREA SQ.MI.	DURATION OF RAINFALL IN HOURS 6	12	18
10	17.3	20.8	21.3
100	14.4	17.1	17.7
200	13.3	15.7	16.4
1000	9.1	10.7	11.1

STORM INDEX NO. 54 (LMV 4-21) DATE 5/16-20/1935
RAINFALL CENTER SIMMESPORT,LA MOIST.ADJ.=128

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

AREA SQ.MI.	DURATION OF RAINFALL IN HOURS 6	12	18	24	30	36	48	60	72	96
10	13.8	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1
100	13.1	13.2	13.3	13.3	13.3	13.3	13.3	13.3	13.4	13.4
200	12.5	12.6	12.7	12.7	12.7	12.7	12.7	12.7	12.8	12.8
1000	10.2	10.3	10.4	10.4	10.5	10.7	10.8	10.8	10.9	11.0
5000	7.1	7.6	7.7	7.7	8.1	8.3	8.7	8.8	8.8	8.8
10000	5.7	6.2	6.3	6.4	6.9	7.2	7.7	7.8	7.8	7.8
20000	4.1	4.7	4.9	5.0	5.5	5.7	6.5	6.6	6.7	6.8
50000	2.0	2.6	2.9	3.2	3.4	3.7	4.6	4.9	5.0	5.3

STORM INDEX NO. 56 (- -) DATE 5/30-31/1935
RAINFALL CENTER HALE,CO MOIST.ADJ.=122

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

AREA SQ.MI.	DURATION OF RAINFALL IN HOURS 6	12	18	24
10	16.5	22.2	22.2	22.2
100	11.0	15.4	15.4	15.4
200	9.9	12.6	12.6	12.6
1000	4.6	7.2	7.2	7.2
5000	1.9	3.5	3.8	4.0

APPENDIX - - IMPORTANT STORMS

STORM INDEX NO. 57 (GM 5-20) DATE 5/31/1935
RAINFALL CENTER WOODWARD RANCH,TX MOIST.ADJ.=121

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

AREA SQ.MI.	DURATION OF RAINFALL IN HOURS 6	10
10	20.4	20.4
100	16.3	16.5
200	14.1	14.6
1000	8.6	8.8
5000	3.9	4.2

STORM INDEX NO. 59 (NA 1-27) DATE 7/ 6-10/1935
RAINFALL CENTER HECTOR,NY MOIST.ADJ.=122

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

AREA	DURATION OF RAINFALL IN HOURS									
SQ.MI.	6	12	18	24	30	36	48	60	72	90
10	5.2	10.2	11.4	11.8	12.0	13.4	14.2	14.2	14.2	14.2
100	4.9	8.6	10.1	10.5	10.7	11.5	13.0	13.1	13.4	13.6
200	4.7	8.0	9.6	10.0	10.3	10.9	12.5	12.6	12.9	13.2
1000	4.0	6.7	8.2	8.6	8.8	9.0	10.6	10.8	11.1	11.5
5000	2.7	4.8	5.9	6.4	6.6	6.8	7.7	8.2	8.5	8.7
10000	2.1	3.7	4.6	5.1	5.4	5.7	6.4	7.0	7.2	7.5
20000	1.3	2.6	3.2	3.7	4.1	4.5	5.1	5.6	5.9	6.2

STORM INDEX NO. 65 (- -) DATE 6/19-20/1939
RAINFALL CENTER SNYDER,TX MOIST.ADJ.=128

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

AREA	DURATION OF RAINFALL IN HOURS
SQ.MI.	6
10	18.8
100	14.2
200	11.9
1000	6.5

STORM INDEX NO. 67 (MR 4-5) DATE 6/3-4/1940
RAINFALL CENTER GRANT TOWNSHIP,NB MOIST.ADJ.=163

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

AREA	DURATION OF RAINFALL IN HOURS		
SQ.MI.	6	12	18
10	13.0	13.0	13.0
100	10.6	11.7	11.7
200	9.6	11.2	11.2
1000	7.2	8.9	9.0
5000	4.2	5.5	5.7
10000	3.1	4.4	4.6
20000	2.1	3.3	3.5

