Rainfall Frequency/Magnitude Atlas for the South-Central United States

by

Gregory E. Faiers
Department of Geography
University of Pittsburgh at Johnstown
Johnstown, PA 15902

Barry D. Keim
Department of Geography
University of New Hampshire
Durham, NH 03824

Robert A. Muller, Director
Southern Regional Climate Center
Department of Geography and Anthropology
Louisiana State University
Baton Rouge, LA 70803

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MAPS

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INTRODUCTION

Frequency-magnitude relationships of heavy rainfall events are commonly utilized in design projects by providing useful guidelines to engineers, planners, and hydrologists about future expectable storm events. Despite its age, the most widely used publication employing these relationships is *Technical Paper No. 40* (hereafter referred to as TP40) by David Hershfield (1961). TP40 examined extreme rainfall events in the United States and provided "expectable" precipitation amounts for recurrence intervals from 1 to 100 years for durations from 30 minutes to 24 hours. Other papers addressing this topic include Weather Bureau *Technical Papers No. 2* (1947) on maximum recorded rainfall from 5 minutes to 24 hours at first-order stations; *No. 24* (1954) rainfall return periods for 5 minutes to 4 hours; *No. 29* (1958) which presents rainfall intensity-duration-frequency distributions; *No. 49* (1964) on 2 to 10 day rainfalls for return periods from 2 to 100 years; and *Hydro-35* (Frederick et al., 1977) which examines 5 to 60 minute rainfall for the central and eastern United States.

The rainfall frequency and magnitude patterns illustrated in TP40 need to be reexamined:

* because there are 35 additional years of precipitation data since its publication in 1961

* because of recent concerns about global climate change

* because of the short periods of record in TP40 with less than half of the stations having more than 15 years of record; and

* because of the very generalized analysis for the 48 conterminous states.

There can also be great spatial variability in frequency-magnitude relationships over short distances, especially in mountainous areas (Haiden et al., 1992; Zurndorfer, 1990).

Another serious limitation is that since the publication of TP40, it has become widely accepted that there is no single statistical distribution which provides the best fit for extreme precipitation data in all climate regions of the country (Sevruk and Geiger, 1981; Huff 1990). Alternative statistical approaches have also been suggested in recent publications (Hosking, 199; Huff and Angel, 1992; Wilks, 1992; Zwiers and Ross, 1992). Concerns were further increased by the findings of Sorrell and Hamilton (1989) who found that the 24-hour, 100-year value from TP40 was exceeded over 3 times more often than expected in Michigan and by Angel and Huff (1991) who found that Illinois and Wisconsin had almost twice as many 100-year, 24-hour events as anticipated by TP40.

In the South Central United States, extreme precipitation events, and the floods they generate have occurred frequently in the 1980s and 1990s. Recent examples include:

* June 26-July 1, 1989 – rainfall up to 20 inches from Tropical Storm Allison resulted in flooding across Much of Louisiana and portions of eastern Texas and western Mississippi;

* November 7, 1989 – heavy rains of up to 19 inches fell in the New Orleans area (NOAA, 1989);

* May 18, 1990 – 13 inches of rain were observed in just nine hours at Hot Springs, Arkansas;

* October 5, 1991 – a 75 minute accumulation of 6 inches, along with a 12-hour accumulation of 10 inches, was reported at Tuskahoma, Oklahoma;

* October 15-19, 1994 – storm totals of near 30 inches occurred north of Houston and 8-inch storm totals or more were widespread across southeastern Texas (Muller and Faiers, 1995);

* May 8-9, 1995 – rainfall in excess of 25 inches fell in parts of Hancock County,

Mississippi, with 10 to 20 inches over much of metropolitan New Orleans accompanied by significant flooding over much of low-lying New Orleans and Slidell, Louisiana (Muller et al., 1995),

The question of an increasing frequency of events in recent decades has also been noted in professional publications and reports. Belville and Stewart (1983) found an unusual number of rain events in excess of 10 inches in Louisiana in 1982 and 1983. Widespread record flooding associated with persistent frontal rainfall was reported during March and April of 1990 in eastern Texas and Oklahoma by Jensen (1990). It was also found that recent magnitudes of New Orleans storms were significantly larger than storms over the preceding 100 years and heavy rainfall events appear to be increasing in frequency (Keim and Muller, 1992; 1993). Muller and Faiers (1984) had found earlier that most record peak stages on rivers in the East-Central climate division of Louisiana had occurred since 1973 with an increasing trend throughout the 1970s and early 1980s. Hirschboeck and Coxe (1991) detected increases in urban flash flooding in the Louisiana cities of Monroe and Alexandria. Finally, Keim (1997) found an increasing trend in heavy rainfalls at several locations along an axis extending from northeastern Texas through the Appalachians.

Collectively, these studies indicate that excessive rainfall and flooding events were becoming more common in the U.S. South in the recent past, especially in the 1980s and early 1990s. Impacts of these extreme events included disruption of transportation systems, river-basin flooding, inundation of farm lands and homes, loss of life, thus creating an obvious need for evaluations of the temporal and spatial characteristics of extreme rainfalls across this region (Fig. 1).

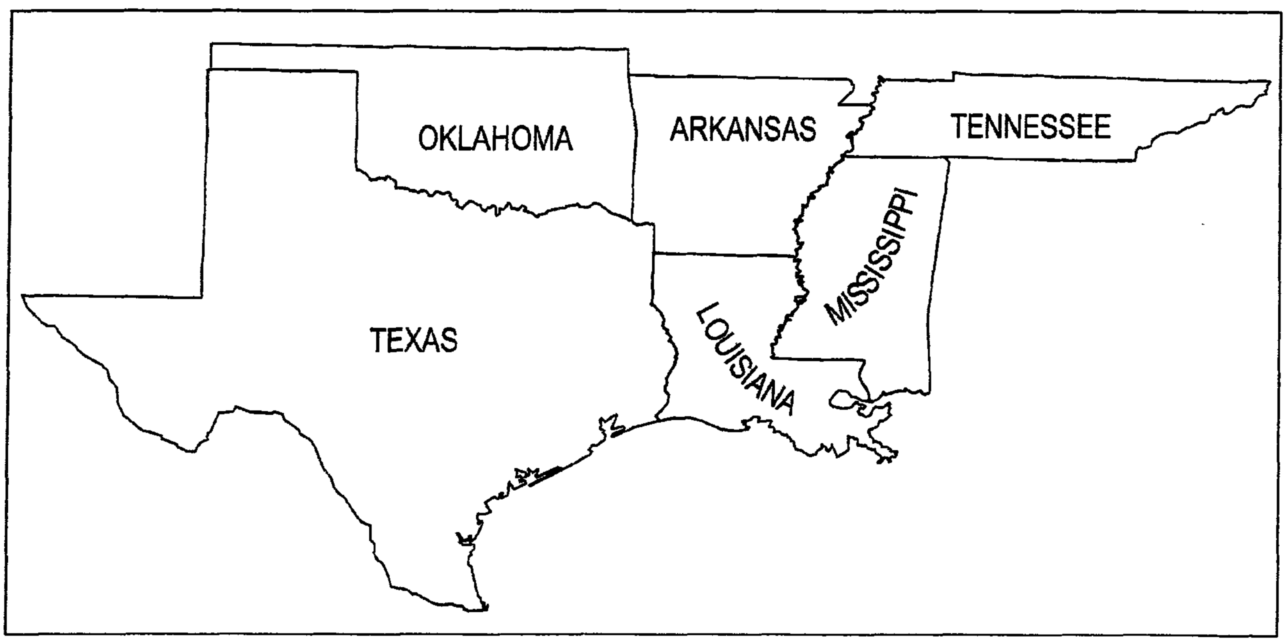

Fig. 1. the six-state region of the Southern Regional Climate Center

JUSTIFICATION

Several of the Regional Climate Centers (RCCs) have undertaken re-evaluations of extreme rainfall frequency-magnitude relationships within their respective regions (Changnon et al., 1992; Huff and Angel. 1992; Knappenberger and Michaels, 1993; Wilks and Cember, 1993). A pilot study was also undertaken by the Southern Regional Climate Center (SRCC) to evaluate extreme rainfall frequency-magnitude relationships across the state of Louisiana (Faiers et al., 1994a). In this study, methods used were similar to those employed in TP40, but longer periods of record, including data through the 1980s and part of the 1990s, were used to derive the quantile estimates; quantiles are estimates represeting return periods and associated storm magnitudes. Patterns from the updated maps for Louisiana were compared to those in TP40 (Fig. 2). Overall storm magnitudes did not vary greatly between the two studies, but the SRCC product depicted a more complex spatial pattern with shifts in the regions of extreme rainfall maxima from southeastern to southwestern Louisiana.

The findings from this pilot study, as well as results from other regional studies, verified the need for a regional format across the six-state region of the SRCC, and for greater spatial resolution of the "expected" extreme rainfalls than depicted in TP40. Furthermore, frequency-magnitude relationships of extreme rainfall have had a high user demand, ranking among the most commonly requested data sets at the SRCC. As a result, deriving accurate frequency-magnitude estimates of extreme precipitation across the six southern states of the

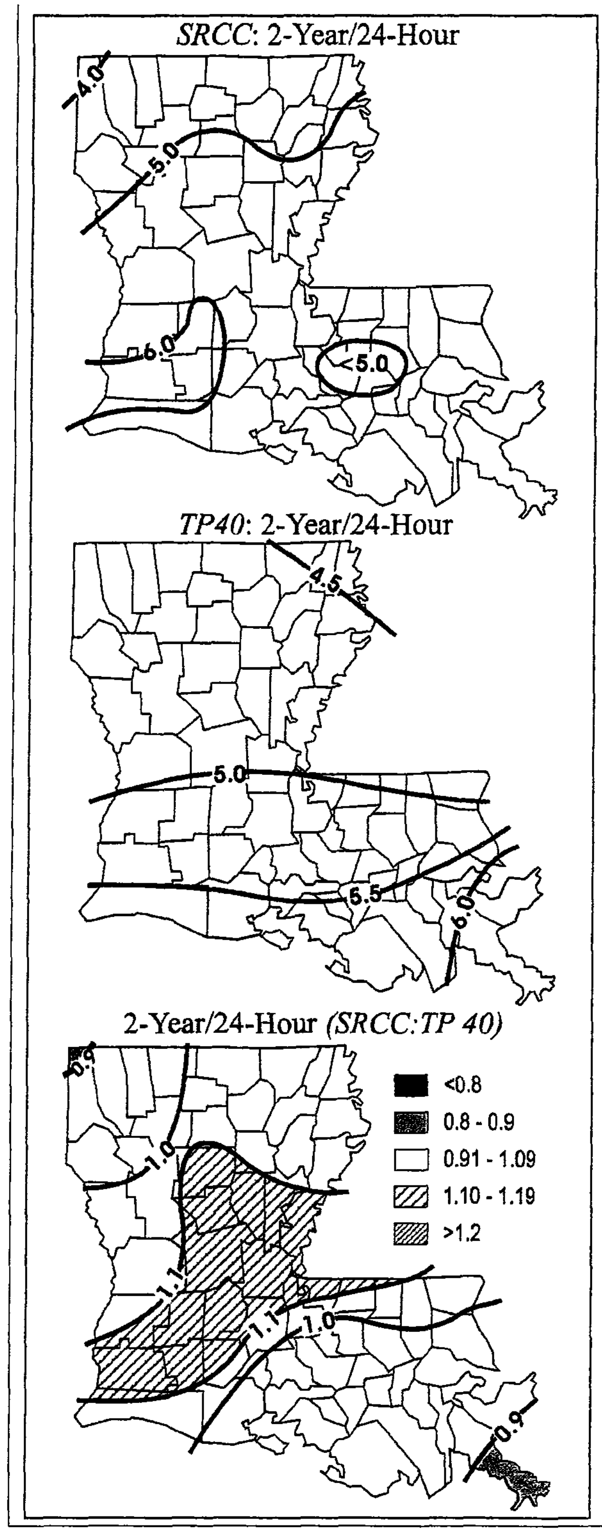

Fig. 2. Twenty-four-hour 2-year rainfalls in Louisiana according to the Technical Paper No. 40 and our updated version using similar methods. Source: Faiers et al., 1994a.

SRCC (Fig. 2) became part of the research agenda at the SRCC. This research yielded more regionally representative estimates than TP40, and it should support improved drainage and containment designs. This document summarizes the new estimates of the relationships for durations of 3, 6, 12, and 24 hours for 2-, 5-, 10-, 25-, 50-, and 100-year return periods with regional-scale maps. Text sections describe the geographical patterns and the primary differences to TP40. The development of the data sets and methods are included as an appendix.

GEOGRAPHICAL PATTERNS AND RELATIONSHIPS TO TP40

Figures 3.1 through 6.6 referred to in this section are all located in the atlas section starting on page 11

Three-Hour Storms

Figures 3.1 to 3.6 represent the rainfall magnitudes for 3-hour storms at each of the selected recurrence intervals. Much of the geographical pattern that emerges here becomes even more apparent at the longer recurrence intervals and extended durations. The general pattern of quantile estimates depicts a regional maxima along the Gulf Coast extending from southeastern Texas into southwestern Louisiana. Another area with relatively large storm magnitudes occurs over the coastal areas of southeastern Louisiana and coastal Mississippi. At the longer recurrence intervals, the southeastern Texas to southwestern Louisiana coastal maxima becomes larger than the estimates for southeastern Louisiana and coastal Mississippi. Storm magnitudes decrease to the north and west of these two maximum areas along the coast, with another local maximum developing over the Ouachita-Ozark mountain regions of Arkansas and eastern Oklahoma were orographic precipitation increases storm magnitudes. Another region of greater storm magnitudes generated by orographic precipitation occurs along the Balcones Escarpment and Hill Country west and southwest of Austin and San Antonio extending southwestward towards the Rio Grande River. This is an area plagued by an unusually high number of catastrophic flood events (Hirschboeck, 1987a).

In eastern Tennessee, there is again a strong orographic increase of average precipitation and magnitudes of individual storm events across the western margins of the Great Smoky Mountains and the Appalachian system of mountains and valleys as a whole. As detailed by Haiden et al. (1992) local variations in extreme rainfall magnitudes can vary greatly over short distances, but they cannot be depicted in this regional study because of the geographical scale of the maps and also because of insufficient station densities in the mountainous terrain, with high mountain crests adjacent to deep valleys.

The upper tributaries of the Tennessee River system have eroded "rain-shadow" valleys where average precipitation and the magnitudes of extreme events tend to be significantly lower than adjacent uplands. The very broad Holston River Valley northeast of Knoxville is a rain-shadow region large enough to be represented on the maps. Storm magnitudes there are much lower and similar to those found in the semi-arid and arid regions of western Texas and Oklahoma. Another smaller region with relatively lower magnitudes is located west of Lake Pontchartrain is southern Louisiana. The anomalous region was also identified in a regional study conducted by the National Weather Service Office of Hydrology (Vogel, 1992). At this time, a definitive explanation for this anomaly has not been found; however some atmospheric mesoscale interaction with Lake Pontchartrain during extreme rainfall events is certainly a possibility.

