EVALUATION OF SIX METHODS FOR ESTIMATING MAGNITUDE AND FREQUENCY OF PEAK DISCHARGES ON URBAN STREAMS IN NEW YORK

By David A. Stedfast

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 84-4350

Prepared in cooperation with

NEW YORK STATE DEPARTMENT OF TRANSPORTATION

Albany, New York

1986

UNITED STATES DEPARTMENT OF THE INTERIOR

DONALD PAUL HODEL, Secretary

GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information write to:

U.S. Geological Survey
P.O. Box 1669
Albany, N.Y. 12201
(518) 472-3107

Copies of this report may be purchased from:

Open-File Services Section
Western Distribution Branch
U.S. Geological Survey
Box 25425, Denver Federal Center
Denver, Colo. 80225
(303) 234-5888

CONTENTS

TABLES

ILLUSTRATIONS

Conversion Factors and Abbreviations

The following factors may be used to convert inch-pound units used in this report to the International System of Units (SI).

Multiply inch-pound units	By	To obtain SI units
inch (in.)	25.4	millmeter (mm)
	2.54	centimeter (cm)
	0.0254	meter (m)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
cubic foot per second (ft^3/s)	28.32	liter per second (L/s)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

EVALUATION OF SIX METHODS FOR ESTIMATING MAGNITUDE AND FREQUENCY OF PEAK DISCHARGES ON URBAN STREAMS IN NEW YORK

By David A. Stedfast

Abstract

Six methods of estimating peak discharges of urban streams were compared and evaluated for applicability to urban streams in New York. Discharge and frequency values developed from a series of synthesized annual flood records were compared with values obtained from the six methods. The synthesized flood records were computed from rainfall-runoff models of 11 urban basins in three counties across the State. Four of these basins had a sufficient period of record to enable rainfall-runoff modeling of two different 5-year periods so that increases in peak flow due to increased urbanization could also be used for comparison of the six methods.

A graph analysis and three statistical analyses were made to evaluate the closeness of fit and bias of the methods. All methods showed a tendency to overestimate synthetic urban flood-magnitude values, but the two that adjust rural flood-frequency estimates on a nationwide basis showed smaller standard errors of estimate and bias. The standard errors for these two methods ranged from 44 to 57 percent over the six recurrence intervals (2, 5, 10, 25, 50, and 100 year), and the bias ranged from +28 to +53 percent. The bias, however, is probably due to errors inherent in using synthetic records and in applying the New York rural flood-frequency equations to urban basins with small drainage areas.

INTRODUCTION

Peak discharges of a stream increase markedly as a result of urbanization within the drainage basin. The paving of open areas for roads, parking lots, and buildings prevents stormwater from soaking into the ground and thus increases overland runoff to stream channels--either directly or through storm-sewer systems. This rapid discharge to streams increases the magnitudes of peak flows and can lead to local flooding of streams and storm sewers.

To avoid causing floods or increasing their severity within or near a developing area, community planners, land developers, and hydraulic engineers need to understand how urbanization affects stormflows and to what degree. Also, communities contemplating replacement of hydraulic structures need accurate estimates of a design flood to accommodate the expected flows.

No comprehensive studies have been made to define or quantify the effects of urbanization on the floodflow characteristics of streams in New York. Such studies have been made for streams in other states and for urban flooding in general, however, and methods developed from them may be applicable to several areas in New York.

In 1981, the U.S. Geological Survey, in cooperation with New York State Department of Transportation, began a 3-year study to evaluate several published methods of estimating flood discharges of ungaged urban streams in New York State. Long-term peak-discharge records synthesized from previously developed rainfall-runoff models were used to test each method's applicability. These models were calibrated and verified with data from gaged streams in urbanized basins.

Purpose and Scope

This report evaluates six published methods of estimating peak discharges of ungaged streams in urban areas and identifies those that most closely match the synthesized flood peaks. Results are plotted on a series of graphs and summarized in several tables that give the standard errors, bias, and percent differences between estimated and synthetic peak-discharge increases due to urbanization for each of the methods evaluated.

Acknowledgments

This report was done in cooperation with the New York State Department of Transportation, which also provided the 7.5-minute planimetric maps that were used to measure impervious areas within the basins studied. The National Climatic Center in Asheville, N.C., provided long-term 60-minute interval rainfall data (59 years for Central Park in New York City and 33 years for all other sites). The Rockland County Highway Department, Westchester County Department of Public Works, Onondaga County Department of Drainage and Sewers, and the Albany City Engineer provided information on the urban characteristics of the basins within their jurisdictions.

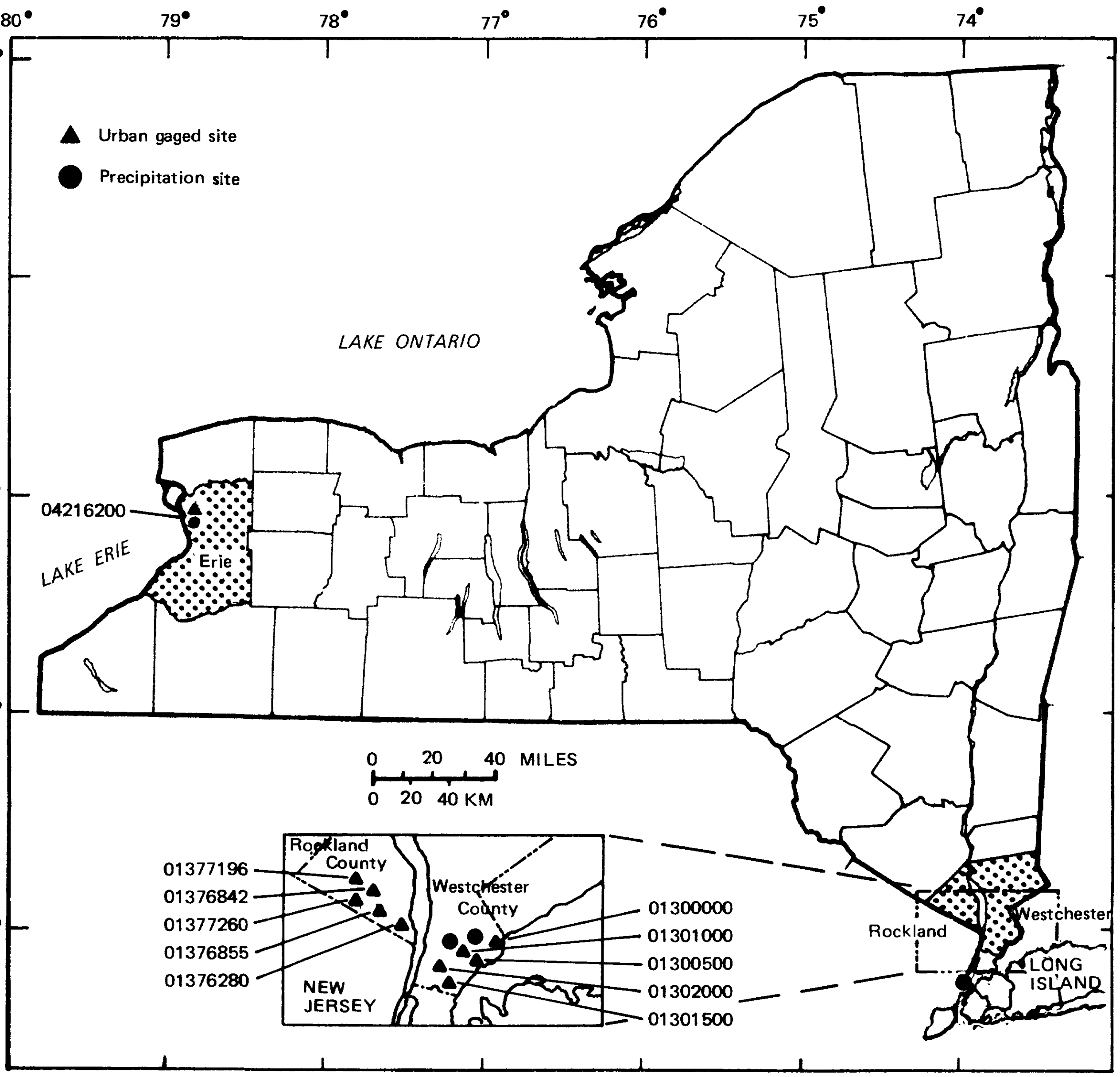
APPROACH

Urban development within most gaged urban watersheds in New York has been increasing during the streams' period of record. This constant increase has resulted in a set of nonhomogenous annual peaks that are unsuitable for log-Pearson flood-frequency analyses. Therefore, a rainfall-runoff model was developed for each basin for short periods (5 years or less) during which the impervious area increased less than 5 percent. These models, combined with long-term rainfall data (33 to 59 years of record) from nearby precipitation stations (fig. 1) were used to generate long-term synthetic streamflow records. The peak discharges computed from these synthetic records were then compared to those obtained through the six estimating methods, and analyses were then made to evaluate the methods.

