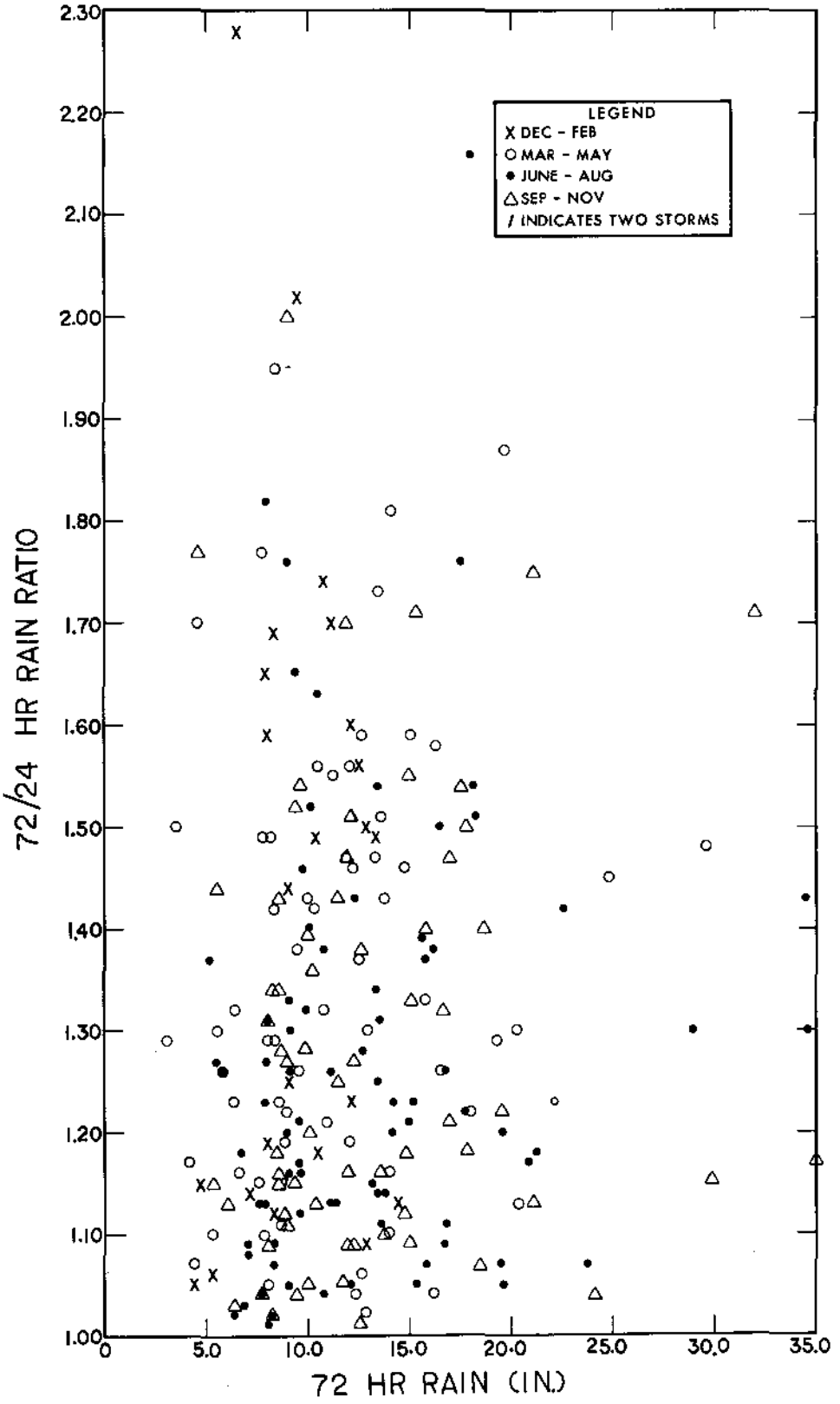

Figure 13.--Within storm 72/24-hr rain ratios vs. magnitude of 72-hr depths.

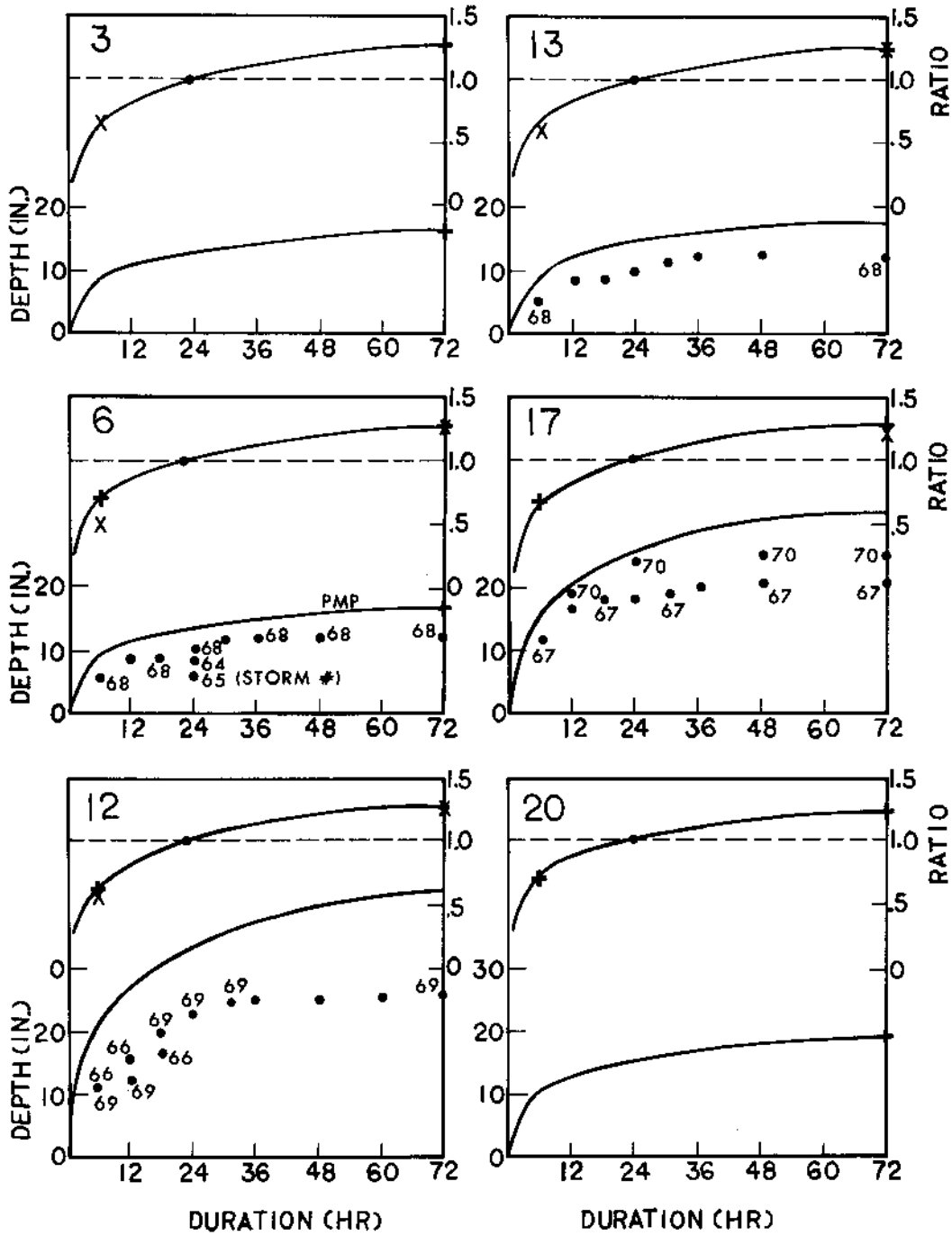

Figure 14.--Depth-duration plots for November (grid points 3, 6, 12, 13, 17, 20). Upper curves are the ratios of rainfall for various durations to the 24-hr values (+ from PMP; X from 4% probability values). Lower curves show PMP values. Maximized rainfall values transposed to the grid point are shown with storm number (table 2).

We found an inverse relation between the 6/24 ratio and that for 72/24. That is, if the 6/24 ratio is high, the 72/24 ratio is low, and visa versa. This appears to be meteorologically reasonable. For example, a high 6/24 ratio, expected in summer with brief thunderstorm type rainfall, is associated with a low 72/24 ratio.

4.8 Regional PMP Gradients

We have insisted PMP should not show sharp demarcations or changes from one point to the next unless explainable by terrain effects. Thus, we have plotted the 6-, 24-, and 72-hr PMP depths against selected latitudes and longitudes, covering the region in order to eliminate sharp changes. Figure 15 is an example of such plots .... showing 6-hr PMP along longitude 91°W for latitudes 30° to 47°N for each month.

4.9 Some Observations on PMP Patterns

The objectives or requirements of a) smooth patterns and gradients of PMP for each month and each duration (6, 24, 72 hours), b) smooth progression of increasing depths with duration, c) a smooth progression of PMP depths from month to month, and d) envelopment of moisture maximized and transposed storm rainfalls required numerous iterations. As one of the four objectives is approached, changes in analysis effect the other three. We should repeat a fifth objective uppermost in our thoughts during the study; this was to avoid undue indirect maximization and envelopment in achieving the objectives.

Some specific indications from the guidance material that were incorporated in the PMP patterns are as follows:

The semimonthly maximum w_p maps (see example in fig. 7a) indicate a gradual progression of moisture from the Gulf Coast northward in early spring. A ridge of high moisture extending from the Gulf coast to the Great Plains can be identified easily in the summer months. The maximum w_p maps indicate that moisture remains high through September.

The maps of 4 percent probability rainfall also show higher values extending inland from the Louisiana and Mississippi coasts during April and May than in adjacent months.

Maps of greatest observed rainfall depths show maximum precipitation in June in the northwestern portion of our study region. This set of maps reveals that maximum rainfall occurs in September along the eastern seaboard and in the gulf states. Scattered high values also appear in early October in some coastal regions, especially in Texas.

Some of the data, particularly the probability level values, show a longer season of maximum rainfall for the states bordering the Gulf and Atlantic coasts than for the interior regions. The plateau extends into September and early October. This can be explained by the greater opportunity for tropical

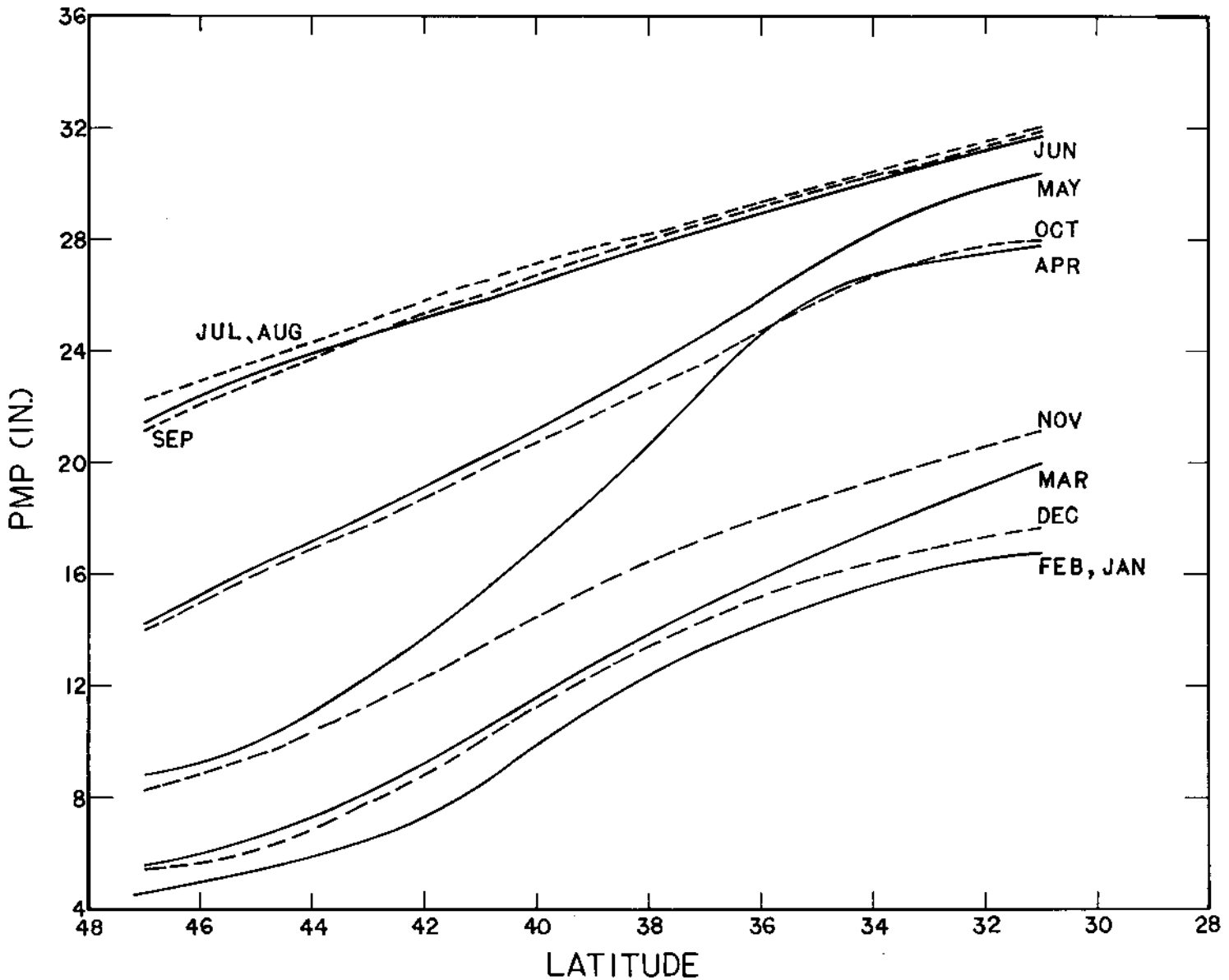

Figure 15.--Latitudinal variation by month of 6-hr PMP along longitudinal 91°W.

storm rainfall there .... and the fact that such storms can occur well into October. This aspect has been preserved in the seasonal variation of PMP. All-season PMP values extend to October for the coastal states and to September for much of the interior.

Comparison of maximum rainfall values in the interior for durations from 6 to 72 hours shows some tendency for peak values to extend over a longer season for 72 hours than for 6 hours. We find however, that the peak season for 24 and 72 hours have about the same length. This last indication has guided us to show the same length for all-season PMP for all durations.

5. RESULTING PMP

Figures 16 to 45 show midmonth maps of PMP for 6, 24, and 72 hours. A plot of depths for 6, 24, and 72 hours on a depth-duration chart joined by a curve through the point of origin (0,0) can be used to interpolate PMP for other durations. If PMP is required for some other data than midmonth, interpolate arithmetically.

6. EXAMPLE OF USE OF PMP MAPS

In this example, assume 10-mi^2 PMP is required for exactly April 8 for 22 hours duration at 40° 30'N latitude and 87°30'W longitude.

		March 15	April 15
a.	6-hr PMP (fig. 17)	= 9.5 in.	(fig. 18) = 13.1 in.
	24-hr PMP (fig. 27)	= 14.9 in.	(fig. 28) = 19.0 in.
	72-hr PMP (fig. 37)	= 18.8 in.	(fig. 38) = 23.5 in.

b. Depth-duration plots (fig. 46) of these depths joined by smooth curves through (0,0) give 14.7 in. for March 15 and 18.9 in. for April 15, for 22 hours.

c. Linear interpolation for April 8 gives 18.0 inches.

7. SPECIAL PROBLEMS

7.1 Stippled Regions on PMP Maps

As for the all-season generalized PMP, our maps are stippled in two regions, (a) the Appalachian Mountains extending from Georgia to Maine and (b) a strip between the 103rd and 105th meridians. 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 or from higher terrain. Determination of storm transposition limits (par. 3.4.2) took into account topographic homogeneity in a general sense, thereby avoiding major topographic considerations. However, regional analysis required definition across mountains such as the Appalachians.

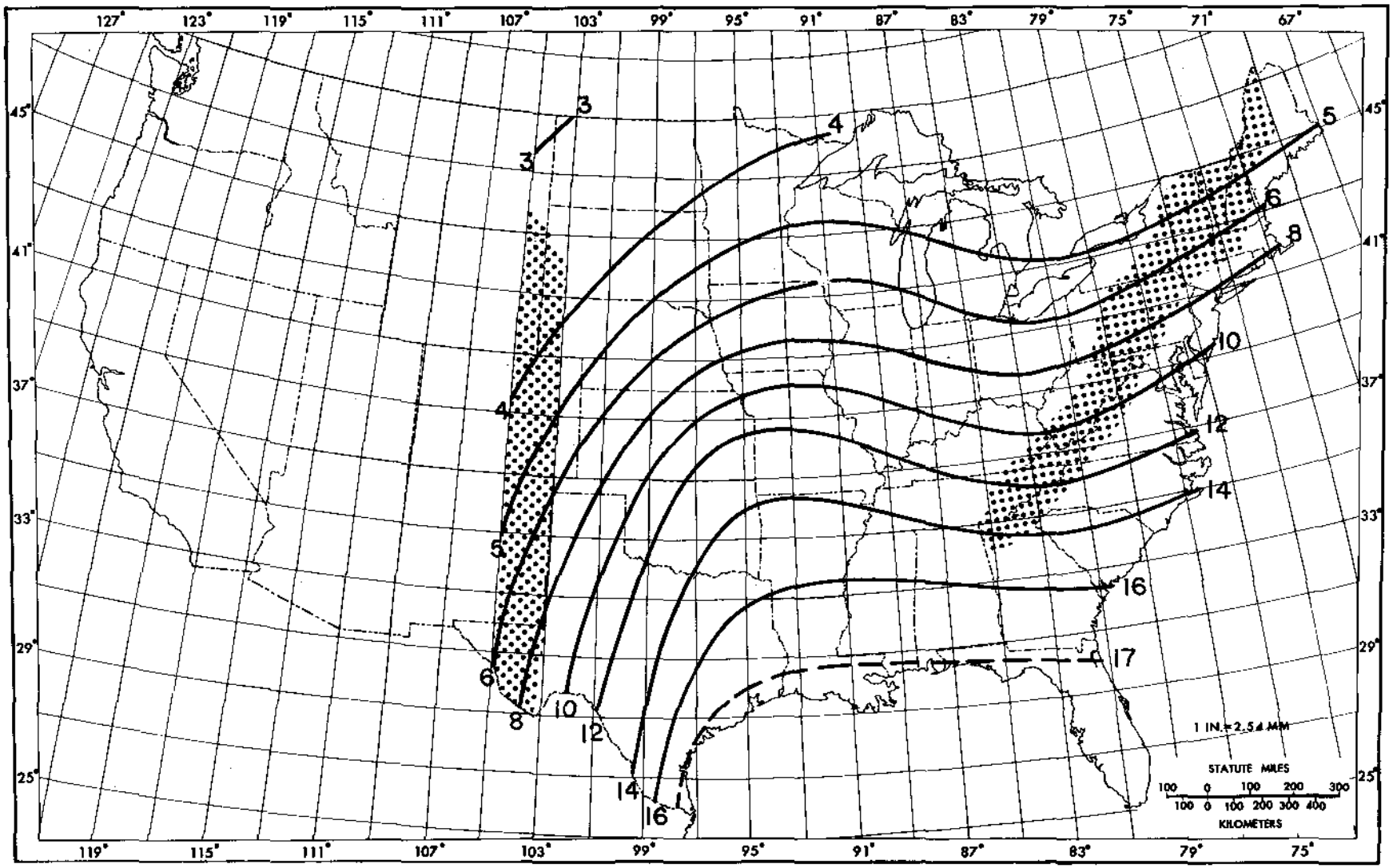

Figure 16.--6-hr 10-mi^2 PMP, January and February , (in.).