When comparing the 3-hour storm maps to those in TP40, the 2-year recurrence interval is strikingly similar in magnitude and spatial pattern, but the likeness decreases with successively longer recurrence intervals. This is not surprising because TP40 was able to accurately estimate shorter recurrence intervals even with its short station records, but at longer recurrence intervals, these records were inadequate. With the longer periods of record used in this analysis, we are more comfortable with the longer recurrence interval estimates than those displayed in TP40. In both versions of the 3-hour 2-year storm, the 3.5-inch isohyet extends roughly from coastal Mississippi westward along the coast. The SRCC version, however, continues this interrupted isohyet westward to Gavleston, while TP40 terminates this isohyet south of Lake Charles, LA. The 3-inch and 2.5 inch isohyets in the SRCC map are displaced farther to the north than in TP40, and TP40 does not depict the orographic enhancements of the Ouachitas and Ozarks, which are not captured at any recurrence interval nor for any duration in TP40. This northward displacement suggests higher rainfall totals in the SRCC maps. The two documents tend to be more similar to the west and east, with the following exceptions depicted in the SRCC maps: (1) the recognition of the Balcones Escarpment and Hill Country in Texas as a zone of increased storm magnitudes, (2) more of a southeast-northwest orientation of the isohyets in extreme western Texas, which mirror the orientation of the Davis Mountains, (3) a greater emphasis placed on the rain shadow in eastern Tennessee, and (4) the lower magnitude anomaly depicted west of Lake Pontchartrain in Louisiana.

These differences appear in maps of all durations and recurrence intervals, with the differences accentuated at longer recurrence intervals. Finally, with the 3-hour 100-year storms, it becomes apparent that the coastal areas of the region have the greatest increases in magnitude over those found in TP40, while the differences to the west and north are more in interpretations of orographic and rain-shadow patterns. There is also a shift in the location of storm maxima, with the SRCC product showing the greatest magnitudes from the upper Texas Coast into southwestern Louisiana, while TP40 always has the regional maxima in the extreme Mississippi River Delta area of Louisiana. It is also interesting to note that the magnitudes of 3-hour 100-year storms range as high as 11 inches along the southeastern Texas and southwestern Louisiana coasts. Quantile estimates drop to about 5 inches along the northern borders of the region, and down to less than 3 inches across much of extreme western Texas around and southeast of El Paso, and also in the rainshadow of the Holston River valley in northeastern Tennessee in the vicinity of Bristol.

Six-Hour Storms

At the shorter recurrence intervals, 6-hour storms (Figs. 4.1 to 4.6) are relatively similar between this document and TP40, and geographical patterns and deviations are similar to the relationships found for the 3-hour storms. Again, as the recurrence intervals increase, the differences increase with the same changes as previously discussed. For example, for the 6-hour 100-year storm, the greatest magnitude depicted is 10 inches in extreme southeastern Louisiana in the TP40 version, while the SRCC map (Fig. 4.6) depicts the greatest magnitudes (12 inches) along an axis from west of Galveston into coastal southwestern Louisiana. Along the north and west fringes of the study region, both reports still depict similar magnitudes. The lowest estimates are less than 3 inches from El Paso southeastward down the Rio Grande. In the rainshadow valley of the Holston River in northeastern, Tennessee, the estimates are less than 4 inches.

Twelve-Hour Storms

As storm durations increase to 12 hours (Figs. 5.1 to 5.6) and magnitudes increase, the previously established relationships between the documents are sustained and the absolute increases in magnitudes along the Gulf Coast become more apparent. For example, on the 12-hour 100- year SRCC isohyet map (Fig. 5.6), the Lake Charles area of southwestern Louisiana has a magnitude of approximately 14 inches, while TP40 depicts a value of just under 11 inches. Also, in the upland areas of western Arkansas, there are locations with 100-year return estimates of more than 11 inches, about 3 inches greater than in TP40. There are still small areas in the vicinity of El Paso with less than 3 inches, and less than 4 inches in the Holston River valley in northeastern Tennessee.

Twenty-Four-Hour Storms

Finally, for the 24-hour durations (Figs. 6.1 to 6.6), there are similar differences between TP40 and this document, with the differences tending to be greater for the longer return periods. The maximum differences in storm estimates are found in the coastal Texas-southwestern Louisiana areas and in the Ouachita-Ozark Mountains where the 100-year storm magnitudes are again about 3 inches greater in the SRCC product (Fig 6.6). The greatest magnitudes for 100-year events are about 16 inches between Galveston and Lake Charles, more than 14 inches over extreme southeastern Louisiana, and more than 12 inches across most of the Ouachita Mountains in western Arkansas and eastern Oklahoma. Minimum storm magnitudes of less than 4 inches are restricted to the Rio Grande Valley southeast of El Paso toward the Big Bend country, and again less than 5 inches in the rainshadow areas of the Holston River valley in northeastern Tennessee. Quantile estimates are almost the same as in TP40 for the west, north and east fringes of the region.

Summary and Conclusions

* The magnitudes of extreme events vary in systematic patterns geographically for all durations and return periods, with maximum intensities along the Gulf Coast in the vicinity of the Texas and Louisiana border, decreasing gradually to the northeast and north, and much more rapidly towards the northwest, west, and southwest.

* This generalized regional pattern is interrupted with steep increases where mountain barriers and broad uplands induce additional orographic precipitation, and equally steep decreases across "rainshadow" valleys.

* Three-hour two-year storms range from about 3.5 inches along the southeastern Texas and southern Louisiana coasts down to less than 1.5 inches in extreme western Texas and Oklahoma, with the magnitudes of 100-year storms ranging from 11 inches along the coasts of southeastern Texas and southwestern Louisiana down to less than 3 inches in extreme western Texas and in rainshadow valleys of northeastern Tennessee.

* Twenty-four-hour two-year storms range from 6 inches along the southeastern Texas and southern Louisiana coasts down to less than 2 inches in extreme western Texas, with the magnitudes of 100-year storms ranging from 16 inches along the southeastern Texas to southwestern Louisiana coasts, down to about 4 inches along the Rio Grande valley southeast of El Paso.

* When magnitudes in this report are compared to TP40, differences are small and insignificant over the western half of Texas and all of Oklahoma.

* Magnitudes in this report are greater than TP40 across most of Louisiana, Mississippi, and Tennessee, with the greater increases of about 10 percent for the longer return periods from 25 to 100 years.

* Magnitudes in this report are also greater for upland areas with orographic precipitation such as the Ouachitas and Ozarks of Arkansas and Oklahoma, and lower in large rainshadow valleys in northeastern Tennessee.

Rainfall Frequency/Magnitude Maps

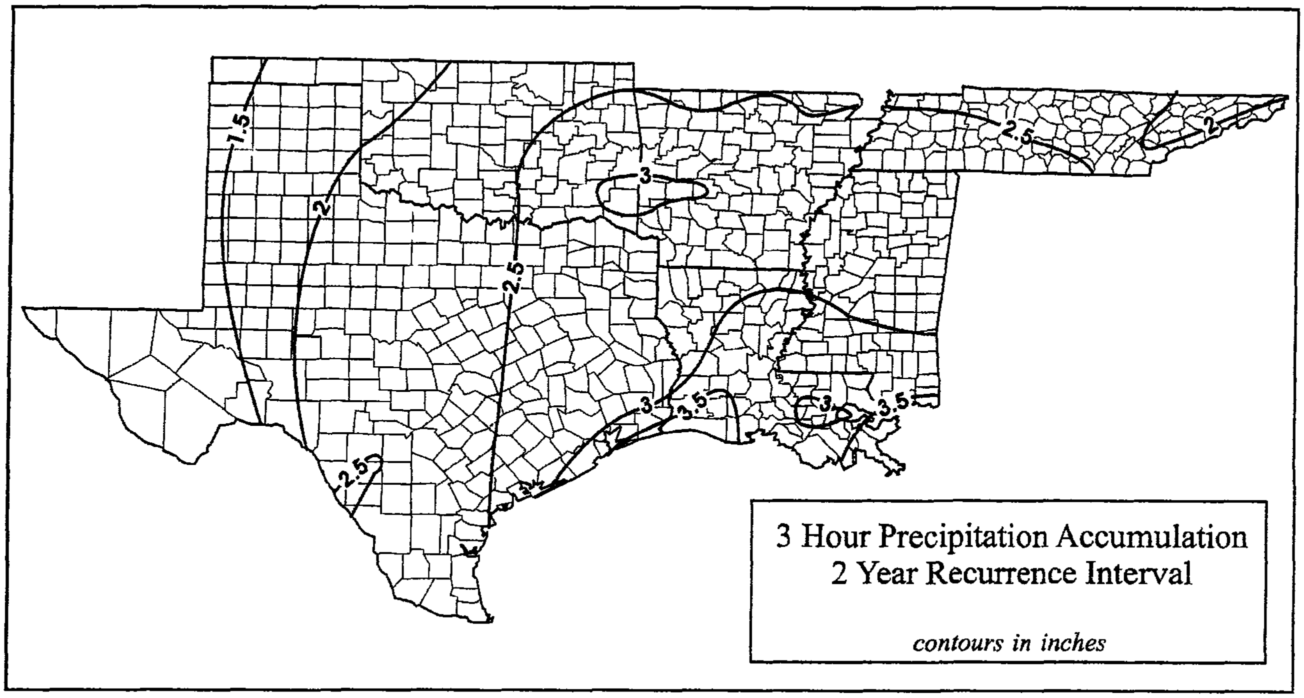

Fig. 3.1 3-hour 2-year rainfall pattern.

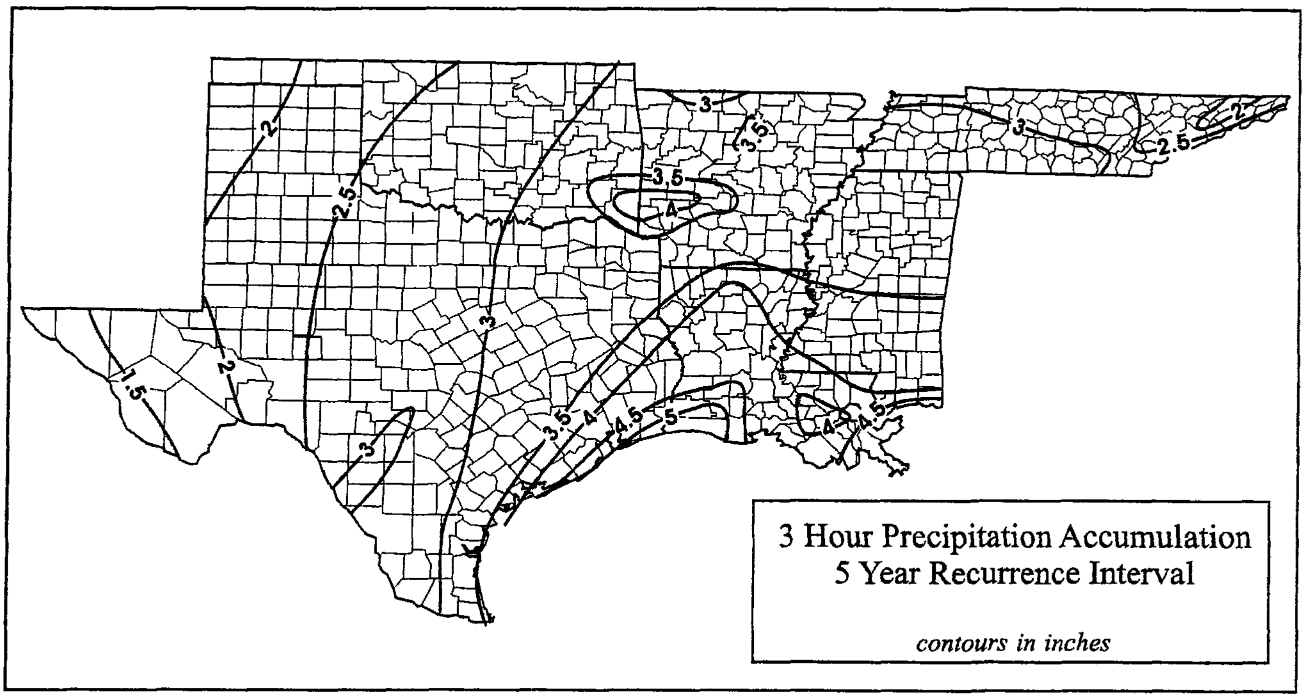

Fig. 3.2. 3-hour 5-year rainfall pattern.

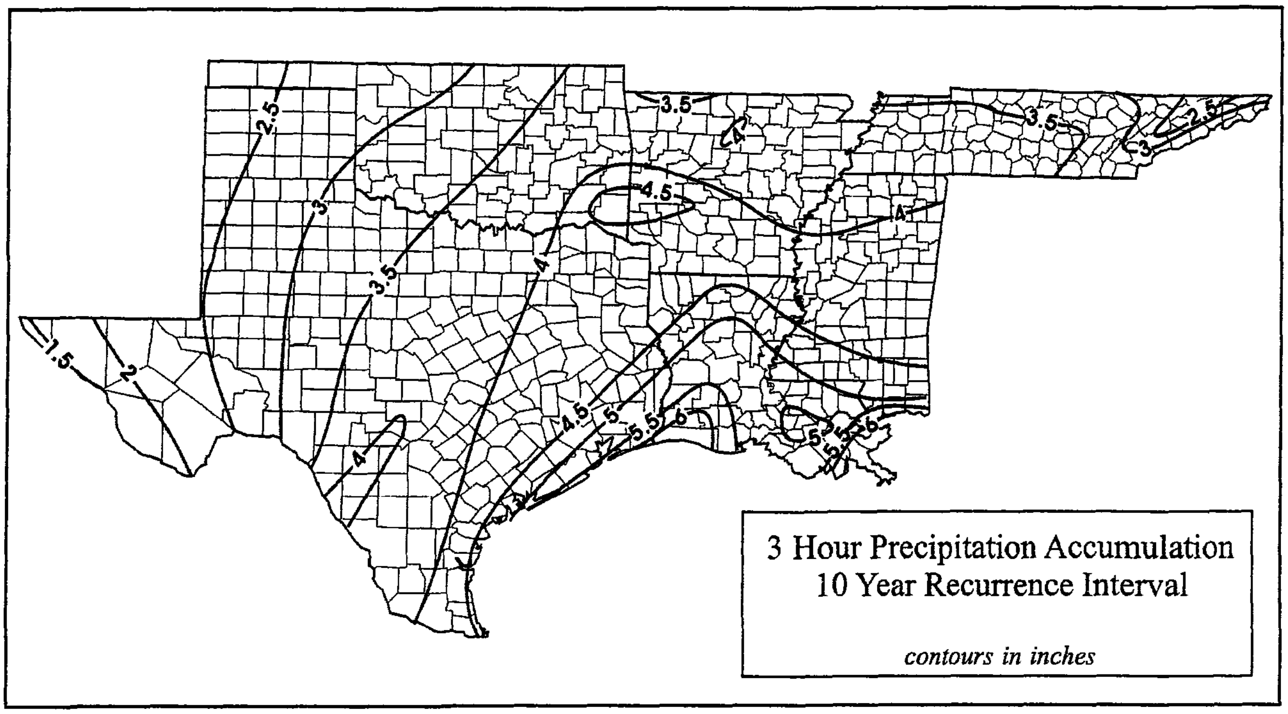

Fig. 3.3 3-hour 10-year rainfall pattern.

