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Frequency Analysis of Illinois Floods Using Observed and Synthetic Streamflow Records

Geological Survey, Champaign, Ill Water Resources Div

Jul 77

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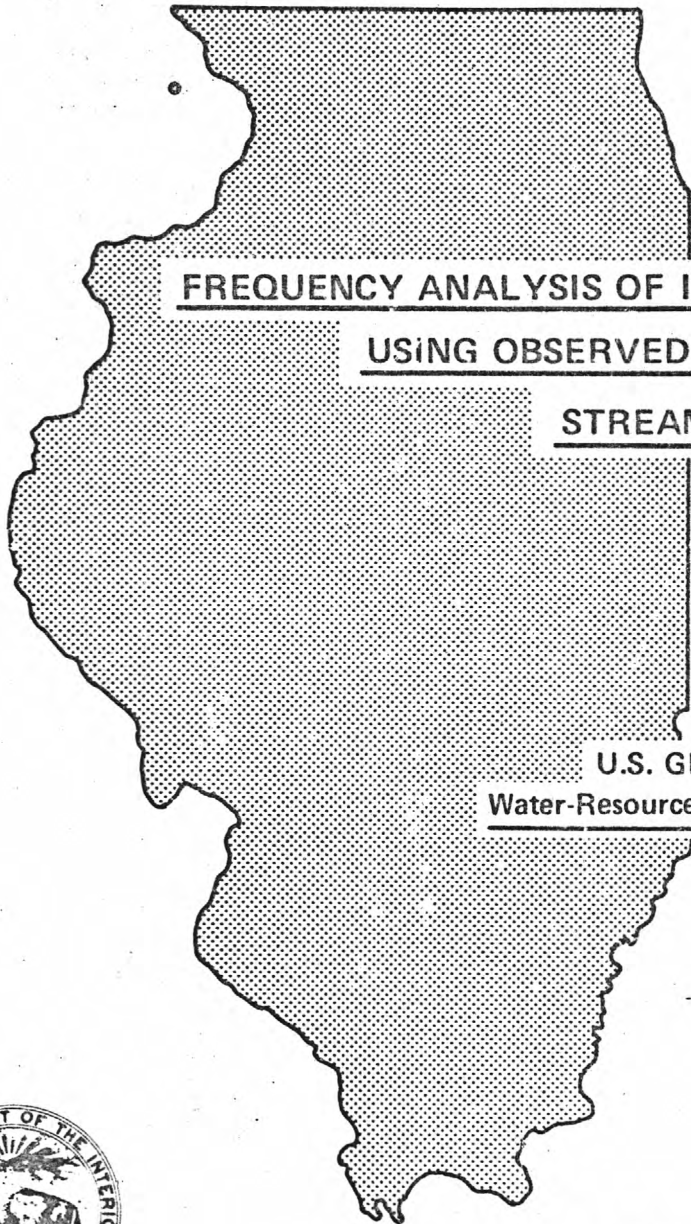

FREQUENCY ANALYSIS OF ILLINOIS FLOODS USING OBSERVED AND SYNTHETIC STREAMFLOW RECORDS

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations 77-104

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Prepared in cooperation with
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16. Abstracts

Equations, applicable Statewide, for estimating flood magnitudes having recurrence intervals ranging from 2 to 500 years for unregulated rural streams, with drainage areas ranging from 0.02 to 10,000 square miles (0.05 to 25,900 square kilometers), were derived by multiple regression analyses. A rainfall-runoff model was used in the synthesis of long-term annual peak data for each of 54 small watersheds (drainage areas less than 10.2 mi^2, 26.4 km^2). Synthetic frequency curves generated from five long-term precipitation stations were combined into one synthetic curve and then this synthetic curve was combined with the observed station frequency curve to define the station frequency curve. Synthetic data from the 54 small streams, observed data at 33 small streams, and observed data at 154 large streams were used in the analyses. The most significant independent variables in the regression analysis for estimating flood peaks on Illinois streams were drainage area, slope, rainfall intensity, and an areal factor.

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Prepared in cooperation with
STATE OF ILLINOIS
DEPARTMENT OF TRANSPORTATION
DIVISION OF HIGHWAYS

1977

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UNITED STATES DEPARTMENT OF THE INTERIOR
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GEOLOGICAL SURVEY
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GLOSSARY

Annual peak discharge. The highest instantaneous peak discharge in a water year.

Cubic feet per second (ft^3/s). The rate of discharge representing a volume of 1 cubic foot of water passing a given point during 1 second and is equivalent to 7.48 gallons per second, 448.8 gallons per minute, or 0.028 cubic meters per second.

Discharge. The rate of flow of water in a stream at a given place and within a given period of time.

Drainage area. An area from which surface runoff is carried away by a single drainage system. Also called watershed, drainage basin.

Evapotranspiration. The amount of precipitation that returns to the atmosphere as vapor by the combined action of evaporation and transpiration by plants.

Flood. A relatively high flow, as measured by either gage height or discharge, which usually overtops the natural banks along some reaches of a stream.

Flood peak. The maximum rate of flow, usually expressed in cubic feet per second, that occurred during a flood.

Frequency. The number of occurrences of a certain phenomenon in a given period of time.

Gaging station. A particular site on a stream where systematic observations of gage height and discharge are obtained. The station usually has a recording gage for continuous measurement of the elevation of the water surface in the channel.

Physiographic region. Areas where soils and drainage have been developed on geologically similar materials.

Probability. The likelihood or chance that a flood or storm will occur or that the magnitude of a flood or storm will be exceeded.

Q_T. The discharge for a recurrence interval of T-years. It is the annual maximum peak flow that will be exceeded every T-number of years on the average.

Rainfall intensity. The maximum 24-hour rainfall, in inches, expected to be exceeded on an average of once every 2 years.

Recurrence interval. The average interval of time within which a given flood will be exceeded once. Also called return period.

Regression equation. An equation derived by methods of regression. It is a mathematical relationship between a dependent variable and one or more independent variables.

Regulated stream. A stream that has been subjected to control by reservoirs, diversions, or other manmade hydraulic structures.

Return period. See recurrence interval.

Standard error of regression. Refers to the standard error of estimate of the dependent variable. It is the standard deviation of the residual errors about a regression line used to predict the dependent variable converted to an average percentage. Approximately two-thirds of the data values for the dependent variable are included within one standard error of estimate.

Time of concentration. The time required for storm runoff from the most remote part of a watershed to reach the outlet or point of discharge on the stream.

Water year. A continuous 12-month period from October 1 to September 30, during which streamflow data are collected, compiled, and reported.

Watershed. See drainage area.

SYSTEM OF MEASUREMENT UNITS

The following report uses both the English and the metric systems of units. In the text the English units are given first, and the equivalent measurement in metric units is given in parentheses. The units are frequently abbreviated, using the notations shown below. The English units can be converted to metric units by multiplying by the factors given in the following list.

Multiply English unit	By	To obtain metric unit
Inches (in)	2.54×10^{1}	Millimeters (mm).
	2.54×10^{0}	Centimeters (cm).
	2.54×10^{-2}	Meters (m).
Feet (ft)	3.048×10^{-1}	Meters (m).
Miles (mi)	1.609×10^{0}	Kilometers (km).
Square miles (mi^2)	2.590×10^{0}	Square kilometers (km^2).
Feet per mile (ft/mi)	1.894×10^{-1}	Meters per kilometers (m/km).
Cubic feet (ft^3)	2.832×10^{1}	Cubic decimeters (dm^3).
	2.832×10^{-2}	Cubic meters (m^3).
Cfs-day (ft^3/s-day)	2.447×10^{3}	Cubic meters (m^3).
Cubic feet per second (ft^3/s)	2.832×10^{1}	Liters per second (L/s).
	2.832×10^{1}	Cubic decimeters per second (dm^3/s).
	2.832×10^{-2}	Cubic meters per second (m^3/s).

FREQUENCY ANALYSIS OF ILLINOIS FLOODS USING OBSERVED AND SYNTHETIC STREAMFLOW RECORDS

By George W. Curtis

ABSTRACT

Equations, applicable Statewide, for estimating flood magnitudes having recurrence intervals ranging from 2 to 500 years for unregulated rural streams, with drainage areas ranging from 0.02 to 10,000 square miles (0.05 to 25,900 square kilometers), were derived by multiple regression analyses. A rainfall-runoff model was used in the synthesis of long-term annual peak data for each of 54 small watersheds (drainage areas less than 10.2 mi², 26.4 km²). Synthetic frequency curves generated from five long-term precipitation stations were combined into one synthetic curve and then this synthetic curve was combined with the observed station frequency curve to define the station frequency curve. Synthetic data from the 54 small streams, observed data at 33 small streams, and observed data at 154 large streams were used in the analyses. The most significant independent variables in the regression analysis for estimating flood peaks on Illinois streams were drainage area, slope, rainfall intensity, and an areal factor.

INTRODUCTION

Purpose

The proper design of engineering projects such as highways, bridges, culverts, flood-control structures, and drainage systems requires a reliable estimate of the magnitude and frequency of future floods. The establishment of realistic flood insurance rates and proper flood plain management also are based on estimates of magnitudes of potential floods. Although the need for flood-frequency relations has long been recognized, emphasis in the past has been placed on the collection of records and development of frequency relations for areas greater than 50 mi² (130 km²). In the past decade, or so, the need for better definition of flood-frequency relations for small drainage areas has become increasingly important, particularly in the design needs for expanding and improving the highway systems.

The purpose of this project was to collect flood records on small streams having drainage areas of less than about 10 mi² (26 km²), and to develop methods and techniques suitable for estimating flood frequencies for small streams where records are not available. The flood-frequency relations for the small streams were combined with flood-frequency relations for the large streams to develop Statewide flood-frequency relations applicable to all unregulated rural streams in Illinois.

This report documents the procedures used to develop the techniques for estimating flood-frequency relations for streams in Illinois having drainage areas larger than 0.02 mi² (0.05 km²), and to evaluate the reliability of these estimates.

Acknowledgments

Special acknowledgment is made to the Project Advisory Committee whose recommendations have guided the development of the project. The present committee members are: Mr. Donald R. Schwartz, engineer of physical research, Illinois Division of Highways; Messrs. Daniel G. Ghere and Martin J. Siebrasse, highway engineers, Illinois Division of Highways; and Messrs. Donald M. Thomas and James F. Bailey, hydrologists, U.S. Geological Survey, Reston, Va.

Long-term daily precipitation records and storm reductions to 5-minute increments were obtained from the National Oceanic and Atmospheric Administration (NOAA), Environmental Data Service, National Climatic Center at Asheville, N.C.

