APPLICATION OF A RAINFALL-RUNOFF MODEL IN ESTIMATING FLOOD PEAKS FOR SELECTED SMALL NATURAL DRAINAGE BASINS IN TEXAS

UNITED STATES DEPARTMENT OF THE INTERIOR

Geological Survey

Prepared in cooperation with the State Department of Highways and Public Transportation and the Department of Transportation, Federal Highway Administration

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GEOLOGICAL SURVEY

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ABSTRACT

A parametric rainfall-runoff simulation model was used to synthesize long-term records of annual peak discharges for small natural drainage basins in Texas. Optimum model-parameter values were determined for each of the 40 basins studied by using short-term rainfall, evaporation, and discharge data. The calibrated model was used in conjunction with long-term records of rainfall and evaporation to synthesize a record of annual peaks for each site. Because the frequency curves of the simulated peaks had flatter slopes than those of the observed peaks, the synthetic frequency curves were adjusted for the loss of variance inherent in the modeling process.

INTRODUCTION

The demand for flood-frequency information on small drainage areas has greatly increased in recent years because of the design needs for expanding and improving highway systems and because of the growing necessity for the regulation of flood-prone lands. Long-term records of flood-peak discharges for large drainage basins in Texas are readily available, but such information is notably lacking for small drainage basins. In this study, a rainfall-runoff model developed by the U.S. Geological Survey was used in conjunction with long-term rainfall and evaporation data to improve flood-frequency estimates for 40 small natural drainage basins in Texas. These flood-frequency characteristics were included with those obtained from long-term records in the analyses presented in a report by Schroeder and Massey (1977) to define flood-frequency relations for Texas streams.

The purpose of this report is to document the methods used in defining the flood-frequency characteristics for 40 small natural drainage basins in Texas. A brief description of the rainfall-runoff model is given, together with a discussion of the methods used in data selection and processing, model calibrations, and model simulations of annual peak-discharge records.

Acknowledgments

This report was prepared by the U.S. Geological Survey in cooperation with the Texas State Department of Highways and Public Transportation. Much of the data on small streams were collected by the Geological Survey through a special project in cooperation with the Texas State Department of Highways and Public Transportation and the Federal Highway Administration. The opinions, findings, and conclusions expressed in this report, however, are not necessarily those of the Federal Highway Administration.

Metric Conversions

The English units used in this report may be converted to metric units by the following factors:

From		Multiply	To obtain	
Unit	Abbreviation	by	Unit	Abbreviation
inches	--	25.4	millimeters	mm
miles	--	1.609	kilometers	km
square miles	--	2.590	square kilometers	km^2

RELATED STUDIES IN TEXAS

In a study to determine the effects of urbanization on flood characteristics of streams in the Dallas, Texas, metropolitan area, Dempster (1974) used a version of the U.S. Geological Survey rainfall-runoff model to synthesize 57 years of annual peak discharges for 14 drainage basins that ranged in area from 1.84 to 29.4 square miles.

Johnson and Sayre (1973) developed a relationship between rainfall and discharge for each of 26 small drainage basins that ranged in area from 0.5 to 88.4 square miles in the Houston, Texas, metropolitan area. These relationships were used with a 60-year rainfall record for the National Weather Service station in Houston to synthesize a 60-year record of annual peaks for each site. These data were then used to develop flood-frequency relations in a study to determine the effects of urbanization on floods in the Houston, Texas, metropolitan area.

MODEL DESCRIPTION

The rainfall-runoff model used in this study was developed by Dawdy, Lichty, and Bergmann (1972) specifically for the purpose of modeling flood hydrographs for small watersheds. The model was conceived as an alternative to the collection of long-term records to obtain reliable flood-frequency estimates for small drainage basins. The records synthesized by the model are based on bulk-parameter approximations of the physical laws governing the antecedent soil-moisture, infiltration, and surface-runoff components of the hydrologic cycle. The only input required for an acceptable level of accuracy is rainfall, discharge, and evaporation data.

The antecedent soil-moisture accounting component accepts daily-rainfall and daily-evaporation values as input and maintains a continuous assessment of soil-moisture conditions. The changes in moisture storage are determined on a daily basis during nonstorm periods and on a unit-time basis during storm periods. The moisture-storage component is an important facet of the model because the rate of infiltration at the beginning of a storm is highly dependent upon antecedent soil-moisture conditions.

The infiltration component is considered to be the critical part of the model. This component accepts the output from the soil-moisture accounting component along with unit-rainfall data and determines the rainfall excess after abstractions for infiltration. It is based on an equation described by Phillip (1954) in which infiltration rates are computed as a function of soil moisture and rainfall intensity.

The surface-runoff component is based on a modification of the Clark (1945) form of the unit hydrograph. The rainfall excess, as determined in the infiltration component, is converted into a translation hydrograph for the basin. Attenuation of the translation hydrograph is achieved by routing through linear storage by use of a storage constant.

The 10 model parameters are listed in table 1, which also describes their application in the modeling process. Seven of these parameters are used in computing rainfall excess and the other three are used in routing.

Calibration of the model to a specific site involves trial and error adjustments of the parameter values to improve the comparison between observed input and simulated output. The comparison is made by testing for the minimum value of an objective function. The user must specify the initial magnitudes and the upper and lower limits for all parameters.

The calibration is carried out in three separate phases, each optimizing on a different objective function. Phase one involves the soil-moisture and infiltration components of the model. The objective function for this phase is the sum of the squared deviations between observed and simulated-runoff volumes. Parameters pertaining to the first two components of the model are optimized in phase one to lower the objective function, which achieves a better correlation between observed and computed runoff volumes.

In phase two of the calibration, the surface-runoff parameters are optimized, and volume adjusted peak flows are used in the objective function. The third phase of the calibration procedure optimizes the soil-moisture and infiltration parameters by using peak flows in the objective function. Model calibration is achieved when the final parameter values are determined in phase three. A long-term record of rainfall and evaporation may then be used with the calibrated model to synthesize a flood record.

Both the calibration and simulation processes of the model require storm rainfall data from a single rain gage. Uniform distribution of rainfall over the basin is assumed. The model also assumes that the long-term rainfall and evaporation records used are applicable to the drainage basin.

DATA COLLECTION AND PROCESSING

Daily values of concurrent rainfall and evaporation data are required for the entire period used in calibrating the rainfall-runoff model to a specific site. Storm rainfall and discharge data, defined at unit time intervals (usually 5, 15, or 30 minutes), are required for each storm used in the calibration.

Rainfall and Runoff

A careful screening of the data available on small natural drainage areas in Texas yielded 40 sites (table 2) with sufficient data for calibration. The basins, which range in size from 0.36 to 48.6 square miles are located mostly in the central and eastern parts of the State (fig. 1).