STORM INDEX NO. 68 (NA 2-4) DATE 9/1/1940
RAINFALL CENTER EWAN,NJ MOIST.ADJ.=122

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

AREA	DURATION OF RAINFALL IN HOURS	
SQ.MI.	6	12
10	20.1	22.7
100	17.1	18.8
200	15.0	16.5
1000	8.8	10.5

STORM INDEX NO. 69 (SW 2-18) DATE 9/2-6/1940
RAINFALL CENTER HALLETT,OK MOIST.ADJ.=141

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

AREA	DURATION OF RAINFALL IN HOURS							
SQ.MI.	6	12	18	24	30	36	48	54
10	18.4	23.4	23.6	23.6	23.6	23.6	23.6	23.6
100	14.7	19.2	19.4	19.6	19.7	19.8	19.8	19.8
200	12.5	17.6	17.8	18.0	18.1	18.2	18.3	18.3
1000	7.9	13.3	13.4	13.6	13.7	14.0	14.1	14.1
5000	4.3	7.3	7.4	7.5	7.7	7.8	7.9	8.0
10000	3.0	5.3	5.4	5.5	5.6	5.7	5.8	5.9
20000	2.0	3.9	4.1	4.2	4.3	4.4	4.5	4.6

APPENDIX - - IMPORTANT STORMS

STORM INDEX NO. 71 (UMV 1-22) DATE 8/28-31/1941
RAINFALL CENTER HAYWARD,WI MOIST.ADJ.=134

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

AREA	DURATION OF RAINFALL IN HOURS								
SQ.MI.	6	12	18	24	30	36	48	60	72
10	8.5	11.5	12.4	12.4	13.3	13.8	14.4	15.0	15.0
100	8.1	11.0	11.8	11.8	12.7	13.3	13.8	14.3	14.5
200	7.8	10.6	11.3	11.3	12.3	13.0	13.4	13.9	14.1
1000	5.6	8.2	9.0	9.1	10.0	10.9	11.5	11.9	12.0
5000	3.0	5.2	5.9	6.3	7.2	8.1	8.9	9.3	9.5
10000	2.1	3.8	4.6	5.1	5.9	6.8	7.8	8.2	8.4
20000	1.5	2.7	3.4	3.8	4.7	5.5	6.5	7.1	7.3
50000	.9	1.6	2.1	2.5	3.1	3.6	4.5	5.1	5.2

STORM INDEX NO. 77 (SW 2-20) DATE 5/6-12/1943
RAINFALL CENTER WARNER,OK MOIST.ADJ.=141

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

AREA	DURATION OF RAINFALL IN HOURS									
SQ.MI.	6	12	18	24	30	36	48	60	72	96
10	9.9	12.3	14.6	17.2	19.5	21.5	24.4	24.9	24.9	24.9
100	8.7	10.8	12.4	14.9	17.1	19.3	21.8	22.5	22.5	22.5
200	7.4	9.5	11.4	13.8	16.0	18.3	20.6	21.3	21.3	21.3
1000	4.3	6.3	9.0	11.1	13.3	15.4	17.1	18.0	18.0	18.0
5000	3.0	4.5	6.8	8.3	10.5	12.1	13.4	14.4	14.4	14.4
10000	2.6	3.9	5.8	7.2	9.1	10.4	11.7	12.6	12.6	12.8
20000	2.1	3.3	4.9	6.1	7.6	8.7	10.0	10.7	10.8	11.1
50000	1.6	2.5	3.7	4.6	5.7	6.5	7.7	8.1	8.3	8.8

STORM INDEX NO. 74 (OR 9-23) DATE 7/17-18/1942
RAINFALL CENTER SMETHPORT,PA MOIST.ADJ.=110

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

AREA	DURATION OF RAINFALL IN HOURS			
SQ.MI.	6	12	18	24
10	24.7	26.7	28.7	29.2
100	16.4	19.4	21.8	22.4
200	13.1	16.8	19.3	19.9
1000	6.4	10.3	12.6	13.3

