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16. Abstract

Four popular regional flood frequency methods were compared using Louisiana stream flow series. The state was divided into four homogeneous regions and all undistorted, long-term stream gages are used in the analysis. The GEV, TCEV, regional LP3 and USGS regression methods were applied to this data base and compared in terms of descriptive capabilities. Based upon several factors, the GEV method was selected as the superior method overall. A procedure to apply this method to ungaged watersheds using regression equations and regional non-dimensional flood distribution was then developed. It was found that the procedure performed well when applied to data not used in the calibration of the model. The method is easier to apply and more accurate in terms of descriptive and probably predictive ability than any other feasible method.

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regional frequency, stochastic hydrology, ungaged watersheds

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# PREDICTION OF FLOOD QUANTILES AT UNGAGED WATERSHEDS IN LOUISIANA

FINAL REPORT

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# ABSTRACT

Four popular regional flood frequency methods were compared using Louisiana stream flow series. The state was divided into four homogeneous regions and all undistorted, long-term stream gages were used in the analysis. The generalized extreme value (GEV), two-component extreme value (TCEV), regional log Pearson type 3 (LP3) and U.S. Geological Survey (USGS) methods were applied to this data base and compared in terms of descriptive capabilities. Based upon several factors, the GEV method was selected as the superior method overall. A procedure to apply this method to ungaged watersheds using regression equations and a regional non-dimensional flood distribution was then developed. It was found that the procedure performed well when applied to data not used in the calibration of the model. The method is easier to apply and more accurate in terms of descriptive and probably predictive ability than other feasible methods.

Key Words: regional frequency, stochastic hydrology, ungaged watersheds.

# IMPLEMENTATION STATEMENT

The method of quantile prediction developed in this study has been derived using all undistorted, long-term stream records in Louisiana as well as a few nearby gages. It has been shown to be clearly superior, at least in descriptive ability, to the method currently in use by LADOTD engineers. There appear to be no costs associated with the implementation of the recommended procedure. Less information about the watershed is required for its application than is required for the method currently in use. Thus actual savings in terms of labor costs may accrue if the procedure developed here is adopted. In addition, if more accurate quantile estimates result, additional savings may result from more optimal structural designs.

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$A$ = drainage area

$a$ = scale parameter of LP3

$b$ = shape parameter of LP3

$c$ = location parameter of LP3

$N$ = number of years of observation

$f(x)$ = density function of observed series

$F(x)$ = non-exceedance probability of event of magnitude $x$

$H(x)$ = entropy function

$E_i$ = predicted value for $x_i$

$m_i$ = rank of event $x_i$

$\hat{m}_0$ = estimate of 0th probability weighted moment (PWM)

$\hat{m}_1$ = estimate of 1st PWM

$\hat{m}_2$ = estimate of 2nd PWM

$M_r$ = rth PWM (= $M_{1,r,0}$)

$p_i$ = unbiased plotting position for event $x_i$

$k$ = shape parameter of generalized extreme value (GEV) distribution

$\alpha$ = scale parameter of GEV

$\xi$ = location parameter of GEV

$\Gamma(\cdot)$ = Gamma function

$\lambda_i$ = shape parameter of two component extreme value (TCEV) distribution

$\theta_i$ = scale parameter of TCEV

$\bar{x}$ = mean of x series

$S^2$ = variance of x series

$G$ = skew coefficient of x series

$\mu$ = mean of ln(x) series

$\sigma^2$ = variance of ln(x) series

$\Upsilon$ = skew coefficient of ln(x) series

$\bar{\theta}$ = mean basin flood

$R^2$ = coefficient of determination

cv = coefficient of variance

$Q_M$ = mean discharge

# INTRODUCTION

There are many instances in highway construction and maintenance work when stream discharges must be estimated for sites at which stream gage records are not available such as future or present bridge sites. It is very rare that a stream gage is located at the precise spot at which a bridge is to be constructed. In addition, much recent attention has been focused on the monitoring of existing bridges for pier scour. A recent FHWA Technical Advisory (1) recommends that all bridges for which scour problems may be suspected should be evaluated for possible failure during large floods of recurrence intervals of 100 years and higher. In order to accomplish these evaluations, as well as for design considerations for future bridges, discharge estimates corresponding to given exceedance probabilities must be obtained. In light of recent disasters due to pier scour failures, it is essential that accurate estimates of flood quantiles be obtained. These estimates should be based upon the most recent data and the most modern and accurate technology available.

The present method of obtaining discharge estimates at ungaged sites in the state (drainage areas $\geq$ 2000 acres) is the use of generalized regression equations developed by the U.S. Geological Survey (2). These equations are based on a gage frequency analysis using the log Pearson type 3 (LP3) distribution. However, because of the variability of the skewness coefficient, which is used in parameter estimation of the LP3, this distribution does not lend itself easily to regionalization techniques. The U.S. Geological Survey (USGS) procedure involves deriving a regression equation to relate various quantiles from the LP3 distribution to basin physiographic and climatic variables. The error reported for these equations (typically 40-50%) is the standard error of the regression estimates and does not include possible errors in fitting the LP3 to the observations. Nevertheless, this procedure has recently become very popular, and studies have shown that it may possess some favorable asymptotic characteristics.

However, the basin characteristics (such as average stream slope), which must be obtained from USGS topo maps, are sometimes difficult to obtain and may increase the error in the analysis, especially in areas of small relief. Thus, a methodology which will better reflect the actual data in this region (Louisiana), which will contain an accurate error analysis and which will be easier to apply (requiring less physical data) is needed.

In this study, all of the stream gages in the state with more than 20 years of record are employed. Two methods which are currently highly regarded by professionals in the field are applied and compared to the traditional (LP3) method recommended by the U.S. Water Resources Council (3). The two-component extreme value (TCEV) method of Rossi et al. (4) is applied using the principle of maximum entropy (5). In addition, the generalized extreme value distribution (GEV) (6) is fitted and indexed by the method of probability weighted moments (PWM) (7). The indexing procedure outlined by Greis and Wood (8) is utilized. These methods are compared to the traditional WRC method, which uses the LP3 distribution with a regional skew value obtained from the arithmetic mean of the station skew values in each region. These are the most advanced methods currently considered feasible.

# OBJECTIVES

The objective of this research was to develop an improved methodology of flood prediction at ungaged locations for Louisiana streams. In order to accomplish this task, the study encompassed the following objectives:

(1) To determine hydrologically and physiographically homogeneous regions within Louisiana.

(2) Based upon long-term streamflow records in each region, to select the superior regional frequency method from among the two-component extreme value (TCEV), generalized extreme value (GEV) and regionalized log Pearson type 3 (LP3) distributions.

(3) To formulate the method selected in (2) into a procedure which can be applied at ungaged sites.

(4) To compare the procedure formulated in (3) with the method currently used by LADOTD.

(5) To verify the procedure using data not used in its derivation and formulation.

# SCOPE

The scope of this study encompassed the development and testing of a procedure to predict flood quantiles at ungaged watersheds in Louisiana. The selected method was compared to the method currently employed by LADOTD. In performing this study, the following detailed tasks were performed:

(1) The annual flood series data for all Louisiana stream gages with at least 20 years of record were compiled.

(2) Hydrologically and physiographically homogeneous regions within the state were identified.

(3) Regional frequency analyses were performed on the data of each region using the two-component extreme value, generalized extreme value and log Pearson type 3 regional distributions.

(4) The results of these methods were compared to the observed data at each site in terms of root mean square error (RMSE).

(5) The parameters of the method with the smallest average RMSE were related to basin characteristics.

(6) The selected method was verified based upon data which were not used in the derivation and calibration.

(7) The selected method was compared to the USGS regression equations currently used by LADOTD. The comparison was in terms of RMSE.

# METHODOLOGY

## General

The state of Louisiana was divided into four hydrologically homogeneous regions. These regions were determined from criteria such as physiographic, geomorphic and climatic similarity among drainage basins. The U.S. Geological survey has divided the state into three regions; i.e., northern Louisiana (9), southeastern Louisiana (10), and southwestern Louisiana (11). These regions were determined from the similarity of streamflow series within each region and served as a starting point for the more sophisticated regionalization performed in this study.

The annual maximum flood series for each gage within each region with at least 20 years of record was obtained. A few gages were included in the analysis which fell in the general physiographical regions of Louisiana but were physically located outside state boundaries. Regional frequency analyses were then performed for each homogeneous region based upon all of the observed annual series in each region. In a regional frequency analysis, a parent distribution of flood magnitudes is derived from the observed data at each site in the region. In this study, three distributions were tested against the observed data: the two component extreme value, the generalized extreme value, and the log Pearson type 3. As the parameters of these distributions were estimated and regionalized by entirely different procedures, three different methods of obtaining regional quantile estimates were tested.

The regionalization method which resulted in the best overall fit to the observed data in the entire state was selected, and the parameters of this distribution were related to the drainage basin characteristics of the watersheds in each region. Once these relationships were formed, the procedu could then be applied to any ungaged sites in the region which fall withi limits of the data used in the analysis.

## Regionalization

The homogeneous regions within the state were determined with the aid of soil, topographic and climatic maps. The purpose of this analysis was to divide the state into regions such that the hydrologic response of watersheds within each region could be expected to be comparable. Thus, the regions should have relatively homogeneous soil and topographic characteristics. In addition, the watersheds within each region should be subjected to similar climatic conditions. Information needed to make the determinations was readily available from previously published sources. The preliminary regional analysis of the U.S. Geological Survey (9,10,11), Atlas of Louisiana (12), and the General Soil Map of Louisiana (13) were used in forming the regional groupings.

Once preliminary regions had been identified, the annual streamflow series of gaged watersheds within each region were analyzed for similarities. This was accomplished by plotting the log mean of the flood series against the corresponding drainage area for each watershed in the region (in log space). A linear relationship should be observed in these data. Watersheds which fell outside this trend would not be expected to behave similarly to the other basins within the region. In this way, minor revisions to the regional groupings were determined.

## Flood Frequency Analysis

Flood frequency analyses consist of fitting preselected probability distributions to recorded flood data at individual sites and then estimating the magnitudes (quantiles) of flood events corresponding to given exceedance probabilities from these distributions. However, the use of the observed data at only the site under investigation has come to be viewed as resulting in unreliable estimates. This is true because the length of record at a single site is relatively short when compared to the recurrence intervals to be estimated from the data. For instance, it may be necessary to estimate the 100-year flood from only 20 to 30 years of record at an individual site. Regional frequency analysis consists of using data at other sites considered similar to the site in question to augment the information at a single individual site. Regionalization techniques have emerged as effective solutions for reducing the uncertainty inherent in short, systematic records.

Recently, regional flood frequency analyses have been receiving much attention in the engineering literature. Two of the most popular regional techniques are the TCEV regional/at-site procedure and the index method using probability weighted moments (PWM). The TCEV has been derived as a mixture of two exponential marginal distributions from a Poisson counting process (14,4). Thus its cumulative distribution function (CDF) can be expressed as the product of two extremal distributions:

$$F(x) = \exp[- \lambda_1 \exp(- x/\theta_1) - \lambda_2 \exp(- x/\theta_2)] \qquad (1)$$

where $\lambda_i$, $\theta_i$ are shape and scale parameters respectively and F(x) is the non-exceedance probability of an event of magnitude x. This distribution attempts to account for the possibility that two distinct sub-distributions make up the total annual distribution of flood peaks. In cases where the marginal distributions can be shown to be exponential or the asymptotic distribution is Gumbel, the TCEV has been shown to give accurate results. In a preliminary study, Cruise and Arora (15) found that about 60% of the limited data in their analysis could be adequately represented by the exponential model. These results are encouraging enough to justify further research.

The TCEV was fitted to the regional data series by the method of maximum entropy proposed by Fiorentino et al. (5). This method has been shown to be computationally less cumbersome and more reliable than the maximum likelihood procedure originally proposed by Rossi et al. (4). Entropy represents a measure of the information content imbued in a set of data. It can be expressed (16) as:

$$H(x) = - \int_{-\infty}^{\infty} f(x) \ln f(x)\, dx \tag{2}$$

where H(x) is entropy and f(x) represents the probability density function (pdf) of the data series. By maximizing H(x), the parameters of f(x) can be obtained.

In the regionalization technique, two dimensionless parameters, $\theta = \theta_2/\theta_1$ and $\lambda = \lambda_2/\lambda_1^{1/\theta}$ are considered to be constant for the homogeneous region and the other two parameters $\theta_1$ and $\lambda_1$ are allowed to vary from site to site. The parameters $\theta_1$ and $\lambda_1$ are called the basic component, and $\theta$ and $\lambda$ are the regional component parameters of the distribution. Conceptually, $\theta_1$ and $\lambda_1$ represent the smaller, more frequently occurring events that would be expected to vary from site to site within the region. Essentially, $\theta_1$ represents the mean flood for this distribution, while $\lambda_1$ represents the number of floods per year over the watershed. The parameters $\theta$ and $\lambda$ represent the regional distribution, thus they would be expected to behave similarly within the homogeneous region. As in the previous case, $\theta$ represents the mean flood of this distribution, while $\lambda$ represents the number of such events occurring per year.

The maximum entropy procedure results in four equations to be solved for the four unknowns described above. A computer program was previously developed to solve these equations simultaneously. The program was found to converge successfully in all of the cases in which it has been applied.

The index method has been receiving a great deal of attention in the recent literature, although its basic premise was outlined by Dalrymple (17) almost thirty years ago. In this procedure, an assumed distribution is fitted to the observed flood series at each site in a hydrologically similar region. The statistics (or parameters) of the distributions at each location are standardized by dividing by the at-site mean in each case. Regional estimates of the parameters (regional mean = 1.0) are obtained by an averaging technique over the region. These regional parameters are then used to generate flood quantiles for the site of interest and are subsequently readjusted to account for the differences in scale between watersheds.

The index method has gained momentum since the introduction of the probability weighted moments (PWM) method of parameter estimation by Greenwood et al. (7). This technique, which is applicable only to distributions which can be expressed in inverse form, offers a method of parameter estimation that may be more robust and less biased than the traditional methods. The PWM method is therefore ideal for use in the index flood procedure. It has recently been used by Greis and Wood (8), Landwehr et al. (18), Wallis (19), and Stedinger (20). Distributions to which it may be particularly applicable include the Gumbel (8), the Wakeby (21) and the generalized extreme value (GEV).

The PWM method has been applied to the GEV by Hosking et al. (6) and is the recommended procedure in the U.K. The r-th PWM ($M_{1,r,0}$) is given by

$$M_r = E[x\ F(x)^r],\quad r = 0, 1, 2, \ldots \tag{3}$$

These moments are estimated from the observed data sample by:

$$\hat{M}_r = \frac{\sum_{i=1}^{n} p_i^r x_i}{n} \tag{4}$$

where $p_i$ is an unbiased plotting position for observation $x_i$, and n is the number of observations. The $p_i$'s are obtained by ranking the data in ascending order and using any unbiased plotting position formula such as:

$$p_i = \frac{m_i}{n + 1} \tag{5}$$

where $m_i$ is the rank of observation $x_i$. It can be noted that when r = 0,

$$\hat{M}_0 = \frac{\sum_{i=1}^{n} x_i}{n} = \bar{x} \tag{6}$$

which is the first conventional moment about the origin.

The GEV can be expressed in inverse form as (6):

$$\begin{aligned} x(F) &= \xi + \alpha(1 - (-\log F)^k)/k & k \neq 0 \\ &= \xi - \alpha \log(-\log F) & k = 0 \end{aligned} \tag{7}$$

where F is the nonexceedance probability point in the distribution corresponding to the quantile x and $\xi$, $\alpha$ and k are the parameters of the distribution. When k = 0, the GEV reduces to the extreme value type I (EVI) (Gumbel). The parameters $\xi$, $\alpha$ and k are related to the PWM by Hosking et al. (6) as:

$$\hat{k} = 7.8590\ c + 2.9554\ c^2 \tag{8}$$

$$\hat{\alpha} = \frac{(2\,\hat{m}_1 - \hat{m}_0)\,\hat{k}}{\Gamma(1 + \hat{k})(1 - 2^{-\hat{k}})} \tag{9}$$

$$\hat{\xi} = \hat{m}_0 + \hat{\alpha}(\Gamma(1 + \hat{k}) - 1)/\hat{k} \tag{10}$$

where

$$c = \frac{2\,\hat{m}_1 - \hat{m}_0}{3\,\hat{m}_2 - \hat{m}_0} - \frac{\log 2}{\log 3}$$

$\Gamma(\cdot)$ = gamma function

The index procedure is applied by calculating the PWM from the observed data at each site in the region from equation 4. The PWM are standardized at each site by dividing each PWM by the at-site mean. The standardized PWM are then averaged over all of the sites in the region. These regional average PWM are then used in equations 8 to 10 to obtain the parameters of the regional GEV distribution. Regional indexed quantiles can then be generated for any exceedance probability (1-F) from equation 7. These quantiles are then rescaled for any site of interest by multiplying back by the at-site mean. This procedure has been applied to the EVI distribution by Greis and Wood (8) and was found to give favorable results. A computer program (Appendix I) was developed to perform this analysis.

