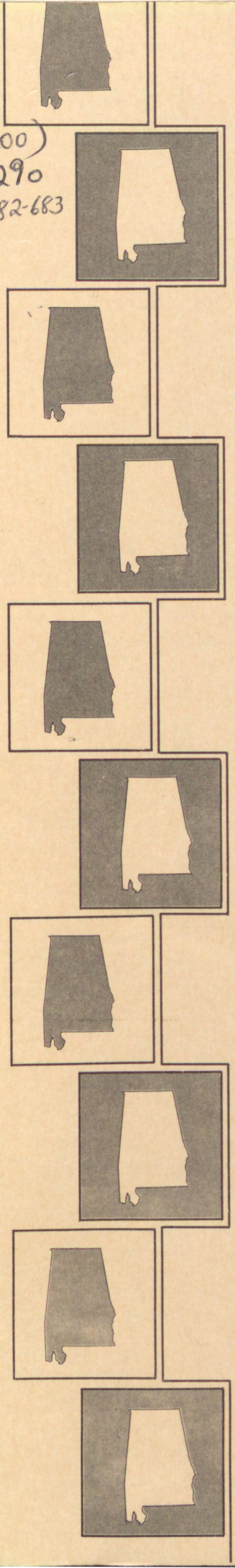

Water-Resources Investigations Open File Report 82-683

Synthesized Flood Frequency of Urban Streams in Alabama

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Prepared by
the United States Department of the Interior, Geological Survey
In cooperation with
the Alabama Highway Department and the U.S. Department of Transportation
Federal Highway Administration

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By D. A. Olin and R. H. Bingham

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Open-File Report 82-683

U.S. DEPARTMENT OF THE INTERIOR
March 3, 1849

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UNITED STATES DEPARTMENT OF THE INTERIOR

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FACTORS FOR CONVERTING INCH-POUND UNITS TO METRIC UNITS

The analyses and compilations used in this report were made in inch-pound units of measurements. Conversion factors for inch-pound units and metric units are listed below. Multiply inch-pound units by the conversion factor to obtain metric units.

Conversion Factors

Inch-pound units	Conversion factor	Metric units
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.59	square kilometer (km^2)
foot per mile (ft/mi)	0.189	meter per kilometer (m/km)
cubic foot per second (ft^3)	0.0283	cubic meter per second (m^3)

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ABSTRACT

Equations have been developed for estimating future floods for 2-, 5-, 10-, 25-, 50-, and 100-year recurrence intervals on urban streams in Alabama with drainage areas of about 0.15 to 85 square miles. One equation for each recurrence interval applies statewide. The equations were derived by multiple regression analyses of flood magnitudes obtained from synthetic discharge data generated with a calibrated rainfall-runoff model and basin characteristics. The regression analyses indicated that drainage area size and percent of the basin occupied by impervious materials are the most significant basin characteristics affecting flood frequency and magnitude of urban streams.

Mathematical procedures used to analyze the observed and synthetic data are described. Also included are flood-frequency data for stations used in the analyses and example computations demonstrating application of the regression equations to urban streams in Alabama.

INTRODUCTION

The planning and economic design of streets, highways, bridges, culverts, and other structures near urban streams requires knowledge of the magnitude and frequency of floods. Such knowledge is also needed for flood-plain management and development, and for determining flood insurance rates. The purpose of this report is to provide methods of estimating the magnitude and frequency of flooding along urban streams with a drainage area of about 0.15 to 85 mi^2 in Alabama. However, these methods do not apply to streams where temporary in-channel storage and/or overbank storage caused by detention structures or roadway embankments significantly affect the magnitude of peak flows. The estimating methods consist of regression equations which were derived from synthetic peak discharge data and physical characteristics of basins.

Methods of estimating magnitude and frequency of floods in urban areas have been the subject of many reports during recent years. The usual approach, given data for an area, is to relate selected flood magnitudes, such as the mean annual flood or 50-year flood, to basin and climatic characteristics, and to a measure of urban development. Urban development, from a hydraulic viewpoint, is usually measured by the amount of impervious area in a basin and the percentage of the basin served by storm sewers and channel improvements. Examples of such reports are Anderson (1970), Carter (1961), Gann (1971), Espey and others (1966), Espey and Winslow (1974), Leopold (1968), Martens (1968), James (1965), Sauer (1974), and Wilson (1966).

This report extends streamflow data collected in urban areas and provides a method of estimating floods along certain ungaged streams. The data were collected as a part of a cooperative program with the Alabama Highway Department and the Federal Highway Administration.

Acknowledgment and appreciation are expressed to city officials in Huntsville for providing precipitation and runoff data for streams and stream basins in their area.

FLOOD FREQUENCY ANALYSIS

The relation of flood-peak magnitude to the probability of occurrence, or recurrence interval, is referred to as a flood-frequency relation. As applied to annual floods, recurrence interval is the average interval of time between exceedance of the indicated flood magnitude. For example, a flood with a 50-year recurrence interval has a 1 in 50 chance, on the average, of occurring in any given year. However, the fact that a major flood occurs in one year does not reduce the probability of a flood as great or greater occurring within the same year or during the next year.

Observed Data

Systematic collection of flood records (peak stage and discharge) and concurrent rainfall data began in Alabama in 1971 on seven selected urban streams. Between 1974 and 1977, the collection of similar records was begun on 20 additional selected urban streams to supplement data collected since 1971 in order to provide urban runoff information statewide. Collection of records at some original sites was discontinued before 1977 because it was considered that sufficient data were available or because the data were unusable.

The flood-frequency analyses for streams presented in this report are based on 23 stations (fig. 1). Four other stations (fig. 1) were deleted from the analysis because of problems with data collection. Flood frequencies at these stations were unreliable. The length of record of observed flood peak and rainfall data for the 23 stations used in the flood-frequency analysis ranges from 2 to 6 years.

The reliability of flood-frequency data computed from observed flood peaks is primarily dependent upon the length of observed record. For all stations used in this report, the length of record was too short to produce reliable flood-frequency estimates from the observed data. Thus, to improve the reliability, observed rainfall and runoff data were used to develop synthetic flood-frequency data with a U.S. Geological Survey rainfall-runoff model developed by Dawdy and others (1972). Calibrated parameters from this model were used to estimate T-year (annual) flood magnitudes using procedures described by Lichty and Liscum (1978).

Lichty and Liscum (1978) used the U.S. Geological Survey rainfall-runoff model to synthesize a sample of 550 annual-flood series from 98 small streamflow stations in six states. In their report they state that: "a flood-frequency curve was developed for each annual-flood series, and a single-coefficient, regression relation for the 2-, 25-, and 100-year floods was developed for each one of the rainfall sites...Site-to-site synthetic T-year (annual) flood relation was interpreted as reflecting the spatially verying influence of local climatic factors, C_i, on the results of synthesis...Estimates of the C_i values taken from maps were used in conjunction with fitted rainfall-runoff model parameters and the synthetic T-year flood relation to develop map-model, T-year flood estimates for the 98 rural-area streamflow stations."

Rainfall records were collected at Birmingham by the National Weather Service for the period 1903 to 1973 and pan-evaporation data were collected at Martin Dam on the Tallapoosa River by the Alabama Power Company for the period 1951 to 1973. These long-term records, extended to the period 1897 to 1980, were used to extend annual flood peaks in time by a rainfall runoff model for three gaging stations in the Birmingham area. The flood data were extended to test a map-model flood magnitude procedure developed by Lichty and Liscum (1978) for combining frequency curves based on several long-term rainfall gages.

Rainfall-Runoff Model

The rainfall-runoff model, developed by Dawdy and others (1972) and modified by Carrigan (1973), simulates flood peaks for small drainage basins. The general structure of the model, as summarized by Lichty and Liscum (1978), is given in the following paragraph:

"It is a simplified, conceptual, bulk-parameter, mathematical model of the surface-runoff component of flood-hydrograph response to storm rainfall. The model deals with three components of the hydrologic cycle - antecedent soil moisture, storm infiltration, and surface runoff routing. The first component simulates soil-moisture conditions of the storm period through the application of moisture-accounting techniques on a daily cycle. Estimates of daily rainfall, evaporation, and initial values of the moisture storage variables are elements used in this component. The second component involves an infiltration equation (Philip, 1954) and certain assumptions by which rainfall excess is determined on a 5-minute accounting cycle from storm-period rainfall. Storm rainfall may be de-

Figure 1. Location of gaging stations in urban areas of Alabama.

fined at 5-, 10-, 15-, 30-, and 60-minute intervals, but loss rates and rainfall excess amounts are computed at 5 minute intervals. The third component transforms the simulated time pattern of rainfall excess into a flood hydrograph by translation and linear storage attenuation (Clark, 1945)." The structure of the model is shown in figure 2. The model parameters and their application in the modeling process, taken from Lichty and Liscum (1978), are summarized in table 1. For a more complete description of the model, see Dawdy and others (1972).

The parameters used to define the hydrograph are KSW, TC, and TP/TC. KSW is a linear reservoir routing coefficient which defines the slope of the recession limb of the hydrograph. The time of discharge concentration, TC, and the time of discharge peak, TP, define the inflection point and time of the hydrograph peak, respectively. The ratio TP/TC is a constant equal to 0.5 which utilizes an isosceles triangle for the translation hydrograph as described by Carrigan (1973).

Model Calibration

The model was calibrated for the 23 gaging stations (fig. 1) by adjusting the parameters to achieve acceptable synthetic discharge results using concurrent rainfall and discharge data. The data were carefully screened and some storms were deleted from the calibration procedure primarily because of station equipment malfunction, unacceptable timing of flood peak and rainfall, or lack of rainfall distribution. The calibrated parameters for the 23 stations are given in table 2.

Four stations were deleted from the analyses because calibration results for them were unacceptable. Many attempts were made to calibrate the model for Fivemile Creek (02456900) near Huffman in the Birmingham area. Those attempts produced unacceptable results owing to the geometry of the flood plain. The flood plain is about 1,000 feet wide at the gage and converges to about 400 feet wide about one-quarter mile downstream. The convergence creates some ponding at the gage and, during flooding, much of the water leaves the channel upstream from the gage, flows almost perpendicular to the basin, and enters a tributary to Fivemile Creek. Water that leaves the channel by-passes the gage. This resulted in problems with the rainfall-runoff relationship. Consequently, the model overestimates most of the medium to high discharges.

