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TECHNICAL PAPER NO. 40

RAINFALL FREQUENCY ATLAS OF THE UNITED STATES

for Durations from 30 Minutes to 24 Hours and Return Periods from 1 to 100 Years

Prepared by
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for
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PREFACE

This publication is intended as a convenient summary of empirical relationships, working guides, and maps, useful in practical problems requiring rainfall frequency data. It is an outgrowth of several previous Weather Bureau publications on this subject prepared under the direction of the author and contains an expansion and generalization of the ideas and results in earlier papers. This work has been supported and financed by the Soil Conservation Service, Department of Agriculture, to provide material for use in developing planning and design criteria for the Watershed Protection and Flood Prevention program (P.L. 566, 83d Congress and as amended).

The paper is divided into two parts. The first part presents the rainfall analyses. Included are measures of the quality of the various relationships, comparisons with previous works of a similar nature, numerical examples, discussions of the limitations of the results, transformation from point to areal frequency, and seasonal variation. The second part presents 49 rainfall frequency maps based on a comprehensive and integrated collection of up-to-date statistics, several related maps, and seasonal variation diagrams. The rainfall frequency (isopluvial) maps are for selected durations from 30 minutes to 24 hours and return periods from 1 to 100 years.

This study was prepared in the Cooperative Studies Section (Joseph L. H. Paulhus, Chief) of Hydrologic Services Division (William E. Hiatt, Chief). Coordination with the Soil Conservation Service, Department of Agriculture, was maintained through Harold O. Ogrosky, Chief, Hydrology Branch, Engineering Division. Assistance in the study was received from several people. In particular, the author wishes to acknowledge the help of William E. Miller who programmed the frequency and duration functions and supervised the processing of all the data; Normalee S. Foat who supervised the collection of the basic data; Howard Thompson who prepared the maps for analysis; Walter T. Wilson, a former colleague, who was associated with the development of a large portion of the material presented here; Max A. Kohler, A. L. Shands, and Leonard L. Weiss, of the Weather Bureau, and V. Mockus and R. G. Andrews, of the Soil Conservation Service, who reviewed the manuscript and made many helpful suggestions. Caroll W. Gardner performed the drafting.

CONTENTS

RAINFALL FREQUENCY ATLAS OF THE UNITED STATES
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INTRODUCTION

Historical review

Until about 1953, economic and engineering design requiring rainfall frequency data was based largely on Yarnell's paper [1] which contains a series of generalized maps for several combinations of durations and return periods. Yarnell's maps are based on data from about 200 first-order Weather Bureau stations which maintained complete recording-gage records. In 1940, about 5 years after Yarnell's paper was published, a hydrologic network of recording gages was installed to supplement both the Weather Bureau recording gages and the relatively larger number of nonrecording gages. The additional recording gages have subsequently increased the amount of short-duration data by a factor of 20.

Weather Bureau *Technical Paper No. 24*, Parts I and II [2], prepared for the Corps of Engineers in connection with their military construction program, contained the first studies covering an extended area which exploited the hydrologic network data. The results of this work showed the importance of the additional data in defining the short-duration rainfall frequency regime in the mountainous regions of the West. In many instances, the differences between *Technical Paper No. 24* and Yarnell reach a factor of three, with the former generally being larger. Relationships developed and knowledge gained from these studies in the United States were then used to prepare similar reports for the coastal regions of North Africa [3] and several Arctic regions [4] where recording-gage data were lacking.

Cooperation between the Weather Bureau and the Soil Conservation Service began in 1955 for the purpose of defining the depth-area-duration-frequency regime in the United States. *Technical Paper No. 25* [5], which was partly a by-product of previous work performed for the Corps of Engineers, was the first paper published under the sponsorship of the Soil Conservation Service. This paper contains a series of rainfall intensity-duration-frequency curves for 200 first-order Weather Bureau stations. This was followed by *Technical Paper No. 28* [6], which is an expansion of *Technical Paper No. 24* to longer return periods and durations. Next to be published were the five parts of the *Technical Paper No. 29* series [7], which cover the region east of 90° W. Included in this series are seasonal variation on a frequency basis and area-depth curves so that the point frequency values can be transformed to areal frequency. Except for the region between 90° W. and 105° W., the contiguous United States has been covered by generalized rainfall frequency studies prepared by the Weather Bureau since 1953.

General approach

The approach followed in the present study is basically that utilized in [6] and [7]. In these references, simplified duration and return-period relationships and several key maps were used to determine additional combinations of return periods and durations. In this study, four key maps provided the basic data for these two relationships which were programmed to permit digital computer computations for a 3500-point grid on each of 45 additional maps.

PART I: ANALYSES

Basic data

Types of data.—The data used in this study are divided into three categories. First, there are the recording-gage data from the long-record first-order Weather Bureau stations. There are 200 such stations with records long enough to provide adequate results within the range of return periods of this paper. These data are for the n-minute period containing the maximum rainfall. Second, there are the recording-gage data of the hydrologic network which are published for clock-hour intervals. These data were processed for the 24 consecutive clock-hour intervals containing the maximum rainfall—not calendar-day. Finally, there is the very large amount of nonrecording-gage data with observations made once daily. Use was made of these data to help define both the 24-hour rainfall regime and also the shorter duration regimes through applications of empirical relationships.

Station data.—The sources of data are indicated in table 1. The data from the 200 long-record Weather Bureau stations were used to develop most of the relationships which will be described later. Long records from more than 1600 stations were analyzed to define the relationships for the rarer frequencies (return periods), and statistics from short portions of the record from about 5000 stations were used as an aid in defining the regional pattern for the 2-year return period. Several thousand additional stations were considered but not plotted where the station density was adjudged to be adequate.

Period and length of record.—The nonrecording short-record data were compiled for the period 1938–1957 and long-record data from the earliest year available through 1957. The recording-gage data cover the period 1940–1958. Data from the long-record Weather Bureau stations were processed through 1958. No record of less than five years was used to estimate the 2-year values.

TABLE 1.—*Sources of point rainfall data*

Duration	No. of stations	Average length of record (yr.)	Reference No.
30-min. to 24-hr	200	48	8, 9, 10
Hourly	2081	14	11, 12
Daily (recording)	1350	16	11, 12
Daily (nonrecording)	3409	15	13
Daily (nonrecording)	1426	47	13

Clock-hour vs. 60-minute and observational-day vs. 1440-minute rainfall.—In order to exploit the clock-hour and observational-day data, it was necessary to determine their relationship to the 60-minute and 1440-minute periods containing the maximum rainfall. It was found that 1.13 times a rainfall value for a particular return period based on a series of annual maximum clock-hour rainfalls was equivalent to the amount for the same return period obtained from a series of 60-minute rainfalls. By coincidence, it was found that the same factor can be used to transform observational-day amounts to corresponding 1440-minute return-period amounts. The equation, n-year 1440-minute rainfall (or 60-minute) equals 1.13 times n-year observational-day (or clock-hour) rainfall, is not built on a causal relationship. This is an average index relationship because the distributions of 60-minute and 1440-minute rainfall are very irregular or unpredictable during their respective time intervals. In addition, the annual maxima from the two series for the same year from corresponding durations do not necessarily come from the same storm. Graphical comparisons of these data are presented in figure 1, which shows very good agreement.

24 consecutive clock-hour rainfall vs. 1440-minute rainfall.—The recording-gage data were collected from published sources for the 24 consecutive clock-hours containing the maximum rainfall. Because of the arbitrary beginning and ending on the hour, a series of these data provides statistics which are slightly smaller in magnitude than those from the 1440-minute series The average bias was found to be approximately one percent. All such data in this paper have been adjusted by this factor.

Station exposure.—In refined analysis of mean annual and mean seasonal rainfall data it is necessary to evaluate station exposures by methods such as double-mass curve analysis [14]. Such methods do not appear to apply to extreme values. Except for some subjective selections (particularly for long records) of stations that have had consistent exposures, no attempt has been made to adjust rainfall values to a standard exposure. The effects of varying exposure are implicitly included in the areal sampling error and are probably averaged out in the process of smoothing the isopluvial lines.

Rain or snow.—The term rainfall has been used in reference to all durations even though some snow as well as rain is included in some of the smaller 24-hour amounts for the high-elevation stations. Comparison of arrays of all ranking snow events with those known to have only rain has shown trivial differences in the frequency relations for several high-elevation stations tested. The heavier (rarer frequency) 24-hour events and all short-duration events consist entirely of rain.

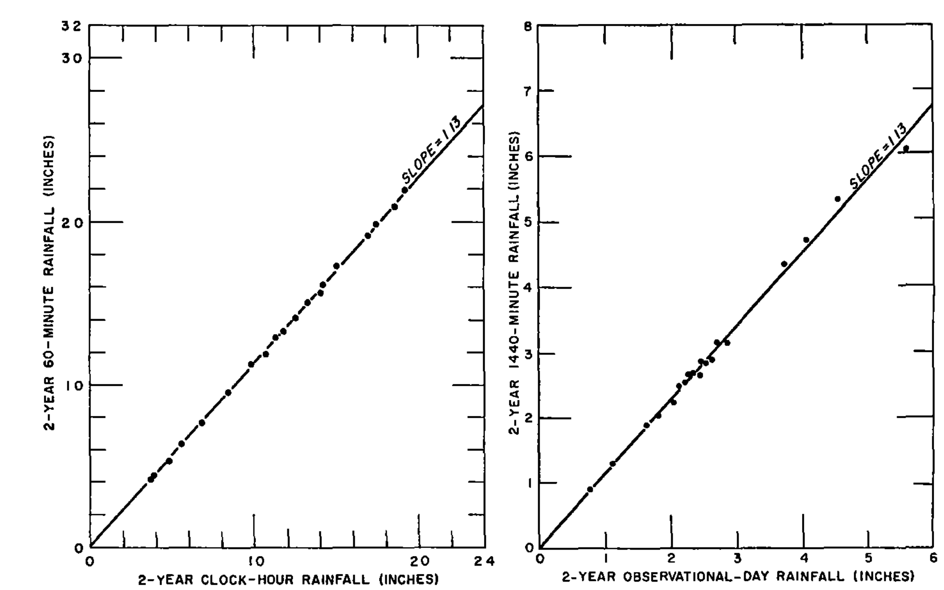

FIGURE 1.—Relation between 2-year 60-minute rainfall and 2-year clock-hour rainfall; relation between 2-year 1440-minute rainfall and 2-year observational-day rainfall.

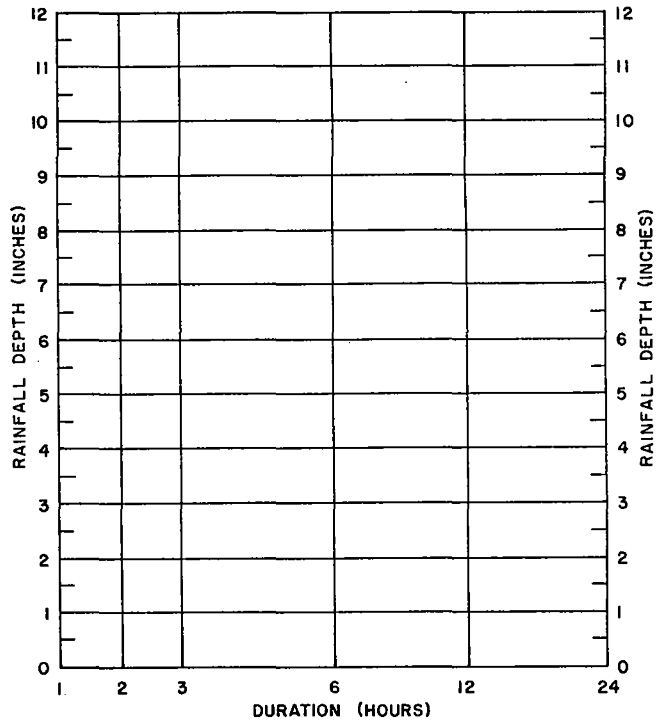

FIGURE 2.—Rainfall depth-duration diagram.

Duration analysis

Duration interpolation diagram.—A generalized duration relationship was developed with which the rainfall depth for a selected return period can be computed for any duration between 1 and 24 hours, when the 1- and 24-hour values for that particular return period are given (see fig. 2). This generalization was obtained empirically from data for the 200 Weather Bureau first-order stations. To use this diagram, a straightedge is laid across the values given for 1 and 24 hours and the values for other durations are read at the proper intersections. The quality of this relationship for the 2- and 6-hour durations is illustrated in figures 3 and 4 for stations with a wide range in rainfall magnitude.

Relationship between 30-minute and 60-minute rainfall.—If a 30-minute ordinate is positioned to the left of the 60-minute ordinate on the duration interpolation diagram of figure 2, acceptable estimates can be made of the 30-minute rainfall. This relationship was used in several previous studies. However, tests showed that better results can be obtained by simply multiplying the 60-minute rainfall by the average 30- to 60-minute ratio. The empirical relationship used for estimating the 30-minute rainfall is 0.79 times the 60-minute rainfall. The quality of this relationship is illustrated in figure 5.

Frequency analysis

Two types of series.—This discussion requires consideration of two methods of selecting and analyzing intense rainfall data. One method, using the partial-duration series, includes all the high values. The other uses the annual series which consists only of the highest value for each year. The highest value of record, of course, is the top value of each series, but at lower frequency levels (shorter return periods) the two series diverge. The partial-duration series, having the highest values regardless of the year in which they occur, recognizes that the second highest of some year occasionally exceeds the highest of some other year. The purposes to be served by the atlas require that the results be expressed in terms of partial-duration

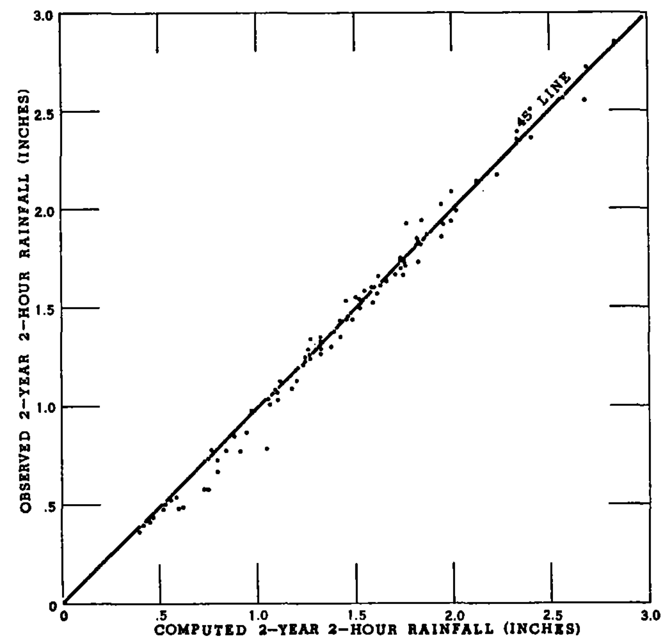

FIGURE 3.—Relation between observed 2-year 2-hour rainfall and 2-year 2-hour rainfall computed from duration diagram.

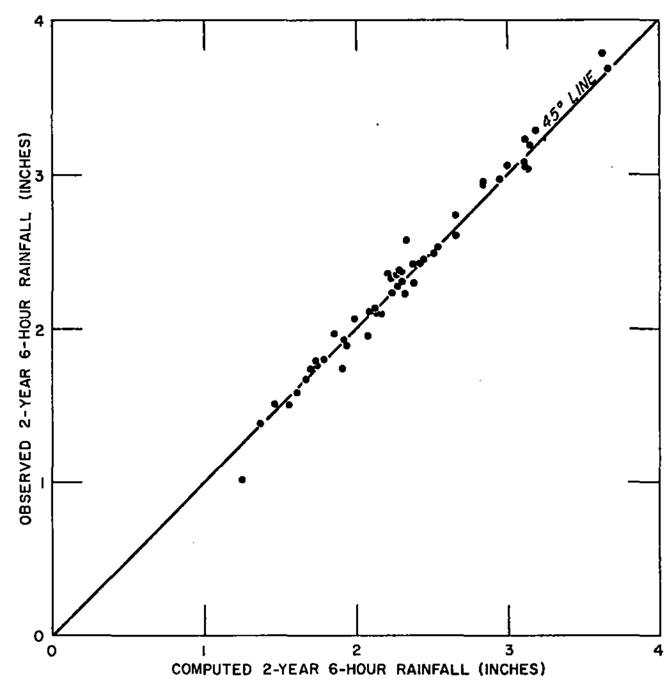

FIGURE 4.—Relation between observed 2-year 6-hour rainfall and 2-year 6-hour rainfall computed from duration diagram.

frequencies. In order to avoid laborious processing of partial-duration data, the annual series were collected, analyzed, and the resulting statistics transformed to partial-duration statistics.

Conversion factors for two series.—Table 2, based on a sample of a number of widely scattered Weather Bureau first-order stations, gives the empirical factors for converting the partial-duration series to the annual series.

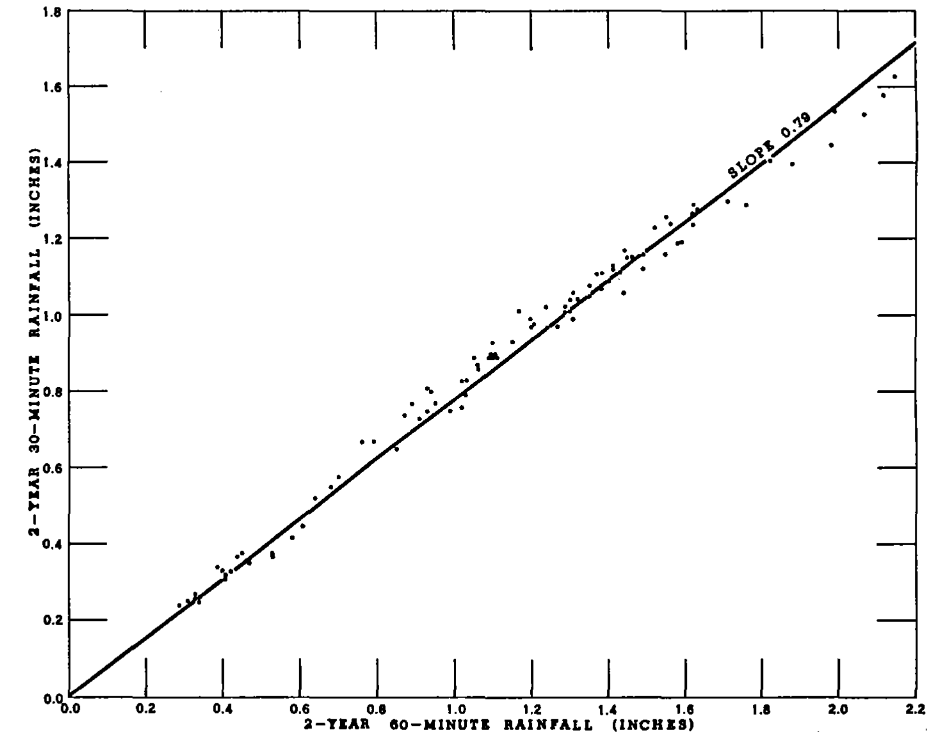

FIGURE 5.—Relation between 2-year 30-minute rainfall and 2-year 60-minute rainfall.

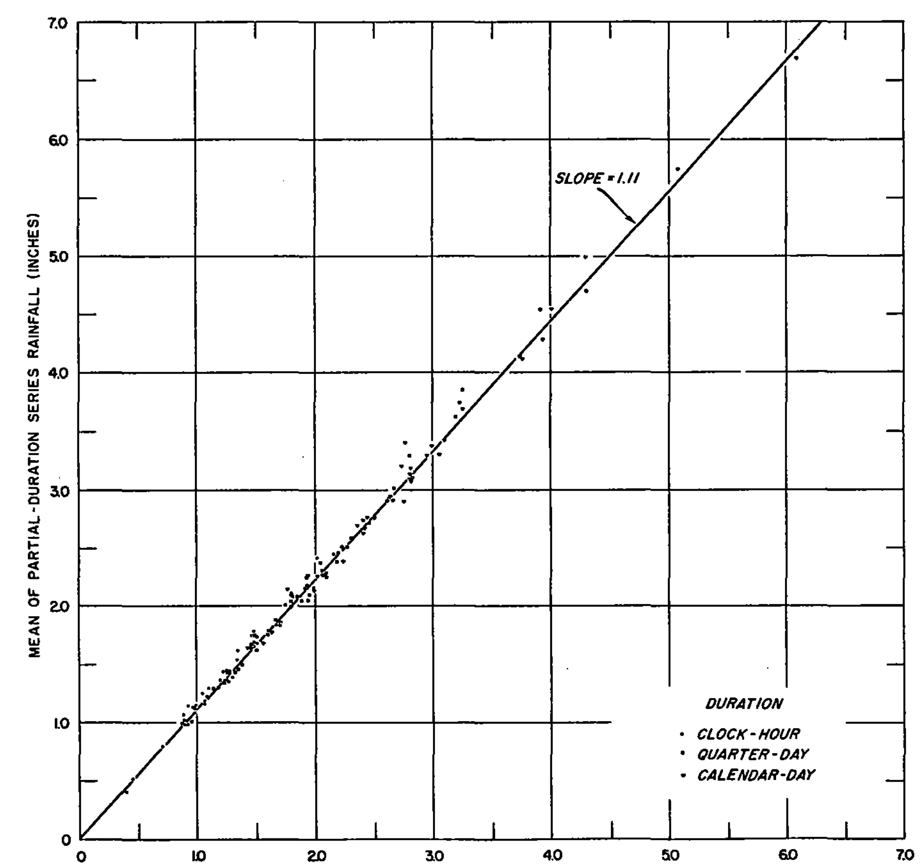

FIGURE 6.—Relation between partial-duration and annual series.

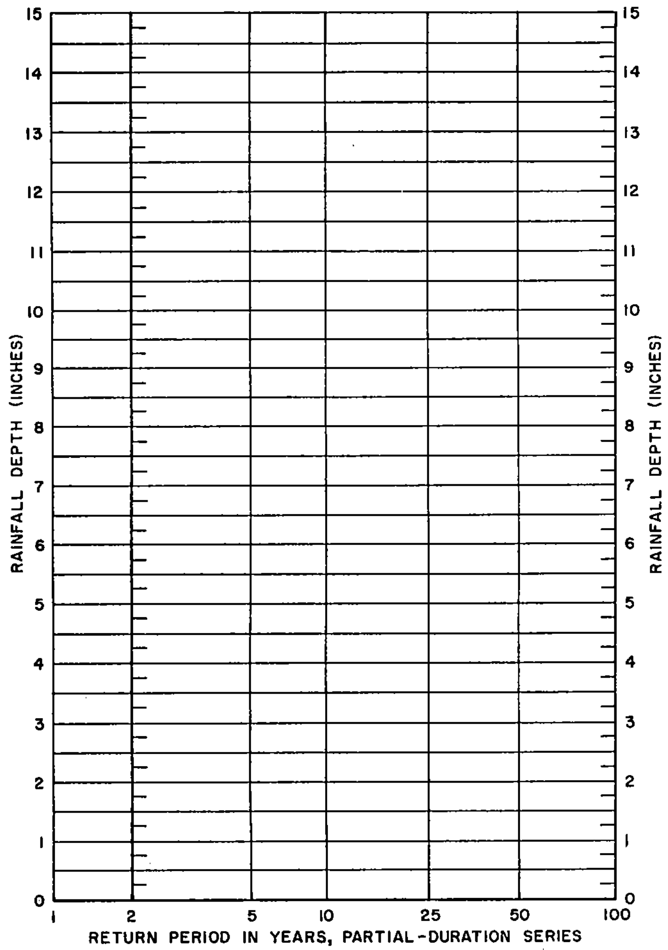

FIGURE 7.—Rainfall depth versus return period.

EXAMPLE. If the 2-, 5-, and 10-year partial-duration series values estimated from the maps at a particular point are 3.00, 3.75, and 4.21 inches, respectively, what are the annual series values for corresponding return periods? Multiplying by the appropriate conversion factors of table 2 gives 2.64, 3.60, and 4.17 inches.

The quality of the relationship between the mean of the partial-duration series and the mean of the annual series data for the 1-, 6-, and 24-hour durations is illustrated in figure 6. The means for both series are equivalent to the 2.3-year return period. Tests with samples of record length from 10 to 50 years indicate that the factors of table 2 are independent of record length.

TABLE 2.—*Empirical factors for converting partial-duration series to annual series*

Return period	Conversion factor
2-year	0.88
5-year	0.96
10-year	0.99

Frequency considerations.—Extreme values of rainfall depth form a frequency distribution which may be defined in terms of its moments. Investigations of hundreds of rainfall distributions with lengths of record ordinarily encountered in practice (less than 50 years) indicate that these records are too short to provide reliable statistics beyond the first and second moments. The distribution must therefore be regarded as a function of the first two moments. The 2-year value is a measure of the first moment—the central tendency of the distribution. The relationship of the 2-year to the 100-year value is a measure of the second moment—the dispersion of the distribution. These two parameters, 2-year and 100-year rainfall, are used in conjunction with the return-period diagram of figure 7 for estimating values for other return periods.

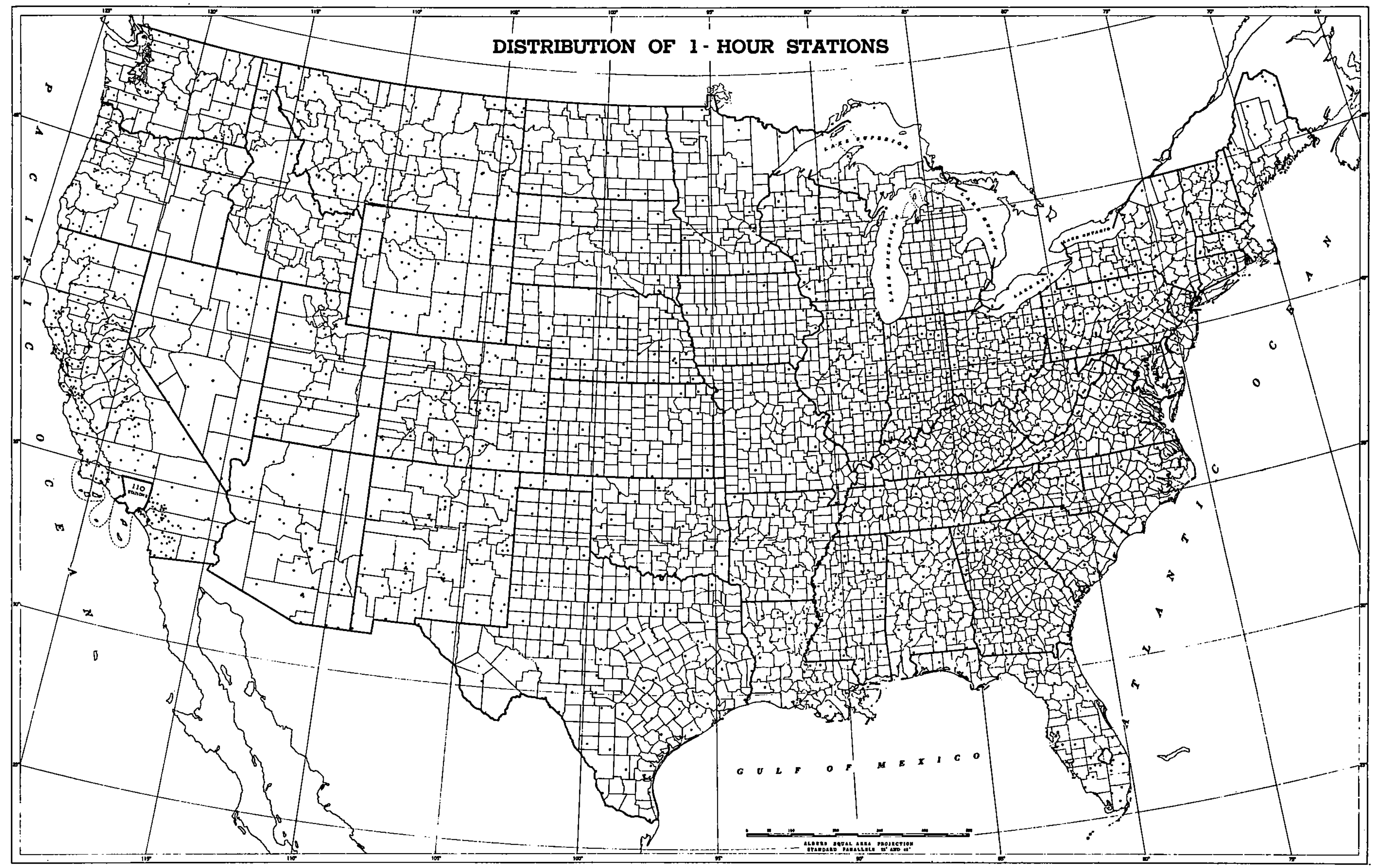

FIGURE 8.—Distribution of 1-hour stations.

Construction of return-period diagram.—The return-period diagram of figure 7 is based on data from the long-record Weather Bureau stations. The spacing of the vertical lines on the diagram is partly empirical and partly theoretical. From 1 to 10 years it is entirely empirical, based on freehand curves drawn through plottings of partial-duration series data. For the 20-year and longer return periods reliance was placed on the Gumbel procedure for fitting annual series data to the Fisher-Tippett type I distribution [15]. The transition was smoothed subjectively between 10- and 20-year return periods. If rainfall values for return periods between 2 and 100 years are taken from the return-period diagram of figure 7, converted to annual series values by applying the factors of table 2, and plotted on either Gumbel or log-normal paper, the points will very nearly approximate a straight line.

Use of diagram.—The two intercepts needed for the frequency relation in the diagram of figure 7 are the 2-year values obtained from the 2-year maps and the 100-year values from the 100-year maps. Thus, given the rainfall values for both 2- and 100-year return periods, values for other return periods are functionally related and may be determined from the frequency diagram which is entered with the 2- and 100-year values.

General applicability of return-period relationship.—Tests have shown that within the range of the data and the purpose of this paper, the return-period relationship is also independent of duration. In other words, for 30 minutes, or 24 hours, or any other duration within the scope of this report, the 2-year and 100-year values define the values for other return periods in a consistent manner. Studies have disclosed no regional pattern that would improve the return-period diagram which appears to have application over the entire United States.

Secular trend.—The use of short-record data introduces the question of possible secular trend and biased sample. Routine tests with subsamples of equal size from different periods of record for the same station showed no appreciable trend, indicating that the direct use of the relatively recent short-record data is legitimate.

Storms combined into one distribution.—The question of whether a distribution of extreme rainfall is a function of storm type (tropical or nontropical storm) has been investigated and the results presented in a recent paper [16]. It was found that no well-defined dichotomy exists between the hydrologic characteristics of hurricane or tropical storm rainfall and those of rainfall from other types of storms. The conventional procedure of analyzing the annual maxima without regard to storm type is to be preferred because it avoids nonsystematic sampling. It also eliminates having to attach a storm-type label to the rainfall, which in some cases of intermediate storm type (as when a tropical storm becomes extratropical) is arbitrary.

Predictive value of theoretical distribution.—Estimation of return periods requires an assumption concerning the parametric form of the distribution function. Since less than 10 percent of the more than 6000 stations used in this study have records for 60 years or longer, this raises the question of the predictive value of the results—particularly, for the longer return periods. As indicated previously,

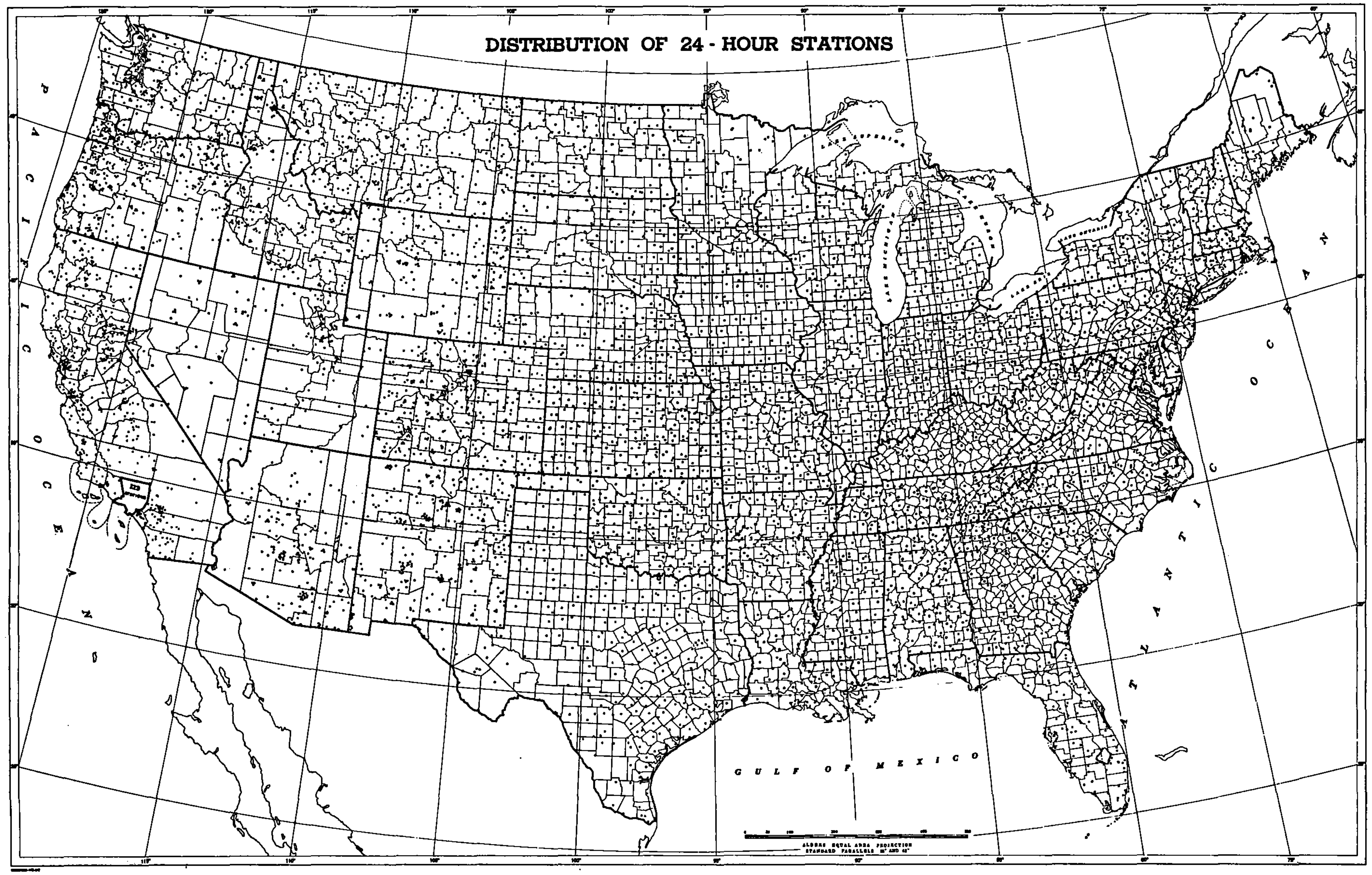

FIGURE 9.—Distribution of 24-hour stations.

reliance was placed on the Gumbel procedure for fitting data to the Fisher-Tippett type I distribution to determine the longer return periods. A recent study [17] of 60-minute data which was designed to appraise the predictive value of the Gumbel procedure provided definite evidence for its acceptability.

