Draft

Analysis of Storm Event Characteristics for Selected Rainfall Gages Thoughout The United States

by

Eugene D. Driscoll
Gary E. Palhegyi
Eric W. Strecker
and
Philip E. Shelley

November 1989

Prepared for

U.S. Environmental Protection Agency
Washington DC

Woodward-Clyde Consultants
500 12th Street, Suite 100, Oakland, CA 94607- 4014

8910148B 1100

PEF009
June 26, 2012

DISCLAIMER

The information in this document has been funded wholly by the United States Environmental Protection Agency. It has been subjected to the Agency's peer and administrative review, and it has been approved for publication as an EPA document. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

TABLE OF CONTENTS

LIST OF FIGURES

Figure		Page

LIST OF TABLES

Table Number		Page

1. Introduction

1.1 Background

Precipitation is the driving force that mobilizes and transports pollutants from a nonpoint source (NPS) to receiving waters. Relevant information on the precipitation characteristics of an area is essential to address issues such as the estimation of NPS pollutant loads, the water quality impacts they produce, and the assessment of control strategies.

There is a growing tendency to apply probabilistic analysis techniques to the evaluation of a variety of water quality issues, particularly those associated with the intermittent and variable NPS load-generating process. Rainfall is a key input for many of the methodologies, and this requires an appropriate definition of the statistical characteristics of storm events. The Environmental Protection Agency (EPA) supported the development of a statistical rainfall analysis program SYNOP (EPA, 1976), which has seen considerable use during the past decade and has been adopted for use by the U.S. Geological Survey (USGS), Federal Highway Administration (FHWA), and others. Further, statistical summaries of rainfall properties for a considerable number of gages in different areas of the country have been assembled and reproduced in a number of reports for use as general reference material.

Currently, summaries of rainfall statistics are available, but much of the information is based on records that reach only to 1973. Also, some of the results were assembled from diverse sources and their reliability is uncertain. Furthermore, there have been changes in the format of the original source files provided by the US Weather Service, which have introduced output errors when the original SYNOP program was applied to a record having these new formats. In addition, a simplified rain zone map, developed some time ago for preliminary screening and based on SYNOP results available at the time, has found relatively wide circulation. For the foregoing reasons, it was considered appropriate to update the information on rainfall statistics.

1.2 Objective and Scope

The objective of this study was to develop an updated and expanded summary of storm event statistics for locations throughout the country, and to make this information available for use by probabilistic analysis procedures used for NPS investigations.

This report presents a summary of storm event statistics for 160 (mostly urban) locations spatially distributed throughout the country. The summary tables are organized into groupings of gage locations (or rain zones) having comparable storm event characteristics, which are also delineated on a map. Regional differences in pertinent storm event parameters are illustrated by contour maps showing the overall pattern by which individual parameters vary with location. In addition to this national scale, a similar analysis is applied for a single state for illustrative purposes, to examine results on a smaller spatial scale.

Chapter 2 describes the important features of the technical approach employed in developing the rainfall event statistics for the selected rain gages. It provides a brief description of the nature of the computations performed by the SYNOP statistical rainfall analysis program and identifies the additional features that were added during this study effort to improve its reliability and usefulness. This chapter also presents the results and conclusions from sensitivity analyses that were performed to examine several important issues relating to the application of the program.

PEF009
June 26, 2012

Chapter 3 presents and discusses the analysis results for the nationwide array of gages and for the higher spatial density gage network within a single state. The results are summarized in tables and maps, in a format that is designed to make them suitable for use as reference material.

An appendix is provided under a separate cover, which provides a complete summary of the rainfall statistics generated for each gage. It is noted that even this expanded listing represents only a small part of the complete statistical output that can be generated by the SYNOP program.

2. TECHNICAL APPROACH

2.1 General

Hourly rainfall records for rain gages in the United States are available from the National Climatic Data Center (NCDC) of the US Weather Service in Asheville, North Carolina. The records that were analyzed for this study were taken from commercially available optical laser disks, which provided a compact record of the data originally provided by NCDC. These disks can be obtained from commercial sources.

Each particular record is identified by a unique 6-digit number, consisting of a 2-digit state code followed by a 4-digit gage number. In the tabulated results presented later, each state is identified by its standard abbreviation, rather than the state code. The information in a gage record includes the location name, latitude and longitude, elevation of the measurement site, and the depth of hourly rainfall recorded (in1/100 inches). The date and hour are recorded for each depth in the record. The records examined cover the entire period of record for each of the gages selected for analysis. In all but a few cases, these records begin in mid-1948, and for most of the selected gages extend through mid-1988.

We attempted to utilize a common period of record (1949-1987) for all gages to be included in the analysis. We further attempted to limit the selection to include only gages with high degrees of completeness, because it is not uncommon for a gage record to have considerable stretches of incomplete data. Both of these items of information were provided by a summary listing identifying the gages contained on the optical disks. Even so, during our analysis there was a number of cases where the selected records were found to be incomplete. In such cases, the data were re-analyzed using only that part of the record that was not defective or, in a number of cases, substituting a gage that was different than the original selection. While it was generally possible to meet the gage selection objectives, shorter periods of record have been accepted in some cases in order to provide the desired spatial distribution of gage locations.

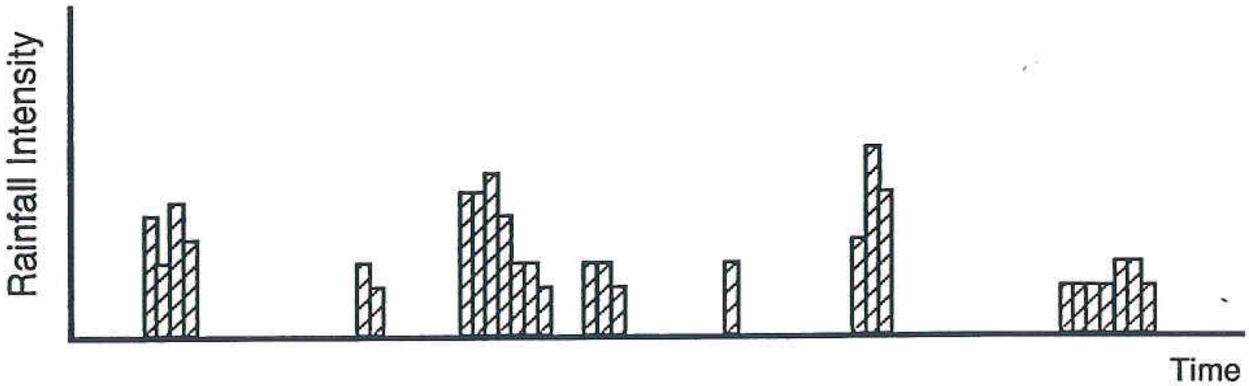
2.2 SYNOP - Statistical Rainfall Analysis Program

Rainfall data provided in the NCDC hourly records may be viewed, as illustrated by Figure 1(a), as a series of hours with either no precipitation, or an intensity recorded by the gage for that hour. This pattern is simplified by grouping the hours with rainfall into a set of separate "storm events" and representing each event as a uniform, rectangular hyetograph as in sketch (b). Each event may then be characterized by its duration (d), volume (v), average intensity (i), and the time interval between the midpoints of successive events (d).

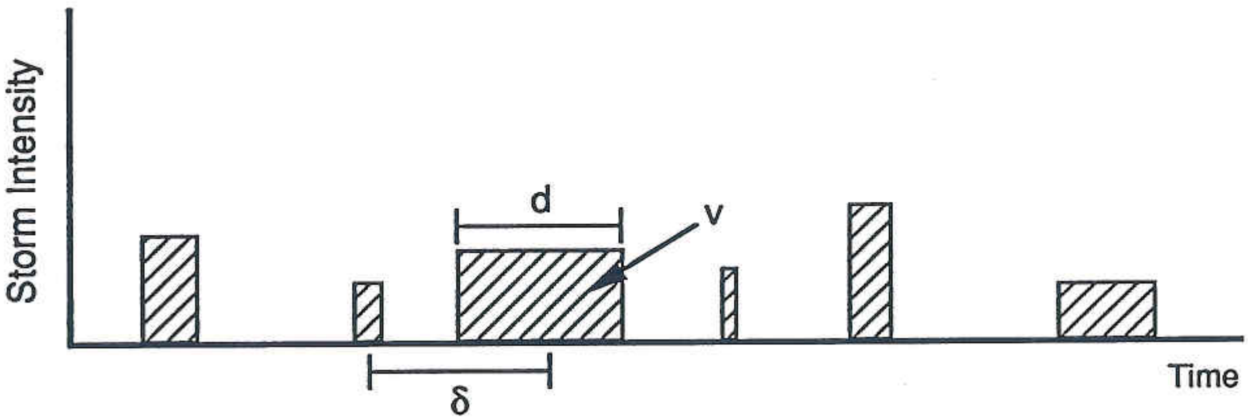
The rainfall volume in a particular hour is assigned to an event in progress, or as the start of a subsequent independent event, on the basis of an assigned minimum inter-event time (IET), the number of dry hours beyond which the occurrence of rainfall marks the beginning of a new event. The IET is selected such that the resulting storm events are independent and occur randomly. The selection of the IET to meet the independence requirement is discussed below.

The SYNOP program, developed about a decade ago for EPA reads an hourly precipitation record, organizes data for the wet (rainfall) hours into events, and computes the statistics of the storm event parameters (EPA, 1976). When a complete hourly record has been organized into a sequence of individual storm events, the mean and standard deviation may be determined for each of the event parameters. In the summaries presented, the coefficient of variation (COV), which is the ratio of the standard deviation to the mean, is presented rather than the standard deviation.

(a) Hourly Rainfall Variation



(b) Storm Event Variation



Storm Event Statistic	PARAMETER			
	For each storm event		For all storm events	
			Mean	Coef. Var.
Volume	v	(inches)	V	CV_v
Duration	d	(hours)	D	CV_d
Average intensity	i	(inches/hour)	I	CV_i
Interval between event midpoint	δ	(hours)	Δ	CV_δ

Figure 1. Storm event characterization of a rainfall record.

The analyses were performed on Apple Macintosh and IBM-PC (or compatible) microcomputers, using SYNOP II, a microcomputer version of the original SYNOP program. SYNOP II, prepared by Woodward-Clyde Consultants, continues to utilize the basic code and computations of the original, but incorporates some important new features, which are described below.

There have been format changes in the NCDC records at different points in time, resulting in differences between one part of a long record and another. Although these changes are minor, they can produce anomalous results at isolated parts of the record which can significantly distort the statistics generated. SYNOP II eliminates this potential for error.

The following computational features have been added or modified to improve the applicability of this program to different situations, and to make it easy for the user to select the specific options that will apply for an analysis.

- The user may select the beginning and ending year for an analysis, to permit developing statistics for different periods of time.
- The user may select beginning and ending months. This allows annual statistics to be generated on either a calendar year basis, or on a water year basis for ease of comparison with stream flow records. This feature also permits the development of rainfall statistics for selected seasons, an important consideration in western US. areas having pronounced wet and dry seasons.
- The user may select a minimum storm volume for events to be included in the analysis. Since very small storm volumes (usually a significant fraction of the total number of storms, but not annual volumes) do not result in runoff, the statistical characteristics of runoff-producing events can be generated.
- The user may select the "inter-event time" (IET), minimum number of dry hours used to assign an hourly rainfall volume to the current event, or to a new one. Alternatively, the program will make successive iterations using a pair of user-selected IETs and then interpolate to estimate a value that will result in storm intervals (times between storm mid-points) that are approximately exponentially distributed.
- The user may select any or all of a variety of output summaries that provide different degrees of detail or different organizations of results. For example, summary statistics stratified by month and by year are generated, as well as results for the entire storm sequence for the total period of record analyzed.

2.3 SENSITIVITY ANALYSIS OF SYNOP

Before begining the statistical analysis, a sensitivity analysis was performed to identify a set of uniform parameters to be assigned to each of the rainfall gages. The following sections discuss the evaluation of inter-event time, independence of storm arrival time, minimum storm volume, and wet season characteristics.

2.3.1 INTER-EVENT TIME

An underlying assumption necessary for the manipulation of probability density functions, is that the events must be independent. One of the requirements associated with storm event analysis is selecting an appropriate inter-event time (IET) such that the arrival time of storm events are independent. Several authors have discussed methods for choosing an appropriate IET (Heaney et al., 1977; Hydroscience, 1979; and Restrepo-Posada et al., 1982).

A common approach for the separation of precipitation records into statistically independent events was discussed by Restrepo-Posada and Eagleson (1982). They consider the arrival time of storm events to be random and to conform to a Poisson process. If the events are independent the intervals between Poisson arrival times are distributed exponentially. They note that the Poisson process describes the random arrival time of storms as point or instantaneous occurrences with durations of zero, but conclude that the Poisson process can adequately describe the arrival of independent storm events when the mean duration is much smaller than the mean arrival time. Precipitation data has this characteristic.

The exponential distribution is a special case of the gamma, and results when the coefficient of variation is 1. Rainfall event parameters have been shown to be well represented by a gamma distribution (Hydroscience, 1979). It has also been shown by these authors and by this study, that the COV of arrival times changes in a consistent way with IET, and that by the assignment of an appropriate IET, storm event statistics can be developed that are based on exponential (and hence independent) arrival times. As Restrepo-Posada et al (1892) suggest, this will also result in the independence of other event parameters (durations, volumes, intensities).

To use this approach, trial values of IET are chosen until a coefficient of variation of approximately 1 is obtained for the arrival times. In the analysis performed by SYNOP, the arrival time is computed as the time interval between storm midpoints, designated DELTA in the summary tables.

Restrepo-Posada et al (1982) suggest that a coefficient of variation equal to 1, although less sufficient than a chi-square test, provides a convenient test for the exponential distribution. The rainfall data analyses reported by Hydroscience (1979) also indicated that when the COV of delta is approximately 1, the actual distribution of deltas is closely described by an exponential distribution. The poisson assumption has proved to be both convenient and realistic. Therefore, assigning an IET such that the resulting COV of delta is about 1, is considered to provide a sufficient indication of the independence of storm events.

Sensitivity analyses to examine the effect of IET on the resulting storm event statistics were conducted. The analysis was performed on three arbitrary locations in the eastern, middle and western part of the country. These results are listed in Table 1 and shown graphically in Figures 2. The results for the three sample locations indicate the substantial differences in IET required to produce a COV of 1 for storm intervals (DELTA's). IET values of about 6 hours are found to be suitable for locations in the eastern part of the country but are seen to increase as the gage location

TABLE 1. Effect of Minimum Inter-event Time (IET) on Storm Event Statistics

Rain Gage Location	IET hrs	DELTA Avg	DELTA COV	Duration Avg	Duration COV	Intensity Avg	Intensity COV	Volume Avg	Volume COV
	1	45	1.70	1.8	1.09	0.130	0.61	0.30	1.92
	2	61	1.40	2.8	1.21	0.127	0.66	0.40	1.75
EAST COAST	3	72	1.24	3.6	1.22	0.124	0.71	0.47	1.65
	4	81	1.12	4.5	1.23	0.122	0.76	0.53	1.57
Charlottesburg	5	88	1.06	5.1	1.19	0.118	0.76	0.57	1.53
Reservoir	6	92	1.02	5.6	1.21	0.116	0.78	0.59	1.51
NEW JERSEY	9	102	0.92	7.0	1.17	0.111	0.81	0.66	1.44
	12	110	0.87	8.1	1.13	0.105	0.83	0.71	1.49
Gage # 1582	15	116	0.82	9.2	1.12	0.100	0.80	0.74	1.46
	24	131	0.73	12.7	1.15	0.093	0.88	0.84	1.41
	36	146	0.65	17.4	1.17	0.085	0.93	0.93	1.35
	48	167	0.59	25.8	1.22	0.075	0.92	1.07	1.28
	2	110	1.49	4.5	0.96	0.094	1.20	0.45	1.53
	3	124	1.36	5.3	0.96	0.096	1.14	0.51	1.45
MID COUNTRY	4	134	1.29	5.9	0.96	0.096	1.14	0.54	1.40
	5	141	1.24	6.4	0.99	0.096	1.15	0.57	1.38
Ferris	6	146	1.20	6.8	1.02	0.097	1.15	0.59	1.37
TEXAS	7	153	1.17	7.3	1.03	0.095	1.14	0.61	1.36
	8	156	1.14	7.6	1.04	0.095	1.12	0.62	1.35
Gage # 3133	9	161	1.12	8.0	1.05	0.094	1.12	0.64	1.34
	10	164	1.10	8.3	1.05	0.094	1.13	0.65	1.34
	14	176	1.05	9.5	1.10	0.092	1.15	0.69	1.34
	18	185	1.01	10.7	1.13	0.090	1.17	0.72	1.32
	22	194	0.97	12.0	1.21	0.088	1.19	0.76	1.32
	6	536	2.17	11.7	0.84	0.063	0.73	0.67	1.16
	10	584	2.09	15.1	0.99	0.059	0.75	0.75	1.17
	15	633	1.99	18.7	1.04	0.054	0.79	0.82	1.17
WEST COAST	18	650	1.95	20.0	1.09	0.053	0.80	0.84	1.23
	24	685	1.89	23.9	1.12	0.049	0.85	0.89	1.27
Los Angeles	30	717	1.83	27.1	1.16	0.048	0.88	0.93	1.28
Airport	50	818	1.68	37.9	1.14	0.041	0.92	1.06	1.27
CALIFORNIA	75	946	1.53	58.7	1.19	0.036	1.08	1.23	1.30
	100	1025	1.47	75.5	1.28	0.034	1.15	1.33	1.34
Gage # 5114	150	1198	1.32	119.2	1.27	0.028	1.29	1.54	1.32
	200	1367	1.12	185.3	1.27	0.024	1.40	1.81	1.33
	250	1694	1.09	283.5	1.27	0.020	1.36	2.18	1.33
	300	1878	1.01	366.8	1.27	0.020	1.34	2.43	1.34

