NOAA Technical Report NWS 25

Comparison of Generalized Estimates of Probable Maximum Precipitation With Greatest Observed Rainfalls

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WB 10 Hemispheric Teleconnections of Mean Circulation Anomalies at 700 Millibars. James F. O'Connor, National Meteorological Center, February 1969, 103 p.

WB 11 Monthly Mean 100-, 50-, 30-, and 10-Millibar Charts and Standard Deviation Maps, 1966-1967. Staff, Upper Air Branch, National Meteorological Center, April 1969, 124 p.

WB 12 Weekly Synoptic Analyses, 5-, 2-, and 0.4-Millibar Surfaces for 1967. Staff, Upper Air Branch, National Meteorological Center, January 1970, 169 p.

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NWS 13 The March-April 1969 Snowmelt Floods in the Red River of the North, Upper Mississippi, and Missouri Basins. Joseph L. H. Paulhus, Office of Hydrology, October 1970, 92 p. (COM-71-50269)

NWS 14 Weekly Synoptic Analyses, 5-, 2-, and 0.4-Millibar Surfaces for 1968. Staff, Upper Air Branch, National Meteorological Center, May 1971, 169 p. (COM-71-50383)

NWS 15 Some Climatological Characteristics of Hurricanes and Tropical Storms, Gulf and East Coasts of the United States. Francis P. Ho, Richard W. Schwerdt, and Hugo V. Goodyear, May 1975, 87 p. (COM-75-11088)

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TABLES

ILLUSTRATIONS

COMPARISONS OF GENERALIZED ESTIMATES OF PROBABLE MAXIMUM PRECIPITATION WITH GREATEST OBSERVED RAINFALLS

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ABSTRACT. This study summarizes known storms of record over the United States east of the 105th meridian and west of the Continental Divide that have point or areal rainfall depths that are ≥ 50 percent of PMP. More than 240 storms met this criteria. The storms are identified and percentages of PMP are shown on maps. Some judgement on the relative magnitude of PMP in the two large regions is given by comparison of the ratios of PMP to 100-yr return period rainfall. Such ratios for 24 hours range from 4 to 6 east of the 105th meridian. For the western mountainous states, these ratios are as low as 2 in the more mountainous locations and as high as 6 in the desert and sheltered spots.

1. INTRODUCTION

Studies by the Hydrometeorological Branch of the National Weather Service giving generalized estimates of probable maximum precipitation (PMP) have now been completed for the United States east of the 105th meridian and for the region west of the Continental Divide. These studies are used extensively by Federal, State and local government agencies, as well as private companies and individuals as a standard in planning and designing water control structures. The purpose of this report is to list and show on maps those storms of record that are within 50 percent of PMP. Additionally, we show ratios of point PMP values to values for the 100-year recurrence interval.

2. DEFINITIONS

PMP is defined as "the theoretically greatest depth of precipitation for a given duration that is physically possible over a particular drainage basin at a certain time of year." (American Meteorological Society 1959). Realizing there are yet unknowns in our understanding of the physical process responsible for extreme rainfall, we usually refer to the PMP values as estimates. Procedures for developing PMP estimates are not discussed in this study. These are given in detail in the referenced hydrometeorological studies and summarized in *Operational Hydrology Report No. 1, "Manual for Estimation of Probable Maximum Precipitation,"* (World Meteorological Organization 1973).

Generalized PMP estimates provide results for large regions and are presented on a series of maps or a combination of maps and computational procedures. Thus, the user can obtain PMP estimates for any basin within the range in area sizes and durations now required or expected to be required in the future. Other estimates are at times determined for specific drainages. These may be termed *site specific* PMP estimates.

Both *local* or *thunderstorm* PMP and *general storm* PMP were determined for the western states. These are both needed since the most intense station or point rainfalls of record in these states occur locally, not in connection with large scale weather patterns that produce rains over large areas for durations of a day or more*. This differs from storm experience in the United States east of the 105th meridian where extreme point rainfalls occur within general longer duration rain situations covering large areas. *Local storm* PMP is developed from storms that cover areas less than 500 mi^2 and have durations less than 6 hours. These are either thunderstorms or intense convective showers. Examples of this storm category are the 6.75-in. value in 1 hour at Morgan, Utah (8/16/1958), and the 8.25-in. value in 150 minutes at Chiatovich Flat, California (7/19/1955), with rainfall covering an area less than 100 mi^2. *General storm* PMP is based on storms covering areas larger than 1000 mi^2 and lasting a day or more. They are generally related to broadscale synoptic weather patterns, as exemplified by the September 3-5, 1970 tropical storm in Arizona and the January 19-24, 1943 storm in California. In these storms, 24-hour point rainfall amounts were 11.4 and 25.8 inches, respectively, and rain amounts over an inch covered areas of several thousand square miles.

All-season PMP is the greatest PMP regardless of season. As an example for large drainages, the *all-season* PMP is a late fall or winter event in California but a summer or early fall event in states bordering the Gulf of Mexico and Atlantic Ocean.

3. SOURCES OF PMP VALUES

Figure 1 outlines four regions for which generalized PMP estimates are available and table 1 lists the PMP studies and some pertinent information. Other generalized PMP studies are available but were not used in the comparisons. These include studies for specific large drainages, such as those for the Susquehanna River drainage (Goodyear and Riedel 1965) and the Tennessee River drainage (Schwarz and Helfert 1969). Valid comparisons with PMP in these reports would require an individual PMP estimate for the exact location of the isohyet encompassing the desired

*The area of Oregon and Washington West of the Cascade Divide is an exception. Here rainfall climatology shows that the most extreme point rainfalls have occurred in general storm situations.

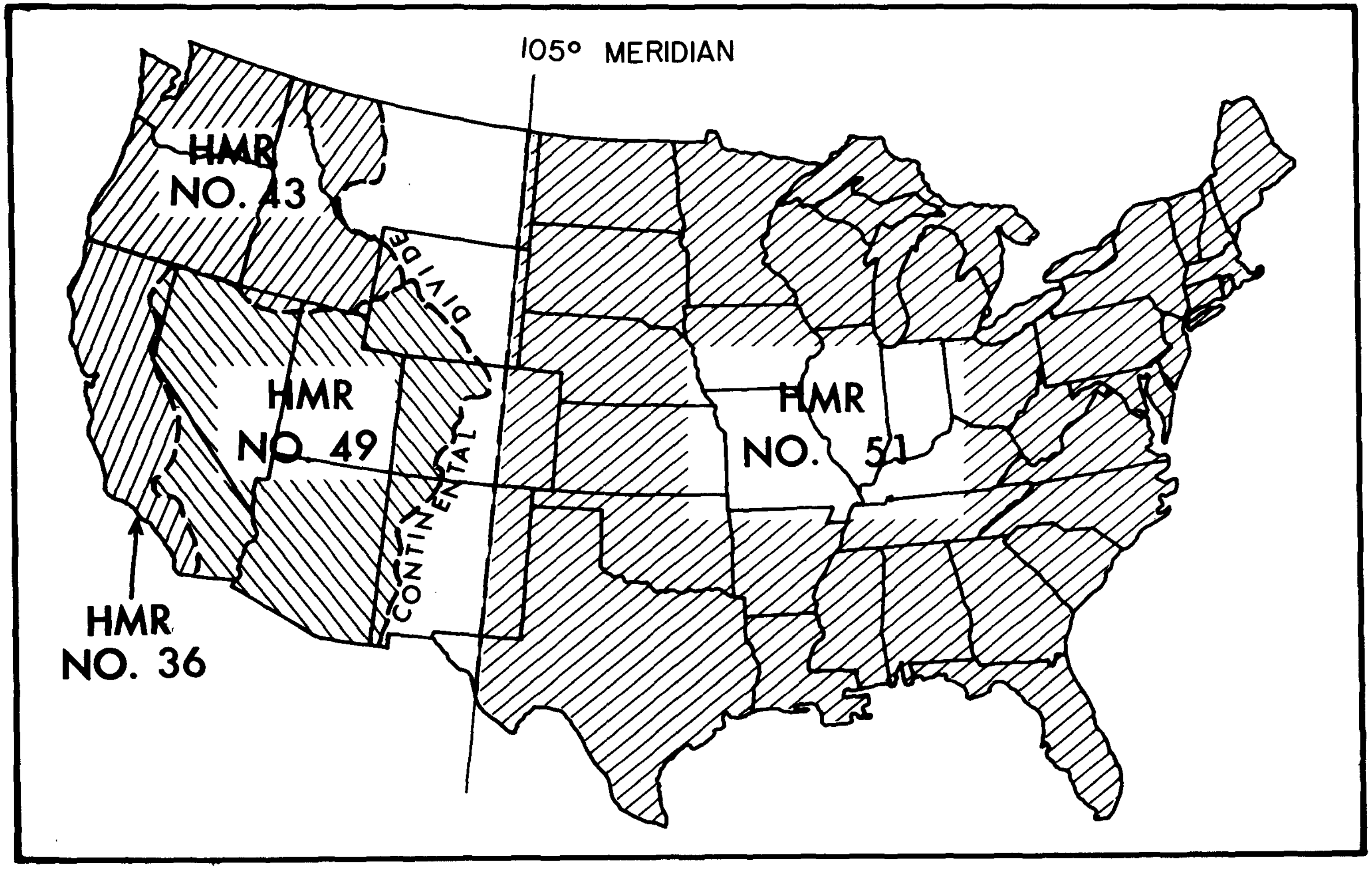

Figure 1.--Regions covered by generalized PMP studies used in comparisons.

area size. Since the average values of PMP in these studies are equivalent to that from *Hydrometeorological Report (HMR) No. 51, "Probable Maximum Precipitation Estimates, United States East of the 105th Meridian,"* (Schreiner and Riedel 1978), we consider such comparisons unnecessary for the present report. We have not included comparisons for the region between the Continental Divide and the 105th meridian even though a generalized study covers this region (U.S. Weather Bureau 1960). That study provides estimates for durations to only 24 hours and area sizes to 400 mi^2. This is a more restrictive range than in the other studies used in this comparison. In addition, the 1960 study provided estimates for the entire United States west of the 105th meridian, using a degree of generalization not comparable with that used in the other studies.

Table 1.--Generalized PMP Studies Used in Comparisons

Hydrometeorological Report	Geographic Bounds	Scope
No. 36 (U.S. Weather Bureau 1961 Revision, U.S. Weather Bureau 1969)	Pacific coast drainage of California	General storm PMP areas up to 5000 mi^2; 6 to 72 hrs. Each month, October-April
No. 43 (U.S. Weather Bureau 1966)	Columbia River and coastal drainages of Oregon and Washington	General storm PMP, areas up to 5000 mi^2; 6 to 72 hrs. Each month, October-June Local storm PMP, east of Cascades Ridge, areas up to 500 mi^2; durations to 6 hrs. Each month May-September
No. 49 (Hansen et. al 1977)	Colorado River and Great Basin drainages (also all of California for local storm PMP)	General storm PMP, areas up to 5000 mi^2; 6 to 72 hrs. Each of the 12 months Local storm PMP, areas up to 500 mi^2; durations up to 6 hrs. All season
No. 51 (Schreiner and Riedel 1978)	U.S. east of the 105th meridian	Areas from 10 to 20,000 mi^2; 6 to 72 hrs. All season

4. SOURCES OF GREATEST OBSERVED RAINFALLS

Surveys made after extreme storm and flood events usually uncover greater rainfall depths than those measured at stations that report regularly. This is so since there is little chance that the most intense (or near most intense) rainfall in a storm will occur over a preselected rain gage.

Many of the greatest rain catches from postflood surveys are used in storm depth-area-duration studies. Results of these studies giving maximum areal rainfall depths are included in a published catalog titled *Storm Rainfall in the United States, Depth-Area-Duration Data* (Corps of Engineers 1945-). Other accounts of extreme areal rainfall events studied in less detail have been added to a more inclusive catalog (Shipe and Riedel 1976). While this latter publication covers depths for selected areas between 100 and 10,000 mi^2, maximum depths for smaller areas down to station values and for larger areas are available in the data file used to prepare this publication. This augmented catalog is a comprehensive source for known maximum areal rainfall depths that have occurred over the contiguous United States.

Several studies of maximum station rainfalls for regular observing stations have been published. *Weather Bureau Technical Paper No. 15, "Maximum Station Precipitation for 1, 2, 3, 6, 12, and 24 hours,"* (U.S. Weather Bureau 1951-61) shows greatest depths for 1-, 2-, 3-, 6-, 12-, and 24-hr durations on a monthly basis for the period from 1940 to about 1950 for all regularly published recording gage stations in 33 states. *U.S. Weather Bureau Technical Paper No. 2, "Maximum Recorded United States Point Rainfall for 5 Minutes to 24 Hours at 207 First-Order Stations,"* (Jennings revised 1963) gives the greatest recorded depths through 1961 for various durations from 5 minutes to 24 hours at 296 first-order Weather Bureau stations. *U.S Weather Bureau Technical Paper No. 16, "Maximum 24-Hour Precipitation in the United States,"* (Jennings 1952) gives the greatest 24-hr or 1-day value of record through 1950 for each month for the regular reporting stations. This last report has been updated for the present comparisons through 1973 for all states.

5. PROCEDURE

5.1 Introduction

Our procedure was restricted to comparing large observed values with the all-season PMP. An alternative, would be to compare storms with the PMP for the month of the storm. We chose also to compare 10 mi^2 PMP with maximum station values, where these are available. In some cases, station values were not available and average depths over 10 mi^2 were used. For many earlier storms, there were insufficient data to distinguish between the two. Therefore, in *Storm Rainfall in the United States* (Corps of Engineers 1945-), station depths are used sometimes as 10-mi^2 depths.

5.2 U.S. East of the 105th Meridian

Generalized *all-season* PMP estimates for this region are given in *HMR No. 51* in map form for 10, 200, 1,000, 5,000, 10,000, and 20,000 mi^2 for durations of 6, 12, 24, 48, and 72 hours (30 maps). For each of these area size and duration combinations we have found all known storm depths that are 50 percent or more of PMP. These storm depths, in percent of PMP, are plotted in place of occurrence on charts 1 through 30. Table 2 lists these storms chronologically with index letters for identification on maps, a Corps of Engineers assignment number, if applicable from *Storm Rainfall in the United States* (Corps of Engineers 1945-), location of the storm center (by town, state and latitude/longitude), and chart numbers on which each storm appears. As an example, the 6/9-10/1905 storm, index AZ, Assignment No. UMV 2-5, centered near Bonaparte, Iowa, 40°42'N latitude and 91°48'W longitude, has observed values $\geq$ 50 percent of PMP for:

6 hr/1,000 mi^2 chart 11 (56%)	6 hr/10,000 mi^2, chart 21 (66%)
12 hr/1,000 mi^2, chart 12 (57%)	12 hr/10,000 mi^2, chart 22 (61%)
24 hr/1,000 mi^2, chart 13 (52%)	24 hr/10,000 mi^2, chart 23 (52%)
6 hr/5,000 mi^2, chart 16 (67%)	6 hr/20,000 mi^2, chart 26 (61%)
12 hr/5,000 mi^2, chart 17 (63%)	12 hr/20,000 mi^2, chart 27 (54%)
24 hr/5,000 mi^2, chart 18 (54%)	

A total of 177 separate storms are listed in table 2. Major rain centers, separated by more than 200 miles were listed as separate storms even if they occurred on the same date. In some cases depth-area-duration data from *Storm Rainfall in the United States* (Corps of Engineers 1945-) are given separately for different storm centers as well as for the entire storm area covered by individual centers. When this occurred, values for the different storm centers were compared if the centers were more than 200 miles apart. If the centers were closer together, comparisons were made for only the storm center giving the greatest rainfall depth.

The areal rainfall depths were compared with the PMP at the location of the maximum observed point rainfalls. This approximation avoided determining the actual location of the maximum depth, and determining the average PMP for possibly an odd-shaped isohyet. Generally, if the location of the maximum areal depth is farther south than the maximum point depth, the true percentage of PMP is less than shown; on the other hand, if the location is farther north, the true percentage is greater than that shown on the charts. Except for unusually shaped isohyets these differences would be only a few percent.

5.3 U.S. West of the Continental Divide

Topographic influences in the western states make it difficult to prepare simple mapped values of PMP as is done for the region east of the 105th meridian*. Without such PMP maps for selected area sizes and durations, it

*We should note that the PMP maps for *HMR No. 51* are stippled in the regions near the 105th Meridian and the Appalachian Mountains to indicate possible topographic influences on PMP estimates that are not covered in *HMR No. 51*. Such complications were not considered in the comparisons.

Table 2.--Storms with rainfall ≥ 50% of PMP (6 area sizes and 5 durations) U.S. east of the 105th meridian

Storm date	Index	Corps assignment	No.	Town	Storm center State	Lat.	Long.	Chart(s) on which storm appears
7/26/1819	AA			Catskill	NY	42°12	73°53	1,2,3,4,5
8/5/1843	AB			Concordville	PA	39°53	75°32	1
10/3-4/1869	AC	NA	1-2	Canton	CT	41°50	72°54	17,18
9/28-10/1/1870	AD	SA	5-17	Lexington	VA	37°41	79°25	18,22,23,27,28
9/10-13/1878	AE	OR	9-19	Jefferson	OH	41°45	80°46	8,9,10,12,13,14,15,16,17,18,19,20, 21,22,23,24,25,26,27,28,29,30
9/20-24/1882	AF	NA	1-3	Paterson	NJ	40°55	74°10	9,10,14,15,20,24,25
3/26-4/1/1886	AG			Pink Beds	NC	35°22	82°47	29,30
6/13-17/1886	AH	LMV	4-27	Alexandria	LA	31°19	92°33	4,5,7,8,9,10,11,12,13,14,15,16,17, 18,19,20
5/30-6/1/1889	AI	SA	1-1	Wellsboro	PA	41°45	77°17	11,16,18,19,23,24,25,26,28,29,30
6/23-27/1891	AJ	MR	4-2	Larrabee	IA	42°52	95°30	13,18
8/24-27/1892	AK	GL	1-3	N. Hammond	NY	44°27	75°46	26
12/16-20/1895	AL	MR	1-1	Phillipsburg	MO	37°34	92°47	19,20,24,25,29,30
6/4-7/1896	AM	MR	4-3	Greeley	NE	41°33	98°32	6,7,11,12,13
9/27-30/1896	AN	SA	1-19	Bloomery	WV	39°23	78°22	26,28
7/18-22/1897	AO	UMV	1-2	Lambert	MN	47°47	95°55	28
7/25-27/1897	AP	GL	4-5	Butternut	WI	46°00	90°30	13,18,19,23
6/27-7/1/1899	AQ	GM	3-4	Hearne	TX	30°52	96°32	3,4,5,8,9,10,13,14,15,17,18,19,20, 22,23,24,25,26,27,28,29,30
4/15-18/1900	AR	LMV	2-5	Eutaw	AL	32°47	87°50	17,18,21,22,23,24,26,27,28,29,30
7/14-17/1900	AS	MR	1-5	Primghar	IA	43°05	95°38	18,19,20,23,24,25,28,29
9/7-11/1900	AT	UMV	1-6	Elk Point	SD	42°41	96°40	28
8/24-28/1903	AU	MR	1-10	Woodburn	IA	40°57	93°35	12,13,14,17,18,19,20,22,23,24,27, 28,29
10/7-11/1903	AV	GL	4-9	Paterson	NJ	40°55	74°10	8,13,14,15,18,19,20,23,24,25,28, 29,30
6/1-5 1904	AW	SW	1-5	Hartshorne	OK	34°51	95°33	16,21,26

Table 2.--Storms with rainfall ≥ 50% of PMP (6 area sizes and 5 durations) U.S. east of the 105th meridian (continued).

Storm date	Index	Corps assignment	No.	Town	Storm center State	Lat.	Long.	Chart(s) on which storm appears
12/23-27/1904	AX	LMV	3-10	Liberty Hill	LA	32°20	92°52	28
6/3-8/1905	AY	GL	2-12	Medford	WI	45°08	90°20	21,24,26,28,29,30
6/9-10/1905	AZ	UMV	2-5	Nr. Bonaparte	IA	40°42	91°48	11,12,13,16,17,18,21,22,23,26,27
8/4-6/1906	BA	GM	3-14	Knickerbocker	TX	31°17	100°48	16,17,21,22,26,27
11/17-21/1906	BB	LMV	1-4	Austin	MS	34°39	90°28	30
5/28-31/1907	BC	LMV	3-13	Sugarland	TX	29°36	95°38	16,21,26
5/21-25/1908	BD	SW	1-10A	Chattanooga	OK	34°25	98°39	29,30
5/21-25/1908	BDD	SW	1-10B	Sabinal	TX	29°19	99°28	26
8/23-28/1908	BE	SA	2-5	Vademecum	NC	36°26	80°28	19,20,24,25,29,30
10/18-19/1908	BF	SW	2-23	May Valley	CO	38°03	102°38	22,23,26,27,28
10/19-24/1908	BG	SW	1-11	Meeker	OK	35°30	96°54	19,20,24,25,29,30
7/18-23/1909	BH	UMV	1-11B	Ironwood	MI	46°27	90°11	14,15,19,20,24
7/18-23/1909	BHH	UMV	1-11A	Beaulieu	MN	47°21	95°48	6,7,8,11,12,13,14,15,16,17,18,19,20
10/3-6/1910	BI	OR	4-8	Golconda	IL	37°22	88°29	15,19,20,23,24,25,28,29,30
7/22-23/1911	BJ			Swede Home	NE	40°22	96°54	1,6,7,11
8/28-31/1911	BK	SA	3-11	St. George	GA	30°30	82°02	6,11
12/9-10/1911	BL			Nr. Knickerbkr	TX	31°17	100°38	26
7/19-24/1912	BM	GL	2-29	Merrill	WI	45°11	89°41	8,13,18,23,28
3/23-27/1913	BN	OR	1-15	Bellefontaine	OH	40°22	83°46	19,20,23,24,25,28,29,30
6/28/1913	BO			Montell	TX	29°32	100°01	3
3/24-28/1914	BP	LMV	3-19	Merryville	LA	30°46	93°32	16,17,21,22,26
4/29-5/2/1914	BQ	SW	1-16	Clayton	NM	36°20	103°06	18,23,24,28,29
6/25-28/1914	BR	MR	4-14A	Hazelton	ND	46°29	100°17	21,26,27
8/31-9/1/1914	BS	GL	2-16	Cooper	MI	42°25	85°35	6
4/22-26/1915	BT	GM	4-1	Austin	TX	30°18	97°42	16,21,26
8/16-21/1915	BU	LMV	1-10	San Augustine	TX	31°31	94°07	19,20,24,25,29,30
9/28-30/1915	BV	LMV	2-13	Franklinton	LA	30°51	90°10	16,17,21,22,26,27,28

Table 2.--Storms with rainfall ≥ 50% of PMP (6 area sizes and 5 durations) U.S. east of the 105th meridian (continued).

Storm date	Index	Corps assignment No.		Town	Storm center State	Lat.	Long.	Chart(s) on which storm appears
7/5-10/1916	BW	GM	1-19	Bonifay	FL	30°49	86°19	11,12,16,17,18,19,20,21,22,23,24, 25,26,27,28,29,30
7/13-17/1916	BX	SA	2-9	Altapass	NC	35°53	82°01	3,4,5,8,9,10,12,13,14,15,17,18,19, 20,22,23,24,25,28,29,30
10/26-31/1918	BY	SA	3-14	Highlands	NC	35°02	83°12	26
3/15-17/1919	BZ	LMV	1-12	Henderson	TN	35°25	88°39	21,22,23,26,27,28
9/14-15/1919	CA	GM	5-15A	George West	TX	28°21	98°07	28
9/16-19/1919	CB	MR	2-23	Bruning	NE	40°20	97°34	23,28,29
10/25-28/1919	CC	LMV	1-13A	Steelville	MO	37°59	91°22	24,29,30
9/8-10/1921	CD	GM	4-12	Thrall	TX	30°35	97°18	1,2,3,4,5,6,7,8,9,10,11,12,13,14, 15,16,17,18,19,20,21,22,23,24
7/9-12/1922	CE	MR	2-29	Grant City	MO	40°29	94°25	11
9/13-17/1924	CF	SA	3-16	Beaufort	NC	34°44	76°39	23,28,29,30
10/4-11/1924	CG	SA	4-20	New Smyrna	FL	29°07	80°55	7,8
5/27-29/1925	CH	GM	4-21	Eagle Pass	TX	28°43	100°30	21,26
9/8-9/1926	CI	OR	4-22	Charleston	IL	39°30	88°11	26
9/11-16/1926	CJ	SW	2-1	Neosha Falls	KS	38°00	95°33	6,11
9/17-19/1926	CK	MR	4-24	Nr. Boyden	IA	43°12	96°00	1,2,3,4,5,6,7,8,9,10,11,12,13,14, 16,17,18,22,23,27,28
9/17-21/1926	CL	SA	4-23	Bay Minette	AL	30°53	87°47	17,18,22,23,24,26,27,28,29
2/11-14/1927	CM	LMV	4-6	Clinton	LA	30°32	91°00	21,26
4/12-16/1927	CN	LMV	4-8	Jeff-Plaq.Dr.Di.	LA	29°40	90°05	7,12,16,17,18,21,22,23,26,27,28
7/12-15/1927	CO	SW	2-5	Ardmore	OK	34°12	97°08	16,21
8/11-14/1927	CP	MR	3-13	Bison	KS	38°31	99°12	16,21

Table 2.--Storms with rainfall ≥ 50% of PMP (6 area sizes and 5 durations) U.S. East of the 105th meridian (continued).

