Developing Rainfall Insurance Rates for the Contiguous United States

STANLEY A. CHANGNON* AND JOYCE M. CHANGNON*

Changnon Climatologist, Mahomet, Illinois

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ABSTRACT

Historical hourly rainfall data (1950–84) were subjected to spatial and temporal analyses to provide information for developing rainfall insurance rates for the contiguous United States. The dimensions of the study illustrate a balance between insurance needs, funding, and adequate climatic analyses. Assessment of the hourly rainfall data from 2092 stations in the United States revealed that only 211 had data deemed useful to this study. Seventeen regions with similar probabilities of rainfall (rate areas) were defined. The average patterns of hourly rainfall closely resemble the nation's average annual precipitation pattern. Separate seasonal rain-hour probabilities were defined throughout the United States because of marked differences between wetter and drier portions of the year. Temporal analyses of rain hours defined the length of record to use in rate determinations, and how often new rates should be calculated. Long-term trends were not present during 1950–84 in any area, and 78% of the 5- and 10-year values were within ±5% of the long-term average, reflecting generally low interannual variability; however, 15% of these short-term fluctuations deviated greatly (>20%) from average. Results led to the recommendation that rerating should be done once every 5 years in most rate areas, and that values of the most recent 25 years should be used for rating. Analysis of in-day hourly rain probabilities revealed major diurnal differences existed during the wet seasons in the central and southeastern United States, and different (night and day) rates were recommended.

1. Introduction

Historical precipitation data were analyzed to develop a plan for setting rates for rainfall insurance in the contiguous United States. The plan was sought by insurance firms operating as members of the National Crop Insurance Service (NCIS) involved in the provision of "rain insurance." They desired an analysis of current precipitation data as the basis for a plan to establish new rain insurance rates. Rain insurance is used to provide coverage against losses due to short-term rain periods (lasting from an hour up to 3 days) that affect outdoor events like state fairs, drying of high value crops, weddings, etc. The use of "rain" in this paper is identical to "precipitation," and rain is the term used in the insurance business.

As in any applied climatological study, certain factors set the objectives and established the extent of the effort. The project dimensions were controlled by three factors: the needs of the insurance industry for information, available funding, and the climatological factors necessary for an adequate analysis to meet customer objectives. This paper provides an example of how customer and analyst worked together to define an appropriate level of investigation.

The approach used was based on insurance practices. The companies involved through NCIS handle rain insurance by utilizing a "rain rate plan." Any company offering insurance has to determine rates "in advance" for all points in each state, and then file for rate approval with state insurance departments. Normally, most crop-related insurance is based on rates that are calculated on a recurrent basis, generally once every 2, 3, or 5 years for a given state. In between these "rate adjustment years," data on sales and losses are accumulated, and these are used by NCIS to help establish whether new rates are needed at the next rating interval and what the rate levels should be (Changnon and Fosse 1981).

This approach is contrary to that used by certain other rain insurance firms, which set rates for rainfall levels based on the historical rain data at the weather station nearest the point of insurance (Fox 1986). In this approach, if one wanted to have coverage for a locale near Washington, D.C. and for a specific series of hours or days, one would ask for a quote on a rate. This is then computed at that time by the insurance company based on the available data for the Washington Airport station. This is a very different approach than used by most insurance companies. It allows for greater flexibility for rate setting, but it has recently been challenged by state insurance officials for its use

* Also affiliated with the Illinois State Water Survey.

Corresponding author address: Stanley A. Changnon, 801 Buckthorn Circle, Mahomet, IL 61853.

in the summer 1988 drought (Champaign–Urbana New Gazette 1988).

2. Dimensions of the study

Performance of a contracted applied climatological study involves an interaction between the analyst (climatologist) and the person desiring the product (customer). The customer has certain relatively fixed conditions (usually funding and time) and specific desires for information, including formats of presentation. The climatologist has to work closely with the customer so as to evolve a product that fits the customer's needs, funding, and time limits, and is also "climatologically sound."[1]

The insurance industry desired a "rainfall rate book" that would be comprehensive with rates for all parts of the contiguous United States with tables of risks (probability) of different rainfall amounts for all parts of the United States. It was to be accompanied by an explanatory text and be sufficiently understandable such that any insurance agent in the United States could use it to quote rates and sell insurance. The industry desired delineation of rate areas for the contiguous United States with a condition that there be 20 or fewer rate areas defined, as well as rates (probabilities) of rainfall for six levels of precipitation (0.01, 0.05, 0.1, 0.25, 0.5 and 1.0 inch or more), and for hourly intervals of 1 hour up to 72 hours.[2] The insurance industry also wanted guidelines as to how often they should rerate each area, and what length of historical record should be used to calculate probabilities for rates. Through discussions with the industry, other design information was sought about: 1) how many seasons during the year they wanted to consider (the response was no more than two, potentially a "wet" and a "dry" season); and 2) how many diurnal periods they wanted to have ("a maximum of two periods during each day to handle major diurnal variations," was their response).

The study was conducted in two phases. Phase 1 was a regional and temporal climatological assessment designed to reach certain tentative conclusions and recommendations requiring industry reaction before proceeding to Phase 2. Phase 2 was an extensive analysis of a large volume of hourly rain data to develop the desired rate area probabilities and the preparation by the user guidebook. The findings herein are organized around these phases of study.

[1] Personal experience on other projects has revealed that customers often are unwilling to agree to a cost or timing of a "climatologically sound" study; hence, some studies are not pursued.

[2] Since this study produced values in inches to meet insurance desires, all results are herein presented in inches without repeating SI units. The conversion values are 0.01 inch = 2.5 mm; 0.05 inch = 12.5 mm; 0.1 inch = 25 mm; 0.25 inch = 62 mm; 0.5 inch = 1.25 cm; and 1.0 inch = 2.5 cm.

3. Phase 1: climatological basis for rain insurance

This phase of the study addressed five objectives: 1) to delineate rate areas (areas of relative uniform rainfall probabilities); 2) to determine the best length of period for developing rates; 3) to define the frequency of rerating for each of the rate areas; 4) to determine the wet and dry seasons in each rate area; and 5) to define those areas and seasons with marked diurnal differences in the rainfall probabilities. In many instances, definitions had to be derived based on knowledge of the insurance industry problems and needs, and through discussions with insurance experts.