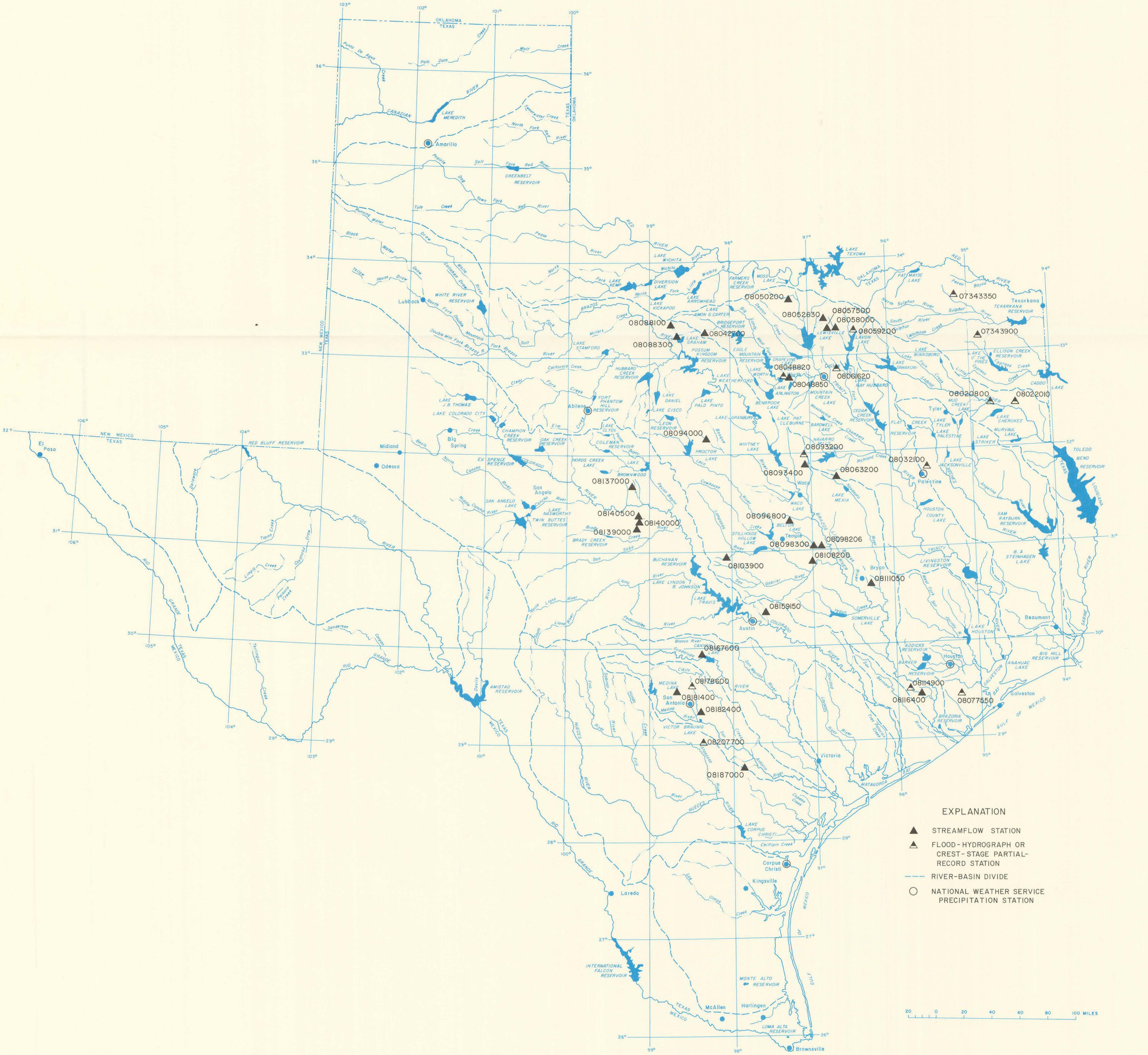

FIGURE 1.-Location of calibrated sites and National Weather Service precipitation stations

Table 1.--Model parameters and their applications in the modeling process

Parameter	Units	Definition and application
		Antecedent-moisture component
EVC	--	Coefficient to convert pan evaporation to potential-evapotranspiration values.
RR	--	Proportion of daily rainfall that infiltrates the soil.
BMSM	inches	Soil-moisture storage volume at field capacity.
DRN	--	Drainage parameter for redistribution of soil moisture (fraction of KSAT).
		Infiltration component
PSP	inches	Product of moisture deficit and suction at the wetted front for soil moisture at field capacity.
KSAT	inches/hour	The minimum (saturated) hydraulic conductivity used to determine infiltration rates.
RGF	--	Ratio of the product of moisture deficit and suction at the wetted front for soil moisture at wilting point to that at field capacity.
		Surface-runoff component (routing)
KSW	hours	Time characteristic for linear reservoir routing.
TC	minutes	Length of the base of the triangular translation hydrograph.
TP/TC	--	Ratio of time to peak to base length of the triangular translation hydrograph.

Table 2.--Stations for which the model was calibrated

Station number	Station name
07343350	Dial Branch near Bagwell, Tex.
07343900	Buck Creek near Cookville, Tex.
08020800	Grace Creek tributary at Longview, Tex.
08022010	Redmon Branch near Hallsville, Tex.
08032100	Hurricane Creek tributary near Palestine, Tex.
08042700	North Creek near Jacksboro, Tex.
08048820	Little Fossil Creek at Interstate Highway 820, Fort Worth, Tex.
08048850	Little Fossil Creek at Mesquite Street, Fort Worth, Tex.
08050200	Elm Fork Trinity River subwatershed No. 6-0 near Muenster, Tex.
08052630	Little Elm Creek subwatershed No. 10 near Gunter, Tex.
08057500	Honey Creek subwatershed No. 11 near McKinney, Tex.
08058000	Honey Creek subwatershed No. 12 near McKinney, Tex.
08059200	Arls Branch near Westminster, Tex.
08061620	Duck Creek at Buckingham Road, Garland, Tex.
08063200	Pin Oak Creek near Hubbard, Tex.
08077550	Cowart Creek near Friendswood, Tex.
08088100	Salt Creek at Olney, Tex.
08088300	Briar Creek at Graham, Tex.
08093200	Bond Branch near Hillsboro, Tex.
08093400	Cobb Creek near Abbot, Tex.
08094000	Green Creek subwatershed No. 1 near Dublin, Tex.
08096800	Cow Bayou subwatershed No. 4 near Bruceville, Tex.
08098206	Brushy Creek Watershed D near Riesel, Tex.
08098300	Little Pond Creek at Burlington, Tex.
08103900	South Fork Rocky Creek near Briggs, Tex.
08108200	North Elm Creek near Cameron, Tex.
08111050	Hudson Creek near Bryan, Tex.
08114900	Seabourne Creek near Rosenberg, Tex.
08116400	Dry Creek near Rosenberg, Tex.
08137000	Mukewater Creek subwatershed No. 9 near Trickam, Tex.
08139000	Deep Creek subwatershed No. 3 near Placid, Tex.

Table 2.--Stations for which the model was calibrated--Continued

Station number	Station name
08140000	Deep Creek subwatershed No. 8 near Mercury, Tex.
08140500	Dry Prong Deep Creek near Mercury, Tex.
08159150	Wilbarger Creek near Pflugerville, Tex.
08167600	Rebecca Creek near Spring Branch, Tex.
08178600	Panther Springs Creek at Farm Road 2696 near San Antonio, Tex.
08181400	Helotes Creek at Helotes, Tex.
08182400	Calaveras Creek subwatershed No. 6 near Elmendorf, Tex.
08187000	Escondido Creek subwatershed No. 1 near Kenedy, Tex.
08207700	Lucas Creek near Pleasanton, Tex.

