IMPROVEMENT OF FLOOD-FREQUENCY ESTIMATES FOR SELECTED SMALL WATERSHEDS IN EASTERN KANSAS USING A RAINFALL-RUNOFF MODEL

by R. W. Clement

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CONTENTS

ILLUSTRATIONS

TABLES

INCH-POUND TO METRIC UNIT CONVERSION FACTORS

In this report all measurements are expressed in inch-pound units. The following table contains factors for converting these measurements to the International System of Units (SI).

Multiply inch-pound unit	By	To obtain SI unit
inch	25.4	millimeter
foot	0.3048	meter
mile	1.609	kilometer
square mile	2.590	square kilometer
cubic foot per second	0.02832	cubic meter per second
foot per mile	0.1894	meter per kilometer

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ABSTRACT

The U.S. Geological Survey rainfall-runoff model was calibrated for 13 small watersheds in eastern Kansas with drainage areas of less than 11 square miles and was used to synthesize long-term records of peak discharges for each watershed based on long-term rainfall records. Final flood-frequency relations were developed from weighted estimates of flood magnitude for specified recurrence intervals calculated from the long-term synthesized and from the short-term observed records. Use of long-term synthesized records provide better estimates of the flood-frequency relations by increasing the effective length of record.

INTRODUCTION

Streamflow data, including records of floods, have been collected for Kansas streams since 1895; however, the majority of these long-term data were collected for streams draining areas greater than 100 square miles. Prior to 1956, few data were available for streams draining areas of less than 100 square miles, and those data that were available were of insufficient length to develop reliable statewide flood-frequency estimates. This was especially true for streams having drainage areas of less than 10 square miles. Flood-frequency estimates for small streams are of vital concern to planners, designers, and engineers who are responsible for designing highway drainage structures and flood-control facilities.

In 1956, under a joint-funding agreement with the Kansas Department of Transportation, a study of flood-frequency relations for small streams was begun with the installation of 95 crest-stage gages at stream locations throughout the State; drainage areas upstream from the gages were less than 100 square miles. The objective of the program was to collect records of annual peak flows at a nominal expense, to use the collected peak data to develop flood-frequency relations at the gaged locations, and to extend the relations to ungaged sites. The primary disadvantage of the program was the time required to collect records of sufficient length to adequately define flood-frequency relations for long return periods.

In 1965, the program was expanded to take advantage of the U.S. Geological Survey rainfall-runoff model (Dawdy and others, 1972), which can synthesize long-term records of peak-flow data using long-term records of rainfall and evaporation. Model calibration is accomplished using short-term records of rainfall, runoff, and evaporation. Thirteen rainfall-runoff stations in eastern Kansas were selected for intensive data collection. Data collected at each station included simultaneous records of precipitation and stream discharge.

The results of this investigation will provide better estimates of the flood magnitudes and frequencies for small watersheds through increased reliability of estimates based on long-term data. These estimates will be included along with those from other long- and short-term records in a regional flood-frequency study that will investigate techniques for estimating flood magnitude and frequency at ungaged sites.

Purpose and Scope of Study

The purpose of this study was to improve flood-frequency estimates for small watersheds, generally those less than 10 square miles in size, using short-term observed and long-term synthesized data. Few long-term data were available for such watersheds, and the time required to collect the data was prohibitive. Hence, short-term records (8-10 years) of simultaneous rainfall and runoff were collected at 13 stations, and the runoff records extended (synthesized) based on long-term records of rainfall. The short- and long-term records were then used to develop improved floodfrequency estimates.

This report was prepared in cooperation with the Kansas Department of Transportation. Data for small watersheds used in this study were collected under a joint-funding agreement with the Department. Annual maximum-discharge data have been published by the U.S. Geological Survey (published annually). Long-term rainfall and evaporation data were obtained from the National Oceanic and Atmospheric Administration.

Previous Studies

Several investigations of the magnitude and frequency of floods for Kansas streams have been conducted in recent years. These studies used data collected at gaging stations and developed techniques for estimating flood magnitude and frequency at ungaged locations. The earliest of these studies was done by Ellis and Edelen (1960), who used data collected prior to 1956. However, the majority of these early data were collected at stations that had drainage areas larger than 150 square miles.

The first study that used data collected under the joint-funding agreement with the Kansas Department of Transportation was conducted by Irza (1966). The data included 8 years of record collected at 75 stations whose contributing-drainage areas ranged from 0.41 to 72.0 square miles. Statewide flood-frequency relations were developed by Irza (1966) using regression models to estimate the magnitude of floods having recurrence intervals of 1.2, 2.33, 5, and 10 years.

Patterson (1964) and Matthai (1968) used the index-flood method to estimate flood magnitudes in regional studies of the lower Mississippi River basin and the Missouri River basin below Sioux City, Iowa, respectively. Hedman and others (1974) investigated the relation of active-channel geometry to selected streamflow characteristics, including flood magnitudes.

Jordan and Irza (1975) developed statewide regression equations to determine flood magnitudes and frequencies using all available data through 1972 from streams having contributing drainages ranging from 0.41 to 19,260 square miles. The log-linear equations used contributing-drainage area and 2-year, 24-hour rainfall to estimate floods having recurrence intervals of 2, 5, 10, 25, 50, and 100 years.

Description of Study Area

The study area includes about one-third of Kansas and generally is east of the 97th meridian. Location of the 13 rainfall-runoff stations is shown in figure 1, and the stations are described in table 1.