Selection of Methods for Comparison

A literature search for published estimating techniques that could be applied to urbanized basins of New York was done. Preference was given to methods that allow adjustments to the rural flood-frequency estimates for the amount of urbanization. Six estimating methods that seemed applicable to urban streams in New York were identified and applied to streamflow data from gaged urban stream sites.

A report by Rawls, Stricker, and Wilson (1980) identifies 128 published and unpublished reports on floodflow-frequency procedures written during 1962-79. All of these, as well as a few reports on urban floodflow frequency that were written after 1979, were reviewed. Although these reports do not define methods for predicting urban flood magnitudes and frequencies specifically for New York streams, they present five methods that adjust published floodflow-frequency equations for New York (Zembrzuski and Dunn, 1979) for the effects of urbanization. The sixth method does not require rural peak-discharge values but gives urban floodflow-frequency equations that may be applicable to urban streams in New York. The six methods are presented in detail further on.



Base from U.S. Geological Survey
State base map, 1:500,000, 1974

Figure 1.--Location of precipitation sites and urban gaged sites used in study. (Stream names are given in table 1.)

Selection of Basins

A search was conducted to identify urban gaged sites in New York State having a precipitation station nearby with more than 30 years of record. Sixteen sites were identified, but successful calibrations (with statistically significant relationships) were obtained for only 11--five in Westchester County, five in Rockland County, and one in Erie County (fig. 1). All 11 basins have drainage areas smaller than or equal to 30 mi^2 and impervious areas covering from 8 to 34 percent of the basin.

Rockland County Sites

The five basins in Rockland County had been studied previously, during which time a rainfall-runoff model was calibrated and verified for each basin (Lumia, 1982). These five urban basins are Sparkill Creek at Sparkill (01376280), Nauraushaun Brook at Nanuet (01376842), Nauraushaun Brook at Pearl River (01376855), Pascack Brook Tributary at Spring Valley (01377196), and Pascack Brook near Pearl River (01377260) (fig. 1). The flood-frequency characteristics of these basins have also been calculated and are given in Lumia (1983).

Westchester County Sites

The five basins in Westchester County had gaged discharge records from the mid-1940's through 1983, which enabled two 5-year periods with differing degrees of urbanization to be modeled for three of the basins. These five basins are Blind Brook at Rye (01300000), Beaver Swamp Brook at Mamaroneck (01300500), Mamaroneck River at Mamaroneck (01301000), Hutchinson River at Pelham (01301500), and Bronx River at Bronxville (010302000). The three basins that were successfully modeled for two periods of urbanization are Blind Brook at Rye, Mamaroneck River at Mamaroneck, and Bronx River at Bronxville.

Upstate Sites

The only upstate basin, Scajaquada Creek at Buffalo (04216200) in Erie County, had a sufficiently long period of record to enable two periods with different degrees of urbanization to be modeled.

BASIN CHARACTERISTICS

The six methods for estimating urban floodflow and the flood-frequency equations for rural New York streams require 11 basin characteristics, described below, as independent variables. Four of these, identified by an asterisk, are urbanization factors. Values obtained for these characteristics among the 16 basins studied are given in table 1.

Drainage area, A, in mi^2.—The planimetric surface area of a watershed that contributes runoff to the site of interest. Drainage areas were delineated on 7.5-minute U.S. Geological Survey topographic maps and measured by planimeter.

Main-channel slope, SL, in ft/mi.--The difference in altitude (ft) between the 10-percent and 85-percent points of distance along the main channel from the site of interest to the basin divide, divided by the distance (mi) along the main channel between the two points. The channel slope was scaled from 7.5-minute U.S. Geological Survey topographic maps.

Basin storage, ST, in percent.--The percentage of total drainage area that can store surface water, such as lakes and marshes. Storage areas were measured from 7.5-minute U.S. Geological Survey topographic maps by planimeter.

Mean annual precipitation, P, in inches.--The average amount of precipitation that falls on the basin each year. This quantity was calculated from a precipitation map given by Zembrzuski and Dunn (1979).

2-year,2-hour rainfall, R2, in inches.--The quantity of precipitation occurring over a 2-hour period with a recurrence interval of 2 years. This quantity was obtained from U.S. Weather Bureau (1958).

6-hour rainfall, $R6_x$, in inches.--The quantity of precipitation that falls over a 6-hour period for the x recurrence interval at the site of interest. This amount was also obtained from U.S. Weather Bureau (1958).

Rainfall intensity ratio, RI_x, dimensionless.--The average ratio of the rainfall intensity for the x-year recurrence interval to the rainfall intensity for the 2-year recurrence interval at the site of interest. These ratios were determined from curves published by U.S. Weather Bureau (1955).

*Impervious area, I, in percent.--The percentage of total drainage area covered by impervious surfaces such as roads, buildings, and parking lots. This term, hereafter referred to as "percent impervious area," was the most difficult basin characteristic to calculate. The values were obtained as follows: (1) The surface area of each land-use category on 7.5-minute 1968 land-use maps (Cornell, Univ., 1968) was calculated from the New York State Land Use and Natural Resources Inventory (LUNR). (2) Surface-area values were adjusted to correspond to conditions of the time periods selected for modeling. Adjustments were determined through use of aerial photography, 7.5-minute U.S. Geological Survey topographic maps, 7.5-minute New York State Department of Transportation planimetric maps, and field inspection. (3) The percentage of impervious area within each land-use category was then assigned on the basis of values measured in the Albany, N.Y. area by the grid method of Martens (1968) and suggested values from reports by Stankowski (1974), Carter (1961), and Leopold (1968). Occasional spot checks were also made in the study basins by the grid method mentioned above to verify the values.

Simpler methods for computing impervious area have been used by Stankowski (1974) and Allen and Bejceck (1979) but were not used in this study because they may lead to large errors. These methods are based on a relationship between percent impervious area and population density, street density, or housing density. As an example, the relationship between impervious area and population density, based on data from the two above-mentioned reports, is plotted in figure 2. This method yields only rough approximations and can lead to error if the assumptions on which the method is based do not apply to the stream basin of interest. (These simpler methods for computing

Table 1.--Basin characteristics at urban gaging stations.