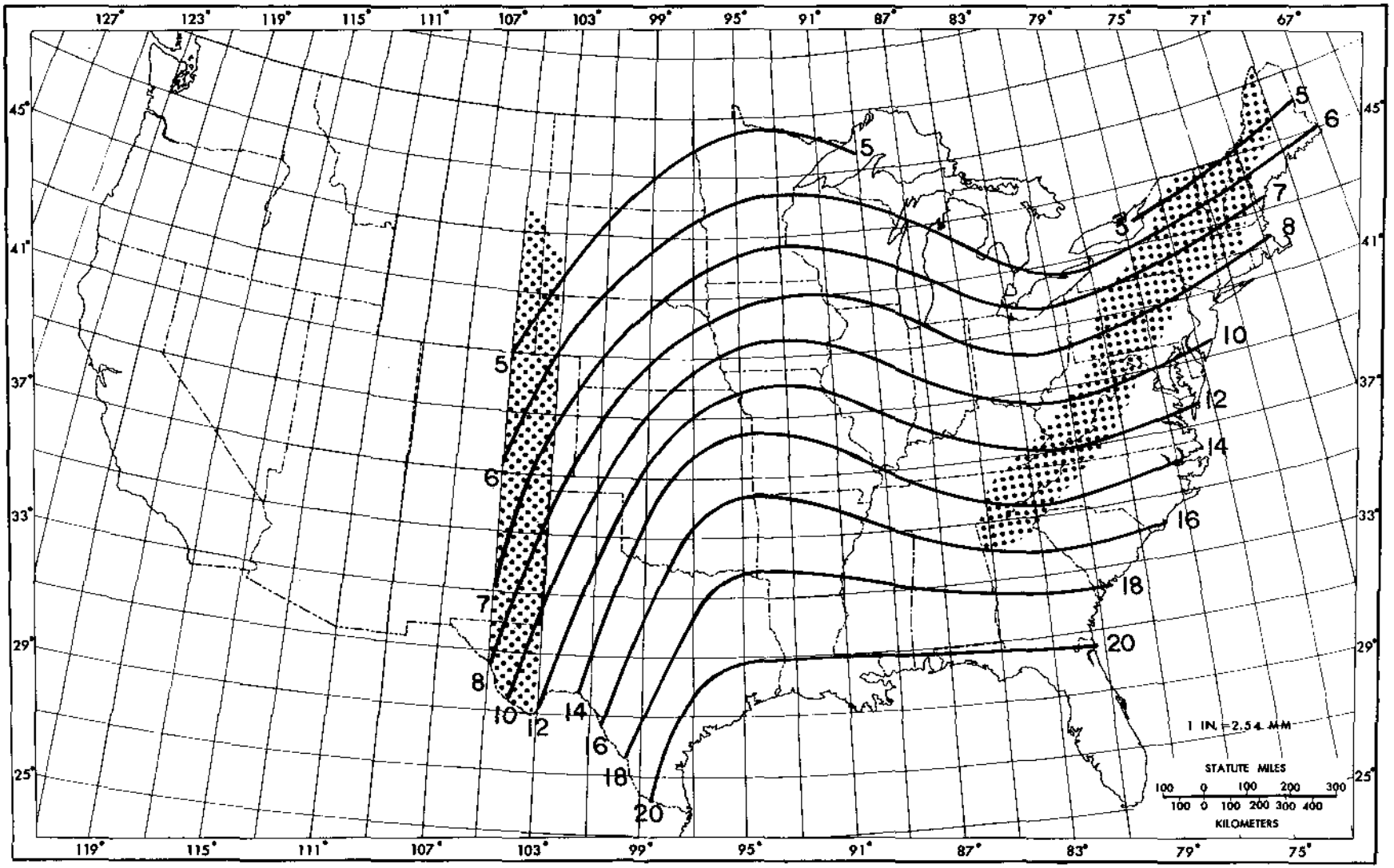

Figure 17.--6-hr 10-mi^2 PMP, March, (in.).

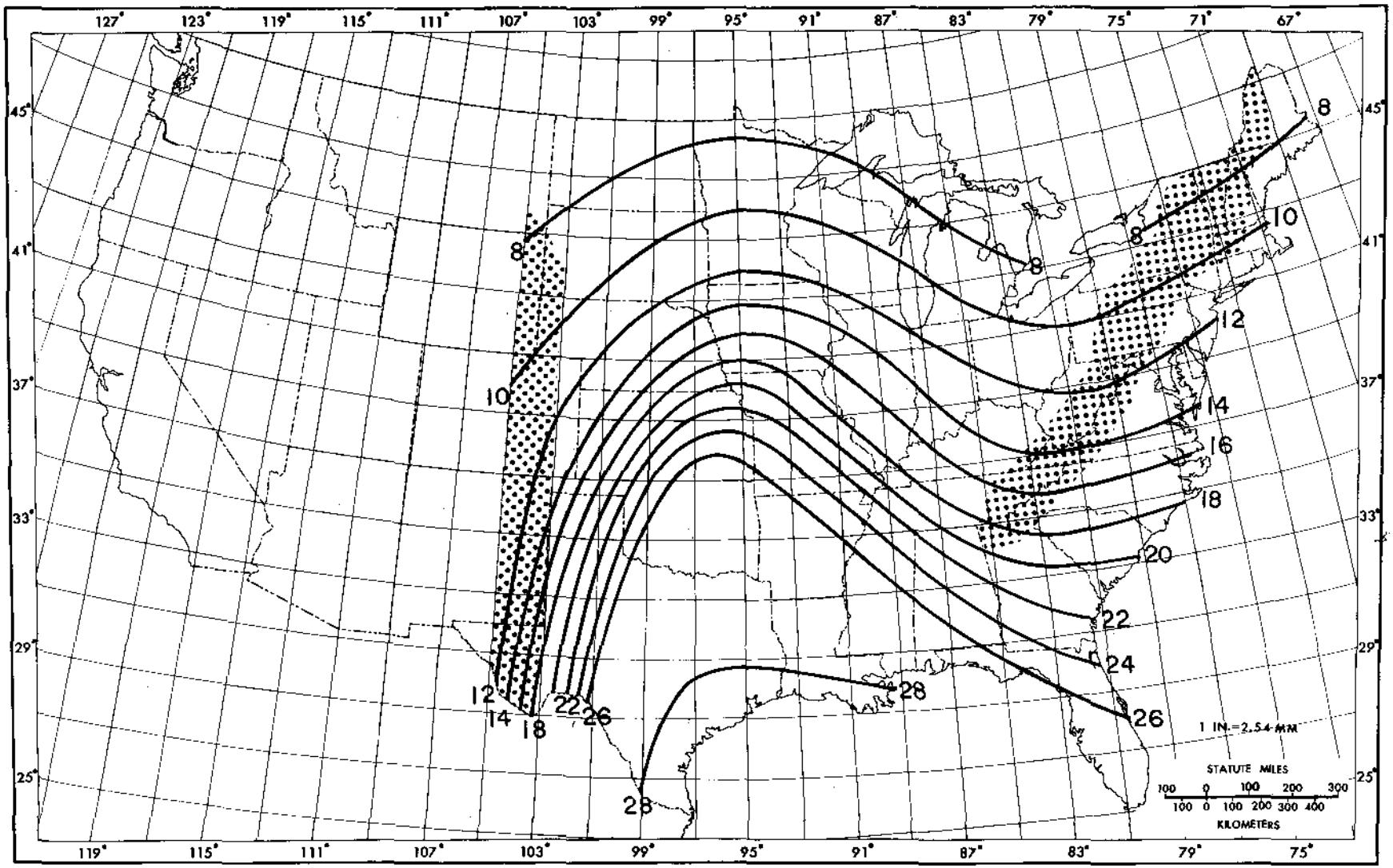

Figure 18.--10-mi^2 PMP, April, (in.).

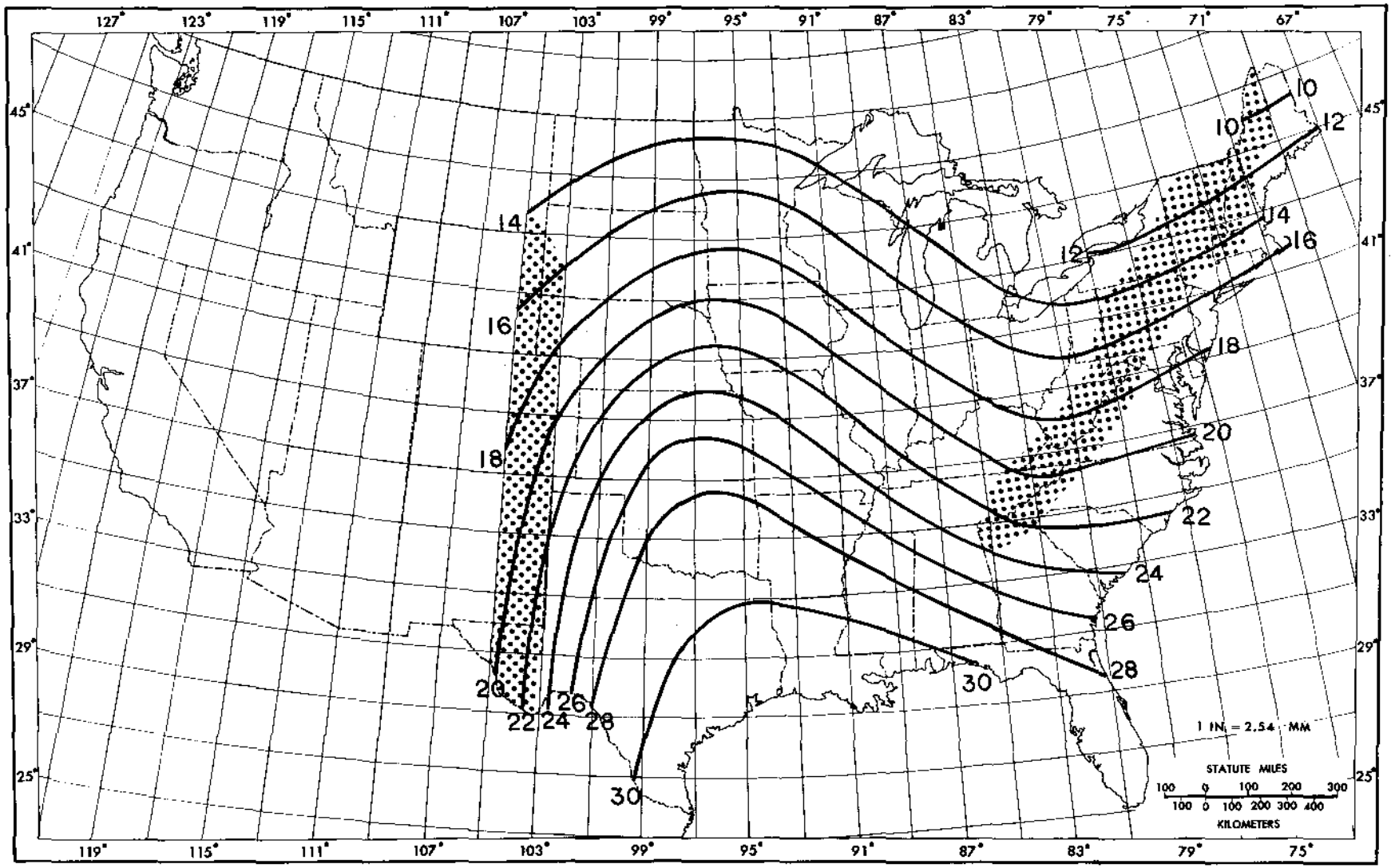

Figure 19.--6-hr 10-mi^2 PMP, May, (in.).

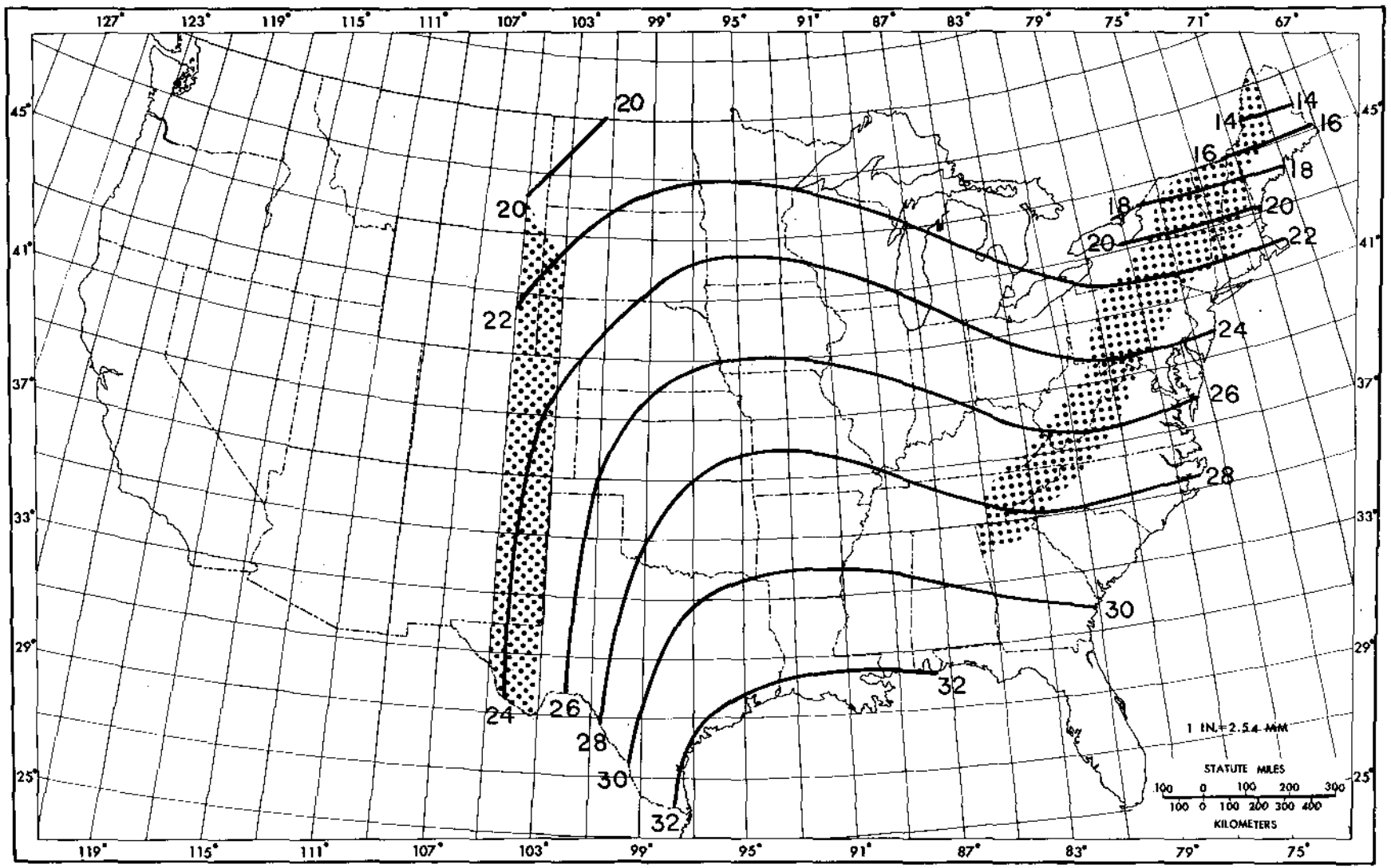

Figure 20.--6-hr 10-mi^2 PMP, June, (in.).

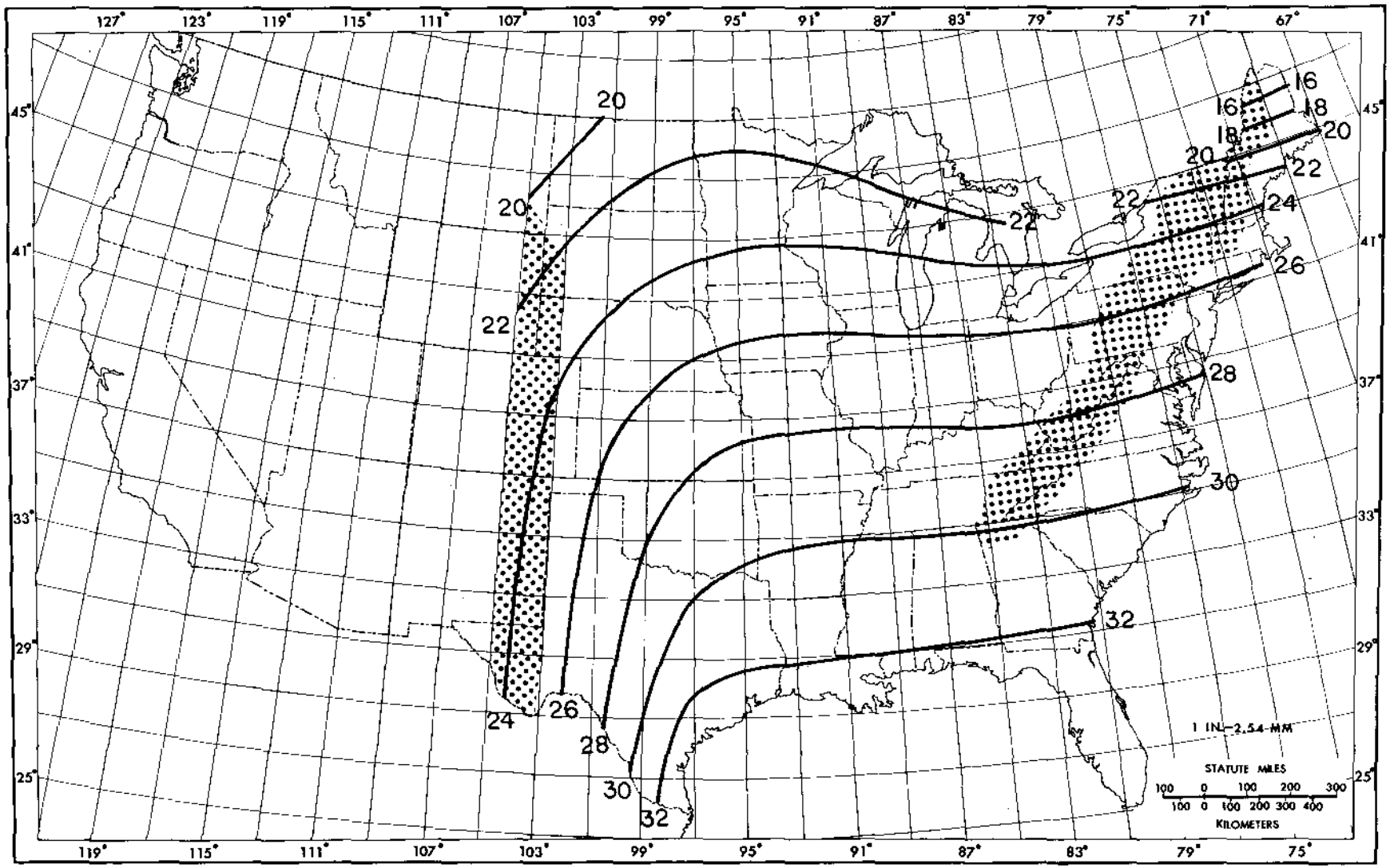

Figure 21.--6-hr 10-mi^2 PMP, July and August, (in.).