Isopluvial maps

Methodology.—The factors considered in the construction of the isopluvial maps were availability of data, reliability of the return period estimates, and the range of duration and return periods required for this paper. Because of the large amount of data for the 1- and 24-hour durations and the relatively small standard error associated with the estimates of the 2-year values, the 2-year 1- and 24-hour maps were constructed first. Except for the 30-minute duration, the 1- and 24-hour durations envelop the durations required for this study. The 100-year 1- and 24-hour maps were then prepared because this is the upper limit of return period. The four key maps: 2-year 1-hour, 2-year 24-hour, 100-year 1-hour, and 100-year 24-hour, provided the data to be used jointly with the duration and frequency relationships of the previous sections for obtaining values for the other 45 maps. This procedure permits variation in two directions—one for duration and the other for return period. The 49 isopluvial maps are presented in Part II as Charts 1 to 49.

Data for 2-year 1-hour map.—The dot map of figure 8 shows the location of the stations for which data were actually plotted on the map. Additional stations were considered in the analysis but not plotted in regions where the physiography could have no conceivable influence on systematic changes in the rainfall regime. All available recording-gage data with at least 5 years of record were plotted for the mountainous region west of 104° W. In all, a total of 2281 stations were used to define the 2-year 1-hour pattern of which 60 percent are for the western third of the country.

Data for 2-year 24-hour map.—Figure 9 shows the locations of the 6000 stations which provided the 24-hour data used to define the 2-year 24-hour isopluvial pattern. Use was made of most of the stations in mountainous regions including those with only 5 years of record. As indicated previously, the data have been adjusted where necessary so that they are for the 1440-minute period containing the maximum rainfall rather than observational-day.

Smoothing of 2-year 1-hour and 2-year 24-hour isopluvial lines.—The manner of construction involves the question of how much to smooth the data, and an understanding of the problem of data smoothing is necessary to the most effective use of the maps. The problem of drawing isopluvial lines through a field of data is analogous in some important respects to drawing regression lines through the data of a scatter diagram. Just as isolines can be drawn so as to fit every point on the map, an irregular regression line can be drawn to pass through every point; but the complicated pattern in each case would be unrealistic in most instances. The two qualities, smoothness and fit, are basically inconsistent in the sense that smoothness may not be improved beyond a certain point without some sacrifice of closeness of fit, and vice versa. The 2-year 1- and 24-hour maps were deliberately drawn so that the standard error of estimate (the inherent error of interpolation) was commensurate with the sampling and other errors in the data and methods of analysis.

Ratio of 100-year to 2-year 1- and 24-hour rainfall.—Two working maps were prepared showing the 100-year to 2-year ratio for the 1- and 24-hour durations. In order to minimize the exaggerated effect that an outlier (anomalous event) from a short record has on the magnitude of the 100-year value, only the data from stations with minimum record lengths of 18 years for the 1-hour and 40 years for the 24-hour were used in this analysis. As a result of the large sampling errors associated with these ratios, it is not unusual to find a station with a ratio of 2.0 located near a 3.0 ratio even in regions where orographic influences on the rainfall regime are absent. As a group, the stations' ratios mask out the station-to-station disparities and provide a more reliable indication of the direction of distribution than the individual station data. A macro-examination revealed that some systematic geographical variation was present which would justify the construction of smoothed ratio maps with a small range. The isopleth patterns constructed for the two maps are not identical but the ratios on both maps range from about 2.0 to 3.0. The average ratio is about 2.3 for the 24-hour duration and 2.2 for the 1-hour.

100-year 1-hour and 24-hour maps.—The 100-year values which were computed for 3500 selected points (fig. 10) are the product of the values from the 2-year maps and the 100-year to 2-year ratio maps. Good definition of the complexity of pattern and steepness of gradient of the 2-year 1- and 24-hour maps determined the geographically unbalanced grid density of figure 10.

45 additional maps.—The 3500-point grid of figure 10 was also used to define the isopluvial patterns of the 45 additional maps. Four values—one from each of the four key maps—were read for each grid point. Programming of the duration and return-period relationships plus the four values for each point permitted digital computer computation for the 45 additional points. The isolines were positioned by interpolation with reference to numbers at the grid points. This was necessary to maintain the internal consistency of the series of maps. Pronounced "highs" and "lows" are positioned in consistent locations on all maps. Where the 1- to 24-hour ratio for a particular area is small, the 24-hour values have the greatest influence on the pattern of the intermediate duration maps. Where the 1- to 24-hour ratio is large, the 1-hour value appears to have the most influence on the intermediate duration pattern.

Reliability of results.—The term reliability is used here in the statistical sense to refer to the degree of confidence that can be placed in the accuracy of the results. The reliability of results is influenced by sampling error in time, sampling error in space, and by the manner in which the maps were constructed. Sampling error in space is a result of the two factors: (1) the chance occurrence of an anomalous storm which has a disproportionate effect on one station's statistics but not on the statistics of a nearby station, and (2) the geographical distribution of stations. Where stations are farther apart than in the dense networks studied for this project, stations may experience rainfalls that are nonrepresentative of their vicinity, or may completely miss rainfalls that are representative. Similarly, sampling error in time results from rainfalls not occurring according to their average regime during a brief record. A brief period of record may include some nonrepresentative large storms, or may miss some important storms that occurred before or after the period of record at a given station. In evaluating the effects of areal and time sampling errors, it is pertinent to look for and to evaluate bias and dispersion. This is discussed in the following paragraphs.

Spatial sampling error.—In developing the area-depth relations, it was necessary to examine data from several dense networks. Some of these dense networks were in regions where the physiography could have little or no effect on the rainfall regime. Examination of these data showed, for example, that the standard deviation of point rainfall for the 2-year return period for a flat area of 300 square miles is about 20 percent of the mean value. Seventy 24-hour stations in Iowa, each with more than 40 years of record, provided another indication of the effect of spatial sampling error. Iowa's rainfall regime is not influenced locally by orography or bodies of water. The 2-year 24-hour isopluvials in Iowa show a range from 3.0 to 3.3 inches. The average deviation of the 70 2-year values from the smoothed isopluvials is about 0.2 inch. Since there are no assignable causes for these dispersions, they must be regarded as a residual error in sampling the relatively small amount of extreme-value data available for each station.

The geographical distribution of the stations used in the analysis is portrayed on the dot maps of figures 8 and 9. Even this relatively dense network cannot reveal very accurately the fine structure of the isopluvial pattern in the mountainous regions of the West. A measure of the sampling error is provided by a comparison of a 2-year 1-hour generalized map for Los Angeles County (4000 square miles) based on 30 stations with one based on 110 stations. The average difference for values from randomly selected points from both maps was found to be approximately 20 percent.

Sampling error in time.—Sampling error in time is present because the data at individual stations are intended to represent a mean condition that would hold over a long period of time. Daily data from 200 geographically dispersed long-record stations were analyzed for 10- and 50-year records to determine the reliability or level of confidence that should be placed on the results from the short-record data. The diagram of figure 11 shows the scatter of the means of the extreme-value distributions for the two different lengths of record. The slight bias which is exhibited is a result of the skewness of the extreme-value distribution. Accordingly, more weight was given to the longer-record stations in the construction of the isopluvials.

Isoline interval.—The isoline intervals are 0.2, 0.5, or 1.0 inch depending on the range and magnitude of the rainfall values. A uniform interval has been used on a particular map except in the two following instances: (1) a dashed intermediate line has been placed between two widely separated lines as an aid to interpolation, and (2) a larger interval was used where necessitated by a steep gradient. "Lows" that close within the boundaries of the United States have been hatched inwardly.

Maintenance of consistency.—Numerous statistical maps were made in the course of these investigations in order to maintain the internal consistency. In situations where it has been necessary to estimate hourly data from daily observations, experience has demonstrated that the ratio of 1-hour to corresponding 24-hour values for the same return period does not vary greatly over a small region. This knowledge served as a useful guide in smoothing the isopluvials. On the windward sides of high mountains in western United States, the 1- to 24-hour ratio is as low as 10 percent. In southern Arizona and some parts of midwestern United States, it is greater than 60 percent. In general, except for Arizona, the ratio is less than 40 percent west of the Continental Divide and greater than 40 percent to the east. There is a fair relationship between this ratio and the climatic factor, mean annual number of thunderstorm days. The two parameters, 2-year daily rainfall and the mean annual number of thunderstorm days, have been used jointly to provide an estimate of short-duration rainfalls [18]. A 1- to 24-hour ratio of 40 percent is approximately the average for the United States.

Examination of physiographic parameters.—Work with mean annual and mean seasonal rainfall has resulted in the derivation of empirically defined parameters relating rainfall data to the physiography of a region. Elevation, slope, orientation, distance from moisture source, and other parameters have been useful in drawing maps of mean rainfall. These and other parameters were examined in an effort to refine the maps presented here. However, tests showed that the use of these parameters would result in no improvement in the rainfall-frequency pattern because of the sampling and other error inherent in values obtained for each station.

Evaluation.—In general, the standard error of estimate ranges from a minimum of about 10 percent, where a point value can be used directly as taken from a flat region of one of the 2-year maps to 50 percent where a 100-year value of short-duration rainfall must be estimated for an appreciable area in a more rugged region.

Internal inconsistency.—On some maps the isoline interval does not reveal the fact that the magnitude does not vary linearly by interpolation. Therefore, interpolation of several combinations of durations and return periods for the point of interest might result in such inconsistencies as a 12-hour value being larger than a 24-hour value for the same return period or that a 50-year value exceeds the 100-year value for the same duration. These errors, however, are well within the acknowledged margin of error. If the reader is interested in more than one duration or return period this potential source of inconsistency can be eliminated by constructing a series of depth-duration-frequency curves by fitting smoothed curves on logarithmic paper to the values interpolated from all 49 maps. Figure 12 illustrates a set of curves for the point at 35° N., 90° W. The interpolated values for a particular duration should very nearly approximate a straight line on the return-period diagram of figure 7.

Obsolescence.—Additional stations rather than longer records will speed obsolescence and lessen the current accuracy of the maps. The comparison with Yarnell's paper [1] is a case in point. Where data for new stations are available, particularly in the mountainous regions, the isopluvial patterns of the two papers show pronounced differences. At stations which were used for both papers, even with 25 years of additional data, the differences are negligible.

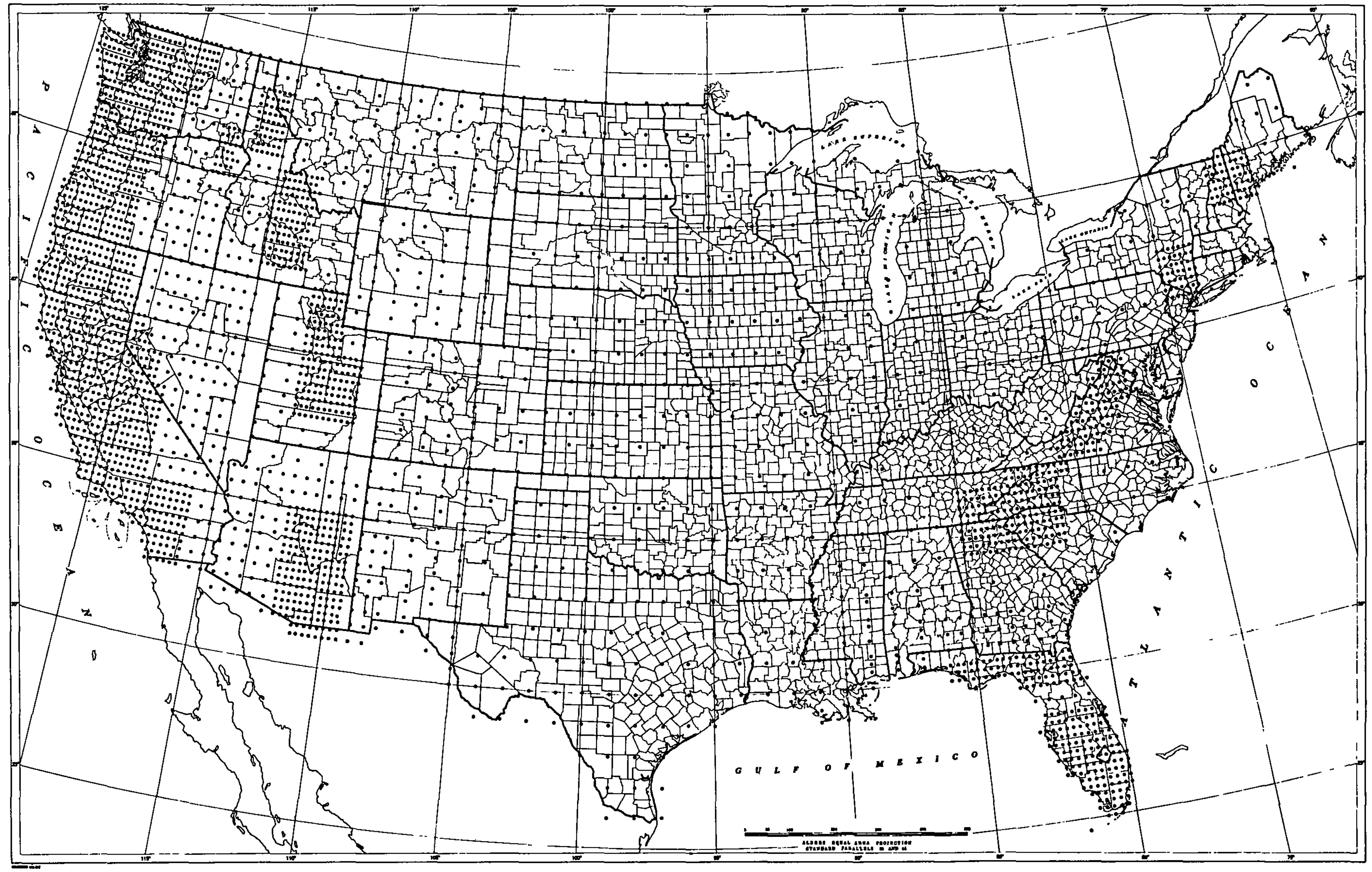

FIGURE 10.—Grid density used to construct additional maps.

Guides for estimating durations and/or return periods not presented on the maps

Intermediate durations and return periods.—In some instances, it might be required to obtain values within the range of return periods and durations presented in this paper but for which no maps have been prepared. A diagram similar to that illustrated in figure 12 can serve as a nomogram for estimating these required values.

Return periods longer than 100 years.—Values for return periods longer than 100 years can be obtained by plotting several values from 2 to 100 years from the same point on all the maps on either log-normal or extreme-value probability paper. A straight line fitted to the data and extrapolated will provide an acceptable estimate of, say, the 200-year value. It should be remembered that the values on the maps are for the partial-duration series, therefore, the 2-, 5-, and 10-year values should first be reduced by the factors of table 2.

EXAMPLE. The 200-year 1-hour value is required for the point at 35° N., 90° W. The 2-, 5-, 10-, 25-, 50-, and 100-year values are estimated from the maps to be 1.7, 2.2, 2.5, 2.9, 3.1, and 3.5 inches. After multiplying the 2-year value by 0.88, the 5-year value by 0.96, and the 10-year value by 0.99, the six values are plotted on extreme-value probability paper, a line is fitted to the data and extrapolated linearly. The 200-year value is thus estimated to be about 3.8 inches (see fig. 13).

Durations shorter than 30 minutes.—If durations shorter than 30 minutes are required, the average relationships between 30-minute rainfall on the one hand and the 5-, 10-, and 15-minute rainfall on the other can be obtained from table 3. These relationships were developed from the data of the 200 Weather Bureau first-order stations.

TABLE 3.—*Average relationship between 30-minute rainfall and shorter duration rainfall for the same return period*

Duration (min.)	5	10	15
Ratio	0.37	0.57	0.72
Average error (percent)	8	7	5

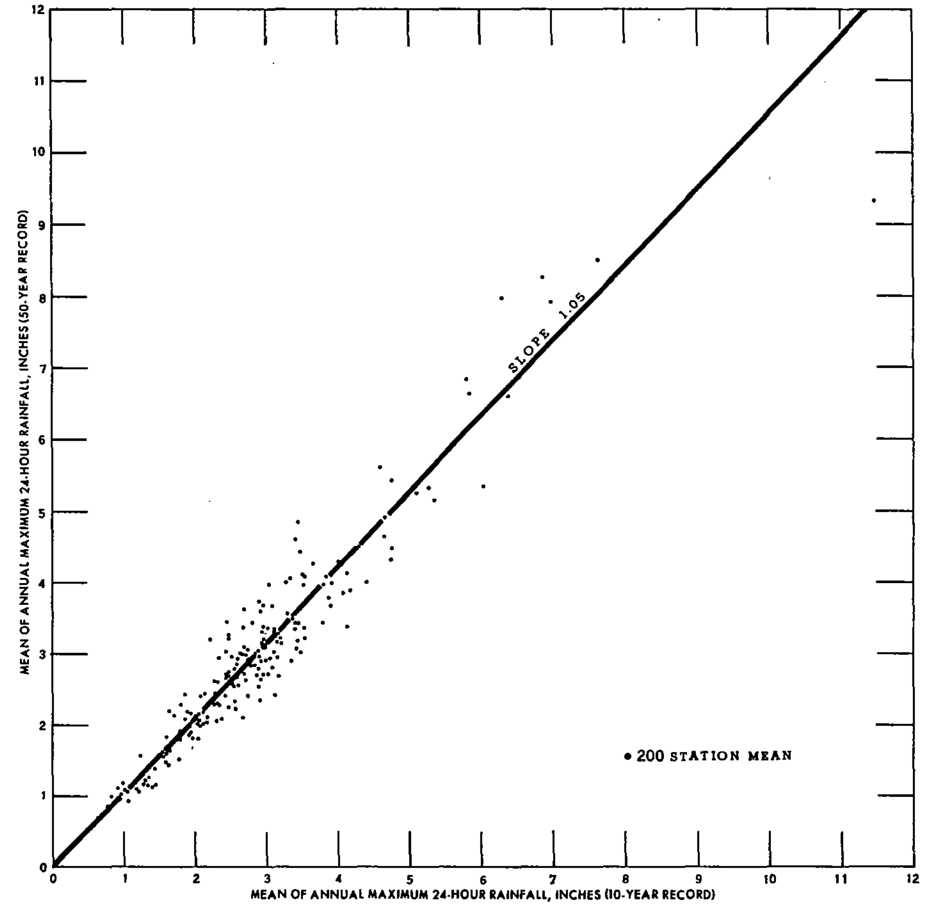

FIGURE 11.—Relation between means from 50-year and 10-year records (24-hour duration).

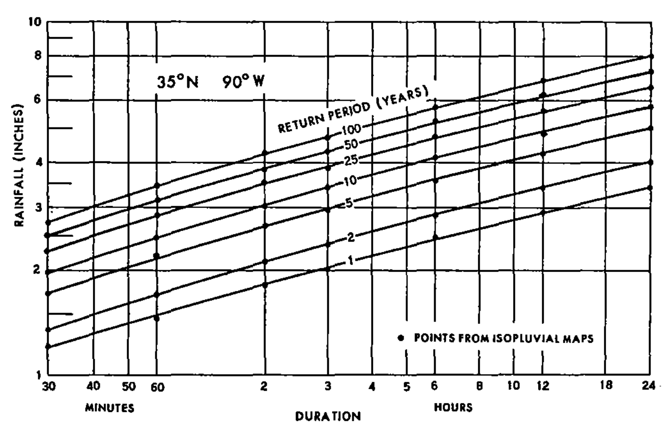

FIGURE 12.—Example of internal consistency check.

Comparisons with previous rainfall frequency studies

Yarnell.—A comparison of the results of this paper with those obtained by Yarnell's paper [1] brings out several interesting points. First, both papers show approximately the same values for the Weather Bureau first-order stations even though 25 years of additional data are now available. Second, even though thousands of additional stations were used in this study, the differences between the two papers in the eastern half of the country are quite small and rarely exceed 10 percent. However, in the mountainous regions of the West, the enlarged inventory of data now available has had a profound effect on the isopluvial pattern. In general, the results from this paper are larger in the West with the differences occasionally reaching a factor of three.

Technical Paper No. 25.—*Technical Paper No. 25* [5] contains a series of rainfall intensity-duration-frequency curves for the 200 Weather Bureau stations. The curves were developed from each station's data with no consideration given to anomalous events or to areal generalization. The average difference between the two papers is approximately 10 percent with no bias. After accounting for the fact that this atlas is for the partial-duration series and *Technical Paper No. 25* is for the annual series, the differences can be ascribed to the considerable areal generalization used in this paper.

Technical Paper No. 24, Parts I and II; Technical Paper No. 28.—The differences in refinement between *Technical Paper No. 24* [2] and *Technical Paper No. 28* [6] on the one hand and this paper on the other do not, however, seem to influence the end results to an important degree. Inspection of the values in several rugged areas, as well as in flat areas, reveals disparities which average about 20 percent. This is attributable to the much larger amount of data (both longer records and more stations) and the greater areal generalization used in this paper.

Technical Paper No. 29, Parts 1 through 5.—The salient feature of the comparison of *Technical Paper No. 29* [7] with this paper is the very small disparities between the four key maps and the slightly larger disparities between the intermediate maps. The average differences are of the order of magnitude of 10 and 20 percent, respectively. The larger difference between the intermediate maps is attributable to the smoothing of these maps in a consistent manner for this paper.

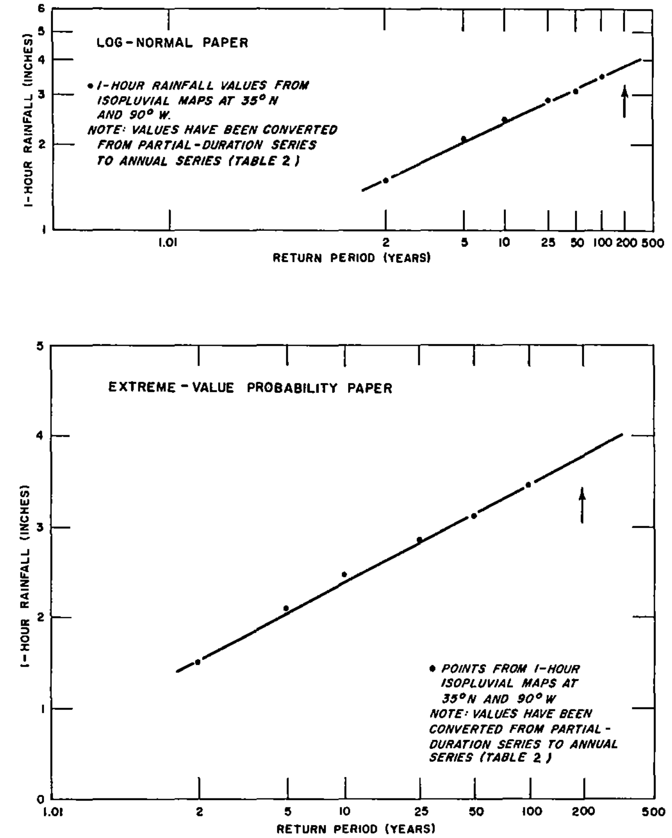

FIGURE 13.—Example of extrapolating to long return periods.

Probability considerations

General.—The analysis presented thus far has been mainly concerned with attaching a probability to a particular magnitude of rainfall at a particular location. Once this probability has been determined, consideration must also be given to the corollary question: What is the probability that the *n*-year event will occur at least once in the next *n* years?

From elementary probability theory it is known that there is a good chance that the *n*-year event will occur at least once before *n* years have elapsed. For example, if an event has the probability $1/n$ of occurring in a particular year (assume the annual ssries is being used), where *n* is 10 or greater, the probability, *P*, of the event occurring at least once among *n* observations (or years) is

$$P=1-(1-1/n)^n \approx 1-e^{-1}=0.63$$

Thus, for example, the probability that the 10-year event will occur at least once in the next 10 years is 0.63, or about 2 chances out of 3.

Relationship between design return period, T years, design period, T_d, and probability of not being exceeded in T_d years.—Figure 14, prepared from theoretical computations, shows the relationship between the design return period, *T* years, design period, T_d, and probability of not being exceeded in T_d years [19].

EXAMPLE. What design return period should the engineer use to be approximately 90 percent certain that it will not be exceeded in the next 10 years? Entering the design period coordinate at 10 years until the 90 percent line is intersected, the design return period is estimated to be 100 years. In terms of rainfall magnitude, the 100-year value is approximately 50 percent larger than the 10-year value.

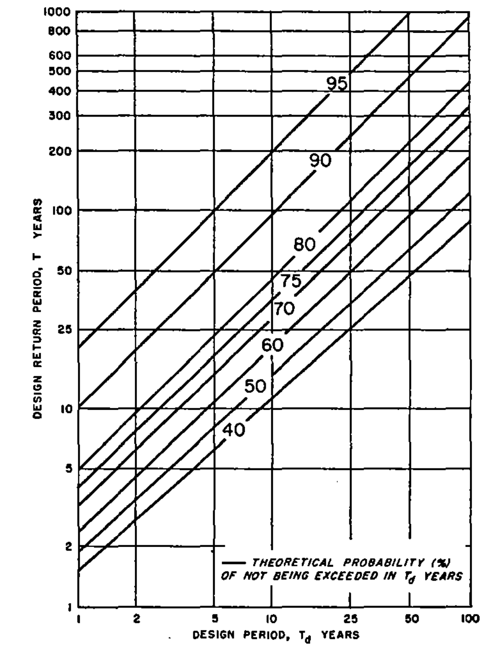

FIGURE 14.—Relationship between design return period, *T* years, design period, T_d, and probability of not being exceeded in T_d years.

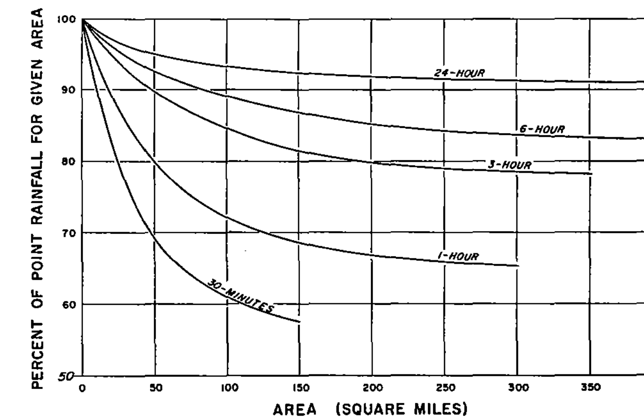

FIGURE 15.—Area-depth curves.

Probable maximum precipitation (PMP)

The 6-hour PMP and its relationship to the 100-year 6-hour rainfall.—Opposed to the probability method of rainfall estimation presented in this paper is the probable maximum precipitation (PMP) method which uses a combination of physical model and several estimated meteorological parameters. The main purpose of the PMP method is to provide complete-safety design criteria in cases where structure failure would be disastrous. The 6-hour PMP map of Chart 50 is based on the 10-square-mile values of *Hydrometeorological Report No. 33* [20] for the region east of 105° W. and on Weather Bureau *Technical Paper No. 38* [21] for the West. Chart 51 presents the ratios of the PMP values to the 100-year point rainfalls of this paper. Examination of this map shows that the ratios vary from less than 2 to about 9. These results must be considered merely indicative of the order of magnitude of extremely rare rainfalls.

Area-depth relationships

General.—For drainage areas larger than a few square miles consideration must be given not only to point rainfall, but to the average depth over the entire drainage area. The average area-depth relationship, as a percent of the point values, has been determined for 20 dense networks up to 400 square miles from various regions in the United States [7].

The area-depth curves of figure 15 must be viewed operationally The operation is related to the purpose and application. In application the process is to select a point value from an isopluvial map. This point value is the average depth for the location concerned, for a given frequency and duration It is a composite. The area-depth curve relates this average point value, for a given duration and frequency and within a given area, to the average depth over that area for the corresponding duration and frequency.

The data used to develop the area-depth curves of figure 15 exhibited no systematic regional pattern [7]. Duration turned out to be the major parameter. None of the dense networks had sufficient length of record to evaluate the effect of magnitude (or return period) on the area-depth relationship. For areas up to 400 square miles, it is tentatively accepted that storm magnitude (or return period) is not a parameter in the area-depth relationship. The reliability of this relationship appears to be best for the longer durations.

EXAMPLE What is the average depth of 2-year 3-hour rainfall for a 200-square-mile drainage area in the vicinity of 37° N, 86° W.? From the 2-year 3-hour map, 2.0 inches is estimated as the average depth for points in the area. However, the average 3-hour depth over the drainage area would be less than 2 0 inches for the 2-year return period Referring to figure 15, it is seen that the 3-hour curve intersects the area scale at 200 square miles at ratio 0.8. Accordingly, the 2-year 3-hour average depth over 200 square miles is 0.8 times 2 0, or 1.6 inches.

Seasonal variation

Introduction.—To this point, the frequency analysis has followed the conventional procedures of using only the annual maxima or the n-maximum events for n years of record Obviously, some months contribute more events to these series than others and, in fact, some months might not contribute at all to these two series. Seasonal variation serves the purpose of showing how often these rainfall events occur during a specific month. For example, a practical problem concerned with seasonal variation may be illustrated by the fact that the 100-year 1-hour rain may come from a summer thunderstorm, with considerable infiltration, whereas the 100-year flood may come from a lesser storm occurring on frozen or snow-covered ground in the late winter or early spring.

Seasonal probability diagrams.—A total of 24 seasonal variation diagrams is presented in Charts 52, 53, and 54 for the 1-, 6-, and 24-hour durations for 8 subregions of the United States east of 105° W. The 15 diagrams covering the region east of 90° W. are identical to those presented previously in *Technical Paper No. 29* [7]. The smoothed isopleths of a diagram for a particular duration are based on the average relationship from approximately 15 stations in each subregion. Some variation exists from station to station, suggesting a slight subregional pattern, but no attempt was made to define it because there is no conclusive method of determining whether this pattern is a climatic fact or an accident of sampling. The slight regional discontinuities between curves of adjacent subregions can be smoothed locally for all practical purposes. No seasonal variation relationships are presented for the mountainous region west of 105° W. because of the influence of local climatic and topographic conditions. This would call for seasonal distribution curves constructed from each station's data instead of average and more reliable curves based on groups of stations.

Application to areal rainfall.—The analysis of a limited amount of areal rainfall data in the same manner as the point data gave seasonal variations which exhibited no substantial difference from those of the point data. This lends some confidence in using these diagrams as a guide for small areas.

EXAMPLE. Determine the probability of occurrence of a 10-year 1-hour rainfall for the months May through August for the point at 45° N., 85° W. From Chart 52, the probabilities for each month are interpolated to be 1, 2, 4, and 2 percent, respectively. In other words, the probability of occurrence of a 10-year 1-hour rainfall in May of any particular year is 1 percent; for June, 2 percent; and so forth. (Additional examples are given in all five parts of *Technical Paper No. 29*.)