These basins, which have an average record length of 12.7 years, compose 40 percent of the basins with drainage areas less than 50 square miles that were analyzed in a related report (Schroeder and Massey, 1977) to define the flood-frequency characteristics of Texas streams.

Stage and rainfall records at 13 of these sites were recorded by SR (stage-rainfall) recorders on a circular graphic chart. Conversion of the storm data from these charts to a computer readable form was time consuming and expensive. In addition, daily rainfall amounts could not be taken from these charts with any degree of accuracy. Daily rainfall to use in model calibrations for these sites was taken from the nearest National Weather Service gage (usually less than 10 miles away).

At the remaining 27 sites, stage records were recorded on strip charts and(or) ADR (automatic-digital recorder) punched tapes. Daily rainfall for each of these sites was taken from a recording rain gage located in each basin. Where more than one rain gage was located in a basin, the one considered to be most representative of the basin was selected to fulfill the model requirement of a single rain-gage input.

In the selection of storms to be used in calibrating the model to each site, several criteria were involved. A basic assumption of the model is that the rainfall recorded at a single gage is representative of that occurring throughout the basin. Storms producing the highest peak discharges in small drainage basins in Texas are typically thunderstorms of high intensity and short duration. These storms are often very localized. For each storm used with the model, rainfall distribution over the basin was checked for uniformity. Where sufficient data were available, storms were selected to sample a range of storm types, antecedent conditions, and peak-discharge magnitudes.

Because the model calibrates to direct runoff only, a separation of base flow from direct storm runoff is required for all events. For the basins used in this study, base flows composed only a small part of the total flow and hydrograph separation was fairly simple. Storms that produced peak discharges that were very low in relation to base flow were not used in the study.

Evaporation

The network of pan-evaporation stations in Texas is quite sparse, and the records are notably incomplete. The Texas Water Rights Commission has determined, by a "Climatic Index Method" (McDaniels, 1960), monthly lake-evaporation values for each 1-degree quadrangle in the State for 1903-74. This climatic-index evaporation value is a number expressing a relationship of air temperature, wind movement, dewpoint temperature, and solar radiation. The method is believed to yield the most consistent and reliable estimates of lake evaporation available for Texas.

Evaporation records for 12 of the quadrangles were selected for use in this study. The monthly values for each of the records were converted to daily amounts and used in both the calibration and simulation processes.

These daily evaporation records, along with the concurrent records of daily rainfall, storm rainfall, and discharge data were stored on a computer accessible magnetic disk to facilitate retrieval of the large quantities of data involved.

MODEL CALIBRATIONS

Initial parameter values for the antecedent-moisture and infiltration components were estimated for each basin on the basis of geology, soil types, forest cover, and land use. Upper and lower limits were placed on the values to control the range in which they could vary during calibration.

The hydrographs of observed discharge from each basin were used to obtain estimates of the routing parameters. KSW (Carrigan, 1973, equation 15) was given an initial value equal to the average time in hours from the time of peak discharge to the time on the recession limb when the discharge had dropped 63 percent below that of the peak. In general, the hydrographs of the larger storms showed more consistent recession rates, and the routing parameters were weighted toward these storms. The resulting values tend to sacrifice simulation accuracy of the small storms in order to better estimate the larger ones.

With basin lag defined as the time in hours from centroid of rainfall to centroid of runoff (Chow, 1964) the relation

$$\text{BASIN LAG} = \text{KSW} + \tfrac{1}{2}\,\text{TC}$$

was used to solve for an estimate of TC from observed data. The value TP was estimated as the time in minutes from start of storm runoff to peak.

Because initial values for the routing parameters were estimated from observed data, these values were severely constrained during optimization to prevent excessive distortion. Although TP/TC was optimized for the first few sites calibrated, it was found to be somewhat insensitive and was held at 0.50 for later calibrations.

In the first calibration run for each basin, all storm data were used to obtain phase one and phase two computations along with computer plots of observed and simulated discharge hydrographs. The first-run results were used as an aid in a screening process to locate and remove storm data unsuitable for further computations. This screening process was essential to insure that the final parameter values were based on accurate data. Storm rainfall was compared with runoff for each event, and the discharge hydrographs were scanned for shape characteristics not explained by rainfall. Storms having large data errors, as well as those for which the observed rainfall was obviously not representative of basin rainfall, were not used in subsequent calibrations. The hydrograph plots from the initial calibrations were used as aids in estimating base flows and in adjusting the starting and ending times for storms. The optimization of parameter values was then repeated on the reduced set of storms.

Interaction was particularly noticeable in the phase one optimization of the soil-moisture and infiltration parameters. Large variations in some parameter values occurred between basins having similar physical characteristics. It was apparent at times that some parameters were deviating from their true values to minimize the differences between observed and simulated volumes as specified in the objective function. This parameter interaction prevented attaining positive results in relating the derived parameter values to measurable physical characteristics in the basins modeled. Therefore, regionalization of model-parameter values could not be accomplished with confidence.

A final set of parameter values was determined for each site modeled by a phase three computation. The average error of simulated peak discharges was 31 percent. No bias was evident from the final hydrograph plots of observed and simulated discharges. The final parameter values for the 40 basins modeled are given in table 3.

MODEL SYNTHESIS

Data Processing

Model synthesis requires long-term records of daily rainfall for non-storm periods and unit rainfall for storm periods. These data were obtained from the National Weather Service for eight triple-register stations in Texas. In addition, rainfall data for the National Weather Service station at Shreveport, Louisiana, were available. Rainfall stations and the periods for which data were used are as follows:

National Weather Service Station	Period
Abilene, Tex.	1912-74
Amarillo, Tex.	1913-74
Austin, Tex.	1926-74
Corpus Christi, Tex.	1912-74
Dallas, Tex.	1914-72
Houston, Tex.	1914-74
Palestine, Tex.	1912-74
San Antonio, Tex.	1912-74
Shreveport, La.	1912-72

