Flood Characteristics of Urban Watersheds in the United States

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Prepared in Cooperation with U.S. Department of Transportation Federal Highway Administration

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GLOSSARY

A The contributing drainage area, in square miles. In urban areas, drainage systems sometimes cross topographic divides. Such drainage changes should be accounted for when computing A.

BDF The basin development factor, an index of the prevalence of the drainage aspects of (a) storm sewers, (b) channel improvements, (c) impervious channel linings, and (d) curb-and-gutter streets. The range of BDF is 0–12. A value of zero for BDF indicates the above drainage aspects are not prevalent, but does not necessarily mean the basin is nonurban. A value of 12 indicates full development of the drainage aspects throughout the basin. See text for details of computing BDF.

CN A soil-cover-complex curve number as described by the Soil Conservation Service (1975).

E An index of local runoff volume, in inches, for the 2-hour 25-year rainfall, computed by procedures described by the Soil Conservation Service (1975).

Gs The logarithmic skew coefficient of the annual peak discharges for a gaging station.

IA The percentage of the drainage basin occupied by impervious surfaces, such as houses, buildings, streets, and parking lots.

K An index of impervious area, computed by the equation $K = 1 + 0.015*IA$ (Carter, 1961).

L The basin length, in miles, measured on topographic maps along the main channel from the gaging station to the basin divide.

LT Lagtime, in hours, for the urban watershed, computed as the time from center-of-mass of rainfall excess to the center-of-mass of the corresponding runoff. Computed only for stations having continuous rainfall and runoff data.

R^2 Coefficient of determination, a measure of the proportion of the total variance of the dependent variable that is accounted for by the independent variables in a regression analysis.

RH The ratio of a specified recurrence-interval flood to the 2-year recurrence-interval flood. (Harley, 1978).

RI100 Rainfall intensity, in inches, for the 2-hour 100-year occurrence. Determined from Weather Bureau (1961) or Miller and others (1973).

RI2 Rainfall intensity, in inches, for the 2-hour 2-year occurrence. Determined from Weather Bureau (1961) or Miller and others (1973).

RQx The peak discharge, in cubic feet per second (ft^3/s), for an equivalent rural drainage basin in the same hydrologic area as the urban basin, and for recurrence interval x. For this study equivalent rural discharges were computed from applicable Geological Survey regional flood-frequency reports, as indicated in table 1.

S The logarithmic standard deviation of annual peak discharges for a gaging station.

SCSS An index of potential infiltration, in inches, computed by the equation $SCSS = (1{,}000/CN) - 10$ (Soil Conservation Service, 1975).

SL The main channel slope, in feet per mile (ft/mi), measured between points which are 10 percent and 85 percent of the main channel length upstream from the study site. For sites where SL is greater than 70 ft/mi, 70 ft/mi is used in the equations.

ST Basin storage, the percentage of the drainage basin occupied by lakes, reservoirs, swamps, and wetlands. In-channel storage of a temporary nature, resulting from detention ponds or roadway embankments, is not included in the computation of ST.

UQx The peak discharge, in cubic feet per second (ft^3/s), for the urban watershed for recurrence interval x. That is, UQ2 = 2-year urban peak discharge, UQ5 = 5-year urban peak discharge, and so forth.

$\overline{X}$ The logarithmic mean of annual peak discharges for a gaging station.

Flood Characteristics of Urban Watersheds in the United States

By V. B. Sauer, W. O. Thomas, Jr., V. A. Stricker, *and* K. V. Wilson

Abstract

A nationwide study of flood magnitude and frequency in urban areas was made for the purpose of reviewing available literature, compiling an urban flood data base, and developing methods of estimating urban floodflow characteristics in ungaged areas. The literature review contains synopses of 128 recent publications related to urban floodflow. A data base of 269 gaged basins in 56 cities and 31 States, including Hawaii, contains a wide variety of topographic and climatic characteristics, land-use variables, indices of urbanization, and flood-frequency estimates.

Three sets of regression equations were developed to estimate flood discharges for ungaged sites for recurrence intervals of 2, 5, 10, 25, 50, 100, and 500 years. Two sets of regression equations are based on seven independent parameters and the third is based on three independent parameters. The only difference in the two sets of seven-parameter equations is the use of basin lag time in one and lake and reservoir storage in the other. Of primary importance in these equations is an independent estimate of the equivalent rural discharge for the ungaged basin. The equations adjust the equivalent rural discharge to an urban condition. The primary adjustment factor, or index of urbanization, is the basin development factor, a measure of the extent of development of the drainage system in the basin. This measure includes evaluations of storm drains (sewers), channel improvements, and curb-and-gutter streets.

The basin development factor is statistically very significant and offers a simple and effective way of accounting for drainage development and runoff response in urban areas. Percentage of impervious area is also included in the seven-parameter equations as an additional measure of urbanization and apparently accounts for increased runoff volumes. This factor is not highly significant for large floods, which supports the generally held concept that imperviousness is not a dominant factor when soils become more saturated during large storms. Other parameters in the seven-parameter equations include drainage area size, channel slope, rainfall intensity, lake and reservoir storage, and basin lag time. These factors are all statistically significant and provide logical indices of basin conditions. The three-parameter equations include only the three most significant parameters: rural discharge, basin-development factor, and drainage area size.

All three sets of regression equations provide unbiased estimates of urban flood frequency. The seven-parameter regression equations without basin lag time have average standard errors of regression varying from ±37 percent for the 5-year flood to ±44 percent for the 100-year flood and ±49 percent for the 500-year flood. The other two sets of regression equations have similar accuracy. Several tests for bias, sensitivity, and hydrologic consistency are included which support the conclusion that the equations are useful throughout the United States. All estimating equations were developed from data collected on drainage basins where temporary in-channel storage, due to highway embankments, was not significant. Consequently, estimates made with these equations do not account for the reducing effect of this temporary detention storage.

INTRODUCTION

The U.S. Geological Survey, in cooperation with State, local, and other Federal agencies, conducts programs to collect and analyze flood-runoff data in numerous cities throughout the United States to provide hydraulic and hydrologic data needed for zoning, planning, and designing. Most of these urban programs were started during the past 10 or 15 years, but some data are available for longer periods. Analyses of the data have been made mostly for individual cities and metropolitan areas and have provided those areas with valuable planning and design information.

With urban growth and development, there is an ever-increasing need for flood information and estimating techniques in areas where little or no data exist. In 1978 the Federal Highway Administration, Department of Transportation (FHWA), contracted with the Geological Survey to make a nationwide study of urban flood frequency. The purposes of the study were (1) to review the literature of urban flood studies; (2) to compile a nationwide data base of flood-frequency characteristics; topographic, physical, and climatic characteristics; and land-use variables for as many urbanized watersheds as possible; and (3) to define estimating techniques that could be used in ungaged urban areas. This report describes the results of that study.

The authors wish to acknowledge the Federal Highway Administration, which provided financial support, and Dr. Roy Trent, FHWA, who provided the leadership and guidance to initiate the project. Special assistance from Dr. Walter J. Rawls, Department of Agriculture, Science and Education Administration, is also acknowledged. Dr. Rawls acquired and provided to the Geological Survey a large part of the data used in the study, specifically data on land use and soils. He also collaborated with the Geological Survey to compile and publish the literature review. Finally, special acknowledgment is given to the many Geological Survey personnel in district offices throughout the nation who assisted in compiling the gaging-station data used in this study.

LITERATURE REVIEW

The first phase of the study was a major search of the literature to compile a bibliography of reports that describe urban runoff, primarily those concerning the magnitude and frequency of peak discharge. Shortly after the project began, it was learned that a similar literature review was being made by the U.S. Department of Agriculture, Science and Education Administration (SEA); thereafter, the USGS and SEA worked together and published their reviews jointly (Rawls and others, 1980). That report contains synopses of 128 recent publications on urban floodflow frequency that describe procedures ranging from simple statistical methods for estimating peak discharge and recurrence intervals, to procedures for estimating flood hydrographs, to sophisticated modeling procedures for estimating complete storm hydrographs. In the literature review, the following information is presented for each reference:

1. Bibliographic citation.
2. Abstract, or synopsis, including a brief description of the procedure and data requirements for calibrating and applying it.
3. General classification of the type of procedure.
4. Geographical location for which the procedure appears applicable.

In this review it was observed that many urban equations and models were derived for use in a specific geographical area. Although most of the models designed for flood-hydrograph and continuous-record synthesis could be applied regionally or nationally, statistical techniques for estimating the magnitude and frequency of instantaneous peak discharges are much more limited areally and generally cannot be transferred outside the specific area for which they were developed. Some of the widely applicable techniques described in the literature review are highlighted in the following discussion.

Leopold (1968) defined the ratio of the urban to equivalent rural mean annual flood for several metropolitan areas and graphically related this ratio to the percentage of the basin served by storm sewers and the percent of the basin covered by impervious surfaces. Sauer (1974) used the Leopold curves for mean annual floods, combined with a method suggested by Anderson (1970) to estimate peaks of any magnitude up to a 100-year event for urban sites in Oklahoma. Using local rainfall intensity data to define the slope of flood-frequency curves, Sauer estimated flood magnitude based on the mean annual flood for rural conditions adjusted by the Leopold ratio. A characteristic of the Sauer method is that the urban flood-frequency curve will always be greater than the rural curve for watersheds which do not have significant in-channel or detention storage.

Espey and Winslow (1974) derived regression equations from data obtained for 60 urban watersheds located in cities along the East Coast and in Texas, Mississippi, Michigan, and Illinois. These regression equations relate flood peaks of various frequencies to drainage-area size, percent impervious area, channel slope, rainfall for 6-hour duration, and an index numerically describing the channel condition and the storm-sewer network.

Harley (1978) proposed methods to evaluate the effects of urbanization on flood peaks. He concluded that with certain modifications, a combination of procedures described by Anderson (1970) and Carter (1961) offers a simplified and accurate approach to developing a nationally applicable technique. He proposed a regression equation that included factors accounting for local runoff, imperviousness, drainage-area size, lagtime, and surface storage. Alternate procedures using modifications of the proposed equation were employed to estimate either the ratio of urban to rural discharge or the difference between them. Harley tested his proposed methods on a small number of sites in a few cities and reported encouraging results. Among his recommendations was the compilation of a large data base for use in testing and refining the proposed methods.

The literature review supported the generally held concept that urbanizing a natural drainage basin usually causes runoff volume to increase and basin response time to decrease; it also found that peak discharges generally increase for those watersheds which do not have significant in-channel or detention storage. These increases are usually most dramatic for low-order floods which occur frequently; they become less pronounced as flood magnitude increases.

In a recent report not included in the literature review, Malcolm (1980) presents the results of modeling several basins in Charlotte, North Carolina. This report shows that temporary in-channel and detention storage can be highly effective in reducing peak discharges, and that much of this storage can be the result of unintentional in-channel storage behind undersized roadway culverts and bridges. The effect of such structures is sharply reduced at points further downstream, however, and when stream crossings are improved (enlarged), peak discharges increase. Malcolm's report nonetheless shows that because of in-channel and detention storage, urban peak discharges can be less than equivalent rural peaks in spite of other urbanization effects.

In urbanizing a basin, naturally pervious surfaces are converted to impervious surfaces. Because infiltration is reduced, such areas cause increased runoff; the usually smoother surface allows more rapid drainage; and depression storage usually is reduced. In addition, the drainage system is often altered by enlarging, straightening, and smoothing its channels and by installing storm sewers and curb-and-gutter systems. These alterations usually facilitate rapid runoff with a resultant increase in flood peaks. Urbanization does not always increase floods, however. Some aspects of urbanization can decrease an area's flood potential. For instance, if the lower part of a basin is urbanized and the upper part left in its natural condition, rapid removal of floodwaters from the lower part may occur before the upper part can contribute significant runoff. Some cities reduce flooding by storing the water in designated areas (detention ponds) and releasing it slowly. As discussed above (Malcolm, 1980), culverts, bridges, storm sewers, and roadway embankments may inhibit flooding and cause temporary storage behind them, thus reducing peak-flow rates. Obviously, evaluating the effects of urbanization on flood potential involves many factors. The data accumulated for this study show that for some basins the urban flood-frequency curve is below an equivalent rural curve. Also, there are several instances in which the two flood-frequency curves cross, with low-order floods increased by urbanization and high-order floods decreased.

DATA BASE

The second phase of this study was the compilation of a comprehensive data base for drainage basins affected by urbanization. Contact with district offices of the Geological Survey revealed that at least 3 years of runoff data from almost 600 urbanized sites were available nationwide. Data collected by other agencies were also sought, but these data did not meet the following selection criteria established for the study:

1. A watershed selected must have at least 15 percent of the drainage area covered with commercial, industrial, or residential development.
2. Reliable flood-frequency data must be available for the watershed. These could be based on actual peak flow records if records were available for 10 or more years, or from synthesized data if such data were based on a rainfall-runoff model specifically calibrated from actual flood and rainfall data for that basin.
3. The period of actual flood data, or the period of calibration for synthesized data, must have been one of relatively constant urbanization. This was the most difficult criterion to meet, and in some cases only part of a long record could be used. As a general guideline, "relatively constant urbanization" was defined as a change in development of less than 50 percent during the period of record. If a basin was 30 percent urbanized at the beginning of the period of record, it could be no more than 45 percent urbanized at the end of the period.

An appraisal of all available sites resulted in a final list of 269 sites that met the selection criteria. These sites represent a broad spectrum of watershed conditions and metropolitan areas, ranging from the East Coast to the West Coast and Hawaii. A few States, such as Illinois, Texas, and Missouri, have had extensive urban data-collection programs, as reflected by the large number of sites for which records are available in those States. Many other States, however, also are well represented. Gaging sites are included for 31 States and 56 cities or metropolitan areas. Table 1 lists cities or metropolitan areas and the number of sites used in this study. Table 1 also includes a city skew value and the source of equivalent rural discharges, which will be discussed later. Figure 1 illustrates the geographical distribution of sites.

The data compiled for each urban site includes a comprehensive list of topographic and climatic variables, land-use variables, indices of urbanization, and flood-frequency estimates. The main sources of information were as follows:

1. Department of the Interior, U.S. Geological Survey, Water Resources Division, District Offices
   a. Peak-discharge data
   b. Basin characteristics
   c. Indices of urbanization
2. Department of the Interior, U.S. Geological Survey, Topographic Division
   a. Topographic maps
   b. Land-use maps
3. Department of Agriculture, Soil Conservation Service
   a. Land-use data
   b. Soils data
   c. Basin characteristics
4. Department of Commerce, Bureau of the Census
   a. Population data, 1970 census reports

A complete listing of the data base cannot be included in this report because of its size. The complete data base is stored on the Geological Survey computer in a "Statistical Analysis System" (SAS) data set (SAS Institute, Inc., 1979), to which access can be obtained from the Chief, Data Management Section, U.S. Geological Survey, Mail Stop 437, National Center, Reston, Va. 22092. A brief description of all variables, as well as a detailed description of the significant variables, is provided in the following paragraphs and the glossary. Appendix I contains a listing of selected data for all gaging stations used in this study. Data descriptions are subdivided into four groups: (1) topographic and climatic variables, (2) land-use variables, (3) indices of urbanization, and (4) flood-frequency estimates. Some parameters could justifiably fit in more than one of these groups but were assigned to only one group for convenience. Not all data items are available for all gaging sites, mostly because base maps were not universally available.

Most of the basin parameters, or variables, were compiled for the entire drainage basin and represent a

Table 1. Metropolitan areas included in nationwide urban flood-frequency study

State	Metropolitan area	Number of sites	City skew	Source of equivalent rural discharge (see references)
Alabama	Birmingham	1	0.0	Hains (1973), Olin and Bingham (1977)
Arizona	Flagstaff	2	.0	Roeske (1978)
Arizona	Tucson	4	.0	Do.
California	Orange County	1	.0	Waananen and Crippen (1977)
California	Sacramento	1	.0	Do.
California	San Francisco	8	−.4	Do.
Colorado	Boulder	2	.0	Livingston (1980)
Colorado	Denver	5	−.2	Do.
Connecticut	Hartford	2	.5	Weiss (1975)
D.C.	Washington	12	.3	Walker (1971), Miller (1978)
Delaware	Wilmington	1	.1	Simmons and Carpenter (1978)
Georgia	Atlanta	5	.2	Price (1979)
Hawaii	Hilo	1	.2	Not available
Hawaii	Honolulu	5	.2	Nakahara (1980)
Hawaii	Kaneohe	1	.2	Do.
Hawaii	Pearl City	1	.2	Do.
Illinois	Chicago	41	−.1	Allen and Bejcek (1979)
Illinois	Urbana	1	−.4	Curtis (1977)
Indiana	Indianapolis	2	−.3	Davis (1974)
Iowa	Iowa City	1	−.4	Lara (1973)
Kentucky	Louisville	4	.3	Hannum (1976)
Louisiana	Baton Rouge	1	−.2	Neely (1976)
Maryland	Baltimore	6	.4	Walker (1971)
Massachusetts	Boston	4	.2	Wandle (1981)
Michigan	Detroit	2	.0	Bent (1970)
Minnesota	Duluth	1	.0	Guetzkow (1977)
Mississippi	Canton	1	.0	Colson and Hudson (1976)
Mississippi	Hattiesburg	1	−.4	Do.
Mississippi	Jackson	4	−.4	Do.
Mississippi	Natchez	1	−.2	Do.
Missouri	St. Louis	25	.0	Spencer and Alexander (1978)
New Jersey	Newark	4	.3	Stankowski (1974)
New Jersey	Patterson-Clif-Pass	9	.3	Do.
New Jersey	Trenton	1	.1	Do.
New York	Buffalo	1	.0	Zembrzuski and Dunn (1979)
New York	New York	1	.3	Do.
New York	Rochester	1	.0	Do.
New York	Rockland County	1	.0	Do.
New York	Syracuse	1	.0	Do.
North Carolina	Charlotte	4	.0	Jackson (1976)
North Carolina	Lenoir	1	.4	Do.
Ohio	Columbus	2	−.1	Webber and Bartlett (1976)
Oklahoma	Oklahoma City	3	−.1	Thomas and Corley (1977)
Oregon	Portland-Vancouver	19	.1	Laenen (1980)
Pennsylvania	Harrisburg	1	.0	Flippo (1977)
Pennsylvania	Philadelphia	7	.1	Do.
Pennsylvania	Pittsburgh	1	.0	Do.
Pennsylvania	Indiana	1	.0	Do.
Rhode Island	Providence	1	.4	Wandle (1981)
Tennessee	Nashville	12	.3	Randolph and Gamble (1976)
Texas	Austin	3	−.2	Schroeder and Massey (1977)
Texas	Dallas	12	−.2	Dempster (1974)
Texas	Ft. Worth	1	−.2	Do.

Table 1. Metropolitan areas included in nationwide urban flood-frequency study—Continued

State	Metropolitan area	Number of sites	City skew	Source of equivalent rural discharge (see references)
Texas	Houston	21	-.3	Liscum and Massey (1980)
Texas	San Antonio	5	-.6	Schroeder and Massey (1977)
Washington	Portland-Vancouver	3	.1	Cummans and others (1975)
Washington	Seattle-Tacoma	6	.0	Do.

total, an average, a percentage, or an index for the total drainage basin. A few of the variables were computed for "thirds" of the basin in an attempt to define some variables further and to provide locations of basin development. For this study, some basins were divided into upper, middle, and lower thirds on a drainage map with the drainage divide delineated. Each third contains approximately one-third of the contributing drainage area and drains the upper, middle, or lower reaches of the basin. Because travel time or flow time was considered in drawing the lines separating the basin thirds distances along main streams and tributaries were marked to help locate the boundaries of the thirds. This drawing of the boundaries means not that all thirds of the basin have equal travel distances but that within each third the travel distances of two or more streams are about equal. Since precise definition of the lines dividing the basin into thirds was not considered necessary for the variables that utilize this concept, the lines can generally be drawn on the drainage map by eye, without precise measurements. Figure 2 shows schematics of three typical basin shapes and their division into thirds. Complex basin shapes and drainage patterns are sometimes encountered; they require more judgment in subdividing.

Topographic and Climatic Variables

The physical and climatic conditions existing in each basin are described by a selected set of topographic and climatic variables. Parameters of physical characteristics include drainage-area size, channel length, valley length, stream slope, storage, Soil Conservation Service (SCS) soil classification, SCS soil-cover-complex curve number, and SCS index of potential infiltration. Each basin is divided into thirds, as previously described, and dominant soil classifications are given for the upper third, middle third, and lower third of the basin. The percentage of the total basin covered by each soil type is included. The channel and drainage system efficiency is described by a coefficient estimated according to procedures defined by Espey and Winslow (1974). Bankfull discharge at each gaging station is included, and each basin that has significant in-channel storage is identified. In-channel storage, distinguished from basin storage, is defined as temporary storage created by detention ponds or ponding at roadway embankments. Climatic variables include mean annual precipitation, rainfall intensity of the 2-hour-duration 2-year recurrence interval, and rainfall intensity of the 2-hour-duration 100-year recurrence interval.

Land-Use Variables

Land use within each drainage basin is described with two sets of land-use variables. Each set is derived from an independent source, and although similar results were obtained for most stations, there are some stations for which the two data sources yielded quite dissimilar results. No attempt was made to resolve the differences nor to indicate which was more nearly correct. Land use was not significant in the final results of this study.

The first set of land-use data was obtained from 1:250,000 land-use maps compiled by the Geological Survey from recent high-altitude photography. Because maps are not available for all cities, these data are not available for some basins. Classifications of land use follow the standard system for remote sensing described by Anderson and others (1976) and include percentages of the basin occupied by residential areas, commercial areas, industrial areas, transportation facilities, mixed urban areas, cropland, forests, lakes and reservoirs, wetlands, rangelands, and a few other miscellaneous types of land use. Dates of the maps used are given in the data base.

The second set of land-use data was compiled from recent maps and field surveys by the Soil Conservation Service. Again, because of a lack of suitable maps for some cities, these data were not determined for some stations. Categories of land use follow the SCS classification system and include residential areas (percentages of the basin having lot sizes of ⅛, ¼, ⅓, ½, and 1 acre are provided), paved areas, streets, industrial areas, commercial areas, forests, meadows, pasture and rangelands, cultivated lands, and open spaces.