Storm date	Index	Corps assignment No.		Storm center: Town	State	Lat.	Long.	Chart(s) on which storm appears
11/2-4/1927	CQ	NA	1-17	Kinsman Notch	NH	44°03	71°45	12,17,18,19,20,22,23,24,25,26,27, 28,29,30
6/1-5/1928	CR	LMV	2-18	Thomasville	AL	31°55	87°45	19,23,24,27,28,29,30
8/10-13/1928	CS	NA	1-18	Cheltenham	MD	38°44	76°51	24,29
9/10-14/1928	CT	MR	3-19	Centerville	IA	40°43	92°53	26
9/16-19/1928	CU	SA	2-15	Darlington	SC	34°17	79°52	17,18,22,23,24,26,27,28,29,30
11/15-17/1928	CV	MR	3-20	Lebo	KS	37°55	95°26	19,23,24,25,28,29,30
3/11-16/1929	CW	LMV	2-20	Elba	AL	31°25	86°04	4,5,6,9,10,11,14,15,16,17,18,19,20, 21,22,23,24,25,26,27,28,29,30
3/21-23/1929	CX	OR	7-15	Rock Island	TN	35°48	85°38	21,22,26,27,28
5/25-30/1929	CY	GM	4-26	Henly	TX	30°12	98°13	21,26
9/23-28/1929	CZ	SA	3-20	Washington	GA	31°56	81°56	16,17,19,24,29,30
6/30-7/2/1932	DA	GM	5-1	State Fish Hatchery	TX	30°10	99°21	1,2,3,4,5,7,8,9,10,13,14,15,16,17, 18,19,20,21,22,23,24,25,28,29
8/30-9/5/1932	DB	GM	5-16A	Fairfield	TX	31°44	96°10	13
9/16-17/1932	DC	NA	1-20B	Ripogenus Dam	ME	45°53	69°09	6,7,8,11,12,13,14,16,17,18,19,20, 21,22,23,24,25
9/16-17/1932	DD	NA	1-20A	Westerly	RI	41°22	71°50	12,13,16,17,18,21,22,23
10/4-6/1932	DE	NA	1-21	Elka Park	NY	42°10	74°14	28
10/15-18/1932	DF	SA	5-11A	Rocky Mount	VA	37°00	79°54	28
7/22-27/1933	DG	LMV	2-26	Logansport	LA	31°58	94°00	14,15,18,19,20,23,24,25,28,29,30
8/20-24/1933	DH	NA	1-24B	York	PA	39°55	76°45	18,20,22,23,25,26,27,28,30
9/13-18/1933	DI			Provincetown	MA	42°03	70°17	12,20
2/27-3/4/1934	DJ	LMV	4-19	DeRidder	LA	30°50	93°16	21,26

Table 2.--Storms with rainfall ≥ 50% of PMP (6 area sizes and 5 durations) U.S. East of the 105th meridian (continued).

Storm date	Index	Corps assignment No.		Town	Storm center State	Lat.	Long.	Chart(s) on which storm appears
4/3-4/1934	DK	SW	2-11	Cheyenne	OK	35°37	99°40	1,2,3,4,5,6,7,8,9,10,11,12,13
1/18-21/1935	DL	LMV	1-19	Hernando	MS	34°50	90°00	29
5/16-20/1935	DM	LMV	4-21	Simmesport	LA	30°59	91°48	6,11,16,17,21,22,26,27
5/30-31/1935	DN	MR	3-28A	Cherry Creek	CO	39°13	104°32	1,2,3,4,5,6,7,8,9,10,11,12
5/31/1935	DO	GM	5-20	Woodward Ranch	TX	29°20	99°18	1,2,6,7,11
6/10-15/1935	DP	GM	5-2	Segovia	TX	30°22	99°38	17
7/6-10/1935	DQ	NA	1-27	Hector	NY	42°30	76°53	9,13,14,15,18,19,20,23,24,25,30
9/2-6/1935	DR	SA	1-26	Easton	MD	38°46	76°01	14,15,18,19,20,22,23,24,25,26,27, 28,29,30
6/27-7/4/1936	DS	GM	5-6	Bebe	TX	29°24	97°39	6,11,12,16,17,21,22,26,27
9/14-18/1936	DT	GM	5-7	Broome	TX	31°47	100°50	1,2,3,4,5,7,8,9,10,12,13,14,15,17, 18,19,20,23,24,25,28,29,30
9/25-28/1936	DU	GM	5-8	Hillsboro	TX	32°01	97°08	28
1/5-25/1937	DV	OR	5-6	McKenzie	TN	36°07	88°33	29,30
8/31-9/3/1937	DW	GL	3-5	Wolverine	MI	45°17	84°37	16
5/30-31/1938	DX	MR	3-29	Sharon Springs	KS	38°54	101°45	16,21
7/19-25/1938	DY	GM	5-10	Eldorado	TX	30°46	100°44	15,20,25,30
8/12-15/1938	DZ	LMV	4-23	Koll	LA	30°20	92°45	16,21,26
9/17-22/1938	EA	NA	2-2	Buck	CT	41°40	72°40	10,15,19,20,24,25,28,29,30
6/19-20/1939	EB			Snyder	TX	32°44	100°55	1,2,3,6
7/4-5/1939	EC	OR	2-15	Simpson	KY	38°13	83°22	1,2,3,4,6,7,8,11,12
8/19/1939	ED	NA	2-3	Manahawkin	NJ	39°42	74°16	2,3,7,8,9,11,12,13,17
6/3-4/1940	EE	MR	4-5	Grant Township	NE	42°01	96°53	1,6,7,11,12,16,17,22,27
6/28-30/1940	EF	GM	5-11	Engle	TX	29°41	97°01	7
6/30-7/2/1940	EG	LMV	4-25	Index	AR	33°35	94°03	16
8/6-9/1940	EH	LMV	4-24	Miller Island	LA	29°45	92°10	3,4,5,8,9,10,13,14,15,18,19,20,24, 25,29,30
8/10-17/1940	EI	SA	5-19A	Keysville	VA	37°03	78°30	14,15,19,20,24,25,29,30

Table 2.--Storms with rainfall ≥ 50% of PMP (6 area sizes and 5 durations) U.S. east of the 105th meridian (continued).

Storm date	Index	Corps assignment	No.	Town	State	Storm Center Lat.	Storm Center Long.	Chart(s) on which storm appears
9/1/1940	EJ	NA	2-4	Ewan	NJ	39°42	75°12	1,2,3,4,5,6,7,8,9,10,11,12
9/2-6/1940	EK	SW	2-18	Hallett	OK	36°15	96°36	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15 17,22
11/22-25/1940	EL	GM	5-13	Hempstead	TX	30°08	96°08	19,20,23,24,25,29,30
8/28-31/1941	EM	UMV	1-22	Hayward	WI	46°00	91°28	7,8,9,10,12,13,14,15,17,18,19,20, 23,24,25,28,29,30
9/20-23/1941	EN	GM	5-19	Dave McColleum Ranch	NM	32°10	104°44	4,5,24,25,27,28,29,30
10/17-22/1941	EO	SA	5-6	Trenton	FL	29°48	82°57	2,3,4,5,7,8,9,10,12,13,14,15,17,18, 19
7/17-18/1942	EP	OR	9-23	Smethport	PA	41°50	78°25	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15
10/11-17/1942	EQ	SA	1-28A	Big Meadows	VA	38°31	78°26	9,10,14,15,19,20,24,25,29,30
12/27-30/1942	ER			Ashville	AL	33°51	86°20	17,21,22,26,27
5/6-12/1943	ES	SW	2-20	Warner	OK	35°29	95°18	4,5,9,10,14,15,18,19,20,23,24,25, 28,29,30
5/12-20/1943	ET	SW	2-21	Nr. Mounds	OK	35°52	96°04	1,6,7,20,25,29,30
6/5-7/1943	EU	SW	3-3	Silver Lake	TX	32°40	95°36	7,12,17
7/27-29/1943	EV	GM	5-21	Devers	TX	30°02	94°35	14,19,20,24,29
8/4-5/1943	EW	OR	3-30	Nr. Glenville	WV	38°56	80°50	1
6/10-13/1944	EX	MR	6-15	Nr. Stanton	NE	41°52	97°03	1,2,3,6,7,8,9,10,11,12,13
6/26-27/1944	EY			Portal	ND	49°00	102°23	19,23,24,28,29,30
9/12-15/1944	EZ	NA	2-16	New Brunswick	NJ	40°29	74°27	20,21,25,26,30
3/28-4/2/1945	FA	SW	3-5	Nr. Van	TX	32°20	95°42	24,29
8/26-29/1945	FB	GM	5-23	Hockley	TX	30°02	95°51	23,28
8/12-15/1946	FC	MR	7-2A	Cole Camp	MO	38°29	93°13	9,10,14,15,19,20,24,25,29,30
8/12-16/1946	FD	MR	7-2B	Nr. Collins-ville	IL	38°40	89°59	9,10,14,15,19,20,24,25
9/26-27/1946	FE	GM	5-24	Nr. San Antonio	TX	29°20	98°29	1,6,7

Table 2.--Storms with rainfall ≥ 50% of PMP (6 area sizes and 5 durations) U.S. east of the 105th meridian (continued).

Storm date	Index	Corps assignment	No.	Town	Storm center State	Lat.	Long.	Chart(s) on which storm appears
10/3-5/1946	FF			Nr. Brewster	NE	41°57	99°52	22,27,28
4/4-5/1947	FG			Lockport	IL	41°34	88°05	26
8/27-28/1947	FH	SW	3-7A	Wickes	AR	34°14	94°20	6,11
6/23-24/1948	FI			Nr. Del Rio	TX	29°22	100°37	2,3,4,5,7,8,9,10,11,12,13,14,15,16, 17,18,19,21,22,23
12/29/1948-1/1/1949	FJ			Berlin	NY	42°40	73°19	19,20
9/3-7/1950	FK	SA	5-8	Yankeetown	FL	29°03	82°42	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15, 16,17,18,19,20,22,23,24,25,28,29,30
7/8-9/1951	FL			Gridley	IL	40°45	88°49	6,11,16,21
7/9-13/1951	FM	MR	10-2	Nr. Council Grove	KS	38°40	96°49	10,15,19,20,24,25,29,30
4/23-5/4/1953	FN	LMV	5-3	Camp Polk	LA	31°04	93°12	17,21,22,23,26,27,28
5/11-19/1953	FO	LMV	5-4	Harrisonburg Dam	LA	31°46	91°49	19,25,29,30
6/7/1953	FP	MR	10-8	Ritter	IA	43°15	95°48	16,17,18,21,22,23
6/23-28/1954	FQ	SW	3-22	Vic Pierce	TX	30°22	101°23	1,2,3,4,5,6,7,8,9,10,12,13,14,15,18, 19,20,24,25,29
10/9-10/1954	FR			Aurora	IL	41°45	88°20	13,18,23
8/10-15/1955	FS	NA	2-21B	New Bern	NC	35°07	77°03	27,28
8/11-15/1955	FT	NA	2-21A	Slide Mt.	NY	42°01	74°25	19,20,24,25,29,30
8/17-20/1955	FU	NA	2-22A	Westfield	MA	42°07	72°45	3,4,5,7,8,9,10,11,12,13,14,15,16,17, 18,19,20,21,22,23,24,25,26,27,28,29, 30
5/15-16/1957	FV			Hennessey	OK	36°02	97°56	3,8,9,13
6/14-15/1957	FW			Nr. E. St. Louis	IL	38°37	90°27	7,8,12,13

Storm 2.--Storms with rainfall ≥ 50% of PMP (6 area sizes and 5 durations) U.S. east of the 105th meridian (concluded)

Storm date	Index	Corps Assignment	No.	Town	State	Storm center Lat.	Storm center Long.	Chart(s) on which storm appears
6/27-28/1957	FX			Nr.Win-chester	IL	39°38	87°42	16,18,21,23
7/1-2/1958	FY			Audubon	IA	41°43	94°56	6
9/10-13/1961	FZ	LMV	5-16	Bay City	TX	28°58	95°57	24,27,28,29,30
9/11-13/1961	GA			Shelbina	MO	39°41	92°03	22,23,27,28,29,30
6/23-24/1963	GB			David City	NE	41°14	97°05	1,2,3,6,7,8
6/13-20/1965	GC			Holly	CO	37°43	102°23	8,9,10,13,14,15,18
7/20/1965	GD			Edgerton	MO	39°30	94°37	3
6/24/1966	GE			Glen Ullin	ND	47°21	101°19	1,2,6
8/12-13/1966	GF			Nr. Greely	NE	41°33	98°32	2,3,6,7,8,11,12,13
9/19-24/1967	GG	SW	3-24	Falfurrias	TX	27°16	98°12	4,5,9,10,14,15,19,20,24,25,29,30
7/16-17/1968	GH			Waterloo	IA	42°30	92°19	8,13
6/22-23/1969	GI			Scottsville	KY	36°44	86°13	17,21,22
7/4-5/1969	GJ			Nr. Wooster	OH	40°50	82°00	7,8,9,11,12,13,14,15,16,17,18,19
8/19-20/1969	GK	NA	2-23	Nr. Tyro	VA	37°49	79°00	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15, 16,17,18,22
6/9/1972	GL	MR	10-12	Rapid City	SD	44°12	103°31	2,3,7,8
6/19-23/1972	GM	NA	2-24A	Zerbe	PA	40°37	76°31	8,9,10,12,13,14,15,17,18,19,20,21,22, 23,24,25,26,27,28,29,30
7/21-22/1972	GN			Nr. Cushing	MN	46°10	94°30	9,10,11,12,13,14,15
9/10-12/1972	GO			Harlan	IA	41°43	95°15	4,5,9,10,14,15
10/10-11/1973	GP			Enid	OK	36°25	97°52	1,2,3,6,7,8,9
9/11-13/1977	GQ			Nr. Kansas City	MO	39°00	94°30	18
8/1-3/1978	GR*			Nr. Medina	TX	29°55	99°21	1,2,3,4,6,7,8,9,11,12,13,14
7/31/1979	GS*			Nr. Alvin	TX	29°30	95°18	3

*Preliminary limited comparisons.

is extremely time consuming to compare maximum areal depths with PMP. For example, say for a 1,000-mi^2 maximum depth, the exact location of the isohyet encompassing this 1,000-mi^2 area would need to be determined and the PMP computed for this location. The simplifying assumption (used east of the 105th meridian) that the center of this 1,000-mi^2 area would coincide with that of the maximum point rainfall cannot be used.

We therefore have compared in detail only generalized all-season PMP estimates for 10-mi^2 for 6- and 24-hr durations with maximum observed station depths for these durations. For 10-mi^2 the limitations on computing PMP are not as great. Generalized all-season PMP maps for these durations were based on PMP computations for each month specified in each of the three reports, (see table 1) on a quarter degree latitude-longitude grid for both the general storm and local storm. The greatest all-season value from the two storm types was then selected for each grid point. The local storm 10-mi^2 PMP for 6 hours exceeds the 6-hr general storm 10-mi^2 PMP over much of the western states. In fact, it exceeds the 24-hr 10-mi^2 general storm values for some regions, and is therefore used for those cases in the comparisons with 24-hr observed rainfalls.

We have made less detailed comparisons of maximum observed areal depths with PMP for 500 and 1000 mi^2 for both 24 and 48 hours. For the most part, these comparisons used the limited storm samplings provided in *Hydrometeorological Reports No. 36, "Interim Report--Probable Maximum Precipitation in California," No. 43, "Probable Maximum Precipitation, Northwest States," and No. 49, "Probable Maximum Precipitation Estimates, Colorado River and Great Basin Drainages."* For each of the comparisons we estimated the location covered by the maximum depth over 500 and 1000 mi^2 and computed PMP for each month for that location. The highest PMP or *all-season* value was then used.

Charts 31 through 36 of the United States west of the Continental Divide show observed storm rainfalls* that are 50 percent or more of PMP. Table 3 lists the storms chronologically as in table 2. There are 66 separate storm events for these six combinations of area sizes and durations. Major rain centers separated by more than 200 miles, although with the same storm date, are listed as separate events.

6. RESULTS

6.1 Comments

Chart 1 for 6 hours, 10 mi^2 shows two storms with percentages greater than 100 implying observed values greater than PMP. These are:

a) The Smethport, Pa. storm of July 17-18, 1942 (observed 30.8 + inches in 4-1/2 hours -- a world record for this duration);

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*The maximum station values for four storms are from isohyetal maps obtained by expressing observed storm depths in percent of mean annual precipitation and then through isopercental analyses obtaining a greater point depth. These cases are marked with an asterisk in table 3.

Table 3.--Storms with rainfall ≥ 50% of PMP, (3 area sizes and 3 durations) U.S. west of Continental Divide

	Index	Corps	Storm center				
Storm date	No.	assignment No.	Town	State	Lat	Long	Chart(s) on which storm appears
12/19-20/1866	HA		San Francisco	CA	37°46	122°28	32
11/22/1874	HB		Ft. Ross	CA	38°31	123°15	32
4/20/1880	HC		Sacramento	CA	38°35	121°30	32
12/12/1882	HD		Portland	OR	45°30	133°43	32
1/30/1888	HE		Upper Mattole	CA	40°15	124°11	32
10/12/1889	HF		Encinitas	CA	32°59	117°15	32
8/11/1890	HG		Palmetto	NV	37°27	117°42	31,32
8/12/1891	HH		Campo	CA	32°36	116°28	31,32
11/8/1893	HI		Glenora	OR	45°37	123°35	32
8/28/1898	HJ		Ft. Mohave	AZ	35°03	114°36	31,32
1/6/1901	HK		SantaMargarita	CA	35°23	120°36	32
2/12/1904	HL		Kentfield	CA	37°57	122°33	32
3/23-26/1906	HM		Nellie	CA	33°19	116°53	32,33,34,36
1/3/1907	HN		Port Orford	OR	42°45	124°30	32
2/1-5/1907	HO*		Nr. Charleston	NV	41°40	115°25	32
3/15-27/1907	HP		Nr. Stirling City	CA	39°55	121°25	32,34,36
1/11-16/1909	HQ		Nr. Meeks Bay	CA	39°00	120°25	32
11/18-23/1909	HR	NP4-6	Rattlesnake	ID	43°35	115°40	32
5/18/1911	HS		LaPorte	CA	39°41	120°59	32
10/4-6/1911	HT	SW2-30	Gladstone	CO	37°53	107°39	31,32,35
12/29/1913-1/3/1914	HU	SP1-19	Nr. Stirling City	CA	39°55	121°25	31,32
2/17-22/1914	HV		Colby Ranch	CA	34°18	118°07	31,32
1/23-2/2/1915	HW		Nr. McCloud	CA	41°10	122°00	32
12/21/1915	HX		Glenora	OR	45°37	123°35	32
1/14-19/1916	HY		Squirrel Inn	CA	34°15	117°16	32

Table 3.--Storms with rainfall $\geq$ 50% of PMP (3 area sizes and 3 durations) U.S. west of Continental Divide (continued)

Storm date	Index No.	Corps assignment No.	Town	State	Lat	Long	Chart(s) on which storm appears
2/20-25/1917	HZ		Nr. Wawona	CA	37°35	119°35	31,32
9/13/1918	IA		Red Bluff	CA	40°10	122°14	31
1/22/1919	IB		Astoria	OR	46°11	123°50	32
11/18/1920	IC		Fort Ross	CA	38°31	123°15	32
12/17-27/1921	ID	SP1-23	Opid's Camp	CA	34°15	118°06	32
2/10-22/1927	IE	SP-29	Raywood Flats	CA	34°04	116°50	32,33,34,35,36
11/12-17/1930	IF*		Nr. Charleston	NV	41°40	115°25	32
3/30-4/2/1931	IG*		Nr. Fish Lake	ID	46°30	114°50	32,33,34,35,36
2/26/1932	IH		Big Four	WA	48°05	121°30	31,32
6/9/1933	II		Brookings	OR	42°03	124°17	32
11/21/1933	IJ		Tatoosh Is.	WA	48°23	124°44	31
12/31/1933	IK		Lechuza	CA	34°05	118°53	32
1/20-25/1935	IL		Nr. Elk Park	WA	47°30	123°30	31,33,34,35,36
2/4-8/1937	IN		Cuyamaca Dam	CA	33°00	116°35	31
12/9-12/1937	IO		Hobergs	CA	38°51	122°43	31,32,34,36
2/26-3/4/1938	IP		Kelley's Camp	CA	34°14	117°36	31,32
10/31/1942	IR		Naselle	WA	46°22	123°49	32
1/19-24/1943	IS*		Nr. So. Entrance Yosemite N.P.	CA	37°35	119°25	32,35,36
1/19-24/1943	IT		Hoegees Camp	CA	34°13	118°02	31,32,33,34,35,36
2/22/1944	IU		Big Pines Park	CA	34°23	117°41	32

Table 3.--Storms with rainfall ≥ 50% of PMP (3 area sizes and 3 durations) U.S. west of Continental Divide (concluded)

Storm date	Index No.	Corps assignment No.	Town	State	Lat	Long	Chart(s) on which storm appears
1/30-2/3/1945	IV		Nr. Yosemite Nat'l. Pk.	CA	37 35	119 30	31,32,33,34,35,36
12/27/1945	IW		Mt. Tamalpais	CA	37°54	122°34	31
10/27-29/1946	IX		Bvr. Dam St. Pk.	NV	37°25	114°02	32
11/17-18/1946	IY		Nehalem	OR	45°43	123°55	32
2/9-10/1949	IZ		Haskins Dam	OR	45°19	123°21	32
11/19-21/1950	JA		Nr. Silver Cty	CA	36°30	118°30	31,32,33,35
11/20/1950	JB		Orick Prairie Crk.	CA	41°22	124°01	32
8/25-30/1951	JC		Sunflower	AZ	34°07	112°21	34,36
7/19/1955	JD		Chiatovich Flt.	CA	37°44	118°15	31,32
12/21-24/1955	JE		Strawberry Vly.	CA	39°36	121°06	34
8/16/1958	JF		Morgan	UT	41°03	111°38	31,32
9/18/1959	JG		Newton	CA	40°39	122°24	31,32
11/20/1959	JH		Pt. Grenville	WA	47°20	124°30	32
10/11-13/1962	JI		Nr. Brush Crk.	CA	39°42	121°18	34,36
6/7-8/1964	JJ	NP2-23	Summit	MT	48°18	113°22	33,35,36
12/22/1964	JK		Cave Junction	OR	44°38	123°12	32
12/19-23/1964	JL		Brush Crk. 12E	CA	39°42	121°12	34,36
8/1/1968	JM		Nr. Blanding	UT	37°49	109°23	32
9/3-7/1970	JN		Bug Point	UT	37°38	109°04	31,32
9/3-5/1970	JO	SP2-23B	Workman Crk.	AZ	33°49	110°56	35
6/7/1972	JP		Bakersfield	CA	35°25	119°03	31

*Maximum station value used was not observed. Obtained from isopercental analysis. See footnote page 15.

b) The Cherry Creek, Colo., storm of May 30-31, 1935 (observed 24 inches in less than 6 hours).

For both of these storms there are sufficient data to define 10-mi^2 average observed rainfalls distinct from the point values. The 6-hr 10-mi^2 value is 24.7 inches for storm (a) and 20.6 inches for storm (b). These 10 mi^2 average 6-hr depths are 97 percent and 89 percent of 6-hr 10-mi^2 PMP, respectively. The apparent greater than 100 percent of PMP values extend into the 12-, 24-, and 48-hr durations (charts 2, 3, and 4) in the case of the Smethport storm. Here, if 10 mi^2 average values are compared, the percentages of PMP are 93, 94, and 86, respectively.

For many individual storm events, numerous recorded station rainfalls are 50 percent or more of PMP. We have listed only the comparison of PMP with the *one greatest observed value* in each storm. This is particularly important for the western states. With sharp gradients in PMP, there is a strong probability of higher percentages of PMP for some of the lesser observed values in a storm. An example is the January 19-24, 1943 storm in southern California. The maximum observed point at Hoegees Camp, California, (24-hr value) is 25.8 inches (PMP=34.1 inches) which gives 76 percent of PMP. In the same storm 20.3 inches was observed at Mount Wilson Airway station which is located only a few miles west of Hoegees Camp. This 20.3-inch amount is 82 percent of PMP at the location where it occurred. A detailed time-consuming search for such higher percents in all storms would (a) uncover many more storms within 50 percent of PMP and (b) raise the percents, especially for those given on charts 31 and 32 for the western states.

6.2 East of the 105th Meridian

Table 4A gives the number of storms that are 50 percent or more of PMP for each combination of area size and duration. In general, an increase in this count with increasing area size is noted. This is contrary to what one might expect if all other factors were equal since we have studied fewer rain storms with maximum average depths for 20,000 mi^2 than for 10 mi^2. One factor that is not equal is that for small areas a few extreme point values, when considered over the region within which they could occur, i.e., transposed, are so much greater than most other storms. This reduces the storm count, as shown in table 4A for small areas. The larger the area, the less the effect of the point extreme; that is, differences between large area rainfalls and PMP are less. We also note in many cases an increasing count of storms with increasing duration. The same reason is given for this as for the increase with area size.

In all except two instances (east of the 105th meridian), the station, or 10 mi^2 cases $\geq$50 percent of PMP came either from *Storm Rainfall in the United States* (Corps of Engineers 1945-) or *Greatest Known Areal Storm Rainfall Depths for the Contiguous United States* (Shipe and Riedel 1976). Many of the rainfall analyses of the largest storms in these publications e.g., Cherry Creek, Colorado, May 30-31, 1935; Smethport, Pennsylvania, July 17-18, 1942; Rapid City, South Dakota, June 9, 1972; Enid, Oklahoma, October 10-11, 1973; Kansas City, September 11-13, 1977; etc., are based on post storm surveys made to determine maximum rainfall amounts. This

Table 4.--Number of storms per area size and duration with rainfalls ≥ 50 percent of PMP

A. U.S. east of 105th meridian

Chart no.	No. of storms	Area (mi^2)	Duration (hrs)	Chart no.	No. of storms	Area (mi^2)	Duration (hrs)
1	27	10	6	16	37	5000	6
2	26	10	12	17	44	5000	12
3	32	10	24	18	49	5000	24
4	27	10	48	19	53	5000	48
5	25	10	72	20	49	5000	72
6	35	200	6	21	40	10000	6
7	39	200	12	22	41	10000	12
8	40	200	24	23	51	10000	24
9	39	200	48	24	57	10000	48
10	35	200	72	25	45	10000	72
11	36	1000	6	26	44	20000	6
12	40	1000	12	27	34	20000	12
13	43	1000	24	28	56	20000	24
14	41	1000	48	29	59	20000	48
15	40	1000	72	30	53	20000	72

Total number of separate storm events: 177

B. U.S. west of Continental Divide

31	23	10	6	34	12	500	48
32	54	10	24	35	10	1000	24
33	8	500	24	36	13	1000	48

Total number of separate storm events: 66

indicates the importance of these surveys in determining maximum observed rainfall amounts and in developing estimates of PMP.