Table 3.--Summary of model parameters

Station no.	Drainage area (square miles)	No. storms used	PSP (inches)	KSAT (inches/ hour)	DRN	RGF (inches)	BMSM (inches)	EVC	RR	KSW (hours)	TC (minutes)	TP/TC
07343350	1.00	9	0.64	0.02	0.20	10.0	9.84	0.77	0.95	0.68	47.2	0.73
07343900	.78	7	2.71	.10	.92	9.46	7.10	.94	.75	.82	46.7	.50
08020800	5.05	9	3.77	.10	.99	7.03	2.63	.74	.96	1.22	108	.50
08022010	.46	9	2.85	.11	.36	8.12	5.12	.95	.51	.90	108	.27
08032100	.39	7	3.92	.14	.49	8.69	2.76	1.00	.46	.71	43.2	.86
08042700	21.6	21	4.64	.05	.87	21.6	3.93	.52	.94	2.00	300	.95
08048820	5.64	10	1.95	.04	.85	22.8	4.46	.50	.99	4.20	197	.39
08048850	12.3	12	2.11	.05	.56	25.2	4.85	.52	.98	2.78	302	.63
08050200	.77	13	2.55	.05	.76	9.84	1.40	.77	.76	.76	41.0	.50
08052630	2.10	10	1.48	.08	.43	8.36	1.16	.99	.71	.69	52.2	.80
08057500	2.14	22	2.82	.06	.08	24.9	5.66	.68	.98	.69	60.3	.66
08058000	1.26	22	4.57	.02	.01	48.6	4.46	.56	.90	.41	65.8	.61
08059200	.52	7	2.55	.09	.49	13.3	5.76	.82	.94	.40	62.1	.50
08061620	8.05	14	2.20	.06	.61	14.5	9.45	.71	1.00	1.80	110	.50
08063200	17.6	9	1.30	.08	.23	16.7	5.41	.51	.93	2.20	558	.50
08077550	18.0	8	1.99	.07	.55	7.44	3.90	.60	.95	20.8	692	.31
08088100	9.6	10	3.33	.10	.41	7.60	4.02	.75	.86	4.72	351	.72
08088300	19.7	8	3.53	.14	.47	15.9	1.66	.51	.96	7.60	528	.67
08093200	.36	9	1.86	.08	.40	19.1	3.11	.49	.99	.61	25.0	.26
08093400	11.7	17	2.92	.04	.72	11.4	4.82	.79	.97	2.38	146	.37
08094000	3.34	12	3.64	.08	.80	17.6	4.12	.65	.99	1.10	100	.50
08096800	5.25	11	3.50	.18	.61	20.6	7.06	.68	.93	.68	31.5	.50
08098206	1.73	13	1.74	.04	.38	20.7	4.42	.74	.98	1.16	98.5	.50
08098300	22.2	11	1.54	.03	1.00	15.8	1.85	.72	.90	4.27	475	.50
08103900	34.2	12	2.87	.09	.66	11.5	5.38	.87	.97	1.00	122	.63
08108200	48.6	16	.89	.05	.86	9.72	2.01	.65	.89	4.83	517	.50
08111050	1.94	15	1.81	.06	.55	18.8	3.15	.70	1.00	2.84	125	.65
08114900	5.70	9	.98	.05	.26	10.1	1.66	.55	.98	9.70	385	.50
08116400	8.53	14	1.60	.05	.99	10.9	2.28	.63	.98	7.42	528	.75
08137000	4.02	17	2.84	.08	.80	10.5	1.73	.62	.99	1.50	136	.30
08139000	3.42	18	3.70	.10	.99	12.6	2.02	.50	.99	.90	49.5	.80
08140000	5.40	10	5.06	.12	.86	14.7	1.85	.42	1.00	1.11	48.4	.85
08140500	2.90	12	2.04	.08	.95	20.4	.46	.63	1.00	1.10	140	.50
08159150	4.61	12	3.29	.08	.23	9.04	3.36	.70	.96	1.33	77.1	.50
08167600	10.9	10	3.93	.06	.38	14.9	14.0	.76	.99	.68	54.0	.60
08178600	9.54	8	3.48	.12	.97	14.2	5.82	.99	.73	.60	66.0	.80
08181400	15.0	7	7.14	.10	.68	37.7	5.20	.78	.96	1.38	148	.50
08182400	7.01	11	3.02	.05	.99	26.3	2.71	.73	.86	1.60	135	.50
08187000	3.29	10	5.10	.10	.68	3.23	1.05	.86	.99	.78	78.0	.60
08207700	32.8	7	11.1	.08	.60	12.4	1.04	.80	1.00	4.65	351	.49

The daily rainfall records for the stations listed are complete for the periods shown. The unit or storm-rainfall records contain the two-to-five largest storms to occur each year. The criteria for selecting the storms used in the model simulations were based on an analysis of the daily rainfall records. All events that could have produced the annual maximum discharge at the gaged sites were selected. Rainfall for these storms was tabulated in 5-minute increments. The evaporation records used in the simulations were the same as those used in the calibrations.

Peak-Discharge Simulations

Final parameter values for each site, together with drainage-area and evaporation data, were used with the appropriate long-term rainfall records to generate a series of annual peak discharges for each of the calibrated sites (table 4).

In selecting the long-term rain gage to use with each site, two choices were available. One choice was to use the three or four nearest rain gages to generate several sets of annual peak discharges for each site. Each set of annual peaks could then be used to compute a log-Pearson frequency curve, with some method of weighting used to determine an average or composite frequency curve for each site.

The second choice was to select a single long-term rain gage to use with each site and to synthesize a single set of annual peaks and compute a single flood-frequency curve for each site. The second choice was generally used. For each site the long-term rain gage considered to be most representative of the basin rainfall was chosen. At two sites, however, no single rain gage was considered to be representative of rainfall in the basin, and two rain gages were used to generate two series of annual peaks for each site.

DEFINING SYNTHETIC FLOOD FREQUENCIES

The flood-frequency curve for each of the modeled sites was defined by mathematically fitting a log-Pearson type III distribution to the logarithms of each series of synthesized annual peak discharges, following the guidelines recommended by the U.S. Water Resources Council (1976). For those sites in which two flood-frequency curves were computed, an average of the two was used.

For comparison, a log-Pearson frequency curve was computed from the observed flood-peak record for each of the modeled sites. Frequency curves of the synthesized records invariably exhibited less variance (flatter slopes) than did those of the observed records. Part of this trend is undoubtedly due to the long-term rainfall data used in the peak-discharge simulations. An examination of short-term rainfall records from both the

Geological Survey and National Weather Service gages in Texas show many storms having more rainfall and greater intensities than have been recorded at any of the long-term stations used in this study. These long-term rainfall stations have recorded so few extreme storms that it might be questioned if this phenomenon can be attributed to the time-sampling error inherent in hydrologic data.

Another cause for the difference in variance between the simulated and observed peak discharges is the smoothing effect of the model in the calibration process. In a study of this phenomenon, Kirby (1975) found that a substantial loss of variance is an unavoidable consequence of the modeling process. Kirby's findings are based on the idea that a watershed and a deterministic rainfall-runoff model have essentially the same structure. They differ only in that the watershed is subject to many secondary inputs that are not represented in the model. It is these secondary inputs that are responsible for the discrepancies between observed and modeled peaks. They represent a part of the variance in the observed data that cannot be reproduced by the model.

The variance of the model output, then, is necessarily smaller than that of the variable being modeled. Kirby (oral commun., 1975) proposed a method for adjusting the synthetic-frequency curves to account for this loss of variance. This adjustment is applied to the standard deviation of the log-Pearson distribution of simulated annual peak discharges as follows:

$$X^1 = \frac{X}{Y}$$

where X^1 = standard deviation adjusted for loss of variance,
X = unadjusted standard deviation, and
Y = correlation coefficient of observed and simulated peak discharge from the final (phase three) calibration.

This adjustment is included in an experimental version of the Geological Survey's log-Pearson program. The adjustment was applied to the synthetic frequency curves of all sites modeled in this study, and an example of the application is shown on figure 2.

SUMMARY AND CONCLUSIONS

This report illustrates that a rainfall-runoff model can be an effective tool in extending observed streamflow data in time. Such a model was used in conjunction with long-term rainfall and evaporation data to improve flood-frequency estimates for 40 small natural drainage basins.