Figure 1. Location of metropolitan areas included in the nationwide urban flood-frequency study.

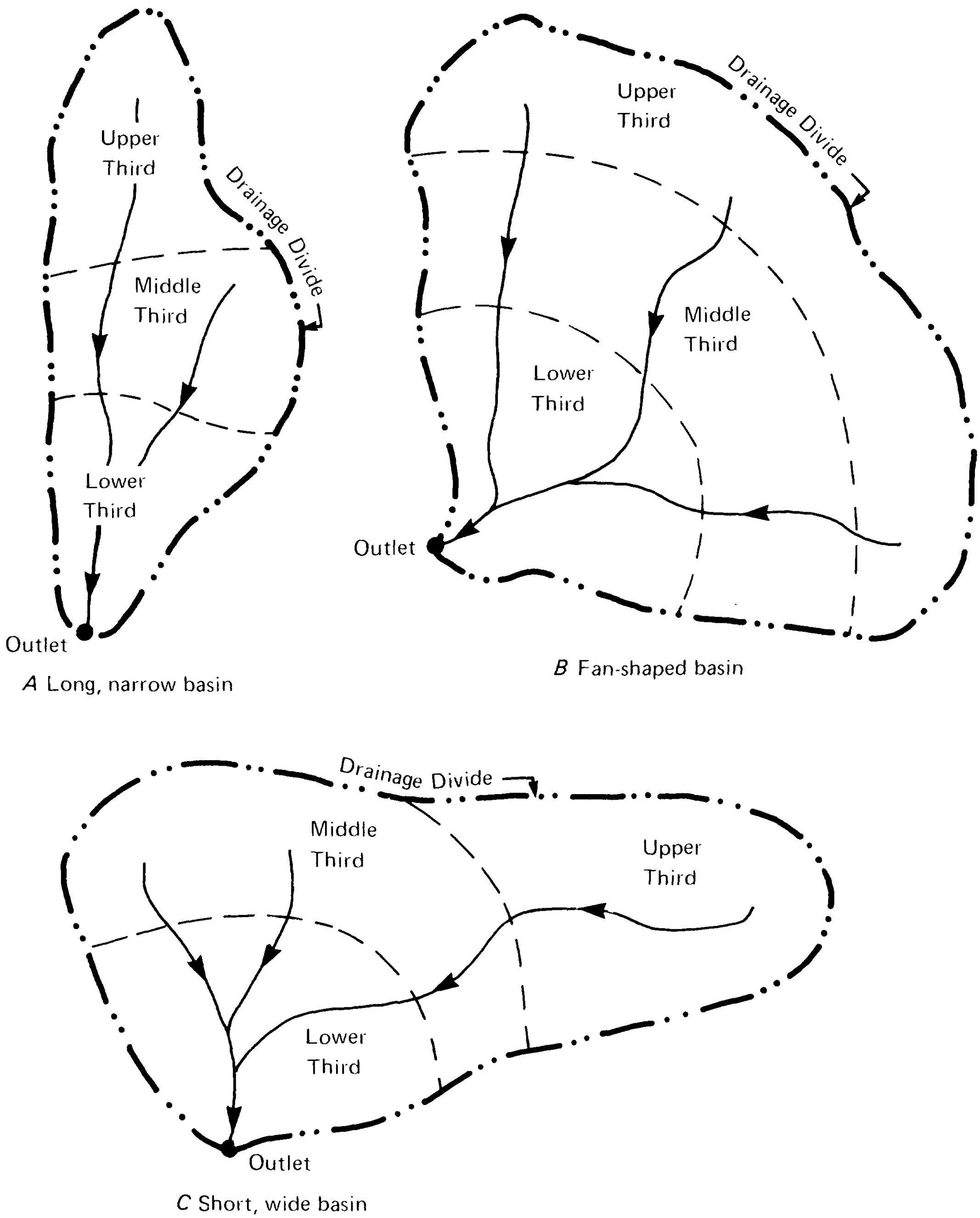

Figure 2. Schematic of typical drainage basin shapes and subdivision into basin thirds. Note that stream-channel distances within any given third of a basin in the examples are approximately equal, but between basin thirds the distances are not equal, to compensate for relative basin width of the thirds.

Indices of Urbanization

Several parameters were evaluated for each basin in an attempt to measure the degree to which a basin had been urbanized. Among these indices are percentage of the basin occupied by impervious surfaces; population and population density determined from Census Bureau data for 1970; and basin response time, or lagtime.

Impervious area, IA, is a significant variable in some of the regression equations, particularly for low recurrence intervals. It is defined as the percentage of the drainage basin occupied by impervious surfaces. The IA variable was computed from the best available maps or aerial photographs showing buildings, streets, parking lots, and other impervious surfaces. Field inspections to supplement the maps were useful. Impervious area for this study was computed by various methods, but primarily by the grid-overlay method.

The most significant index of urbanization that resulted from this study is a basin development factor (BDF), which provides a measure of the efficiency of the drainage system. This parameter, which proved to be highly significant in the regression equations, can be easily determined from drainage maps and field inspections of the drainage basin. The basin is first divided into thirds as described earlier in this report. Then, within each third, four aspects of the drainage system are evaluated and each assigned a code as follows:

1. Channel improvements.—If channel improvements such as straightening, enlarging, deepening, and clearing are prevalent for the main drainage channels and principal tributaries (those that drain directly into the main channel), then a code of 1 is assigned. Any or all of these improvements would qualify for a code of 1. To be considered prevalent, at least 50 percent of the main drainage channels and principal tributaries must be improved to some degree over natural conditions. If channel improvements are not prevalent, then a code of zero is assigned.
2. Channel linings.—If more than 50 percent of the length of the main drainage channels and principal tributaries has been lined with an impervious material, such as concrete, then a code of 1 is assigned to this aspect. If less than 50 percent of these channels is lined, then a code of zero is assigned. The presence of channel linings would obviously indicate the presence of channel improvements as well. Therefore, this is an added factor and indicates a more highly developed drainage system.
3. Storm drains, or storm sewers.—Storm drains are defined as enclosed drainage structures (usually pipes), frequently used on the secondary tributaries where the drainage is received directly from streets or parking lots. Many of these drains empty into open channels; however, in some basins they empty into channels enclosed as box or pipe culverts. When more than 50 percent of the secondary tributaries within a subarea (third) consists of storm drains, then a code of 1 is assigned to this aspect; if less than 50 percent of the secondary tributaries consists of storm drains, then a code of zero is assigned. It should be noted that if 50 percent or more of the main drainage channels and principal tributaries are enclosed, then the aspects of channel improvements and channel linings would also be assigned a code of 1.
4. Curb-and-gutter streets.—If more than 50 percent of a subarea (third) is urbanized (covered by residential, commercial, and/or industrial development), and if more than 50 percent of the streets and highways in the subarea are constructed with curbs and gutters, then a code of 1 would be assigned to this aspect. Otherwise, it would receive a code of zero. Drainage from curb-and-gutter streets frequently empties into storm drains.

The above guidelines for determining the various drainage-system codes are not intended to be precise measurements. A certain amount of subjectivity will necessarily be involved. Field checking should be performed to obtain the best estimate. The basin development factor (BDF) is the sum of the assigned codes; therefore, with three subareas (thirds) per basin, and four drainage aspects to which codes are assigned in each subarea, the maximum value for a fully developed drainage system would be 12. Conversely, if the drainage system were totally undeveloped, then a BDF of zero would result. Such a condition does not necessarily mean that the basin is unaffected by urbanization. In fact, a basin could be partially urbanized, have some impervious area, have some improvement of secondary tributaries, and still have an assigned BDF of zero. As is discussed later in this report, such a condition still frequently causes peak discharges to increase.

The BDF is a fairly easy index to estimate for an existing urban basin. The 50-percent guideline will usually not be difficult to evaluate because many urban areas tend to use the same design criteria, and therefore have similar drainage aspects, throughout. Also, the BDF is convenient for projecting future development. Obviously, full development and maximum urban effects on peaks would occur when BDF = 12. Projections of full development or intermediate stages of development can usually be obtained from city engineers.

A basin development factor was evaluated for each of the 269 sites used in this study. Approximately 30 people were involved in making these evaluations, using guidelines similar to the ones described in the preceding paragraphs but somewhat less explicit. Tests have not been made to see how consistently two or more people can estimate the BDF for a basin. However, this study indicates that fairly consistent estimates can be made by different people. A relatively large group of individuals made the estimates for this study and the parameter was statistically very significant in the regression equations. If the results obtained by various individuals had not been consistent, it is doubtful that the statistical results would be so significant.

Flood-Frequency Estimates

Two primary sets of flood-frequency estimates (see appendix 1) for selected recurrence intervals were defined, in cubic feet per second, for each station. One set represents an estimated flood-frequency relationship for the urbanized basin during a period of constant urbanization; another represents the estimated relationship for an equivalent rural basin. For each station, peak discharge was estimated for the 2-, 5-, 10-, 25-, 50-, 100-, and 500-year recurrence intervals.

For the urbanized basin the flood-frequency estimates were derived either from actual peak discharge data or from synthesized data using a calibrated rainfall-runoff model. When both types of data were available, a weighted estimate was computed. Log-Pearson Type III procedures, as recommended by the Water Resources Council (1977), were used to fit each frequency curve to the data.

Estimation of the skew coefficient of the annual peak data for urban basins was given considerable attention because there are no recommended or generally accepted procedures available for estimating skew coefficients for urban areas. The regional skew map provided by the Water Resources Council (1977) was developed from rural data and does not necessarily represent urban conditions. Therefore, this map was not used directly for estimates of skew in the urban basins. Skew is possibly related to basin characteristics, including urban factors which probably affect the magnitude of the skew coefficient. With these considerations in mind, attempts were made to relate station skew values to various basin and urban parameters. Many parameters were tried, and the only one that showed a relation to skew was a soils index, SCSS. SCSS is computed from equation 1:

$$SCSS = \frac{1000}{CN} - 10 \tag{1}$$

where CN is the soil-cover-complex curve number as described by the Soil Conservation Service (1975). This parameter is an index of potential infiltration that could be related to the skew coefficient. The relationship defined by regression was:

$$Gs = 0.15(SCSS) - 0.45 \tag{2}$$

where Gs is the skew coefficient computed from the urban peak flow data. Even though the equation is statistically significant, the standard error of regression is approximately equal to the standard deviation of the skew values, so the equation offers little practical improvement over the use of a mean skew and consequently the relationship was not used in this study. Stations with synthesized data were also studied, and it was found that the skew coefficient computed from these data related to an infiltration index defined from the calibrated model parameters. Again, the relationship was poor and was not used to estimate the skew coefficients for this study.

To provide regional skew estimates for this study it was decided that the most practical approach would be to define an average skew value for each city or metropolitan area. For cities having three or more gaging sites, skew coefficients computed from the gaged flood records were averaged and then compared for consistency to (1) the mean skews from nearby cities, (2) the regional skew given by the Water Resources Council (1977), and (3) the mean skew defined by synthesized data if available. A skew coefficient was assigned to each metropolitan area on the basis of the computed mean and the above comparisons. These assigned city skew coefficients (see table 1) were weighted with skew coefficients computed from actual flood-peak records according to the Water Resources Council (1977). For those stations having long-term (50- to 100-year) synthetic peaks based on rainfall-runoff modeling, the skew coefficients used were computed directly from the synthesized data because these data were considered more reliable than the city average skew values.

Flood-frequency data for equivalent rural conditions at each study basin were estimated from the applicable Geological Survey flood-frequency reports. The specific report used for each city is referenced in table 1 by the author's name and date of the publication. Complete bibliographic references are given in the "References" section of this report.

Appendix II provides a listing of the most recent (1981) flood-frequency reports for all 50 States. These reports can be used to estimate the equivalent rural discharge at most sites in the United States. As future reports become available they should be used in place of the reports in this list.

In addition to the two sets of flood-frequency data thus far described, the data base also includes flood-frequency estimates based on skew computed from the actual peak record, and flood-frequency estimates computed from model-synthesized data. Related information includes log-Pearson Type III mean and standard deviation, periods of record, Water Resources Council (1977) regional skew, average city skew, and weighted station skews.

ESTIMATING PROCEDURES FOR UNGAGED URBAN SITES

The third phase of this project was to relate urban flood magnitude and frequency to watershed characteristics so that flood magnitude and frequency could be estimated for ungaged watersheds. Many attempts to derive a practical, easy-to-use method were made, most of which involved linear multiple regression of several dependent and many independent variables. This section of the report describes the more significant results. The three sets of estimating equations will be referred to as the seven-parameter equations, the three-parameter equations, and the seven-parameter alternate equations. A description of some of the models and variables that were partially successful, and even unsuccessful, is included to document the analytical efforts more fully. These models included the ratio method, the difference method, the log-Pearson Type III parameter method (method of moments), and a method described by Harley (1978).

The suitability and accuracy of each method were assessed for the purpose of recommending a practical and accurate method. Suitability was evaluated on the basis of the relative ease of application and the logic of independent variables. Accuracy was judged primarily on the basis of computed standard error of estimates. Bias, linearity, and sensitivity were tested in various ways, as described in subsequent paragraphs.

Selection of Data

Previous parts of this report described the data base compiled for this study, which comprises 269 urban sites. For purposes of analysis, sites were selected from the data base according to certain assumptions and the availability of specific variables. When a variable selected for a specific analysis was unavailable for a site, that site was omitted from the analysis. No attempts were made to estimate missing variables. Because of missing data, fewer than 269 sites were used for most analyses.

It was assumed that measures, or indexes, of temporary in-channel storage, or temporary detention storage, could not easily be quantified for inclusion in a statistical model of the type planned for this study. Storage of this type will be referred to in this report as detention storage, and is defined as that occurring in planned or unplanned detention areas, intentionally behind such structures as detention dams and unintentionally behind highway or railroad embankments. The peak outflow rate from these detention areas is usually less than the peak inflow rate because of the effects of storage. The distinction between detention storage and other storage, ST, in the basin is that ST is storage in the permanent lakes, reservoirs, swamps, and wetlands depicted on topographic maps.

Even though detention storage could not be easily quantified, sites were identified where such storage was believed or known to occur, and where this storage significantly reduced all or some peak discharges. A significant reduction was assumed to be about 15 percent or more. Subjective determinations were made by examining available high-water profile data, maps, bridge and highway plans, and surveys, and by making field inspections. Of the 269 sites, 204 sites were identified as not having significant detention storage, 55 as having detention storage, and the remaining 10 as unknown. All analyses were based on sites without detention storage to provide estimating procedures that would yield results unaffected by detention storage. More discussion regarding detention storage is given in a subsequent section of the report.

Seven-Parameter Estimating Equations

Peak discharges for the 2-, 5-, 10-, 25-, 50-, 100-, and 500-year urban floods were related to seven independent variables by linear multiple-regression techniques. The significant variables account for the effect of basin size, A; channel slope, SL; basin rainfall, RI2; basin storage, ST; manmade changes to the drainage system, BDF; and impervious surfaces, IA. Regional runoff variations are accounted for in the equations through the use of the equivalent rural peak discharge, RQ. A detailed description of these variables is given in the Glossary and Data Base sections of this report. The equations, which follow, can be used to estimate the magnitude of urban peak discharges at ungaged sites within the accuracy and limitations discussed in subsequent parts of this report.

$$UQ2 = 2.35A^{.41}SL^{.17}(RI2+3)^{2.04}(ST+8)^{-.65}(13-BDF)^{-.32}IA^{.15}RQ2^{.47} \quad (3)$$

$$UQ5 = 2.70A^{.35}SL^{.16}(RI2+3)^{1.86}(ST+8)^{-.59}(13-BDF)^{-.31}IA^{.11}RQ5^{.54} \quad (4)$$

$$UQ10 = 2.99A^{.32}SL^{.15}(RI2+3)^{1.75}(ST+8)^{-.57}(13-BDF)^{-.30}IA^{.09}RQ10^{.58} \quad (5)$$

$$UQ25 = 2.78A^{.31}SL^{.15}(RI2+3)^{1.76}(ST+8)^{-.55}(13-BDF)^{-.29}IA^{.07}RQ25^{.60} \quad (6)$$

$$UQ50 = 2.67A^{.29}SL^{.15}(RI2+3)^{1.74}(ST+8)^{-.53}(13-BDF)^{-.28}IA^{.06}RQ50^{.62} \quad (7)$$

$$UQ100 = 2.50A^{.29}SL^{.15}(RI2+3)^{1.76}(ST+8)^{-.52}(13-BDF)^{-.28}IA^{.06}RQ100^{.63} \quad (8)$$

$$UQ500 = 2.27A^{.29}SL^{.16}(RI2+3)^{1.86}(ST+8)^{-.54}(13-BDF)^{-.27}IA^{.05}RQ500^{.63} \quad (9)$$

The accuracy of the above equations can be expressed by two standard statistical measures, the coefficient of determination, R^2, and the standard error of regression. The coefficient of determination, R^2, indicates the proportion of the total variation of the dependent variable that is explained by the independent variables. For instance, an R^2 of 0.93 would indicate that 93 percent of the variation is accounted for by the independent variables. The standard error of regression is, by definition, one standard deviation on each side of the regression equation and contains about two-thirds of the data within this range. Conversely, about one-third of the data will fall outside of the standard error of regression. For example, a standard error of regression of 0.1630 log units would indicate that about two-thirds of the dependent variables used for a given regression analysis were within 0.1630 log units of the regression estimate. Converted to a percentage, this would indicate that about two-thirds of the dependent variables are within 45 percent and -31 percent, or an average of ± 38 percent, of the regression estimate. The following table shows the coefficients of determination, R^2, and the standard errors of regression for equations 3-9.

Statistic	Flood characteristic						
	UQ2	UQ5	UQ10	UQ25	UQ50	UQ100	UQ500
Coefficient of determination, R^2	.93	.93	.93	.93	.92	.92	.90
Standard error of regression:							
Log units	.1630	.1584	.1618	.1705	.1774	.1860	.2071
Average percent	±38	±37	±38	±40	±42	±44	±49

Because of their suitability and accuracy, these equations provide a good method of estimating the effects of urbanization on magnitude and frequency of peak discharge. From the 269 sites available for analysis, 55 were omitted because of known detention storage, 10 were omitted because detention storage effects were uncertain, and 5 were omitted because of missing data. Therefore, the equations are derived from 199 sites. Figures 3, 4, and 5 compare the 2-year, 10-year, and 100-year observed peak discharges to the respective peaks estimated from equations 3, 5, and 8.

All independent variables in equations 3-9 are statistically significant at the 1-percent level with the following exceptions. The percent of impervious area, IA, was statistically significant at the 1-percent level in equation 3 and at the 2-percent level in equation 4, but was not significant at the 5-percent level for equations 5-9. The change in significance of the variable IA suggests that impervious area in a basin will effectively increase runoff (primarily volumes) for low-order floods, but will rapidly become less effective during large floods when soils become saturated and approach a runoff condition similar to that produced by impervious surfaces. Even though IA is not highly significant for equations 5-9, it was retained to provide continuity with equations 3 and 4. Storage, ST, and slope, SL, for equations 8 and 9 were significant at the 2-percent level.

The most significant variable in each of the equations is the equivalent rural discharge, RQ, because it is closely related to the urban peak discharge. Rural discharge is the key for explaining geographical variations in runoff in different parts of the country. Consequently, the equations are suitable for use in urban areas throughout the United States, with no expected geographical bias. The tests made to substantiate this conclusion are

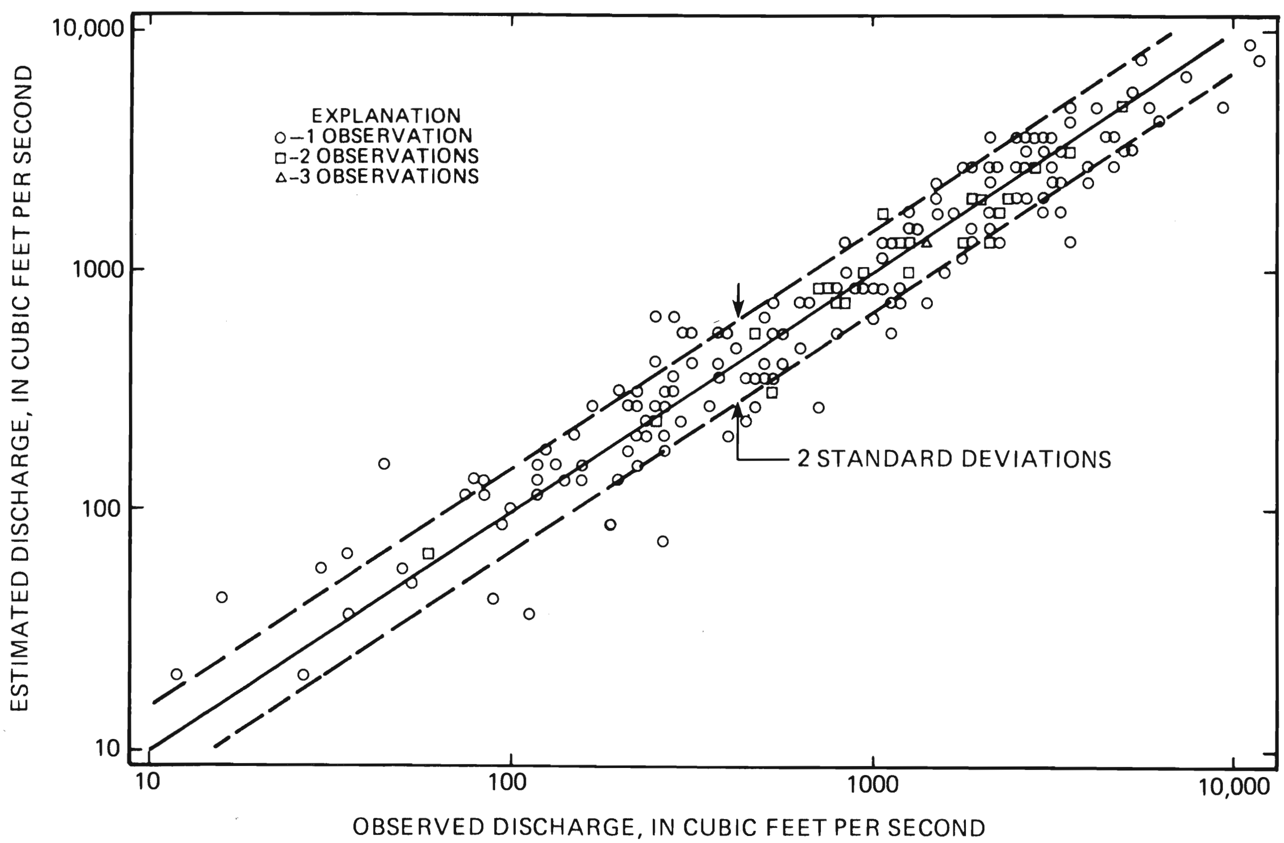

Figure 3. Comparison of observed 2-year urban peak discharge to peak discharge estimated from equation 3.