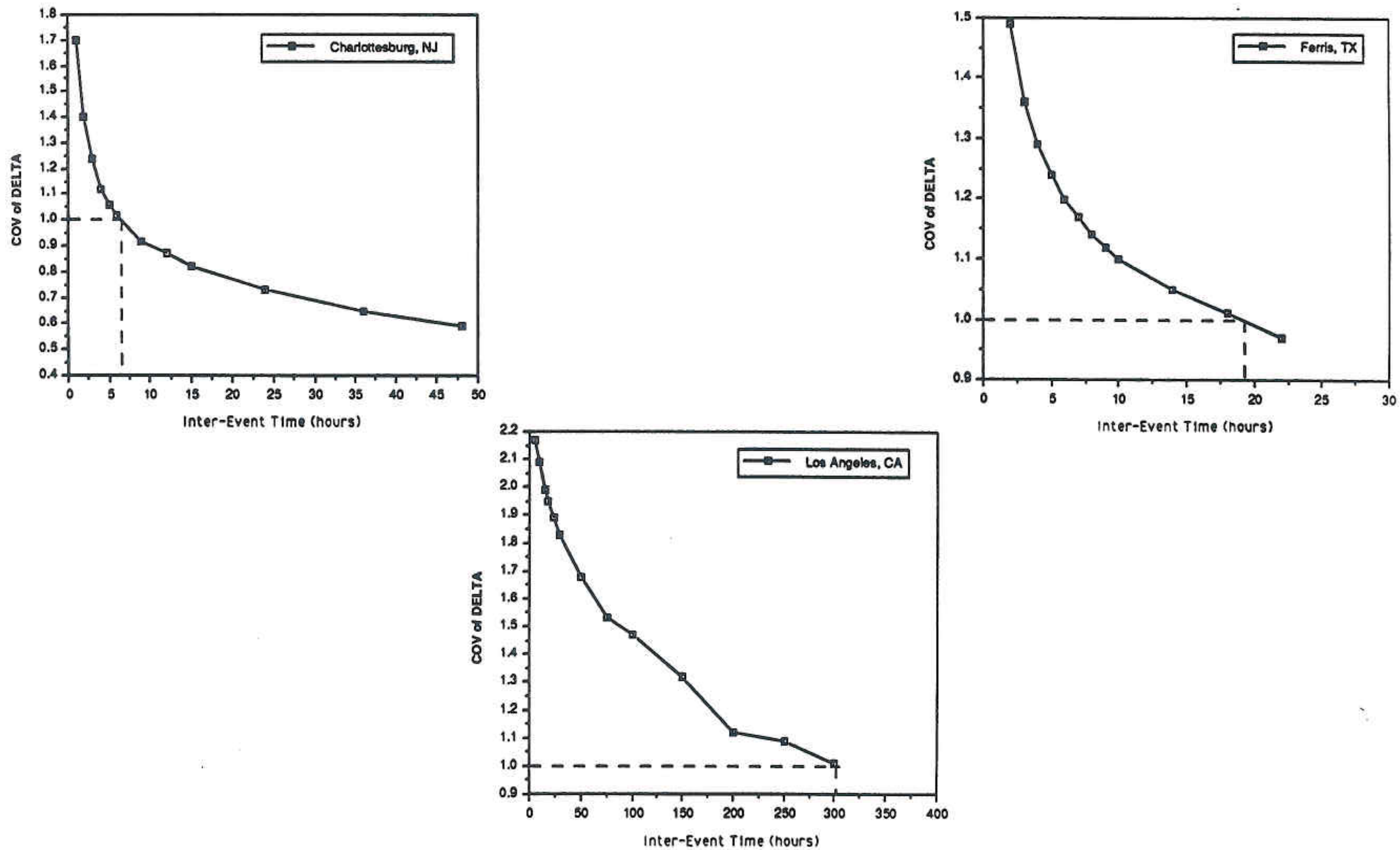


Figure 2. Effect of inter-event time on the COV of DELTA for three rainfall gages

moves to the west. IET values of about 20 hours are required in mid-country and become extremely high (300 hours) for west coast sites where rainfall has a pronounced seasonal distribution (Figure 2). The vary high IETs on the west coast result in abnormally high storm volumes and durations followed by low intensities.

We concluded that while the method for assigning IET based on the COV for DELTA provides a basis for assuring that the events are independent, for some locations the resulting event statistics are not meaningful for the types of NPS analyses for which the rainfall statistics will most commonly be applied. A similar determination was made by the authors of a study of sites in Saudi Arabia and the western US. (Restreop-Posada and Eagleson, 1982).

We selected an IET of 6 dry hours as being a reasonable value to use for two reasons; 1) so that the statistics for rain gages throughout the country would have a common basis, and 2) event statistical parameters would relate more meaningfully for evaluating NPS water quality issues. This choice is consistent with conclusions by other investigators (Hydroscience, Inc., 1979). Analyses of selected gages performed during this study indicate that a 6 hour IET is sufficient to produce event arrival times that are independent. The results presented below illustrate a test for independence for an east coast and a west coast gage, by examining the degree of correlation between paired values of the interval between successive events.

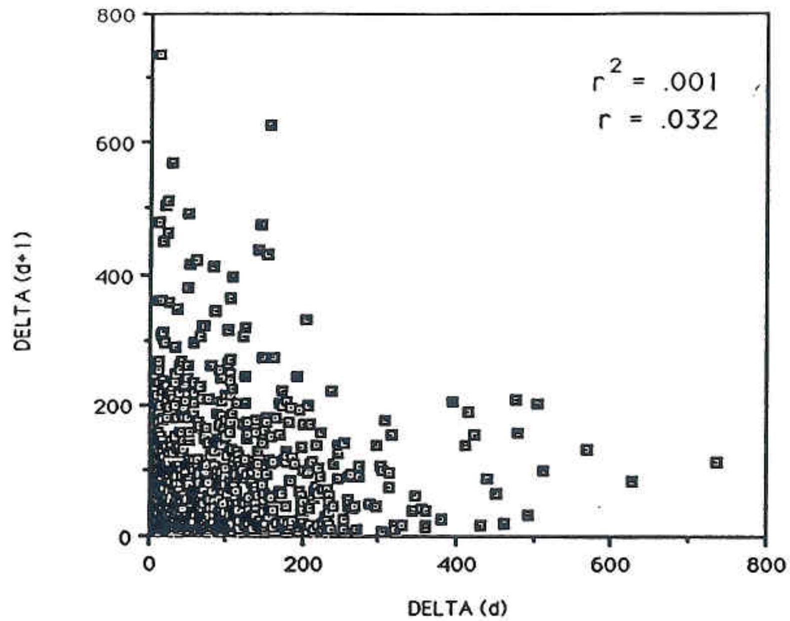
2.3.2 TEST FOR INDEPENDENCE OF STORM EVENTS

An analysis of the influence of the assigned IET on the independence of storm arrival times was performed by investigating the autocorrelation of the set of individual values for DELTA (time between storm midpoints) produced when the hourly record was sorted into storm events using different values for IET. This analysis included a determination of the statistical significance of the resulting correlation coefficients.

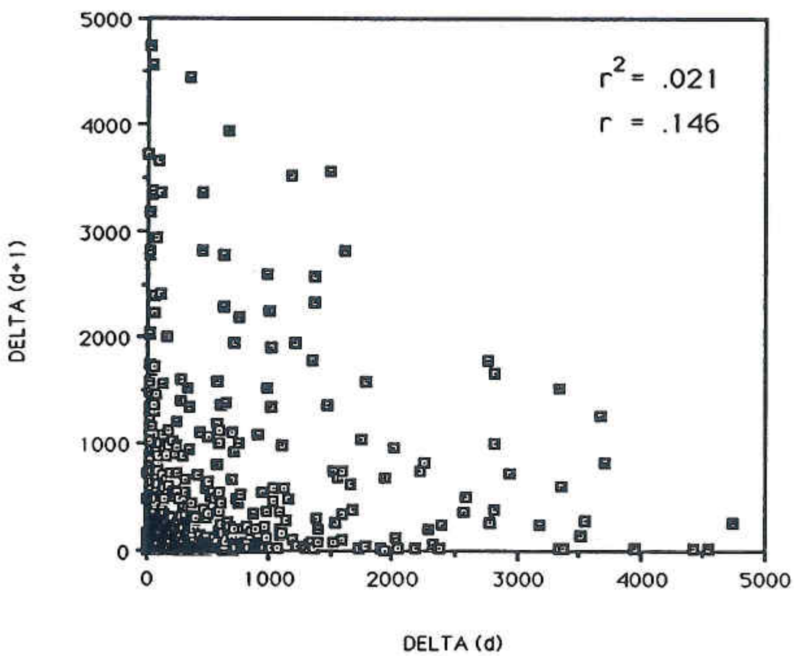
Separate SYNOP analyses of this record, using IETs of 2, 4, 6, 12 and 24 hours, resulted in different sets of DELTAs. Autocorrelation was tested by creating paired values consisting of the DELTA for an event and the DELTA for a subsequent event as defined by a specified lag period. Separate determinations were made using lags of 1 through 10. For example, lag 1 used the values for an event and the one immediately following, lag 2 for an event value paired with that for the second event later, and so forth. A standard linear correlation test was then performed using the paired sets that were produced and the correlation coefficient (r) was computed. Figure 3 presents the correlation plots of such paired values for gages on the east and west coasts. For both, the results shown are for a single gage, an IET of 6 hours, and a lag interval of 1.

Figure 4, based on Los Angeles rainfall gage #5114, presents a correlagram summarizing the the relationship between the computed autocorrelation coefficients and the lag interval, for a set of IETs. The upper plot (a) illustrates the pattern over a range of IET values; plot (b) isolates results for the 6 hour IET that was selected to be uniformly applied to all gages in the study.

If a correlagram curve were to decrease gradually from r=1 to r=0 as a function of the lag interval, it would suggest a lack of independence in the arrival time of successive storms. A curve that falls to zero (or near zero) at the first lag of the data suggests that the arrival times of successive storms are independent. Differences in the observed pattern for the individual IETs would indicate the influence of IET on the independence of storm events. The relationships shown by Figure 4 suggest that for any of the IETs examined, the arrival times of successive storms are either independent, or at most only very weakly correlated.

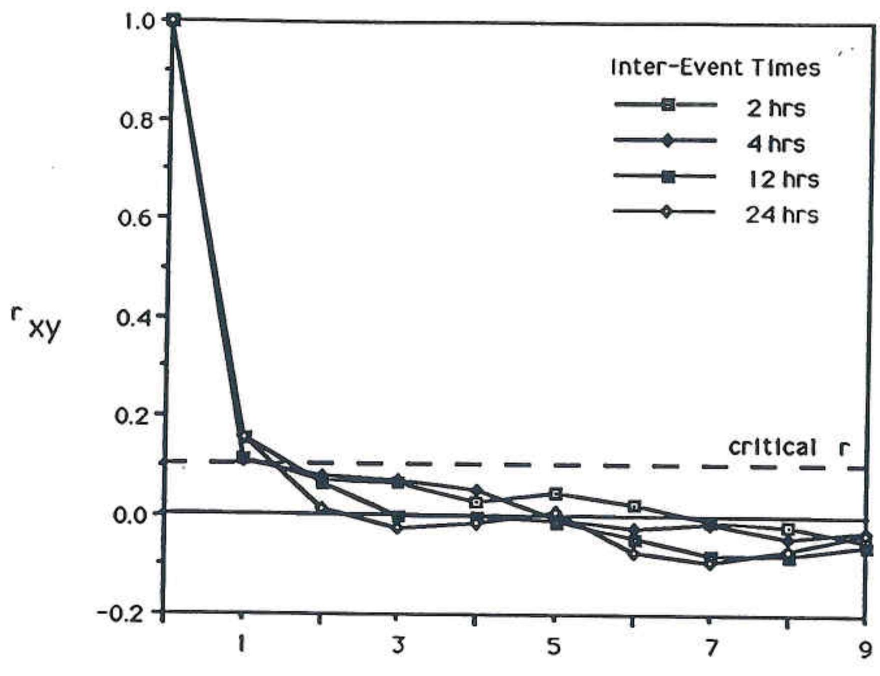


Lag 1 correlation plot for Charlottesburg, N.J. gage # 1582.
(a)

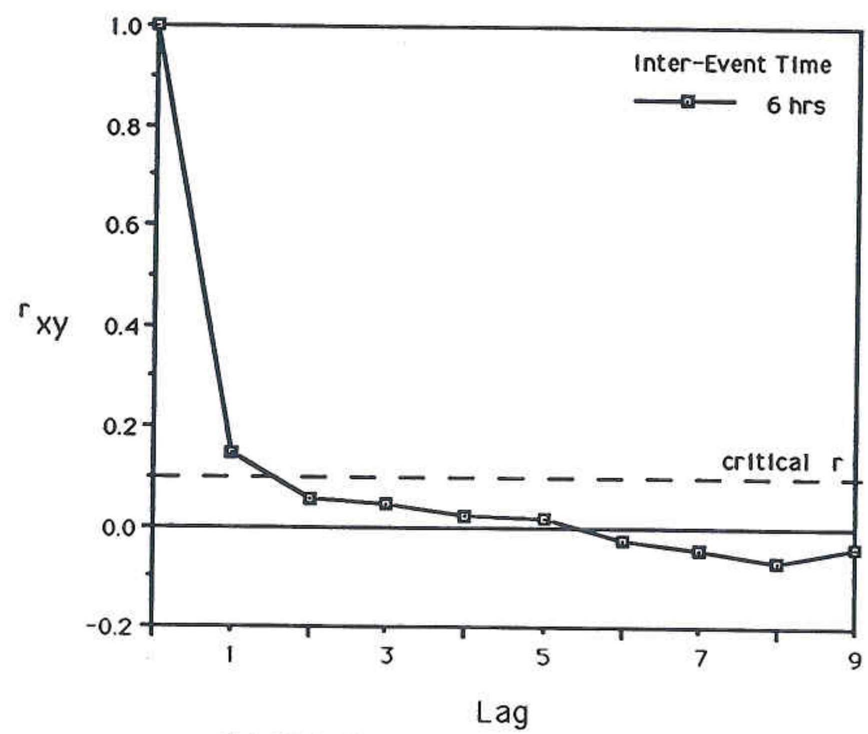


Lag 1 correlation plot for Los Angeles, CA. gage # 5114
(b)

Figure 3. Test for independence of storm events using a 6 hour minimum inter-event time.



(a) Plot showing a variety of inter-event times.



(b) Plot showing the 6 hour inter-event time.

Figure 4. Correlagram showing autocorrelations for various IET's

To evaluate the statistical significance of the correlation coefficients obtained, a hypothesis test was conducted to determine whether the computed correlation coefficients are significantly different from zero. A procedure to test the hypothesis that the correlation coefficient is significantly different from zero is described by Sokal and Rohlf (1969). The null hypothesis is:

$$Ho:\ r = 0 \qquad (1)$$

This implies that the paired data is uncorrelated, or independent. The hypothesis is tested with the Student's t-test using n-2 degrees of freedom:

$$t = r \bullet \mathrm{SQRT}(\ (n\text{-}2)/(1\text{-}r^2)\ ) \qquad (2)$$

Using Equation 2 and the common Student "t-tables", the hypothesis can be tested. Alternatively, by solving Equation 2 for r a critical value of the correlation coefficient can be computed and compared to those computed from the raw data. Thus:

$$r = \mathrm{SQRT}(\ t^2 / (\ t^2 + n\text{-}2\ )\ ) \qquad (3)$$

As a result, given a confidence level (e.g. 99%) and the number of data points (n), a critical value of r can be computed. When the computed value of r is less than the "critical r", the correlation is not significantly different from zero.

For the gage records examined, the number of DELTAs computed using a 6 hour inter-event time and .10 inches as a minimum storm volume are 653 for the west coast gage and 858 for the east coast gage. Given a 99% confidence level (Student's t = 2.576), the following critical values of r are computed as:

west coast gage	n = 653	r = 0.100
east coast gage	n = 858	r = 0. 088

Thus, for a computed correlation coefficient less than the critical value, one would conclude that the correlation coefficient is not significantly different from zero, and as a result, the paired data are independent.

The results of this analysis indicate that the lag 1 correlation coefficient is not significantly different from zero for the east coast gage (r=.032), and a 6 hour IET results in independent storm events. For the west coast location (r=0.146), the correlation is significantly different from zero. However, the critical value is quite small because of the very large number of data pairs (n), and while statistically not zero, the degree of correlation is quite small. For this and similar locations, although events cannot be considered completely independent at a 99% confidence level, the degree of independence is considered high enough for the purposees of this study.

On this basis, a uniform dry hour storm event separation period (IET) of 6 hours was applied uniformly for the analysis of all of the rain gages examined in this study.

2.3.3 MINIMUM STORM VOLUME

Since the smallest volume reported in any hour is generally 0.01 inch (some gages only report rainfall to the nearest 0.10 inch), this value (or zero), assigned as a minimum storm volume when the SYNOP program is run, results in all measured precipitation being included in the statistics. Higher values for the minimum storm volume can be used to estimate statistics for only those events that would be expected to produce runoff. Such minimum storm volumes are estimated to be in the order of 0.08 to 0.12 inches (Schueler, 1987).