The two regional procedures described above were applied to the flood series on Louisiana streams. The results of these analyses were then compared to the regional procedure recommended in the WRC guidelines (1981). This procedure involves the log Pearson type 3 (LP3) distribution. The probability density function (pdf) of the LP3 is

$$f(x) = \frac{1}{|a| \cdot \Gamma(b)} \left(\frac{\ln x - c}{a}\right)^{b-1} \exp\left(-\frac{\ln x - c}{a}\right) \tag{11}$$

where x = raw (untransformed) flood data, and a, b, and c are the scale, shape and location parameters, respectively. The parameter b is always positive and

$\Gamma(\cdot)$ is the gamma function. The LP3 density function is very flexible and can take many different forms. The mean, variance, and skew coefficient of the variate $y = \ln x$ are given by

Mean: $\mu = c + ab$ (12)

Variance: $\sigma^2 = b\ a^2$ (13)

Skew: $\gamma = \frac{|a|}{a} \frac{2}{b^{1/2}}$ (14)

a, b, and c are estimated by substituting for $\mu$, $\sigma^2$, and $\gamma$ by the mean, variance and skewness coefficient estimates of the log-transformed sample. The sample mean, variance, and skewness coefficient equations are:

$$\bar{x} = \frac{1}{N} \sum_{i=1}^{N} x_i \qquad (15)$$

$$S^2 = \frac{1}{N-1} \sum_{i=1}^{N} (x_i - \bar{x})^2 \qquad (16)$$

$$G = \frac{N}{(N-1)(N-2)S^3} \sum_{i=1}^{N} (x_i - \bar{x})^3 \qquad (17)$$

The skew coefficient of the station record is sensitive to extreme events; thus it is difficult to obtain accurate skew estimates from small samples. For this reason, the generalized skew values are used in place of at-site skew values, or the at-site skew values are corrected using the generalized skew when skew estimates are to be obtained from small samples.

A generalized skew coefficient for each region was obtained from the arithmetic mean of the station skew values. The generalized skew value was then used to estimate LP3 parameters.

Regional quantiles are generated at each site of interest by using the at-site mean and standard deviation of the logarithms of the observed data series, together with the regionalized skew value. The three regional methods were compared at each gaged location by computing the SRMSE between the observed and predicted quantiles.

## Regional Frequency Analysis and Comparisons

The research followed the general plan previously outlined. In general, the study consisted of five phases. Phase one consisted of the determination of the homogeneous regions within the state.

The second phase of the study consisted of the acquisition of a suitable data base for the study. The records for all stream gages in the physiographical regions of the state with a minimum of 20 years of systematic record were obtained. These data consisted of 110 long-term, continuous stream gage records. These records were then screened for possible anomalies resulting from lack of channel control, interbasin transfers at high discharges, missing records, or other undesirable factors. The records that passed this screening were further analyzed for consistency within the homogeneous regions previously defined. This was accomplished by plotting the log mean of each flood series against its corresponding drainage area for each region and observing the trend. In doing this, several anomalous gages were found. It was ascertained that gages with drainage areas less than 10 $mi^2$ generally did not follow the trend of the rest of the data. Therefore, these records were excluded from the analysis and the results will not be applicable to these small watersheds. These plots were also used in making minor adjustments to the regional boundaries as it became obvious that certain gages should be shifted from one region to another. In the end, 85 gages passed the screening process and thus form the data base for the rest of the analysis.

Phase three consisted of comparing the three regional frequency techniques previously discussed utilizing the undistorted flood series for each region. The TCEV, GEV, and LP3 distributions were tested with regionalization accomplished by the methods described previously.

The SRMSE between the observed and predicted values can be computed by:

$$\mathrm{SRMSE} = \left[\frac{1}{N} \sum_{i=1}^{N} \left(\frac{\hat{x}_i - x_i}{\bar{x}}\right)^2\right]^{1/2} \tag{18}$$

where

SRMSE = standardized root mean square error

$x_i$ = observed value of standardized variate x

$\hat{x}_i$ = predicted value of variate at the same probability point as $x_i$

N = sample size

$\bar{x}$ = sample mean - used to standardize the root mean square error (RMSE)

and $\hat{x}_i$ is calculated as $F^{-1}(p(x_i))$, where $p(x_i)$ is approximated by the plotting position formula given previously (equation 5). The RMSE is standardized by dividing by the sample mean, thus deriving a standardized distribution with a mean of 1.0. This is done in order to remove the effects of scale and thus make comparison meaningful.

Of course, this index only measures the descriptive capability of the methods. That is, SRMSE is an index of the ability of each method to interpolate the observed data at each gaged location. It is assumed that if a method describes the data well at gaged sites, it will probably also describe the ungaged data as well. Of course, a frequency method must not only describe the observed data well, but also should be capable of extending the data accurately. Many times quantiles must be predicted that are beyond the systematic record. The SRMSE index does not directly measure this ability. However, studies by Greis and Wood (8), Hosking et al. (6), Landwehr et al. (18) and Potter and Lettenmaier (22) have examined the predictive capabilities of various regional and at-site frequency techniques. Based on Monte Carlo or Boot Strap sampling methods, these studies all concluded that methods based on probability weighted moments possessed superior asymptotic characteristics in terms of bias and variability of long-term quantile estimates to other conventional methods. Potter and Lettenmaier (22) tested 10 commonly used frequency methods and found that the GEV method recommended here possessed predictive characteristics superior to the other methods tested.

The three regional methods previously described were applied to the undistorted stream flow series obtained in Phase 2 of the study. The method that consistently resulted in the best fit (lowest SRMSE) for each region was selected as the regional method and its parameters were related to the basin characteristics of the watershed in the region. This procedure constituted the fourth phase of the study. Although past research has shown that the regional LP 3 results in a generally good fit to observed data at most sites, it does not lend itself to prediction at ungaged sites due to variability in the skew coefficient. The parameters of the LP 3 cannot be easily related to physical watershed characteristics. Conversely, in the TCEV and index procedures, the drainage area of the site of interest can be related to distributional parameters. In the case of the TCEV, the dimensionless parameters $\theta$ and $\lambda$ are constant for any homogeneous region; thus they are known in advance from the data analysis. The parameter $\lambda_1$, which represents the number of floods in the basic component, will also be fairly consistent for any homogeneous region. Therefore it only remains to determine $\theta_1$ for any desired area in this region from its drainage area plot. Thus the regional TCEV can be obtained for any ungaged area in the region.

The application of the GEV index distribution is even easier. Once the regionalized quantiles are generated for each region in this study, at-site quantiles are obtained by multiplying by the mean flood for the site in question. This value can be determined from the plot of log mean Q versus drainage area. With the mean for any ungaged site determined, the quantiles are obtained by simply multiplying the regional quantiles by this value.

Once a regional method was selected and its parameters were related to basin characteristics, the fifth phase of the study was undertaken. It consisted of verifying the selected method, using both original data sets and new data not used in the calibration phase. The parameters of the distribution were obtained from basin characteristics and used to fit the regional curve and generate at-site quantiles for both the original and new sites. The predicted quantiles were then compared to the observed quantiles by SRMSE. The average SRMSE over the entire region (using either the old or new data, as preferred) represents the overall error in the procedure for the particular region.

# DISCUSSION OF RESULTS

## Regionalization

The regional groupings were formed by first consulting topographic and geologic maps of the state. Figure 1 shows a typical map of the geology of Louisiana (12). The figure shows that the state is composed of three main geologic features: the alluvium associated with the Mississippi delta region; the Pleistocene Terraces, which dominate most of the rest of the state; and the extreme northwest, where the Paleocene Wilcox feature is predominate. The map shows that the state is divided into four general regions by the Mississippi alluvium.

The division is further reinforced by the relief map shown in Figure 2 (12). The alluvium appears as the band of very small relief (0-5 feet) that runs through the state in a generally northwesterly direction until the confluence of the Red and Atchafalaya Rivers, after which it forks into an east prong (Mississippi) and west prong (Red). Relief features within these boundaries are generally distinct and homogeneous. The western region (bounded on the east by the Mississippi alluvium in the south and the Red in the north) shows uniformly varying topography draining to the southeast. We label this area the southwest region. The area in the north central part of the state (bounded on the west by the Red and on the east by the Mississippi alluvium) again appears as a fairly uniform topographical region. We call this area the northwest region. The area in the southeast comprised of the Florida Parishes (bounded on the west by the Mississippi alluvium), which uniformly drains toward Lake Pontchartrain, we label the southeast region. In general, there are no streamgages located in the alluvium itself because of

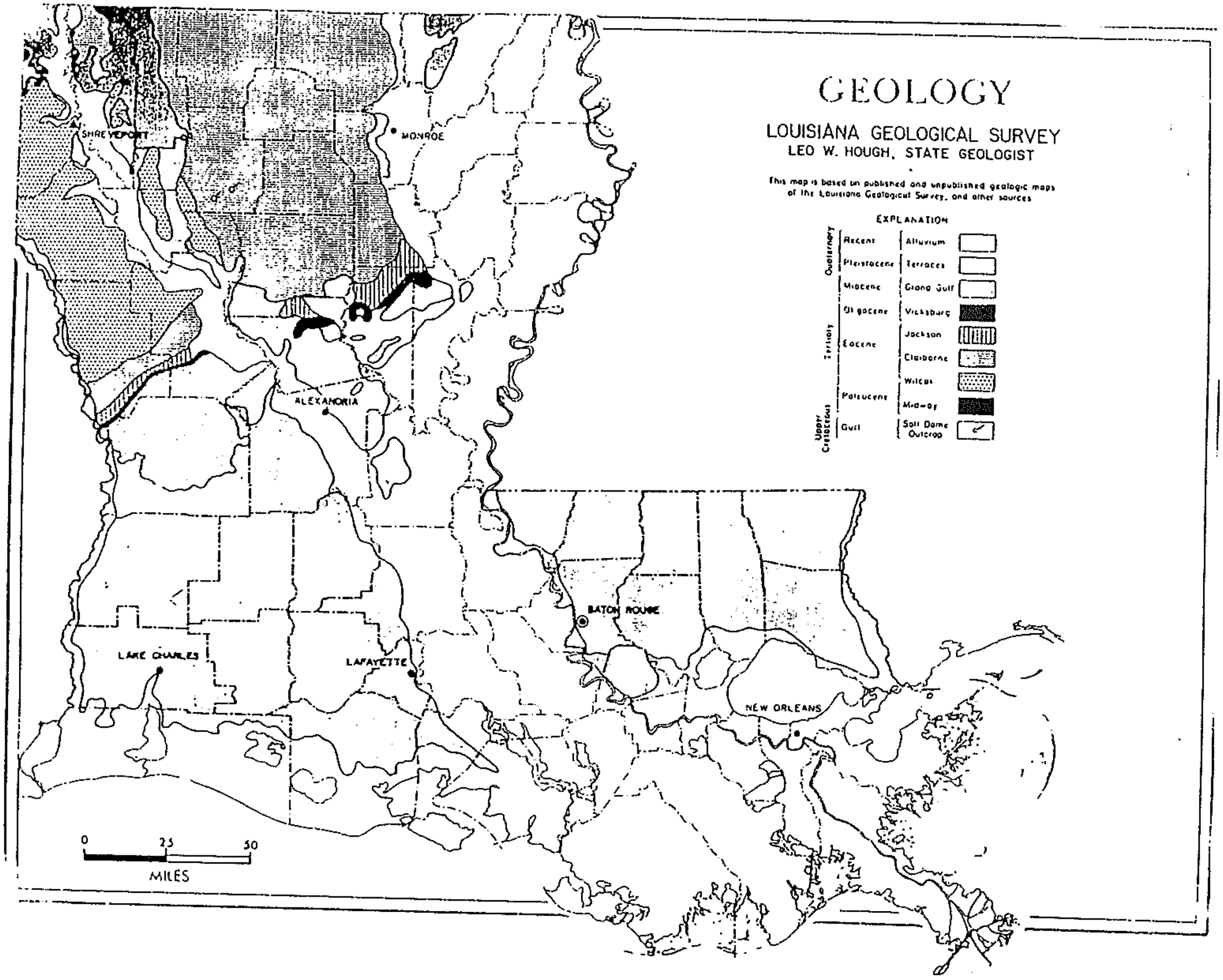


Figure 1. Geology of Louisiana (Newton, 1972)

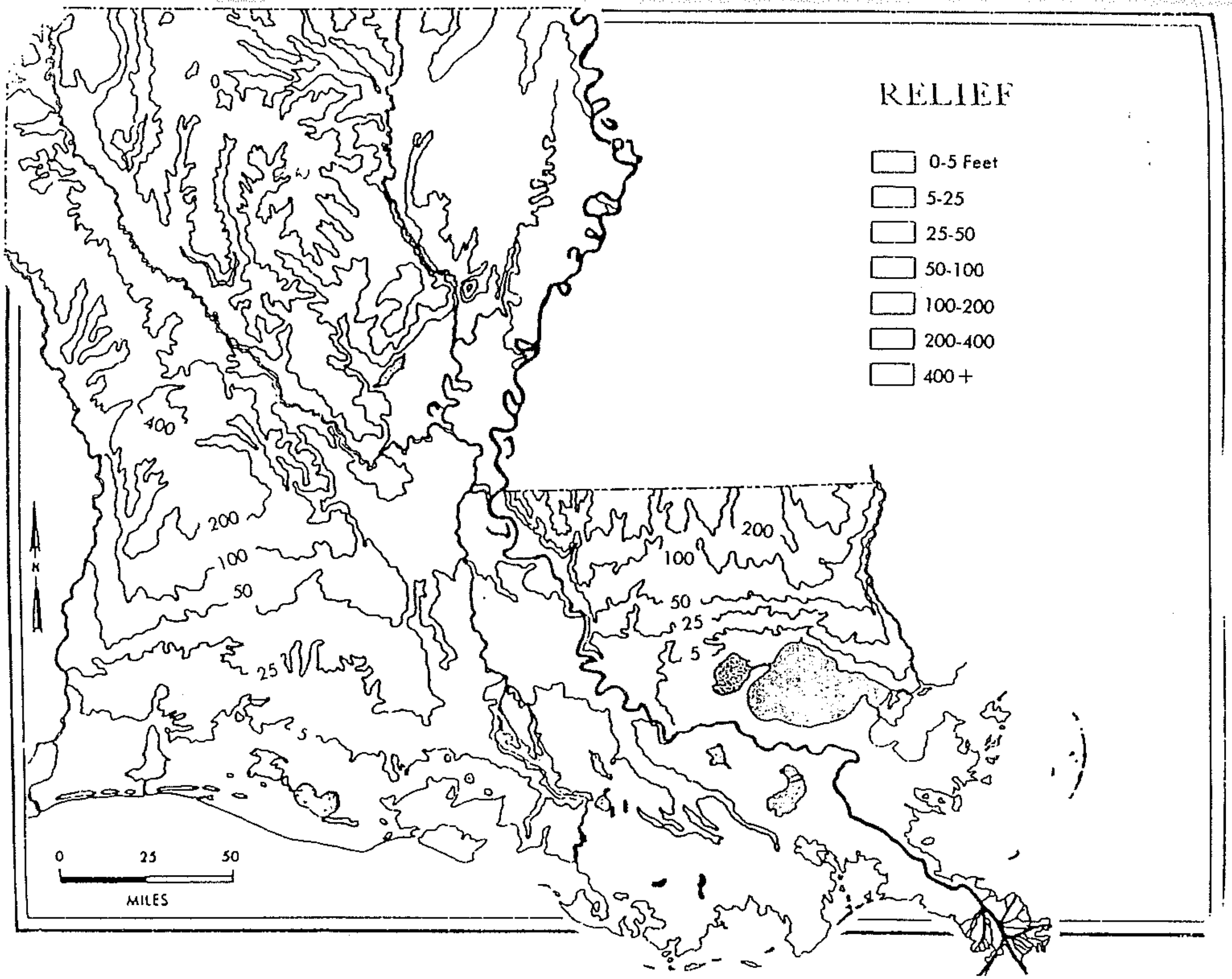


Figure 2. Topographical relief of Louisiana (Newton, 1972)

the low relief and consequent lack of channel control. The exception is in the extreme northeastern corner of the state, where the whole area is comprised of the alluvium. Since a few gages are located in this area, it is designated as an independent region and labeled the northeast region.

These regional boundaries are delineated in Figure 3. The locations of all the streamgages used in the analysis are also plotted on this figure. Note the absence of gages in all the alluvium areas except the extreme northeast. This paucity of data effectively eliminates these areas from the analysis. Therefore, the results will also not be applicable in these regions.

The regional groupings were further compared based upon climatic and soils information available for the state. Figure 4 (12) shows the general climatic trends throughout Louisiana. The regional boundaries are traced on the climatic maps. Of particular interest is the plot showing the trends in average annual precipitation throughout the state. This graph shows that annual precipitation varies from approximately 48 to 60 in. in the southwest region, while the other regions exhibit considerably less climatic variability. No regionalization based upon climate that would be superior to the one already delineated is evident from this figure.