Location and station number		Modeled time period	Recurrence interval (years): 6-hour rainfall (inches) 5	10	50	Rainfall-intensity ratios 2	5	10	25	50	100
			Westchester County								
Blind Brook at Rye	01300000	1950-54 1975-79	3.2	3.6	4.7	1.00	1.38	1.64	1.99	2.26	2.45
Beaver Swamp Brook at Mamaroneck	01300500	1950-54 1975-79	3.2	3.6	4.7	1.00	1.38	1.64	1.99	2.26	2.45
Mamaroneck River at Mamaroneck	01301000	1945-49 1975-79	3.2	3.6	4.7	1.00	1.38	1.64	1.99	2.26	2.45
Hutchinson River at Pelham	01301500	1945-49 1975-79	3.2	3.6	4.7	1.00	1.38	1.64	1.99	2.26	2.45
Bronx River at at Bronxville	01302000	1945-49 1975-79	3.2	3.6	4.7	1.00	1.38	1.64	1.99	2.26	2.45
			Rockland County								
Sparkill Creek at Sparkill	01376280	1975-79	3.2	3.6	4.8	1.00	1.38	1.64	1.99	2.26	2.45
Nauraushaun Brook at Nanuet	01376842	1975-78	3.2	3.6	4.8	1.00	1.38	1.64	1.99	2.26	2.45
Nauraushaun Brook at Pearl River	01376855	1975-79	3.2	3.6	4.8	1.00	1.38	1.64	1.99	2.26	2.45
Pascack Brook Trib. at Spring Valley	01377196	1975-79	3.2	3.6	4.8	1.00	1.38	1.64	1.99	2.26	2.45
Pascack Brook near Pearl River	01377260	1975-79	3.2	3.6	4.8	1.00	1.38	1.64	1.99	2.26	2.45
			Erie County								
Scajaquada Creek at Buffalo	04216200	1957-61 1975-79	2.1	2.4	3.3	1.00	1.39	1.66	1.92	2.15	2.31

A = drainage area, in m^2
SL = main-channel slope, in ft/mi
SR = basin storage, in percent
P = mean annual precipitation, in inches
R2 = 2-year, 2-hour rainfall, in inches

I = impervious area, in percent
RL = urban development factor, dimensionless
BDF = basin development factor, dimensionless
ϕ = channel-urbanization factor, dimensionless

Table 1.--Basin characteristics at urban gaging stations (continued).

[Locations are shown in fig. 1.]

Location and station number		Modeled time period	Basin characteristics[1] A	SL	ST	P	R2	I	RL	BDF	ϕ
			Westchester County								
Blind Brook at Rye	01300000	1950-54	9.20	58.3	0.8	48	1.85	8	1.2	2	1.1
		1975-79						30	2.3	4	1.0
Beaver Swamp Brook at Mamaroneck	01300500	1950-54 1975-79	4.71	27.8	.8	48	1.85	12	1.4	2	1.2
Mamaroneck River at Mamaroneck	01301000	1945-49	23.4	19.3	2.1	48	1.85	8	1.2	2	1.2
		1975-79						24	2.1	7	1.0
Hutchinson River at Pelham	01301500	1945-49 1975-79	6.10	35.8	3.4	48	1.85	25	2.1	4	1.1
Bronx River at Bronxville	01302000	1945-49	28.3	13.8	2.2	48	1.85	17	1.6	4	1.1
		1975-79						31	2.5	6	1.0
			Rockland County								
Sparkill Creek at Sparkill	01376280	1975-79	10.7	42.4	3.9	48	1.75	13	1.4	2	1.0
Nauraushaun Brook at Nanuet	01376842	1975-78	21.2	74.6	1.4	48	1.75	26	2.2	6	0.9
Nauraushaun Brook at Pearl River	01376855	1975-79	5.97	40.4	2.2	48	1.75	29	2.3	8	.9
Pascack Brook Trib. at Spring Valley	01377196	1975-79	3.89	69.8	4.9	48	1.75	29	2.3	9	.8
Pascack Brook near Pearl River	01377260	1975-79	8.39	37.4	3.1	48	1.75	26	2.2	9	.9
			Erie County								
Scajaquada Creek at Buffalo	04216200	1957-61	15.4	7.5	0.3	34	1.25	23	2.0	6	1.0
		1975-79						34	2.7	8	0.9

percent impervious area are mentioned here so that users of this report may consider them as an alternative to the more time-consuming and difficult methods used in this study.)

*<u>Basin-development factor, BDF, a dimensionless number from 0 through 12</u>.--A factor developed by Sauer and others (1983), calculated as follows: (1) The basin area is divided into upper, middle, and lower thirds. (2) Four urban characteristics are then evaluated for each third--presence of (a) storm sewers, (b) curbs and gutters, (c) improved stream channels, and (d) impervious stream-channel lining. (3) A value of 0 is given for each characteristic if it is insignificant or a value of 1 if it is significant. (A characteristic is significant if it affects more than 50 percent of the channel or drainage area in that third of the basin.) (4) The values given for the four characteristics in each third of the basin are then summed to give the basin-development factor. This factor was obtained through inspection of topographic and land-use maps and, where possible, by field inspection. In some areas, local planning boards were also consulted.

*<u>Urban-development factor, RL, dimensionless</u>.--A value that is derived from a graph relating percent impervious area to percentage of basin served by storm sewers. This relationship was developed by Leopold (1968) and used by Sauer (1974) to develop a flood-frequency-estimating equation. The percentages of impervious area and area served by storm sewers were obtained from field inspection, land-use maps, sewer maps, and, in some areas, by consultation with local planning boards.

*<u>Channel-urbanization factor, ϕ, dimensionless</u>.--The sum of two channel factors defined by Espey and Winslow (1974) and based on the amount of channel vegetation and channel improvement. These channel characterisics at each site were evaluated by field inspection and from topographic maps and land-use maps; the corresponding values were obtained from Espey and Winslow (1974).

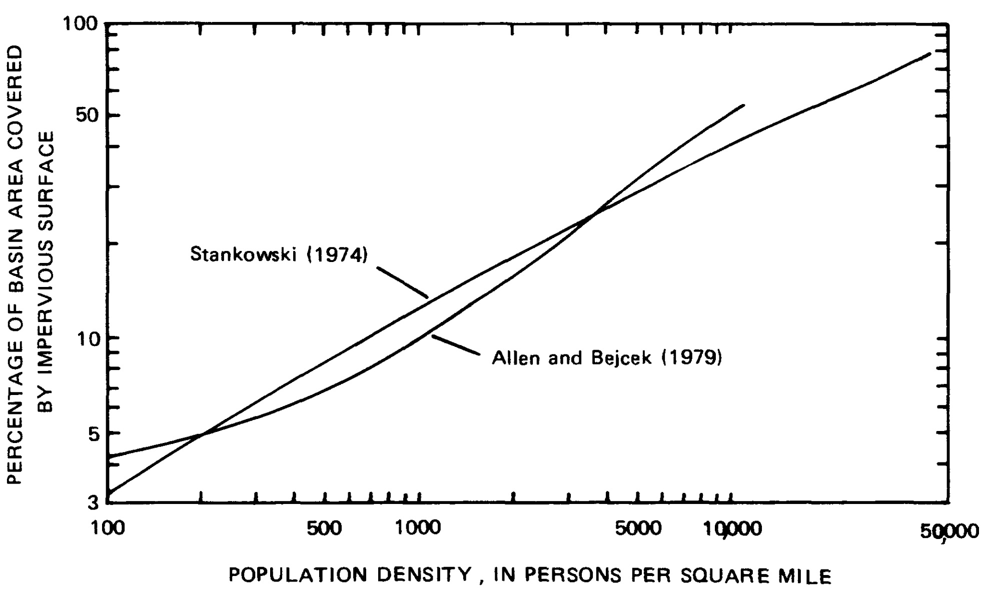


Figure 2.--Relationships between population density and percent impervious area developed by Stankowski (1974) and Allen and Bejcek (1979).

METHODS FOR ESTIMATING PEAK DISCHARGE

No floodflow-estimation techniques have been developed specifically for New York streams in urban areas, but six methods developed for general use, some only for certain states or regions, were applied to the 16 study basins to determine which method most closely matched the rainfall-runoff estimates. Two of the methods are presented in Sauer and others (1983); the other four are in Allen and Bejcek (1979), Stankowski (1974), Sauer (1974), and Espey and Winslow (1974). The equations used for flood-recurrence intervals ranging from 2 years to 100 years are given later in this section. All methods except the one by Espey and Winslow (1974) require values for rural flood-peak discharges. Because flood-peak discharges for rural conditions cannot be calculated from observed records from urban gaged sites, they were computed from rural flood-frequency equations developed for New York by Zembrzuski and Dunn (1979). These equations are described below.