The physiographic setting of the study area is the Central Lowlands province of the Interior Plains (Schoewe, 1949). This province is characterized by moderately rolling terrain typical of the tilted strata of the underlying bedrock, with relief of generally 250 to 350 feet. In Kansas, the Central Lowlands province is separated in a general way by the Kansas River into the Dissected Till Plains to the north and the Osage Plains to the south (fig. 1). The area north of the river has been modified by glacial drift that conceals or mantles the typically cuesta-type topography. The erodible surface of the till results in a more gentle, rounded landscape with somewhat wider basins. Five rainfall-runoff stations (06813700, 06815700, 06887600, 06888900, and 06890700) are located in the Dissected Till Plains. The remainder of the stations are located in the Osage Plains, which are characterized by westward-dipping bedrock of varying hardness that result in "east-facing" escarpments. Only one station (06856800) is located in the Flint Hills Upland section of the Osage Plains, and seven stations (06912300, 06913600, 06916700, 07166200, 06169200, 06169700, and 07182520) are in the Osage Cuestas section. Surface rock in the Flint Hills Upland is more resistant to erosion, hence the terrain is more gently rolling, whereas the alternating soft and hard strata of the rock in the Osage Cuestas result in greater erosion of the softer material, resulting in a more rolling terrain.

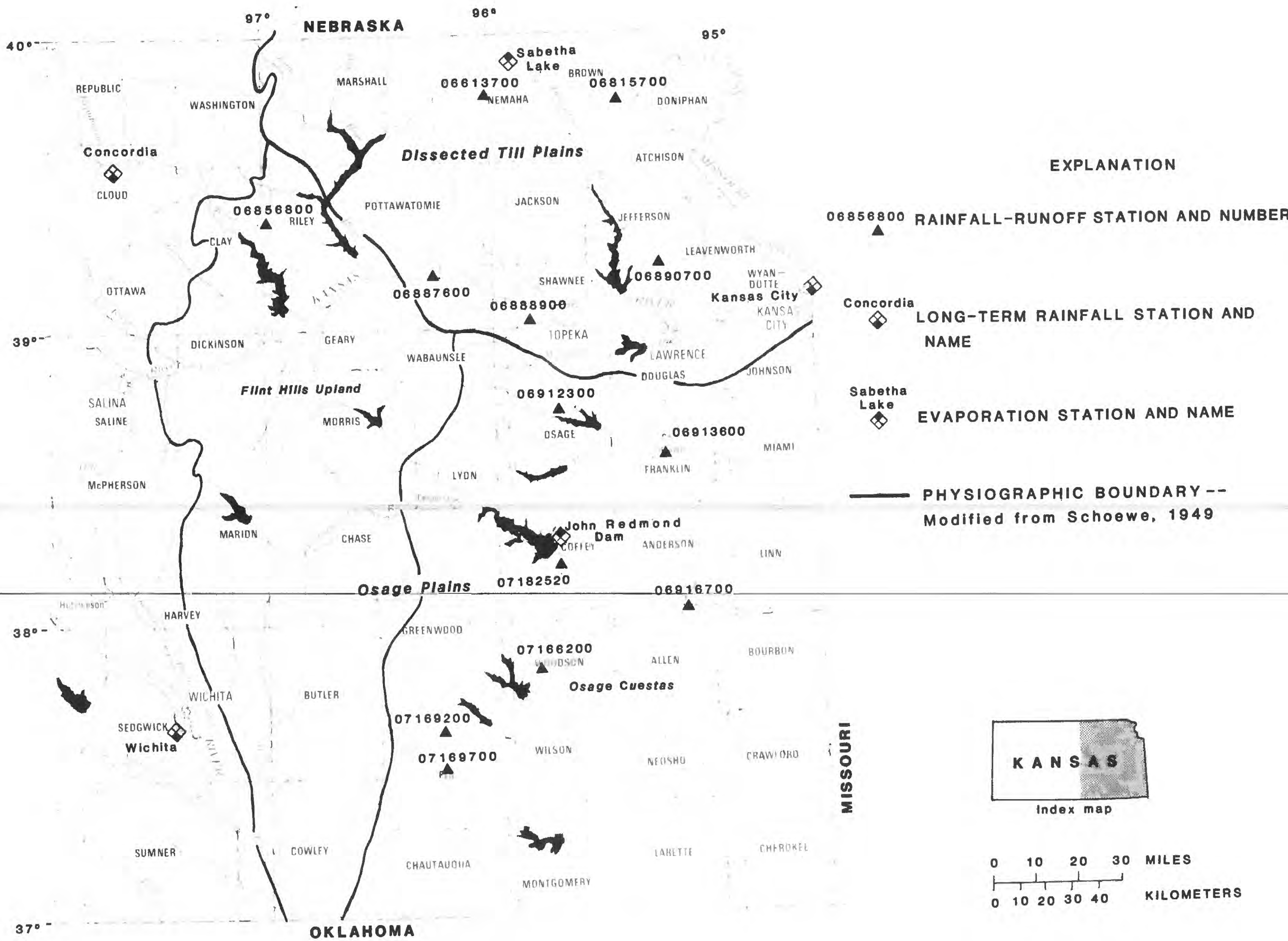

Figure 1.--Location of rainfall-runoff, evaporation, and long-term rainfall measurement stations.