PREVIOUS STUDIES

The first flood-frequency report for Illinois (Mitchell, 1954) was based on known flood events at 108 gaging stations and presented a method for estimating the magnitudes of floods having recurrence intervals ranging from 1.1 to 50 years at ungaged rural sites. In Mitchell's report 5 of the 11 regions had no stations for which the drainage area was less than 100 mi^2 (259 km^2) and none of the regions contained stations for which the drainage area was less than 10 mi^2 (26 km^2). Consequently, the application of the estimating method presented in his report was limited to drainage areas of 10 mi^2 (26 km^2) or greater.

Ellis (1968) presented a flood estimating technique to help meet the need of engineers involved in expanding and improving the highway system in Illinois. His technique was based on the analyses of 97 stations with drainage areas ranging from 0.02 to 40 mi^2 (0.05 to 104 km^2). Of these stations, 61 had 12 years of record available for analyses and 36 had 7 years.

A second Statewide flood-frequency report was published by Carns (1973), which updated Mitchell's 1954 report and included a method for estimating frequencies for drainage areas as small as 0.02 mi^2 (0.05 km^2). Carns' report utilized the log-Pearson Type III method of frequency analysis as recommended by the U.S. Water Resources Council (1967). His analysis was based on data from 172 rural gaging stations having 10 or more years of flood records through September 1967. An estimating equation was included in the report to predict the magnitude of the 100-year recurrence-interval flood at an ungaged site.

Speer and Gamble (1965), Wiitala (1965), and Patterson and Gamble (1968) included data from Illinois in reports on the magnitude and frequency of floods for the Ohio, St. Lawrence, and Hudson Bay and Upper Mississippi River basins, respectively.

SMALL STREAMS

Data Network

A small streams data network was established by considering such factors as: geographic distribution, drainage area, and basin characteristics including slope, shape, stream density, channel geometry, and natural storage. Eighty-seven small-stream stations having drainage areas ranging from 0.02 to 10.2 mi^2 (0.05 to 26.4 km^2) were selected considering these factors. A small stream as used in this report is defined as a stream having a drainage area of about 10 mi^2 (26 km^2) or less.

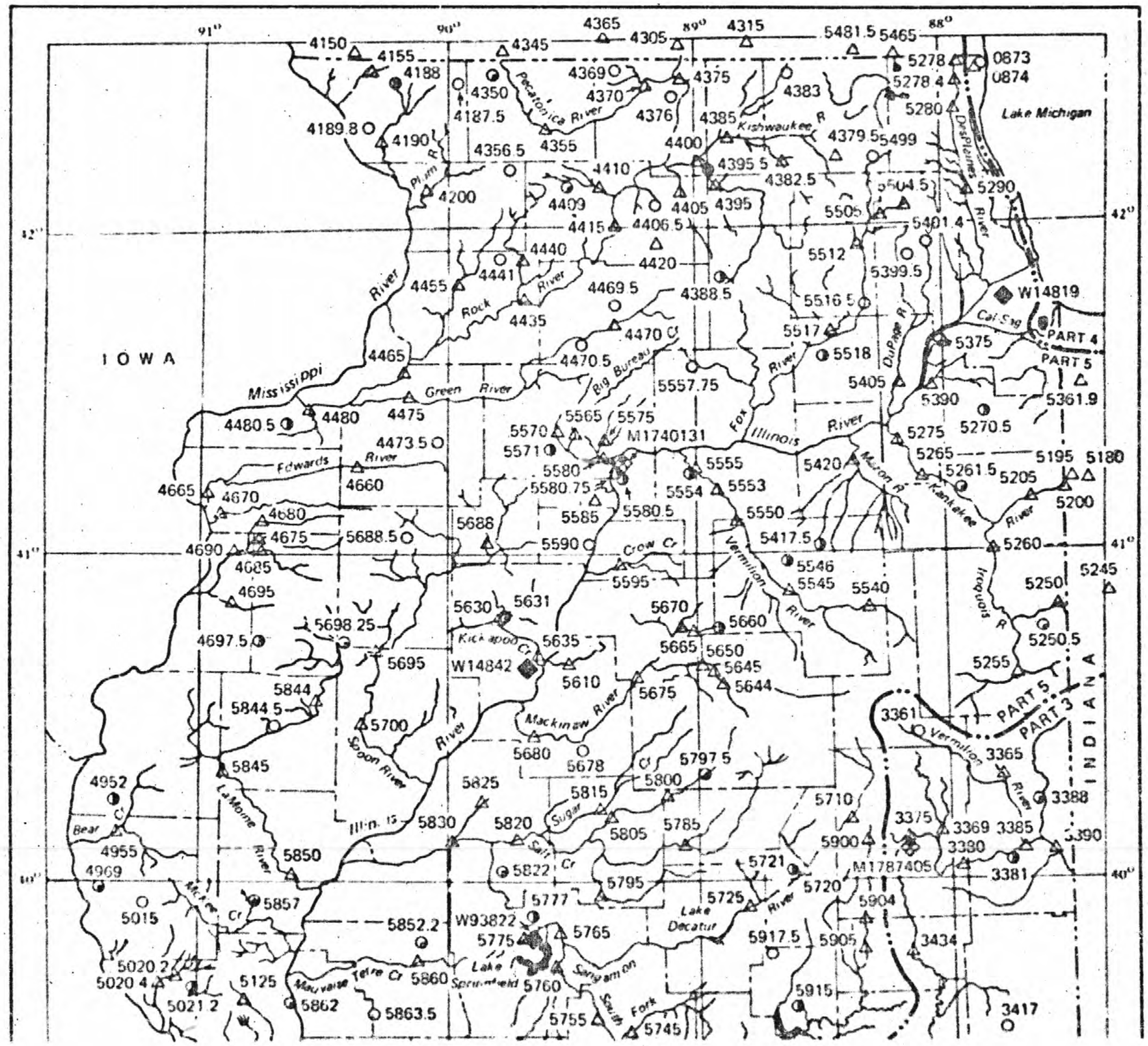
A crest-stage gage provided a record of the highest stream stage above a selected base between visits by field personnel. Discharge for each flood crest was determined by means of a stage-discharge relation curve. Several values were recorded for a given year; however, only the highest or annual peak discharge was utilized in this study. The initial network of crest-stage gages was installed during the summer of 1955 and was essentially complete by October 1, the beginning of the 1956 water year. Forty-six stations constituted this initial group. A second group of 36 crest-stage gages was added to the network in 1960 to increase the sample size. Five continuous-record long-term gaging stations were operated on streams having small drainage areas as a part of the basic data collection program and these were also utilized in this study.

Three types of gaging-station data, utilized for the study, are (1) instantaneous annual peak stages and discharges; (2) complete flood hydrographs for selected stations and for selected periods; and (3) precipitation records associated with the complete flood hydrographs. Rainfall-runoff data were collected until sufficient information had been obtained to define various streamflow and basin characteristics at a station. The equipment was then moved to another site. Generally, 2 to 4 years were required to collect sufficient flood hydrographs to identify the needed characteristics.

The most fundamental element of data at each of the observation stations is the annual peak discharge. Annual peak discharge for 10 or more years at a station is necessary to warrant defining a station frequency curve. The 87 small-stream stations were classified into three groups (fig. 1) depending upon the data available and on how they were treated and used in developing the station-frequency curve. Stations were grouped according to: (1) stations for which the rainfall-runoff model was calibrated; (2) stations for which the model was partially calibrated; and (3) stations for which observed data only were used.

Description of the Rainfall-Runoff Model

The lack of sufficient records on small areas indicated the need to extend peak records in time to provide a longer data base for a more reliable frequency analysis. Several digital computer models have been developed to synthesize peak flow records. For this study a rainfall-runoff model developed by Dawdy, Lichty, and Bergmann (1972) was utilized to synthesize record and increase the annual peak sampling size at 30 of the small-stream stations.



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DuPage R
Mazon R
Kankakee River
Iroquois R
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Mackinaw River
Spoon River
La Moine River
Bear Cr
McKee Cr
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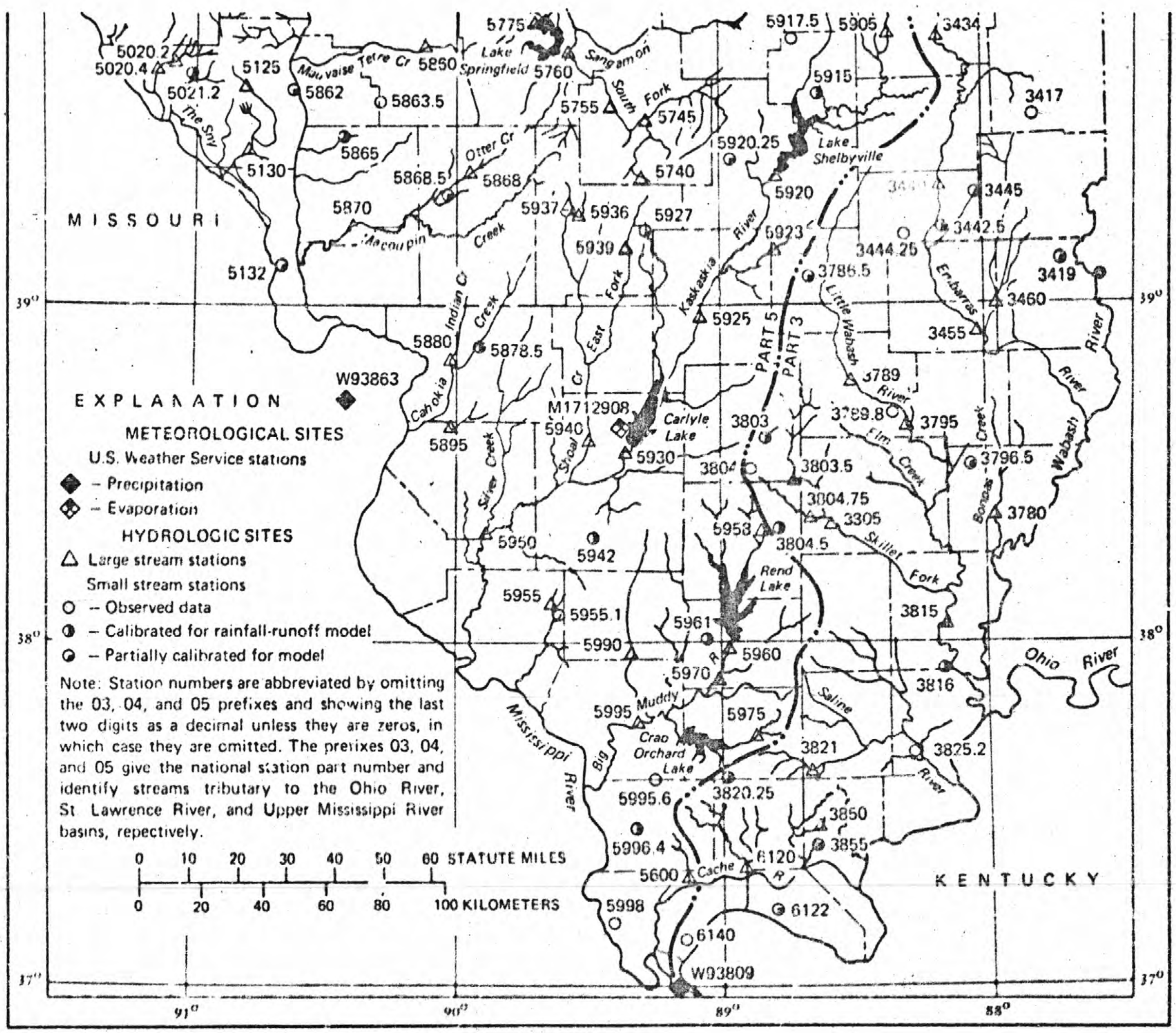

Figure 1.--Hydrologic and meteorologic data collection sites.