The primary climatological assessment was based on historical hourly rainfall data for ≥0.1 inch. The choice of 0.1 inch per hour for determining rate areas and for making other climatologically based decisions was responsive to the industry's desires; they sell most coverage for this level of precipitation. The data analyzed were from the 1950–84 period and from 83 first-order stations (those manned 24 hours a day by Weather Service personnel) evenly distributed across the contiguous United States.

a. Rain rate areas

Three measures of the nation's precipitation climatology were assessed, and then statistically integrated to select rain rate areas. The first of these was based on the average annual frequencies of rain hours (at ≥0.1 inch). The resulting pattern (Fig. 1) displays considerable spatial variability. More than 130 rain hours occur in the southeast, with less than 10 hours in the Arizona–Nevada desert. This tenfold range indicates the necessity for different rate areas. Doeskin and Eckrich (1987) examined national average patterns of rain hours by expressing them as percentages of the total hours per year. Their 0.1-inch pattern shows these rain hours represent 1.5% of all hours per year in the southeast maximum (Fig. 1), with less than 0.5% of the total hours in the far west.

The 0.1-inch hour pattern (Fig. 1) closely resembles the annual average precipitation pattern (Environmental Data Service 1968). The 130-hour isoline matches the 45-inch (112 cm) isohyet, and the 50-hour isoline in the central United States is close to the 25-inch (62.5 cm) isohyet. In the far west, the area of low incidence of rain hours (<20 per year) matches the area of 10 inches (25 cm) or less annual precipitation, and the peak in rain hours along the west coast is matched by heavy precipitation. There, the 70 hours of ≥0.1 inch rain is matched by 70 inches (175 cm) of annual precipitation. East of the Rocky Mountains, the annual average number of thunderstorms has a pattern very similar to that of the 0.1-inch rain hours (Changnon 1988), but in and west of the Rockies, their patterns do not agree because synoptic weather conditions producing most rains yielding ≥0.1 inch per hour are cyclonic in scale and do not often contain

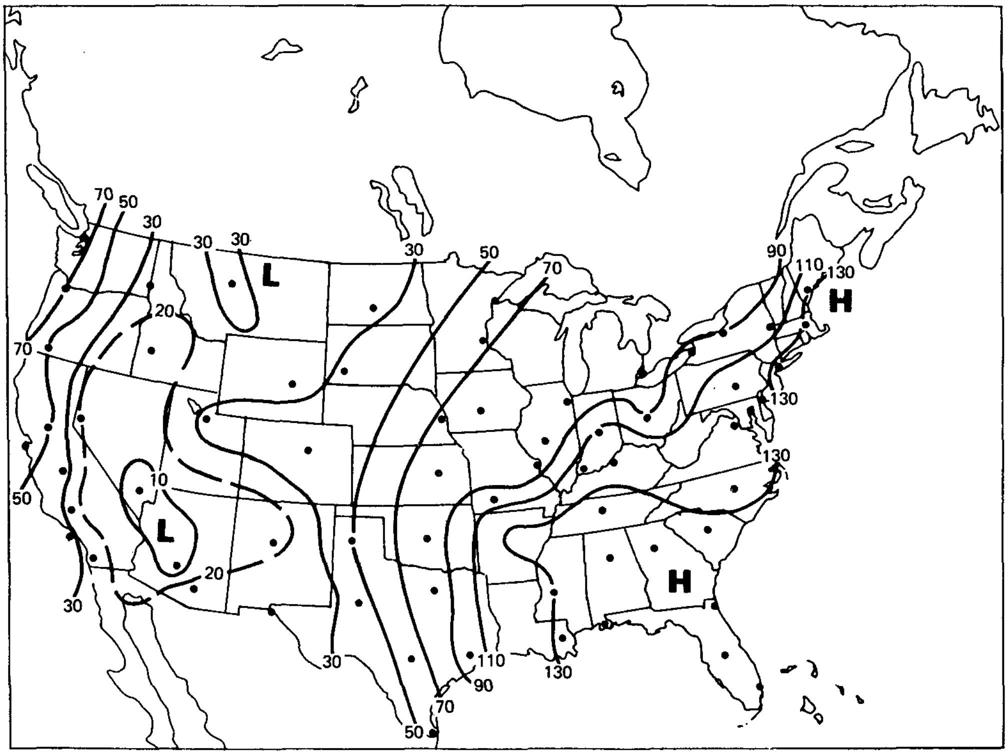

FIG. 1. Annual average number of hours with ≥0.1 inch rainfall.

thunderstorms. The average pattern based on hours of rain ≥ 1.0 inch (U.S. Weather Bureau 1947) has a pattern very similar to the 0.1-inch pattern east of the Rockies. The 1 inch or greater isoline for 1 hour per year closely matches the 50-hour isoline on Fig. 1, and the position of the 130-hour isoline (for ≥0.1 inch) matches the 5-hour isoline for ≥1-inch rain hours.

Seasonality was the second climatological condition investigated because most areas of the United States have distinct wet and dry seasons, and the frequency of rain hours within these have different characteristics that affect the probability of occurrence. Two definitions were tested to select seasons. One was based on a series of consecutive months that contained 60% of the total rain hours as the wet season, and the second on a series of consecutive months that contained 70% or more of the total rain hours (≥0.1 in). The dry seasons were the remaining months. The patterns of the seasons defined in both ways were analyzed. Comparisons of the beginning and ending months of the two candidate wet seasons revealed that patterns based on the 60% values were less regionally coherent than those based on the 70% values. Hence, wet season periods were selected based on "a series of consecutive months containing 70% (or more) of the average number of 0.1-inch rain hours," and the dry season represented 30% or less of the total annual rain hours.

Areas defined as wet seasons are shown in Fig. 2, which also identifies the beginning and ending months of the wet season. In certain areas two adjacent months were often intermingled as the start or ending month at various stations. Where these occurred, two months are shown. For example, in the New Mexico–West Texas area, the starting month was spatially mixed between stations, some stations showing May and others June as the starting month. Similarly, either October or November was the month ending the series of months containing 70% or more of the total rain hours.