Table 1.--Description of and periods of record for rainfall-runoff stations used in study

Station number and name		Period of record (water years) Annual peak data	Rainfall-runoff data
06813700	Tennessee Creek tributary near Seneca, Kans.	1957-79	1966-76
06815700	Buttermilk Creek near Willis, Kans.	1957-79	1966-74
06856800	Moll Creek near Green, Kans.	1957-79	1966-74
06887600	Kansas River tributary near Wamego, Kans.	1957-79	1966-76
06888900	Blacksmith Creek tributary near Valencia, Kans.	1957-79	1966-76
06890700	Slough Creek tributary near Oskaloosa, Kans.	1957-77	1966-76
06912300	Dragoon Creek tributary near Lyndon, Kans.	1957-79	1966-76
06913600	Rock Creek near Ottawa, Kans.	1957-77	1966-74
06916700	Middle Creek near Kincaid, Kans.	1957-79	1966-74
07166200	Sandy Creek near Yates Center, Kans.	1957-79	1966-76
07169200	Salt Creek near Severy, Kans.	1957-77	1966-76
07169700	Snake Creek near Howard, Kans.	1957-77	1966-76
07182520	Rock Creek at Burlington, Kans.	1957-77	1966-76

The climate of the study area generally is humid with cold winter and hot summer months. Average annual precipitation ranges from about 28 inches at the western edge of the study area to about 42 inches at the extreme southeast corner. Average annual lake evaporation ranges from about 43 inches at the eastern fringe to about 53 inches at the western edge. Most of the runoff originating in the area occurs as a result of severe thunderstorm activity during late spring and early summer; snowmelt flooding is not significant.

RAINFALL-RUNOFF MODEL

Description

The model used for this study is the U.S. Geological Survey rainfall-runoff model for rural watersheds, which has been described by Dawdy and others (1972) and documented for users by Carrigan and others (1977). The model generates a runoff hydrograph in response to a storm-rainfall sequence, using 10 parameters in the operation of the model. Each parameter or combination of parameters approximates a functional hydraulic or hydrologic process in the watershed as it represents one of the components of the hydrologic cycle. These components are antecedent soil-moisture accounting, infiltration, and surface-runoff routing. The parameters and their application in the model are listed in table 2. Each component is evaluated sequentially at which time the values of selected variables are computed based on mathematical relations using current parameter values and the input data. The resulting variables are used either within the component or passed on to the succeeding component. The basic structure of the model is illustrated in figure 2.

The antecedent soil-moisture component uses an accounting system to continually monitor the quantity of soil-moisture storage on a daily basis during non-storm periods. Accumulated rainfall and pan evaporation are used by the model on a daily basis to estimate the soil-moisture content prior to each major storm. At storm onset, the moisture-storage variables are passed to the infiltration component, which uses Philip's (1954) equation to estimate the infiltration-rate capability. The infiltration component continually monitors the changes in moisture storage and compares the infiltration rate with the storm-rainfall rate at each 15-minute interval. When the rainfall rate exceeds the infiltration rate the component determines the quantity of excess rainfall that becomes surface runoff. In the surface-runoff routing component, elements of excess rainfall are translated into a storm hydrograph using a modification of a routing procedure presented by Clark (1945).

The model is used with the assumption that the model parameters and the meteorological data represent average conditions for the entire watershed being modeled. Hence, applicability of the model is limited to watersheds that are small enough to ensure that these assumptions are reasonably valid. It generally is accepted that the model is best suited for watersheds smaller than 10 square miles.

Operation

The rainfall-runoff model operates in one of two separate modes--calibration and long-term synthesis. Model operation basically is the same in both modes. In both modes, the model uses records of daily rainfall and evaporation, rainfall sequences recorded at 15-minute intervals for selected storms, and a set of 10 model parameters to produce a synthesized runoff hydrograph for each storm by sequentially evaluating the three model components in response to the data. The primary differences between the two modes are the source of the rainfall data and the ultimate use of the resulting hydrographs. For example, the calibration mode requires the additional input of a runoff hydrograph derived from recorded data for each storm, which then is compared to the synthesized hydrograph.