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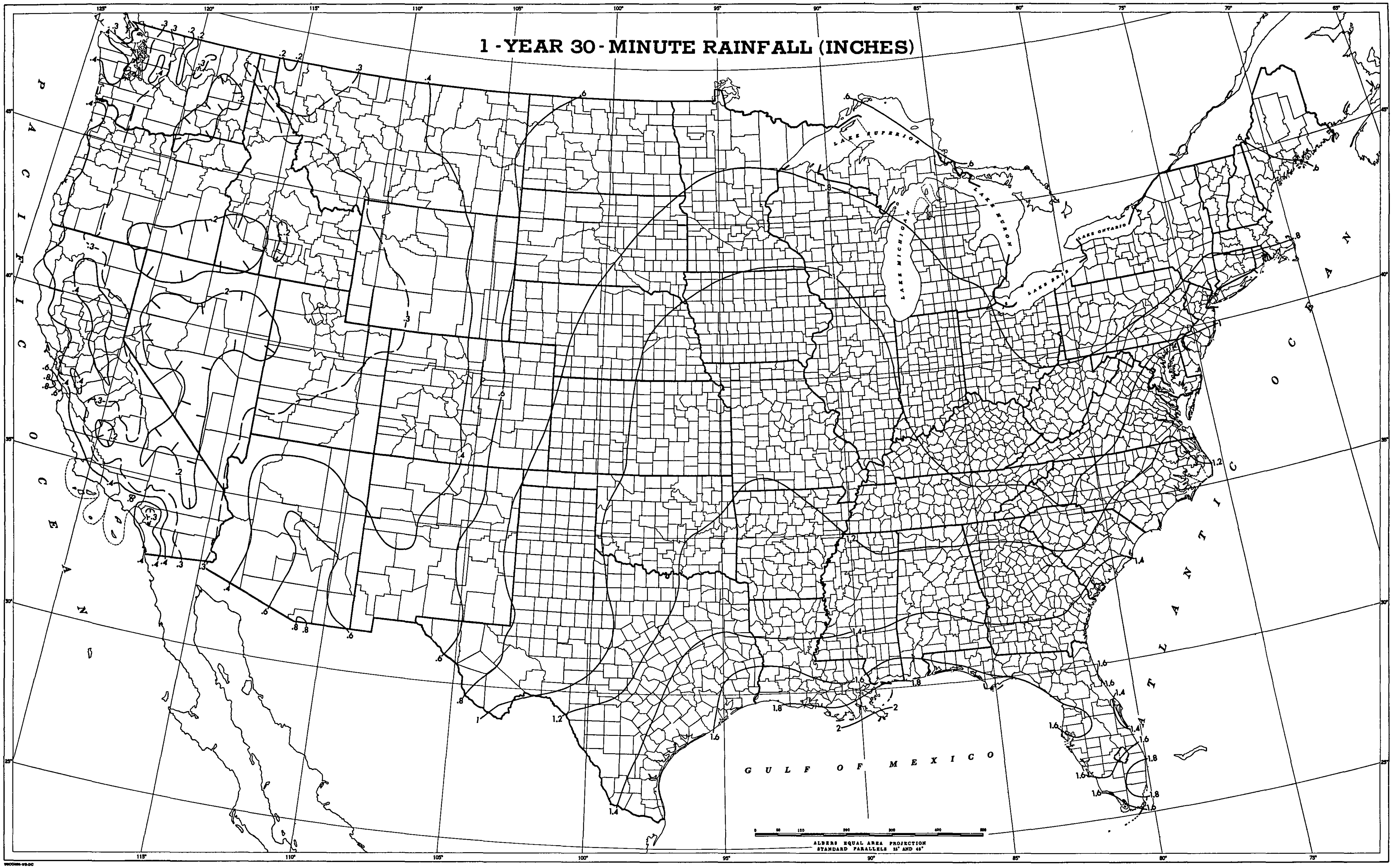
PART II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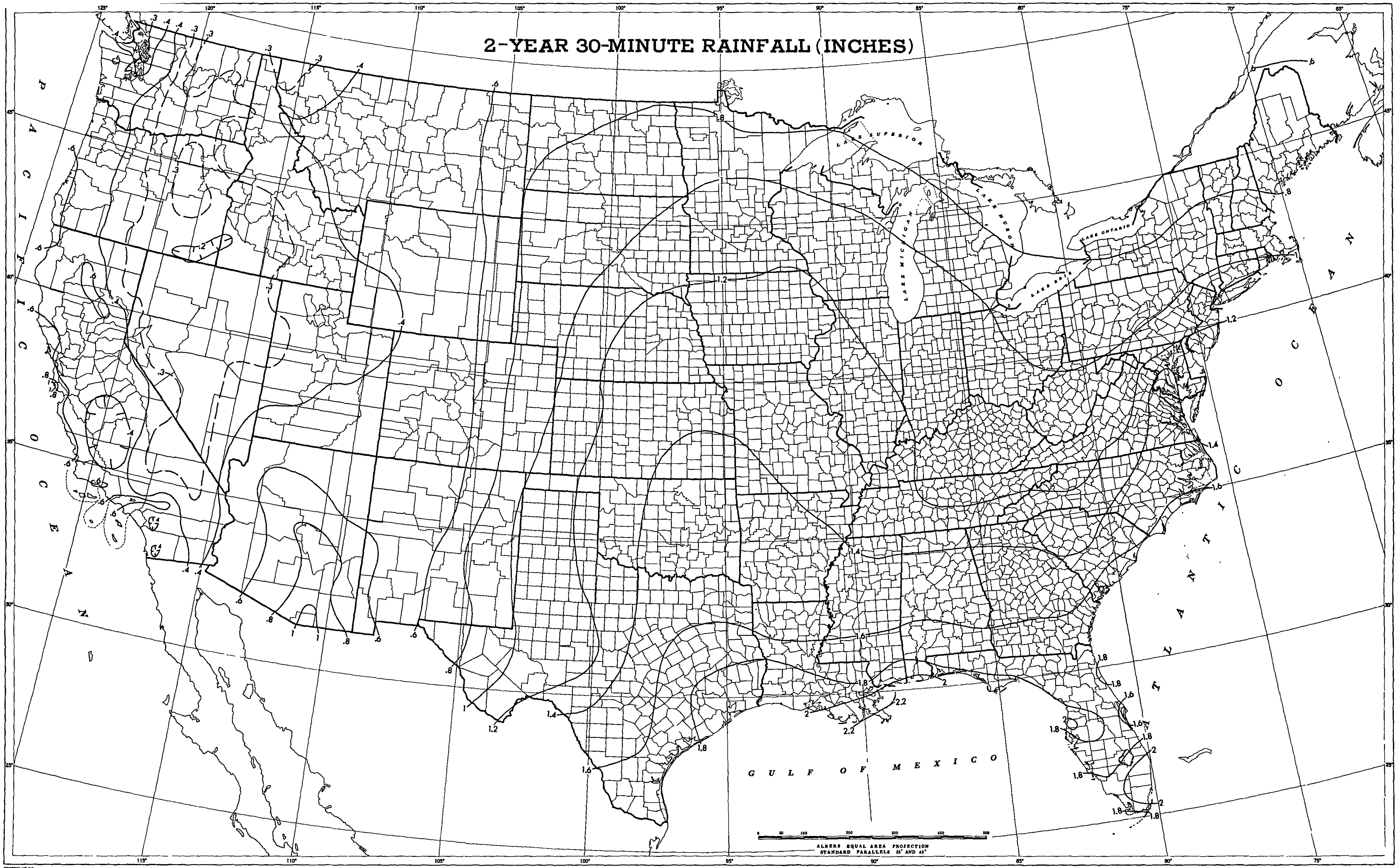
STANDARD PARALLELS 29° AND 45°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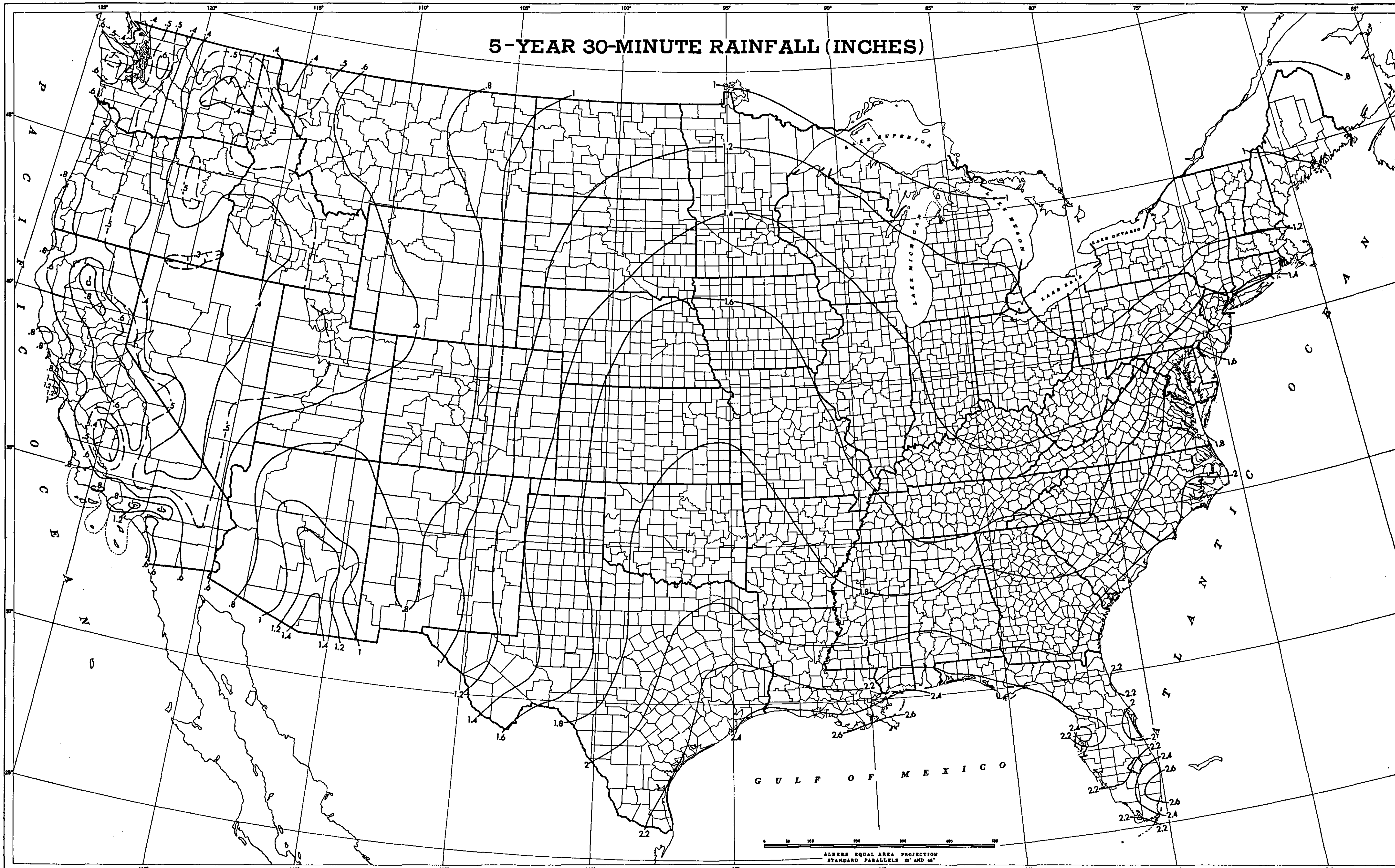
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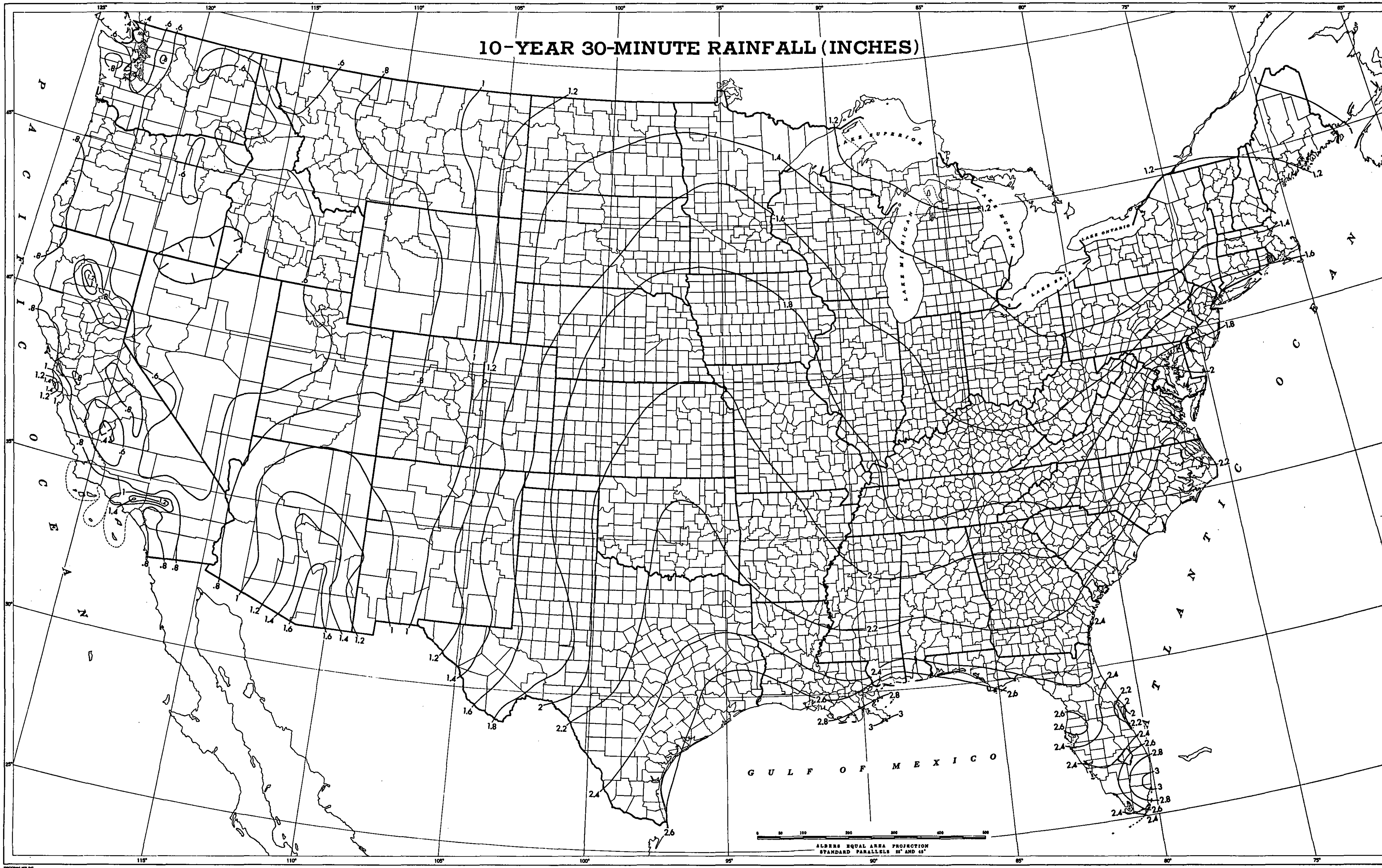
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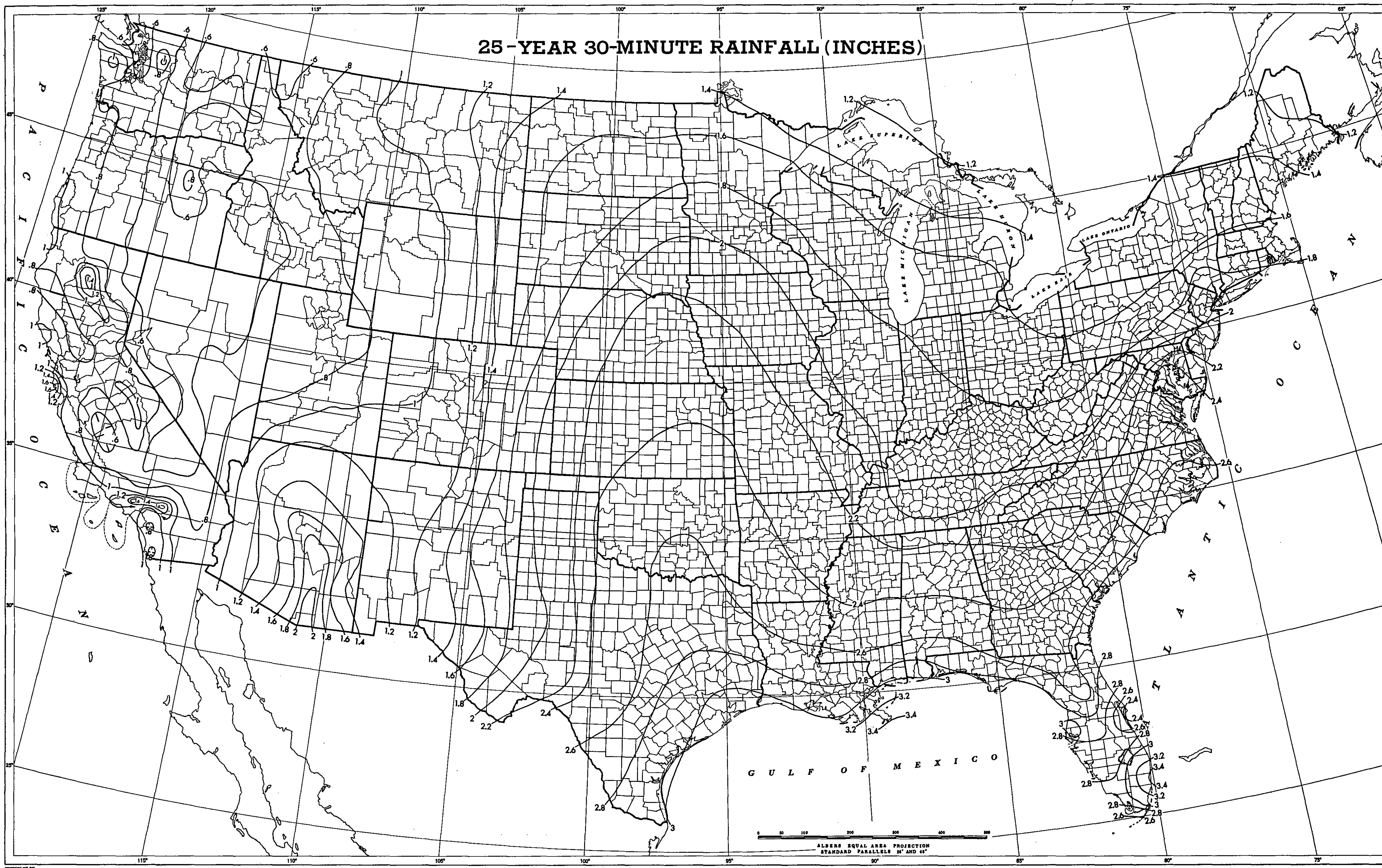
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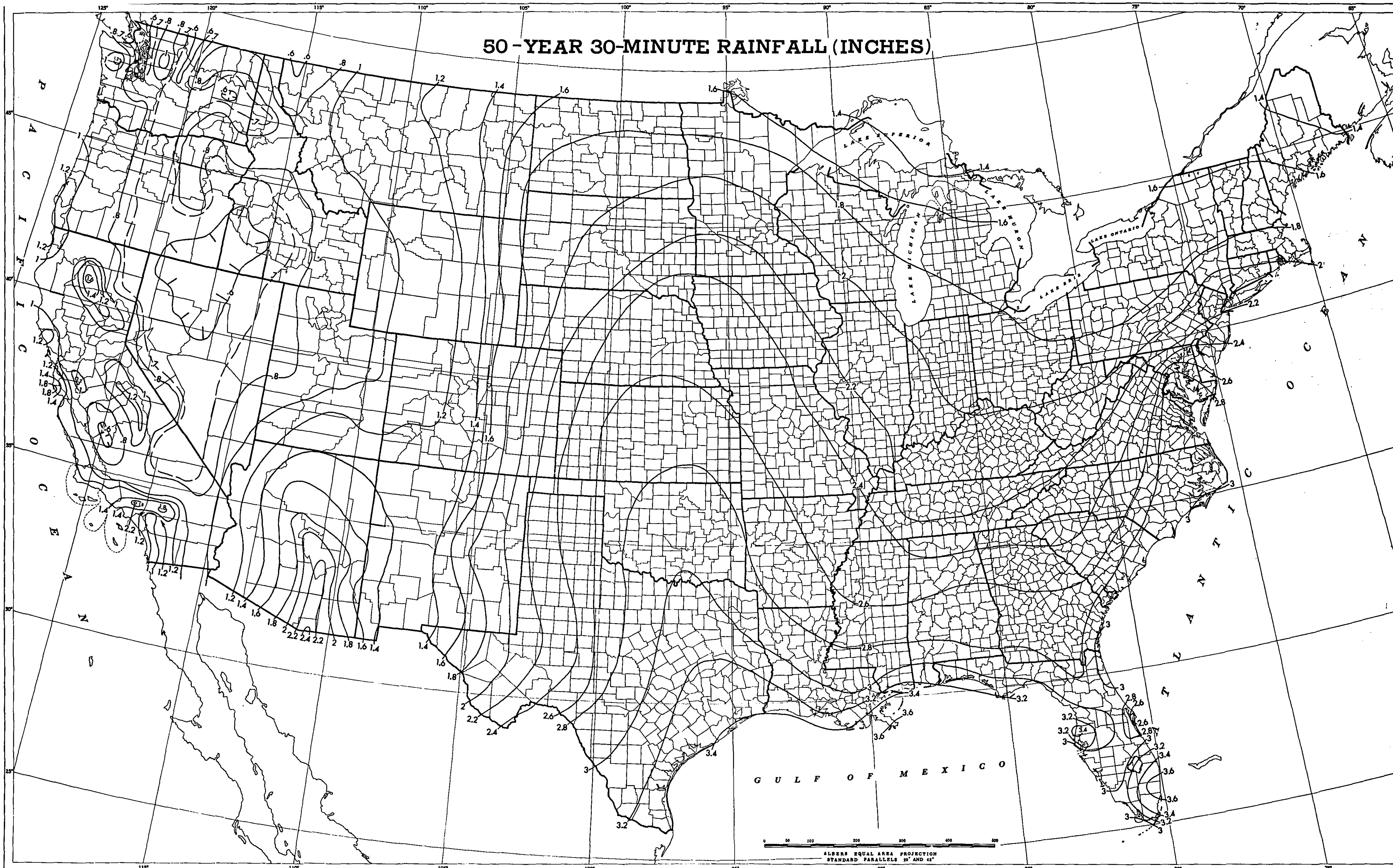
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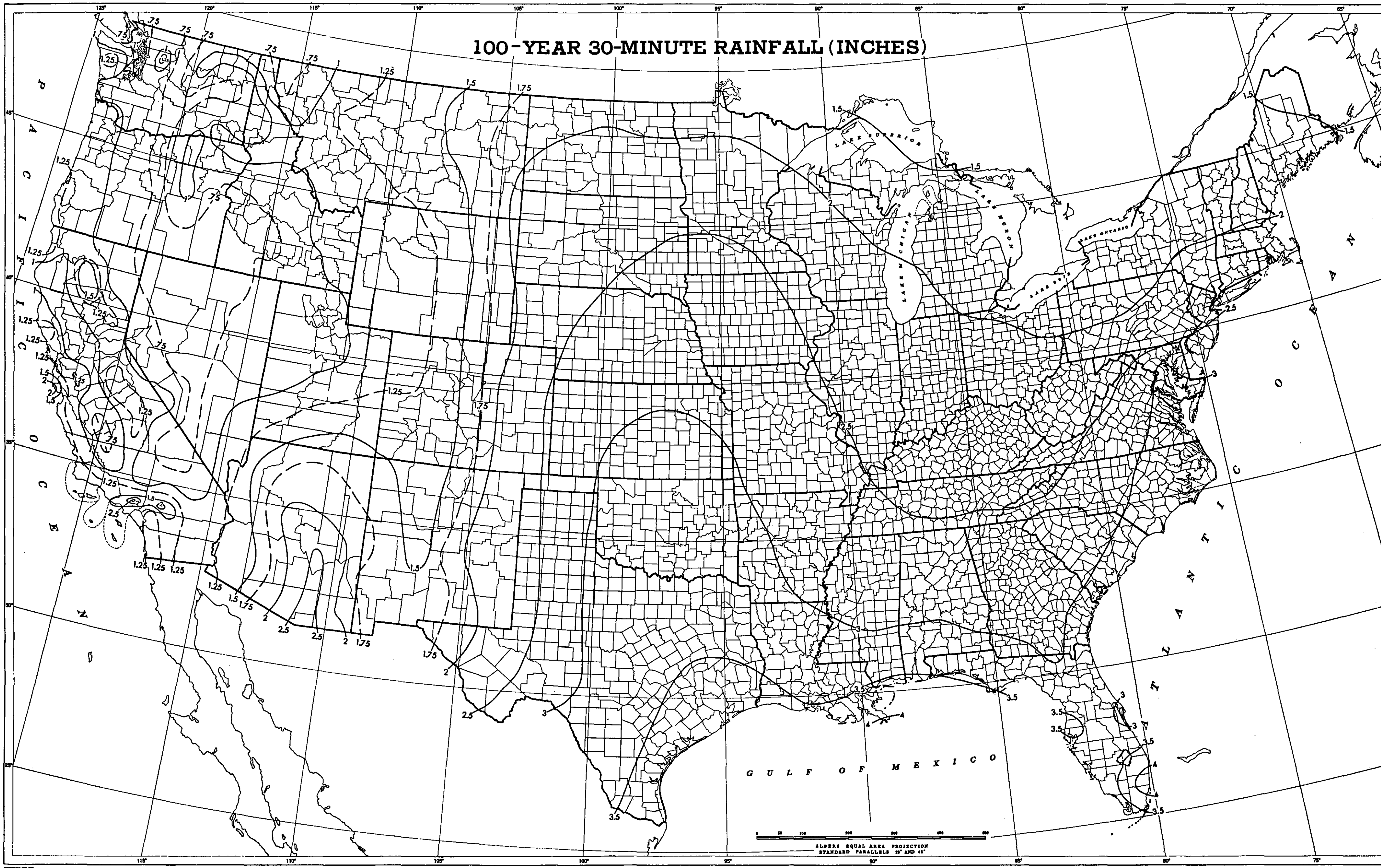

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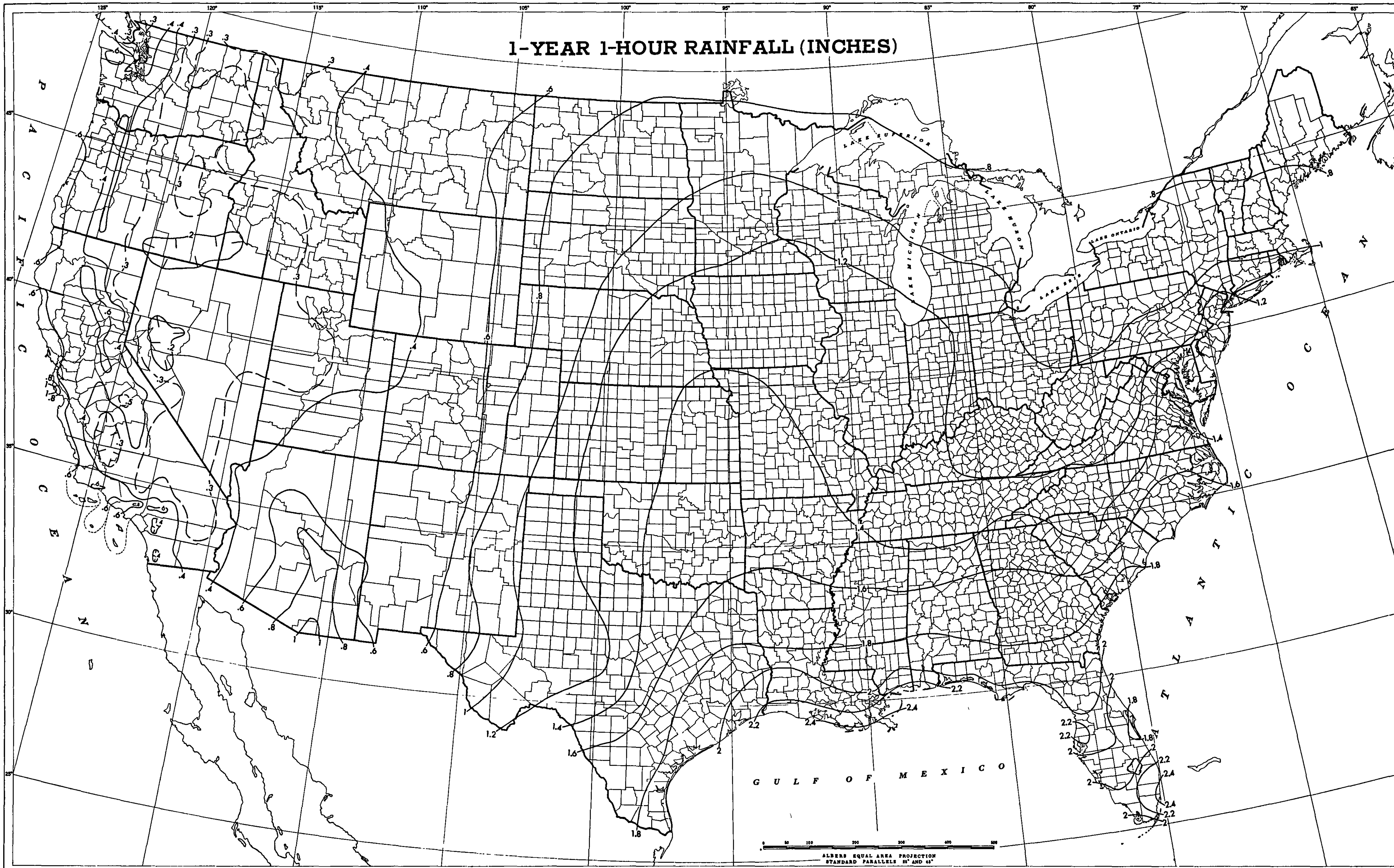