Short periods of concurrent rainfall and discharge data were used to calibrate the model to each site. The average error of peak discharge simulation in the calibrations was about 31 percent. Long-term records of rainfall and evaporation were then put into the model to generate a long-term record of annual peak discharges for each site.

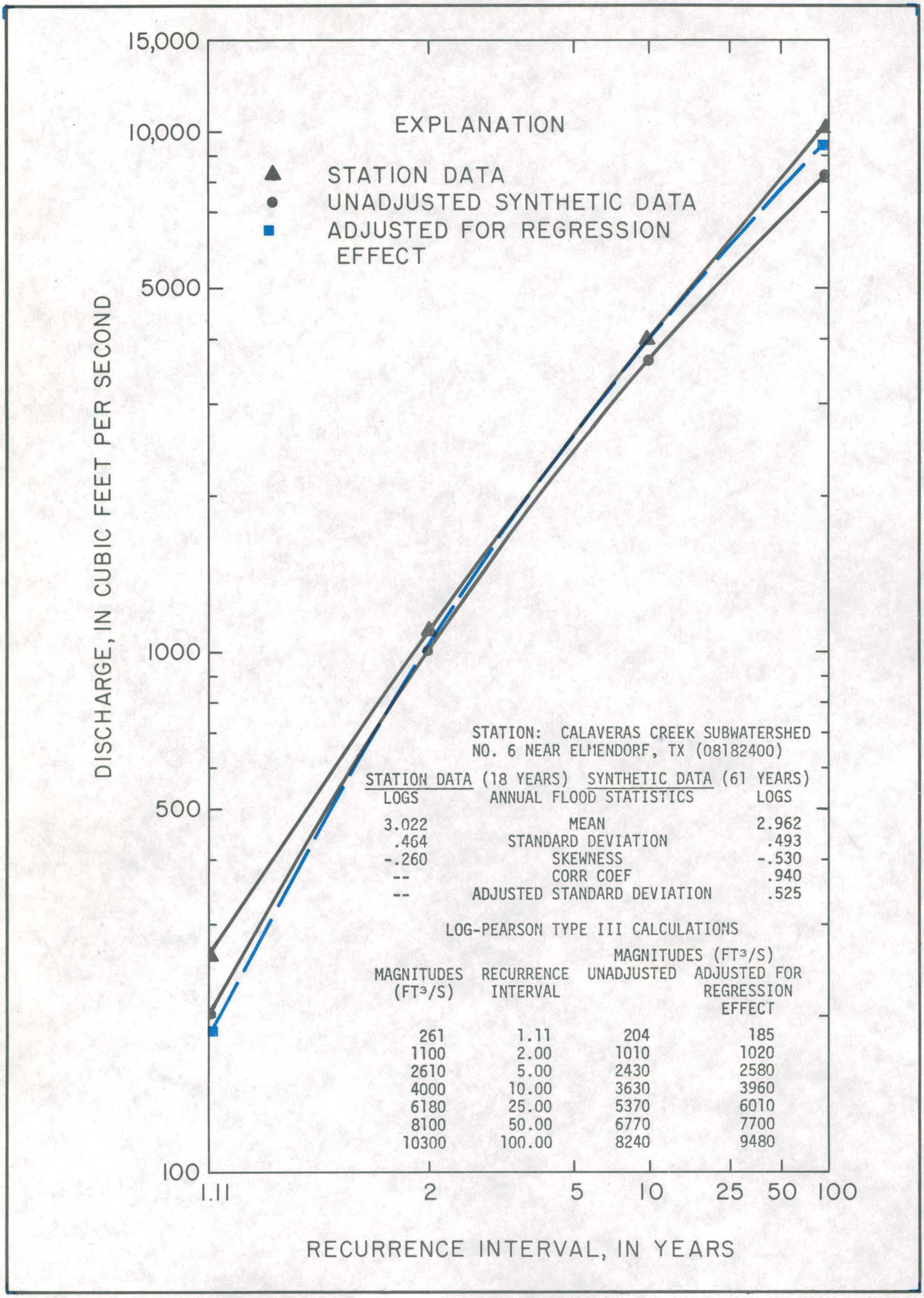

FIGURE 2.-Log-Pearson frequency curve for a modeled site

Frequency curves computed from the synthesized data exhibited less variance (flatter slopes) than did those computed from observed data for the modeled sites. Much of this loss of variance was attributed to the smoothing effect of the model in the calibration process. An adjustment was applied to the frequency curves of the synthetic data to account for this loss of variance.

The rainfall-runoff model was used in this study to extend the record of annual peak discharges for each basin modeled. These extended records of annual peaks add confidence to our estimates of flood-frequency characteristics for these sites. A second use of the model is to relate the derived parameter values to measurable physical characteristics in the basins simulated. The derived relations can then be used to estimate parameter values for ungaged sites. In this study, however, actual values were significantly affected by parameter interaction. The physical equivalence of the model was to some extent lost in the fitting process. Regionalization of model-parameter values could not be accomplished with confidence.

The modeled basins range in size from 0.36 to 48.6 square miles and have an average record length of 12.7 years. They compose 40 percent of the basins with drainage areas less than 50 square miles that were analyzed in a related report (Schroeder and Massey, 1977) to define the flood-frequency characteristics of Texas streams.

SELECTED REFERENCES

Carrigan, P. H., Jr., 1973, Calibration of U.S. Geological Survey rainfall/runoff model for peak flow synthesis--natural basins: U.S. Dept. Commerce, Natl. Tech. Inf. Service, PB-226 217, 115 p.

Chow, V. T., 1964, Runoff in Handbook of applied hydrology: New York, McGraw-Hill Book Co., Inc., p. 9.

Clark, C. O., 1945, Storage and the unit hydrograph: Am. Soc. Civil Engineers Trans., v. 110, p. 1419-1488.

Conover, W. J., 1971, Practical nonparametric statistics: New York, John Wiley, p. 314-316.

Dawdy, D. E., Lichty, R. W., and Bergmann, J. M., 1972, A rainfall-runoff simulation model for estimation of flood peaks for small drainage basins: U.S. Geol. Survey Prof. Paper 506-B, 28 p.

Dempster, G. R., Jr., 1974, Effects of urbanization on floods in the Dallas, Texas metropolitan area: U.S. Geol. Survey Water-Resources Inv. 60-73, 51 p.

Hauth, L. D., 1974, Model synthesis in frequency analysis of Missouri floods: U.S. Geol. Survey Circ. 708, 16 p.

Johnson, S. L., and Sayre, D. M., 1973, Effects of urbanization on floods in the Houston, Texas metropolitan area: U.S. Geol. Survey Water-Resources Inv. 3-73, 50 p.

Kirby, W. H., 1975, Model smoothing effect diminishes simulated flood peak variance: Am. Geophys. Union Trans., June 18, 1975, v. 56, no. 6, p. 361.

McDaniels, L. L., 1960, Consumptive use of water by major crops in Texas: Texas Water Commission Bull. 6019, 51 p.

