FLOOD-FREQUENCY ESTIMATES FOR FIVE GAGED BASINS IN WICHITA, KANSAS

by

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CONVERSION FACTORS

The following factors may be used to convert the inch-pound units published herein to the International System of Units (SI):

Multiply inch-pound unit	By	To obtain SI unit
	Length	
inch	[1]2.54	centimeter
foot	.3048	meter
mile	1.609	kilometer
foot per mile	.1894	meter per kilometer
	Area	
square mile	2.590	square kilometer
	Volume per unit time	
cubic foot per second	0.02832	cubic meter per second

[1] Exact conversion factor.

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ABSTRACT

The effects of urbanization on flood-frequency relationships in the city of Wichita, south-central Kansas, were determined from a study of five drainage basins with varying degrees of urbanization. A rainfall-runoff model was calibrated for these basins with an average calibrated model error of 27.5 percent. The calibrations were used to synthesize 69 water years of peak-discharge record for each basin, and a log-Pearson Type-III flood-frequency analysis was performed on each record.

Results of four other methods of determining flood frequencies were evaluated by comparison with modeled results. The four methods used were analysis of a short-term record of observed annual peak discharges, the modified Soil Conservation Service method, the Oklahoma method, and the National method. Flood-frequency estimates from the rainfall-runoff model were considered to be the most reliable for the five basins in this study. Comparison of the model estimates with the estimates made by the other flood-frequency techniques indicated that the National and Oklahoma methods could be used on ungaged basins with comparable results.

Evaluation of all methods revealed the necessity of including a basin area-channel length factor for urban basins. An analysis of the effect of increasing imperviousness on peak flows indicated an average factor of 6.3 between the 2-year rural and urbanized flood and an average factor of 2.3 between the 100-year rural and urbanized flood.

INTRODUCTION

The city of Wichita, located in south-central Kansas, has continued to expand into the surrounding rural areas. The conversion of rural areas into large shopping centers surrounded by high-density office or dwelling structures that, in turn, are surrounded by high-density residential subdivisions (urbanization) has modified the storm-runoff characteristics for streams within these areas. As rural areas are developed, the most notable changes in streamflow are that the depth of flooding tends to increase and that the lag time (center of mass of rainfall to center of mass of runoff) is decreased (Carter, 1961; Anderson, 1970; Harris and Rantz, 1964).

These changes were graphically illustrated by Leopold (1972) and are shown in figure 1. The effects of urbanization can increase property damage from flooding and decrease flood-warning time. Effective planning of urban development includes designing storm sewers, bridges, channel improvements, and other hydraulic structures for peak flows that will occur after development has been completed.

In 1964, a cooperative study by the city of Wichita and the U.S. Geological Survey was started to determine the effects of urbanization on rainfall-runoff relationships in the urbanized areas of the city and the adjacent rural regions. The initial objective of the study was to measure rainfall, runoff, and the degree of urbanization and, from these data, develop rainfall-runoff relationships applicable to various degrees of urbanization.

Since 1964, the study has been modified by the addition and deletion of studied basins and by changes in methods of data collection. Many of these changes were a result of urban development not progressing as anticipated. Consequently, data have been collected for 12 different basins in the Wichita area--rural, partly urbanized, and fully urbanized. The data vary in format, period of record, and quality from basin to basin. Five of the 12 basins were chosen for this modeling study. The study area and location of the data-collection sites for the five basins used in this report are shown in figure 2.

Interpretation of the data collected from all 12 basins has resulted in four reports. The first two reports, "Report No. 1: Analysis of Initial Conditions" (James, 1967) and "Report No. 2: Analysis of Progressing Conditions" (Richards, 1971) basically describe unit-hydrograph analyses for evaluation of the effects of varying degrees of urbanization. A 1973 unpublished progress report (D. B. Richards, U.S. Geological Survey, written commun., 1973) described changes in the data collection. This third report also stated the revised objective of the overall study. The revised objective was to use a digital computer model to establish a more comprehensive rainfall-runoff/urbanization relationship and, with basin characteristics, to transfer this relationship to ungaged basins. These reports are on file at the U.S. Geological Survey, Lawrence, Kansas.

Peek and Jordan (1978) reported on the results of a temporary alternative to more complete and complex modeling by digital computer. This fourth report provided verification of a modified version of the Soil Conservation Service method of developing a synthetic hydrograph from a standardized "design storm."

Purpose and Scope

The purpose of this study was to define the flood-frequency relationships for selected urbanized basins in the city of Wichita and to investigate the effect of urbanization on these relationships. Results obtained from the study were used to evaluate several available methods for calculating flood-frequency relations for urbanized basins. Five basins within the city of Wichita having a total imperviousness of 12 percent or more were used in this study. The data-collection sites and respective basin characteristics are listed in table 1. Lack of a sufficient number of basins prevented regionalization of flood-frequency relationships for transfer of information to ungaged basins.