The model is a parametric rainfall-runoff simulation model used to estimate flood volumes and peak discharges of runoff for natural small-drainage areas. It is based on bulk-parameter approximations to the physical laws governing three components of the hydrologic cycle; antecedent soil moisture, infiltration, and surface-runoff routing.

The antecedent moisture accounting component is designed to determine the starting infiltration rate for a storm. The component continually assesses the change in soil moisture, as a basis for determining the portion of rainfall that becomes surface runoff. This assessment is made on a daily basis during periods of non-event days and for a unit-time increment during periods of selected storm events. Unit time increments of 5, 10, 15, 30, or 60 minutes may be selected to provide a suitable degree of refinement in the calibration to reproduce the observed hydrograph.

The infiltration component uses an approximation of the Philip (1954) differential equation for unsaturated flow. This component determines the portion of unit rainfall that infiltrates and becomes surface runoff.

The surface runoff routing component is based on the Clark (1945) form of the instantaneous hydrograph. In the model, the rainfall excess is distributed by time to determine the outflow hydrograph using a modified Clark routing method.

Ten parameter values (table 1) approximate the above components and are used in the operation of the model. The parameters are evaluated during the calibration of the model to a specific site.

Modeling Stations with Full Calibration

The rainfall-runoff modeling was done in three distinct phases. The first phase was to calibrate the model for each small-stream station. The second phase was to use the calibrated model to generate long-term synthetic annual peak discharge records for each station. The third phase was to use the synthesized record to develop station frequency curves for the modeled stations.

The model is calibrated using a trial and error parameter optimization technique, and for any specific site requires the concurrent values for unit streamflow and unit precipitation, daily precipitation and daily pan evaporation. The stations used in the calibrations are shown in figure 1.

Daily precipitation and daily pan evaporation data used for the calibrations were obtained from the U.S. Department of Commerce, Weather Service publication "Climatological Data for Illinois." Daily rainfall record between storm periods was compiled from the nearest Weather Service precipitation station.

In general, the calibration technique determines optimum parameter values to be used in the model synthesis of a flood record from long-term rainfall and pan evaporation data. The best estimate of parameter values is accomplished by: (1) optimizing the parameters PSP, KSAT, DRN, RGF, BMSM, EVC, and RR (table 1) that control the volume of runoff until the volume of observed runoff is reproduced with

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	Inches per hour	A constant drainage rate for redistribution of soil moisture.
		Infiltration component
PSP	Inches	Product of moisture deficit and suction at the wetted front for soil moisture at field capacity.
KSAT	Inches per 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.

minimum variance. Optimal values for the model parameters were determined by minimizing the sum of the squared differences between the computed and actual runoff (minimum objective function); (2) holding the above volume parameters constant and optimizing the routing parameters KSW, TC, and TP/TC that control the shape of the synthetic hydrograph to reproduce the observed peak with minimum variance; and (3) holding the routing parameters constant and readjusting the volume parameters to produce the best fit between the observed and simulated peaks. Several parameters, DRN, EVC, and in some instances RR and TP/TC, are considered to vary only slightly and by holding them constant, the fitting process will better estimate the values of the other parameters. Parameter values determined in (3) were used to synthesize long-term peak discharges from long-term precipitation data.

The initial value and the values for the upper and lower limits for all parameters must be estimated for the fitting process. Initial values for the parameters that control the volume were estimated on the basis of geology, soil type, basin cover, and climate. The initial magnitudes for the routing parameters were estimated from observed discharge hydrographs. Constraints were placed on the parameter values based on experience at each location, and on upper and lower limit values suggested by Lichty and Bauer (1974).

EVC, the ratio of potential evapotranspiration to pan evaporation, should represent an effective average pan coefficient for the basin. There are three pan evaporation stations in Illinois, one in the northern, one in the central, and one in the southern part of the State. Presently, they are located at Hennepin (M1740131), Urbana (M1787405), and Carlyle (M1712908), respectively. Prior to 1963 the northern station was at Rockford, the central station at another site in Urbana, and the southern station at Carbondale. Streamflow records used for calibration purposes were collected within the period 1955-74. For calibration purposes, potential evapotranspiration was determined by utilizing the model to optimize EVC at each stream station for the period during which continuous discharge hydrographs were obtained using the pan evaporation at the nearest pan evaporation station. All the potential evapotranspiration values thus estimated were used to obtain an average annual potential evapotranspiration of 34 inches for the State. In order to achieve the objective of holding EVC constant for calibration, and to avoid bias in pan evaporation data caused by gage relocation, the pan evaporation of 48.97 inches (124.4 cm) at Urbana for the 12-year period 1963-74 was used with the average potential evaporation of 34 inches (86.4 cm) to estimate EVC as 34/48.97 = 0.694. EVC was rounded to 0.70 and held constant for all calibrations.

In the subsequent synthesizing of streamflow records, the value of EVC was adjusted to account for differences in latitude. The adjustment was based on observed differences in the initial station by station optimization procedure and, varied from the Statewide average by about -10 percent in the north to a +10 percent in the south. A coefficient of 0.63, 0.70, and 0.77 thus was held constant for streamflow record synthesis in the northern, central, and southern parts of the State, respectively.

It is desirable to calibrate the model with data from several storm events and for this study six usable storm events, with the exception of one station which had five events, was the criterion for including a station for modeling. Sufficient data were available for the calibration of the model for 30 stations (table 2) ranging in drainage area from 0.03 to 8.05 mi^2 (0.08 to 20.8 km^2). These stations will be referred to as calibrated stations.

Synchronized rainfall and stage were recorded at each of the 30 stations either on the same strip chart or by dual digital recorders operated by a common timer. At these sites rainfall was collected using a tipping-bucket gage or a float arrangement that measured precipitation to the nearest 0.1 inch (2.5 mm).

The final parameter values to be used in the synthesizing of peaks were graphically checked for possible bias in the calibrated model by plotting observed peaks versus simulated peaks. The measure of "goodness of fit" is the average of the squared deviations of logarithms of observed and simulated peaks and is analogous to a variance or the square of a standard error. The average standard error of estimate of the observed to simulated peaks was about 37 percent. Table 3 lists in downstream order the 30 stations for which the model was calibrated (fig. 1) and the best-fit parameter values.

The calibrated rainfall-runoff model was used to synthesize a flood peak resulting from any selected storm rainfall and antecedent moisture conditions. Long-term rainfall and daily evaporation data were required as input to the model to generate a long series of flood peaks. Four long-term first-order precipitation stations in Illinois and one in Missouri (fig. 1) operated by the National Weather Service were used to provide the necessary rainfall data. These stations, including periods of continuous records, are listed in table 4.

Table 2.—Small-stream stations for which the model was calibrated

Station Number	Station Name	Drainage Area (mi^2)	Annual Peak Record (water years)	Continuous Record (water years)	Unit Time Increment (min)	Number of Storms Used in Calibration
03338100	Salt Fork trib. nr Catlin	2.20	1959-75	1969-74	5	10
03344250	Embarras River trib. nr Greenup	.08	1956-75	1956-60	5	6
03380300	Dums Creek trib. nr Iuka	.08	1956-75	1958-60	5	9
03380450	White Feather Creek near Marlow	.43	1956-75	1958-61	5	7
03381600	Little Wabash River trib. nr New Haven	.16	1960-75	1967-69	5	7
03382025	Little Saline Creek trib. nr Goreville	.52	1959-75	1970-73	5	6
05418800	Mill Creek trib. nr Scales Mound	.86	1956-75	1965-71	5	9
05438850	MB SB Kishwaukee River nr Malta	1.67	1956-75	1966-74	5	9
05439550	SB Kishwaukee River trib. nr Irene	1.71	1959-75	1970-74	5	12
05448050	Sand Creek nr Milan	.22	1956-75	1964-69	5	6
05469750	Ellison Creek trib. nr Roseville	.26	1956-75	1964-70	5	7
05495200	Little Creek nr Breckenridge	1.45	1956-75	1963-65, 1973-74	5	17
05502120	Kiser Creek trib. nr Barry	.78	1956-75	1962, 1973-74	5	14
05527050	Prairie Creek nr Frankfort	.80	1956-72	1966-71	5	6
05541750	Mazon River trib. nr Gardner	4.52	1959-75	1970-74	30	12
05551800	Fox River trib. No. 2 nr Fox	.45	1961-75	1969-74	5	6
05554600	Mud Creek trib. nr Odell	.16	1959-75	1966-74	5	13
05555400	Vermilion River trib. at Lowell	.14	1956-75	1956-68	5	9
05557100	West Bureau Creek trib. nr Wyanet	.33	1956-75	1964-74	5	12
05558050	Coffee Creek trib. nr Florid	.03	1956-75	1964-74	5	12
05558075	Coffee Creek trib. nr Hennepin	.22	1956-75	1964-74	5	9
05566000	EB Panther Creek nr Gridley	6.30	1950-72	1960-68	30	9
05572100	Wildcat Creek trib. nr Monticello	.10	1956-75	1956-60	5	10
05577700	Sangamon River trib. at Andrew	1.50	1956-75	1961-65, 1972-74	5	15
05586500	Hurriance Creek nr Roodhouse	2.30	1951-75	1960-62	5	10
05587850	Cahokia Creek trib. nr Carpenter	.45	1956-75	1961-62	5	11
05591500	Asa Creek at Sullivan	8.05	1951-75	1965-72	30	15
05594200	Williams Creek nr Cordes	1.90	1956-72	1961	5	8
05596100	Andy Creek trib. at Valier	1.03	1956-72	1959-60	5	8
05599640	Green Creek trib. nr Jonesboro	.43	1956-75	1960-66	5	5