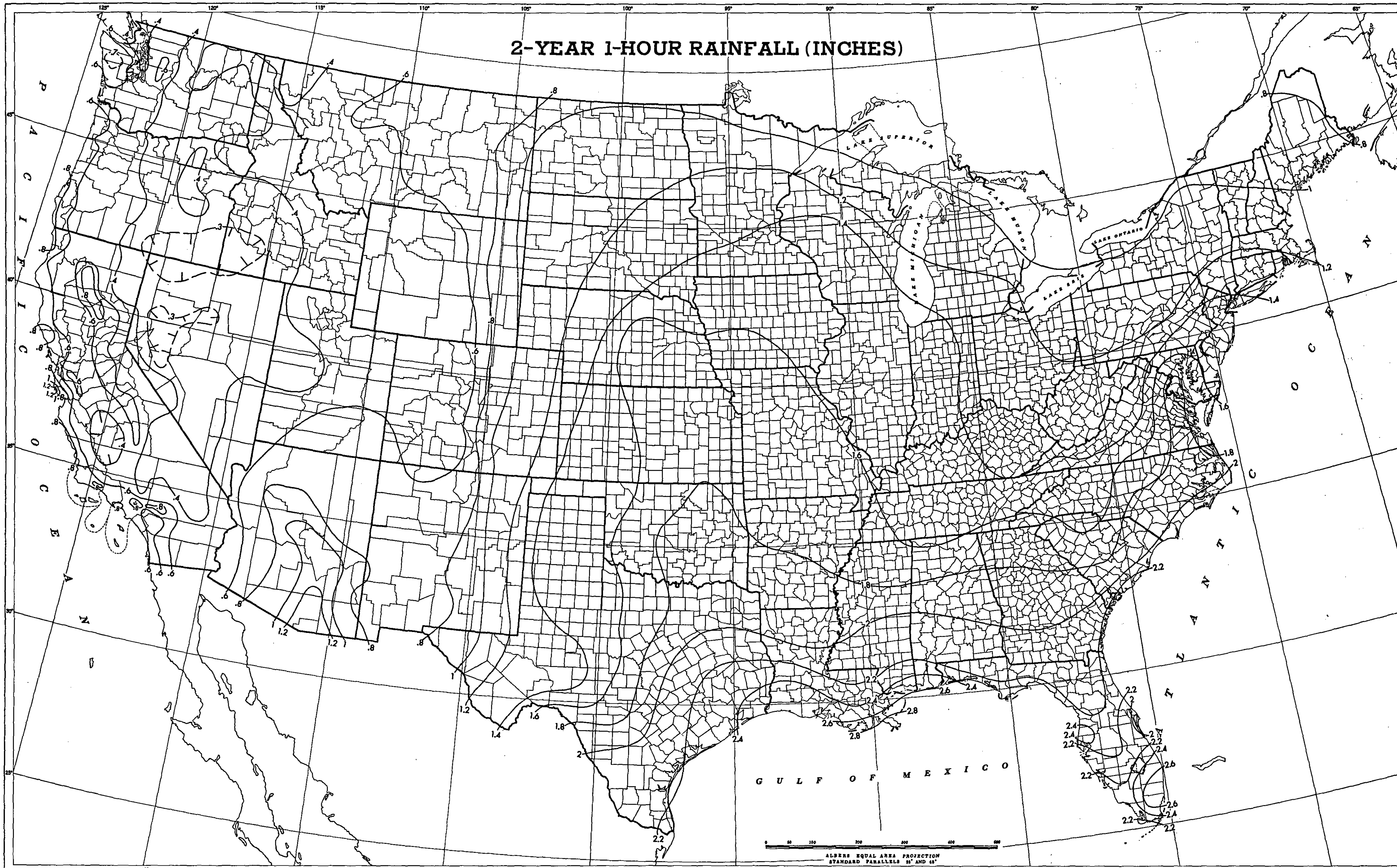
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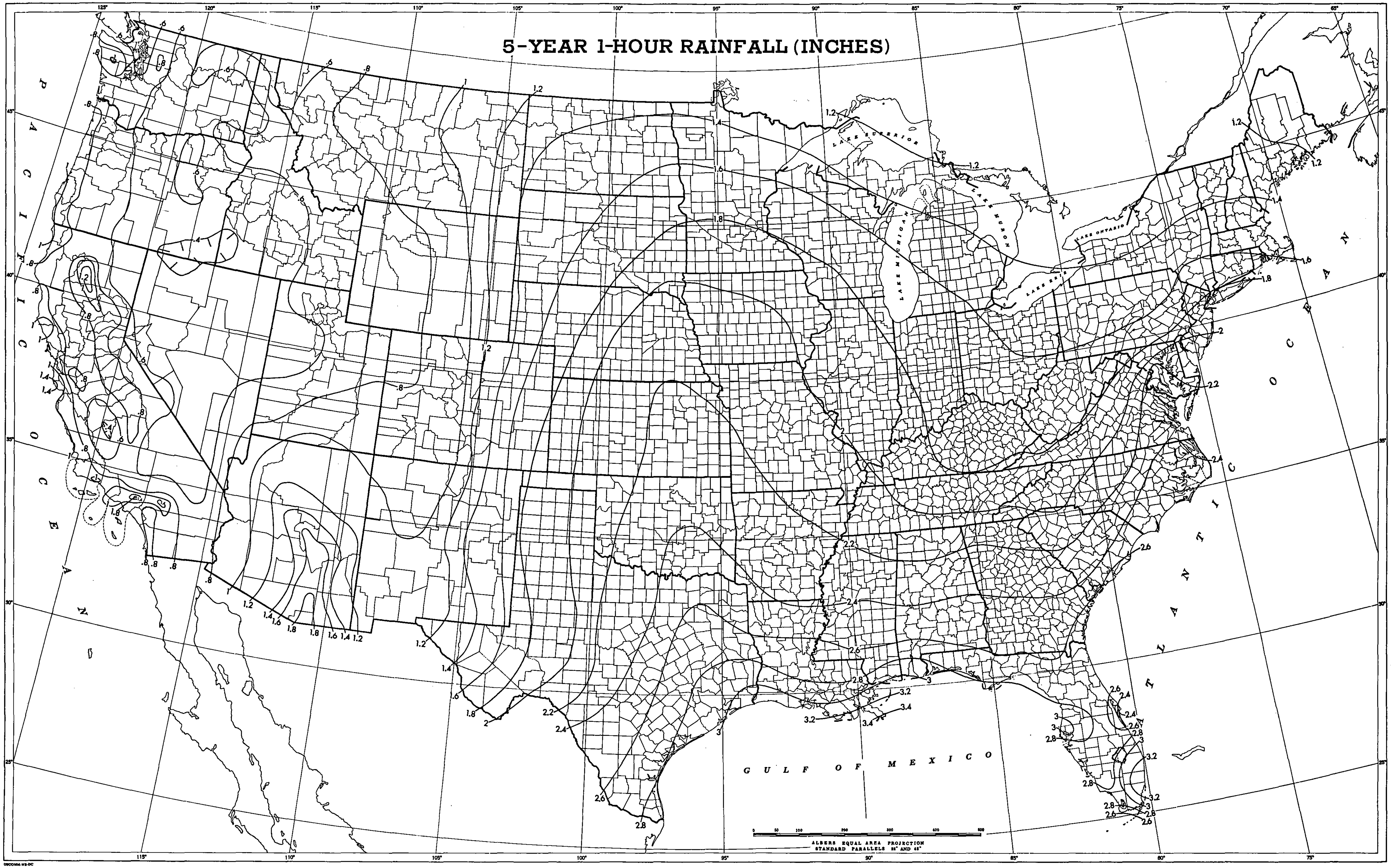
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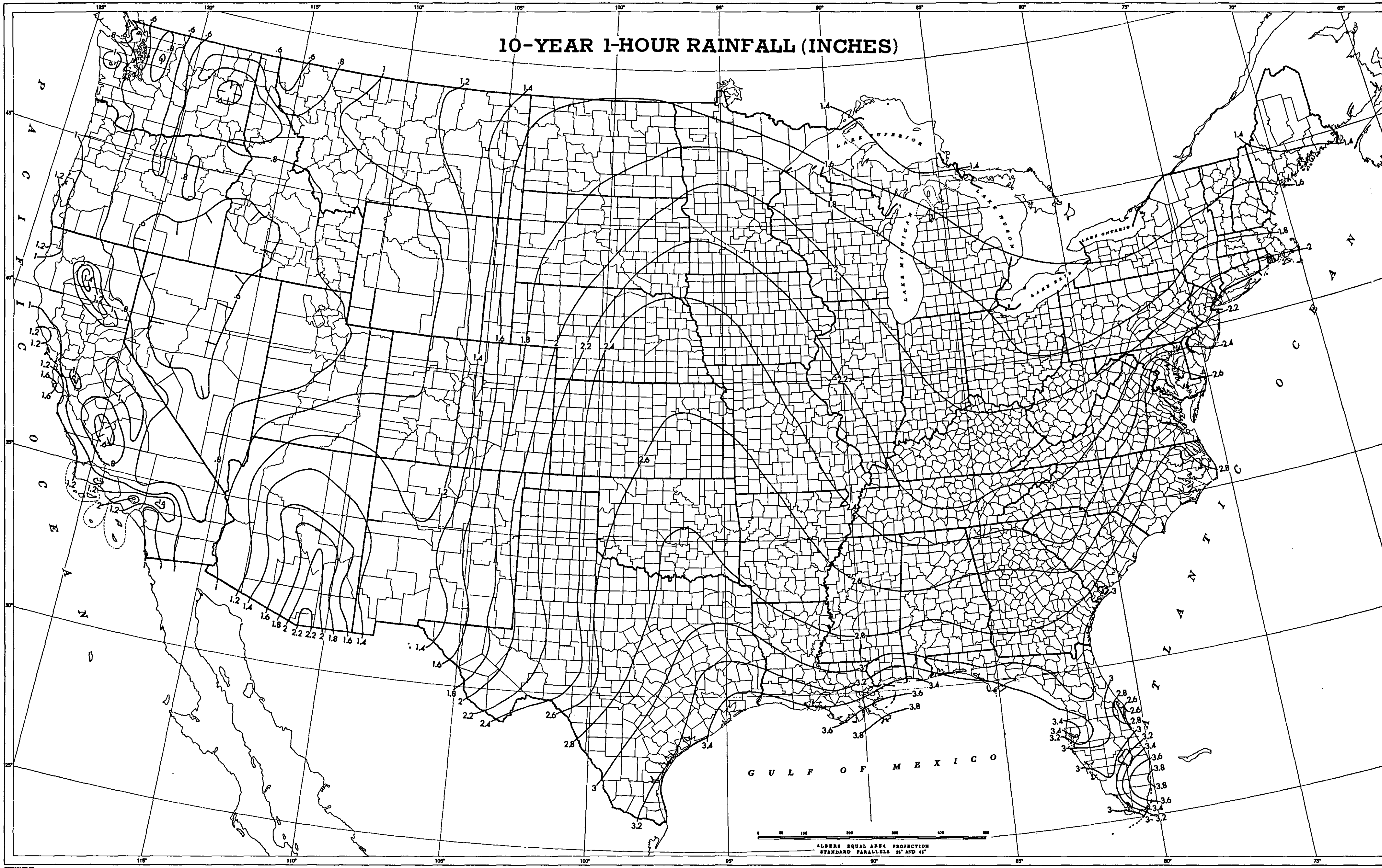
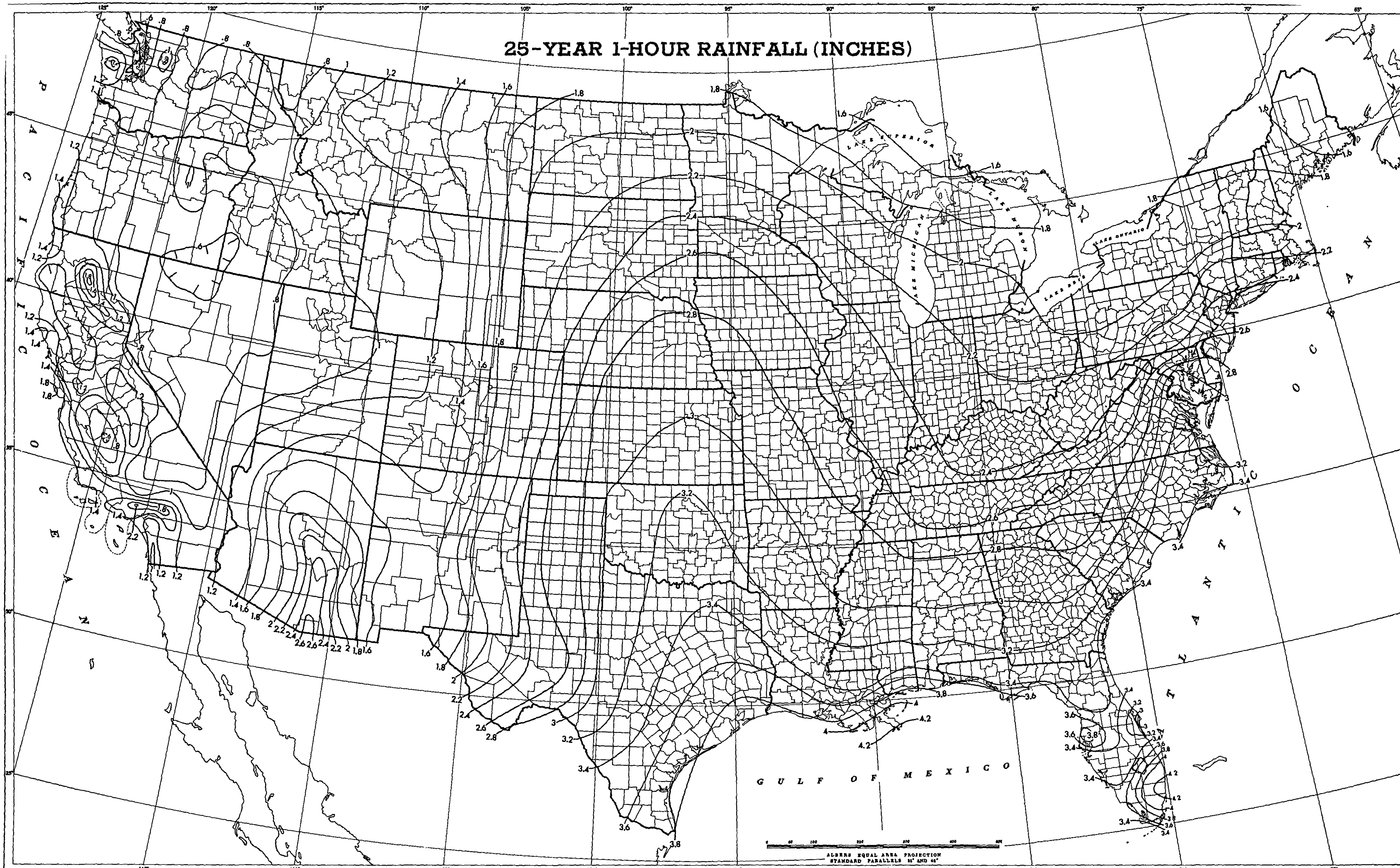
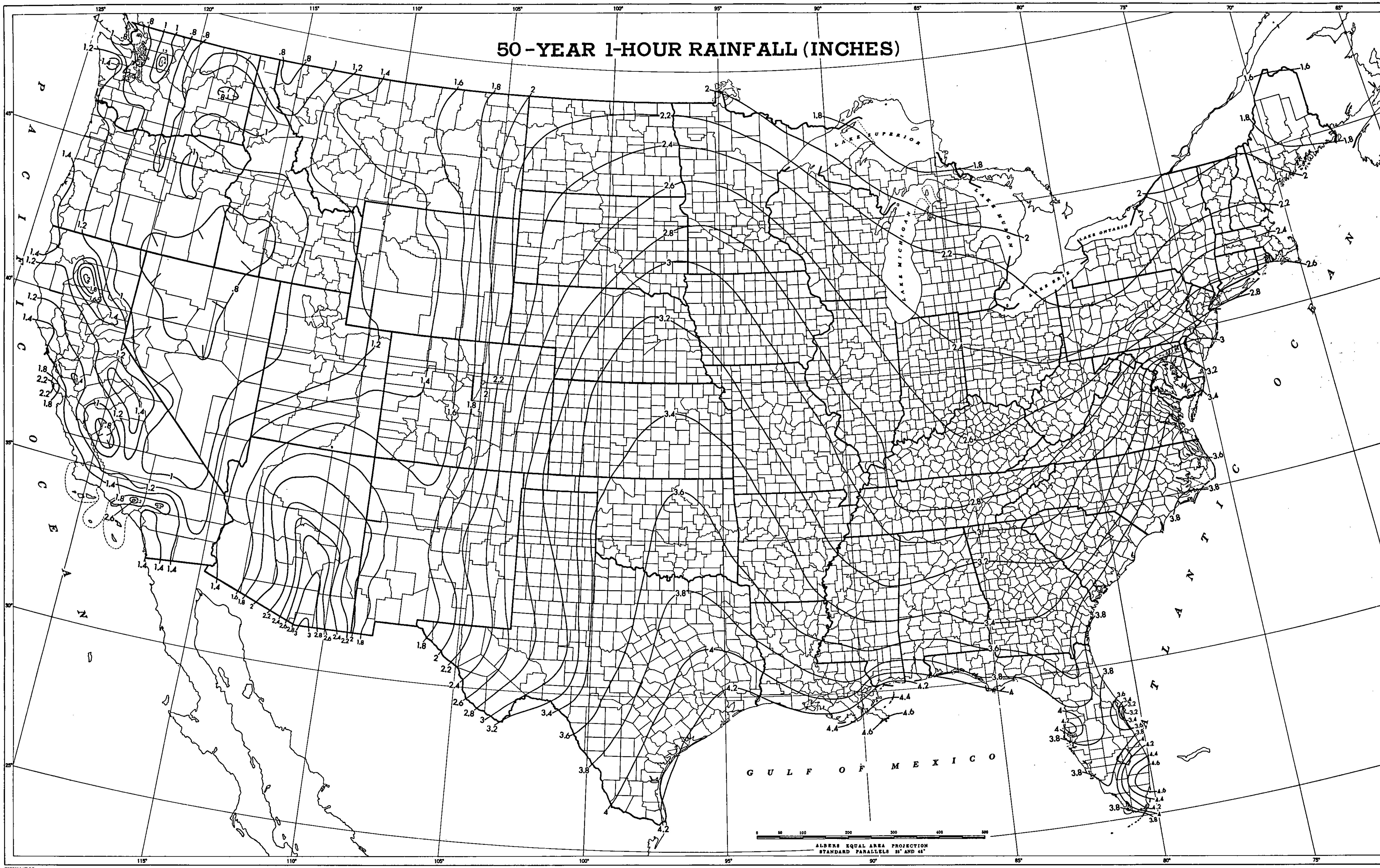
LAKE ONTARIO
LAKE ERIE
ALBERS EQUAL AREA PROJECTION
STANDARD PARALLELS 29° AND 45°

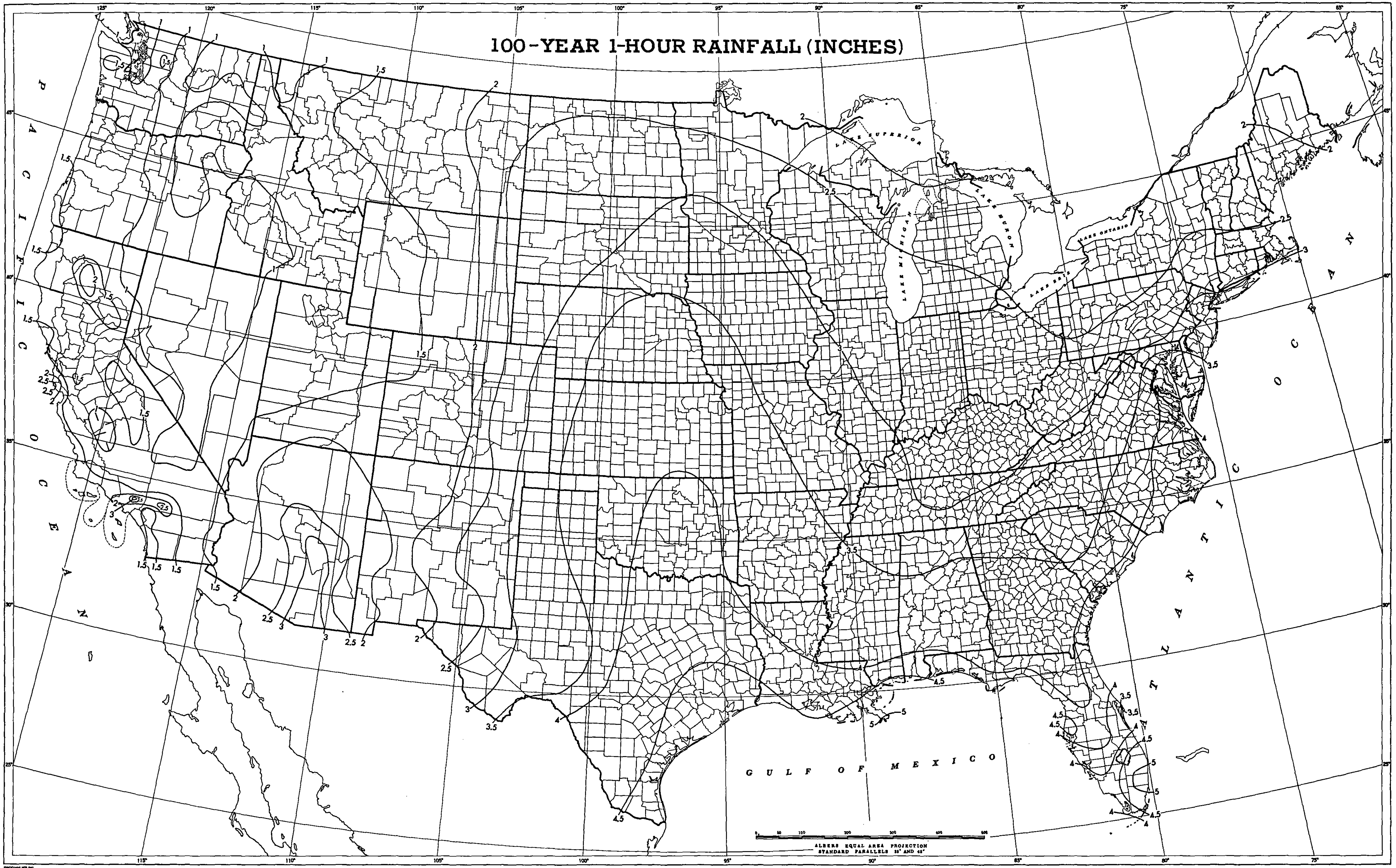

10-YEAR 1-HOUR RAINFALL (INCHES)
PACIFIC OCEAN
ATLANTIC OCEAN
GULF OF MEXICO
LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
LAKE ONTARIO
LAKE ERIE
ALBERS EQUAL AREA PROJECTION
STANDARD PARALLELS 29° AND 45°

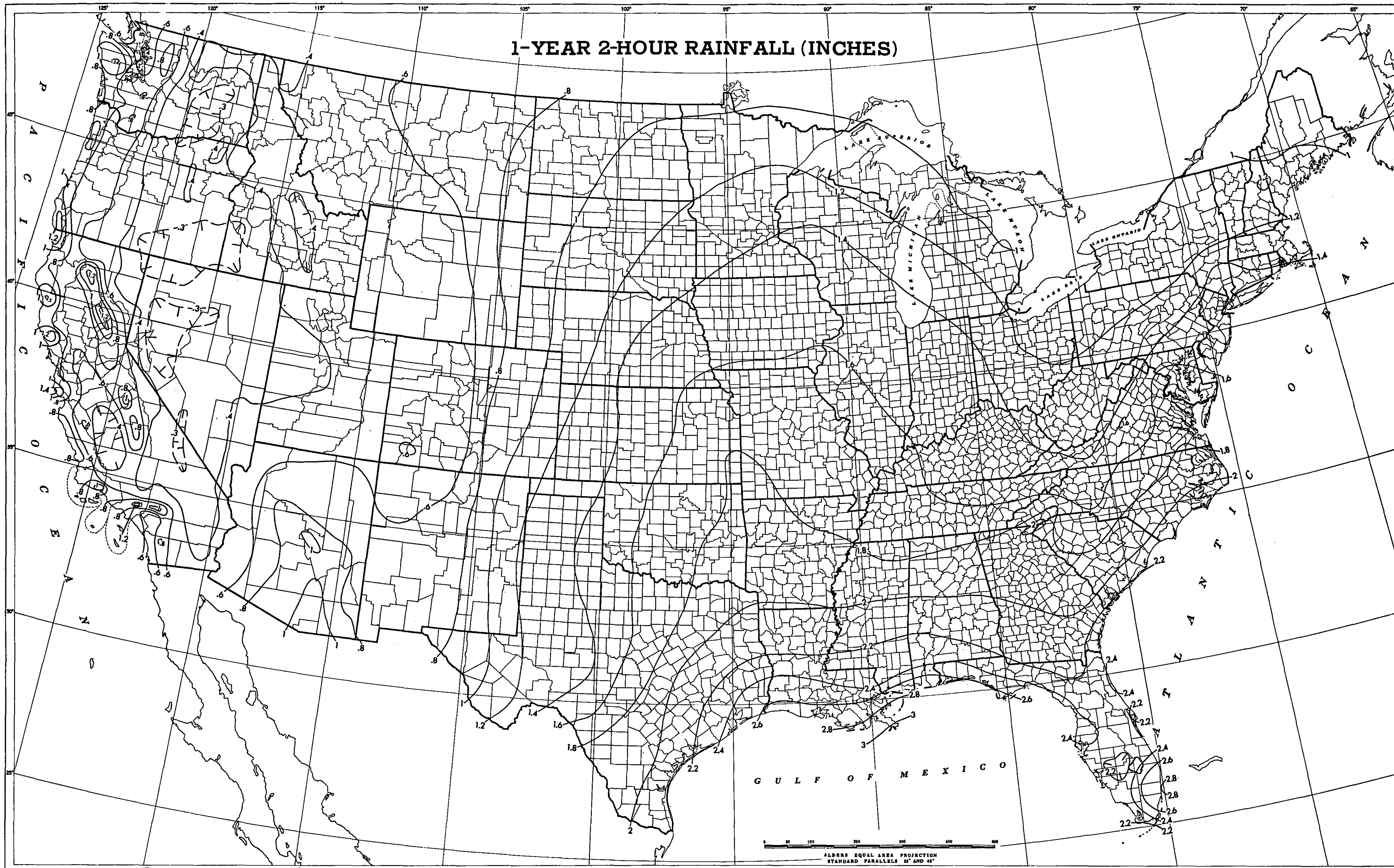
25-YEAR 1-HOUR RAINFALL (INCHES)

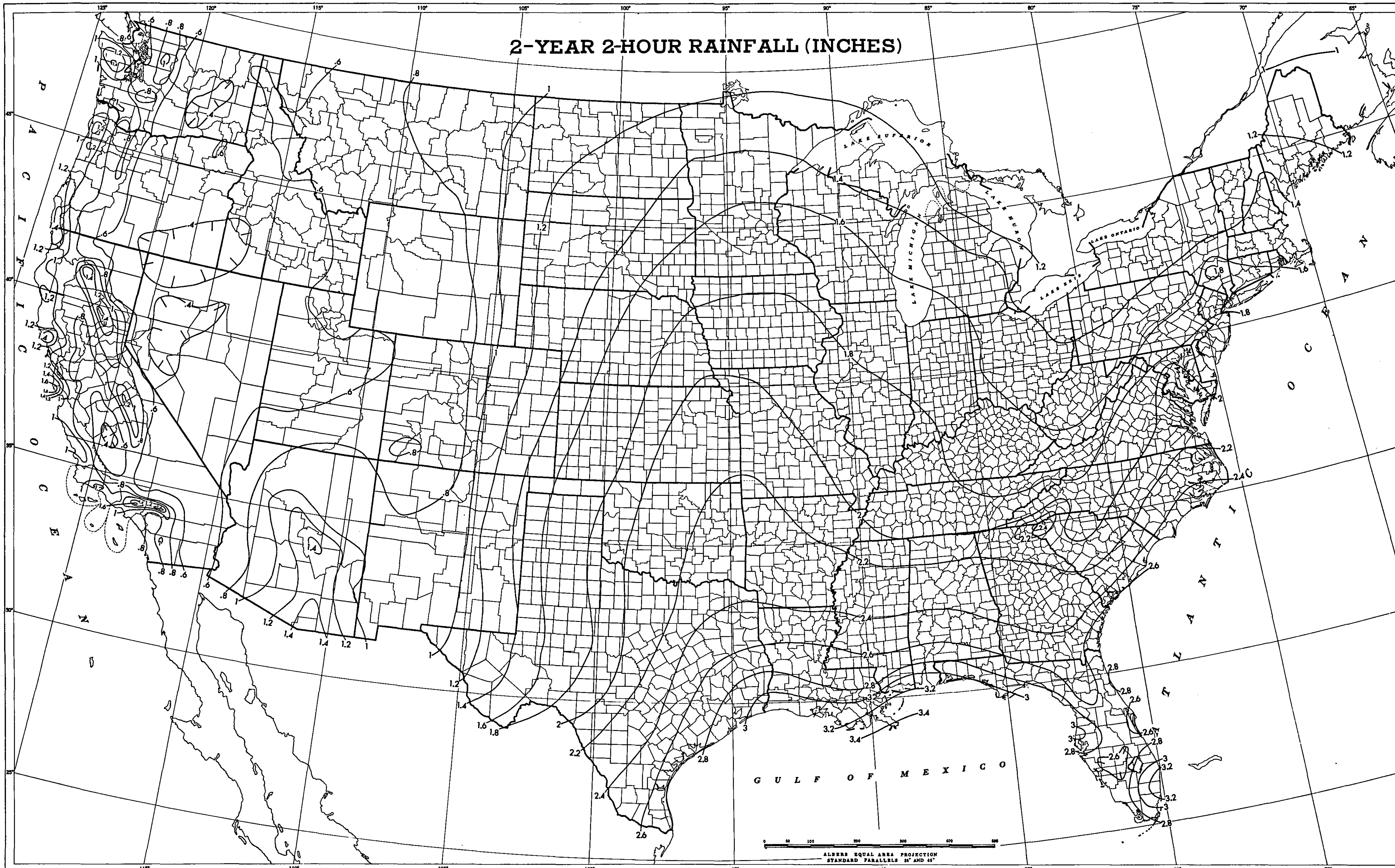


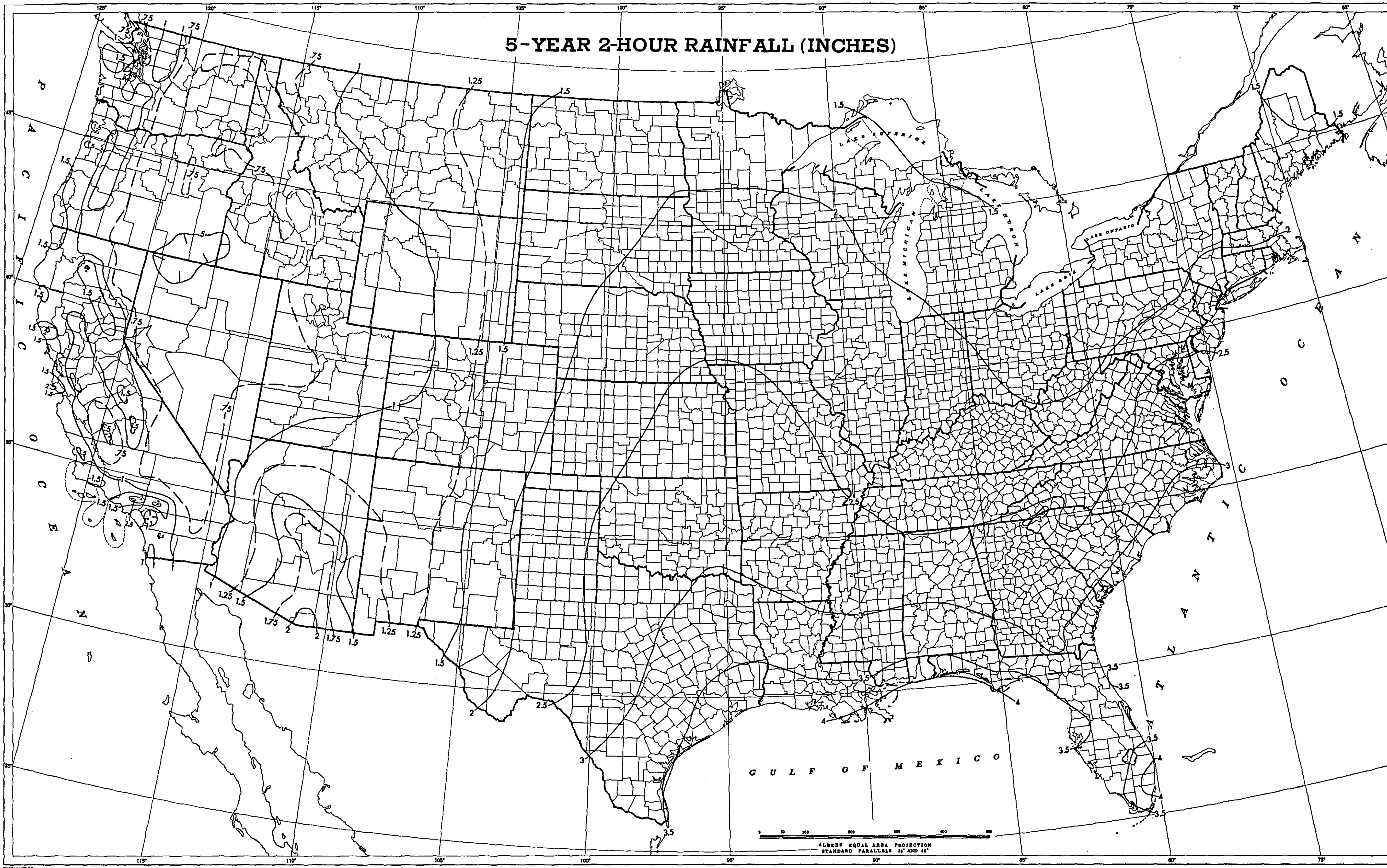


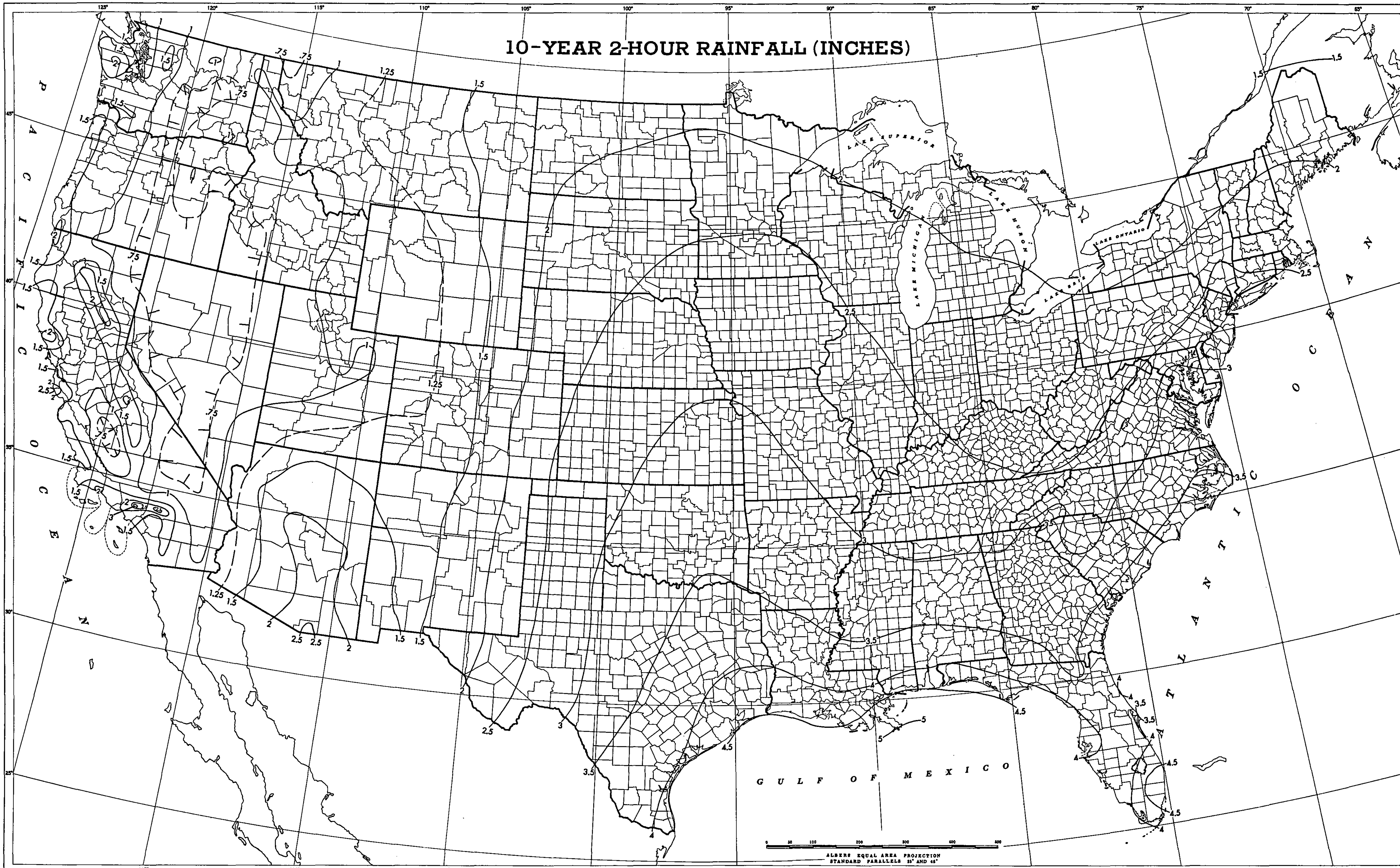
50-YEAR 1-HOUR RAINFALL (INCHES)
PACIFIC OCEAN
ATLANTIC OCEAN
GULF OF MEXICO
LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
LAKE ERIE
LAKE ONTARIO
ALBERS EQUAL AREA PROJECTION
STANDARD PARALLELS 29° AND 45°


100-YEAR 1-HOUR RAINFALL (INCHES)
PACIFIC OCEAN
ATLANTIC OCEAN
GULF OF MEXICO
LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
LAKE ONTARIO
LAKE ERIE
ALBERS EQUAL AREA PROJECTION
STANDARD PARALLELS 29° AND 45°