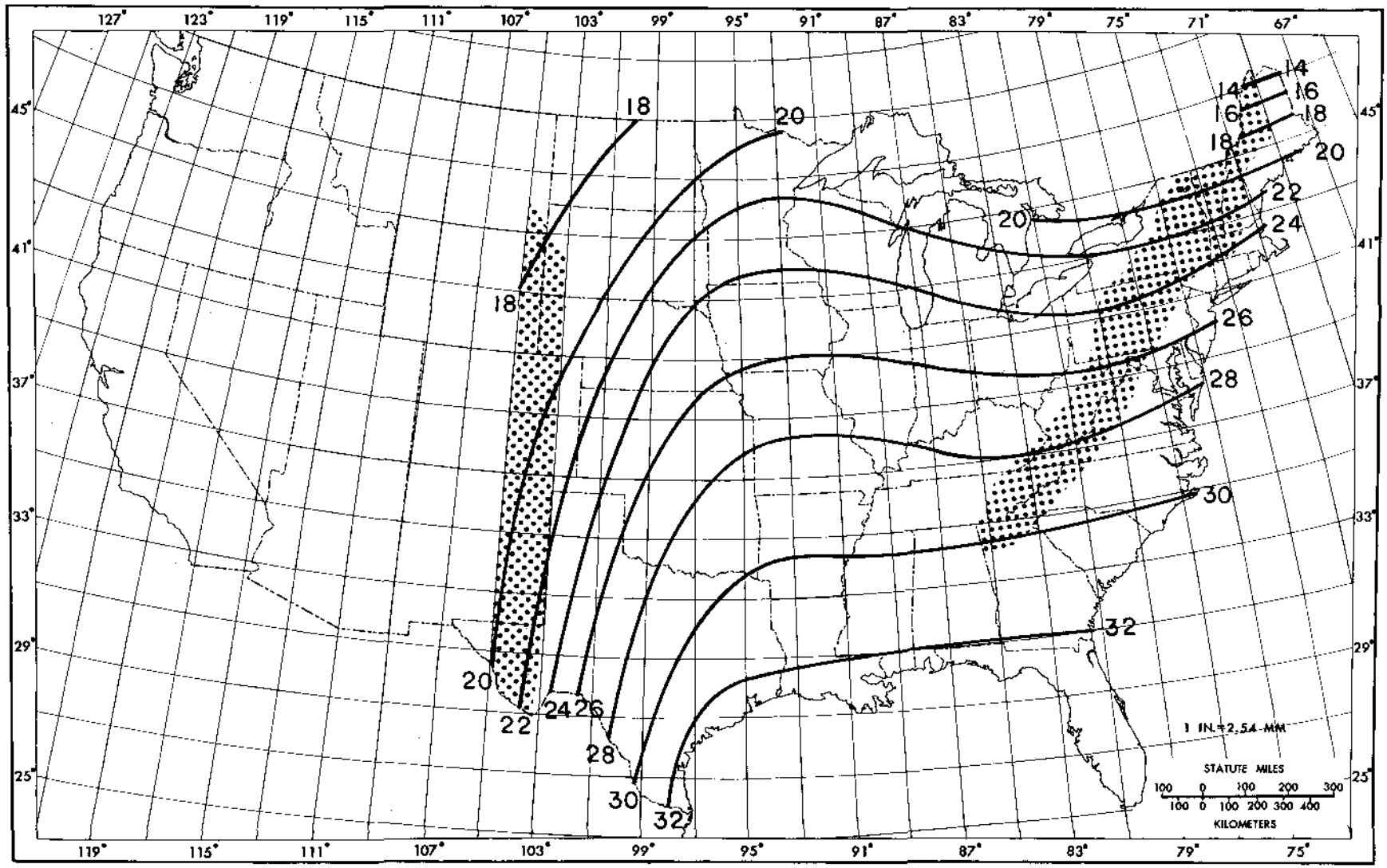

Figure 22.--6-hr 10-mi^2 PMP, September, (in.).

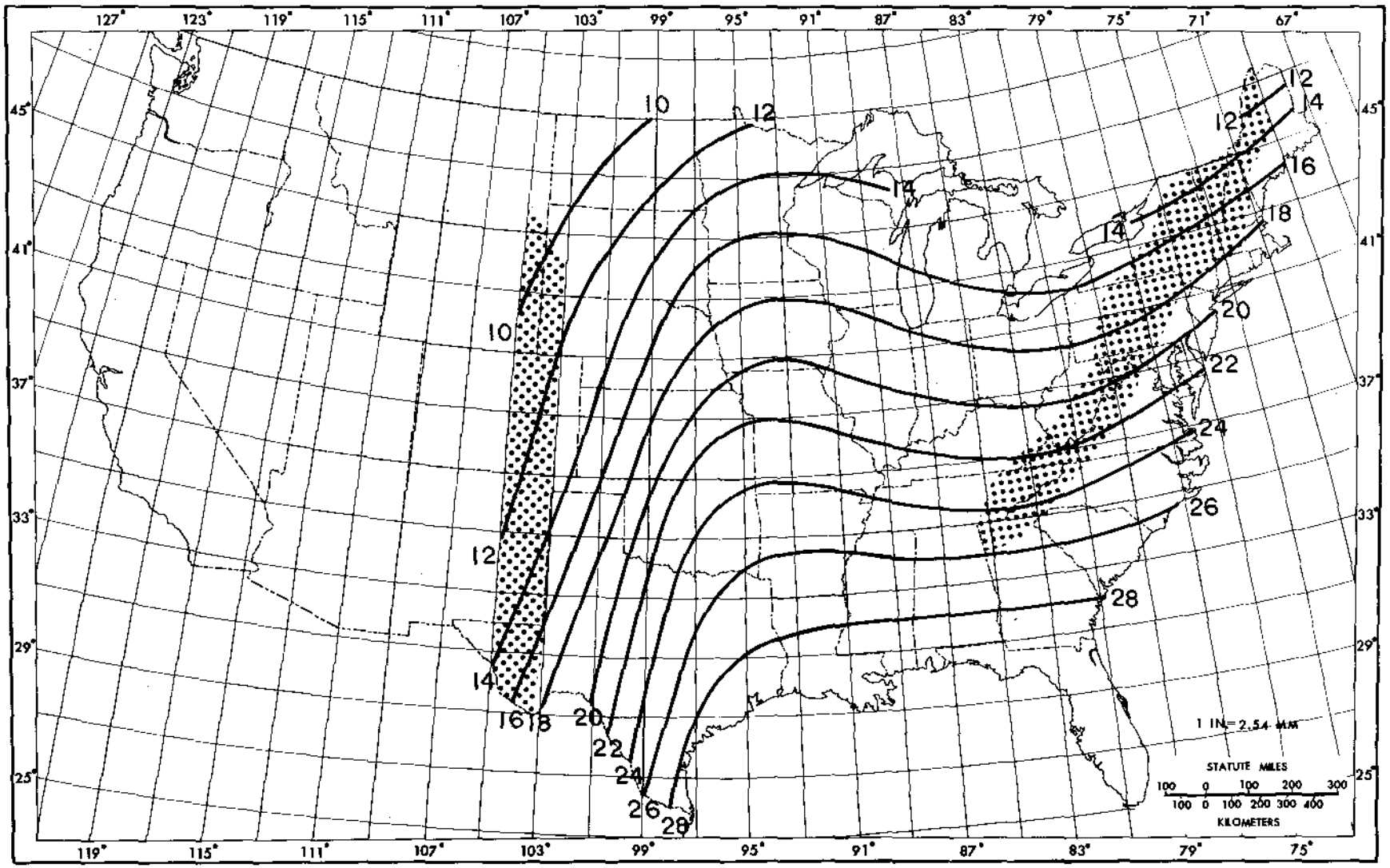

Figure 23.--6-hr 10-mi^2 PMP, October, (in.).

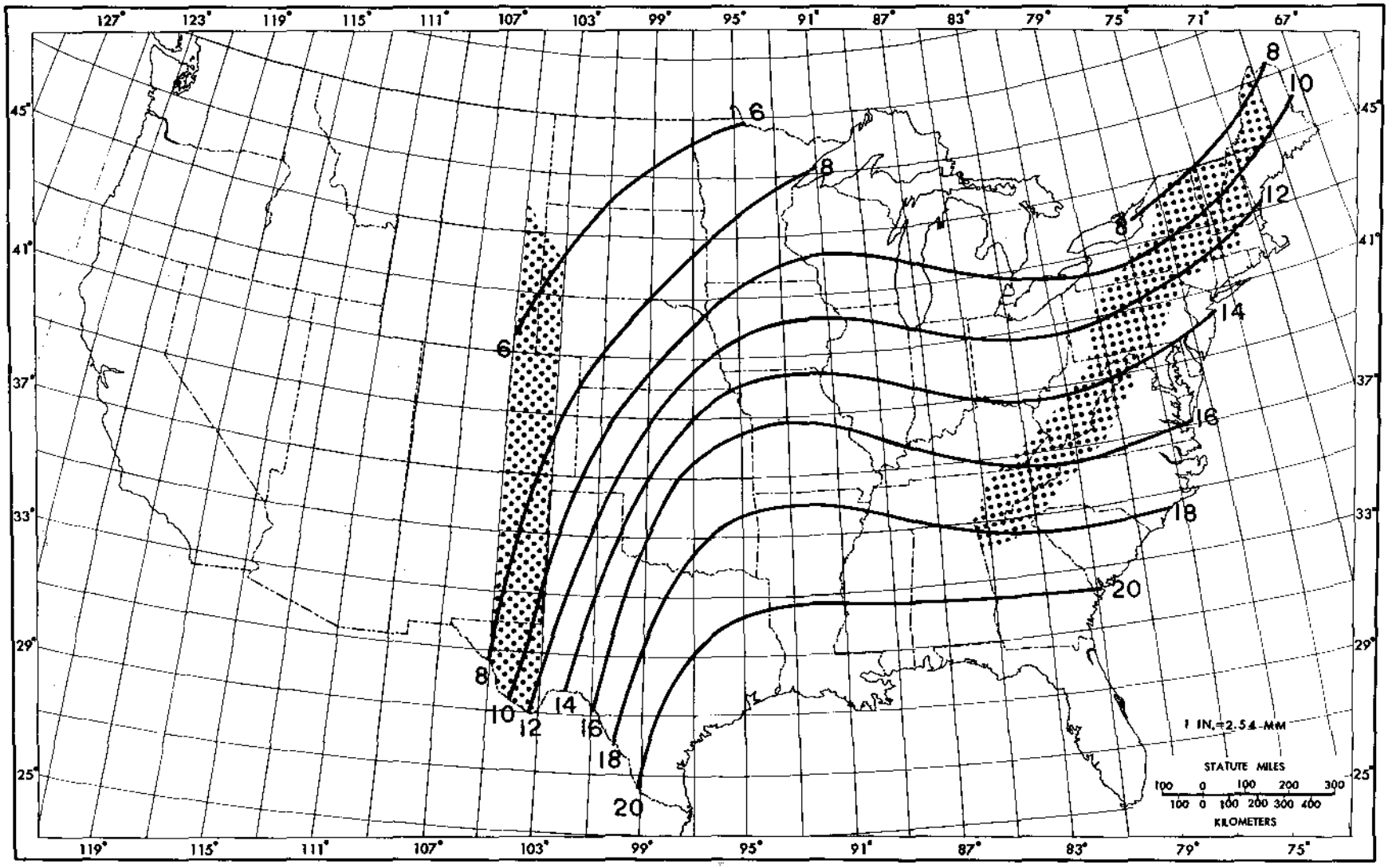

Figure 24.--6-hr 10-mi^2 PMP, November, (in.).

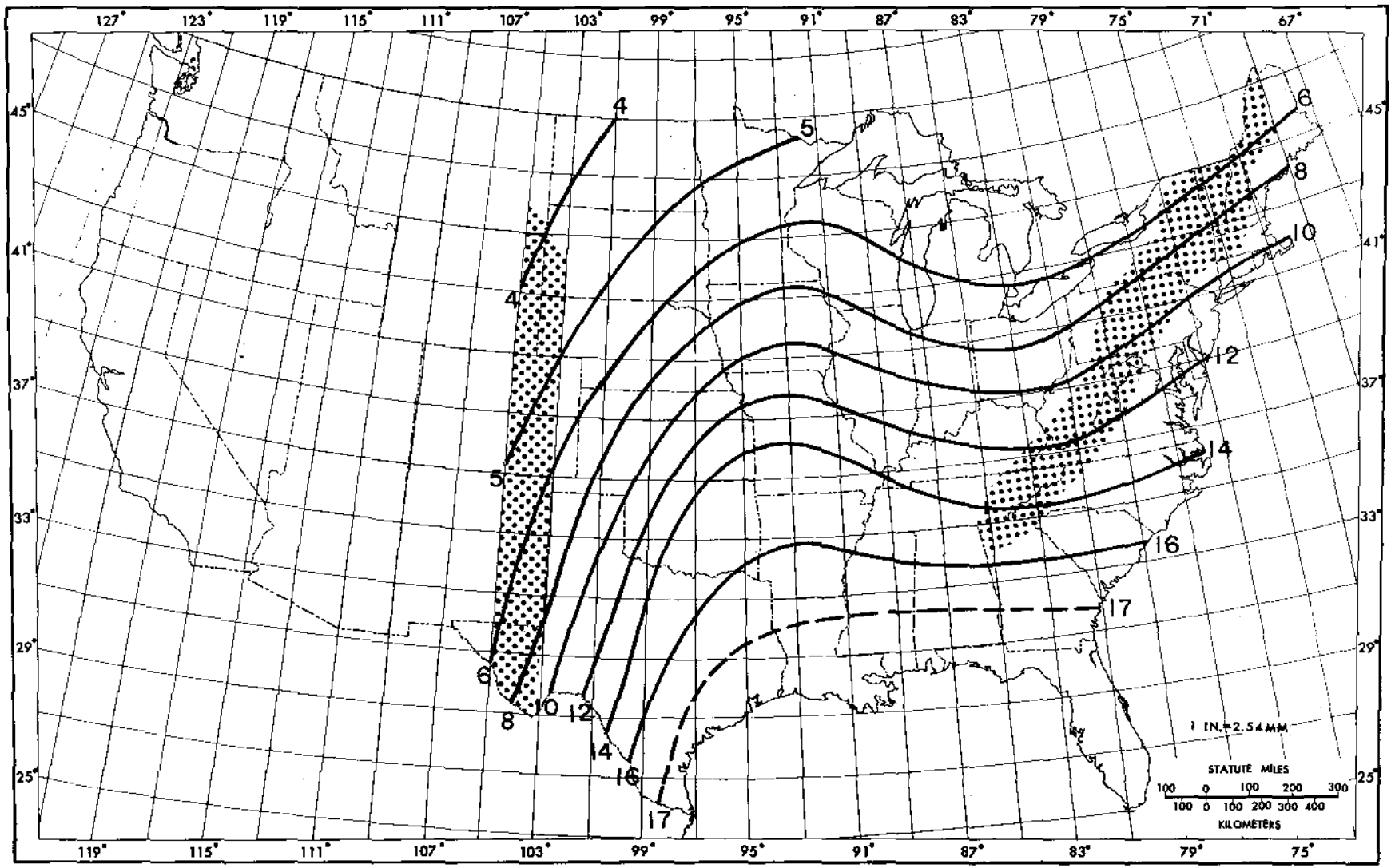

Figure 25.--6-hr 10-mi^2 PMP, December, (in.).

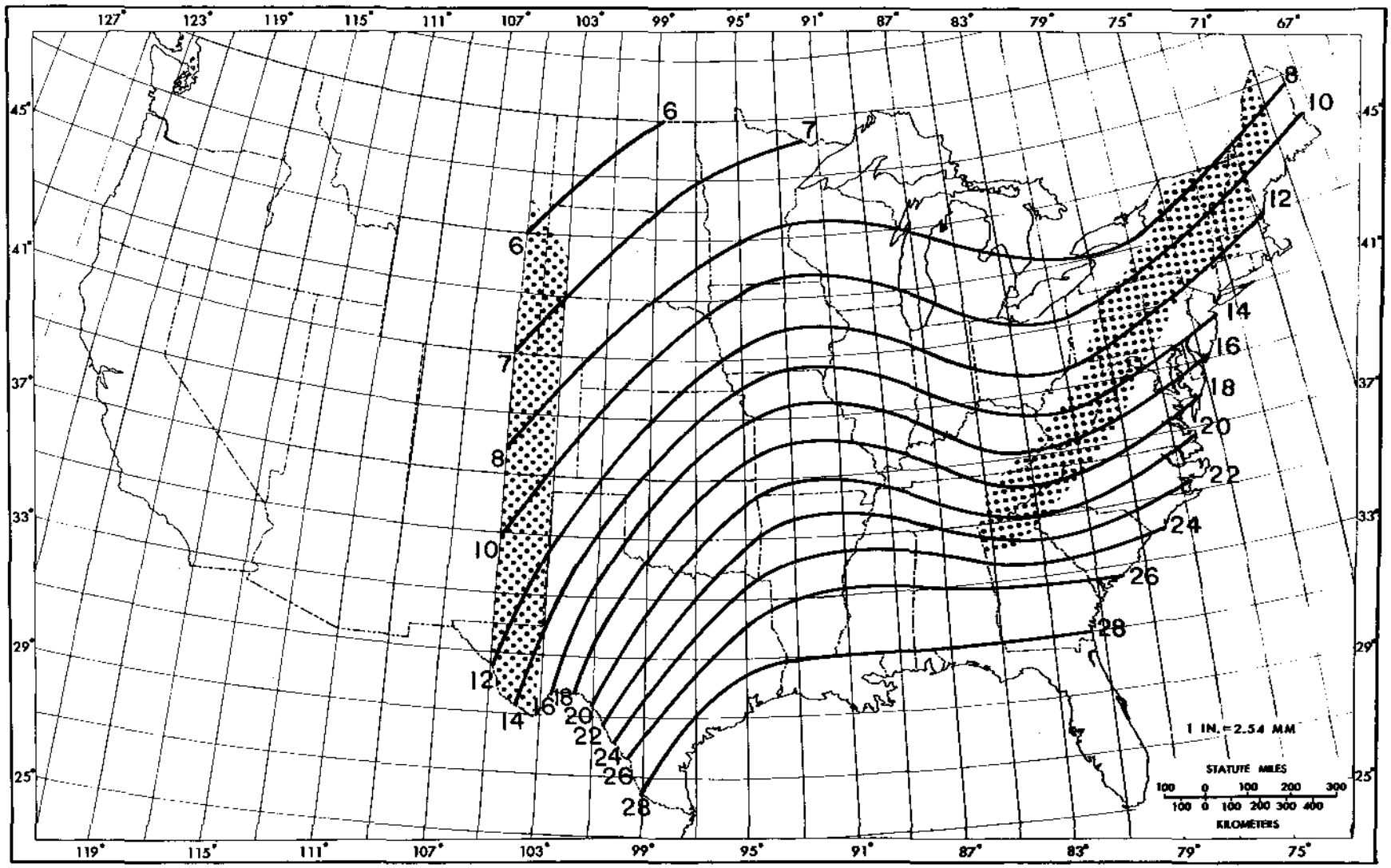

Figure 26.--24-hr 10-mi^2 PMP, January and February, (in.).