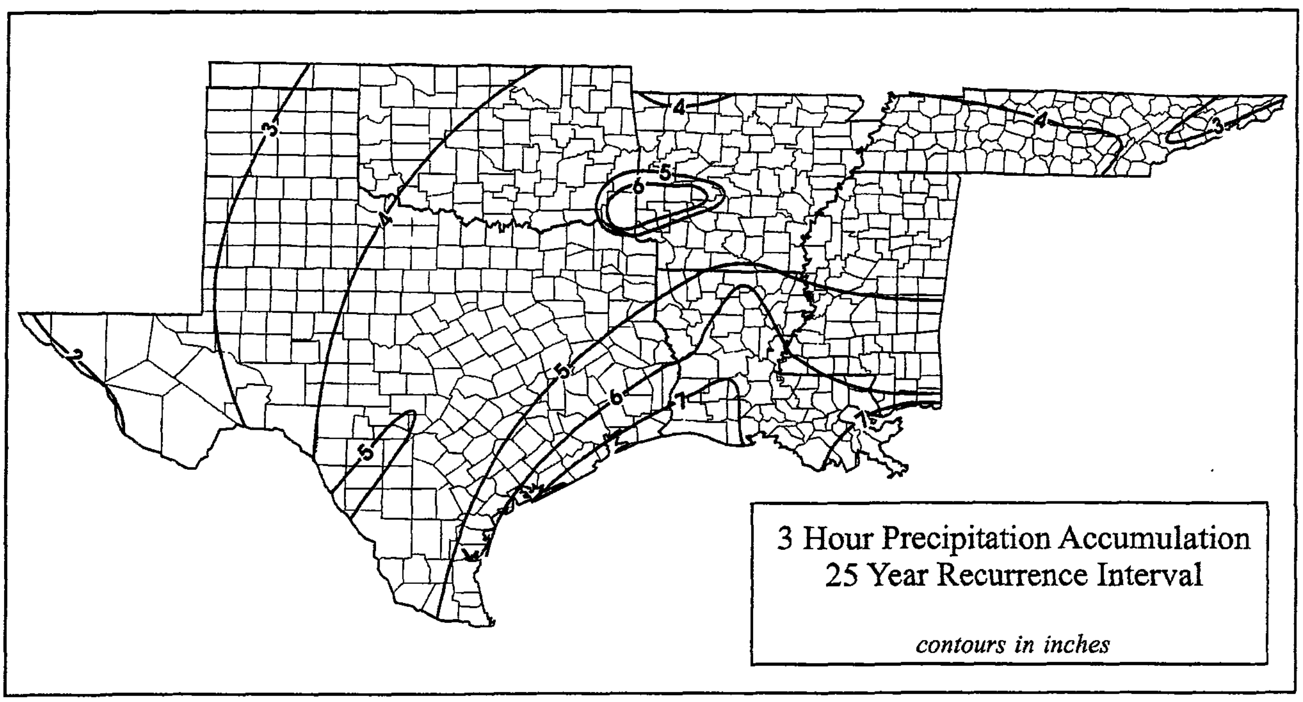

Fig. 3.4. 3-hour 25-year rainfall pattern

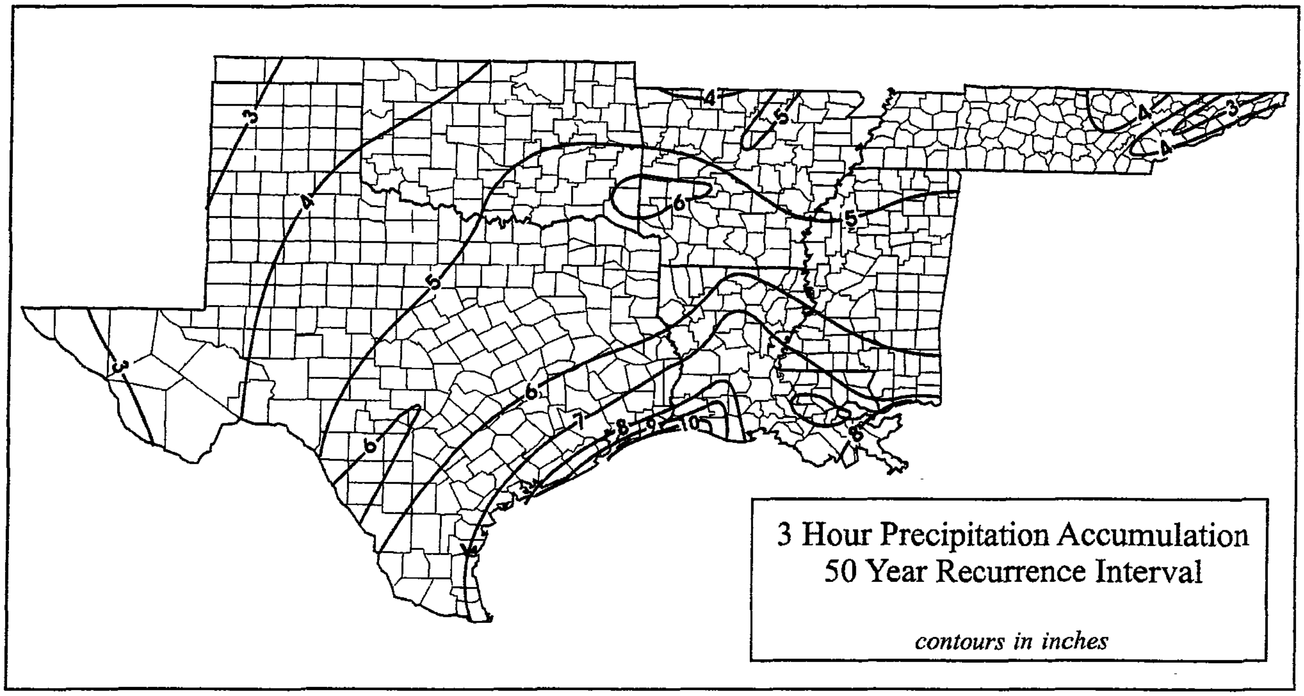

Fig. 3.5. 3-hour 50-year rainfall pattern.

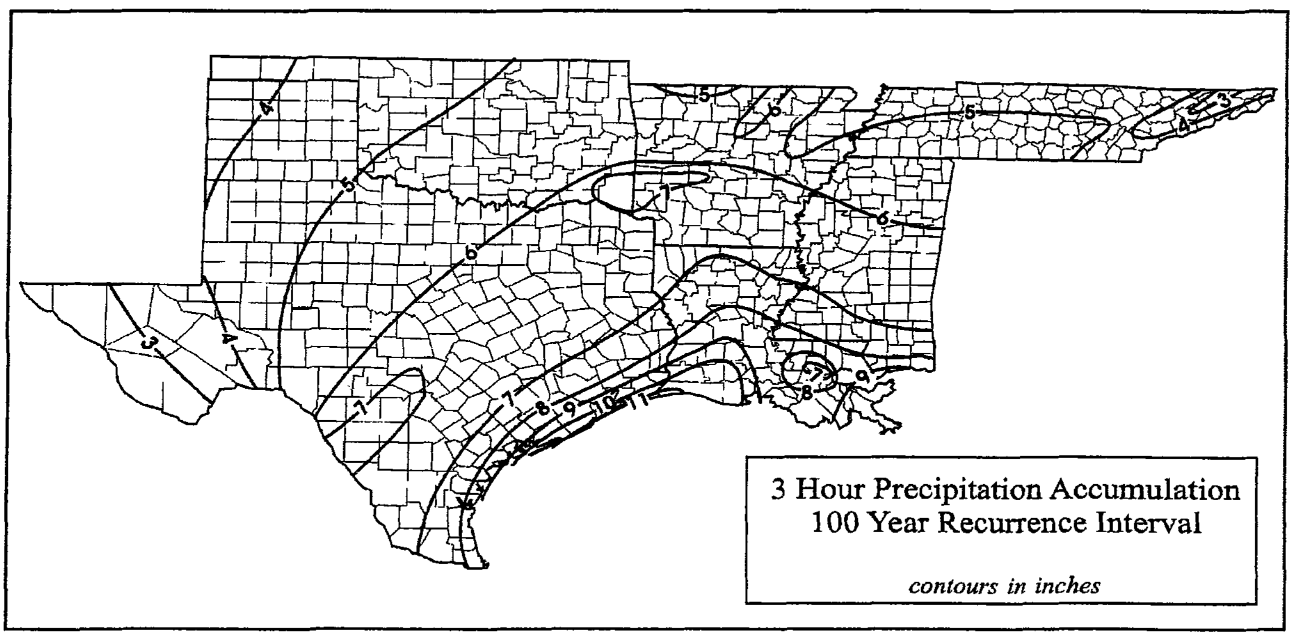

Fig. 3.6. 3-hour 100-year rainfall pattern.

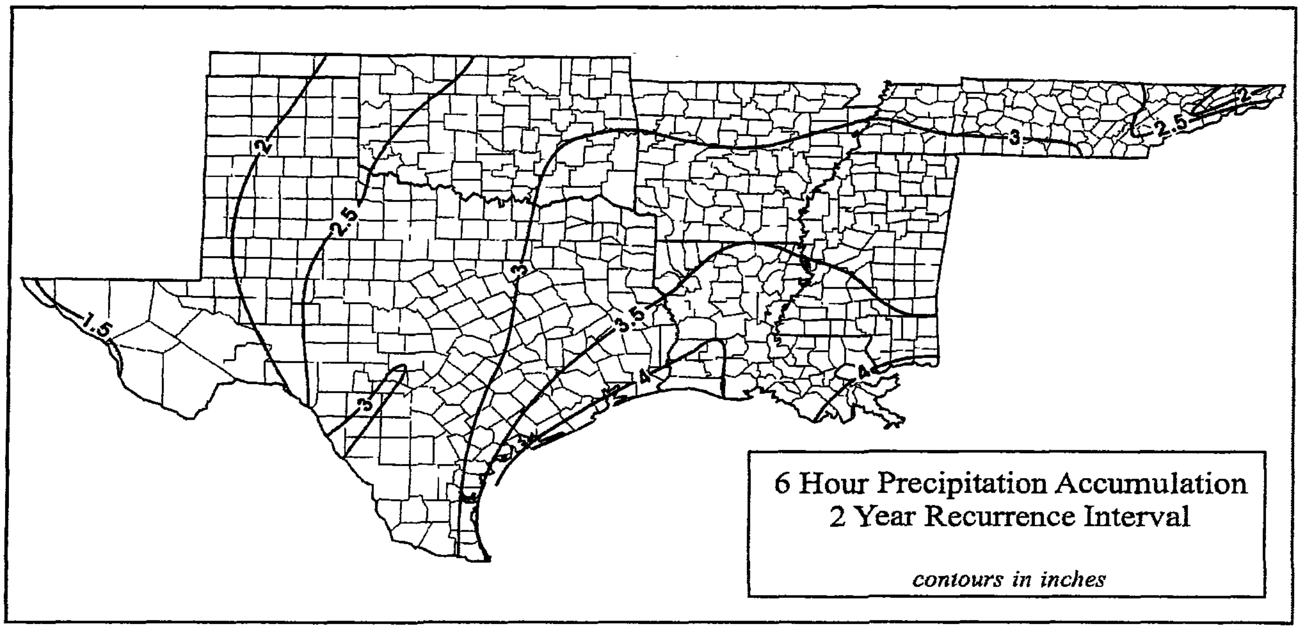

Fig. 4.1. 6-hour 2-year rainfall pattern

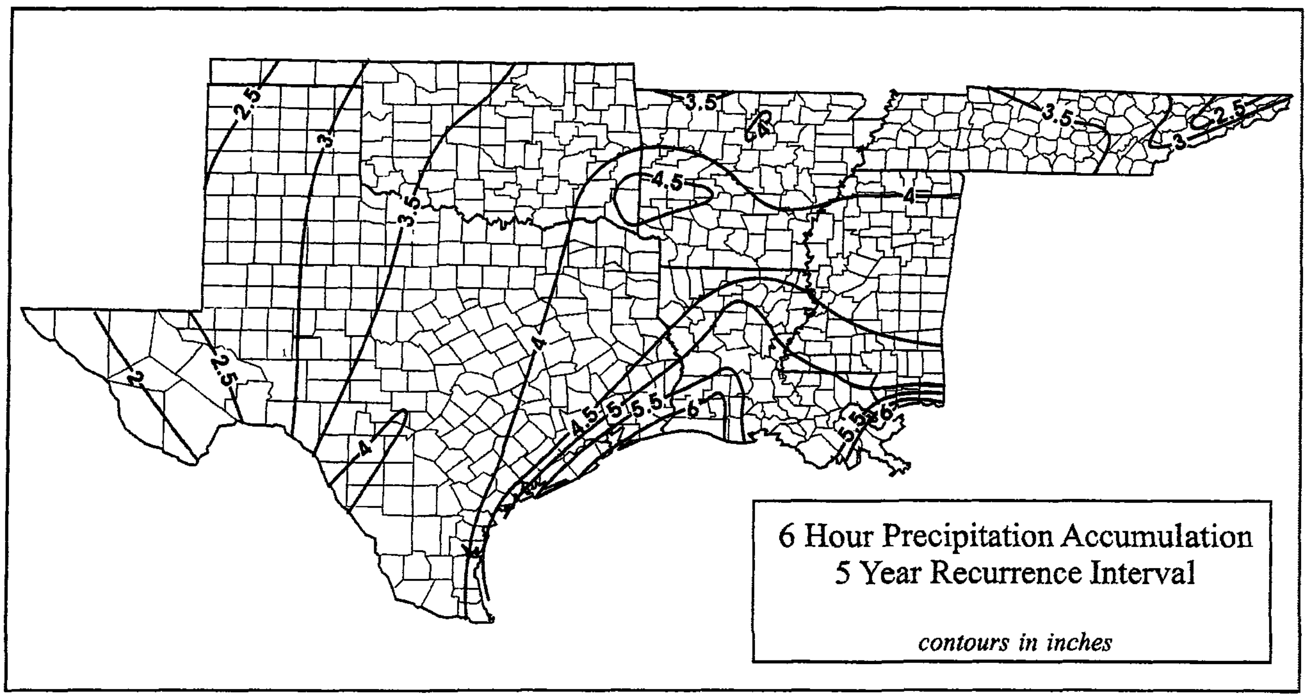

Fig. 4.2. 6-hour 5-year rainfall pattern.