Phillip, J. R., 1954, An infiltration equation with physical significance: Soil Sci. Soc. Am. Proc., v. 77, p. 153-157.

Schroeder, E. E., and Massey, B. C., 1977, Technique for estimating the magnitude and frequency of floods in Texas: U.S. Geol. Survey Water-Resources Inv. 77-110, 13 figs.

U.S. Water Resources Council, 1976, Guidelines for determining flood flow frequency: U.S. Water-Resources Council, Hydrology Comm. Bull. 17, 26 p., 14 apps.

Table 4.--Summary of simulated annual peak discharges for each site calibrated
(in cubic feet per second)

Discharge station:	07343350	07343350	07343900	07343900	08020800	08022010	08032100	08042700
Rainfall station:	Palestine, Tex.	Shreveport, La.	Shreveport, La.	Dallas, Tex.	Dallas, Tex.	Dallas, Tex.	Palestine, Tex.	Amarillo, Tex.
Water year	Discharge	Discharge	Discharge	Discharge	Discharge	Discharge	Discharge	Discharge
1913	428	770	231	--	--	--	17	--
1914	474	613	361	--	--	--	48	398
1915	842	691	274	114	619	77	89	753
1916	362	725	208	219	1551	82	20	509
1917	1148	1021	549	255	937	103	243	106
1918	538	815	254	213	785	86	85	256
1919	318	645	143	227	1560	94	13	548
1920	1116	668	263	438	2249	178	268	1471
1921	1658	597	163	97	447	37	354	2677
1922	682	719	396	508	2754	258	95	1395
1923	790	1042	494	256	1926	112	96	5325
1924	783	465	90	240	969	106	90	428
1925	197	268	28	409	1513	165	5	1250
1926	1274	944	368	183	861	71	216	425
1927	761	747	386	234	1614	100	73	715
1928	1078	797	214	167	727	73	194	4218
1929	639	936	376	738	3179	288	64	978
1930	886	466	187	220	1516	102	71	301
1931	1277	647	168	312	1323	148	258	355
1932	890	626	330	383	2019	219	293	2628
1933	652	801	452	379	1606	172	63	700
1934	--	916	354	280	1225	128	--	--
1935	--	1009	568	349	1725	177	--	482
1936	--	510	125	148	712	77	--	1793
1937	--	608	141	69	244	26	--	684
1938	950	537	243	339	1682	112	133	28
1939	694	661	174	87	604	39	64	1364
1940	1131	1318	559	40	158	18	210	--
1941	1335	871	402	398	1300	134	416	515
1942	813	1299	799	318	1858	136	88	1308
1943	778	495	118	178	724	79	95	3929
1944	780	769	402	222	1140	92	182	990
1945	664	919	415	751	3914	373	73	1257
1946	576	989	576	791	3916	361	39	844
1947	863	1069	593	878	4825	483	122	1411
1948	529	901	371	78	473	38	37	4626
1949	976	643	239	528	2828	215	123	2059
1950	951	848	259	202	1679	87	138	1438
1951	697	501	104	259	1220	120	81	3454
1952	621	493	161	189	689	76	65	778
1953	420	--	--	177	739	74	52	43
1954	478	--	--	89	314	35	31	--
1955	243	--	--	108	379	42	8	266
1956	1028	--	--	209	1399	100	130	349
1957	440	--	--	534	2467	219	23	759
1958	1463	--	--	426	2084	169	435	4123
1959	2045	--	--	214	775	84	535	841
1960	721	1000	372	847	3389	359	122	4695
1961	367	1038	476	45	233	24	37	1951
1962	473	624	107	567	3140	311	26	5243
1963	745	601	125	454	2118	217	113	244
1964	479	501	219	330	1450	147	28	875
1965	1032	560	193	264	1041	106	243	1679
1966	614	928	365	707	3275	285	126	743
1967	513	894	378	84	353	36	18	613
1968	1278	973	523	261	956	104	198	405
1969	583	399	161	419	2881	190	50	361
1970	656	770	280	321	1220	131	145	255
1971	834	644	156	181	757	85	154	324
1972	1074	639	262	213	1122	101	152	144
1973	837	--	--	--	--	--	117	128
1974	582	--	--	--	--	--	30	794

Table 4.--Summary of simulated annual peak discharges for each site calibrated--Continued

Discharge station:	08048820	08048850	08050200	08052630	08057500	08058000	08059200	08061620
Rainfall station:	Dallas, Tex.	Dallas, Tex.	Dallas, Tex.	Dallas, Tex.	Dallas, Tex.	Dallas, Tex.	Dallas, Tex.	Dallas, Tex.
Water year	Discharge	Discharge	Discharge	Discharge	Discharge	Discharge	Discharge	Discharge
1915	795	1738	136	336	399	258	105	926
1916	832	1837	462	1162	688	594	231	1478
1917	603	1236	363	1140	508	359	220	1525
1918	481	875	306	962	470	338	187	1256
1919	1003	2177	393	1068	569	564	204	1509
1920	1491	3603	526	1359	1548	1092	441	3225
1921	416	937	140	485	383	305	92	943
1922	2048	5006	547	1655	1734	1211	454	3817
1923	966	2405	455	1123	995	1010	238	1939
1924	671	1383	318	954	516	343	185	2005
1925	845	1875	506	1559	917	687	350	2366
1926	667	1556	250	770	679	534	178	1205
1927	1120	2617	381	935	707	604	208	1896
1928	601	1259	238	770	395	375	136	1247
1929	1822	4541	940	2537	2357	1866	665	4932
1930	888	1810	444	1151	610	500	206	1658
1931	732	1430	418	1275	603	415	259	2198
1932	1192	2697	505	1507	1195	816	339	3169
1933	1160	2654	483	1483	1128	797	319	2833
1934	857	1706	350	994	610	398	202	2045
1935	1538	3567	438	1264	1220	799	271	3172
1936	628	1167	271	800	481	369	165	1280
1937	211	353	112	376	114	85	53	428
1938	1027	2625	480	1265	1376	1094	390	2648
1939	603	1416	136	359	338	299	88	899
1940	114	199	63	218	66	45	31	315
1941	876	2020	353	1056	1035	750	321	2526
1942	1141	2727	477	1278	1050	965	335	2114
1943	617	1296	281	909	419	367	152	1315
1944	916	2071	338	993	784	598	187	1599
1945	2132	5236	990	2828	2374	1735	643	5724
1946	2519	6387	922	2651	2680	1998	662	5632
1947	3216	7458	955	2675	2215	1454	689	7419
1948	579	1128	168	449	242	181	68	1135
1949	1704	3721	658	1762	1501	1117	446	3359
1950	1035	2063	408	1110	604	525	196	1638
1951	690	1376	363	1016	498	341	198	1813
1952	449	894	258	810	333	230	158	1161
1953	511	1100	244	679	551	445	168	1172
1954	296	601	90	322	173	122	69	582
1955	327	529	175	576	191	171	92	682
1956	586	1192	480	1301	495	400	188	1357
1957	1537	3806	637	1768	1746	1269	490	3871
1958	1393	3457	612	1494	1880	1444	532	3410
1959	441	838	313	958	377	266	168	1299
1960	1689	3834	979	2786	2038	1455	729	4907
1961	260	423	79	249	81	50	32	493
1962	1599	3838	788	2250	1973	1427	566	4335
1963	1752	4071	518	1494	1352	857	356	3950
1964	773	1697	455	1300	1053	784	332	2039
1965	924	2134	406	1216	972	746	281	2493
1966	1702	4187	817	2329	2299	1667	698	4828
1967	214	372	142	460	145	97	69	612
1968	755	1817	366	1113	557	486	217	1667
1969	1778	4628	688	1961	1632	1407	407	3281
1970	662	1390	415	1262	736	544	285	1866
1971	498	1012	265	851	557	453	158	1354
1972	869	1897	407	1165	1152	852	254	1496