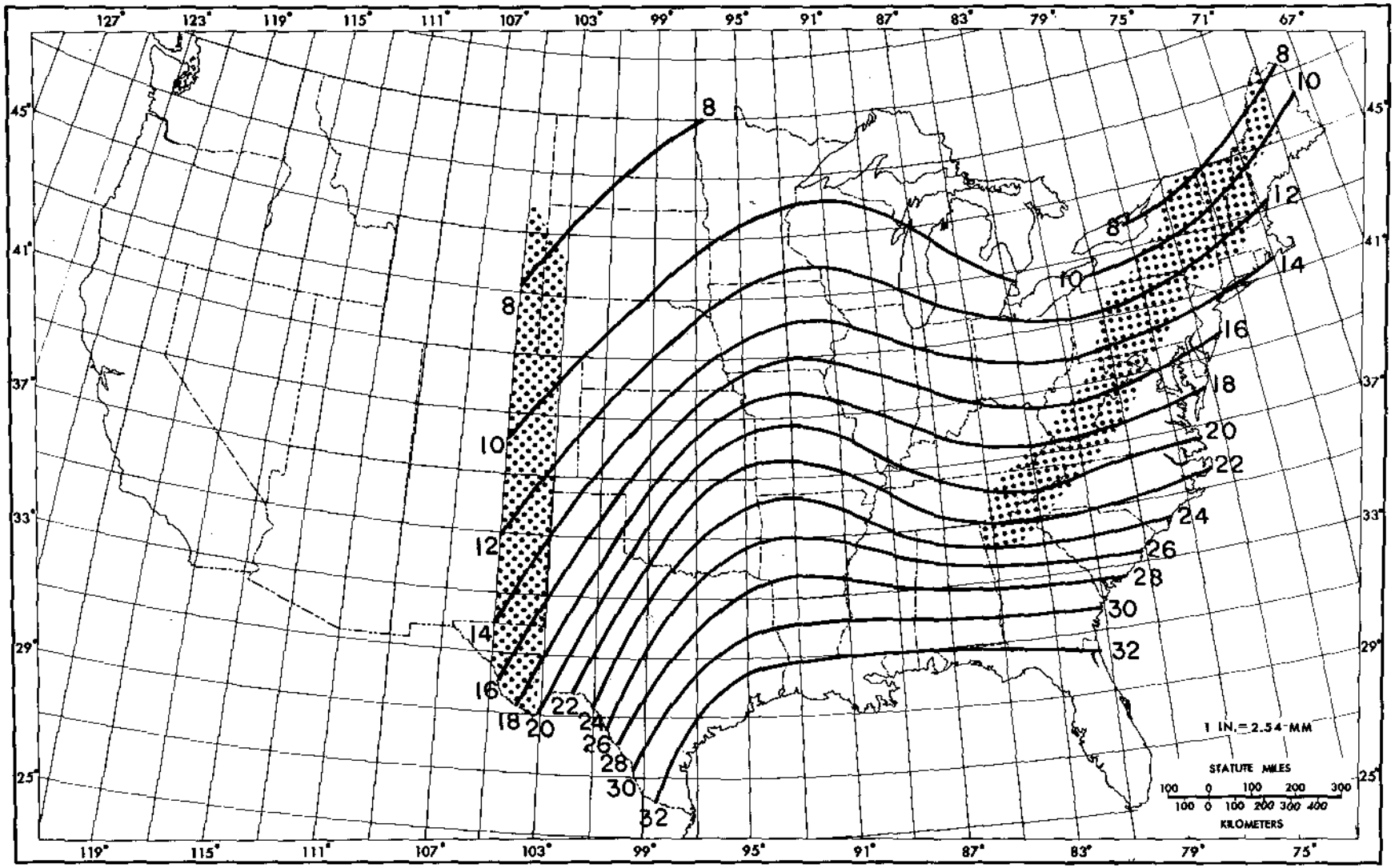

Figure 27.--24-hr 10-mi^2 PMP, March, (in.).

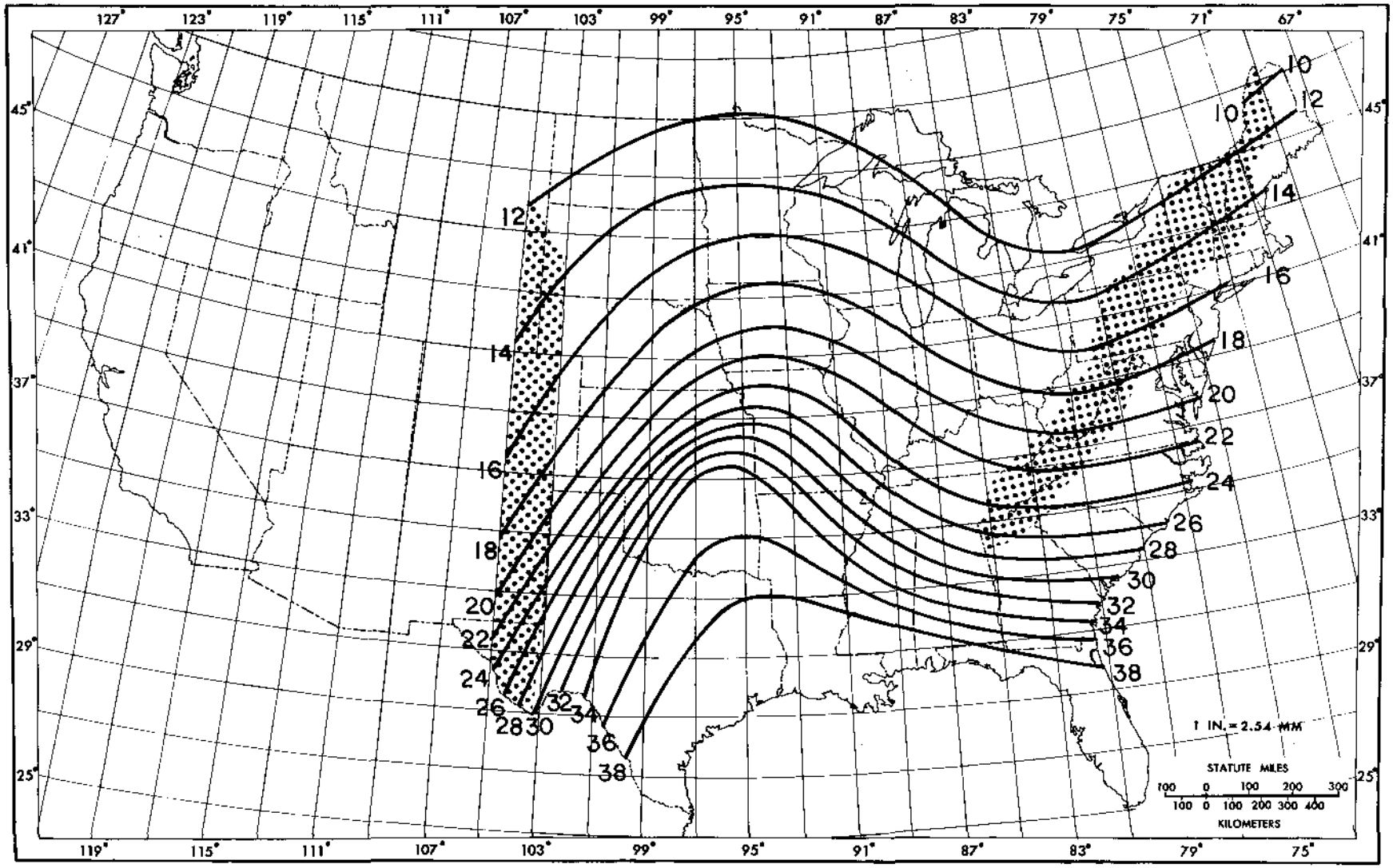

Figure 28.--24-hr 10-mi^2 PMP, April, (in.).

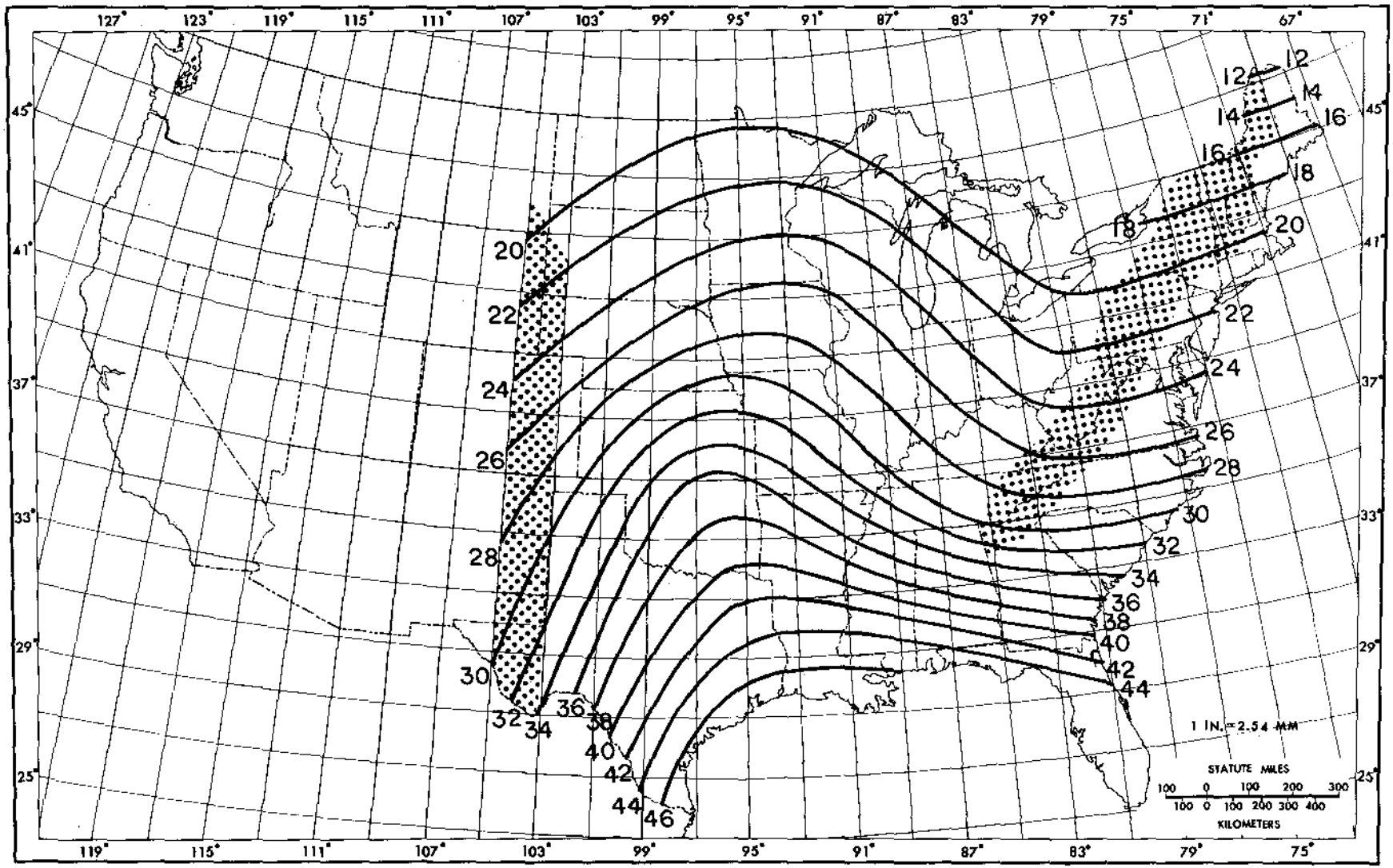

Figure 29.--24-hr 10-mi^2 PMP, May, (in.).

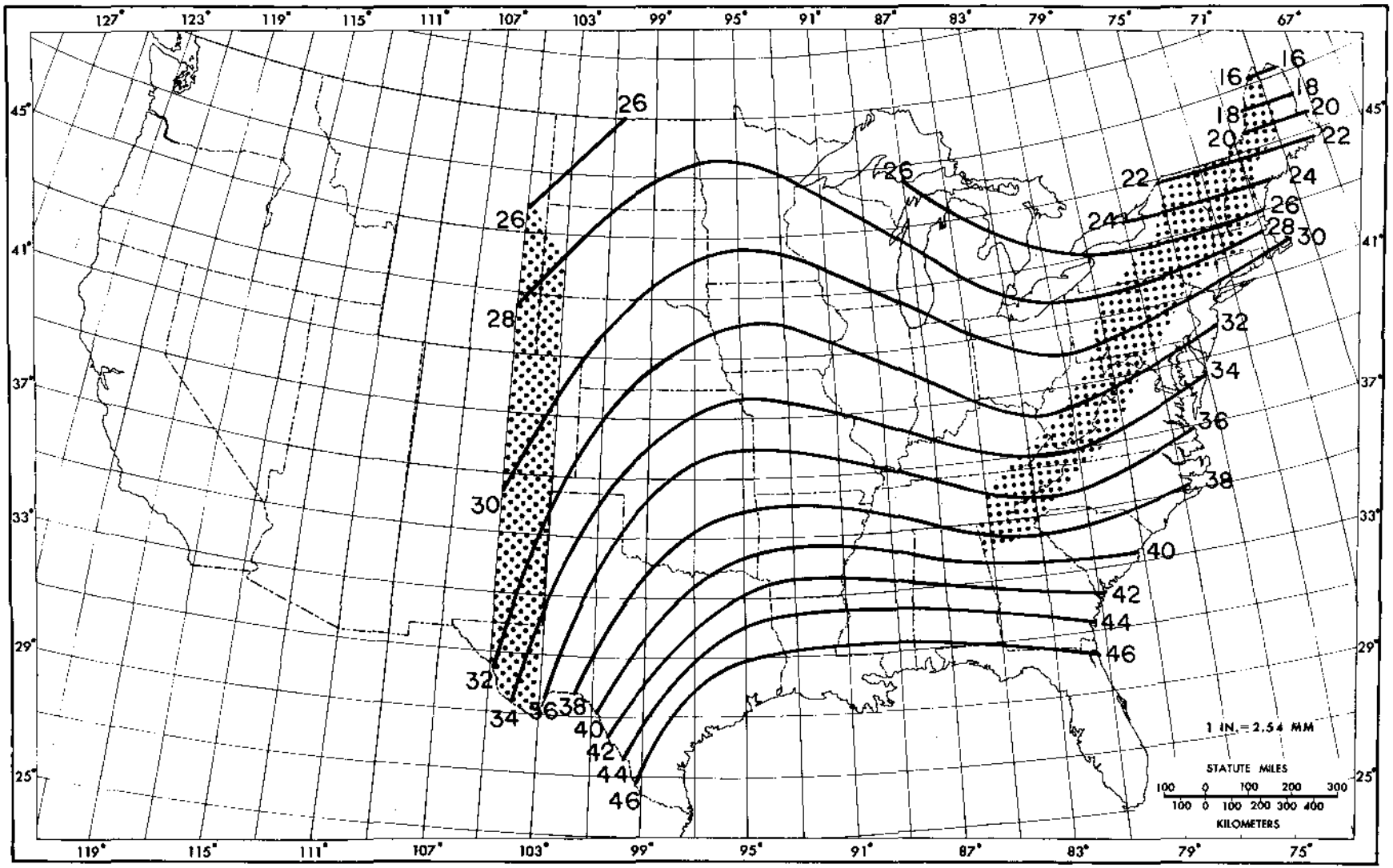

Figure 30.--24-hr 10-mi^2 PMP, June, (in.).