Problems in calibration of the model for Valley Creek (02461500) at Bessemer are attributed to large volumes of flood water diverted into quarries and sinkholes in the flood plain immediately upstream from the station. Soluble limestone underlies the basin and, in addition to the sinkholes and quarries, solution cavities are exposed in the stream channel and in outcrops near the headwaters of the stream. Because of the diversion of large volumes of water, the model overestimates most of the medium to high flood discharges. The problems of overestimating flood magnitudes probably exist in stream basins underlain by soluble limestone in other areas of Alabama, and caution should be used in estimating floods.

Attempts to calibrate the model for Cribbs Mill Creek (02465291) at Tuscaloosa produced unacceptable results. The calibration problems resulted from a flood retention reservoir and small lakes upstream and from inadequate streamflow data to define runoff volume and hydrograph shape. Lack of observed data to define the recession limb of the hydrograph caused the model to significantly overestimate runoff volume and underestimate lag time. The observed data indicate a minimum discharge rate of 150 ft^3/s for this small basin with a drainage area of 10.7 mi^2. Some peaks used in the calibration attempts barely exceeded 150 ft^3/s.

East Eslava Creek (02471041) in Mobile was omitted from the analyses because of inadequate streamflow data to define runoff volume and hydrograph shape. Lack of observed data to obtain the recession limb of the hydrograph caused the model to significantly overestimate runoff volume and underestimate lag time.

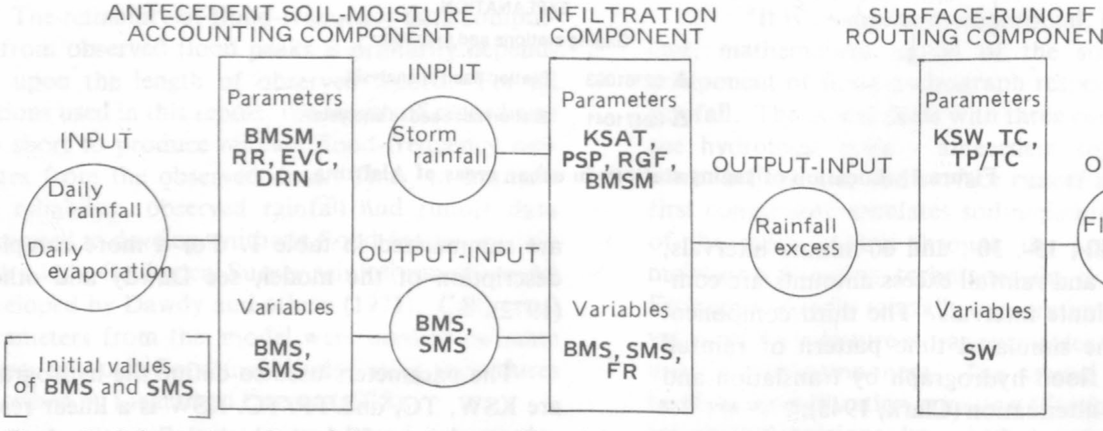

Figure 2. Schematic outline of the rainfall-runoff model structure, showing components, parameters, variables, and input-output data; flow is left to right. (From Lichty, R. W., and F. Liscum, 1978).

The four stations described were not used in the analyses because of the problems associated with model calibration. Synthetic flood magnitudes developed from the model parameters for such stations are assumed unreliable.

SYNTHETIC DATA

Calibrated parameters and climatic factors were used to generate synthetic flood magnitudes for each of the 23 gaging stations (fig. 1). The procedures for estimating flood magnitudes for 2-, 25-, and 100-years are described by Lichty and Liscum (1978). The calibrated parameters are listed in table 2, and the climatic factors were taken from illustrations (figures 5, 6, and 7) in Lichty and Liscum (1978).

Lichty and Liscum (1978) have indicated that the map-model procedure has a tendency to underestimate the higher recurrence interval floods. The adjustment for this apparent bias is made by the following equation,

$$\text{"unbiased"}\ q_i = B_i\, q_i$$

where B_i is the bias factors averaged from data for a 6-state area covered in their report, and q_i is the map-model estimate of flood magnitudes for recurrence interval $_i$. The values for B_i are: $B_2 = 0.98$, $B_{25} = 1.19$, and $B_{100} = 1.29$. One reason for the underestimation is because the rainfall distribution is not uniform over a given watershed. Lichty and Liscum (1978) state in their report: "This tendency for underestimation of the higher recurrence interval events may be attributed to several factors, including:

1. A loss of variance associated with a model smoothing effect, as described by Matalas and Jacobs (1964), and Kirby (1975);

2. The effect of unmodeled, real-world nonlinearities in the tranformation of rainfall excess to discharge hydrograph (routing)--a limitation of the unit-hydrograph concept as used in the rainfall-runoff model;

3. Incorrectly modeled nonlinearities in the synthesis of rainfall excess (volume of runoff), due to inadequacies in either antecedent soil-moisture accounting or infiltration computations;

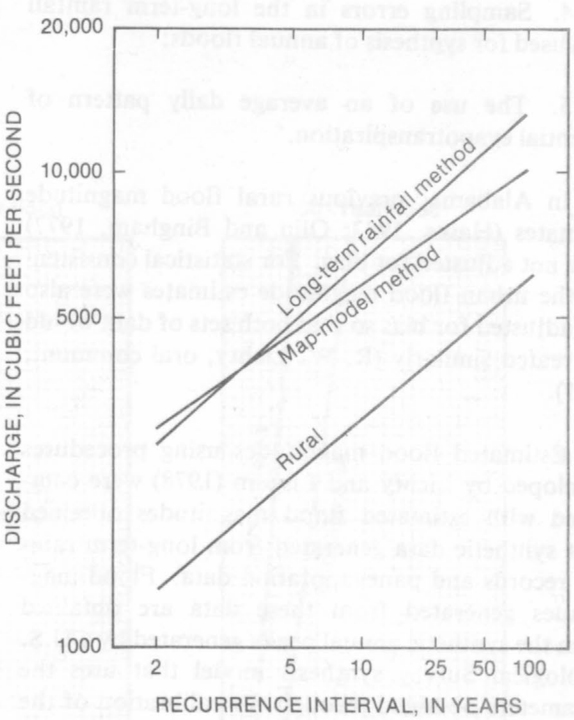

Figure 3. Flood-frequency curves representing different estimating methods for Shades Creek (02423580) at Homewood near Birminham, Alabama.

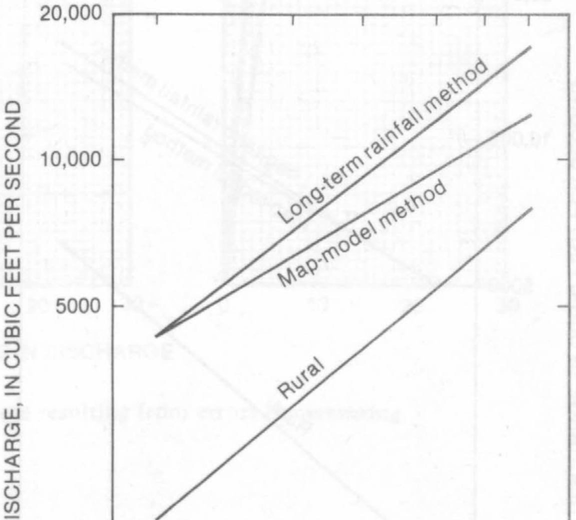

Figure 4. Flood-frequency curves representing different estimating methods for Fivemile Creek (02457000) at Ketona near Birmingham, Alabama.

4. Sampling errors in the long-term rainfall data used for synthesis of annual floods;

5. The use of an average daily pattern of potential evapotranspiration."

In Alabama, previous rural flood magnitude estimates (Hains, 1973; Olin and Bingham, 1977) were not adjusted for bias. For statistical consistency, the urban flood magnitude estimates were also not adjusted for bias so that both sets of data would be treated similarly (R. W. Lichty, oral commun., 1981).

Estimated flood magnitudes using procedures developed by Lichty and Liscum (1978) were compared with estimated flood magnitudes obtained with synthetic data generated from long-term rainfall records and panevaporation data. Flood magnitudes generated from these data are obtained from the synthetic annual peaks generated by a U.S. Geological Survey synthesis model that uses the parameters obtained through the calibration of the rainfall-runoff model, and the long-term rainfall and evaporation data. For each year of long-term rainfall record, five storm periods are selected and the peak discharge for each period is estimated. The highest annual peak for each year is then used in a log-Pearson Type III analysis to estimate flood magnitudes for selected recurrence intervals. Three stations in the Birmingham area were used: Shades Creek (02423580) at Homewood, Fivemile Creek (02457000) at Ketona, and Valley Creek (02461200) in Birmingham. The calibrated model parameters were used with long-term rainfall records collected by the National Weather Service at Birmingham and pan-evaporation data collected by Alabama Power Company at Martin Dam. The results of the two methods along with estimated rural flood magnitudes are illustrated in figures 3, 4, and 5. Comparison of the results indicates that both methods provide similar estimates of flood magnitudes. The differences (up to 28 percent at 100-year recurrence) are mainly due to the differences in skew. The flood frequency curves obtained with synthetic data generated from long-term rainfall and pan-evaporation data have a more positive skew than those from the Lichty and Liscum (1978) method. It is assumed that this comparison for other stations in Alabama would be similar, therefore, the methods given by Lichty and Liscum (1978) were used to estimate long term flood magnitudes for all stations used in this report.