The soil classification series across the state are demonstrated in Figure 5 (13). The figure shows that the soils in the northwest, northeast and southeast regions are generally homogeneous within the particular region. The southwest region, however, is composed of a mixture of two major soil groups: Caddo-Beauregard in the south and Shubuta-Susquehanna in the north. The soils that predominate the northern part of this region are defined as moderately permeable, while the soils in the south are termed poorly drained. However, both of these series are classified in hydrologic groups C-D by the

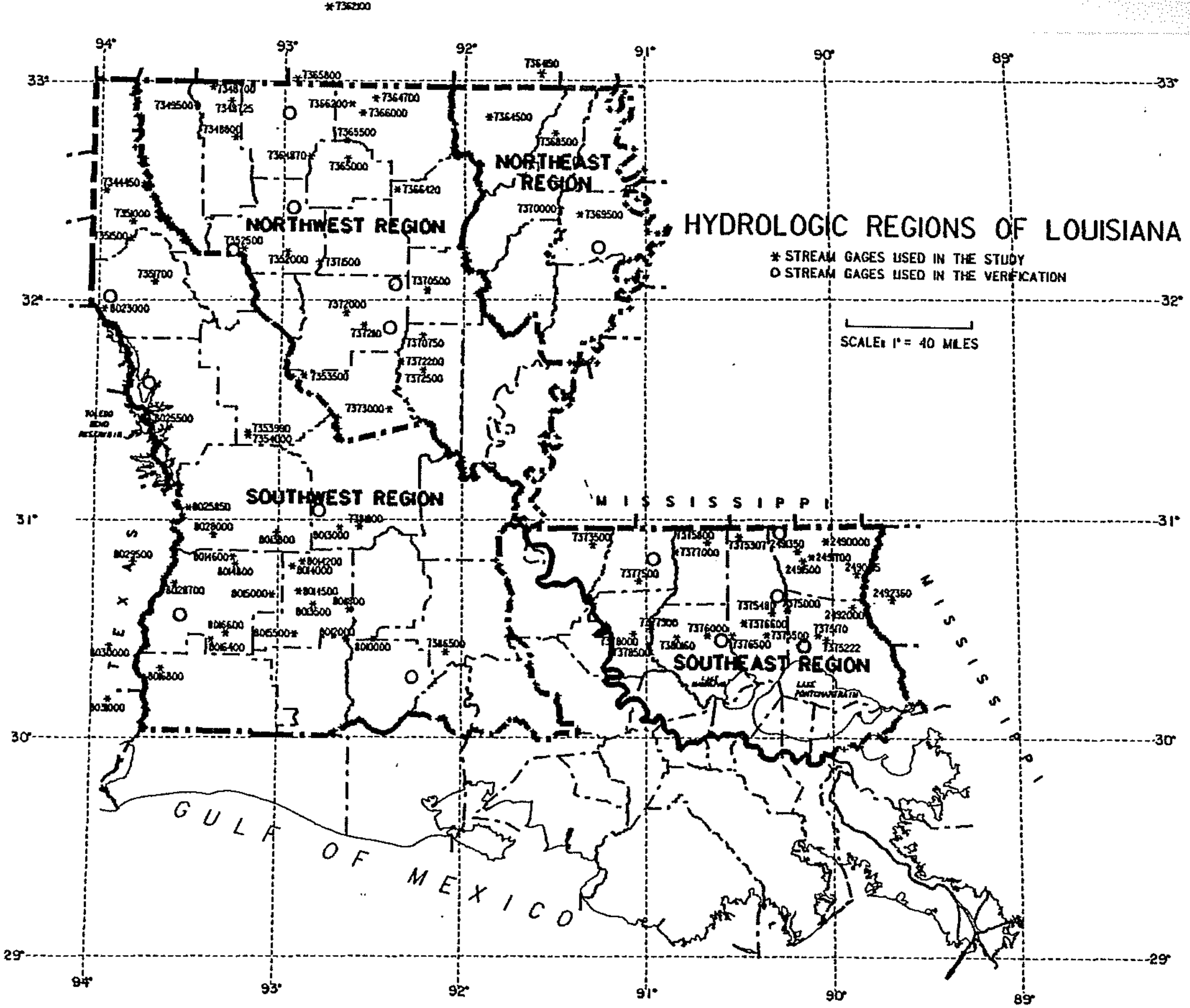


Figure 3. Hydrologic regions of Louisiana

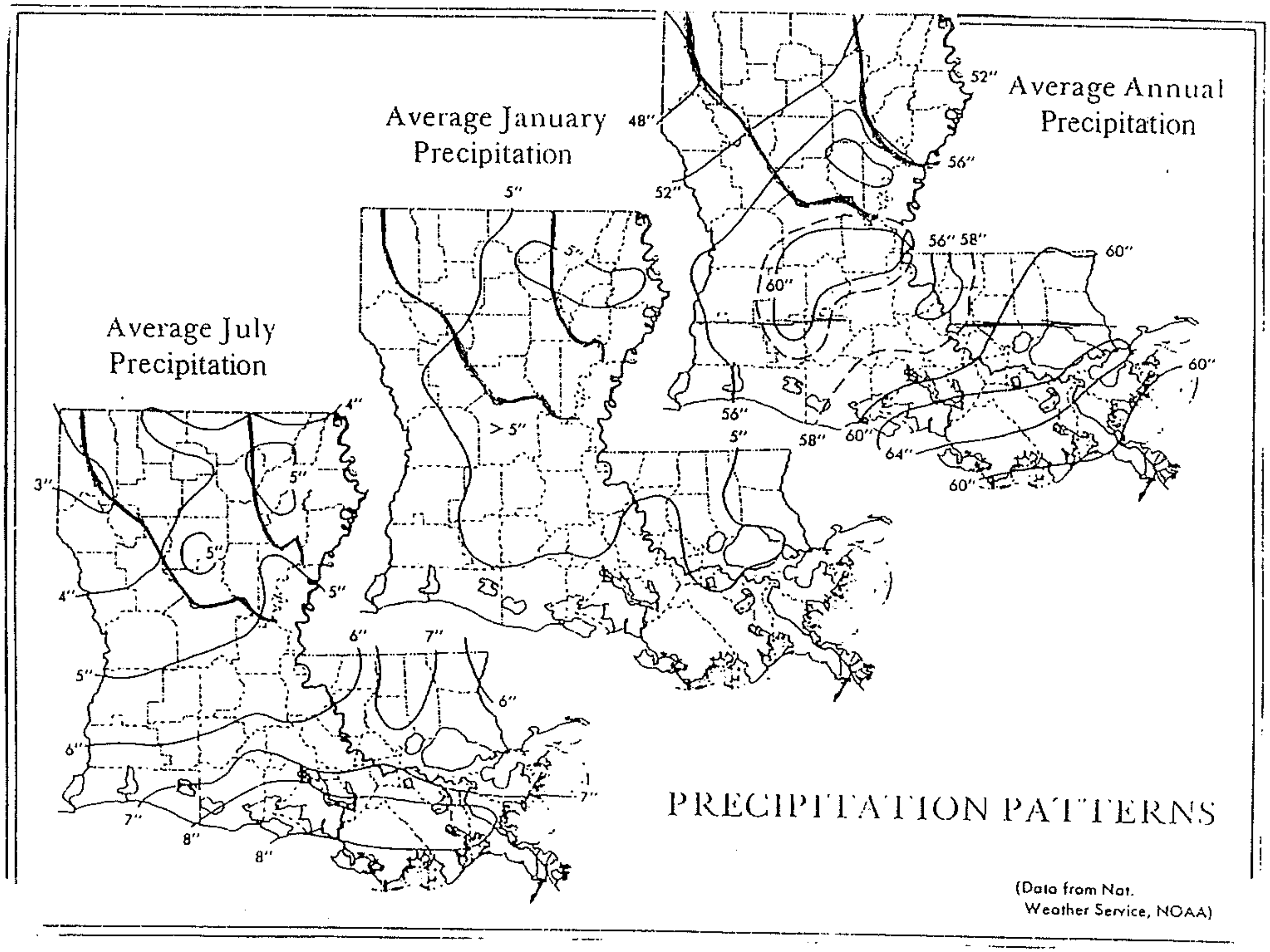


Figure 4. Precipitation patterns of Louisiana (Newton, 1972)

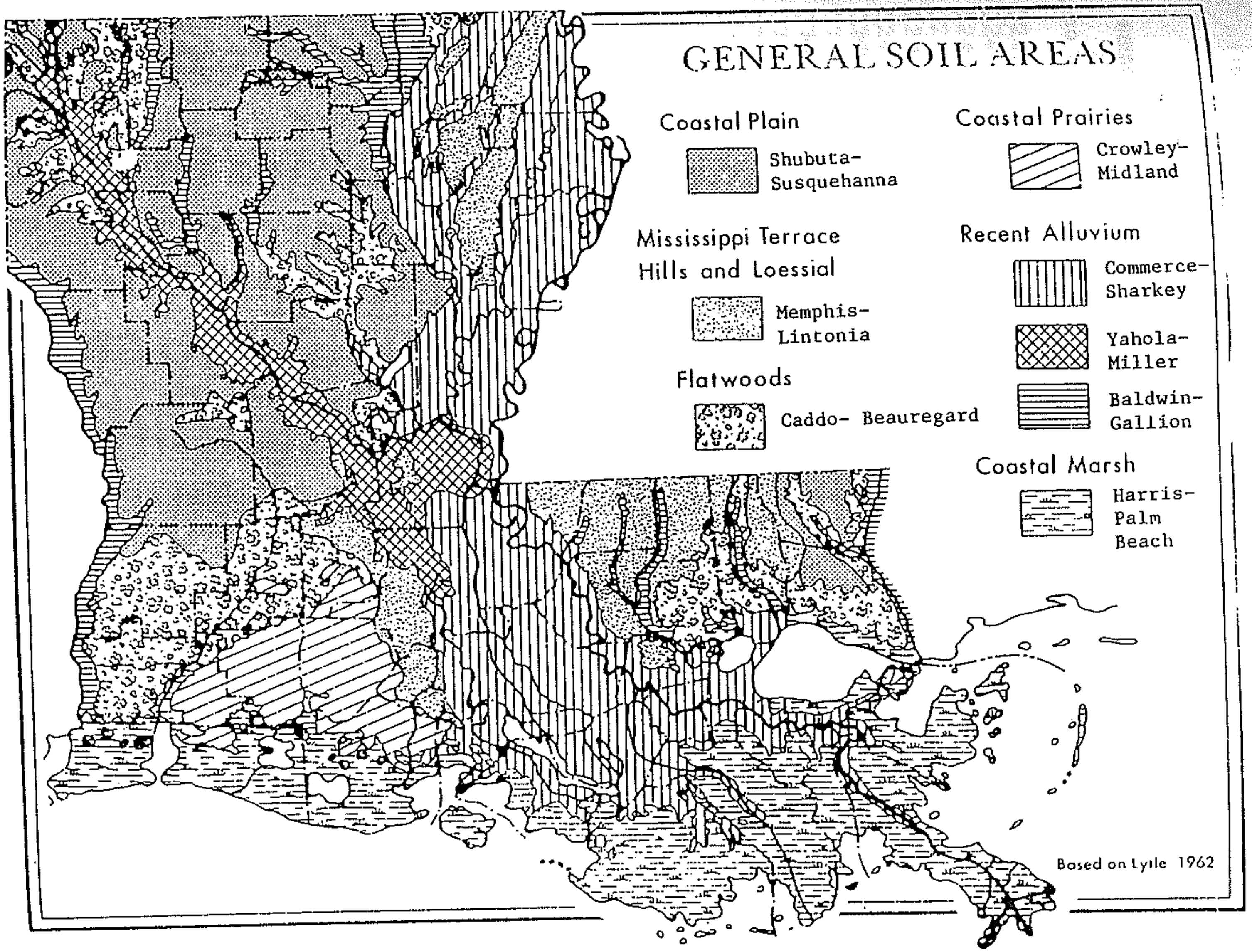


Figure 5. General soil areas of Louisiana (Newton, 1972)

Soil Conservation Service. Thus, while there is some degree of variability in runoff potential among these soils, this variability would not be expected to be prohibitive.

From the evidence presented above, it appears that from the preponderance of geologic, topographic, climatic and soil data, the regional groups shown on Figure 3 are the best that can be accomplished for Louisiana. The U.S. Geological Survey study (2) did not explicitly divide the state into regions but used variables such as average annual precipitation and slope to account for the variability in climate and physiography across the state. We believe that our procedure, based entirely upon homogeneous regions, may lead to more accurate results.

## Frequency Analysis

The frequency analysis was performed using the recorded annual series observed at the 85 stream gages listed in Tables 1-4 and plotted on Figure 3. The tables show the drainage area, period of record, and skew of the log transformed data for each gage. These 85 gages remained after the screening process previously described. Tables 1-4 show that these gages were grouped as follows: 24 in the southeast region, 32 in the southwest region, 24 in the northwest region and five in the northeast region. The combined records of all the gages within each region comprised the data base for that particular region. The southeast region contained a combined total of 818 years of data, the southwest totaled 1,085 years, the northwest region had 799 years, while the northeast total was 236 years. However, the northeast region, with only five total gages, contained four of the longest gaging records in the state.

# TABLE 1

## PERTINENT DATA OF WATERSHEDS IN SOUTHEAST LOUISIANA

| STATION NO. | AREA (sq.mile) | YEARS OF OBS. | SKEW OF LOG TRAN. DATA | SRMSE | | |
|---|---|---|---|---|---|---|
| | | | | GEV | TCEV | LP3 |
| 02492000 | 1213 | 50 | -0.08 | 0.256 | 0.317 | 0.327 |
| 02492360 | 175 | 21 | -0.02 | 0.149 | 0.107 | 0.111 |
| 02490105 | 73 | 22 | 0.12 | 0.209 | 0.222 | 0.215 |
| 02491500 | 990 | 66 | -0.34 | 0.171 | 0.186 | 0.201 |
| 02491700 | 44 | 20 | -0.69 | 0.280 | 0.236 | 0.188 |
| 02491350 | 42 | 21 | 0.70 | 0.186 | 0.188 | 0.179 |
| 02490000 | 12 | 20 | -0.63 | 0.357 | 0.319 | 0.173 |
| 07378500 | 1280 | 49 | -0.12 | 0.122 | 0.142 | 0.130 |
| 07375222 | 46 | 22 | -0.69 | 0.324 | 0.227 | 0.244 |
| 07380160 | 20 | 33 | -0.34 | 0.298 | 0.111 | 0.084 |
| 07375170 | 88 | 20 | 0.33 | 0.144 | 0.145 | 0.169 |
| 07376000 | 247 | 47 | -0.20 | 0.129 | 0.152 | 0.108 |
| 07376500 | 80 | 44 | -0.08 | 0.183 | 0.097 | 0.090 |
| 07375500 | 646 | 49 | -0.14 | 0.157 | 0.211 | 0.193 |
| 07377300 | 884 | 35 | 0.17 | 0.159 | 0.110 | 0.125 |
| 07376600 | 14 | 32 | -0.89 | 0.394 | 0.122 | 0.081 |
| 07375480 | 91 | 20 | -0.23 | 0.191 | 0.200 | 0.166 |
| 07375000 | 103 | 44 | -0.13 | 0.266 | 0.244 | 0.164 |
| 07377000 | 580 | 39 | -0.44 | 0.183 | 0.150 | 0.198 |
| 07375800 | 90 | 32 | 0.24 | 0.439 | 0.411 | 0.379 |
| 07375307 | 52 | 22 | 0.20 | 0.406 | 0.329 | 0.262 |
| 07378000 | 284 | 44 | -0.53 | 0.189 | 0.069 | 0.090 |
| 07377500 | 145 | 45 | -0.22 | 0.215 | 0.171 | 0.179 |
| 07373500 | 35 | 21 | -0.32 | 0.172 | 0.110 | 0.104 |
| | REGIONAL AVR. | | -0.21 | 0.232 | 0.191 | 0.173 |

# TABLE 2

## PERTINENT DATA OF WATERSHEDS IN SOUTHWEST LOUISIANA

| STATION NO. | AREA (sq.mile) | YEARS OF OBS. | SKEW OF LOG TRAN. DATA | SRMSE | | |
|---|---|---|---|---|---|---|
| | | | | GEV | TCEV | LP3 |
| 07386500 | 19 | 28 | -1.33 | 0.346 | 0.100 | 0.110 |
| 07381800 | 68 | 33 | -0.22 | 0.169 | 0.168 | 0.105 |
| 08012000 | 527 | 49 | 0.95 | 0.188 | 0.247 | 0.321 |
| 08010000 | 131 | 49 | -0.96 | 0.355 | 0.155 | 0.087 |
| 08011800 | 44 | 24 | -0.32 | 0.153 | 0.110 | 0.109 |
| 08015500 | 1700 | 49 | 0.46 | 0.215 | 0.255 | 0.351 |
| 08013500 | 753 | 49 | -0.17 | 0.104 | 0.098 | 0.165 |
| 08014500 | 510 | 48 | 0.16 | 0.656 | 0.642 | 0.720 |
| 08014000 | 171 | 27 | 0.29 | 0.263 | 0.314 | 0.323 |
| 08014200 | 94 | 37 | -0.02 | 0.370 | 0.387 | 0.422 |
| 08013000 | 499 | 44 | -0.46 | 0.139 | 0.131 | 0.113 |
| 08016800 | 177 | 31 | 0.08 | 0.186 | 0.272 | 0.328 |
| 08016400 | 148 | 39 | 0.21 | 0.161 | 0.179 | 0.168 |
| 08016600 | 82 | 38 | 0.36 | 0.278 | 0.211 | 0.161 |
| 08015000 | 238 | 31 | 0.02 | 0.262 | 0.218 | 0.181 |
| 08014800 | 120 | 24 | -0.30 | 0.111 | 0.129 | 0.121 |
| 08014600 | 26 | 20 | 0.13 | 0.249 | 0.284 | 0.270 |
| 08013800 | 10 | 21 | -0.50 | 0.116 | 0.150 | 0.103 |
| 08031000 | 83 | 34 | -0.78 | 0.221 | 0.199 | 0.147 |
| 08030000 | 69 | 32 | -0.17 | 0.199 | 0.156 | 0.145 |
| 08028700 | 13 | 26 | 0.68 | 0.173 | 0.253 | 0.332 |
| 08029500 | 128 | 36 | 0.84 | 0.453 | 0.445 | 0.514 |
| 08028000 | 365 | 36 | 0.38 | 0.430 | 0.352 | 0.301 |
| 08025850 | 10 | 20 | 0.80 | 0.306 | 0.371 | 0.437 |
| 08025500 | 148 | 31 | 0.72 | 0.461 | 0.419 | 0.457 |
| 08023000 | 97 | 28 | -0.25 | 0.140 | 0.136 | 0.119 |
| 07354000 | 21 | 30 | -0.71 | 0.353 | 0.176 | 0.118 |
| 07353990 | 37 | 22 | -0.02 | 0.326 | 0.285 | 0.219 |
| 07351700 | 20 | 26 | 0.36 | 0.978 | 0.981 | 1.050 |
| 07351500 | 66 | 49 | -1.12 | 0.121 | 0.095 | 0.219 |
| 07351000 | 79 | 43 | -1.12 | 0.192 | 0.136 | 0.270 |
| 07344450 | 81 | 31 | 0.05 | 0.354 | 0.372 | 0.352 |
| | REGIONAL AVG. | | -0.06 | 0.282 | 0.263 | 0.273 |