The two West Coast areas (Fig. 2) have a 5-month wet season in winter, the season of greatest average precipitation (Environmental Data Service 1968). The southwestern area with a July–December wet season reveals the influence of the summer monsoon (Bryson and Lowry 1955). Winter–spring precipitation produces the 8-month wet season in the intermontane region, whereas the summer months form the wet season in the High Plains, the period when thunderstorms predominate (Changnon 1988). The Midwest shows a spring–summer wet period of 6 months duration (the period of maximum thunderstorm activity), and the summer–fall wet season in the Florida area reflects the influence of the fall hurricane season (Environmental Data Service 1968). Other eastern U.S. areas including the Gulf Coast, the southern states, the Southeast, and the Northeast all have relatively long, 7- to 8-month wet seasons, reflecting the relatively uniform precipitation distribution throughout the year. Their wet seasons include 1) part of the winter season in most of

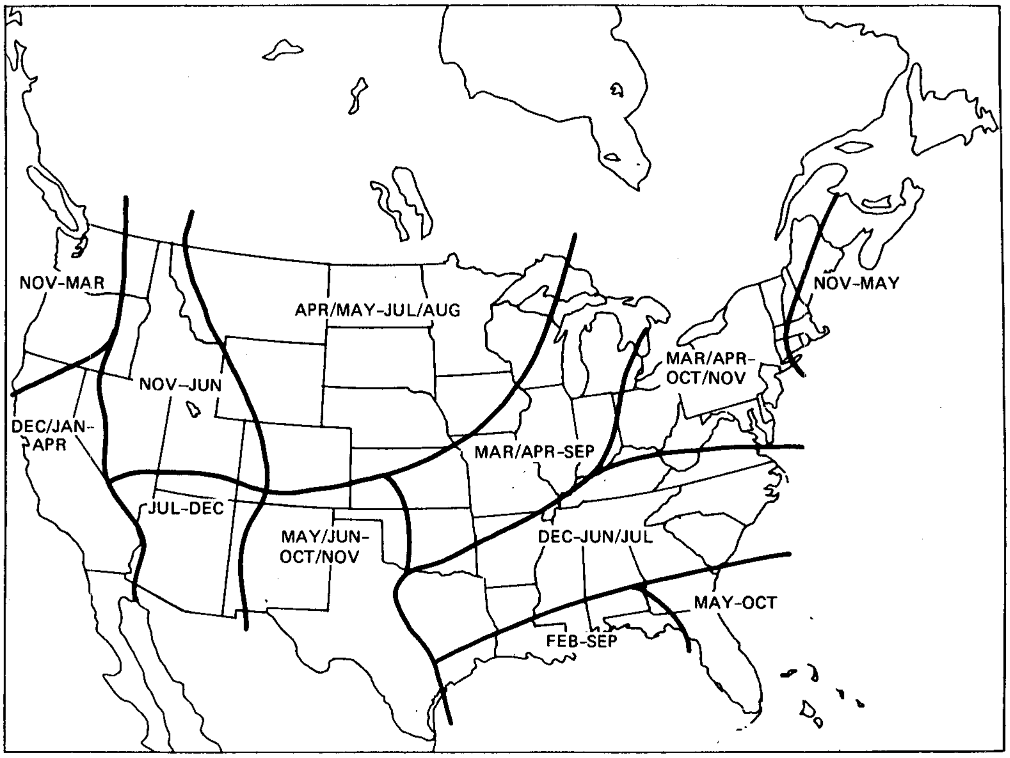

FIG. 2. Areas defined by wet seasons.

this region, 2) all the spring season, and 3) part of the summer season (in the Northeast and South). In these areas, the wet season includes 66% of the year (8 months) to achieve 70% of the total 0.1-inch rain hours.

The third climatological measure used in the rate area analysis involved comparisons of the frequency of 0.1-inch rain hours with those based on ≥0.25 inch and ≥0.01 inch. Comparisons were based on the average frequency of rain hours in the seasons (as previously defined), with the 0.01- and 0.25-inch frequencies each expressed as a ratio of the average 0.1-inch frequencies. A ratio map for the 0.25–0.1-inch hourly frequencies in the wet season (Fig. 3) reveals how the ratios varied, ranging from less than 5% in the northwest (indicating relatively few ≥0.25 inch hours) to greater than 45% in southern Florida. The number of 0.1-inch hours in the Northwest is 8%–10% the average number of 0.01-inch hours. This percentage increases eastward with the 0.1-inch hours becoming 30%–35% of all 0.01-inch rain hours in the southeastern United States. None of the rain-hour patterns east of the Rockies match closely with the number of measurable rain days. Rain days increase eastward and maximize in the northeast (150 to 160 days per year) (Environmental Data Service 1968), and not in the Southeast where rain hours peaked (Fig. 1); however, the major features on the patterns for both of the other levels assessed (0.01 and 0.25 in.) closely resembled the 0.1-inch pattern (Fig. 1).

A statistical technique was used to delineate rain areas for establishing rates. A cluster analysis based on data from the 83 stations was accomplished by incorporating the three sets of values used in assessing potential regionality. These included each station's 35 annual values of 0.1-inch per hour, the 35 seasonal rain-hour frequencies, and the ratios of the 0.1-inch hour annual frequencies to those of 0.01 and 0.25 inch (70 values). Correlation coefficients between the annual and seasonal values were high, typically ≥ +0.96, and those between 0.1-inch hours and 0.01- and 0.25-inch hours were all > +0.85. The Euclidian distances, based on the sum of the squares of the values of each pair of stations, became the basis for a hierarchical cluster analysis. It provided a sequential grouping of station values which revealed the following sequence of rain regions in the United States: 2 areas, 3 areas, 5 areas, 7 areas, 9 areas, 13 areas, 17 areas, 25 areas, etc. The resulting 13- and 17-area patterns were provided to the insurance industry for consideration. The areas selected, given their requirement of fewer than 20 areas, were 17. The resulting "rate areas" are depicted in Fig. 4. Original area boundaries located near state boundaries were relocated to state lines to conform to industry desires. This desire relates to ease in obtaining state insurance department approval of requested rates. In some states like California, Oregon, and Texas where major regional differences existed, however, three or more different rate areas were established.