Table 3.–Summation of model parameters

Station Number	Station Name	Parameters									
		PSP	KSAT	DRN	RGF	BMSM	EVC	RR	KSW	TC	TP/TC
03338100	Salt Creek trib. nr Catlin	1.711	0.0540	1.000	24.908	1.915	0.700	0.800	2.540	174.0	0.50
03344250	Embarras River trib. nr Greenup	.776	.0273	1.000	24.620	1.313	.700	.900	1.660	23.8	.50
03380300	Dums Creek trib. nr Iuka	3.330	.0400	1.000	16.300	1.500	.700	.800	.086	45.0	.50
03380450	White Feather Creek nr Marlow	1.618	.0404	1.000	28.001	1.998	.700	.900	.337	90.0	.50
03338160	Little Wabash River trib. nr New Haven	3.492	.0758	1.000	16.171	1.171	.700	.900	.214	46.2	.95
03382025	Little Saline Creek trib. nr Goreville	.863	.0665	1.000	2.089	7.151	.700	.800	.500	94.0	.50
05418800	Mill Creek trib. nr Scales Mound	2.547	.0661	1.000	22.119	1.658	.700	.800	.420	87.0	.50
05438850	MB SB Kishwaukee River nr Malta	4.676	.0811	1.000	27.315	5.402	.700	.800	1.450	55.0	.50
05439550	SB Kishwaukee River trib. nr Irene	2.813	.0950	1.000	12.699	1.462	.700	.800	.800	110.0	.50
05448050	Sand Creek nr Milan	3.310	.1720	1.000	15.525	8.162	.700	.800	.420	67.2	.50
05469750	Ellison Creek trib. nr Roseville	2.652	.1310	1.000	16.951	6.000	.700	.800	.630	73.8	.50
05495200	Little Creek nr Breckenridge	1.412	.0700	1.000	21.948	3.072	.700	.800	.724	67.9	.50
05502120	Kiser Creek trib. nr Barry	1.924	.0510	1.000	11.868	1.181	.700	.800	.572	58.6	.50
05527050	Prairie Creek nr Frankfort	1.083	.0502	1.000	5.790	1.693	.700	.800	1.500	250.0	.50
05541750	Mazon River trib. nr Gardner	.452	.0819	1.000	9.376	2.743	.700	.800	19.000	333.0	.50
05551800	Fox River trib. No. 2 nr Fox	.606	.0575	1.000	20.580	1.164	.700	.800	.690	113.0	.50
05554600	Mud Creek trib. nr Odell	.301	.0502	1.000	4.835	4.988	.700	.800	.819	49.0	.50
05555400	Vermilion River trib. nr Lowell	2.309	.0930	1.000	17.255	1.768	.700	.800	.341	15.3	.60
05557100	West Bureau Creek trib. nr Wyanet	2.133	.1440	1.000	13.058	4.980	.700	.900	.360	33.2	.60
05558050	Coffee Creek trib. nr Florid	3.063	.0651	1.000	9.415	3.420	.700	.800	.096	24.6	.50
05558075	Coffee Creek trib. nr Hennepin	3.882	.0810	1.000	11.751	5.986	.700	.800	.106	63.4	.60
05566000	EB Panther Creek nr Gridley	1.285	.0505	1.000	39.204	4.991	.700	.800	7.500	205.0	.50
05572100	Wildcat Creek trib. nr Monticello	.848	.0818	1.000	20.095	3.999	.700	.900	.430	35.1	.50
05577700	Sangamon River trib. at Andrew	2.705	.0956	1.000	27.655	2.256	.700	.800	1.440	66.0	.50
05586500	Hurricane Creek nr Roodhouse	2.777	.2120	1.000	22.360	4.916	.700	.800	1.450	93.7	.50
05587850	Cahokia Creek trib. nr Carpenter	3.489	.0552	1.000	18.274	3.000	.700	.900	.714	32.9	.60
05591500	Asa Creek at Sullivan	.735	.0508	1.000	19.178	2.349	.700	.800	17.300	360.0	.50
05594200	Williams Creek nr Cordes	1.184	.0506	1.000	3.984	1.931	.700	.900	1.620	182.0	.50
05596100	Andy Creek trib. at Valier	1.490	.0512	1.000	27.359	1.996	.700	.900	.500	203.0	.50
05599640	Green Creek trib. nr Jonesboro	4.488	.1350	1.000	23.049	1.316	.700	.800	.319	16.2	1.00

Table 4.—U.S. Weather Service first-order precipitation stations used in synthesis of peak-flow data

Station number	Station name	Latitude	Longitude	Period of record (water years)
W14819	Chicago, Ill.	41°47′	87°45′	1902-74
W14842	Peoria, Ill.	40°40′	89°41′	1905-74
W93822	Springfield, Ill.	39°50′	89°40′	1904-74
W93863	St. Louis, Mo.	38°45′	90°23′	1905-70
W93809	Cairo, Ill.	37°00′	89°10′	1908-74

Generating synthetic flow data required records of daily precipitation for nonstorm periods and unit precipitation for storm periods. Both daily and unit precipitation data for the five sites were obtained from the Weather Service. The retrieval of unit rainfall information in 5-minute increments from recorder charts is tedious, time consuming, and expensive. Therefore, only those periods most likely to produce the annual peak were retrieved. In many instances more than one peak was retrieved for a given water year in order to insure that the peak having the maximum discharge (annual peak) would be used in the frequency study.

The daily evaporation data at Urbana was used for flood-peak synthesis at the 30 sites for which the model was calibrated. Data at the present location is significantly different from that at the previous site. The 1963-74 evaporation record was used to generate a synthetic daily evaporation record for the period 1901-63 using a harmonic (sine-cosine) function. Experience had shown that model outputs were relatively insensitive to the day-to-day variations in evaporation data and that an evaporation record may be applicable to large regions.

Five series of synthetic annual peak discharges were generated for each of the 30 sites by utilizing the data from each of the five long-term rainfall gages and one evaporation gage. These five series of synthetic annual peaks were then used to develop flood-frequency curves.

Flood-frequency Analyses

A flood-frequency relation or curve defines the relation of flood-peak magnitude to exceedance probability or recurrence interval. Exceedance probability is the percentage chance that a given magnitude will be exceeded in any one year. Recurrence interval is the reciprocal of the exceedance probability times 100, and is the average time interval between actual occurrences of a flood peak of a given or greater magnitude. For example, a flood having an exceedance probability of 1 percent has a recurrence interval of 100 years; or, a 100-year flood may be exceeded on the average of once in 100 years. However, probability only describes the likelihood of a random event occurring and a flood magnitude of a given recurrence interval may be exceeded in a much shorter period of time, such as successive weeks or months.

Flood-frequency relations for gaging stations were defined using the U.S. Water Resources Council (1976) guidelines. These guidelines outline procedures to fit observed annual peak data to the log-Pearson Type III distribution.

A computer program was used to perform log-Pearson Type III computations and frequency plots for each gaging station. The computer operation was performed in the following manner:

An array of N annual flood peak discharges (Q) at a station were transformed into an array of corresponding base 10 logarithmic values (Xi)

$$X_1, X_2, \ldots\ldots\ldots\ldots X_N$$

and the means of the logarithms were computed by

$$\bar{X} = \frac{\Sigma X}{N}. \tag{1}$$

Next the standard deviation (SD) and skew coefficient (G) were computed by

$$SD = \left[\frac{(\Sigma X^2) - (\Sigma X)^2/N}{(N-1)}\right]^{0.5} \tag{2}$$

and

$$G = \frac{N\,\Sigma(X-\bar{X})^3}{(N-1)(N-2)(SD)^3}\text{, respectively.} \tag{3}$$

The technique for fitting log-Pearson Type III distributions to observed annual peaks is to compute the base 10 logarithms of the discharge, Q, at selected exceedance probability, P, by the equation:

$$\text{Log } Q = \bar{X} + K(SD) \tag{4}$$

where $\bar{X}$ is the mean of the logs of the annual peaks at a gaging station, K is a factor from tables in U.S. Water Resources Council Guidelines (1976) that is a function of the skew coefficient (G) and selected exceedance probability. The antilog of log Q is the flood discharge (Q).

The skew coefficient of a station record is sensitive to extreme events. Therefore accurate estimates require a long period of record and use a generalized estimate of the skew is recommended (U.S. Water Resources Council, 1976) for stations with short periods of record.

For this study logarithms of annual peak discharges were fitted to the log-Pearson Type III distribution giving weight to historical peaks and high outliers, omitting low outliers and using the generalized skew map of the U.S. Water Resources Council (1976). For stations having less than 25 years of record the generalized skew was used directly for computing the frequency relation. For those stations with record lengths longer than 25 years, the station skew was weighted with the generalized skew. A weighted skew is calculated by giving the station skew a weight of (N - 25)/75 in which N is the length of record and the generalized skew is given a weight of 1.0 minus (N - 25)/75. If records of 100 years or more were available, station skew would have been used. Log-Pearson Type III statistics used to develop the frequency relations are shown for each station in Curtis (1977).

Five synthetic station frequency curves were developed at each of the 30 modeled stations, and a sixth frequency curve was developed at each station using actual data. Two separate procedures were necessary to combine the various frequency curves into one meaningful station frequency curve. The first procedure combined the five synthetic curves at each site into one synthetic curve. The second combined the synthetic curve with the frequency curve derived from observed data. The combination of synthetic estimates of selected frequency floods with similar estimates from actual station data at each site increased the effective length of record.

In the first procedure, the synthetic flood estimate for any specified recurrence interval in years (T-year) is related to drainage area and a combination of model parameters given in table 3. The relationship was defined by regression analyses using the five synthetic frequencies for a given T-year flood as the dependent variable and the model parameters for volume and shape of the hydrograph as the independent variables. The estimating equation for the long-term precipitation stations is written as:

$$Q_{T_S} = a\, VAR^b\, FR^c\, DA \tag{5}$$

where: Q_{T_S} - the synthetic T-year flood estimate based on rainfall data at the respective rainfall station, in cubic feet per second. Q_{T_S} was normalized by drainage area for each precipitation station; therefore, drainage area is equal to 1.

a - regression constant.

VAR - an index of the dispersion about the mean arrival time (lag), in hours. This factor describes the hydrograph shape. R. W. Lichty (oral commun., 1976) states that the variance, VAR, of the routing system is defined by:

$$VAR = KSW^2 + (TC/60)^2/24. \tag{6}$$

FR - infiltration rate, in inches per hour. This factor describes the hydrograph volume. The infiltration rate was computed using a simplification of equations 5 and 6 in Dawdy, Lichty, and Bergmann (1972, p. B6).

$$FR = KSAT\,[1.0 + 0.50\, PSP\, (0.15\, RGF + 0.85)] \tag{7}$$

b,c - regression coefficients.

DA - contributing drainage in square miles.