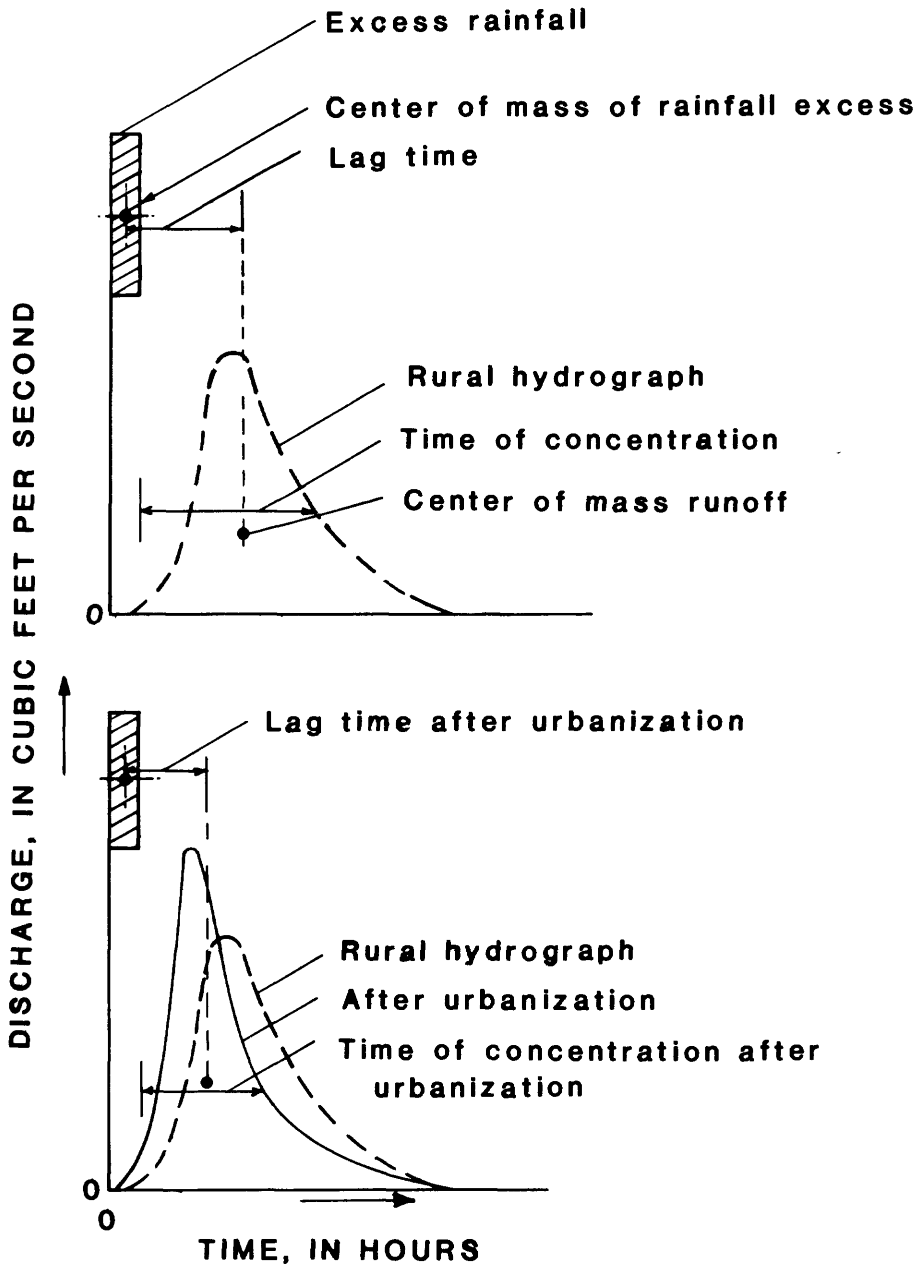


Figure 1.--Hypothetical relation of runoff to rainfall, effects of urbanization, and relationship of lag time and time of concentration (modified from Leopold, 1972).

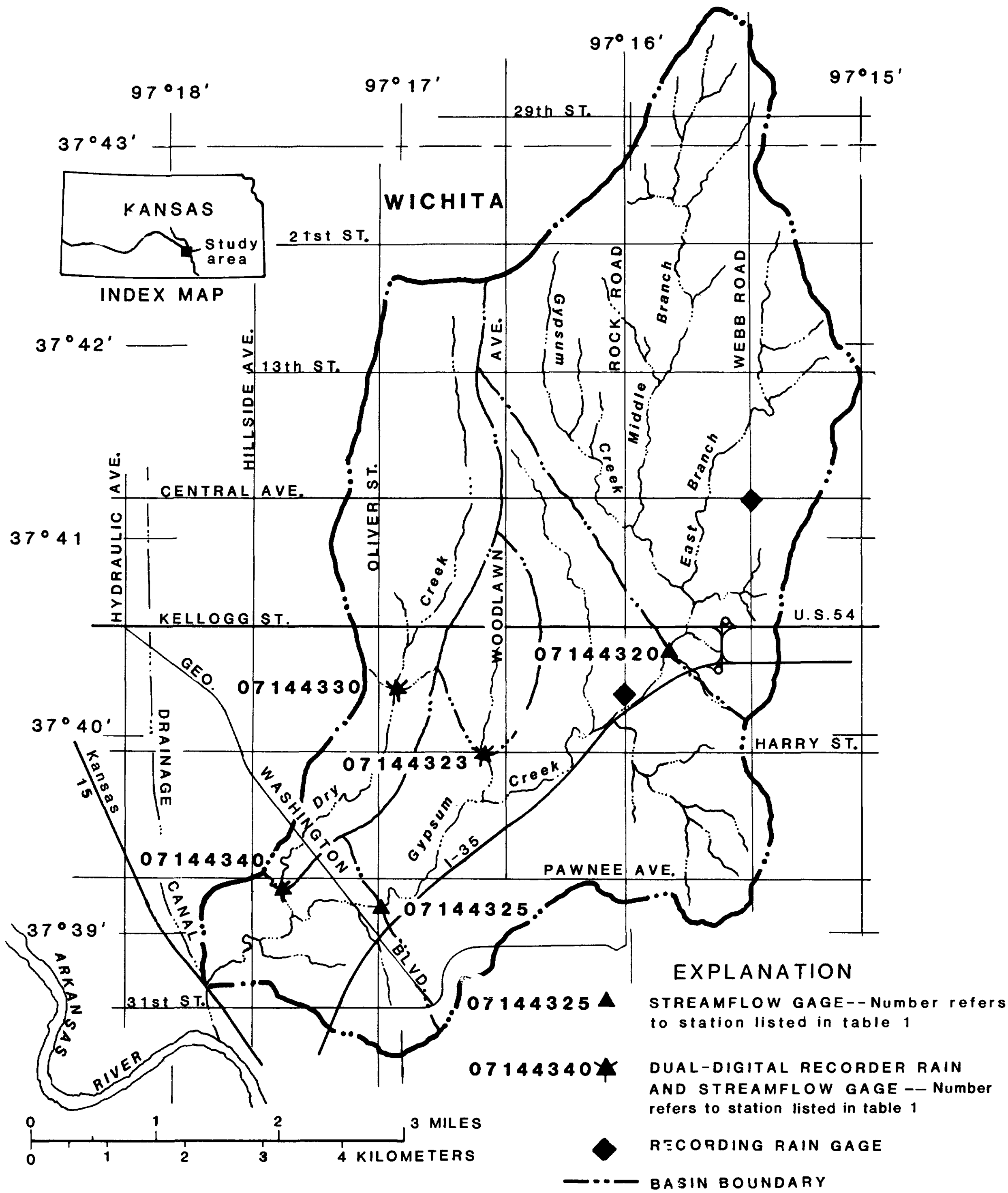


Figure 2.--Location of study area, selected drainage basins, and data-collection sites.

Table 1.--Basin characteristics for five urbanized basins within Wichita

Station identification number	Period of record	Station name	Drainage area (square miles)	Length of main channel (miles)	Channel slope[1] (feet per mile)	Impervious area (percentage of drainage area)[2]
07144320	March 1964 to September 1982	Gypsum Creek at Gilbert Street.	8.92	5.65	16.3	12
07144323	March 1971 to September 1982	Fabrique Branch of Gypsum Creek at Harry Street.	1.14	1.26	30.7	40
07144325	March 1968 to September 1982	Gypsum Creek at Oliver Street.	16.43	8.41	13.7	15
07144330	March 1964 to September 1982	Dry Creek at Lincoln Street.	2.94	2.30	23.0	32
07144340	March 1971 to September 1982	Dry Creek at Pawnee Avenue.	3.86	4.29	19.1	31

1 Elevation difference, in feet, divided by horizontal distance, in miles, between points at 10 percent and 85 percent of channel length.

2 Estimated from 1974 aerial photographs.

DESCRIPTION OF RAINFALL-RUNOFF MODEL

The present shortage of hydrologic data collected in urban environments has led to the development and use of many different mathematical models capable of extending short periods of rainfall-runoff data to provide a more reliable flood-frequency analysis (Spencer and Alexander, 1978).

The U.S. Geological Survey rainfall-runoff model developed by Dawdy and others (1972) was selected for this study. This parametric simulation model is based on parameters (table 2) that approximate the physical characteristics of antecedent soil moisture, infiltration, and routing of surface runoff. A schematic outline of the model is given in figure 3. Daily rainfall, daily pan evaporation, and the station unit-time (5-, 10-, 15-, 30-, or 60-minute) rainfall-runoff data are required input to the model (Spencer and Alexander, 1978).