Rural Peak-Discharge Equations

Flood peaks for six recurrence intervals (2, 5, 10, 25, 50, 100 years) were calculated for the 16 sites through equations developed by Zembrzuski and Dunn (1979) for rural streams in New York. It was soon noted, however, through comparison of New York and New Jersey rural-flood-frequency equations, that basin storage might affect the resulting peak discharges of streams in southeastern New York. Therefore, the original data set for southeastern New York used by Zembrzuski and Dunn (1979) was reanalyzed through regression analysis to evaluate the significance of basin storage. Results indicated that basin storage was significant and that including it in the analyses improved the standard error of estimate by 1 to 8 percent. These adjusted flood-frequency equations (eq. 1A-1F below) were then applied to the selected basins and the results compared with those obtained through the six methods being evaluated. The rural-stream equations for southeastern New York are shown below with their standard errors. A complete description of the variables, stream basins, regression techniques, and other details is given in Zembrzuski and Dunn (1979).

Rural floodflow-estimation equations* for southeastern region New York (Subscript for Q is recurrence interval, in years)	Standard error of regression (percent)	Eq. Number
$Q_2 = 6.03\ A^{0.943}\ SL^{0.194}\ (ST + 10)^{-1.103}\ (P - 20)^{1.27}$	22	1A
$Q_5 = 3.28\ A^{0.972}\ SL^{0.260}\ (ST + 10)^{-0.929}\ (P - 20)^{1.35}$	21	1B
$Q_{10} = 2.202\ A^{0.989}\ SL^{0.297}\ (ST + 10)^{-0.811}\ (P - 20)^{1.40}$	23	1C
$Q_{25} = 1.351\ A^{1.01}\ SL^{0.340}\ (ST + 10)^{-0.655}\ (P - 20)^{1.44}$	26	1D
$Q_{50} = 0.953\ A^{1.02}\ SL^{0.368}\ (ST + 10)^{-0.542}\ (P - 20)^{1.48}$	30	1E
$Q_{100} = 0.681\ A^{1.03}\ SL^{0.395}\ (ST + 10)^{-0.432}\ (P - 20)^{1.51}$	32	1F

* Terms are explained on pp. 4, 5, 8.

The rural-stream equations above are based on discharge records of 65 gaged streams, most of which have drainage areas larger than 30 mi^2, whereas sites used in this study have drainage areas smaller than 30 mi^2. To evaluate the accuracy of these rural equations for streams having small drainage areas, the peak discharges computed from these equations were compared to those computed from streamflow records (methods were those recommended by U.S. Water Resources Council, 1981) for basins with drainage areas smaller than 30 mi^2. A graph of peak discharges computed from regression equations in relation to log-Pearson analysis of observed data at the 50-year recurrence interval in western New York is shown in figure 3A and for southeastern New York in figure 3B. Statistical analyses of the data shown in these graphs indicate a slight bias that causes the equations to overestimate flood peaks of small drainage basins, but because the observed values are within the equations' standard error of estimate, no adjustments were made to the rural flood-peak values.

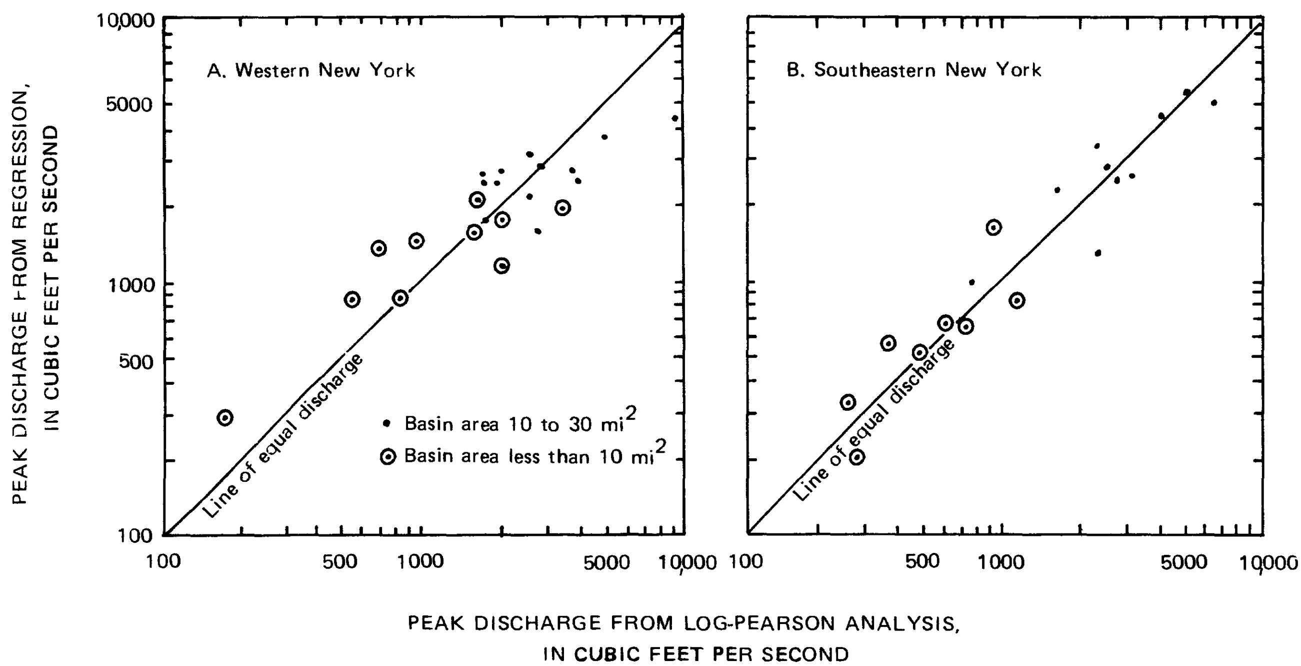


Figure 3.--Relationship between 50-year peak discharges calculated from log-Pearson analysis of observed data and from rural-stream regression equations: A. Western New York, from equation of Zembrzuski and Dunn (1979). B. Southeastern New York, from eq. 1E.

Urban Discharge Equations

The six methods of peak-flow estimation that were selected for comparison are described below. The subscripts 2, 5, 10, 25, 50, and 100 in the following equations represent the recurrence interval, in years, and the subscripts "u" and "r" refer to urban and rural conditions, respectively. The independent variables are described in the previous section, "Basin Characteristics."

Methods 1 and 2 (Sauer and others, 1983)

Sauer and others (1983) present two sets of urban flood-frequency equations, both of which were developed from data from 199 gaged urban basins throughout the United States. The amount of impervious area within these basins ranged from 3 to 50 percent. These two methods are designated herein as methods 1 and 2 of Sauer and others (1983).

The standard error of regression for the first method (eq. 2A-2F below) ranged from 43 to 46 percent. This set uses three independent variables--drainage area, basin-development factor, and rural peak discharge.

$$(Q_2)_u = 13.2A^{0.21} (13 - BDF)^{-0.43} (Q_2)_r^{0.73} \quad (2A)$$

$$(Q_5)_u = 10.6A^{0.17} (13 - BDF)^{-0.39} (Q_5)_r^{0.78} \quad (2B)$$

$$(Q_{10})_u = 9.51A^{0.16} (13 - BDF)^{-0.36} (Q_{10})_r^{0.79} \quad (2C)$$

$$(Q_{25})_u = 8.68A^{0.15} (13 - BDF)^{-0.34} (Q_{25})_r^{0.80} \quad (2D)$$

$$(Q_{50})_u = 8.04A^{0.15} (13 - BDF)^{-0.32} (Q_{50})_r^{0.81} \quad (2E)$$

$$(Q_{100})_u = 7.70A^{0.15} (13 - BDF)^{-0.32} (Q_{100})_r^{0.82} \quad (2F)$$

The standard error of regression for the second method (eq. 3A-3F below) ranged from 38 to 44 percent. This set uses seven independent variables--drainage area, main-channel slope, 2-year 2-hour rainfall, basin storage, basin-development factor, percent impervious area, and the rural peak discharge for the selected recurrence interval.