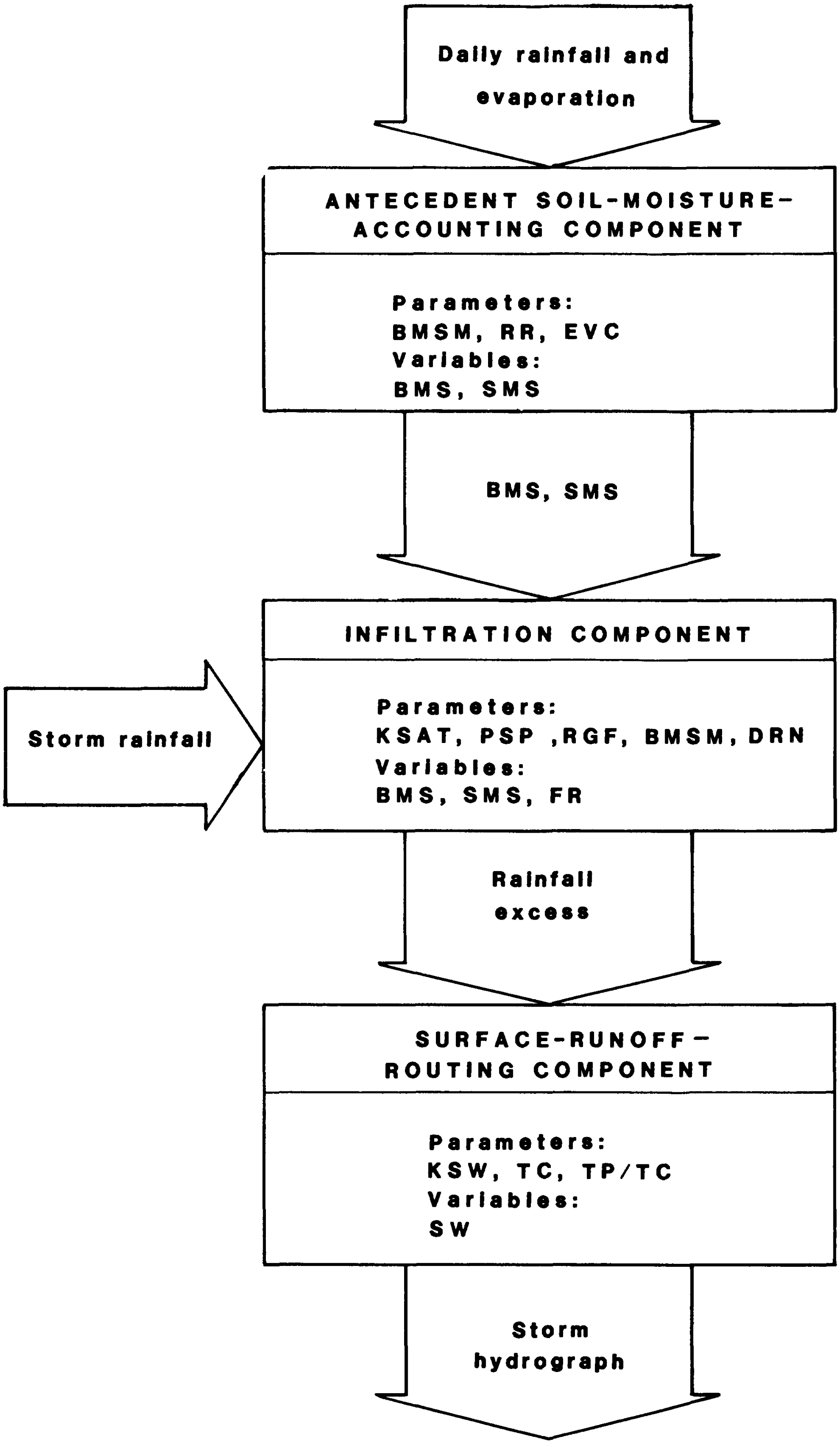

Figure 2.--Rainfall-runoff model operation.

Table 2.--Model parameters and variables

[Modified from Lichty and Liscum, 1978]

Parameter	Variable	Unit	Application in model
			Antecedent Soil-Moisture-Accounting Component
BMSM	-	Inches	Soil-moisture storage at field capacity. Primarily a function of the soil type.
RR	-	-	Coefficient that represents the proportion of daily rainfall that infiltrates the soil.
EVC	-	-	Coefficient to convert pan evaporation to potential evapotranspiration.
DRN	-	-	Drainage factor used with KSAT for redistribution of variable SMS to variable BMS - generally accepted as 1.0.
-	BMS	Inches	Base (unsaturated) moisture storage in soil column. Simulates antecedent moisture content - ranges from BMS=0 (wilting point) to BMS=BMSM (field capacity).
-	SMS	do	Saturated moisture storage in wetted surface layer (infiltrated moisture) that is redistributed by parameters DRN and KSAT.
			Infiltration Component
-	FR	Inches per hour	Infiltration rate - function of parameters KSAT, PSP, RGF, and BMSM and variables SMS and BMS.
KSAT	-	do	Maximum hydraulic conductivity of saturated soil - function of soil type.

Table 2.--Model parameters and variables--Continued

Parameter	Variable	Unit	Application in model
			Infiltration Component--Continued
PSP	-	Inches	Effect of moisture content and soil suction at wetted front for field capacity.
RGF	-	-	Ratio that varies the soil suction at wetted front when BMS = 0 (wilting point) to that when BMS = BMSM (field capacity) - function of soil types in watershed.
			Surface-Runoff-Routing Component
KSW	-	Hours	Storage coefficient for land-surface and channel-flow routing--function of watershed characteristics.
TC	-	Minutes	Base time of unit translation hydrograph (time of concentration)--function of watershed characteristics.
TP/TC	-	-	Ratio of time to peak, TP, for triangular translation hydrograph to base (duration) translation hydrograph, TC.
-	SW	Inches	Rainfall excess routed through linear reservoir storage.

Calibration Mode

The purpose of the calibration mode is to determine the best estimate of each of the 10 model parameters. The initial parameter values are estimated based on selected meteorological and physical characteristics of the individual watershed. The model uses these values as a starting point and then varies them within limits and at incremental rates that are specified by the user. Additional data include records of daily rainfall collected at the rainfall-runoff station and pan evaporation from the nearest, most representative evaporation station (fig. 1). Also included are records of the unit-rainfall and discharge sequences recorded at 15-minute intervals for selected storms.

Initially, discharge hydrographs are developed based on the estimated parameters and the rainfall and evaporation records for selected storms. The resulting hydrographs are compared to the observed hydrographs for the respective storm runoff, based on the peak discharge. The measure used to determine the goodness of fit, termed the objective function, during calibration is the sum of the squared differences in the natural logarithms between the observed and the synthetic peak discharges.

Calibration continues as the model methodically adjusts the values of selected parameters in a step-wise manner that results in the minimization of the size of the objective function. The selected model parameters are evaluated in each of the three model components and are adjusted using a step-wise, trial-and-error technique described by Rosenbrock (1960) and modified by Carrigan (1972) for use in the rainfall-runoff model. In the first component, the antecedent soil-moisture-accounting and infiltration-volume parameters are adjusted while the surface-runoff-routing parameters are held constant in an attempt to decrease the runoff-volume objective function. In the second component, the resulting volume parameters are held constant, and the routing parameters are then adjusted using the peak-discharge objective function. The third component holds the resulting routing parameters constant and readjusts the volume parameters while decreasing the objective function for peak discharges. The final model error is represented by the objective function for the peak discharges.

Synthesis Mode

The purpose of the synthesis mode is to produce a record of individual runoff hydrographs using the model parameters and a set of long-term rainfall and evaporation records. Data entered into the model include the 10 calibrated model parameters, a record of daily and unit rainfall from a nearby long-term rainfall station, and a concurrent record of daily pan evaporation. The unit-rainfall record generally consists of rainfall from 2 to 5 storms per year recorded at 5-minute intervals for the period of rainfall records. The result is a record of synthesized runoff hydrographs with associated flood volumes and peak discharges for the period of long-term record. This record represents the watershed's response to rainfall and may be used in further analysis. For the purpose of this study, the annual maximum discharges for the long-term period were used to develop flood frequencies and magnitudes, which are discussed later in this report.