A minimum storm volume of 0.10 inches was specified for the analyses that were performed, so that the analysis would produce statistics of "runoff-producing" events. This choice was made because an important current use of the type of information developed will be for the examination of NPS issues, where the principal use of the rainfall data is to provide estimates of runoff quantities.

The user should note that these statistics for "runoff producing events" will differ from those for "all precipitation events". The effect on the storm event statistics is indicated by the sensitivity test results for 3 gages summarized in Table 2 and shown graphically in Figure 5. Because the Charlottesburg, NJ gage used in the previous analysis only recorded rainfall to the nearest .1 inches it was replaced with the Newark, NJ gage for this analysis.

As the results indicate, the average number of storms per year may be reduced by as much as 25 to 45 percent, but these small storm events account for only a small percent of the annual precipitation volume. Increasing the value for the minimum volume assigned, results in a significant increase in the average value, and a decrease in the COV of each parameter.

2.3.4 WET SEASON CHARACTERISTICS

The results presented in the report analyzed the entire calendar year (months 1-12) for all gages. As a result, for those locations having distinct wet and dry seasons, the statistics include conditions with extended periods with little or no rainfall. A sensitivity analysis was performed to examine the extent to which the precipitation statistics might be distorted by the presence of long dry periods. For selected gage locations in the west, an additional analysis was performed, using the full period of record, but including in the analysis only those months assigned to the wet season. The wet season was arbitrarily chosen as the months between October and March, inclusive, and was based on the total precipitation volume computed for each month in the original analysis. The results are summarized in Table 3, for a sample of six western locations. Results are seen to vary appreciably for the different locations.

For Phoenix, AZ. and Las Vegas, NV., only about 60 percent of the storms and annual precipitation volume occur in the winter months. For these sites, the average storm durations are 20-25 percent longer during the "wet" period, and the average interval between storms is significantly shorter. Mean storm volumes are virtually identical, but the average storm intensity is 40 percent lower during the winter period.

In contrast, the Los Angeles and Oakland CA statistics show the effect of the strong seasonal rainfall pattern in these areas. Approximately 85 percent of the total rainfall and number of independent storm events occur during the 6 month period assigned as the wet season. As a result of this period containing most of the storms, the individual event statistics for storm durations, volumes and intensities are essentially the same. The interval between storms is naturally much shorter, since the average is not influenced by the very long intervals during the summer months.

TABLE 2 Effect of Minimum Storm Volume on Storm Event Statistics
Inter-event Time (IET) = 6 hours

Rain Gage Location	min Vol	Avg No Storms	Avg Volume	DELTA Avg	DELTA COV	Duration Avg	Duration COV	Intensity Avg	Intensity COV	Volume Avg	Volume COV
	0.01	101	47.4	87	0.90	8.1	1.02	0.057	1.22	0.47	1.49
EAST COAST	0.02	94	47.3	94	0.87	8.7	0.96	0.060	1.17	0.50	1.41
	0.03	87	47.2	102	0.87	9.2	0.92	0.064	1.12	0.54	1.34
Newark	0.04	84	47.1	105	0.87	9.5	0.90	0.066	1.11	0.56	1.31
NEW JERSEY	0.05	76	46.7	117	0.86	10.1	0.85	0.070	1.07	0.62	1.22
1975-1985	0.06	74	46.6	119	0.85	10.2	0.84	0.071	1.06	0.63	1.20
	0.08	70	46.4	126	0.85	10.6	0.83	0.074	1.04	0.66	1.16
Gage # 6062	0.10	65	45.9	137	0.86	11.1	0.80	0.078	1.01	0.71	1.09
	0.12	62	45.6	144	0.87	11.4	0.78	0.080	1.00	0.74	1.06
pct change .01/.10		**-36**	**-3.2**	**56**	**-4**	**37**	**-22**	**37**	**-17**	**51**	**-27**
	0.01	54	32.0	146	1.20	6.8	1.02	0.097	1.15	0.59	1.37
MID COUNTRY	0.02	53	32.0	149	1.20	6.9	1.01	0.098	1.13	0.60	1.35
	0.03	52	32.0	153	1.19	7.0	0.99	0.101	1.12	0.61	1.33
Ferris	0.04	50	31.9	159	1.18	7.2	0.97	0.104	1.09	0.63	1.29
TEXAS	0.05	46	31.7	174	1.15	7.6	0.93	0.111	1.05	0.68	1.22
	0.06	46	31.7	176	1.15	7.7	0.93	0.112	1.04	0.69	1.21
Gage # 3133	0.08	44	31.6	184	1.15	7.9	0.92	0.115	1.02	0.72	1.17
	0.10	40	31.2	203	1.14	8.4	0.88	0.121	0.99	0.78	1.10
	0.12	39	31.1	210	1.15	8.5	0.88	0.124	0.98	0.79	1.09
pct change .01/.10		**-26**	**-2.4**	**39**	**-5**	**24**	**-14**	**25**	**-14**	**32**	**-20**
	0.01	30	12.1	299	1.94	8.0	1.15	0.044	0.93	0.41	1.63
WEST COAST	0.02	26	12.1	342	2.02	8.9	1.05	0.049	0.85	0.47	1.50
	0.03	24	12.1	371	2.01	9.5	1.00	0.052	0.81	0.51	1.42
Los Angeles	0.04	23	12.0	390	2.00	9.8	0.98	0.052	0.79	0.53	1.37
Airport	0.05	21	11.9	442	2.20	10.6	0.93	0.058	0.75	0.59	1.27
CALIFORNIA	0.06	20	11.9	448	2.18	10.7	0.92	0.058	0.74	0.59	1.26
	0.08	19	11.8	480	2.27	11.2	0.90	0.060	0.73	0.63	1.21
Gage # 5114	0.10	17	11.7	531	2.21	11.8	0.87	0.063	0.70	0.68	1.14
	0.12	17	11.6	550	2.17	12.0	0.86	0.064	0.69	0.70	1.12
pct change .01/.10		**-43**	**-3.3**	**78**	**14**	**48**	**-24**	**43**	**-25**	**66**	**-30**

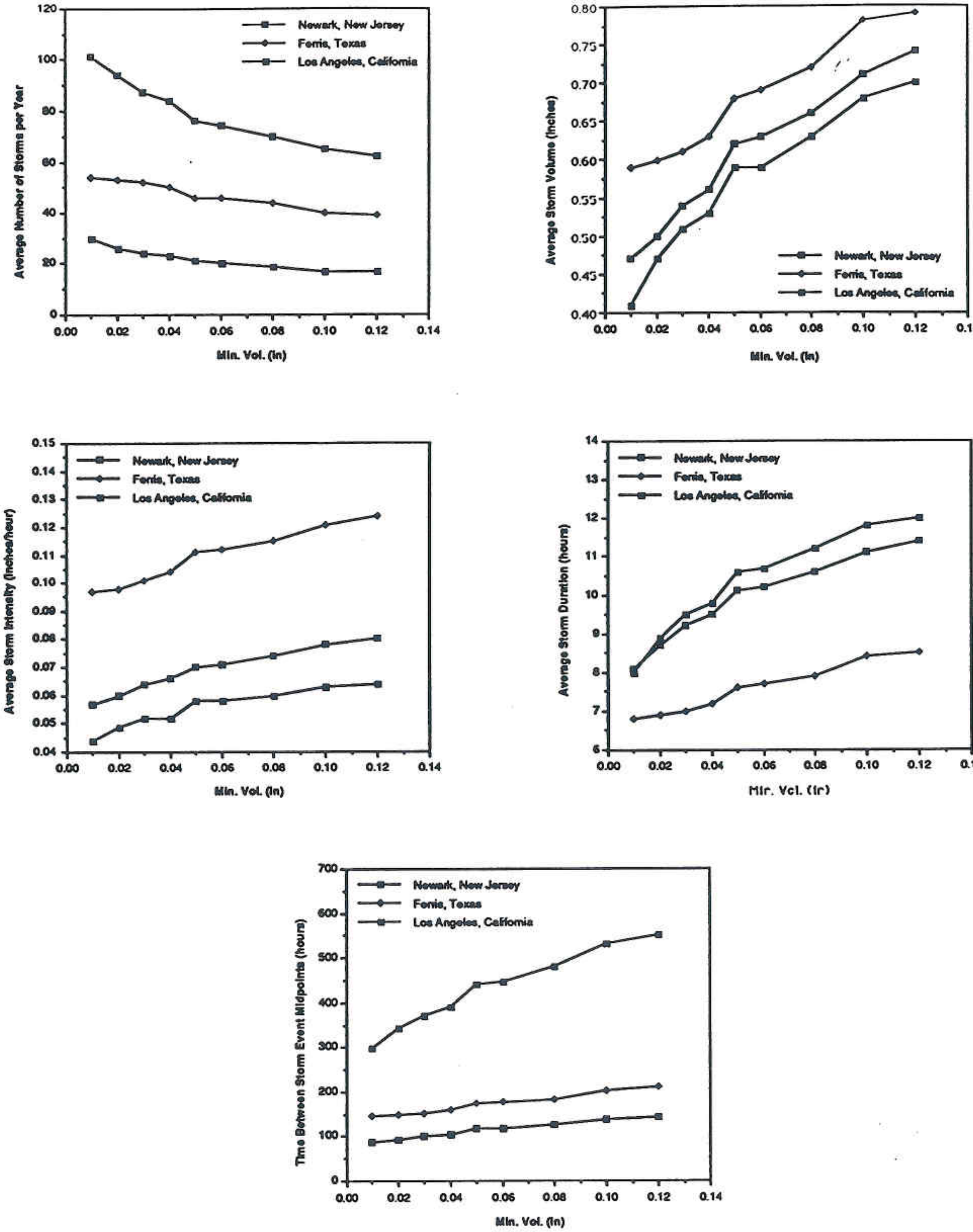


Figure 5. Effect of minimum strom volume on storm event statistics.

TABLE 3. Comparison Between Wet Season and Calendar Year Statistics

Rain Gage	Annual Statistics				Independent Storm Event Statistics							
	No. Storms/yr		Precip in/yr		Duration (hr)		Intensity (in/hr)		Volume (in)		DELTA (hr)	
	Avg	COV	Avg	COV	Avg	COV	Avg	COV	Avg	COV	Avg	COV
CALIFORNIA												
Los Angeles, gage #5114												
Total Year	17	0.39	11.65	0.45	11.7	0.84	0.063	0.73	0.67	1.16	536	2.17
Wet period	15	0.38	10.30	0.52	12.0	0.85	0.065	0.73	0.71	1.16	232	1.32
Wet - % of Total	88		88									
Oakland, gage #6335												
Total Year	30	0.22	17.06	0.32	13.3	0.79	0.048	0.69	0.57	1.01	295	2.28
Wet period	25	0.35	14.91	0.42	13.8	0.79	0.049	0.68	0.60	0.99	148	1.30
Wet - % of Total	83		87									
Redding, gage #7295												
Total Year	30	0.34	26.59	0.40	14.5	0.90	0.072	0.94	0.88	1.08	248	2.13
Wet period	23	0.35	22.69	0.43	16.5	0.84	0.063	0.64	0.98	1.05	136	1.36
Wet - % of Total	77		85									
OREGON												
Medford, gage #5429												
Total Year	40	0.17	17.71	0.26	12.9	0.77	0.040	0.98	0.44	1.14	222	1.63
Wet period	29	0.25	14.07	0.36	14.0	0.75	0.037	0.65	0.49	1.14	139	1.12
Wet - % of Total	73		79									
NEVADA												
Las Vegas, gage #4436												
Total Year	10	0.45	3.63	0.51	8.8	0.75	0.064	1.09	0.37	0.82	967	1.49
Wet period	6	0.59	2.05	0.68	10.9	0.62	0.038	0.66	0.36	0.73	491	1.25
Wet - % of Total	60		56									
ARIZONA												
Phoenix, gage #6481												
Total Year	16	0.29	6.77	0.44	8.1	0.92	0.085	1.23	0.42	0.95	579	1.46
Wet period	9	0.46	3.88	0.61	10.4	0.80	0.053	0.84	0.42	0.85	369	1.15
Wet - % of Total	56		57									

A pattern that is intermediate between those described above is shown by the Medford OR and Redding CA sites. Here, a relatively strong seasonal distribution of precipitation is shown by the fact that 75 percent of the storm events, and 80-85 percent of the annual volume, occur during the wet period. The individual event statistics also exhibit intermediate differences. As with the other sites, the average interval between storms is shorter. Durations are longer and intensities lower, but the difference is only about 10 percent. The average event volume is about 10 percent higher.

The seasonal comparison presented here provides some general information that will assist a user in determining how seasonal patterns might influence different rainfall parameters that are relevant to a particular NPS study. It was not considered feasible to attempt a regional generalization of wet/dry seasonal effects, because of the differences indicated by the sample locations examined.

3 RESULTS

3.1 Summary of Storm Event Statistics in the United States

This section presents a summary of the storm event statistics developed from a statistical analysis of a national cross-section of rain gage locations. The geographical distribution of the gages selected is shown on the map presented in Figure 6. Table 4 lists the gage name, number, elevation, latitude and longitude, together with information on the length of the record. It also presents the period of record analyzed for each gage. Appendix provides a summary sheet for each gage analyzed, with a more complete set of statistics. It was not practical to include a complete output of all of the summaries due to the large output that can be generated by the SYNOP program.

There were a number of guidelines applied in selecting the gages to be analyzed. Because of current emphasis on urban nonpoint source issues, the locations sought were those either in or near large metropolitan areas. Project resources allowed the analysis of 163 gages at various location throughout the US. Our guideline included selecting 2 gages per state, with a larger number selected where the size of the state or climatic variation within the state argued for more, and a smaller number where the state was small or population centers were few. The guidelines resulted in a denser spatial matrix in the east where most of the population is located, and therefor a relatively good delineation. To compensate for the relatively sparse spatial matrix in the western regions that resulted from the emphasis on population centers, additional gages were analyzed to fill in spatial gaps.

The statistical characteristics of storm events computed using an IET of 6 hours and a minimum storm volume of 0.10 inches are summarized for the national matrix of rain gages. As addressed in the following section, for one state (North Carolina) a dense statewide matrix of 30 gages was analyzed. The national summary incorporates only 7 of these gages, to avoid introducing a bias to the grouping analysis discussed below, and to permit an evaluation of how well a small number of gages can represent an entire state.

Table 5 presents results for both annual precipitation characteristics, and for the statistics of individual storm events.

- Annual Statistics: The analysis program counts the number of independent storm events and the total volume of precipitation for each year analyzed, and averages the annual values obtained. The COV measures the variability of the event counts and annual volumes obtained for the separate years.

- Independent Storm Event Statistics: Individual event values for duration, volume, average intensity and DELTA are computed for each of the storm events in the period of record. The arithmetic average of the individual values is listed as the "Avg". The standard deviation of the individual values is also computed. This value is divided by the average to compute the coefficient of variation listed under the column heading COV. Accordingly, the listing provides the parameter magnitude for the mean storm and a measure of the event-to-event variability of the parameter, based on all storms in the record analyzed.