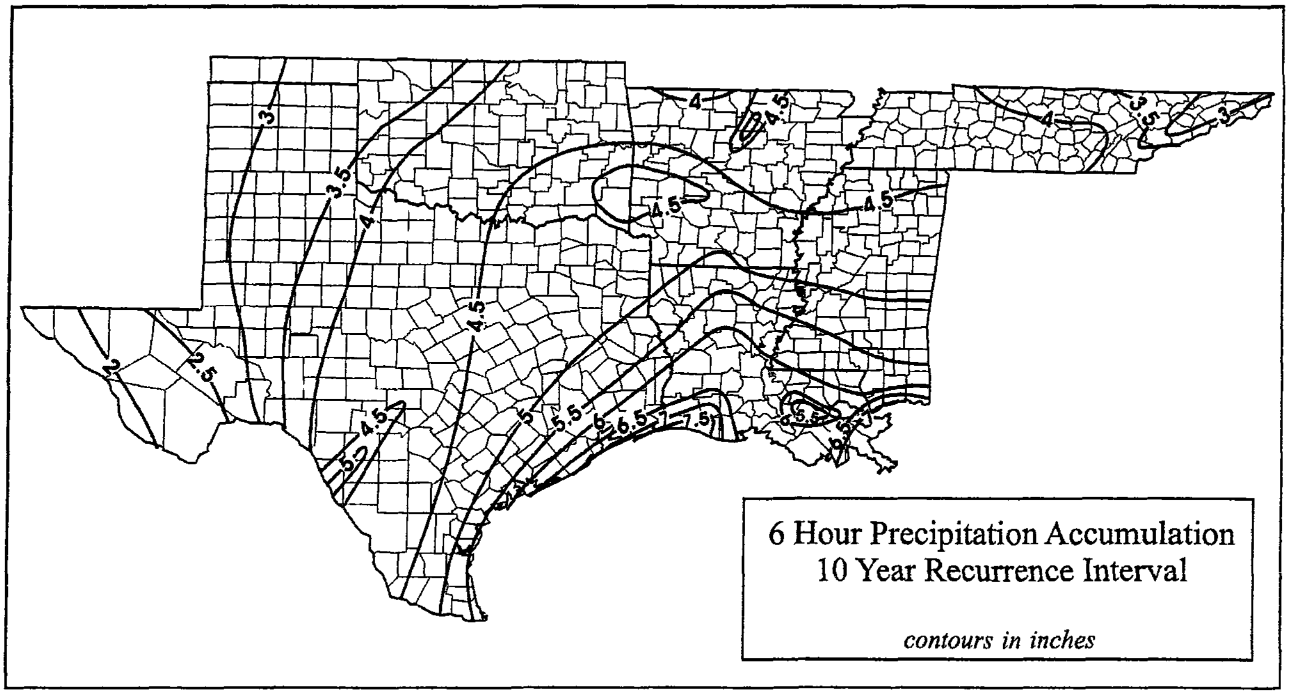

Fig. 4.3. 6-hour 10-year rainfall pattern

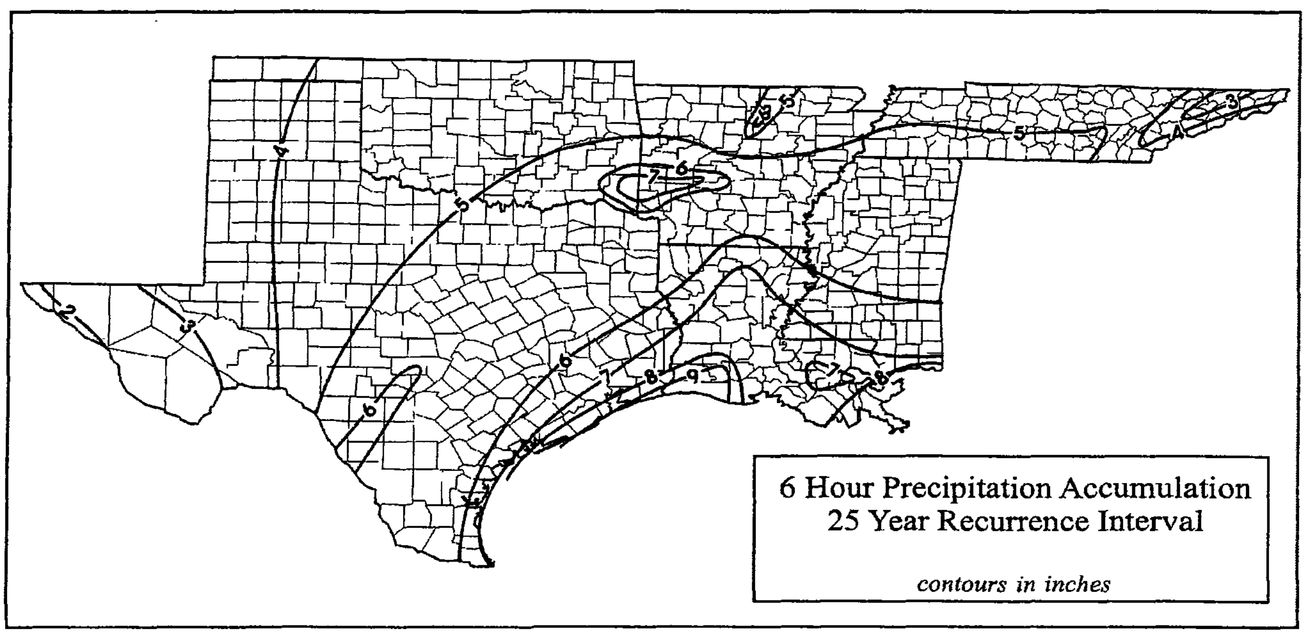

Fig. 4.4 6-hour 25-year rainfall pattern

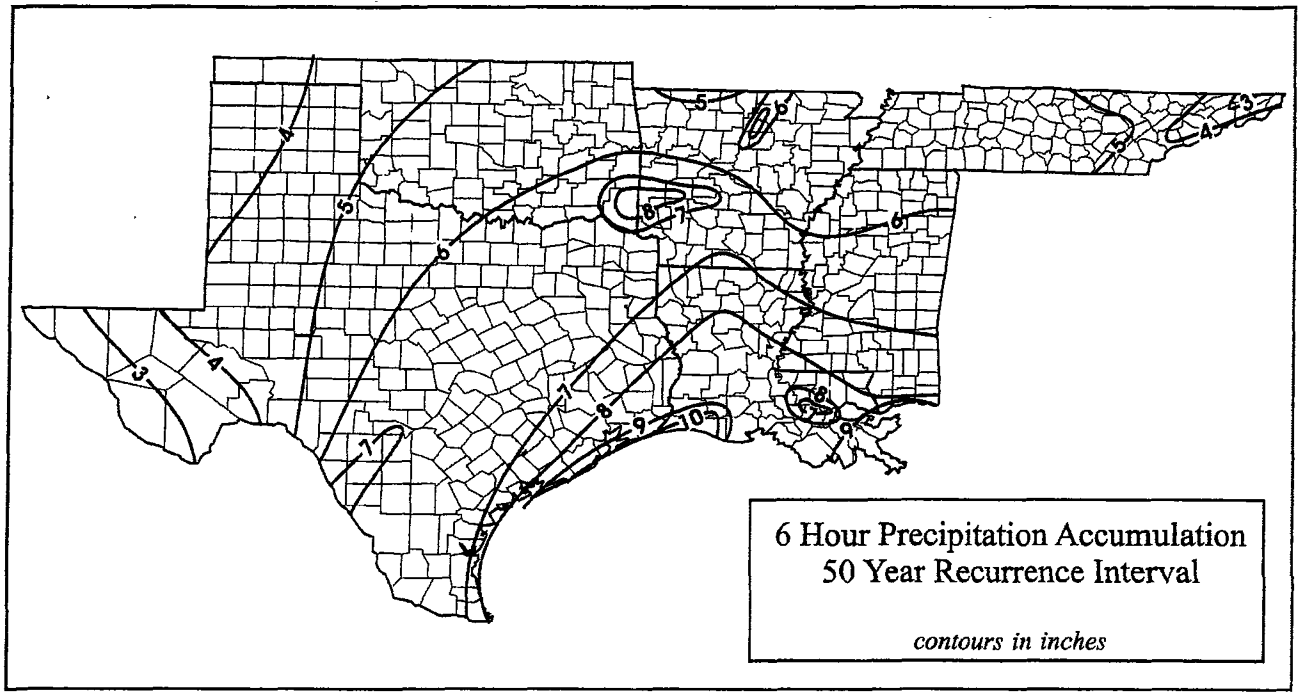

Fig. 6-hour 50-year rainfall pattern.

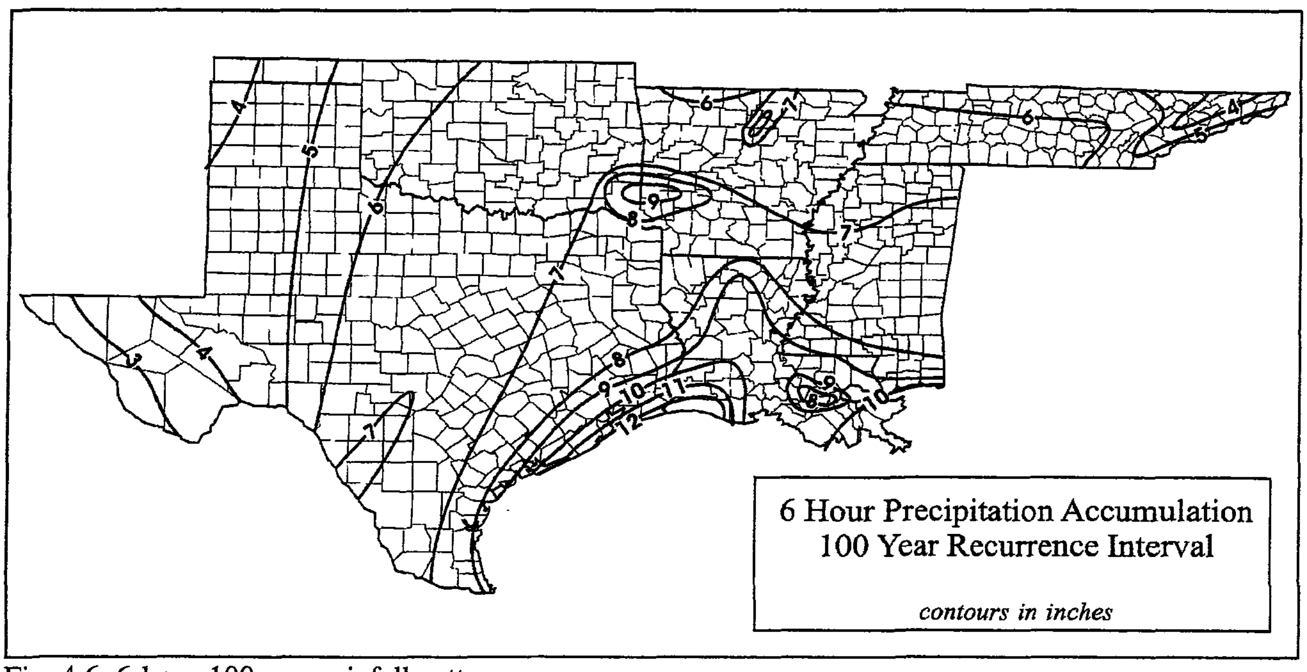

Fig. 4.6. 6-hour 100-year rainfall pattern.

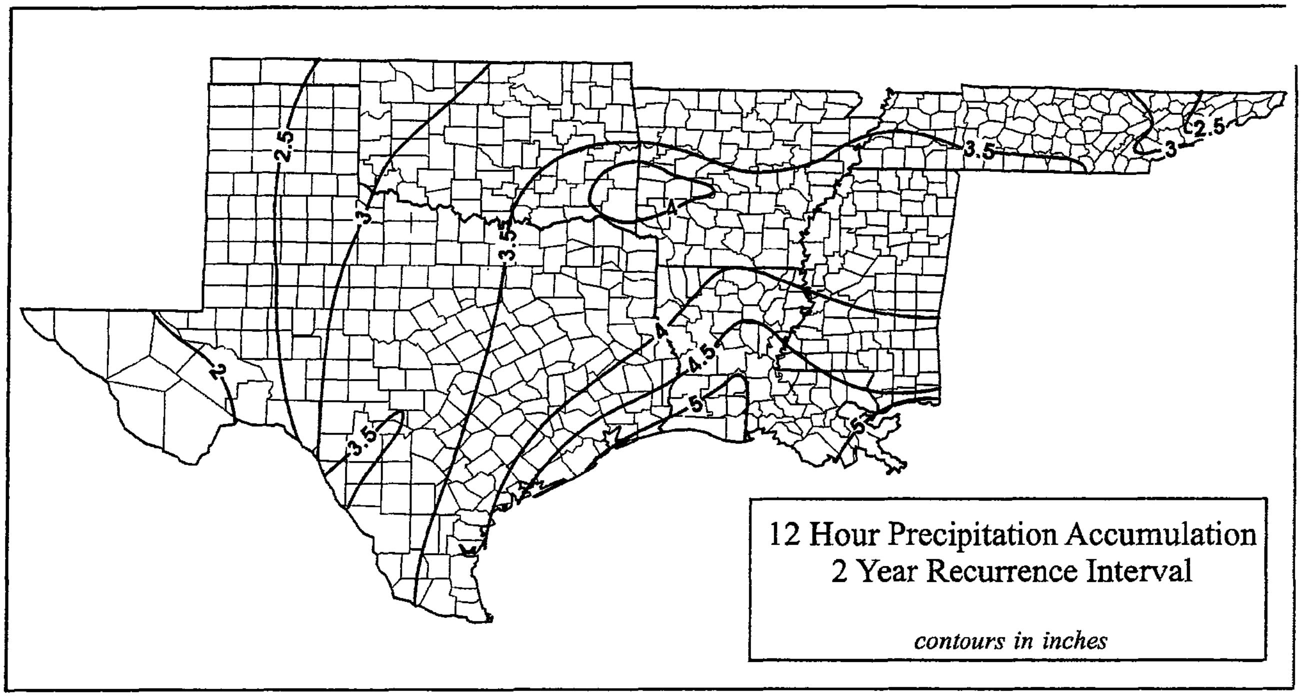

Fig. 5.1. 12-hour 2-year rainfall pattern.

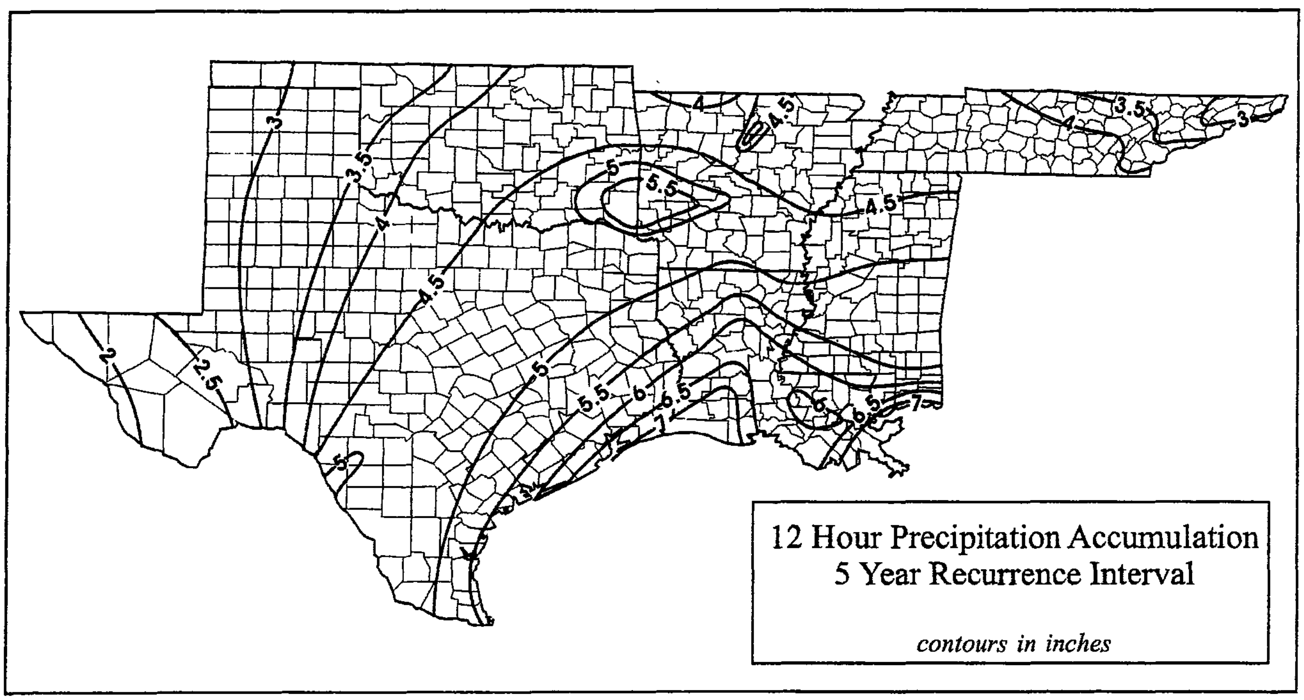

Fig. 5.2. 12-hour 5-year rainfall pattern

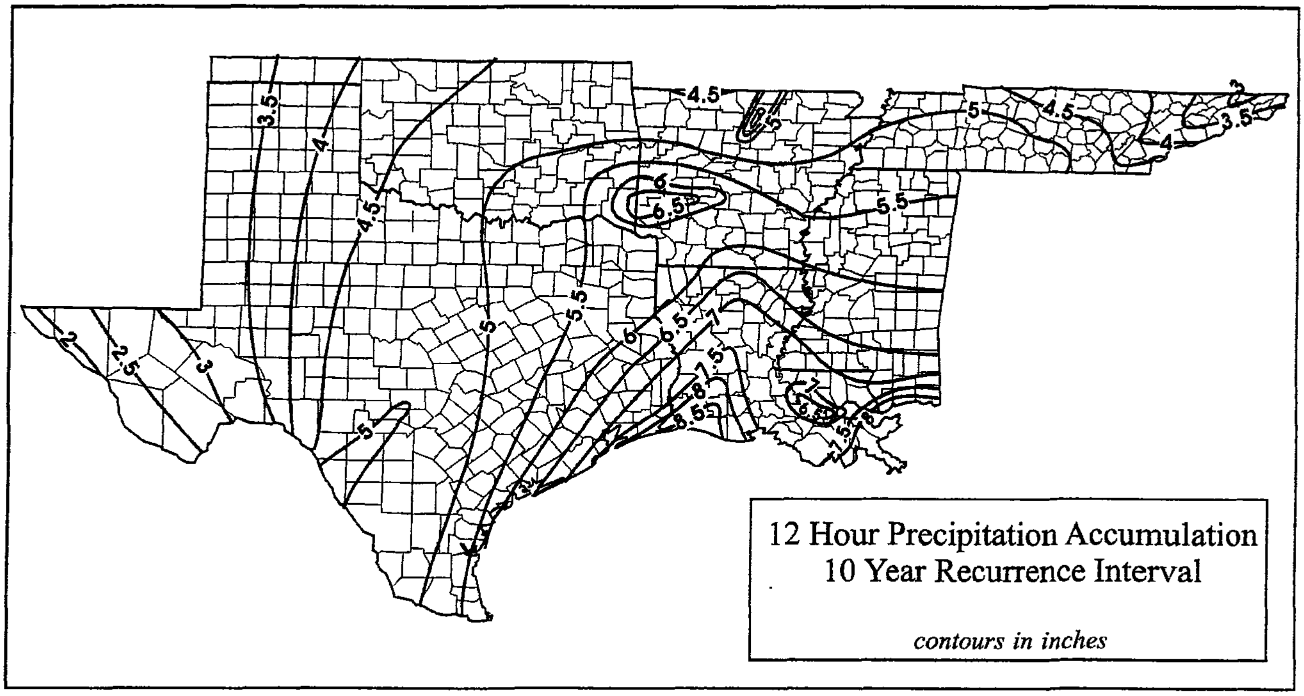

Fig. 5.3. 12-hour 10-year rainfall pattern.