The overall functions of the three model components shown in table 2 are as follows:

1. The antecedent-moisture-accounting component calculates the initial infiltration rate of the soil, the distribution of soil moisture, and evapotranspiration.

2. The infiltration component uses the modified Philip equation (Philip, 1957) to compute that proportion of rainfall that infiltrates the soil.

3. The routing component uses the modified Clark unit hydrograph (Clark, 1945) to translate the rainfall excess into a flood-discharge hydrograph at the station location.

The version of the model used for rural areas also can be used to calibrate a rainfall-runoff model for urban basins considered to have a uniform distribution of impervious area. The optimum values of 1 to 10 model parameters of the rural basin rainfall-runoff model are determined by comparing computed runoff-volume and runoff-discharge estimates with observed values.

DATA COLLECTION

As part of the Wichita urban-runoff study, rainfall and runoff data were collected from five highly urbanized basins in the city of Wichita. These basins were Gypsum Creek at Gilbert Street (07144320), Fabrique Branch of Gypsum Creek at Harry Street (07144323), Gypsum Creek at Oliver Street (07144325), Dry Creek at Lincoln Street (07144330), and Dry Creek at Pawnee Avenue (07144340). Dual-digital recorders were installed at three of these sites, Fabrique Branch of Gypsum Creek at Harry Street, Dry Creek at Lincoln Street, and Dry Creek at Pawnee Avenue. The rainfall and the stage recorders at these three sites were operated using a single timer, which recorded at 5-minute intervals. Operating both digital recorders from a single timer eliminated time discrepancies between rainfall and stream stage but required the location of the two gages at the same site. Therefore, rainfall was recorded only at the outlet of each basin and not at the centroid. Digital recorders for rainfall and graphic

Table 2.--U.S. Geological Survey rainfall-runoff model parameters and variables and their application in the modeling process (modified from Curtis, 1977)

Parameter	Variable	Units	Definition and application in model
			Antecedent-moisture-accounting component
EVC	---	---	Coefficient to convert pan evaporation to potential evapotranspiration values.
RR	---	---	Proportion of daily rainfall that infiltrates the soil.
	BMS	Inches	Base (unsaturated) moisture storage in active soil column. Simulates antecedent-moisture content throughout the range from wilting-point conditions (BMS = 0) to field capacity (BMS = BMSM).
BMSM	---	Inches	Soil-moisture storage volume at field capacity.
	SMS	Inches	"Saturated" moisture storage in wetted surface layer developed by infiltration of storm rainfall.
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.

Table 2.--U.S. Geological Survey rainfall-runoff model parameters and variables and their application in the modeling process (modified from Curtis, 1977)--Continued

Parameter	Variable	Units	Definition and application in model
			Routing component (surface runoff)
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.

recorders for stream stage were used at the other two larger basins, Gypsum Creek at Gilbert Street and Gypsum Creek at Oliver Street. The rainfall was recorded at 15-minute intervals. The rainfall gages for these two stations were located upstream from the stage gages nearer the centroids of the basins.

METHODS OF ANALYSIS

The analysis of the data from this study included four separate processes:

1. Determination of optimum model-parameter values for each station by calibration of rainfall-runoff model.

2. Development of synthetic annual flood peaks using the calibrated models and long-term rainfall data, and performance of a flood-frequency analysis.

3. Evaluation of modeled flood-frequency values with other urban runoff techniques.

4. Definition of the 2-, 5-, 10-, 25-, 50-, and 100-year flood-frequency relationships for varying degrees of imperviousness.

Calibration of Model Parameters

Initial parameter values for each site were estimated based on the geology, soil cover, and hydrographs of measured runoff. Parameter constraints (upper and lower limits) were those suggested by Carrigan and others (1977).

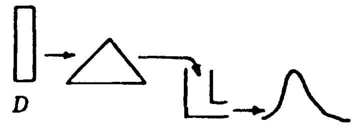
ANTECEDENT-MOISTURE-ACCOUNTING COMPONENT	INFILTRATION COMPONENT	ROUTING COMPONENT
Saturated-unsaturated soil moisture regimes	Philip infiltration equation	Modified Clark instantaneous unit hydrograph
Parameter: *EVC*, *RR*, *BMSM*, *DRN* Variable: *BMS*, *SMS*	$\frac{di}{dt} = K[1+\frac{P(\bar{m}-m_o)}{i}]$ Parameter: *PSP*, *KSAT*, *RGF* Variable: *BMS*, *SMS*	 Parameter: *KSW*, *TC*, *TP*
INPUT DATA		
Daily rainfall Daily pan evaporation Initial conditions	Unit rainfall *BMS* *SMS*	Rainfall excess
OUTPUT DATA		
BMS *SMS*	Rainfall excess	Discharge

Figure 3.--Schematic outline of U.S. Geological Survey rainfall-runoff model showing components, parameters, and variables (from Wibben, 1976).

Initially, simulated-discharge hydrographs were calculated from the estimated model parameters and the rainfall and evaporation records for selected storms. The simulated hydrographs then were compared with the recorded hydrographs. The measure used to determine the "goodness" of fit, termed the objective function, during calibration was the sum of the squared differences in the natural logarithms between the observed and the synthetic runoff values resulting from the storms selected for calibration.

Calibration continued as the model methodically adjusted the values of the selected parameters, within the specified constraints, in a stepwise manner that resulted in the minimization of the size of the objective function. This method for optimizing parameter values is referred to as the modified Rosenbrock method (Dawdy and others, 1972). The calibration of the model for each site required three separate phases. Phase one optimized the parameters affecting runoff volumes while the routing parameters were held constant in an attempt to decrease the runoff-volume objective function. The second phase held the runoff-volume parameters constant and optimized the three routing parameters (hydrograph shape) until the objective function of synthesized peak discharges versus the observed peak discharges had been minimized. The third phase was a combination of phases one and two. The routing parameters from phase two were held constant, while the runoff-volume parameters were readjusted to produce the best fit between simulated and observed peaks (Spencer and Alexander, 1978).

Seven of the 10 model parameters were optimized by the calibration program for each basin. The values of two soil-moisture-accounting parameters, EVC and DRN, and one routing parameter, TP/TC, were held constant for all sites. The model parameters are listed in table 3. The average calibrated model error for the third phase of the optimization for the five sites was 27.5 percent.

Table 3.--Summary of U.S. Geological Survey rainfall-runoff model parameters for five urbanized basins within Wichita

[BMSM and PSP, inches; DRN and KSAT, inches per hour; KSW, hours; TC, minutes; remaining parameters, unitless]

Station	EVC	RR	BMSM	DRN	PSP	KSAT	RGF	KSW	TC	TP/TC
07144320	0.85	0.73	1.62	1.00	1.73	0.039	15.6	2.93	115	0.50
07144323	.85	.64	1.10	1.00	4.49	.086	10.8	0.67	15.5	.50
07144325	.85	.73	1.20	1.00	3.01	.105	9.43	3.55	133	.50
07144330	.85	.64	1.08	1.00	3.94	.288	19.9	.43	53.7	.50
07144340	.85	.64	0.66	1.00	1.61	.157	6.23	1.22	144	.50

Flood-Frequency Analysis

In order to determine the flood-frequency estimates, it was necessary to first generate a series of annual floods using the calibrated model and a long-term climatological record. The following stations provided the climatic data required for synthesizing 69 water years of annual peak discharges for each basin:

Wichita FAA (station 37390097250001)...daily and unit rainfall, 1904-73;

John Redmond Reservoir (station 381500095450001)...daily evaporation, 1965-75.