The synthetic estimating equations derived for the 2- and 50-year floods for each long-term rainfall station are:

Precipitation Station	Equation	Standard Error in Percent	
Chicago	$Q_2 = 70\ VAR^{-0.393}\ FR^{-0.678}\ DA$	14.6	(8)
	$Q_{50} = 442\ VAR^{-0.348}\ FR^{-0.259}\ DA$	13.2	(9)
Peoria	$Q_2 = 103\ VAR^{-0.378}\ FR^{-0.556}\ DA$	13.9	(10)
	$Q_{50} = 472\ VAR^{-0.338}\ FR^{-0.166}\ DA$	12.3	(11)
Springfield	$Q_2 = 94\ VAR^{-0.373}\ FR^{-0.556}\ DA$	14.6	(12)
	$Q_{50} = 525\ VAR^{-0.342}\ FR^{-0.177}\ DA$	12.1	(13)
St. Louis	$Q_2 = 98\ VAR^{-0.378}\ FR^{-0.577}\ DA$	14.6	(14)
	$Q_{50} = 605\ VAR^{-0.323}\ FR^{-0.181}\ DA$	12.3	(15)
Cairo	$Q_2 = 155\ VAR^{-0.328}\ FR^{-0.397}\ DA$	12.3	(16)
	$Q_{50} = 646\ VAR^{-0.306}\ FR^{-0.141}\ DA$	9.9	(17)

The constant and coefficients in equations 8-17 were plotted against latitude to develop the relationships in figure 2. A combined synthetic frequency curve was computed for each modeled station by selecting the appropriate regression constant and coefficients from figure 2 and solving equation 5.

The combined station synthetic Q_2 for one station with a drainage area of 2.20 mi^2 and located at latitude of 40.07 degrees (03338100) is determined step-wise as follows:

1. VAR is computed from equation 6

$$VAR = KSW^2 + (TC/60)^2/24$$

$$= 2.540^2 + 2.900^2/24$$

$$= 6.802 \text{ hours}$$

KSW and TC are obtained from table 3. Note: TC was transformed into hours by dividing TC/60.

2. FR is computed by equation 7

$$FR = KSAT\ [1.0 + 0.50\ PSP\ (0.15\ RGF + 0.85)]$$

$$= 0.054\ [1.0 + 0.50 \cdot 1.711\ (0.15 \cdot 24.908 + 0.85)]$$

$$= 0.266 \text{ inches/hour}$$

KSAT, PSP, and RGF are obtained from table 3.

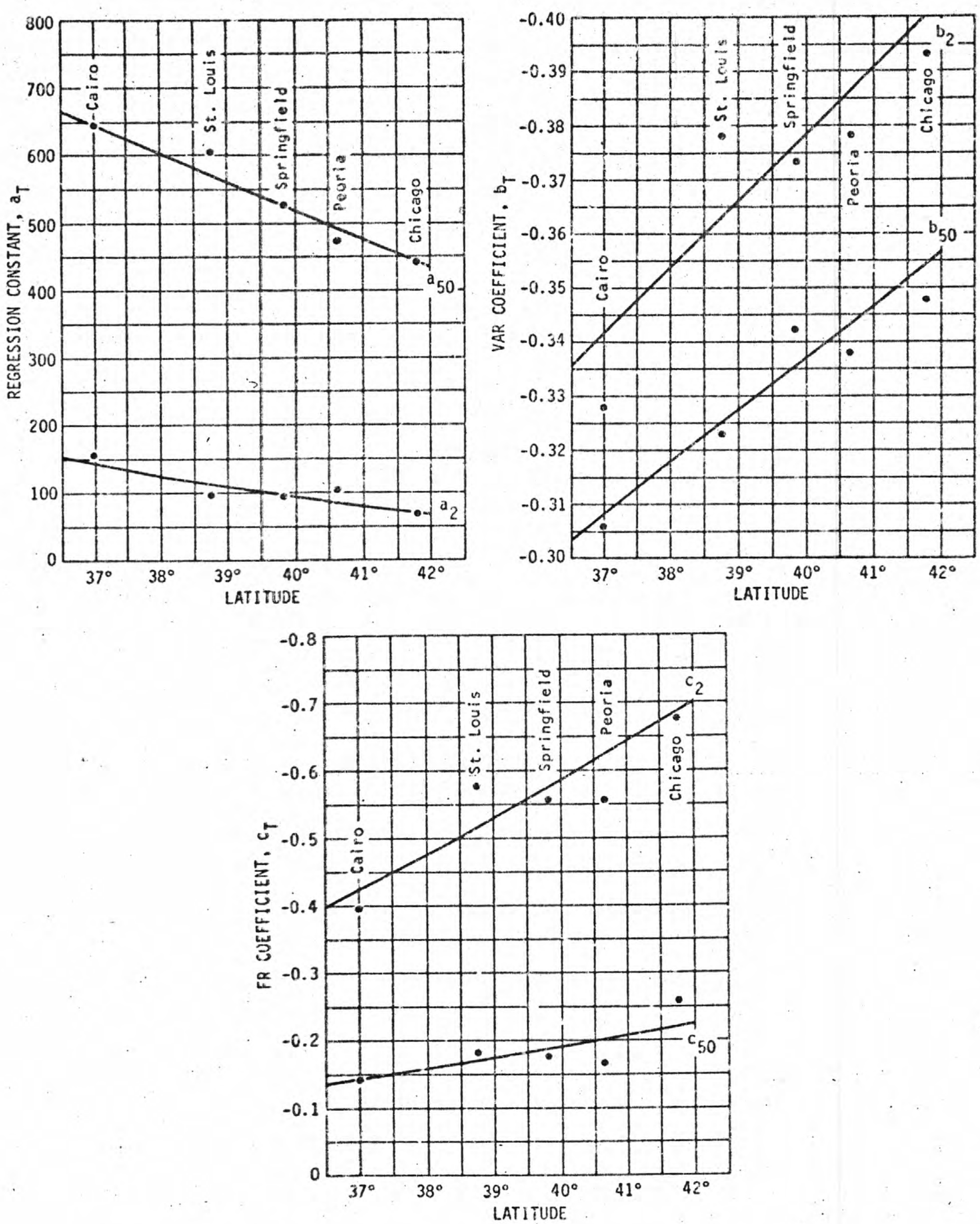

Figure 2.-- Relation between latitude and regression constant (a_T), VAR coefficient (b_T), and FR coefficient (c_T).

3. The regression constant, a_2, for latitude 40.07° from the a_2 curve in figure 2 = 95.

4. The VAR coefficient, b_2, for latitude 40.07° from the b_2 curve in figure 2 = -0.380.

5. The FR coefficient, c_2, for latitude 40.07° from the c_2 curve in figure 2 = -0.590.

6. Using equation 5 and the above values

$$Q_2 = a\,VAR^b\,FR^c\,DA$$

$$= 95\,(6.802^{-0.380})\,(0.266^{-0.590})\,(2.20)$$

$$= 220 \text{ cubic feet per second.}$$

The "VAR-FR" method (equation 5) produces estimates of Q_2 and Q_{50} for any site after the model parameters are determined. It is not necessary to generate synthetic flood peaks from each of the long-term rainfall stations.

The second procedure combined the station synthetic frequency curve and the observed station frequency curve into a final curve. Small stream stations had record lengths ranging from 15 to 25 years. Because of the significant amount of observed data, a frequency curve developed by combining the observed and synthetic data was desirable.

In order to objectively proportion the difference in the two estimates, some measure of their relative accuracy at various recurrence intervals was required. A technique was used which weighted the pairs of T-year discharges on the inverse ratio of their variance. The variance of the synthetic data could not be directly estimated but was obtained in the following analysis. The total variance between synthetic and observed estimates of discharge was computed as the mean square error using the equation:

$$V_r = \frac{1}{N} \sum_{i=1}^{N} (\log \hat{q}/q)^2 \tag{18}$$

where: V_r = total variance.

$\hat{q}$ = estimated discharge from synthetic station curve.

q = estimated discharge from observed station curve.

N = number of stations.

The variance, V_r, is predominately caused by errors associated with the observed data and regression model error or errors associated with the synthesized data. The equation for total error may then be written as (R. W. Lichty, oral commun., 1976):

$$V_r = \bar{V}_m + \bar{V}_t\,(1 - \rho) \tag{19}$$

where: $\overline{V}_m$ = average variance of synthetic estimates of discharge for a T-year recurrence interval.

$\overline{V}_t$ = average time-sampling variance of the observed estimate of discharge for a T-year recurrence interval.

ρ = the average interstation correlation coefficient for annual peaks.

The average time-sampling variance and average interstation correlation coefficients are described by Hardison (1971). An interstation correlation coefficient of 0.10 was computed for the modeled stations. Because the coefficient has negligible effect, independence of data was assumed and ρ was set at zero. The equation now becomes:

$$V_r = \overline{V}_m + \overline{V}_t \tag{20}$$

The average time-sampling variance of the observed estimate of Q_T was computed using:

$$\overline{V}_t = \frac{1}{N} \sum_{i=1}^{N} V_t \tag{21}$$

where: V_t = time-sampling variance of the observed estimate of Q_T at a station.

N = number of stations used in the sample size.

The station time-sampling variance, V_t, was computed using the equation:

$$V_t = R^2 I_v^2/N \tag{22}$$

where: R = a factor relating standard error of a T-year event to I_v and $\sqrt{N}$.

I_v = index of variability equal to standard deviation of logarithms of annual events.

N = number of annual events.

Equation 22 is a modification of Hardison's (1971, p. C231) equation for computing the average variance of the time-sampling error. Values of R were obtained from Hardison (1971, table 2, p. C230). The index of variability, I_v, was obtained from the log-Pearson Type III frequency distribution for the station.

The average variance of the synthetic estimates of discharge can be obtained by transposing equation 20:

$$\overline{V}_m = V_r - \overline{V}_t . \tag{23}$$

The weighting factors for obtaining the best curve from the observed and synthetic frequency curves was determined by:

$$W_{obs_T} = \frac{\bar{V}_m}{V_m + V_t} \tag{24}$$

and

$$W_{syn_T} = 1 - W_{obs_T} \tag{25}$$

where: W_{obs_T} = the weighting factor for the observed station curve for a T-year recurrence interval.

W_{syn_T} = the weighting factor for the synthetic station curve for a T-year recurrence interval.

The final weighted station frequency value was computed using:

$$Q_T = W_{obs}\,Q_{T_{obs}} + W_{syn}\,Q_{T_{syn}} \tag{26}$$

The individual station weighting factors were computed for the 2- and 50-year floods at each of the 30 calibrated stations, and for the 50-year flood at the 24 partially calibrated stations. Weighting factors were not used for the 2-year flood for the partially calibrated stations (see following sections for explanation). The average weighting factors for the observed and synthetic estimates are given below:

Recurrence interval, in years	Weighting factors	
	Observed	Synthetic
2	.85	.15
50	.50	.50

Modeling Stations with Partial Calibration

The "VAR-FR" method made it feasible to utilize a second group of 24 small-stream stations, having less than six recorded storm events, in the modeling phase. These stations are referred to as the partially-calibrated stations (fig. 1) and have drainage areas ranging from 0.02 to 10.2 mi^2 (table 5). The basin routing characteristics (shaping effect) TC and KSW (table 5) for these stations were determined and used as unpublished supporting data in Mitchell's (1972) report. Mitchell referred to the characteristics as T and k, respectively. By using an estimated infiltration rate (volume effect) FR, a long-term station synthetic discharge was determined from equation 5. The estimated infiltration rate for the partially-calibrated stations was the average infiltration value computed, using equation 7, for the 30 calibrated stations. Thus, by using an average infiltration value and the "VAR-FR" method the record for each partially-calibrated station was extended in time in the same manner as the calibrated stations.