DATA AVAILABLE FOR STUDY

Data used in this study were collected by the U.S. Geological Survey and obtained from records of the National Oceanic and Atmospheric Administration. The data collected by the U.S. Geological Survey included records of simultaneous discharge and rainfall at the 13 rainfall-runoff stations established specifically for this study. Data obtained from the National Oceanic and Atmospheric Administration were daily and unit rainfall at three locations and daily pan evaporation at two locations. All data entered into the computer for use by the rainfall-runoff model have subsequently been made a part of the computer files maintained by the U.S. Geological Survey and may be obtained through the Survey office in Lawrence, Kans. The rainfall-runoff data collected at the 13 stations were used exclusively during calibration, whereas the long-term rainfall data were used during long-term synthesis. However, the evaporation data were used during both calibration and synthesis.

Data Collection

The streamflow-gaging-station network, consisting of 13 stations, was designed to include watersheds that have a wide range of values representing watershed characteristics, such as soil index, main-channel length and slope, and watershed size and shape, and a wide variety of physiographic settings and soil types. However, the sizes of the watersheds were restricted to those with less than 11 square miles of drainage area in order to ensure applicability of the model.

Operation of the network was started during 1965 and continued through October 1976. Four stations were discontinued as early as October 1974. The stations were operated seasonally during April through October. The data available from each station consisted of simultaneous records of discharge and rainfall, at 15-minute intervals, and accumulated daily rainfall.

Instrumentation

Each of the 13 stations was equipped with two digital recorders, one to measure the stage in the channel and the other to measure accumulated rainfall, and a crest-stage gage. The two digital recorders were operated with a common timer, which insured a simultaneous record of stage and rainfall at 15-minute intervals. The crest-stage indicator was used to determine the maximum stage, which usually occurs during the recording interval between punches.

Each recorder was housed in a 24-inch steel shelter that was secured to the top of a 4-inch diameter plastic pipe. The pipe for the stage recorder acted as the stilling well for the water-level float, while the pipe on the rain recorder served as a storage device for accumulated rainfall. The two recorders are connected electrically to a single timer with a three-conductor cable to ensure simultaneous operation.

The crest-stage indicator is a standard 2-inch crest-stage gage that is located in close proximity to the stage gage and is referenced to the same datum. The entire facility is attached to a supporting structure, normally the downstream side of a culvert or bridge.

Record Processing

The record produced by the digital recorders, which was punched onto a 16-channel paper tape, was entered into a computer via a binary translator and magnetic tape. The stage data were converted to discharge data using the stage-discharge rating, and rainfall quantities were entered directly. The data then were stored and subsequently retrieved for use by the rainfall-runoff model.

Before calibration was started, the collected data for each of the 13 stations were reviewed to ensure their completeness and validity for modeling purposes. Data were checked for completeness of the rainfall record and reliability of the stage-discharge relation. Some of the runoff periods were eliminated if, in the judgment of the modeler, they were not representative (for example, runoff resulting from apparently zero rainfall).

Long-Term Rainfall and Evaporation Data

Long-term rainfall data obtained from records of the National Oceanic and Atmospheric Administration were those measured at National Weather Service stations at Concordia and Wichita, Kans., and Kansas City, Mo. These data consisted of daily rainfall totals and unit rainfall for selected storms during the period of record for each respective station. The Concordia station had 65 years of concurrent daily and unit record; Wichita, 70 years; and Kansas City, 78 years. Due to a large number of storms in each year of the long-term record, it was necessary to select only a few storms for each year based on the greatest intensity and total depth of rain. This screening process resulted in the selection of the 2 to 5 largest storms occurring in any selected year. These daily and unit-rainfall data then were stored for use subsequently in the long-term synthesis mode of the rainfall-runoff model.

The evaporation data were from class-A evaporation pans located at Sabetha Lake and at John Redmond Dam, supplemented by estimates for winter periods. These two data-collection sites were selected based on their location relative to the 13 rainfall-runoff stations. The length of record was 11 years (1963-76) at Sabetha Lake and 14 years (1966-76) at John Redmond Dam. The period of record for both stations was concurrent with those records collected at the 13 rainfall-runoff stations; hence, these data were sufficient for calibration. However, it was necessary to extend the evaporation records for use in the long-term synthesis. This was accomplished by computing a 3-day average centered on each calendar day of record and then using the averaged daily values for each year of the missing record back to the beginning of the longest record of unit-rainfall data (1893). A summary of the rainfall and evaporation records used in this study is given in table 3.

Table 3.--Summary of long-term rainfall and evaporation records used in study

Station name and location		Period of record (water years)
	LONG-TERM RAINFALL	
Concordia, Kans.	39°33'-97°39'	1907-71
Wichita, Kans.	37°39'-97°25'	1903-72
Kansas City, Mo.	39°07'-94°35'	1893-1970
	EVAPORATION	
Sabetha Lake, Kans.	39°51'30"-95°54'15"	1963-76
John Redmond Dam, Kans.	38°15'-95°45'	1966-76

APPLICATION OF MODEL

The U.S. Geological Survey rainfall-runoff model was used to calibrate the model parameters for each of 13 watersheds and then, using the results of the respective calibrations and the long-term data, to develop long-term, synthesized peak discharges. The following is a summary of the procedures and special methods used.