STORM INDEX NO. 78 (MR 6-15) DATE 6/10-13/1944
RAINFALL CENTER STANTON,NB MOIST.ADJ.=141

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

AREA	DURATION OF RAINFALL IN HOURS									
SQ.MI.	6	12	18	24	30	36	48	60	72	78
10	13.4	15.3	15.3	15.3	15.3	15.3	16.2	16.4	16.7	16.7
100	11.7	13.6	13.6	13.6	13.6	13.7	14.8	14.9	15.1	15.1
200	11.1	12.9	12.9	12.9	12.9	13.1	14.1	14.3	14.4	14.4
1000	7.8	9.0	9.3	9.3	9.3	9.4	10.1	10.4	10.4	10.4
5000	3.4	4.0	4.2	4.6	4.7	4.9	5.3	5.5	5.7	5.8
10000	2.2	2.5	2.7	3.5	3.9	4.1	4.5	4.7	4.9	5.0

STORM INDEX NO. 76 (SA 1-28A) DATE 10/11-17/1942
RAINFALL CENTER BIG MEADOWS,VA MOIST.ADJ.=148

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

AREA	DURATION OF RAINFALL IN HOURS									
SQ.MI.	6	12	18	24	30	36	48	60	72	96
10	6.0	8.4	10.9	13.4	14.2	15.6	17.4	18.4	18.7	18.8
100	4.3	6.0	9.2	11.2	12.5	13.8	16.6	18.0	18.4	18.6
200	3.9	5.6	8.6	10.5	11.8	13.0	16.1	17.5	17.8	18.1
1000	3.1	4.9	7.4	9.1	10.3	11.1	13.8	15.0	15.3	15.5
5000	2.3	3.8	5.9	7.2	8.1	8.9	10.7	11.6	11.8	12.1
10000	1.8	3.2	4.5	5.7	6.5	7.1	8.9	9.6	9.8	10.1
20000	1.1	2.2	3.0	3.9	4.6	5.1	6.8	7.3	7.5	7.9

STORM INDEX NO. 80 (MR 7-2B) DATE 8/12-16/1946
RAINFALL CENTER COLLINSVILLE,IL MOIST.ADJ.=121

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

AREA	DURATION OF RAINFALL IN HOURS									
SQ.MI.	6	12	18	24	30	36	48	60	72	96
10	6.0	9.8	12.1	12.1	13.7	17.5	17.6	18.3	18.3	18.9
100	5.6	8.8	10.9	11.1	13.2	16.6	16.7	17.5	17.6	18.0
200	5.4	8.3	10.5	10.6	13.0	16.2	16.3	17.2	17.3	17.7
1000	4.9	7.0	8.9	9.0	12.6	14.7	14.8	15.9	16.0	16.3
5000	3.3	4.8	5.9	6.0	8.6	10.4	10.6	11.3	11.4	11.6
10000	2.4	3.7	4.5	4.6	6.6	8.0	8.2	8.7	8.8	9.0
20000	1.5	2.5	3.1	3.2	4.6	5.6	5.8	6.0	6.1	6.3

APPENDIX - - IMPORTANT STORMS

STORM INDEX NO. 82 (- -) DATE 6/23-24/1948
RAINFALL CENTER DEL RIO,TX MOIST.ADJ.=121

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

AREA SQ.MI.	6	12	18	24
	DURATION OF RAINFALL IN HOURS			
10	13.2	20.7	25.2	26.2
100	11.3	18.2	22.5	23.8
200	10.3	16.9	21.1	22.5
1000	7.7	13.6	16.8	17.9
5000	4.7	8.0	9.9	10.8
10000	3.2	5.5	6.8	7.2

STORM INDEX NO. 85 (SA 5-8) DATE 9/3-7/1950
RAINFALL CENTER YANKEETOWN,FL MOIST.ADJ.=110

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

AREA SQ.MI.	6	12	18	24	30	36	48	60	72	96
	DURATION OF RAINFALL IN HOURS									
10	16.0	28.6	36.3	38.7	40.6	41.8	43.1	44.7	45.2	45.2
100	14.0	26.3	32.5	35.2	36.5	37.9	38.9	40.2	40.6	40.8
200	13.4	25.6	31.4	34.2	35.3	36.7	37.7	38.8	39.2	39.6
1000	11.4	22.6	27.4	30.2	31.6	32.9	33.7	34.4	34.9	35.4
5000	5.4	9.7	13.3	15.5	17.5	18.4	19.7	20.2	21.0	21.8
10000	3.3	6.6	8.6	10.6	12.1	13.1	14.7	15.6	16.4	17.3
20000	2.3	4.3	5.8	7.5	8.8	9.6	11.2	12.5	13.5	14.2