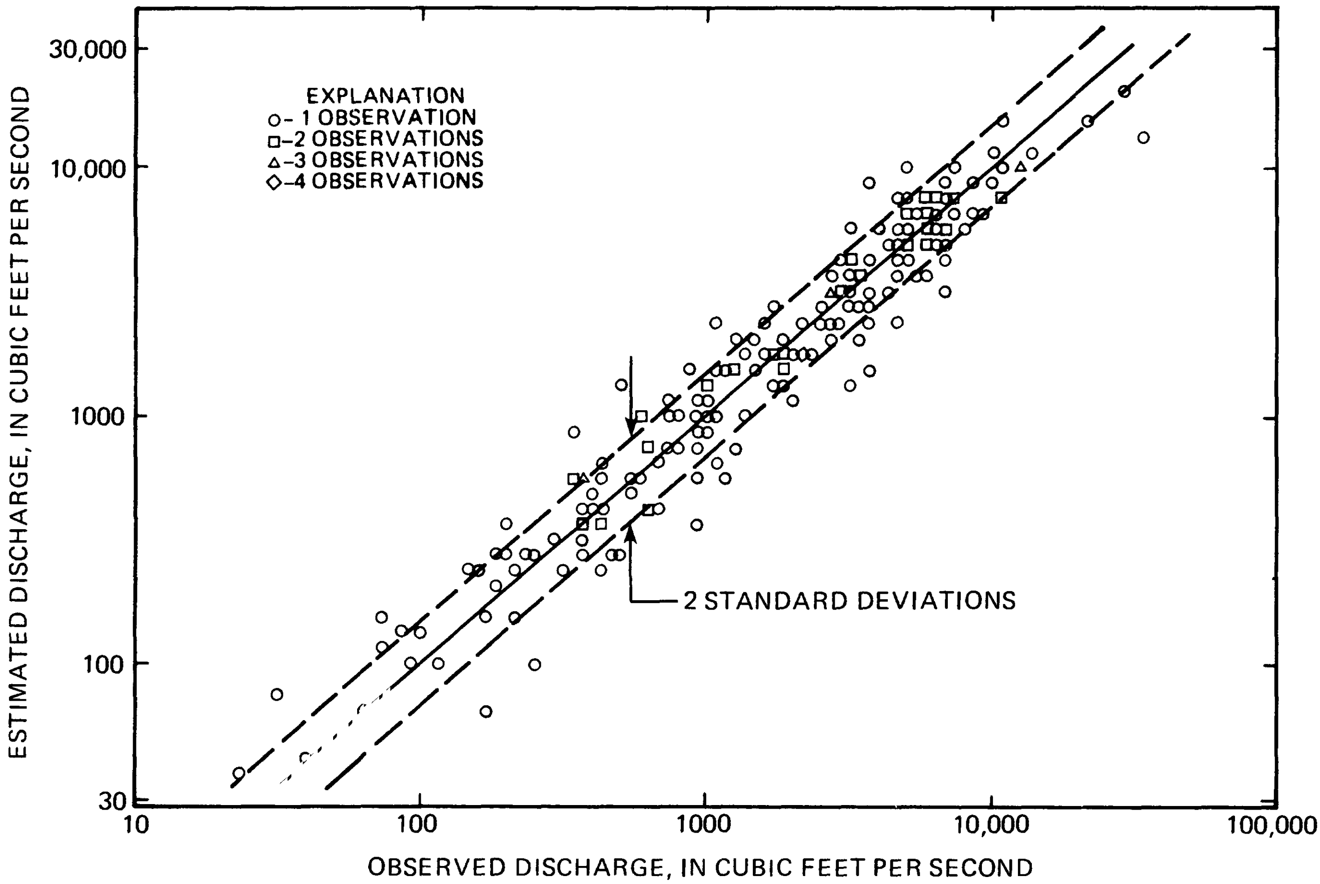

Figure 4. Comparison of observed 10-year urban peak discharge to peak discharge estimated from equation 5.

described in the section "Verification and testing of regression equations."

The second most significant variable is the basin development factor, BDF. This variable is somewhat subjective, but seems very effective in explaining variations in urban peak discharges. BDF is derived from a matrix of codes which not only define the degree of drainage development for the entire basin on a scale of 0 to 12, but also provide a location of development. The present study did not yield any usable results which would show the effects of location of development, because possibly these effects may be small compared to other uncertainties and lack of precision in the data. BDF is used on a reverse scale (13 – BDF) in the equations because it was found that by doing so the linearity of the equation was greatly improved and the standard error was reduced.

Contributing drainage area, A, was highly significant and was the third most significant variable in all equations. The high degree of significance of A implies that a given amount of urbanization will affect small basins differently from large basins. The other variables—slope (SL), rainfall intensity (RI2), storage (ST), and impervious area (IA)—were all much less significant than RQ, BDF, and A, but in total offered enough improvement to warrant inclusion in the equations. The constants added to RI2 and ST are logarithmic scale adjustments which were determined by trial and error procedures. These constants improve linearity of the regression equations and minimize the standard error of estimate. In the case of storage, ST, the addition of the 8-percent constant may suggest that the storage variable is inadequate for expressing the total storage effect in a basin. The method of measuring ST does not account for such factors as depression storage or small ponds. The average value of these unmeasured quantities may be indirectly expressed in the 8-percent constant. In addition, the 8-percent constant has the advantage of reducing sensitivity in the lower range of storage, where a small change in storage may produce unrealistic changes in discharge. The same applies to other variables where constants are added. Slope, SL, is limited to an upper value of 70 feet per mile (ft/mi). For channels having a slope greater than 70 ft/mi, the value of 70 ft/mi was used. This limitation was found to be effective in reducing the standard error of regression, and is logical in that very steep slopes may not cause significant increases in peak discharge.

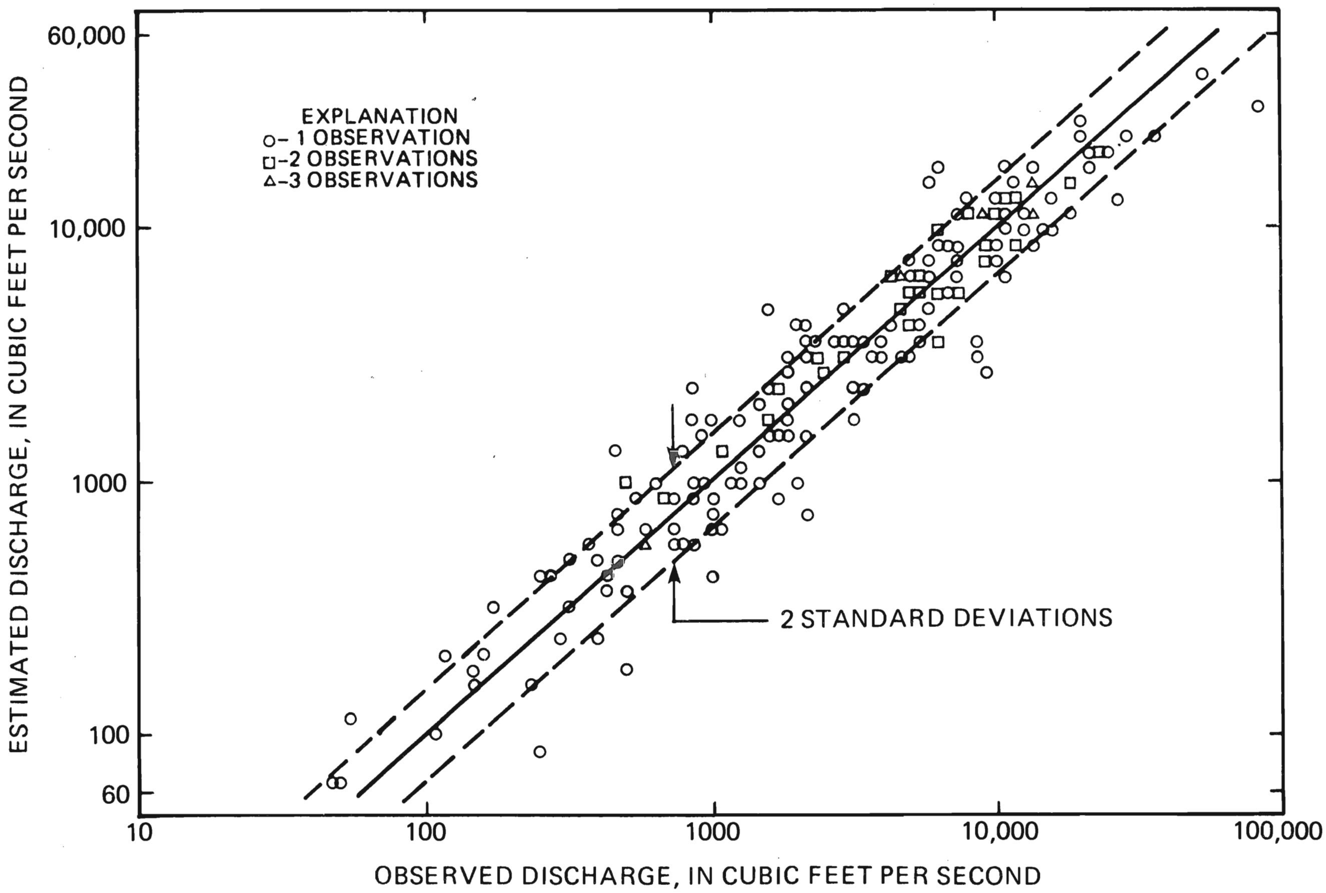

Figure 5. Comparison of observed 100-year urban peak discharge to peak discharge estimated from equation 8.

Three-Parameter Estimating Equations

Equations 3-9 contain seven independent variables which offered a good method of estimating magnitude and frequency of floods on ungaged urban basins. Droping the less significant variables from these equations increases the standard error of regression, but also greatly reduces the amount of data and effort required for application. The following three-parameter equations, which include only the independent variables RQ, BDF, and A, can be used to estimate urban peak discharges for ungaged sites.

$$UQ2 = 13.2A^{.21}(13 - BDF)^{-.43}RQ2^{.73} \quad (10)$$

$$UQ5 = 10.6A^{.17}(13 - BDF)^{-.39}RQ5^{.78} \quad (11)$$

$$UQ10 = 9.51A^{.16}(13 - BDF)^{-.36}RQ10^{.79} \quad (12)$$

$$UQ25 = 8.68A^{.15}(13 - BDF)^{-.34}RQ25^{.80} \quad (13)$$

$$UQ50 = 8.04A^{.15}(13 - BDF)^{-.32}RQ50^{.81} \quad (14)$$

$$UQ100 = 7.70A^{.15}(13 - BDF)^{-.32}RQ100^{.82} \quad (15)$$

$$UQ500 = 7.47A^{.16}(13 - BDF)^{-.30}RQ500^{.82} \quad (16)$$

Coefficient of determination, R^2, and standard errors of regression follow.

Statistic	Flood characteristic						
	UQ2	UQ5	UQ10	UQ25	UQ50	UQ100	UQ500
Coefficient of determination, R^2	.91	.92	.92	.92	.91	.91	.89
Standard error of regression:							
Log units	.1797	.1705	.1720	.1802	.1865	.1949	.2170
Average percent	±43	±40	±41	±43	±44	±46	±52

The three-parameter equations, 10–16, were based on the same 199 sites used to develop equations 3–9. Although the standard error of regression is more than for equations 3-9, equations 10–16 are easier to apply, and it will be shown in a subsequent section of this report that the standard errors of prediction for the two sets of equations are comparable. Figures 6, 7, and 8 graphically compare the observed 2-year, 10-year, and 100-year peak discharges, respectively, to the peak discharges estimated from equations 10, 12, and 15.

Seven-Parameter Alternate Estimating Equations

A third set of estimating equations, the seven-parameter alternate equations, was developed by including lagtime (LT) as an independent variable. This variable is available for 170 sites where in-channel or detention storage is insignificant. Six sites had missing data; therefore, the equations are based on 164 sites, fewer than the number used for equations 3-16.

$$UQ5 = 0.80A^{.43}SL^{.12}(RI2+3)^{1.79}(LT+2)^{-.22}(13-BDF)^{-.24}IA^{.18}RQ2^{.52} \quad (17)$$

$$UQ5 = 1.12A^{.42}SL^{.12}(RI2+3)^{1.75}(LT+2)^{-.27}(13-BDF)^{-.22}IA^{.14}RQ5^{.53} \quad (18)$$

$$UQ10 = 1.42A^{.41}SL^{.12}(RI2+3)^{1.66}(LT+2)^{-.30}(13-BDF)^{-.21}IA^{.11}RQ10^{.55} \quad (19)$$

$$UQ25 = 1.59A^{.40}SL^{.13}(RI2+3)^{1.62}(LT+2)^{-.32}(13-BDF)^{-.20}IA^{.09}RQ25^{.56} \quad (20)$$

$$UQ50 = 1.89A^{.39}SL^{.12}(RI2+3)^{1.51}(LT+2)^{-.32}(13-BDF)^{-.20}IA^{.08}RQ50^{.59} \quad (21)$$

$$UQ100 = 2.13A^{.39}SL^{.11}(RI2+3)^{1.45}(LT+2)^{-.34}(13-BDF)^{-.20}IA^{.07}RQ100^{.60} \quad (22)$$

$$UQ500 = 2.58A^{.39}SL^{.12}(RI2+3)^{1.37}(LT+2)^{-.36}(13-BDF)^{-.20}IA^{.05}RQ500^{.61} \quad (23)$$

Coefficient of determination, R^2, and standard errors of regression follow.

Statistic	Flood characteristic						
	UQ2	UQ5	UQ10	UQ25	UQ50	UQ100	UQ500
Coefficient of determination, R^2	.95	.95	.95	.94	.94	.94	.92
Standard error of regression:							
Log units	.1452	.1385	.1417	.1503	.1565	.1642	.1854
Average percent	±34	±32	±33	±35	±37	±39	±44

The standard errors of regression for equations 17-23 are lower than for the seven-parameter equations 3-9. The lower standard error of regression is attributed

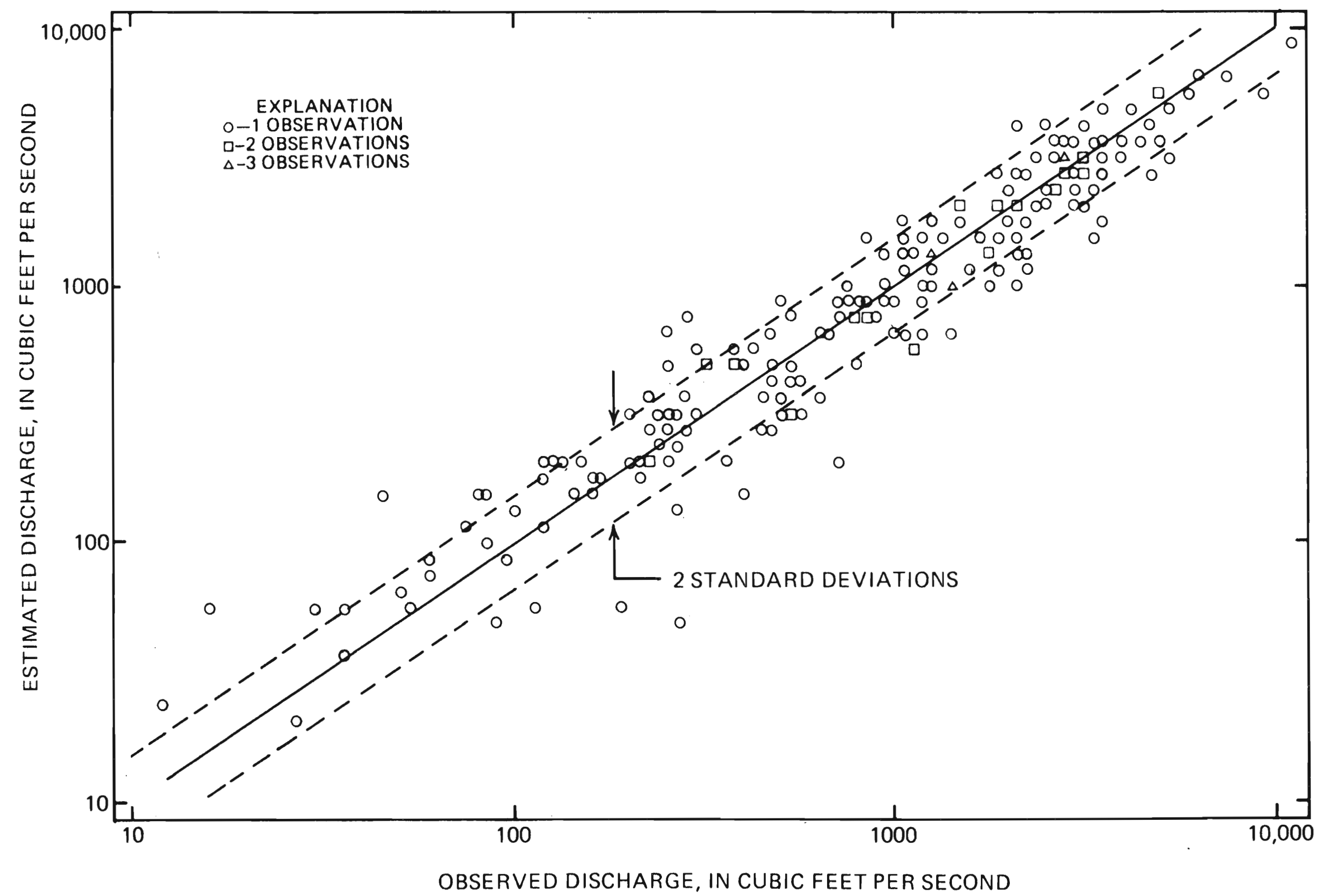

Figure 6. Comparison of observed 2-year urban peak discharge to peak discharge estimated from equation 10.

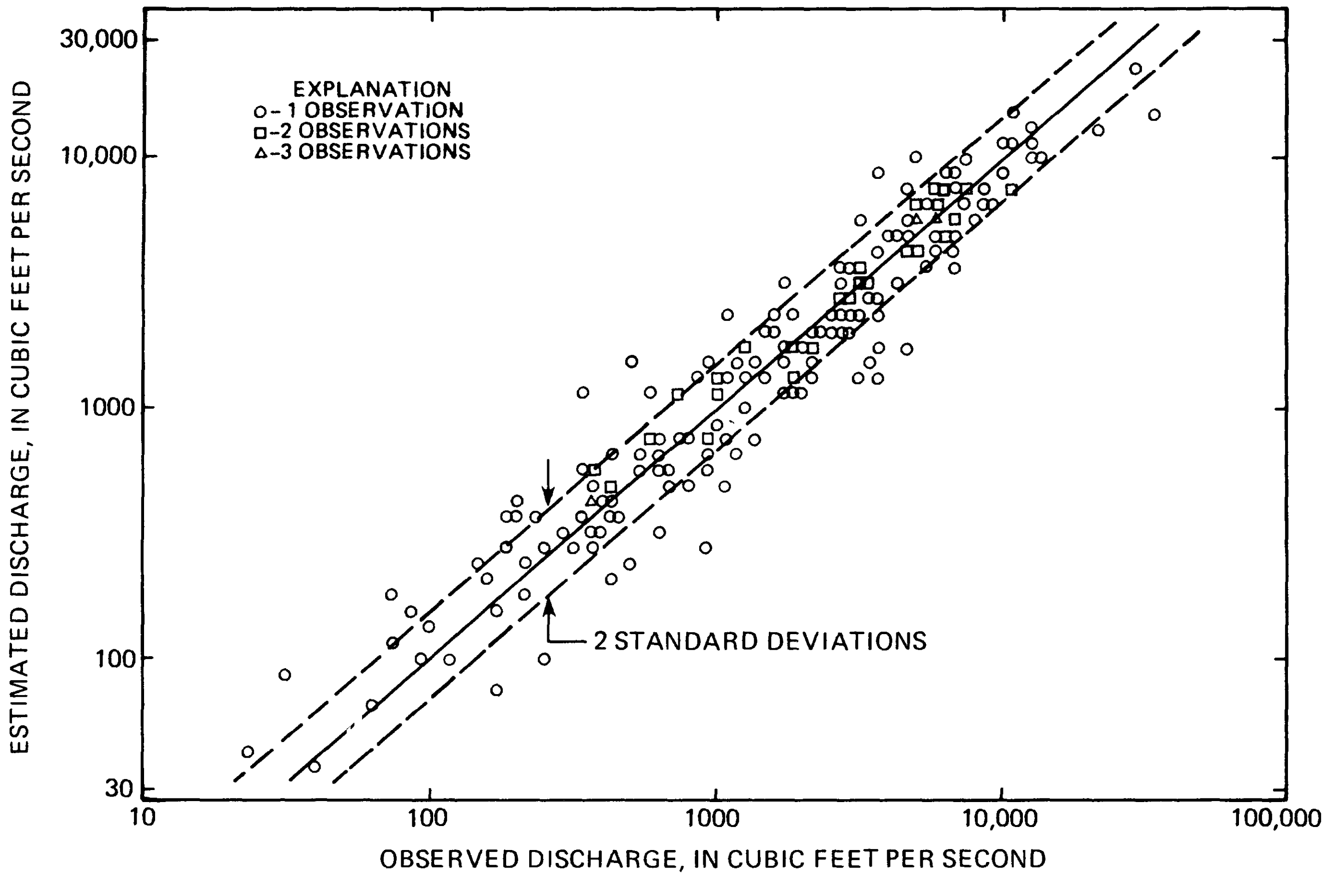

Figure 7. Comparison of observed 10-year urban peak discharge to peak discharge estimated from equation 12.

partly to the deletion of shorter record crest-stage stations from the data set. By using the same 164 sites to recalibrate the seven-parameter equations 3-9, it was found that the standard error of regression was almost identical to that for equations 17-23. Based on this comparison it can be assumed that the seven-parameter alternate equations 17-23 and the seven-parameter equations 3-9 are about equal in accuracy of prediction. Figures 9, 10, and 11 graphically compare the observed 2-year, 10-year, and 100-year peak discharges, respectively, to the peak discharges estimated from equations 17, 19, and 22.