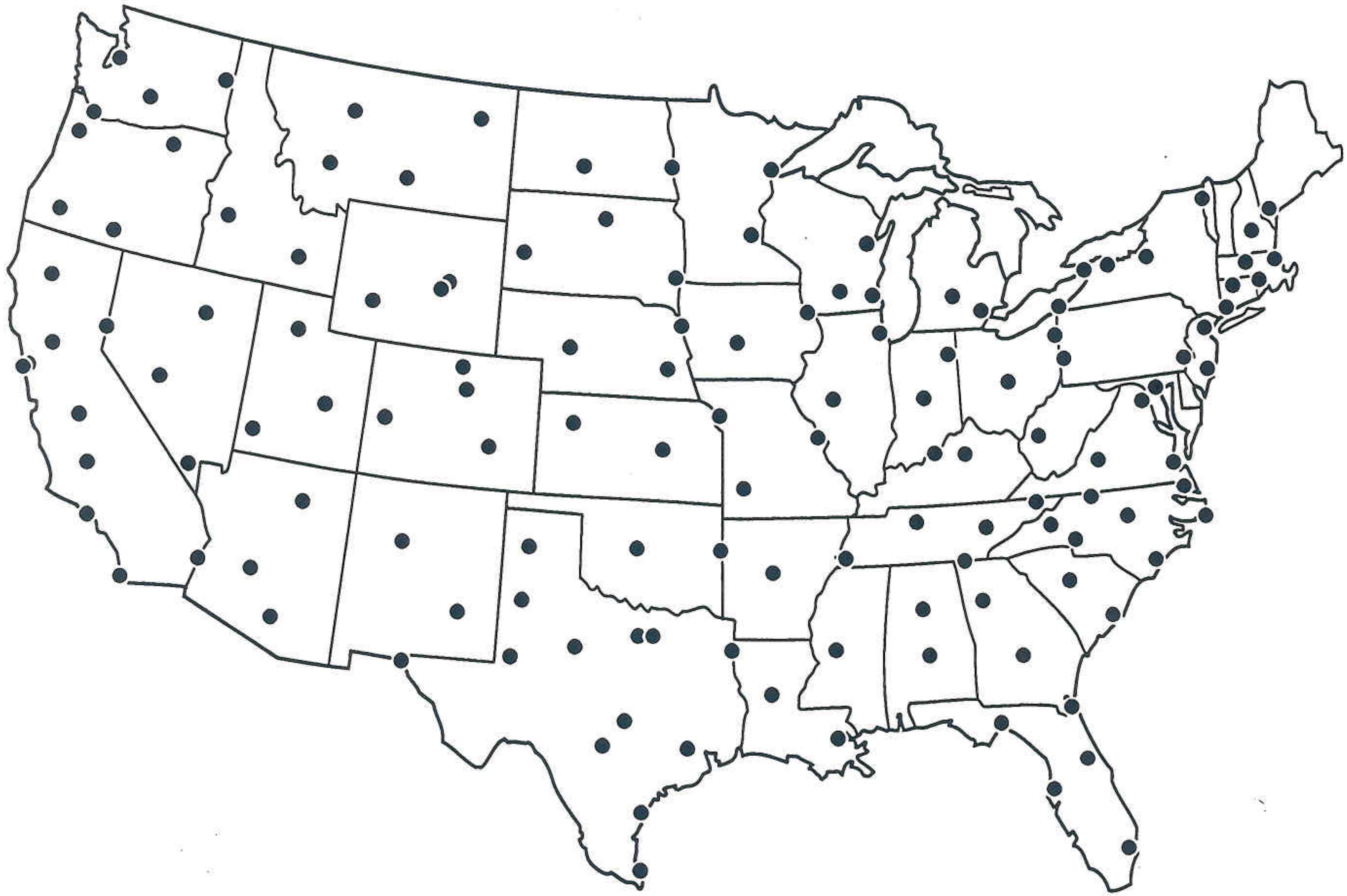


Figure 6. Map showing the location of selected rainfall gages.
(Gages for Hawaii and Alaska not shown)

Table 4. Listing of Selected Rainfall Gages Used in the Analysis

State	Location	Gage No.	Latitude	Longitude	Elevation	Beginning Year	Ending Year	Total Years
AK	ANCHORAGE WSCMO AP	280	61:10:00	150:01:00	110	1963	1987	25
AL	BIRMINGHAM FAA AP	831	33:34:00	086:45:00	630	1949	1987	39
AL	MONTGOMERY WSO AP	5550	32:18:00	086:24:00	220	1949	1987	39
AR	FORT SMITH	2574	35:20:00	194:22:00	450	1949	1987	39
AR	LITTLE ROCK FAA AP	4248	34:44:00	092:14:00	260	1949	1975	27
AZ	PETRIFIED FOREST N.P.	6468	34:49:00	109:53:00	5450	1949	1987	39
AZ	PHOENIX WSFO AP	6481	33:26:00	112:01:00	1110	1949	1987	39
AZ	TUCSON WSO AP	8820	32:08:00	110:57:00	2580	1949	1987	39
CA	FRESNO WSO AP	3257	36:46:00	119:43:00	330	1949	1987	39
CA	BAKERSFIELD WSO AP	442	35:25:00	119:03:00	500	1949	1987	39
CA	BLYTHE	925	33:37:00	114:43:00	390	1954	1987	34
CA	LOS ANGELES WSO AP	5114	33:56:00	118:24:00	110	1949	1987	39
CA	OAKLAND WSO AP	6335	37:45:00	122:12:00	10	1949	1984	36
CA	REDDING 5 SSE	7295	40:30:00	122:22:00	430	1959	1987	29
CA	SACRAMENTO FAA AP	7630	38:31:00	121:30:00	20	1949	1987	39
CA	SAN DIEGO WSO AP	7740	32:44:00	117:10:00	10	1949	1987	39
CA	SAN FRANCISCO WSO AP	7769	37:37:00	122:23:00	10	1949	1987	39
CO	DENVER WSFO AP	2220	39;46;00	104;52;00	5280	1949	1987	39
CO	GRAND JUNCTION WSO AP	3488	39:06:00	108:33:00	4850	1949	1987	39
CO	PUEBLO WSO AP	6740	38:17:00	104:31:00	4640	1955	1987	33
CO	FORT COLLINS	3005	40:35:00	105:05:00	5000	1949	1987	39
CT	HARTFORD BRAINARD FLD	3451	41:44:00	072:39:00	20	1949	1987	39
CT	BRIDGEPORT WSO AP	806	41:10:00	073:08:00	10	1949	1987	39
DE	WILMINGTON WSO AP	9595	39:40:00	075:36:00	80	1949	1987	39
FL	JACKSONVILLE WSO AP	4358	30:30:00	081:42:00	30	1950	1987	38
FL	MIAMI WSCMO AP	5663	25:48:00	080:18:00	10	1949	1987	39
FL	ORLANDO WSO AP	6638	28:33:00	081:20:00	110	1949	1983	35
FL	ST PETERSBURG	7886	27:46:00	082:38:00	10	1949	1987	39
FL	TALLAHASSEE WSO AP	8758	30:23:00	084:22:00	60	1949	1987	39
GA	COLUMBUS WSO AP	2166	32:31:00	084:57:00	450	1949	1987	39
GA	ATLANTA WSO AP	451	33:39:00	084:26:00	1010	1949	1987	39
HI	HONOLULU WSFO 703 AP	1919	21:20:00	157:55:00	10	1963	1987	25
IA	DES MOINES WSFO AP	2203	41:32:00	093:39:00	960	1949	1987	39
IA	DUBUQUE WSO AP	2367	42:24:00	090:42:00	1070	1951	1987	37
IA	SIOUX CENTER 2 SE	7700	43:03:00	096:09:00	1360	1949	1987	39
ID	BOISE WSFO AP	1022	43:34:00	116:13:00	2840	1949	1987	39
ID	POCATELLO WSFO AP	7211	42:55:00	112:36:00	4450	1949	1987	39
IL	CHICAGO MIDWAY AP 3 SW	1577	41:44:00	087:46:00	620	1949	1987	39
IL	SPRINGFIELD WSO AP	8179	39:51:00	089:41:00	590	1949	1987	39
IN	FORT WAYNE WSO AP	3037	41:00:00	085:12:00	800	1949	1987	39
IN	INDIANAPOLIS WSFO	4259	39:44:00	086:16:00	790	1949	1987	39
KS	COLBY 1 SW	1699	39:23:00	101:04:00	3170	1951	1987	37
KS	EMPORIA	2543	38:20:00	096:11:00	1210	1951	1973	23
KY	LEXINGTON WSO AP	4746	38:02:00	084:36:00	970	1949	1987	39
KY	LOUISVILLE WSFO	4954	38:11:00	085:44:00	480	1949	1987	39
LA	NEW ORLEANS WSCMO AP	6660	29:59:00	090:15:00	0	1954	1987	34
LA	ALEXANDRIA	98	31:19:00	092:28:00	90	1949	1987	39
LA	SHREVEPORT WSO AP	8440	32:28:00	093:49:00	250	1949	1987	39
MA	BOSTON WSO AP	770	42:22:00	071:02:00	20	1949	1987	39
MA	WORCESTER WSO AP	9923	42:16:00	071:52:00	990	1949	1987	39
MD	BALTIMORE WSO AP	465	39:11:00	076:40:00	200	1949	1987	39
ME	PORTLAND WSMO AP	6905	43:39:00	070:19:00	60	1949	1987	39
MI	DETROIT METRO WSO AP	2103	42:14:00	083:20:00	630	1960	1987	28
MI	LANSING WSO AP	4641	42:46:00	084:36:00	840	1949	1987	39
MN	MINN-ST PAUL WSO AP	5435	44:53:00	093:13:00	830	1949	1987	39
MN	DULUTH	2248	46:50:00	092:11:00	1430	1949	1987	39
MO	ST LOUIS WSCMO AP	7455	38:45:00	090:22:00	540	1949	1987	39
MO	SPRINGFIELD WSO AP	7976	37:14:00	093:23:00	1270	1949	1987	39
MO	KANSAS CITY U of MO	4379	37:02:00	94:35:00	850	1949	1969	21
MS	JACKSON WSFO AP	4472	32:19:00	090:05:00	330	1964	1987	24
MT	GREAT FALLS WSCMO AP	3751	47:29:00	111:22:00	3660	1949	1987	39
MT	BILLINGS WSO AP	807	45:48:00	108:32:00	3570	1949	1987	39
MT	BUTTE 8 S	1309	45:54:00	112:33:00	5700	1954	1987	34
MT	GLASGOW WSO AP	3558	48:13:00	106:37:00	2280	1958	1987	30
NC	CAPE HATTERAS WSO	1458	35:16:00	075:33:00	10	1958	1987	30
NC	CHARLOTTE WSO AP	1690	35:13:00	080:56:00	700	1949	1987	39
NC	DALTON	2230	36:18:00	080:24:00	1010	1949	1987	39
NC	ELIZABETH CITY	2719	36:19:00	076:12:00	10	1955	1987	33
NC	ASHFORD	312	35:53:00	081:57:00	1760	1949	1987	39
NC	RALEIGH DURHAM WSFO AP	7069	35:52:00	078:47:00	380	1949	1987	39
NC	WILMINGTON WSO AP	9457	34:16:00	077:54:00	70	1950	1987	38
ND	FARGO WSO AP	2859	46:54:00	096:48:00	900	1949	1987	39
ND	BISMARCK WSFO AP	819	46:46:00	100:46:00	1650	1949	1987	39
NE	LINCOLN WSO AP	4795	40:51:00	096:45:00	1190	1949	1987	39
NE	NORTH PLATTE WSO AP	6065	41:08:00	100:41:00	2780	1949	1987	39
NH	CONCORD WSO AP	1683	43:12:00	071:30:00	350	1949	1987	39

Table 4. Listing of Selected Rainfall Gages Used in the Analysis

State	Location	Gage No.	Latitude	Longitude	Elevation	Beginning Year	Ending Year	Total Years
NJ	ATLANTIC CITY WSO AP	311	39:27:00	074:34:00	140	1959	1987	29
NJ	NEWARK WSO AP	6026	40:42:00	074:10:00	30	1949	1987	39
NM	ALBUQUERQUE WSFO AP	234	35:03:00	106:37:00	5310	1949	1987	39
NM	ROSWELL WSO AP	7609	33:24:00	104:32:00	3640	1948	1972	25
NV	LAS VEGAS WSO AP	4436	36:05:00	115:10:00	2160	1950	1987	38
NV	RENO WSFO AP	6779	39:30:00	119:47:00	4400	1949	1987	39
NV	ELKO FAA AP	2573	40:50:00	115:47:00	5080	1949	1987	39
NV	SMOKEY VALLEY	7620	38:47:00	117:10:00	5630	1954	1987	34
NY	BUFFALO WSFO AP	1012	42:56:00	078:44:00	710	1949	1987	39
NY	NEW YORK CENTRAL PARK	5801	40:47:00	073:58:00	130	1949	1987	39
NY	ROCHESTER WB AP	7167	43;07;00	077;40;00	550	1949	1987	39
NY	SYRACUSE WB AP	8383	43:07:00	076:07:00	420	1949	1987	39
OH	COLUMBUS WSO AP	1786	40:00:00	082:53:00	810	1949	1987	39
OH	YOUNGSTOWN WSO AP	9406	41:15:00	080:40:00	1180	1949	1987	39
OK	OKLAHOMA CITY WSFO AP	6661	35:24:00	097:36:00	1280	1949	1987	39
OR	MEDFORD WSO AP	5429	42:23:00	122:53:00	1300	1949	1987	39
OR	PORTLAND WSFO AP	6751	45:36:00	122:36:00	20	1949	1987	39
OR	SALEM WSO AP	7500	44:55:00	123:01:00	200	1949	1987	39
OR	LAKEVIEW 2 NNW	4670	42:13:00	120:22:00	4780	1949	1987	39
OR	PENDELTON WSO AP	6546	45:41:00	118:51:00	1490	1949	1987	39
PA	ERIE WSO AP	2682	42:05:00	080:11:00	730	1949	1987	39
PA	PHILADELPHIA WSCMO AP	6889	39:53:00	075:14:00	10	1949	1987	39
PA	PITTSBURGH WSCMO2 AP	6993	40:30:00	080:13:00	1150	1949	1987	39
SC	CHARLESTON WSO CI	1549	32:47:00	079:56:00	10	1949	1987	39
SC	COLUMBIA WSFO AP	1939	33:57:00	081:07:00	210	1949	1987	39
SD	RAPID CITY WSO AP	6937	44:03:00	103:04:00	3160	1949	1987	39
SD	MOBRIDGE	5691	45:34:00	100:27:00	1700	1949	1987	39
SD	SIOUX FALLS WSFO AP	7667	43:34:00	096:44:00	1420	1949	1987	39
TN	BRISTOL WSO AP	1094	36:29:00	082:24:00	1530	1949	1987	39
TN	CHATTANOOGA WSO AP	1656	35:02:00	085:12:00	680	1949	1987	39
TN	KNOXVILLE WSO AP	4950	35:48:00	084:00:00	950	1949	1987	39
TN	MEMPHIS FAA-AP	5954	35:03:00	090:00:00	270	1949	1987	39
TN	NASHVILLE WSO AP	6402	36:07:00	086:41:00	580	1949	1987	39
TX	BROWNSVILLE WSO AP	1136	25:54:00	097:26:00	20	1949	1987	39
TX	ABILENE WSO AP	16	32:26:00	099:41:00	1760	1949	1987	39
TX	CORPUS CHRISTI WSO AP	2015	27:46:00	097:30:00	40	1949	1987	39
TX	AMARILLO WSO AP	211	35:14:00	101:42:00	3590	1949	1987	39
TX	DALLAS FAA AP	2244	32:51:00	096:51:00	440	1949	1987	39
TX	EL PASO WSO AP	2797	31:48:00	106:24:00	3920	1949	1987	39
TX	FT WORTH MEACH WSO AP	3284	32:49:00	097:21:00	670	1949	1987	39
TX	AUSTIN WSO AP	428	30:18:00	097:42:00	600	1949	1987	39
TX	HOUSTON-ALIEF	4311	29:43:00	095:36:00	70	1949	1987	39
TX	HOUSTON-SATSUMA	4329	29:56:00	095:38:00	120	1949	1987	39
TX	LUBBOCK WSFO AP	5411	33:39:00	101:49:00	3250	1949	1987	39
TX	MIDLAND/ODESSA WSO AP	5890	31:57:00	102:11:00	2860	1949	1987	39
TX	SAN ANTONIO WSFO	7945	29:32:00	098:28:00	790	1949	1987	39
UT	SALT LAKE CITY NWSFO AP	7598	40:47:00	111:57:00	4220	1949	1987	39
UT	GREEN RIVER	3418	39:00:00	110:10:00	4070	1950	1987	38
UT	ST GEORGE	7516	37:07:00	113:34:00	2760	1949	1987	39
VA	LYNCHBURG WSO AP	5120	37:20:00	079:12:00	920	1949	1987	39
VA	NORTHFOLK WSO AP	6139	36:54:00	074:12:00	20	1949	1987	39
VA	WASH NATL WSCMO AP	8906	38:51:00	077:02:00	70	1949	1987	39
VT	BURLINGTON WSO AP	1081	44:28:00	073:09:00	330	1949	1987	39
WA	SEATTLE TAC WSCMO AP	7473	47:27:00	122:18:00	450	1949	1987	39
WA	SPOKANE WSO AP	7938	47:38:00	117:32:00	2360	1949	1987	39
WA	YAKIMA WSO AP	9465	46:34:00	120:32:00	1060	1949	1987	39
WI	GREEN BAY WSO AP	3269	44:29:00	088:08:00	680	1949	1987	39
WI	MADISON WSO AP	4961	43:08:00	089:20:00	860	1949	1987	39
WI	MILWAUKEE WSO AP	5479	42:57:00	087:54:00	670	1949	1987	39
WV	CHARLESTON WFSO AP	1570	38;22;00	081;36;00	1020	1949	1987	39
WY	CASPER WSO AP	1570	42:55:00	106:28:00	5340	1976	1986	11
WY	MUD SPRINGS	6597	41:19:00	108:55:00	6740	1954	1987	34
WY	PATHFINDER DAM	7105	42:28:00	106:51:00	5930	1949	1987	39