There may be concern about the distribution of storms on any particular one of the 30 maps. Consider chart 1 (for 6 hours 10 mi^2) as an example. No storms are shown in the North Central Great Lakes region. However, turning to the 200-mi^2 6-hr map (chart 6), we see several storms in this region. In regionally, durationally, and areally smooth envelopes of PMP, gaps can occur and should be expected on some maps.

6.3 West of the Continental Divide

We note from table 4B there are a total of 66 separate storm events with rains $\geq$ 50 percent of PMP. Of these, the maximum values for at least 20 storms were recorded at regular reporting stations -- that is, surveys which might have uncovered yet greater rainfalls were not made after the storm events. Because of sparse habitation in the Western States, there remains the possibility that greater values would not have been found, although they likely occurred. Probably few surveys have been made after storm events in the Western States because of the small likelihood that additional larger catches would be discovered.

The distribution of storms shows that a large portion of the 66 events occurred either in California or in the coastal region of Washington and Oregon. We expect observed storms to approach PMP more closely in wet regions like the Sierra Nevadas than in dry regions.

7. MAGNITUDE OF PMP: WEST OF CONTINENTAL DIVIDE VS. EAST OF 105TH MERIDIAN

7.1 Comparisons of PMP with Maximum Observed Rainfalls

A question is whether PMP estimates west of the Continental Divide (West) are comparable to those east of the 105th meridian (East) i.e., do the values represent the same degree of "conservatism." All other factors equal one should expect more values $\geq$ 50 percent of PMP for the East because we have more observations there and the region is larger. That is, in the East there are currently about 6500 precipitation reporting stations in a region of almost 2 million square miles, while in the West there are only about 2100 stations in a region of about 800,000 square miles. We have also studied a much larger number of storms in the East, 673, while in the West we have studied only 139. Despite this imbalance of data, examination of table 4 shows 77 10 mi^2 cases for the 6- and 24-hour durations combined that are $\geq$ 50 percent of PMP for the region west of the Continental Divide while for the East there are only 59 such cases. We believe this is due to the few most extreme values for the East that reduce the number of cases $\geq$ 50 percent when these few are transposed (a point already discussed). Some indication of this is found in the data. A count of the number of cases $\geq$ 50-, $\geq$60-, $\geq$70-, $\geq$80-, and $\geq$90-percent of PMP for 10 mi^2 for 6 and 24 hours, East and West is shown in table 5. The total number of cases $\geq$ 50 percent of PMP is higher for the West, but when the criterion is $\geq$70 percent of PMP, there is a higher count for the East.

In summary, obstacles to comparing the frequency of storm rainfalls $\geq$ 50 percent of PMP in the East to those in the West, include difference in a) the number of storms analyzed, b) the number of post storm surveys, and c) the number and variety of record storms.

Table 5.--Number of Storm Rainfall Cases Exceeding Various Percentages of PMP (10 mi², 6 and 24 hours).

	≥50%	≥60%	≥70%	≥80%	≥90%
East of 105th meridian	59	32	19	7	3
West of Continental Divide	77	39	13	4	0

7.2 Comparisons of PMP With 100-yr Rainfalls

Some judgement on PMP in the East compared to that in the West can be made from examining ratios of PMP to 100-yr rainfalls.

Charts 37 and 38 show ratios of 6- and 24-hr PMP (Schreiner and Riedel 1978) to 100-yr rainfall (Hershfield 1961) for 6 and 24 hours, respectively, east of the 105th meridian. The ratios for 6 hours vary from about 4 near the gulf coast to about 7 in the Great Lakes region. For 24 hours the range is about 4 to 6.

Now let's look at the ratios west of the Continental Divide for 6 hours (chart 39) and 24 hours (chart 40). The 100-yr values come from NOAA Atlas 2 (Miller et al. 1973). Both maps show a greater variation in ratios from place-to-place than for east of the 105th meridian. This was to be expected. Mountain masses have a large effect in regional variation of rainfall magnitudes. We would expect, as shown, that for regions where there are frequent large rains occurring at or nearly at the same place because of orographic influences (e.g., Sierra slopes), the storm depths would more closely approach PMP (lower ratio of PMP to 100-yr). Similarly, highest ratios generally occur as shown in locations where heavy rainfalls are infrequent because of sheltering or distance from the moisture source (e.g., central valley of California or the Snake River Valley). Charts 37 and 38 show a similar trend to lower ratios in the eastern Appalachian Mountains and lowest ratios near the Gulf where the storm experience is greatest.

In the west for 6 hours (chart 39), the ratios vary from 2 to 8. For 24 hours (chart 40), the ratios vary from 2 to 6. In general, the western states show a wider range in ratios. The authors of NOAA Atlas 2, however, (personal communication) believe that if rainfall frequency studies were now made for the eastern mountainous regions with the attention to orographic factors used in NOAA Atlas 2, results would be less smooth with more centers of high and low values. If so, this could result in a greater range of PMP to 100-yr ratios.

8. SUMMARY

This report provides some perspective to the user on the relation between PMP and maximum observed rainfalls. In the east, of 675 storms studied, 177 (about one-fourth) had a rainfall depth (for at least one of the standard area sizes and durations considered) that was $\geq$ 50 percent of PMP. This comparison is from documented records of storm rainfalls that extend over approximately 100 years. These storm rainfall amounts are well distributed over the range of durations and area sizes. From the length of record and over this large region, we have a few storms, about 1 percent, that are within 20 percent of PMP.

For the region west of the Continental Divide, the comparisons are more difficult. Our data sample is smaller and because of maps of PMP for a given area size and duration cannot be readily prepared, detailed comparisons analogous to those in the East cannot be made.

In spite of a smaller storm sample in the West, we found there are more cases $\geq$ 50 percent of PMP for 10 mi^2 areas (6 and 24 hours) than in the East. This is due to the much fewer post storm surveys in the West. The many more eastern post storm surveys have resulted in a relatively few very extreme observed point rainfalls which, when considered over the region where they could have occurred, set the magnitude of PMP that exceeds by quite a margin the remaining maxima.

The comparisons of PMP values with the values for the 100-yr occurrence interval indicate a rough comparability in PMP between the East and the West. It is, however, not possible to assign a recurrence interval to PMP, nor even to assume that locations, where the ratio of PMP to 100-year values are the same, have the same recurrence level. The PMP to 100-year ratios give general guidance to approximate PMP magnitudes. In general, they should be low in regions of frequent heavy rains and high where large amounts are uncommon. These trends are seen in charts 37 to 40. The Cascade-Sierra slopes, the Appalachians, Gulf of Mexico coastal region, etc., have the lowest ratios. The highest ratios are in the central valley of California, Snake River Valley, North Dakota, etc. The relative values examined in this study are, therefore, about what would be expected.

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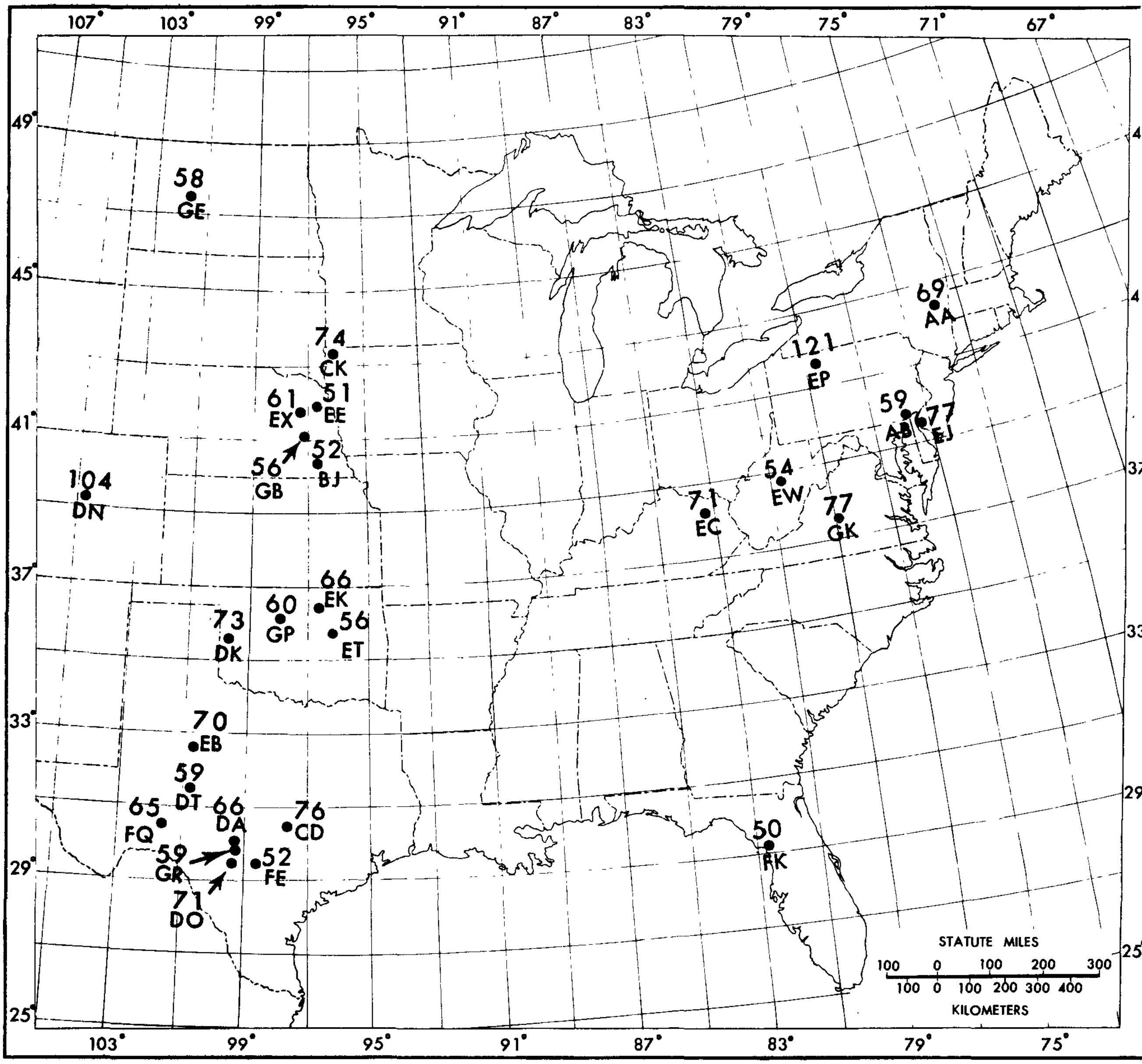

Chart No. 1.--Observed point rainfalls U.S. east of the 105th meridian ≥ 50 percent of all-season PMP for 6 hr/10 mi^2.

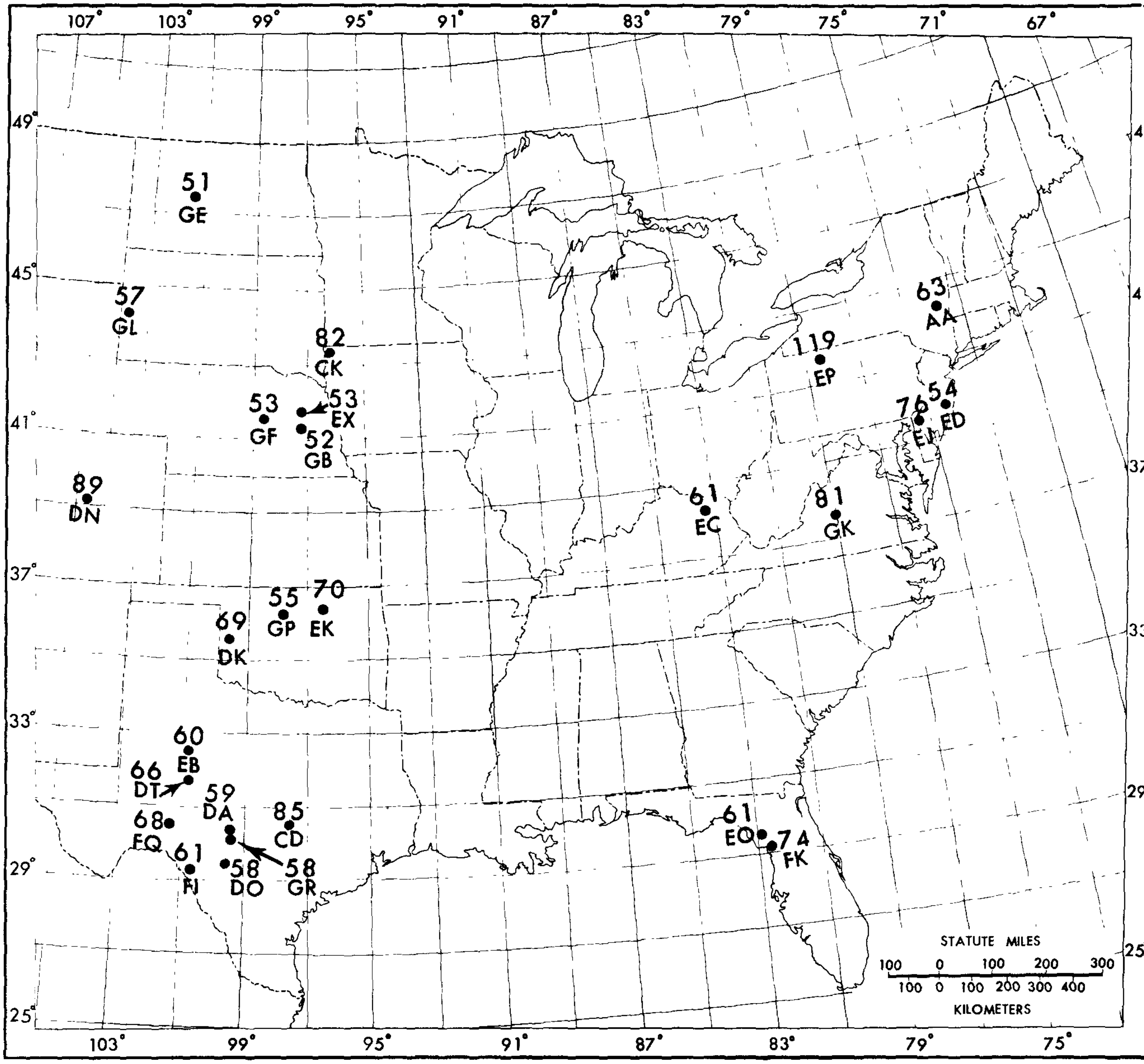

Chart No. 2.--Same as chart 1, for 12 hr/10 mi^2.

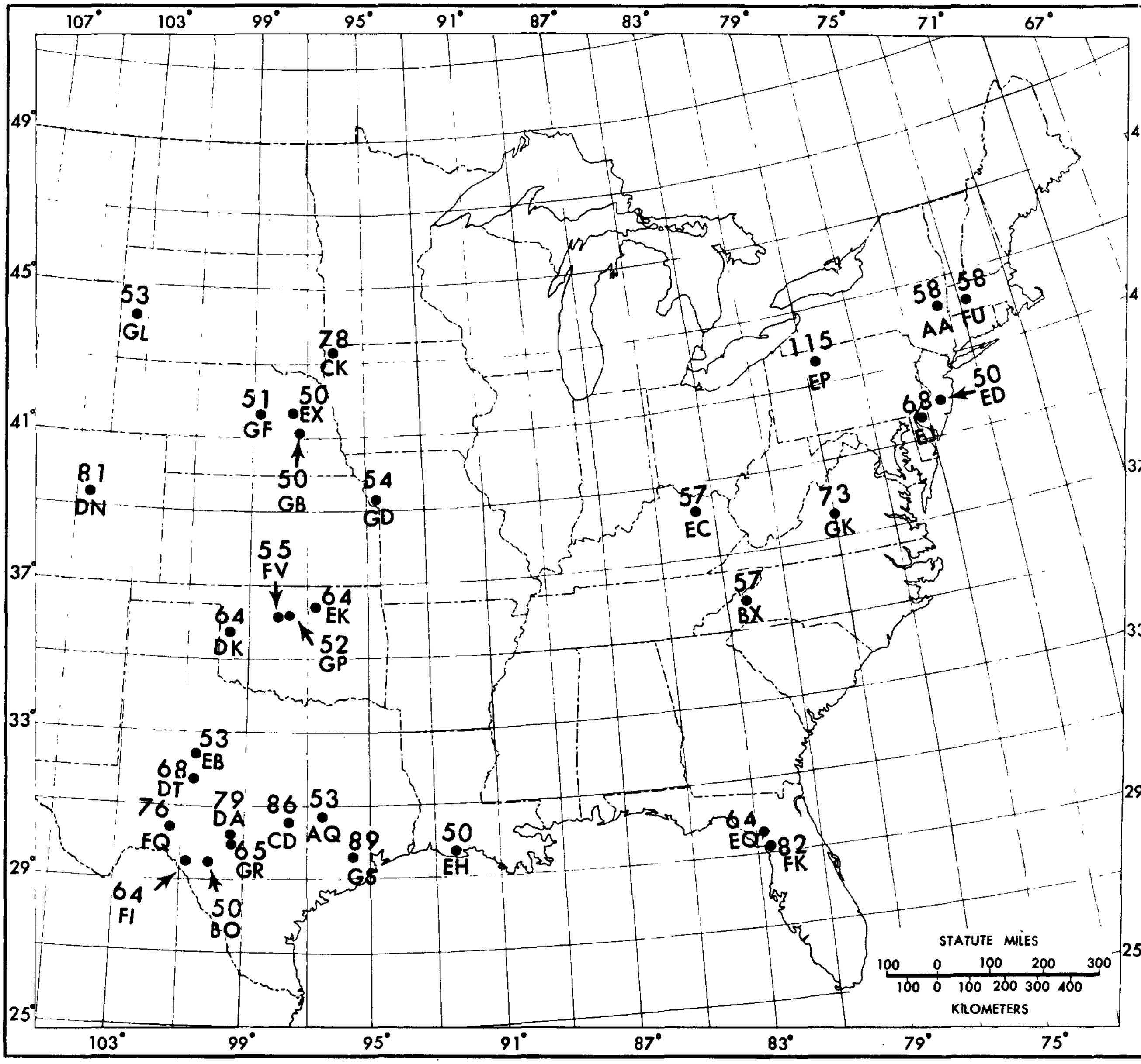

Chart No. 3.--same as chart 1, for 24 hr/10 mi^2.

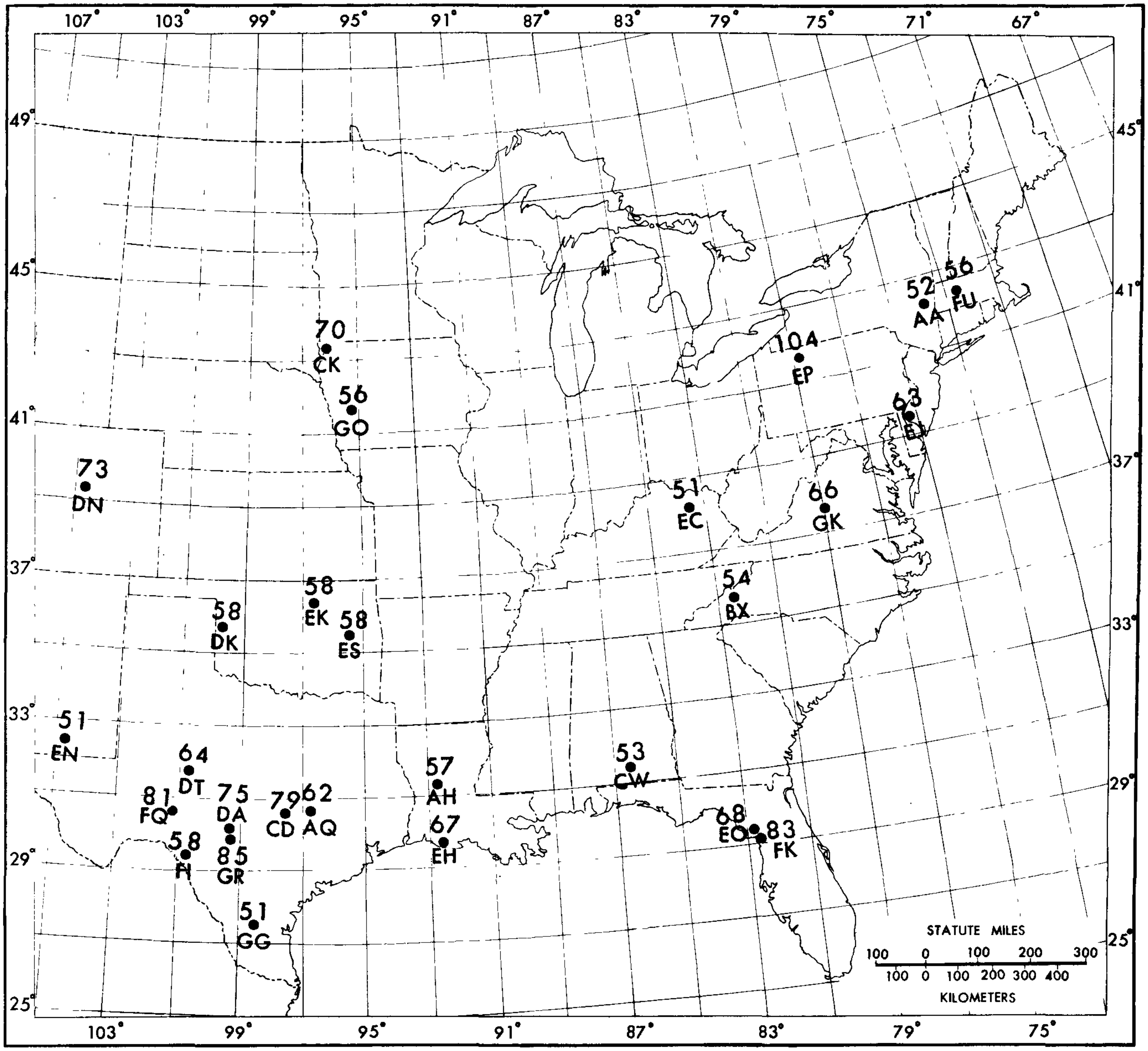

Chart No. 4.--Same as chart 1, for 48 hr/10 mi².

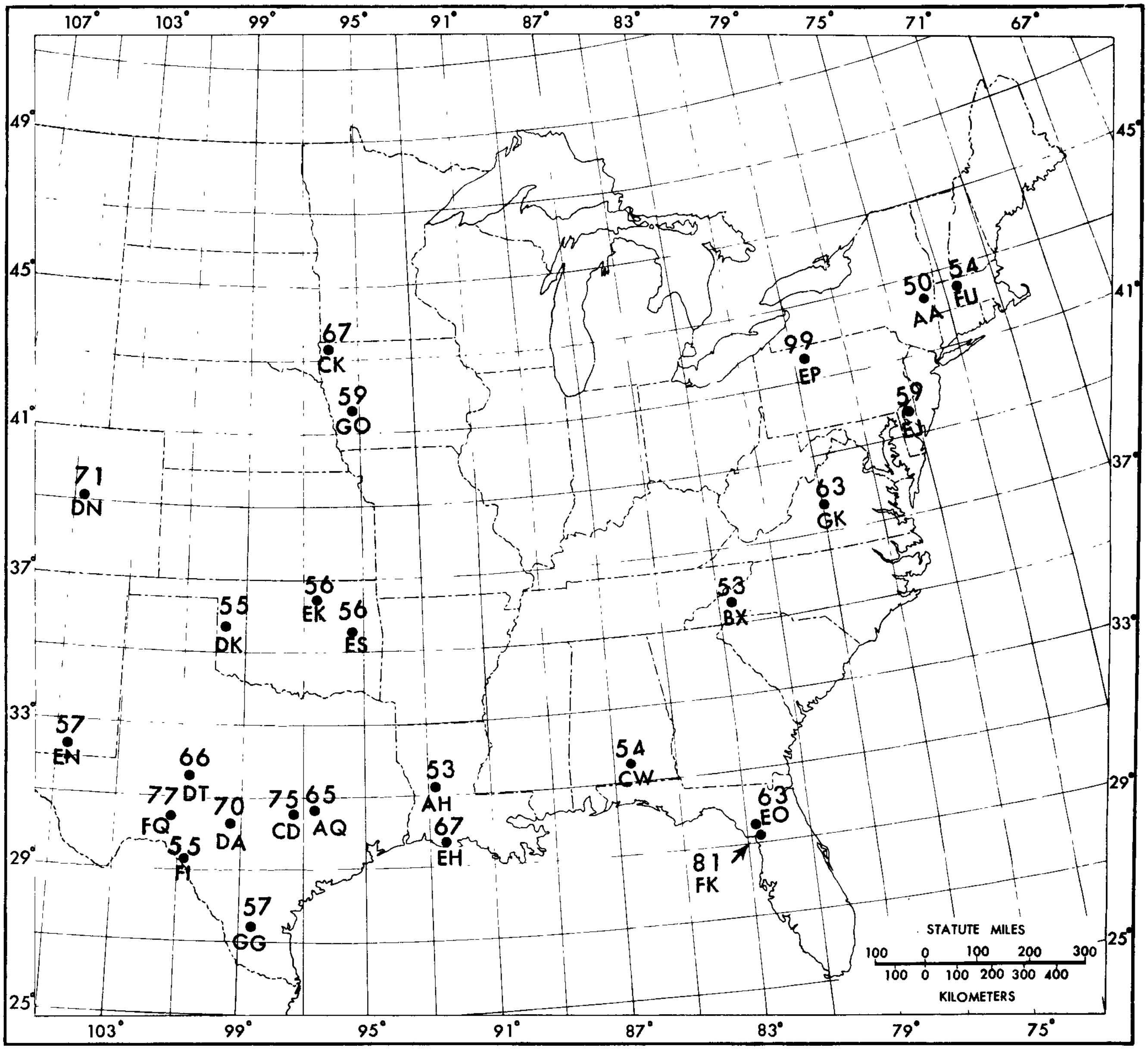

Chart No. 5.--Same as chart 1, for 72 hr/10 mi^2.