A series of daily evaporation data for 1904-64 was generated from the 1965-75 evaporation data using a U.S. Geological Survey computer program (Carrigan and others, 1977). The synthesis of evaporation data was accomplished by least-squares fitting of a harmonic function to observed daily data.

The calibrated model used this long-term climatic data to synthesize 69 water years of annual peak discharges for each basin. A flood-frequency analysis using the log-Pearson Type-III distribution was conducted for each basin using the synthesized record. The flood-frequency analyses incorporated the "station skewness," which was calculated from the synthesized runoff data for each basin. The "station-skewness" values were:

Station	Skewness
07144320	-0.375
07144323	-0.154
07144325	-0.091
07144330	0.064
07144340	-0.254

Flood-frequency estimates obtained for each basin utilized an average station skewness of -0.12. These estimates are listed in table 4.

Table 4.--Modeled flood-frequency estimates for study basins

Recurrence interval (years)	Peak discharge, in cubic feet per second, for stations				
	07144320	07144323	07144325	07144330	07144340
2	1,440	543	1,720	1,010	1,060
5	2,350	849	2,940	1,550	1,630
10	3,010	1,060	3,850	1,930	2,030
25	3,890	1,340	5,100	2,420	2,550
50	4,580	1,560	6,080	2,790	2,950
100	5,300	1,780	7,110	3,160	3,340
200	6,030	2,000	8,190	3,540	3,750

Evaluation of Flood-Frequency Techniques

Various techniques for determining flood discharges for streams in urban areas have been developed nationwide. The techniques evaluated for use in the Wichita area included the rainfall-runoff model, the "observed" method, the modified Soil Conservation Service (SCS) method of determining flood frequencies (Peek and Jordan, 1978), the Oklahoma method (Thomas and Corley, 1977), and the National method (Sauer and others, 1983).

The rainfall-runoff modeling technique, as described in detail in this report, results in good estimates for individual basins provided the initial calibration is reliable and representative long-term precipitation records are available. For large recurrence intervals, the rainfall-runoff model provides a more representative time base (69 years) than does a short-term observed record (5-15 years). The model also can be used, if data for calibration are available, instead of the modified SCS method, the Oklahoma method, and the National method because it is a more complete analysis. However, intensive short-term data collection and computer utilization required of the model make it the most expensive method to implement.

The "observed" method used in this report consisted of log-Pearson Type-III frequency analyses of 10-15 yearly peak discharges for each gaged stream. The U.S. Water Resources Council (1981) flood-frequency estimating methods were used. A sufficient length of record of yearly peak discharges is required before reliable results are obtained. Considerable time for data collection is required, and in an urban environment, factors affecting flood discharges may be subject to considerable change, making the statistical sample nonhomogeneous and the analysis invalid. Confidence in flood-frequency estimates obtained by this method increases with increasing length of record and stability of the basin characteristics.

The rainfall-runoff model and the "observed" methods both require data collection and are applicable for gaged basins only. Three other methods can be used on ungaged basins with minimal computations and data collection. They are the modified SCS, Oklahoma, and the National methods.

The modified SCS method is a version of the design-storm concept. Data requirements include the 2-year, 24-hour rainfall, percentage of imperviousness, soil type, land use, channel slope, length of main channel, and drainage area. This method has the advantage of incorporating area and channel length, which are important factors in determining lag time. As lag time shortens, the flood peak increases. Accuracy in determining a curve number (CN) from soil type and land use is an important requirement for this method.

The Oklahoma method was developed for use in Oklahoma and, because the city of Wichita has similar regional characteristics to Oklahoma, this method was evaluated for possible use in Wichita. The Oklahoma method utilizes a rural flood-frequency relationship, which is adjusted by an urbanization factor (R_L). R_L is a function of the percentage of area served by storm sewers and the area of imperviousness. The equations to calculate urban flood-discharge estimates (UQ) are listed below, and the various parameter values and explanations are listed in table 5.

Table 5.--Parameter values for modified Soil Conservation Service, Oklahoma, and National flood-discharge methods

Parameter	Explanation	Values for stations indicated				
		07144320	07144323	07144325	07144330	07144340
RQ_2	Rural 2-year flood (cubic feet per second)1/	903	292	1,830	491	570
RQ_{10}	Rural 10-year flood (cubic feet per second)1/	2,810	955	4,650	1,570	1,810
RQ_{100}	Rural 100-year flood (cubic feet per second)1/	6,270	2,130	9,530	3,500	4,040
R_L	Oklahoma urban adjustment factor	1.40	2.05	1.45	1.85	1.85
RI2	2-hour, 2-year rainfall depth (inches)	2.05	2.05	2.05	2.05	2.05
ST	Basin storage (percentage of total drainage area)	5	1	8	3	5
BDF	Basin development factor	4	4	4	4	4
IA	Impervious area (percentage)	12	40	15	32	31
A	Drainage area (square miles)	8.92	1.14	16.4	2.94	3.86
SL	Channel slope 10-85 percent channel length (feet per mile)	16.3	30.7	13.7	23.0	19.1
CN	Curve number for modified Soil Conservation Service method	85	85	85	65	70

1 From method of Jordan and Irza (1975).

The equations are:

$$UQ_2 = R_L \; RQ_2; \tag{1}$$

$$UQ_{10} = 1.87 \; (R_L - 1) \; RQ_2 + 0.167 \; (7 - R_L) \; RQ_{10}; \text{ and} \tag{2}$$

$$UQ_{100} = 2.72 \; (R_L - 1) \; RQ_2 + 0.167 \; (7 - R_L) \; RQ_{100}. \tag{3}$$

The National method also utilizes the same rural flood-frequency relationships as did the Oklahoma method but makes more detailed adjustments. The parameters considered in the National method are basin area and slope, channel storage, impervious area, rural peak discharge for an equivalent drainage basin, 2-year, 2-hour rainfall intensity, and a basin-development factor. These parameter values also are listed in table 5. The equations are:

$$UQ_2 = [2.35A^{0.41} \; SL^{0.17} \; (RI2 + 3)^{2.04} \; (ST + 8)^{-0.65} \; (13\text{-}BDF)^{-0.32} \; IA^{0.15}] \; RQ_2^{0.47}; \tag{4}$$

$$UQ_{10} = [2.99A^{0.32} \; SL^{0.15} \; (RI2 + 3)^{1.75} \; (ST + 8)^{-0.57} \; (13\text{-}BDF)^{-0.30} \; IA^{0.09}] RQ_{10}^{0.58}; \tag{5}$$

and

$$UQ_{100} = [2.50A^{0.29} \; SL^{0.15} \; (RI2 + 3)^{1.76} \; (ST + 8)^{-0.52} \; (13\text{-}BDF)^{-0.28} \; IA^{0.06}] RQ_{100}^{0.63}. \tag{6}$$

The results of the five methods of determining flood discharges are summarized in table 6. Evaluation of values for each method indicates that the rainfall-runoff model, the modified SCS method, and "observed" method gave similar peak-discharge values for both the downstream gaging station (07144340) on Dry Creek and for the upstream station (07144330). The downstream station has a basin area 31-percent larger than the upstream station, but the channel length is substantially longer (87 percent) than the upstream station, which allows distribution of the total flood volume along the channel. Peak flood-discharge values for a long narrow basin will be less than those for a short, wide basin of equal area. The relationship between basin area and channel length is an important factor for computing urban flood frequencies. The Oklahoma method and the National method consider this factor indirectly.