# TABLE 3

## PERTINENT DATA OF WATERSHEDS IN NORTHWEST LOUISIANA

| STATION NO. | AREA (sq.mile) | YEARS OF OBS. | SKEW OF LOG TRAN. DATA | SRMSE | | |
|---|---|---|---|---|---|---|
| | | | | GEV | TCEV | LP3 |
| 07373000 | 51 | 46 | 0.03 | 0.285 | 0.295 | 0.164 |
| 07372500 | 92 | 31 | 1.15 | 0.518 | 0.566 | 0.769 |
| 07372200 | 1899 | 30 | -0.31 | 0.124 | 0.142 | 0.208 |
| 07370750 | 48 | 30 | 0.53 | 0.138 | 0.229 | 0.318 |
| 07372110 | 24 | 23 | 0.72 | 0.443 | 0.433 | 0.517 |
| 07372000 | 654 | 42 | -1.10 | 0.320 | 0.254 | 0.275 |
| 07370500 | 271 | 30 | -1.07 | 0.194 | 0.195 | 0.280 |
| 07371500 | 355 | 49 | -0.44 | 0.074 | 0.148 | 0.123 |
| 07366420 | 113 | 22 | 0.16 | 0.462 | 0.463 | 0.533 |
| 07365000 | 355 | 28 | -0.34 | 0.162 | 0.185 | 0.140 |
| 07364870 | 47 | 22 | -1.27 | 0.173 | 0.130 | 0.230 |
| 07365500 | 178 | 30 | 0.96 | 0.547 | 0.561 | 0.765 |
| 07366000 | 462 | 43 | 0.12 | 0.385 | 0.424 | 0.524 |
| 07366200 | 208 | 32 | -0.13 | 0.357 | 0.395 | 0.431 |
| 07364700 | 141 | 22 | 1.28 | 0.737 | 0.725 | 0.875 |
| 07362100 | 385 | 49 | 0.04 | 0.176 | 0.203 | 0.327 |
| 07365800 | 180 | 29 | 0.39 | 0.969 | 0.894 | 1.044 |
| 07352000 | 154 | 47 | -0.12 | 0.183 | 0.240 | 0.097 |
| 07352500 | 423 | 43 | 0.17 | 0.337 | 0.289 | 0.147 |
| 07348700 | 605 | 30 | -0.03 | 0.173 | 0.237 | 0.256 |
| 07349500 | 546 | 49 | -0.36 | 0.285 | 0.172 | 0.122 |
| 07348725 | 33 | 22 | -1.71 | 0.314 | 0.213 | 0.377 |
| 07348800 | 67 | 24 | -0.01 | 0.094 | 0.165 | 0.212 |
| 07353500 | 47 | 26 | -0.17 | 0.311 | 0.270 | 0.180 |
| | REGIONAL AVG. | | -0.06 | 0.323 | 0.328 | 0.380 |

# TABLE 4

## PERTINENT DATA OF WATERSHEDS IN NORTHEAST LOUISIANA

| STATION NO. | AREA (sq.mile) | YEARS OF OBS. | SKEW OF LOG TRAN. DATA | SRMSE | | |
|---|---|---|---|---|---|---|
| | | | | GEV | TCEV | LP3 |
| 07369500 | 309 | 51 | -0.58 | 0.068 | 0.943 | 0.038 |
| 07370000 | 782 | 60 | -0.43 | 0.102 | 1.270 | 0.104 |
| 07368500 | 42 | 28 | -0.55 | 0.048 | 1.070 | 0.075 |
| 07364500 | 1645 | 52 | -1.93 | 0.071 | 1.103 | 0.097 |
| 07364190 | 1170 | 45 | -1.92 | 0.089 | 1.088 | 0.101 |
| | REGIONAL AVG. | | -1.08 | 0.076 | 1.095 | 0.083 |

Therefore, it was considered very important to include these gages in the study.

Each of the three regional frequency methods was fitted to these data by the methods previously described. At-site quantiles were then generated from the regional distributions for each gage location in the study. These quantiles were compared to the observed data at each site in terms of standardized root mean square error (SRMSE). The SRMSE values are also shown in Tables 1-4 for each regional method. As can be seen from these results, no one method gave superior fits for all four regions. The TCEV resulted in the lowest SRMSE for the southwest region, the LP3 method gave superior results in the southeast region, while the GEV resulted in superior fits to observed data in both the northwest and northeast regions. However, the difference between the methods did not appear to be significant in many cases. The TCEV and LP3 methods performed about equally in the southeast region and both performed significantly better than the GEV for this region. All three methods performed about the same in the southwest region where the average SRMSE differences between the methods was less than 10%. In the northwest region, the GEV and TCEV performed evenly and resulted in significantly better fits to observed data than did the LP3, while the LP3 and GEV outperformed the TCEV by a considerable margin in the northeast region. Thus each method was clearly inferior to its counterparts in one region, was clearly superior in one region each, and performed about equally well elsewhere. It would appear difficult, therefore, to choose between them on a statistical goodness-of-fit basis.

Based on the evidence shown in Tables 1-4 and other factors, the GEV method was selected as the superior regional frequency procedure among the three methods analyzed in this study. Among the other factors considered was the extreme ease with which this method can be extended to ungaged sites when compared to the other methods. The only geomorphological relationship that needs to be established is between the indexing factor (mean Q) and basin characteristics. It has been shown by many past studies that mean floods are almost wholly functions of drainage area alone. Thus, a simple mean Q versus drainage area relationship is all that is required to apply this method to ungaged sites.

Another important factor in the selection of the GEV is that parameter estimation is done by PWM. It has been shown by Greenwood et al. (7) and Greis and Wood (8) that PWM are more robust and less biased than conventional methods. Thus, estimates obtained by this method should be better in these respects than those obtained from other methods. This was confirmed in the study by Potter and Lettenmaier (22). The at-site quantiles obtained from the GEV regional method for each gage used in the analysis are shown in Tables 5-8. These can be conveniently compared to quantiles obtained at these locations by the other methods. The nondimensional flood frequency curve for each region is shown on Figures 6-9.

The log mean of the flood series for each location was plotted (in log space) against its corresponding drainage area for each of the four regions. These plots are shown in Figures 10 to 13. A curve through the points was fitted by standard regression techniques. The figures show that the data are generally well fitted by the regression curve. The regression equations for the four regions are as follows:

Southeast: $\log \bar{Q} = 2.695\ A^{0.072}$ (19)

$R^2 = .86$

$CV = 3.1$

Southwest: $\log \bar{Q} = 2.561\ A^{0.076}$ (20)

$R^2 = .84$

$CV = 3.22$

Northwest: $\log \bar{Q} = 2.836\ A^{0.052}$ (21)

$R^2 = .76$

$CV = 2.509$

Northeast: $\log \bar{Q} = 2.406\ A^{0.063}$ (22)

$R^2 = .97$

$CV = 1.36$

In analyzing these equations, the coefficient of determination ($R^2$) represents the percentage of the total variance of the dependent variable ($\log \bar{Q}$) explained by its relationship with the area. The coefficient of variation (CV) represents the ratio of 100 times the root mean square error and the mean of the dependent variable. It represents a dimensionless measure of the error in the regression fit. Standard F tests on the mean square error showed that these equations were all significant at the 1% level. Thus the log linear relationship between mean flood values and drainage areas appears to be well-confirmed in these cases.

# TABLE 5

## REGIONAL AT-SITE FLOOD QUANTILES BY GEV/PWM BASED ON OBSERVED DATA FOR SOUTHEAST LOUISIANA

| STATION NO. | FLOOD QUANTILES FOR RETURN PERIOD | | | | | | OBSER MEAN FLOOD |
|---|---|---|---|---|---|---|---|
| | 2-YR | 10-YR | 25-YR | 50-YR | 100-YR | 200-YR | |
| 02492000 | 19649 | 46483 | 63662 | 78346 | 94791 | 113265 | 24203 |
| 02492360 | 5917 | 13998 | 19171 | 23593 | 28546 | 34109 | 7289 |
| 02490105 | 2440 | 5772 | 7906 | 9729 | 11772 | 14066 | 3006 |
| 02491500 | 21423 | 50679 | 69408 | 85418 | 103348 | 123489 | 26387 |
| 02491700 | 3489 | 8255 | 11306 | 13914 | 16835 | 20116 | 4298 |
| 02491350 | 2494 | 5902 | 8082 | 9946 | 12033 | 14379 | 3073 |
| 02490000 | 1958 | 4633 | 6345 | 7809 | 9448 | 11290 | 2412 |
| 07378500 | 26892 | 63617 | 87128 | 107225 | 129732 | 155016 | 33124 |
| 07375222 | 2128 | 5036 | 6897 | 8488 | 10269 | 12271 | 2622 |
| 07380160 | 969 | 2292 | 3140 | 3864 | 4665 | 5586 | 1194 |
| 07375170 | 3804 | 9000 | 12327 | 15170 | 18355 | 21932 | 4687 |
| 07376000 | 5487 | 12980 | 17778 | 21878 | 26471 | 31630 | 6759 |
| 07376500 | 3026 | 7158 | 9804 | 12065 | 14598 | 17443 | 3727 |
| 07375500 | 14876 | 35192 | 48197 | 59315 | 71765 | 85752 | 18323 |
| 07377300 | 24321 | 57535 | 78798 | 96974 | 117329 | 140196 | 29957 |
| 07376600 | 1114 | 2635 | 3610 | 4442 | 5375 | 6423 | 1372 |
| 07375480 | 6948 | 16436 | 22510 | 27703 | 33518 | 40050 | 8558 |
| 07375000 | 4974 | 11768 | 16117 | 19835 | 23998 | 28675 | 6127 |
| 07377000 | 21208 | 50170 | 68711 | 84560 | 102310 | 122249 | 26122 |
| 07375800 | 4664 | 11035 | 15113 | 18599 | 22503 | 26889 | 5746 |
| 07375307 | 4272 | 10107 | 13842 | 17035 | 20611 | 24627 | 5263 |
| 07378000 | 9826 | 23246 | 31837 | 39181 | 47405 | 56644 | 12104 |
| 07377500 | 6967 | 16482 | 22574 | 22780 | 33612 | 40162 | 8582 |
| 07373500 | 6120 | 14478 | 19829 | 24403 | 29525 | 35279 | 7539 |

## TABLE 6

## REGIONAL AT-SITE FLOOD QUANTILES BY GEV/PWM BASED ON OBSERVED DATA FOR SOUTHWEST LOUISIANA

| STATION NO. | FLOOD QUANTILES FOR RETURN PERIOD | | | | | | OBSER MEAN FLOOD |
|---|---|---|---|---|---|---|---|
| | 2-YR | 10-YR | 25-YR | 50-YR | 100-YR | 200-YR | |
| 07386500 | 931 | 2324 | 3365 | 4343 | 5529 | 6971 | 1223 |
| 07381800 | 2175 | 5424 | 7855 | 10137 | 12904 | 16271 | 2855 |
| 08012000 | 7086 | 17672 | 25592 | 33025 | 42041 | 53088 | 9303 |
| 08010000 | 3880 | 9678 | 14015 | 18085 | 23023 | 29029 | 5095 |
| 08011800 | 2256 | 5628 | 8151 | 10518 | 13389 | 16882 | 2963 |
| 08015500 | 25496 | 63588 | 92085 | 118828 | 151270 | 190731 | 33472 |
| 08013500 | 13365 | 33332 | 48271 | 62289 | 79295 | 99980 | 17546 |
| 08014500 | 12488 | 31146 | 45105 | 58204 | 74095 | 93423 | 16395 |
| 08014000 | 4407 | 10991 | 15917 | 20540 | 26148 | 32969 | 5786 |
| 08014200 | 3981 | 9928 | 14378 | 18554 | 23619 | 29781 | 5227 |
| 08013000 | 12643 | 31531 | 45663 | 58924 | 75011 | 94579 | 16597 |
| 08016800 | 3383 | 8439 | 12221 | 15770 | 20076 | 25313 | 4442 |
| 08016400 | 3726 | 9294 | 13459 | 17367 | 22109 | 27877 | 4892 |
| 08016600 | 3856 | 6916 | 13929 | 17974 | 22881 | 28851 | 5063 |
| 08015000 | 6558 | 16358 | 23689 | 30568 | 38914 | 49065 | 8611 |
| 08014800 | 3932 | 9808 | 14203 | 18328 | 23332 | 29419 | 5163 |
| 08014600 | 1947 | 4856 | 7033 | 9075 | 11553 | 14567 | 2556 |
| 08013800 | 1005 | 2507 | 3631 | 4686 | 5965 | 7522 | 1320 |
| 08031000 | 1295 | 3231 | 4680 | 6039 | 7688 | 9694 | 1701 |
| 08030000 | 1937 | 4833 | 6999 | 9031 | 11497 | 14497 | 2544 |
| 08028700 | 712 | 1776 | 2572 | 3319 | 4225 | 5328 | 935 |
| 08029500 | 2927 | 7300 | 10571 | 13641 | 17366 | 21896 | 3842 |
| 08028000 | 10441 | 26041 | 37712 | 48664 | 61950 | 78111 | 13708 |
| 08025850 | 601 | 1499 | 2171 | 2801 | 3566 | 4497 | 789 |
| 08025500 | 4911 | 12249 | 17739 | 22890 | 29140 | 36742 | 6448 |
| 08023000 | 1894 | 4725 | 6842 | 8830 | 11240 | 14173 | 2487 |
| 07354000 | 2253 | 5619 | 8138 | 10501 | 13368 | 16856 | 2958 |
| 07353990 | 3647 | 9096 | 13173 | 16998 | 21639 | 27284 | 4788 |
| 07351700 | 1143 | 2851 | 4129 | 5328 | 6783 | 8552 | 1501 |
| 07351500 | 4530 | 11299 | 16363 | 21115 | 26880 | 33893 | 5948 |
| 07351000 | 3227 | 8049 | 11656 | 15041 | 19148 | 24143 | 4237 |
| 07344450 | 3147 | 7850 | 11368 | 14670 | 18675 | 23547 | 4132 |

# TABLE 7

## REGIONAL AT-SITE FLOOD QUANTILES BY GEV/PWM BASED ON OBSERVED DATA FOR NORTHWEST LOUISIANA

| STATION NO. | FLOOD QUANTILES FOR RETURN PERIOD | | | | | | OBSER MEAN FLOOD |
|---|---|---|---|---|---|---|---|
| | 2-YR | 10-YR | 25-YR | 50-YR | 100-YR | 200-YR | |
| 07373000 | 3360 | 9352 | 14159 | 18865 | 24785 | 32251 | 4732 |
| 07372500 | 3390 | 9437 | 14288 | 19037 | 25011 | 32545 | 4775 |
| 07372200 | 17159 | 47756 | 71304 | 95335 | 125567 | 164693 | 24164 |
| 07370750 | 1833 | 5103 | 7726 | 10294 | 13525 | 17599 | 2582 |
| 07372110 | 2144 | 5967 | 9034 | 12037 | 15814 | 20578 | 3019 |
| 07372000 | 6610 | 18397 | 27854 | 37111 | 48758 | 63445 | 9309 |
| 07370500 | 4544 | 12647 | 19148 | 25512 | 33518 | 43615 | 6399 |
| 07371500 | 6094 | 16961 | 25680 | 34216 | 44953 | 58494 | 8582 |
| 07366420 | 3319 | 9239 | 13988 | 18638 | 24487 | 31863 | 4675 |
| 07365000 | 5465 | 15210 | 23028 | 30682 | 40311 | 52454 | 7696 |
| 07364870 | 1825 | 5080 | 7692 | 10248 | 13465 | 17521 | 2571 |
| 07365500 | 2841 | 7907 | 11972 | 15951 | 20956 | 27269 | 4001 |
| 07366000 | 5902 | 16426 | 24870 | 33135 | 43534 | 56648 | 8311 |
| 07366200 | 3411 | 9495 | 14376 | 19154 | 25165 | 32745 | 4804 |
| 07364700 | 3184 | 8864 | 13420 | 17881 | 23492 | 30569 | 4485 |
| 07362100 | 6248 | 17389 | 26328 | 35078 | 46086 | 59968 | 8799 |
| 07365800 | 5374 | 14957 | 22646 | 30173 | 39642 | 51583 | 7568 |
| 07352000 | 2411 | 6712 | 10162 | 13539 | 17789 | 23147 | 3396 |
| 07352500 | 3475 | 9672 | 14644 | 19511 | 25634 | 33355 | 4894 |
| 07348700 | 6111 | 17009 | 25752 | 34311 | 45079 | 58658 | 8606 |
| 07349500 | 3612 | 10055 | 15223 | 20283 | 26448 | 34675 | 5088 |
| 07348725 | 1310 | 3646 | 5520 | 7355 | 9664 | 12575 | 1845 |
| 07348800 | 1807 | 5030 | 7616 | 10147 | 13332 | 17348 | 2545 |
| 07353500 | 2175 | 6055 | 9168 | 12215 | 16049 | 20883 | 3064 |