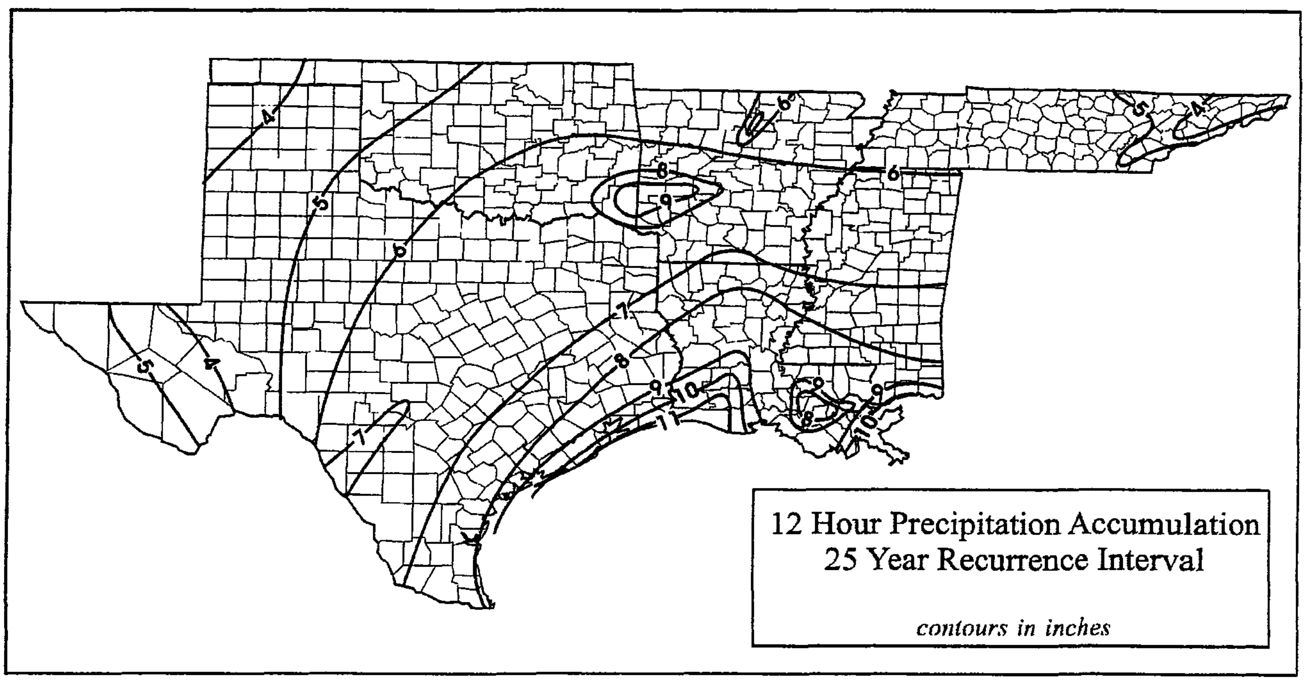

Fig 5.4. 12-hour 25-year rainfall pattern.

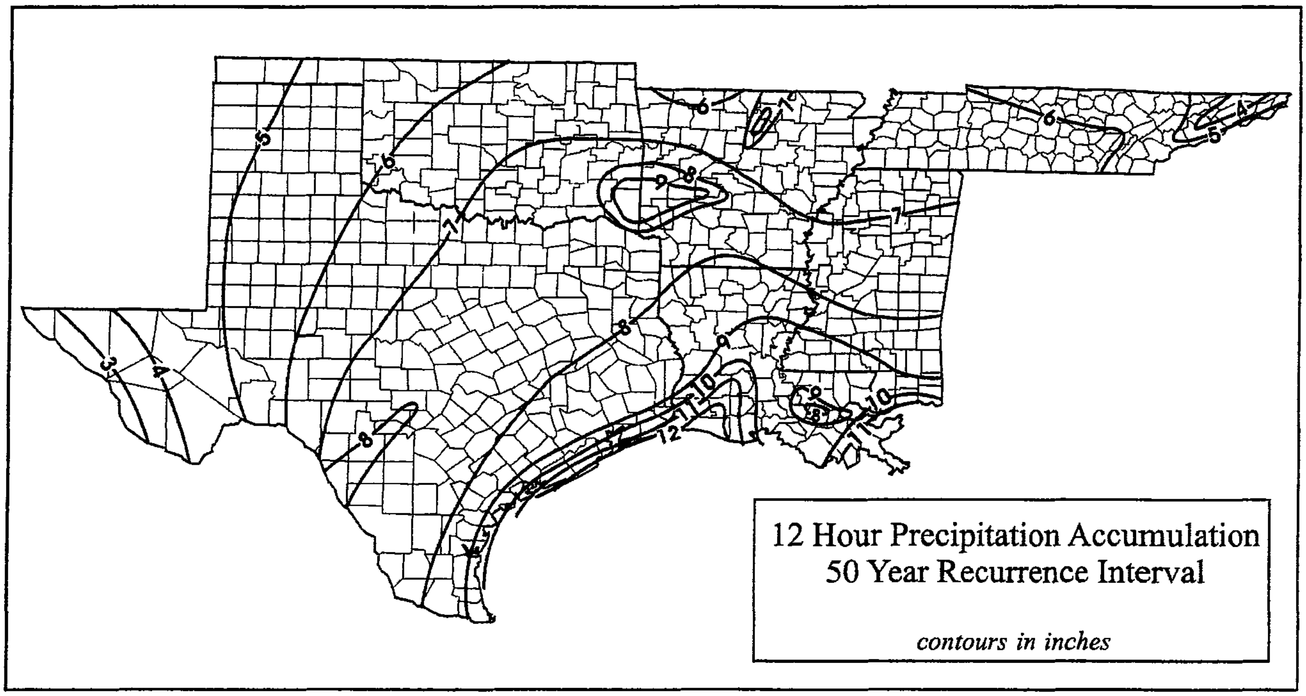

Fig. 5.5. 12-hour 50-year rainfall pattern.

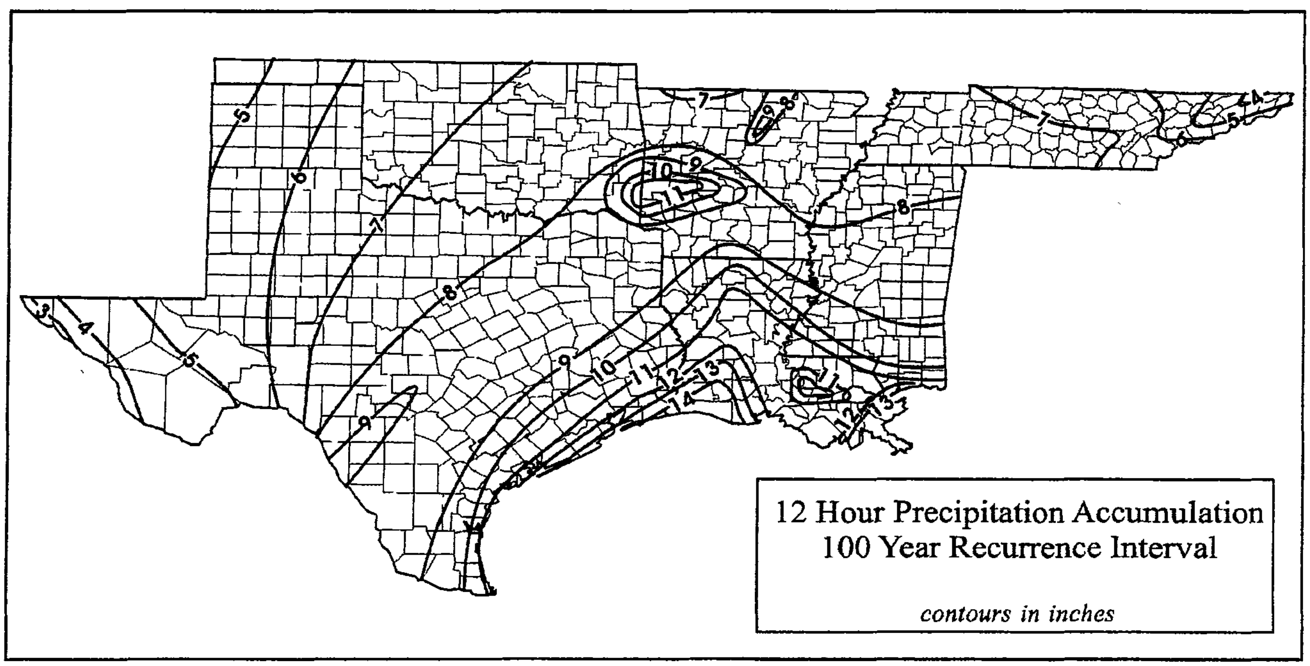

Fig. 5.6. 12-hour 100-year rainfall pattern.

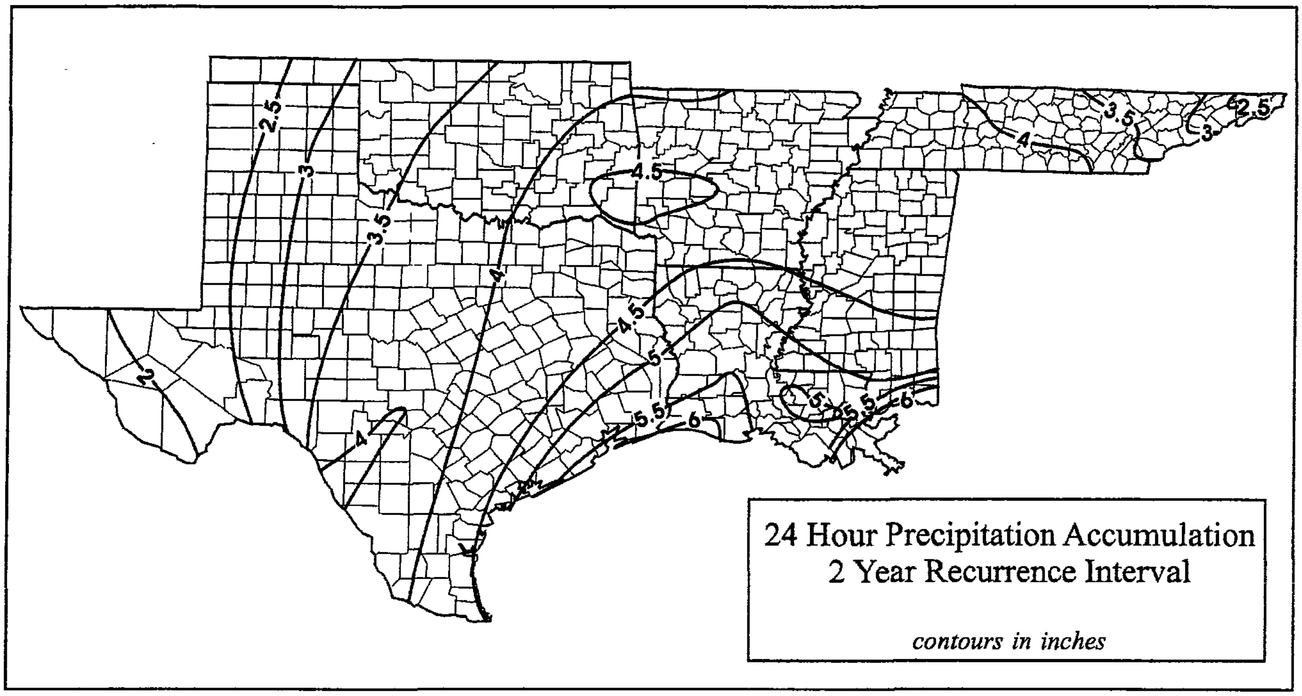

Fig 6.1. 24-hour 2-year rainfall pattern.

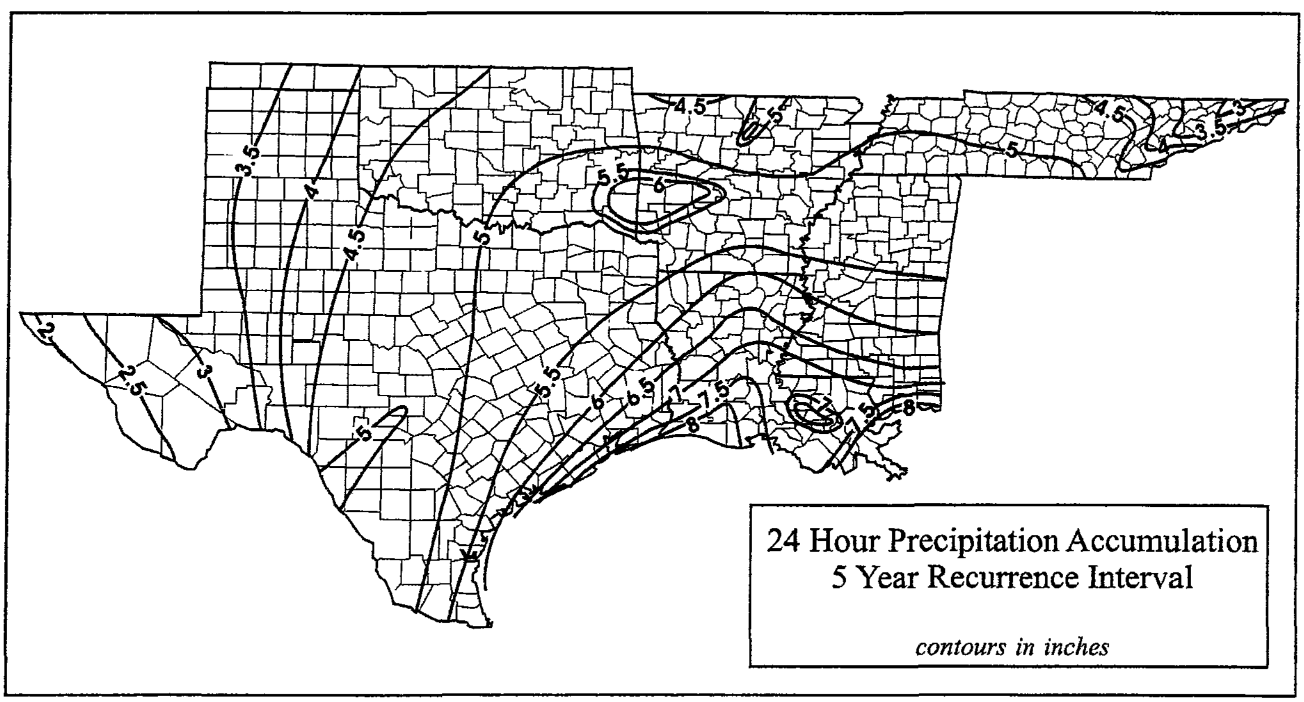

Fig. 6.2. 24-hour 5-year rainfall pattern.