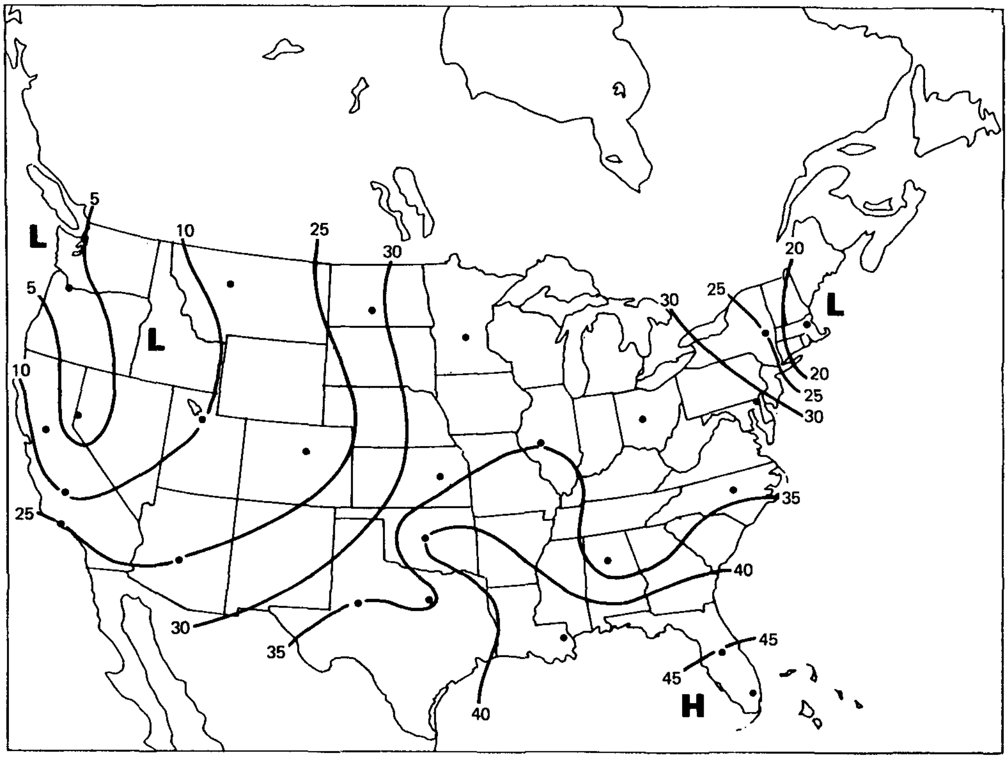

FIG. 3. Frequency of hours with ≥0.25 inch of rainfall expressed as a percent of the number of hours ≥0.1 inch rainfall.

FIG. 4. Rate areas and recording raingage stations used to compute rate area values.

b. Rating period and rerating frequency analyses

Various temporal analyses based on 0.1-inch rain hours were pursued to determine the proper length of historical period to use in calculating rates and how often to rerate (calculate new rates) each rate area. The industry had indicated it wanted to use the shortest possible recent period of data for the rating period and the industry did not desire to rerate any area more often than once in 5 years, in order to reduce costs. Annual data for ≥0.1 inch rain hours, as calculated for the stations in each of the 17 rate areas, were averaged to form "area annual values" to use in the various temporal analyses pursued to address these two needs.

One aspect of temporal variability investigated used 5-year running totals of the 0.1-inch rain hours, reflecting the industry's desire to determine rates on periods no shorter than 5 years. Figure 5 presents resulting curves for four stations. Examination of these, and those of all other 79 stations suggested no marked 35-year trends, but most have sizable 5- to 15-year fluctuations. In general, low incidences of rain hours prevailed during the early 1960s when moderately widespread dry conditions existed, and higher incidences of rain hours prevailed during the relatively wetter periods of the early 1970s and early 1980s (Karl 1988). This further supports the generally good spatial relationship found between total rainfall and frequency of rain hours. These types of fluctuations also suggest frequent rerating, once every 5 or 10 years.

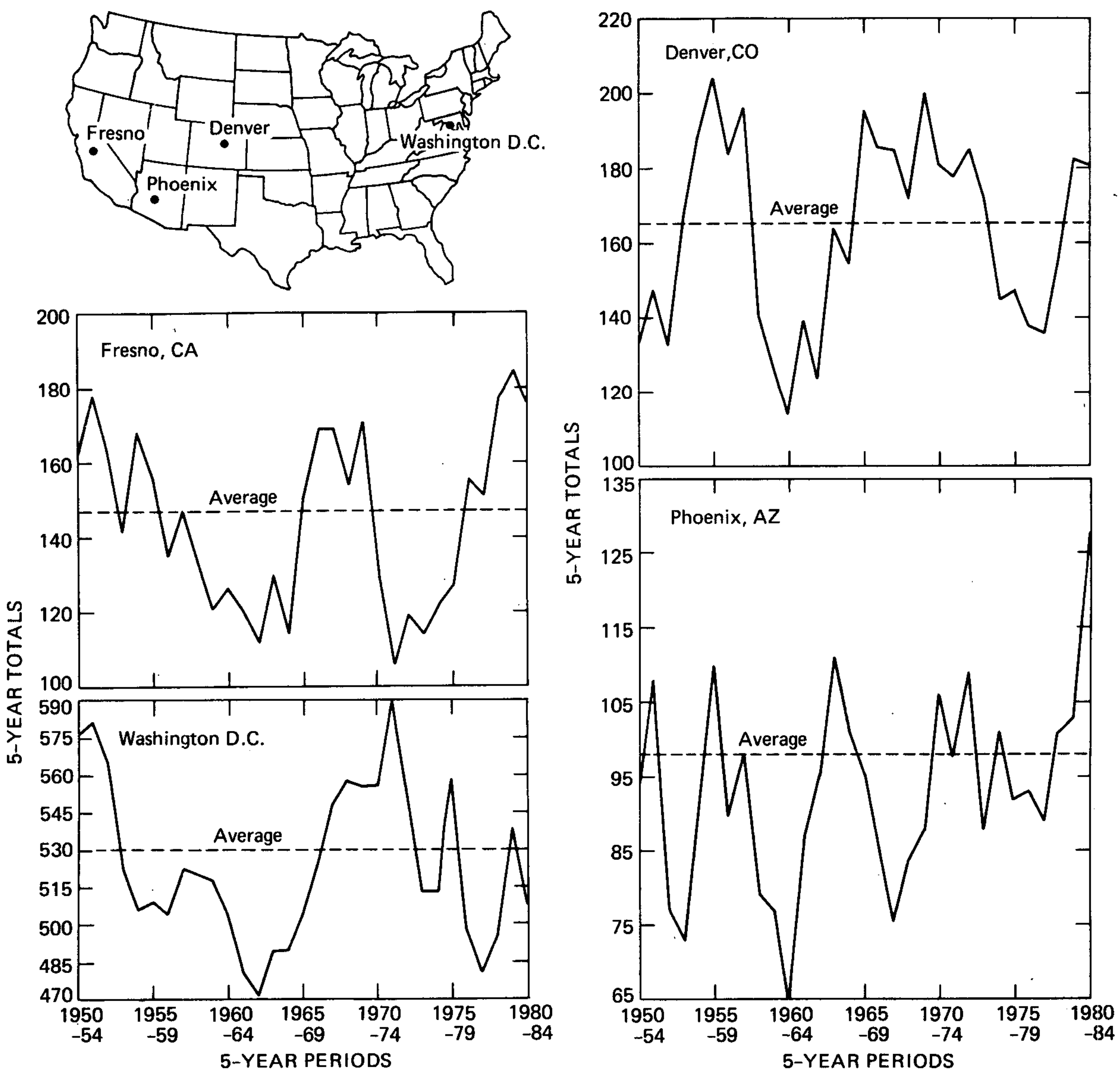

FIG. 5. Five-year running totals of number of hours ≥0.1 inch of rainfall at selected stations, 1950–84.