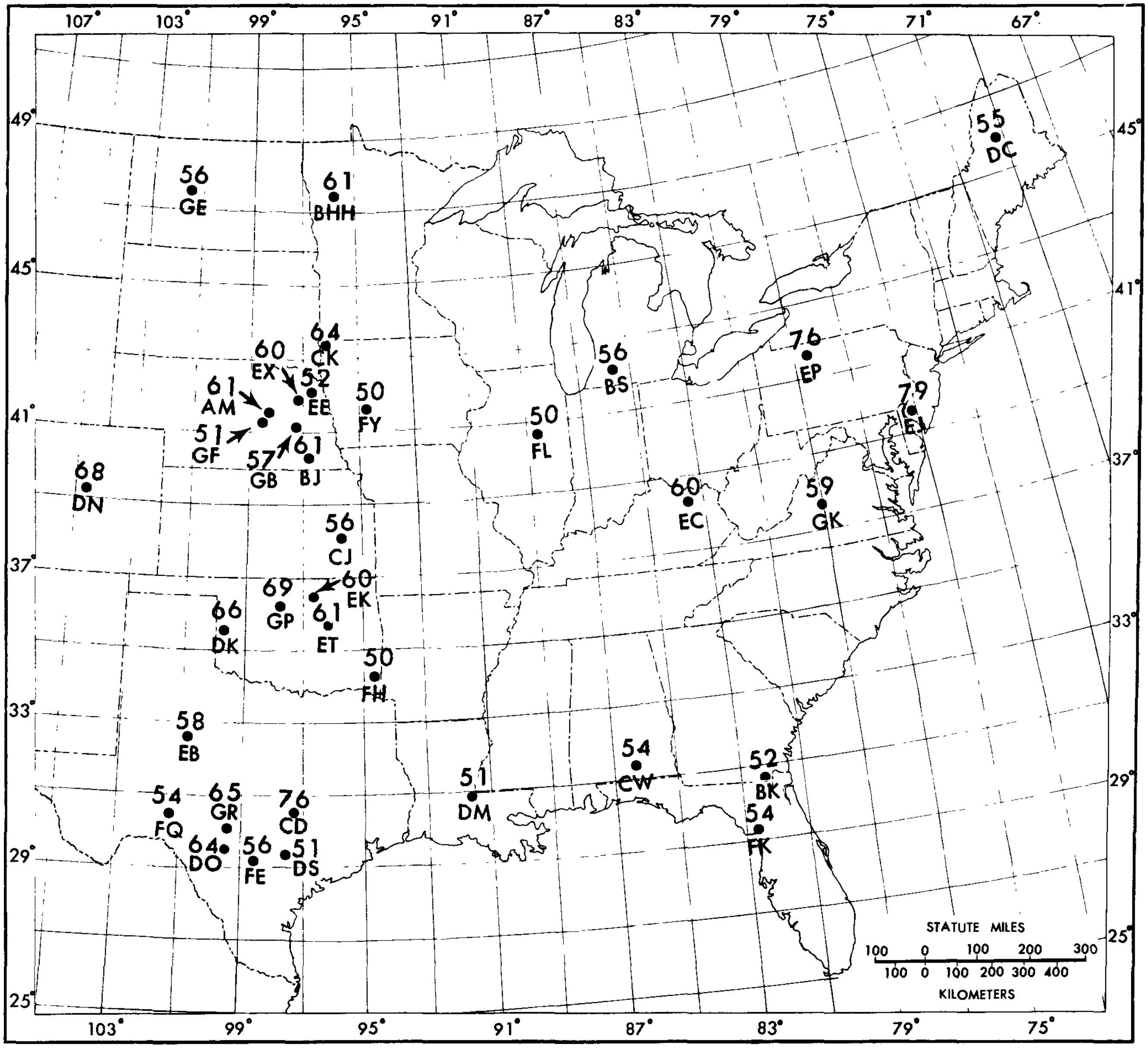

Chart No. 6.--Observed areal rainfalls U.S. east of the 105th meridian ≥ 50 percent of all-season PMP for 6 hr/200 mi^2.

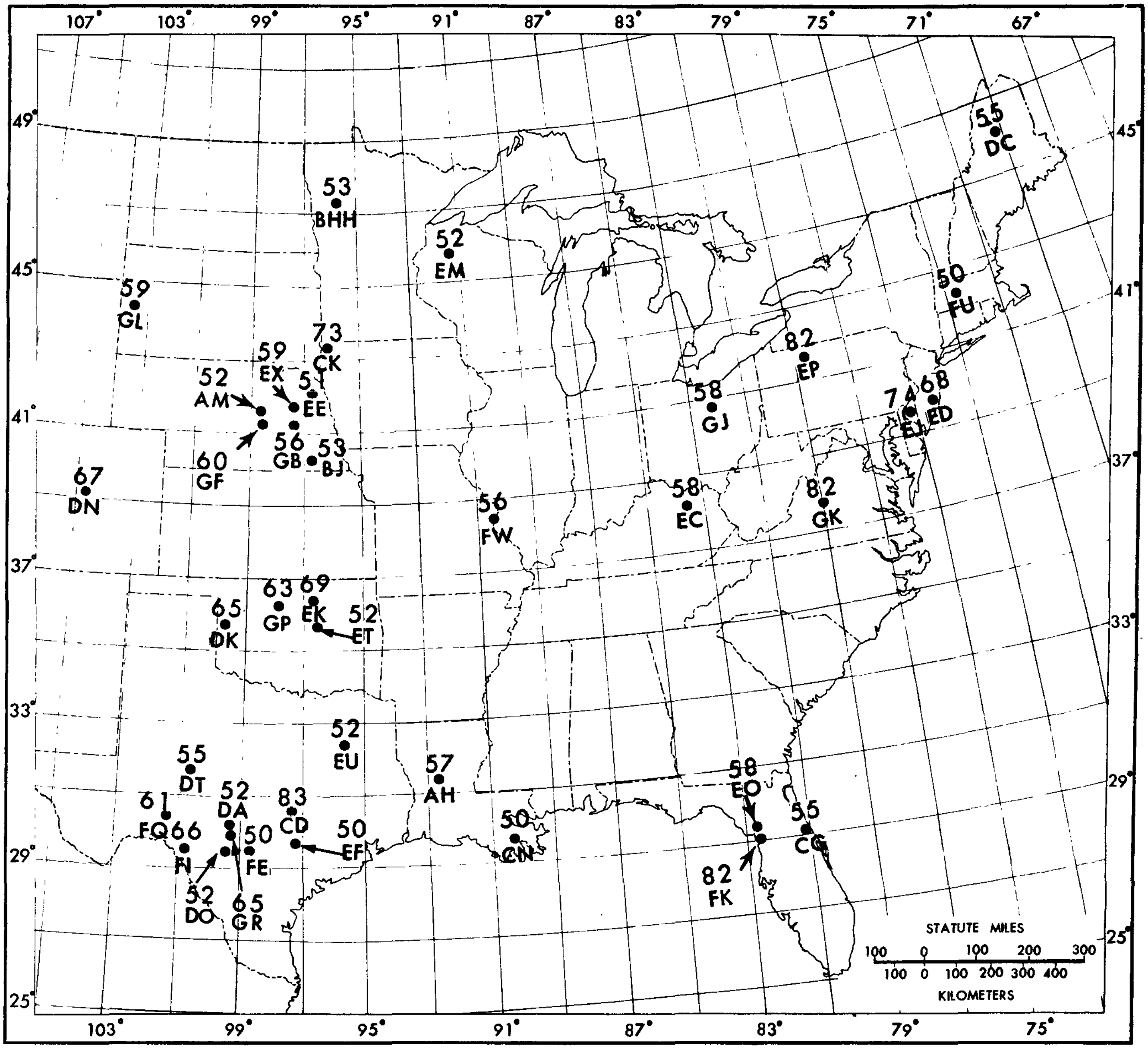

Chart No. 7.--Same as chart 6, for 12 hr/200 mi^2.

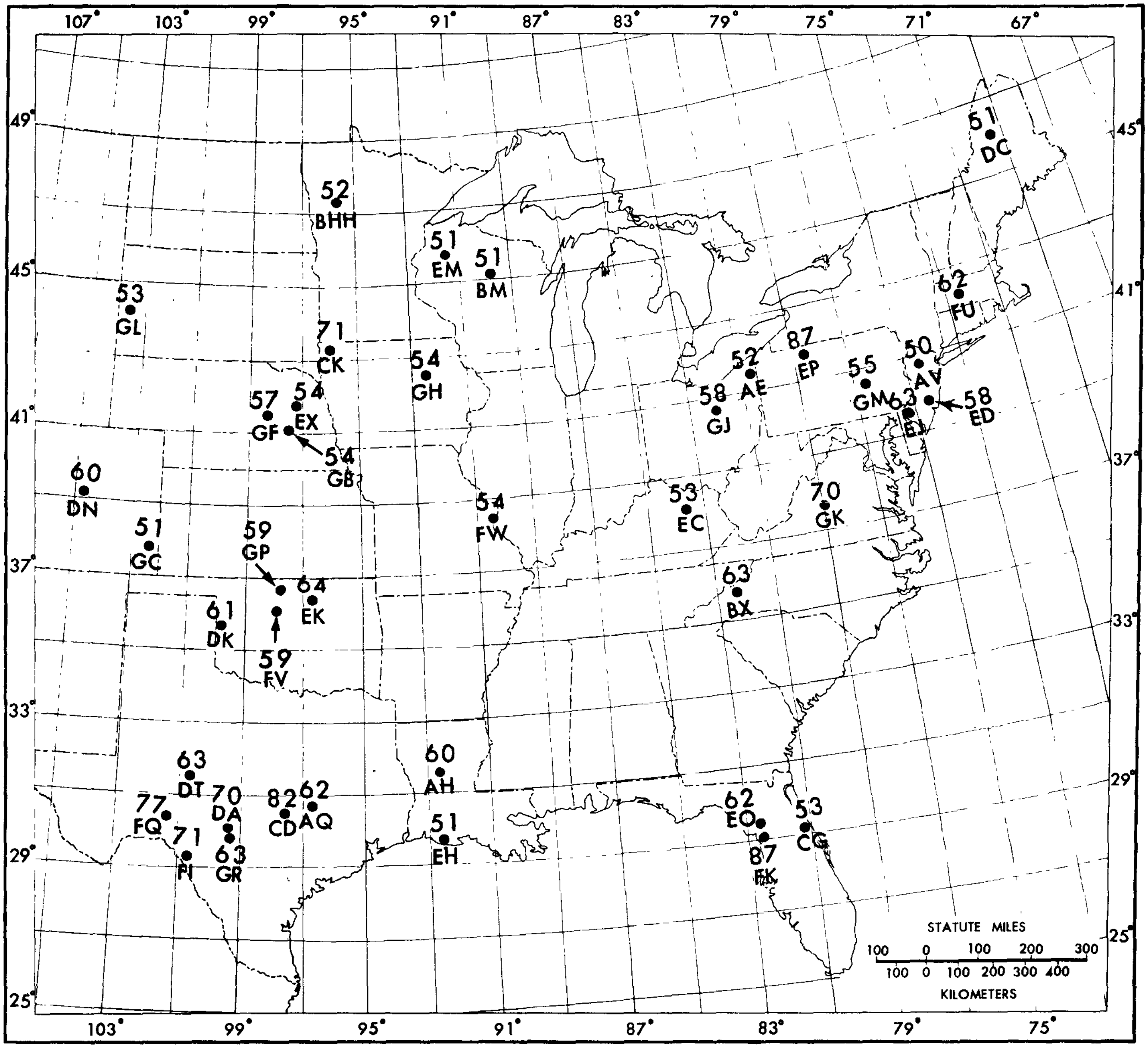

Chart No. 8.--Same as chart 6, for 24 hr/200 mi^2.

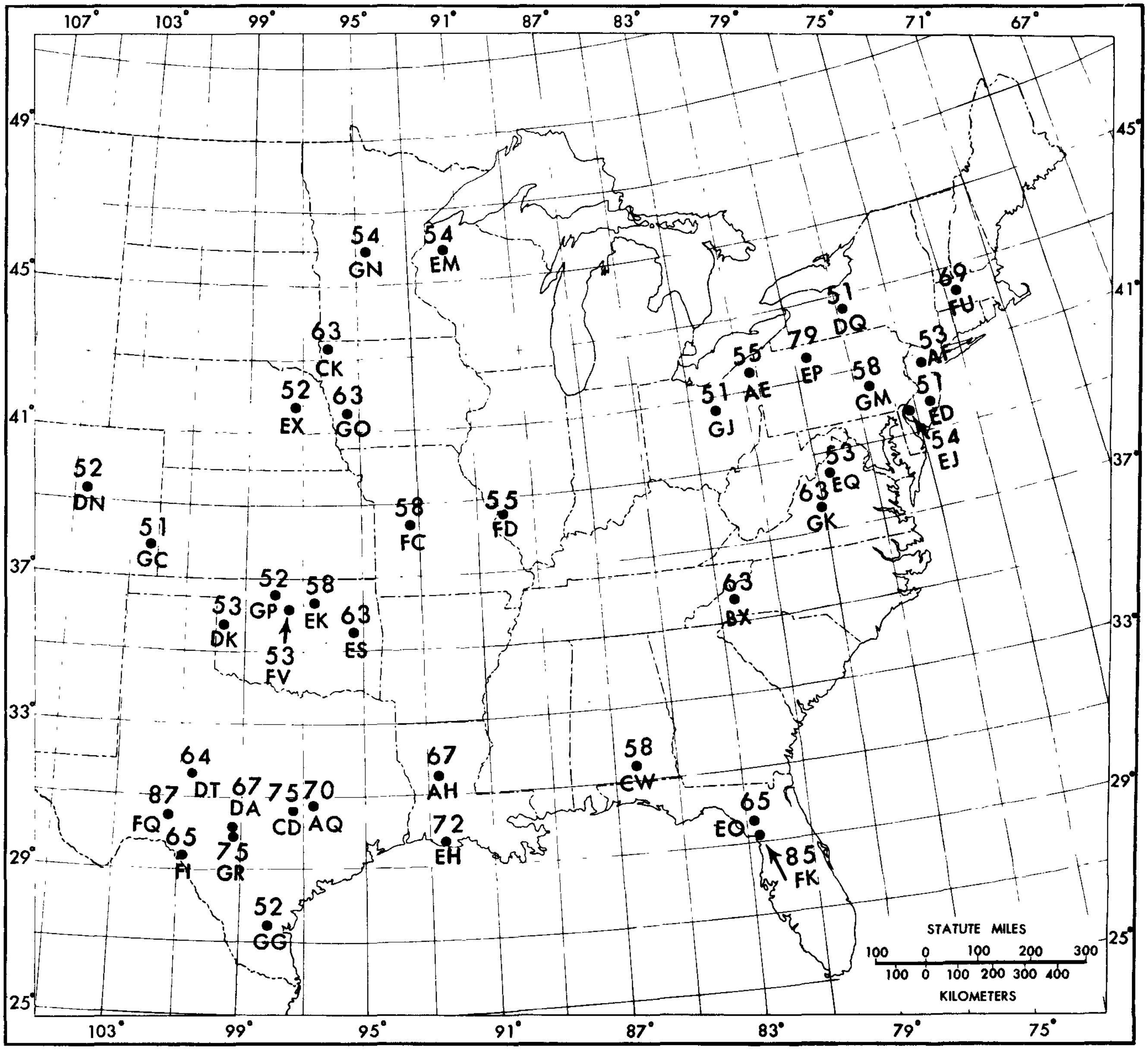

Chart No. 9.--Same as chart 6, for 48 hr/200 mi^2.

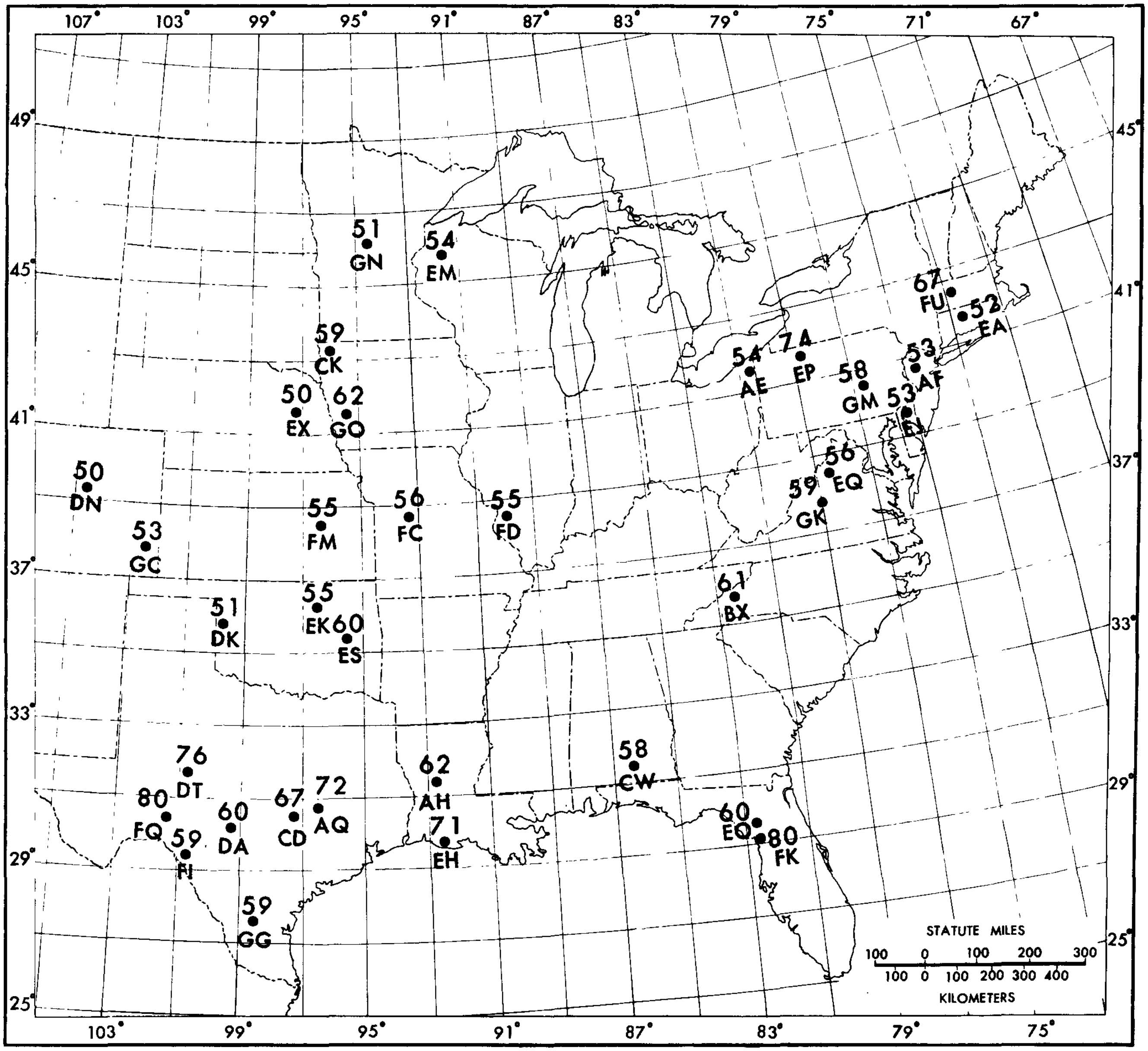

Chart No. 10.--Same as chart 6, for 72 hr/200 mi^2.

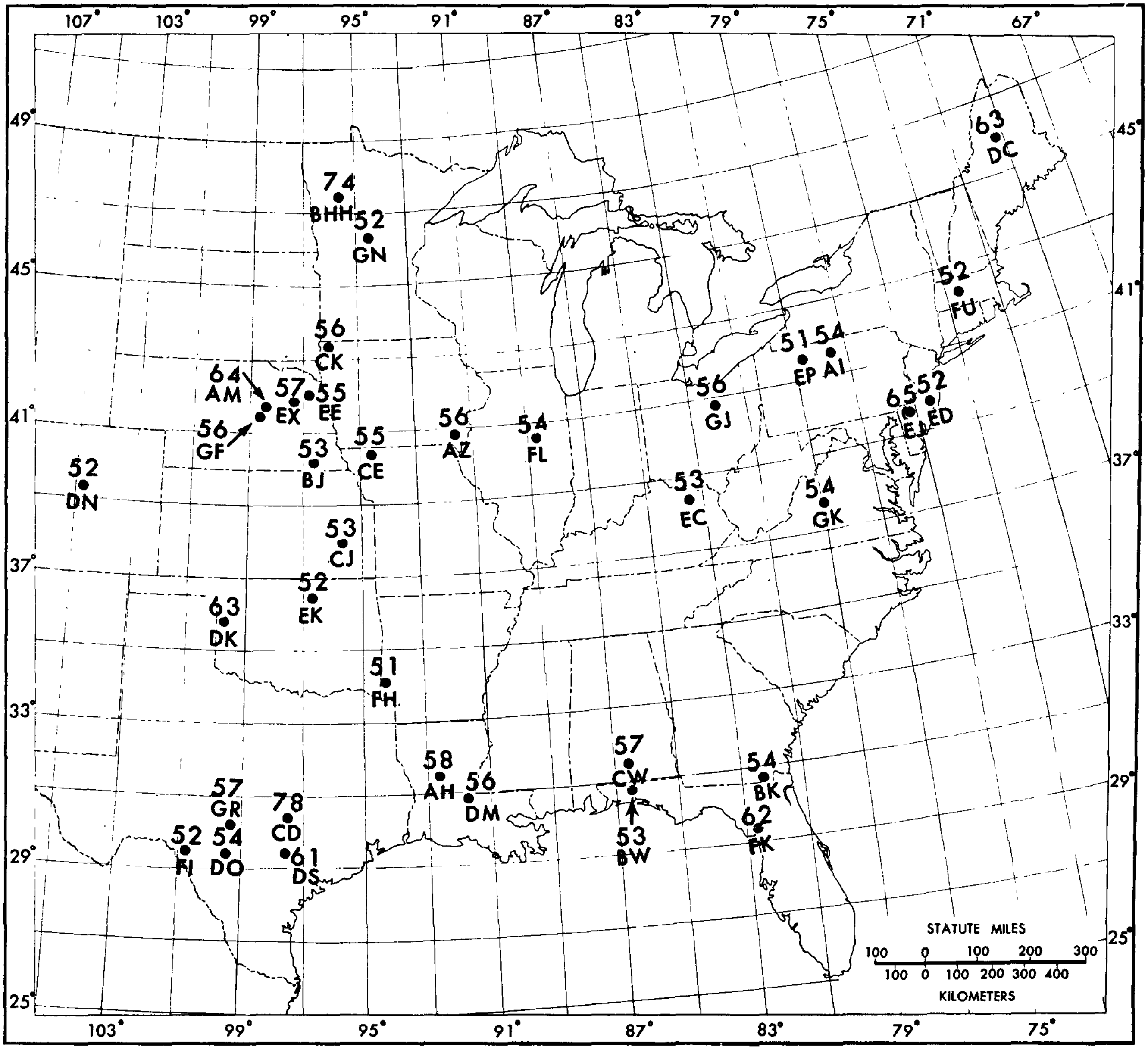

Chart No. 11.--Same as chart 6, for 6 hr/1,000 mi^2.

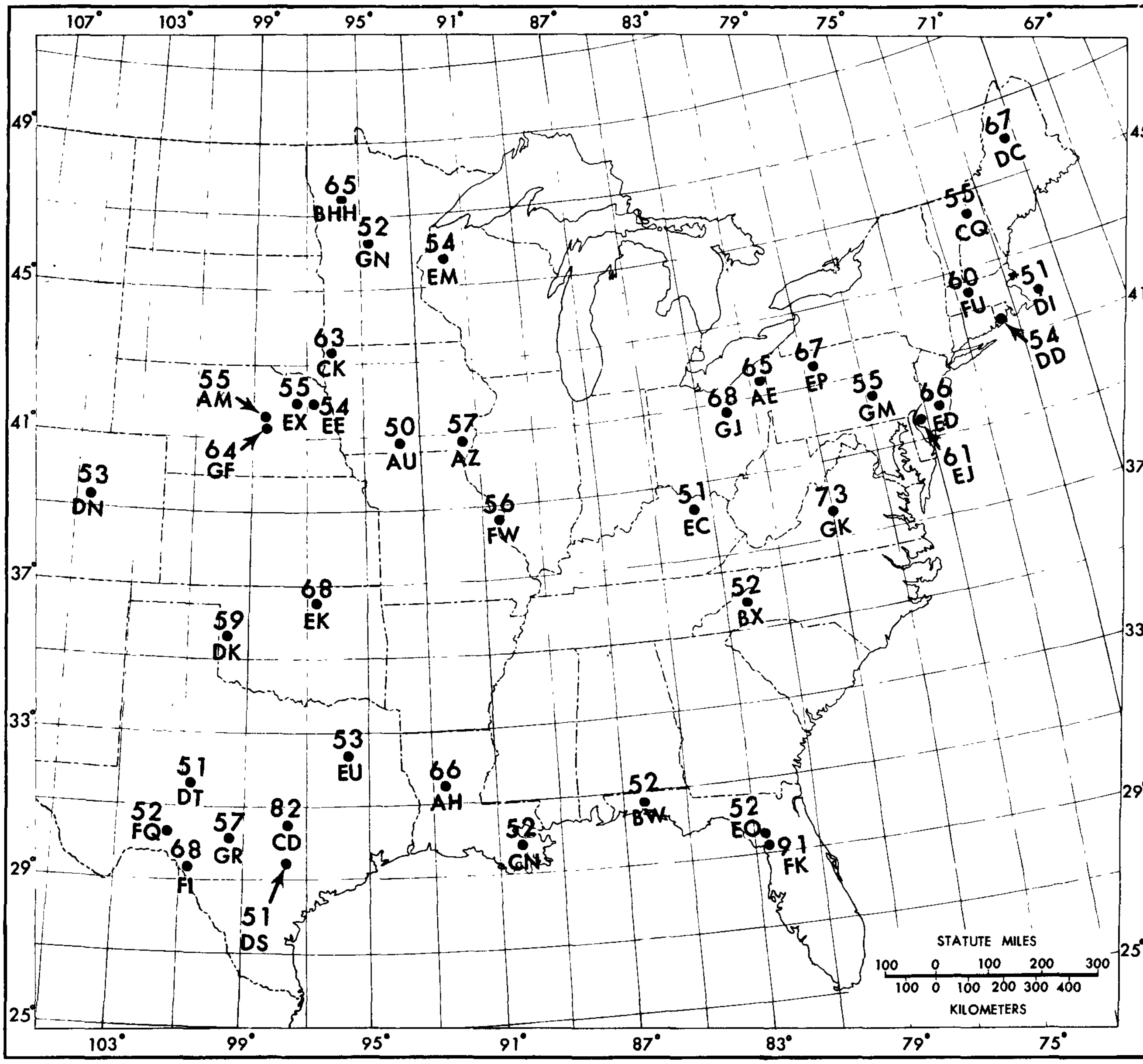

Chart No. 12.--Same as chart 6, for 12 hr/1,000 mi^2.