## TABLE 8

## REGIONAL AT-SITE FLOOD QUANTILES BY GEV/PWM BASED ON OBSERVED DATA FOR NORTHEAST LOUISIANA

| STATION NO. | FLOOD QUANTILES FOR RETURN PERIOD | | | | | | OBSER MEAN FLOOD |
|---|---|---|---|---|---|---|---|
| | 2-YR | 10-YR | 25-YR | 50-YR | 100-YR | 200-YR | |
| 07369500 | 2687 | 4036 | 4554 | 4882 | 5167 | 5416 | 2745 |
| 07370000 | 5279 | 7930 | 8947 | 9592 | 10152 | 10641 | 5392 |
| 07368500 | 1070 | 1620 | 1828 | 1960 | 2074 | 2174 | 1102 |
| 07364500 | 6959 | 10454 | 11794 | 12643 | 13382 | 14027 | 7108 |
| 07364190 | 4600 | 6910 | 7796 | 8358 | 8846 | 9272 | 4699 |

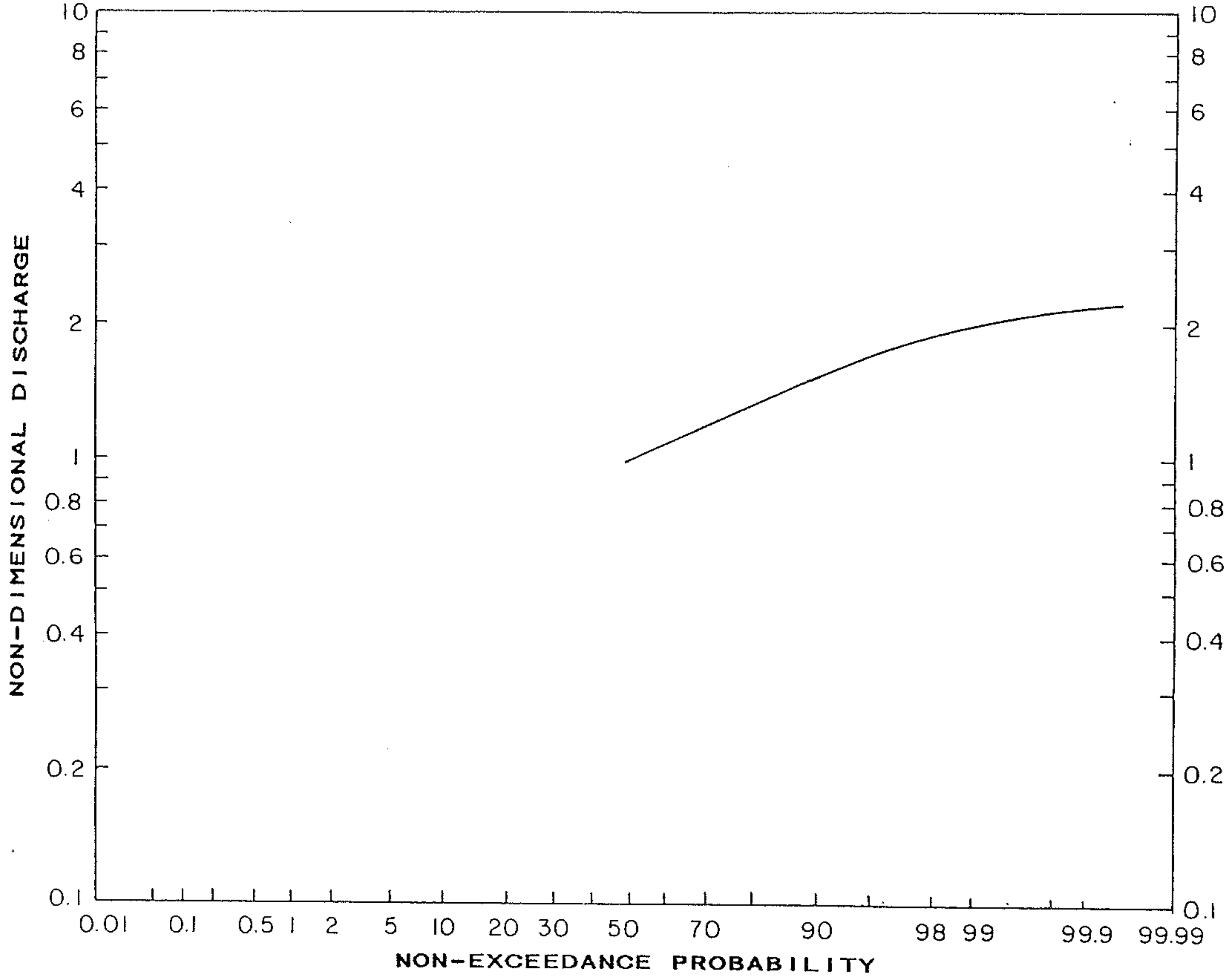


Figure 6. Non-dimensional regional frequency for Northeast Louisiana

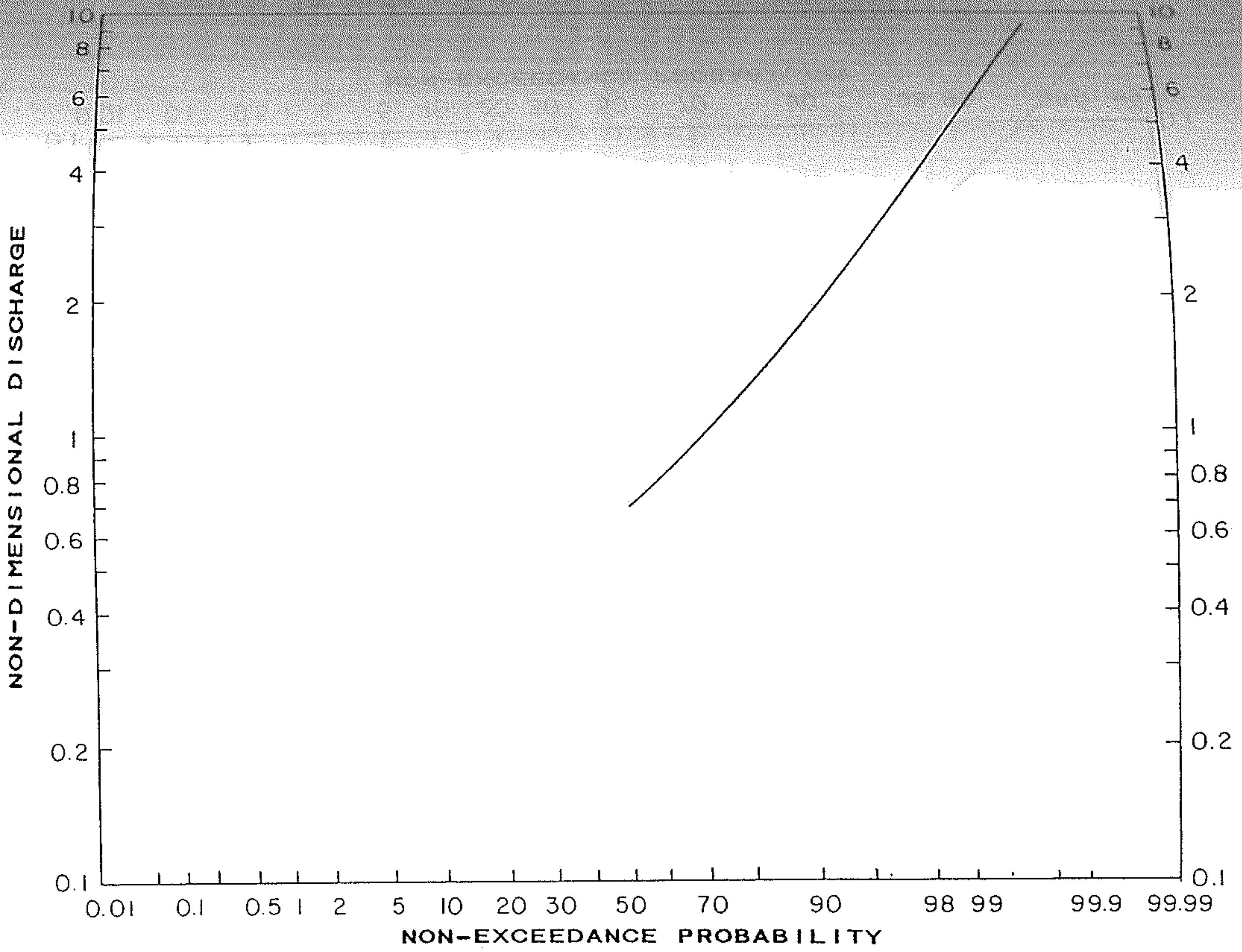


Figure 7. Non-dimensional regional frequency for Northwest Louisiana

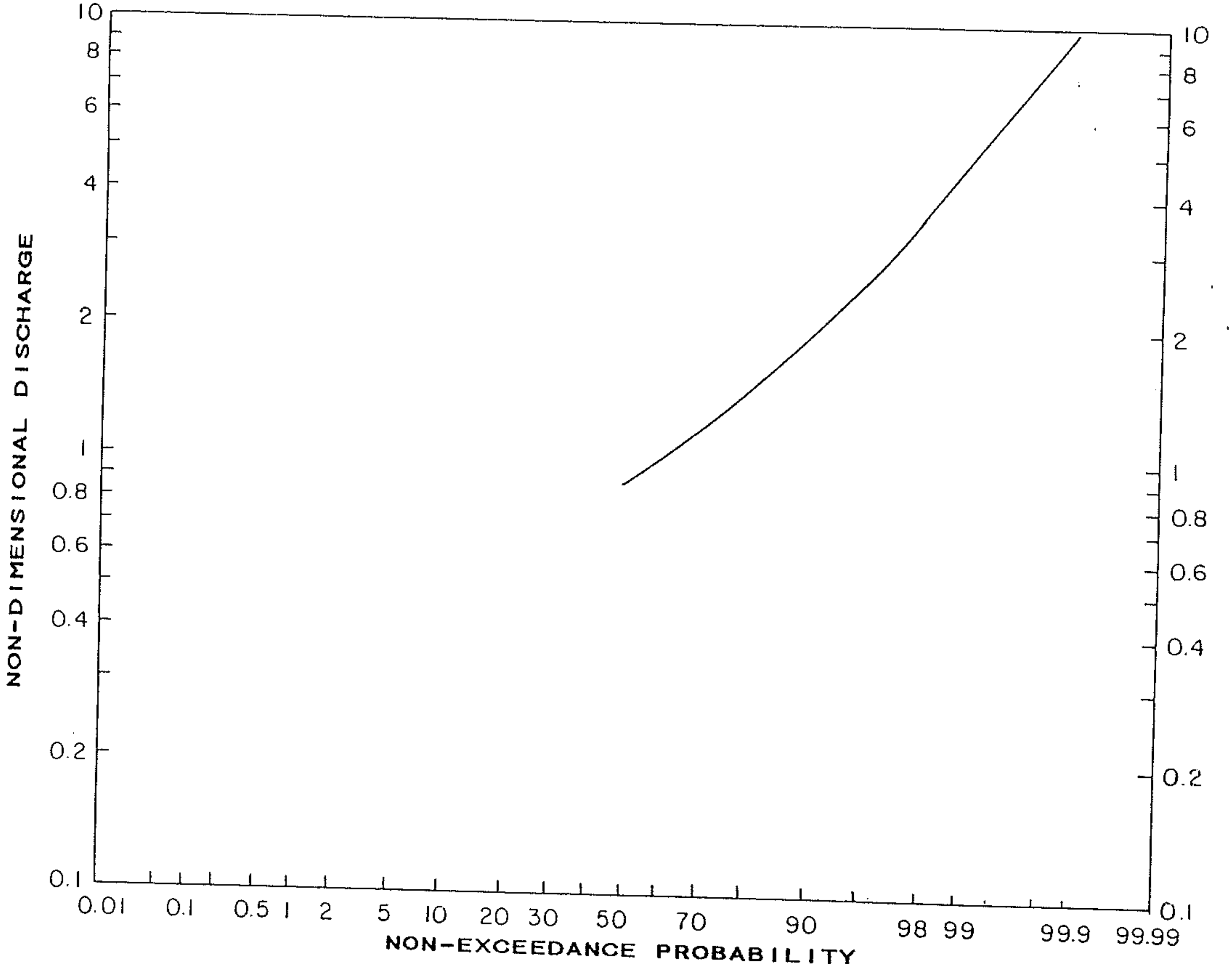


Figure 8. Non-dimensional regional frequency for Southwest Louisiana

Figure 8. Non-dimensional regional frequency for Southwest Louisiana

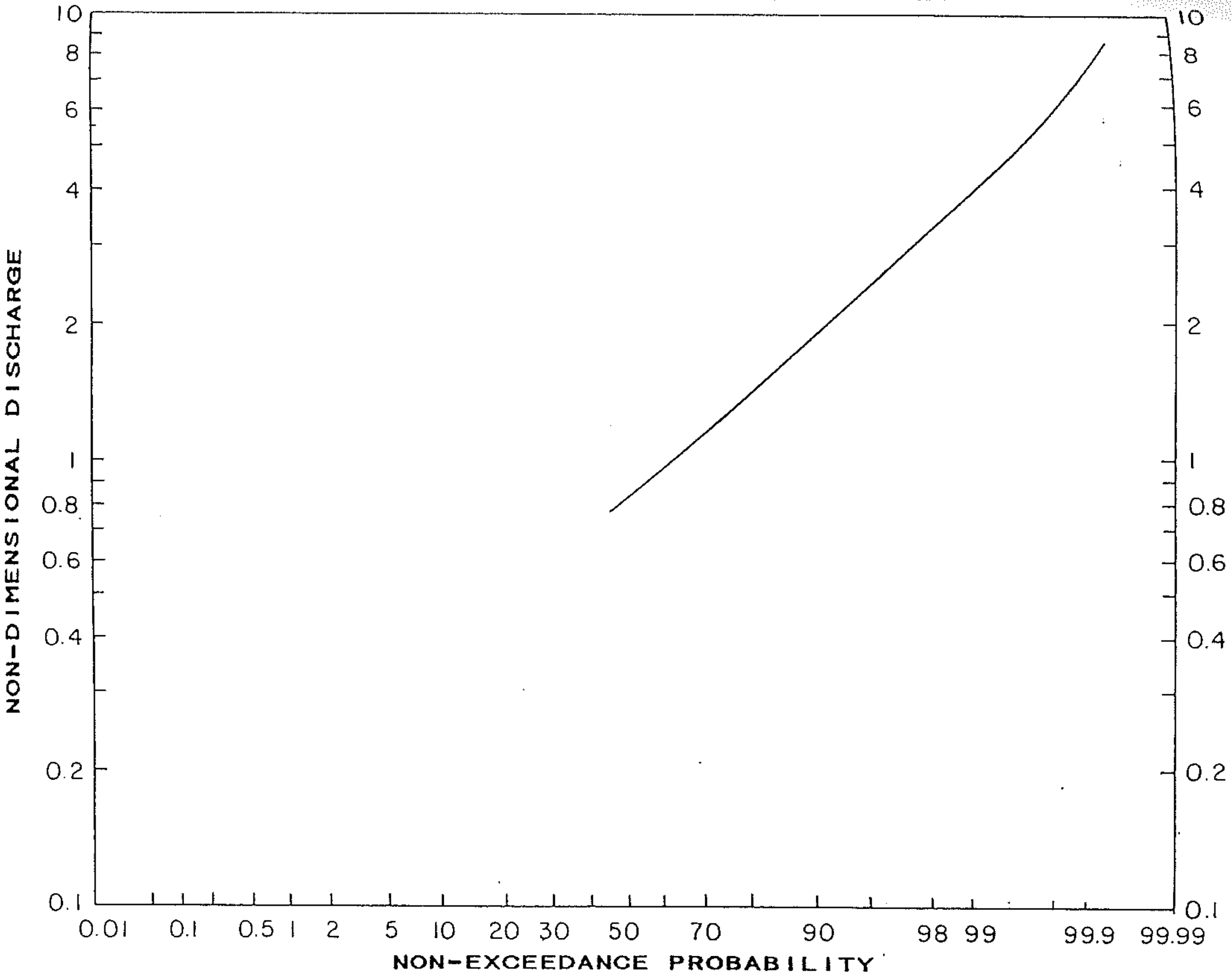
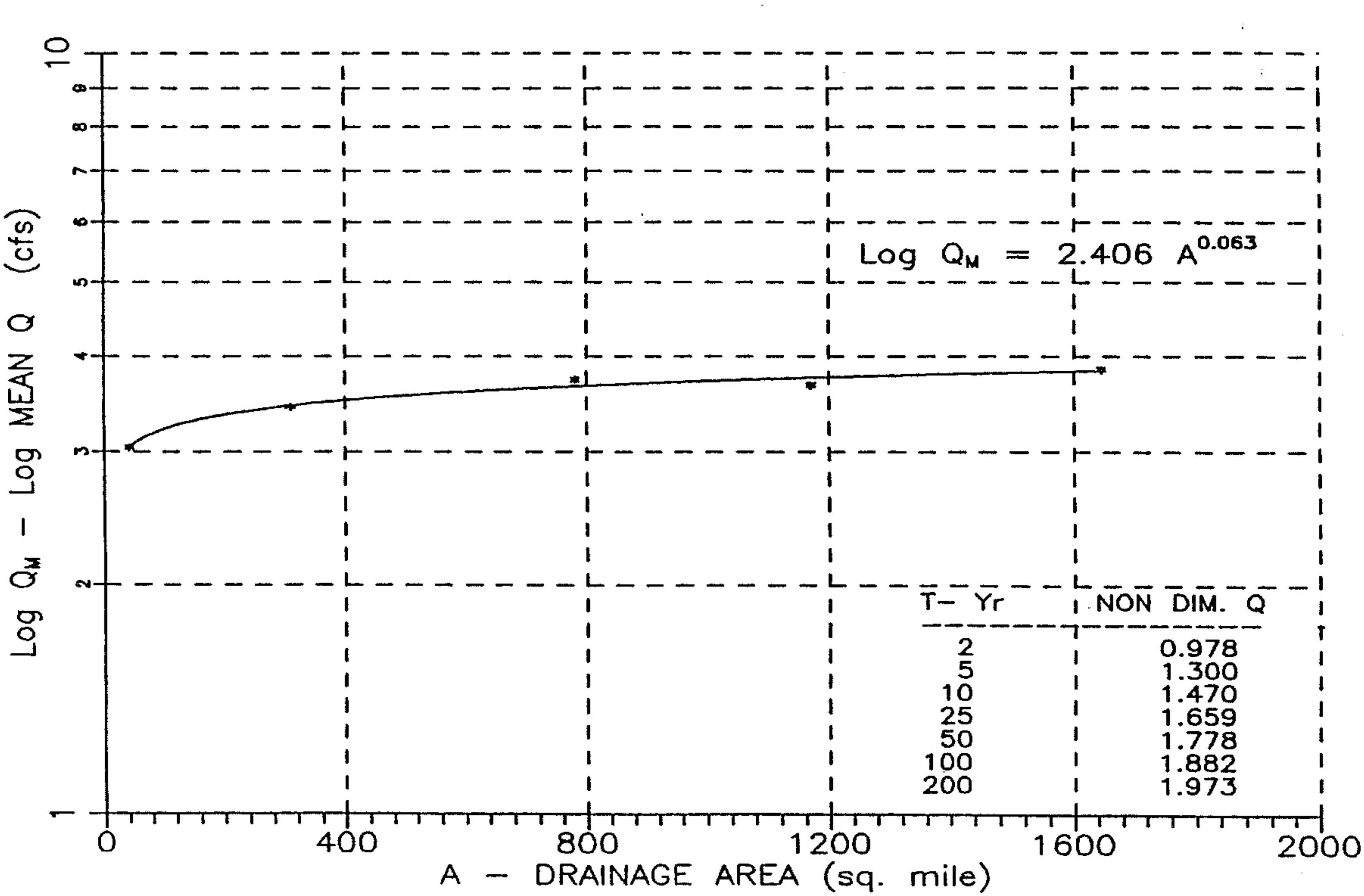