The best flood-frequency estimates usually are derived from measured yearly peak-flood values. However, a basin undergoing urbanization will not give a homogeneous sample of peak-flood values because factors such as imperviousness, channel roughness and constrictions, and land use are constantly changing. This may be one of the possible explanations for the smaller flood-frequency values obtained from the "observed" method for the five basins. Length of record is another important factor to consider. Even with a stable basin, a short record does not provide reliable estimates for long recurrence intervals. Also with records of less than 10 years,

Table 6.--Results of modeled, "observed," modified Soil Conservation Service, Oklahoma, and National methods of estimating flood discharges

Station number	Recurrence interval	Peak discharge, in cubic feet per second				
		Model	"Observed" (Log-Pearson Type-III estimate)[1]	Modified Soil Conservation Service	Oklahoma	National
07144320	2-year	1,440	806	1,550	1,260	839
	10-year	3,010	1,810	3,880	2,630	2,330
	100-year	5,300	3,480	6,700	6,850	5,050
07144323	2-year	543	276	892	599	359
	10-year	1,060	471	1,780	1,360	993
	100-year	1,780	669	2,870	2,600	2,030
07144325	2-year	1,720	1,160	2,540	1,830	1,100
	10-year	3,850	2,020	6,640	4,650	3,010
	100-year	7,110	3,000	11,700	9,530	6,550
07144330	2-year	1,010	898	177	908	572
	10-year	1,930	1,490	1,480	2,130	1,460
	100-year	3,160	2,090	3,430	4,150	3,120
07144340	2-year	1,060	624	244	1,050	574
	10-year	2,030	1,300	1,460	2,460	1,530
	100-year	3,340	2,220	3,080	4,790	3,200

[1] U.S. Water Resources Council, 1981.

normal climatic fluctuations, dry and wet periods of 3-7 years, can interject bias into the flood-frequency relationships. Drier-than-normal conditions are evident from precipitation records during the mid- to late 1970's in the Wichita area. The rainfall-runoff model was calibrated to basin conditions that are presently occurring. A precipitation and evaporation record of 69 years eliminates any short-term wet- or dry-period bias, and the synthesized length of record enables a reliable estimate of floods with a recurrence interval of as much as 100 years. Therefore, it is considered that the model method resulted in the most representative flood-frequency estimates for the five basins in this report.

Selection of the best method of calculating flood-frequency estimates for other basins within the Wichita area is dependent on the recurrence interval desired and the quantity of available data. If the resources or time are not available for modeling, or collecting a series of peak-flood values, one of the nongaging methods (National, Oklahoma, or modified SCS method) needs to be used. These nongaging methods were evaluated in relation to the model method for the five basins in this study.

The method that best agreed with the modeling was the 100-year flood-frequency estimates computed using the National method, followed by the 2-year, flood-frequency estimate computed by the Oklahoma method. Both estimates had average percentage differences of less than 10 percent from the modeled estimates. The 10-year, flood-frequency estimates for both the National and Oklahoma methods were within 20 percent of the modeling method. Using both methods with emphasis on the Oklahoma method for shorter recurrence intervals, the National method for longer recurrence intervals, and either method in between should result in reliable estimates.

The modified SCS method resulted in flood-frequency estimates that differed from the modeled estimates by 31 percent for the 100-year estimates and as much as a 57-percent difference for the 2-year estimate. The modified SCS method could be used as a check on the National and Oklahoma methods or when data for these two methods are not available.

Urbanization Analysis

In order to determine the effects of urbanization, long-term syntheses of flood peaks were conducted using varying percentages of imperviousness and values of TC (time of concentration) in conjunction with other calibrated model parameters. The change in TC for each degree of imperviousness was estimated using the equation developed by Putnam (1972) and found applicable to Wichita by Peek and Jordan (1978):

$$\lambda = 0.49 \left(\frac{L}{\sqrt{S}}\right)^{0.5} I^{-0.57} , \qquad (7)$$

where

λ = lag time, in hours;

L = length of main water course, in miles;

S = channel slope, in feet per mile; and

I = ratio of impervious area to total drainage area (minimum value of 0.02 used for rural conditions).

There is a relationship between lag time and TC as they are both measurements of travel time of a flood through a basin. The difference between the two is that lag time is the time interval from the maximum excess rainfall to the peak rate of runoff and TC is the time interval from the end of excess rainfall to where direct runoff ceases. The effects of urbanization on hydrograph shape and the difference between lag time and TC are shown in figure 1. Changes in lag time from equation 7 were compared with the TC obtained in the model calibration for each basin, and from this comparison, values of TC were obtained for varying degrees of imperviousness.

Synthesized flood discharges for each percentage of imperviousness were plotted against the 2-, 5-, 10-, 25-, 50-, and 100-year recurrence interval. Results are shown in figures 4-8. For each station analyzed, the slope of the flood-frequency relationship becomes smaller as imperviousness increases. Inspection of the 2-year flood revealed an average factor of 6.3 between the rural (2-percent imperviousness) and the urban (60-percent imperviousness) flood. The range for the five stations was between 2.1 and 16.4. The average factor for the 100-year flood was 2.3 with a range of 1.3 to 5.0. These findings are consistent with the concept that urbanization affects the shorter recurrence-interval floods to a greater extent than the longer recurrence-interval floods. The largest increases in flood values were noted in the initial stages of urbanization, from rural to 10-percent imperviousness.