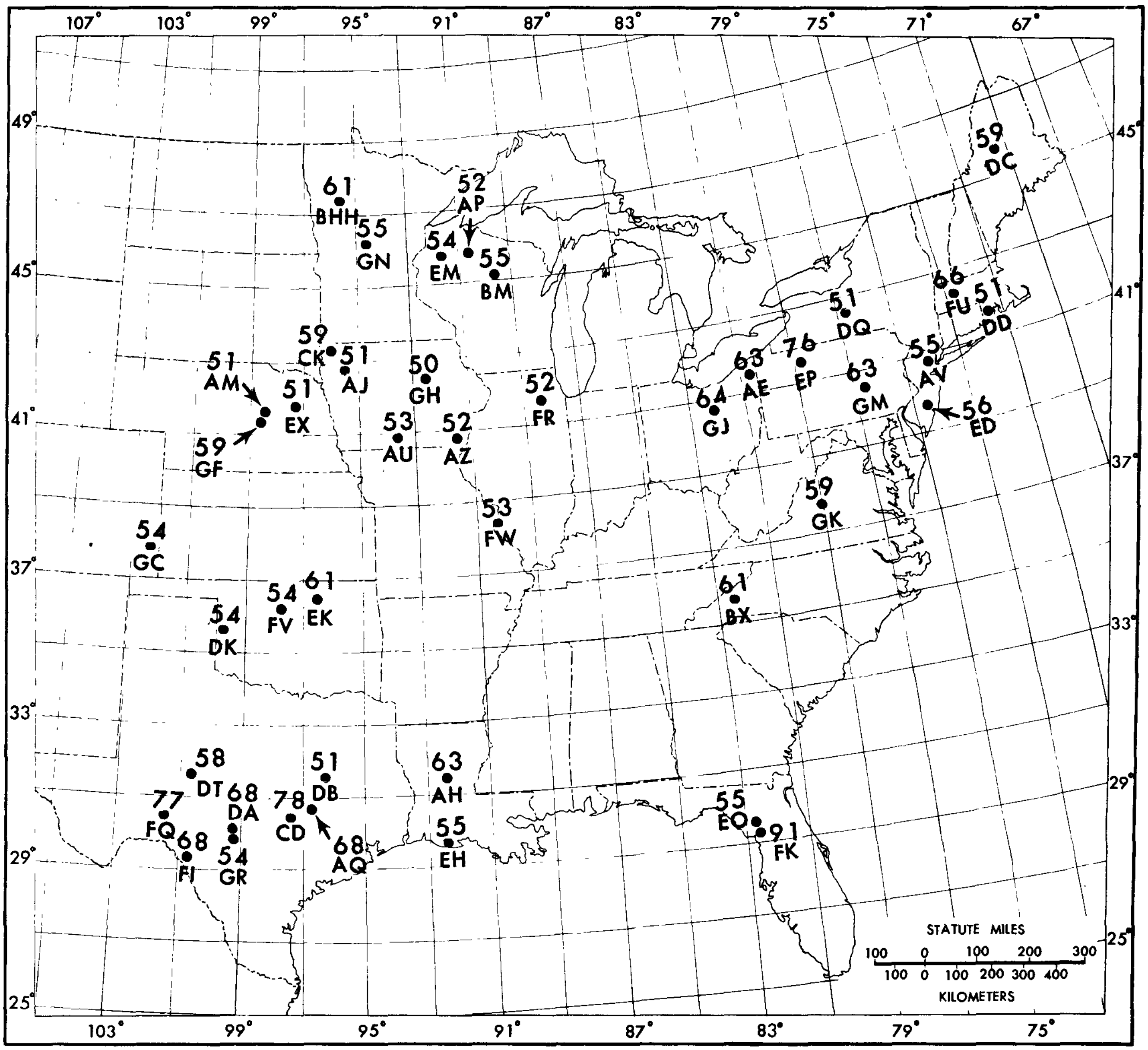

Chart No. 13.--Same as chart 6, for 24 hr/1,000 mi².

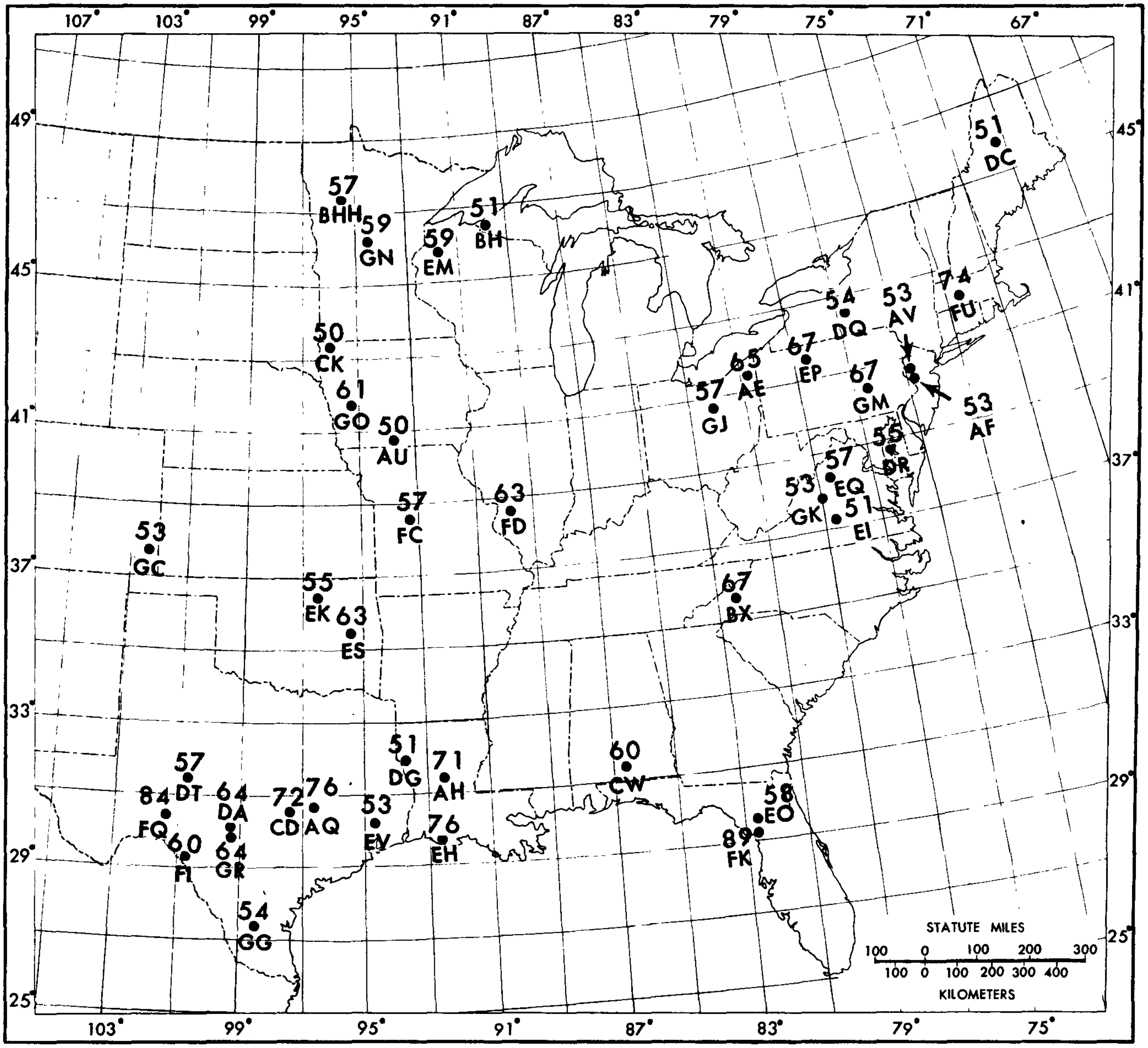

Chart No. 14.--Same as chart 6, for 48 hr/1,000 mi^2.

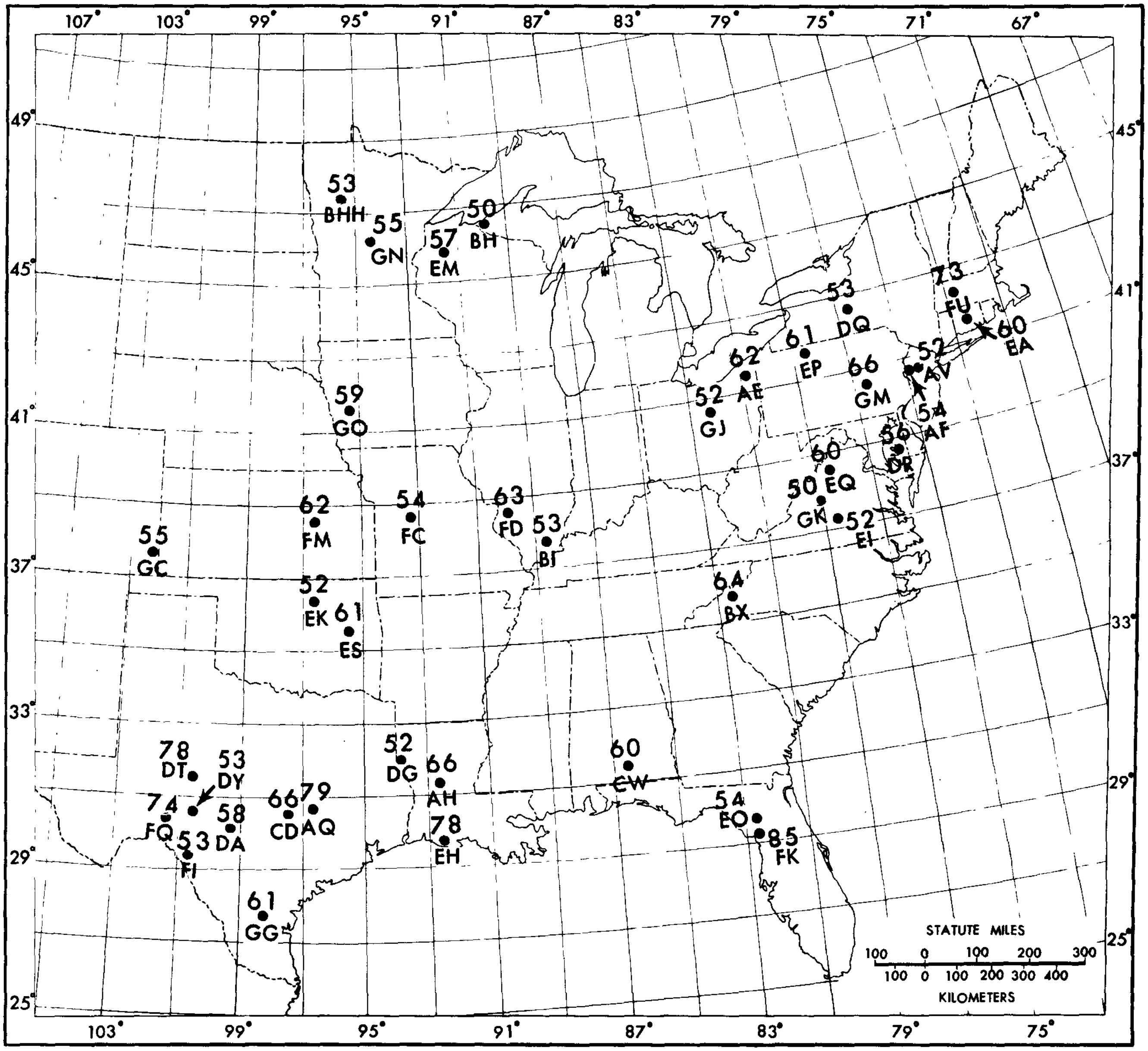

Chart No. 15.--Same as chart 6, for 72 hr/1,000 mi^2.

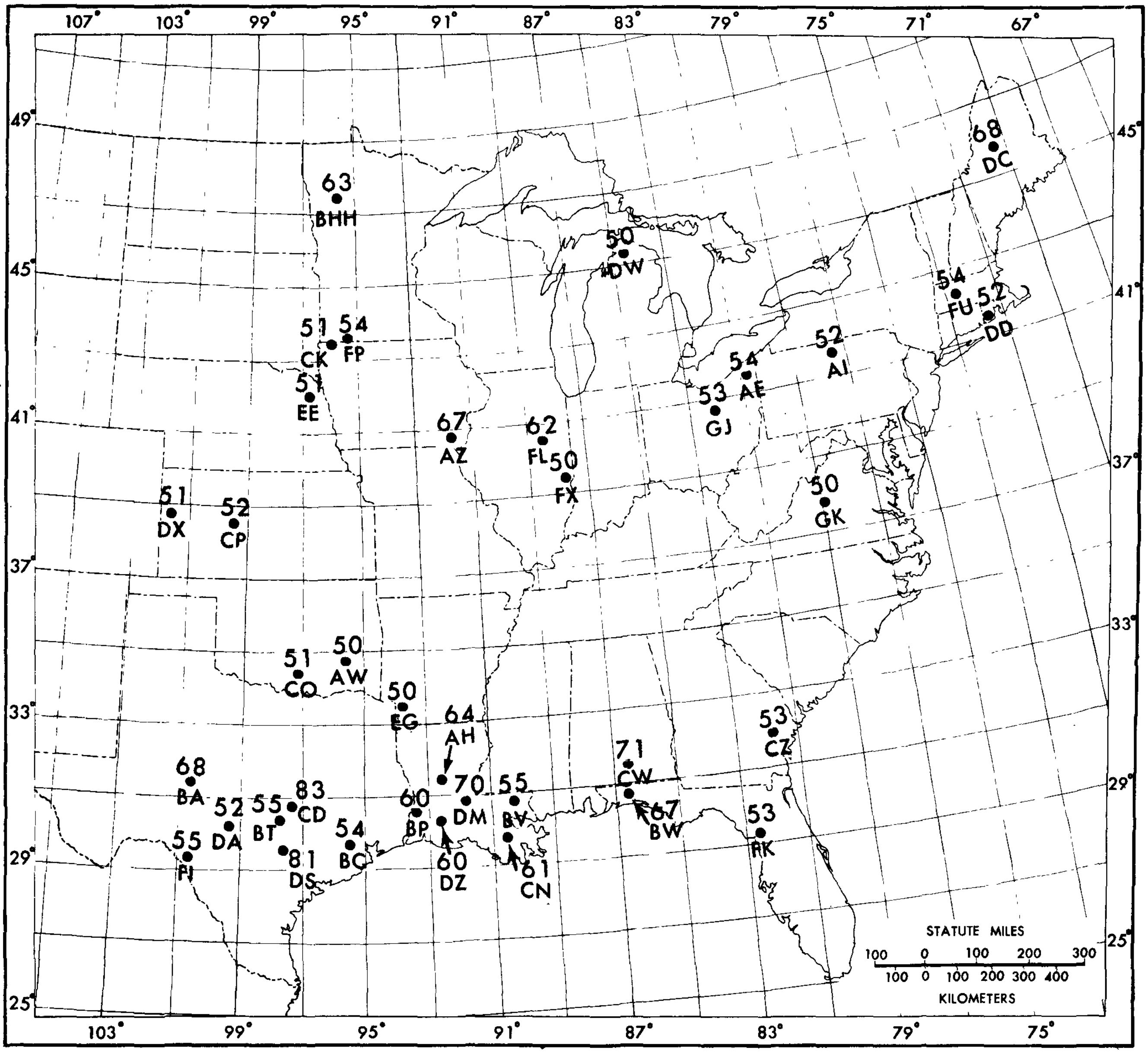

Chart No. 16.--Same as chart 6, for 6 hr/5,000 mi^2.

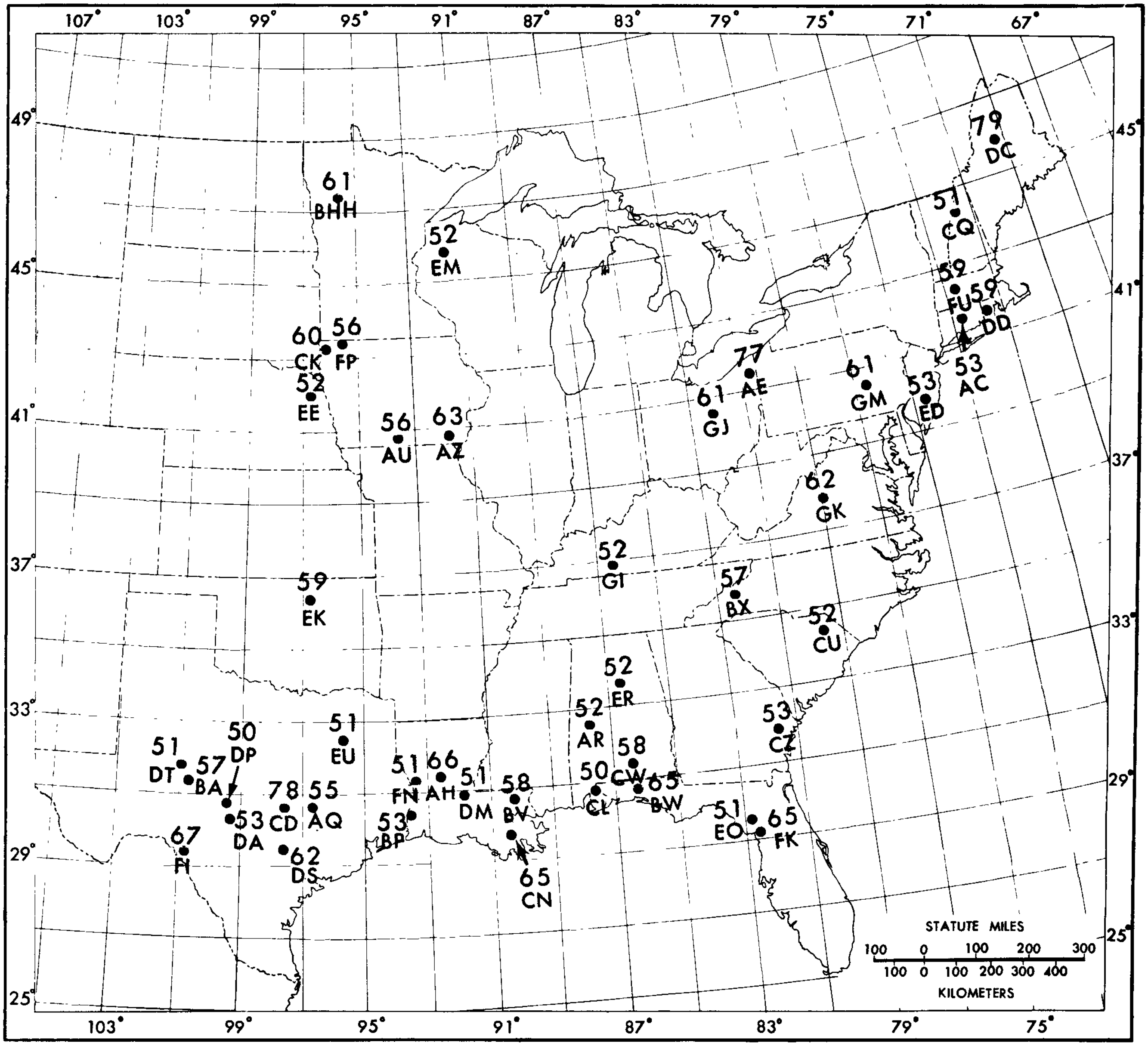

Chart No. 17.--Same as chart 6, for 12 hr/5,000 mi²

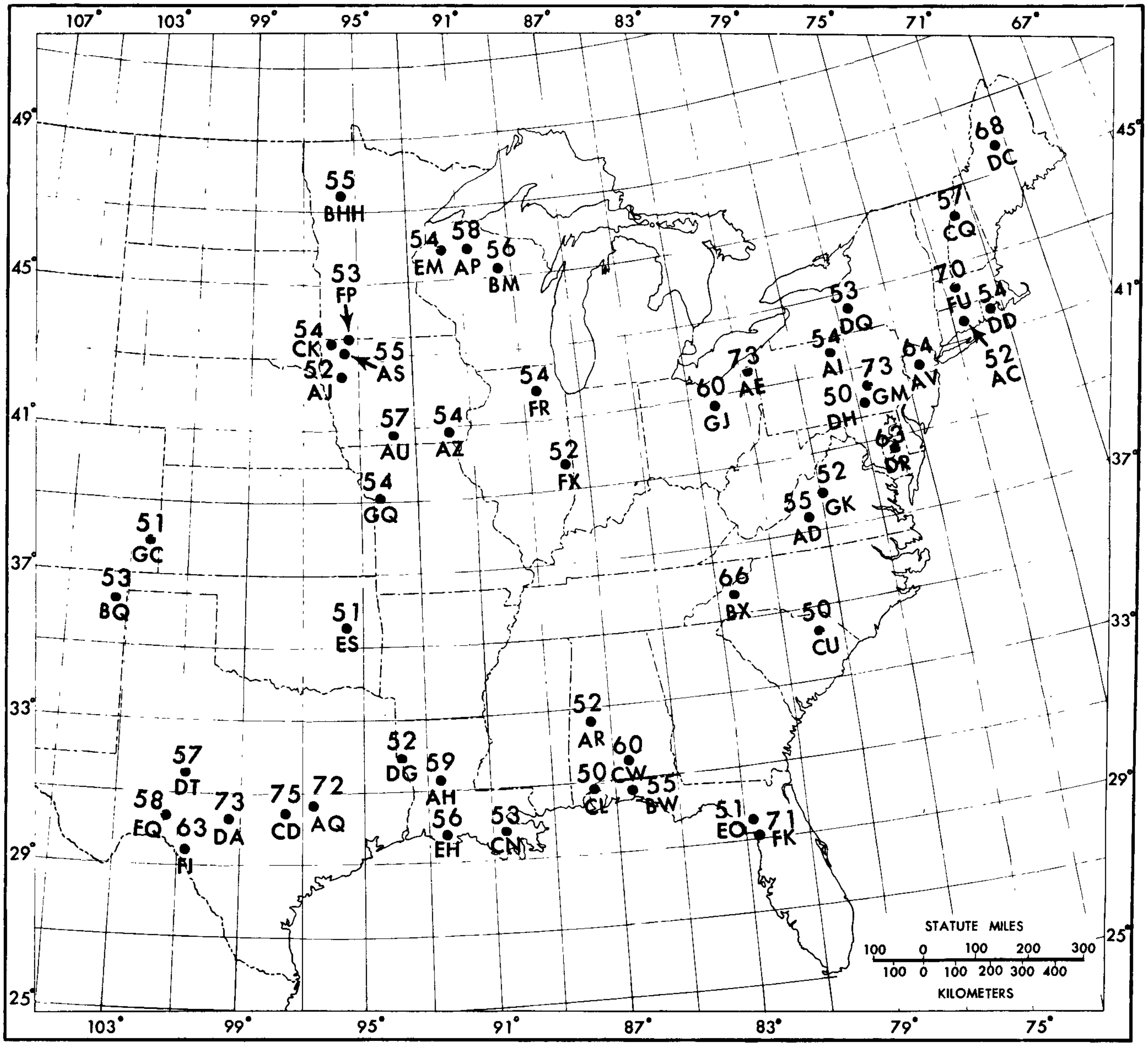

Chart No. 18.--Same as chart 6, for 24 hr/5,000 mi^2.

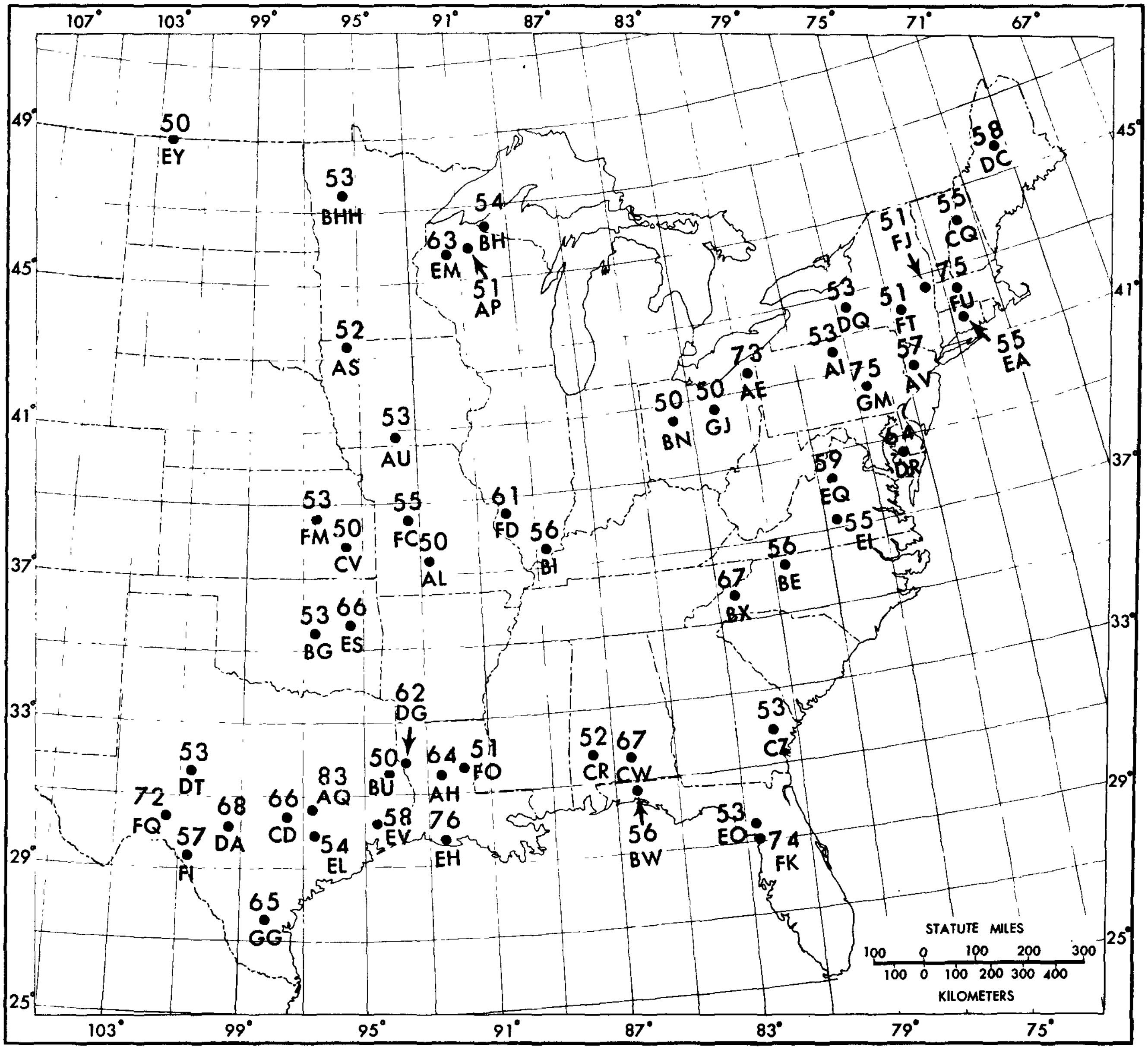

Chart No. 19.--Same as chart 6, for 48 hr/5,000 mi^2.