All annual station values in each area were averaged to develop a ⩾0.1-inch area-average point value for each of the 35 years, and these were used to compute area annual averages, standard deviations (SD), and coefficients of variation (CV) (Table 1). The SD values reveal generally low levels of variability relative to the averages. The greatest variability (based on CVs) exists in the West (areas 2 to 5, and 7, Fig. 4) where the area mean point averages are lowest. Least variability exists in the Southeast (areas 11, 12, and 13).

An expression of temporal variability relevant to the insurance industry concerns the time between the highest and lowest annual values. The incidence of major extremes greatly influences rating and insurance purchases. The potential time differences could range up to 33 years, and the expected difference would be 16 to 17 years if the two extremes were randomly distributed. The number of years separating the highest and lowest annual values (hours ⩾0.1 inch) in the 17 areas varied from a low of 4 years in one area to a high of 20 years in another area. Differences between the highest and lowest values were less than 10 years in all areas except those in the extreme southern United States; areas 5, 12, and 13 (see Fig. 4) had differences in their extremes of 20, 20, and 18 years, respectively. The median difference (based on all areas) was 8 years, much less than expected. This suggests that atmospheric conditions leading to extremely high or low annual incidences of rain hours often change relatively rapidly, leading to opposite extremes within a relatively short time.

The presence of long-term trends in the rate area values can affect the length of the rate period selected. Linear curves were fit to the 35 annual average rain-hour values of each area (⩾0.1 in) by the method of least-squares, and the resulting slope values are shown in Table 1. All trends were slight, most much less than 1.0, indicating no major 35-year trends in any rate area. The low correlation coefficients (and their squares, Table 1) show a lack of statistical significance in the trends, revealing that progressing time did not explain well the number of hours of rain. Even for areas 10 and 12, which had the highest slope values and coefficients, the years (or time) explained less than 10% of the variability found in their annual frequencies of rain hours. The pattern of the 17 slope values indicated that areas in the central United States had slight downward trends for 1950–84, whereas the Gulf Coast, Northeast, and areas in the West all had slight upward trends. These results indicated that for rating considerations, long-term trends were not a concern.

Another temporal analyses investigated the characteristics of 10-year totals of the 0.1-inch rain hours in each area. Six 10-year periods (each with 5-year overlap) were defined 1950–59, 1955–64, etc.). Results revealed that in most areas one extremely high and one very low 10-year value occurred among the six. Sixteen percent of all 10-year periods had values more than 20% different from the 35-year average probability, but 72% of all 10-year values were within 5% of the 35-year area average. Thus, major short-term fluctuations were present but not common. A test for periodicities was also made for each area using the annual rainfall frequencies for each 0.1-inch hour. No cycles of significance were detected in any of the areas.

A test was devised using each area's values (⩾0.1-inch hours) from 1950 to 1975 in a comparison with those in the series of five 5-year values in the 1976–84 period (1976–80, 1977–81 up through 1980–84). The rain-hour frequency in each 5-year period was com-

TABLE 1. Rate area data based on annual frequencies of rain hours ⩾ 0.1 inch, 1950–1984.

Rate area	Annual average*	Standard deviation*	Coefficient of variation	Slope*	Correlation coefficient	Square of correlation coefficient
1	59	14.6	24.7	0.24	.17	.03
2	58	21.7	37.4	0.04	.01	.00
3	29	13.5	46.5	0.01	.01	.00
4	24	12.6	52.5	0.21	.17	.03
5	20	9.4	47.0	0.16	.18	.03
6	48	14.4	30.0	−0.15	.11	.01
7	33	11.3	34.2	0.10	.09	.01
8	79	17.4	22.0	−0.34	.18	.03
9	106	20.1	18.9	−0.07	.04	.01
10	127	31.5	24.8	0.81	.26	.07
11	132	26.1	19.8	−0.04	.02	.00
12	145	30.7	21.2	0.77	.28	.08
13	131	36.8	28.1	0.34	.12	.01
14	49	15.3	31.2	−0.09	.16	.03
15	89	26.1	28.8	−0.41	.25	.06
16	124	26.4	21.4	0.10	.17	.03
17	122	24.1	19.8	−0.06	.05	.01

* Values are number of rain hours (⩾0.1 in) per year.

pared with those of the preceding periods of varying lengths; the prior 5, 10, 15, 20, and 25 years. From these comparisons we determined 1) the best and worst estimating periods (defined as the prior periods closest to or farthest from the test value), and 2) the degree of difference between the test periods and their preceding estimating periods.

Table 2 presents the frequency of the best and worst relationships. For the 17 areas there were 85 possible best outcomes (17 × 5 test periods), and 85 worst outcomes. The best values reveal that the prior 20 years with 21 best, and the prior 25 years with 19 best were most often the "best" prior periods.

The values of the prior 5 years were most often the worst. This is contrary to findings on a test of annual rainfall amounts in Illinois which showed that the most recent 5-year value was most often the best estimator (Lamb and Changnon 1982); however, 1-year values were tested in that study, as compared to 5-year totals in the rain-hour study. Examination of the "worst" frequencies (Table 2) reveals that the 25-year periods were least frequently the worst. The differences between the best and worst frequencies, or net scores, are also shown in Table 2. These reveal that the 20- and 25-year values performed best, whereas the 5-year values performed worst. This suggested the selection of a 25-year period for rating.

A second measure of the relationship of prior periods to the test periods is the amount of difference between the prior period frequencies (of rain hours) and those of the test periods. These differences, expressed as percent of the test period values, are shown in the two lower lines of Table 2. The averages and medians are based on the values of all 17 areas. These show decreasing percentage differences with length of time. The average and median values both indicating the 25-year values exhibit the least difference from the tested 5-year values.

The regional differences (not shown in Table 2) indicated that the 25-year prior values were most frequently the best in the westernmost rate areas (1–4) and in areas 7, 8, 11, 12, 13, 14, and 15. Data for areas 5 and 6 (Southwest) showed that the 15-year prior periods served as their best estimator of the 5-year test periods. The 20- and 25-year values behaved equally well in areas 9, 10, 16, and 17 (Northeast).

TABLE 2. Number of times that prior period value was the best (closest) or worst estimate of the next 5-year total of hours ≥ 0.1 inch. (Based on a test of 5 periods: 1976–80, 1977–81, 1978–82, 1979–83, and 1980–84 for all 17 rate areas.)