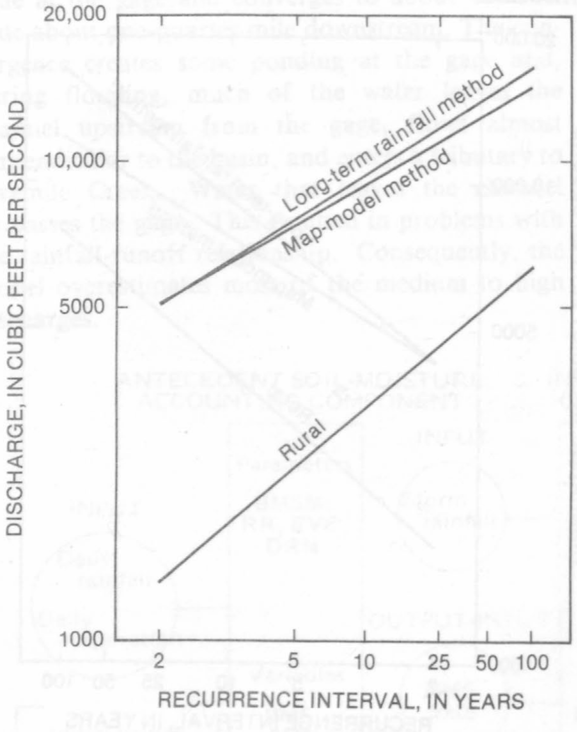

Figure 5. Flood-frequency curves representing different estimating methods for Valley Creek (02461200) at Birmingham, Alabama.

Estimates of T-Year (Annual) Floods

Estimating T-year (annual) floods using the Lichty and Liscum (1978) procedures provides an indication of the adequacy of the calibration results. The estimating procedure required computation of an infiltration factor (F), in inches per hour, and lag time (L), in hours, to be used in the equations for synthetic flood magnitudes. The infiltration factor (F) is computed by the following equation;

$$F = KSAT\,[1.0 + 0.5\,PSP\,(0.15\,RGF + 0.85)]$$

and lag time (L) by;

$$L = KSW + 0.5\,TC$$

For Alabama streams, the values for F should generally be no larger than 2.50; larger values indicate unacceptable calibrations. Values of KSAT, PSP, RGF, KSW, and TC are listed in table 2 for each station.

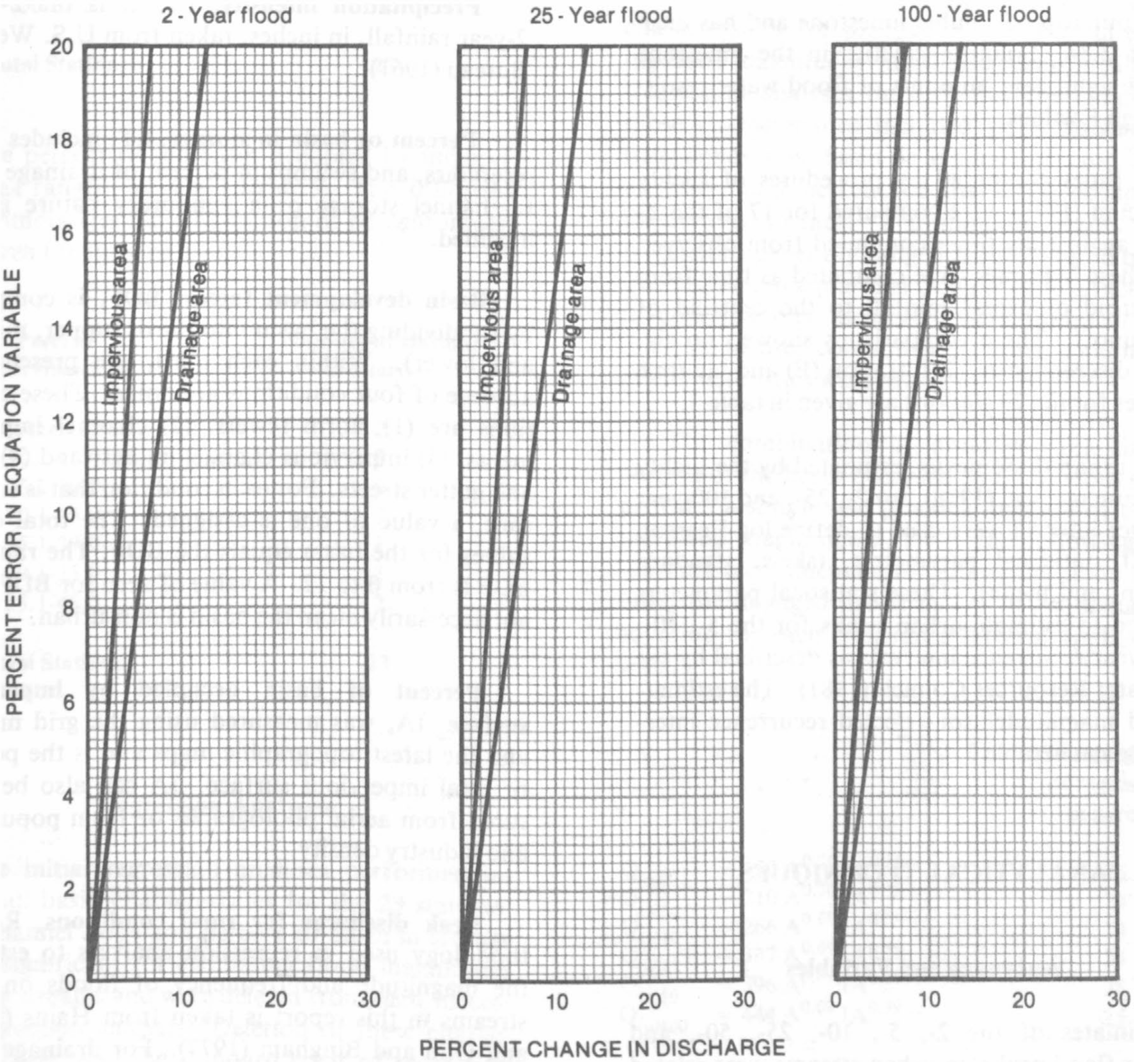

Figure 6. Percent change in flood discharge resulting from errors in measuring drainage area and impervious area.

Infiltration factors (F values) are related to the surface material in a basin. For example, Hannon Slough (02420987) in Montgomery, underlain by clay and chalk, has an F value of 0.17, whereas, Three Mile Branch (02419975) in Montgomery, underlain primarily by sand and clay, has an F value of 0.94. Five Points Ditch (03575880) in Huntsville is in an outcrop of soluble limestone and has an F value of 2.34. Solution cavities in the limestone intercept significant amounts of flood water resulting in high F values.

Lag times computed by procedures of Lichty and Liscum (1978) were compared for 17 of the 23 stations against lag times computed from observed data. These lag times were computed as time from the centroid of excess rainfall to the centroid of storm runoff. These comparisons showed no significant discrepancies. Infiltration (F) and lag time (L) values for the 23 stations are given in table 3.

The urban flood peaks, estimated by the Lichty and Liscum method (1978), for 2-, 25-, and 100-year recurrence interval were used to define log-Pearson Type III statistical parameters, (skew, standard deviation, and mean). These statistical parameters were used to estimate urban peaks for the 5-, 10-, and 50-year recurrence intervals as described by the U.S. Water Resources Council (1981). The estimated flood magnitudes for selected recurrence intervals are given in table 3.

ANALYTICAL TECHNIQUES

Approach and Variables

Estimates of the 2-, 5-, 10-, 25-, 50-, and 100-year flood peaks on urban streams were related to various basin and climatic characteristics by multiple regression techniques. Characteristics tested were: drainage area, main-channel slope, precipitation intensity, percent of basin in storage, a basin development factor, percent of basin occupied by impervious surface, and peak discharge for rural conditions. Information for, or definitions of each, follows.

Drainage area, A, is the contributing drainage area, in square miles. In urban areas, drainage systems sometimes cross topographic divides and should be accounted for in computations.

Main channel slope, SL, is the slope in feet per mile, determined from the difference in elevation at points 10 and 85 percent of the distance along the main channel from the discharge site to the drainage-basin divide.

Precipitation intensity, P2, 2, is the 2-hour, 2-year rainfall, in inches, taken from U.S. Weather Bureau (1961).

Percent of basin in storage, ST, includes lakes, reservoirs, and swamps in percent of drainage area. In-channel storage of a temporary nature is not included.

Basin development factor, BDF, is computed by subdividing the basin into thirds (upper, middle, and lower). Within each third, the presence or absence of four conditions are noted. These conditions are (1) storm sewers, (2) channel improvements, (3) impervious channel linings, and (4) curb and gutter streets. For each condition that is significant, a value of one is assigned. The total of all values for the basin equals the BDF. The range of BDF is from 0 to 12. A value of zero for BDF does not necessarily mean the basin is non-urban.

Percent of basin occupied by impervious surface, IA, was measured using the grid method and the latest topographic maps and is the percent of total impervious surface. IA can also be measured from aerial photographs or from population and industry density.

Peak discharge for rural conditions, R. Methodology used in regression analyses to estimate the magnitude and frequency of floods on rural streams in this report is taken from Hains (1973), and Olin and Bingham (1977). For drainage areas of 1 to 15 mi^2, the Olin and Bingham report is used. For drainage areas larger than 25 mi^2, the Hains report is used and for those between 15 and 25 mi^2 estimates using both reports are averaged.

Of the characteristics tested, only drainage area size and the percent of the basin occupied by impervious area were chosen to be used. Both of these characteristics are significant at the 5 percent level. Drainage area size used in the regression analyses ranged from 0.16 mi^2 to 83.5 mi^2. However, the distribution of size varied considerably within that range. The following table summarizes the distribution of drainage area size for stations used.

Range in drainage area size (mi^2)	Number of stations in analyses
0-1	2
1-5	7
5-25	9
25-50	3
50-83.5	2
Total Stations	**23**

The percent of the basin occupied by impervious area ranged from 8.3 to 42.9. The following table summarizes the distribution of percent impervious area for stations used.

Percent impervious area	Number of stations in analyses
less than 10.0	2
10.1-15.0	2
15.1-20.0	6
20.1-25.0	7
25.1-30.0	1
30.1-35.0	3
35.1-43.0	2
Total Stations	**23**

Regression Analyses

The initial regression analyses performed included all basin characteristics for the 23 stations. Main channel slope and percent of basin in storage were insignificant for estimating flood magnitudes in urban streams and were deleted from each successive regression analysis. Deletion of these characteristics decreased the standard error of regression and simplified the equations.