Figure 9. Non-dimensional regional frequency for Southeast Louisiana



$\text{Log } Q_M = 2.406\ A^{0.063}$

| T– Yr | NON DIM. Q |
|---|---|
| 2 | 0.978 |
| 5 | 1.300 |
| 10 | 1.470 |
| 25 | 1.659 |
| 50 | 1.778 |
| 100 | 1.882 |
| 200 | 1.973 |

Figure 10. Log mean Q versus drainage areas-Northeast Louisiana

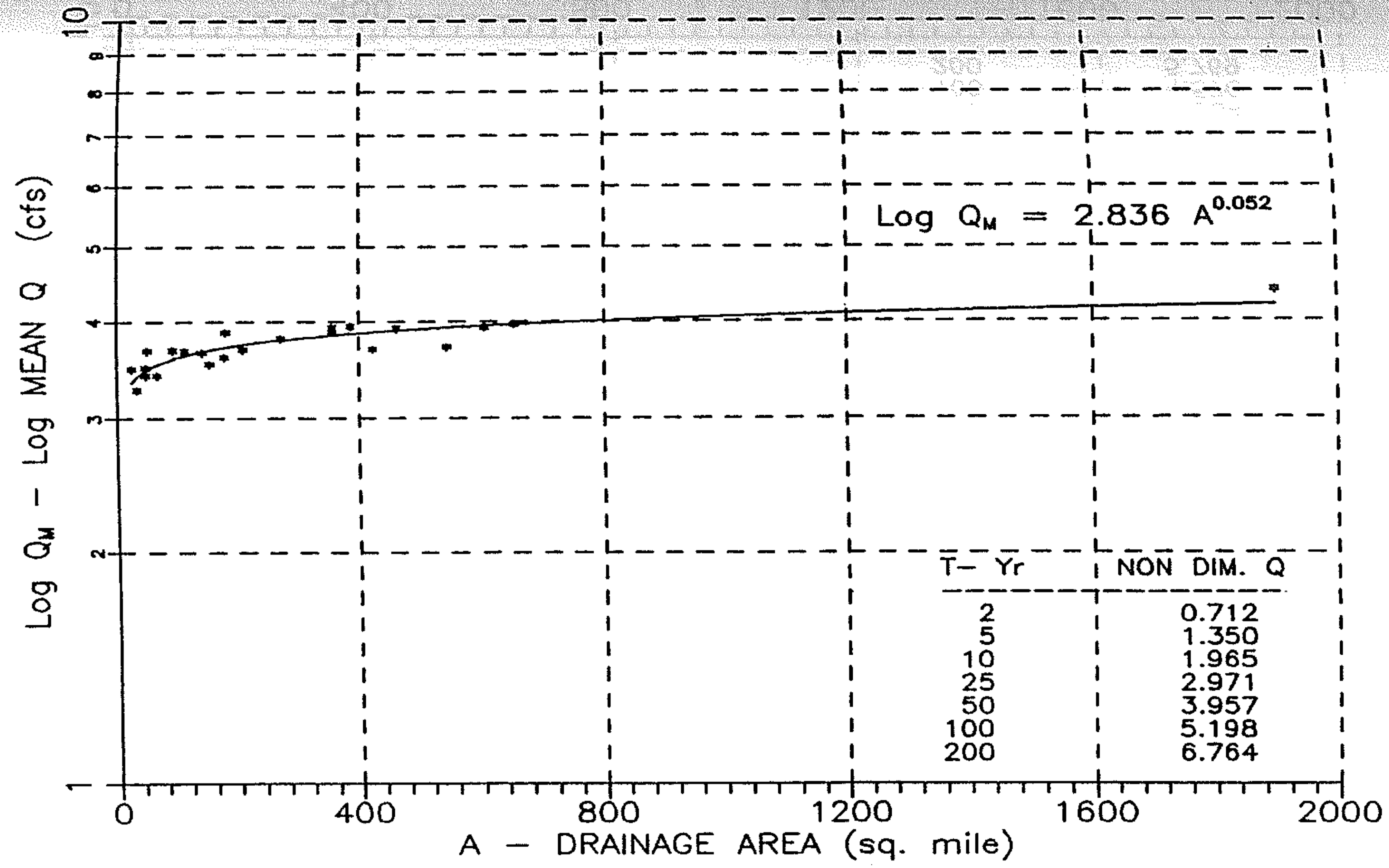
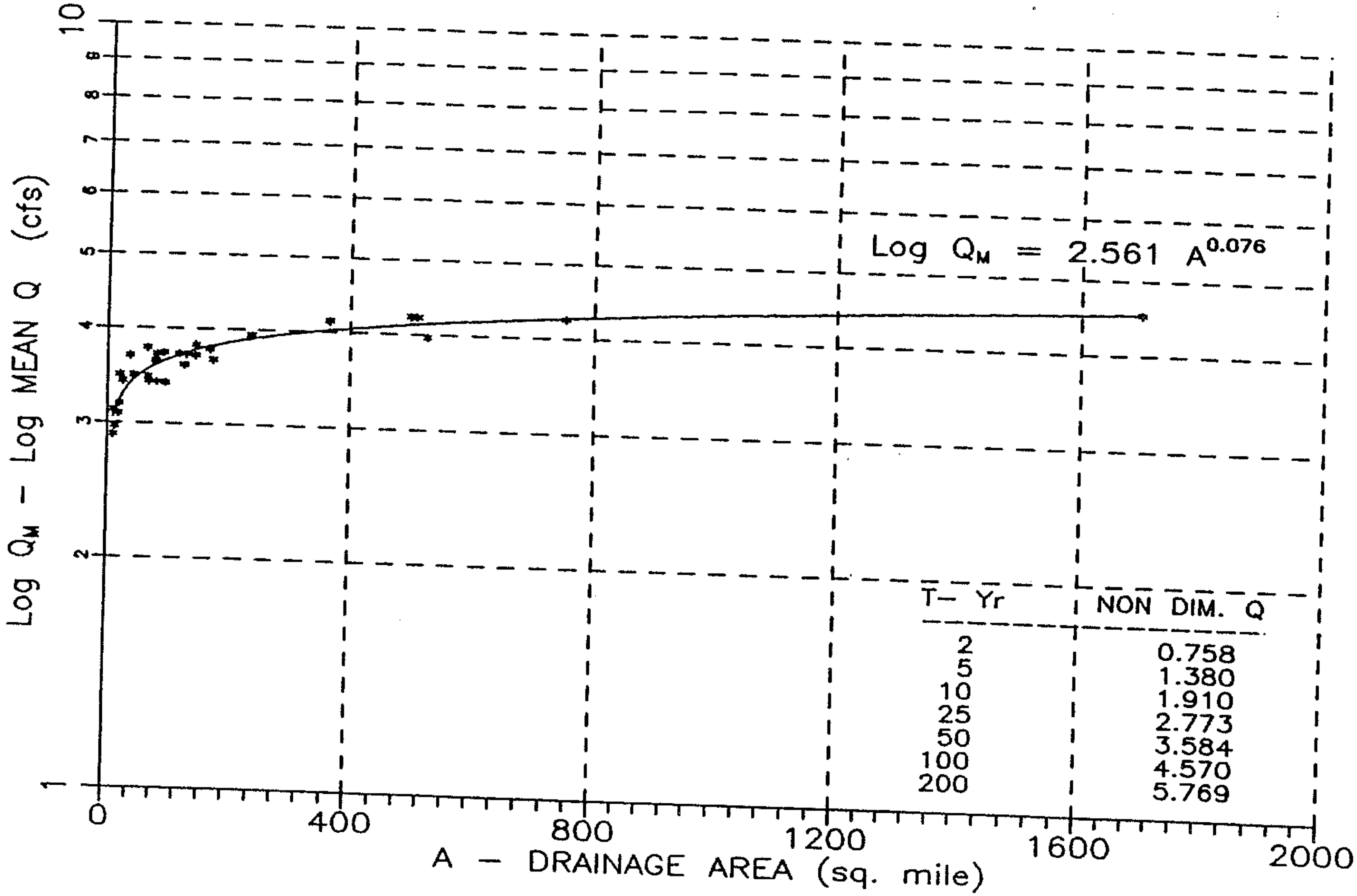
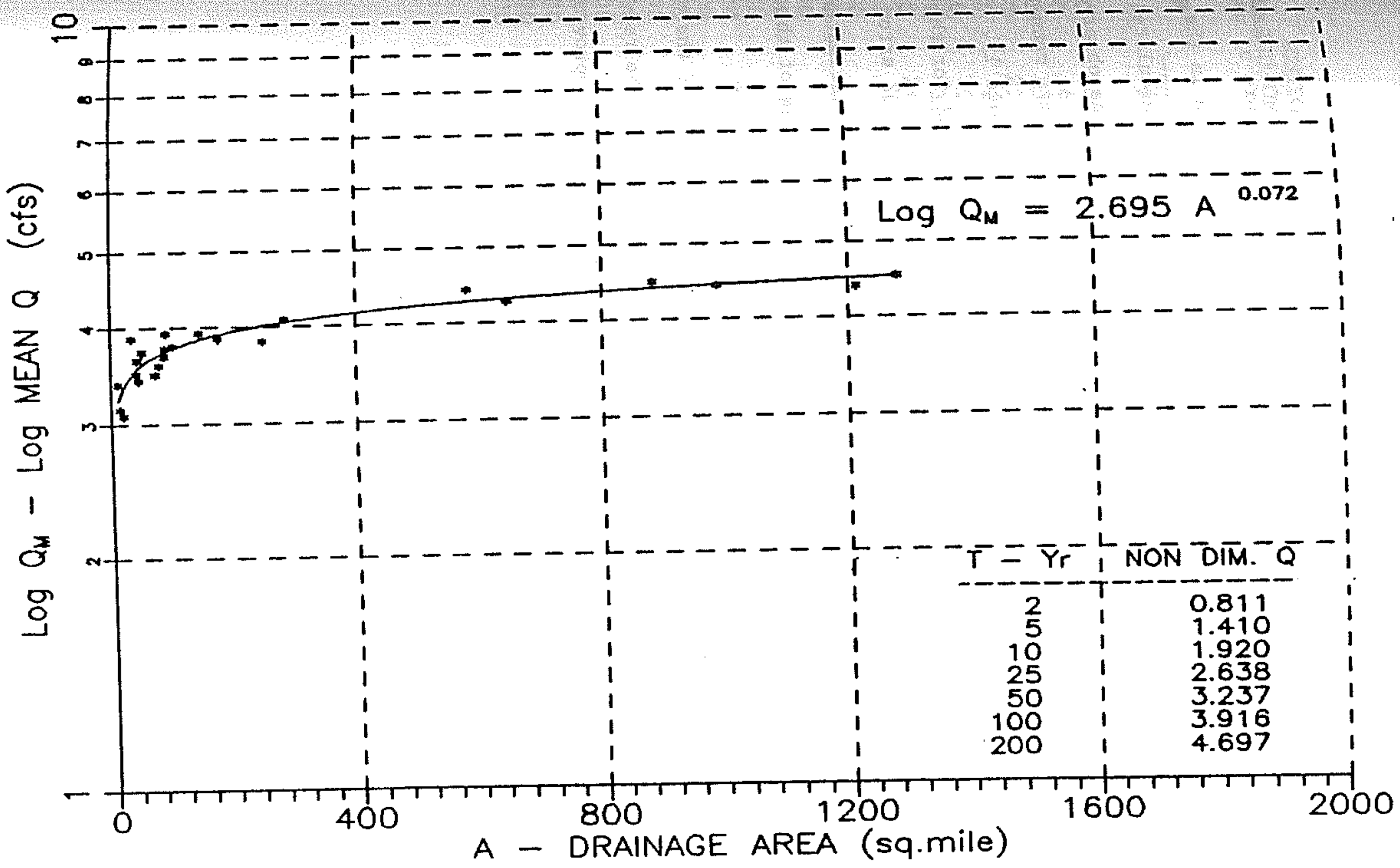


Figure 11. Log mean Q versus drainage areas-Northwest Louisiana



| T- Yr | NON DIM. Q |
|---|---|
| 2 | 0.758 |
| 5 | 1.380 |
| 10 | 1.910 |
| 25 | 2.773 |
| 50 | 3.584 |
| 100 | 4.570 |
| 200 | 5.769 |

Figure 12. Log mean Q versus drainage areas-Southwest Louisiana



| T – Yr | NON DIM. Q |
|---|---|
| 2 | 0.811 |
| 5 | 1.410 |
| 10 | 1.920 |
| 25 | 2.638 |
| 50 | 3.237 |
| 100 | 3.916 |
| 200 | 4.697 |

Figure 13. Log mean Q versus drainage areas-Southeast Louisiana

## Error Analysis

Error analyses were performed on the GEV regional procedure by using the regression equations to approximate the means at each location in the study. Using these values as indices, the at-site quantiles were recalculated from the regional values. These quantiles were then compared to the observed data at each site by SRMSE. The at-site quantiles calculated in this manner are given in Tables 9-12, while the SRMSE results are given in Table 13. The table shows that the error in the procedure averages about 48% for the southeast, southwest and northwest regions with only about a 13% error showing for the northeast region. However, the error in the quantile estimates from the distribution itself will be greater for this region because of the small data base.

Table 13 also shows SRMSE values obtained by a comparison of the USGS equations with the observed data at each site in each region. The results show that in every case the GEV procedure showed a significant improvement over the USGS equations in terms of fit to observed data.