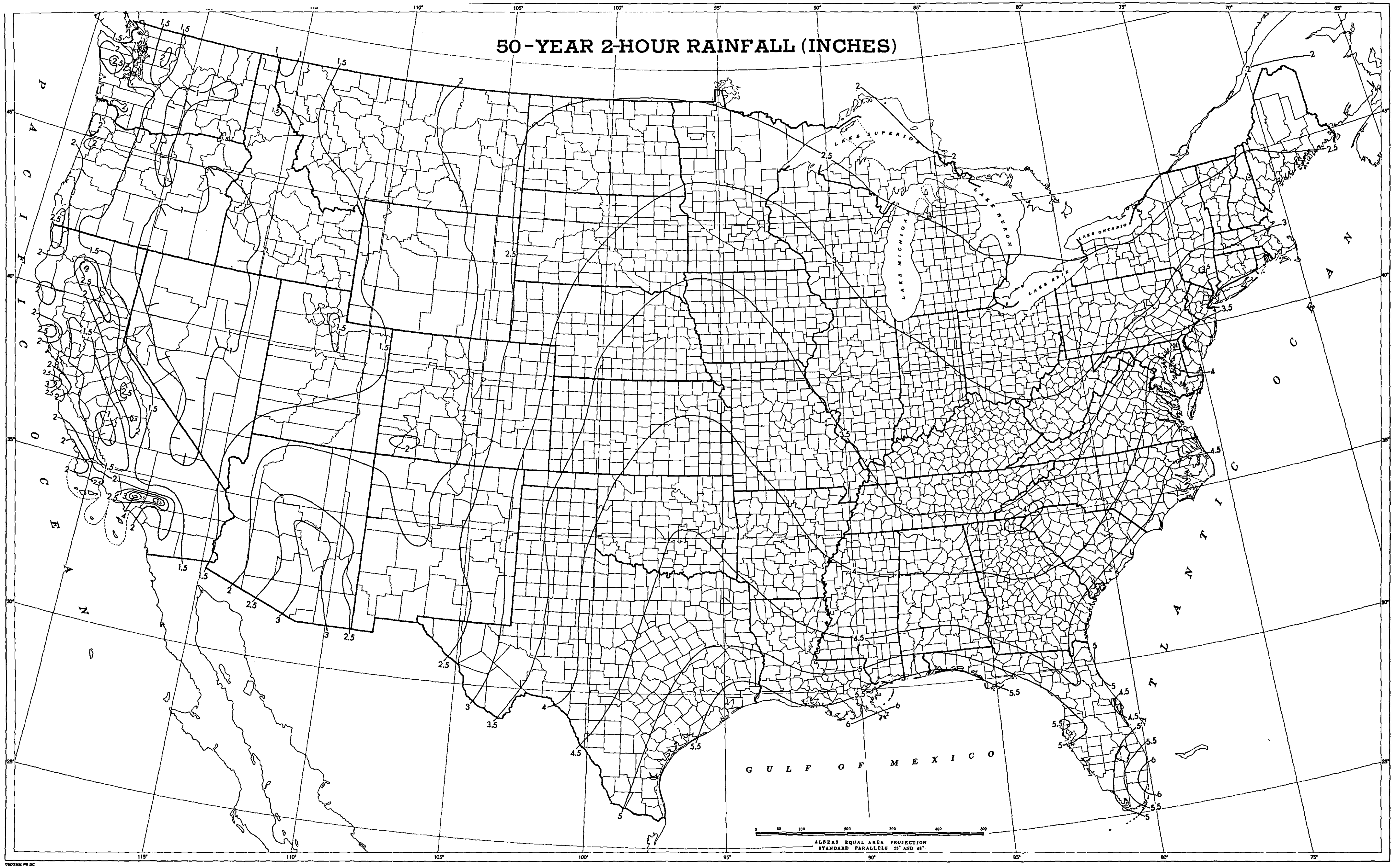

1-YEAR 2-HOUR RAINFALL (INCHES)
PACIFIC OCEAN
ATLANTIC OCEAN
GULF OF MEXICO
LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
LAKE ONTARIO
LAKE ERIE
ALBERS EQUAL AREA PROJECTION
STANDARD PARALLELS 29° AND 45°


2-YEAR 2-HOUR RAINFALL (INCHES)
PACIFIC OCEAN
ATLANTIC OCEAN
GULF OF MEXICO
LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
LAKE ONTARIO
LAKE ERIE
ALBERS EQUAL AREA PROJECTION
STANDARD PARALLELS 29° AND 45°

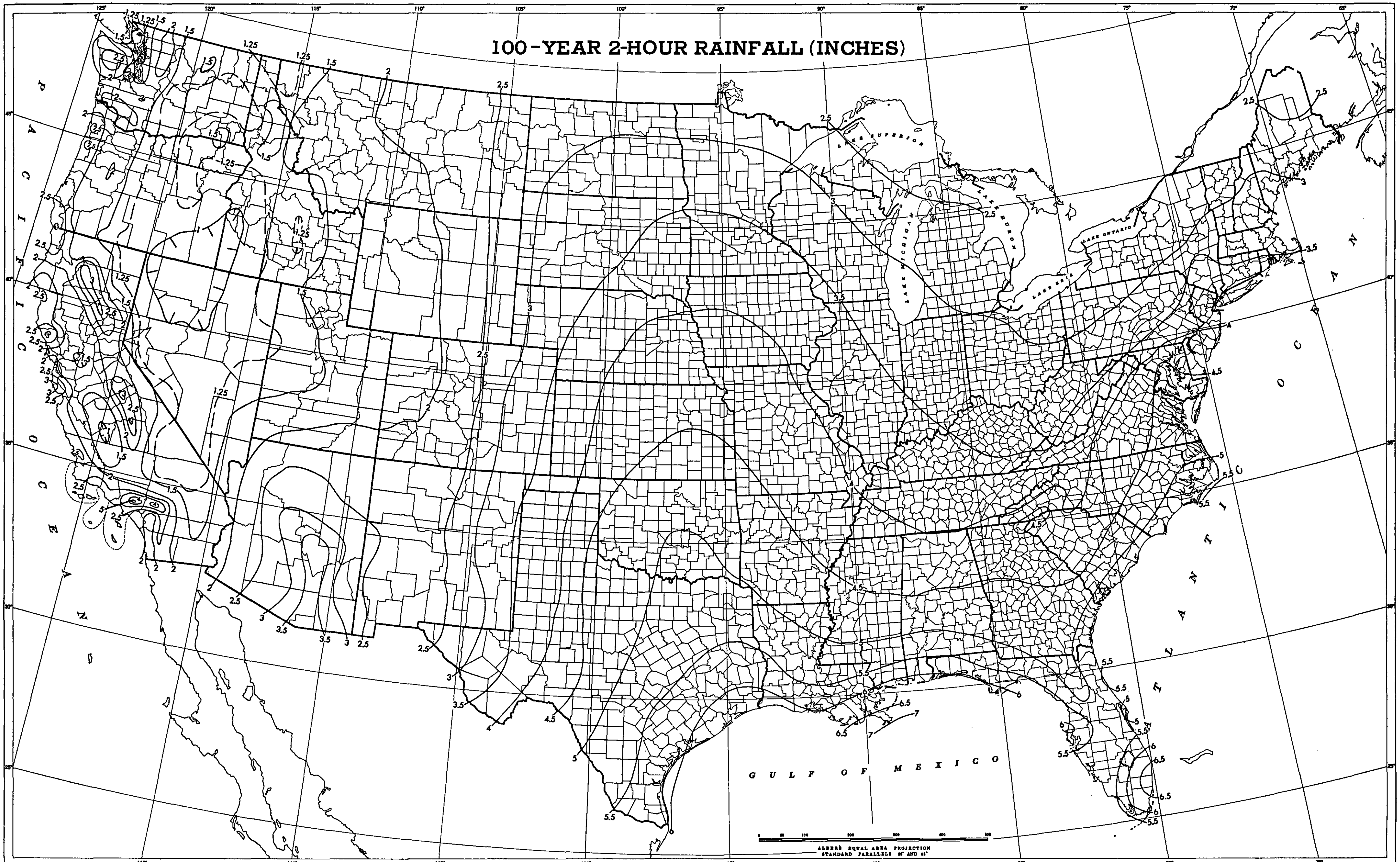

5-YEAR 2-HOUR RAINFALL (INCHES)
PACIFIC OCEAN
ATLANTIC OCEAN
GULF OF MEXICO
LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
LAKE ONTARIO
LAKE ERIE
ALBERS EQUAL AREA PROJECTION
STANDARD PARALLELS 29° AND 45°

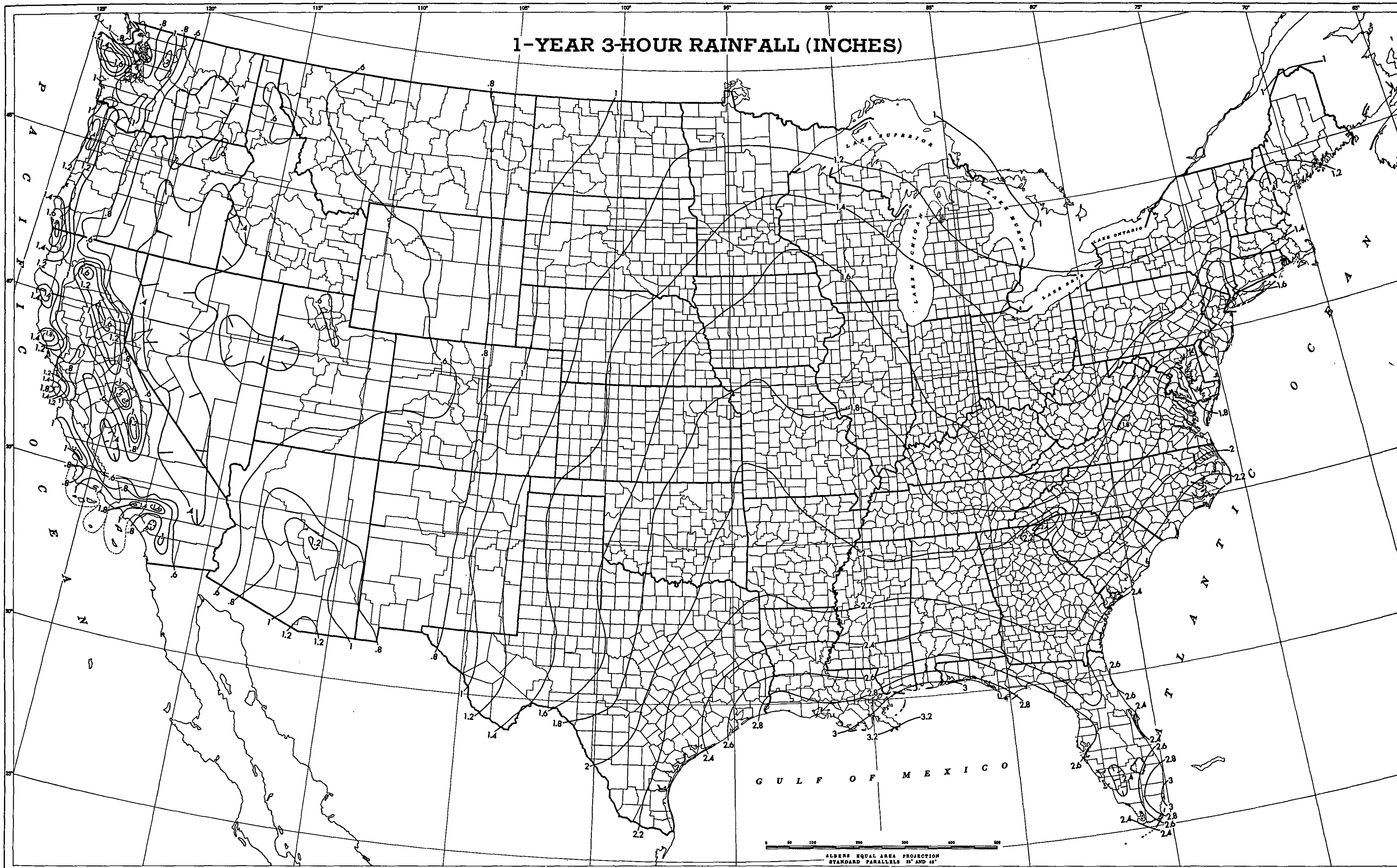

10-YEAR 2-HOUR RAINFALL (INCHES)
P A C I F I C O C E A N
A T L A N T I C O C E A N
G U L F O F M E X I C O
LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
LAKE ONTARIO
LAKE ERIE
ALBERS EQUAL AREA PROJECTION
STANDARD PARALLELS 29° AND 45°


25-YEAR 2-HOUR RAINFALL (INCHES)
P A C I F I C O C E A N
A T L A N T I C O C E A N
G U L F O F M E X I C O
LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
LAKE ONTARIO
LAKE ERIE
ALBERS EQUAL AREA PROJECTION
STANDARD PARALLELS 29° AND 45°

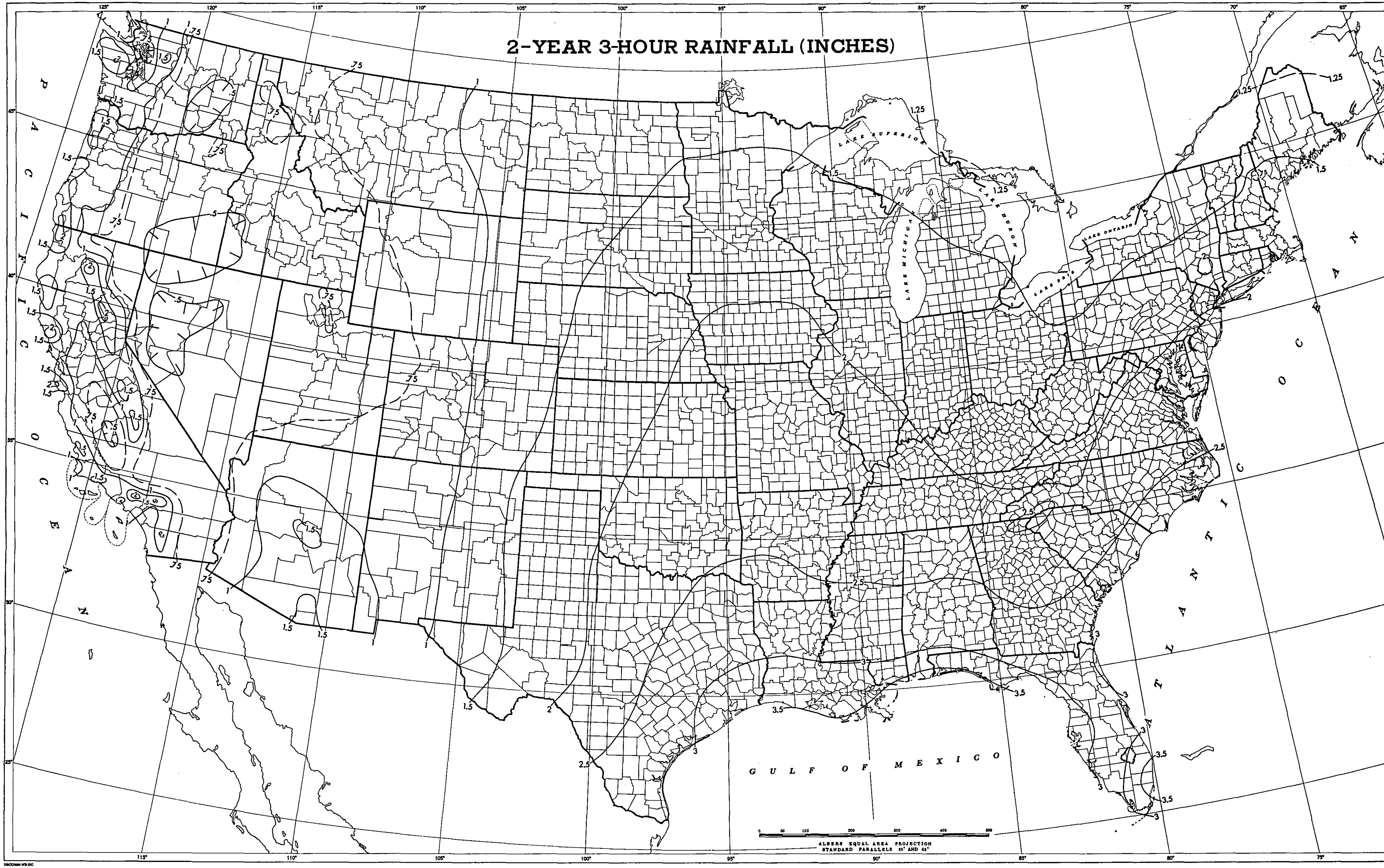

50-YEAR 2-HOUR RAINFALL (INCHES)
PACIFIC OCEAN
ATLANTIC OCEAN
GULF OF MEXICO
LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
LAKE ONTARIO
LAKE ERIE
ALBERS EQUAL AREA PROJECTION
STANDARD PARALLELS 29° AND 45°

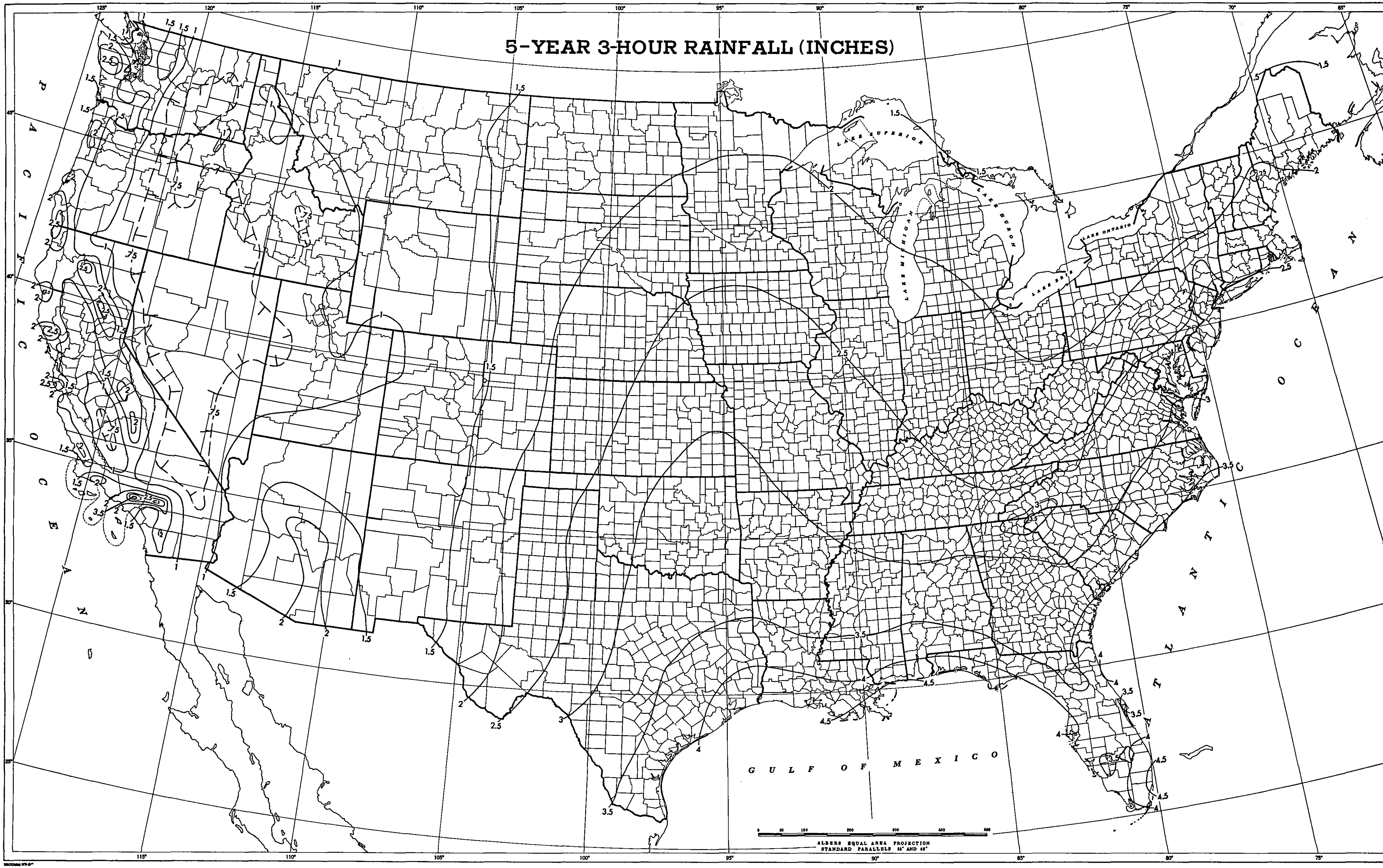
100-YEAR 2-HOUR RAINFALL (INCHES)

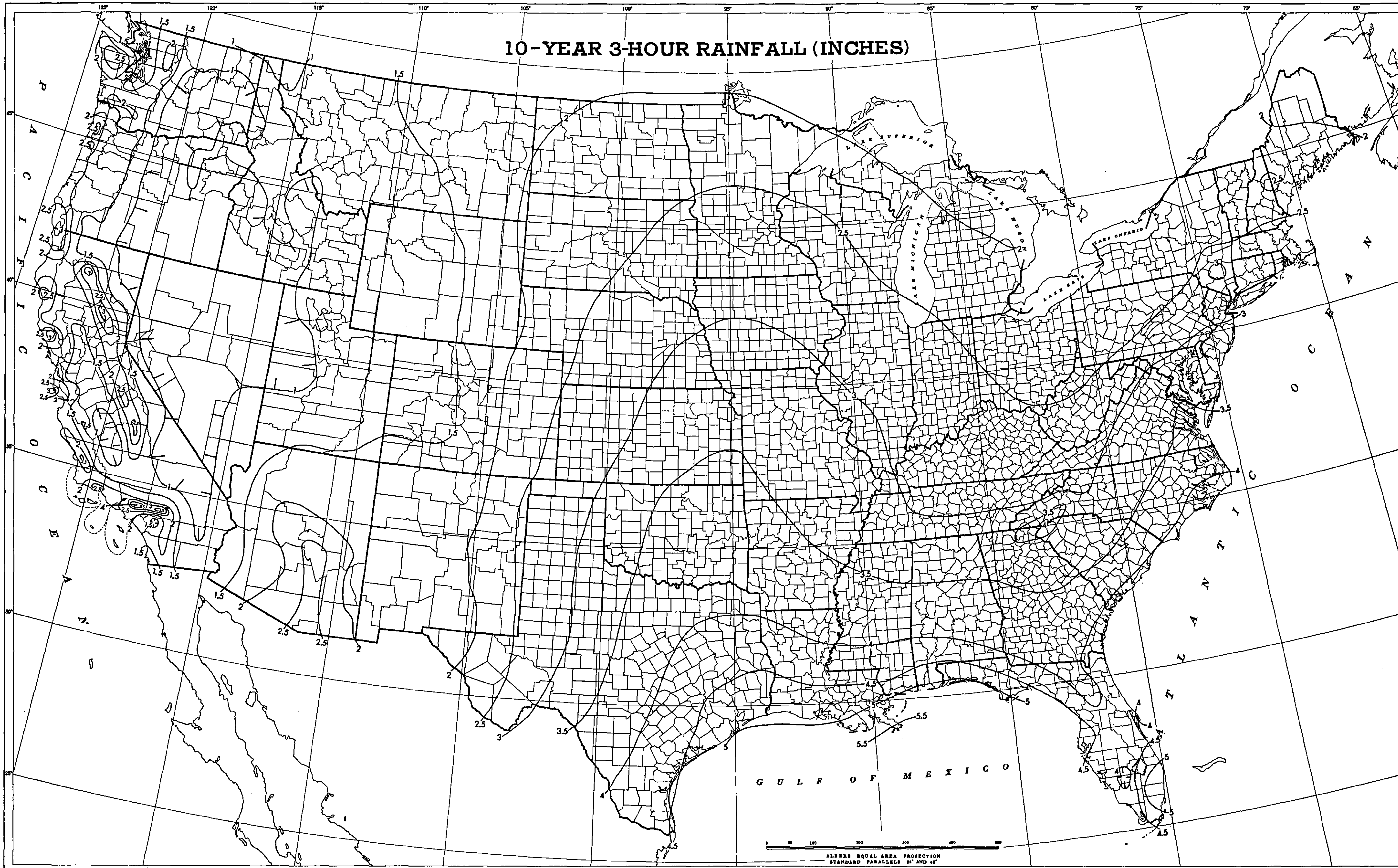


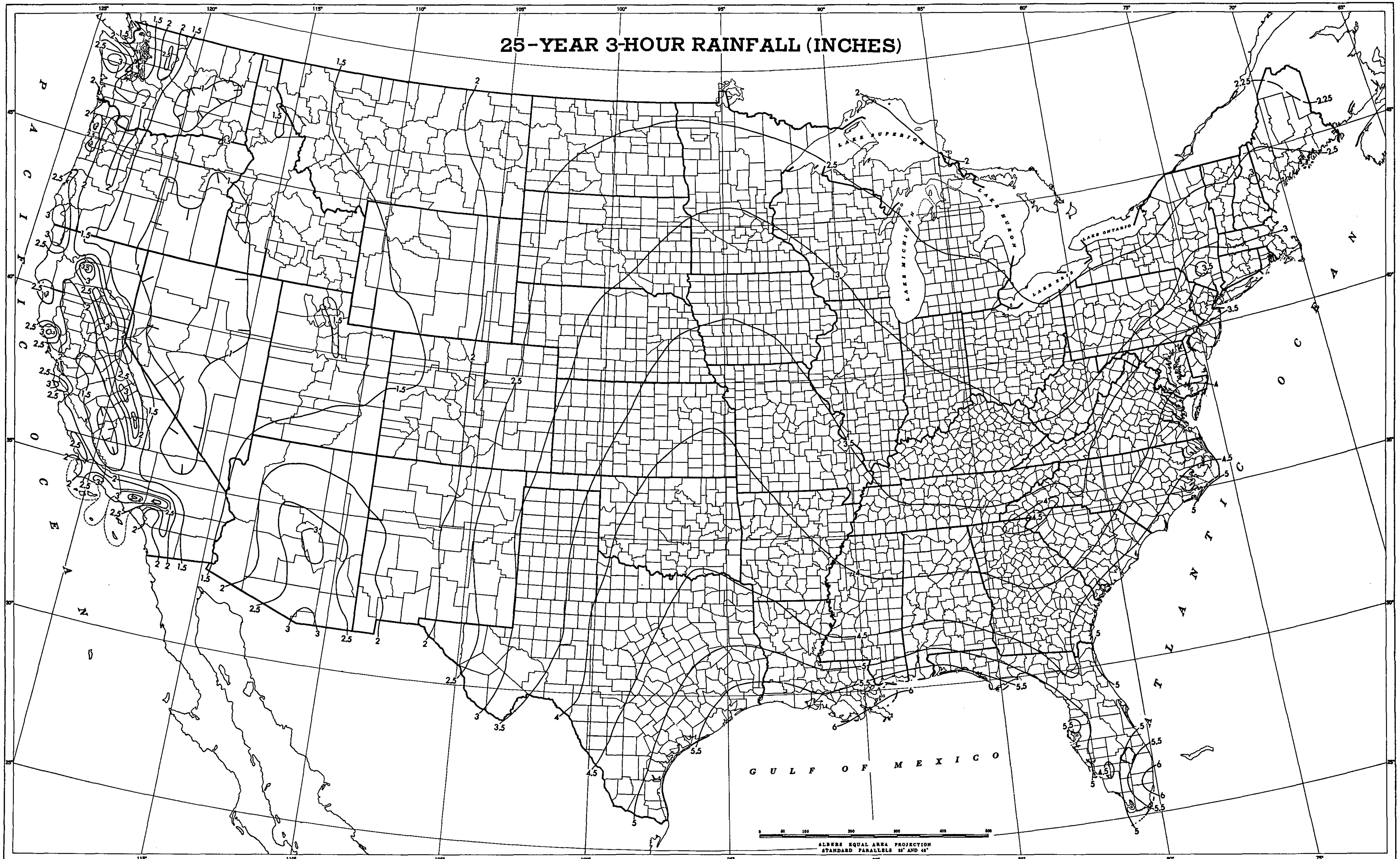

1-YEAR 3-HOUR RAINFALL (INCHES)
PACIFIC OCEAN
ATLANTIC OCEAN
GULF OF MEXICO
LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
LAKE ERIE
LAKE ONTARIO
ALBERS EQUAL AREA PROJECTION
STANDARD PARALLELS 29° AND 45°

2-YEAR 3-HOUR RAINFALL (INCHES)

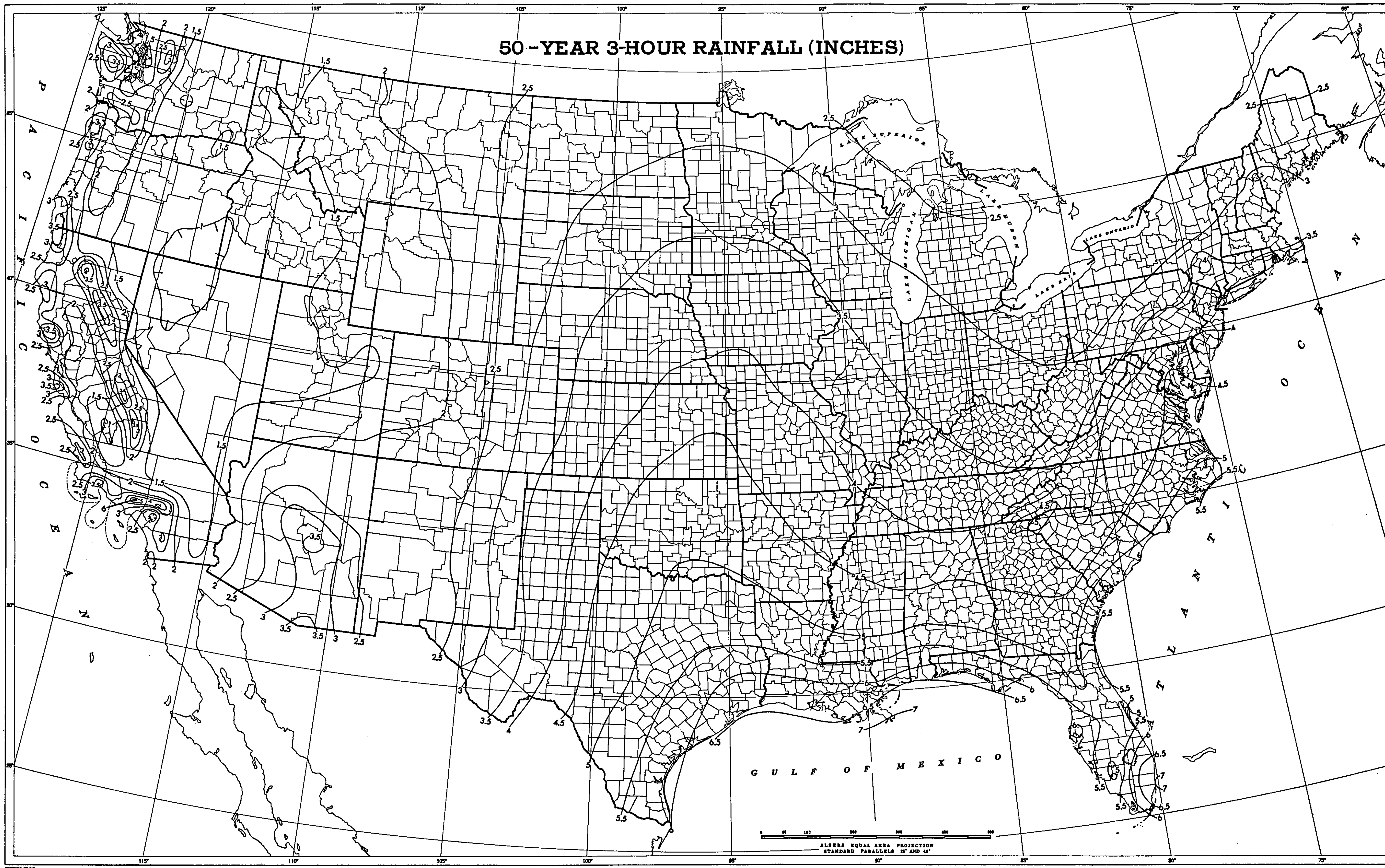


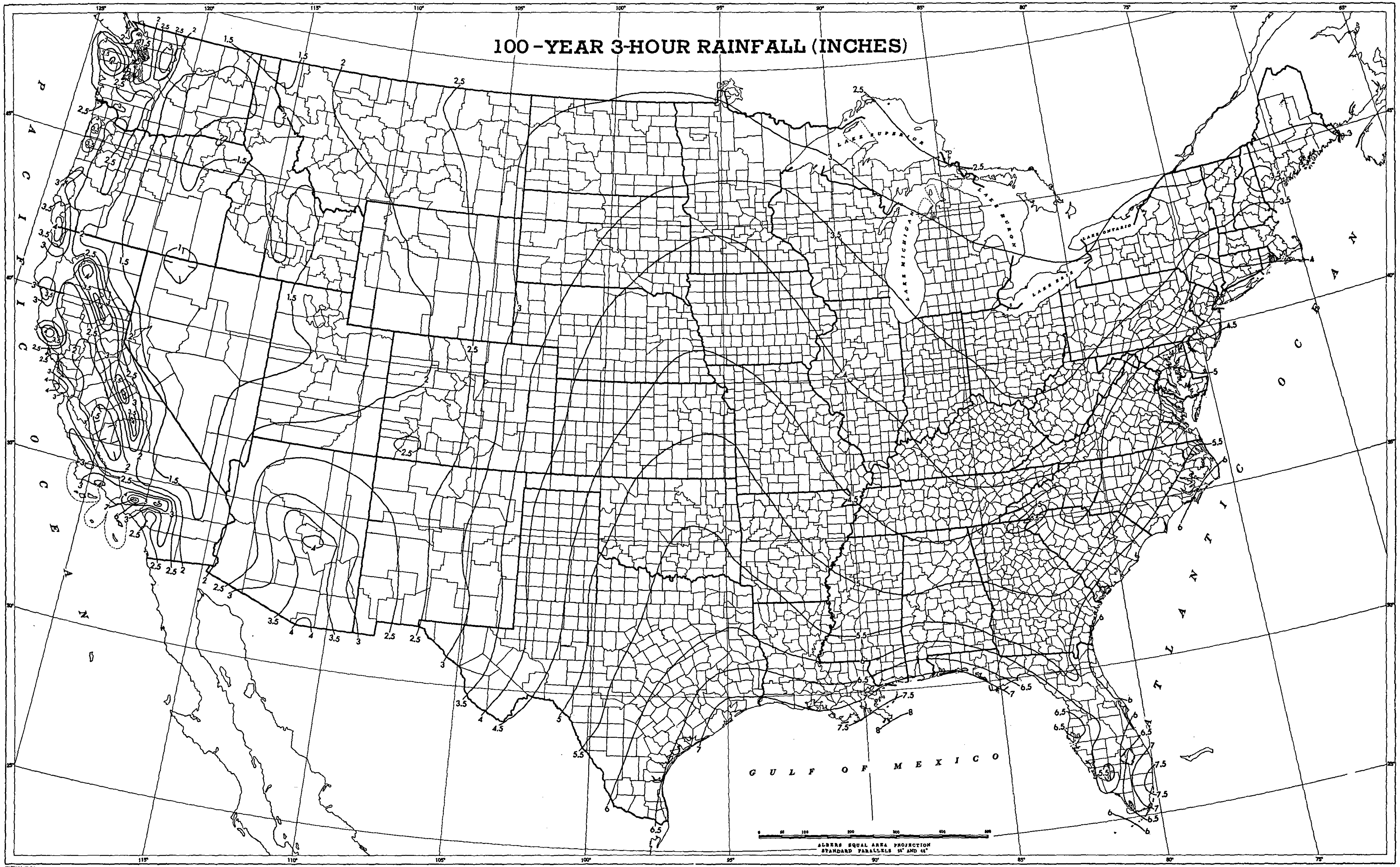

5-YEAR 3-HOUR RAINFALL (INCHES)
PACIFIC OCEAN
ATLANTIC OCEAN
GULF OF MEXICO
LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
LAKE ONTARIO
LAKE ERIE
ALBERS EQUAL AREA PROJECTION
STANDARD PARALLELS 29° AND 45°