Calibration

The initial values of the model parameters were based primarily on the suggestions of Carrigan (1973), Carrigan and others (1977), and Lichty and Liscum (1978). Lichty and Liscum (1978) found that parameters DRN and TP/TC (table 2) had little effect on calibration results; hence, they were assigned representative values of 1.0 and 0.5, respectively, and not allowed to vary during the computations.

EVC is a scaling factor used to estimate evapotranspiration using measured pan evaporation. In the model, it was the ratio of the average annual lake evaporation for the rainfall-runoff station (see Kohler and others, 1959, figure 2) to the average annual pan evaporation at the evaporation station used in calibration of the model. The Sabetha Lake pan-evaporation data were used for those stations near or north of Topeka, and the John Redmond data were used for stations located south of Topeka. Once computed, the value of EVC was not changed. The remaining three parameters, RR, KSW, and TC, were assigned uniform initial values for all stations and were allowed to vary during the first several calibration trials. Assigned values were 0.85 for RR, 0.95 hour for KSW, and 57.0 minutes for TC.

The U.S. Geological Survey computer program for calibration of rainfall-runoff models produced a number of variables and statistics, and presented graphical results, including runoff hydrographs, which were valuable in evaluating the calibrations. Hence, the results of the first two trial calibrations of the models for each of the 13 watersheds served three primary functions: (1) To compute initial estimates of the model parameters, PSP, KSAT, RGF, and BMSM, within specified limits, (2) to compute final values of model parameters, RR, KSW, and TC, and (3) to identify and screen rainfall-runoff sequences that appeared to be unrepresentative. The model computed the value of RR from runoff for each storm. The final value used was the average value of RR for all storms. The value of KSW was determined directly from the recession curve of the observed hydrograph. Likewise, the observed and synthesized hydrographs were used to determine the adjustment to the value of parameter TC. The adjustment to the value of TC was equal to two times (reciprocal of TP/TC) the difference between the times of the peaks, as indicated by the observed and synthesized hydrographs. Once the adjustments to the RR, KSW, and TC parameters were made, the respective parameters were not changed during the remainder of the calibrations.

Subsequent trials of the calibration routine were used to "fine tune" each of the 13 models by adjusting the base-flow discharges for selected storms and the starting values for the remaining four model parameters. Calibration was ended when such changes resulted in few or no changes in final parameter values or improvement in the total model error.

An average of 25 storms was used to calibrate the models of each of the 13 watersheds. The actual number of storms used varied from 12 to 39, depending on the data available for each station. Generally, the peak discharges associated with the resulting runoff were less than the magnitude of the 10-year flood. Although models of three watersheds used runoff with larger peak discharges, no peaks were greater than the 50-year flood.

The general reliability of each model to compute the peak discharges from rainfall data was measured by using a regression model that related the base-10 logarithm of the observed to the synthesized peak discharges. The three statistics used in the test were the correlation coefficient, the regression coefficient, and the mean values of the two variables. The criteria used were:

(1) correlation coefficient significantly different from zero,

(2) regression coefficient not significantly different from 1.0, and

(3) mean values not significantly different.

Results of each of the 13 models met all of the prescribed criteria at the 5-percent level of significance and, therefore, were considered successful. The results of the calibration of the 13 models are listed in table 4.

Table 4.--Summary of model statistics and parameter values resulting from model calibration and watershed characteristics used in regression analyses

Station number	Statistics of calibration: Number of storms used	Range of peak discharges: Minimum (cubic feet per second)	Range of peak discharges: Maximum (cubic feet per second)	Total model error (percent)	Correlation coefficient	Model parameter[1]: RMSM (inches)	RR	EVC	DRN	KSAT (inches per hour)	PSP (inches)	RGF	KSW (hours)	TC (minutes)	TP/TC	Watershed characteristic: Drainage area (square miles)	Main-channel: Slope (feet per mile)	Main-channel: Length (miles)	2-year, 24-hour rainfall depth (inches)
06813700	12	37	212	24	0.94	1.00	0.60	0.88	1.00	0.051	0.67	15.03	1.20	95	0.50	0.90	62.1	1.76	3.3
06815700	15	98	3,180	36	.93	0.92	.60	.85	1.00	.009	3.72	20.46	1.20	150	.50	3.74	26.3	3.50	3.2
06856800	17	14	920	26	.98	3.40	.76	.89	1.00	.045	2.74	7.78	2.00	200	.50	3.60	22.2	3.90	3.2
06887600	22	24	860	26	.96	19.70	.79	.95	1.00	.056	2.16	11.17	0.64	60	.50	.83	96.4	1.84	3.4
06888900	18	16	630	29	.97	1.54	.68	.93	1.00	.037	1.69	17.02	0.90	60	.50	1.31	68.6	1.75	3.5
06890700	23	21	360	33	.90	1.89	.75	.87	1.00	.074	0.87	15.79	0.81	90	.50	.83	55.4	1.42	3.5
06912300	16	106	3,180	33	.95	10.76	.58	.80	1.00	.025	0.80	9.17	1.20	100	.50	3.76	52.1	2.74	3.6
06913600	21	111	2,450	36	.92	1.22	.59	.77	1.00	.054	0.58	4.37	2.50	350	.50	10.20	14.4	7.85	3.7
06916700	39	37	1,630	39	.94	2.24	.54	.78	1.00	.021	0.83	19.22	1.20	120	.50	2.02	39.1	2.15	3.7
07166200	36	139	2,870	38	.91	1.39	.54	.84	1.00	.023	2.68	4.17	2.00	260	.50	6.80	23.1	4.74	3.8
07169200	34	34	3,500	44	.92	1.51	.69	.87	1.00	.033	1.73	10.05	1.90	140	.50	7.59	43.6	3.55	3.8
07169700	35	67	3,050	41	.84	3.45	.54	.87	1.00	.011	2.12	12.36	1.35	110	.50	1.84	48.6	1.95	3.8
07182520	31	99	2,860	37	.91	1.45	.67	.82	1.00	.055	0.99	6.02	3.50	420	.50	8.27	17.2	5.49	3.7

1 Model parameters are explained in table 2.

The resulting model parameters were investigated further to determine if their values could be regionalized and extended to ungaged watersheds for modeling purposes. The values of 3 of the 10 model parameters, EVC, DRN, and TP/TC, were determined prior to the start of calibration; hence they were not considered for regionalization. Regression equations were computed for each of the remaining seven model parameters using the parameter values as the dependent variable and the watershed characteristics as the independent variables. The independent variables included watershed size (drainage area), main-channel slope and length, and 2-year, 24-hour rainfall depth. It should be noted that 13 watersheds represented a rather small sample, but the results should indicate whether or not a relationship existed.