The synthetic and observed station-frequency curves for the 50-year flood for the 24 partially-calibrated stations were combined using the same weighting technique as used for the calibrated stations.

Table 5.—Small-stream stations for which the model was partially calibrated

Station Number	Station Name	Drainage Area (mi²)	Annual Peak Record (water years)	Continuous Record (water years)	KSW (hr)	TC (min)
03336100	Big Four Ditch trib. nr Paxton	1.05	1956-75	1956-57	1.350	221.0
03338800	N. Fk. Vermilion River trib. nr Danville	1.31	1956-75	1956	1.030	102.0
03341900	Raccoon Creek trib. nr Annapolis	.04	1956-75	1957-59	.250	16.4
03344500	Range Creek nr Casey	7.61	1951-75	1960-62	2.980	215.0
03378650	Second Creek trib. at Keptown	1.62	1956-72	1957	1.460	91.2
03379650	Madden Creek nr West Salem	1.62	1956-75	1958-59	.750	150.0
03385500	Lake Glendale Inlet nr Dixon Springs	1.05	1955-75	1960-63	.683	60.6
03612200	Q ditch trib. nr Choat	.27	1956-75	1960	.398	51.3
05435000	Cedar Creek nr Winslow	1.31	1951-75	1960-69	1.340	96.6
05440900	Leaf River trib. nr Forreston	.15	1956-75	1965-71	.218	19.7
05496900	Homan Creek trib. nr Quincy	.50	1956-75	1963-65	.296	30.1
05513200	Salt Spring Creek nr Gilead	1.20	1956-75	1961-62	.288	34.5
05525050	Eastburn Hollow nr Sheldon	10.2	1956-72	1956	7.180	419.0
05526150	Kankakee River trib. nr Bourbonnais	.19	1956-75	1956-57	.405	53.0
05563100	Kickapoo Creek trib. nr Kickapoo	.07	1956-75	1964-66	.284	28.5
05569825	Cedar Creek trib. at St. Augustine	4.06	1956-75	1963-70	1.700	201.0
05579750	Kickapoo Creek trib. at Heyworth	3.06	1956-73	1957-67	1.780	151.0
05582200	Cabiness Creek trib. nr Petersburg	.94	1956-75	1962-68	1.100	82.8
05585220	Indian Creek trib. nr Sinclair	3.58	1956-75	1962-68	.945	100.0
05585700	Dry Fork trib. nr Mount Sterling	.15	1956-75	1963-64	.392	21.9
05586200	Illinois River trib. at Florence	.49	1956-75	1961-68	.175	30.9
05586850	Bear Creek trib. nr Reeders	.02	1956-75	1961-68	.583	12.9
05592025	Mud Creek trib. nr Tower Hill	.20	1956-75	1956	.463	34.8
05592700	Hurricane Creek trib. nr Witt	.14	1956-75	1958-61	.557	53.3

Definition of Station-Frequency Curve for Modeled Stations

The 2- and 50-year flood discharges for the calibrated stations were determined using the method outlined in a previous section and are considered the best estimate of the 2- and 50-year floods at the station.

The synthetic record obtained using a value for average infiltration rate in the "VAR-FR" method of record extension, does not improve the estimate at the 2-year flood level for the partially-calibrated stations. Because the record was of sufficient length, the 2-year floods for the partially-calibrated stations were based on observed data. (See table 5.) The 50-year flood discharges for these 24 stations were determined using the same method as for the calibrated stations.

The 2- and 50-year flood estimates provided two points on the station frequency curve and a basis for determining the magnitudes for other recurrence intervals. The magnitudes (Q_T) for the 5-, 10-, 25-, 100-, and 500-year recurrence-interval floods were computed using the 2- and 50-year flood magnitudes obtained from modeling and the generalized skew coefficient from U.S. Water Resources Council (1976, Plate I). The first step was to compute a synthetic logarithmic standard deviation, SD_s, required to make a log-Pearson Type III curve with a generalized skew coefficient pass through the computed Q_2 and Q_{50}, using the equation:

$$SD_s = \log(Q_{50}/Q_2)/DK \qquad (27)$$

in which DK, the increment ($K_{50} - K_2$) from the table of K values in U.S. Water Resources Council (1976) varies with the generalized skew coefficient. The next step was to compute a logarithmic mean, $\overline{X}$, by the equation:

$$\overline{X} = \log(Q_2) - K_2\,(SD_s)\,. \qquad (28)$$

The logarithmic mean and synthetic standard deviation, when used with the generalized skew coefficient, gave a log-Pearson Type III curve that passed through the 2- and 50-year discharges. In the last step, discharges were computed for the 5-, 10-, 25-, 100-, and 500-year floods using the equation:

$$\log Q_T = \overline{X} + K\,(SD_s)\,. \qquad (29)$$

Non-Modeled Stations

The crest-stage gaging stations from which only observed flood peaks were used constitute the third and last group of small-stream stations used in the frequency study. There were 33 crest-stage gaging stations (table 6) where adequate lengths of annual peak flow records were available. Flood-frequency curves were developed for these stations using observed data and the log-Pearson Type III frequency distribution.

Magnitudes for the 2-, 5-, 10-, 25-, 50-, and 100-year floods for all small-stream stations are included in Curtis (1977).

Table 6.–Period of record and drainage area for non-modeled small-stream stations

Station Number	Station name	Drainage Area (mi^2)	Annual Peak Record (water years)
03341700	Big Creek trib. nr Dudley	1.08	1961-75
03344425	Muddy Creek trib. at Woodbury	.07	1959-75
03378980	Little Wabash River trib. at Clay City	.43	1959-75
03380400	Horse Creek trib. nr Cartter	1.13	1961-72
03382520	Black Branch trib. nr Junction	1.10	1960-72
03614000	Hess Bayou trib. nr Mound City	1.95	1959-72
04087300	Lake Michigan trib. at Winthrop Harbor	1.50	1956-72
05418750	South Fork Apple River nr Nora	1.93	1961-75
05418980	Apple River trib. nr Hanover	1.55	1968-75
05435650	Lost Creek trib. nr Shannon	1.95	1961-75
05436900	Otter Creek trib. nr Durand	.52	1961-75
05437600	Rock River trib. nr Rockton	2.21	1951-75
05438300	Lawrence Creek trib. nr Harvard	.84	1961-75
05440650	Stillman Creek trib. nr Holcomb	1.00	1959-75
05444100	Spring Creek trib. nr Coleta	1.42	1959-72
05446950	Green River trib. nr Amboy	.53	1961-75
05447050	Green River trib. nr Ohio	4.95	1959-72
05447350	Mud Creek trib. nr Atkinson	1.22	1961-75
05501500	Burton Creek trib. nr Burton	.32	1961-74
05539950	Klein Creek at Carol Stream	8.81	1961-75
05540140	East Branch Du Page River nr Bloomingdale	3.03	1961-75
05549900	Fox River trib. nr Cary	.07	1956-75
05551650	Lake Run trib. nr Batavia	2.11	1961-75
05555775	Vermilion Creek trib. at Meriden	.36	1959-71
05559000	Gimlet Creek at Sparland	5.66	1946-47, 1950-75
05567800	Indian Creek trib. nr Hopedale	.98	1960-71
05568850	Forman Creek trib. nr Victoria	1.00	1961-75
05584450	Wigwam Hollow Creek nr Macomb	.60	1961-75
05586350	Little Sandy Creek trib. nr Murrayville	1.82	1961-72
05591750	Stringtown Branch trib. nr Lake City	.70	1961-75
05595510	Lick Branch nr Eden	1.22	1959-72
05599560	Clay Lick Creek nr Makanda	1.94	1960-75
05599800	Orchard Creek nr Fayville	.09	1961-72

LARGE STREAMS

Peak discharges from 154 stations having drainage areas ranging from 11.0 to 9,550 mi^2 (28.5 to 24,700 km^2) were used in defining flood-frequency relations for Illinois. A large stream, as used in this report, is defined as a stream having a drainage area larger than about 10 mi^2 (26 km^2). One hundred forty-three (143) of these stations were located in Illinois, 4 stations in Indiana, and 7 stations in Wisconsin. Locations of the gaging stations are shown in figure 1.

The frequency analyses for this report were based on flood records collected through September 30, 1975. Only those records with at least 10 years of flood peak data were used. The flood-frequency curves for the individual stations were computed using equation 4. The discharge values from the individual station curve for recurrence intervals of 2-, 5-, 10-, 25-, 50-, and 100-years are included in Curtis (1977).

REGIONAL ANALYSES

Streamflow records are not available at most sites where information is needed. Therefore, gaging-station data must be interpreted and relationships developed to apply to ungaged sites. Because flood-frequency data from individual gaging stations have limited transferability, estimates of flood magnitudes and frequencies at ungaged sites should be based on regionalized relationships developed from all applicable station data. The advantage of a regional analysis is that flood-frequency relationships are applicable to an entire region rather than to an individual station. Stations were omitted from the regional analyses if 25 percent or more of the drainage area at a gage was above a reservoir or if flood peaks at that gage were known to be regulated.

Multiple-regression analyses were used to develop equations relating the most significant watershed characteristics to peak-flow characteristics. Discharges corresponding to the 2-, 5-, 10-, 25-, 50-, 100-, and 500-year recurrence-interval flood developed at all stations by using the log-Pearson Type III distribution were regressed against various watershed and climatic variables using the multiple regression model:

$$Q_T = a A^b B^c \ldots\ldots\ldots N^n \qquad (30)$$

where: Q_T = flood magnitude, in cubic feet per second, having a T-year recurrence interval.

A,B,...N = drainage basin and climatic variables.

b, c,...n = regression coefficients.

a = regression constant.

The computer program for the regression analysis defined the regression constant and coefficients, evaluated the statistical significance of each watershed characteristic, and provided a standard error of estimate.

Many exploratory analyses were made to evaluate watershed characteristics. Equations were developed using combinations of independent variables such as drainage area, main channel length, main channel slope basin shape, soil index factor, forest cover, mean annual precipitation, rainfall intensity index, storage (lakes and ponds), and soil runoff coefficient versus the dependent variable T-year recurrence interval flood in the multiple regression analyses. The most significant independent variables were drainage area (A) slope (S), and rainfall intensity (I).