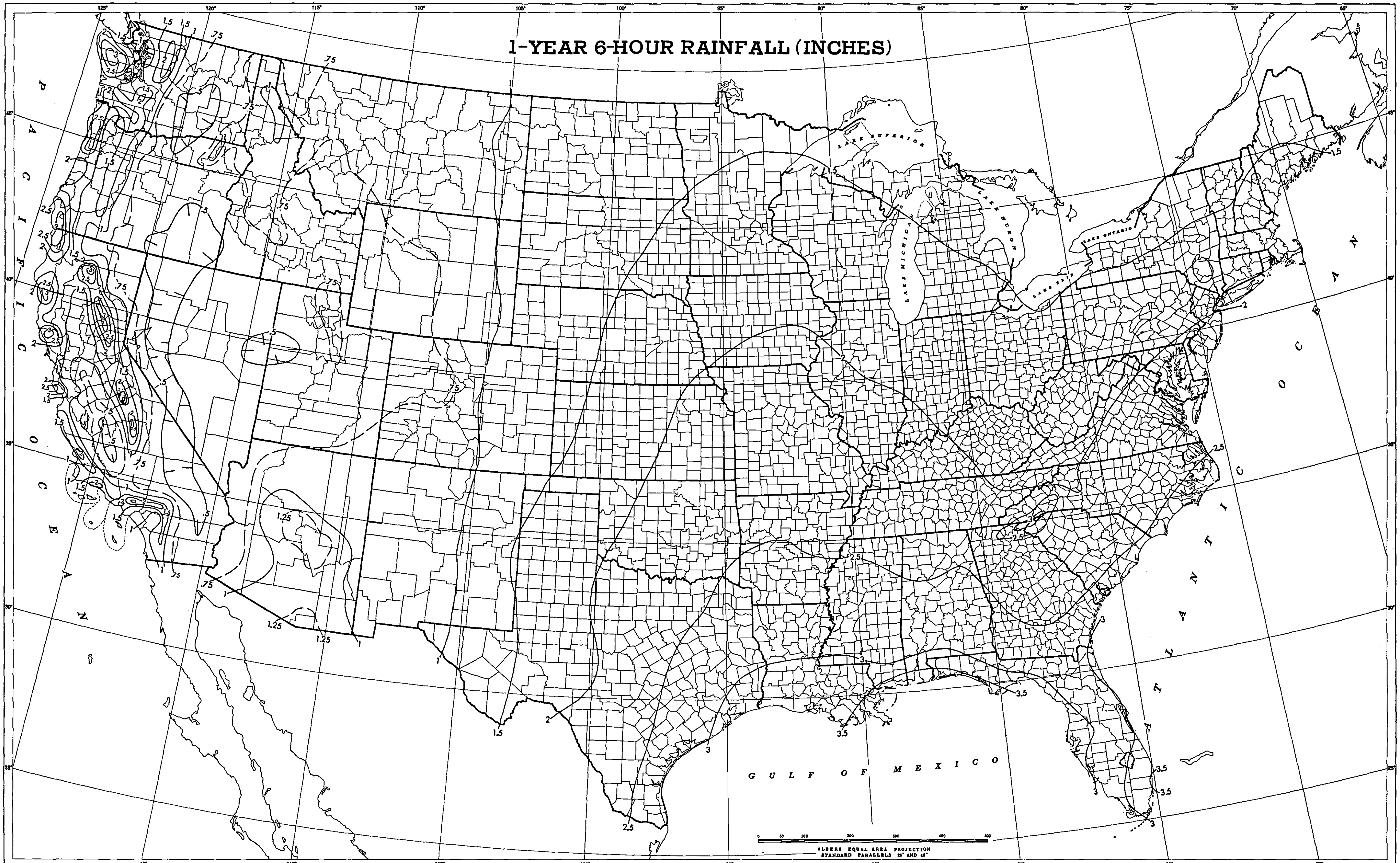

10-YEAR 3-HOUR RAINFALL (INCHES)
PACIFIC OCEAN
ATLANTIC OCEAN
GULF OF MEXICO
LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
LAKE ONTARIO
LAKE ERIE
ALBERS EQUAL AREA PROJECTION
STANDARD PARALLELS 29° AND 45°



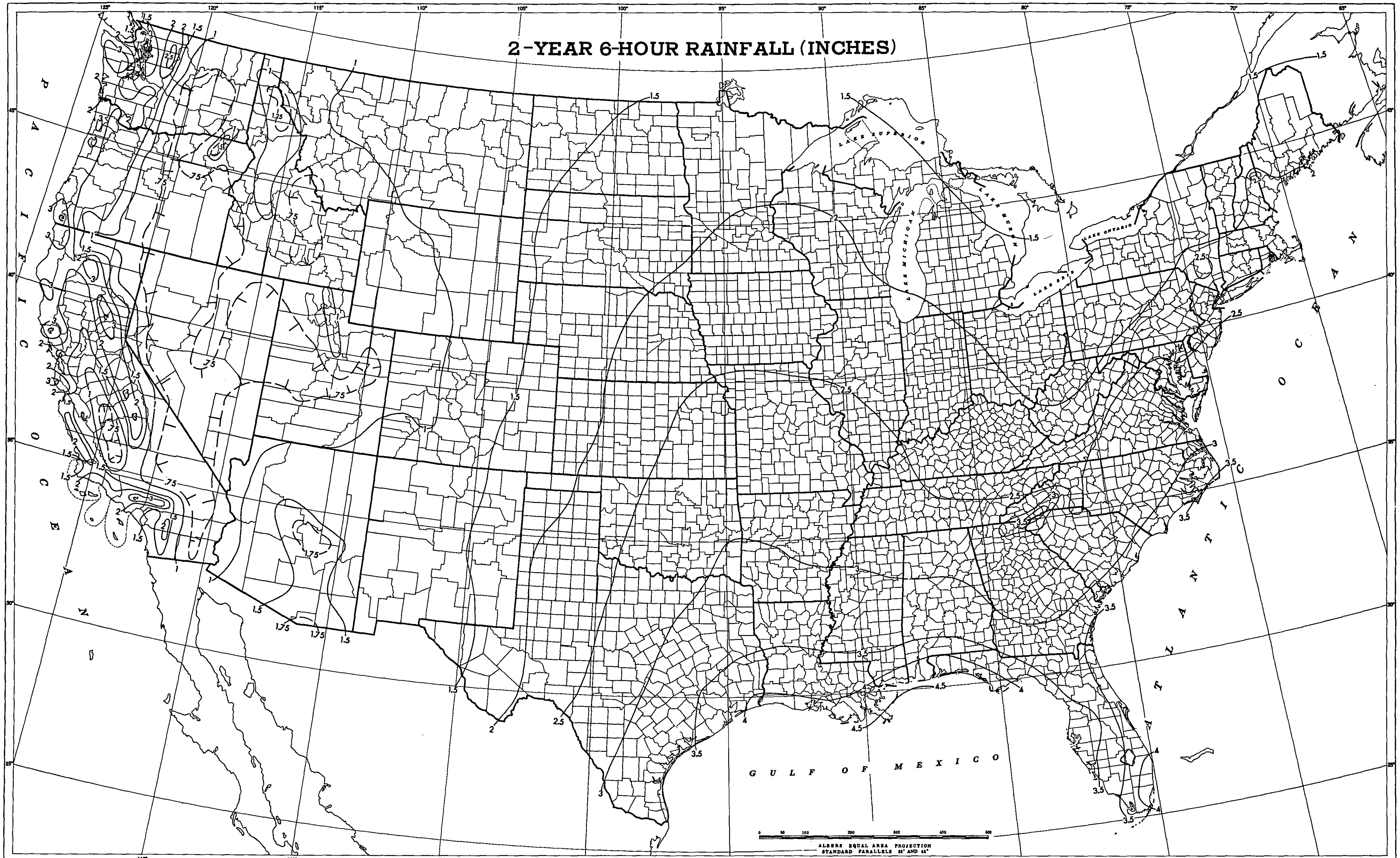
25-YEAR 3-HOUR RAINFALL (INCHES)


50-YEAR 3-HOUR RAINFALL (INCHES)
PACIFIC OCEAN
ATLANTIC OCEAN
GULF OF MEXICO
LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
LAKE ONTARIO
LAKE ERIE
ALBERS EQUAL AREA PROJECTION
STANDARD PARALLELS 29° AND 45°

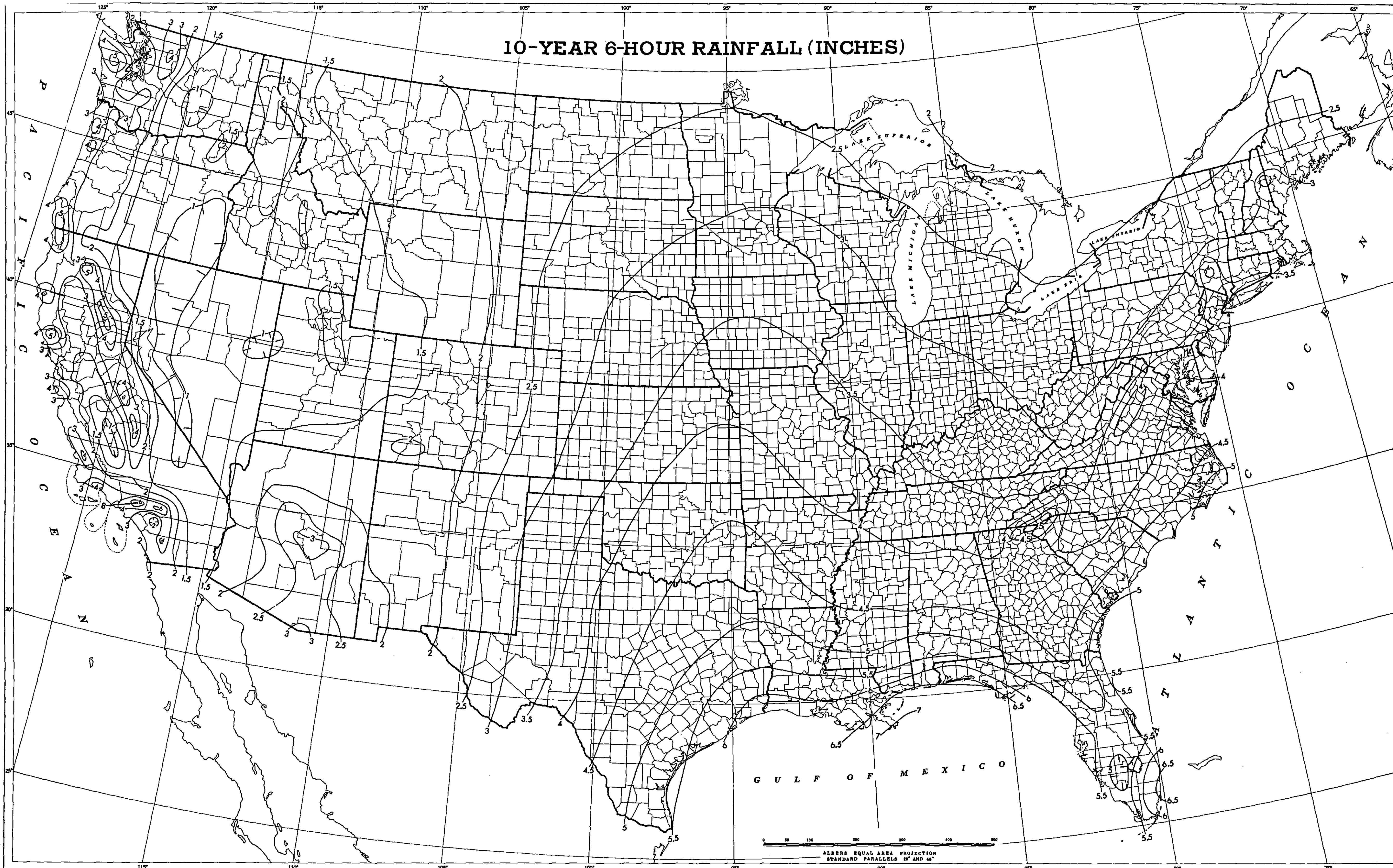

100-YEAR 3-HOUR RAINFALL (INCHES)
PACIFIC OCEAN
ATLANTIC OCEAN
GULF OF MEXICO
LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
LAKE ONTARIO
LAKE ERIE
ALBERS EQUAL AREA PROJECTION
STANDARD PARALLELS 29° AND 45°

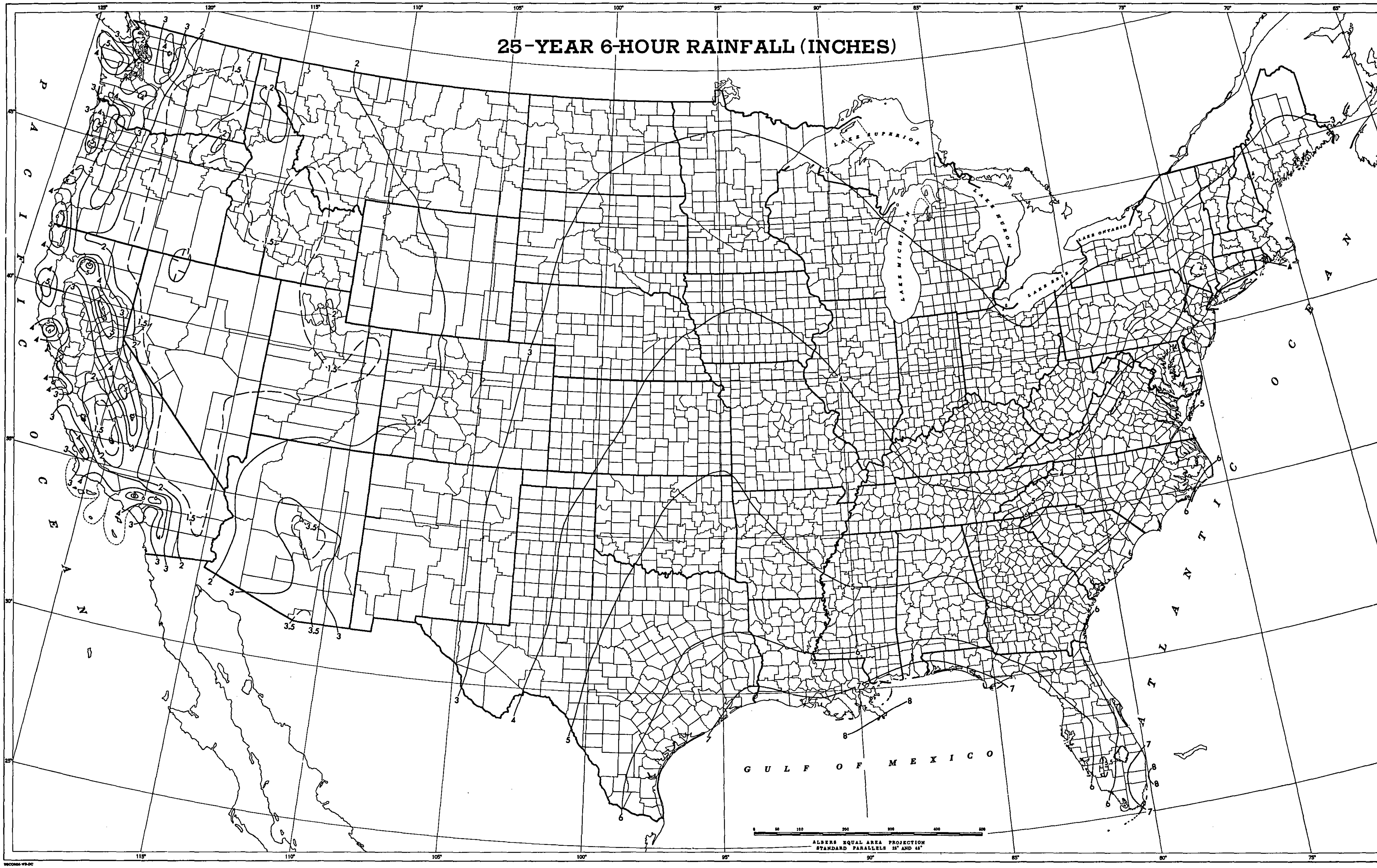


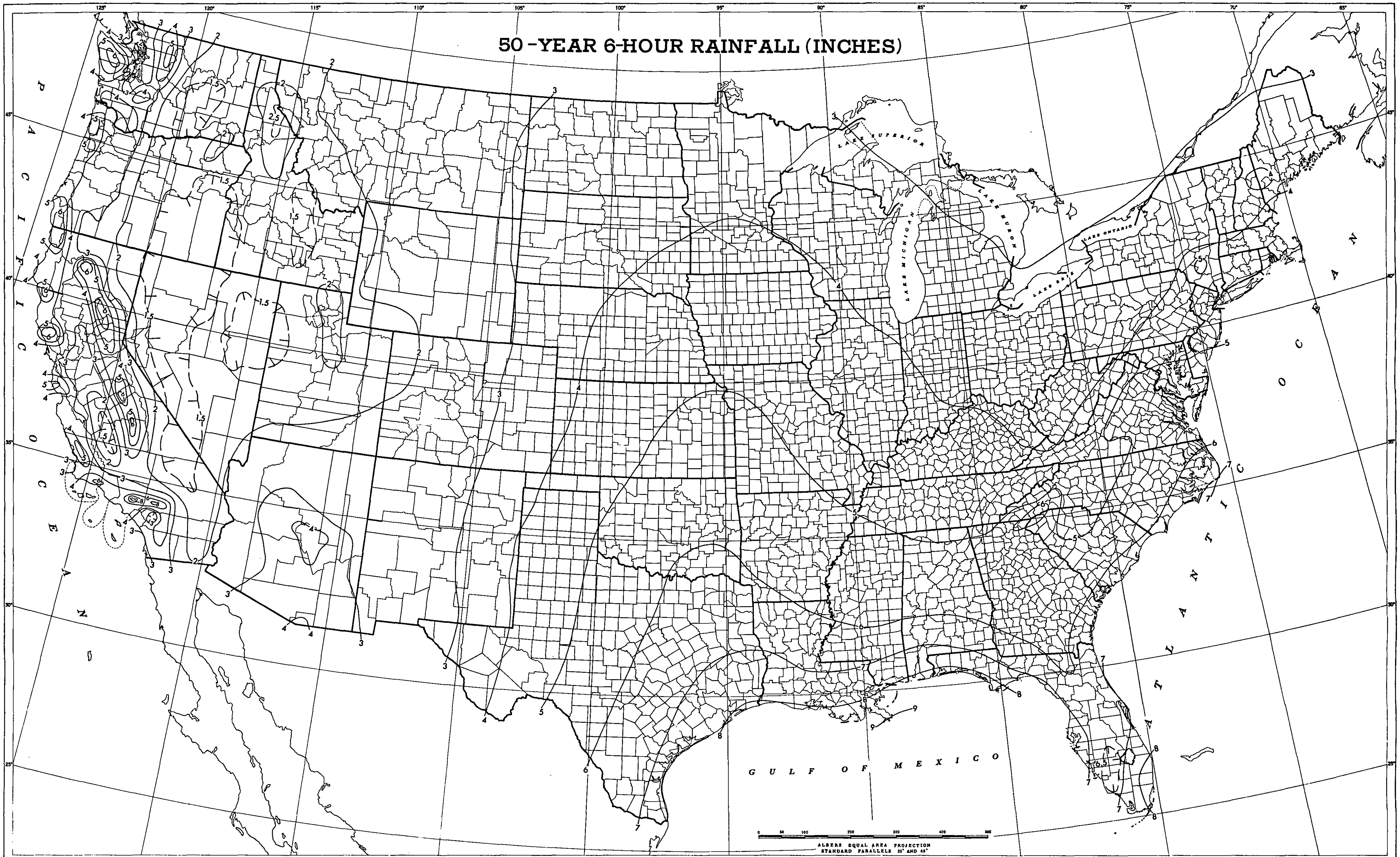
1-YEAR 6-HOUR RAINFALL (INCHES)


2-YEAR 6-HOUR RAINFALL (INCHES)
PACIFIC OCEAN
ATLANTIC OCEAN
GULF OF MEXICO
LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
LAKE ERIE
LAKE ONTARIO
ALBERS EQUAL AREA PROJECTION
STANDARD PARALLELS 29° AND 45°


5-YEAR 6-HOUR RAINFALL (INCHES)
PACIFIC OCEAN
ATLANTIC OCEAN
GULF OF MEXICO
LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
LAKE ERIE
LAKE ONTARIO
ALBERS EQUAL AREA PROJECTION
STANDARD PARALLELS 29° AND 45°

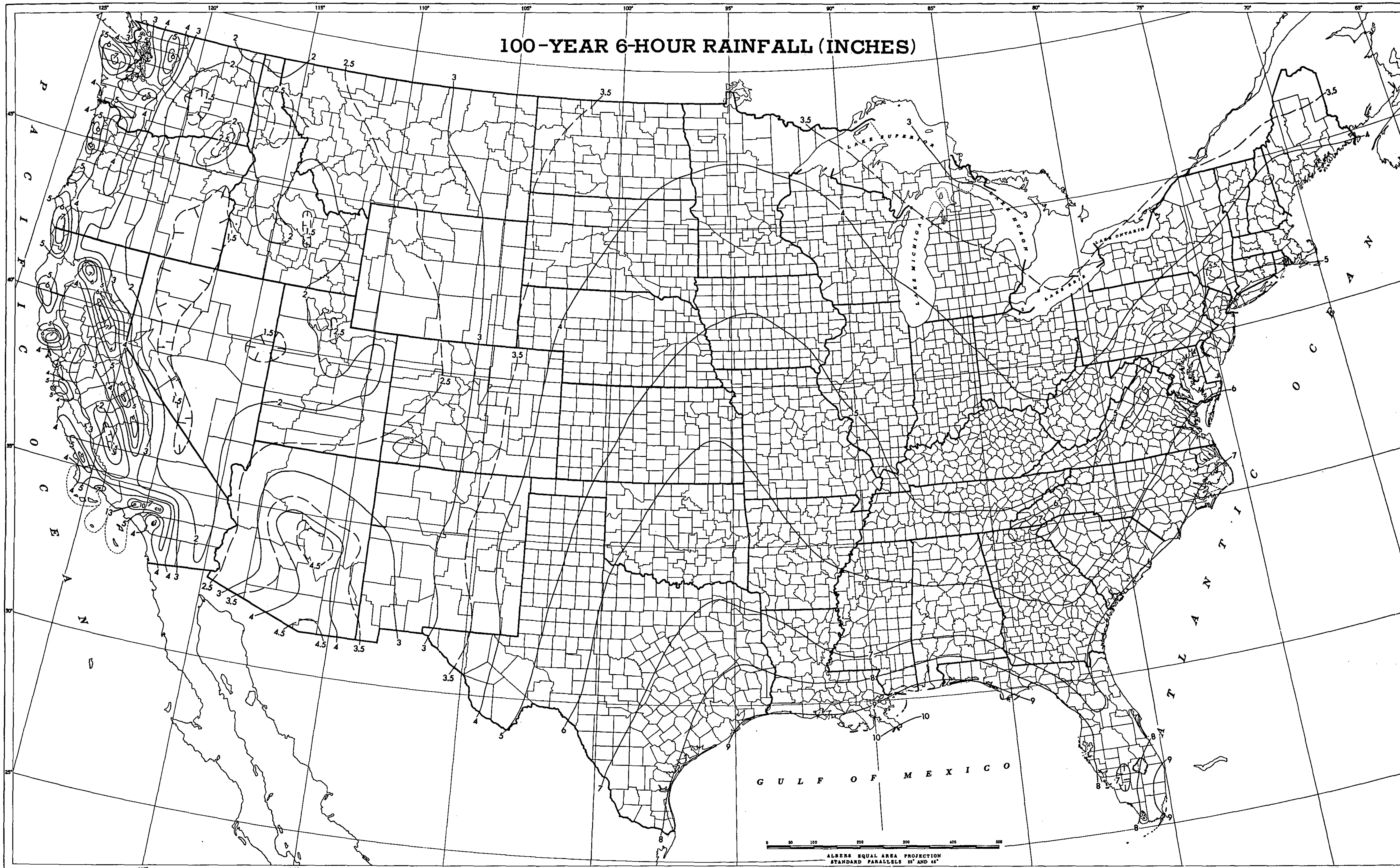

10-YEAR 6-HOUR RAINFALL (INCHES)
PACIFIC OCEAN
ATLANTIC OCEAN
GULF OF MEXICO
LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
LAKE ERIE
LAKE ONTARIO
ALBERS EQUAL AREA PROJECTION
STANDARD PARALLELS 29° AND 45°


25-YEAR 6-HOUR RAINFALL (INCHES)
PACIFIC OCEAN
ATLANTIC OCEAN
GULF OF MEXICO
LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
LAKE ERIE
LAKE ONTARIO
ALBERS EQUAL AREA PROJECTION
STANDARD PARALLELS 29° AND 45°

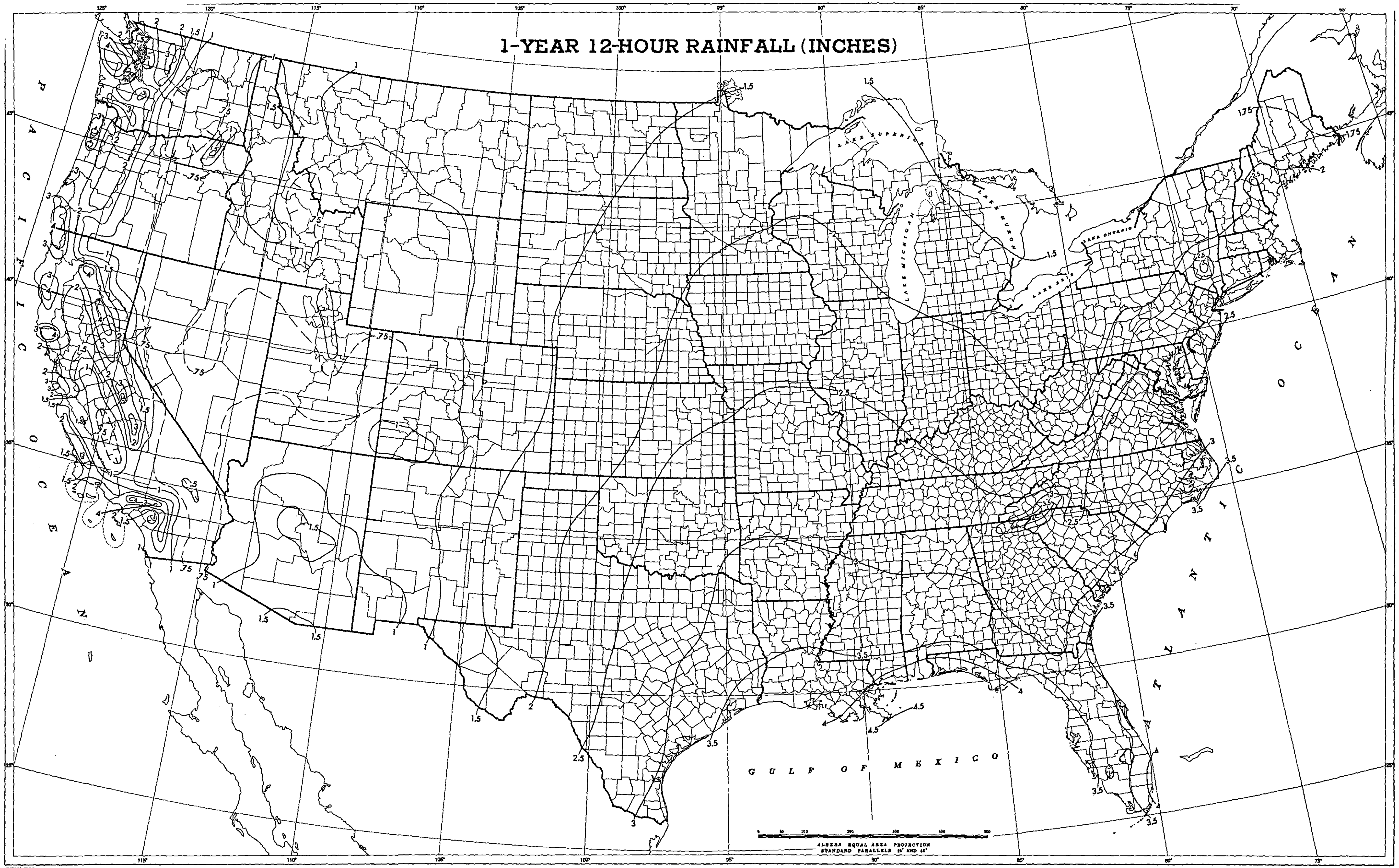

50-YEAR 6-HOUR RAINFALL (INCHES)
PACIFIC OCEAN
ATLANTIC OCEAN
GULF OF MEXICO
LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
LAKE ONTARIO
LAKE ERIE
ALBERS EQUAL AREA PROJECTION
STANDARD PARALLELS 29° AND 45°