The values of both routing parameters, KSW and TC, were found to be related directly to watershed size and inversely related to the main-channel slope. Regression equations were developed for both parameters as follows:

$$KSW = 4.52\ A^{0.250}\ S^{-0.392}, \quad SE = 21.5 \text{ percent; and} \qquad (1)$$

$$TC = 1{,}890\ A^{0.178}\ S^{-0.766}, \quad SE = 17.9 \text{ percent;} \qquad (2)$$

where

A is drainage area, in square miles;
S is main-channel slope, in feet per mile; and
SE is the standard error of estimate for each equation.

Values for the independent variables A and S are listed in table 4. Because of the significant degree of intercorrelation of the four volume parameters, BMSM, KSAT, PSP, and RFG, and the effect of varying antecedent conditions on the value of the RR parameter, no viable relationship could be identified for the remaining five model parameters. Hence, no further attempts were made to relate their values to watershed characteristics.

Long-Term Synthesis

The 10 calibrated model parameters for each of 13 stations were applied to each of the three long-term rainfall records to develop a record of long-term, synthesized peak discharges at each station. The three rainfall records used were Concordia and Wichita, Kans., and Kansas City, Mo. The result was three annual series of synthesized peak discharges for each station. A log-Pearson Type-III distribution then was fitted to each series to provide estimates of the T-year peak discharges for recurrence intervals (T) of 2, 5, 10, 25, 50, 100, and 200 years.

In order to compensate for the differences in rainfall depths and intensities between the rainfall-runoff stations and each of the long-term rainfall stations, a rainfall-adjustment factor was applied to the long-term rainfall records. The rainfall adjustment applied was the ratio of the 2-year, 24-hour rainfall depths at the rainfall-runoff site to that at the respective long-term rainfall station. The values for the 2-year, 24-hour rainfall were obtained from Hershfield (1961). The following 2-year, 24-hour rainfall depths were used for the three long-term rainfall stations:

Station	2-year, 24-hour rainfall depth, in inches
Concordia, Kans.	2.9
Wichita, Kans.	3.5
Kansas City, Mo.	3.5

The depths used for the 13 rainfall-runoff stations are listed in table 4. The adjustments factors used ranged from 0.91 to 1.29. The resulting synthesized T-year estimates are listed in table 5.

The estimates derived from 65 to 78 years of synthesized records provide a unique opportunity to use long records in studying the skewness coefficients of flood-peak distributions for small watersheds. It should be noted that, because of the weighted averaging, the estimates listed in table 5 from synthesized records do not represent a statistical distribution as such. However, the estimates of T-year peak discharges can be plotted on log-probability paper, and the direction of skewness (negative, near-zero, or positive) determined by inspection. Individual plots of the 13 sets of weighted synthesized estimates of T-year peaks indicate that each set has a negative skewness that is consistent with the regionalized skew coefficients derived from shorter records for larger watersheds by the U.S. Water Resources Council (1977).

Estimating T-year Floods Using Observed and Synthesized Discharges

In addition to the records (annual series) of synthesized peak discharges, records of annual peak discharges also were collected (observed) at each rainfall-runoff station prior to and during the modeling period. Length of these records ranged from 21 to 23 years. Log-Pearson Type-III distributions were fitted to each of the 13 observed records, and T-year peaks were estimated for the same recurrence intervals as for the synthesized records. Flood discharges estimated from the observed records generally were greater than those from the synthesized records, and the observed frequency curves generally had steeper slopes (greater standard deviations). For five stations the "observed" T-year magnitudes for long recurrence intervals were considerably larger than the synthesized (long-term) T-year magnitudes. These differences are a manifestation of the time-sampling error in both the "long-term" and "observed" records. A study of the rainfall records for the "long-term" and "observed" periods for the five rainfall-runoff stations that exhibited large discrepancies showed that the rainfall depths for the period of observed peak-flow record at these stations were greater than those for the long-term period. These relations indicate that, although observed records for 21 to 23 years usually provide reliable estimates of the recurrence-interval floods, the long synthetic records are of value in deriving more accurate estimates, especially for floods having long recurrence intervals.