Equations 17-23 are more difficult to apply than equations 3-9. Most of the variables are the same in both sets of equations and the basic discussion described in the section for the seven-parameter equations applies. The variable LT, however, is not easily determined and requires access to both rainfall and runoff hydrograph data applicable to the basin. A reliable determination of LT should be based on at least 4 to 6 storms of varying magnitude. The calculations are tedious if done manually. It is recommended that actual rainfall and runoff data be used to estimate LT; if these data are not available, equations 17-23 should not be used. The section of this report on "Estimating Basin Lagtime" discusses the relationship of lagtime to basin characteristics. These relationships could be used to derive an estimate of LT for use in equations 17-23, but such an estimate is not recommended because the error introduced by estimated LT negates any advantage gained from using equations 17-23.

The introduction of lagtime in the regression analysis resulted in storage, ST, becoming statistically insignificant. Slope, SL, was significant at the 5-percent level for the low-order floods (2-year through 10-year) and became insignificant at higher levels, but was retained in the equations for continuity. All other variables were significant at the 1-percent level, with the three most important variables being RQ, BDF, and A, in that order.

Correlation of Significant Variables

Regression analysis assumes that variables in the regression equation which explain the variation of another variable are independent of one another, hence the term "independent" variable. The variable being explained is termed the "dependent" variable. When

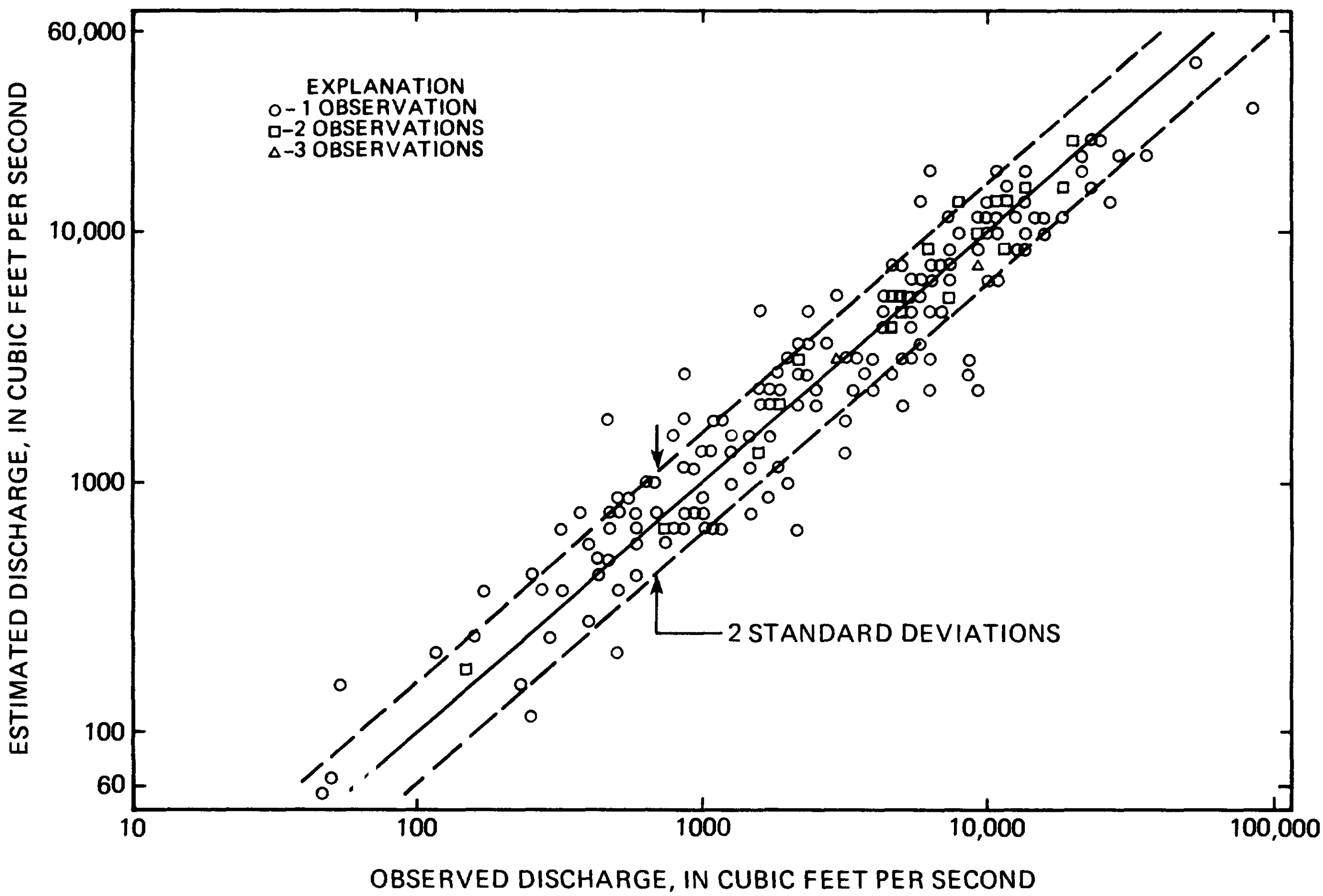

Figure 8. Comparison of observed 100-year urban peak discharge to peak discharge estimated from equation 15.

independent variables are not fully independent, that is, when they are intercorrelated, tests for significance in the regression analysis may not be accurate, and in some instances the resulting equations may not be valid. For instance, if two independent variables are high correlated, the regression analysis will divide their effect on the dependent variable, thus reducing the significance of each. The danger of this effect is that one or both of the variables may seem, erroneously, to be statistically insignificant. Table 2 is a correlation matrix of significant variables used in this study. In this table, a correlation coefficient of zero would indicate complete independence of two variables, whereas a coefficient of 1.00 represents total dependence. Negative values indicate inverse correlations. Some of the independent variables in table 2 show relatively high intercorrelations (0.5 to 0.7). Separate analyses were made to remove the intercorrelation of such selected variables as A′ and RQ. The resulting regression equations were unchanged, and the tests for significance showed either the same or slightly higher significance. It was concluded, therefore, that the regression equations are valid, and that all independent variables are significant for explaining the variation of the dependent variables.

Limitations of Significant Variables

For use in estimating equations described in this report, the effective usable range of basin and climatic variables is as follows. If values outside these ranges are used, the standard error may be considerably higher than for sites where all variables are within the specified range.

Variable	Minimum	Maximum	Units
A ----------	0.2	100	square miles
SL ----------	3.0	[1]70	feet per mile
RI2----------	0.2	2.8	inches
ST ----------	0	11	percent
BDF----------	0	12	
IA-----------	3	50	percent
LT ----------	0.2	45	hours

[1]Maximum value of slope for use in equations is 70 ft/mi, although numerous watersheds used in this study had SL values up to 500 ft/mi.

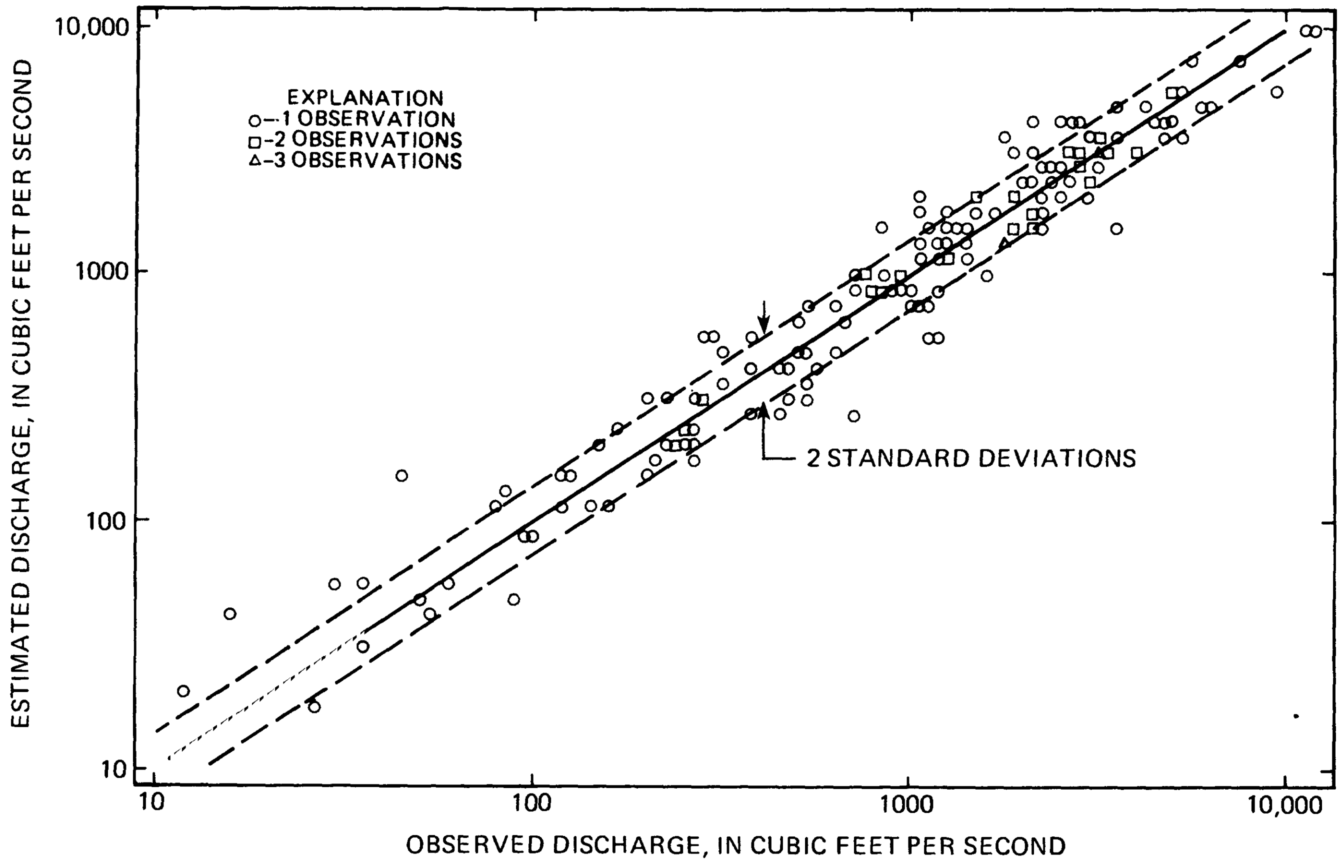

Figure 9. Comparison of observed 2-year urban peak discharge to peak discharge estimated from equation 17.

Table 2. Correlation matrix for significant variables

[All variables are in log units]

	A	SL	RI2+3	ST+8	LT	IA	13-BDF	L	RQ5	RQ100	UQ5	UQ100
A	1.00	−.62	.38	.23	.76	−.40	.23	.96	.71	.67	.74	.69
SL		1.00	−.42	−.34	−.53	.36	−.11	−.58	−.30	−.22	−.34	−.27
RI2+3			1.00	.00	.12	−.16	.08	−.35	.65	.62	.63	.61
ST+8				1.00	.52	−.16	.18	.25	−.15	−.17	−.15	−.17
LT					1.00	−.50	.42	.75	.30	.27	.31	.28
IA						1.00	−.49	−.37	−.11	−.06	−.06	−.04
13−BDF							1.00	.23	.14	.11	−.02	−.02
L								1.00	.66	.63	.68	.64
RQ5									1.00	.98	.94	.93
RQ100										1.00	.93	.94
UQ5											1.00	.98
UQ100												1.00

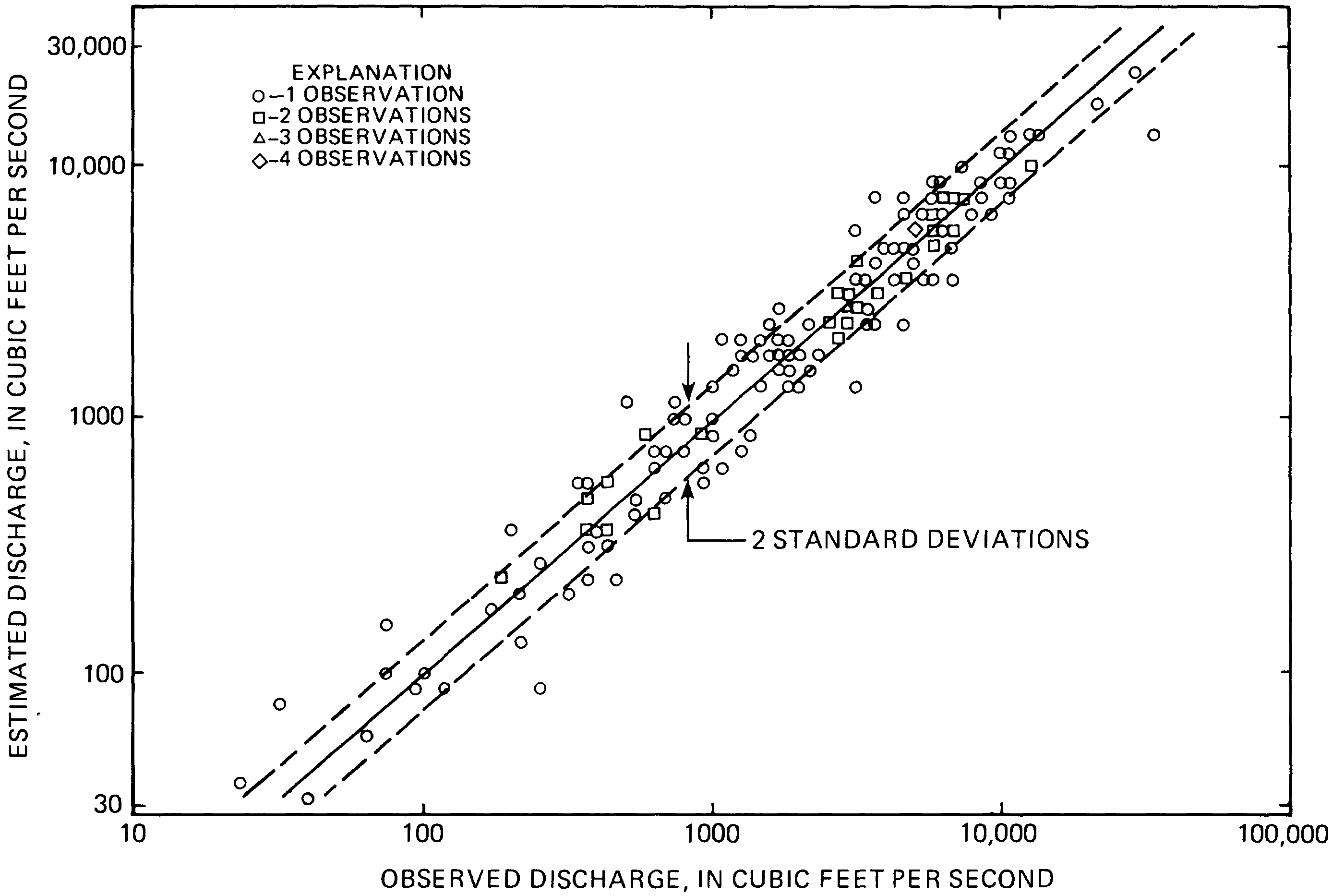

Figure 10. Comparison of observed 10-year urban peak discharge to peak discharge estimated from equation 19.

Other Independent Variables

The regression analyses and other techniques which will be described later in this report, utilize various basin and climatic variables which proved logical and statistically significant. During this study, many other independent variables were tried and found to offer little or nothing toward improvement of the estimating equations. In some cases the variables were highly correlated to each other and a choice of one was made, usually of the one more easily determined or readily available. The following discussion is intended to describe briefly some of the independent variables which were tried but found to be statistically insignificant; however, these variables are potentially significant and should be considered in future studies.

Two independent sets of land-use data were available for many sites, one set from maps compiled from USGS high-altitude photography and the other from SCS maps and field surveys. No consistently significant parameters were derived from either of these sets of data. Those investigated included percentage of the basin occupied by various land uses such as residential, commercial, industrial, water bodies, and total urbanized. Impervious area was estimated from land-use data by using various distributions of imperviousness, but these did not prove as useful as the variable IA.

Soil data were available for most sites, and in a few instances some of the variables, such as percentage of soil type A and soil type D, and the potential infiltration, SCSS, were significant. For the most part, however, the use of hydrologic soil classifications, soil-cover-complex-curve numbers, and potential infiltration indexes did not significantly reduce standard errors.

Population data were used to compute population density of the whole or parts of each basin. These were not highly significant. Harley (1978) and Stankowski (1974) proposed equations for estimating impervious area from population data. These were tried and not found highly significant. In addition, population data are difficult to determine and therefore less practical than others that accomplish the same results.

It is probable that some of the land use, soils, and topographic variables are significant and do explain some of the hydrologic variations. Methods of estimating these parameters are sometimes crude, or are based on

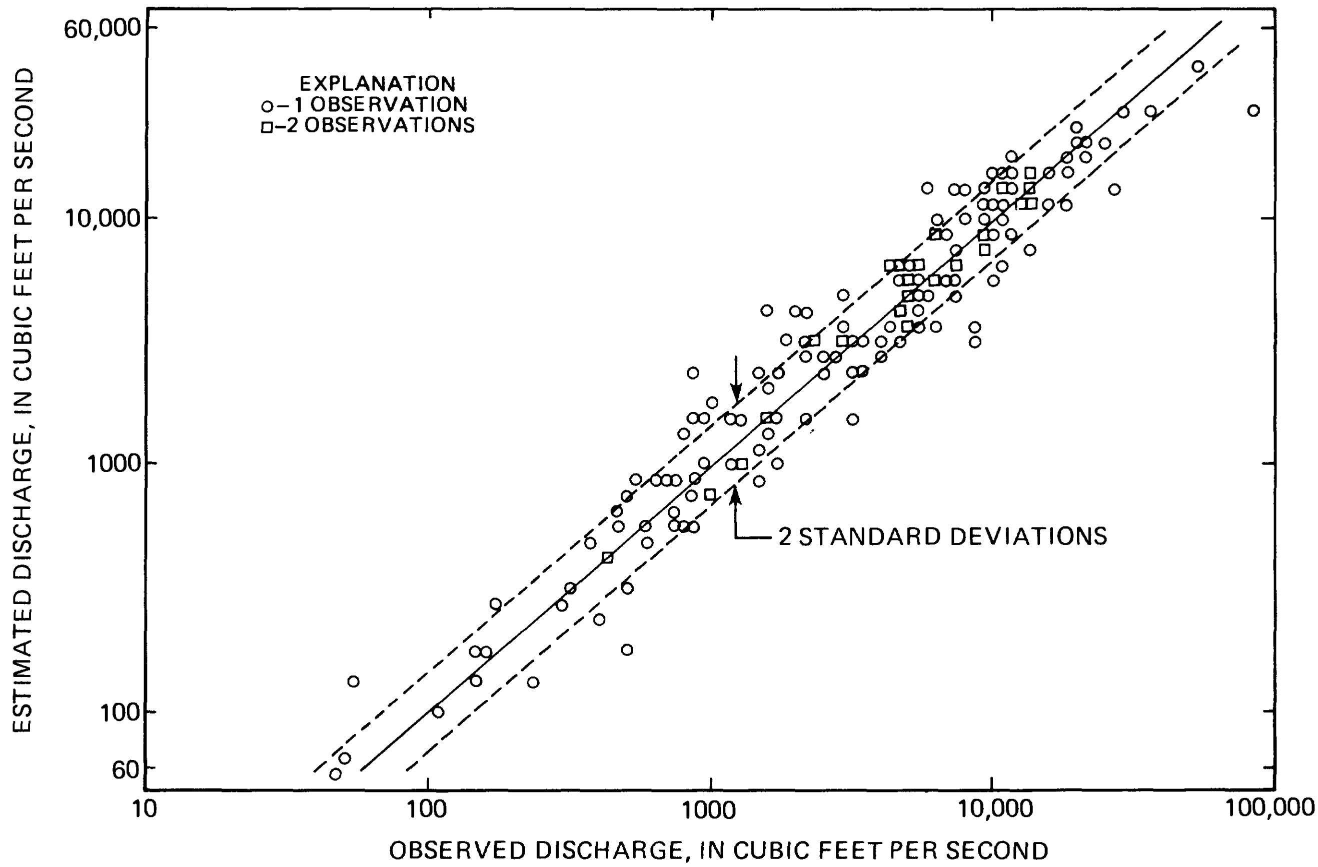

Figure 11. Comparison of observed 100-year urban peak discharge to peak discharge estimated from equation 22.

poor maps or other data. Parameter estimation most likely will improve as new sources of information, such as digitized satellite imagery and digitized maps, become available. Future studies should explore the use of such information.

Other Methods and Models

This part of the report is included to show the applicability or inapplicability of four other methods, or models, used by other investigators. Although these methods do not work as well on a nationwide basis as the equations previously described, one should not infer from this discussion that the methods are not valid. If the methods are calibrated on a local basis, they may provide very reliable results. However, on a nationwide basis, the previously described equations are preferable.