$$(Q_2)_u = 2.35A^{0.41}SL^{0.17}(R2+3)^{2.04}(ST+8)^{-0.65}(13-BDF)^{-0.32}I^{.15}(Q_2)_r^{0.47} \quad (3A)$$

$$(Q_5)_u = 2.70A^{0.35}SL^{0.16}(R2+3)^{1.86}(ST+8)^{-0.59}(13-BDF)^{-0.31}I^{.11}(Q_5)_r^{0.54} \quad (3B)$$

$$(Q_{10})_u = 2.99A^{0.32}SL^{0.15}(R2+3)^{1.75}(ST+8)^{-0.57}(13-BDF)^{-0.30}I^{.09}(Q_{10})_r^{0.58} \quad (3C)$$

$$(Q_{25})_u = 2.78A^{0.31}SL^{0.15}(R2+3)^{1.76}(ST+8)^{-0.55}(13-BDF)^{-0.29}I^{.07}(Q_{25})_r^{0.60} \quad (3D)$$

$$(Q_{50})_u = 2.67A^{0.29}SL^{0.15}(R2+3)^{1.74}(ST+8)^{-0.53}(13-BDF)^{-0.28}I^{.06}(Q_{50})_r^{0.62} \quad (3E)$$

$$(Q_{100})_u = 2.50A^{0.29}SL^{0.15}(R2+3)^{1.76}(ST+8)^{-0.52}(13-BDF)^{-0.28}I^{.06}(Q_{100})_r^{0.63} \quad (3F)$$

Method 3 (Allen and Bejcek, 1979)

Allen and Bejcek (1979) used data from 103 gaged watersheds in northeastern Illinois to develop flood-frequency relationships for that region. This method uses three independent variables--drainage area, slope, and percent impervious area, which exceeded 10 percent in 55 of these basins. Their 1979 report also contains a graph relating the ratio of urban flood discharges to rural flood discharges for various recurrence intervals to the percent impervious area. These ratios were computed from the regression equations on the assumption that the drainage area and main-channel slope remain relatively unchanged as urbanization progresses. If this assumption is valid, the urban peak discharge for each recurrence interval depends only on rural peak discharge and percent impervious area because the other independent variables cancel out. The complete regression equations for Illinois streams as reported by Allen and Bejcek (1979) had standard errors of estimates ranging from 36 to 52 percent for the six recurrence intervals. These equations (eq. 4A-4F) are shown below.

$$(Q_2)_u = (Q_2)_r I^{0.313} \quad (4A)$$

$$(Q_5)_u = (Q_5)_r I^{0.255} \quad (4B)$$

$$(Q_{10})_u = (Q_{10})_r I^{0.228} \quad (4C)$$

$$(Q_{25})_u = (Q_{25})_r I^{0.202} \quad (4D)$$

$$(Q_{50})_u = (Q_{50})_r I^{0.180} \quad (4E)$$

$$(Q_{100})_u = (Q_{100})_r I^{0.172} \quad (4F)$$

Method 4 (Stankowski, 1974)

Stankowski (1974) developed flood-frequency equations from data on 103 urban and rural river basins in New Jersey. This method uses four independent variables--drainage area, channel slope, basin storage, and percent impervious area. The percent impervious area was calculated from a relationship with population density. Stankowski (1974) states that the effects of urbanization on peak discharge can be expressed by the ratio of urban discharge (Q_u) to rural discharge (Q_r) because all other independent variables except percent impervious area cancel. The standard errors of estimate for the complete regression equations for New Jersey streams ranged from 48 to 54 percent for the six recurrence intervals. The resulting equations (eq. 5A-5F) are:

$$(Q_2)_u = (Q_2)_r I^{0.25} \quad (5A)$$

$$(Q_5)_u = (Q_5)_r I^{0.22} \quad (5B)$$

$$(Q_{10})_u = (Q_{10})_r I^{0.20} \quad (5C)$$

$$(Q_{25})_u = (Q_{25})_r I^{0.18} \quad (5D)$$

$$(Q_{50})_u = (Q_{50})_r I^{0.16} \quad (5E)$$

$$(Q_{100})_u = (Q_{100})_r I^{0.14} \quad (5F)$$

Method 5 (Sauer, 1974)

Sauer (1974) combined the analysis of Leopold (1968) with that of Anderson (1970) to formulate a general urban-flow-adjustment equation for basins in Oklahoma that can be used for any desired recurrence interval. Leopold (1968) had developed an urban-adjustment factor, RL, which can be used to adjust the rural 2-year flood peak for urbanization. Anderson (1970) reported a relationship between rainfall-intensity ratios and flood peaks for the various recurrence intervals. Sauer (1974) incorporated these two relationships into his urban-adjustment equation (eq. 6), which uses five variables--rainfall-intensity ratio (RI_x), rural peak discharge with a 2-year (Q_2) and x-year (Q_x) recurrence interval, and the urban-development factor (RL).

$$(Q_x)_u = [7RI_x \ (Q_2)_r \ (RL - 1) \ (Q_x)_r \ (7 - RL)]/6 \qquad (6)$$

No error analysis was made by Sauer for this equation because he had no observed flood-frequency data for urban basins in Oklahoma.

Method 6 (Espey and Winslow, 1974)

Espey and Winslow (1974) developed the only urban flood-frequency equations that do not require adjustment of the rural flood peaks. Their regression equations were developed from data from 60 urban basins, 27 of which were in Texas, 15 in Virginia, 8 in Maryland, 4 in Mississippi, 2 in Michigan, 2 in Delaware, 1 in Illinois, and 1 in Washington, D.C. This method (eq. 7A-7E) is given below with the reported average absolute errors. The main-channel slope, S, is given in ft/ft instead of ft/mi, and some of the recurrence intervals differ from those used in the other equations. For consistency, only flood discharges of the 5-, 10-, and 50-year recurrence interval (eq. 7B, 7C, 7E) were used in this study.

Equation	Average absolute error, in percent	
$Q_{2.33} = 169A^{0.77} \ I^{0.29} \ S^{0.42} \ R6_{2.33}^{1.80} \ \phi^{-1.17}$	30	(7A)
$Q_5 = 172A^{0.80} \ I^{0.27} \ S^{0.43} \ R6_{5}^{1.73} \ \phi^{-1.21}$	31	(7B)
$Q_{10} = 178A^{0.82} \ I^{0.26} \ S^{0.44} \ R6_{10}^{1.71} \ \phi^{-1.32}$	31	(7C)
$Q_{20} = 243A^{0.84} \ I^{0.24} \ S^{0.48} \ R6_{20}^{1.62} \ \phi^{-1.38}$	32	(7D)
$Q_{50} = 297A^{0.85} \ I^{0.22} \ S^{0.50} \ R6_{50}^{1.57} \ \phi^{-1.61}$	34	(7E)

Comparison of the Six Methods

Investigation of the six flood-frequency estimating methods for urban streams revealed three significant facts: (1) only the two methods of Sauer and others (1983) and Stankowski (1974) include gaging-station data from urban areas in New York or neighboring states; (2) the methods of Sauer and others (1983) are the two that used the largest data base to develop regression equations; and (3) only the method 1 of Sauer and others (1983) does not require percent impervious area. The first two facts suggest that the two methods of Sauer and others (1983) may give the most accurate estimates for urban New York streams, and the third favors method 1 by Sauer and others over the rest for its relative simplicity.

SYNTHESIS OF PEAK DISCHARGE THROUGH RAINFALL-RUNOFF MODELING

The peak discharges for the six recurrence intervals in each of the urban gaged sites were calculated from long-term synthetic peak-discharge records, which had been synthesized by rainfall-runoff models based on precipitation data that were obtained from the National Climatic Center in Asheville, N.C. One HEC-1 rainfall-runoff model (U.S. Army Corps of Engineers, 1973) was calibrated and verified for seven of the 11 urban basins, and two models were calibrated for each of the other four. Log-Pearson analyses as specified in the Water Resources Council Bulletin 17B (1981) were then run on the synthetic discharge record for each basin model to obtain the peak-discharge values for the six recurrence intervals.

Calculation of the urban flood magnitudes was based on long-term synthetic records for three reasons. First, at least 10 years of record are recommended for log-Pearson type III analysis, but five of the basins in this study had less than that. Second, urbanization in the basins with at least 10 years of record has been increasing constantly, which would cause the gaged record of annual peaks to be nonhomogenous and thus unsuitable for frequency analysis (Water Resources Council, 1981). Third, the long-term synthetic record is not biased by short-term climatic variations.