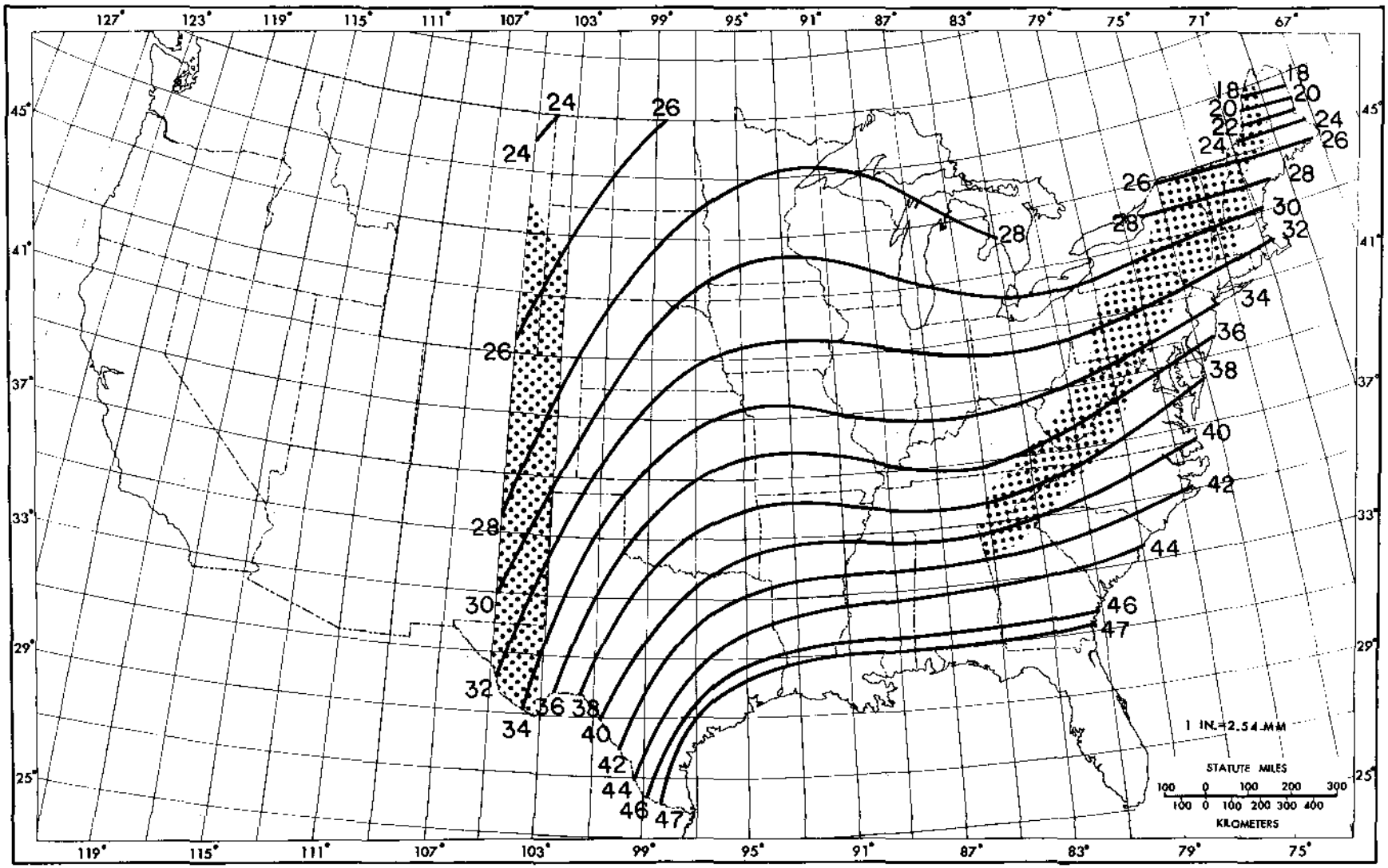

Figure 3~.--24-hr 10-mi^2 PMP, ~~July and August~~ September, (in.).

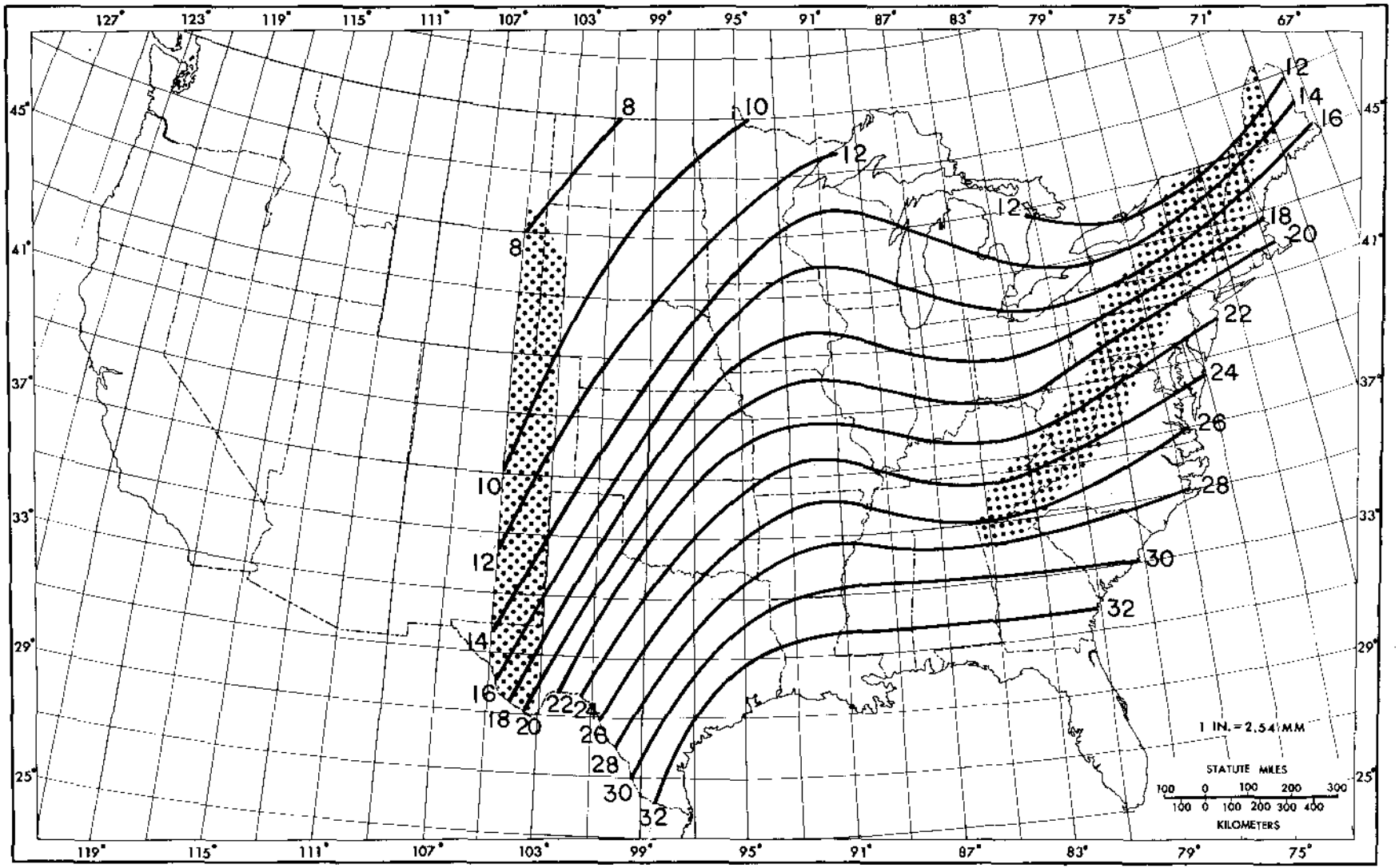

Figure 34.--24-hr 10-mi^2 PMP, November, (in.).

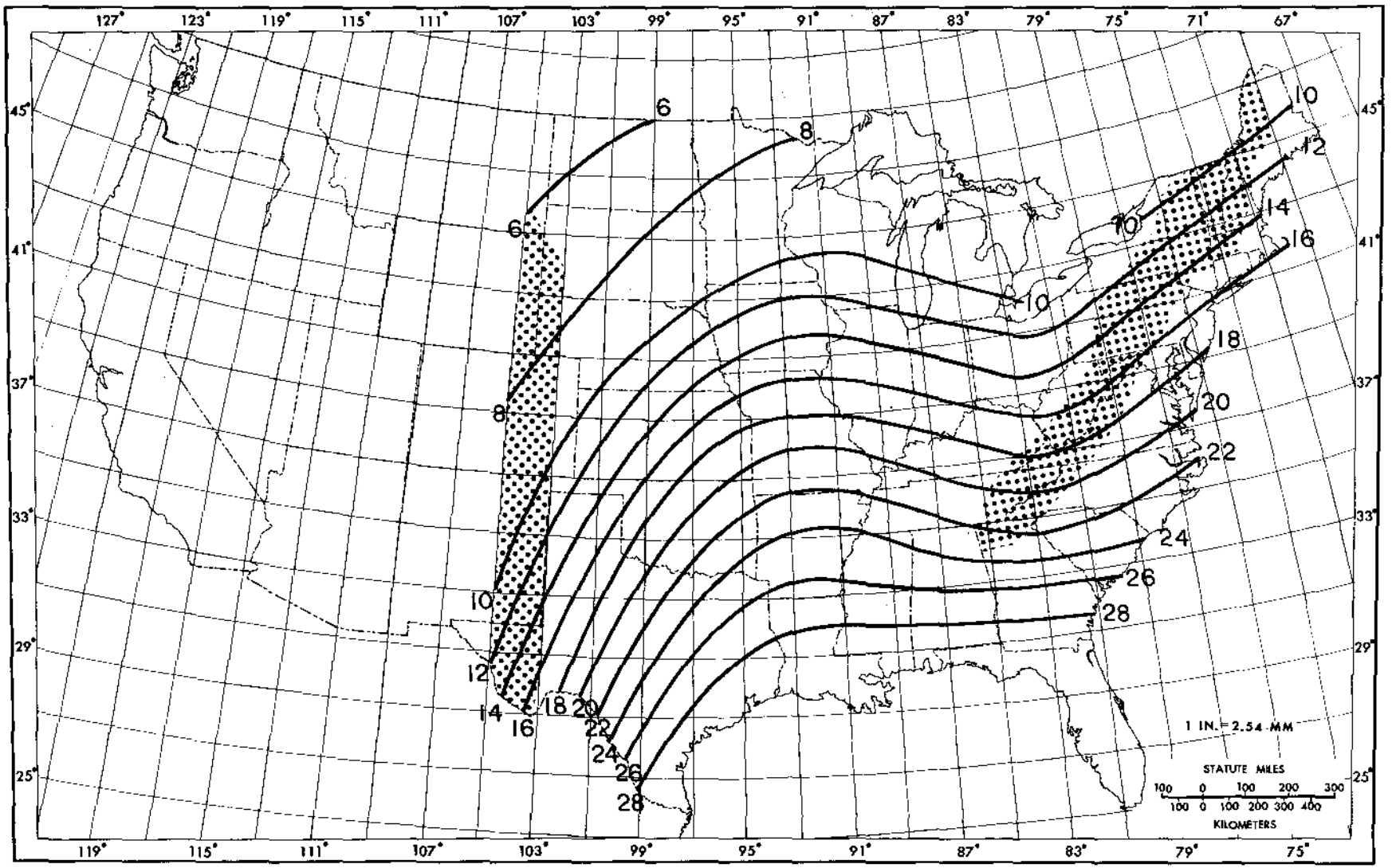

Figure 35.--24-hr 10-mi^2 PMP, December, (in.).

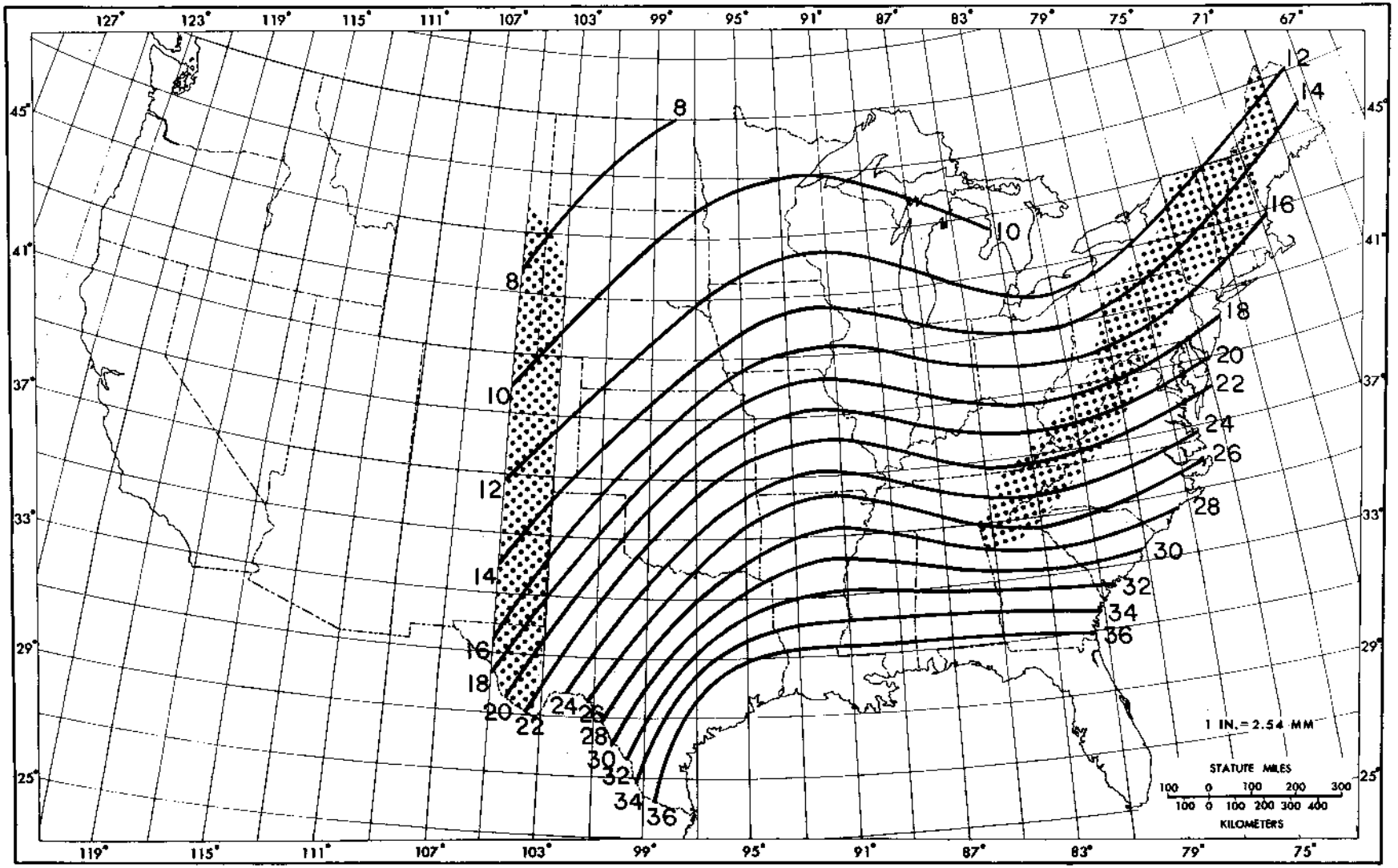

Figure 36.--72-hr 10-mi^2 PMP, January and February, (in.).

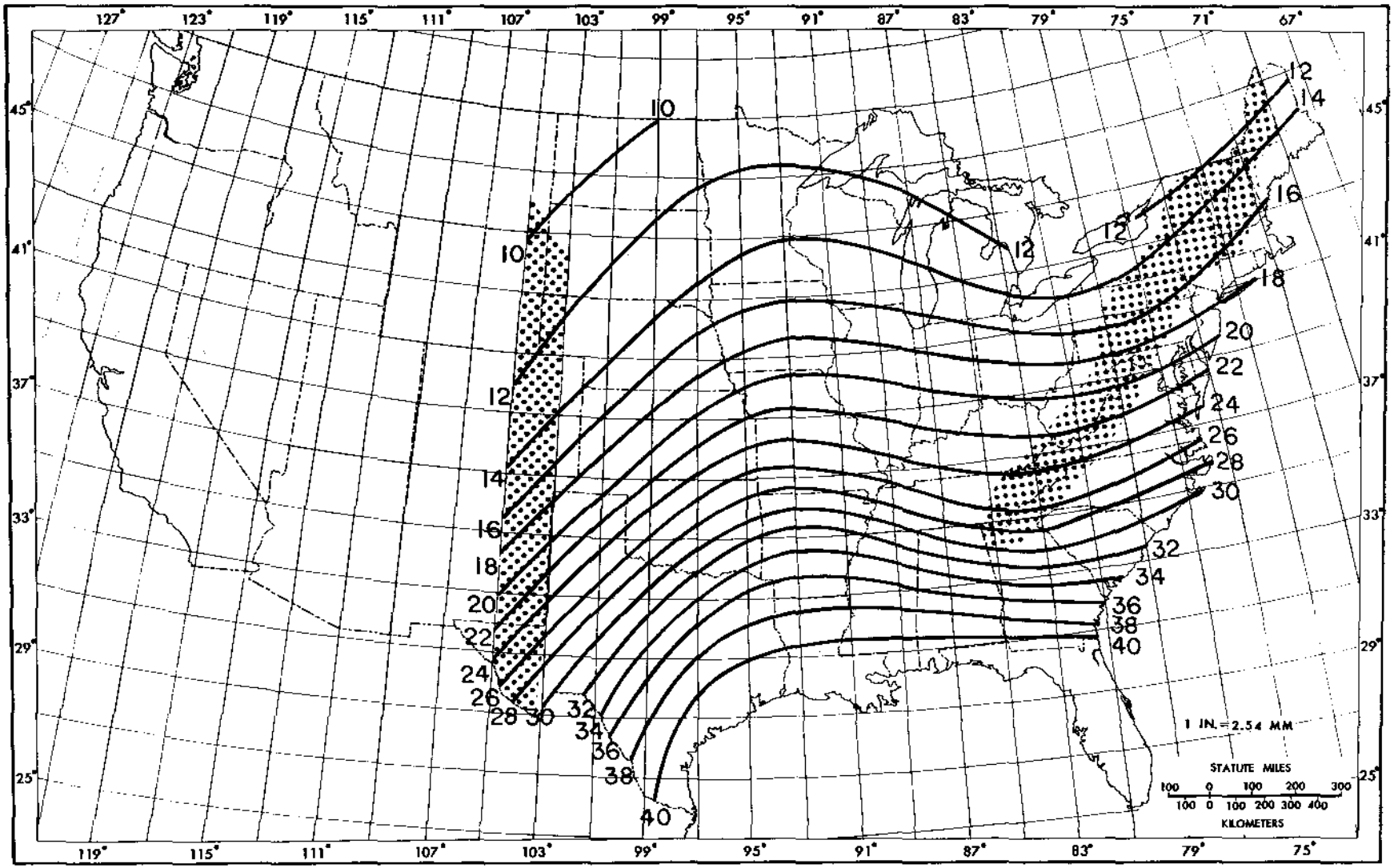

Figure 37.--72-hr 10-mi^2 PMP, March, (in.).