	Prior 5 years	Prior 10 years	Prior 15 years	Prior 20 years	Prior 25 years
Best	15	16	14	21	19
Worst	38	19	11	13	4
Net value (B − W)	−23	−3	+4	+8	+10
Average*	16.5	13.6	13.2	13.0	12.0
Median*	11	10	9	9	8

* Differences of prior period values (0.1 in or more) from test 5-year period values, expressed as a percent of the predicted period values.

c. *Assessment of diurnal variations*

The potential for sizable diurnal differences in rain-hour probabilities existed and these were assessed to decide whether different in-day rates should be used. The decision to use two different probability levels for rain values during the day in a given area and season was to be based on a large amount of in-day variation. The hourly probabilities for the ≥0.1-inch rain level in each season and in each rate area were calculated along with their coefficient of variation. The resulting hourly probabilities are illustrated for three areas and their wet seasons in Fig. 6. Examination of such plots and study of the in-day variances led to the conclusion that those areas/seasons achieving CV values >2.5 had diurnal variations sufficiently large to justify separate in-day rate differences. Nine rate area/seasons were selected for in-day rate periods, and as shown in Table 3, most occurred during wet seasons in the central and southeastern United States where daytime convective rainfall in the wet (warm) season predominates in rainfall and thunderstorm development (Changnon 1988).

4. Phase 2: developing multiple rainfall level values for 2- and 72-hour periods

The final product desired related to the probabilities of occurrence of any one of six levels of rainfall (ranging from 0.01 to 1.0 in or more) during 1 hour, 2 hours, 3 hours, and so on up to a 72-hour period. This required extensive computer analysis. The largest possible rain-hour database was desired to help ensure adequate representation of points in each possible area.

Since the smallest number of possible tables was desired for use of the insurance industry, means for condensing the probabilities were employed. The potential matrix was the incidence of six levels of rainfall occurring over all possible 1-hour periods ranging from 1 hour up to 72 hours (72 combinations × 6 levels) for each area, each season, and for two periods in a day (where major diurnal differences existed). Without considering the diurnal differences, probabilities had to be developed for 864 possible combinations in each rate area (72 hours × 6 rainfall levels × 2 seasons). The final "rate book" for use by the insurance industry included nearly 30 000 probability values.

a. *Data assessment*

The data used were for 1950–84 (35 years). Data were available from 2092 hourly raingage stations in the United States. Since the temporal analyses indicated

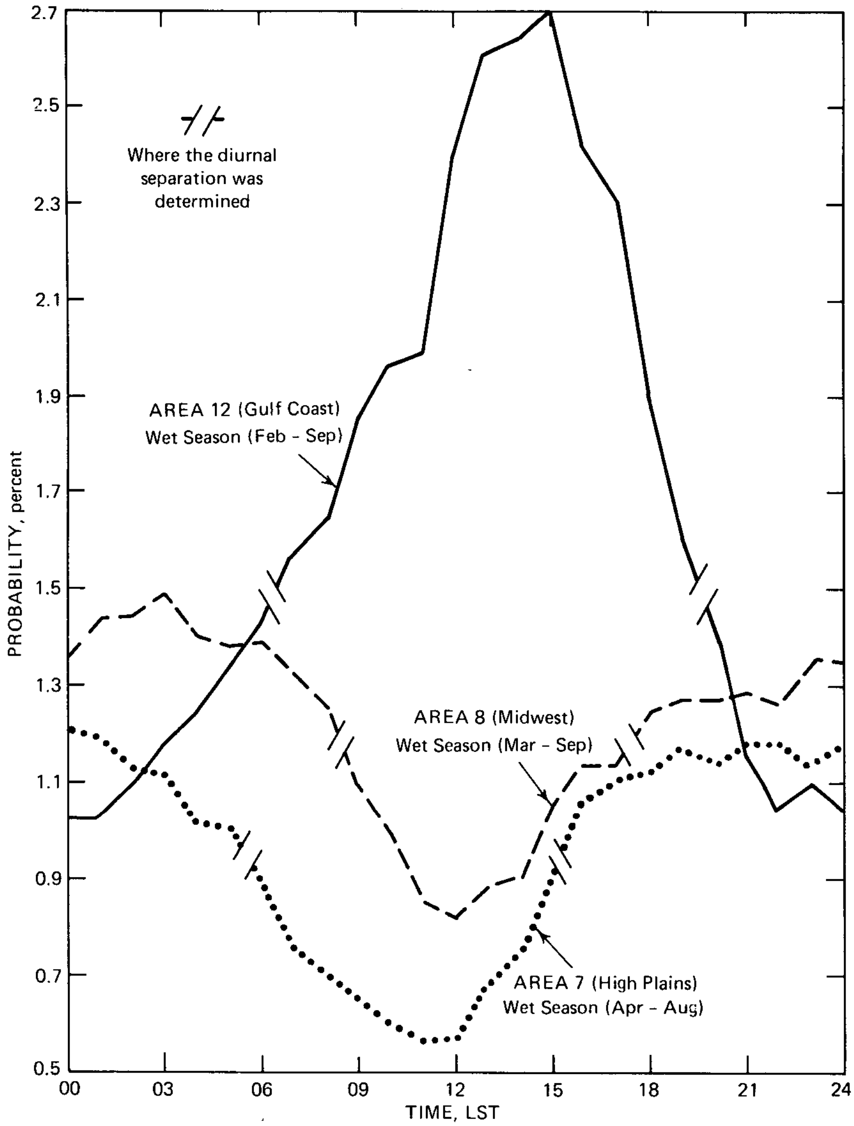

FIG. 6. Average hourly probabilities for ≥0.1 inch of rain in an hour for the wet seasons of three areas.

that the most recent 25-year period had the best relationship to any future 5-year (rerate) period, the data from the most recent 25 years (1960–84) were used to develop the rate area average values. The data for each station in each area were screened for large amounts (>5 years) of missing data, resulting in the initial rejection of more than 1600 stations. Subsequent examination of the data for the remaining 400 stations revealed either spurious values or critical periods of missing data. This led to elimination of many more stations, with only 211 stations with quality hourly rainfall data from 1960–84. Each rate area had between 6 and 16, as shown on Fig. 4. These data were used to calculate "area average monthly and seasonal rainfall probabilities" for the six rain levels, the wet and dry seasons, and the two in-day periods.

The average monthly probabilities (based on ≥0.1 in) for the wet and dry seasons of two areas (1 and 13) are shown in Fig. 7. Such plots were used in checking for errors in station and area values. One notes (Fig. 7) the exceptionally higher probabilities for the wet seasons in both areas, as compared to their dry season monthly probabilities. The area monthly probabilities were also compared (differences expressed as percent of area values) with those for the individual stations within each area to discern whether the individual station values were generally "representative." This helped examine for potential errors as station monthly values. These forms of data evaluation helped lead to the aforementioned final selection of 211 stations with quality data. Very few of the hourly rainfall stations of the United States, roughly 10%, have data of sufficient

TABLE 3. Rate areas and seasons with sizable in-day variations (CV >25) in hourly rainfall probabilities, and the different rate periods.