Rainfall-runoff models had been calibrated and verified for 12 basins in Rockland County by Lumia (1982); five of these basins are urban and were therefore selected for use in this study. The flood-frequency characteristics, the values used in the HEC-1 model, and a detailed description of the model analysis of these basins are given in Lumia (1983).

Model Calibration and Verification

The HEC-1 rainfall-runoff model was calibrated and verified for 11 of the 16 basins studied. A short period of record (5 years) was chosen for the calibration periods because the degree of change in urbanization over 5 years would be small, with less than a 5-percent increase in impervious area. Four of the 11 basins had long enough periods of record to enable rainfall-runoff modeling of two time periods, giving a total of 15 calibrations.

Storms exceeding 1 inch of precipitation in a 48-hour period during these periods of record were identified, and hourly rainfall and flood-discharge data were used to calibrate the models. The hourly rainfall data were obtained from a nearby precipitation station (fig. 1), and the hourly discharge data were obtained from U.S. Geological Survey gaging-station records.

The HEC-1 model uses four precipitation loss-rate and two unit-hydrograph terms (Clark, 1975) to describe a stream's response to a storm. The Clark (1975) unit hydrograph method uses the terms TC and R, where TC is the basin's time of concentration, in hours, and R is the storage coefficient, also in hours. The four loss-rate terms are DLTKR, which represents the initial rain loss (infiltration) due to surface storage and antecedent soil-moisture conditions, in inches; STRKR, which represents the starting value for the rain loss rate due to infiltration, in inches per hour; RTIOL, which is the rate at which rain loss to infiltration decreases as saturation develops (dimensionless);

and ERAIN, which represents the effect of precipitation rate on the infiltration characteristics of the basin (dimensionless). An optimization routine in the computer program was used to help determine best-fit values for both the unit hydrograph and loss-rate terms.

Seasonal variations in the STRKR and DLTKR terms for streams in Rockland County were reported by Lumia (1982) and were also observed among most of the basins investigated in this study. The variations in these terms are probably due to the absorption of moisture by vegetation during the growing season and to the lack of infiltration during winter when the ground is frozen.

Verification of the 15 rainfall-runoff model calibrations was made through comparison of model-generated flood peaks with observed values that had not been used for calibration. Typically, 7 to 11 floods during the modeled period were used for verification. The average mean error of synthetic peak discharges for the 15 calibrations was 22 percent. Verification results for the six urban basins outside Rockland County are given in table 2.

Table 2.--Mean errors for modeled urban sites outside Rockland County.
[Locations are shown in fig. 1, data are given in Lumia (1982).]

Site number	Time period	Number of verification storms	Mean error (in percent)
01300000	1950-54	8	38
	1975-79	11	26
01300500	1975-79	11	21
01301000	1945-49	8	21
	1975-79	9	14
01301500	1975-79	9	23
01302000	1945-49	7	28
	1975-79	9	19
04216200	1957-61	8	16
	1975-79	11	18

Synthesis of Long-Term Record

The 15 verified rainfall-runoff models were used to synthesize the long-term peak discharges for each basin. The National Climatic Center provided magnetic tapes with 33 years of hourly precipitation data for the precipitation stations at Buffalo Airport and 59 years at Central Park in New York City. (The 59 years of hourly precipitation data for Central Park were also used in the Rockland County study by Lumia, 1983.) These long-term data were edited and adapted for use in a HEC-1 model designed to generate long-term record. Because the HEC-1 model can be used only for discrete storms, only those producing at least 1 inch of rainfall in a 48-hour period were chosen. This generally yielded 7 to 10 storms for each year of record, and the largest peak discharge of each water year was then chosen from these synthetic floods.

Flood-Frequency Relationships

The synthetic annual flood series for each basin was used to determine flood-magnitude and frequency relationships in accordance with recommendations of the Water Resources Council (1981). The flood-frequency relationships for the Westchester and Rockland County sites were based on 59 years of synthetic record developed from rainfall records at Central Park in New York City from 1921 through 1979. Flood-frequency relationships for Scajaquada Creek in Erie County were developed from 33 years of rainfall record from 1947 through 1979 at the Buffalo Airport. A weighted skew was used in the log-Pearson Type III analysis of the synthetic records in computing the peak discharges at each recurrence interval. A total of 15 flood-frequency relationships were developed for the 11 urban basins with verified rainfall-runoff models. These relationships were then used as the basis for evaluation of the six urban flood magnitude- and frequency-estimating techniques described earlier.

Flood-frequency relationships based on synthetic flood series are less accurate than those based on observed data with the same record length. No standard procedures are currently available for evaluating the errors associated with values derived from synthetic peak-flow data that are based on rainfall-runoff relationships, but two recent studies (Thomas, U.S. Geological Survey, written commun, 1980 and 1982; and Lichty and Liscum, 1978), which examine errors associated with rainfall-runoff modeling and flood-frequency estimates, suggest that 60 years of synthetic record is probably equivalent to 10 to 30 years of observed record for predicting the peak flood discharge of a 100-year recurrence interval. Also, Thomas indicated that synthetic records may yield lower peak flood values than the observed data.

COMPARISON OF ESTIMATED AND SYNTHETIC PEAK DISCHARGES

The flood-frequency values computed by the six selected methods were compared to those computed from the 15 synthetic records to assess their closeness of fit and bias, and each method's ability to estimate increases in peak flow due to urbanization. Four methods of comparison were used--a graph analysis and three statistical analyses, described below.

Graph Comparison

The graph comparisons give a visual interpretation of the closeness of fit and bias of the six estimating methods. The 50-year flood peaks calculated from the synthetic data are plotted against those calculated by the six methods in figures 4B through 4G. Figure 4A, based on the equations for rural New York streams, reveals trends in the rural flood-frequency values that may affect the other estimating techniques. The locations of data points on figure 4A show that the rural-stream equations overpredicted the flood peaks generated by four of the 15 models evaluated. This means that methods that incorporate rural flood peaks will inherently overestimate flood peaks of at least four of the modeled sites. The clustering of data points above the line in figures 4B through 4G shows that all six methods overpredicted synthetic peak discharges and that all six, especially the two by Sauer and others (fig. 4B, 4C), overpredicted flood peaks of small basins more than those of larger basins.