## TABLE 9

### REGIONAL AT-SITE FLOOD QUANTILES BY GEV/PWM BASED ON MEAN-AREA CURVE FOR SOUTHEAST LOUISIANA

| STATION NO. | FLOOD QUANTILES FOR RETURN PERIOD | | | | | | ESTIM MEAN FLOOD |
|---|---|---|---|---|---|---|---|
| | 2-YR | 10-YR | 25-YR | 50-YR | 100-YR | 200-YR | |
| 02492000 | 25464 | 60252 | 82514 | 101540 | 122845 | 146776 | 31365 |
| 02492360 | 6614 | 15647 | 21429 | 26370 | 31903 | 38118 | 8145 |
| 02490105 | 3816 | 9029 | 12365 | 15216 | 18409 | 21995 | 4700 |
| 02491500 | 21911 | 51836 | 70988 | 87356 | 105685 | 126273 | 26984 |
| 02491700 | 2819 | 6669 | 9133 | 11240 | 13598 | 16247 | 3471 |
| 02491350 | 2743 | 6490 | 8888 | 10937 | 13232 | 15810 | 3377 |
| 02490000 | 1360 | 3218 | 4407 | 5424 | 6562 | 7840 | 1675 |
| 07378500 | 26513 | 62723 | 85898 | 105704 | 127882 | 152794 | 32651 |
| 07375222 | 2897 | 6846 | 9376 | 11537 | 13958 | 16677 | 3563 |
| 07380160 | 1797 | 4251 | 5822 | 7164 | 8668 | 10356 | 2212 |
| 07375170 | 4280 | 10126 | 13867 | 17064 | 20645 | 24667 | 5270 |
| 07376000 | 8295 | 19624 | 26874 | 33071 | 40010 | 47804 | 10215 |
| 07376500 | 4036 | 9549 | 13077 | 16092 | 19469 | 23261 | 4970 |
| 07375500 | 16085 | 38053 | 52113 | 64129 | 77585 | 92698 | 19809 |
| 07377300 | 20168 | 47711 | 65339 | 80405 | 97275 | 116224 | 24837 |
| 07376600 | 1478 | 3496 | 4788 | 5893 | 7129 | 8518 | 1819 |
| 07375480 | 4370 | 10338 | 14157 | 17422 | 21077 | 25183 | 5381 |
| 07375000 | 4719 | 11165 | 15291 | 18817 | 22765 | 27200 | 5812 |
| 07377000 | 14900 | 35249 | 48273 | 59404 | 71868 | 85868 | 18349 |
| 07375800 | 4340 | 10267 | 14061 | 17303 | 20934 | 25012 | 5344 |
| 07375307 | 3111 | 7361 | 10081 | 12406 | 15009 | 17933 | 3832 |
| 07378000 | 9106 | 21543 | 29503 | 36306 | 43924 | 52480 | 11214 |
| 07377500 | 5859 | 13861 | 18983 | 23360 | 28261 | 33767 | 7215 |
| 07373500 | 2467 | 5837 | 7993 | 9836 | 11900 | 14219 | 3037 |

## TABLE 10

## REGIONAL AT-SITE FLOOD QUANTILES BY GEV/PWM BASED ON MEAN-AREA CURVE FOR SOUTHWEST LOUISIANA

| STATION NO. | FLOOD QUANTILES FOR RETURN PERIOD | | | | | | ESTIM MEAN FLOOD |
|---|---|---|---|---|---|---|---|
| | 2-YR | 10-YR | 25-YR | 50-YR | 100-YR | 200-YR | |
| 07386500 | 1223 | 3080 | 4472 | 5781 | 7371 | 9306 | 1622 |
| 07381800 | 2607 | 6565 | 9533 | 12322 | 15710 | 19836 | 3454 |
| 08012000 | 10373 | 26121 | 37931 | 49028 | 62507 | 78921 | 13703 |
| 08010000 | 3963 | 9981 | 14493 | 18733 | 23884 | 30156 | 5247 |
| 08011800 | 1996 | 5028 | 7301 | 9438 | 12032 | 15192 | 2646 |
| 08015500 | 25328 | 63782 | 92617 | 119714 | 152625 | 192705 | 33387 |
| 08013500 | 13501 | 33999 | 49370 | 63815 | 81358 | 102723 | 17825 |
| 08014500 | 10128 | 25505 | 37036 | 47872 | 61033 | 77060 | 13380 |
| 08014000 | 4727 | 11905 | 17288 | 22346 | 28489 | 35971 | 6256 |
| 08014200 | 3297 | 8053 | 11693 | 15114 | 19270 | 24330 | 4235 |
| 08013000 | 9969 | 25105 | 36454 | 47120 | 60074 | 75850 | 13170 |
| 08016800 | 4838 | 12183 | 17692 | 22868 | 29154 | 36811 | 6401 |
| 08016400 | 4395 | 10815 | 15705 | 20300 | 25881 | 32677 | 5685 |
| 08016600 | 2932 | 7383 | 10721 | 13858 | 17668 | 22308 | 3884 |
| 08015000 | 5913 | 14892 | 21625 | 27951 | 35636 | 44994 | 7822 |
| 08014800 | 3743 | 9425 | 13687 | 17691 | 22555 | 28478 | 4955 |
| 08014600 | 1463 | 3685 | 5351 | 6917 | 8819 | 11135 | 1940 |
| 08013800 | 858 | 2162 | 3139 | 4058 | 5173 | 6532 | 1138 |
| 08031000 | 2954 | 7440 | 10804 | 13965 | 17804 | 22480 | 3913 |
| 08030000 | 2631 | 6625 | 9620 | 12435 | 15854 | 20017 | 3485 |
| 08028700 | 990 | 2493 | 3620 | 4680 | 5966 | 7533 | 1314 |
| 08029500 | 3903 | 9831 | 14275 | 18452 | 23524 | 29702 | 5167 |
| 08028000 | 7967 | 20063 | 29133 | 37656 | 48009 | 60616 | 10530 |
| 08025850 | 858 | 2162 | 3139 | 4058 | 5173 | 6532 | 1138 |
| 08025500 | 4395 | 10815 | 15705 | 20300 | 25881 | 32677 | 5685 |
| 08023000 | 3262 | 8216 | 11930 | 15421 | 19661 | 24824 | 4320 |
| 07354000 | 1294 | 3260 | 4734 | 6119 | 7801 | 9850 | 1716 |
| 07353990 | 1800 | 4533 | 6582 | 8508 | 10847 | 13695 | 2386 |
| 07351700 | 1259 | 3171 | 4604 | 5951 | 7588 | 9580 | 1670 |
| 07351500 | 2559 | 6444 | 9358 | 12096 | 15421 | 19471 | 3390 |
| 07351000 | 2864 | 7212 | 10472 | 13536 | 17258 | 21790 | 3793 |
| 07344450 | 2909 | 7326 | 10639 | 13751 | 17532 | 22136 | 3853 |

# TABLE 11

## REGIONAL AT-SITE FLOOD QUANTILES BY GEV/PWM BASED ON MEAN-AREA CURVE FOR NORTHWEST LOUISIANA

| STATION NO. | FLOOD QUANTILES FOR RETURN PERIOD | | | | | | ESTIM MEAN FLOOD |
|---|---|---|---|---|---|---|---|
| | 2-YR | 10-YR | 25-YR | 50-YR | 100-YR | 200-YR | |
| 07373000 | 2130 | 5878 | 8888 | 11836 | 15548 | 20232 | 2966 |
| 07372500 | 2730 | 7531 | 11388 | 15167 | 19923 | 25924 | 3808 |
| 07372200 | 11051 | 30489 | 46102 | 61397 | 80650 | 104944 | 15598 |
| 07370750 | 2077 | 5732 | 8668 | 11544 | 15164 | 19731 | 2893 |
| 07372110 | 1569 | 4328 | 6545 | 8717 | 11450 | 14899 | 2180 |
| 07372000 | 6586 | 18172 | 27477 | 36593 | 48068 | 62547 | 9255 |
| 07370500 | 4385 | 12100 | 18296 | 24366 | 32006 | 41648 | 6142 |
| 07371500 | 4958 | 13679 | 20684 | 27546 | 36184 | 47083 | 6950 |
| 07366420 | 2981 | 8226 | 12438 | 16565 | 21760 | 28315 | 4163 |
| 07365000 | 4958 | 13679 | 20684 | 27546 | 36184 | 47083 | 6950 |
| 07364870 | 2059 | 5683 | 8593 | 11444 | 15032 | 19561 | 2868 |
| 07365500 | 3635 | 10030 | 15166 | 20198 | 26531 | 34524 | 5084 |
| 07366000 | 5597 | 15444 | 23353 | 31100 | 40852 | 53158 | 7856 |
| 07366200 | 3895 | 10747 | 16250 | 21642 | 28428 | 36991 | 5450 |
| 07364700 | 3282 | 9055 | 13692 | 18234 | 23952 | 31168 | 4586 |
| 07362100 | 5146 | 14197 | 21468 | 28590 | 37555 | 48868 | 7216 |
| 07365800 | 3653 | 10080 | 15241 | 20298 | 26663 | 34694 | 5109 |
| 07352000 | 3411 | 9411 | 14230 | 18951 | 24894 | 32393 | 4768 |
| 07352500 | 5372 | 14826 | 22419 | 29857 | 39219 | 51033 | 7538 |
| 07348700 | 6349 | 17517 | 26487 | 35275 | 46336 | 60294 | 8919 |
| 07349500 | 6050 | 16694 | 25242 | 33617 | 44158 | 57460 | 8497 |
| 07348725 | 1782 | 4918 | 7437 | 9905 | 13011 | 16930 | 2479 |
| 07348800 | 2387 | 6586 | 9958 | 13262 | 17421 | 22669 | 3327 |
| 07353500 | 2059 | 5683 | 8593 | 11444 | 15032 | 19561 | 2753 |

# TABLE 12

## REGIONAL AT-SITE FLOOD QUANTILES BY GEV/PWM BASED ON MEAN-AREA CURVE FOR NORTHEAST LOUISIANA

| STATION NO. | FLOOD QUANTILES FOR RETURN PERIOD | | | | | | ESTIM MEAN FLOOD |
|---|---|---|---|---|---|---|---|
| | 2-YR | 10-YR | 25-YR | 50-YR | 100-YR | 200-YR | |
| 07369500 | 2752 | 4137 | 4668 | 5005 | 5298 | 5553 | 2811 |
| 07370000 | 4435 | 6665 | 7520 | 8063 | 8535 | 8947 | 4530 |
| 07368500 | 1079 | 1623 | 1831 | 1963 | 2077 | 2179 | 1103 |
| 07364500 | 6632 | 9968 | 11248 | 12060 | 12766 | 13382 | 6776 |
| 07364190 | 5502 | 8270 | 9332 | 10005 | 10591 | 11102 | 5621 |

## TABLE 13

MODEL COMPARSION BASED ON SRMSE FOR EACH REGION

| REGION | REGIONAL AVG. SRMSE | | % DIFF. |
|---|---|---|---|
| | GEV/PWM | USGS/REG | |
| SE | 0.468 | 0.536 | + 15 |
| SW | 0.491 | 0.695 | + 42 |
| NW | 0.532 | 0.872 | + 64 |
| NE | 0.132 | 0.563 | + 327 |

## Verification of Results

In order to verify the regional procedure that is being recommended, it was compared to data not used in the development and calibration phases. This was accomplished by using short-term gages not used in the development of the distribution. Five of these gages were selected in each region, except in the northeast where only one additional gage was available. These sites were selected in order to gain maximum coverage of each region where possible. The locations of these gages are shown by the open circles on the regional map in Figure 3, p. 21.

In performing this analysis, these sites were treated as if they were ungaged areas. The mean floods were estimated from the appropriate drainage area plots and used to scale the respective regional quantiles for each test site. The regional at-site quantiles were then compared to original data for each gage record by SRMSE. Each gage used in this phase of the study had between 15 and 20 years of record. Thus, the SRMSE values are based on those number of events in each case.

The results of this analysis are shown in Table 14. The table gives the SRMSE value for each site by the GEV regional method as well as values obtained using an at-site fitting of the LP3 distribution and the USGS equations. The LP3 value is given for comparison considering that the at-site LP3 would be the best possible distributional fit to the observed data. Analysis of the results in the table shows that the average SRMSE value by the regional method was .278 for the southeast region, .483 for the southwest region and .546 for the northwest region. Comparison of these values with those given in Table 13 reveals that the method performed as well or better when compared to the new data as it did when compared to the data that was

# TABLE 14

## VERIFICATION OF REGIONAL GEV MODEL

| REGION | STATION NO. | | SRMSE | | |
|---|---|---|---|---|---|
| | | | REGIONAL GEV/PWM | USGS REGRESSION | AT-SITE LP3 |
| SE | 07375050 | | 0.220 | 0.433 | 0.201 |
| | 07376520 | | 0.230 | 0.623 | 0.140 |
| | 07375463 | | 0.314 | 0.315 | 0.339 |
| | 07377190 | | 0.449 | 0.407 | 0.248 |
| | 02491200 | | 0.176 | 0.307 | 0.169 |
| | | AVG. | 0.278 | 0.417 | 0.219 |
| SW | 08010500 | | 0.435 | - | 0.147 |
| | 08012900 | | 0.578 | 0.824 | 0.277 |
| | 08016700 | | 0.661 | 0.158 | 0.356 |
| | 08022765 | | 0.515 | 0.389 | 0.102 |
| | 08024000 | | 0.225 | 0.530 | 0.267 |
| | | AVG. | 0.483 | 0.475 | 0.230 |
| NW | 07370700 | | 0.402 | 0.520 | 0.339 |
| | 07370600 | | 0.145 | 0.113 | 0.161 |
| | 07365300 | | 0.888 | 1.140 | 0.682 |
| | 07352700 | | 0.638 | 1.291 | 0.367 |
| | 07351980 | | 0.658 | 1.151 | 0.155 |
| | | AVG. | 0.546 | 0.843 | 0.341 |
| NE | 07369640 | | 0.693 | - | 0.121 |

NOTE:

REGIONAL GEV/PWM ... 'Regional GEV/PWM Model' (Input: DA)
USGS REGRESSION ... 'USGS Regression Model' (Input: DA, S, P)
ATSITE LP3 ......... 'LP3 - USWRC Model' (Input: Obs. Flood Data)

used in its derivation. Furthermore, the GEV method was generally superior by a wide margin to the USGS equations and even compared fairly well with the at-site LP3 in two regions. These results suggest that the method can be used confidently throughout the regions delineated in Figure 3, p. 21.

The applications of the results of this study are limited by the range of data that were available for its use. First, the procedure should not be applied outside the physical bounds of the areas where gage data were available. These areas are delineated on Figure 3 and should be strictly adhered to. This particularly eliminates the coastal zones and the Mississippi alluvium (except the northeast region) from applicability. Second, the range of drainage basin sizes available in each region also limit the areas where the procedure can be applied. The drainage areas of each basin used in the study are given in Tables 1-4. Particularly, the method should not be applied to drainage areas smaller than 10 $mi^2$ as our preliminary work clearly showed that these areas respond differently to a storm event than do the larger areas. A sufficient number of these small gages was not available to perform a separate study on them alone.

An example application of the proposed method will be demonstrated for a hypothetical watershed located in the northwestern region. Assume this watershed contains a drainage area of 400 square miles. From Figure 11 we find that the log mean flood for this region is approximately 3.85. Alternatively, using equation 21, we find that: $\log \bar{Q} = 2.836\ (400)^{.052} =$ 3.87. In order to obtain the flood quantiles for this basin, we only need to multiply the dimensionless quantiles for this region given in the table in Figure 11 by the antilog of the mean flood. For instance, the 100-year flood would be found by multiplying $\log^{-1}$ (3.87) times 5.198. The resulting quantile is 38533 cfs for this 400 square mile area. Dimensionless quantiles for recurrence intervals other than those given in the tables shown on Figures 10-13 can be obtained directly from Figures 6-9.

# CONCLUSIONS AND RECOMMENDATIONS

From the results of this study, it is concluded that the generalized extreme value distribution fitted by the method of probability-weighted moments describes the annual flood series of Louisiana streams as well or better than any other feasible method. Because of the ease with which this method can be extended to ungaged sites, it is recommended that LADOTD adopt it for future design flood estimates. Verification analyses revealed that the recommended procedure describes data not used in its development better than the current method employed by LADOTD in the vast majority of cases. Past Monte Carlo studies have shown that this procedure also possesses superior predictive capability in the cases for which flood estimates are required that may be out of the range of the recorded data. Therefore, based upon the results of this analysis as well as previous studies cited in the literature, it is concluded that the recommended procedure results in overall superior flood estimates from both descriptive and predictive points of view. It is emphasized, however, that the procedure should not be applied outside of the range of data that were used in its development and verification. These limitations are given in detail in the discussion section of this report.