TABLE . Storm Event Statistics on the National Scale

Rain Gage Location	Gage No.	Annual Statistics: No. Storms/yr Avg	No. Storms/yr COV	Precip in/yr Avg	Precip in/yr COV	Independent Storm Event Statistics: Duration (hr) Avg	Duration (hr) COV	Intensity (in/hr) Avg	Intensity (in/hr) COV	Volume (in) Avg	Volume (in) COV	DELTA (hr) Avg	DELTA (hr) COV
NORTH EAST													
VT BURLINGTON	1081	69	0.11	31.42	0.17	11.5	0.77	0.059	1.20	0.45	0.89	128	0.90
NH CONCORD	1683	62	0.09	35.17	0.18	12.0	0.74	0.061	1.18	0.56	0.95	143	0.86
CT HARTFORD	3451	55	0.23	36.10	0.22	10.9	0.78	0.076	1.06	0.65	0.98	147	0.92
NY ROCHESTER	7167	67	0.11	28.62	0.15	11.2	0.83	0.059	1.21	0.43	0.93	133	0.97
NY SYRACUSE	8383	75	0.11	35.34	0.22	12.2	0.83	0.062	1.41	0.47	0.97	118	0.89
NY BUFFALO	1012	75	0.10	34.86	0.14	12.0	0.81	0.059	1.26	0.47	0.99	119	0.92
OH COLUMBUS	1786	70	0.11	34.93	0.15	10.0	0.82	0.078	1.25	0.50	0.94	127	0.97
OH YOUNGSTOWN	9406	74	0.10	34.54	0.15	10.4	0.81	0.073	1.25	0.47	0.93	121	0.93
PA ERIE	2682	77	0.17	37.05	0.23	11.0	0.83	0.067	1.20	0.48	1.01	112	0.93
PA PITTSBURGH	6993	70	0.18	32.77	0.20	11.0	0.81	0.067	1.23	0.47	0.90	126	1.13
WV CHARLESTON	1570	77	0.11	39.95	0.17	10.9	0.85	0.076	1.31	0.52	0.95	115	0.92
	AVG =	70	0.13	34.61	0.18	11.2	0.81	0.067	1.23	0.50	0.95	126.1	0.94
	COV =	0.10	0.34	0.09	0.18	0.06	0.04	0.11	0.07	0.12	0.04	0.09	0.08
NORTH EAST - COASTAL													
ME PORTLAND	6905	64	0.11	41.77	0.20	12.6	0.76	0.065	1.06	0.65	1.04	139	0.83
MA BOSTON	770	62	0.11	41.49	0.21	12.3	0.79	0.066	0.94	0.67	1.08	144	0.85
MA WORCESTER	9923	65	0.12	45.07	0.20	12.7	0.80	0.070	1.06	0.69	1.00	134	0.80
CT BRIDGEPORT	806	62	0.11	39.35	0.24	10.5	0.73	0.076	1.03	0.64	1.03	143	0.91
NY NEW YORK CITY	5801	63	0.13	42.67	0.22	11.0	0.76	0.079	1.10	0.67	1.06	140	0.92
NJ NEWARK	6026	63	0.12	38.25	0.20	11.1	0.77	0.072	1.10	0.61	0.94	139	0.91
	AVG =	63	0.12	41.43	0.21	11.7	0.77	0.071	1.05	0.66	1.03	140	0.87
	COV =	0.02	0.07	0.06	0.08	0.08	0.03	0.07	0.06	0.04	0.05	0.03	0.06

TABLE 5. ·torm Event Statistics on the National Scale (continued)

Rain Gage Location	Gage No.	Annual Statistics Avg	Annual Statistics COV	Precip in/yr Avg	Precip in/yr COV	Duration (hr) Avg	Duration (hr) COV	Intensity (in/hr) Avg	Intensity (in/hr) COV	Volume (in) Avg	Volume (in) COV	DELTA (hr) Avg	DELTA (hr) COV
ΜID ATLANTIC													
NJ ATLANTIC CITY	311	60	0.13	38.80	0.16	10.0	0.76	0.087	1.11	0.65	0.99	149	0.87
PA PHILADELPHIA	6889	62	0.12	39.68	0.16	10.3	0.76	0.085	1.19	0.64	0.98	144	0.96
DE WILMINGTON	9595	59	0.17	38.24	0.23	10.6	0.74	0.083	1.13	0.64	0.96	146	0.90
MD BALTIMORE	465	60	0.11	39.41	0.19	10.6	0.84	0.088	1.22	0.65	1.04	149	0.96
VA LYNCHBURG	5120	62	0.13	38.26	0.20	10.9	0.83	0.085	1.16	0.62	0.98	142	0.95
VA WASHINGTON DC	8906	61	0.12	37.46	0.18	10.0	0.83	0.094	1.25	0.62	1.00	148	0.97
VA NORFOLK	6139	63	0.15	42.28	0.28	9.9	0.87	0.098	1.17	0.67	1.11	138	0.90
NC ASHFORD	312	58	0.26	40.9	0.29	9.9	0.90	0.101	1.16	0.69	1.05	141	1.56
NC CHARLOTTE	1690	63	0.13	40.79	0.16	9.5	0.91	0.098	1.11	0.65	1.01	141	1.01
NC RALEIGH-DURHAM	7069	62	0.12	40.12	0.12	9.6	0.86	0.099	1.10	0.65	0.94	144	0.94
NC DALTON	2230	55	0.20	38.1	0.24	7.8	0.88	0.127	1.10	0.69	1.08	147	1.12
NC ELIZABETH CITY	2719	56	0.18	41.3	0.21	7.7	0.89	0.130	1.13	0.73	1.08	145	1.03
	AVG =	**60**	**0.15**	**39.61**	**0.20**	**9.7**	**0.84**	**0.098**	**1.15**	**0.66**	**1.02**	**144**	**1.01**
	COV =	**0.04**	**0.29**	**0.04**	**0.25**	**0.10**	**0.07**	**0.16**	**0.04**	**0.05**	**0.05**	**0.02**	**0.18**
EAST GULF													
FL ORLANDO	6638	69	0.22	47.15	0.26	5.9	1.16	0.169	1.12	0.69	1.25	126	1.32
FL ST PETERSBURG	7886	59	0.20	46.86	0.25	5.5	1.06	0.209	0.98	0.80	1.12	145	1.39
FL MIAMI	5663	78	0.16	55.17	0.23	6.0	1.06	0.163	1.02	0.71	1.33	115	1.56
FL TALLAHASSEE	8758	72	0.12	62.95	0.25	7.1	1.00	0.172	1.03	0.87	1.17	119	1.11
LA ALEXANDRIA	98	57	0.18	51.43	0.18	6.5	1.01	0.190	0.92	0.91	1.10	151	1.06
LA NEW ORLEANS	6660	70	0.14	58.70	0.21	7.3	0.99	0.165	1.11	0.83	1.14	126	1.08
	AVG =	**68**	**0.17**	**53.71**	**0.23**	**6.4**	**1.05**	**0.178**	**1.03**	**0.80**	**1.19**	**130**	**1.25**
	COV =	**0.12**	**0.22**	**0.12**	**0.13**	**0.11**	**0.06**	**0.10**	**0.07**	**0.11**	**0.07**	**0.11**	**0.16**

TABLE Storm Event Statistics on the National Scale (continued)

Rain Gage Location	Gage No.	Annual Statistics Avg	COV	Precip in/yr Avg	COV	Duration (hr) Avg	COV	Intensity (in/hr) Avg	COV	Volume (in) Avg	COV	DELTA (hr) Avg	COV
SOUTHEAST													
GA COLUMBUS	2166	68	0.12	48.79	0.18	8.0	0.93	0.131	1.08	0.72	1.06	131	1.10
GA ATLANTA	451	67	0.12	46.87	0.15	9.3	0.89	0.112	1.09	0.70	0.99	133	1.00
AL BIRMINGHAM	831	69	0.18	50.71	0.22	8.4	0.89	0.121	1.04	0.73	1.10	124	1.01
AL MONTGOMERY	5550	65	0.12	49.05	0.20	8.0	0.91	0.135	1.02	0.76	1.07	137	1.01
FL JACKSONVILLE	4358	69	0.13	50.02	0.18	7.4	1.04	0.142	1.10	0.73	1.27	130	1.22
SC CHARLESTON	1549	63	0.12	44.57	0.18	8.2	0.91	0.123	1.33	0.71	1.17	141	1.08
SC COLUMBIA	1939	61	0.21	45.50	0.28	9.1	0.93	0.121	1.21	0.74	1.05	140	1.04
NC CAPE HATTERAS	1458	67	0.17	52.33	0.22	9.2	0.90	0.108	0.96	0.79	1.21	130	0.95
NC WILMINGTON	9457	69	0.11	51.79	0.13	8.8	0.90	0.119	1.18	0.75	1.19	129	0.98
TN CHATTANOOGA	1656	71	0.11	50.90	0.18	10.0	0.85	0.099	1.04	0.72	1.05	125	0.96
LA SHREVEPORT	8440	54	0.22	42.27	0.27	8.8	0.94	0.124	1.01	0.79	1.07	161	1.03
MS JACKSON	4472	67	0.12	55.01	0.23	8.2	0.95	0.140	1.02	0.82	1.09	133	1.00
AR LITTLE ROCK	4248	60	0.16	48.36	0.21	9.4	0.88	0.117	1.08	0.80	1.05	147	1.02
TN MEMPHIS	5954	64	0.16	50.28	0.20	9.2	0.90	0.123	1.10	0.79	1.02	138	0.97
	AVG =	65	0.15	49.03	0.20	8.7	0.9	0.122	1.09	0.75	1.10	136	1.03
	COV =	0.07	0.25	0.07	0.20	0.08	0.05	0.10	0.09	0.05	0.07	0.07	0.07
EAST TEXAS													
OK OKLAHOMA CITY	6661	44	0.17	31.39	0.24	8.3	0.87	0.123	1.05	0.71	1.07	206	1.29
TX BROWNSVILLE	1136	35	0.22	24.73	0.30	8.2	1.05	0.135	1.20	0.71	1.44	262	1.44
TX CORPUS CHRISTI	2015	38	0.24	28.85	0.30	8.2	1.06	0.141	1.14	0.77	1.39	241	1.40
TX DALLAS	2244	40	0.28	31.32	0.32	7.6	1.00	0.148	1.05	0.78	1.07	213	1.20
TX FT WORTH	3284	38	0.23	28.31	0.28	6.8	0.96	0.155	1.04	0.74	1.00	223	1.27
TX AUSTIN	428	45	0.14	31.46	0.20	8.4	0.91	0.119	1.01	0.70	1.13	200	1.33
TX SAN ANTONIO	7945	39	0.22	28.57	0.31	8.9	0.95	0.125	1.10	0.73	1.16	230	1.32
TX HOUSTON-ALIEF	4311	46	0.26	39.26	0.33	7.7	1.00	0.144	1.11	0.86	1.17	169	1.14
TX HOUSTON-SATS	4329	46	0.26	37.08	0.30	7.7	0.97	0.139	1.04	0.80	1.17	170	1.11
	AVG =	41	0.22	31.22	0.29	8.0	0.97	0.137	1.08	0.76	1.18	213	1.28
	COV =	0.10	0.20	0.14	0.14	0.08	0.06	0.09	0.06	0.07	0.12	0.14	0.09

TABLE 5. torm Event Statistics on the National Scale (continued)

Rain Gage Location	Gage No.	Annual Statistics Avg	COV	Precip in/yr Avg	COV	Independent Storm Event Statistics: Duration (hr) Avg	COV	Intensity (in/hr) Avg	COV	Volume (in) Avg	COV	DELTA (hr) Avg	COV
ENTRAL													
Y LEXINGTON	4746	72	0.12	42.71	0.18	9.8	0.83	0.089	1.09	0.60	0.97	124	0.97
Y LOUISVILLE	4954	69	0.13	41.65	0.18	9.5	0.85	0.092	1.13	0.60	1.02	128	0.95
N BRISTOL	1094	74	0.13	38.97	0.15	9.4	0.83	0.087	1.24	0.53	0.91	120	0.92
N KNOXVILLE	4950	74	0.10	44.57	0.16	9.3	0.84	0.090	1.04	0.60	0.98	119	0.92
N NASHVILLE	6402	70	0.14	46.03	0.20	9.1	0.88	0.103	1.06	0.66	1.04	127	0.97
O SPRINGFIELD	7976	60	0.16	39.74	0.23	9.0	0.85	0.104	1.07	0.66	1.04	148	1.10
R FORT SMITH	2574	55	0.18	39.43	0.22	8.6	0.85	0.113	0.99	0.72	1.07	163	1.09
	AVG =	68	0.14	41.87	0.19	9.2	0.85	0.097	1.09	0.62	1.00	133	0.99
	COV =	0.11	0.19	0.06	0.16	0.04	0.02	0.10	0.07	0.10	0.05	0.12	0.08
ORTH CENTRAL													
D FARGO	2859	37	0.17	17.79	0.25	9.3	0.91	0.084	1.26	0.48	1.18	251	1.44
SD SIOUX FALLS	7667	42	0.18	22.56	0.24	9.6	0.90	0.091	1.20	0.54	1.02	220	1.42
MN MINN-ST PAUL	5435	52	0.16	25.52	0.25	9.8	0.85	0.080	1.34	0.49	1.09	175	1.31
IA DES MOINES	2203	53	0.16	30.09	0.23	9.8	0.84	0.089	1.25	0.57	1.02	172	1.24
IA DUBUQUE	2367	58	0.19	35.59	0.28	9.7	0.83	0.091	1.09	0.61	1.07	149	1.11
NE LINCOLN	4795	48	0.18	28.81	0.25	9.5	0.87	0.095	1.15	0.60	1.03	196	1.40
KS EMPORIA	2543	46	0.23	32.21	0.31	8.5	0.80	0.110	1.17	0.70	1.06	192	1.39
MO ST LOUIS	7455	60	0.13	34.73	0.22	8.9	0.85	0.096	1.14	0.58	1.01	149	1.10
MO KANSAS CITY	4379	46	0.23	31.34	0.27	7.6	0.84	0.129	1.09	0.67	1.00	165	1.20
MI DETROIT	2103	63	0.11	30.05	0.16	9.8	0.79	0.075	1.27	0.48	0.94	141	0.97
MI LANSING	4641	58	0.14	26.72	0.18	10.2	0.80	0.070	1.22	0.46	0.94	149	1.03
IN FORT WAYNE	3037	66	0.10	33.30	0.18	9.7	0.80	0.079	1.17	0.50	0.91	135	0.96
IN INDIANAPOLIS	4259	67	0.12	37.83	0.15	9.7	0.82	0.087	1.20	0.56	0.99	133	1.02
IL CHICAGO	1577	59	0.18	33.38	0.22	9.2	0.84	0.093	1.19	0.57	1.05	148	1.05
IL SPRINGFIELD	8179	60	0.15	33.00	0.17	9.1	0.86	0.090	1.15	0.55	1.05	150	1.08
MN DULUTH	2248	55	0.14	27.84	0.20	11.6	0.85	0.068	1.26	0.51	1.03	164	1.13
WI GREEN BAY	3269	55	0.13	26.28	0.18	9.8	0.81	0.074	1.18	0.47	0.92	162	1.12
WI MADISON	4961	56	0.15	29.41	0.17	9.5	0.79	0.084	1.24	0.53	0.99	161	1.14
WI MILWAUKEE	5479	58	0.16	30.02	0.20	10.1	0.80	0.076	1.22	0.52	0.97	155	1.07
	AVG =	55	0.16	29.81	0.22	9.5	0.83	0.087	1.20	0.55	1.01	167	1.17
	COV =	0.15	0.22	0.16	0.21	0.08	0.04	0.16	0.05	0.12	0.06	0.18	0.13

TABL. Storm Event Statistics on the National Scale (continued)

Rain Gage Location	Gage No.	Annual Statistics Avg	COV	Precip in/yr Avg	COV	Duration (hr) Avg	COV	Intensity (in/hr) Avg	COV	Volume (in) Avg	COV	DELTA (hr) Avg	COV
NORTH WEST INLAND													
WA SPOKANE	7938	46	0.18	14.57	0.20	11.6	0.70	0.034	0.84	0.31	0.73	190	1.32
WA YAKIMA	9465	23	0.28	6.73	0.28	10.0	0.65	0.037	1.06	0.29	0.74	383	1.47
OR PENDLETON	6546	35	0.16	9.88	0.21	10.1	0.71	0.036	0.86	0.28	0.76	251	1.32
ID BOISE	1022	33	0.20	9.92	0.25	10.5	0.72	0.037	0.88	0.30	0.76	269	1.46
ID POCATELLO	7211	31	0.27	9.07	0.33	10.3	0.74	0.038	0.83	0.29	0.76	289	1.30
UT SALT LAKE CITY	7598	39	0.24	14.13	0.25	10.6	0.71	0.045	0.95	0.37	0.81	231	1.43
MT GREAT FALLS	3751	35	0.20	13.26	0.30	12.9	0.81	0.045	1.31	0.38	1.25	261	1.25
MT BILLINGS	807	33	0.19	12.72	0.28	12.3	0.87	0.053	1.62	0.38	0.99	277	1.21
MT BUTTE	1309	30	0.31	10.32	0.33	8.6	0.96	0.073	1.17	0.35	0.80	311	1.62
MT GLASGOW	3558	23	0.18	8.88	0.33	9.8	0.90	0.066	1.31	0.39	1.11	417	1.59
SD RAPID CITY	6937	34	0.16	14.27	0.24	10.4	0.94	0.076	1.42	0.42	1.02	275	1.62
SD MOBRIDGE	5691	31	0.23	13.64	0.31	9.0	0.87	0.084	1.44	0.45	1.00	271	1.74
ND BISMARCK	819	32	0.17	13.66	0.23	10.2	0.91	0.077	1.33	0.42	0.93	290	1.55
NE N.PLATTE WSO	6065	37	0.20	18.34	0.27	8.7	0.95	0.098	1.19	0.49	0.97	249	1.60
WY MUD SPRINGS	6597	18	0.40	5.21	0.34	7.9	0.81	0.057	1.06	0.29	0.80	506	1.71
WY PATHFINDER DAM	7105	22	0.26	7.19	0.27	11.0	0.74	0.043	1.33	0.33	1.00	399	1.34
WY CASPER	1570	33	0.20	11.66	0.31	12.4	0.82	0.048	1.56	0.35	1.06	274	1.01
CO DENVER	2220	32	0.21	13.74	0.29	11.2	0.89	0.067	1.29	0.43	1.06	290	1.23
CO FT COLLINS	3005	26	0.32	11.25	0.41	10.4	0.84	0.062	1.37	0.43	1.17	340	1.39
	AVG =	**31**	**0.23**	**11.50**	**0.29**	**10.4**	**0.82**	**0.057**	**1.20**	**0.37**	**0.93**	**304**	**1.43**
	COV =	**0.21**	**0.28**	**0.28**	**0.18**	**0.13**	**0.12**	**0.33**	**0.21**	**0.17**	**0.17**	**0.25**	**0.13**
WEST TEXAS													
KS COLBY	1699	27	0.39	14.44	0.39	6.7	0.86	0.126	1.11	0.53	0.97	312	1.77
TX LUBBOCK	5411	31	0.25	17.67	0.27	7.5	1.00	0.116	1.09	0.57	1.10	296	1.66
TX MIDLAND/ODESSA	5890	24	0.29	13.32	0.43	7.6	1.07	0.121	1.28	0.55	1.10	369	1.42
TX AMARILLO	211	33	0.23	18.33	0.29	7.5	0.98	0.114	1.11	0.55	1.14	275	1.47
TX ABILENE	16	35	0.18	22.66	0.27	7.9	0.98	0.128	1.06	0.65	1.04	261	1.35
	AVG =	**30**	**0.27**	**17.28**	**0.33**	**7.4**	**0.98**	**0.12**	**1.13**	**0.57**	**1.07**	**302**	**1.53**
	COV =	**0.15**	**0.29**	**0.21**	**0.23**	**0.06**	**0.08**	**0.05**	**0.08**	**0.08**	**0.06**	**0.14**	**0.11**