Area	Season	Hours in separate periods, LST
4	Dry	12–22, 22–12
5	Wet	12–24, 00–12
7	Wet	12–22, 22–12
8	Wet	08–18, 18–08
11	Wet	06–20, 20–06
12	Wet	06–20, 20–06
13	Wet	10–20, 20–10
13	Dry	14–20, 20–14
14	Wet	06–16, 16–06

quality for a climatological analysis of this type, and most were first-order stations.

Other assessments of the values for the wet and dry seasons were made. The spatial coherence of hourly probability values was examined for each area and hour by comparing adjacent area values such as those shown for four times as shown in Figs. 8a–d. These also reveal interesting climatological information. The lowest probabilities in the two wet season values (midnight and noon, Figs. 8c, d) occurred in the intermontane rate areas (4 and 5), with the highest probabilities occurring in the southeast and western United States. Marked day–night differences exist; note areas 12 and 13 where the noontime wet season values are more than double those at midnight.

b. Calculations of multiple-hour values

With the rate areas, seasons, and diurnal rate differences defined, and the data quality assessed, the final

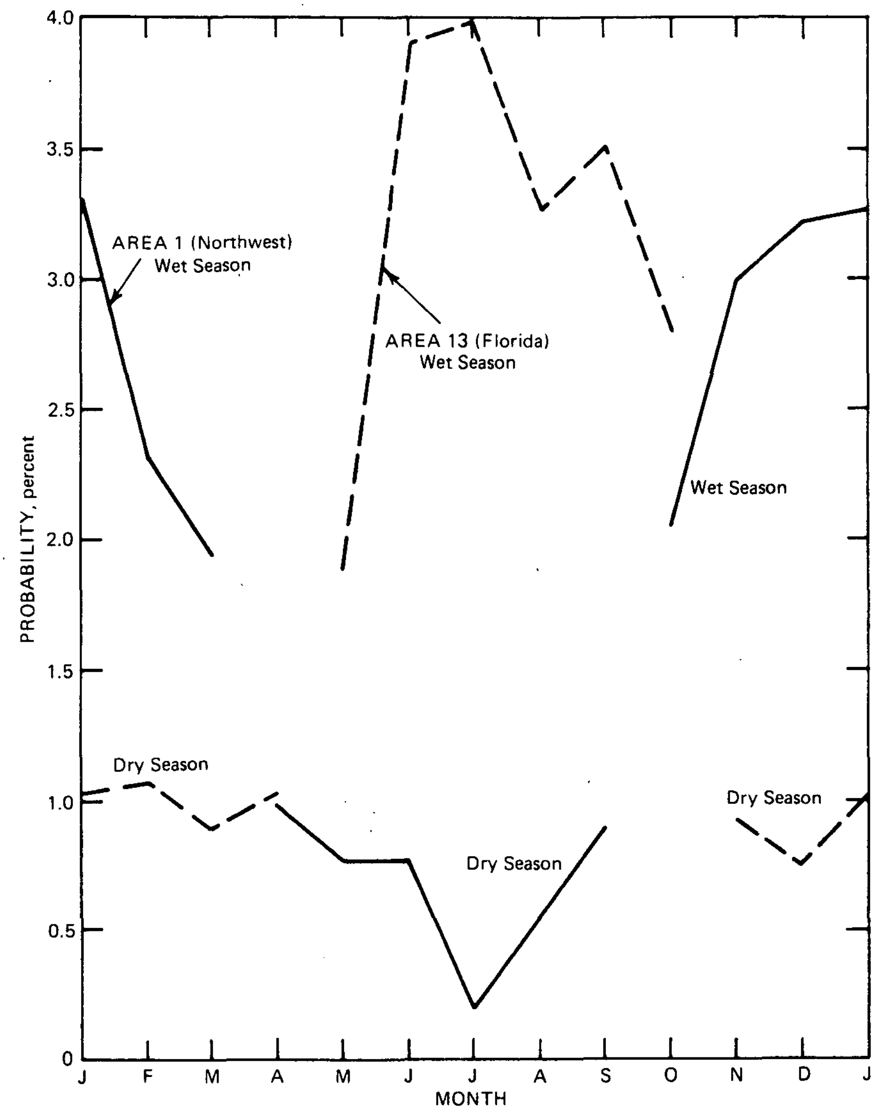

FIG. 7. Average monthly probabilities for ≥0.1 inch of rain in 1 hour in two areas.

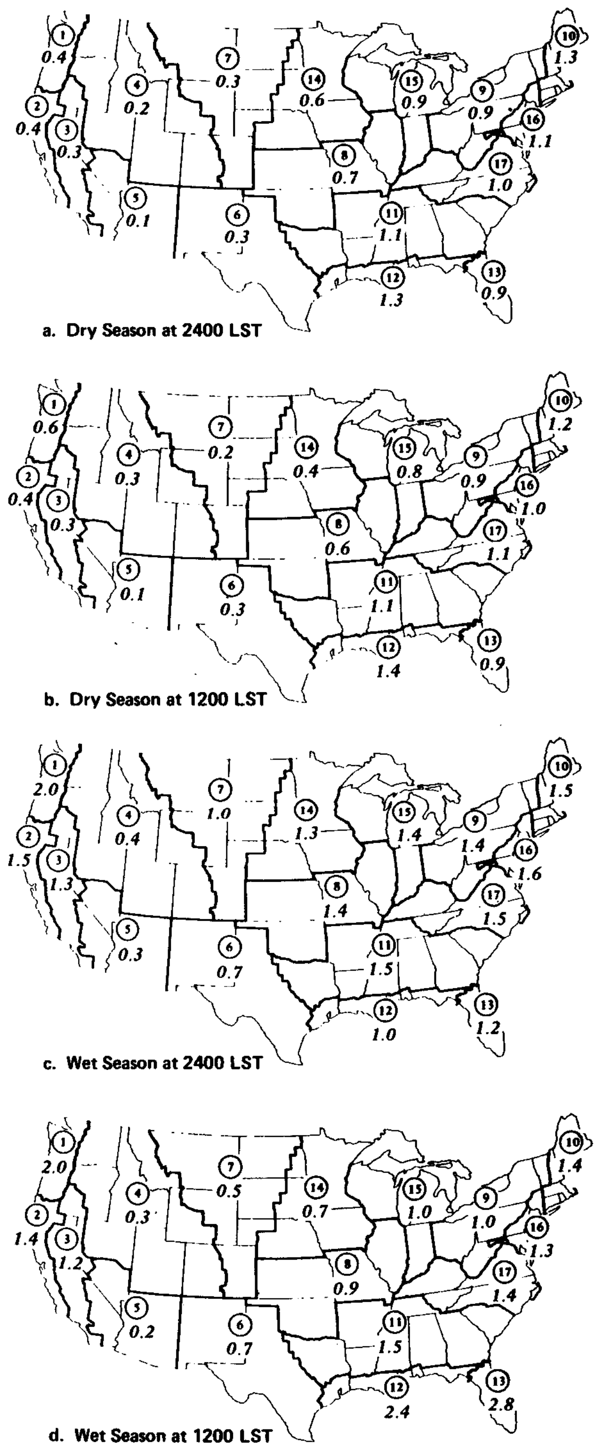

FIG. 8. Probabilities for ≥0.1 inch of rain in specified 1-hour periods in 17 rate areas and in wet and dry seasons.