Flood-frequency equations, applicable Statewide, were developed to estimate magnitude and frequency of floods on natural-flow streams in Illinois. The equations were developed from 241 stream-gaging station data collected throughout Illinois and near the boundaries in adjoining states for drainage areas ranging from 0.02 to 9,550 mi^2 (0.05 to 24,700 km^2). The recommended final Statewide flood-frequency estimating equations are as follows:

<u>Equation</u>

$$Q_2 = 42.7\, A^{0.776}\, S^{0.466}\, (I - 2.5)^{0.834}\, Af \quad (31)$$

$$Q_5 = 71.1\, A^{0.769}\, S^{0.485}\, (I - 2.5)^{0.833}\, Af \quad (32)$$

$$Q_{10} = 90.8\, A^{0.767}\, S^{0.494}\, (I - 2.5)^{0.833}\, Af \quad (33)$$

$$Q_{25} = 115\, A^{0.764}\, S^{0.504}\, (I - 2.5)^{0.834}\, Af \quad (34)$$

$$Q_{50} = 134\, A^{0.763}\, S^{0.510}\, (I - 2.5)^{0.836}\, Af \quad (35)$$

$$Q_{100} = 152\, A^{0.762}\, S^{0.515}\, (I - 2.5)^{0.836}\, Af \quad (36)$$

$$Q_{500} = 191\, A^{0.761}\, S^{0.528}\, (I - 2.5)^{0.837}\, Af \quad (37)$$

These equations give the best estimate with a minimum number of independent variables. There are four variables required to solve the equations: drainage area (A), main-channel slope (S), rainfall intensity (I), and areal factor (Af). Drainage area, in square miles, and main-channel slope, in feet per mile, are determined from topographic maps. Slope is the main-channel slope and is determined between points 10 percent and 85 percent of the total distance measured along the low-water channel from the site to the basin divide. The rainfall intensity is the maximum 24-hour rainfall, in inches, expected to be equaled or exceeded on an average of once every 2 years. Rainfall intensity was obtained from Hershfield (1961). A constant of 2.5 was subtracted from the rainfall intensity so that the range and the magnitude of the regression coefficients for each recurrence interval would be small. The rainfall intensity and areal factor are determined from figures 3 and 4, respectively.

The techniques for estimating T-year floods on non-gaged streams using equations 31-37 and the necessary modifications applicable to making estimates of gaged streams are explained in Curtis (1977).

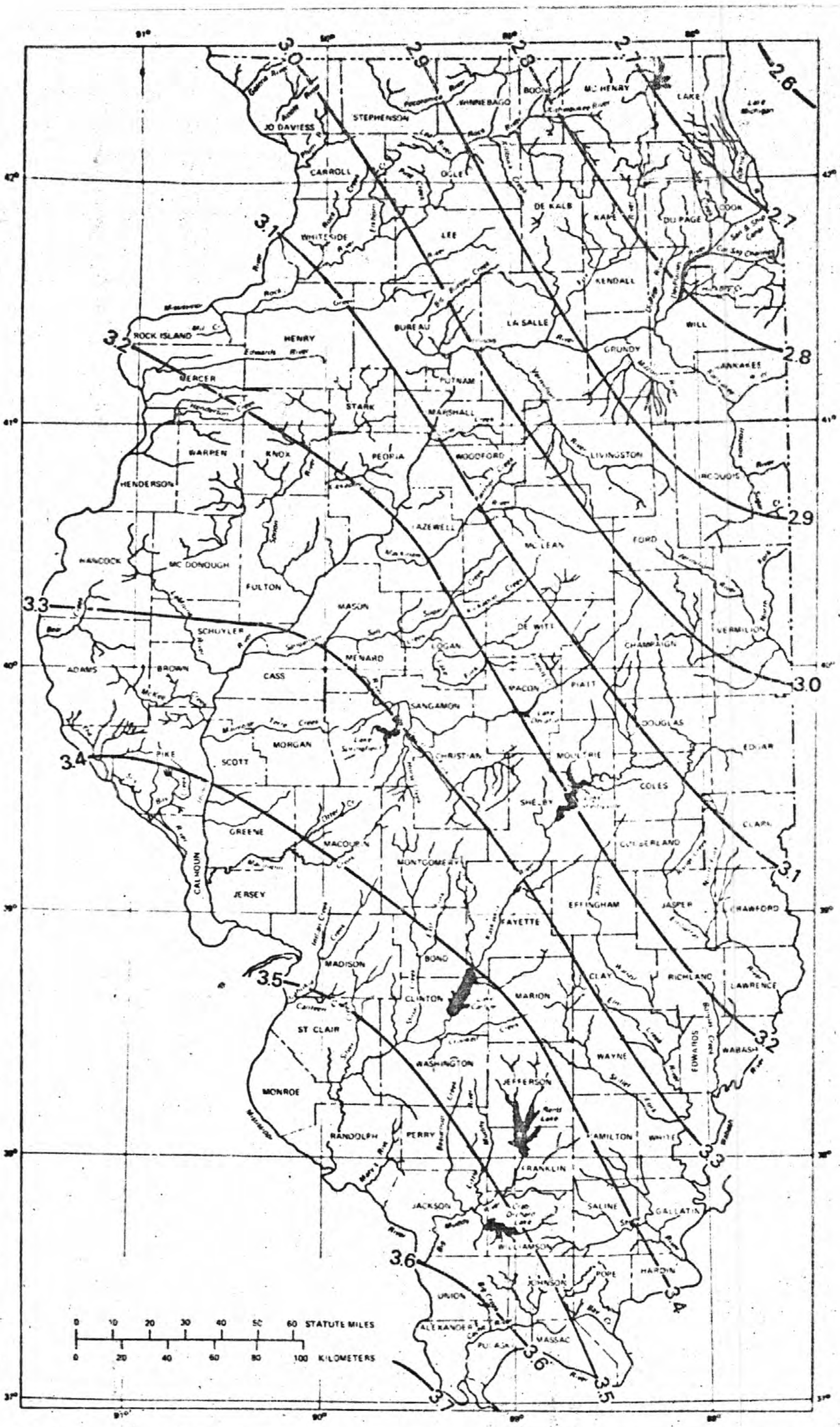

Figure 3.--Values of 24-hour 2-year rainfall, I, in inches (from Hershfield, 1961, and Carns, 1973).

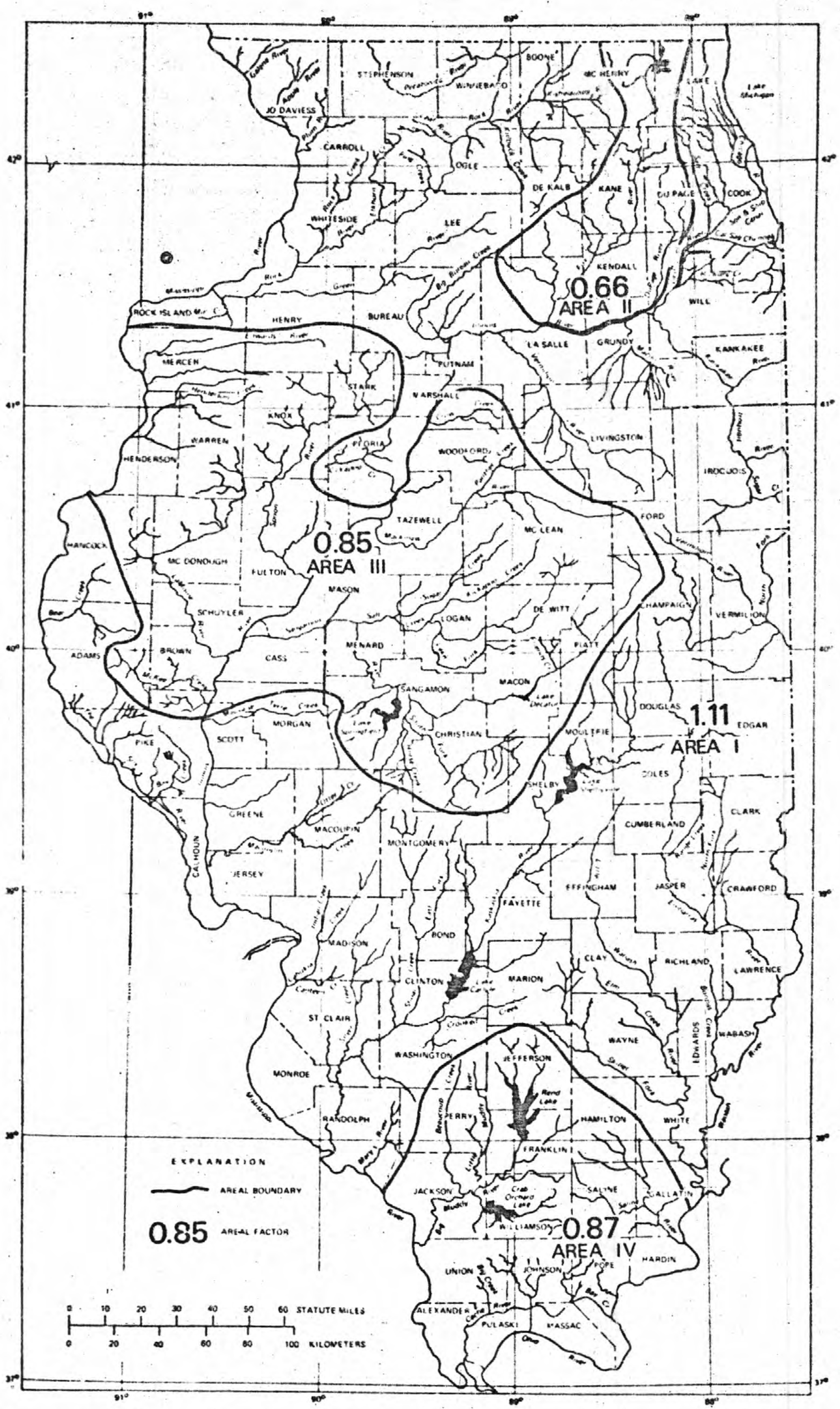

Figure 4.--Values and boundaries of areal adjustment factor, Af.

The Af was included in the estimating equations to remove areal bias in the flood estimates. The station values of T-year floods for each station were compared with the computed values using the regression equations to investigate possible areal variations. The residuals of station peak value to computed peak value were plotted on State maps and similar residual values showed areal patterns. Areal boundaries for four areas (fig. 4) were delineated giving consideration to physiographic divisions, watershed boundaries, and residual patterns. The areal factor was defined as the anti-log of the average residual within each area. The average residual, $\overline{Re}$, was computed by the equation:

$$\overline{Re} = \frac{1}{M} \sum_{i=1}^{M} (\text{log actual peak value} - \text{log computed peak value}) \qquad (38)$$

where: M = the number of stations in each area.

A summary of the areal factors determined for the estimating equations developed for drainage areas greater than 0.02 mi² (0.05 km²) is shown in table 7. Most design project floods are based on recurrence intervals not exceeding the 100-year flood, therefore, the 500-year flood was excluded from the averaging. The computed 500-year flood areal factors were 1.12, 0.63, 0.89, and 0.77 for areas I, II, III, and IV, respectively. The factors for the 500-year event, if included, would not significantly alter the average.