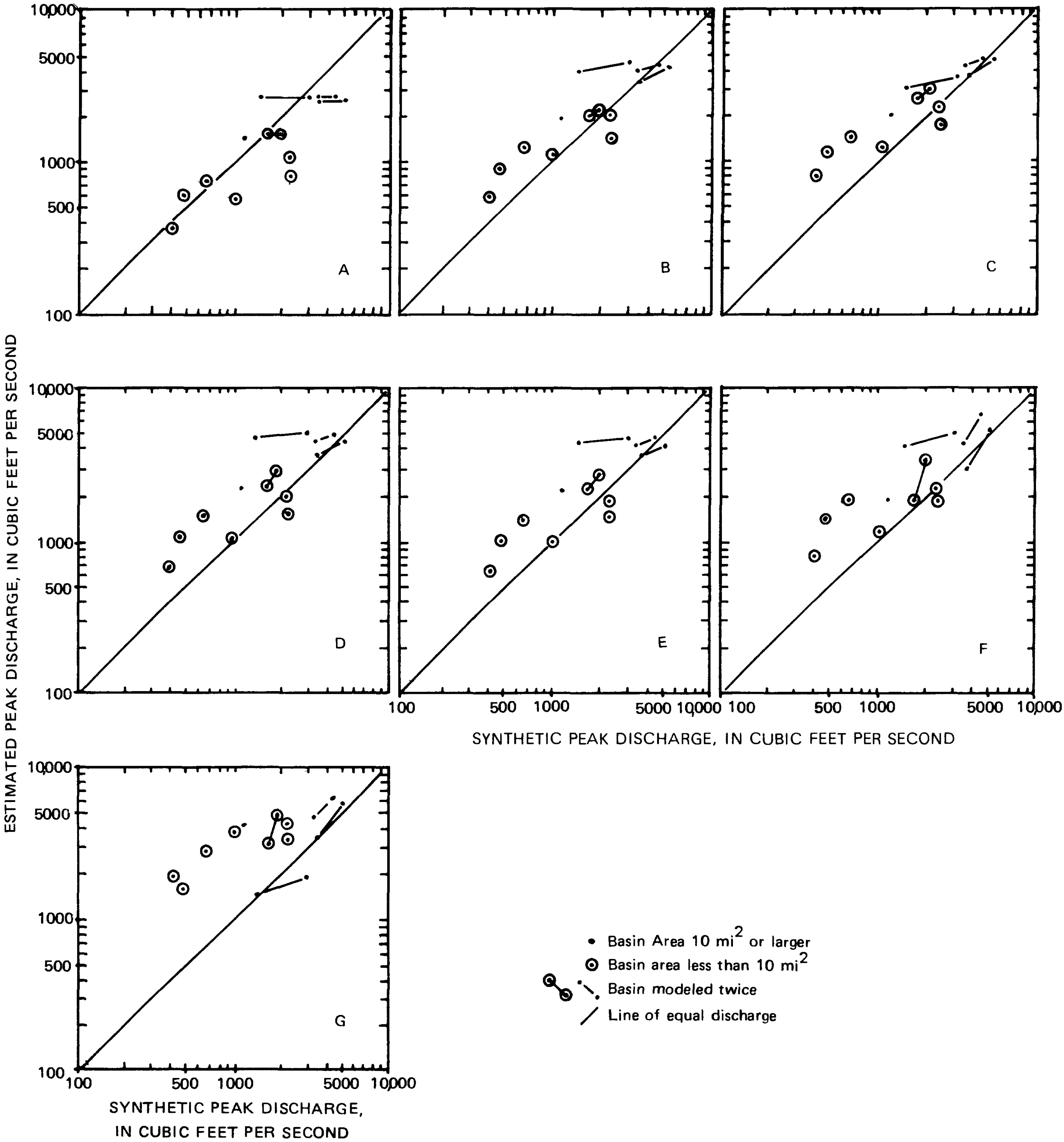


Figure 4.--Comparison of 50-year flood discharges derived from synthetic records with those calculated from seven estimating techniques. [Each plot represents all 11 sites.]

A. New York rural flood-frequency equations
B. Sauer and others I (1983)
C. Sauer and others II (1983)
D. Allen and Bejcek (1979)
E. Stankowski (1974)
F. Sauer (1974)
G. Espey and Winslow (1974)

Standard-Error Analysis

A standard-error analysis was made to ascertain which estimating method most closely predicts the synthetic urban peak discharges of the selected urban gaged sites in New York. The standard error of estimate for each of the estimating equations was obtained from equation 8:

$$\text{Standard error, in log units} = \left[\frac{\sum_{1}^{N} (LQ_E - LQ_S)^2}{N - 1} \right]^{1/2} \qquad (8)$$

where: LQ_E = $\log_{10}$ estimated (regression equation) peak discharge,
LQ_S = $\log_{10}$ synthetic peak discharge, and
N = number of modeled periods (15).

These logarithmic standard errors, expressed as percentages for each method at the six recurrence intervals, are given in table 3.

The smallest standard errors in relation to the synthetic peak discharges resulted from the two methods of Sauer and others (1983); these standard errors ranged from 44 to 57 percent. The largest standard errors resulted from the method of Espey and Winslow (1974) and ranged from 116 to 118 percent (table 3).

Bias Analysis

All six urban-stream methods tend to overpredict the synthetic peak discharges, as seen in the graphs in figure 4. The amount of bias for each method is summarized in table 4. This bias was computed through equation 9:

$$\text{Bias} = \sum_{1}^{N} \left[\frac{(Q_E - Q_S)\,(100)}{Q_S N} \right] \qquad (9)$$

where: Q_E = estimated (regression equation) peak flow,
Q_S = synthetic peak flow, and
N = number of modeled periods (15)

The tendency to overpredict urban peak discharge may be partly due to bias inherent in the synthetic records, especially those for small stream basins. Thomas (U.S. Geological Survey, written commun., 1980, 1982) reported that peak discharges computed from synthetic records based on rainfall-runoff relationships are typically slightly lower than those computed from the observed record. He specifically reported that

> ... the synthetic estimates from the rainfall-runoff model range from about 8 percent more than to 12 percent less than the observed estimates depending on the recurrence interval.

(These values were determined from an analysis of records and models for 42 gaging stations in the eastern United States.) The bias from the synthetic estimates of peak flows used in this study may be even larger. In addition, the rural flood-frequency equations of Zembrzuski and Dunn (1979) and equations 1A-1F seem to slightly overpredict peak discharges of streams with

Table 3.--Standard errors of estimate in the rural-discharge and six urban-discharge estimating methods.

[Values are in percent]

Method	Recurrence interval (years)					
	2	5	10	25	50	100
Rural streams						
Zembrzuski and Dunn (1979)[1]	50	56	54	54	52	52
Urban streams						
Sauer and others I (1983)	49	44	44	44	45	48
Sauer and others II (1983)	57	49	51	50	52	53
Allen and Bejcek (1979)	114	69	65	61	61	60
Stankowski (1974)	80	60	58	56	54	53
Sauer (1974)	72	66	65	65	65	64
Espey and Winslow (1974)	--	118	116	--	117	--

Table 4.--Bias in the rural-discharge and six urban-discharge estimating methods.

[Values are in percent]

Methods	Recurrence interval (years)					
	2	5	10	25	50	100
Rural streams						
Zembrzuski and Dunn (1979)[1]	-11	-21	-18	-16	-12	- 9
Urban streams						
Sauer and others I (1983)	46	34	32	28	33	37
Sauer and others II (1983)	53	42	45	42	46	50
Allen and Bejcek (1979)	134	74	66	58	56	54
Stankowski (1974)	92	56	53	47	44	40
Sauer (1974)	79	66	66	64	65	62
Espey and Winslow (1974)	--	130	123	--	130	--

[1] Eq. 1A-1F (p. 9) for southeastern New York.

drainage areas smaller than 10 mi^2. For gaging stations in southeastern New York, this bias was found to range from 5 to 10 percent, and in western New York from 18 to 20 percent. However, these small errors are based on records of only 8 to 10 gaging stations in each area and therefore should not be used to adjust peak discharge. Together these errors may account for some or all of the overprediction seen in the graphs in figure 4. These errors when summed could easily account for bias as high as 32 percent for the 100-year peak discharge.

Part of the tendency to overestimate peak discharges may also be inherent in the six estimating methods themselves; however, the data are insufficient to confirm this or to indicate its magnitude. None of the seven methods showed bias when they were developed with their original data sets. Although the equations for rural streams showed the smallest bias, these values have not been adjusted for errors associated with the use of the equations for drainage areas smaller than 10 mi^2 or the use of long-term synthetic records developed from rainfall-runoff models. Redeveloping rural flood-frequency regression equations from a larger number of basins having small drainage area would remove the bias associated with estimating peak discharges for small drainage areas.

Of the six urban methods evaluated, the two developed by Sauer and others (1983) had the smallest bias, which ranged from 28 to 53 percent (table 3); this is within the range of bias inherent in the methods used.

Analysis of Peak-Discharge Increases Due to Urbanization

The final method used to evaluate the estimating methods is based on the increases in peak flow during the interval between the two calibration periods. Four of the basins had a sufficient period of record for this procedure, and the increases in peak flow can be attributed to urbanization at the gaging site. In figure 4, these two periods are indicated by a straight line connecting two data points. Ideally, these lines would be parallel to the line of equal discharge, even if above it as a result of overprediction. Where the lines are parallel, the equation reflects the percent increase in synthetic flow, even if the discharge values differ. The average percent difference between the estimated and synthetic increases due to urbanization among the four basins was obtained through equation 10:

$$\text{Average difference, in percent} = \frac{\sum_{1}^{N} \left| EPI - SPI \right|}{N} \qquad (10)$$

Where N = number of basins modeled twice (4),
EPI = increase in estimated (regression equation) peak flow, in percent, and
SPI = increase in synthetic peak flow, in percent.