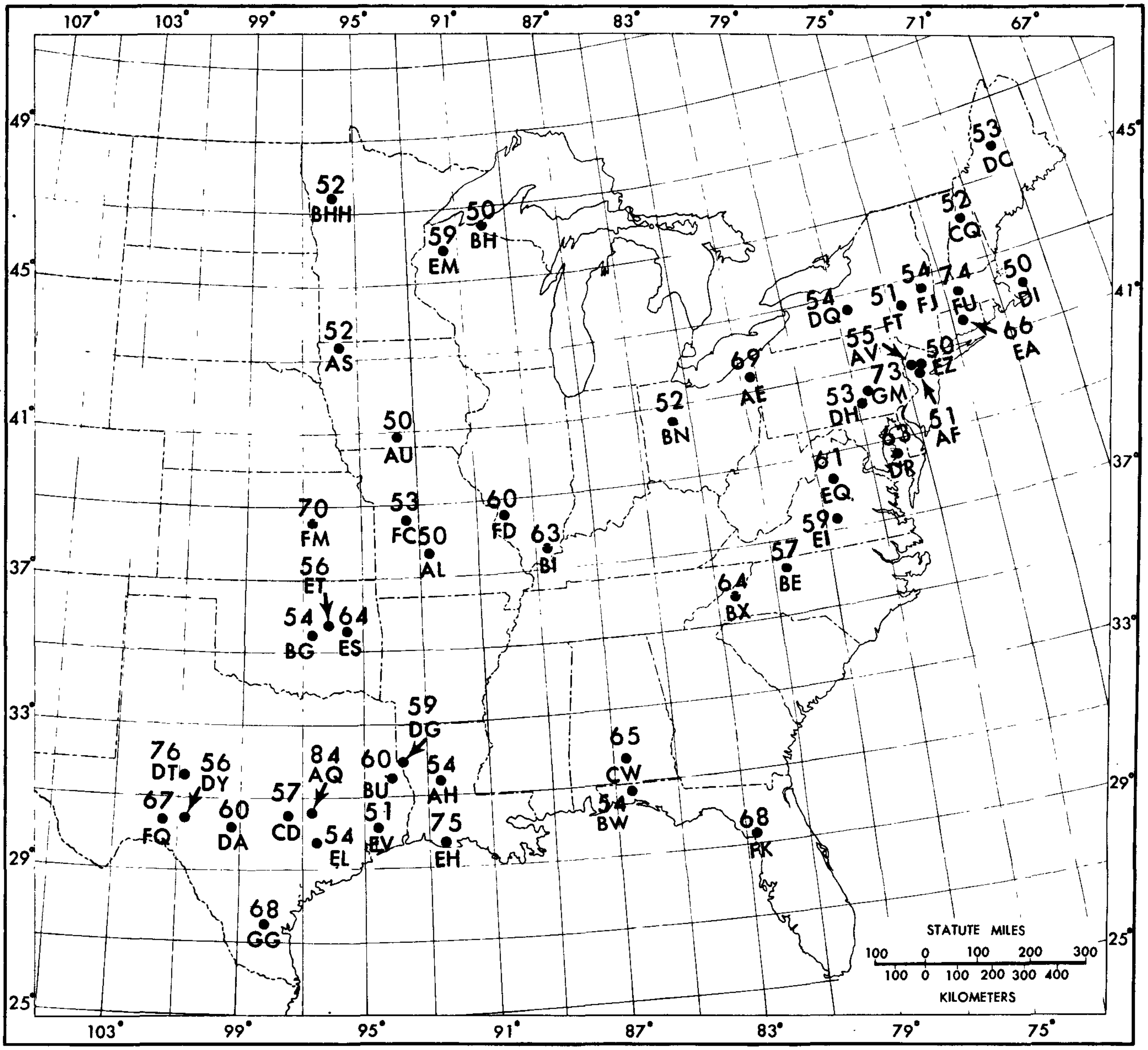

Chart No. 20.--Same as chart 6, for 72 hr/5,000 mi^2.

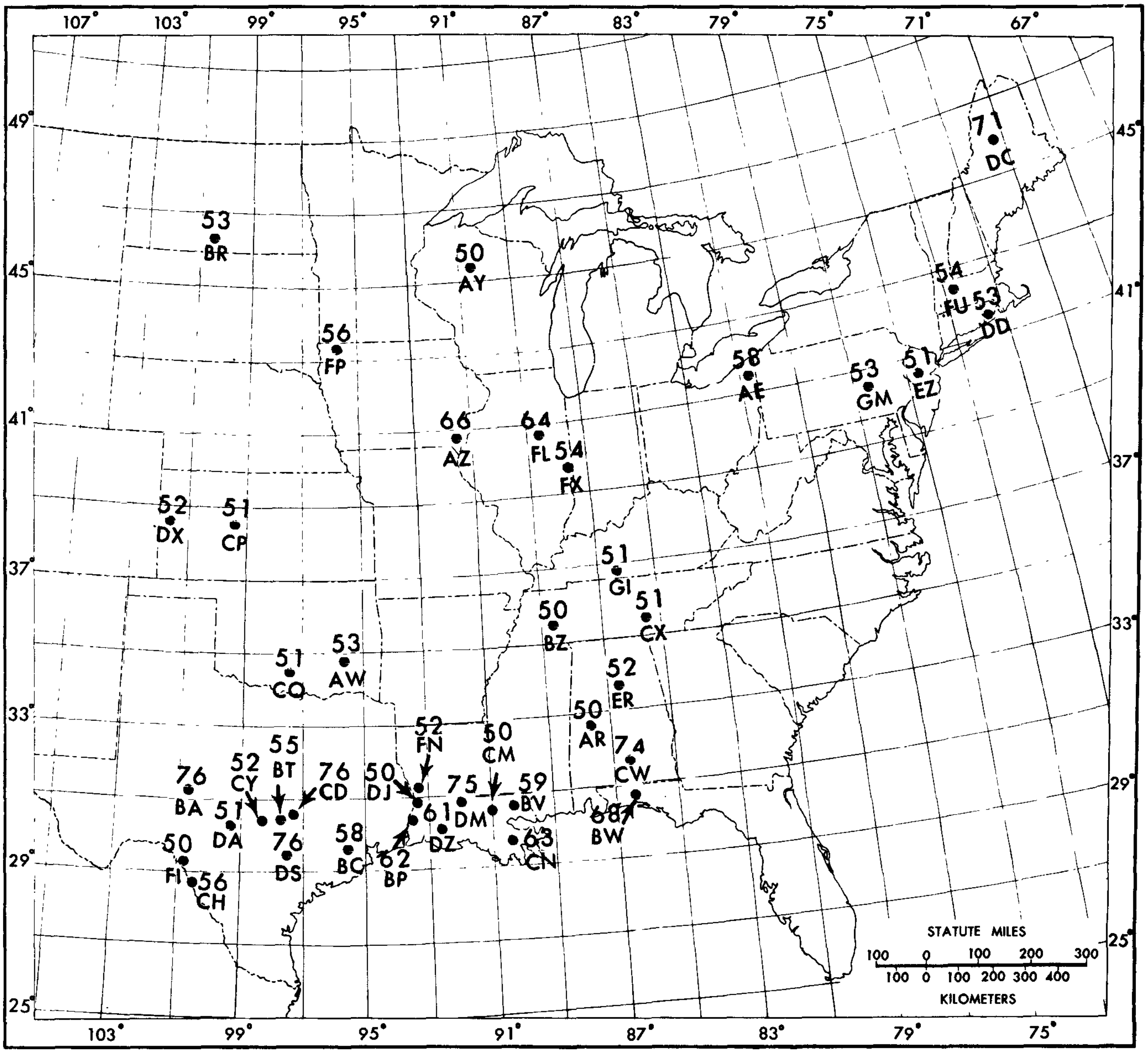

Chart No. 21.--Same as chart 6, for 6 hr/10,000 mi^2.

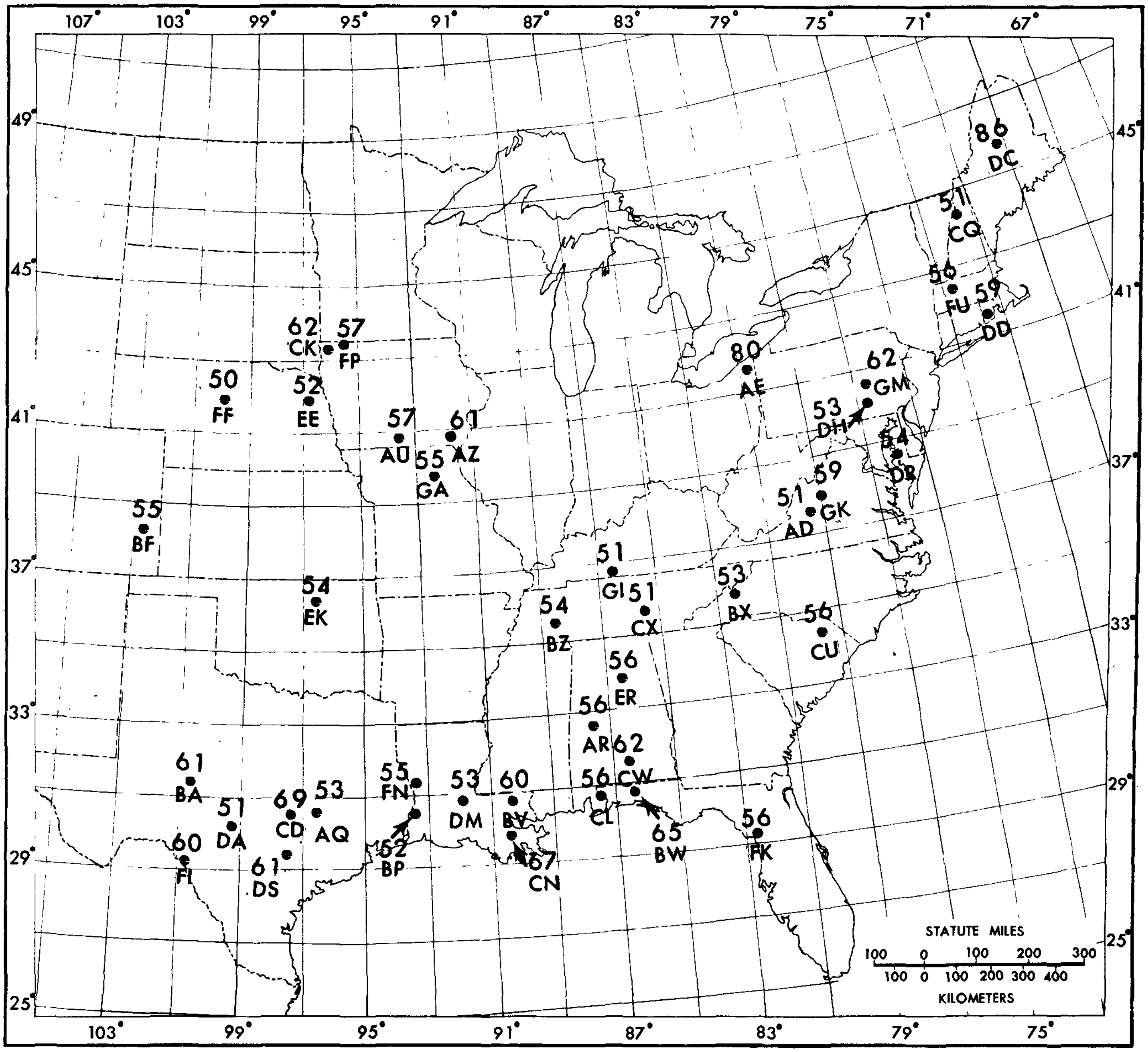

Chart No. 22.--Same as chart 6, for 12 hr/10,000 mi^2.

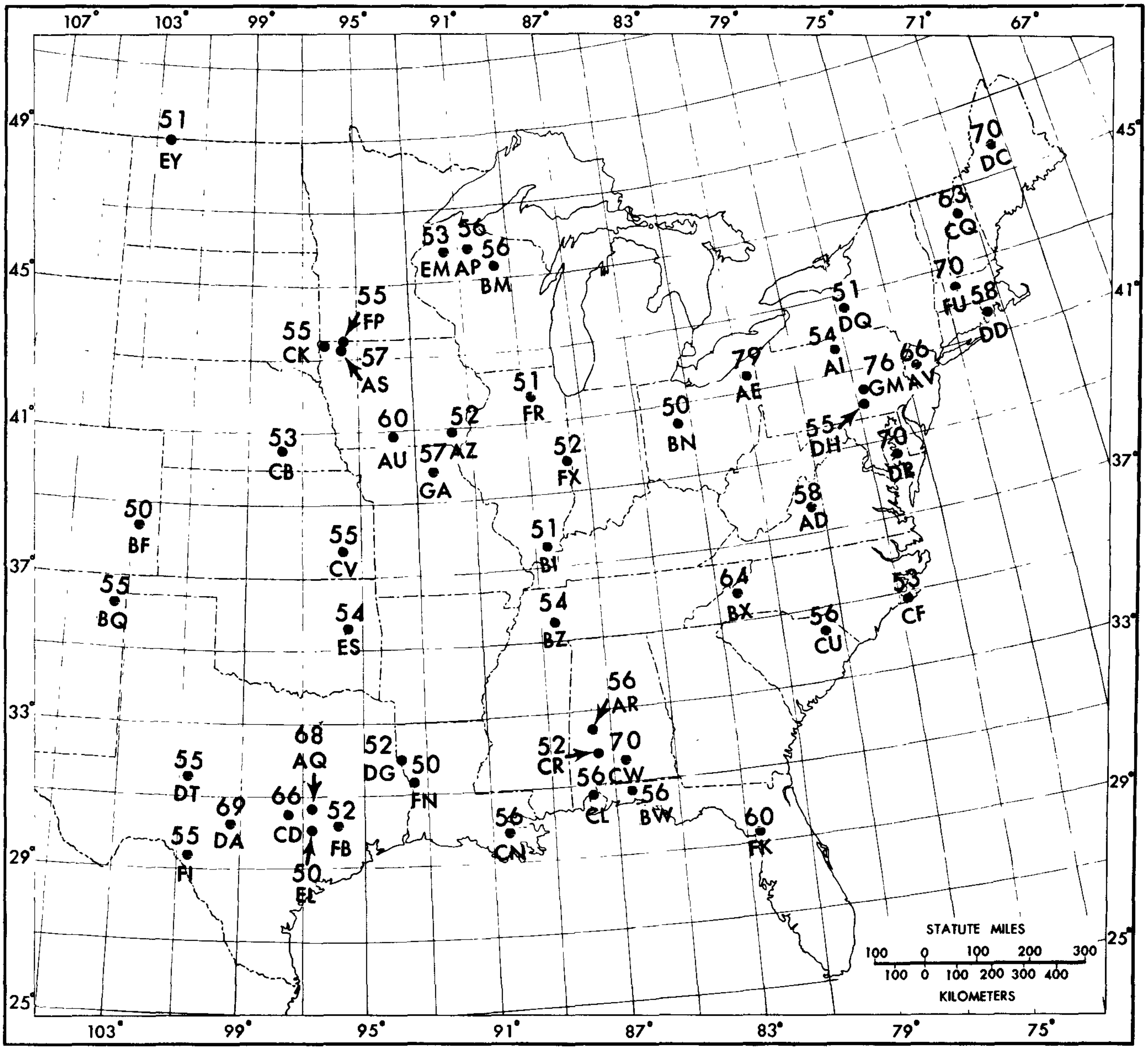

Chart No. 23.--Same as chart 6, for 24 hr/10,000 mi².

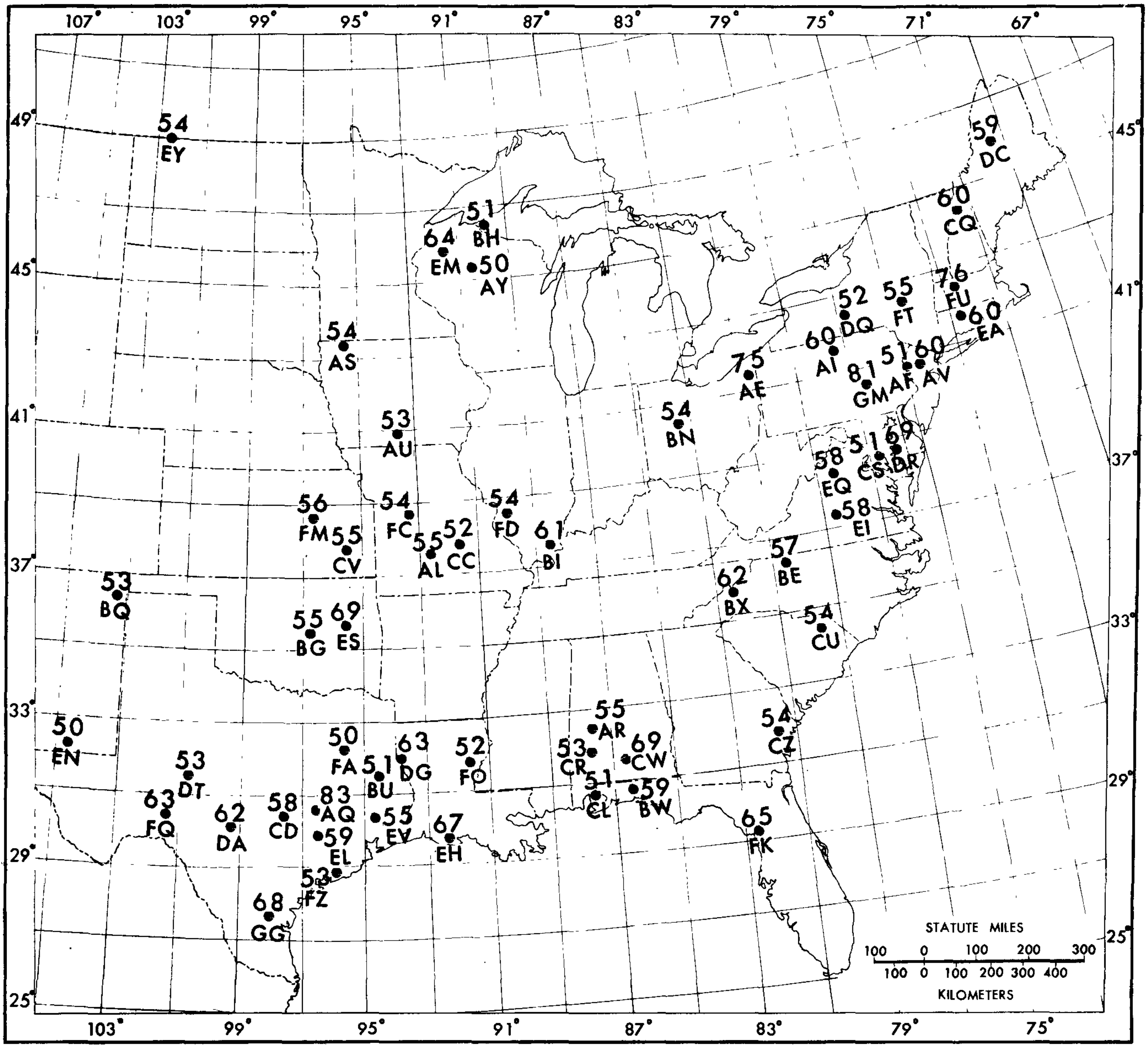

Chart No. 24.--Same as chart 6, for 48 hr/10,000 mi^2.

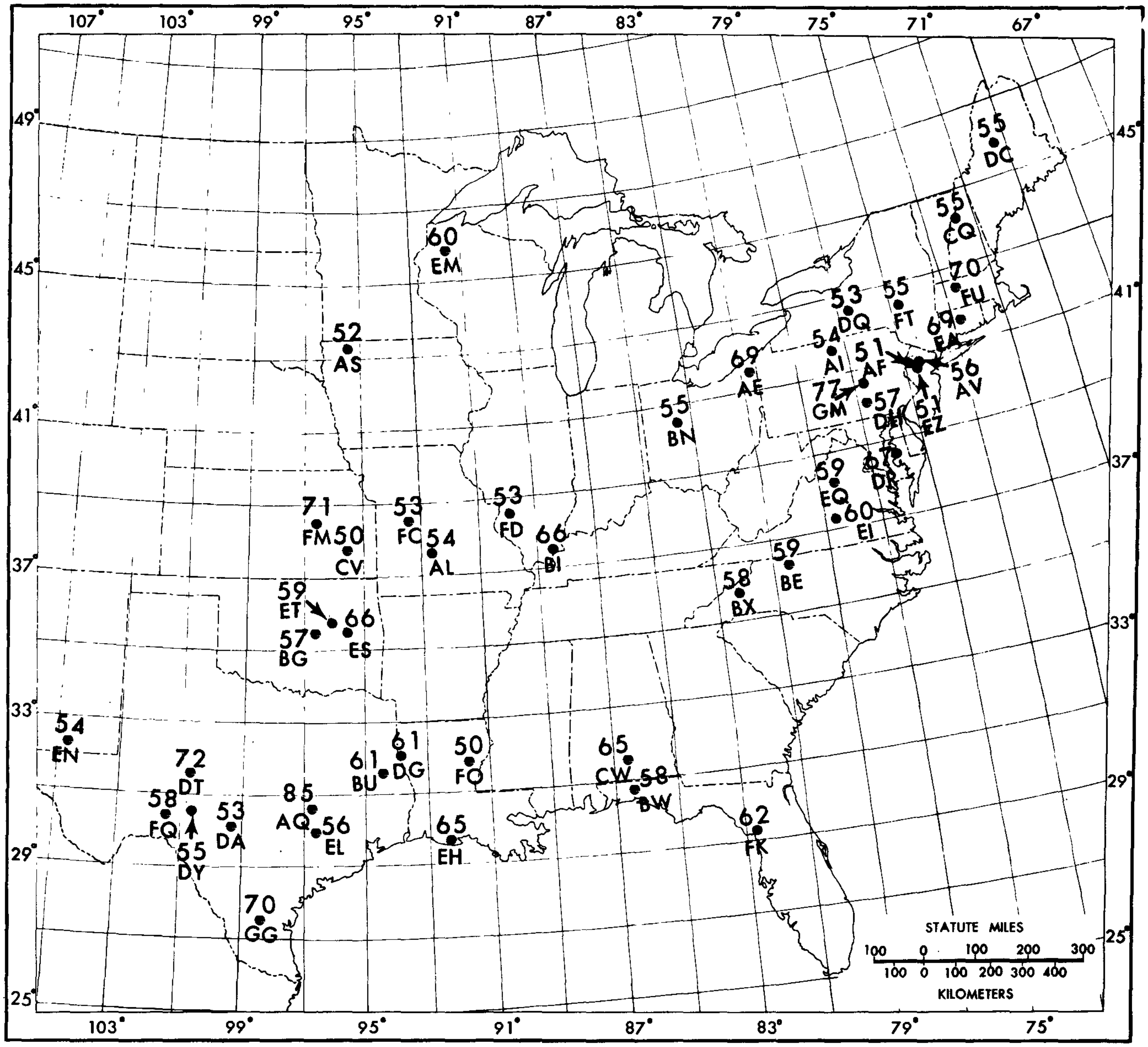

Chart No. 25.--Same as chart 6, for 72 hr/10,000 mi².