TABLE 5. Storm Event Statistics on the National Scale (continued)

Rain Gage Location	Gage No.	Annual Statistics Avg	COV	Precip in/yr Avg	COV	Independent Storm Event Statistics: Duration (hr) Avg	COV	Intensity (in/hr) Avg	COV	Volume (in) Avg	COV	DELTA (hr) Avg	COV
SOUTHWEST													
TX EL PASO	2797	19	0.32	7.47	0.42	7.4	0.97	0.090	1.13	0.40	0.98	500	1.56
NM ROSWELL	7609	20	0.29	9.41	0.37	8.0	1.07	0.101	1.15	0.46	1.08	458	1.58
NM ALBUQUERQUE	234	22	0.24	6.92	0.30	6.6	0.84	0.079	1.13	0.31	0.77	419	1.38
UT GREEN RIVER	3418	14	0.34	4.27	0.43	8.9	0.75	0.048	1.05	0.30	0.79	634	1.35
UT ST. GEORGE	7516	15	0.36	5.50	0.41	7.6	0.83	0.076	1.19	0.36	0.68	579	1.51
CO GRAND JUNCTION	3488	25	0.27	6.76	0.35	9.4	0.73	0.044	1.15	0.28	0.70	370	1.21
CO PUEBLO	6740	24	0.26	9.70	0.37	8.5	0.92	0.091	1.39	0.41	0.96	386	1.46
AZ TUCSON	8820	25	0.23	10.56	0.31	7.1	0.90	0.093	1.10	0.42	0.96	359	1.56
AZ PHOENIX	6481	16	0.29	6.77	0.44	8.1	0.92	0.085	1.23	0.42	0.95	579	1.46
AZ PET. FOREST NP	6468	19	0.36	6.61	0.33	6.5	0.87	0.086	1.11	0.35	0.94	447	1.53
	AVG =	**20**	**0.30**	**7.40**	**0.37**	**7.8**	**0.88**	**0.079**	**1.16**	**0.37**	**0.88**	**473**	**1.46**
	COV =	**0.20**	**0.16**	**0.26**	**0.14**	**0.12**	**0.11**	**0.24**	**0.08**	**0.16**	**0.15**	**0.20**	**0.08**
WEST INLAND													
NV LAS VEGAS	4436	10	0.45	3.63	0.51	8.8	0.75	0.064	1.09	0.37	0.82	967	1.49
NV RENO	6779	18	0.32	6.55	0.31	10.9	0.78	0.042	1.02	0.36	0.92	498	1.40
NV ELKO	2573	24	0.35	7.04	0.43	10.0	0.72	0.043	1.32	0.30	0.89	382	1.49
NV SMOKEY VALLEY	7620	13	0.34	4.60	0.39	8.9	0.78	0.055	0.89	0.36	0.84	670	1.43
CA BLYTHE	925	6	0.48	2.64	0.58	8.3	0.77	0.075	1.13	0.45	0.91	1583	1.56
CA BAKERSFIELD	442	15	0.34	5.02	0.36	9.3	0.71	0.048	0.93	0.34	0.81	617	1.89
	AVG =	**14**	**0.38**	**4.9133**	**0.43**	**9.4**	**0.75**	**0.05468**	**1.06**	**0.36**	**0.87**	**786**	**1.54**
	COV =	**0.44**	**0.18**	**0.34**	**0.23**	**0.10**	**0.04**	**0.23**	**0.15**	**0.14**	**0.06**	**0.56**	**0.12**

TABLE 3. **Storm Event Statistics on the National Scale (continued)**

Rain Gage Location	Gage No.	Annual Statistics Avg	COV	Precip in/yr Avg	COV	Duration (hr) Avg	COV	Intensity (in/hr) Avg	COV	Volume (in) Avg	COV	DELTA (hr) Avg	COV
PACIFIC NORTHWEST													
WA SEATTLE	7473	71	0.17	34.31	0.21	14.6	0.78	0.036	0.66	0.48	1.07	121	1.38
OR PORTLAND	6751	72	0.14	34.60	0.18	15.9	0.77	0.034	0.80	0.48	1.06	122	1.51
OR SALEM	7500	70	0.13	38.27	0.19	17.2	0.86	0.035	0.73	0.55	1.15	126	1.61
	AVG =	**71**	**0.15**	**35.73**	**0.19**	**15.9**	**0.80**	**0.035**	**0.73**	**0.50**	**1.09**	**122.9**	**1.50**
	COV =	**0.01**	**0.14**	**0.06**	**0.08**	**0.08**	**0.06**	**0.03**	**0.10**	**0.08**	**0.05**	**0.02**	**0.08**
PACIFIC CENTRAL													
OR MEDFORD	5429	40	0.17	17.71	0.26	12.9	0.77	0.040	0.98	0.44	1.14	222	1.63
OR LAKEVIEW	4670	36	0.23	13.06	0.27	13.4	0.73	0.032	0.94	0.37	0.93	230	1.67
CA REDDING	7295	30	0.34	26.59	0.40	14.5	0.90	0.072	0.94	0.88	1.08	248	2.13
CA SACRAMENTO	7630	28	0.26	16.72	0.38	13.7	0.79	0.048	0.87	0.59	1.06	306	2.00
CA OAKLAND	6335	30	0.22	17.06	0.32	13.3	0.79	0.048	0.69	0.57	1.01	295	2.28
CA SAN FRANCISCO	7769	30	0.25	19.22	0.36	14.2	0.81	0.048	0.66	0.64	1.07	288	2.26
	AVG =	**32**	**0.25**	**18.39**	**0.33**	**13.7**	**0.80**	**0.04797**	**0.85**	**0.58**	**1.05**	**264.7**	**2.00**
	COV =	**0.14**	**0.23**	**0.24**	**0.18**	**0.04**	**0.07**	**0.28**	**0.16**	**0.31**	**0.07**	**0.14**	**0.14**
PACIFIC SOUTHWEST													
CA FRESNO	3257	23	0.27	10.07	0.38	11.3	0.74	0.046	0.74	0.44	0.88	389	2.09
CA LOS ANGELES	5114	17	0.39	11.65	0.45	11.7	0.84	0.063	0.73	0.67	1.16	536	2.17
CA SAN DIEGO	7740	18	0.41	8.97	0.44	11.8	0.75	0.052	0.82	0.51	0.89	503	2.00
	AVG =	**19**	**0.36**	**10.23**	**0.42**	**11.6**	**0.78**	**0.05363**	**0.76**	**0.54**	**0.98**	**475.8**	**2.09**
	COV =	**0.17**	**0.21**	**0.13**	**0.09**	**0.02**	**0.07**	**0.16**	**0.06**	**0.22**	**0.16**	**0.16**	**0.04**

The important information produced by the analysis is represented by the set of parameter statistics listed for each specific gage location. However, in the belief that the ability to assign "typical" approximate values for relatively broad regions will be of value in situations where areawide or regional assessments are desired, we have organized the summary of study results so that gage locations are placed in a series of regional groups.

The results were arranged by geographical location and then the gages were grouped by similarities in the overall set of statistical characteristics. A measure of how closely the individual sites in a group compare (how reasonable are the assigned geographic rainfall zone) is provided by inspection of the summary at the end of each group. The value of a parameter at a particular site may be compared with the mean for the group to provide a sense of how well it fits. The coefficient of variation (COV) for the group provides a measure of the variability in the values of a parameter at all of the sites in the group.

An attempt was made to make the geographical area assigned to a group as large as possible, though obviously a greater number of smaller groupings would improve the match within a zone. The results appear to provide a geographic zone breakdown that will provide reasonable estimates for broad-scale screening analyses, but the user should recognize that local deviations could be significant in the western parts of the country. Mountains, deserts, and coastal patterns in the west result in large differences over small distances. For this part of the country, data are grouped as suggested by apparent similarities, but the user is cautioned that specific locations within an apparent grouping might be quite different than the sites analyzed.

Figure 7 shows the selected rainfall "zones" for the continental United States, based on the sample of rain gages that were analyzed in this study and the gage groupings assigned in Table 6. This is presented to provide an overview of the number of appreciably different rainfall patterns (as measured by storm event statistics) that are present, and as a way to graphically summarize the study results. Table 6 summarizes the "typical" values for the storm event statistics for each of the zones, which are taken as the group average presented previously in Table 5.

It is re-emphasized here that the required values should be used for screening purposes only, especially for western states. The SYNOP II program should be used with a local gage for more reliable results in areas where a local gage has not been analyzed.

The regional groupings presented above can be used as a guide for assessing regional patterns. A group average may be used in the east to provide an estimate of the characteristics of an ungaged site. In all cases, especially in the western part of the country, estimates will be best made by inspecting the specific results for pertinent sites in the list. Obviously, wherever accurate local estimates are important, the record for a local gage or gages should be analyzed directly.

An informative picture of regional patterns for the storm event parameters (event mean durations, intensities, volumes, and interval between storms), is provided by a mapped display of the long term averages. The number of storms per year is a direct reflection of the average interval between storm events and has been presented instead. Figures 8 through 11 illustrate the national patterns for each of these parameters, using smoothed contours to reflect broad patterns that ignore smaller scale spatial variations and localized deviations.

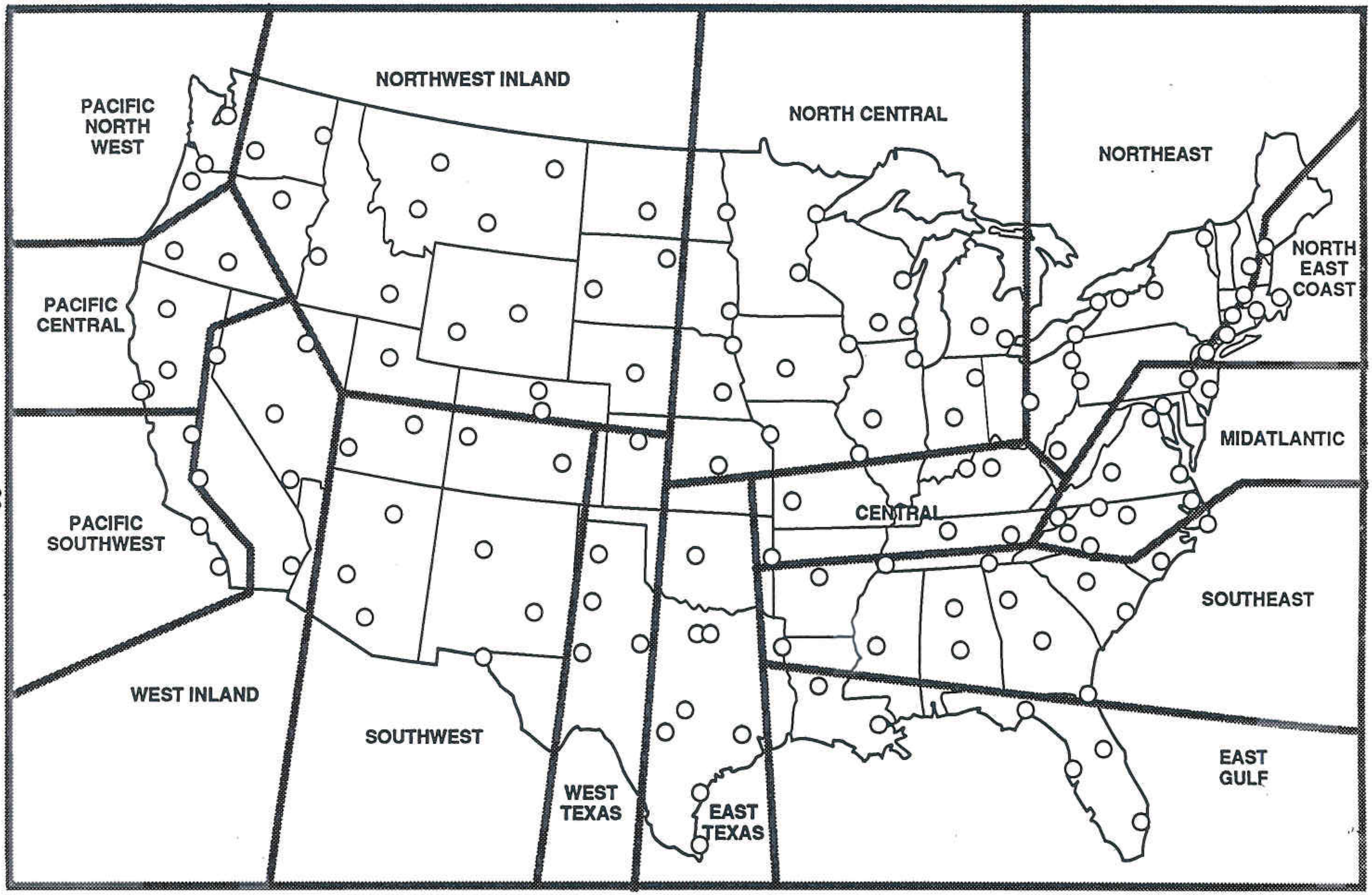


Figure 7. Rain zones of the United States.

TABLE 6. Typical Vaules of Storm Event Statistics for Zones

RAIN ZONE	Annual Statistics: No. of Storms Avg	Annual Statistics: No. of Storms COV	Annual Statistics: Precip in/yr Avg	Annual Statistics: Precip in/yr COV	Independent Storm Event Statistics: Duration Avg	Duration COV	Intensity Avg	Intensity COV	Volume Avg	Volume COV	DELTA Avg	DELTA COV
NORTH EAST	70	0.13	34.6	0.18	11.2	0.81	0.067	1.23	0.50	0.95	126	0.94
NORTH EAST - COASTAL	63	0.12	41.4	0.21	11.7	0.77	0.071	1.05	0.66	1.03	140	0.87
MIDATLANTIC	62	0.13	39.5	0.18	10.1	0.84	0.092	1.20	0.64	1.01	143	0.97
CENTRAL	68	0.14	41.9	0.19	9.2	0.85	0.097	1.09	0.62	1.00	133	0.99
NORTH CENTRAL	55	0.16	29.8	0.22	9.5	0.83	0.087	1.20	0.55	1.01	167	1.17
SOUTHEAST	65	0.15	49.0	0.20	8.7	0.92	0.122	1.09	0.75	1.10	136	1.03
EAST GULF	68	0.17	53.7	0.23	6.4	1.05	0.178	1.03	0.80	1.19	130	1.25
EAST TEXAS	41	0.22	31.2	0.29	8.0	0.97	0.137	1.08	0.76	1.18	213	1.28
WEST TEXAS	30	0.27	17.3	0.33	7.4	0.98	0.121	1.13	0.57	1.07	302	1.53
SOUTHWEST	20	0.30	7.4	0.37	7.8	0.88	0.079	1.16	0.37	0.88	473	1.46
WEST INLAND	14	0.38	4.9	0.43	9.4	0.75	0.055	1.06	0.36	0.87	786	1.54
PACIFIC SOUTH	19	0.36	10.2	0.42	11.6	0.78	0.054	0.76	0.54	0.98	476	2.09
NORTHWEST INLAND	31	0.23	11.5	0.29	10.4	0.82	0.057	1.20	0.37	0.93	304	1.43
PACIFIC CENTRAL	32	0.25	18.4	0.33	13.7	0.80	0.048	0.85	0.58	1.05	265	2.00
PACIFIC NORTHWEST	71	0.15	35.7	0.19	15.9	0.80	0.035	0.73	0.50	1.09	123	1.50