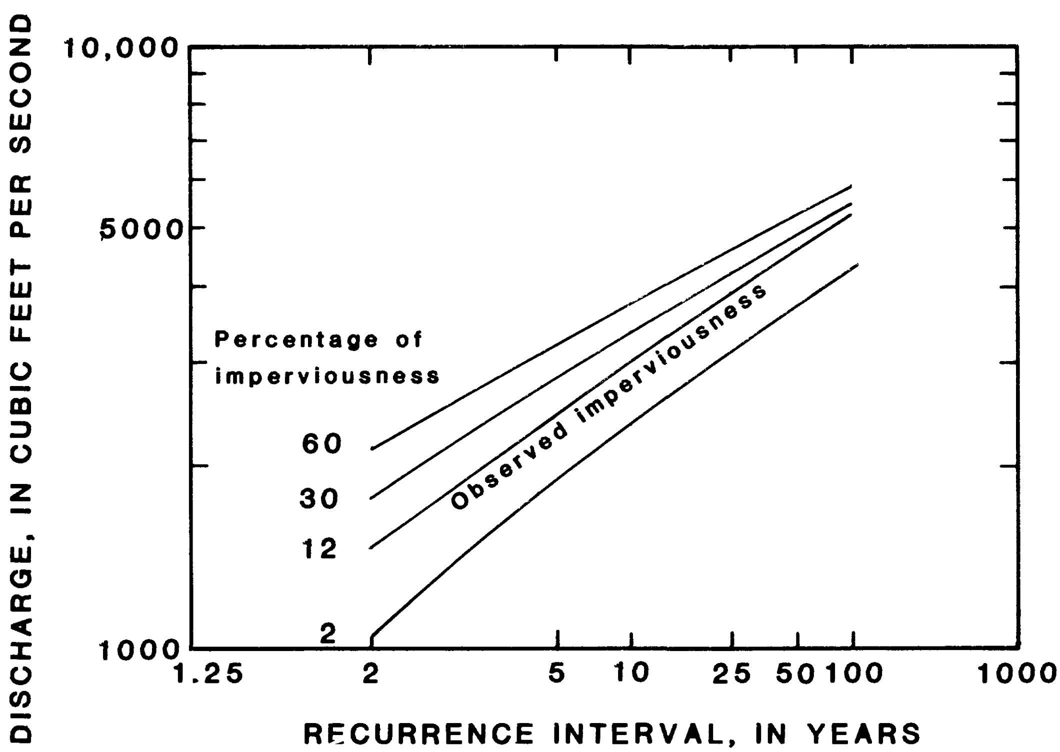


Figure 4.--Effect of increasing urbanization on flood-frequency relationships for Gypsum Creek at Gilbert Street (07144320).

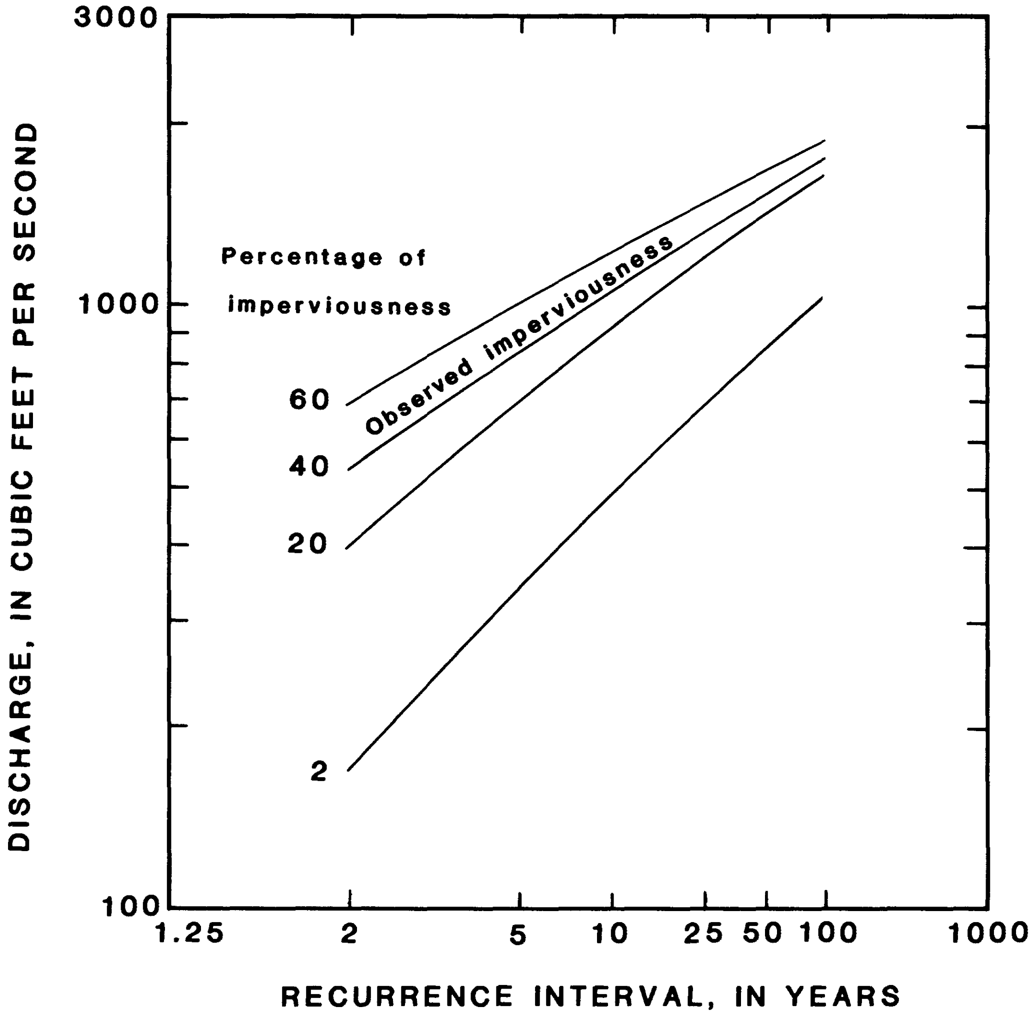


Figure 5.--Effect of increasing urbanization on flood-frequency relationships for Fabrique Branch of Gypsum Creek at Harry Street (07144323).

SUMMARY

The U.S. Geological Survey rainfall-runoff model was calibrated for five small basins in the city of Wichita, Kansas. The average calibrated model error was 27.5 percent. Using 10 calibrated model parameters for each basin and 69 years of rainfall data from Wichita, annual flood peaks for 69 water years for each basin were synthesized. A log-Pearson Type-III frequency analysis was conducted for each basin using the synthetic flood discharges.

The model flood-frequency analysis was used as the basis for the evaluation of four other methods of flood-frequency analysis, which included the "observed" method, the modified SCS method, the Oklahoma method, and the National method. The model, the modified SCS, and the "observed" method were consistent in showing similar discharge values between the downstream-gaging station on Dry Creek and for the upstream station. This indicates the need for including basin area and channel length in urban flood-frequency computations. The "observed" values were less than those using the other methods possibly because the relatively short series of annual flood peaks used were biased by drier-than-normal climatic conditions during the 1970's.