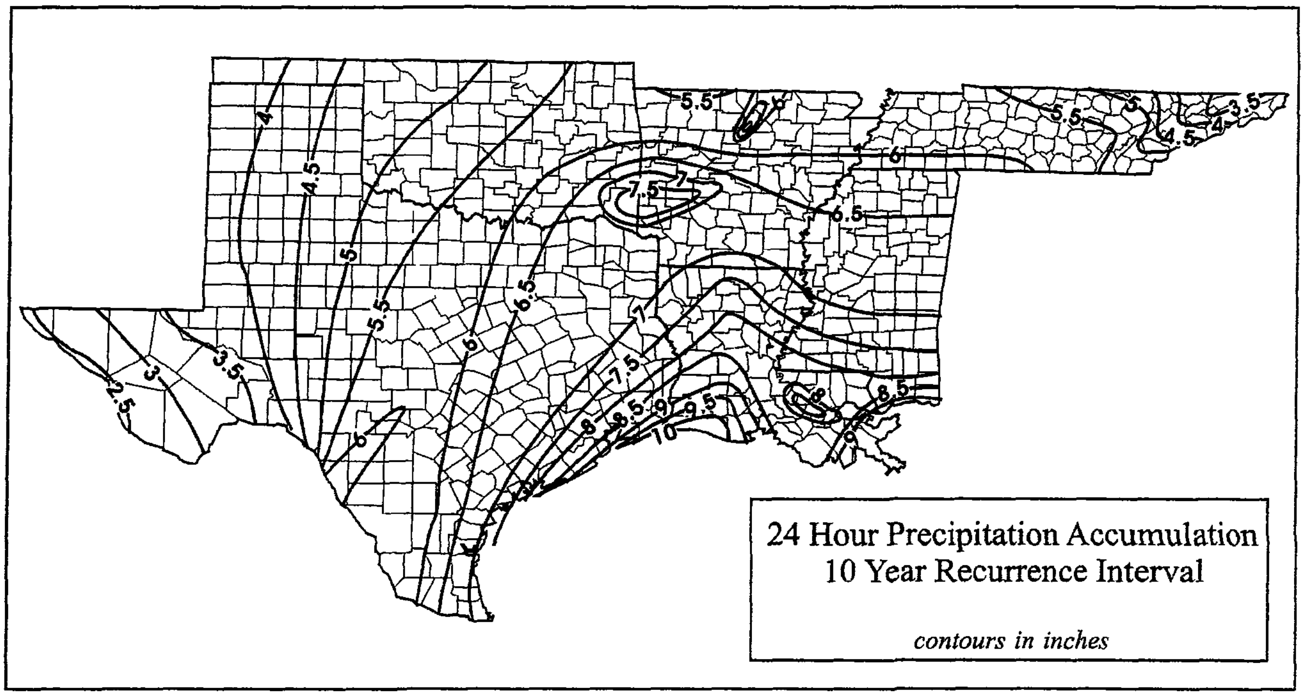

Fig. 6.3. 24-hour 10-year rainfall pattern.

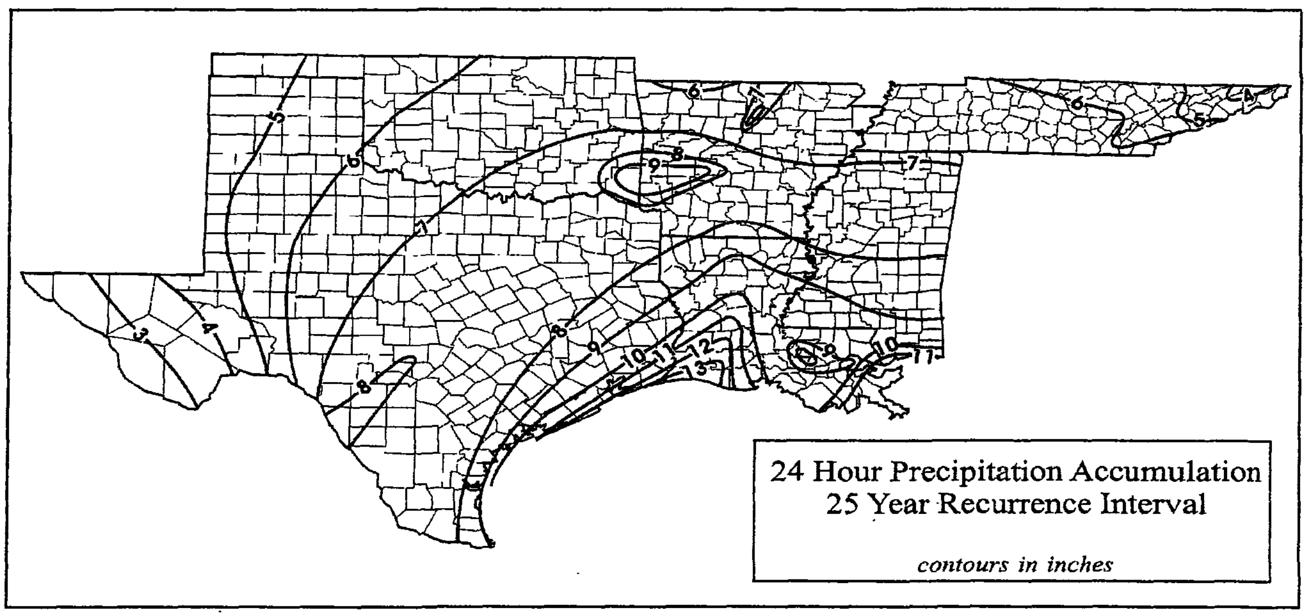

Fig. 6.4. 24-hour 25-year rainfall pattern.

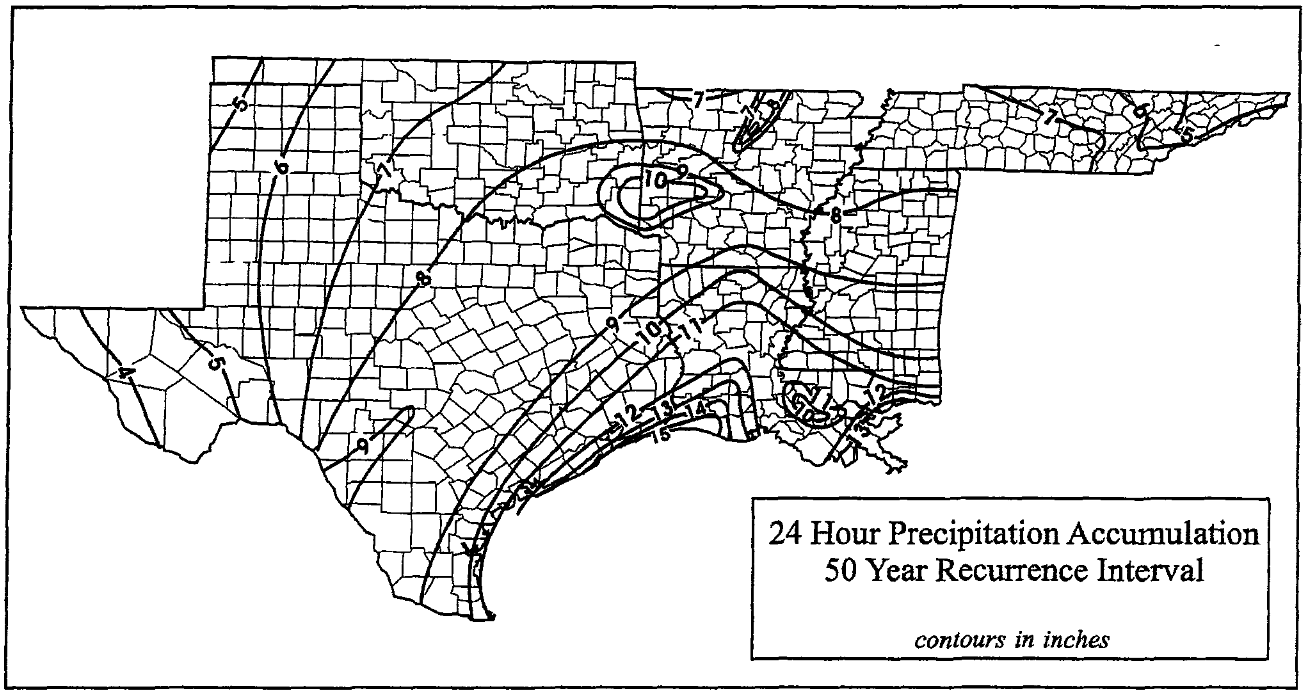

Fig. 6.5. 24-hour 50-year rainfall pattern.

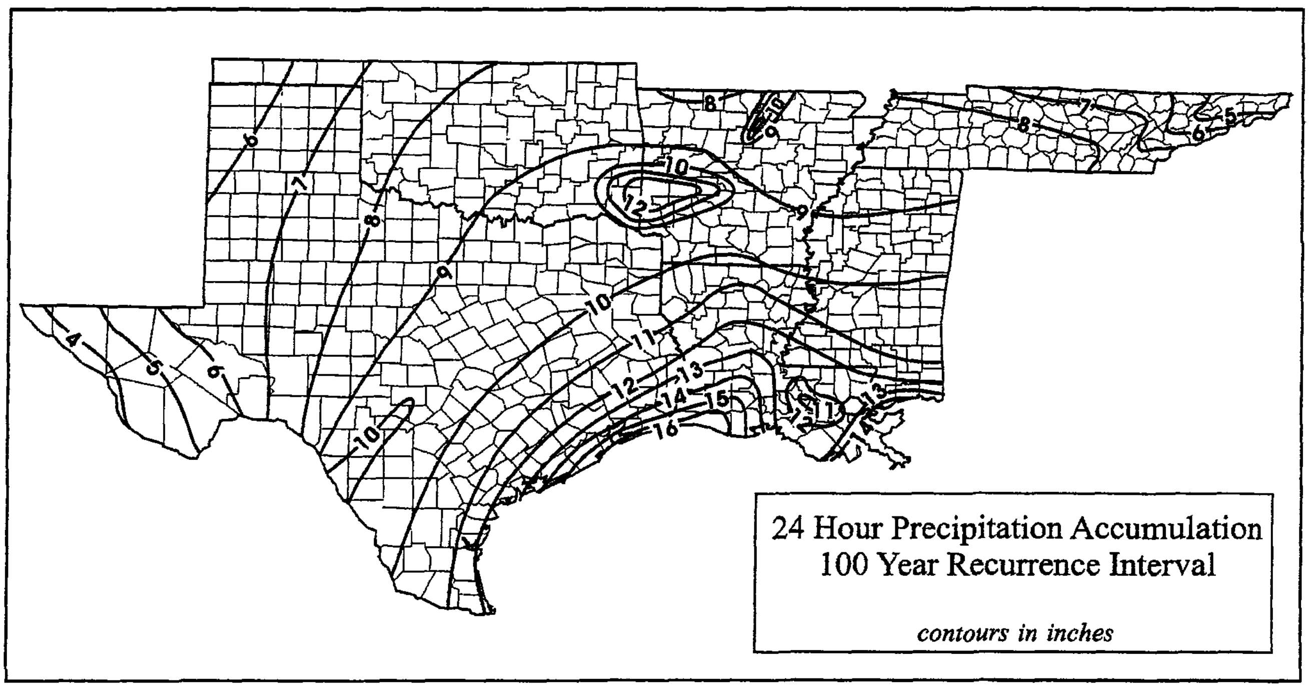

Fig. 6.6. 24-hour 100-year rainfall pattern.

APPENDIX

APPENDIX: DATA AND METHODS

Data Series

Only cooperative and first-order station data of National Weather Service (NWS) are utilized in this study. The data were organized into partial duration series (PDS). PDS were selected over annual series (AS) data because they generate more accurate exceedence probabilities in extreme rainfall analyses (Hershfield 1961; Dunne and Leopold 1978). The primary difference between these two series is that an AS includes only the largest precipitation event from every year, while PDS contain the largest events at a given site regardless of when they occur during the period of record. The difference is important because some calendar years have several extreme events which are included in the PDS, but would be excluded in an AS. Typically AS data are adjusted to PDS using coefficients (Hershfield, 1961), but use of PDS in this study made these transformations unnecessary.

Climatic variability from year to year is recognized, but there is no recognition of climatic trends or changes through the years of record. The period of record for most sites ranges from 1949 through 1991, but records at some sites began around 1930, and a few sites have data which date back into the late 1800s. Only in cases where regional anomalies were studied in detail were records with less than 40 years utilized in this research, with some records being updated through 1994 when needed.

Homogeneity of Data

Initially, PDS were extracted for the 3-hour and 24-hour series at 27 first-order sites across the region (Fig. 7). These sites were selected based upon quality of data (especially with respect to minimizing missing observations) and a minimum length of record criterion of 35 years. Each PDS for each location was then tested for homogeneity in an attempt to avoid assumption violations inherent to extreme probability statistics. In this case, an inhomogeneous PDS would contain significantly different storm magnitudes based upon varying storm characteristics, resulting in a "mixed distribution." A distribution is considered mixed when the overall 'parent" population may, in actuality, be composed of two or more subpopulations, each with its own distinct distribution" (Hirschboeck 1987b, 200). If a series of extreme rainfall contains distinctly different distributions, statistically-derived exceedence probabilities were found to contain a strong negative bias (Ekanayake and Cruise, 1994).