STORM INDEX NO. 86 (MR 10-2) DATE 7/9-13/1951
RAINFALL CENTER COUNCIL GROVE,KS MOIST.ADJ.=128

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

AREA SQ.MI.	6	12	18	24	30	36	48	60	72	96
	DURATION OF RAINFALL IN HOURS									
10	5.3	7.0	7.9	8.6	11.8	13.1	14.3	17.2	18.2	18.2
100	4.7	6.4	7.4	7.9	10.6	12.4	13.8	16.3	17.5	17.5
200	4.6	6.2	7.2	7.5	10.2	12.0	13.3	15.9	17.0	17.0
1000	4.0	5.5	6.3	6.6	9.0	10.5	11.5	14.2	15.5	15.5
5000	3.4	4.5	5.1	5.4	7.2	8.4	9.3	11.7	13.0	13.1
10000	2.9	3.9	4.4	4.8	6.2	7.3	8.2	10.4	11.4	11.5
20000	2.4	3.2	3.7	4.1	5.1	6.1	6.9	8.6	9.4	9.6
50000	1.3	2.0	2.5	2.8	3.4	4.0	4.7	5.8	6.3	6.5

STORM INDEX NO. 87 (MR 10-8) DATE 6/7/1953
RAINFALL CENTER RITTER,IA MOIST.ADJ.=171

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

AREA SQ.MI.	6	12	20
	DURATION OF RAINFALL IN HOURS		
10	9.1	10.5	10.7
100	7.4	9.4	10.0
1000	6.1	7.9	8.4
5000	4.4	5.9	6.5
10000	3.5	4.8	5.4

STORM INDEX NO. 88 (SW 3-22) DATE 6/23-28/1954
RAINFALL CENTER VIC PIERCE,TX MOIST.ADJ.=116

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

AREA SQ.MI.	6	12	18	24	30	36	48	60	72
	DURATION OF RAINFALL IN HOURS								
10	16.0	20.1	22.5	26.7	30.7	32.0	34.6	34.6	34.6
100	12.6	16.5	19.7	23.6	27.6	29.2	31.5	31.5	31.5
200	10.9	14.9	18.6	22.5	25.9	27.5	29.5	29.5	29.5
1000	6.6	9.7	14.6	18.4	20.1	21.5	23.0	23.0	23.0
5000	2.8	4.9	7.4	8.9	10.4	11.9	13.7	14.3	14.3
10000	1.7	3.2	4.7	5.7	7.1	8.0	9.8	10.4	10.5
20000	1.2	2.0	2.8	3.6	4.5	5.2	6.5	7.0	7.2

STORM INDEX NO. 90 (ONT 10-54) DATE 10/14-15/1954
RAINFALL CENTER NR. BOLTON,CANADA MOIST.ADJ.=122

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

AREA SQ.MI.	6	12	24	30	48	78
	DURATION OF RAINFALL IN HOURS					
10	5.4	7.2	9.0	9.4	10.0	10.4
100	4.6	6.5	8.1	8.5	8.9	9.2
200	4.4	6.2	7.5	8.1	8.5	8.8
1000	3.6	5.2	6.4	6.8	7.3	7.5
5000	2.1	3.4	4.8	5.4	5.8	6.2
10000	1.6	2.7	4.2	4.6	5.3	5.5
20000	1.1	2.1	3.4	3.9	4.6	4.9