analysis addressed the incidence of the six levels of rainfall (0.01 up to 1.0 inch or more) for all combinations of hours from 2 up through 72 hours. That is, for each discrete 2-hour period during the day (00–02, 01–03, etc.) the number of times an amount of rain (in each of the six rain classes) occurred was calculated at each of the stations in each of the 17 areas. For each area, the station frequencies were arithmetically combined along with the total number of days sampled. Area mean probabilities were calculated from these data for all durations and for six levels of rainfall. To ensure the accuracy of the calculations, maps of probabilities for varying periods and rainfall levels were generated, inspected, and compared for anomalous values. Testing included comparisons (based on numerical differences) of the probabilities for different durations since there was a systematic shift in probabilities with time. For example, Fig. 9 presents curves based on the area 1 probability values (and the wet season) for rain in six levels over periods of 1 to 48 hours in length. Tables were generated for each area and season (and for both in-day periods, where needed) for use in the rate determinations.

5. Summary and recommendations

The temporal variability of hours of precipitation of ≥0.1 inch is not excessive in the contiguous United States. The interannual variability was greatest in the western arid areas where average hourly rain incidences are least. The temporal variability is also relatively high in New England and Florida where the incidences of rain hours are the highest in the nation. In general, the spatial relationship between average number of rain hours and the annual average precipitation in the United States is strong. The pattern of incidences of 0.1-inch hourly rains east of the Rocky Mountains also resembles the average thunderstorm pattern. In the far west, other atmospheric conditions control the incidences of rainfall hours.

During the 35-year period of rain data analyzed, there were no significant long-term trends. Most stations and rate areas had two marked 5- to 15-year fluctuations. For example, low values were found during 1950–65 in the western and east-central rate areas, with relatively high values in the same areas during portions of 1970–84. About 15% of all 10-year periods during 1950–84 had probabilities markedly different from the 35-year average values, but 78% of the 10-year periods had probabilities within 5% of the 35-year averages. The occurrence of these short-term fluctuations, when considered with the relatively short time spans found between the highest and lowest annual rain hour values (a median of 8 years), suggested that atmospheric conditions capable of causing such extremes tend to occur relatively close in time.

Study of the relationship of rain hour values from the 5-, 10-, 15-, 20-, and 25-year periods with hours in the ensuing 5 years revealed that the prior 5-year period had the poorest relationship. The prior 15-year values had the highest relationships in areas 5 and 6 (Southwest), but the 25-year preceding period, both as to fre-

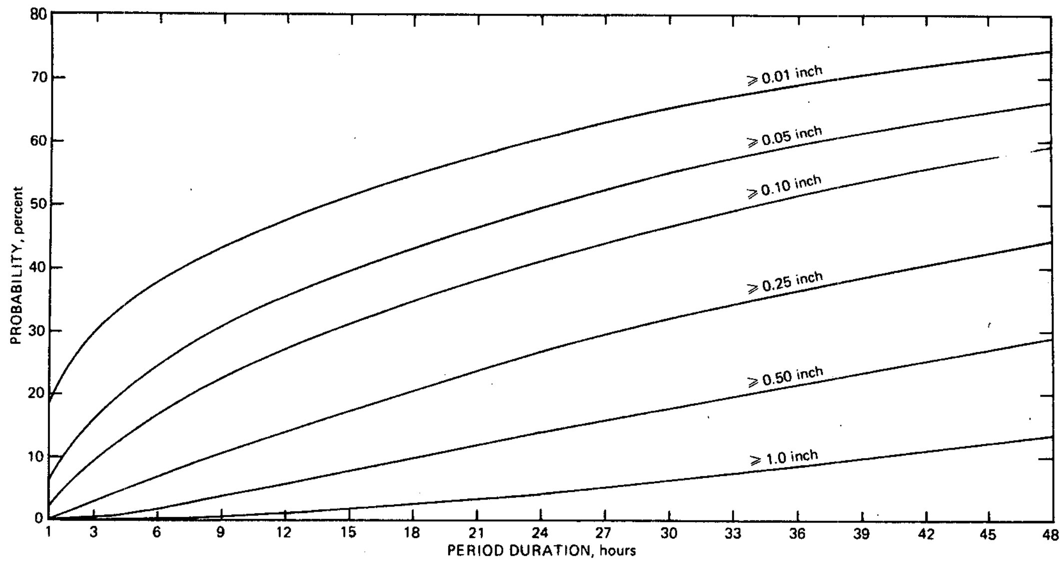

FIG. 9. Area average probabilities for six levels of rainfall occurring in periods of 1 hour up to 48 hours for area 1 (northwest United States) and the wet season (Nov–Mar).

quency of being best and the closeness of the values, had the best relationship with the values of the ensuing five years in all other parts of the United States.

Insurance interests wanted to use the shortest possible, yet relevant, recent historical period for rate determination, and also to not rerate more often than once every 5 years. Consideration of their interests and the results from the various temporal analyses collectively indicated that the latest 25 years of hourly rainfall data should be used for establishing rates if done on a nationwide basis. The results further indicate that the process of rerating, if done on a nationwide basis, should occur once every 5–10 years to incorporate and adjust for the occasional 5- to 15-year fluctuations. If rerating is done on a rate area basis, rate areas 2, 3, 4, 5 and 7 (with large CVs and more 5- to 10-year fluctuations) should be rerated every 5 years. All other areas should be rerated at least once every 10 years.

The areas and seasons exhibiting marked diurnal differences in hourly rainfall probabilities included the wet seasons in the High Plains, Midwest, and southeastern United States. These are regions with marked warm season convective rainfall activity, and the marked night–day differences in hourly rainfall probabilities reflects the strong influence of convective heating on the incidence of hourly rainfall values of ≥0.1 inch.

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