Previous research by Hershfield and Wilson (1960) investigated mixed distributions in extreme rainfall series in the eastern United States. This work was conducted to determine methods implemented in TP40. They found no significant differences between "tropical" and "non-tropical" extreme rainfall distributions. However, they classified tropical events as only those associated with "named" tropical storms or hurricanes, while all other events were classified as non-tropical. This method of classification has serious limitations because there are storms of tropical origin near the Gulf Coast that produce heavy rainfall but never reach tropical storm or hurricane status and were erroneously included in the non-tropical class. Furthermore, in the non-tropical classification there are at least two physically-based mechanisms (frontal and air mass) that produce heavy rainfall in the eastern United States which should be partitioned in the search for physically-based mixed distributions. Others have also investigated mixed distributions in a variety of extreme event studies (Diehl and

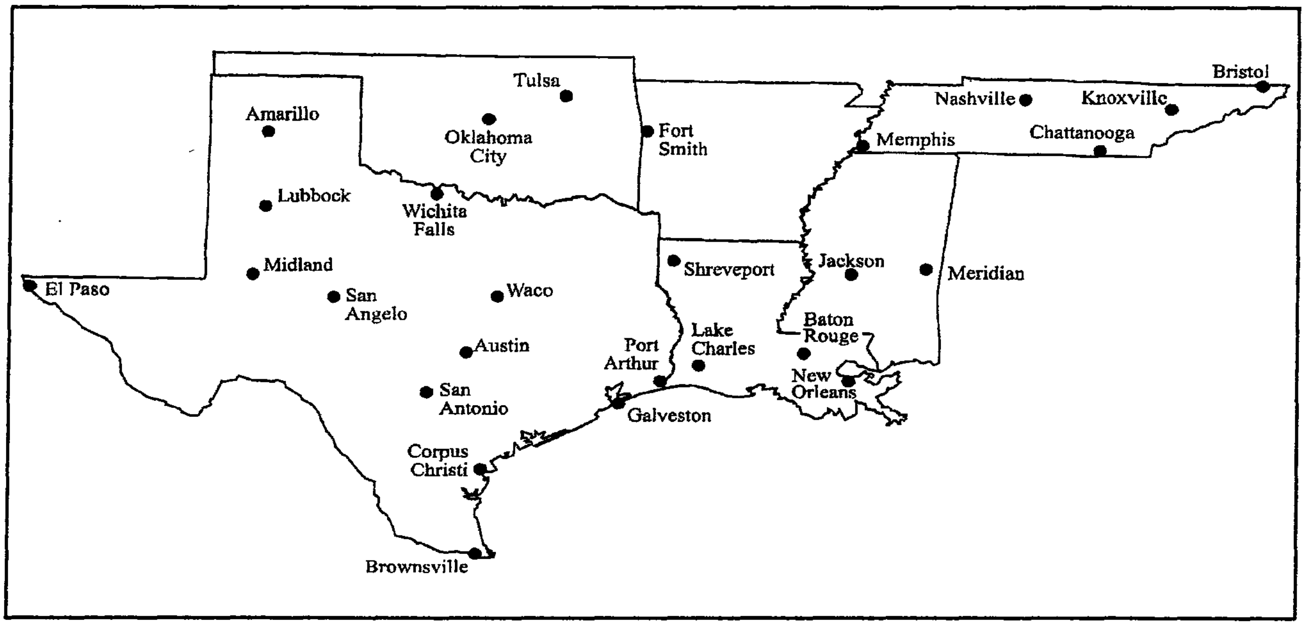

Fig. 7. Twenty-seven first-order stations of the National Weather Service.

Potter, 1987; Singh, 1987; Cruise and Arora, 1990).

To test for mixed distributions, each storm in each series was classified as frontal (FR), tropical disturbance (TD), combined frontal and tropical disturbances (FTD), and air mass (AM). Similar classifications have been utilized and described in detail in previous studies of heavy rainfall (Matsumoto, 1989; Faiers et al. 1994b;Keim and Faiers, 1996). The combined FTD category was created because these synoptic weather systems sometimes interact to produce great atmospheric instability and enhanced heavy rainfall. An analysis of these heavy-rainfall producing classes allow for the determination of whether extreme rainfall events of different origins can be pooled together as members of the same probability distribution across the South Central United States.

To determine statistically whether there are differences between the magnitudes of the storms by synoptic weather types, the Kruskal-Wallis one way non-parametric analysis of variance test (Barber 1988), an extension of the Mann-Whitney test, was used. In situations when data are censored at a fixed point (as is the case with these data), Bradley (1968) recommends use of the Mann-Whitney test and that the truncated data be accounted for using a technique developed by Halperin (1960). However, this modification is only accurate if no more than 75% of the population is censored. Clearly, in the analysis of extreme rainfall events, well over 75% of rain events are censored from the samples, making the recommended adjustment inappropriate. This adjustment was found appropriate for analysis of flood data, but has never been applied to the analysis of extreme rainfall because of the large percentage of censored rainfall events. Therefore, the unadjusted Kruskal-Wallis test was used and potential errors in the results were recognized.

Table 1 shows the Kruskal-Wallis test for statistics and probabilities for 3-hour and 24-hour storm distributions at the 27 NWS sites across the region. Only 26 sites are shown in each table because, in both cases, there was one station which had all of its series produced by one weather type. None of the 24-hour series indicated mixed distributions. However, four sites, Chattanooga, Galveston, New Orleans, and San Angelo, have significantly different distributions at the .05 level in the 3-hour series. These differences result from the fact that there are more air mass storms in the shorter duration events, and these storms tend to be clustered on the lower end of the distributions. Given that only four of the 27 sites indicate the presence of mixed distributions, the region-wide data were treated as though they were homogeneous, and pooling together storms produced by these various mechanisms does not produce the negative bias an noted by Ekanayake and Cruise (1994).

Deriving Quantile Estimates

Since no mixed distribution problems exist in the PDS for the region, valid quantile estimates can be derived. To derive the quantiles several probability distributions and other techniques were investigated to determine the best single method for region-wide implementation. Random sampling using PDS across the region produced highly varied results. To demonstrate these differences, a pilot study of the arid Trans-Pecos climate division (Fig. 8) was undertaken. This was conducted to evaluate the performance of four commonly used probability distributions, in addition to the Huff-Angel log-log regression method wich was used to create the *Rainfall Frequency Atlas of the Midwest* (Huff and Angel, 1992) and a related semi-log regression method developed at the SRCC. The four additional probability distributions used to fit the PDS include the Generalized Extreme Value (GEV), Three Parameter Log Normal (3PLOGN), Log Pearson Type III (LOGP III), and Wakeby. Daily rainfall records at 24

Table 1. Kruskal-Wallis Probabilities of "Mixed" Rainfall Distributions.

LOCATION	3-HOUR K-W STATISTIC AND P.		24-HOUR K-W STATISTIC AND P.	
AMARILLO	1.85	.17	----	----
AUSTIN	5.27	.15	3.06	.22
BATON ROUGE	2.77	.43	6.92	.07
BRISTOL	3.84	.28	6.34	.10
BROWNSVILLE	2.28	.52	3.03	.39
CHATTANOOGA	8.62	.03	2.41	.12
CORPUS CHRISTI	3.81	.28	6.54	.09
EL PASO	2.10	.55	3.19	.36
FORT SMITH	1.30	.52	3.86	.28
GALVESTON	9.97	.01	6.53	.09
JACKSON	1.09	.78	5.53	.14
KNOXVILLE	1.09	.58	0.21	.65
LAKE CHARLES	1.08	.78	5.08	.17
LUBBOCK	1.63	.44	5.42	.14
MEMPHIS	5.12	.16	1.28	.53
MERIDIAN	3.55	.31	2.10	.35
MIDLAND	5.49	.14	0.67	.88
NASHVILLE	1.17	.56	0.32	.85
NEW ORLEANS	7.62	.05	1.29	.52
OKLAHOMA CITY	0.43	.81	0.50	.78
PORT ARTHUR	1.32	.73	5.88	.12
SAN ANGELO	6.37	.04	3.66	.16
SAN ANTONIO	0.41	.81	0.56	.90
SHREVEPORT	----	----	2.49	.48
TULSA	0.77	.68	2.04	.36
WACO	1.23	.75	3.73	.29
WICHITA FALLS	2.92	.23	3.35	.19

cooperative stations of the NWS in the Trans-Pecos climate division (Fig. 8) provided the data necessary to derive the extreme rainfall frequency-magnitude relationships. These selected sites have record lengths between 30 and 74 years, while most are approximately 45 years in length, beginning in the late 1940s and continuing through 1991. PDS were extracted from these daily records.

Each of the six methods were fit to the PDS data using the Weibull plotting position formula:

$$P = R/n + 1$$

where P = probability, R = rank of the storm (where the largest storm = 1), and n= the number of storms in the series (which is based on record length). To determine which method provided the best fit to the Weibull plotting positions, the quantile estimates from each method for the 1-,2-,5-,10-, 25-, and 50-year storms were tested against the plotting positions, the quantile estimates from each method for the 1-,2-,5-, 10-,25-, and 50-year storms were tested against the plotting positions using linear regression and determining the mean square error. The fitting procedure only analyzed recurrence intervals up to the length of the record under examination since recurrence intervals beyond the length of record cannot be derived using the Weibull plotting position formula. For example, the longest record included in this analysis is only 74 years, and return periods up to 75 years (due to the +1 in the numerator of the Weibull formula) were included in the analysis for that site because there are no plots beyond 75 years. This

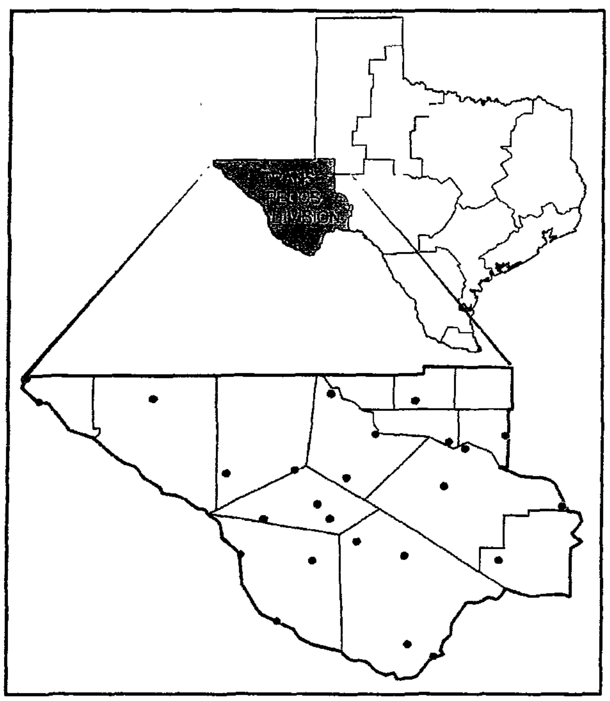

Fig. 8. NWS cooperative stations in the Trans-Pecos climate division of NWS.

technique for determining "best fit" is

commonly used in evaluating frequency-magnitude relationships (Bobee and Robitaille, 1976; Naghavi et al., 1991; Huff and Angel, 1992).

In addition to the probability distributions, the Huff-Angel estimates were derived by determining the base common logs for each of the PDS storm magnitudes and the Weibull estimated quantiles and performing linear regression between these values. In the SRCC method, the only recurrence intervals were logged and linear regression was used again to determine the relationships and allow for the estimation of storm quantiles. The SRCC method is therefore very closely related to the Huff-Angel method.

In the pilot study of the Trans-Pecos climate division, daily cooperative station data were used because of the use of daily cooperative station data in the final analysis of the entire region. Storm estimates based on observational daily records (observations made once every 24 hours, with the hour of observation varying from station to station) were increased by 13 % to make them equivalent to 24-hour moving-window storms (rather than storms based on discrete observational days). Shortcomings of the hourly data records make their utilization less desirable for extreme rainfall studies (Faiers et al., 1994a), thereby making the 1.13 adjustment necessary. This coefficient is becoming standard since it was found to be appropriate across the United States (Hershfield, 1961), in the Midwest (Huff and Angel, 1992), in Louisiana (Faiers et al., 1994a) and SRCC research indicates that it fits across the South Central United States.

In most instances, the mean square error for the four probability distributions were small ranging from .0009 inches (3PLOGN at El Paso) to .3545 inches (GEV at Sanderson). No single distribution performed well at all sites, with every distribution being the worst fit at one site or more. Wakeby and LOGP III fit the observed data across the region most adequately (Table 2). Wakeby was the best fit at 10 sites while LOGP III fit best at six sites. However, the LOGP III distribution was the second best fit at many sites (14) causing it to have almost the same cumulative rank as Wakeby for all sites collectively. The 3PLOGN distribution was the best fit at four sites but did not perform well at many others, while finishing last at six sites. The GEV fit best at four sites but this distribution reacted very strongly to outliers at some sites causing the 50-year and 100-year estimates to be far too large in our best estimation. No geographic pattern was evident in regard to where particular distributions fit best.

Given that no single probability distribution clearly fit the extreme rainfall data from this region, the alternative method developed by Huff and Angel (1992) was investigated. The Huff-Angel method was found to adequately estimate the 1-, 2-, 5-, and 10-year storms in the Trans Pecos, but at sites with extreme outliers this method produced 50- and 100-year quantile estimates which appear excessively large. For example, locations such as Crane and Red Bluff Dam in the northeastern part of the Trans-Pecos have 24-hour 100-year Huff-Angel estimates in excess of 10 inches (Figs. 9 and 10). In TP40, for example, the 10-inch, 100-year storm isohyet is located east of Austin and San Antonio.

Using the semi-log method developed at the SRCC, the excessively large estimates of the Huff-Angel method at the longer recurrence intervals are reduced in this arid environment. For example, in Figures 9 and 10 the 100-year events at Crane and Red Bluff Dam by Huff-Angel are slightly greater than 10 inches, but the SRCC method lowers the 100-year recurrence interval magnitude to slightly less than 8 inches at both sites. Similar excessively large results for the 50- and 100-year estimates were also found using the Huff-Angel method is coastal Louisiana. The SRCC method again decreased these extremes to more climatically appropriate values. For these reasons, the SRCC method was selected to produce the quantile estimates across the South-Central United States, using daily data from 654 NWS cooperative stations across the region (Figure 11).

Table 2. Ranks of Probability Distributions for Trans Pecos Stations, Texas.

LOCATION	GEV	3PLOGN	LOGP III	WAKEBY
Alpine	3	4	2	1
Balmorhea	4	3	2	1
Boquillas	4	2	3	1
Candelaria	2	1	4	3
Chisos Basin	4	2	1	3
Cornudas SS	3	1	2	4
Crane	4	3	2	1
El Paso	2	1	3	4
Fort Davis	4	3	2	1
Fort Stockton	4	3	2	1
Grandfalls	1	4	3	2
Imperial	4	3	1	2
Kent	3	1	4	2
La Tuna	4	3	1	2
Marathon	1	4	2	3
Mount Locke	4	3	2	1
Pecos	3	4	2	1
Presidio	1	4	2	3
Red Bluff Dam	4	3	2	1
Sanderson	4	3	2	1
Sheffield	3	4	1	2
Valentine	4	3	1	2
Van Horn	1	3	2	4
Wink	4	3	1	2
SUM	75	68	49	48

GEV= Generalized Extreme Value
3PLOGN = 3 Parameter Log Normal
LOGP III = Log Pearson Type III
WAKEBY

Three-, Six-, and Twelve-Hour

It would be ideal to extract and analyze 3-, 6-, and 12-hour storms derived from continuous hourly observations. However, because of the limited number of hourly data sets, and frequently missing data during very heavy rainstorms, relationships between short-duration and adjusted daily durations were derived. This derivation of short duration storms from daily storms has proven expeditious in previous studies (Hershfield, 1961; Huff and Angel, 1992). To derive the shorter duration storms, the frequency-magnitude relationships of 3-,6-, and 12-hour storms to 24-hour storms at the NWS first-order station sites in Figure 7 were calculated, and ratios of the 3-,6-, and 12-hour storms relative to the 24-hour storm magnitudes for each recurrence interval were determined for each location.

While some regional variation in ratios was found, average region-wide ratios were determined and applied for each duration (Table 3). The most significant geographic anomaly to these ratios was detected across western Texas where short duration storms (especially 3-hour) are often close to the 24-hour values. Hence, these region-wide average ratios will underestimate the shorter duration quantile estimates in this region.

This because of the propensity for short, intense bursts of heavy rainfall, but with relatively few longer-duration rainstorms associated with midlatitude cyclones and fronts. As a result, there is an atypically large number of short-duration storms included in the longer duration PDS. The ratios of the 3-to 24-hour storms tend to decrease eastward across Texas with the lowest 3-hour ratios for the region found in southeastern Texas. There, the three hour storms were found to be just under 50% of the corresponding 24-hour storm magnitudes. Elsewhere, no consistent regional patterns emerged.