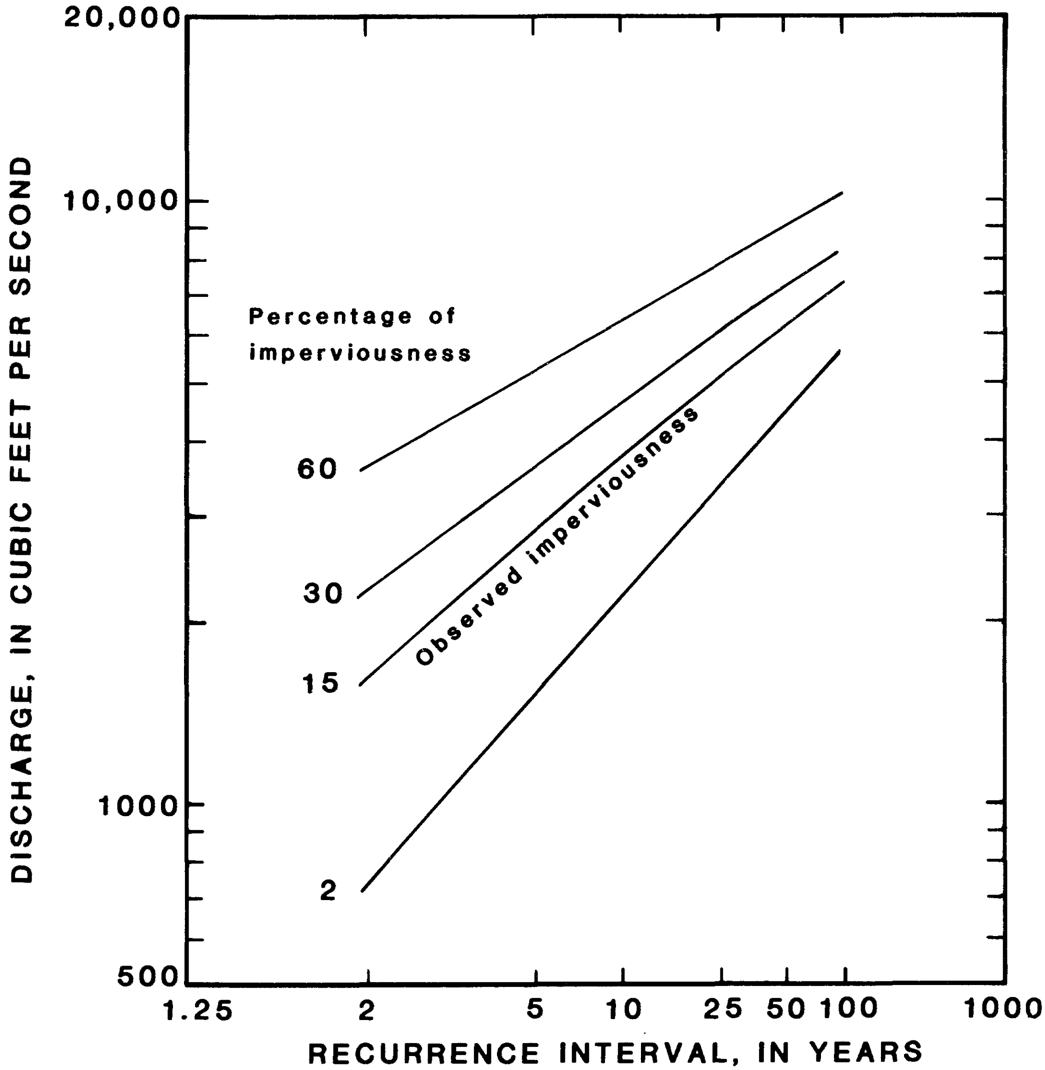


Figure 6.--Effect of increasing urbanization on flood-frequency relationships for Gypsum Creek at Oliver Street (07144325).

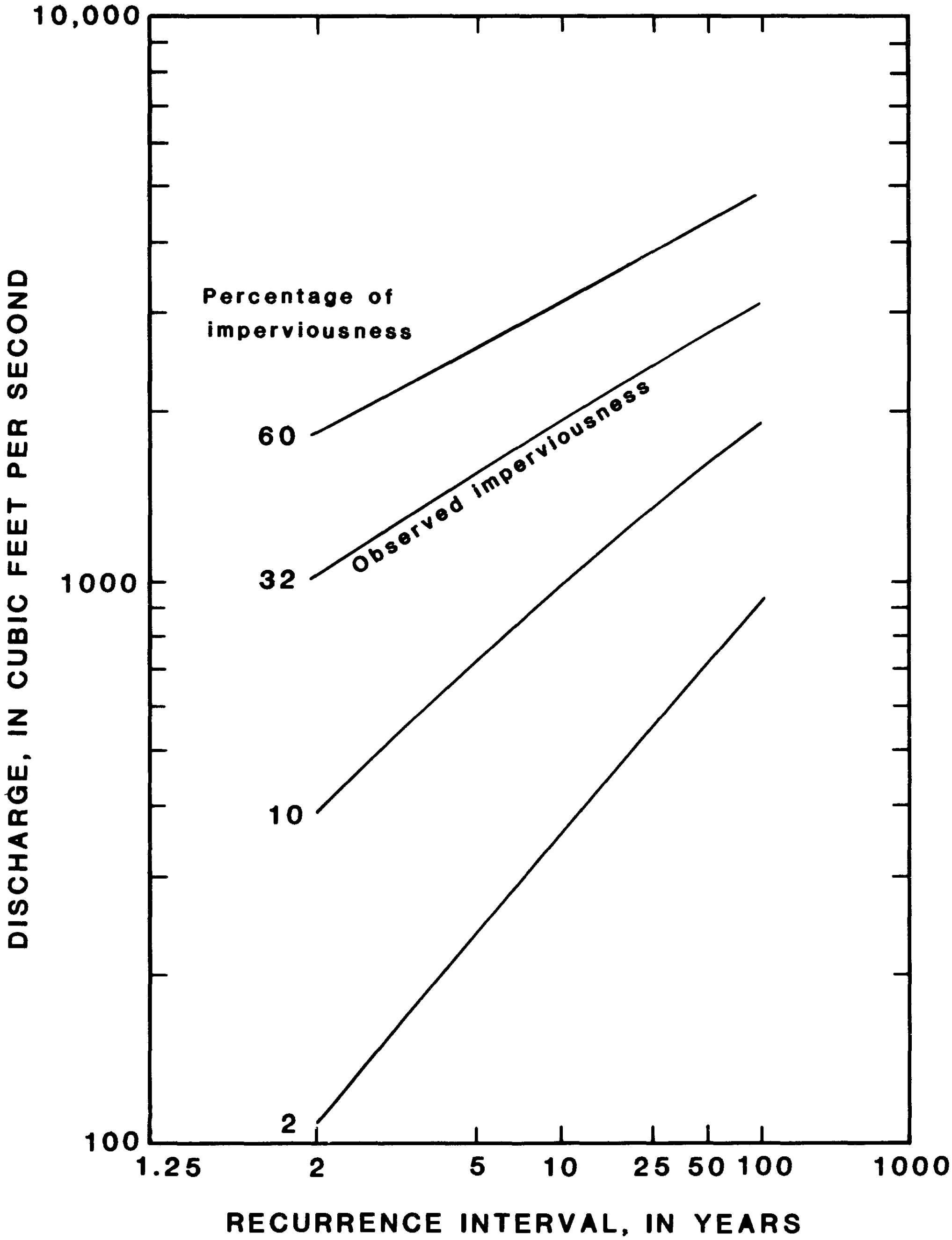


Figure 7.--Effect of increasing urbanization on flood-frequency relationships for Dry Creek at Lincoln Street (07144330).