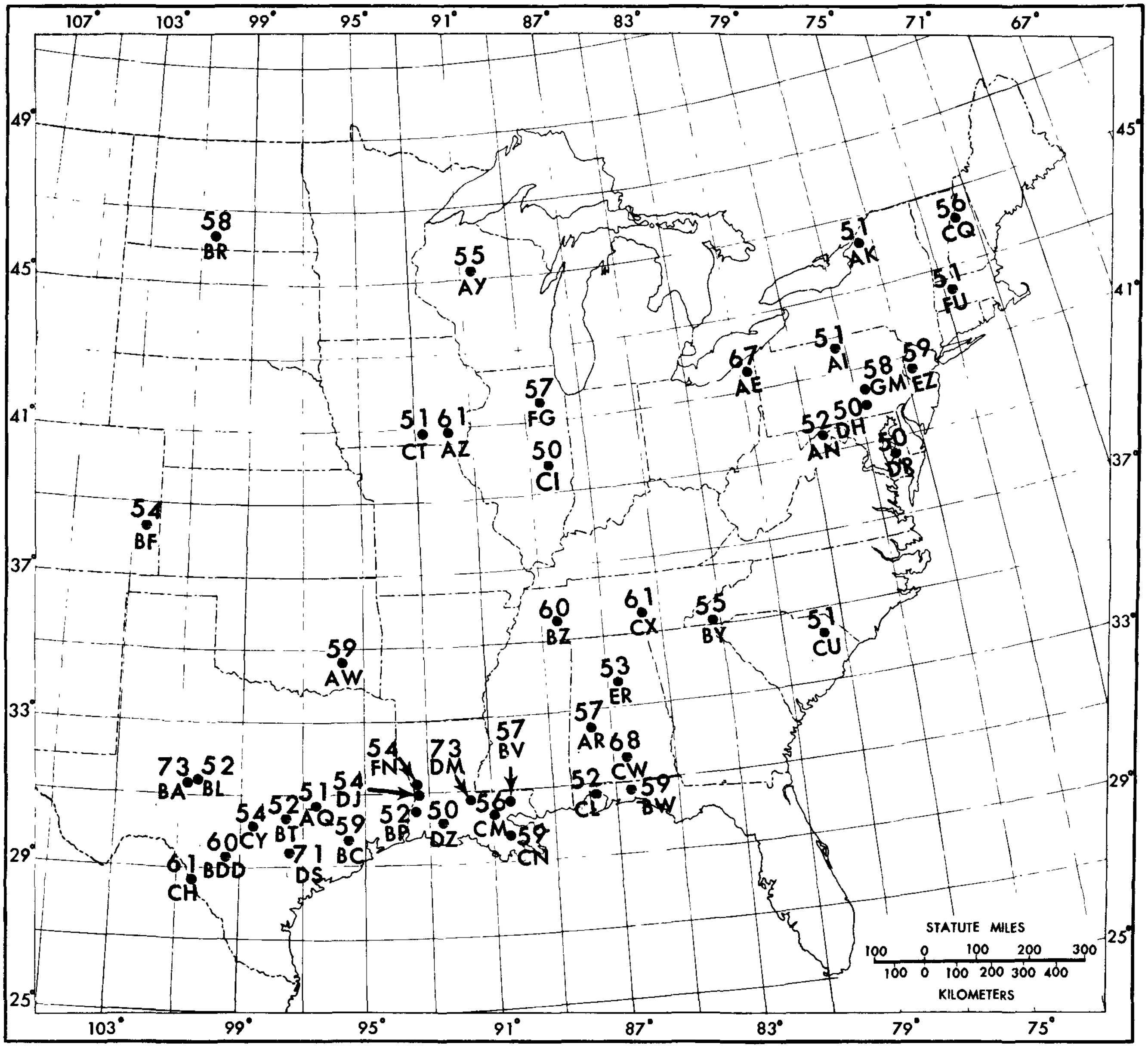

Chart No. 26.--Same as chart 6, for 6 hr/20,000 mi^2.

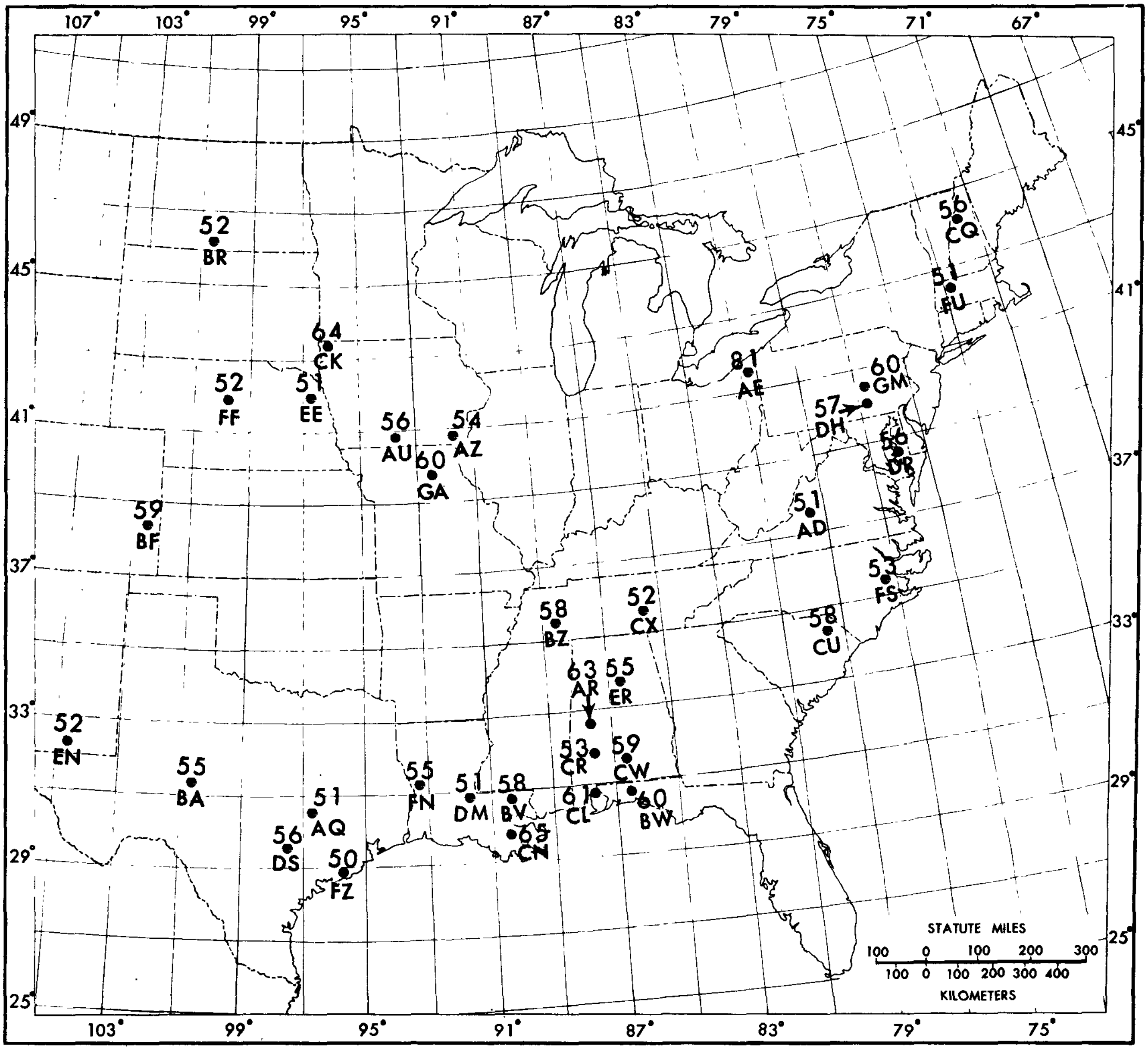

Chart No. 27.--Same as chart 6, for 12 hr/20,000 mi^2.

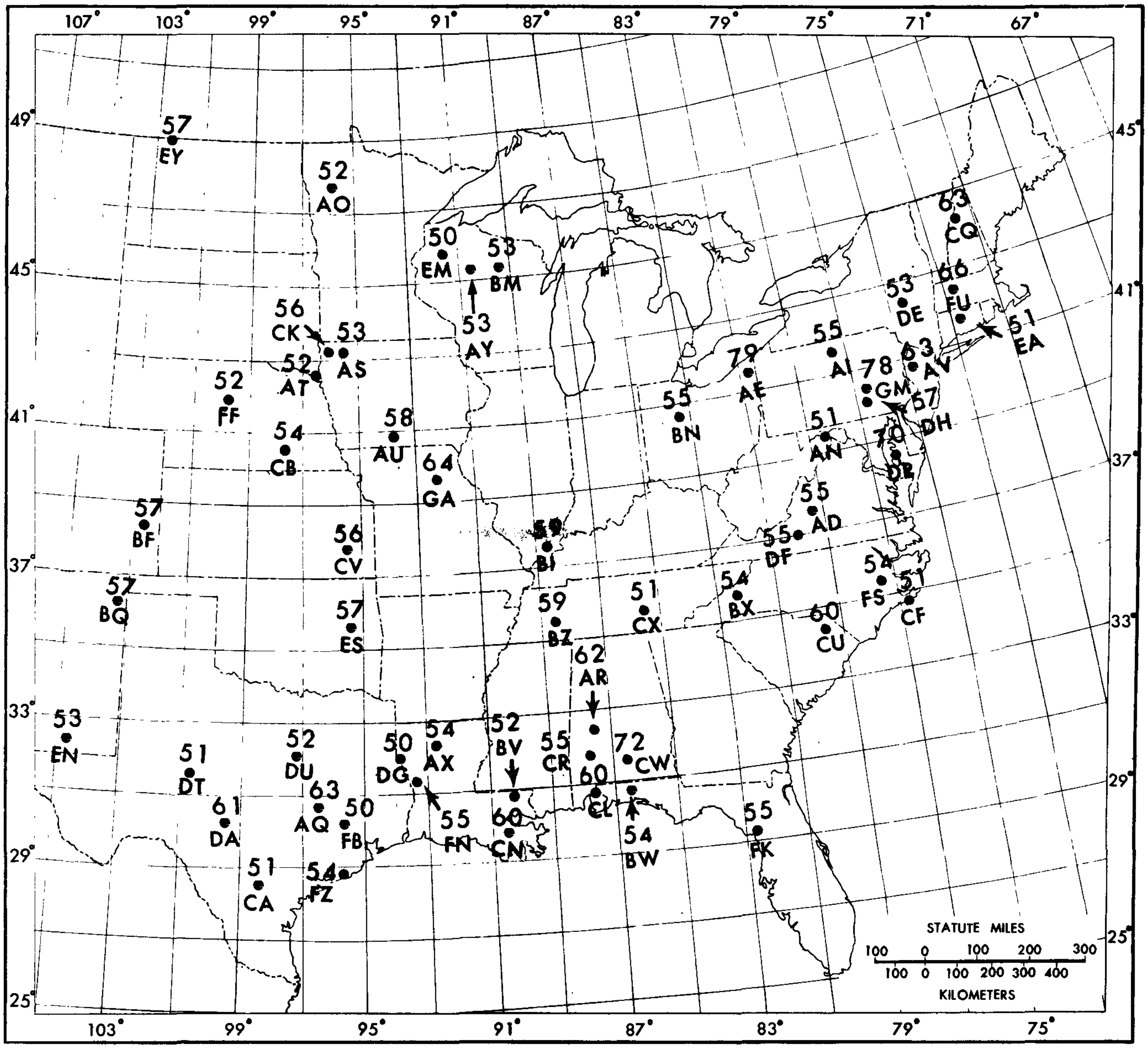

Chart No. 28.--Same as chart 6, for 24 hr/20,000 mi^2.

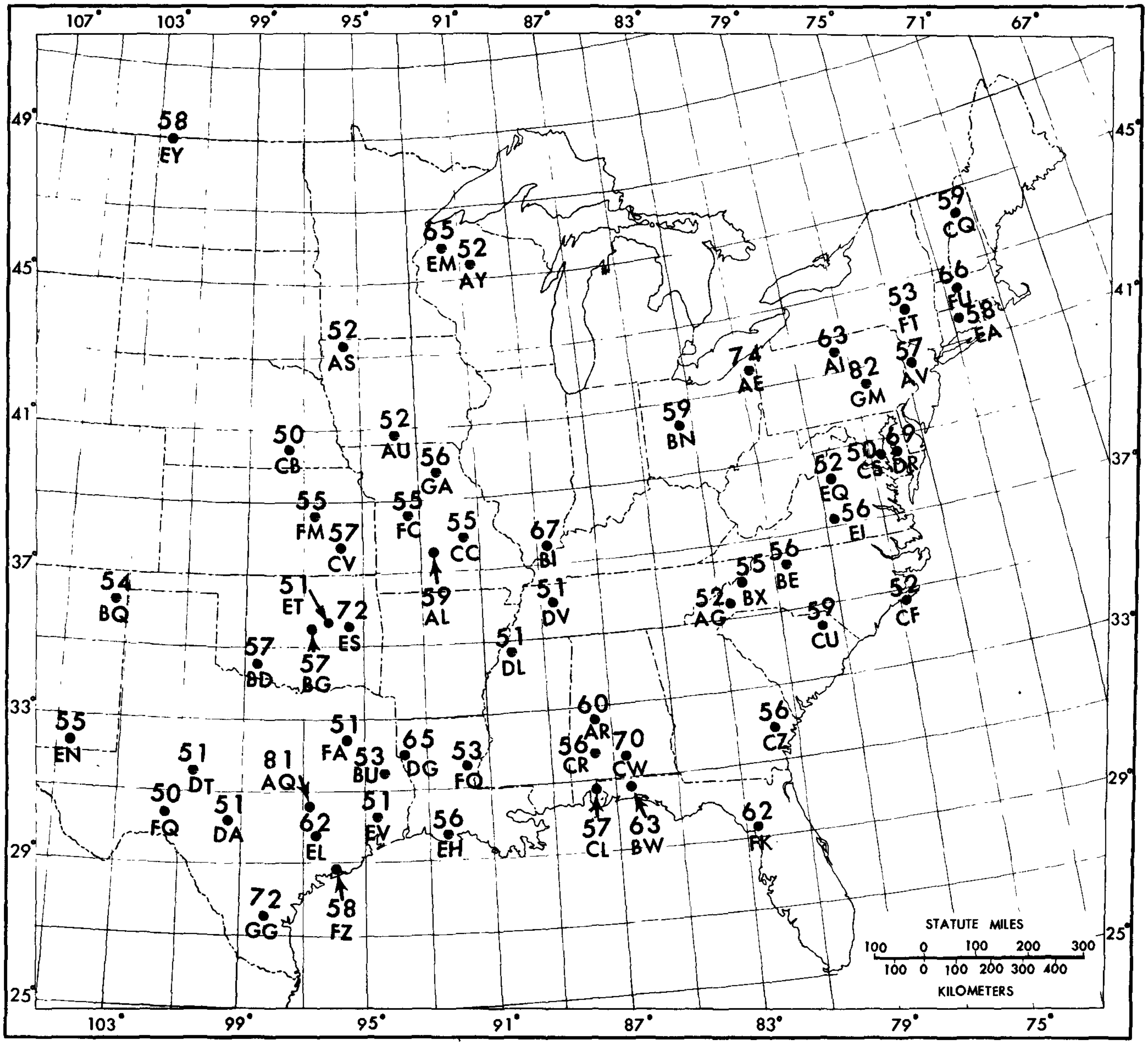

Chart No. 29.--Same as chart 6, for 48 hr/20,000 mi^2.

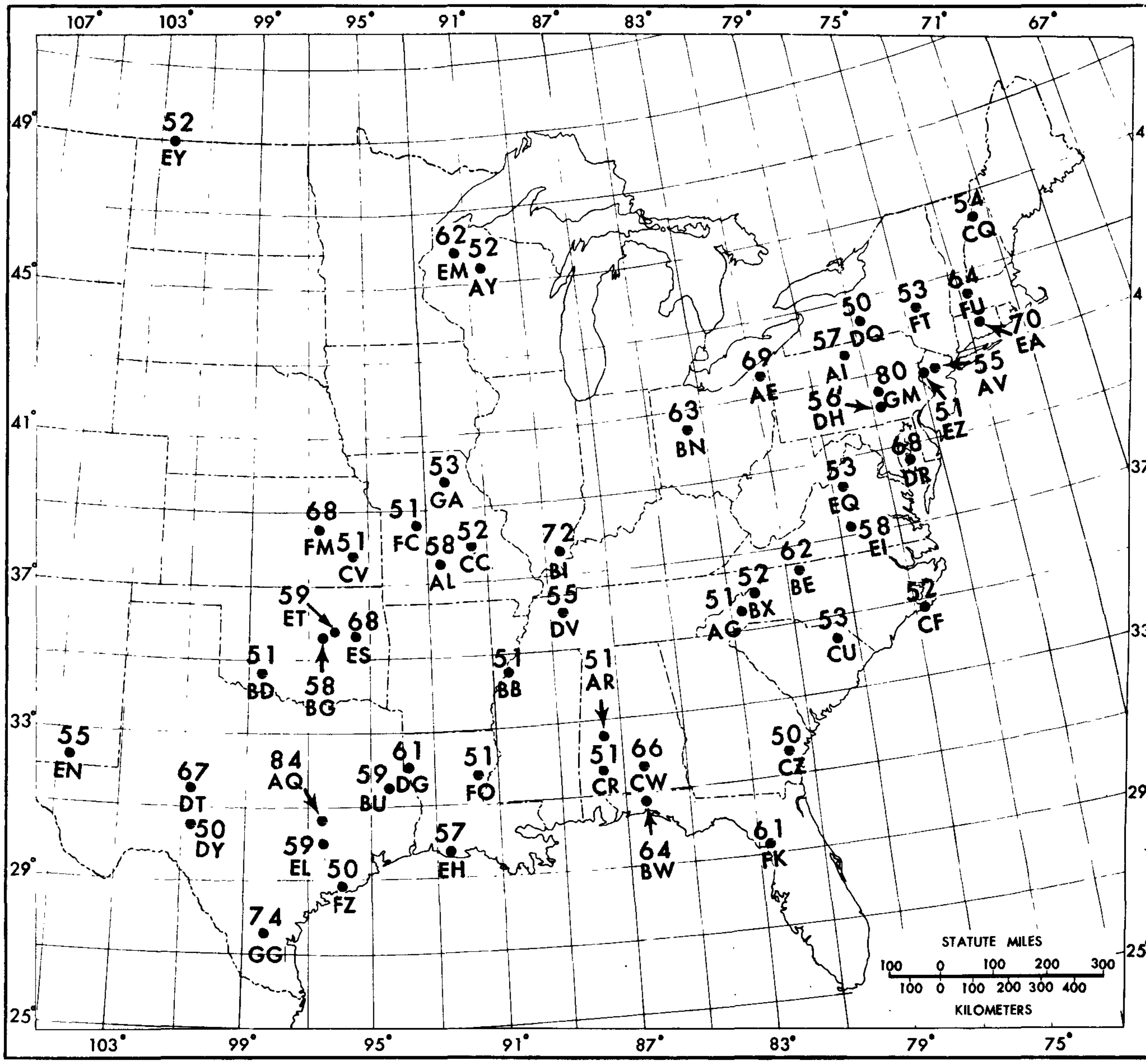

Chart No. 30.--Same as chart 6, for 72 hr/20,000 mi^2

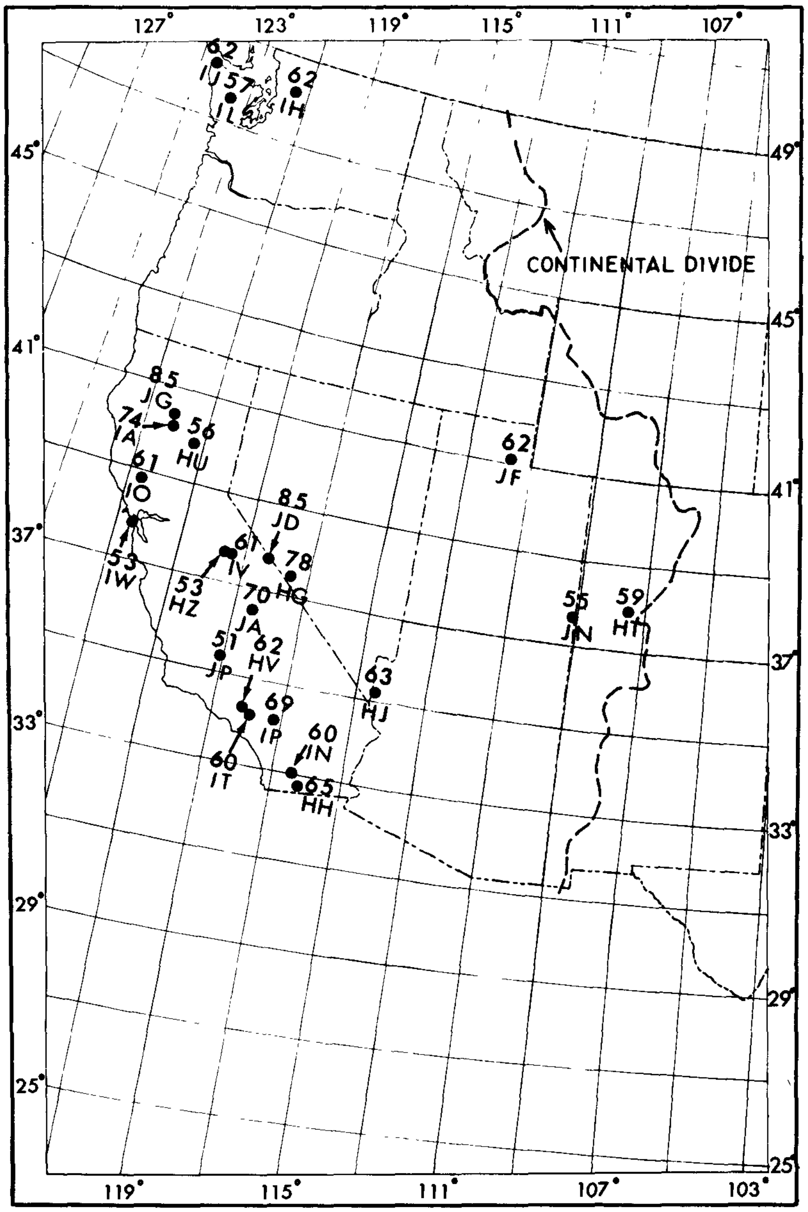

Chart No. 31.--Observed point rainfalls U.S. west of the Continental Divide ≥ 50 percent of all-season PMP for 6 hr/10 mi².

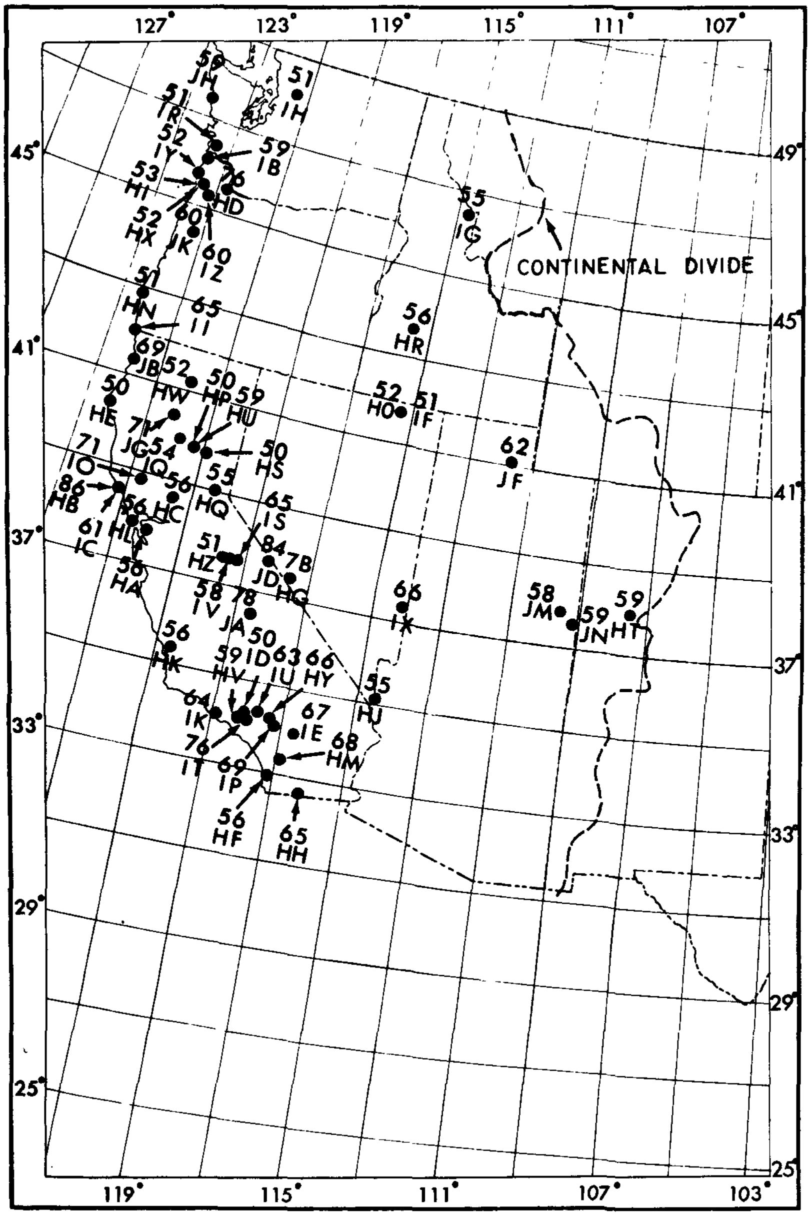

Chart No. 32.--Same as chart 31, for 24 hr/10 mi^2.

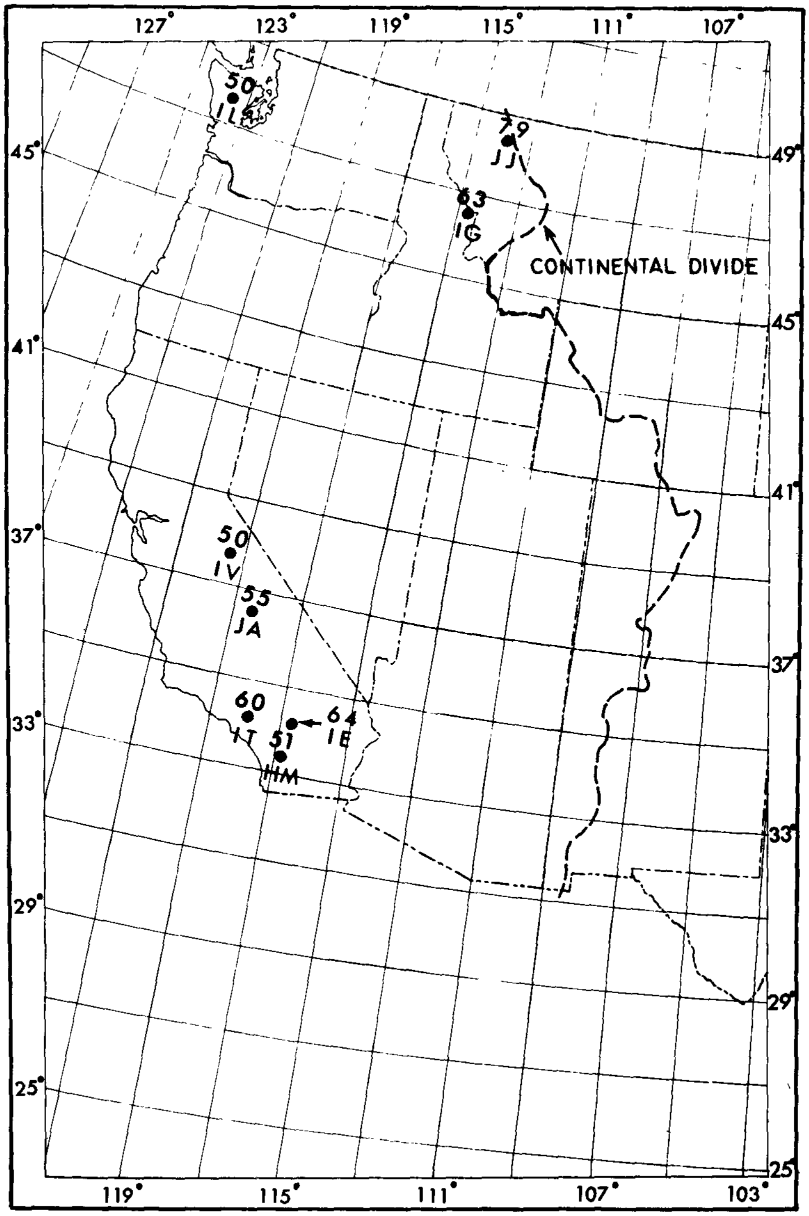

Chart No. 33.--Observed areal rainfalls U.S. west of Continental Divide ≥ 50 percent of all-season PMP for 24 hr/500 mi².