Ratio Method

The concept of the ratio method is that basin and urban parameters are correlated with the ratio of the urban peak discharge to the equivalent rural peak discharge. The equivalent rural peak discharge is defined in a previous section of this report. The ratio method has been used or proposed by several investigators (see section "Literature review") and has proved quite useful for estimating the effects of urbanization on peak discharges. Numerous attempts to relate the urban/rural ratio to various parameters on a nationwide basis were tried and at best were only partially successful. Direct regression methods resulted in a relation in which only BDF and IA were statistically significant, and IA had an inappropriate negative regression coefficient. Furthermore, the standard error for this relation was greater than that for the seven-parameter and three-parameter equations. However, an indirect approach was used to develop a relationship similar to the graphic curves described by Leopold (1968). The analysis uses the seven-parameter equations, 3-9, as the basic underlying relation. In these equations, if BDF is set to zero, and IA to 1 percent, rural conditions are approximated and the computed value of UQ is an estimate of RQ. This estimate will be designated as RQ2e, RQ10e, and so forth. For example, performing this operation on equations 3, 5, and 8 results in the following equations for values of RQ2e, RQ10e, and RQ100e:

$$RQ2e = 1.034A^{.41}SL^{.17}(RI2+3)^{2.04}(ST+8)^{-.65}RQ2^{.47} \quad (24)$$

$$RQ10e = 1.384A^{.32}SL^{.15}(RI2+3)^{1.75}(ST+8)^{-.57}RQ10^{.58} \quad (25)$$

$$RQ100e = 1.220A^{.29}SL^{.15}(RI2+3)^{1.76}(ST+8)^{-.52}RQ100^{.63} \quad (26)$$

This assumption was tested by applying equations 24, 25, and 26 to all 199 sites used in the regression analysis. Individual sites show variations between the estimated rural peaks computed from equations 24, 25, and 26 and the equivalent rural peaks, but the variations are not large, and on the average the assumption appears valid. Figures 12, 13, and 14 graphically compare the estimated rural peaks to the equivalent rural peaks for the 2-year, 10-year, and 100-year recurrence intervals. This assumption should not be used, however, to justify using equations 24–26 to estimate rural peak discharges. The equations require an independent estimate of RQ which is preferable to the one computed from equations 24–26. The assumption was made only for the purpose of developing a UQ/RQ ratio. The ratio for the 2-year recurrence interval is computed by dividing equation 3 by equation 24 as follows:

$$\frac{UQ2}{RQ2e} = \frac{2.53A^{.41}SL^{.17}(RI2+3)^{2.04}(ST+8)^{-.65}(13-BDF)^{-.32}IA^{.15}RQ2^{.47}}{1.034A^{.41}SL^{.17}(RI2+3)^{2.04}(ST+8)^{-.65}RQ2^{.47}}$$

This equation simplifies to:

$$\frac{UQ2}{RQ2e} = 2.27(13-BDF)^{-.32}(IA)^{.15} \quad (27)$$

Similar derivations can be made for the other recurrence intervals. For this report only the 2-year, 10-year, and 100-year equations are discussed. The 10-year and 100-year equations are as follows:

$$\frac{UQ10}{RQ10e} = 2.16(13-BDF)^{-.30}(IA)^{.09} \quad (28)$$

$$\frac{UQ100}{RQ100e} = 2.05(13-BDF)^{-.28}(IA)^{.06} \quad (29)$$

The ratios computed from equations 27–29 were compared to actual ratios derived from the base data,

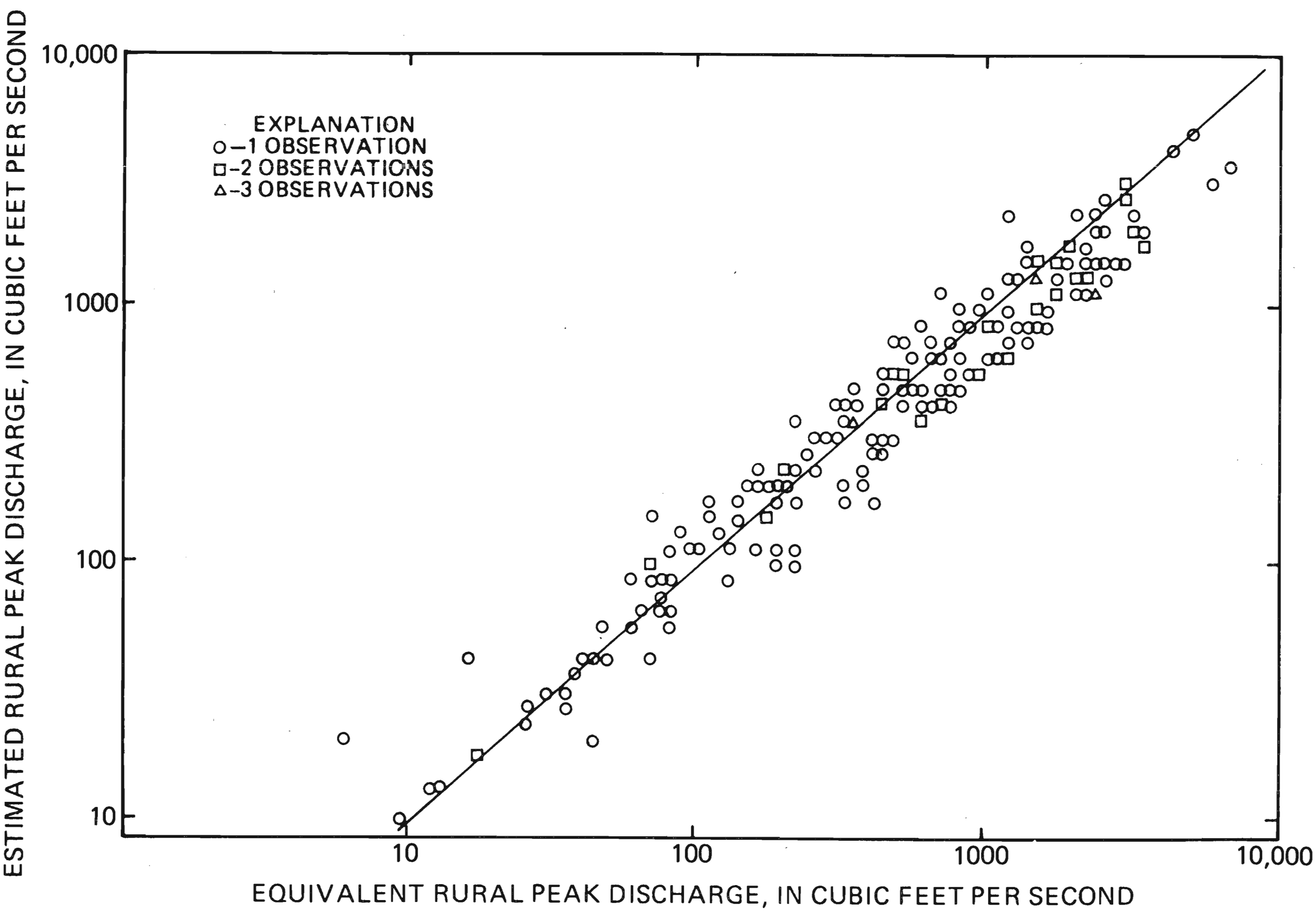

Figure 12. Comparison of equivalent 2-year rural peak discharge to peak discharge estimated from equation 24.

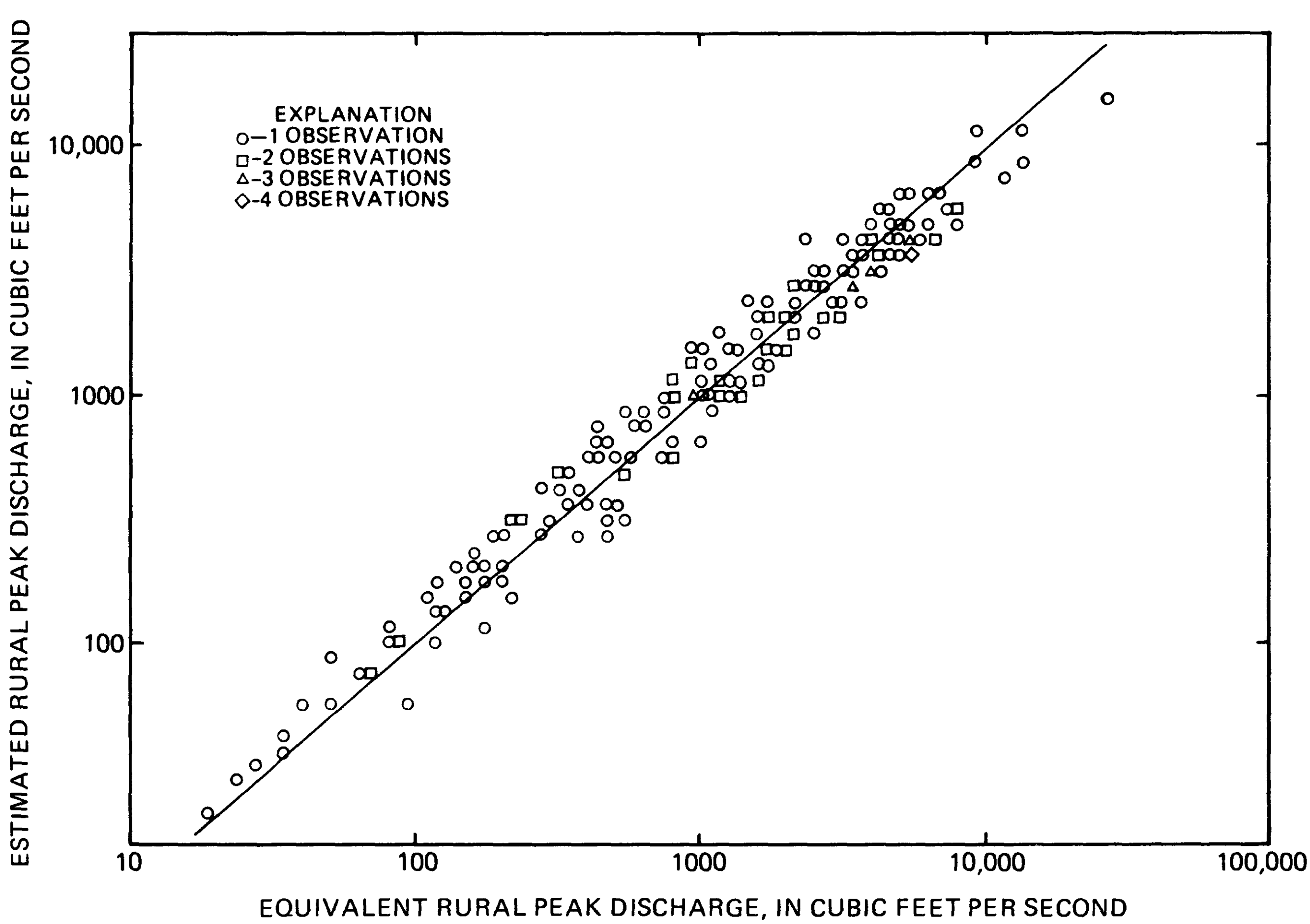

Figure 13. Comparison of equivalent 10-year rural peak discharge to peak discharge estimated from equation 25.

and each equation was found to have an average standard error of estimate of about ±50 percent. This error is somewhat higher than the errors of the seven-parameter and three-parameter equations; however, equations 27–29 can be used for approximating the ratio of urban to equivalent rural peak discharges.

Equations 27–29 are readily adaptable to graphical presentation similar to that given by Leopold (1968). Impervious area is one of the same variables used by Leopold, and BDF is analgous to his "storm sewers" parameter. Figures 15–17 illustrate the graphical results of equations 27–29, respectively.

By converting the ordinate scale in figure 15 to percentage (assuming a BDF of 12 equals 100 percent), a crude comparison to Leopold's curves can be made. This is shown in figure 18 for the 2-year recurrence interval. It is obvious that a similarity exists, but whereas Leopold gave nearly equal weight to the two independent variables, the present analysis gives much less weight to impervious area (IA).

The curves given by Leopold approach a maximum (full-development) urban/rural ratio of about 7. The curves developed from equation 27, as shown in figure 18, approach a full-development ratio of about 4.5. It should be pointed out that the curves in figure 18 are average conditions. Through the use of the seven-parameter equations, 3–9, full-development urban/rural ratios can be computed and these ratios will have considerable variation. The urban/rural ratio is influenced by several of the independent basin parameters. For some basins the seven-parameter equations will show full-development ratios greater than 7, while others will show ratios less than 4.5. To illustrate these relationships, full-development urban/rural ratios were computed for 199 stations used in this study by dividing the estimated full-development 2-year urban peak, UQ2, by the 2-year equivalent rural discharge, RQ2. The estimated full-development 2-year urban peak was computed from equation 3 by assuming BDF = 12 and IA = 100 percent for each of the 199 stations.

Figure 19 relates the full-development urban/rural ratio to drainage-area size, A. The plot indicates little or no trend, presumably implying that the ratio does not vary with drainage area size. This may not be a realistic

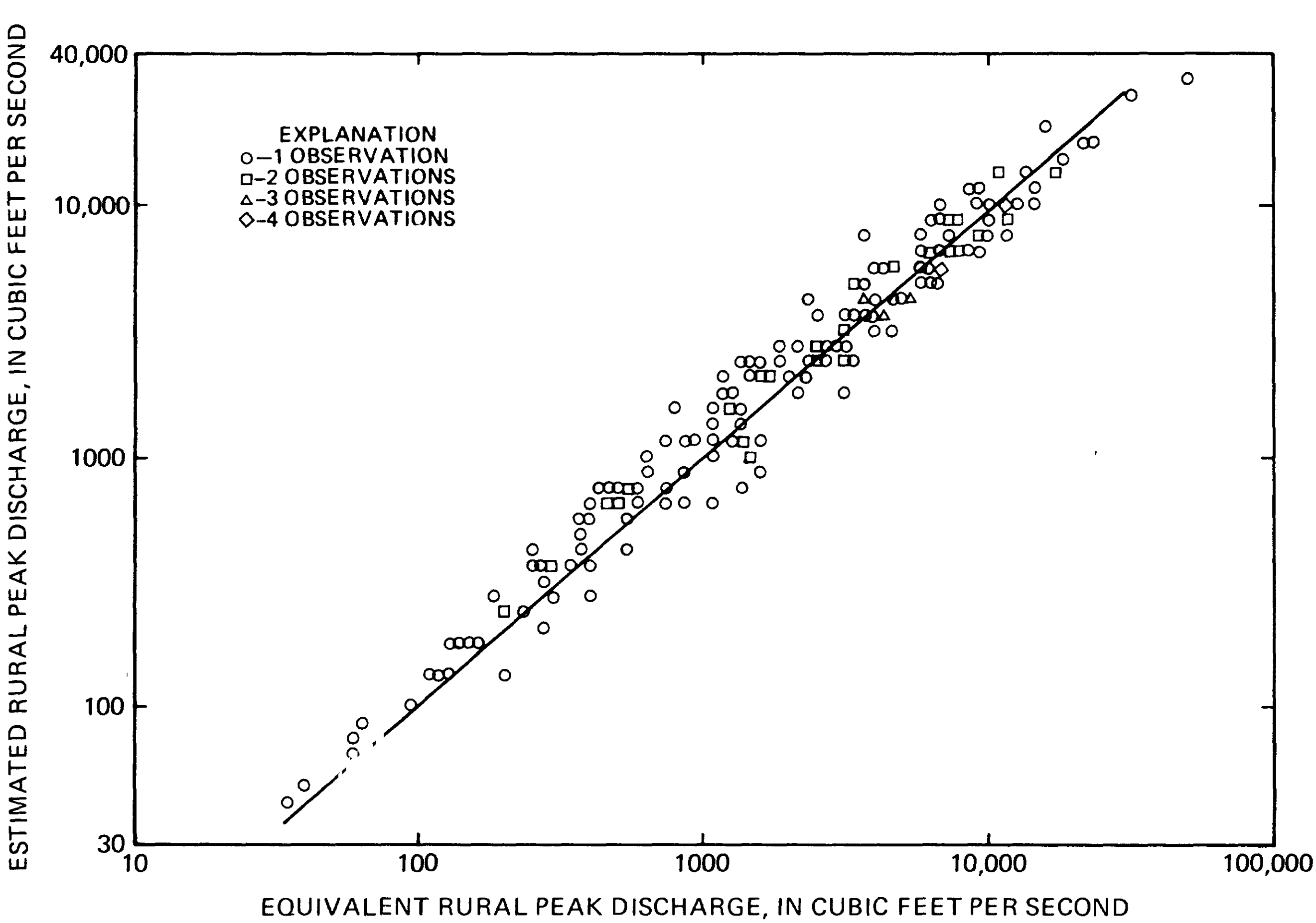

Figure 14. Comparison of equivalent 100-year rural peak discharge to peak discharge estimated from equation 26.

conclusion because of the assumption of 100-percent imperviousness. It is not likely that the large basins would ever approach this condition.

Figure 20 relates the full-development urban/rural ratio to channel slope, SL. This plot seems to show that the ratio decreases as slope increases, indicating that urbanization in steeply sloped basins will have less effect on peak discharges than in flatter basins. Intuitively, this seems logical. That three stations have ratios greater than 10 would seem to refute this conclusion; however, other factors may be exerting a greater influence on these stations.

Figure 21 relates the full-development urban/rural ratio to rainfall intensity, RI2. A first glance at this plot suggests a definite trend, indicating that the ratio decreases in areas where rainfall intensity is the greatest. However, this first interpretation is greatly influenced by the three points having ratios greater than 10. If these three points were removed, the indicated trend would be much less, and one might even conclude no trend exists. Intuitively it would seem logical that urbanization would have a greater effect on peak discharges in regions of low rainfall intensity.

Figure 22 relates the full-development urban/rural ratio to basin storage, ST. The trend is slight, but indicates that ratios logically decrease in basins where storage is the greatest.

Figure 23 relates the full-development urban/rural ratio to the equivalent rural discharge, RQ2. This plot indicates that the urban/rural ratio decreases as the rural discharge increases. Urbanization in basins where equivalent rural discharge is relatively small will have more effect than in basins where the equivalent rural discharge is relatively large.

The plots in figures 19–23 can only be used to show general relationships and are not intended to be used to estimate peak discharges in urban areas. There obviously exist more complex interrelationships which cannot be shown with plots of this type.

Although equations 27–29 could be used as estimating techniques, the user should be aware that several assumptions are involved, and that accuracy is not as good as in the previously described regression equations. The ratio method is logical and easy to use, and could be used for planning and for approximating an increase in rural peak discharge.

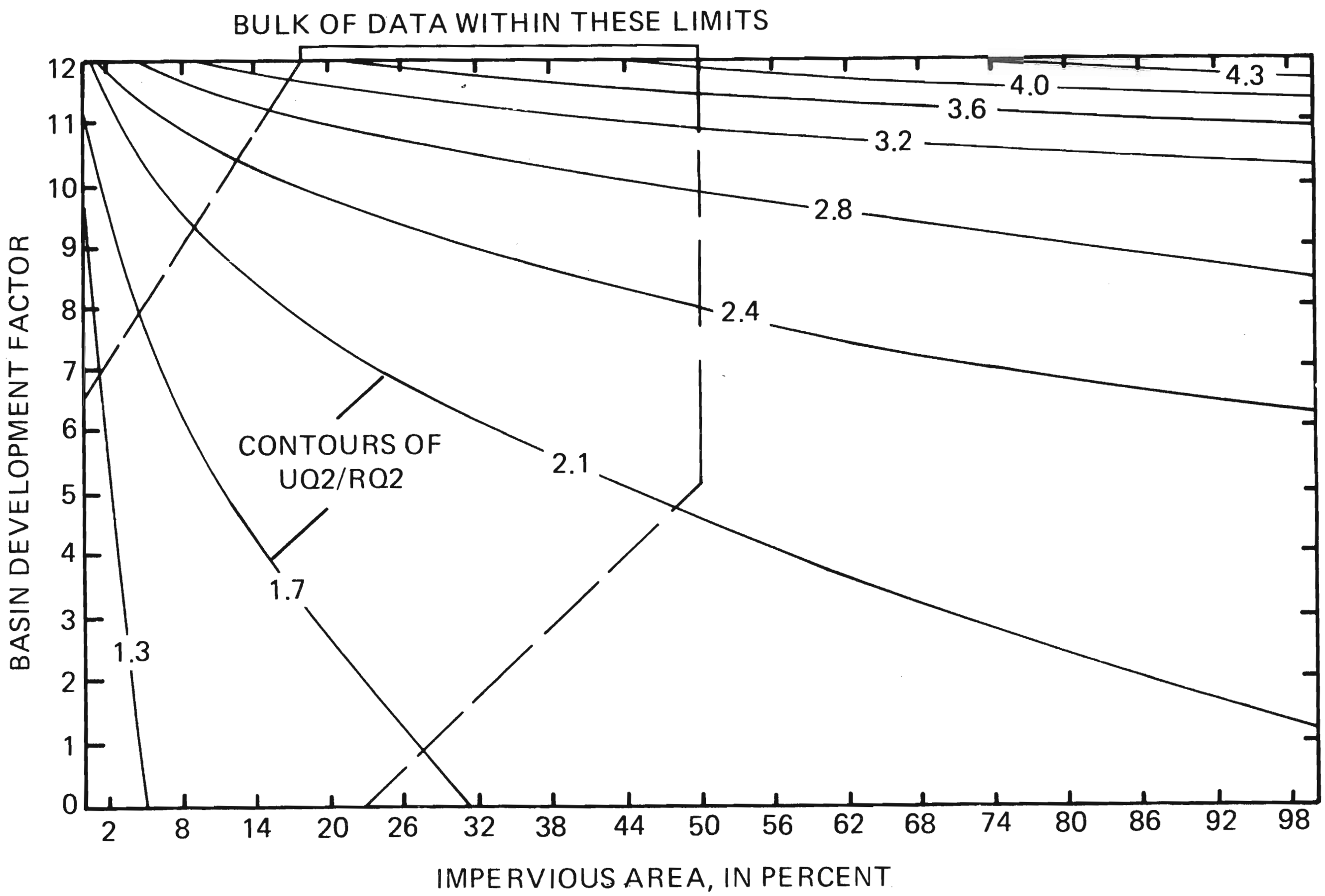

Figure 15. Relation of urban/rural 2-year peak-flow ratio (UQ2/RQ2) to basin development factor and impervious area.

Difference Method

The concept of the difference method is that the difference between UQ and RQ (UQ – RQ) can be related to basin and urban variables. The main problem encountered in trying to develop a technique based on this concept was that many of the sites showed negative differences. After numerous unsuccessful calibration attempts and no significant results, the method was deemed impractical.