Table 3. Average Ratio of 3-6-12-Hour/24-Hour Rainfall.

DURATION (IN HOURS)	*RATIO (3-6-12-HOUR/24-HOUR)*
12	.88
6	.74
3	.62

Storms Shorter Than Three Hours

One primary difference between this new atlas and TP40 is that storms of durations shorter than 3-hours were not examined. Precipitation data for durations less than one hour are severely limited in availability and mapping such data at this scale was impractical. Without region-wide availability of minute-by-minute precipitation data, relationships between discrete hourly data and 60-minute moving-window data were unattainable for the region.

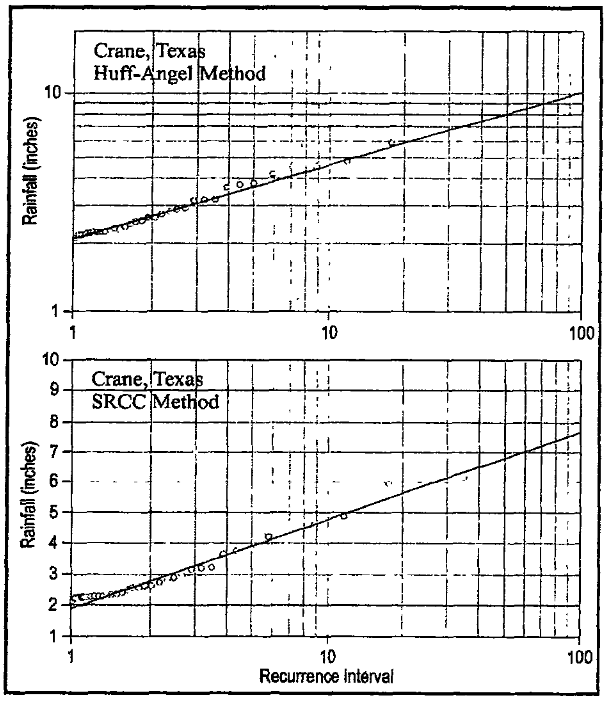

Fig. 9. Quantile estimates of storm rainfall for Crane, Texas, by the Huff-Angel and SRCC methods.

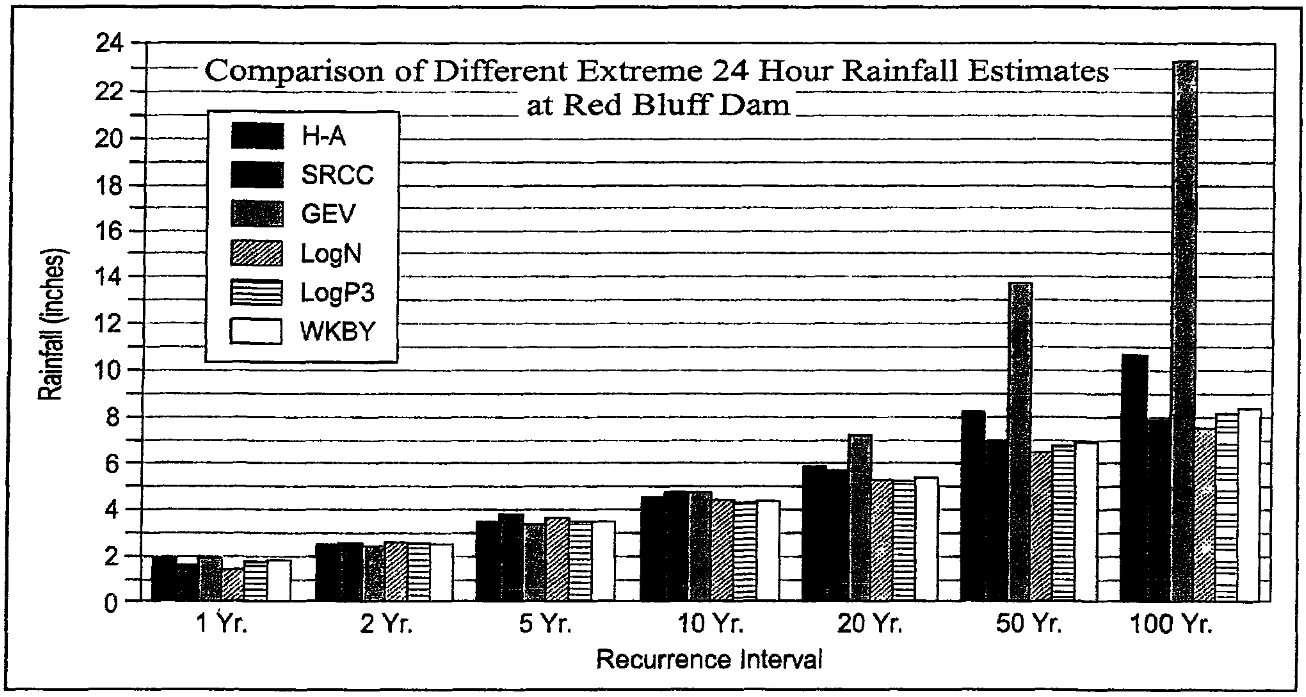

Fig. 10. Quantile estimates of 24-hour storms at Red Bluff Dam, Texas.

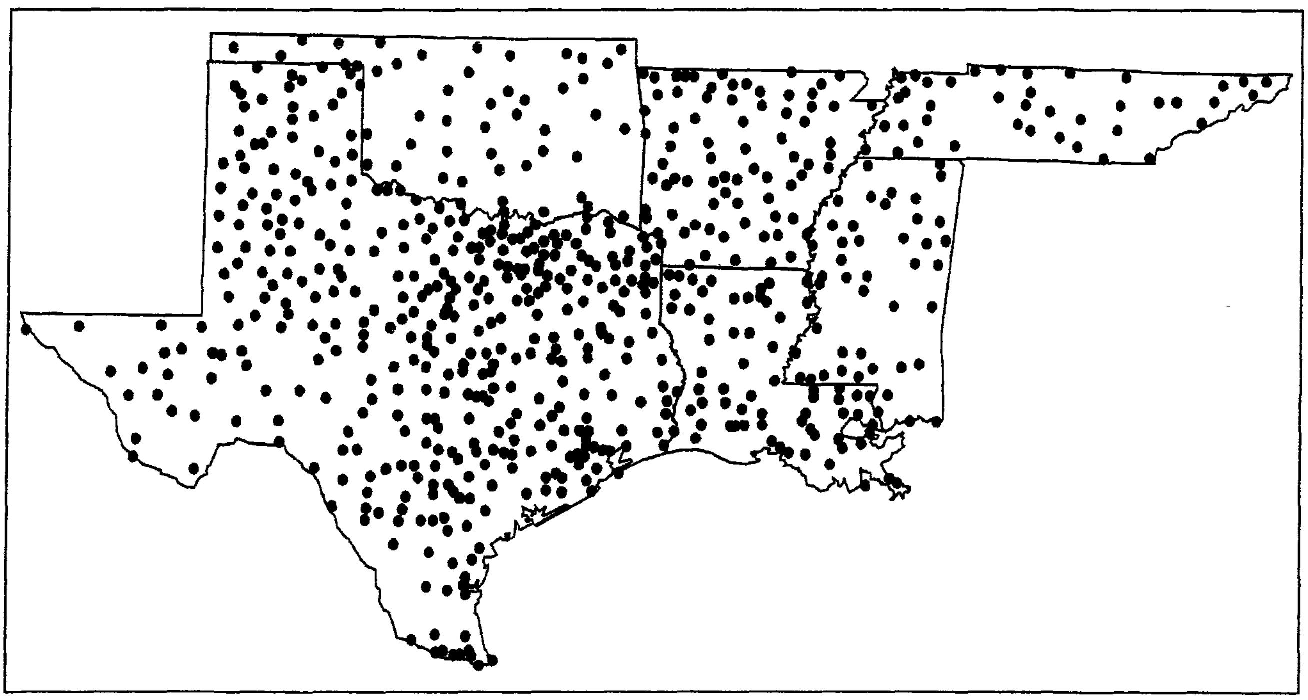

Fig. 11. NWS cooperative stations in the region utilized in this study.

This is similar to the problem where observational-day data were converted to 24-hour moving window equivalents by using the 1.13 coefficient. Therefore, *Hydro-35* (Frederick et al., 1977) still provides the best estimates for storm events of very short duration.

Seasonality

Another problem that may be encountered through use of this document involves the seasonality of storm activity across the region. Hershfield (1961) briefly examined this issue and detected distinct seasonality for selected regions. Angel and Huff (1995) also examined the seasonal variability of storms in the Midwest and discovered that quantile estimates can vary considerably between seasons. Furthermore, Keim and Faiers (1996) found significant differences in PDS heavy rainfall distributions by season in Louisiana. Figure 12 shows that at these four sites in Louisiana, winter tends to have the lowest quantile estimates while spring typically has the largest. These findings, however, are only valid for Louisiana, but they demonstrate the need for awareness that probabilities of heavy rainfall differ by season. Keim (1996) also demonstrated that the seasonal frequency of heavy rainfalls over a 3-inch threshold varied across the United States South and that each season was the peak season somewhere in the region. Peak storm frequencies during spring and autumn are characteristic across much of Texas, winter-spring peaks dominate Louisiana and Arkansas, while summer is the peak season in extreme eastern Tennessee.

Cartographic Procedure and Map Interpretation

Maps for 3-, 6-, 12-, and 24-hour rainstorms with recurrence intervals of 2-, 5-, 10-, 25-, 50-, and 100-years are displayed in Figures 3-6 respectively. These maps were prepared using quantile estimates derived from the methods described in sections of this appendix. Manually-drawn isohyets were used to depict the spatial pattern of heavy rainfall while using meteorological and climatological knowledge of the region to include or exclude some individual station anomalies that were clearly out of character with surrounding environments. In most cases, it was assumed that these anomalies, though few, were generated by extreme outliers in the PDS which obscured the derivation of regionally representative quantile estimates.

Isolines were drawn at 0.5-inch intervals for recurrence intervals between 2- and 10-year design storms and 1-inch intervals were used for the 25-, 50-, and 100-year design storm magnitudes. While automated procedures were considered, such methods often fail to recognize orographic and coastal patterns and generally do not improve the quality of the resulting map when compared to manually-drawn precipitation maps (Mulugeta, 1996). Interpolation of these maps will be required in most cases. For example, a design storm for a specific location will often fall between two isohyets. In this instance, the user must assume that change from one isohyet to the next occurs consistently and must estimate the quantile value from the regional isohyet pattern. In Figure 3.1, if a user wanted the 3-hour 2-year design storm for Memphis, Tennessee (in the extreme southwest corner of the state), interpolation between the 2.5- and the 3-inch isohyet would be required. Since Memphis is displaced approximately 30 percent from the 2.5-inch isohyet relative to the 3-inch line, one can conclude that the design storm at Memphis is 2.65 inches.

Summary

- PDS of observational-day (daily) storms have been extracted for 27 NWS first-order and cooperative stations in the region;
- For each site, Weibull plotting positions have been assigned to each storm in the PDS;
- Semi-log regression relationships have been determined between logged recurrence intervals and storm magnitudes;
- Quantile estimates have been increased by 13% to make daily storm magnitudes equivalent to 24-hour moving-window storm magnitudes;

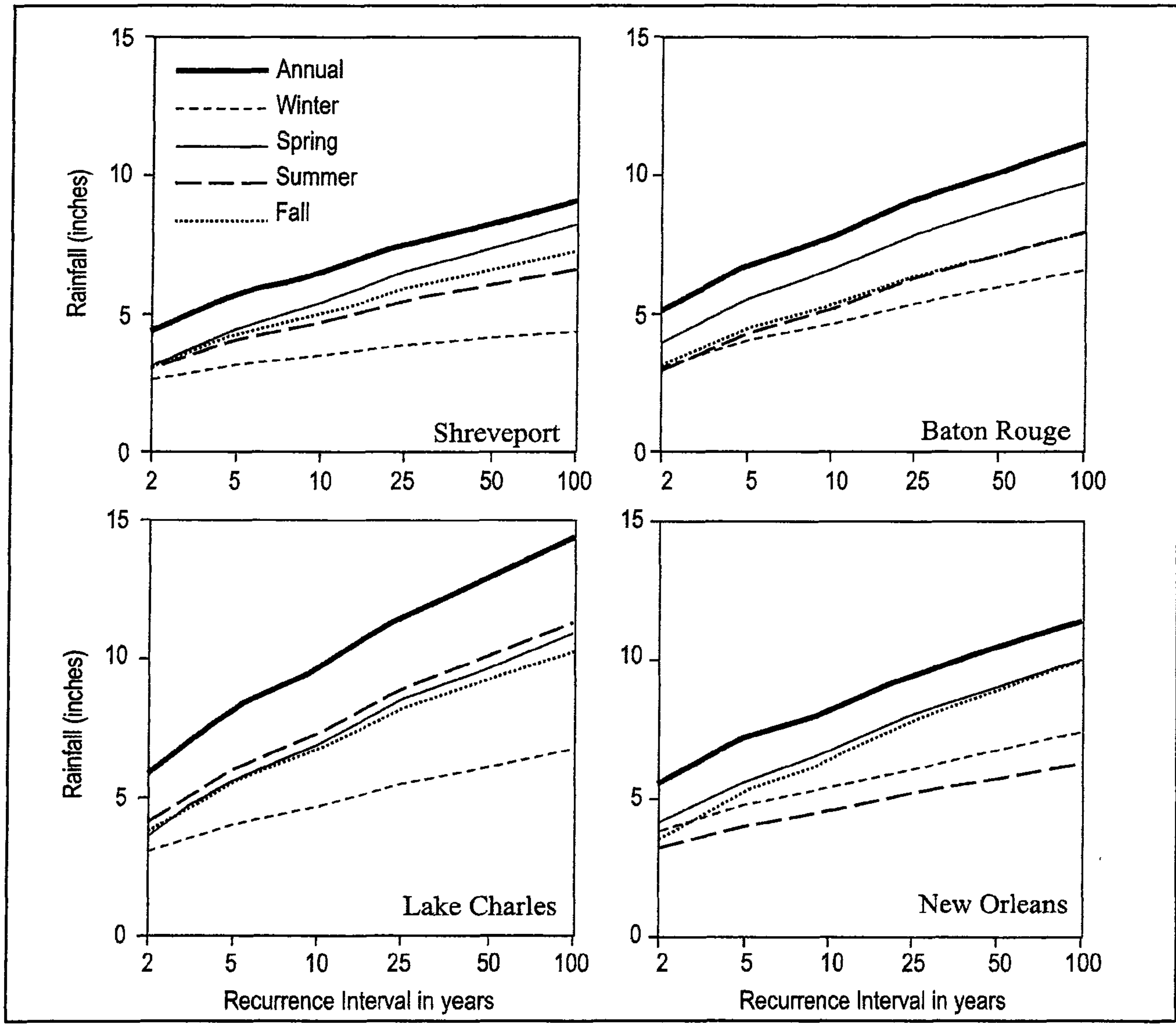

Fig. 12. Quantile estimates by seasons at 4 first-order stations of the NWS in Louisiana. Source: Keim and Faiers 1996. (Printed with permission from the American Water Resources Association.)

- Three-, six- and twelve-hour storm
- magnitudes have been calculated from average regional ratios at first-order stations to adjusted daily magnitudes for each recurrence interval;
- Regional maps have been developed from individual station plots of the 3-, 6-, 12-, and 24-hour storms for recurrence intervals of 2, 5, 10, 25, 50, and 100 years.

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