The initial analyses resulted in a disarray of exponents without apparent causes. The 2- and 5-year equations had negative exponents for the peak rural discharge. The most likely cause, however, was assumed to be the use of drainage area in the same regression, which is highly correlated with rural discharge. Drainage area size was used directly as an independent variable in the analyses and indirectly through use of rural flood peak discharge which is estimated from a combination of drainage area size and main-channel slope. Subsequent regression analyses were performed using either drainage area or rural flood peak discharge separately. These regression analyses resulted in a more realistic set of exponents, and a logical set of constants.

Additional regression analyses were performed to derive an optimum combination of selected characteristics for practical application in estimating flood magnitudes on urban streams in Alabama. Regression analyses on different combinations of those characteristics included peak discharge for rural conditions, basin development factor, rainfall intensity, and percent of the basin occupied by impervious surface. The standard errors of the regressions generally ranged from 25 to 50 percent. The regression equations using these characteristics in combinations, however, were impractical and difficult to use; consequently, other combinations of characteristics were tested.

The combination of drainage area size and percent of the basin occupied by impervious surface provides a simple and practical method of estimating flood magnitudes. Thus, the following equations are recommended for estimating flood magnitudes for ungaged urban basins in Alabama. One equation for each recurrence interval applies statewide.

	Standard error of regression, in percent
$Q_{(u)2} = 150\,A^{0.70}\,IA^{0.36}$	26
$Q_{(u)5} = 210\,A^{0.70}\,IA^{0.39}$	24
$Q_{(u)10} = 266\,A^{0.69}\,IA^{0.39}$	24
$Q_{(u)25} = 337\,A^{0.69}\,IA^{0.39}$	24
$Q_{(u)50} = 396\,A^{0.69}\,IA^{0.38}$	25
$Q_{(u)100} = 444\,A^{0.69}\,IA^{0.39}$	25

where

$Q_{(u)}$ = the estimated urban discharge, in cubic feet per second for the indicated recurrence interval,

A = the contributing drainage area, in square miles, and

IA = percent of the contributing drainage basin occupied by impervious surface.

All regression coefficients are statistically significant at the 5 percent level.

The linearity of the equations in log format for estimating flood magnitudes in this report was checked with graphical plots. The graphs include plots of regression residuals versus drainage area, residuals versus percent of the basin occupied by impervious surfaces, and residuals versus flood magnitude. These plots indicate no bias; thus, the estimating equations are assumed to be linear.

A map plot of the station residuals was used to evaluate geographic variations in the flood frequency equations computed in the regression analyses. Although the residuals varied considerably between some stations, no specific geographic trends could be detected. Station residuals at cities with two or more stations had a tendency to balance between negatives and positives.

The accuracy of each regression equation is expressed as the standard error of estimate in percent. Standard error is computed from the difference between synthetic flood data for each station and the regression equation. The errors resulting from analyses are unusually small and the range between the error values is very narrow.

The tendency for small errors and narrow range in errors between recurrence intervals may be attributed to several factors related to the modeling process. A primary reason for the small standard errors is that drainage area and impervious cover were used to generate the urban flood discharge which were then related to drainage area and impervious cover in a regression analysis. Another factor is that the model averages the parameters for all storm events at each rainfall-runoff site. The averaged or calibrated parameters are used to estimate flood magnitudes for selected recurrence intervals using a map-model procedure developed by Lichty and Liscum (1978). That procedure is based on climatic factors that were averaged or smoothed by regression analyses. Regardless of the reasons there is a considerable amount of uncertainty as to how well the synthetic data developed from the models represent actual data.

The standard errors of perdiction associated with use of the equations to estimate flood magnitudes in ungaged streams are unknown. The data sample (23 stations) is too small to evaluate the standard error of prediction by split-sampling techniques. It is assumed, however, that these errors, statewide, are considerably higher than the standard errors of regression. Particularly, if estimates are made for other sites similar to Valley Creek at Bessemer, Cribbs Mill Creek at Tuscaloosa, or Fivemile Creek near Huffman.

A partial analysis of the sensitivity of the regression equations for the 2-, 25-, and 100-year flood magnitudes to drainage area (A) and percent of the basin occupied by impervious area (IA) was performed for one set of conditions for each variable. Results of sensitivity of the equations for A = 15 mi^2 and IA = 20 percent are given graphically in figure 6. For example, an error of 10 percent in measurement of drainage area results in about 7 percent difference in discharge, and an error of 10 percent in measurement of impervious area results in about 3.5 percent difference in discharge for the 2-year flood. Results of sensitivity are similar for the 25- and 100-year floods.

APPLICATION OF THE ESTIMATING METHODS

The estimating methods consist of the preceding regression equations using drainage area size and percent of the basin occupied by impervious surface. Solution for those equations to estimate $Q_{(u)2}$, $Q_{(u)5}$, $Q_{(u)10}$, $Q_{(u)25}$, $Q_{(u)50}$, and $Q_{(u)100}$ in streams draining urban areas are presented in graphical form as shown in figures 7, 8, 9, 10, 11, and 12, respectively. The following example is given to illustrate use of the curves in figures 7 through 12. The dashed line and arrows in the figures indicate the procedure to follow.

$$A = 20 \text{ mi}^2$$

$$IA = 25 \text{ percent}$$

Enter the figures with drainage area (20 mi^2) along the bottom scale. Move upward to the impervious area curves to 25 percent. Move horizontally to the discharge scale. The following results were obtained for this example:

from figure 7, $Q_{(u)2} = 3{,}900 \text{ ft}^3/\text{s}$

from figure 8, $Q_{(u)5} = 6{,}000 \text{ ft}^3/\text{s}$

from figure 9, $Q_{(u)10} = 7{,}400 \text{ ft}^3/\text{s}$

from figure 10, $Q_{(u)25} = 9{,}300\ \text{ft}^3/\text{s}$

from figure 11, $Q_{(u)50} = 10{,}600\ \text{ft}^3/\text{s}$

from figure 12, $Q_{(u)100} = 12{,}300\ \text{ft}^3/\text{s}$

The following computations demonstrate mathematical application of the regression equations to urban streams in Alabama including a graphical plot (figure 13) of the resultant flood-frequency curve. Assume a drainage area of 30 mi^2, and an impervious area of 25 percent of the basin. By substituting values for drainage area and percent impervious area into the equations and performing the mathematical operation, flood discharge is estimated for the indicated recurrence interval.

$$\begin{aligned}
Q_{(u)2} &= 150\ A^{0.70}\ IA^{0.36} \\
Q_{(u)2} &= 150\ (30)^{0.70}\ (25)^{0.36} \\
Q_{(u)2} &= 150\ (10.81)\ (3.19) \\
Q_{(u)2} &= 5170\ \text{ft}^3/\text{s}
\end{aligned}$$

$$\begin{aligned}
Q_{(u)5} &= 210\ A^{0.70}\ IA^{0.39} \\
Q_{(u)5} &= 210\ (30)^{0.70}\ (25)^{0.39} \\
Q_{(u)5} &= 210\ (10.81)\ (3.51) \\
Q_{(u)5} &= 7970\ \text{ft}^3/\text{s}
\end{aligned}$$

$$\begin{aligned}
Q_{(u)10} &= 266\ A^{0.69}\ IA^{0.39} \\
Q_{(u)10} &= 266\ (30)^{0.69}\ (25)^{0.39} \\
Q_{(u)10} &= 266\ (10.45)\ (3.51) \\
Q_{(u)10} &= 9760\ \text{ft}^3/\text{s}
\end{aligned}$$

$$\begin{aligned}
Q_{(u)25} &= 337\ A^{0.69}\ IA^{0.39} \\
Q_{(u)25} &= 337\ (30)^{0.69}\ (25)^{0.39} \\
Q_{(u)25} &= 337\ (10.45)\ (3.51) \\
Q_{(u)25} &= 12{,}200\ \text{ft}^3/\text{s}
\end{aligned}$$

$$\begin{aligned}
Q_{(u)50} &= 396\ A^{0.69}\ IA^{0.38} \\
Q_{(u)50} &= 396\ (30)^{0.69}\ (25)^{0.38} \\
Q_{(u)50} &= 396\ (10.45)\ (3.40) \\
Q_{(u)50} &= 14{,}100\ \text{ft}^3/\text{s}
\end{aligned}$$

$$\begin{aligned}
Q_{(u)100} &= 444\ A^{0.69}\ IA^{0.39} \\
Q_{(u)100} &= 444\ (30)^{0.69}\ (25)^{0.39} \\
Q_{(u)100} &= 444\ (10.45)\ (3.51) \\
Q_{(u)100} &= 16{,}300\ \text{ft}^3/\text{s}
\end{aligned}$$

Limitations

The regression equations in this report are limited to estimating flood magnitudes of Alabama streams draining urban areas. In deriving the equations, drainage areas ranged from 0.16 mi^2 to 83.5 mi^2, and percent of the basins occupied by impervious surfaces ranged from 8.3 to 42.9. Use of the equations should be limited to the range in drainage area size and percent impervious area used to derive the equations.

Caution should be used in estimating flood magnitudes in basins underlain by soluble limestone and in basins with sinkholes, quarries, or storage reservoirs located upstream from sites being evaluated. Valley Creek at Bessemer and Cribbs Mill Creek at Tuscaloosa were excluded from the analyses for these reasons. Caution also should be used for stream sites where severe contraction of their floodplains causes stages that spill flood waters into other basins or that otherwise causes it to by-pass the points being evaluated. Fivemile Creek near Huffman was eliminated from the analyses for this reason.

The equations in this report do not apply to urban streams where temporary in-channel storage or overbank storage affects the magnitude of peak flows, or where the percent of impervious surface is equal to or less than 5 percent. For the latter case, the basins should be considered rural and flood magnitudes should be estimated using methods given in reports by Hains (1973) and (or) Olin and Bingham (1977).