Table 4.--Summary of simulated annual peak discharges for each site calibrated--Continued

Discharge station:	08063200	08077550	08088100	08088300	08093200	08093400	08094000	08096800
Rainfall station:	Dallas, Tex.	Houston, Tex.	Dallas, Tex.	Abilene, Tex.	Dallas, Tex.	Palestine, Tex.	Dallas, Tex.	Austin, Tex.
Water year	Discharge	Discharge	Discharge	Discharge	Discharge	Discharge	Discharge	Discharge
1913	--	--	--	273	--	601	--	--
1914	--	--	--	1787	--	2103	--	--
1915	2359	1914	1157	1559	72	2501	421	--
1916	1970	814	935	86	284	919	740	--
1917	1895	383	1252	115	140	4721	436	--
1918	1171	1148	868	112	128	1820	389	--
1919	2064	1632	1227	848	210	410	825	--
1920	4307	905	1840	2258	306	4933	1658	--
1921	1065	1074	427	434	120	5804	248	--
1922	6055	2351	2615	598	341	2233	1907	--
1923	2528	1049	1361	214	299	2095	1068	--
1924	2027	1584	1175	170	133	1964	458	--
1925	2383	676	1283	661	222	190	947	--
1926	2061	1641	874	1083	187	4568	504	--
1927	3035	371	1446	276	209	1757	951	--
1928	1764	573	967	1878	124	3983	373	1291
1929	4915	2014	1966	134	602	2382	2177	245
1930	2006	429	1136	331	246	1891	566	923
1931	2081	1186	1362	314	152	4679	625	1080
1932	3587	424	1885	1603	225	3990	992	181
1933	3397	625	1550	2113	266	1653	961	250
1934	2673	461	1819	134	156	--	630	277
1935	4426	529	1989	618	268	--	1237	7205
1936	1731	997	1321	137	152	--	391	1859
1937	685	297	616	139	43	--	102	375
1938	3167	2005	1335	1344	277	2952	1314	1033
1939	2108	1261	852	732	101	1468	369	363
1940	358	750	426	90	18	5574	67	142
1941	2513	1149	1088	755	217	7465	865	4475
1942	3151	919	1335	1130	282	3949	1283	874
1943	1787	2025	1142	249	106	1804	351	1871
1944	2710	2897	1273	61	168	2866	919	2073
1945	6070	1591	2533	105	508	2357	2131	464
1946	7903	1685	3429	61	563	2123	2625	2408
1947	9659	1267	4902	112	442	2263	2911	2798
1948	1577	388	1020	241	69	917	221	177
1949	5429	626	2461	722	408	2607	1654	513
1950	2318	1546	1479	452	203	2688	956	1026
1951	2166	558	1349	224	166	1588	578	1141
1952	1198	253	819	25	115	1550	306	156
1953	1570	798	688	207	151	789	435	112
1954	862	701	514	123	47	1706	139	1851
1955	702	661	545	386	109	409	177	23
1956	1451	250	1038	72	181	2743	585	118
1957	4343	770	1845	946	344	1137	1863	1862
1958	4073	1189	1704	123	399	7676	1605	930
1959	1203	996	830	645	117	9898	340	1260
1960	5223	2239	2988	412	477	2728	1979	177
1961	695	675	882	659	20	1068	98	2796
1962	4647	803	2149	553	391	768	1667	541
1963	5334	651	2446	575	273	1958	1517	221
1964	2301	332	1442	495	249	1016	952	1001
1965	2546	692	1123	800	265	4657	759	4231
1966	4777	849	2014	534	449	2214	2385	613
1967	641	685	610	131	44	789	147	105
1968	2045	805	920	586	171	3765	633	902
1969	5666	748	2462	1538	390	2187	2136	1161
1970	1948	567	1232	476	229	2878	698	428
1971	1361	920	1127	147	189	2846	394	219
1972	2317	367	1457	404	231	3049	889	982
1973	--	990	--	232	--	2982	--	860
1974	--	311	--	683	--	1244	--	4093

Table 4.--Summary of simulated annual peak discharges for each site calibrated--Continued

Discharge station:	08098206	08098300	08103900	08108200	08111050	08114900	08116400	08137000
Rainfall station:	Dallas, Tex.	Austin, Tex.	Abilene, Tex.	Austin, Tex.	Austin, Tex.	Houston, Tex.	Houston, Tex.	Abilene, Tex.
Water year	Discharge	Discharge	Discharge	Discharge	Discharge	Discharge	Discharge	Discharge
1913	--	--	5594	--	--	--	--	540
1914	--	--	11715	--	--	--	--	1340
1915	403	--	14349	--	--	1198	1970	1269
1916	556	--	1507	--	--	618	1030	147
1917	507	--	776	--	--	343	460	112
1918	413	--	1867	--	--	868	1322	186
1919	637	--	5103	--	--	987	1559	796
1920	1038	--	17529	--	--	583	878	1766
1921	289	--	5522	--	--	715	1121	603
1922	1249	--	5254	--	--	1485	2392	378
1923	613	--	1293	--	--	680	1043	271
1924	493	--	2558	--	--	1110	1836	319
1925	750	--	4708	--	--	535	722	719
1926	392	--	14095	--	--	1108	1795	1381
1927	655	--	2922	--	--	300	416	377
1928	410	3022	17775	6362	419	486	764	1806
1929	1351	2032	1836	4303	221	1249	1988	268
1930	612	2141	5737	4681	295	387	500	575
1931	704	2483	4439	5525	318	1003	1416	422
1932	964	1318	8690	3259	222	524	563	1112
1933	847	2400	15777	5234	229	439	712	2020
1934	584	1718	2461	3650	248	359	543	270
1935	957	6480	2576	13454	1071	397	597	537
1936	450	5249	2734	12144	779	657	978	270
1937	154	2720	2593	6436	256	222	295	256
1938	811	2161	12047	4153	261	1356	2117	1485
1939	335	1641	6127	3527	202	855	1114	800
1940	111	1827	1299	4209	205	609	849	182
1941	675	8674	8360	18839	981	840	1341	1113
1942	740	3576	18463	7633	475	547	815	1642
1943	449	3068	5256	6367	467	1196	1803	526
1944	558	4975	818	10458	850	1759	2867	100
1945	1606	4031	2406	8975	378	1097	1546	232
1946	1652	3839	1203	8184	521	1126	1880	128
1947	1909	5445	2159	12085	982	864	1364	219
1948	271	1264	4955	2745	136	336	439	460
1949	988	3187	12626	7019	351	601	780	1259
1950	636	2721	3771	6076	450	924	1433	368
1951	588	3084	3309	7490	460	483	662	380
1952	373	981	297	1951	117	310	288	39
1953	328	1296	1688	2749	120	540	898	234
1954	196	4839	1892	9988	674	533	858	208
1955	239	637	5773	1455	38	481	790	562
1956	516	1454	764	3409	116	323	347	108
1957	1108	3565	10786	7932	478	680	932	948
1958	972	2220	1926	4374	303	799	1193	192
1959	439	3038	9169	6744	532	678	1100	937
1960	1470	2171	6689	5736	306	1435	2370	720
1961	154	7908	9506	16725	1127	473	675	1013
1962	1310	4676	2703	10636	456	650	933	443
1963	1026	1804	11587	4130	154	541	766	1081
1964	660	4908	8993	10216	612	231	345	866
1965	643	4239	5187	8395	724	615	834	813
1966	1384	3254	3327	6924	432	583	953	643
1967	222	1039	1241	2023	93	495	719	209
1968	521	2461	2437	5607	330	593	867	597
1969	1197	3307	10377	6804	458	502	843	1268
1970	592	2566	3308	5305	216	330	421	437
1971	452	2080	761	4684	259	631	974	160
1972	633	3232	5411	6945	484	273	424	642
1973	--	4286	3690	9450	475	653	985	413
1974	--	6049	9345	12357	877	209	214	756