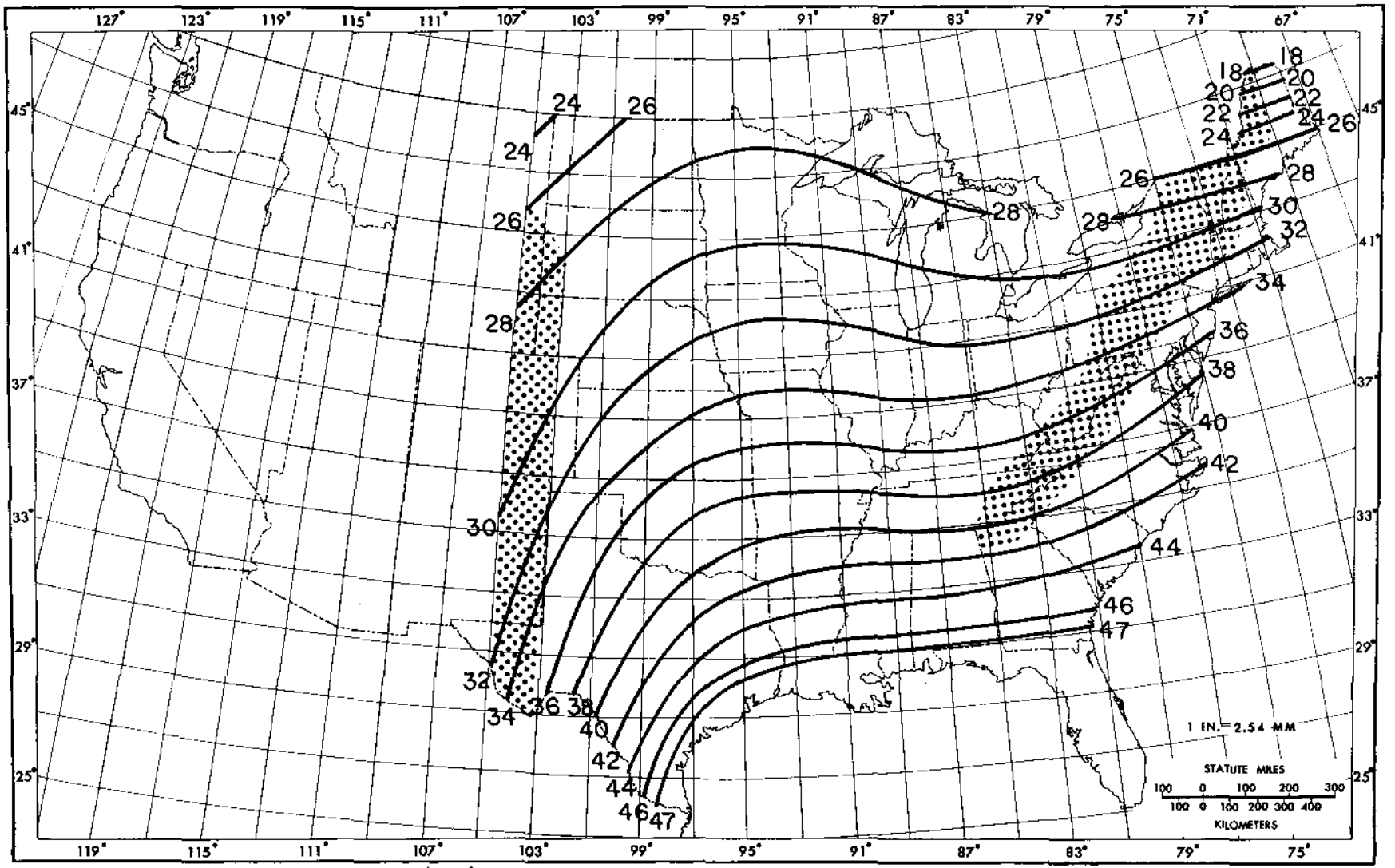

Figure 3a.--24-hr 10-mi^2 PMP, ~~September~~ July-August, (in.).

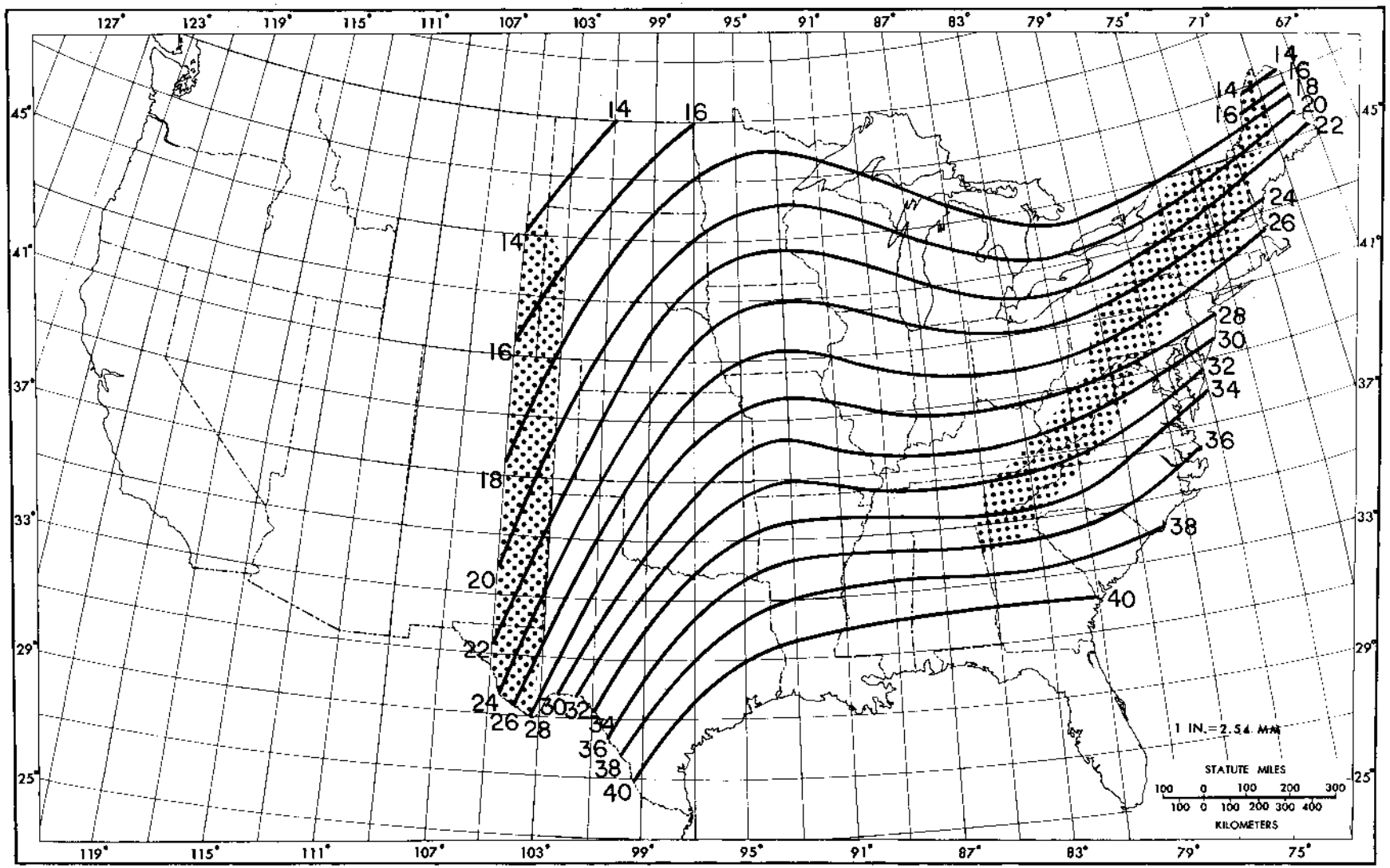

Figure 33.--24-hr 10-mi^2 PMP, October, (in.).

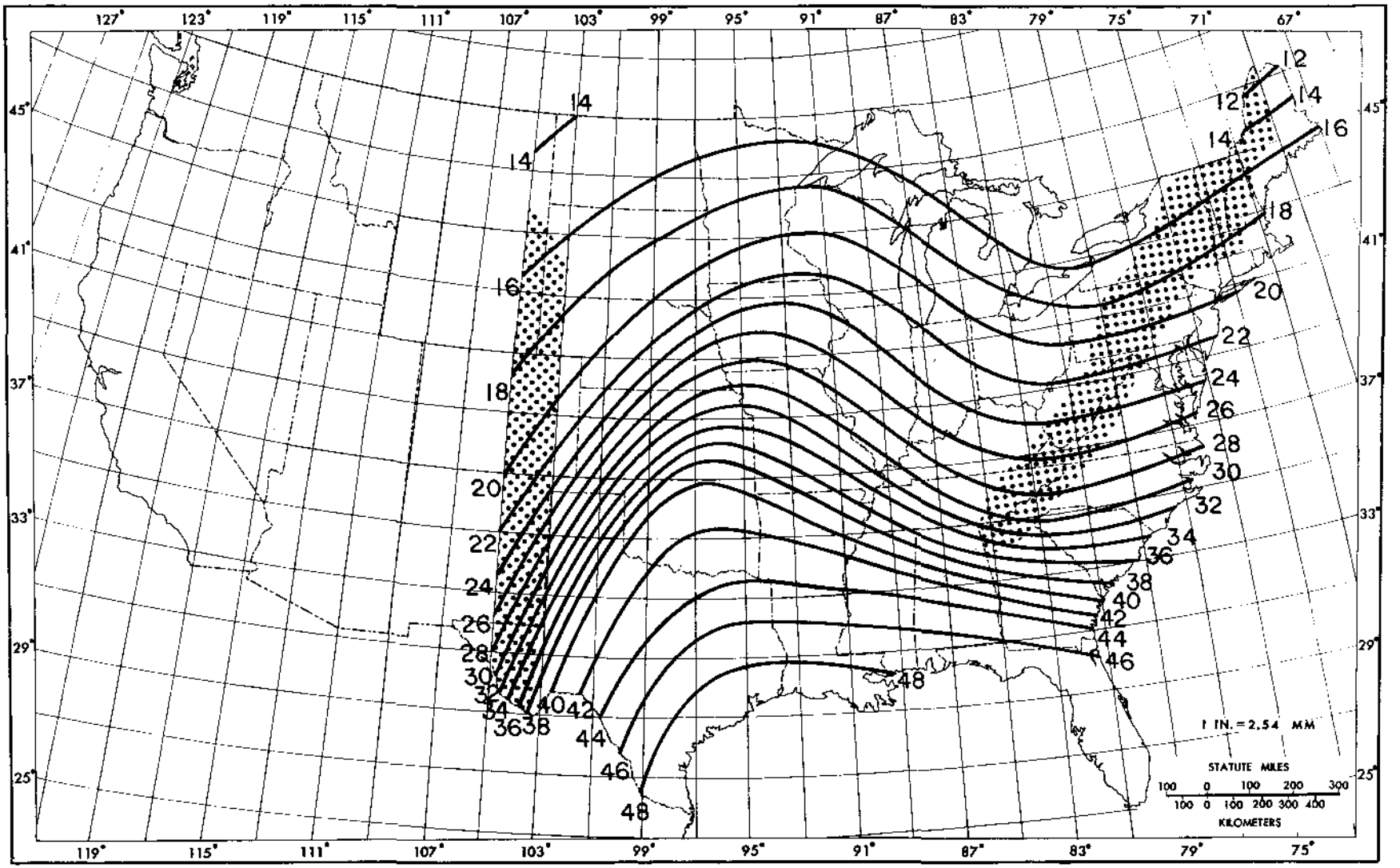

Figure 38.--72-hr 10-mi^2 PMP, April, (in.).

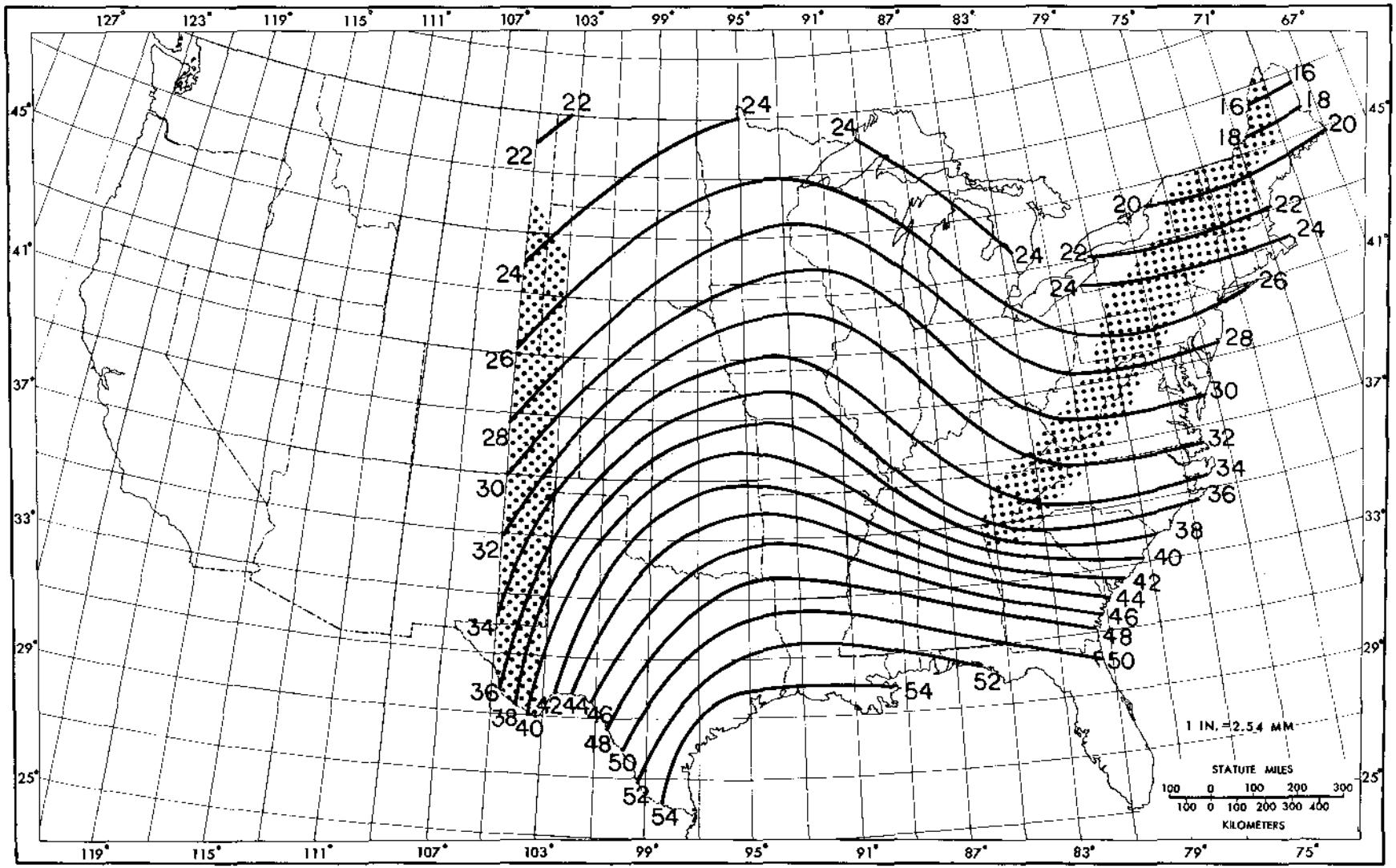

Figure 39.--72-hr 10-mi^2 PMP, May, (in.).

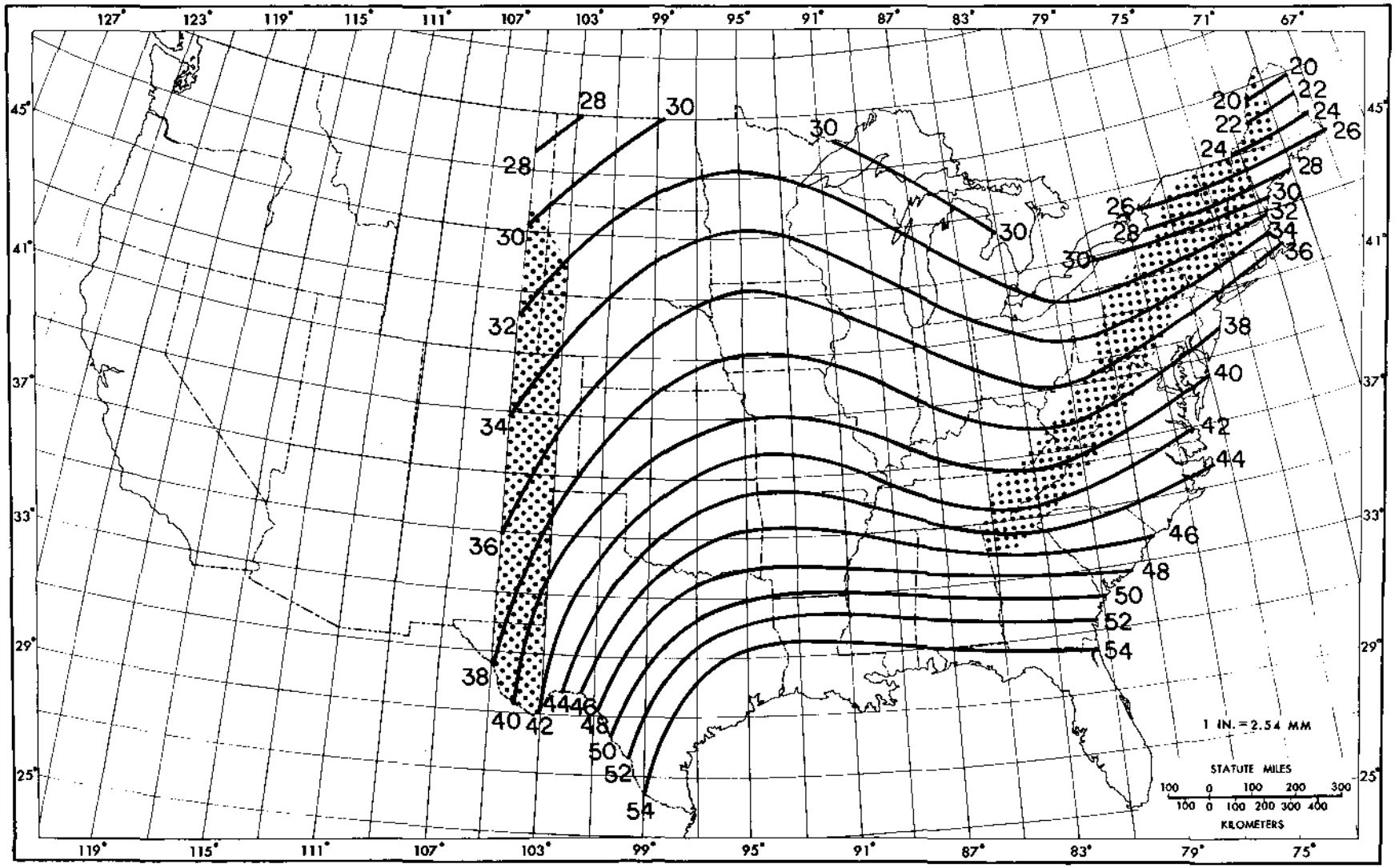

Figure 40.--72-hr 10-mi^2 PMP, June, (in.).