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# APPENDIX I

# PROGRAM LISTING

```
$JOB
C
C *************************************************************
C *                                                           *
C *       REGIONAL GEV/PWM FLOOD FREQUENCY MODEL              *
C *              (MODEL DEVELOPMENT VERSION)                  *
C *                                                           *
C *      THIS PROGRAM COMPUTES REGIONAL AT-SITE FLOOD         *
C *    QUANTILES BY GEV/PWM "BASED ON OBSERVED AFS DATA"      *
C *    IN A HYDROLOGIC REGION(SE,SW,NW,NE) OF LOUISIANA       *
C *             ALSO COMPUTES STANDARDIZED RMSE               *
C *                                                           *
C *************************************************************
C
C                        ==============
C                         MAIN PROGRAM
C                        ==============
C
       REAL X(50,120),PM(50,3),RPM(3),REGQ(8),
     +Q(50,120),RMS(50),SRMS(50)
       INTEGER NYEAR(120),NUSG(50),NSITE,N,R,ISREGQ(50,8)
C
       WRITE(12,5)
 5     FORMAT(//,35X,'REGIONAL AT-SITE FLOOD QUANTILES',/)
       WRITE(12,6)
 6     FORMAT(6X,'USG STN #',5X,'RMSE',34X,'RETURN PERIOD (T)',/)
       WRITE(12,7)
 7     FORMAT(34X,'2',8X,'10',8X,'25',8X,'50',7X,'100',7X,'200',
     +7X,'500',7X,'1000',/)
C
C ============== READ DATA ====================
C
C     NSITE = # OF SITES IN THE REGION
C      NUSG = USGS STATION #
C     NYEAR = # OF YEARS OF RECORDS OF AFS
C     X(   ) = OBSERVED MAXIMUM ANNUAL FLOOD PEAK
C
      READ (11,*) NSITE
      DO 10 I=1,NSITE
         READ (11,15) NUSG(I)
 15      FORMAT(37X,I8)
         READ (11,*) NYEAR(I)
         N=NYEAR(I)
         READ (11,*) (X(I,J),J=1,N)
C
C ======= RANK DATA IN ASSCENDING ORDER ========
C
C        X(   ) = OBSERVED/RANKED DATA
C            I = I TH STATION IN THE REGION
C            N = # OF YEARS OF RECORDS OF STATION I
C
         CALL SORT(X,I,N)
C
C ============ COMPUTE AT SITE PWM ============
C
```

```
C      PM(   ) = AT-SITE  PROBABILITY WEIGHTED MOMENTS
C
         CALL PWM(I,N,X,PM)
C
 10   CONTINUE
C
C ==== STANDARDIZE PWM BY INDEXING METHOD ========
C
C     RPM( ) = STANDARDIZED PWMS BY INDEXING
C
      DO 20 R=1,3
         SUM=0.0
         DO 30 I=1,NSITE
            SPM=PM(I,R)/PM(I,1)
            SUM=SUM+SPM
 30      CONTINUE
         RPM(R)=SUM/NSITE
 20   CONTINUE
C
C ===== ESTIMATE REGIONAL GEV PARAMETERS =========
C
C    RALPA = REGIONAL SCALE PARAMETER OF GEV
C    RZETA = REGIONAL LOCATION  PARAMETER OF GEV
C       RK = REGIONAL SHAPE PARAMETER OF GEV
C
      CALL RPARM(RPM,RALPA,RZETA,RK)
C
C == COMPUTE NON-DIMENSIONAL FLOOD QUANTILES =====
C
C    REGQ( ) =  NON-DIMENSIONAL FLOOD QUANTILES
C
      CALL FLOOD(RALPA,RZETA,RK,REGQ)
C
C == CALCULATE REGIONAL AT-SITE FLOOD QUANTILES ==
C
C    ISREGQ( ) =  AT-SITE FLOOD QUANTILES
C
      DO 40 I=1,NSITE
         DO 50 J=1,8
            SREGQ=PM(I,1)*REGQ(J)
            ISREGQ(I,J)=IFIX(SREGQ)
 50      CONTINUE
 40   CONTINUE
C
      DO 60 I=1,NSITE
         N=NYEAR(I)
C
C == COMPUTE & WRITE, AT-SITE ROOT MEAN SQUARE ERROR ==
C
C        SRMS( ) = STD. ROOT MEAN SQUARE ERROR
C
         CALL RMSE(I,N,X,PM,RALPA,RZETA,RK,SRMS)
C
         WRITE (12,70) NUSG(I),SRMS(I),(ISREGQ(I,J),J=1,8)
 70      FORMAT(/,5X,I8,6X,F5.3,2X,8I10)
```

```
  60  CONTINUE
C
C === WRITE REGIONAL, GEV PARAMETERS & AVG. SRMSE ===
C
        WRITE (12,71)
  71    FORMAT(/,15X,'ALPHA',5X,'ZETA',8X,'K')
        WRITE (12,75) RALPA,RZETA,RK
  75    FORMAT (/,10X,3F10.3)
        RSUM = 0.0
        DO 80 I=1,NSITE
        RSUM = RSUM + SRMS(I)
  80    CONTINUE
        ARMSE = RSUM/NSITE
        WRITE (12,85) ARMSE
  85    FORMAT (/,15X,'AVG. SRMSE = ',F10.3)
C
      STOP
      END
C
C                       =============
C                        SUBROUTINES
C                       =============
C
C ========= RANKING DATA IN ASSCENDING ORDER ========
C
      SUBROUTINE SORT(X,I,N)
      INTEGER A1,A2,L,M,N,I
      REAL X(50,120),TEMP
C
  10  IF(N.LE.1) GO TO 100
      L=N-1
  20  DO 90 A1=1,L
         M=A1+1
  30     DO 80 A2=M,N
  40        IF(X(I,A1).LE.X(I,A2)) GO TO 70
            TEMP=X(I,A1)
            X(I,A1)=X(I,A2)
            X(I,A2)=TEMP
  70        CONTINUE
  80     CONTINUE
  90  CONTINUE
 100  CONTINUE
      RETURN
      END
C
C === COMPUTATION OF PROBABILITY WEIGHTED MOMENTS ====
C
      SUBROUTINE PWM(I,N,X,PM)
      REAL X(50,120),PM(50,3),P,R,S
      INTEGER J,L
C
      DO 10 L=1,3
         SUM=0.0
         DO 20 J=1,N
            R=FLOAT(J)
```

```
            S=FLOAT(N)
            P=(R-0.35)/S
            SUM=SUM+P**(L-1)*X(I,J)
 20      CONTINUE
         PM(I,L)=SUM/N
 10   CONTINUE
      RETURN
      END
C
C ========= ESTIMATION OF REGIONAL GEV PARAMETERS =======
C
      SUBROUTINE RPARM(PM,EA,EZ,EK)
      REAL EA,EZ,EK,PM(3),G
C
      C=(2*PM(2)-PM(1))/(3*PM(3)-PM(1))-ALOG(2.)/ALOG(3.)
      EK=7.859*C+2.9554*C**2
      G=GAMMA(1.+EK)
      EA=((2*PM(2)-PM(1))*EK)/(G*(1-2**(-EK)))
      EZ=PM(1)+EA*(G-1)/EK
      RETURN
      END
C
C ========= CALCULATION OF FLOOD QUANTILES =========
C
      SUBROUTINE FLOOD(EA,EZ,EK,FQ)
      REAL EA,EZ,EK,FQ(8),T(8),PNE(8)
C
      T(1)=2.0
      T(2)=10.0
      T(3)=25.0
      T(4)=50.0
      T(5)=100.0
      T(6)=200.0
      T(7)=500.0
      T(8)=1000.0
C
      DO 10 I=1,8
         PNE(I)=(1.-1./T(I))
         IF(EK.EQ.0.0) GO TO 20
         FQ(I)=EZ+EA*(1-(-ALOG(PNE(I)))**EK)/EK
         GO TO 10
 20      FQ(I)=EZ-EA*ALOG(-ALOG(PNE(I)))
 10   CONTINUE
      RETURN
      END
C
C ========= CALCULATION OF ROOT MEAN SQUARE ERROR ===
C
      SUBROUTINE RMSE(I,N,X,PM,EA,EZ,EK,SRMS)
      REAL EA,EZ,EK,PE,X(50,120),PM(50,3),Q(50,120),RMS(50),SRMS(50)
      INTEGER I,J,N
C
      SUMX=0.0
      SUMSQD=0.0
      DO 10 J=1,N
```

```
C         PE=(N+1.-J)/(N+1.)
          PE=(N+1.-J-0.44)/(N+0.12)
          PNE=1.-PE
          IF(EK.EQ.0.0) GO TO 20
          QN=EZ+EA*(1-(-ALOG(PNE))**EK)/EK
          GO TO 30
 20       QN=EZ-EA*ALOG(-ALOG(PNE))
 30       Q(I,J)=PM(I,1)*QN
          DEV=X(I,J)-Q(I,J)
          SQDEV=DEV*DEV
          SUMSQD=SUMSQD+SQDEV
          SUMX=SUMX+X(I,J)
 10    CONTINUE
       RMS(I)=(SUMSQD/N)**0.5
       XMEAN=SUMX/N
       SRMS(I)=RMS(I)/XMEAN
       RETURN
       END
$ENTRY
//GO.FT11F001    DD    DSN='CEEKAN.SELA.DATA',DISP=SHR
//GO.FT12F001    DD    DSN='CEEKAN.SE.OUT',DISP=SHR
$$
//
```

```
$JOB
C
C **********************************************************
C *                                                        *
C *        REGIONAL GEV/PWM FLOOD FREQUENCY MODEL          *
C *             (MODEL APPLICATION VERSION)                *
C *                                                        *
C *     THIS PROGRAM COMPUTES REGIONAL AT-SITE FLOOD       *
C *    QUANTILES BY GEV/PWM "BASED ON MEAN-AREA CURVE"     *
C *   IN A HYDROLOGIC REGION(SE,SW,NW,NE) OF LOUISIANA     *
C *           ALSO COMPUTES STANDARDIZED RMSE              *
C *                                                        *
C **********************************************************
C
C                    ==============
C                     MAIN PROGRAM
C                    ==============
C
      REAL X(50,120),REGQ(8),
     +Q(50,120),RMS(50),SRMS(50),MQ(50),DA(50)
      INTEGER NYEAR(120),NUSG(50),NSITE,N,R,ISREGQ(50,8),REGION
C
      WRITE(12,5)
 5    FORMAT(//,35X,'REGIONAL AT-SITE FLOOD QUANTILES',/)
      WRITE(12,6)
 6    FORMAT(6X,'USG STN #',5X,'RMSE',34X,'RETURN PERIOD (T)',/)
      WRITE(12,7)
 7    FORMAT(34X,'2',8X,'10',8X,'25',8X,'50',7X,'100',7X,'200',
     +7X,'500',7X,'1000',/)
C
C ============== READ DATA ===================
C
C     REGION = (SE=1,SW=2,NW=3,NE=4)
C      NSITE = # OF SITES IN THE REGION
C         DA = DRAINAGE AREA IN SQ.MILES
C       NUSG = USGS STATION #
C      NYEAR = # OF YEARS OF RECORDS OF AFS
C       X( ) = OBSERVED MAXIMUM ANNUAL FLOOD
C
      READ (11,*) REGION
      READ (11,*) NSITE
      READ (11,*) (DA(I),I=1,NSITE)
      DO 10 I=1,NSITE
         READ (11,15) NUSG(I)
 15      FORMAT(37X,I8)
         READ (11,*) NYEAR(I)
         N=NYEAR(I)
         READ (11,*) (X(I,J),J=1,N)
C
C ======= RANK DATA IN ASSCENDING ORDER ========
C
C      X( ) = OBSERVED/RANKED DATA
C         I = I TH STATION IN THE REGION
C         N = # OF YEARS OF RECORDS OF STATION I
C
```

```
            CALL SORT(X,I,N)
   10    CONTINUE
C
C ===== COMPUTE REGIONAL AT-SITE MEAN FLOOD =====
C
C          MQ = REGIONAL AT-SITE MEAN FLOOD IN CFS
C       RALPA = REGIONAL SCALE PARAMETER
C       RZETA = REGIONAL LOCATION PARAMETER
C          RK = REGIONAL SHAPE PARAMETER
C
        CALL AREAQ(REGION,NSITE,DA,MQ,RALPA,RZETA,RK)
C
C ==== COMPUTE NON-DIMENSIONAL FLOOD QUANTILES ===
C
C       ISREGQ( ) = AT-SITE FLOOD QUANTILE
C
        CALL FLOOD(RALPA,RZETA,RK,REGQ)
C
C == CALCULATE REGIONAL AT-SITE FLOOD QUANTILES ==
C
        DO 40 I=1,NSITE
           DO 50 J=1,8
              SREGQ=MQ(I)*REGQ(J)
              ISREGQ(I,J)=IFIX(SREGQ)
   50      CONTINUE
   40   CONTINUE
C
        DO 60 I=1,NSITE
           N=NYEAR(I)
C
C ==== COMPUTE & WRITE, AT-SITE ROOT MEAN SQUARE ERROR =====
C
C          SRMS( ) = STD. ROOT MEAN SQUARE ERROR
C
           CALL RMSE(I,N,X,MQ,RALPA,RZETA,RK,RMS,SRMS)
C
           WRITE (12,70) NUSG(I),SRMS(I),(ISREGQ(I,J),J=1,8)
   70      FORMAT(/,5X,I8,6X,F5.3,2X,8I10)
   60   CONTINUE
C
C ===== WRITE REGIONAL, GEV PARAMETERS & AVG. SRMSE ======
C
        WRITE (12,71)
   71   FORMAT(/,15X,'ALPHA',5X,'ZETA',8X,'K')
        WRITE (12,75) RALPA,RZETA,RK
   75   FORMAT (/,10X,3F10.3)
        RSUM = 0.0
        DO 80 I=1,NSITE
        RSUM = RSUM + SRMS(I)
   80   CONTINUE
        ARMSE = RSUM/NSITE
        WRITE (12,85) ARMSE
   85   FORMAT (/,15X,'AVG.SRMSE = ',F10.3)
C
      STOP
```

```
      END
C
C                        =============
C                         SUBROUTINES
C                        =============
C
C ========= RANKING DATA IN ASSCENDING ORDER ========
C
      SUBROUTINE SORT(X,I,N)
      INTEGER A1,A2,L,M,N,I
      REAL X(50,120),TEMP
C
 10   IF(N.LE.1) GO TO 100
      L=N-1
 20   DO 90 A1=1,L
         M=A1+1
 30      DO 80 A2=M,N
 40         IF(X(I,A1).LE.X(I,A2)) GO TO 70
            TEMP=X(I,A1)
            X(I,A1)=X(I,A2)
            X(I,A2)=TEMP
 70         CONTINUE
 80      CONTINUE
 90   CONTINUE
 100  CONTINUE
      RETURN
      END
C
C ===== MEAN Q FROM REGIONAL DA VS MEANQ CURVE ====
C
      SUBROUTINE AREAQ(REGION,NSITE,DA,MQ,EA,EZ,EK)
      REAL MQ(50),DA(50)
      INTEGER REGION
C
      DO 10 I=1,NSITE
       IF (REGION.EQ.1) THEN
          MQ(I)=10**(2.69554*(DA(I)**0.07206))
          EA=0.468
          EZ=0.635
          EK=-0.172
       ELSEIF (REGION.EQ.2) THEN
          MQ(I)=10**(2.56086*(DA(I)**0.07650))
          EA=0.410
          EZ=0.603
          EK=-0.286
       ELSEIF (REGION.EQ.3) THEN
          MQ(I)=10**(2.83601*(DA(I)**0.051714))
          EA=0.425
          EZ=0.544
          EK=-0.338
       ELSE
          MQ(I)=10**(2.40601*(DA(I)**0.0628088))
          EA=0.333
          EZ=0.861
          EK=0.189
```

```
        ENDIF
 10    CONTINUE
       RETURN
       END
C
C ========= CALCULATION OF FLOOD QUANTILES =========
C
       SUBROUTINE FLOOD(EA,EZ,EK,FQ)
       REAL EA,EZ,EK,FQ(8),T(8),PNE(8)
C
       T(1)=2.0
       T(2)=10.0
       T(3)=25.0
       T(4)=50.0
       T(5)=100.0
       T(6)=200.0
       T(7)=500.0
       T(8)=1000.0
C
       DO 10 I=1,8
          PNE(I)=(1.-1./T(I))
          IF(EK.EQ.0.0) GO TO 20
          FQ(I)=EZ+EA*(1-(-ALOG(PNE(I)))**EK)/EK
          GO TO 10
 20       FQ(I)=EZ-EA*ALOG(-ALOG(PNE(I)))
 10    CONTINUE
       RETURN
       END
C
C ========= CALCULATION OF ROOT MEAN SQUARE ERROR =======
C
       SUBROUTINE RMSE(I,N,X,MQ,EA,EZ,EK,RMS,SRMS)
       REAL EA,EZ,EK,PE,X(50,120),MQ(50),Q(50,120),RMS(50),SRMS(50)
       INTEGER I,J,N
C
       SUMX=0.0
       SUMSQD=0.0
       DO 10 J=1,N
C         PE=(N+1.-J)/(N+1.)
          PE=(N+1.-J-0.44)/(N+0.12)
          PNE=1.-PE
          IF(EK.EQ.0.0) GO TO 20
          QN=EZ+EA*(1-(-ALOG(PNE))**EK)/EK
          GO TO 30
 20    HGJQN=EZ-EA*ALOG(-ALOG(PNE))
 30       Q(I,J)=MQ(I)*QN
          DEV=X(I,J)-Q(I,J)
          SQDEV=DEV*DEV
          SUMSQD=SUMSQD+SQDEV
          SUMX=SUMX+X(I,J)
 10    CONTINUE
       RMS(I)=(SUMSQD/N)**0.5
       XMEAN=SUMX/N
       SRMS(I)=RMS(I)/MQ(I)
       RETURN
```

```
      END
$ENTRY
//GO.FT11F001     DD     DSN='CEEKAN.SE.APP',DISP=SHR
//GO.FT12F001     DD     DSN='CEEKAN.SE.OUT',DISP=SHR
$$
//
```