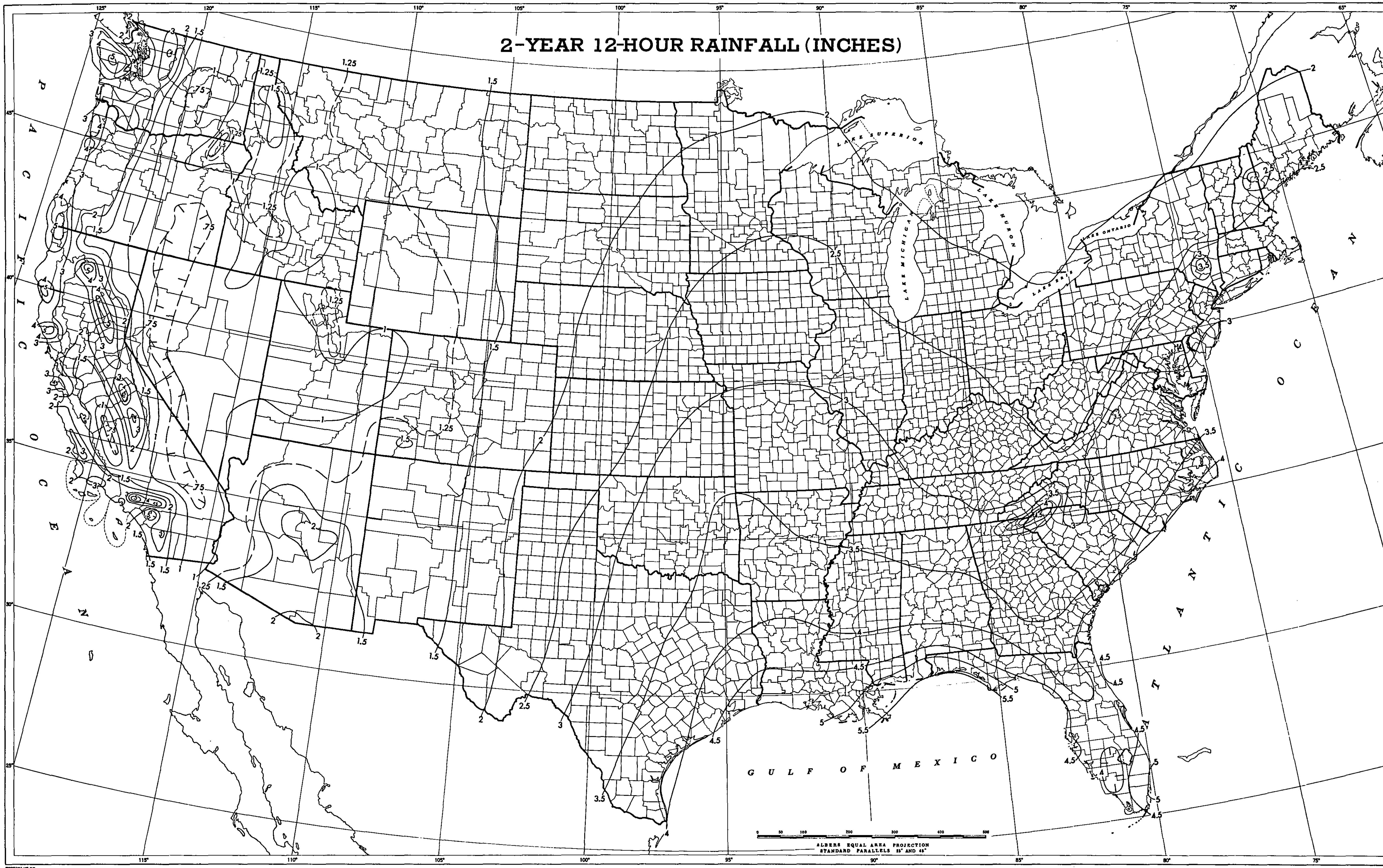
USCOMM-WB-DC

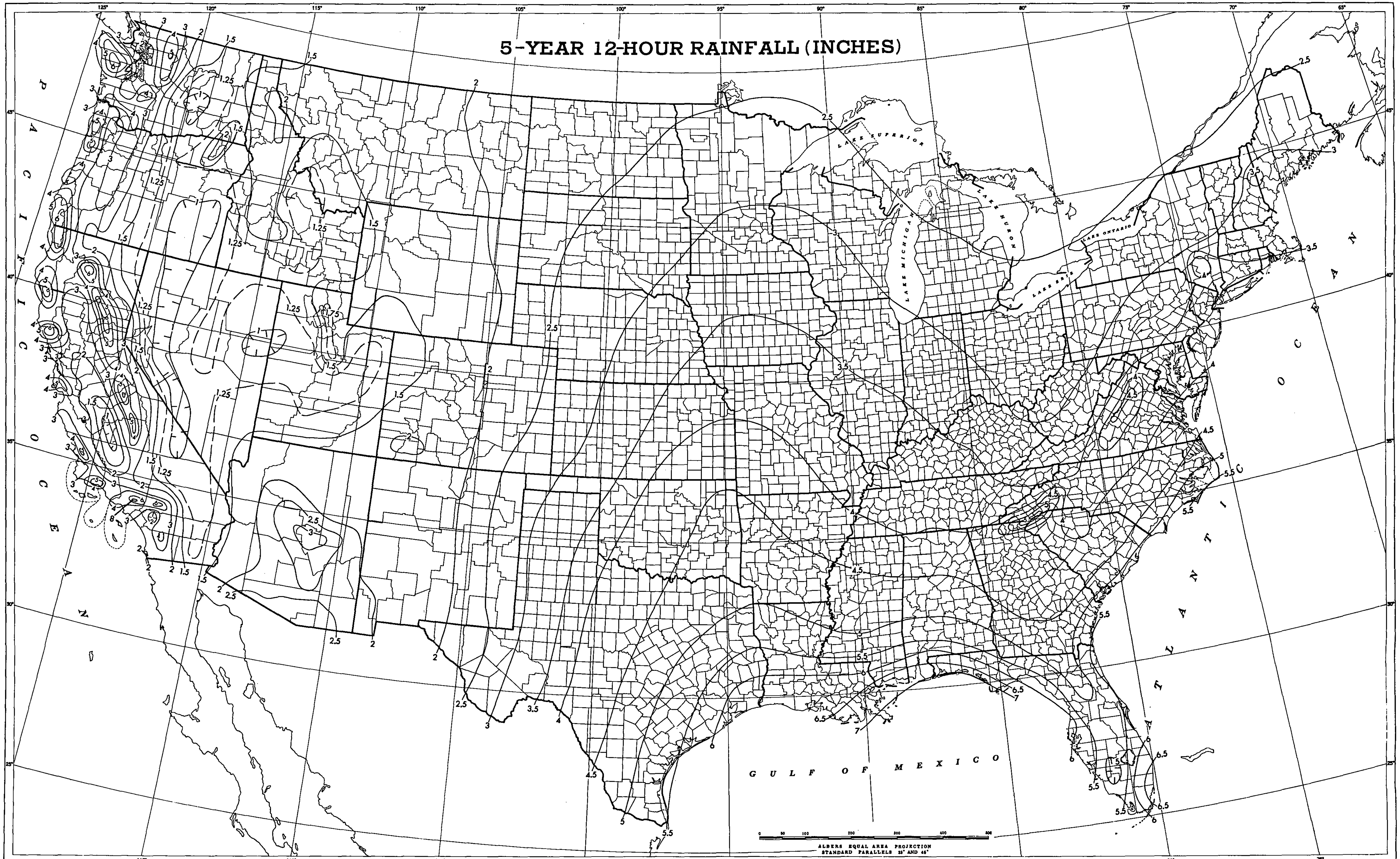
100-YEAR 6-HOUR RAINFALL (INCHES)



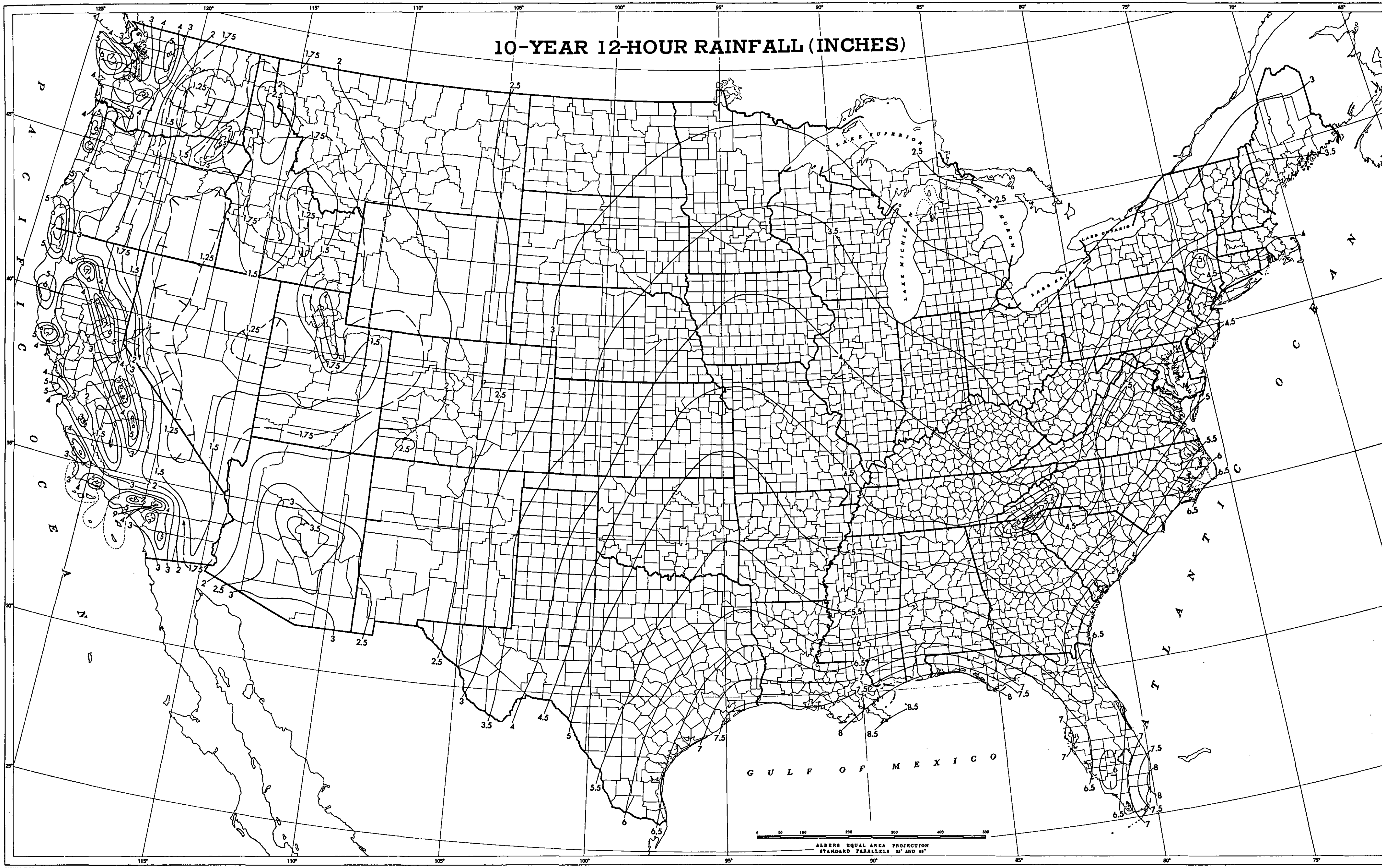
1-YEAR 12-HOUR RAINFALL (INCHES)

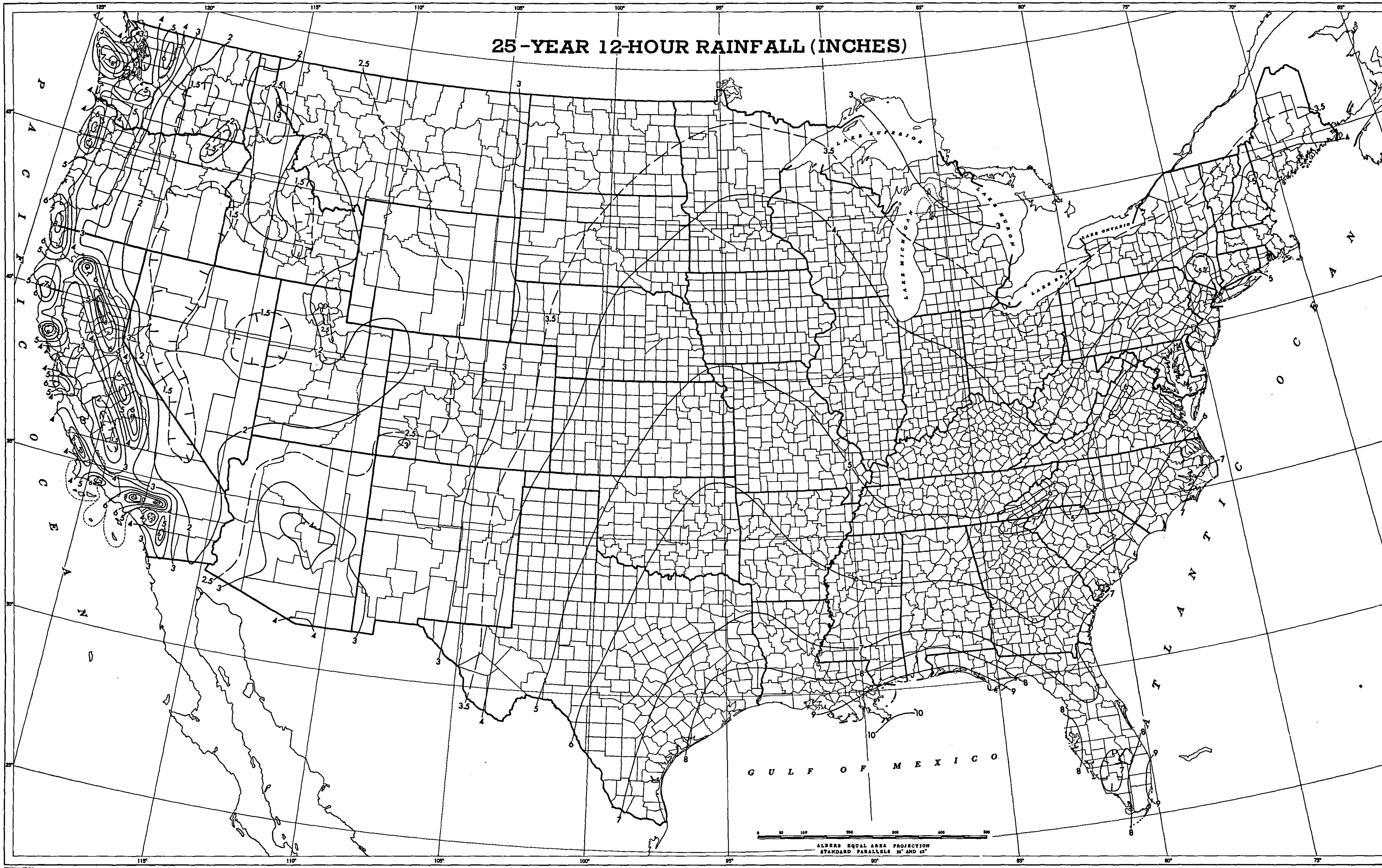


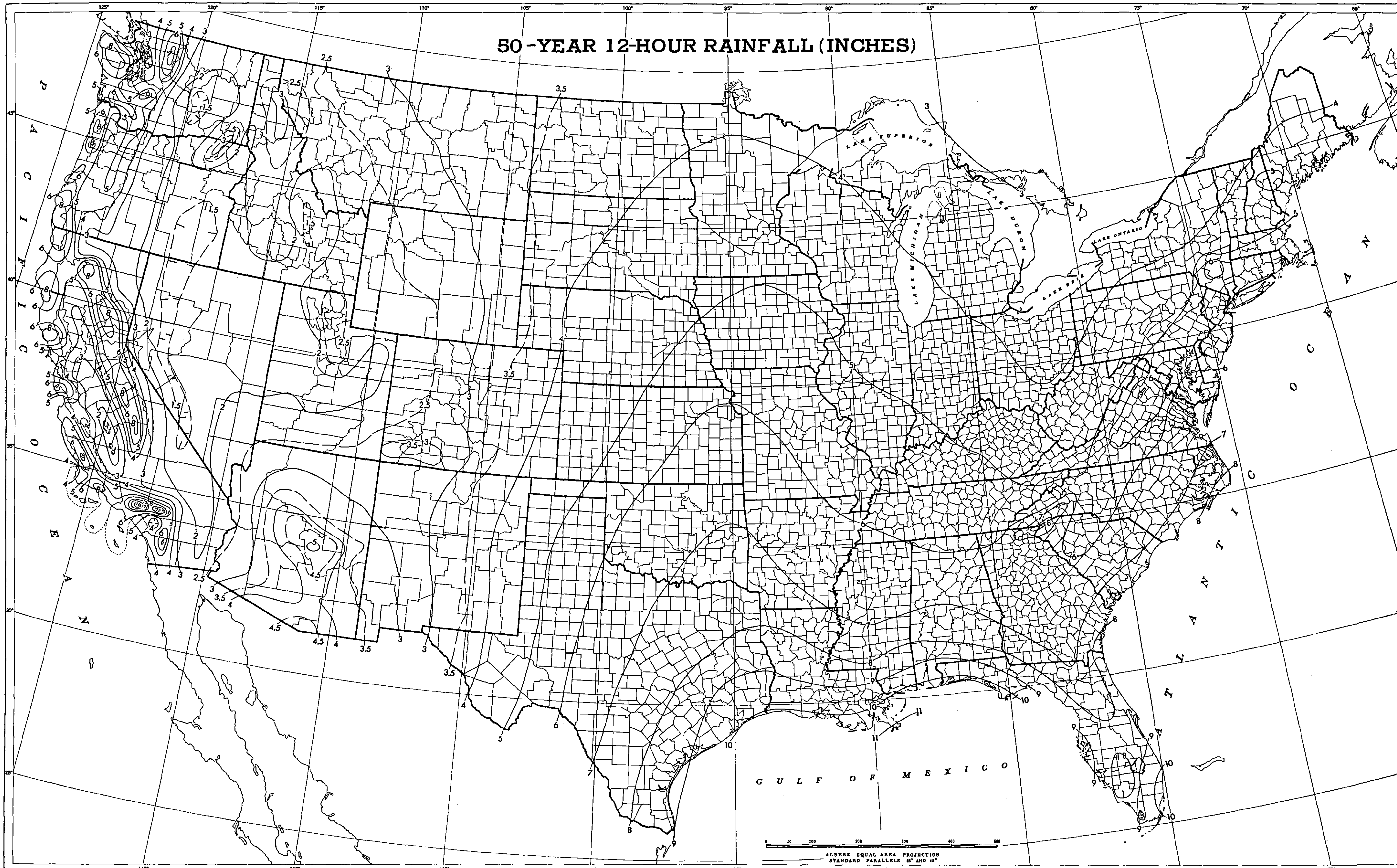

2-YEAR 12-HOUR RAINFALL (INCHES)
PACIFIC OCEAN
ATLANTIC OCEAN
GULF OF MEXICO
LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
LAKE ERIE
LAKE ONTARIO
ALBERS EQUAL AREA PROJECTION
STANDARD PARALLELS 29° AND 45°

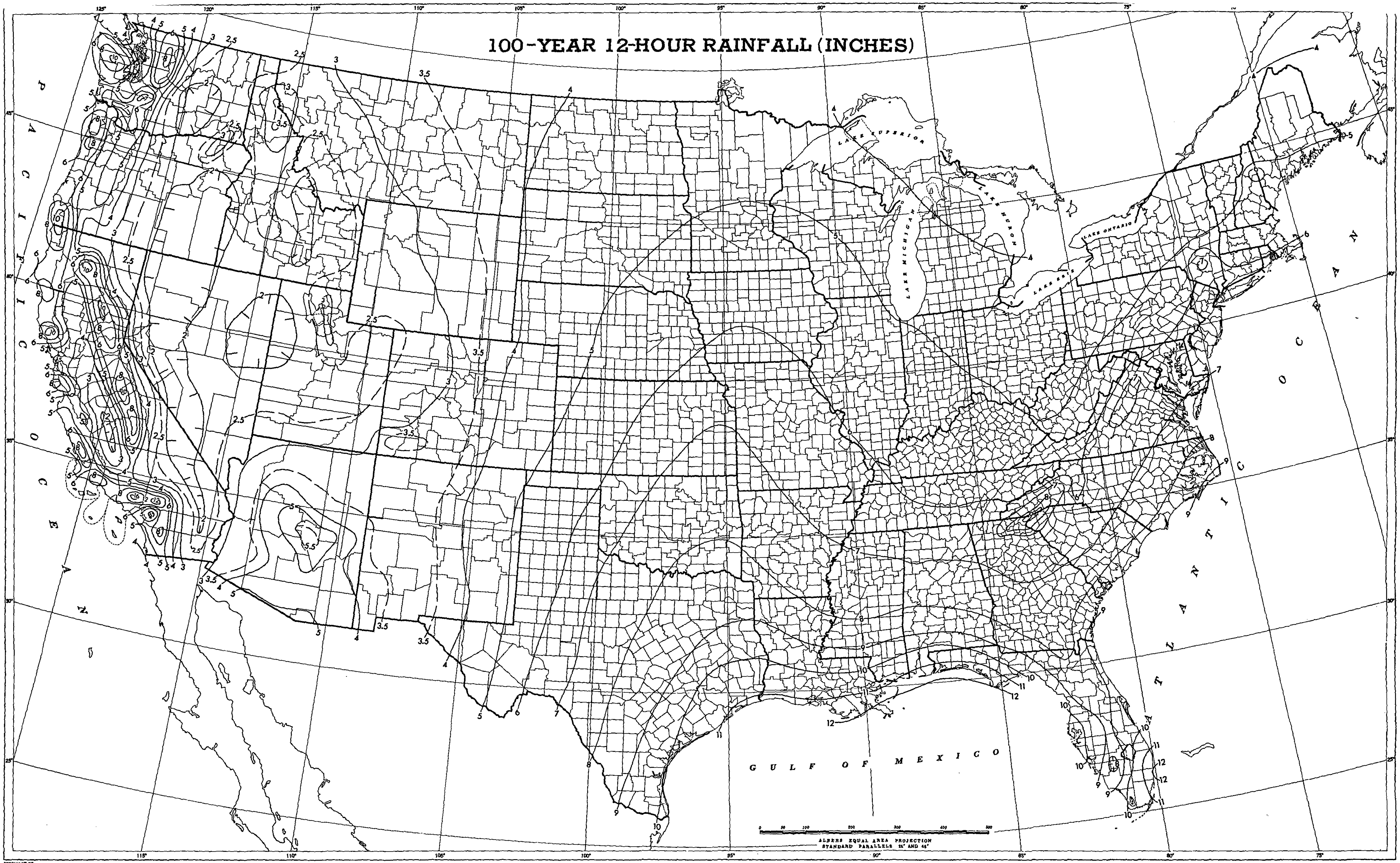

5-YEAR 12-HOUR RAINFALL (INCHES)
PACIFIC OCEAN
ATLANTIC OCEAN
GULF OF MEXICO
LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
LAKE ERIE
LAKE ONTARIO
ALBERS EQUAL AREA PROJECTION
STANDARD PARALLELS 29° AND 45°

10-YEAR 12-HOUR RAINFALL (INCHES)

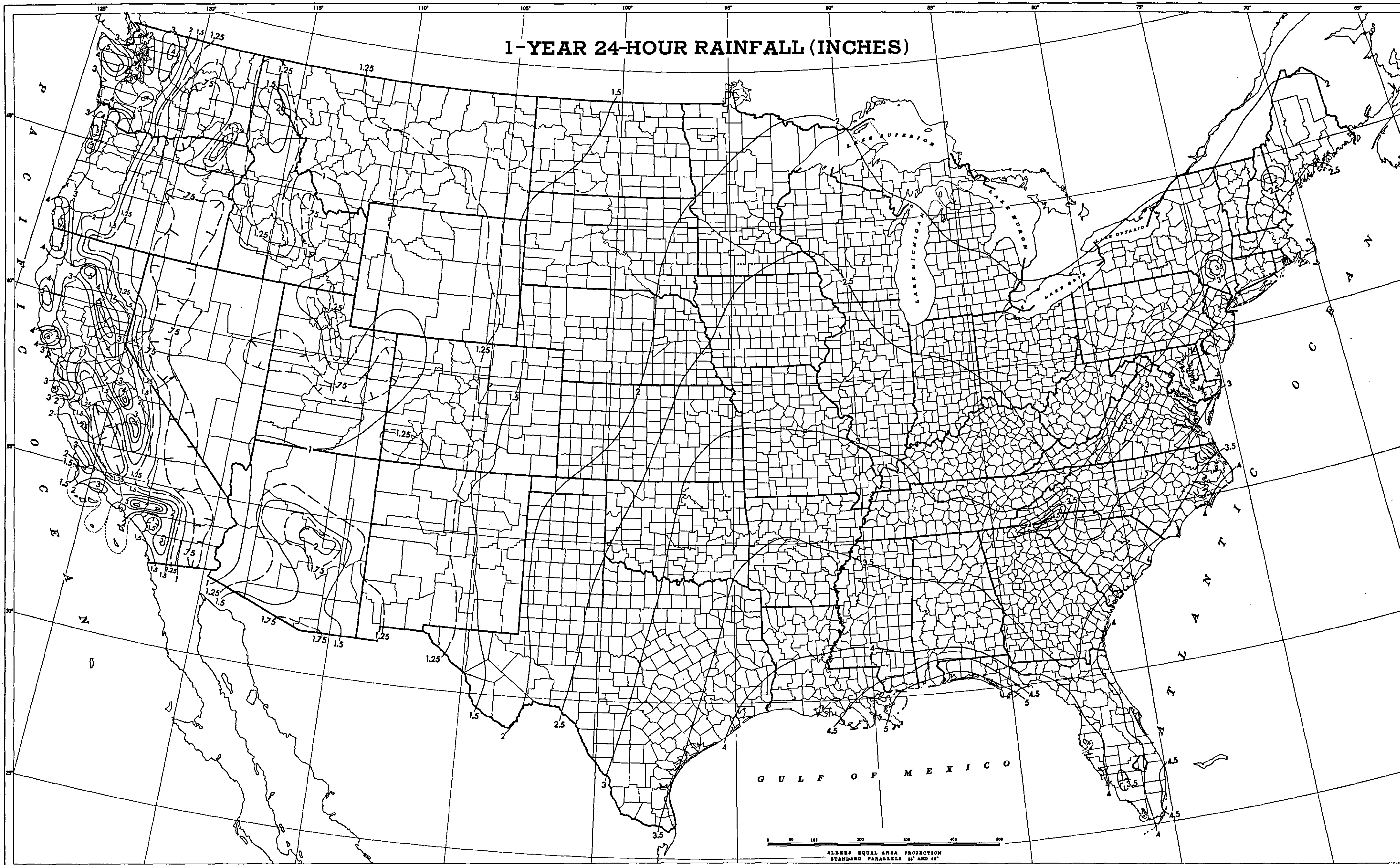


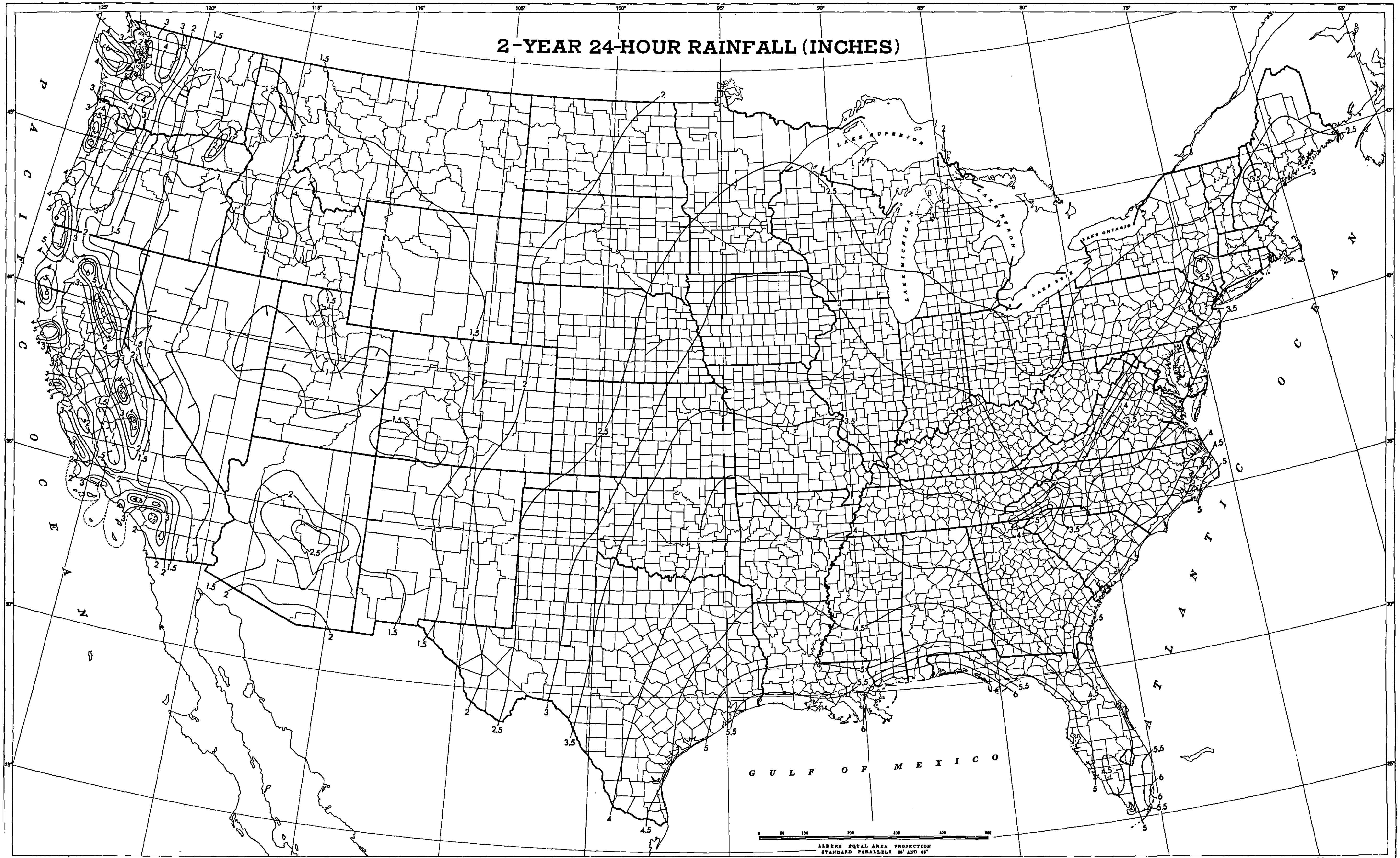

25-YEAR 12-HOUR RAINFALL (INCHES)
P A C I F I C O C E A N
A T L A N T I C O C E A N
G U L F O F M E X I C O
LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
LAKE ERIE
LAKE ONTARIO
ALBERS EQUAL AREA PROJECTION
STANDARD PARALLELS 29° AND 45°


50-YEAR 12-HOUR RAINFALL (INCHES)
PACIFIC OCEAN
ATLANTIC OCEAN
GULF OF MEXICO
LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
LAKE ERIE
LAKE ONTARIO
ALBERS EQUAL AREA PROJECTION
STANDARD PARALLELS 29° AND 45°

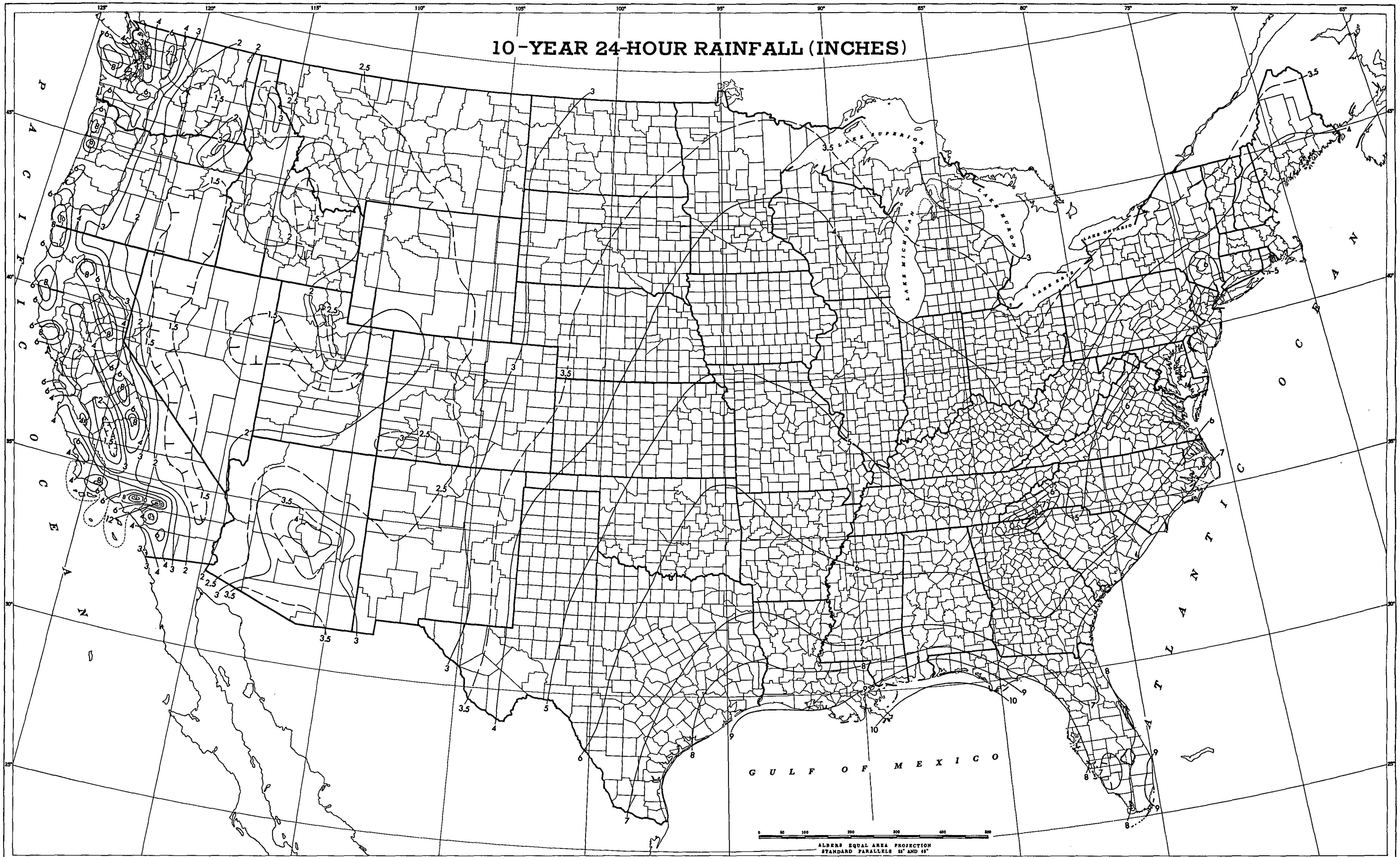

100-YEAR 12-HOUR RAINFALL (INCHES)
PACIFIC OCEAN
ATLANTIC OCEAN
GULF OF MEXICO
LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
LAKE ONTARIO
LAKE ERIE
ALBERS EQUAL AREA PROJECTION
STANDARD PARALLELS 29° AND 45°