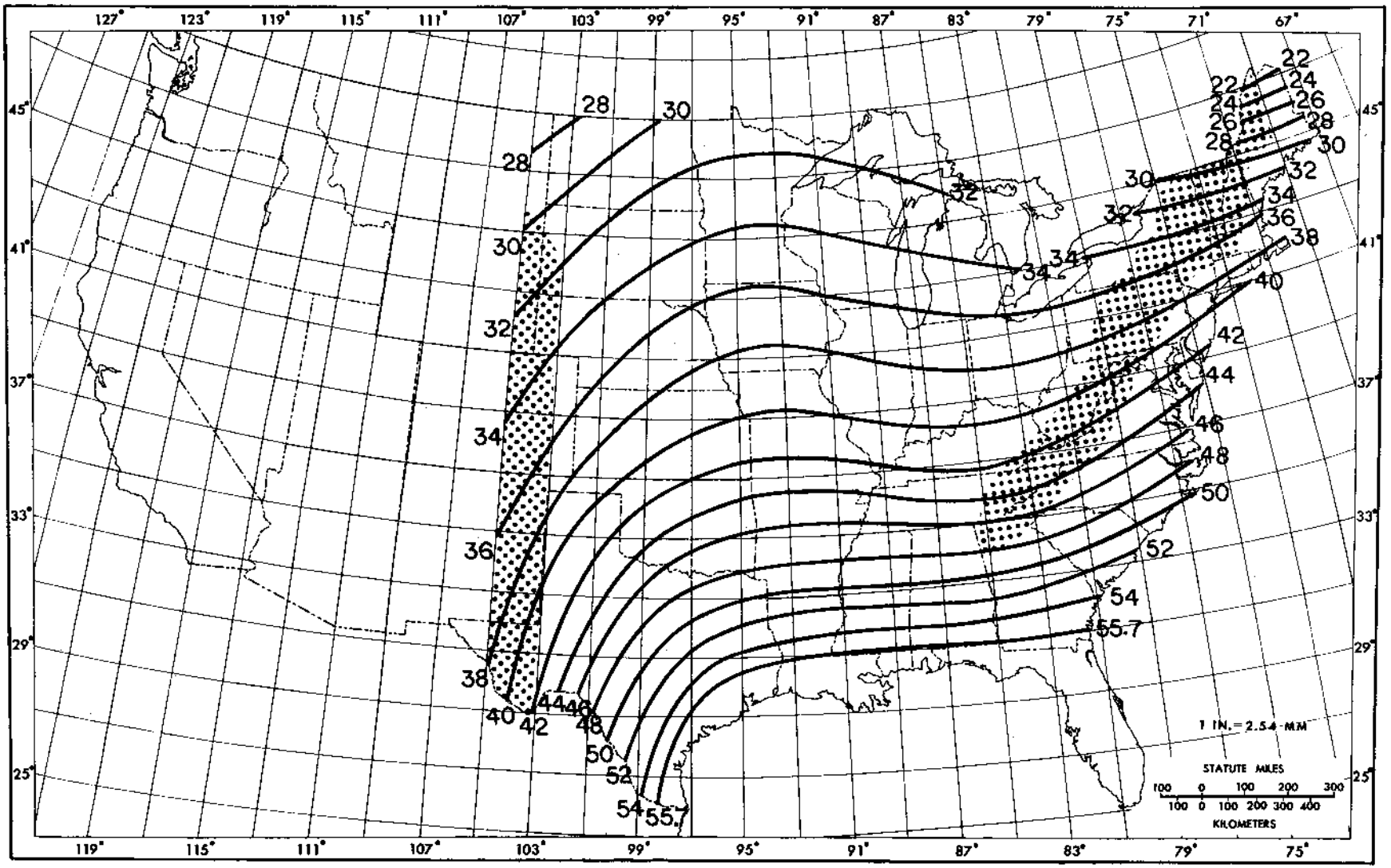

Figure 41.--72-hr 10-mi^2 PMP, July and August, (in.).

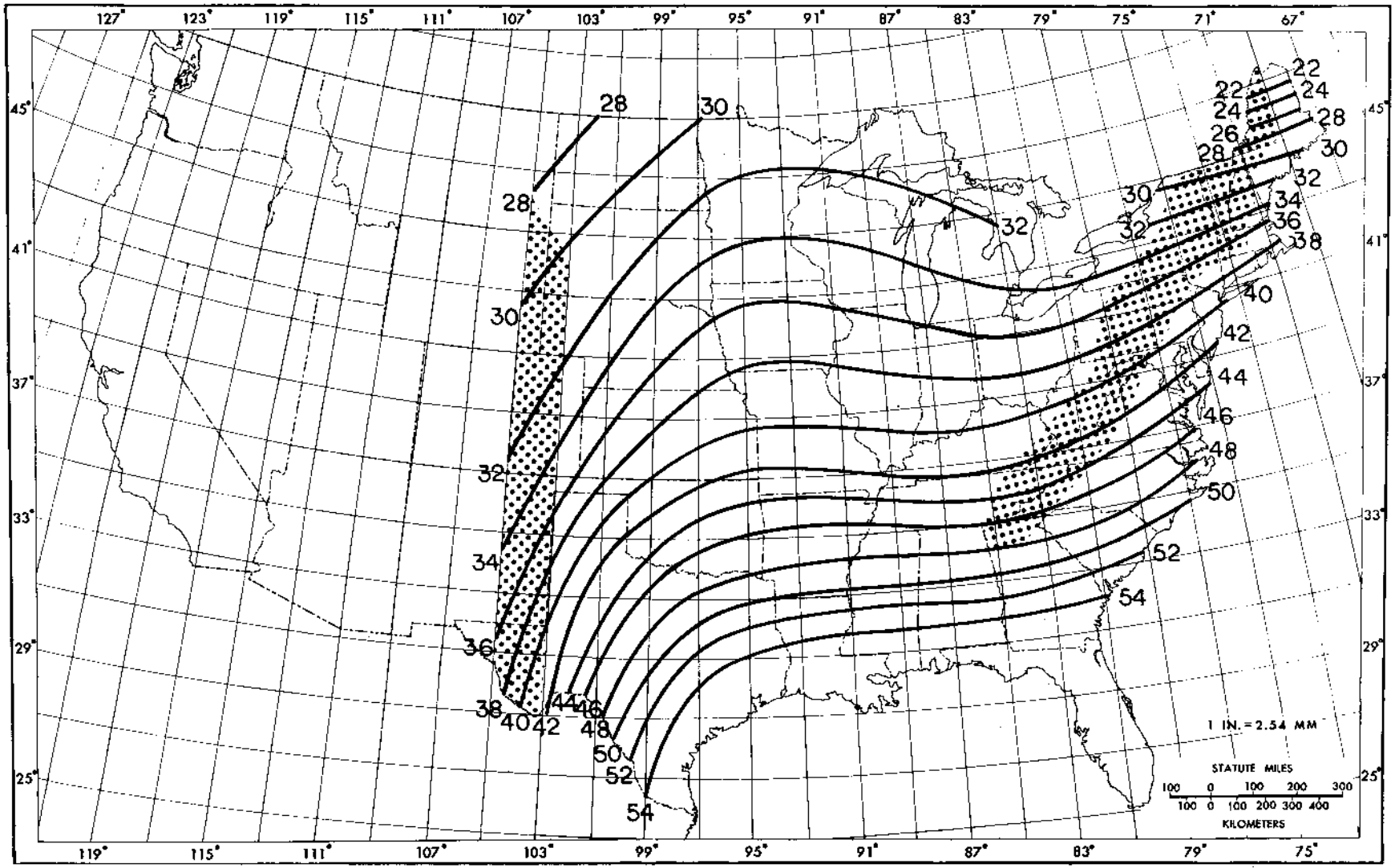

Figure 42.--72-hr 10-mi^2 PMP, September, (in.).

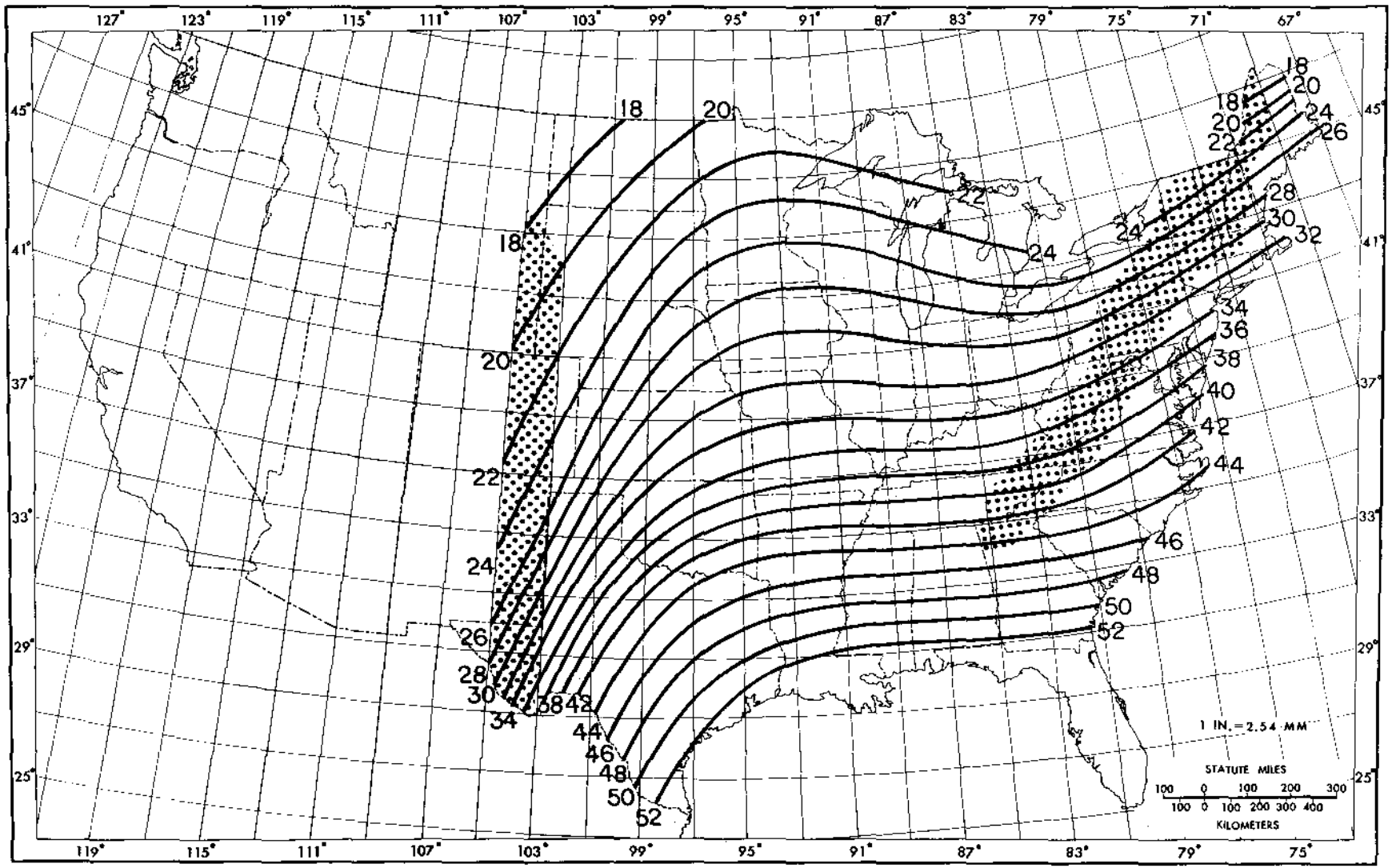

Figure 43.--72-hr 10-mi^2 PMP, October, (in.).

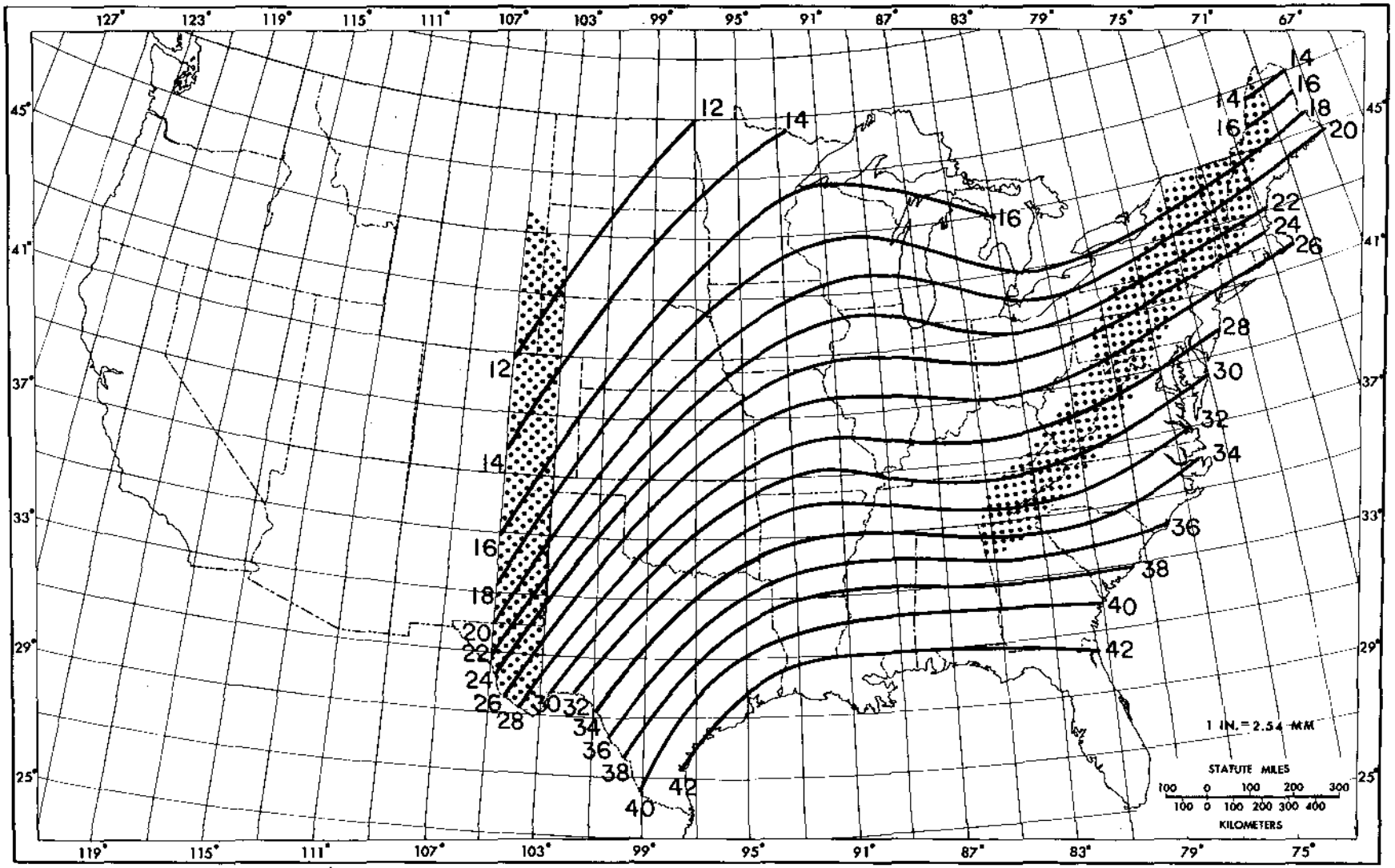

Figure 44.--72-hr 10-mi^2 PMP, November, (in.).

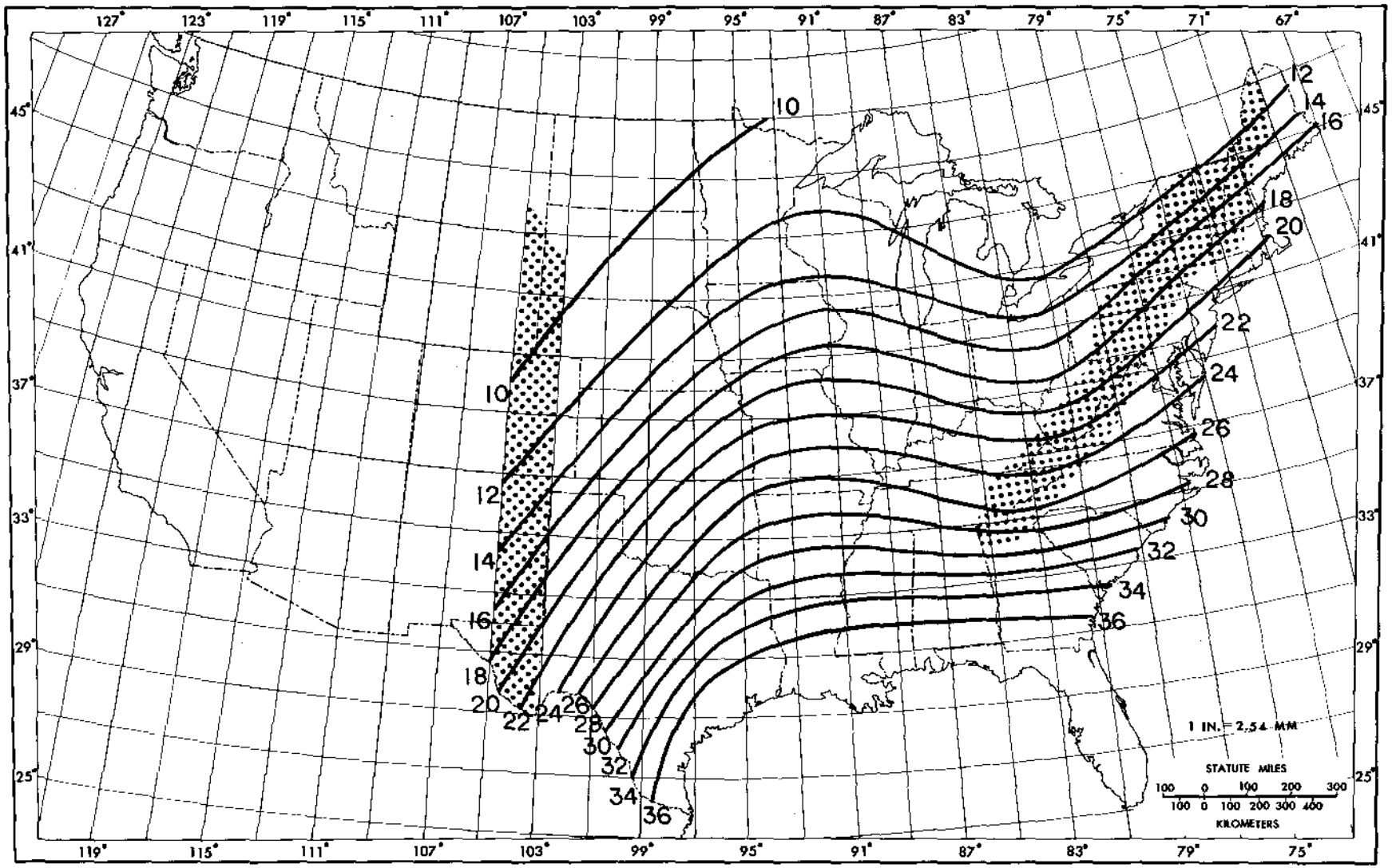

Figure 45.--72-hr 10-mi^2 PMP, December, (in.).