SUMMARY

Synthetic flood magnitudes derived from a rainfall-runoff model were used to develop flood frequency relations for streams draining urban areas in Alabama. The model was calibrated for 23 urban runoff sites with drainage areas ranging from 0.16 mi^2 to 83.5 mi^2. Flood magnitudes for selected recurrence intervals were estimated by a map-model procedure developed by Lichty and Liscum (1978). Input data for that procedure include climatic factors and parameters calibrated in the rainfall-runoff model.

Standard regression techniques were used to derive equations for estimating flood magnitudes for selected recurrence intervals in streams draining urban areas in Alabama. One equation for each recurrence interval applies statewide. Flood discharges derived from the map-model procedure were used as dependent variables, and seven basin and climatic characteristics were used as independent variables. Of the characteristics tested, drainage area size and percent of the basin occupied by impervious surfaces are the most significant charac-

teristics affecting the estimation of flood discharges in these analyses. The equations derived do not apply to urban streams where temporary in-channel storage or overbank storage significantly affect the magnitude of peak flows, or where impervious surface in a basin is less than 5 percent. For the latter, the basin should be considered rural and other equations used.

Standard errors of the regression ranged from 24 percent for the 10-year flood to 26 percent for the 2-year flood. Errors for the 5-, 25-, 50-, and 100-year floods are within that range. The unusually small errors of regression and the narrow range of these errors are probably caused by the smoothing effects of the modeling procedures, and the assumption that rainfall is uniformly distributed over the basin.

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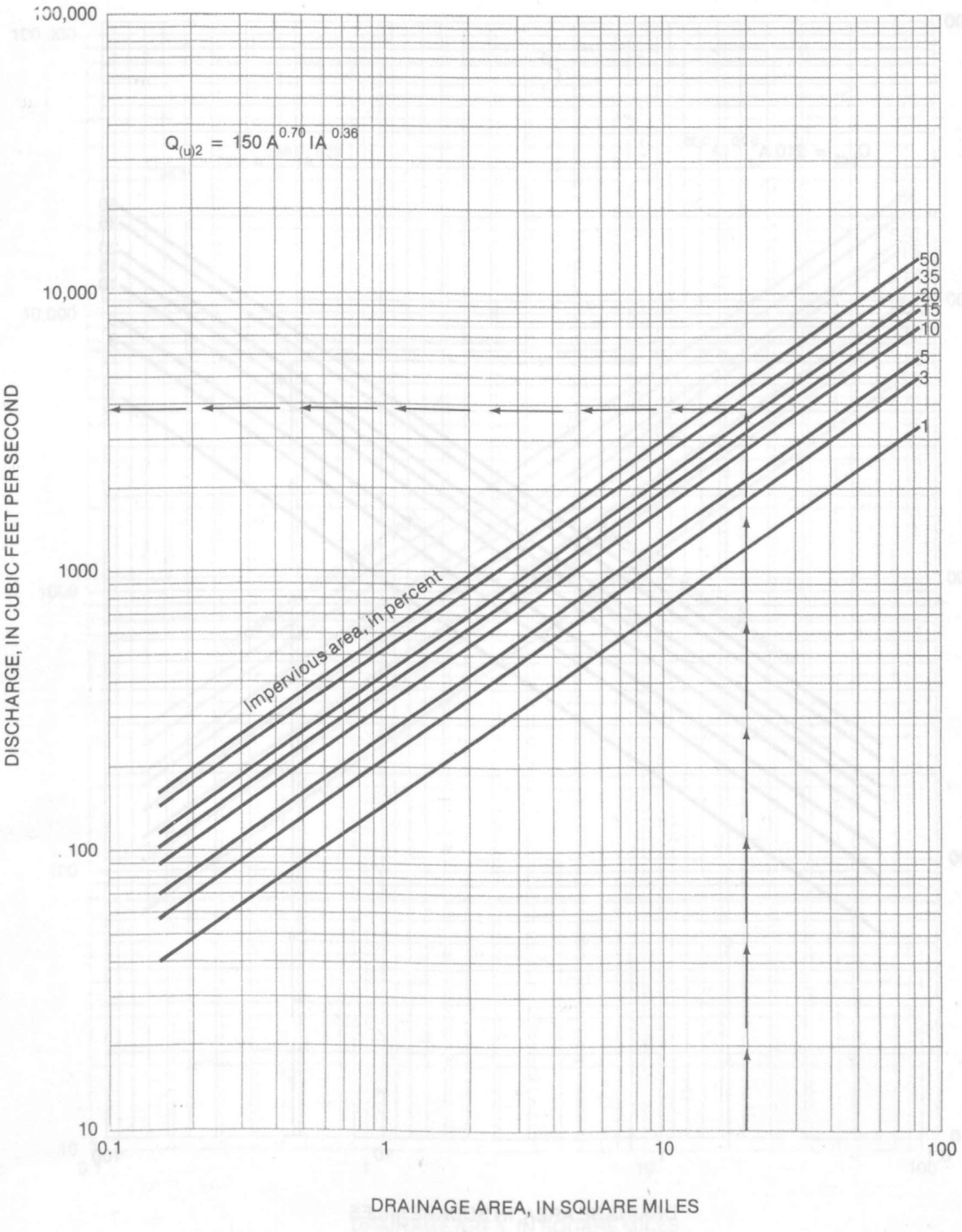

Figure 7. Relation of 2-year flood to drainage area and impervious area.

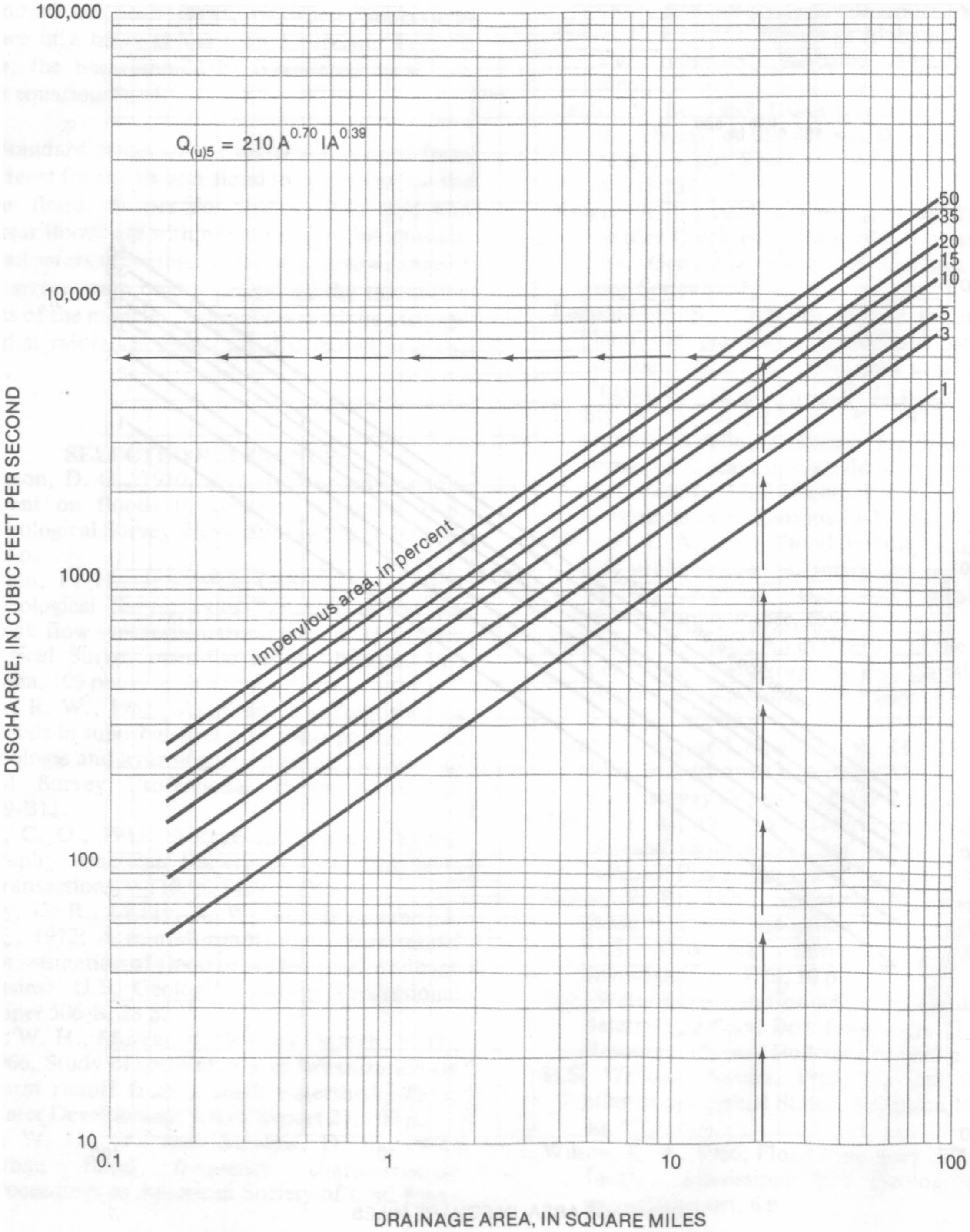

Figure 8. Relation of 5-year flood to drainage area and impervious area.