Table 4.--Summary of simulated annual peak discharges for each site calibrated--Continued

Discharge station:	08139000	08140000	08140500	08159150	08167600	08178600	08181400	08182400
Rainfall station:	Abilene, Tex.	Abilene, Tex.	Austin, Tex.	Austin, Tex.	San Antonio, Tex.	San Antonio, Tex.	San Antonio, Tex.	San Antonio, Tex.
Water year	Discharge	Discharge	Discharge	Discharge	Discharge	Discharge	Discharge	Discharge
1913	451	421	--	--	3180	1902	369	850
1914	1534	2030	--	--	3899	2513	1138	2015
1915	1587	2004	--	--	10096	7923	2860	3488
1916	164	182	--	--	6833	3324	709	1660
1917	86	91	--	--	398	202	63	110
1918	137	120	--	--	5111	3236	562	1239
1919	1230	1463	--	--	3841	2061	498	1331
1920	2160	2932	--	--	2244	1322	915	1048
1921	376	418	--	--	3678	2770	604	993
1922	400	535	--	--	4498	2113	555	1519
1923	229	229	--	--	116	47	25	37
1924	358	339	--	--	4129	1993	438	854
1925	897	1098	--	--	2174	1234	247	610
1926	1422	1597	--	--	7879	4234	6187	4104
1927	438	611	--	--	2577	1473	364	1043
1928	1503	1716	708	1615	3082	1862	330	763
1929	207	205	472	781	3591	1517	387	923
1930	717	719	590	1231	412	244	63	105
1931	702	891	850	1162	1289	622	168	288
1932	1333	1559	442	711	6469	4590	1007	1867
1933	2733	3638	272	866	546	321	60	103
1934	202	181	266	882	2986	1640	281	651
1935	671	729	2178	4360	12609	9519	5345	5244
1936	200	181	1083	2731	2058	1110	212	486
1937	280	268	402	935	--	--	--	--
1938	1382	2211	571	977	2587	1279	568	906
1939	1074	1366	319	789	2877	1648	344	795
1940	156	143	373	619	4205	2623	393	914
1941	1204	1366	1633	3498	1355	747	235	521
1942	2009	1993	1616	1878	5167	3201	826	1850
1943	502	525	808	1876	8105	5510	3187	2315
1944	72	68	1303	3332	861	503	114	449
1945	205	267	1503	1217	3943	2229	456	1056
1946	110	100	1213	1952	9492	7301	3862	3252
1947	187	163	2291	3698	928	356	80	169
1948	389	413	184	490	7328	5119	1221	2653
1949	995	907	1003	1229	6472	3540	625	1366
1950	925	1079	602	1813	5794	3571	998	2246
1951	373	350	939	1927	12423	9191	2940	4462
1952	28	29	138	398	313	179	44	72
1953	193	206	654	380	1479	862	163	350
1954	211	230	1325	2730	569	91	37	92
1955	809	1171	67	121	10835	10398	995	2100
1956	136	133	148	344	3405	1434	264	689
1957	1261	1628	612	1771	6071	6301	3479	2309
1958	132	117	639	1002	12037	7940	2648	4752
1959	850	903	828	1976	2031	1198	235	531
1960	669	614	452	659	5515	3523	915	2000
1961	1009	1054	1826	3854	4610	2527	820	1251
1962	473	553	740	1440	2156	766	128	288
1963	987	901	843	466	7596	5004	1093	2289
1964	817	806	1271	2146	8590	5927	1187	2279
1965	1019	1225	1181	2730	2728	1081	2609	1909
1966	696	787	557	1529	834	248	79	182
1967	184	199	122	317	1797	922	295	1150
1968	653	736	774	1116	4574	1923	1048	1382
1969	1522	2101	859	1847	1281	564	142	403
1970	741	936	521	761	7850	5475	1197	2303
1971	155	176	771	915	925	433	113	338
1972	612	592	912	1919	6938	4281	1271	1847
1973	302	270	789	1676	12260	6845	3626	4742
1974	880	1019	1313	2921	6694	4193	930	2040

Table 4.--Summary of simulated annual peak discharges for each site calibrated--Continued

Discharge station:	08187000	08207700						
Rainfall station:	Corpus Christi, Tex.	Corpus Christi, Tex.						
Water year	Discharge	Discharge	Discharge	Discharge	Discharge	Discharge	Discharge	Discharge
1913	162	2284						
1914	244	2567						
1915	1901	11855						
1916	964	5210						
1917	32	346						
1918	216	3194						
1919	469	2957						
1920	861	4026						
1921	306	2657						
1922	1691	6951						
1923	348	2774						
1924	--	--						
1925	76	1362						
1926	2947	11509						
1927	1048	5336						
1928	1285	6149						
1959	870	4844						
1930	119	1637						
1931	2021	11370						
1932	312	2093						
1933	344	2783						
1934	--	--						
1935	2107	6248						
1936	1166	6571						
1937	23	552						
1938	901	5810						
1939	102	1525						
1940	319	2653						
1941	1878	8562						
1942	1266	5355						
1943	171	1484						
1944	839	4709						
1945	113	2208						
1946	689	4262						
1947	1076	4794						
1948	1886	7524						
1949	1159	4905						
1950	366	3147						
1951	496	3635						
1952	182	2933						
1953	1591	6523						
1954	219	2468						
1955	930	7897						
1956	1451	10637						
1957	1065	3599						
1958	538	4814						
1959	1370	5074						
1960	2371	10325						
1961	2279	10159						
1962	156	1525						
1963	311	3262						
1964	438	3367						
1965	485	3098						
1966	803	5557						
1967	2729	8065						
1968	1871	6018						
1969	225	2772						
1970	2463	9849						
1971	734	4847						
1972	381	4121						
1973	1690	5563						
1974	909	6030						