Method of Moments

The log-Pearson Type III frequency distribution is the method recommended by the Water Resources Council (1977) for fitting flood-frequency curves to annual peak-flow data. This method was used to derive basic frequency data used in this project. The log-Pearson Type III equation contains three statistical variables, or "moments"; the mean, $\bar{X}$; the standard deviation, S; and the skew coefficient, Gs. If these three variables could be estimated for a basin from the physical and climatological characteristics of that basin, then the log-Pearson Type III equation could be used as an estimating procedure for flood magnitude and frequency. Attempts to relate the skew coefficient to basin characteristics are described in the section "Flood-Frequency Estimates." Since these resolutions were judged to be poor, average skew values were assigned to each city as an alternative, as given in table 1. The mean, $\bar{X}$, can be related to basin characteristics with an equation similar to equation 3, and with similar accuracy. The standard deviation, S, was related to basin characteristics by log-linear multiple regression analysis. Two estimating equations of about equal accuracy are worth reporting:

$$S = 0.50\,\frac{RI100^{.96}RQ100^{.19}(13-BDF)^{.11}}{RI2^{.83}RQ2^{.20}} \qquad (30)$$

$$S = 0.52\,\frac{RI100^{1.11}SL^{.04}(13-BDF)^{.08}}{RI2^{1.00}} \qquad (31)$$

In equation 30, it should be noted that the ratio $RI100^{.96}/RI2^{.83}$ is a measure of the slope of the rainfall-intensity curve, and that the ratio $RQ100^{.19}/RQ2^{.20}$ is a measure of the slope of the rural flood-frequency curve. In equation 31 the slope index, SL, replaces the rural discharges RQ100 and RQ2.

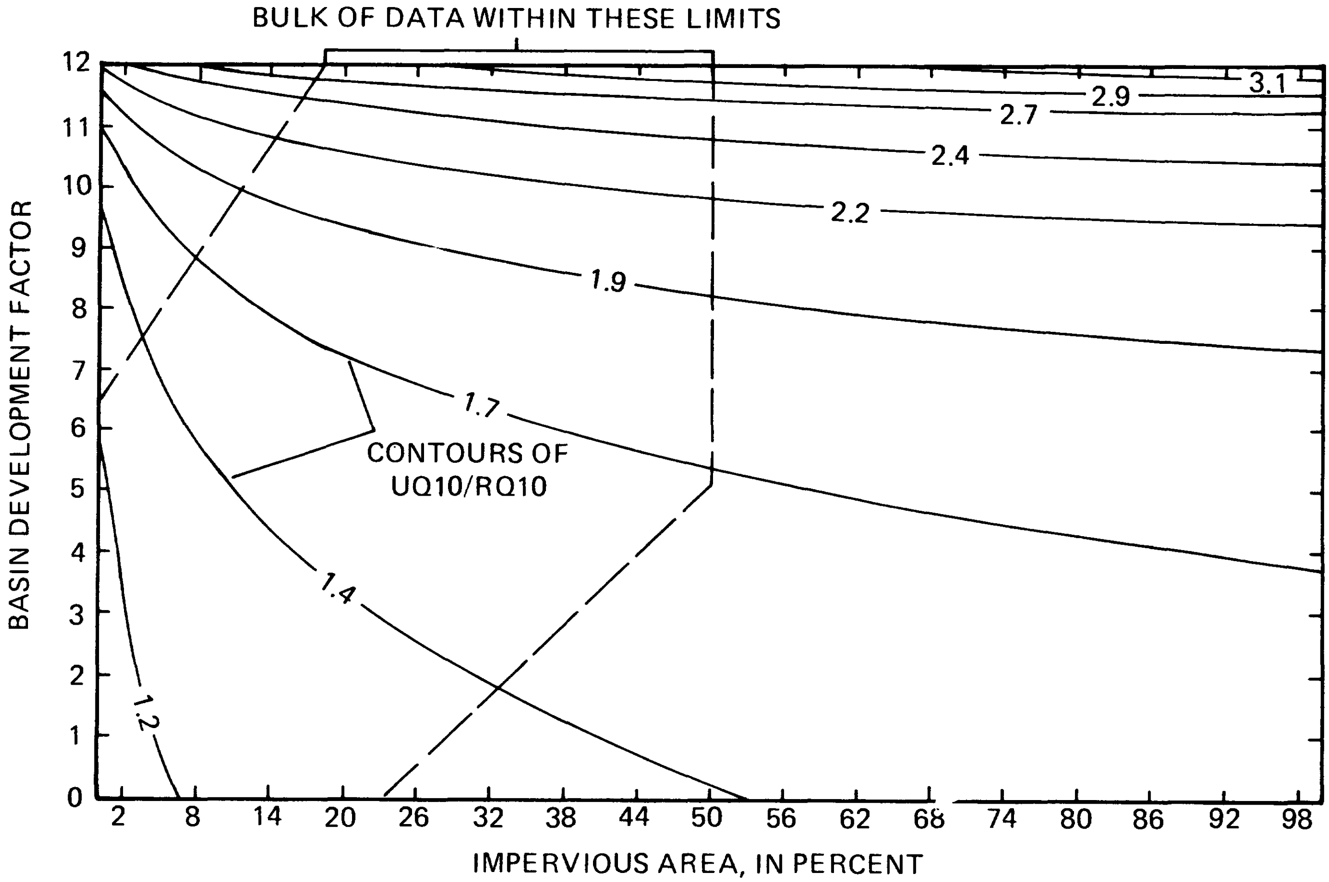

Figure 16. Relation of urban/rural 10-year peak -flow ratio (UQ10/RQ10) to basin development factor and impervious area.

All of the variables are previously defined. The coefficients of determination, R^2, of equations 30 and 31 are .35 and .25, respectively, and the standard errors of regression are .0770 and .0823 log units, or an average of ±18 and ±19 percent, respectively. The independent variables are all statistically significant at the 1-percent level of significance except slope, SL, which is significant at the 3-percent level.

Using the city skew coefficients to estimate Gs; equation 3 to estimate the mean, $\bar{X}$; and equation 30 to estimate the standard deviation, S; log-Pearson Type III estimates of the 10- and 100-year flood peaks were made for 199 stations and compared to the observed values. The standard errors of estimate were .184 and .227 log units (±44 percent and ±55 percent), respectively. These errors are somewhat higher than those of the seven-parameter, three-parameter, and seven-parameter alternate equations, and the method is not as easily applied.

Harley Method

Harley (1978) suggested a set of basin parameters that should logically explain the variations in peak rate of runoff between different basins and different geographical areas. These parameters are (1) an index of local runoff volume, E, in inches, based on the 2-hour, 25-year rainfall intensity and the SCS soil-cover-complex curve number; (2) an index of impervious area, K, based on a conversion equation suggested by Carter (1961); (3) a ratio (RH, which varies with percentage of imperviousness) of the mean annual flood to other recurrence-interval floods; (4) the drainage-basin size, A; (5) the drainage-basin response time, LT, defined as lagtime; and (6) an index of storage, ST, defined as the percentage of surface storage in the basin.

Data for 140 sites were available for evaluation of the parameters in Harley's suggested equation. Of the 204 sites known to be free of significant detention storage, 59 could not be used because of missing values for SCS data or lagtime, and 5 were missing other data. Measured values of lagtime and impervious area were used in place of the estimated values suggested by Harley. The index of local runoff, E, was computed using SCS (1975) procedures for estimating runoff depths for storms of specified recurrence intervals. A log-linear multiple-regression analysis was used to calibrate Harley's equation for the 2-year recurrence interval, and the

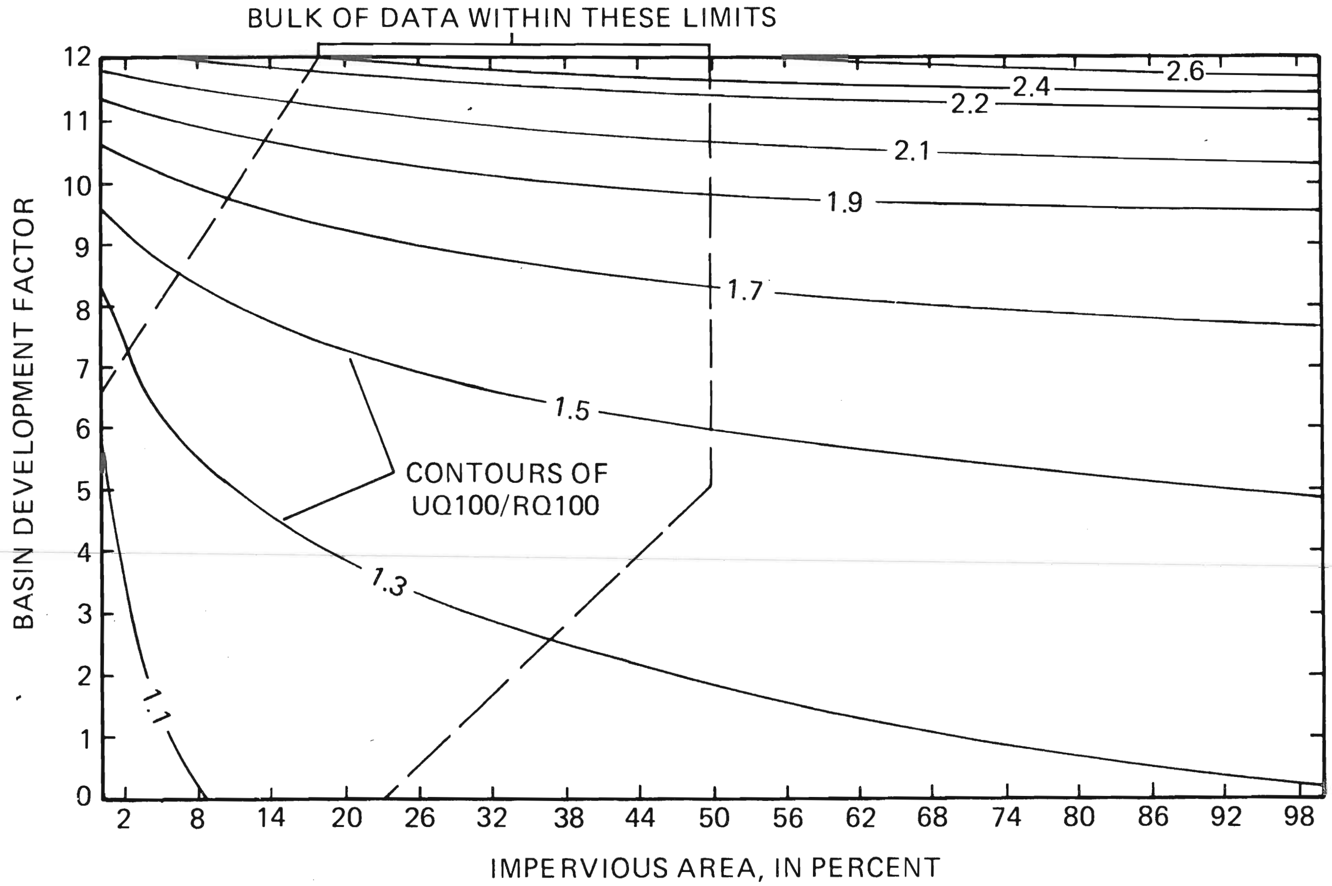

Figure 17. Relation of urban/rural 100-year peak-flow ratio (UQ100/RQ100) to basin development factor and impervious area.

following equation was derived:

$$UQ2 = 154E^{.24}K^{1.34}A^{.96}LT^{-.49}ST^{-.18} \qquad (32)$$

The coefficient of determination, R^2, is 0.83 for the above equation, and the standard error of regression is 0.2099 log units, or an average of ±50 percent.

According to Harley's procedure, floods for larger recurrence intervals would be estimated by multiplying the 2-year event, UQ2, by the ratio, RH. This procedure was tested and resulted in a standard error of estimate of about ±62 percent for the 100-year recurrence interval.

Equation 32 is logical and follows the basic form suggested by Harley; however, some of the exponents are considerably different from those that Harley proposed. These differences resulted from calibration of the equation to provide a least-squares fit and a minimum variance between estimated and observed values of the dependent variable. Direct use of Harley's suggested equation with the 199 sites would result in a larger standard error of estimate than that shown above. The equation is difficult to use because of the computation of the runoff index, E, and lagtime, LT. Statistically better results can be obtained by using the previously described seven-parameter, three-parameter, or seven-parameter alternate equations.

Verification and Testing of Regression Equations

Several tests were made to establish the soundness of the seven- and three-parameter regression equations. These tests included split-sample analysis and bias and sensitivity tests. The results of each of these tests are described briefly in the following paragraphs. Because the seven-parameter alternate equations are basically similar to the seven-parameter equations, some of the tests were not made for the former.

Split-Sample Analysis

The relative accuracy of the various equations given in this report is judged by the standard error of regression, a measure of how well the regression equations will estimate the dependent variable at the sites used to calibrate them. The standard error of prediction, on the other hand, is a measure of how well the regression equations will estimate the dependent variable at

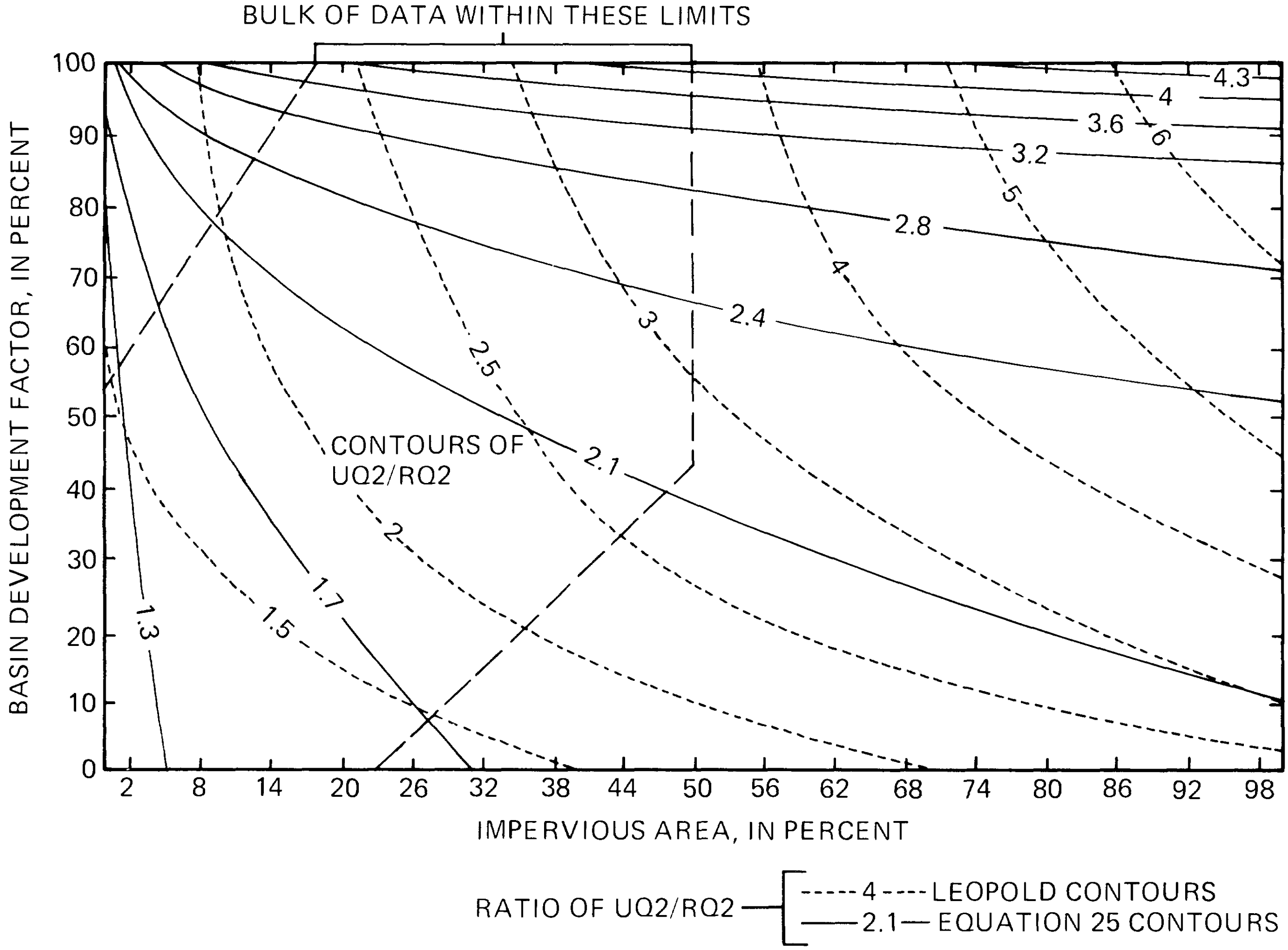

Figure 18. Comparison of urban/rural 2-year peak-flow ratio (UQ2/RQ2) to Leopold (1968) curves.

other than calibration sites. Standard error of prediction is usually greater than standard error of regression. A split-sample analysis of the 199 data sites was made to estimate the magnitude of the average prediction error, and to determine whether the same basic variables were significant. The sites were divided into two groups of about equal size following a systematic procedure to avoid bias. The sites were listed numerically by station number and were assigned alternately to the first or the second group. Multiple-regression analysis performed separately on each group yielded new regression equations very similar to the seven-parameter equations; however in one group the variables SL, ST, and IA were not statistically significant. By using the new regression equations from the first group to estimate flood peaks in the second group, and vice versa, it was found that for the seven-parameter equations the average prediction error is 6 to 9 percent greater than the regression error. Similar tests performed on the three-parameter equations indicate that the average prediction error for that group of equations is 1 to 3 percent greater than the regression error. These tests indicate that in terms of prediction error the three-parameter equations are about as accurate as the seven-parameter equations. Table 3 compares the regression errors and average prediction errors for the 2-year, 10-year, and 100-year recurrence intervals.

Table 3. Comparison of average standard error of regression and average standard error of prediction

Recurrence interval (years)	Average standard error of regression (percent)		Average standard error of prediction (percent)	
	7-parameter equations	3-parameter equations	7-parameter equations	3-parameter equations
2 ------	±38	±43	±44	±44
10 ------	±38	±41	±45	±43
100 ------	±44	±46	±53	±49

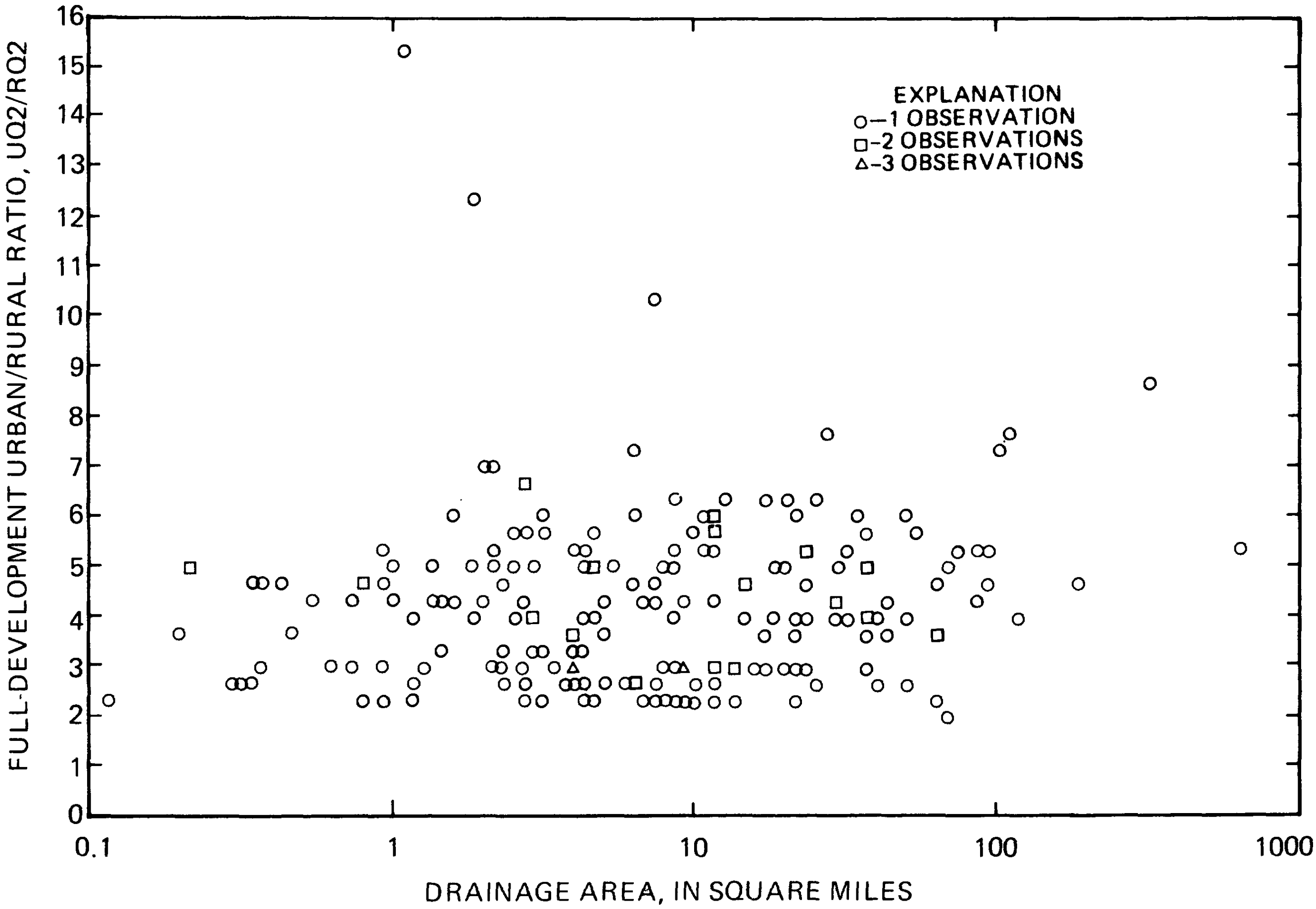

Figure 19. Relation of full-development urban/rural ratio (UQ2/RQ2) to drainage area size.

Bias Testing

Two tests for bias were performed, one for parameter bias and another for geographical bias. The tests were made at the 2-year, 10-year, and 100-year recurrence intervals for the seven-parameter, the three-parameter, and the seven-parameter alternate equations.