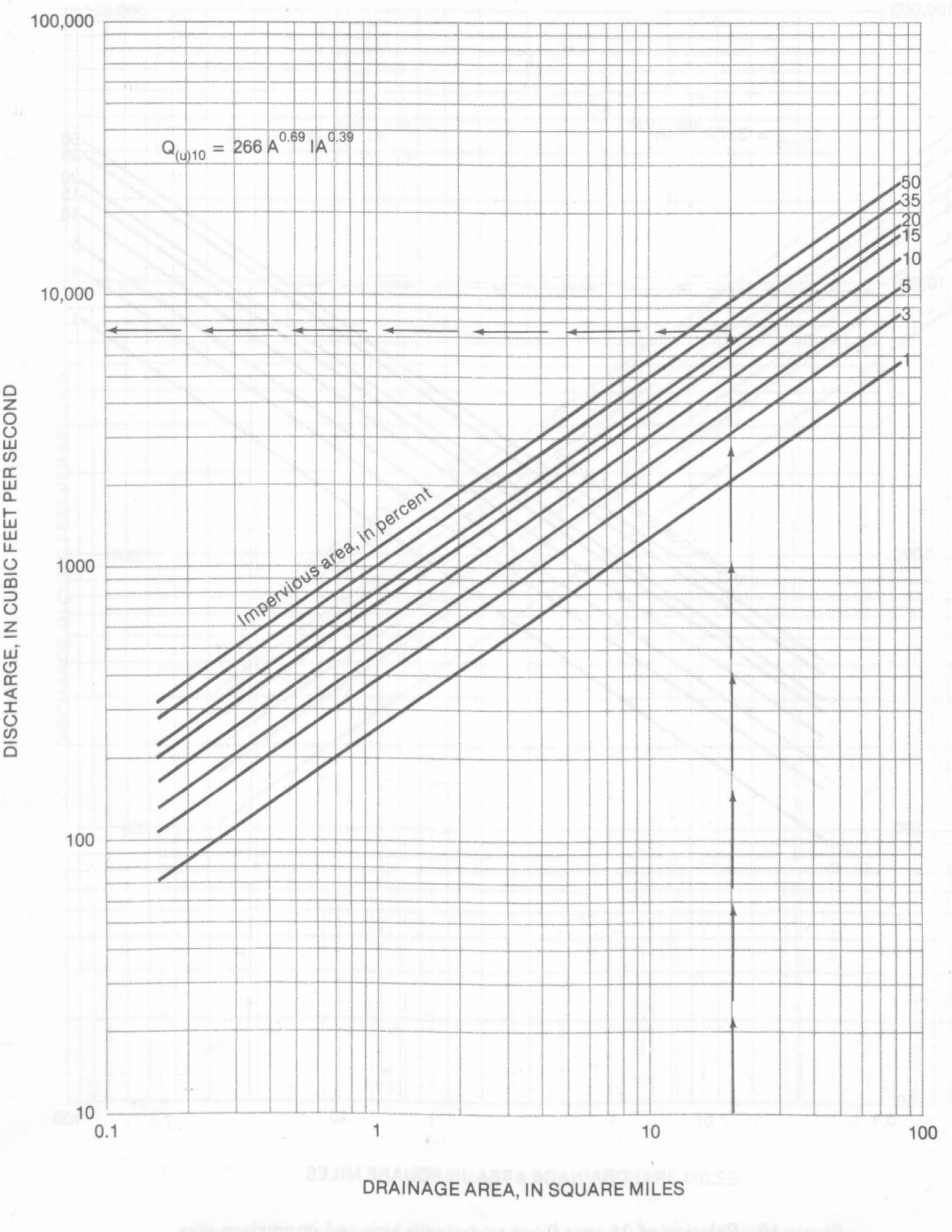

Figure 9. Relation of 10-year flood to drainage area and impervious area.

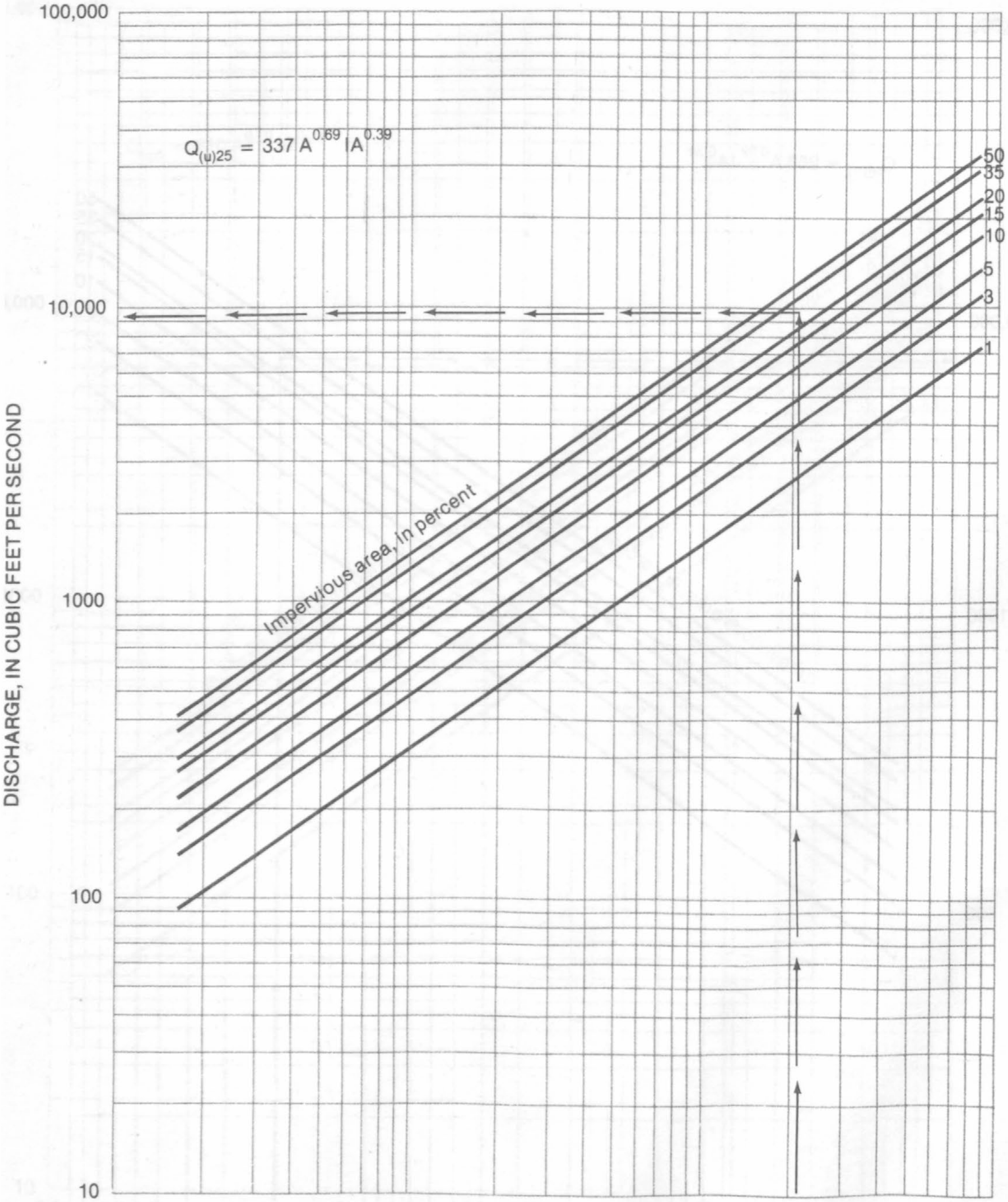

Figure 10. Relation of 25-year flood to drainage area and impervious area.

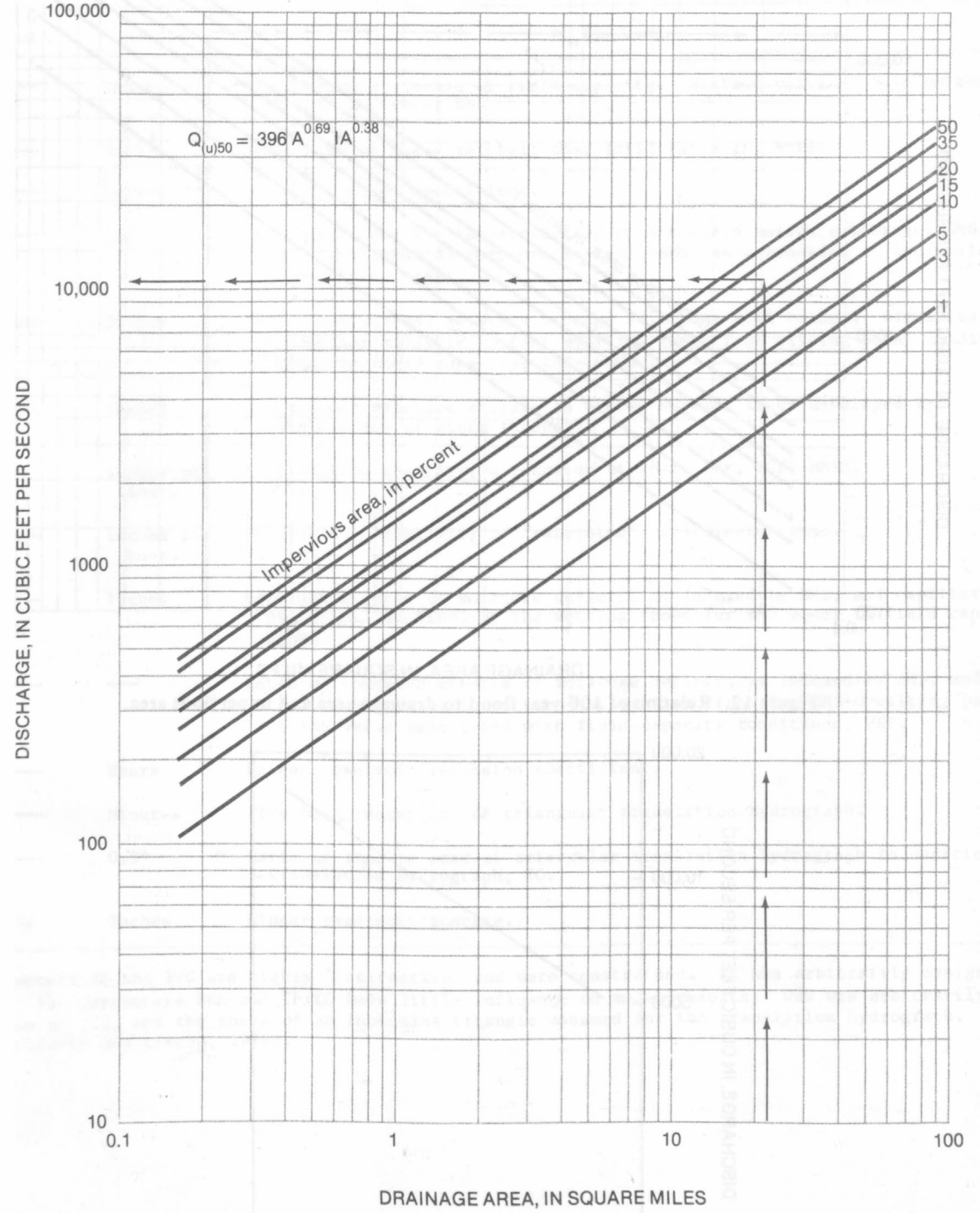

Figure 11. Relation of 50-year flood to drainage area and impervious area.