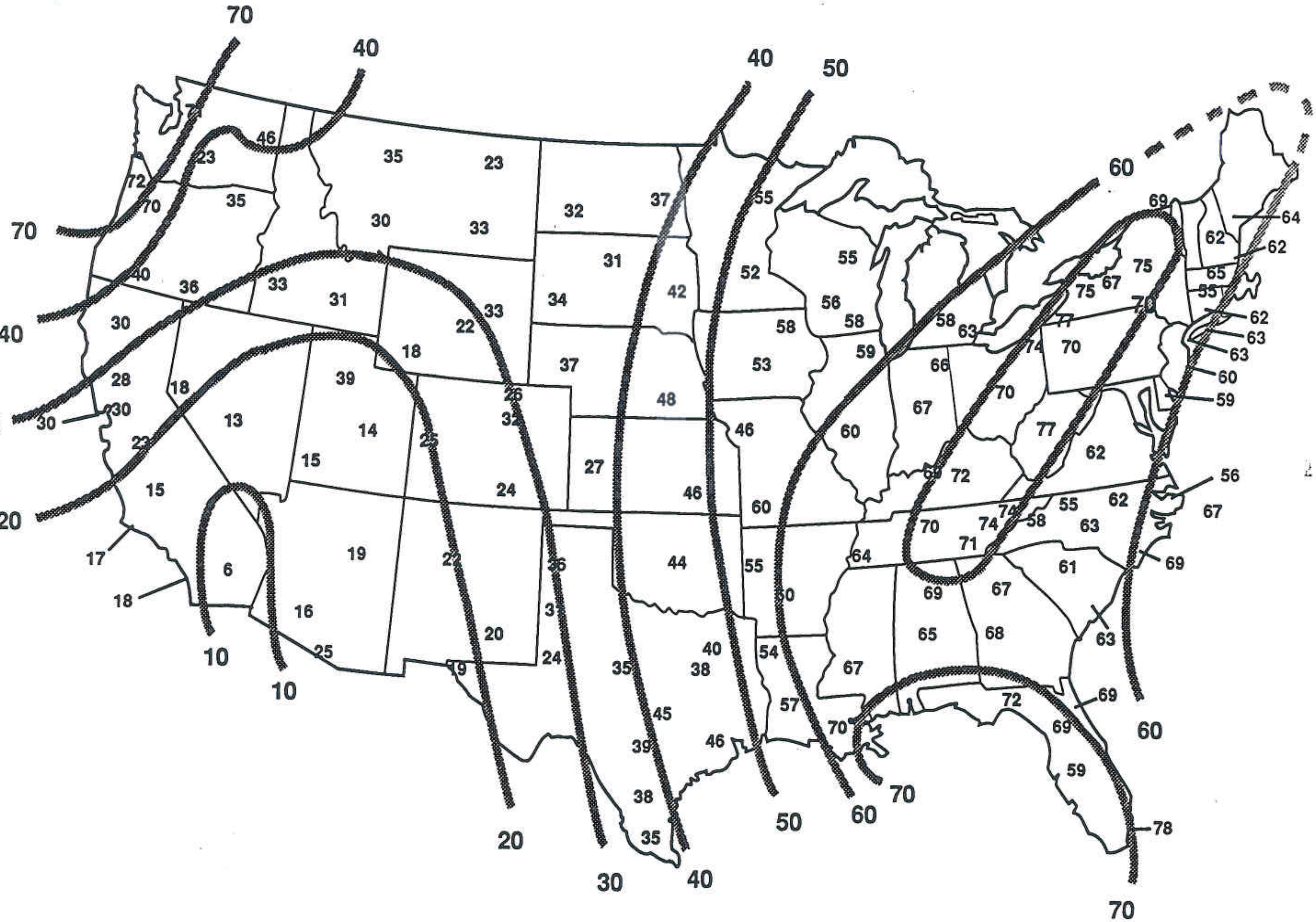


Figure 8. Annual average number of storms.
(storms/year)

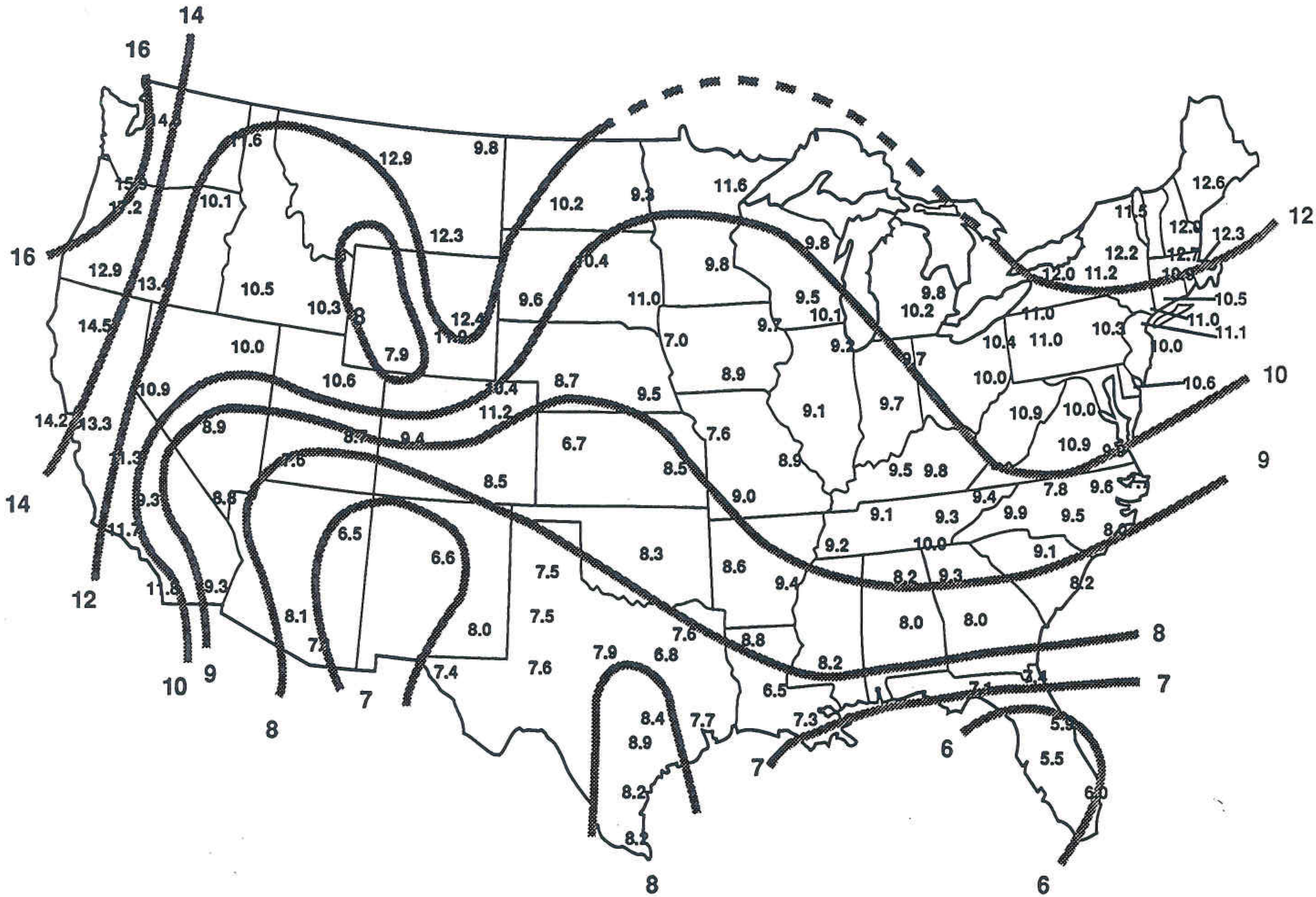


Figure 9. Average storm event duration.
(hours)

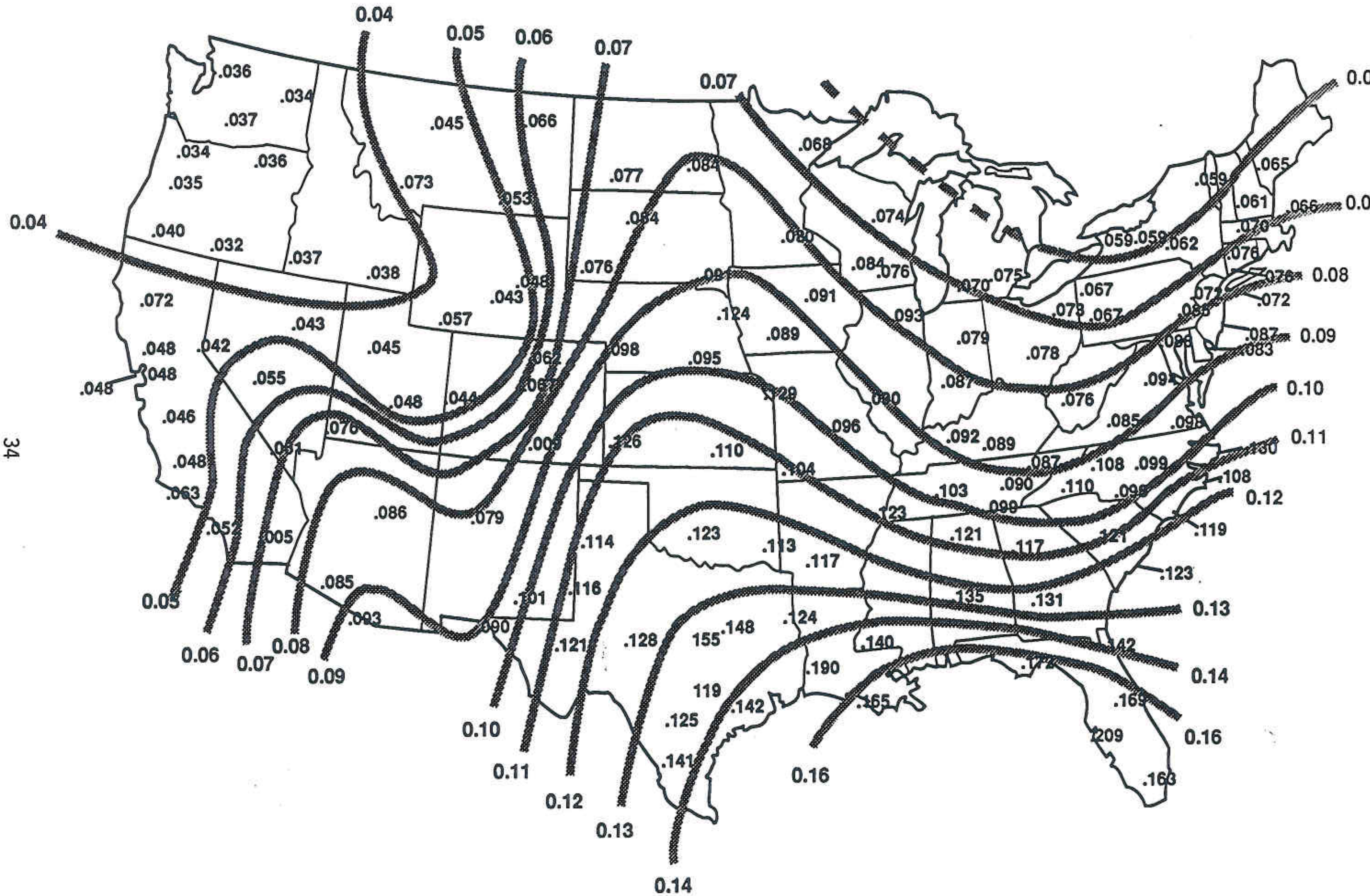


Figure 10. Average Storm Event Intensity.

(inches/hour)

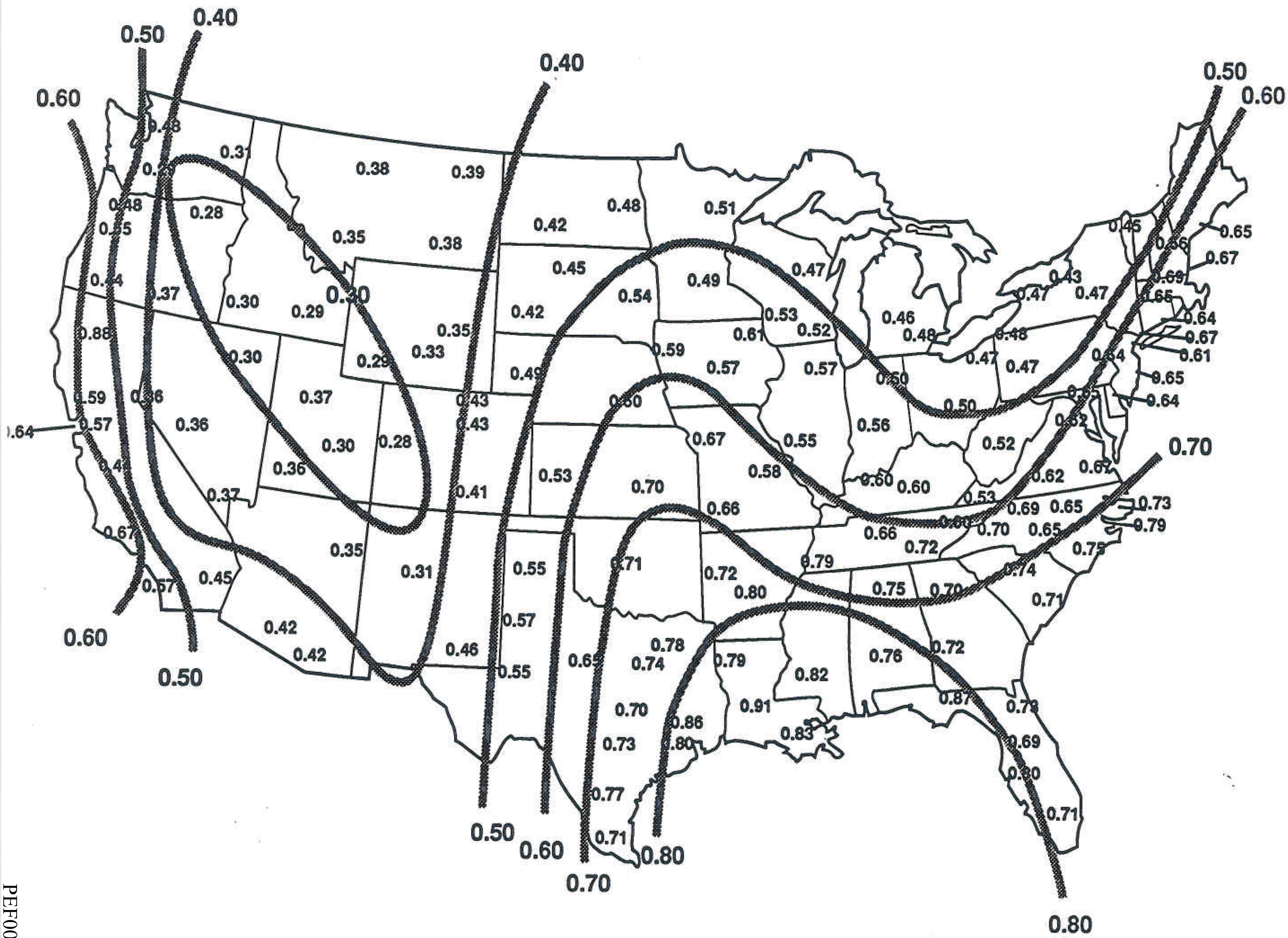


Figure 11. Average Storm Event Volume.
(inches)

The contours indicate a set of rather well defined patterns. Allowing for the modifying influences of mountains and strong coastal effects, they may be generalized as follows.

- NUMBER OF STORMS (Figure 8) - There is a general east-west gradient for the average number of storms per year, with an overlying north-south influence immediately adjacent to the west coast. The greatest number of separate storm events per year occur in the Pacific Northwest and along the Appalachian mountain chain in the east.

- STORM DURATION (Figure 9) - The average storm duration decreases from north to south, with a west to east decrease near the west coast.

- STORM INTENSITY (Figure 10) - The basic trend is increasing average intensity from north to south in the eastern part of the country. The Rocky Mountains impose an east-west influence, but the pattern returns partially to a north-south increasing gradient on the Pacific coast.

- STORM VOLUME (Figure 11) - The general pattern for the average storm volume appears to be a gradient related to distance from a coast and the influence of mountains. Both the Gulf and Atlantic influence the pattern in the eastern half of the country producing a decreasing gradient that is roughly perpendicular to the coastline. In the west, a coastal influence on the pattern is indicated, but is significantly modified by the regional variations in climate and topography.

The presence of the differing national patterns for each of the storm event parameters indicates the problem in identifying very large areas that can be assigned a common set of storm event descriptors. In the northern half of the country and in the southwest, fairly large areas with approximately similar rainfall event characteristics can be delineated. On the west coast, such areas are much smaller.

Whenever possible, analysis of a local rainfall record is the preferred basis for characterizing local rainfall for use in NPS water quality related assessments. For preliminary estimates, or for more generalized assessments, one of the following approaches may be used.

- Use the contour plots of the specific event parameters (Figures 8 to 11), to estimate an approximate value for each parameter. The average interval between storms (DELTA) is related to the average annual number of storms (NST) as follows:

$$DELTA = 8760 \text{ hr/yr} / NST$$

- Identify the appropriate rain zone from Figure 7, and select the event characteristics from the average characteristics for the zone, from the list presented in Table 6. Use Table 5 to examine the differences between specific gages within the zone. This listing arranges the rain gages into regional groups that correspond to the zones shown on the map.

- Use the tables, elect one or more individual gages that are located near the area of concern. Use these values to estimate the storm event parameters for the local area.

Even for cases where storm parameters for a local gage are determined by direct analysis of the gage record, it will be useful to evaluate the results in the context of the data listed in this report for nearby sites. This will provide a check against the possibility of a distortion in the results obtained due to data gaps or other imperfections in the original record analyzed. It will also serve another purpose. There will be situations where differences in rainfall statistics exist for gages that are relatively close to each other, because of topography or other localized factors.

This factor is illustrated by the information summarized in Table 7. Seven different Texas rain gages, located within a radius of approximately 40 miles of Dallas-Ft. Worth, are compared. Results are comparable, but exhibit individual differences for most parameters of plus/minus 10 percent of what would be the area average. A similar analysis is also shown for two gages near Asheville, North Carolina. In this case there is a substantial difference in rainfall for the two gages.