Table 7.—Areal factors, Af

Area	No. of stations	Factors for T-year recurrence interval						
		2	5	10	25	50	100	Average
I	157	1.11	1.11	1.11	1.12	1.12	1.12	1.11
II	13	.68	.67	.66	.65	.64	.64	.66
III	53	.81	.84	.85	.86	.87	.88	.85
IV	19	1.01	.92	.88	.84	.82	.80	.87

The inclusion of the Af reduced the standard error about 3 percent. Table 8 gives the standard error of estimate both with and without the areal factor.

Also, stations were grouped by size of drainage area and estimating equations developed. The standard error of estimates from the regressions were evaluated to determine whether several equations were required to adequately estimate the floods for all drainage areas. A summary of the standard error of estimate for equations developed from regression analyses, using the independent variables A, S, and I - 2.5, but without Af and grouped by drainage area size, is given in table 9. The reduction in standard error for the $.02 < DA < 10$ drainage area class is do to the effects of modeling. The rainfall-runoff model determined "average" model parameter values for a given basin and thereby reduces the variability of runoff. This "artificially" reduces the standard error in the regression analyses.

Table 8.–Standard error of estimate of estimating equations without and with the areal factor
(upper row is without Af and bottom row is with Af)

Area	No. of stations	Standard error (percent) for T-year recurrence interval						
		2	5	10	25	50	100	500
I	157	36.4 34.7	37.1 35.4	39.1 37.4	41.9 40.1	43.6 42.1	45.6 44.1	49.7 48.4
II	13	62.2 44.8	64.9 45.9	67.6 47.9	71.2 51.0	73.8 53.1	76.1 55.4	82.0 60.5
III	53	37.6 31.1	35.7 30.6	35.9 31.6	36.6 33.3	37.6 34.7	38.6 36.2	40.9 39.4
IV	19	28.5 32.1	29.0 28.0	32.8 29.7	37.8 33.3	41.6 36.4	45.1 39.4	52.5 45.9
Statewide	242	37.8 34.5	38.1 34.5	39.8 36.2	42.3 38.8	44.1 40.9	46.1 42.8	49.9 46.9
Percent of improvement	–	3.3	3.6	3.6	3.5	3.2	3.3	3.0

Table 9.–Summary of standard error of estimate for equations developed for drainage area size

Drainage Area (mi^2)	No. of stations	Standard error (percent) for T-year recurrence interval						
		2	5	10	25	50	100	500
>.02	242	37.8	38.1	39.8	42.3	44.1	45.1	49.9
>10	154	36.9	39.6	42.1	45.3	47.3	49.4	53.8
>50	125	28.2	31.6	34.2	37.6	39.6	41.9	46.1
>100	106	26.8	30.2	32.8	36.2	38.4	40.3	44.8
>200	82	25.4	29.0	31.6	34.5	36.4	38.4	42.6
.02<DA<10	87	38.1	35.2	37.4	36.4	37.6	38.8	41.6
10<DA<50	29	52.8	56.5	60.0	64.0	66.8	69.6	76.7
10<DA<100	48	37.8	43.8	52.0	55.9	58.6	61.1	67.0

The evaluation of the values in table 9 indicated that grouping stations by drainage area size does not produce equations having significantly improved standard error from that of one set of equations for all drainage areas. It is therefore recommended that one estimating equation for each flood frequency (equations 31-37) be used for all drainage areas larger than 0.02 mi^2 (0.05 km^2) in Illinois.

The equations are based on English units of measurement and are not applicable for use with metric units. To convert the final answers of discharge from cubic feet per second to cubic meters per second, multiply by the factor 0.0283.

Flood-frequency discharge equations may be developed for any recurrence interval between 2 and 100 years. The regression constant and coefficients for all parameters in equations 31-36 are plotted versus recurrence interval in figure 5. From figure 5 the constant and coefficients may be interpolated for any desired recurrence interval.

ACCURACY AND LIMITATION

The accuracy of a regression equation may be expressed in two ways. The standard error of estimate is the measure of the distribution of the observed data about the regression equation. For example, the standard errors of the estimating equations 31-37 are the ranges of error, expressed as percentages of the estimated values, within which about two-thirds of the estimates should fall. The accuracy of a regression may also be expressed in equivalent years of record. Equivalent years of record for equations 31-37 were determined using techniques developed by Hardison (1971). When converted to equivalent years of record, the standard error of estimate is expressed as the number of actual years of streamflow record needed at an ungaged site to provide an estimate equal in accuracy to the standard error of estimate. The accuracy of equations 31-37 is summarized in table 10.

Table 10.—Accuracy of estimating equations,
$Q_T = a\ A^b\ S^c\ (I - 2.5)^d\ Af$

Recurrence interval, in years	Standard error of estimate, in percent	Equivalent years of record
2	34.5	4
5	34.5	4
10	36.2	5
25	38.8	6
50	40.9	6
100	42.8	7
500	46.9	7

The flood-frequency equations in this report may be used to estimate magnitude and frequency of floods on most Illinois streams for drainage areas ranging from 0.02 to 10,000 mi^2 (0.05 to 25,900 km^2), slopes ranging from 0.7 to 250 ft/mi (0.13 to 47.4 m/km), and 24-hour 2-year rainfall intensity from 2.6 to 3.6 inches (66.0 to 91.4 mm). The equations are not applicable to streams where floodflows are appreciably affected by natural or reservoir storage; channel changes; diversions; urbanization; unusual hydrogeologic or morphologic conditions such as in karst terrane, bluff-flood plain combinations (streams that traverse the bluff and adjacent flood plain of major rivers), and so forth; or other unusual conditions that affect floodflow.

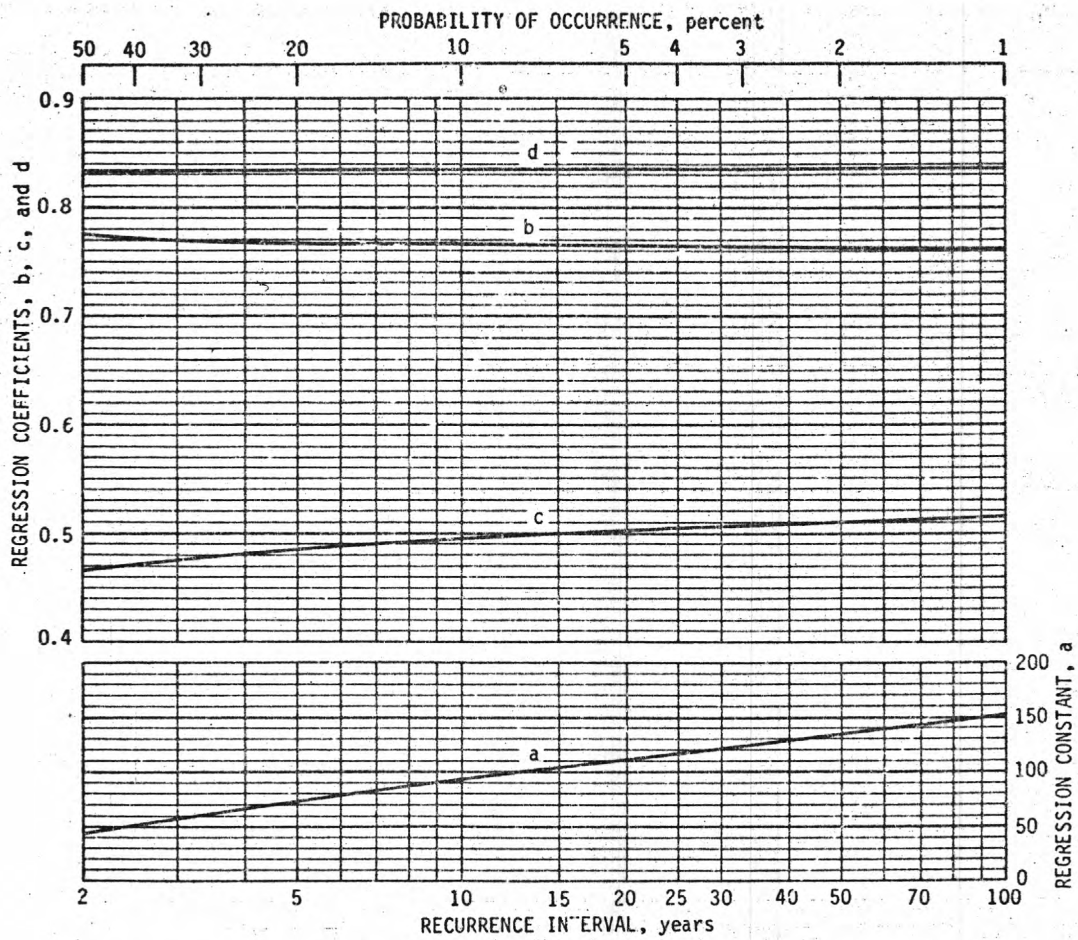

Figure 5.--Regression constant and coefficients for estimating equations, $Q_T = a\ A^b\ S^c\ (I - 2.5)^d\ Af$.

SUMMARY

Analyses of Illinois floods using observed and synthetic streamflow records were made to define magnitude and frequency relations for unregulated rural streams in Illinois. Equations, applicable Statewide, were developed to estimate magnitudes of floods having recurrence intervals of 2, 5, 10, 25, 50, 100, and 500 years for streams with drainage areas larger than 0.02 mi^2 (0.05 km^2). Data from 241 streamflow stations were used in the analyses. Eighty-seven stations were on small streams having drainage areas less than 10.2 mi^2 (26.4 km^2), and 154 stations were on large streams having drainage areas that range from 11.0 to 9,550 mi^2 (28.5 to 24,700 km^2).

Magnitude-frequency relations were defined using the log-Pearson Type III frequency distribution and guidelines outlined by the U.S. Water Resources Council (1976). Multiple regression analyses were used to develop the estimating equations.

A rainfall-runoff parametric model was used to extend records by synthesis on 54 small-stream stations. The model was calibrated for 30 of the stations and partially calibrated for the remaining 24 stations. The calibrated model was then used to generate synthetic flood peaks from rainfall records for each of five long-term U.S. Weather Service precipitation stations. Five synthetic frequency curves, and one frequency curve based on observed data, were defined for each of the 30 stations.

Two procedures were used to combine the curves into one station frequency curve. First, the five synthetic curves were combined into one synthetic curve; and secondly, the synthetic and observed data curves were combined into a final flood-frequency curve for the station. The method used in the procedure to define the one synthetic curve for the calibrated stations was also used to define a synthetic frequency curve for the 24 partially-calibrated stations.

The regression analyses indicated that the independent variables drainage area (A), slope (S), rainfall intensity (I), and an areal factor (Af) are the most significant for estimating flood peaks on Illinois streams. Furthermore, one estimating equation for each recurrence interval and one set of basin characteristics provide a straightforward technique for describing flood frequencies on both small and large Illinois streams.

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