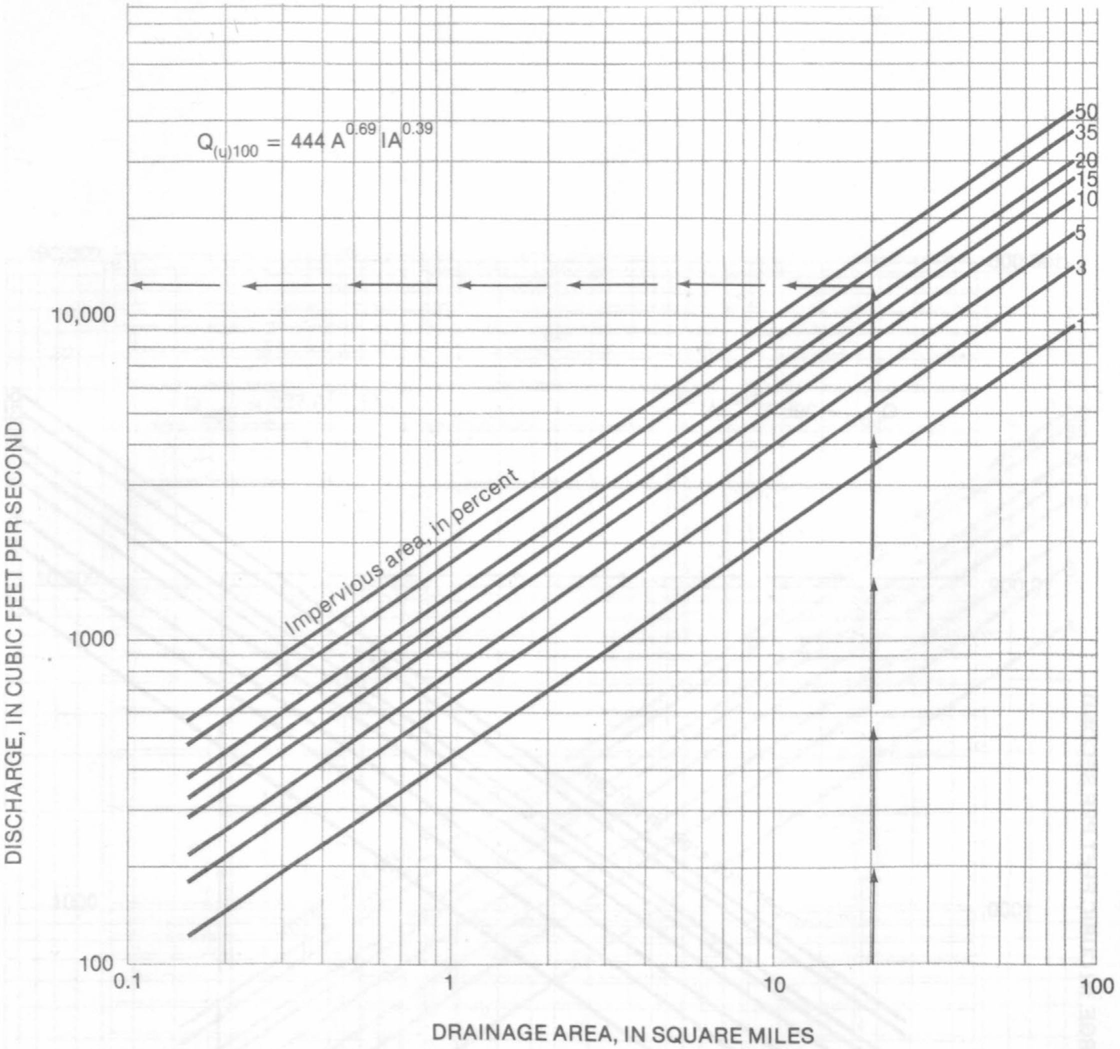

Figure 12. Relation of 100-year flood to drainage area and impervious area.

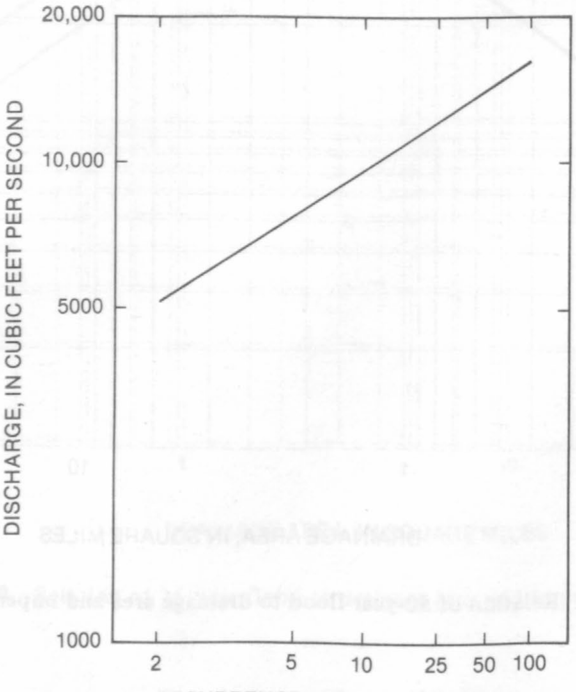

Figure 13. Flood-frequency curve from example computations.

Table 1. Model parameters and variables and their application in the modeling process.

Parameter	Variable	Units	Application
BMSM	---	Inches	Soil-moisture storage at field capacity. Maximum value of base moisture storage variable, BMS.
RR	---	0.85*	Proportion of daily rainfall that infiltrates the soil.
EVC	---	0.76-0.90	Pan evaporation coefficient.
DRN	---	1.0*	Drainage factor for redistribution of saturated moisture storage, SMS, to base (unsaturated) moisture storage, BMS, as a fraction of hydraulic conductivity, KSAT.
---	BMS	Inches	Base (unsaturated) moisture storage in active soil column. Simulates antecedent moisture content over the range from wilting-point conditions, BMS=0, to field capacity, BMS=BMSM.
---	SMS	Inches	"Saturated" moisture storage in wetted surface layer developed by infiltration of storm rainfall.
---	FR	Inches per hour.	Infiltration capacity, a function of KSAT, PSP, RGF, BMSM, SMS, BMS.
KSAT	---	Inches per hour.	Hydraulic conductivity of "saturated" transmission zone.
PSP	---	Inches	Combined effects of moisture deficit, as indexed by BMS, and capillary potential (suction) at the wetting front for BMS equal to field capacity, BMSM.
RGF	---	---	Ratio of combined effects of moisture deficit, as indexed by BMS, and capillary potential (suction) at wetting front for BMS=0=wilting point, to the value associated with field capacity conditions, PSP.
KSW	---	Hours	Linear reservoir recession coefficient.
TC	---	Minutes	Time base (duration) of triangular translation hydrograph.
TP/TC	---	0.5*	Ratio of time to peak of triangular translation hydrograph to duration of translation hydrograph, TC.
---	SW	Inches	Linear reservoir storage.

*The parameters RR and EVC are highly "interactive" and were constrained. RR was arbitrarily assigned the value of 0.85. The parameters DRN and TP/TC have little influence on model results. DRN was arbitrarily assigned a value of 1.0, and the shape of an isosceles triangle assumed for the translation hydrograph. (Modified from Lichty and Liscum, 1978).

Table 2. Summary of calibrated rainfall-runoff model parameters and related basin characteristics for stations used in analysis. (The model variables DRN = 1.00; RR = 0.85; and TP/TC = 0.5 are constant for all stations.)

Station number	Station name	Drainage area (mi^2) (A)	Slope (ft/mi) (SL)	Impervious area (%) (IA)	PSP (in)	KSAT (in/hr)
02361093	Tributary to Beaver Creek at Ross Clark Circle in Dothan, Ala.	1.81	33.8	30.5	4.00	0.231
02416032	Sugar Creek at Alexander City, Ala.	1.67	38.1	20.2	2.22	.069
02419975	Three Mile Branch at Biltmore Avenue in Montgomery, Ala.	7.30	16.0	25.0	3.37	.145
02420987	Hannon Slough at Montgomery, Ala.	1.32	39.3	42.9	1.28	.064
02423580	Shades Creek at Homewood, Ala.	20.8	12.4	16.3	4.96	.177
02423630	Shades Creek at Greenwood, Ala.	72.3	8.17	8.3	2.49	.065
02457000	Fivemile Creek at Ketona, Ala.	23.9	29.0	17.0	2.49	.092
02458200	Village Creek at Apalachee Street in Birmingham, Ala.	15.6	19.9	33.3	5.84	.180
02458300	Village Creek at 24th Street in Birmingham, Ala.	26.0	17.8	25.0	4.76	.159
02458450	Village Creek at Avenue W in Ensley, Ala.	33.5	13.6	25.0	3.75	.111
02460500	Village Creek near Adamsville, Ala.	83.5	11.4	18.0	3.47	.091
02461200	Valley Creek at Cleburn Avenue in Birmingham, Ala.	20.1	15.2	36.8	4.56	.087
02465286	Cribbs Mill Creek at 2nd Avenue East in Tuscaloosa, Ala.	2.75	60.2	28.9	8.91	.179
02471043.15	Woodcock Creek at Airport Boulevard in Mobile, Ala.	1.85	10.6	25.0	0.934	.062
02471065	Montlimar Creek in Mobile, Ala.	8.26	31.8	30.4	5.73	.198
03575686	Aldridge Creek at Dunsmore Street in Huntsville, Ala.	1.15	295.6	10.2	5.19	.106
03575696	Aldridge Creek near Lily Flagg, Ala.	13.9	26.1	8.4	3.06	.058
03575880	Five Points Ditch at Howe Street in Huntsville, Ala.	0.62	75.7	20.0	5.76	.195
03575890	Pinhook Creek at Clinton Avenue in Huntsville, Ala.	22.5	27.8	12.0	5.38	.144
03575910	Pinehaven Ditch at Gayhart Drive in Huntsville, Ala.	0.16	231.3	20.0	5.71	.196
03575930	Broglan Branch at Holmes Avenue in Huntsville, Ala.	8.87	35.6	19.3	5.97	.180
03575950	Huntsville Spring Branch at Johnson Road in Huntsville, Ala.	41.8	21.3	21.4	5.87	.134
03589450	Sweetwater Creek at Florence, Ala.	4.92	55.8	24.1	5.05	.192

Table 2. Summary of calibrated rainfall-runoff model parameters and related basin characteristics for stations used in analysis--Continued. (The model variables DRN = 1.00; RR = 0.85; and TP/TC = 0.5 are constant for all stations.)