For four of the Texas gages, separate results are presented in Table 7 for two different lengths of record to examine the possible effect of longer term trends. It is apparent that the recent storms have been generally larger in intensity but shorter in duration. Storm volumes have remained about the same. The summary at the bottom shows the percent difference in the storm parameters that result from the analysis of different lengths of the available record.

3.2 Summary of Storm Event Statistics in North Carolina

This section presents a summary of the storm event statistics computed for a set of rain gage locations in a single state. North Carolina was selected for this illustration because its ranges in geographic features, from inland mountains to coastal shoreline areas, would be expected to accentuate the variation in rainfall patterns in different parts of the state. The geographical distribution of the sites selected is shown on the map presented in Figure 12. Table 8 lists the site name, gage number, elevation, latitude and longitude, together with information on the length of the record analyzed. The basic guideline applied in selecting the gages within this sample state was to select gages which adequately represent the different geographic regions of the state (coastal, piedmont and mountain).

The gages have been grouped as suggested by similarities in the set of statistical characteristics. In this case the elevation, which correlates closely with distance inland from the coast, proved to be an effective sorting variable. A measure of how closely the individual sites in a group compare (how reasonable it is to define a geographic rainfall zone) is provided by inspection of the mean and COV of all group values for each specific parameter.

Table 9 shows some interesting results regarding the grouped statistics. For example, the average duration of storm events tends to increase with distance from the coastal zone. Furthermore, the average event volume and intensity of a storm event tends to decrease with distance from the coastal zone. In short, storm events appear to be shorter, more intense near the coast and longer, less intense further inland.

Theoretically, a greater refinement of rainfall gages should produce less variability within zones when compared to the variability within regional zones generated on a national scale. The variability (COV) within the regional zones is shown in Table 5 and those for the North Carolina zones are shown in Table 9. This comparison suggest that the variability within the more refined North Carolina zones are generally equal to the Central, Mid Atlantic, and Southeastern zones presented on the national scale.

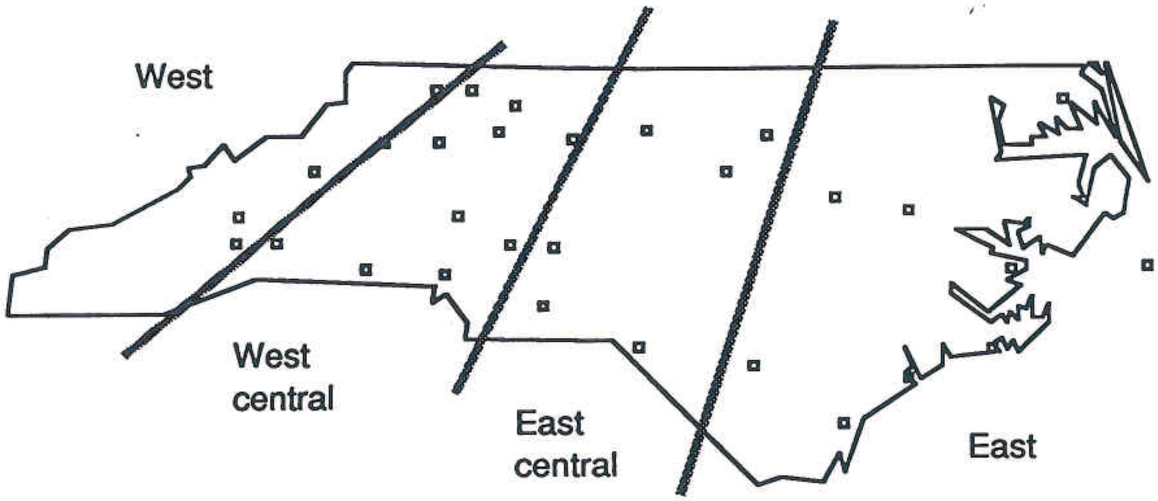
The advantage of the state level discretization of rainfall statistics is that it provides localized results allowing more frequent use of this study. State level contour maps can be developed for each of the individual states, thereby providing greater reliability with the statistics on the localized scale.

TABLE 7. Examples of the Effect of Local Variation and Length of Record on Storm Event Statistics.

		Annual Statistics		Event Statistics							
Station Location	record years	No. of Storms	Annual Volume	Duration Avg	Duration COV	Intensity Avg	Intensity COV	Volume Avg	Volume COV	DELTA Avg	DELTA COV
TEXAS											
Grapevine	76-87	37	27.84	5.8	0.90	0.171	0.80	0.76	0.93	231	1.20
	50-87	38	28.71	6.5	0.91	0.158	0.94	0.75	1.03	220	1.28
Bardwell	76-87	35	28.69	5.3	0.87	0.206	0.90	0.82	1.08	228	1.49
	66-87	40	31.24	6.7	0.92	0.164	0.98	0.78	1.10	210	1.35
Benbrook	76-87	40	28.99	7.5	0.88	0.131	1.09	0.72	1.01	209	1.04
	41-87	39	28.08	7.7	0.92	0.122	0.99	0.72	1.06	212	1.22
Dallas	76-87	41	33.13	5.6	0.89	0.201	0.99	0.81	0.93	211	1.18
	41-87	41	31.73	7.9	0.96	0.144	1.08	0.78	1.08	209	1.20
FW WSO AP	54-73	44	31.80	8.6	0.94	0.122	1.08	0.73	1.05	204	1.12
DFW WSC	75-87	43	29.94	7.5	0.88	0.136	1.01	0.70	0.96	207	1.26
Maypearl	48-80	37	29.12	7.8	0.90	0.129	1.12	0.78	1.04	196	1.15
NORTH CAROLINA											
Asheville #301	65-87	65	34.73	9.5	0.87	0.083	1.17	0.53	0.97	136	1.07
	49-87	65	35.37	9.6	0.85	0.083	1.18	0.54	0.99	136	1.04
Asheville #300	65-87	67	44.65	10.5	0.90	0.093	1.19	0.67	1.07	132	0.99

PERCENT DIFFERENCE BETWEEN THE LENGTH OF RECORD

	No. of Storms	Annual Volume	Duration Avg	Duration COV	Intensity Avg	Intensity COV	Volume Avg	Volume COV	DELTA Avg	DELTA COV
TEXAS										
Grapevine	-2.6	-3.0	-10.2	-1.1	7.7	-15	1.3	-9.7	5.0	-6.3
Bardwell	-12.5	-8.2	-22.0	-5.4	25.1	-8.2	5.1	-1.8	8.6	10.4
Benbrook	2.6	3.2	-2.7	-4.3	7.9	10.1	0.0	-4.7	-1.4	-15
Dallas	0.0	4.4	-29.2	-7.3	39.1	-8.3	3.8	-14	1.0	-1.7
NORTH CAROLINA										
Asheville 301	0.0	-1.8	-1.0	2.4	0.0	-0.8	-1.9	-2.0	0.0	2.9



	West	West central	East central	East
Number of storms	64	58	56	57
Annual volume	44	41	39	43
Average duration	10.0	8.8	8.4	7.9
Average intensity	.099	.118	.121	.132
Average volume	.68	.70	.70	.75
Average DELTA	134	142	150	142

Figure 12. Rain zones of North Carolina and average storm event statistics

Table 8. Location and Period of Record for Rain Gages Analyzed in North Carolina

State	Location	Gage No.	Latitude	Longitude	Elev	Begin Year	End Year	Yrs
NC	BURLINGTON 3 NNE	1241	36:08:00	079:24:00	640	1952	1987	36
NC	CAPE HATTERAS WSO *	1458	35:16:00	075:33:00	10	1958	1987	30
NC	CHARLOTTE WSO AP *	1690	35:13:00	080:56:00	700	1949	1987	39
NC	DALTON *	2230	36:18:00	080:24:00	1010	1949	1987	39
NC	DOBSON	2388	36:24:00	080:44:00	1250	1949	1987	39
NC	ELIZABETH CITY *	2719	36:19:00	076:12:00	10	1955	1987	33
NC	ELIZABETHTOWN LOCK 2	2732	34:38:00	078:35:00	60	1949	1987	39
NC	ELKVILLE	2757	36:04:00	081:24:00	1140	1949	1987	39
NC	ASHEVILLE WSO AP	300	35:26:00	082:33:00	2140	1965	1987	23
NC	ASHEVILLE	301	35:36:00	082:32:00	2240	1949	1987	39
NC	ASHFORD *	312	35:53:00	081:57:00	1760	1949	1987	39
NC	FRANKLINTON	3232	36:06:00	078:28:00	380	1949	1987	39
NC	GREENSBORO WSO AP	3630	36:05:00	079:57:00	890	1949	1987	39
NC	GREENVILLE	3638	35:37:00	077:23:00	30	1956	1987	32
NC	HOBUCKEN BRIDGE	4136	35:14:00	076:36:00	10	1961	1987	27
NC	BADIN	438	35:24:00	080:07:00	530	1949	1987	39
NC	LAKE LURE 2	4764	35:26:00	082:14:00	1040	1949	1987	39
NC	MOREHEAD CITY 2 WNW	5830	34:44:00	076:44:00	10	1949	1987	39
NC	MOUNT PLEASANT	5945	35:25:00	080:26:00	740	1949	1987	39
NC	N WILKESBORO 12 SE	6261	36:04:00	080:59:00	1000	1949	1987	39
NC	POLKTON 2 NE	6867	35:01:00	080:11:00	310	1949	1987	39
NC	RALEIGH DURHAM WSFO AP	7069	35:52:00	078:47:00	380	1949	1987	39
NC	ROARING GAP 1 NW	7324	36:24:00	081:00:00	2800	1949	1987	39
NC	SHELBY 2	7850	35:16:00	081:33:00	780	1949	1987	39
NC	SNEADS FERRY 2 ENE	8037	34:33:00	077:24:00	10	1949	1987	39
NC	WILSON 3 SW	9476	35:42:00	077:57:00	110	1949	1987	39
NC	YADKINVILLE 6 E	9675	36:08:00	080:31:00	860	1949	1987	39
NC	WILMINGTON WSO AP *	9457	34:16:00	077:54:00	70	1950	1987	38
NC	MOORESVILE 2 WNW	5814	35:36:00	080:50:00	910	1950	1987	38
NC	LAURINBURG	4860	34:45:00	079:27:00	210	1949	1987	39

* These gages are used in the national summary

TABLE 9 Storm Event Statistics for North Carolina

Rain Gage Location	Gage No.	Elev. feet	Annual Statistics: No. of Storms Avg	No. of Storms COV	Precip in/yr Avg	Precip in/yr COV	Independent Storm Event Statistics: Duration Avg	Duration COV	Intensity Avg	Intensity COV	Volume Avg	Volume COV	DELTA Avg	DELTA COV
EAST														
NC CAPE HATTERAS	1458	10	67	0.17	52.3	0.22	9.2	0.90	0.108	0.96	0.79	1.21	130	0.95
NC ELIZABETH CITY	2719	10	56	0.18	41.3	0.21	7.7	0.89	0.130	1.13	0.73	1.08	145	1.03
NC HOBUCKEN BRIDGE	4136	10	53	0.32	40.4	0.29	6.4	0.98	0.170	1.12	0.76	1.14	133	1.34
NC MOREHEAD CITY	5830	10	56	0.24	43.5	0.25	7.5	0.89	0.132	0.99	0.77	1.22	143	1.29
NC SNEADS FERRY	8037	10	54	0.26	42.6	0.26	8.7	0.87	0.116	1.04	0.78	1.18	149	1.48
NC GREENVILLE	3638	30	48	0.29	36.5	0.31	7.0	0.94	0.150	1.07	0.76	1.03	151	1.46
NC ELIZABETHTOWN	2732	60	54	0.23	38.1	0.23	7.5	0.88	0.136	1.09	0.70	1.01	149	1.27
NC WILMINGTON	9457	70	69	0.11	51.8	0.13	8.8	0.90	0.119	1.18	0.75	1.19	129	0.98
NC WILSON	9476	110	58	0.19	40.2	0.21	8.1	0.86	0.125	1.15	0.69	1.00	146	1.14
		avg =	57	0.22	43.0	0.23	7.9	0.90	0.132	1.08	0.75	1.12	142	1.22
		cov =	0.12	0.30	0.13	0.22	0.12	0.04	0.14	0.07	0.05	0.08	0.06	0.16
EAST CENTRAL														
NC POLKTON	6867	310	57	0.13	40.9	0.18	8.6	0.93	0.121	1.12	0.72	1.00	148	1.04
NC FRANKLINTON	3232	380	56	0.17	38.6	0.18	7.6	0.91	0.126	0.99	0.69	0.95	152	1.07
NC RALEIGH-DURHAM	7069	380	62	0.12	40.1	0.12	9.6	0.86	0.099	1.10	0.65	0.94	144	0.94
NC BADIN	438	530	59	0.14	41.5	0.17	8.1	0.91	0.124	1.11	0.70	0.99	147	1.06
NC BURLINGTON	1241	640	49	0.27	32.7	0.28	8.6	0.88	0.118	1.19	0.67	0.98	159	1.14
NC LAURINBURG	4860	210	54	0.28	42.5	0.63	7.9	0.88	0.140	1.31	0.79	1.90	149	1.28
		avg =	56	0.19	39.4	0.26	8.4	0.90	0.121	1.14	0.70	1.13	150	1.09
		cov =	0.08	0.39	0.09	0.73	0.08	0.03	0.11	0.09	0.07	0.34	0.03	0.10

TABLE Storm Event Statistics for North Carolina

Rain Gage Location	Gage No.	Elev. feet	Annual Statistics: No. of Storms Avg	No. of Storms COV	Precip in/yr Avg	Precip in/yr COV	Independent Storm Event Statistics: Duration Avg	Duration COV	Intensity Avg	Intensity COV	Volume Avg	Volume COV	DELTA Avg	DELTA COV
WEST CENTRAL														
NC CHARLOTTE	1690	700	63	0.13	40.8	0.16	9.5	0.91	0.098	1.11	0.65	1.01	141	1.01
NC MOUNT PLEASANT	5945	740	57	0.19	38.5	0.21	8.3	0.94	0.119	1.07	0.68	0.98	147	1.10
NC SHELBY	7850	780	56	0.16	40.9	0.16	8.4	0.94	0.130	1.12	0.73	0.98	149	1.03
NC YADKINVILLE	9675	860	60	0.14	40.1	0.17	7.9	0.89	0.126	1.03	0.66	1.00	144	1.01
NC GREENSBORO	3630	890	63	0.11	40.8	0.16	9.8	0.85	0.097	1.15	0.64	1.02	140	1.02
NC MOORESVILLE	5814	910	56	0.20	39.5	0.18	9.1	0.90	0.117	1.57	0.70	1.06	146	1.14
NC N WILKESBORO	6261	1000	61	0.23	45.6	0.24	8.5	0.95	0.129	1.01	0.75	1.07	137	1.10
NC DALTON	2230	1010	55	0.20	38.1	0.24	7.8	0.88	0.127	1.10	0.69	1.08	147	1.12
NC LAKE LURE	4764	1040	53	0.34	42.0	0.32	10.6	0.96	0.101	1.07	0.79	1.15	137	1.29
NC ELKVILLE	2757	1140	60	0.18	44.3	0.22	9.1	0.94	0.120	1.05	0.74	1.08	134	1.04
NC DOBSON	2388	1250	56	0.20	40.1	0.22	8.1	0.90	0.131	1.15	0.71	0.99	143	1.13
		avg =	58	0.19	41.0	0.21	8.8	0.91	0.118	1.13	0.70	1.04	142	1.09
		cov =	0.06	0.33	0.06	0.24	0.10	0.04	0.11	0.14	0.07	0.05	0.04	0.08
WEST														
NC ASHFORD	312	1760	58	0.26	40.3	0.28	9.9	0.90	0.101	1.16	0.69	1.05	141	1.56
NC ASHEVILLE	300	2140	67	0.12	44.7	0.18	10.5	0.90	0.093	1.19	0.67	1.07	132	0.99
NC ASHEVILLE	301	2240	65	0.11	35.4	0.17	9.6	0.85	0.083	1.18	0.54	0.99	136	1.04
NC ROARING GAP	7324	2800	67	0.16	53.6	0.22	10.1	0.94	0.110	1.11	0.80	1.16	125	1.02
		avg =	64	0.16	43.5	0.21	10.0	0.90	0.097	1.16	0.68	1.07	134	1.15
		cov =	0.07	0.42	0.18	0.23	0.04	0.04	0.12	0.03	0.16	0.07	0.05	0.24

4. References

1. EPA, Areawide Assessment Procedures Manual, EPA-600/9-76-014, 3 volumes (Cincinnati, Ohio: EPA, July et seq., 1976).

2. Heaney, J.P., W.C. Huber, M.A. Medina, M.P. Murphy, S.J. Nix, and S.M. Hasan, Nationwide Evaluation of Combined Sewer Overflows and Urban Stormwater Discharges - Vol. II: Cost Assessment and Impacts, EPA-600/2-77-064(b) (NTIS PB-266005) (Cincinnati, Ohio: EPA, March 1977).

3. Hydroscience Inc., A Statistical method for Assessment of Urban Stormwater Loads - Impacts - Controls, EPA-440/3-79-023 (Washington, D.C.: EPA, May 1979).

4. Restrepo-Posada, P.J., and Eagleson, P.S., Identification of Independent Rainstorms, Journal of Hydrology, 55 (1982), 303-319.

5. Schueler, T.B., Controlling Urban Runoff: A Practical manual for Planning and Designing Urban BMPs, Washington Metropolitan Water Resources Planning Board (Washington D.C., July 1987).