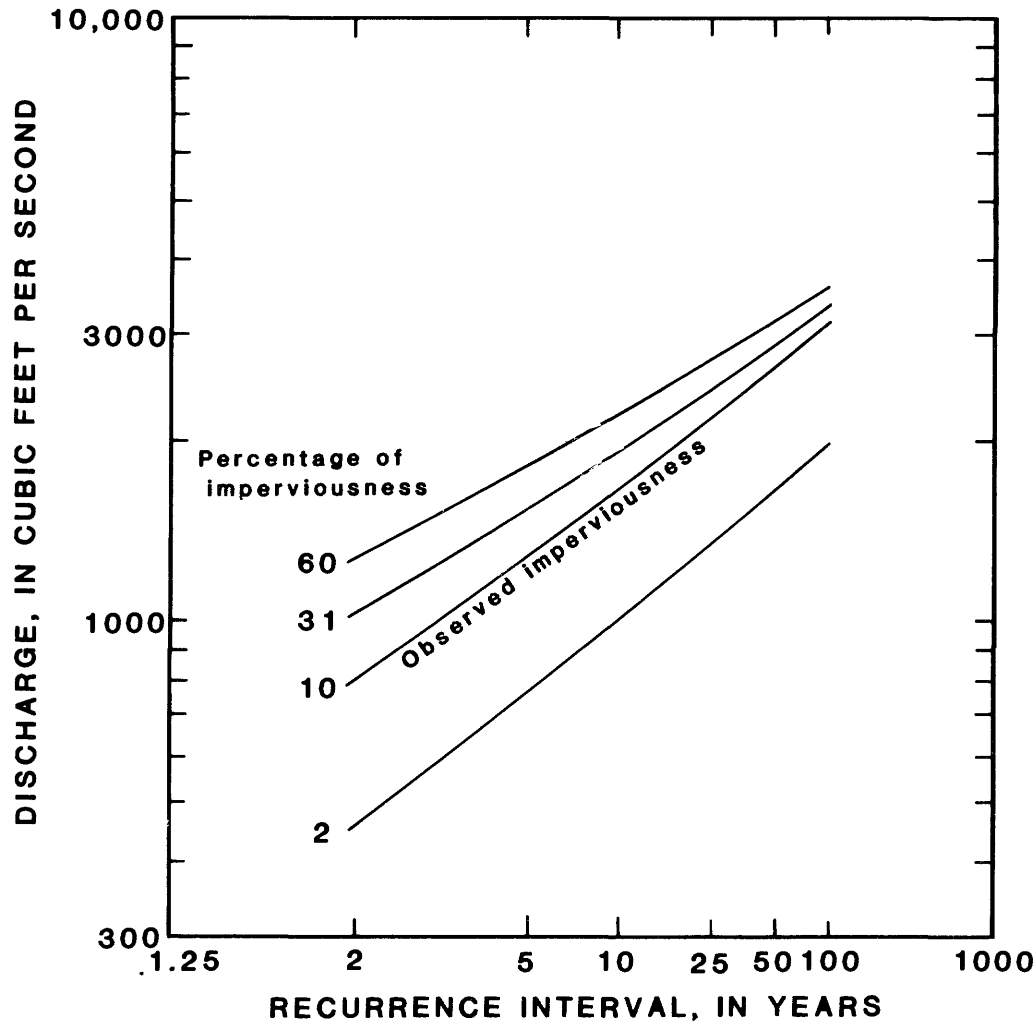


Figure 8.--Effect of increasing urbanization on flood-frequency relationships for Dry Creek at Pawnee Avenue (07144340).

The modeled flood-frequency estimates are considered to be the most reliable of the methods used on basins in this study. The most reliable method of calculating flood-frequency estimates for ungaged basins in the Wichita area is a combination of the National and Oklahoma methods. Modeled flood-frequency estimates were best approximated by the Oklahoma method for the 2- to 10-year recurrence interval and the National method for the 10- to 100-year intervals. The modified SCS method can be used as a check or when data for the National or Oklahoma methods are not available.

An analysis of the effects of urbanization revealed an average increase of 6.3 times the rural 2-year flood and 2.3 times the rural 100-year flood when 60 percent of the basin is impervious under urban conditions. Peak-discharge values for any particular recurrence interval increased most rapidly during the initial stages of urbanization.

SELECTED REFERENCES

Anderson, D. G., 1970, Effects of urban development on floods in northern Virginia: U.S. Geological Survey Water-Supply Paper 2001-C, 22 p.

Carrigan, P. H., Jr., 1973, Calibration of U.S. Geological Survey rainfall/runoff model for peak flow synthesis--Natural basins: U.S. Department of Commerce, National Technical Information Service, PB-226 217, 109 p.

Carrigan, P. H., Jr., Dempster, G. R., Jr., and Bower, D. E., 1977, Users guide for U.S. Geological Survey rainfall-runoff models--Revision of Open-File Report 74-33: U.S. Geological Survey Open-File Report 77-884, p. 13-1 to 15-36.

Carter, R. W., 1961, Magnitude and frequency of floods in suburban areas, in Geological Survey Research 1961: U.S. Geological Survey Professional Paper 424-B, p. B9-B11.

Clark, C. O., 1945, Storage and the unit hydrograph: American Society of Civil Engineers Transactions, v. 110, p. 1419-1488.

Curtis, G. W., 1977, Frequency analysis of Illinois floods using observed and synthetic streamflow records: U.S. Geological Survey Water-Resources Investigations 77-104, 38 p.

Dawdy, D. R., Lichty, R. W., and Bergmann, J. M., 1972, A rainfall-runoff simulation model for estimation of flood peaks for small drainage basins: U.S. Geological Survev Professional Paper 506-B, p. B1-B28.

Harris, E. E., and Rantz, S. E., 1964, Effect of urban growth on streamflow regimen of Permanente Creek, Santa Clara County, California: U.S. Geological Survey Water-Supply Paper 1591-B, p. B1-B18.

James, I. C., II, 1967, Flood runoff from partially urbanized areas, Wichita, Kansas--Report No. 1--Analysis of initial conditions: U.S. Geological Survey open-file report, Lawrence, Kansas, 62 p.

Jordan, P. R., and Irza, T. J., 1975, Magnitude and frequency of floods in Kansas, unregulated streams: Kansas Water Resources Board Technical Report No. 11, 34 p.

Leopold, L. B., 1972, Hydrology for urban land planning--A guidebook on the hydrologic effects of urban land use: U.S. Geological Survey Circular 554, 18 p.

Peek, C. O., and Jordan, P. R., 1978, Determination of peak discharge from rainfall data for urbanized basins, Wichita, Kansas: U.S. Geological Survey Open-File Report 78-974, 49 p.

Penner, H. L., 1978, Soil survey of Sedgwick County, Kansas: U.S. Department of Agriculture, Soil Conservation Service, 126 p.

Philip, J. R., 1957, Numerical solution of equations of the diffusion type with diffusivity concentration dependent: Australian Journal of Physics, v. 10, 29 p.

Putnam, A. L., 1972, Effect of urban development on floods in the Piedmont Province of North Carolina: U.S. Geological Survey open-file report, 87 p.

Richards, D. B., 1971, Flood runoff from partly urbanized areas, Wichita, Kansas--Report No. 2--Analysis of progressing conditions: U.S. Geological Survey open-file report, Lawrence, Kansas, 62 p.

Sauer, V. B., Thomas, W. O., Jr., Stricker, V. A., and Wilson, K. V., 1983, Flood characteristics of urban watersheds in the United States: U.S. Geological Survey Water-Supply Paper 2207, 63 p.

Spencer, D. W., and Alexander, T. W., 1978, Technique for estimating the magnitude and frequency of floods in St. Louis County, Missouri: U.S. Geological Survey Water-Resources Investigations 78-139, 23 p.

Thomas, W. O., Jr., and Corley, R. K., 1977, Techniques for estimating flood discharges for Oklahoma streams: U.S. Geological Survey Water-Resources Investigations 77-54, 180 p.

U.S. Water Resources Council, 1981, Guidelines for determining flood flow frequencies: U.S. Water Resources Bulletin 17B, 28 p.

Wibben, H. C., 1976, Application of the U.S. Geological Survey rainfall-runoff simulation model to improve flood-frequency estimates on small Tennessee streams: U.S. Geological Survey Water-Resources Investigations 76-120, 59 p.

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