Station number	Station name	RGF	BMSM (in)	EVC	KSW (hr)	TC (min)
02361093	Tributary to Beaver Creek at Ross Clark Circle in Dothan, Ala.	19.50	5.12	0.855	0.936	43.0
02416032	Sugar Creek at Alexander City, Ala.	4.55	3.74	.830	1.22	56.2
02419975	Three Mile Branch at Biltmore Avenue in Montgomery, Ala.	15.95	7.04	.847	1.42	85.4
02420987	Hannon Slough at Montgomery, Ala.	11.70	12.68	.847	.776	46.5
02423580	Shades Creek at Homewood, Ala.	15.83	3.29	.810	2.39	144
02423630	Shades Creek at Greenwood, Ala.	5.33	2.80	.810	13.5	278
02457000	Fivemile Creek at Ketona, Ala.	16.79	1.01	.810	2.63	158
02458200	Village Creek at Apalachee Street in Birmingham, Ala.	15.92	2.98	.810	1.27	76.7
02458300	Village Creek at 24th Street in Birmingham, Ala.	11.43	3.47	.810	1.63	97.8
02458450	Village Creek at Avenue W in Ensley, Ala.	9.83	5.89	.810	2.70	163
02460500	Village Creek near Adamsville, Ala.	15.86	4.06	.810	8.56	632
02461200	Valley Creek at Cleburn Avenue in Birmingham, Ala.	28.90	4.67	.810	1.55	115
02465286	Cribbs Mill Creek at 2nd Avenue East in Tuscaloosa, Ala.	11.14	3.21	.813	1.68	96.4
02471043.15	Woodcock Creek at Airport Boulevard in Mobile, Ala.	3.73	9.81	.900	1.61	97.2
02471065	Montlimar Creek in Mobile, Ala.	19.79	5.00	.900	1.10	65.0
03575686	Aldridge Creek at Dunsmore Street in Huntsville, Ala.	24.24	2.58	.755	.748	21.1
03575696	Aldridge Creek near Lily Flagg, Ala.	6.49	3.75	.755	1.82	84.0
03575880	Five Points Ditch at Howe Street in Huntsville, Ala.	19.85	2.94	.755	.237	14.3
03575890	Pinhook Creek at Clinton Avenue in Huntsville, Ala.	19.86	5.96	.755	1.60	96.4
03575910	Pinehaven Ditch at Gayhart Drive in Huntsville, Ala.	18.93	3.84	.755	.180	12.3
03575930	Broglan Branch at Holmes Avenue in Huntsville, Ala.	12.26	3.63	.755	1.17	69.6
03575950	Huntsville Spring Branch at Johnson Road in Huntsville, Ala.	19.86	2.92	.755	2.00	120
03589450	Sweetwater Creek at Florence, Ala.	13.09	4.17	.770	.873	45.4

Table 3. Flood peak discharges for selected recurrence intervals and parameters used to estimate synthetic flood peaks for urban streams.

Station number	Type of estimate	Model lag time (hours)	Model infiltration (inches/hour)	Flood peak discharge (cubic feet/second) for indicated recurrence intervals						Log-Pearson Type III		
				2	5	10	25	50	100	Skew[1]	Standard deviation	Mean
02361093	Urban	1.29	1.98	669	1110	1420	1830	2140	2460	-0.26	0.27065	2.81372
	[2]Rural			314	492	624	808	956	1120			
	Regression			778	1220	1520	1910	2210	2520			
02416032	Urban	1.68	0.186	691	1020	1220	1470	1640	1810	-0.40	.21299	2.82531
	Rural			306	476	602	775	914	1060			
	Regression			634	983	1220	1540	1780	2030			
02419975	Urban	2.13	.939	1910	3220	4110	5190	5970	6710	-0.53	.29579	3.25502
	Rural			646	1100	1460	1990	2430	2900			
	Regression			1910	2990	3700	4650	5360	6110			
02420987	Urban	1.16	.170	824	1240	1490	1780	1980	2160	-0.57	.23140	2.89405
	Rural			265	408	513	658	773	897			
	Regression			706	1120	1390	1760	2020	2310			
02423580	Urban	3.59	1.60	2890	4540	5760	7410	8720	10100	0	.23358	3.46090
	Rural			1310	2270	3020	4100	5000	5940			
	Regression			3400	5240	6480	8130	9380	10700			
02423630	Urban	15.8	.197	5990	8580	10300	12400	14000	15500	-0.17	.19008	3.77206
	Rural			2110	3560	4770	6490	7900	9460			
	Regression			6360	9560	11800	14800	17100	19400			
02457000	Urban	3.95	.476	4230	6290	7710	9560	11000	12400	-0.08	.20715	3.62359
	Rural			1740	3050	4000	5370	6440	7810			
	Regression			3810	5870	7260	9090	10500	11900			
02458200	Urban	1.91	1.88	4260	6320	7790	9730	11200	12800	+0.03	.20313	3.63042
	Rural			1120	1940	2590	3530	4330	5150			
	Regression			3600	5690	7010	8790	10100	11500			
02458300	Urban	2.45	1.13	5790	8760	10800	13600	15700	17900	-0.05	.21500	3.76089
	Rural			1750	2960	3890	5180	6240	7330			
	Regression			4640	7250	8940	11200	12900	14700			
02458450	Urban	4.06	.597	5980	8810	10800	13300	15200	17200	-0.05	.20125	3.77503
	Rural			1980	3350	4400	5850	7050	8290			
	Regression			5540	8650	10700	13300	15400	17500			
02460500	Urban	13.8	.601	5920	8910	11000	13700	15800	17900	-0.08	.21316	3.76949
	Rural			3630	6130	8040	10700	12900	15200			
	Regression			9300	14400	17700	22100	25500	28900			
02461200	Urban	2.51	1.12	5110	7450	9080	11200	12800	14500	0	.19466	3.70842
	Rural			1330	2290	3050	4140	5040	5990			
	Regression			4460	7060	8700	10900	12500	14300			

Station number	Type of estimate	Model lag time (hours)	Model infiltration (inches/hour)	Flood peak discharge (cubic feet/second) for indicated recurrence intervals						Log-Pearson Type III		
				2	5	10	25	50	100	Skew	Standard deviation	Mean
02465286	Urban	2.48	2.19	580	896	1120	1420	1650	1890	-0.07	.22679	2.76079
	Rural			471	731	921	1180	1380	1590			
	Regression			1020	1600	1990	2500	2890	3290			
[3]02471043.15	Urban	2.42	.103	960	1320	1570	1880	2120	2360	+0.08	.16296	2.98444
	Rural			242	399	523	740	855	1020			
	Regression			735	1150	1430	1800	2080	2370			
02471065	Urban	1.64	2.36	3410	5400	6960	9220	11100	13200	+0.26	.22978	3.54269
	Rural			824	1370	1790	2380	2860	3370			
	Regression			2240	3520	4350	5460	6290	7180			
03575686	Urban	0.924	1.34	309	509	654	847	996	1150	-0.20	.26593	2.48112
	Rural			391	548	652	778	873	967			
	Regression			382	579	724	914	1060	1210			
03575696	Urban	2.52	.219	3330	4900	5940	7220	8160	9080	-0.25	.20746	3.51382
	Rural			1100	1880	2490	3360	4090	4840			
	Regression			2020	3040	3780	4750	5510	6240			
03575880	Urban	.356	2.34	351	552	697	894	1050	1210	-0.04	.23469	2.54375
	Rural			190	276	337	417	479	547			
	Regression			317	491	613	774	896	1020			
03575890	Urban	2.40	1.62	3090	5070	6510	8440	9950	11500	-0.16	.26167	3.48300
	Rural			2090	3550	4670	6240	7540	8870			
	Regression			3220	4900	6070	7620	8810	9990			
03575910	Urban	.283	2.27	107	168	212	272	319	368	-0.04	.23420	2.02783
	Rural			103	136	157	183	203	224			
	Regression			123	191	239	303	351	401			
03575930	Urban	1.75	2.02	1700	2670	3380	4320	5060	5830	-0.06	.23551	3.22810
	Rural			886	1470	1920	2540	3050	3580			
	Regression			2000	3090	3830	4810	5560	6320			
03575950	Urban	3.00	1.64	6000	9290	11600	14800	17300	19800	-0.05	.22732	3.77626
	Rural			3330	5630	7390	9840	11900	13900			
	Regression			6110	9490	11700	14600	16900	19200			
03589450	Urban	1.25	1.56	1430	2150	2670	3380	3940	4520	+0.07	.20916	3.15777
	Rural			674	1070	1370	1770	2090	2420			
	Regression			1430	2240	2780	3490	4030	4590			

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[1] Skew values were used in estimating flood peaks for 5-, 10-, and 50-year recurrence intervals as described in Water Resources Council Bulletin 17B. The skews were not weighted with regional skews because effects of urbanization are unknown.

[2] Rural discharges were estimated with methods in reports by Hains (1973), and Olin and Bingham (1977).

[3] Station number used only for this report.

Synthesized Flood Frequency of Urban Streams in Alabama

WRI 82-683

U.S. DEPARTMENT OF THE INTERIOR
March 3, 1849