The average percent differences between the estimated and the synthetic values are shown in table 5. These average differences indicate, in percent, how much each method under- or overestimated the increase in flow due to urbanization. Because only four basins could be analyzed in this way, these values should be interpreted with caution. The method with the smallest average percent difference between the estimated and synthetic peak was the second method of Sauer and others (1983). All other methods except perhaps that of Sauer (1974), which gave slightly higher values, yielded percentages similar to one another. The methods of Sauer (1974) and Espey and Winslow (1974) tended to overestimate the percent increase, whereas the rest tended to underestimate it.

Table 5.--Percent difference between estimated and synthetic peak-discharge increases due to urbanization in four stream basins.

[Estimated increase in average discharge among the five basins minus simulated increase in average discharge expressed as a mean percentage.]

Method	Recurrence interval (years)					
	2	5	10	25	50	100
Sauer and others I (1983)	27	31	34	37	40	42
Sauer and others II (1983)	19	25	28	33	36	37
Allen and Bejcek (1979)	25	30	33	37	39	42
Stankowski (1974)	27	31	34	38	40	43
Sauer (1974)	30	43	45	50	52	53
Espey and Winslow (1974)	--	25	28	--	35	--

SUMMARY AND CONCLUSIONS

Six methods of estimating urban peak flood discharges were evaluated to discern which method would most closely match synthetic floodflows in urban reaches of New York streams. Methods developed by Allen and Bejcek (1979), Stankowski (1974), Sauer (1974), Espey and Winslow (1974), and two by Sauer and others (1983) were selected for evaluation. The discharges computed from these methods are plotted against those computed from synthesized peak-discharge records for urban gaged streams in New York, and the standard error, bias, and percent differences between estimated and synthetic peak discharge increases due to urbanization are evaluated.

Together the equations require values for 11 basin characteristics, but none require all 11. Of these characteristics, only four are related to urbanization. The term most commonly used is percent impervious area, but this term is the most difficult to measure. The only method that does not use percent impervious area is the first method of Sauer and others (1983); this method also yielded the smallest standard error and bias in relation to the synthetic flood peaks of the six methods evaluated.

Eleven gaged urban basins in three counties were selected for study, and models for each were calibrated through the HEC-1 rainfall-runoff model. Four of these basins had sufficient long-term discharge records for two different 5-year calibration periods. This resulted in a total of 15 models (for 11 gaged urban basins) that could be used for comparison. Once these models were calibrated for each period and verified, they were used to synthesize long-term discharge records from hourly rainfall data obtained from the National Climatic Center. Discharges for six recurrence intervals (2, 5, 10, 25, 50, and 100 year) at each site were calculated from the generated records. Then the 50-year discharges obtained through the six estimating methods were plotted against those calculated from the synthetic long-term records to reveal any discrepancies from the synthetic values for each method. Statistical analyses were also made to determine each method's standard error, bias, and percent difference between estimated and synthetic peak-discharge increases due to urbanization.

All six estimating methods tend to overpredict synthetic urban peak floodflow. This bias is attributed to underestimation in the synthetic discharge record and to the rural flood-frequency equations of Zembrzuski and Dunn, 1979 (eq. 1A-1F), which have a slight tendency toward overprediction for streams with drainage areas smaller than 10 mi^2. Also, all six methods yielded similar percent increases in peak discharge due to urbanization. However, the two methods of Sauer and others (1983) yielded the smallest standard errors and bias in relation to the synthetic floodpeaks of the six methods evaluated.

SELECTED REFERENCES

Allen, H. E., Jr., and Bejcek, R. M., 1979, Effects of urbanization on the magnitude and frequency of floods in northeastern Illinois: U.S. Geological Survey Water-Resources Investigations 79-36, 48 p.

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

Carter, R. W., 1961, Magnitude and frequency of floods in suburban areas: U.S. Geological Survey Professional Paper 424-B, article 5, p. B9-B11.

Chow, V. T., 1964, Handbook of applied hydrology: New York, McGraw-Hill Book Co., 1418 p.

Clark, C. O., 1945, Storage and the unit hydrograph: American Society of Civil Engineers, v. 110, p. 1419-1446.

Cornell University, 1968, Land Use and Natural Resource Inventory Maps of New York: Ithaca, N.Y., Resource Information Laboratory, Cornell University, scale 1:24,000.

Espey, W. H., Jr., and Winslow, D. E., 1974, Urban flood-frequency characteristics: Proceedings of the American Society of Civil Engineers, Journal Hydraulics Division, v. 100, no. HY2, p. 279-293.

Hardison, C. H., 1969, Accuracy of streamflow characteristics: U.S. Geological Survey Professional Paper 650-D, p. D210-D214.

_______ 1971, Prediction error of regression estimates of streamflow characteristics at ungaged sites: U.S. Geological Survey Professional Paper 750-C, p. C228-C236.

SELECTED REFERENCES (Continued)

Leopold, L. B., 1968, Hydrology for urban land planning--a guidebook on on the hydrologic effects of urban land use: U.S. Geological Survey Circular 554, 18 p.

Lichty, R. W., and Liscum, F., 1978, A rainfall-runoff modeling procedure for improving estimates of T-year (annual floods for small drainage basins: U.S. Geological Survey Water-Resources Investigations 73-7, 44 p.

Lumia, Richard, 1982, Evaluation of rainfall-runoff data network, Rockland County, New York: U.S. Geological Survey Water-Resources Investigations 81-49, 24 p.

_______ 1984, Flood-discharge profiles of selected streams in Rockland County, New York: U.S. Geological Survey Water-Resources Investigations 84-4049, 32 p.

Martens, L. A., 1968, Flood inundation and effects of urbanization in metropolitan Charlotte, North Carolina: U.S. Geological Survey Water-Supply Paper 1591-C, 60 p.

New York State Economic Development Board, 1976, LUNR Inventory--what is it and how is it used: Albany, N.Y., New York State Economic Development Board, 16 p.

Rawls, W. J., Stricker, V. A., and Wilson, K. V., 1980, Review and evaluation of urban floodflow-frequency procedures: U.S. Department of Agriculture, Science and Education Administration, bibliographies and literature of agriculture, no. 9, 62 p.

Sauer, V. B., 1974, Flood characteristics of Oklahoma streams: U.S. Geological Survey Water-Resources Investigations 52-73, 301 p.

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

Stankowski, S. J., 1974, Magnitude and frequency of floods in New Jersey, with effects of urbanization: State of New Jersey Department of Environmental Protection Division of Water Resources, Special Report 38, 46 p.

U.S. Army Corps of Engineers, 1973, HEC-1 flood hydrograph package: Davis, Calif., U.S. Army Corps of Engineers, Hydrologic Engineering Center, 25 p.

U.S. Geological Survey, 1976, Water resources data for New york, water year 1975: U.S. Geological Survey water data report NY-75-1, 735 p.

U.S. Water Resources Council, 1981, Guidelines for determining flood-flow frequency: Water Resources Council Bulletin No. 17B of the Hydrology Committee, 183 p.

SELECTED REFERENCES (Continued)

U.S. Weather Bureau, 1955, Rainfall intensity-duration-frequency curves: U.S. Department of Commerce, Weather Bureau Technical Paper 25, 1 v.

_______ 1958, Rainfall intensity-frequency regime, part 3, the middle Atlantic region: U.S. Department of Commerce, Weather Bureau Technical Paper 29, 38 p.

_______ 1959, Rainfall intensity-frequency regime, part 4, northeastern United States: U.S. Department of Commerce, U.S. Weather Bureau Technical Paper 29, 35 p.

_______ 1961, Rainfall frequency atlas of the United States: U.S. Department of Commerce, U.S. Weather Bureau Technical Paper 40, 61 p.

Zembrzuski, T. J., Jr., and Dunn, Bernard, 1979, Techniques for estimating magnitude and frequency of floods on rural, unregulated streams in New York State excluding Long Island: U.S. Geological Survey Water-Resources Investigations 79-83, 66 p.

☆ GPO: 1986—613-614