The parameter-bias tests were made by plotting the residuals (the differences between observed and estimated discharges for a specified recurrence interval) against each independent variable for all stations. These plots were inspected visually to determine if overestimation or underestimation was consistently occurring within the range of any of the independent variables. These plots also verified the linearity assumptions of the equations. The equations were found to be free of parameter bias throughout the range of all independent variables.

Geographical bias was tested by plotting estimated against observed discharges by recurrence interval and by city or metropolitan area. The plots were inspected visually to determine if the equations consistently overestimated or underestimated discharges in any of the cities. Where there were fewer than three or four stations in a city, this test might not be conclusive; in such cases the residuals were compared to the standard error of regression. Because these tests indicated no consistent overestimation or underestimation in any of the cities, it can be concluded that little or no geographical bias exists. The inclusion of the equivalent rural discharge as an independent parameter in the equations probably accounts for regional differences in hydrology and therefore significantly reduces or eliminates geographical bias.

Sensitivity Testing

The basin and climatic parameters in the regression equations must be computed or estimated from maps, observations, and other data. These are all subject to errors in measurement and judgment. To illustrate the effect of such errors, one of the seven-parameter regression equations was tested to determine how much error was introduced into the computed urban peak discharge from specified percentage errors in the independent variables. Such tests are referred to as sensitivity tests. Even though only one regression equation (eq 9) was

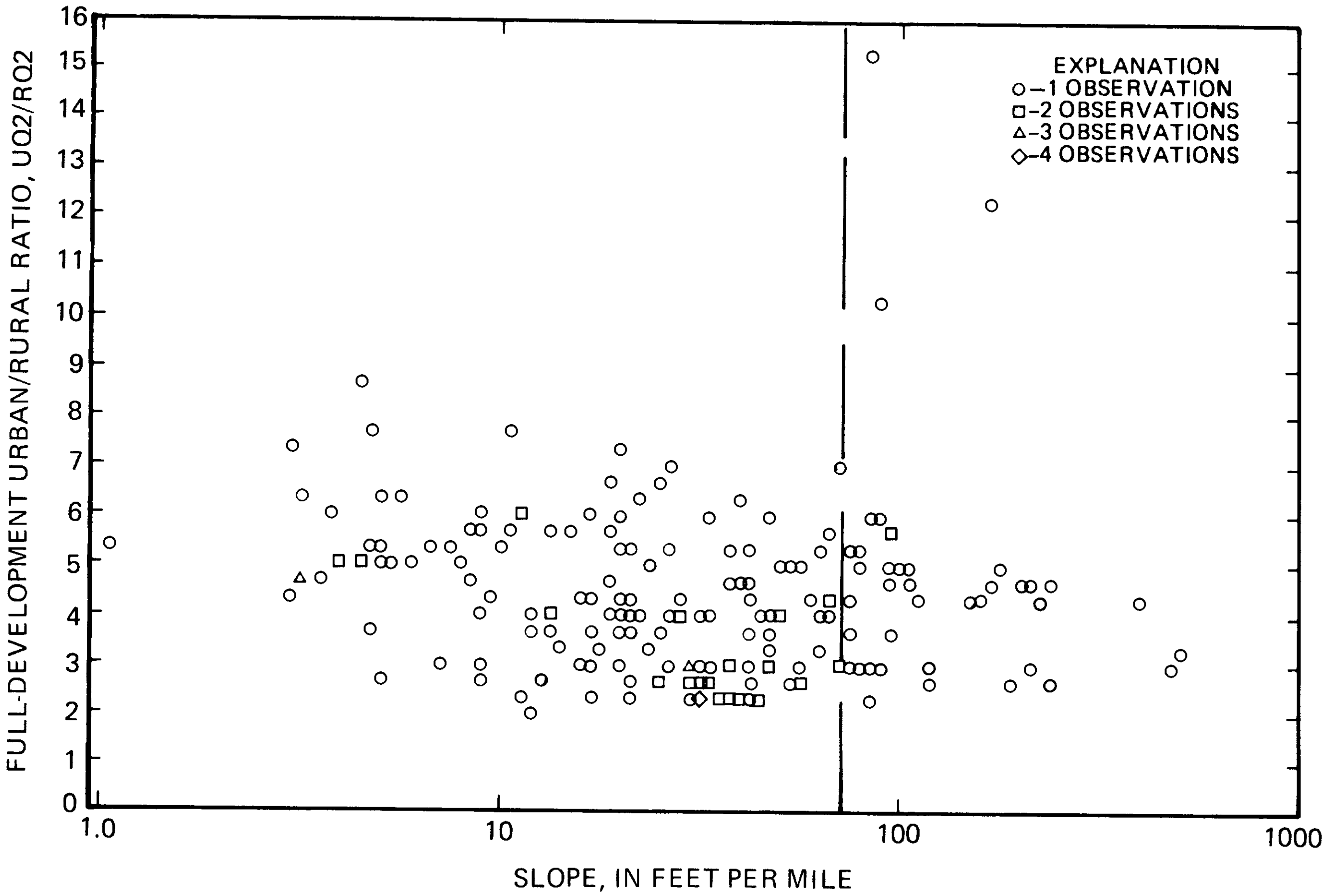

Figure 20. Relation of full-development urban/rural ratio (UQ2/RQ2) to channel slope. Slope = 70 ft/mi is maximum value used for computation in equations.

tested for sensitivity, it can be seen that the other equations, including the three-parameter and seven-parameter alternate equations, have relatively the same sensitivity because their regression coefficients are relatively the same.

The sensitivity of the 100-year estimated peak discharge to errors in the independent variables used in equation 9 is illustrated in table 4. Table 4 is derived by assuming all variables are constant except the one being tested for sensitivity. That variable is assumed to contain an error ranging from +50 percent to −50 percent. For example, assume that slope, SL, contains an error of +30 percent. Then the effect on computed urban peak discharge would be +4.0 percent.

For the variables RI2 and ST it is necessary to evaluate the error at different levels because of the constant added to each of these variables. If the true value of each of these two variables is small, then an error of a given percentage will have significantly less effect than if the true value is large. For example, if the true value of RI2 is 0.2 and the value used for RI2 in equation 9 is 50 percent less, or 0.1, then the computed urban peak discharge would be in error by −5.4 percent. However, if the same −50 percent error occurs when the true value of RI2 is 2.8, then the computed urban peak discharge will be −38.5 percent in error. The constant of 3 added to RI2 has the advantage of reducing sensitivity in the lower range of RI2, where a small change may produce unrealistic changes in discharge.

The effect of an error in the basin development factor, BDF, is illustrated in table 5. BDF is a discrete (not continuous) number; therefore any error can occur only as an integer. Table 5 shows the effect on the urban peak discharge when BDF is small (BDF = 2) and when BDF is large (BDF = 10). Note that when BDF is large, small errors will have significantly more effect than when it is small. This is also illustrated in figure 24, which shows that the ratio of urban to rural peak discharge changes much more rapidly at high values of BDF. The curves in figure 24 were developed from station data and represent average conditions for the 2-year and 100-year recurrence intervals. These curves should not be used to estimate the urban/rural ratio of specific sites because inherent error is large.

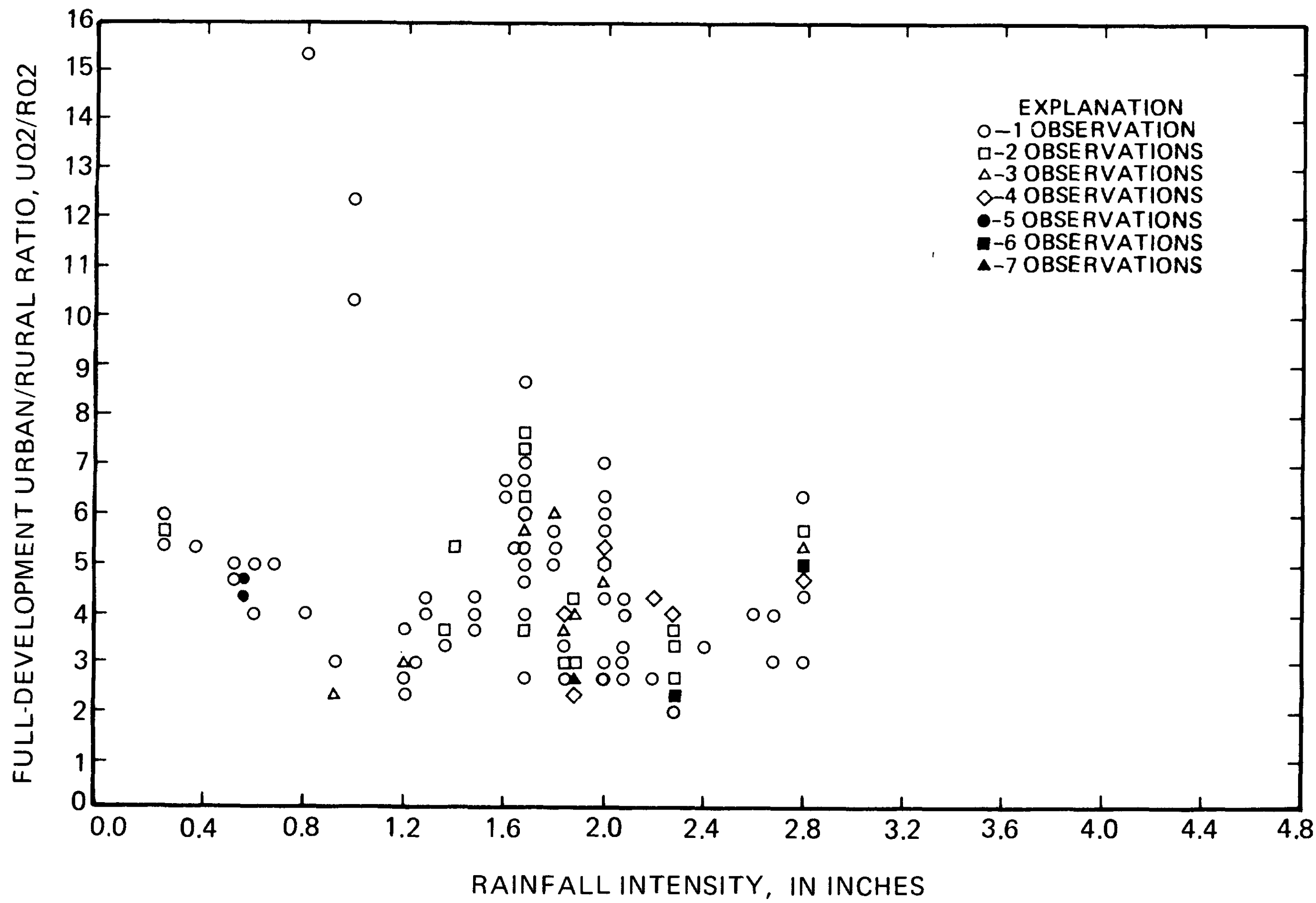

Figure 21. Relation of full-development urban/rural ratio (UQ2/RQ2) to rainfall intensity.

Table 4. Sensitivity of 100-year computed urban peak discharge to errors in independent variables

Percent error in independent variable	Independent variable							
	Percent error in computed urban discharge							
	A	SL	RI2 small values	RI2 large values	ST small values	ST large values	IA	RQ100
50--------	12.5	6.3	5.6	46.3	−2.8	−12.0	2.5	29.1
30--------	7.9	4.0	3.3	26.9	−1.7	−7.7	1.6	18.0
10--------	2.8	1.4	1.1	8.7	−0.6	−2.8	0.6	6.2
−10--------	−3.0	−1.6	−1.1	−8.3	0.6	3.0	−0.6	−6.4
−30--------	−9.8	−5.2	−3.3	−24.1	1.8	9.9	−2.1	−20.1
−50--------	−18.2	−9.9	−5.4	−38.5	3.0	18.4	−4.1	−35.4

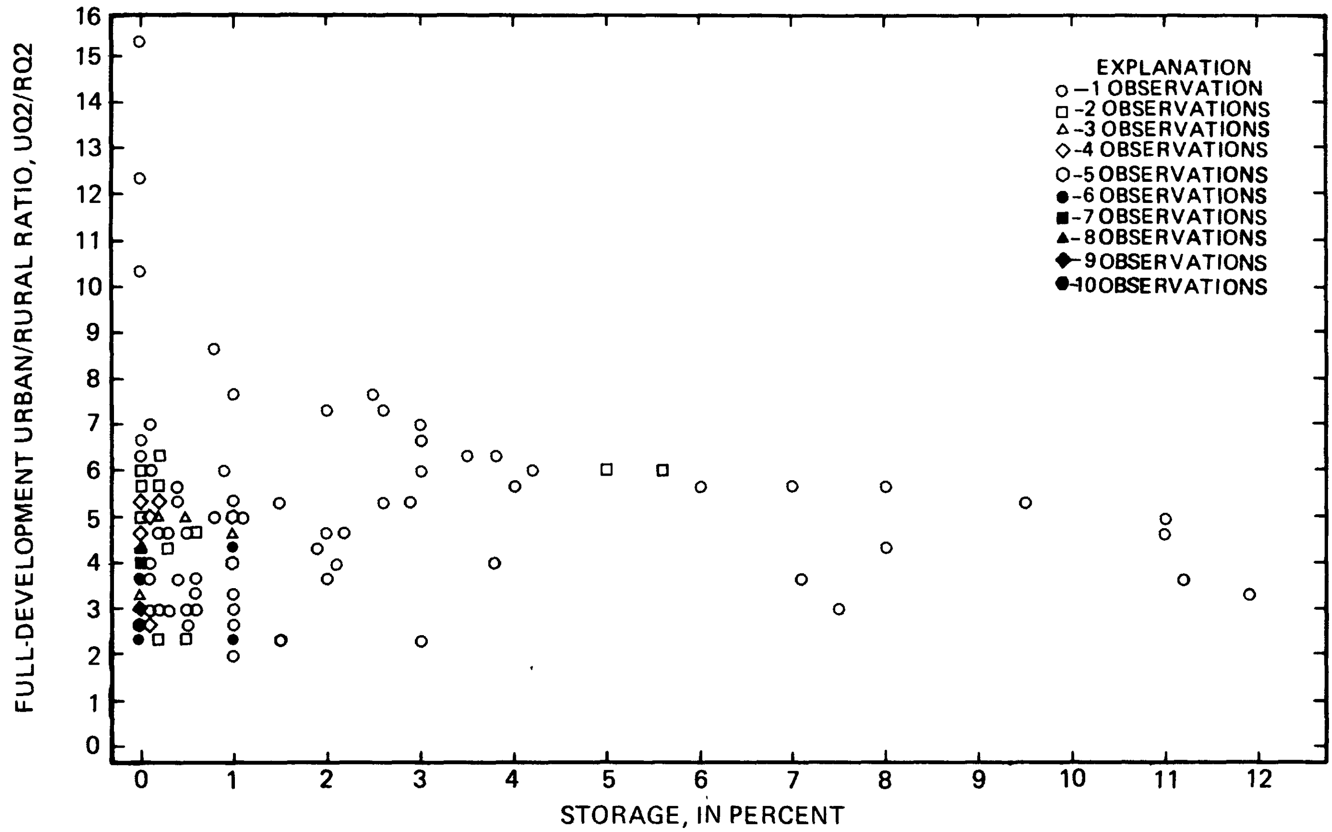

Figure 22. Relation of full-development urban/rural ratio (UQ2/RQ2) to storage.

Table 5. Sensitivity of 100-year computed urban peak discharge to errors in the basin development factor, BDF

Deviation of BDF from true value	Percent error in 100-year urban peak (true BDF = 2)	Percent error in 100-year urban peak (true BDF = 10)
−2	−4.6	−13.3
−1	−2.4	−7.7
0	0.0	0.0
1	2.7	12.0
2	5.8	36.0

It should be noted that quite often the interrelationship of some variables will alter the results of table 4. For instance, an error in one independent variable may cause a corresponding error in another one. The most obvious case is the relation between A and RQ. The rural discharge, RQ, is usually estimated from a relation containing A as an independent variable. If A contains an error, then RQ would likewise contain an error. A common relation between A and RQ is one in which $RQ = f(A^a)$, and the exponent a is commonly in the range of 0.6 to 0.8. To illustrate the compound error that might occur, assume that $RQ = f(A^{0.7})$. Introducing errors in A will cause a compounded error effect on the computed urban peak discharge. Table 6 illustrates these errors. For example, if an error of +10 percent exists in A, the corresponding error in RQ100 will be +6.9 percent, and the compound error in the computed urban peak discharge will be +7.2 percent. Other interrelationships of the independent variables will result in additional compounding of errors, and in some cases in compensating errors.

Table 6. Compound error resulting from interrelation of drainage area size and 100-year rural peak discharge

Percent error in drainage-area size	Percent error in RQ100 if $RQ100 = f(A^{0.7})$	Compound error in 100-year urban peak discharge
50	32.8	34.5
30	20.2	21.1
10	6.9	7.2
−10	−7.1	−7.4
−30	−22.1	−23.0
−50	−38.4	−39.8

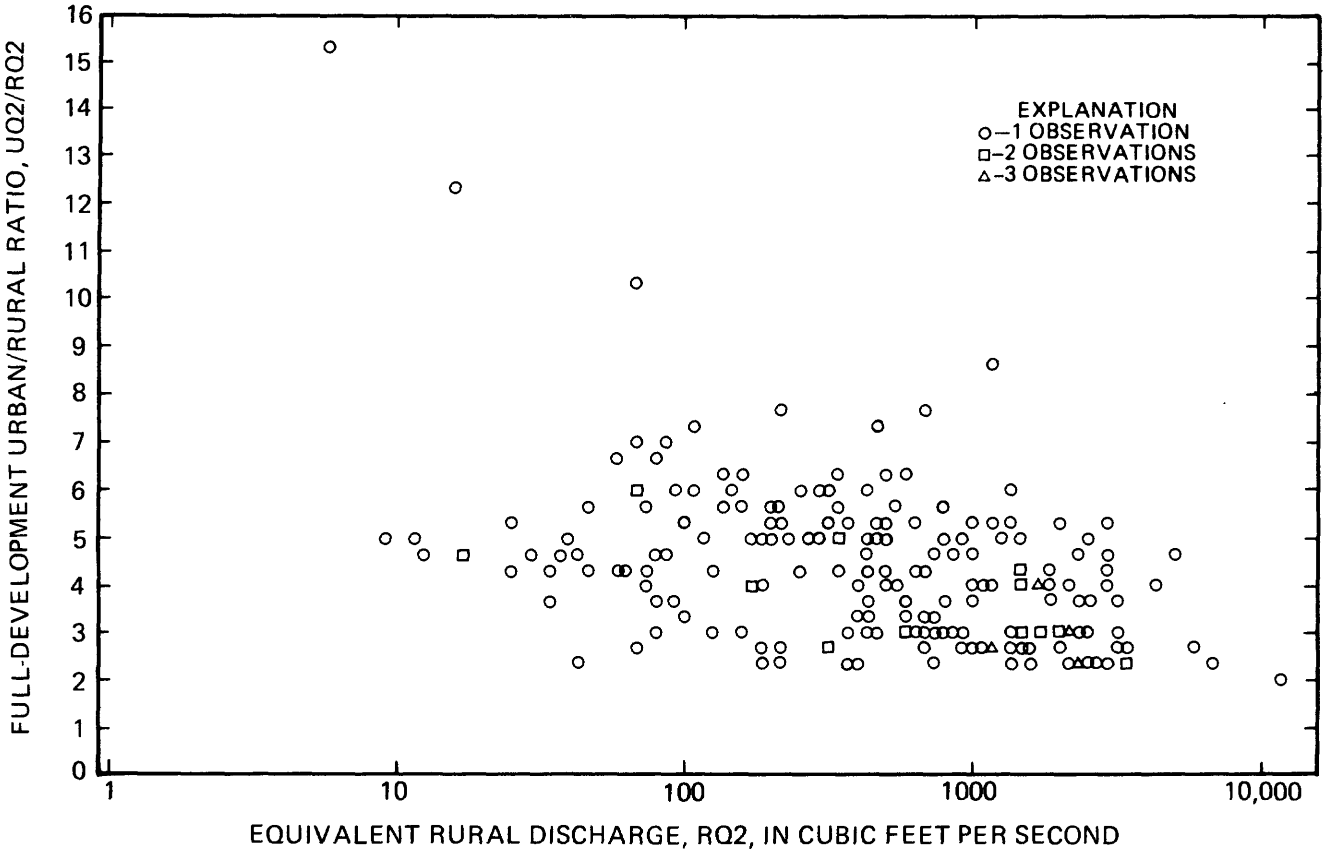

Figure 23. Relation of full-development urban/rural ratio (UQ2/RQ2) to equivalent rural discharge.

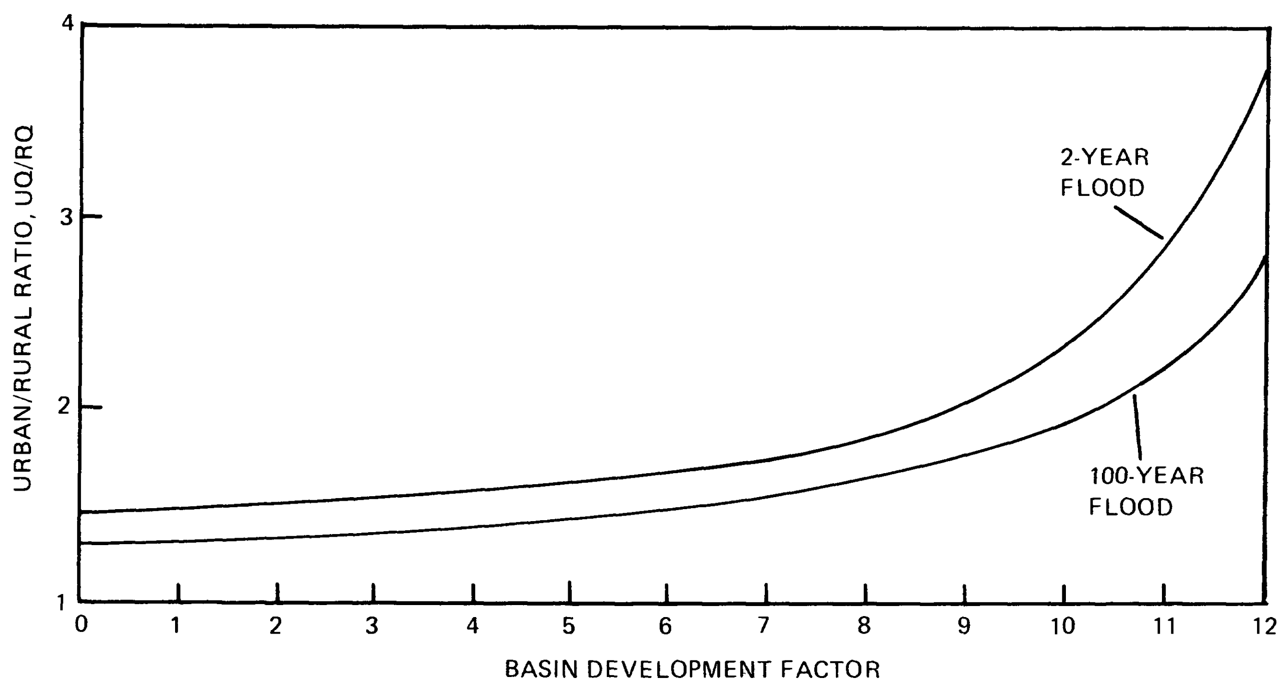

Figure 24. Average relations of urban/rural ratios to basin development factor, BDF, for 2-year and 100-year floods.