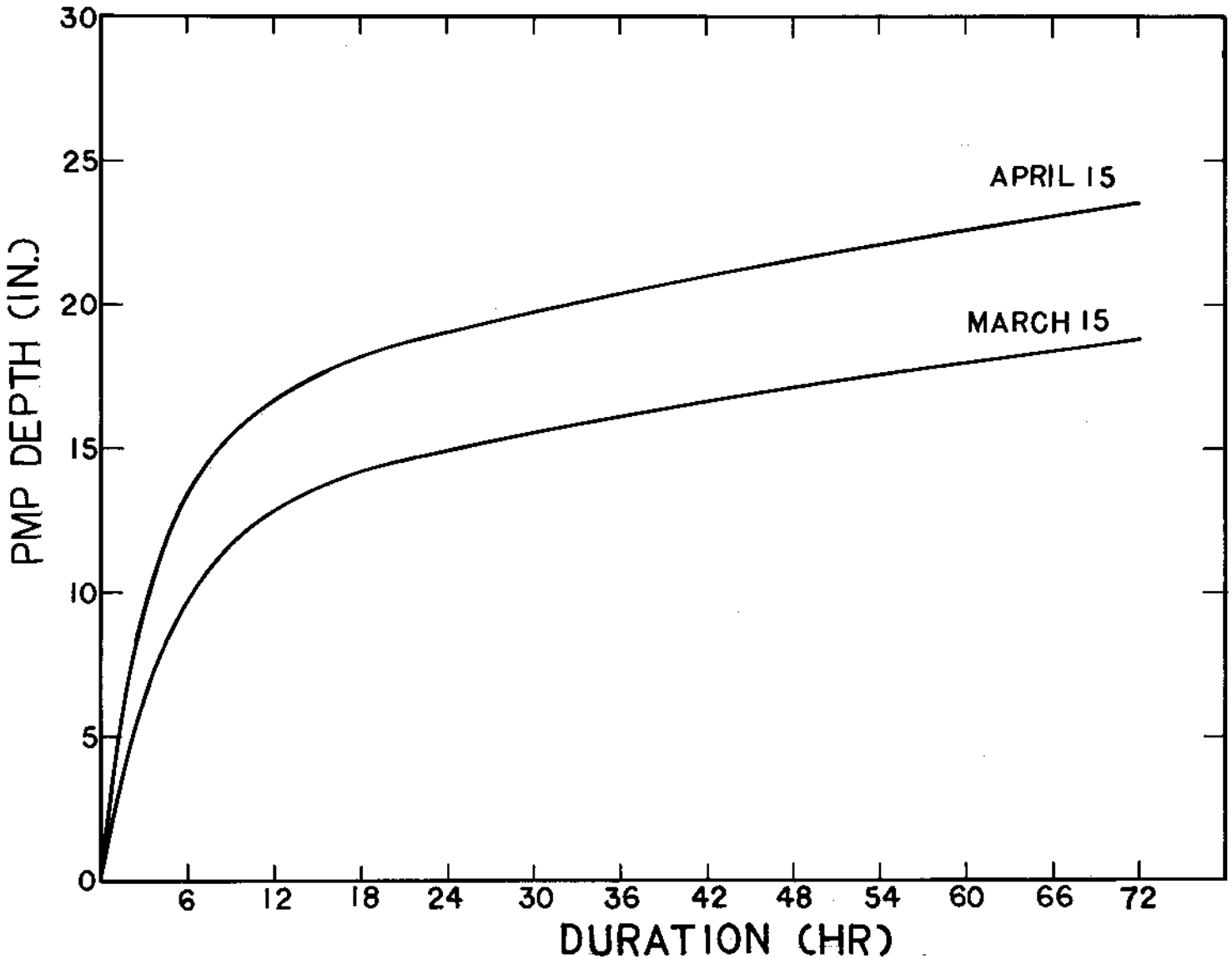

Figure 46.--Example of variation of PMP depths with duration for mid-month of March and April for 40.5°N 87.5°W (see sec. 6).

For such regions, the assumption was made that the reduced height of the column of moisture available for processing at higher elevations is compensated by intensification from steeper terrain slopes at these higher elevations.

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 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, gave detailed definition for some of the Western States. For the Tennessee River drainage, nonorographic PMP was adjusted for terrain effects by considering numerous different rainfall criteria and 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.

7.2 Extreme Precipitation at Mt. Washington, N.H.

Some very extreme precipitation values have been observed in winter at Mt. Washington, a location in the stippled regions of the PMP maps. Three of the most extreme are listed in table 5. The editor of the *Mount Washington Observatory News* Bulletin gives the following description of the February 10-11, 1970 storm:

> *On the 10th and 11th there was a little storm that deposited a whopping 10.12 inches of water equivalent into the precipitation gage in 24 hours for another new record in this department! During part of the storm dense ice accumulated at the rate of five inches per hour and Summit structure eventually exhibited accumulations two feet thick in places. Wind during the storm peaked at 128 mph.*

Since Mount Washington Observatory, at an elevation of 6,262 feet, is located well above the mean elevation in the region we did not attempt to transpose such precipitation to other locations. We did not make adjustments for maximum moisture, but did ensure that the observed values were enveloped by the PMP isolines.

7.3 Point Rainfall vs. 10 mi^2 Average Rainfall

This study estimates PMP for 10-mi^2 areas. The basic data (Corps of Engineers, U.S. Army 1945-) often use point rainfall as 10-mi^2 rainfall depths. 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 would be greater than the 10-mi^2 values of this report. For the all-season PMP taken from HMR No. 51, this is answered by the fact that with few exceptions the

Table 5.--Extreme precipitation amounts observed at Mt. Washington, N.H. (44°16N; 71°18W) during the winter season.

	Duration (hr)					
	6	12	18	24	48	72
Storm date	Recorded precipitation amounts (in.)					
Feb. 10-11, 1970	4.7	9.2		10.1		
Dec. 26-28, 1969	3.3			8.6	10.2	10.3
Feb. 25-27, 1969	3.4			8.4	12.5	14.1

critical storm values establishing PMP for 10 mi^2 came from 10-mi^2 average rainfalls rather than single station values. Therefore, all-season PMP for areas less than 10 mi^2 exceed those given here for 10 mi^2.

What about storms controlling other seasons? PMP estimates for points during the cool season, say October - April, would reasonably be not much different from the 10-mi^2 values given in this report. This is so, since in winter rains are less variable from place to place because there is much less convective activity than in summer.

7.4 Storm Adjustments Greater than 150 Percent

Extreme increase 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, a value obtained by multiplying the observed depth by 150 percent was used. This limitation was also applied to HMR No. 51.

8. OBSERVED STORMS WITHIN 50 PERCENT of PMP

To give the user some insight on the magnitude of PMP, we have identified the known storm depths that are $\geq$ 50 percent of PMP. For simplification the PMP for the midmonth in which the storm occurred is compared with the storm depth. For example, if a storm occurred on any day in March it is compared with PMP for mid-March. A March 1 storm would actually be a higher percent of March 1 PMP and a March 31 storm would be a lower percent of March 31 PMP. No comparisons were made for July and August, the months for which we accept the all-season PMP of HMR No. 51. Comparisons of observed rainfall to all-season PMP in HMR No. 51 are given by Riedel and Schreiner, 1980.

Figure 47 shows a seasonal plot of the number of known storms that are $\geq$ 50 percent of 10-mi^2 PMP for 6, 24, and 72 hours. As discussed earlier, undoubtedly, many more storms have reached 50 percent of PMP than have been sampled by the sparse network. That there are fewer cases in winter than

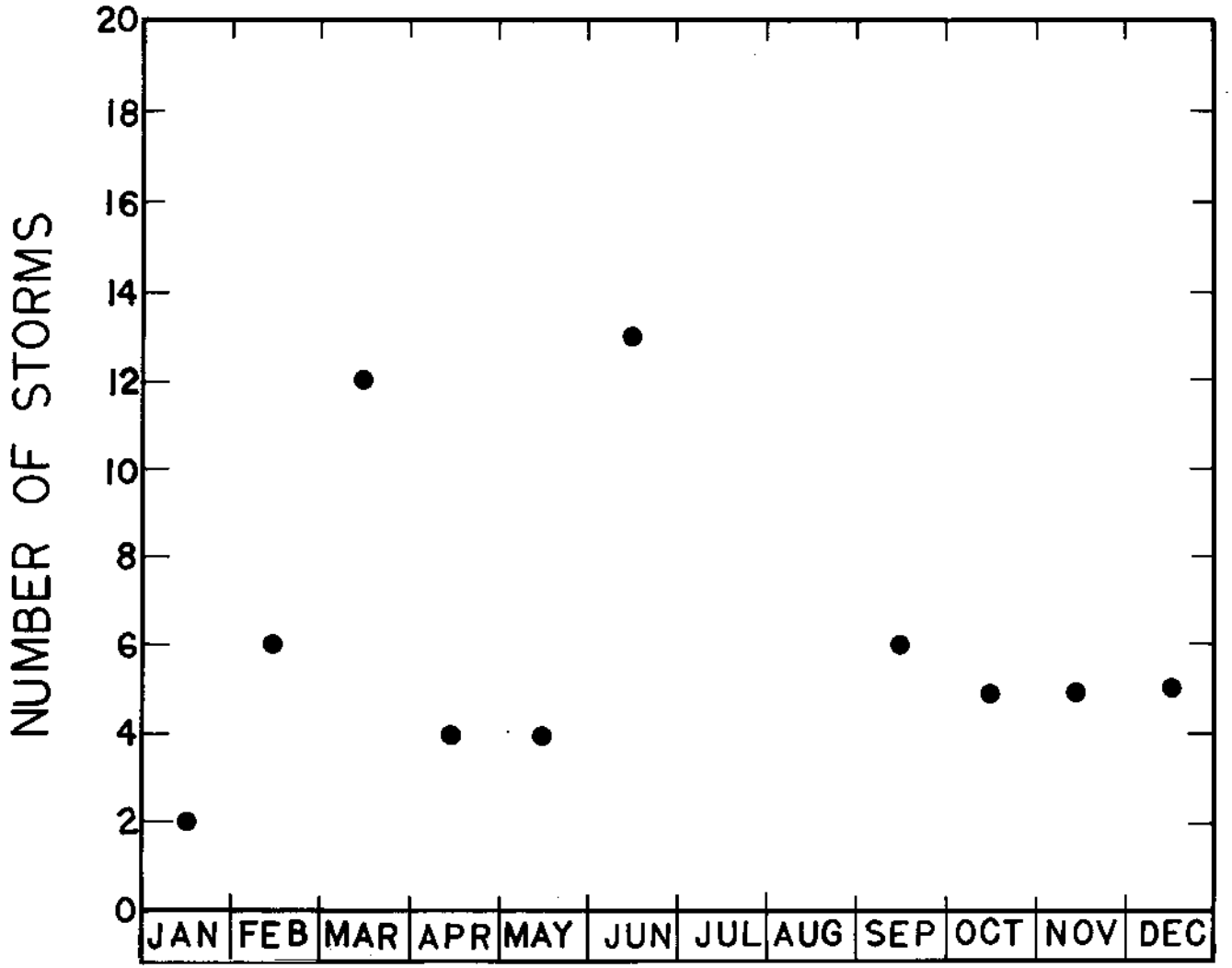

Figure 47.--Number of separate storms with rainfall ≥ 50% of PMP for 6, 24, and 72 hours (number of storms ≥ 50% of PMP for July and August can be obrained from Riedel and Schreiner 1980).

summer is in the right direction: fewer storms have been studied in the cool season and fewer surveys made after storm events to find extremes.

Table 6 lists chronologically the storms that have observed depths $\geq$ 50 percent of PMP for each month. Some of course are identical to the major storms of table 2.

We only show comparisons for rainfall depths for 6, 24, and 72 hours. If more durations were added (between 6 and 72 hours) many more storms would reach 50 percent of PMP and the percentages shown would be higher.

Table 6.--Known storm rainfalls for 6, 24 and 72 hours that are within 50 percent of mid-month PMP for the month in which the storm occurred (July and August storms not included)

Date	Storm number	Lat.	Long.	Dur. (hrs)	Obs. Precip. (in.)	% of PMP	COE Assign. No.	Source*
Jan.1-2,1941	3	48°00	89°42	24	4.7	65		TP No. 16
Jan.22-27,1949	5	35°52	92°19	6	7.5	52	SW3-10	STR
				24	11.7	54		
Feb.2-18,1883		41°42	77°16	6	3.6	60	OR5-11	STR
Feb.12,1886		41°54	71°23	24	7.9	56		STR
Feb.6,1960		43°07	73°35	24	5.1	61		DTD
Feb.25-27,1969	12	44°16	71°18	24	8.4	86		DTD
				72	14.1	68		
Feb.10-11,1970	13	44°16	71°18	6	4.7	89		DTH
				24	10.2	100		
Feb.1,1973	14	32°56	92°36	6	10.6	65		DTH
Mar.13,1888		42°43	73°18	24	6.1	52		TP No. 16
Mar.28,1902		35°41	85°48	24	11.0	50		TP No. 16
Mar.23-27,1913	17	40°22	83°46	24	7.3	55	OR1-15	STR
				72	10.4	61		
Mar.11-16,1929	19	31°25	86°04	6	14.0	73	LMV2-20	STR
				24	20.0	65		
				72	29.6	74		
Mar.12,1936		44°16	71°15	24	6.5	66		TP No. 16
Mar.22,1949		44°25	72°16	24	5.0	55		TP No. 16 (update)
Mar.31,1951		41°56	74°23	24	6.7	57		TP No. 16 (update)
Mar.25,1964	21	35°37	84°12	6	7.5	55		DTH
Mar.16-18,1965	22	46°53	90°49	72	6.6	54		DTD
Mar.25,1965		41°34	75°52	6	4.3	57		DTH
Mar.2-5,1966	23	47°14	98°35	24	4.7	57		STR
Mar.14,1973	24	44°21	103°46	24	5.7	71		DTD
Apr.11-14,1933	26	43°08	70°56	6	4.9	52	NA1-23	STR
Apr.3-4,1934	27	35°37	99°40	6	17.3	73	SW2-11	STR
Apr.24-28,1937	28	39°40	77°54	72	11.3	53	SA5-13	STR
Apr.21,1951		33°21	94°30	6	14.2	53		DTH
May 30-June 1, 1889		41°45	77°17	6	7.4	53	SA1-1	STR
May 30-31,1935	34	39°36	102°08	6	16.5	82	MR 3-28A	STR
				24	22.2	83		
May 6-12,1943	35	35°29	95°18	72	24.9	56	SW2-20	STR
May 12-20,1943		35°52	96°04	6	15.9	56	SW2-21	STR
June 13-18,1886	38	31°19	92°33	72	29.0	53	LMV4-27	STR
June 27-Jul.1, 1899		30°52	96°32	72	34.5	64		STR
June 17-21,1921	39	47°18	105°35	6	10.5	55	MR4-21	STR
				24	13.3	53		
				72	14.6	53		
June 30,1932		30°01	99°07	24	31.7	75	GM5-1	STR
June 19-20,1939		32°44	100°55	6	18.8	71		STR
June 10-13,1944		41°52	97°03	6	13.4	53	MR6-15	STR
June 23-24,1948	42	29°22	100°37	24	26.2	66		STR
June 23-28,1954	43	30°12	101°35	6	16.0	61	SW3-22	STR
				24	26.7	71		
				72	34.6	77		

See notes at the end of the table.

Table 6.--Known storm rainfalls for 6, 24 and 72 hours that are within 50 percent of mid-month PMP for the month in which the storm occurred (July and August storms not included) (Continued)

Date	Storm number	Lat.	Long.	Dur (hrs)	Obs. Precip. (in)	% of PMP	COE Assign. No.	Source
June 8-10,1962		44°12	103°31	72	14.9	62		DTD
June 23-24,1963	45	41°14	97°05	6	14.6	57		STR
				24	16.2	51		
June 24,1966	46	47°21	101°19	6	11.1	53		STR
June 9,1972	47	44°12	103°13	24	14.9	54	MR10-12	STR
June 20-22,1972	48	42°05	78°10	24	14.3	52	NA2-24A	STR
				72	18.5	58		
Sept.8-10,1921	49	30°35	97°18	6	22.4	74	GM4-12	STR
				24	36.5	84		
				72	37.6	72		
Sept.17-19,1926	50	43°12	96°00	6	15.1	62	MR4-24	STR
				24	21.7	71		
Sept.14-18,1936		31°47	100°50	24	26.0	68		STR
				72	30.0	65		
Sept.1,1940	52	39°42	75°12	6	20.1	76	NA2-4	STR
Sept.2-6,1940	53	36°15	96°36	6	18.4	65	SW2-18	STR
				24	23.6	64		
Sept.3-7,1950	54	29°03	82°42	24	38.7	81	SA5-8	STR
				72	45.2	82		
Oct.7-11,1903	56	40°55	74°10	24	13.7	51	GL4-9	STR
Oct.17-22,1941	57	29°48	82°57	24	30.0	73	SA5-6	STR
				72	35.0	66		
Oct.11-18,1942	58	38°31	78°26	72	18.7	52	SA1-28A	STR
Oct.30-Nov.1,	70	30°41	81°28	24	22.0	67		DTD
1969				72	22.6	56		
Oct.10-11,1973	63	36°25	97°52	6	16.9	77		STR
Nov.7,1915	65	48°54	103°18	24	4.0	56		TP No. 16
Nov.2-4,1927	67	44°03	71°45	6	7.8	78	NA1-17	STR
				24	12.0	79		
				72	14.0	71		
Nov.22-25,1940	69	30°08	96°08	24	18.6	59	GM5-13	STR
				72	21.1	53		
Nov.1,1948		37°02	99°59	6	6.1	50		DTH
Nov.13,1954		24°33	81°48	24	19.9	62		TP No. 2
Dec.5-8,1935	72	29°54	95°37	24	18.6	66	GM5-4	STR
				72	20.8	57		
Dec.29-Jan.1,								
1949	73	42°40	73°19	24	8.1	62	NA2-18	STR
				72	12.6	73		
Dec.20,1959		37°25	82°01	6	6.7	56		DTH
Dec.26-28,1969	74	44°16	71°18	6	3.3	55		DTD
				24	8.6	77		
				72	10.4	70		
Dec. 26-28,1969		44°40	70°09	24	6.0	51		TP No. 16
				72	10.0	71		(update)

COE: Corps of Engineers
* : Source
STR: Storm rainfall
TP No. 16: Technical Paper No. 16
DTD: Data tape; daily precipitation
DTH: Data tape; hourly precipitation

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Part XII: Oregon, Part XIII: Kentucky, Part XIV: Louisiana, Part XV: Alabama, Part XVI: Pennsylvania, Part XVII: Mississippi, Part XVIII: West Virginia, Part XIX: Tennessee, Part XX: Indiana, Part XXI: Illinois, Part XXII: Ohio, Part XXIII: California, Part XXIV: Texas, Part XXV: Arkansas, Part XXVI: Oklahoma. *Technical Paper* No. 15, Department of Commerce, Washington, D.C.

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