APPENDIX - - IMPORTANT STORMS

STORM INDEX NO. 91 (NA 2-22A) DATE 8/17-20/1955
RAINFALL CENTER WESTFIELD,MA MOIST.ADJ.=110

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

AREA SQ.MI.	DURATION OF RAINFALL IN HOURS 6	12	18	24	30	36	48	60
10	7.8	11.1	13.0	16.4	18.5	18.9	19.4	19.4
100	7.6	10.5	11.6	14.6	17.6	18.1	18.8	19.0
200	7.4	10.2	11.4	14.2	17.1	17.6	18.2	18.4
1000	6.2	9.2	10.2	12.4	15.4	15.9	16.2	16.4
5000	4.0	6.3	7.9	9.5	11.7	12.1	12.6	13.0
10000	3.1	5.0	6.5	8.0	9.7	10.0	10.6	10.8
20000	2.1	3.6	4.9	6.3	7.6	7.9	8.3	8.5

STORM INDEX NO. 99 (NA 2-23) DATE 8/19-20/1969
RAINFALL CENTER TYRO,VA MOIST.ADJ.=105

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

AREA SQ.MI.	DURATION OF RAINFALL IN HOURS 6	12	18
10	14.2	25.4	25.4
100	12.9	21.7	21.7
200	11.7	19.6	19.6
1000	8.1	13.5	13.5
5000	4.4	7.5	8.0
10000	3.3	5.8	6.3

STORM INDEX NO. 93 (OUE 8-57) DATE 8/3-4/1957
RAINFALL CENTER ST.PIERRE BAPTISTE,CANADA MOIST.ADJ.=121

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

AREA SQ.MI.	DURATION OF RAINFALL IN HOURS 6	12	18
100	8.4	8.6	8.7
200	7.5	7.6	7.8
1000	4.4	5.2	5.4
5000	2.4	3.1	3.3

STORM INDEX NO.100 (NA 2-24A) DATE 6/19-23/1972
RAINFALL CENTER ZERBE,PA MOIST.ADJ.=121

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

AREA SQ.MI.	DURATION OF RAINFALL IN HOURS 6	12	18	24	30	36	48	60	72	96
10	8.0	11.9	13.3	14.3	15.8	16.9	17.8	18.3	18.5	18.6
100	7.1	10.9	12.5	13.7	15.3	16.0	16.7	17.3	17.4	17.5
200	6.6	10.4	12.0	13.4	15.0	15.6	16.3	16.8	16.9	17.0
1000	5.3	8.9	10.5	12.3	13.8	14.4	14.9	15.2	15.3	15.4
5000	3.8	6.8	8.4	10.0	11.2	12.0	12.6	12.9	13.0	13.2
10000	3.2	5.7	7.3	8.7	9.9	10.5	11.3	11.7	11.8	12.0
20000	2.5	4.4	6.0	7.3	8.3	8.9	9.9	10.4	10.5	10.7
50000	1.6	2.8	4.1	5.1	5.9	6.6	7.7	8.4	8.6	8.8

STORM INDEX NO. 97 (SW 3-24) DATE 9/19-24/1967
RAINFALL CENTER SOMBRERETILLO,MEXICO MOIST.ADJ.=116

MAXIMUM AVERAGE DEPTH OF RAINFALL IN INCHES

AREA SQ.MI.	DURATION OF RAINFALL IN HOURS 6	12	18	24	30	36	48	60	72	96
10	9.2	12.2	15.2	18.7	21.8	24.8	26.2	32.0	32.0	32.5
100	7.3	10.4	13.2	17.6	20.7	21.7	23.9	30.0	30.0	30.9
200	6.7	9.7	12.3	16.4	19.2	20.3	23.0	28.8	28.8	29.9
1000	5.3	7.9	10.0	11.9	14.4	16.8	20.3	23.8	25.1	26.0
5000	3.7	5.8	7.6	8.9	10.8	13.1	17.2	19.2	20.7	21.7
10000	3.1	4.9	6.5	7.8	9.5	11.4	15.2	17.3	18.5	20.0
20000	2.4	4.0	5.4	6.7	8.1	9.8	13.0	15.0	16.3	18.2
50000	1.4	2.7	3.9	5.1	6.3	7.6	9.9	11.9	13.2	15.6

☆ U. S. GOVERNMENT PRINTING OFFICE : 1980 311-046/188

(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. In preparation.

NOAA--S/T 80-275