Table 5.--Summary of T-year peak discharges for the 13 rainfall-runoff stations

Station number	Source	Peak discharges, in cubic feet per second, for indicated recurrence interval (T), in years						
		2	5	10	25	50	100	200
06813700	Synthesized	287	481	619	802	941	1,080	1,220
	Observed	253	660	1,060	1,710	2,300	2,980	3,760
	Final	258	595	860	1,220	1,480	1,750	2,000
06815700	Synthesized	960	1,640	2,140	2,820	3,350	3,900	4,480
	Observed	2,210	3,150	3,670	4,240	4,600	4,910	5,190
	Final	2,010	2,590	2,980	3,490	3,870	4,260	4,650
06856800	Synthesized	506	930	1,260	1,710	2,070	2,450	2,850
	Observed	387	902	1,330	1,940	2,430	2,930	3,440
	Final	406	906	1,300	1,820	2,220	2,620	3,010
06887600	Synthesized	286	517	695	943	1,140	1,350	1,570
	Observed	225	519	776	1,160	1,480	1,830	2,210
	Final	235	516	739	1,050	1,280	1,520	1,760
06888900	Synthesized	479	816	1,060	1,370	1,610	1,850	2,090
	Observed	319	576	745	944	1,080	1,200	1,320
	Final	345	657	885	1,180	1,400	1,620	1,840
06890700	Synthesized	233	430	588	816	1,010	1,210	1,430
	Observed	183	490	778	1,230	1,620	2,040	2,500
	Final	191	465	693	1,010	1,250	1,500	1,750
06912300	Synthesized	1,450	2,240	2,790	3,520	4,080	4,650	5,240
	Observed	869	2,150	3,280	4,970	6,390	7,910	9,520
	Final	962	2,160	3,060	4,200	5,020	5,790	6,510
06913600	Synthesized	2,050	3,260	4,160	5,370	6,320	7,320	8,370
	Observed	558	1,200	1,840	2,970	4,090	5,510	7,270
	Final	796	1,920	2,880	4,300	5,460	6,690	7,960
06916700	Synthesized	754	1,200	1,530	1,950	2,270	2,600	2,940
	Observed	601	1,300	1,880	2,720	3,400	4,120	4,870
	Final	626	1,260	1,720	2,310	2,730	3,130	3,520
07166200	Synthesized	1,630	2,650	3,400	4,410	5,210	6,040	6,910
	Observed	1,260	2,260	3,000	3,980	4,740	5,510	6,290
	Final	1,320	2,390	3,180	4,230	5,040	5,860	6,680
07169200	Synthesized	1,970	3,320	4,300	5,600	6,590	7,610	8,650
	Observed	2,870	5,030	6,550	8,500	9,930	11,300	12,700
	Final	2,730	4,410	5,540	6,940	7,940	8,920	9,870
07169700	Synthesized	706	1,180	1,520	2,000	2,370	2,750	3,160
	Observed	511	1,100	1,560	2,180	2,670	3,150	3,640
	Final	542	1,120	1,540	2,090	2,500	2,890	3,270
07182520	Synthesized	1,230	2,020	2,600	3,400	4,030	4,690	5,390
	Observed	1,010	2,230	3,370	5,220	6,920	8,910	11,200
	Final	1,040	2,150	3,020	4,230	5,190	6,170	7,180

Based on the foregoing observations, it is desirable to use both the observed and synthesized flood-frequency estimates to arrive at the best available estimate. This was accomplished by using a method developed by Lichty and Liscum (1978), which evaluates the total variance among the two estimates. The method uses the variance in the model estimates and the time-sampling variance (described by Hardison, 1971) to derive a weighting factor for combining observed and synthesized estimates for selected recurrence intervals. The following weighting factors were computed for eastern Kansas:

Recurrence interval, in years	Weighting factors	
	Observed data	Synthetic data
2	0.81	0.19
10	.58	.42
100	.35	.65

The final weighted estimate for each T-year flood was calculated by multiplying the values of the observed and the synthesized floods by their respective weighting factors and then summing the two products. The resulting weighted estimates for the 2-, 10-, and 100-year floods for each of the 13 stations then were plotted on log-probability paper, and a curve drawn through the points. The magnitudes of the 5-, 25-, 50-, and 200-year floods were taken from the curve. The final weighted T-year floods for the 13 stations are listed in table 5.

This method of combining frequency curves is consistent with methods used to assess the accuracy of frequency curves. The degree of weight assigned to the T-year estimates, which are derived from the observed data, varies under the following conditions:

(1) weight increases with length of record,

(2) weight increases with decreasing recurrence interval, and

(3) weight decreases as standard deviation increases.

The weight factors computed for this study indicate that considerable weight was assigned to the observed record compared to that weight assigned to the synthesized curves for the 2-year recurrence interval. On the other hand, more weight was assigned to the synthesized record for the 100-year recurrence interval than was assigned to the observed record. Analysis of these weight factors indicates that although the observed record can produce reliable estimates of T-year floods, especially those having short recurrence intervals, the synthesized records contribute additional information toward defining less frequent floods, such as the 100-year flood.

The flood-frequency estimates developed as a result of this study will be used in a subsequent investigation to determine statewide relations that will be developed using all streamflow-gaging stations within Kansas. Due to the lack of long-term observed data for small watersheds (less than 10 square miles), the results of this study will contribute to more reliable flood-frequency estimates for smaller watersheds.

SUMMARY

The U.S. Geological Survey rainfall-runoff model was used to calibrate model parameters and to synthesize long-term annual peak-discharge data for 13 small watersheds of generally less than 10 square miles in size in eastern Kansas. Data for the study were collected for 13 watersheds located in eastern Kansas, generally east of the 97th meridian. These data consisted of simultaneous records of instantaneous streamflow and rainfall for a selected number of storms. The size of the 13 watersheds ranged from 0.83 to 10.20 square miles. Most of the rainfall-runoff data were collected during 1966-76. Data collected in the watersheds and evaporation data collected at two evaporation stations were used to calibrate the 13 rainfall-runoff models.

Each of three long-term rainfall records were applied to each model to synthesize records of annual peak flows, which were used to compute log-Pearson Type-III flood-flow statistics for each record. Weighted estimates of T-year floods were developed for each station. Plots of the curves indicated that all have a negative skew. Final estimates for the 2-, 10-, and 100-year floods were computed by weighting each of the observed and synthesized estimates.

The results of this study will be incorporated into a subsequent study that will analyze the areal distribution of statewide flood-frequency estimates.

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