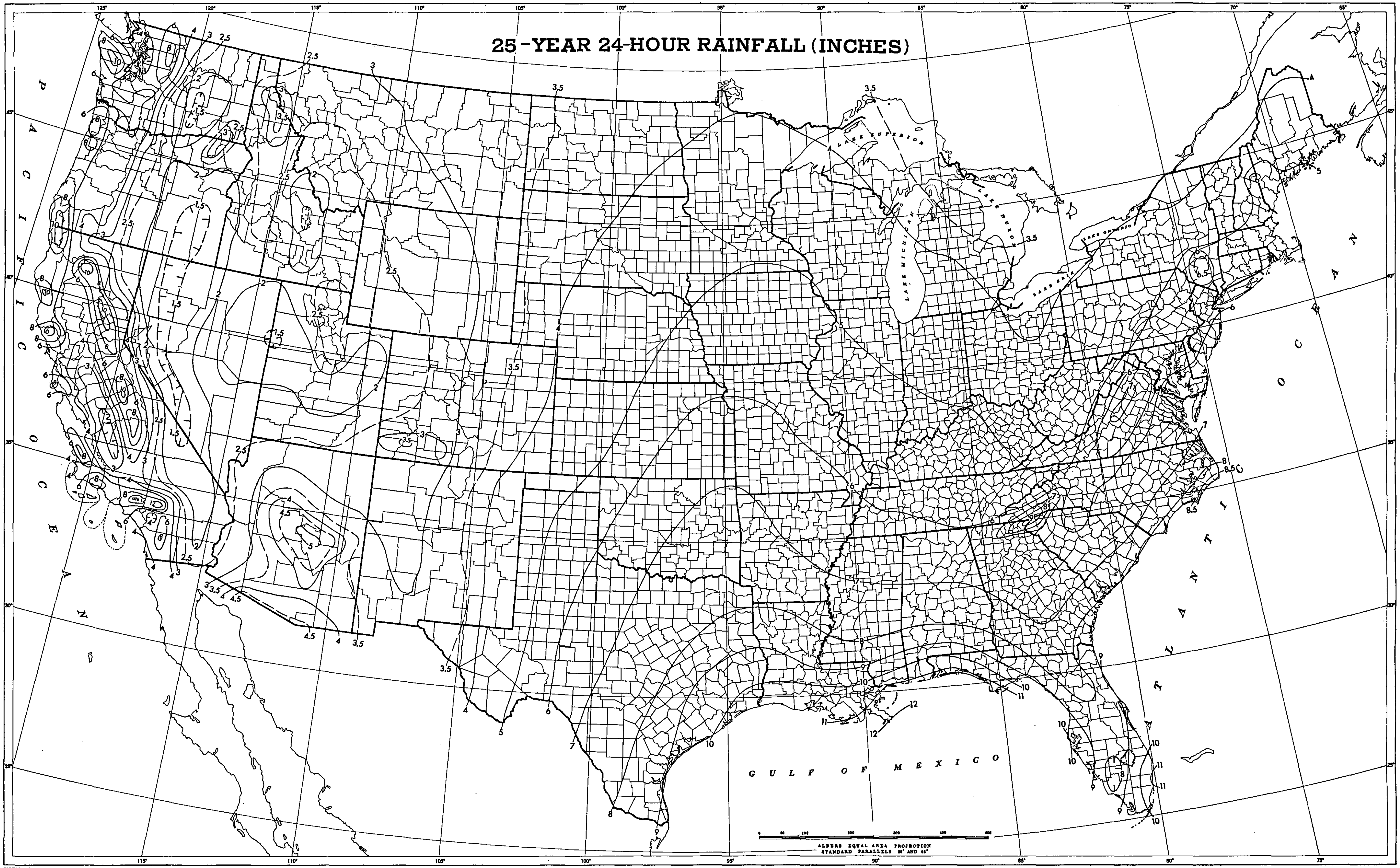
1-YEAR 24-HOUR RAINFALL (INCHES)

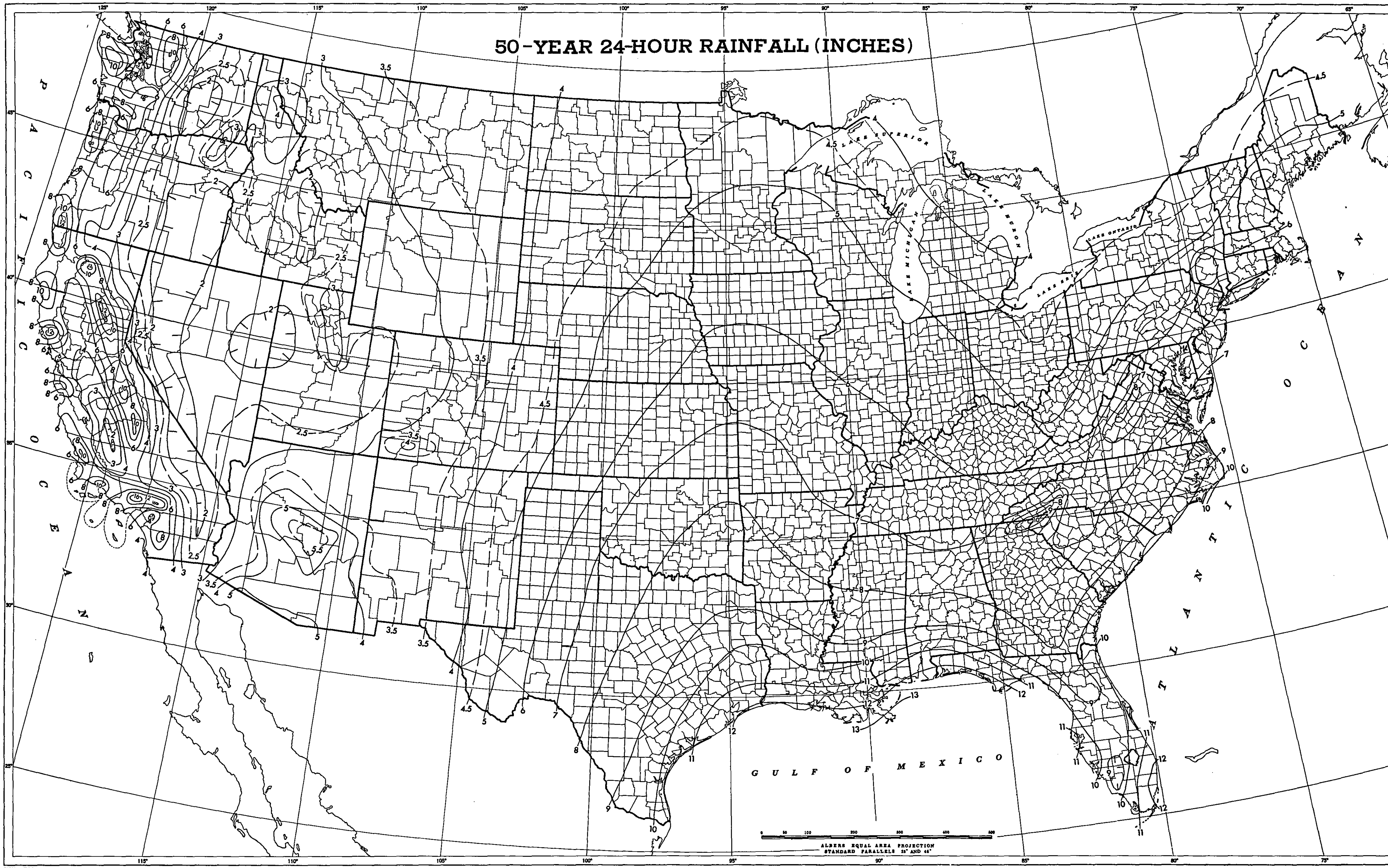


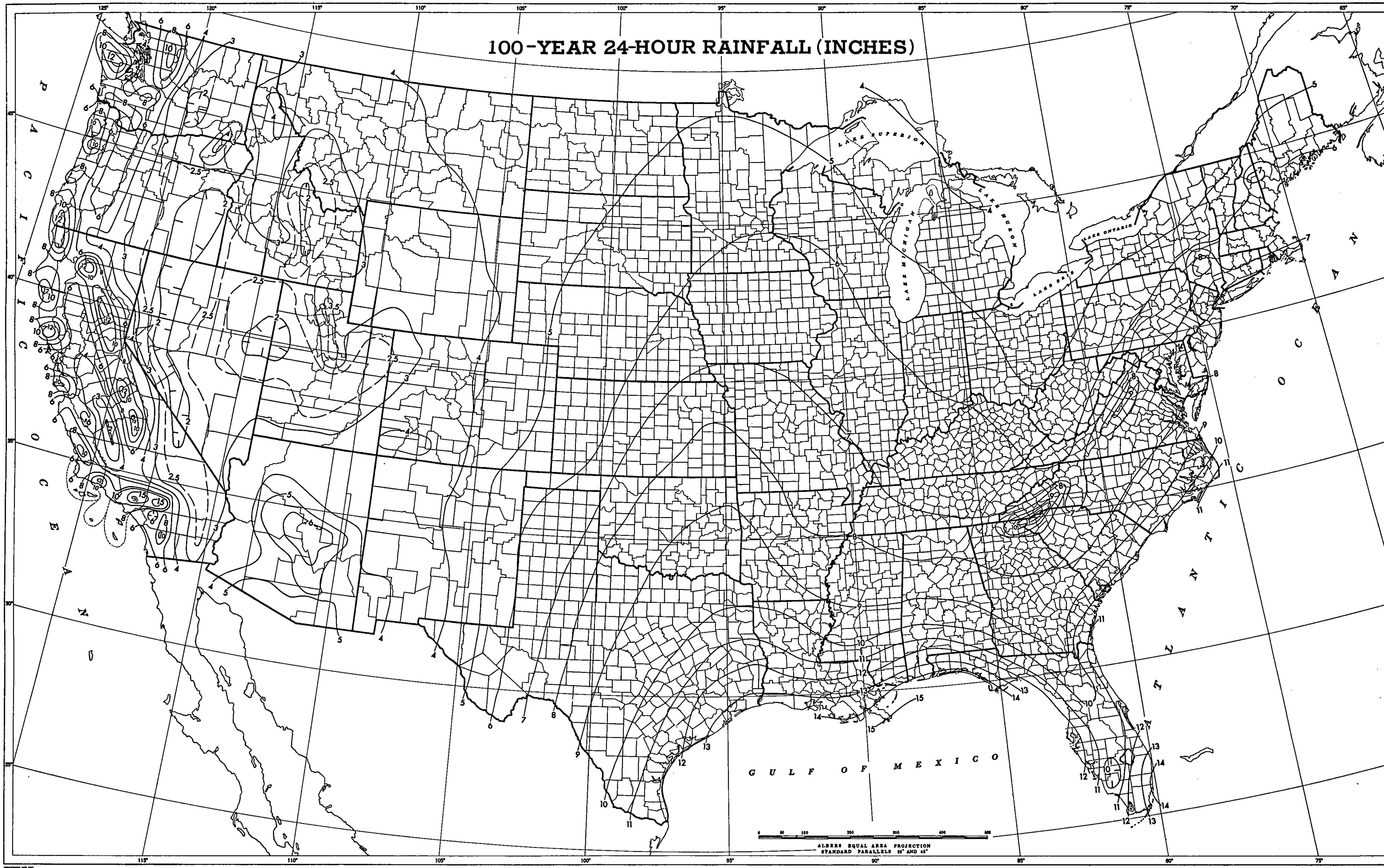

2-YEAR 24-HOUR RAINFALL (INCHES)
PACIFIC OCEAN
ATLANTIC OCEAN
GULF OF MEXICO
LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
LAKE ONTARIO
LAKE ERIE
ALBERS EQUAL AREA PROJECTION
STANDARD PARALLELS 29° AND 45°

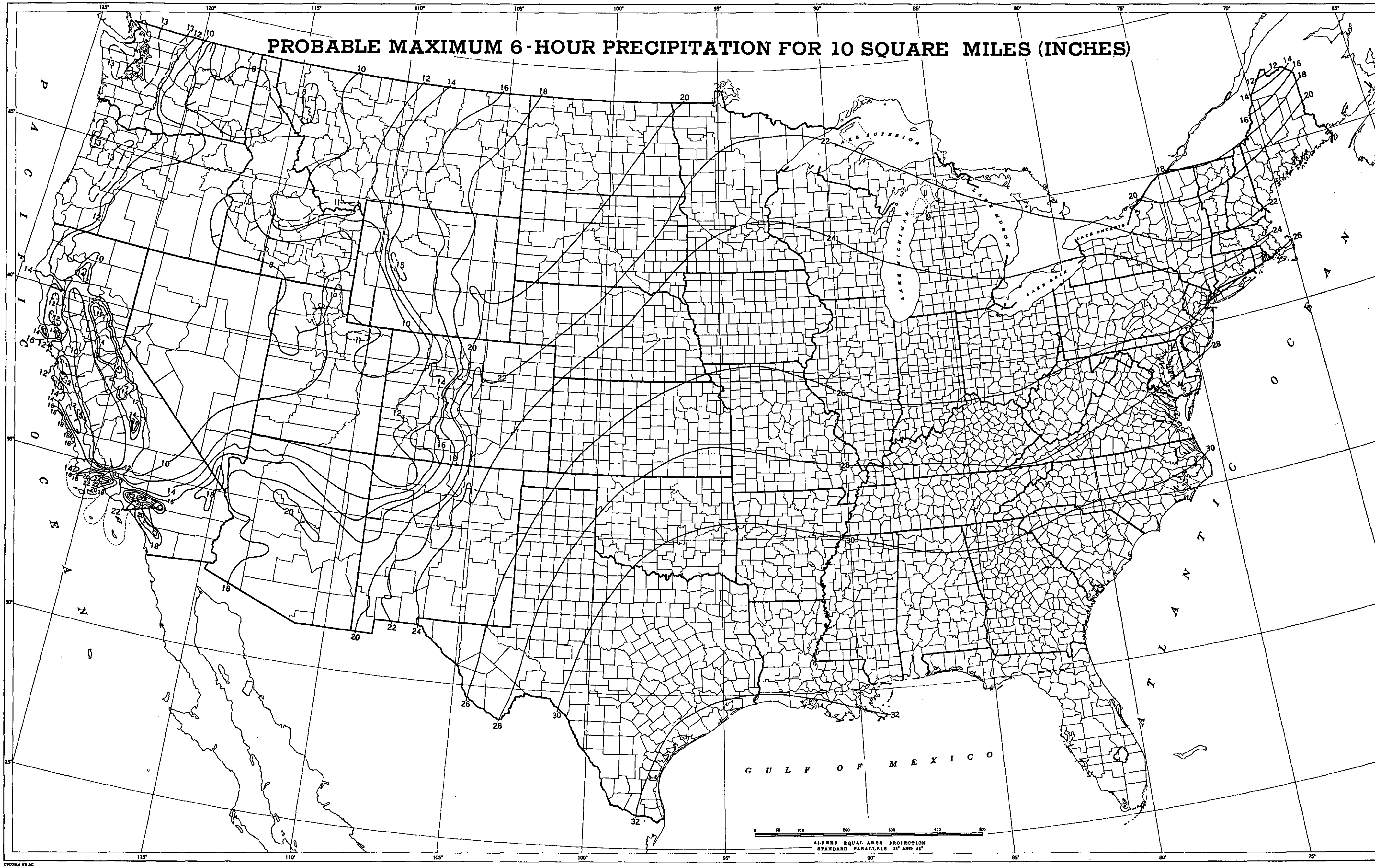

5-YEAR 24-HOUR RAINFALL (INCHES)
PACIFIC OCEAN
ATLANTIC OCEAN
GULF OF MEXICO
LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
LAKE ERIE
LAKE ONTARIO
ALBERS EQUAL AREA PROJECTION
STANDARD PARALLELS 29° AND 45°

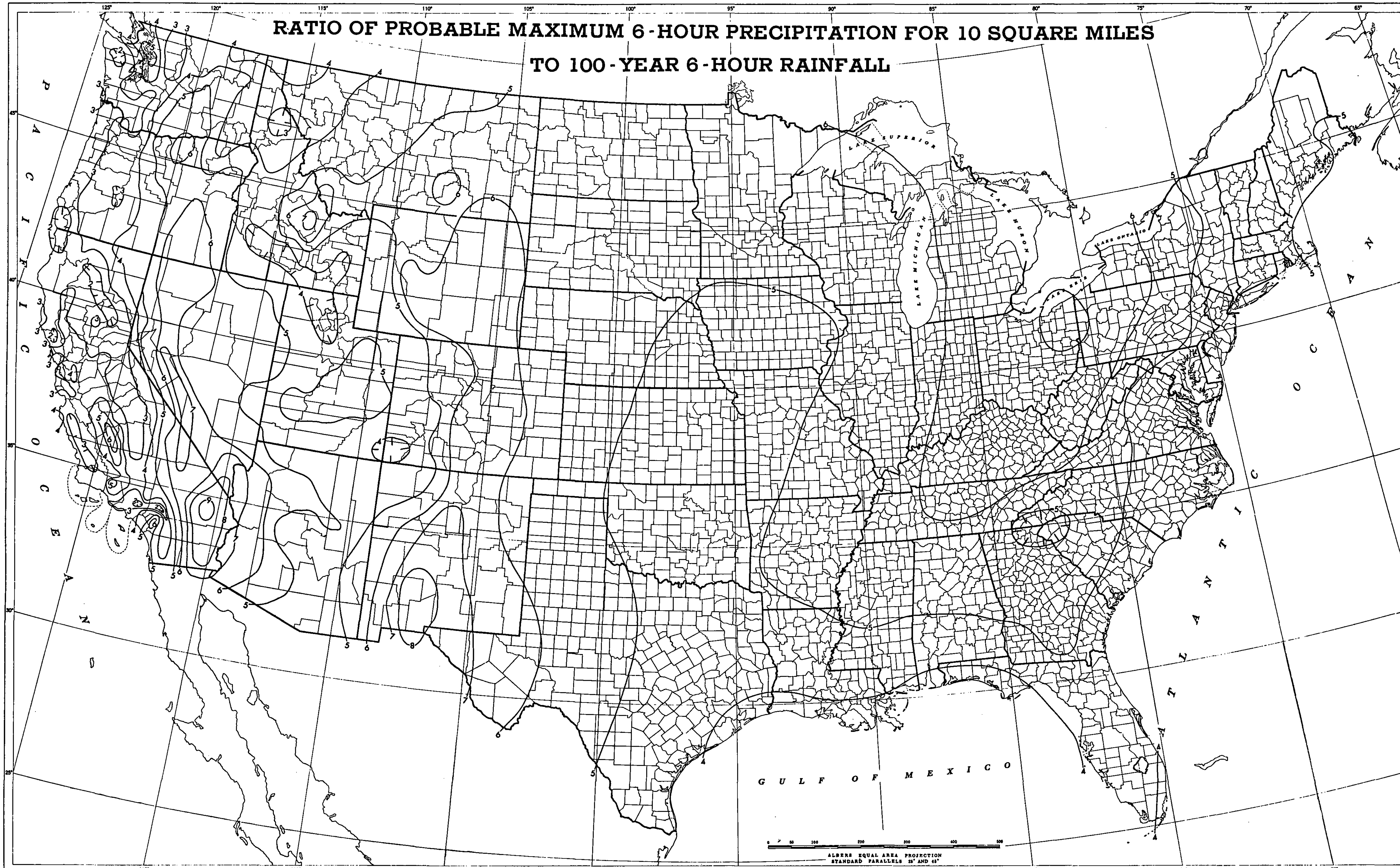

10-YEAR 24-HOUR RAINFALL (INCHES)
PACIFIC OCEAN
ATLANTIC OCEAN
GULF OF MEXICO
LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
LAKE ONTARIO
LAKE ERIE
ALBERS EQUAL AREA PROJECTION
STANDARD PARALLELS 29° AND 45°


25-YEAR 24-HOUR RAINFALL (INCHES)
PACIFIC OCEAN
ATLANTIC OCEAN
GULF OF MEXICO
LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
LAKE ERIE
LAKE ONTARIO
ALBERS EQUAL AREA PROJECTION
STANDARD PARALLELS 29° AND 45°

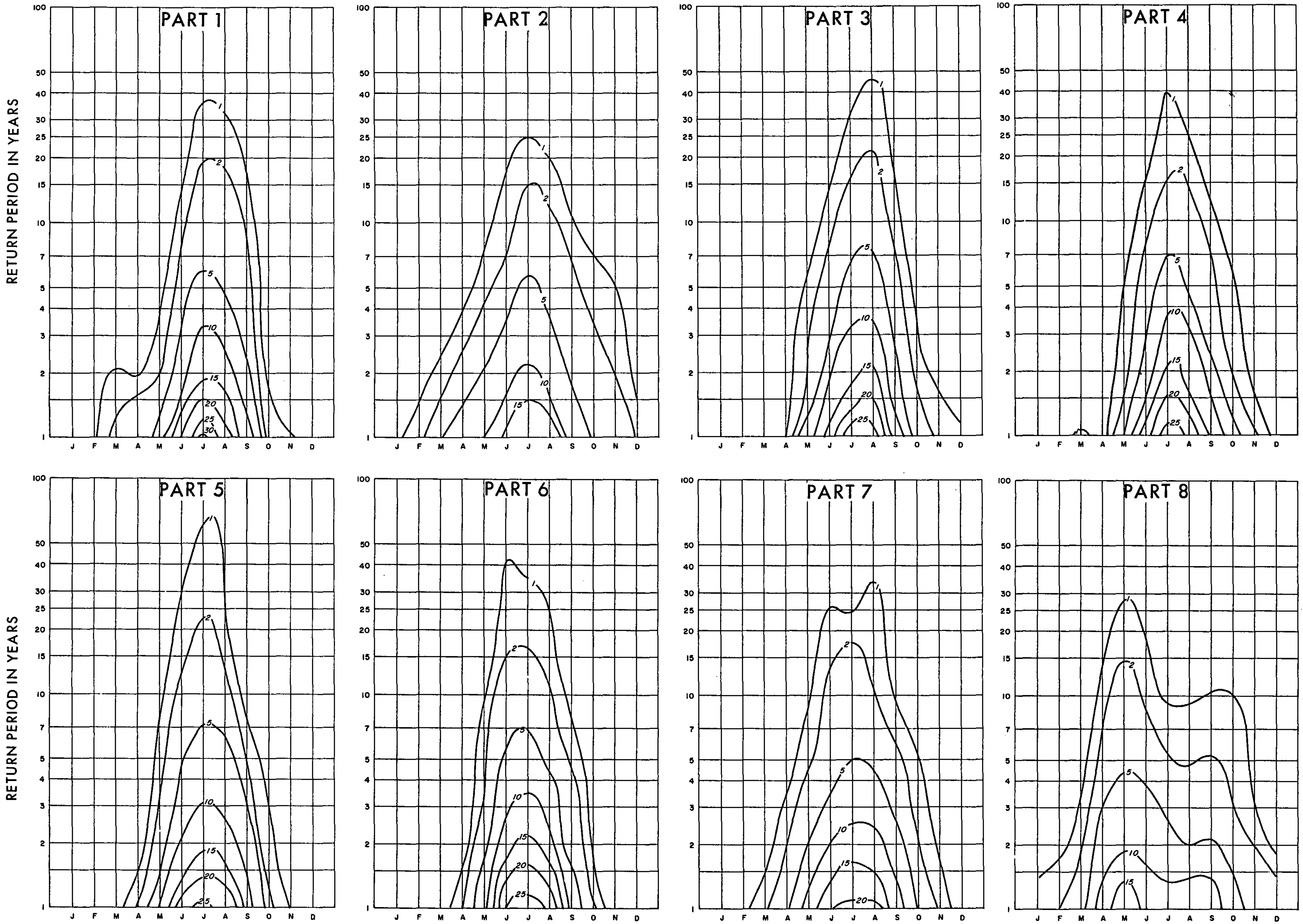

50-YEAR 24-HOUR RAINFALL (INCHES)
PACIFIC OCEAN
ATLANTIC OCEAN
GULF OF MEXICO
LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
LAKE ONTARIO
LAKE ERIE
ALBERS EQUAL AREA PROJECTION
STANDARD PARALLELS 29° AND 45°

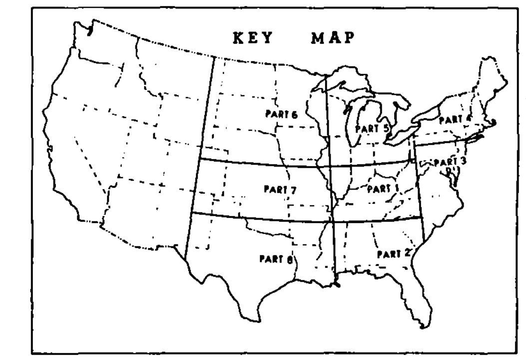

100-YEAR 24-HOUR RAINFALL (INCHES)
PACIFIC OCEAN
ATLANTIC OCEAN
GULF OF MEXICO
LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
LAKE ONTARIO
LAKE ERIE
ALBERS EQUAL AREA PROJECTION
STANDARD PARALLELS 29° AND 45°


PROBABLE MAXIMUM 6-HOUR PRECIPITATION FOR 10 SQUARE MILES (INCHES)
PACIFIC OCEAN
ATLANTIC OCEAN
GULF OF MEXICO
LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
LAKE ONTARIO
LAKE ERIE
ALBERS EQUAL AREA PROJECTION
STANDARD PARALLELS 29° AND 45°


RATIO OF PROBABLE MAXIMUM 6-HOUR PRECIPITATION FOR 10 SQUARE MILES
TO 100-YEAR 6-HOUR RAINFALL
PACIFIC OCEAN
ATLANTIC OCEAN
GULF OF MEXICO
LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
LAKE ONTARIO
LAKE ERIE
ALBERS EQUAL AREA PROJECTION
STANDARD PARALLELS 29° AND 45°

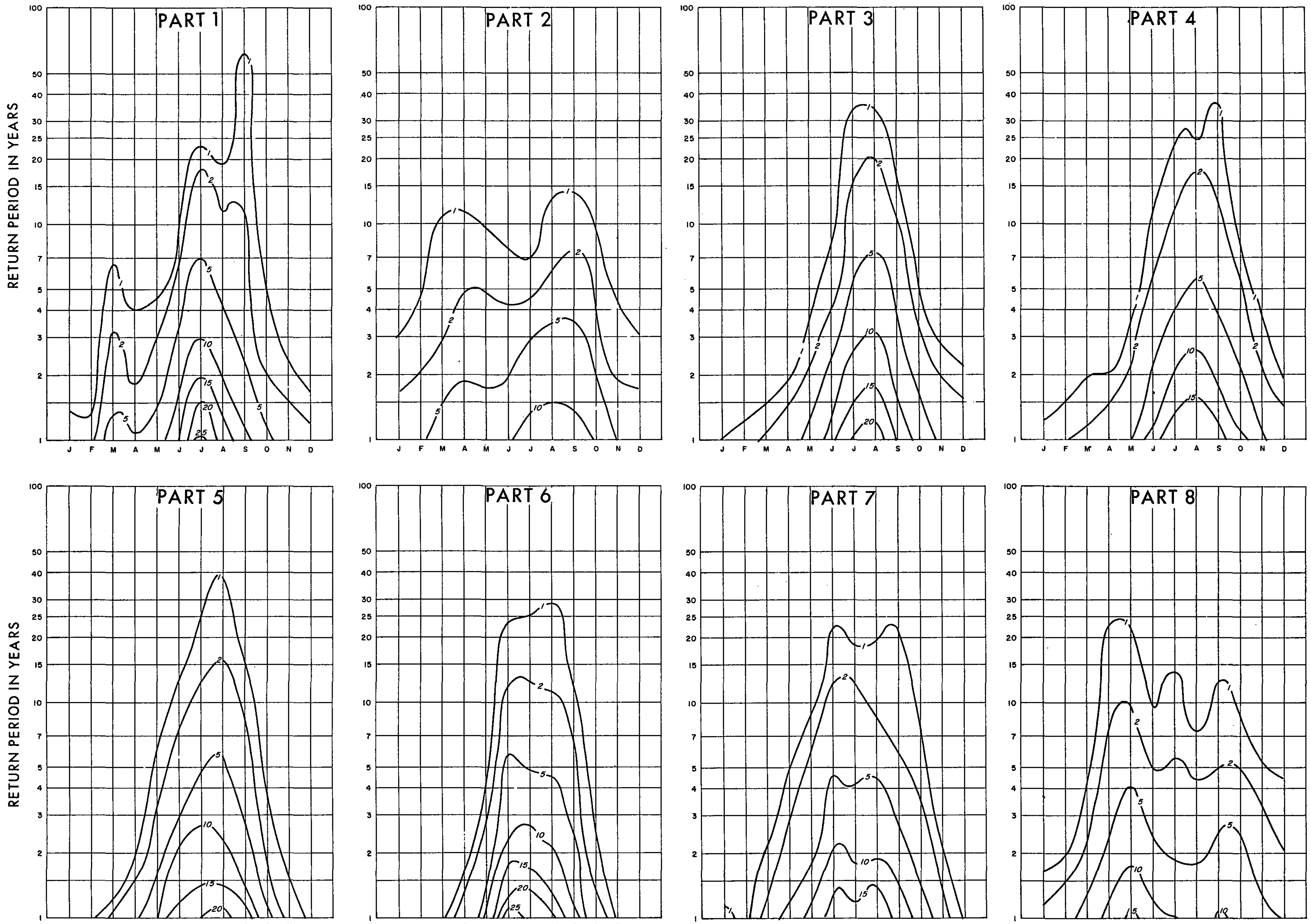
SEASONAL PROBABILITY OF INTENSE 1-HOUR RAINFALL

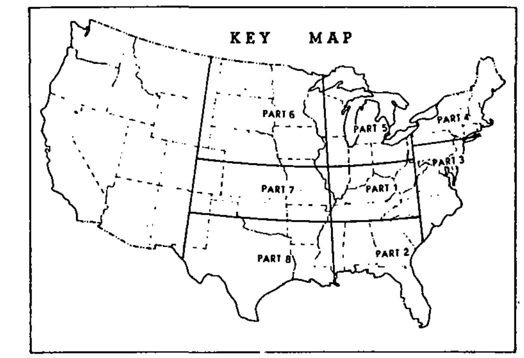




PROBABILITY IN PERCENT OF OBTAINING A RAINFALL IN ANY MONTH OF A PARTICULAR YEAR EQUAL TO OR EXCEEDING THE RETURN PERIOD VALUES TAKEN FROM THE ISOPLUVIAL MAPS.

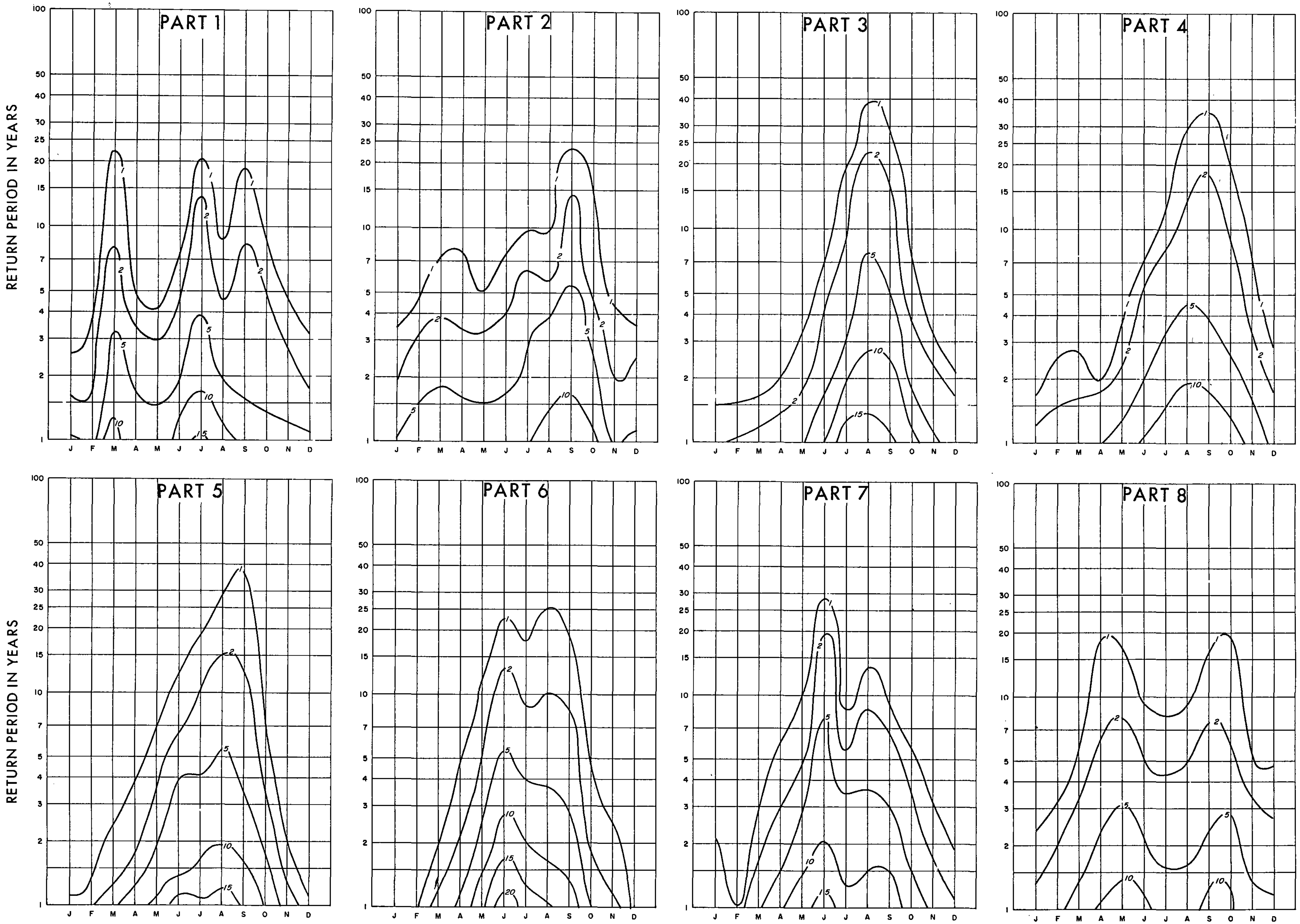
SEASONAL PROBABILITY OF INTENSE 6-HOUR RAINFALL

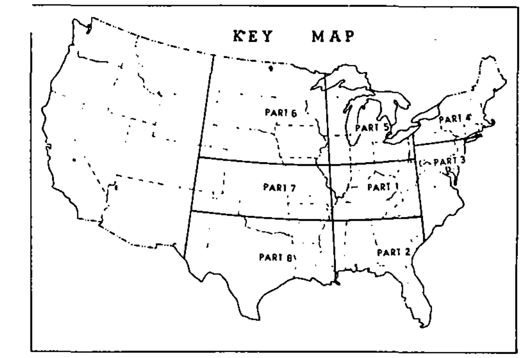




PROBABILITY IN PERCENT OF OBTAINING A RAINFALL IN ANY MONTH OF A PARTICULAR YEAR EQUAL TO OR EXCEEDING THE RETURN PERIOD VALUES TAKEN FROM THE ISOPLUVIAL MAPS.

SEASONAL PROBABILITY OF INTENSE 24-HOUR RAINFALL





PROBABILITY IN PERCENT OF OBTAINING A RAINFALL IN ANY MONTH OF A PARTICULAR YEAR EQUAL TO OR EXCEEDING THE RETURN PERIOD VALUES TAKEN FROM THE ISOPLUVIAL MAPS.

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