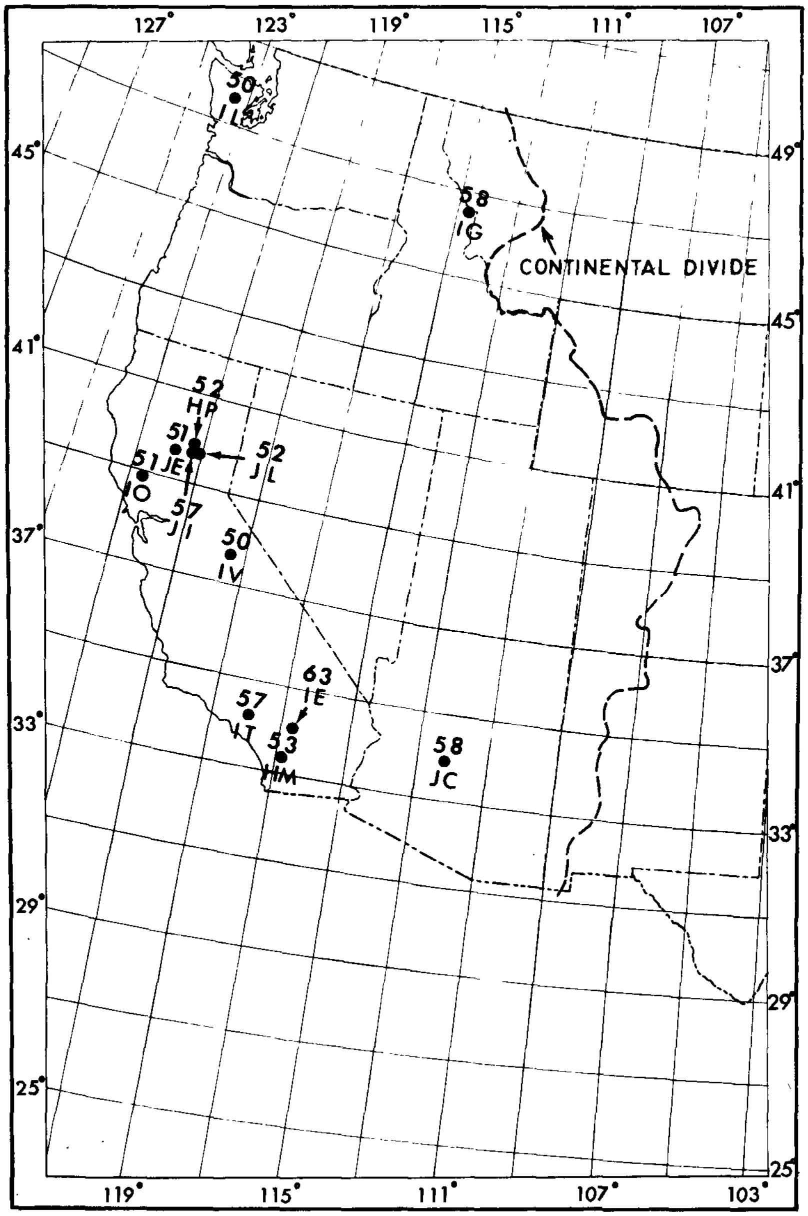

Chart No. 34.--Same as chart 33, for 48 hr/500 mi^2.

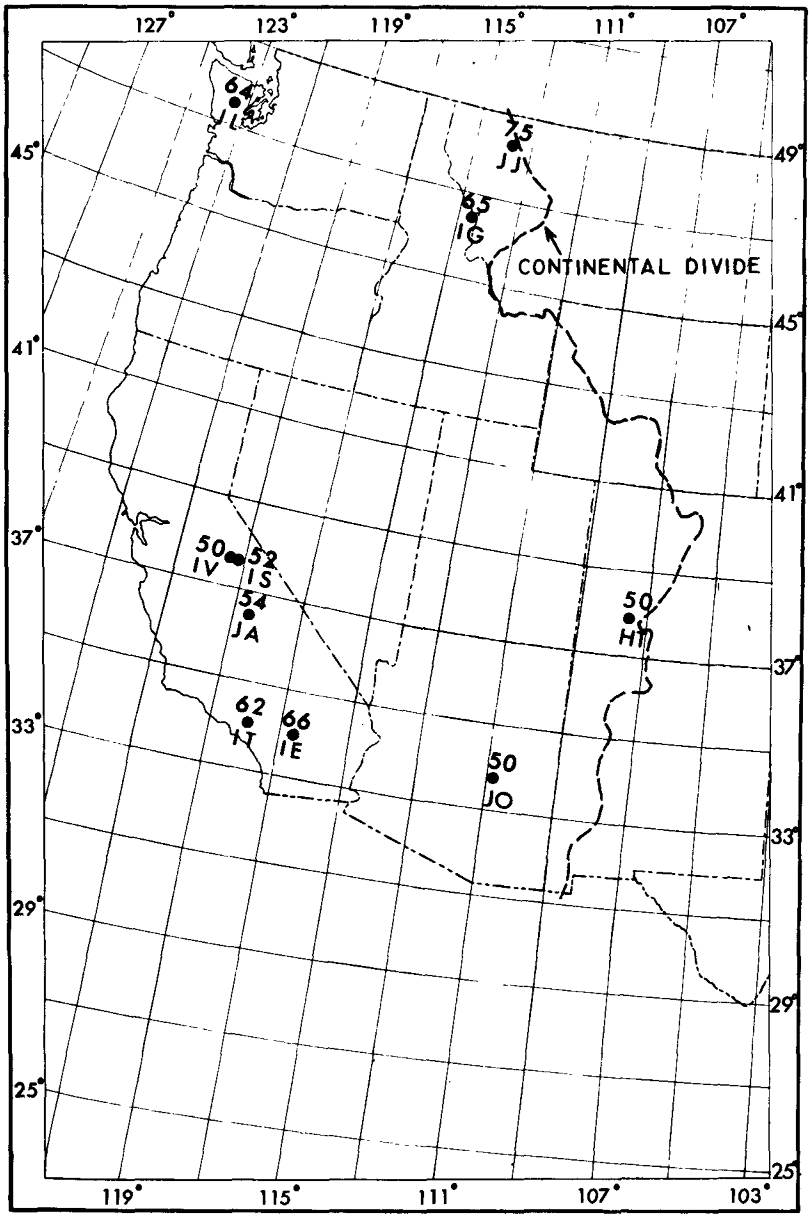

Chart No. 35.--Same as chart 33, for 24 hr/1000 mi^2.

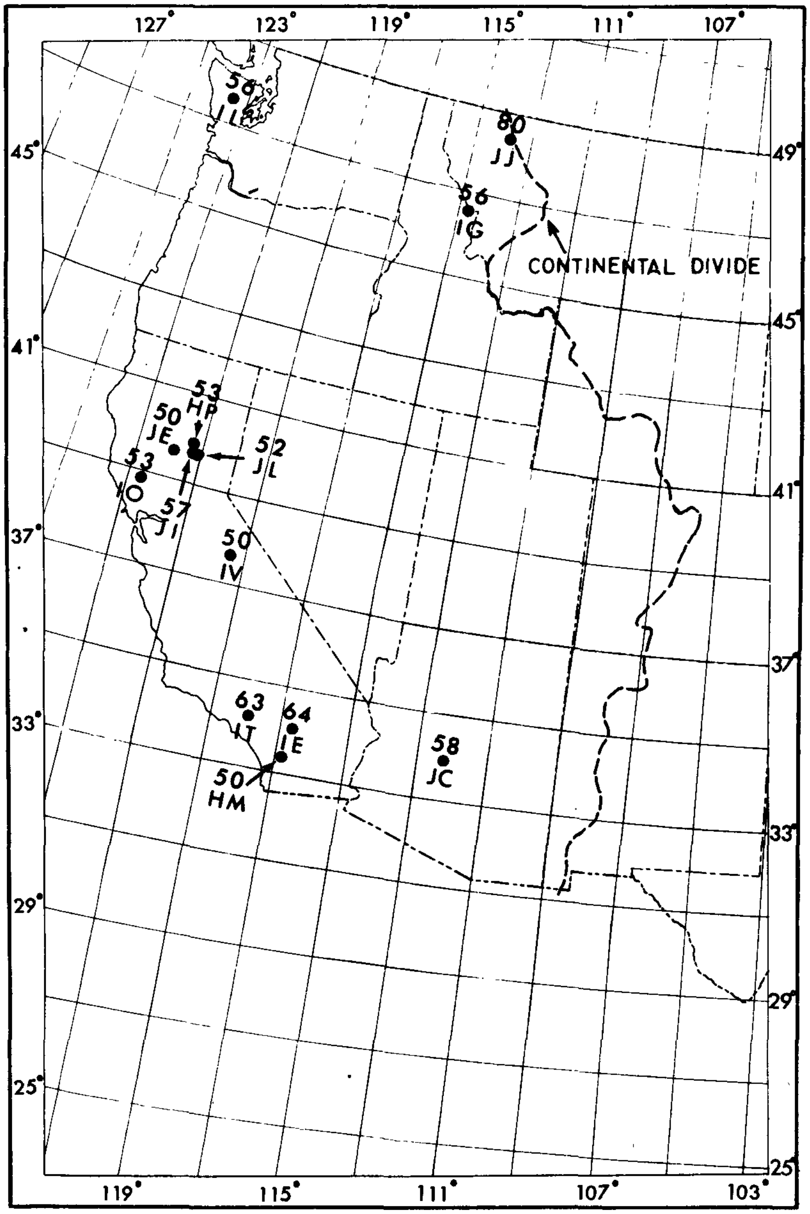

Chart No. 36.--Same as chart 33, for 48 hr/1000 mi^2.

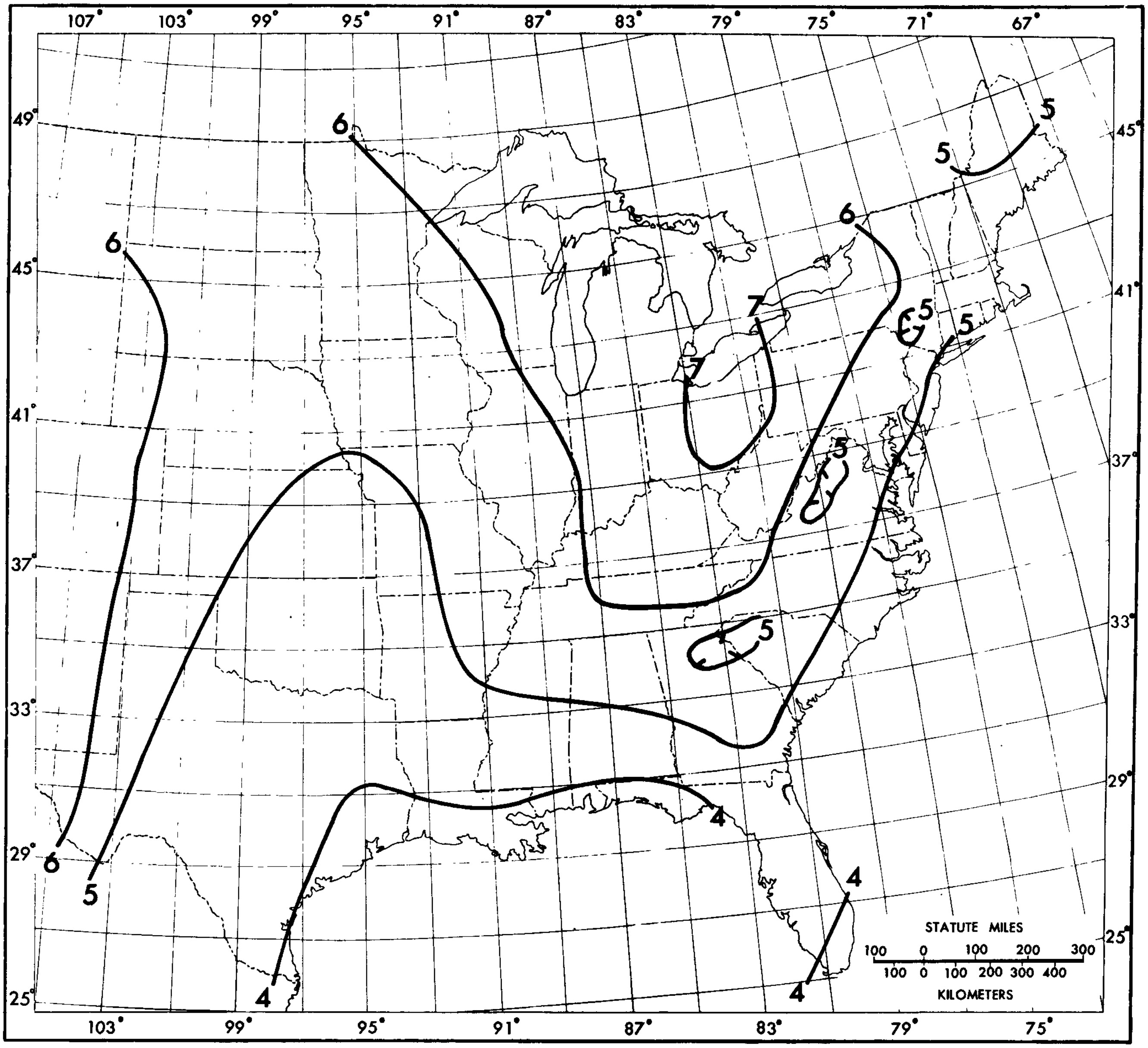

Chart No. 37.--Ratios of 10 mi² PMP (HMR No. 51) to 100 yr rainfalls (T.P. No. 40) for 6 hours.

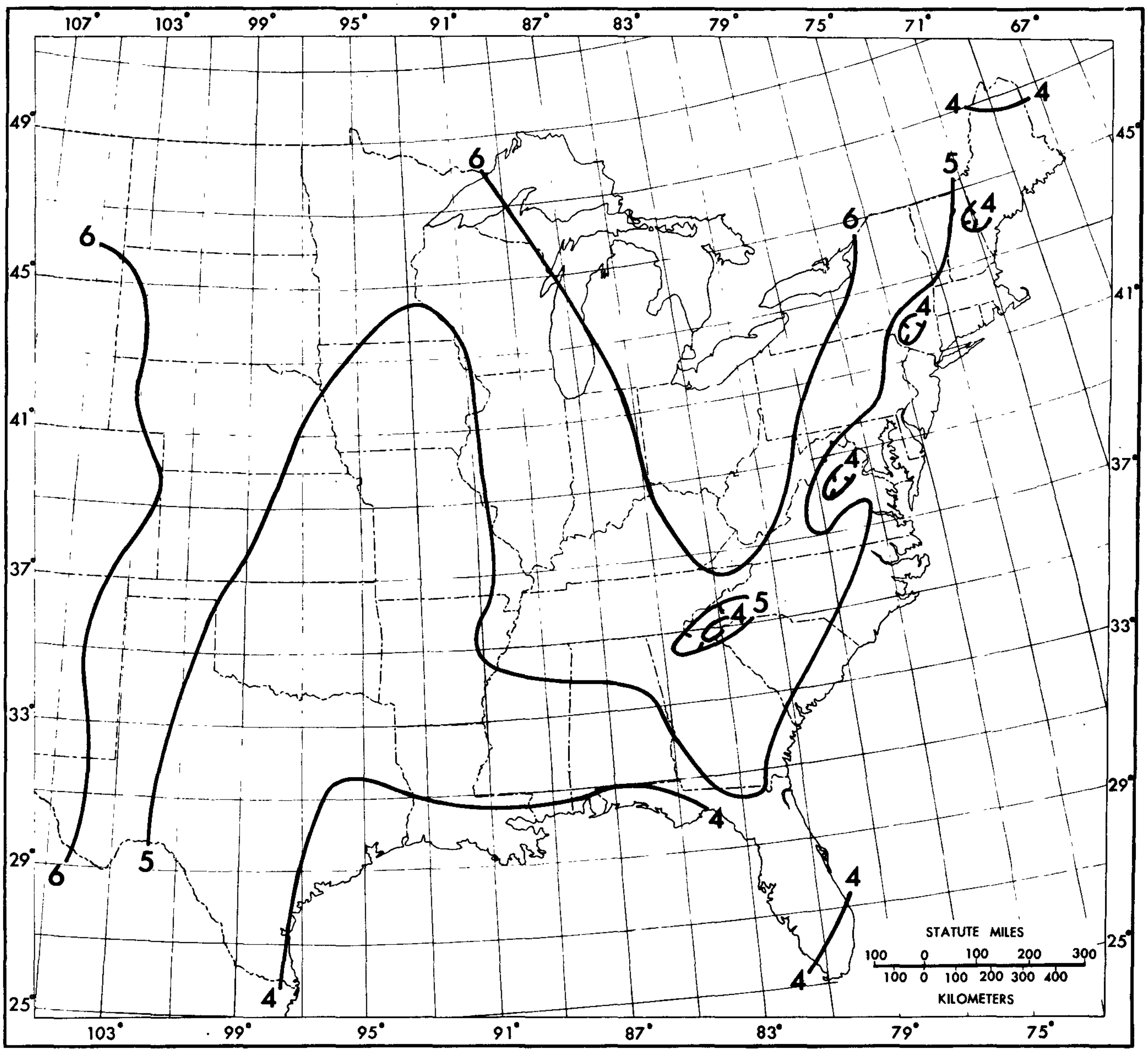

Chart No. 38.--Same as chart 37, for 24 hours.

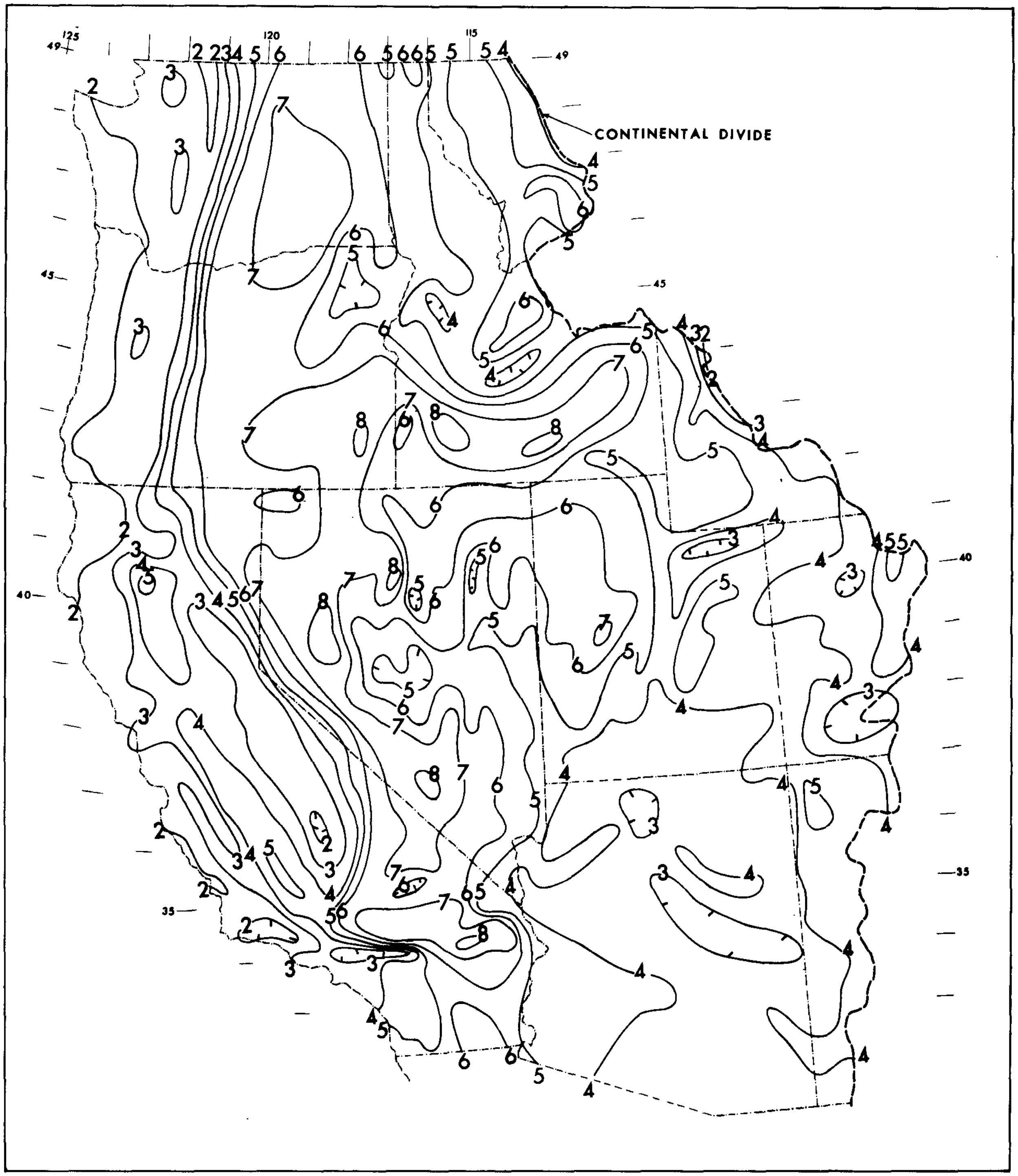

Chart No. 39.--Ratios of 10 mi² PMP (HMR Nos. 36, 43, and 49) to 100-yr rainfalls (NOAA Atlas 2) for 6 hours.

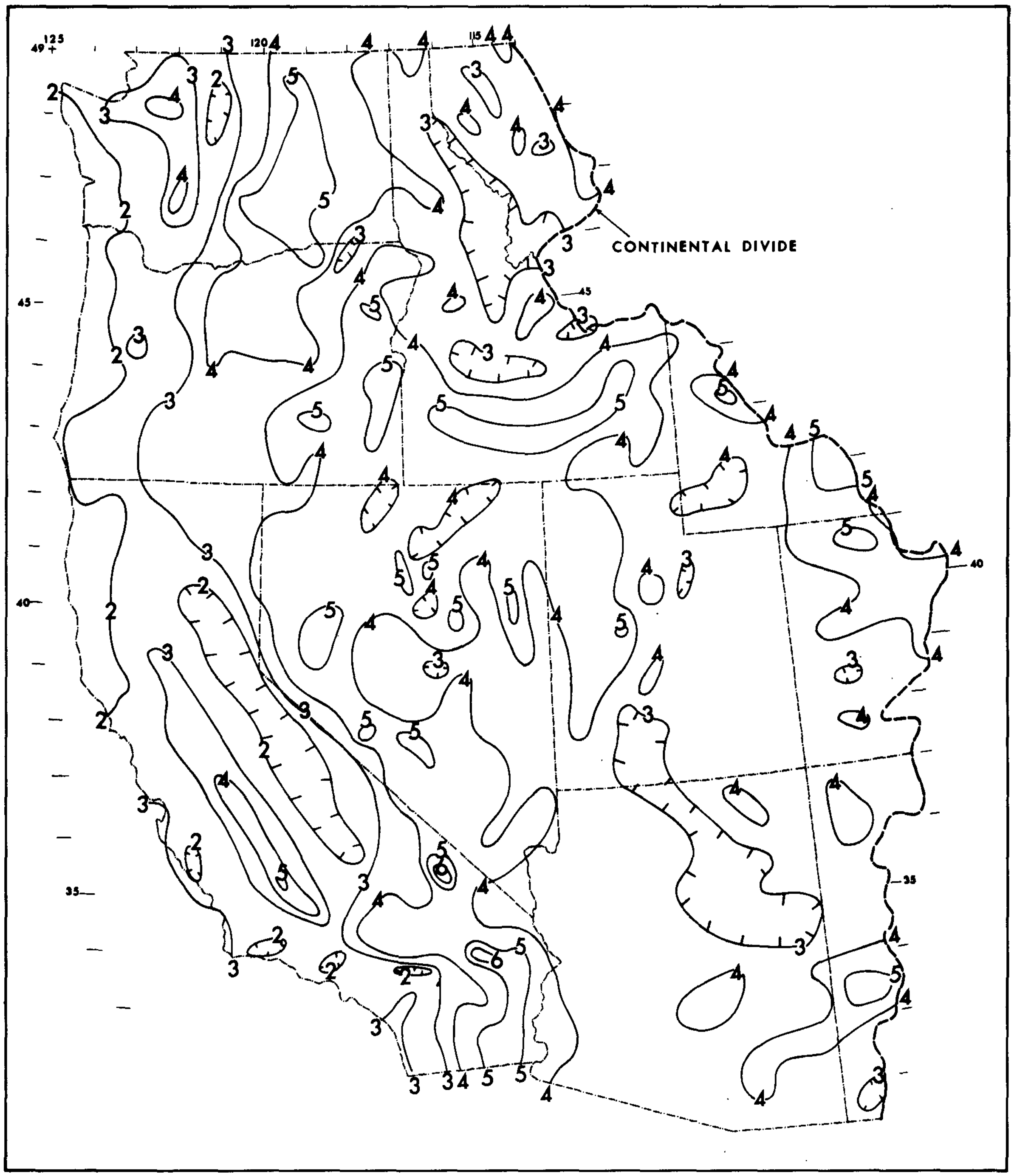

Chart No. 40.--Same as chart 39, for 24 hours.

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(Continued from inside front cover)

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