Urban Peaks Less Than Equivalent Rural Peaks

It is apparent from the data base that all or part of the observed urban flood-frequency curve for some sites is below the equivalent rural flood-frequency curve. As might be expected, this situation occurs more frequently at high recurrence intervals. Of the 269 sites in this study, 22 percent of the urban observed-frequency curves are below the equivalent rural frequency curve at the 100-year level, and 12 percent are below at the 2-year level. This condition is sometimes caused by time-sampling errors in the data and (or) modeling errors in the flood-frequency estimates; however, it occurs frequently enough to suggest that it may not always be the result of these errors. Some of the effects of urbanization were described in the Literature Review section of this report, where it is suggested that factors such as detention storage and location of urbanization, can reduce peak discharges. These and other unidentified urban effects can explain the reduction of flood peaks for some sites. The percentages just mentioned include sites identified as having detention storage.

Tests of the seven-parameter and three-parameter equations were made to determine if the equations ever estimated urban peaks as less than the equivalent rural peaks. Estimation of urban peaks for selected recurrence intervals at the 199 sites used in the initial calibration showed that at 7–8 percent of the sites, the estimated urban peaks were slightly lower than the equivalent rural peaks. In almost all of these cases, however, the differences were insignificant. Figures 25–27 graphically compare the urban peak discharges estimated by the seven-parameter equation to the equivalent rural peak discharges for the 2-year, 10-year, and 100-year recurrence intervals, respectively. Similar comparisons were observed for the three-parameter equations.

Effects of Detention Storage

Temporary in-channel, or detention, storage tends to reduce peak discharges. For this reason, and because a quantitative measure of detention storage was not defined, it was decided to omit from the regression analysis all 55 stations identified as having significant detention storage. The estimating equations described in previous sections were calibrated without the data from these 55 stations, and therefore represent conditions relatively free of the effects of detention storage. These

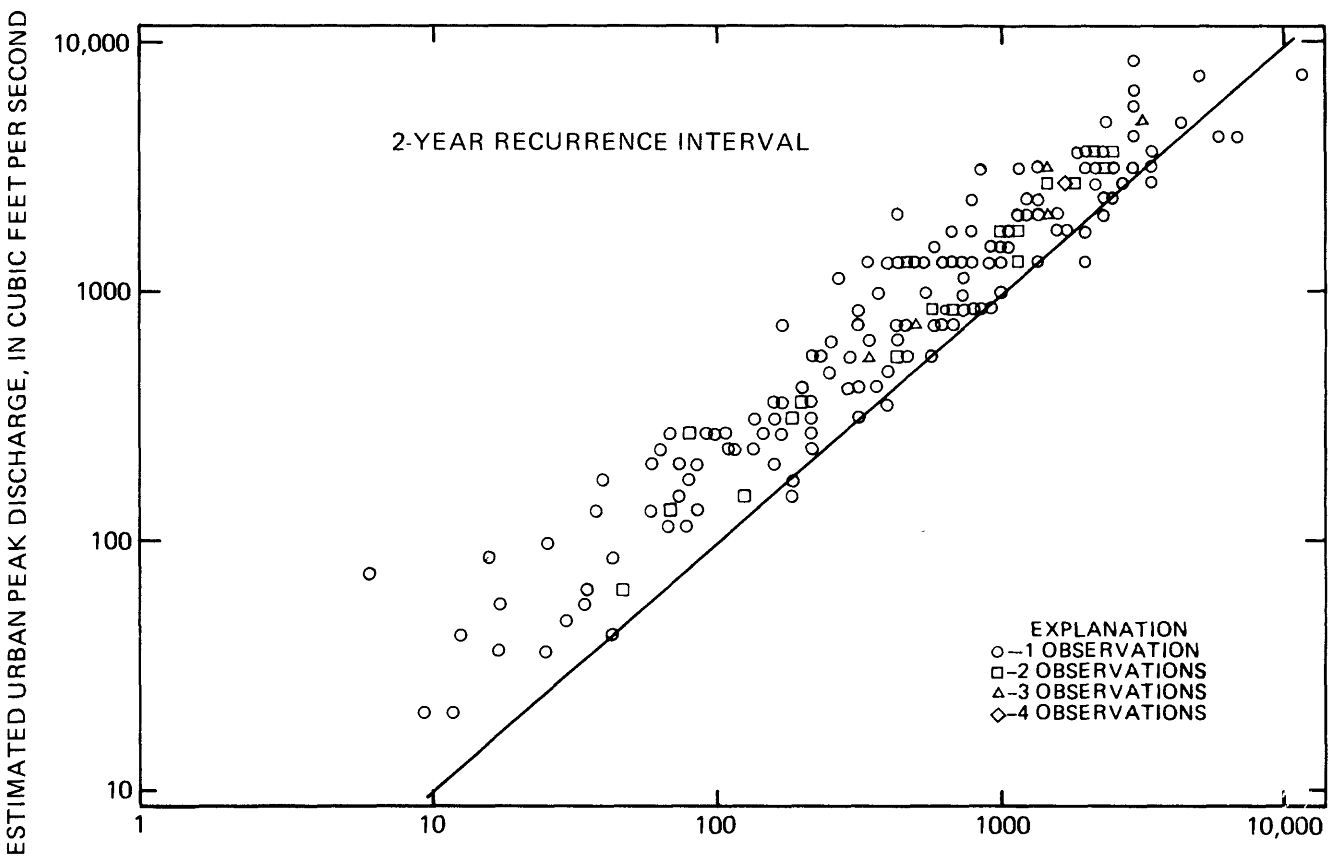

Figure 25. Comparison of estimated 2-year urban peak discharge to 2-year equivalent rural peak discharge.

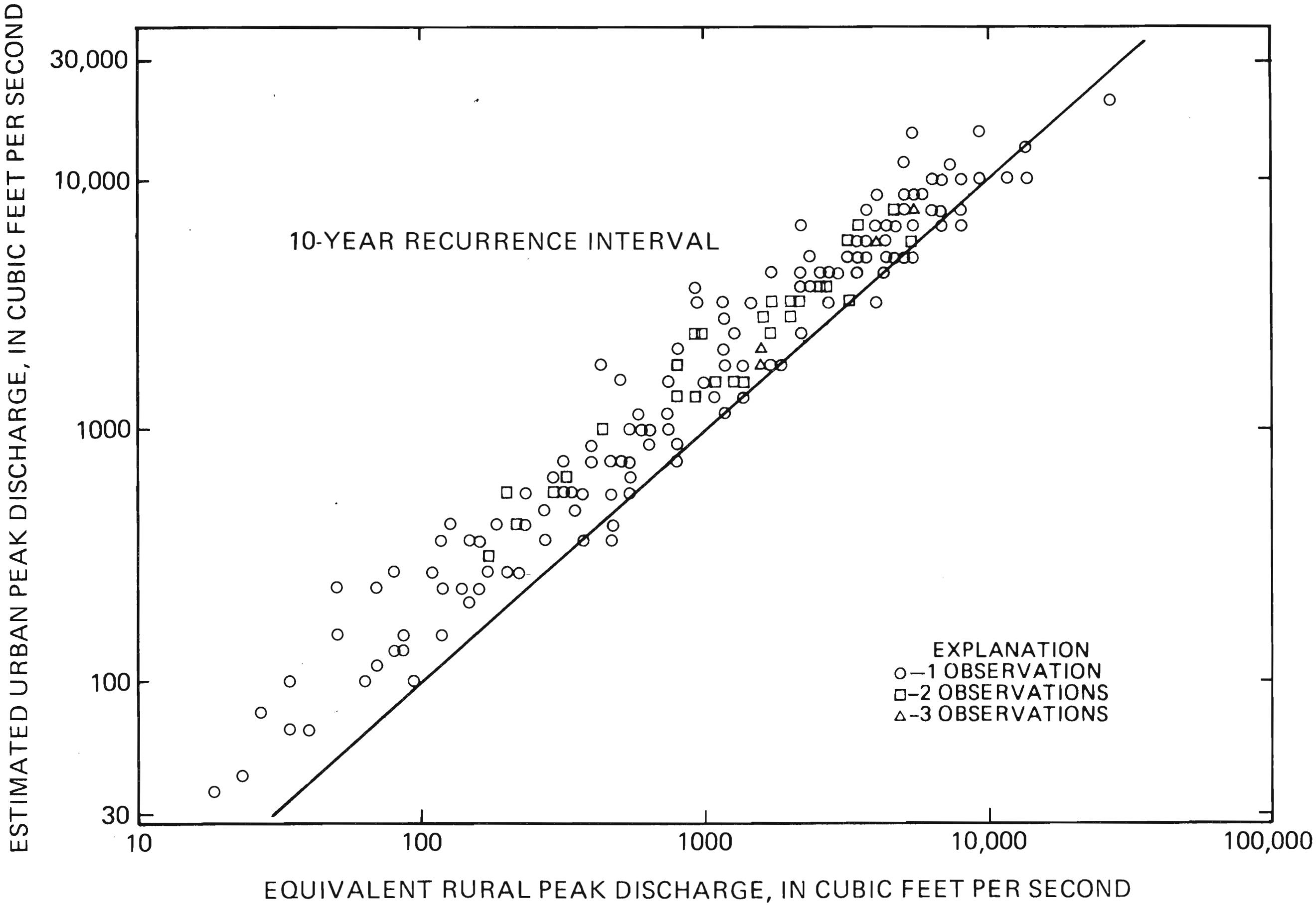

Figure 26. Comparison of estimated 10-year urban peak discharge to 10-year equivalent rural peak discharge.

equations were used to estimate urban frequency curves at 52 of the 55 sites (3 could not be used because some basin indexes were not available). Comparing the observed frequency curve to the regression-equation estimates approximated the effect of detention storage. (See figure 28.)

Figure 28 shows an average relation between the peak discharge estimated by the seven-parameter equations and that observed at sites where detention storage is believed to be significant. Average curves are shown for the 2-year and for the 10-year-and-greater recurrence intervals. These curves are for average storage effects as defined by the available data in this study, and are not intended to be used for making detention-storage adjustments. Individual sites will vary in extent of detention storage, and the net effect could be considerably more or less than indicated by these curves. The recommended way to determine the effect of detention storage at a specific site is to use reservoir- and channel-routing techniques, which are beyond the scope of this report.

Estimating Basin Lagtime

Many investigators have studied the response time, or lagtime, of storm runoff. Lagtime, LT, is generally defined as the time from center-of-mass of rainfall excess to center-of-mass shown on the resultant runoff hydrograph. When basins are modifed by impervious cover and channel changes, LT usually becomes shorter. Most investigators have related LT to basin length, L, and main channel slope, SL, with the independent variable taking the form $L/\sqrt{SL}$. Separate curves of relation are usually defined for different degrees of basin development, such as fully developed, partially developed, or undeveloped. The difficulty with using that kind of relation is that the degree of development is fairly subjective and open to diverse interpretations.

For this study, a log-linear multiple-regression analysis of 170 stations with measured LT was used to define the following equation for lagtime:

$$LT = .0030L^{.71}(13 - BDF)^{.34}(ST + 10)^{2.53}RI2^{-.44}IA^{-.20}SL^{-.14} \quad (33)$$

The standard error of regression is .2523 log units, or an average of ± 61 percent, and the coefficient of determination, R^2, is .75. The equation has two measures of basin development, IA and BDF, and other factors which logically relate to LT. An attempt to develop

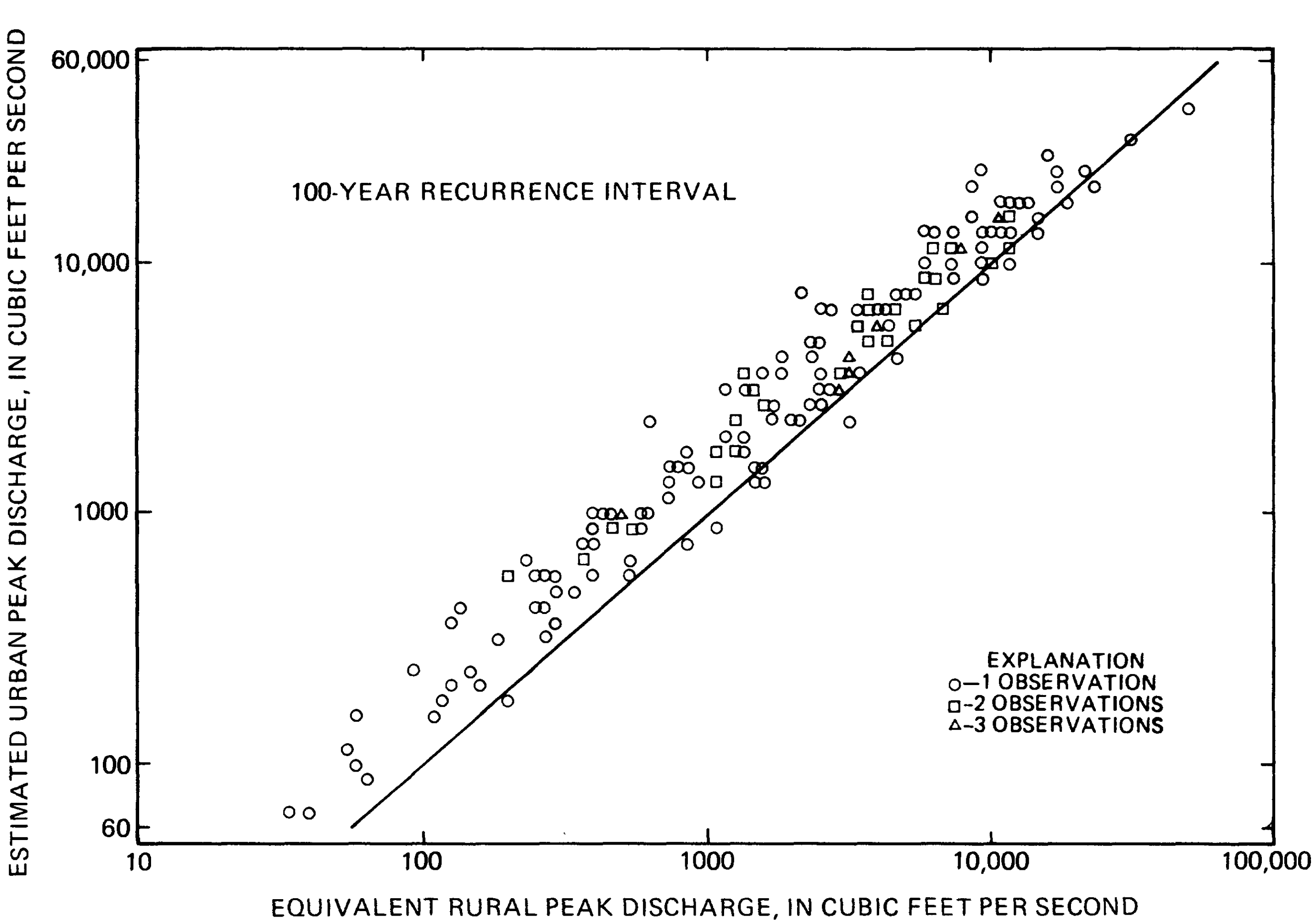

Figure 27. Comparison of estimated 100-year urban peak discharge to 100-year equivalent rural peak discharge.

more simplified relations along the lines explored by previous investigators resulted in the following equation:

$$LT = 0.85(L/\sqrt{SL})^{.62}(13 - BDF)^{.47} \qquad (34)$$

This equation compares favorably with those of previous investigators and has the advantage of containing a more definitive measure of basin development. However, the standard error of regression is .3054 log units, or an average of ± 76 percent, significantly greater than equation 33.

The seven-parameter alternate equations, 17 through 23, for estimating urban peak discharges require the use of LT as an independent variable. Presumably an estimate of LT could be made from equation 33 or 34 for use in equations 17 through 23. This is not recommended because of the high standard error of estimating LT. Statistically better estimates of urban peak discharges can be made by using the seven-parameter or three-parameter equations.

ESTIMATING PROCEDURES FOR GAGED SITES

Estimates of flood magnitude and flood frequency at gaged sites can sometimes be improved by combining independent estimates. A flood-frequency estimate derived from station data, or from a calibrated basin model, would be considered independent of an estimate from one of the regression equations described in this report. These independent estimates can be averaged by using the weighting procedure described by the Water Resources Council (1977).

SUMMARY

This research project investigated the effects of urbanization on peak discharges having recurrence intervals varying from 2 to 500 years. The first stage of the project was to review the literature dealing with the effects of urbanization on storm runoff. The resultant

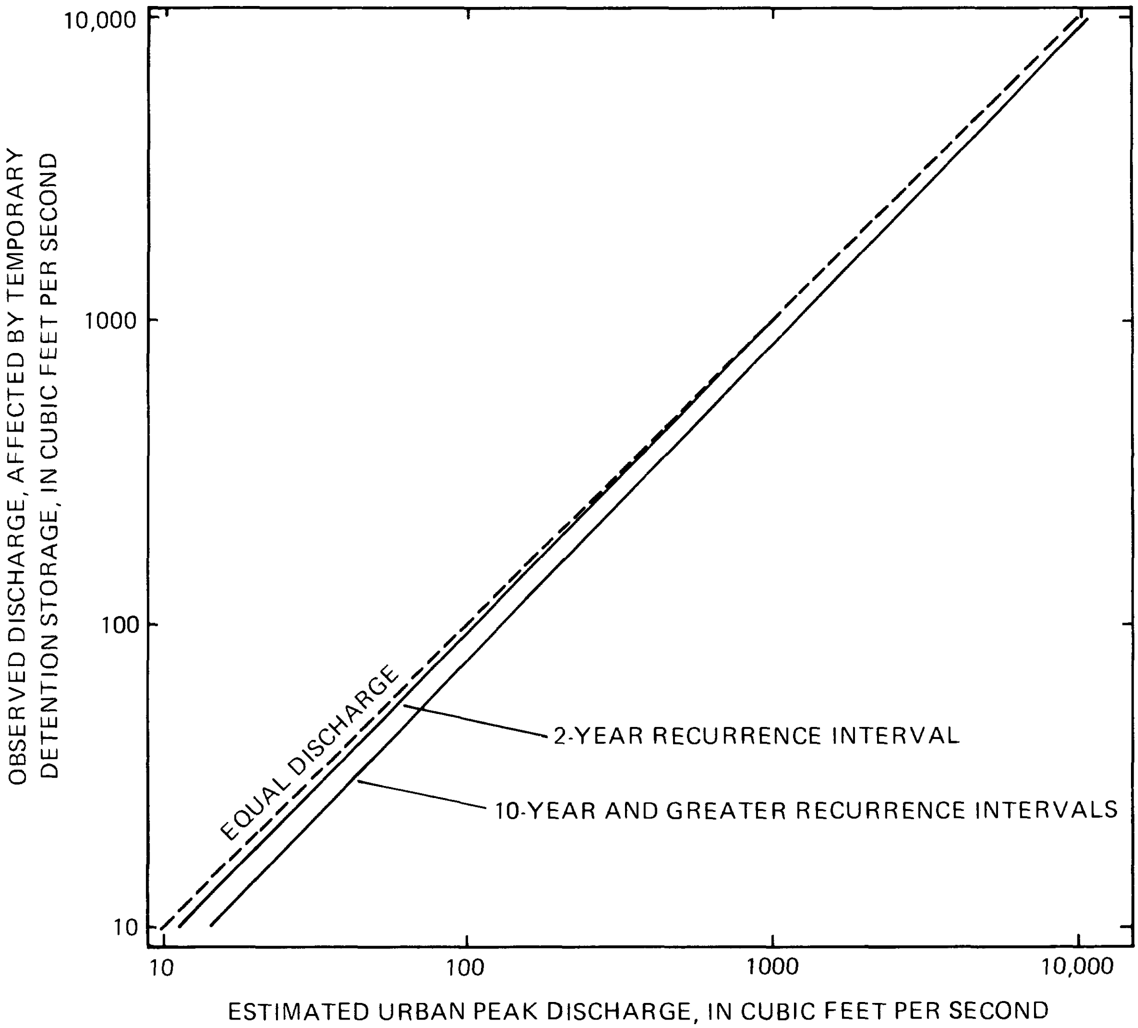

Figure 28. Average relations between urban peak discharges estimated by seven-parameter equations and observed urban peak discharges affected by temporary detention storage.

report, by Rawls and others (1980), reviews 128 publications which describe various methods for estimating the effects of urbanization. The approaches were found to range from simple statistical methods to very complex models, and it was observed that most of the statistical methods are applicable only to specific geographical areas. The ultimate objective of this project was to develop a statistical method which could be used on a nationwide basis.

A data base was established, consisting of topographic, climatic, land-use, urbanization, and flood-frequency parameters, for 269 watersheds in 56 cities or metropolitan areas located in 31 States from the East Coast to the West Coast and Hawaii. This data base was used to develop statistical relationships between urban peak discharge and basin parameters.

Multiple-regression analysis was used to define a three-parameter set, a seven-parameter set, and a seven-parameter alternate set of equations that would relate the urban peak discharge to an equivalent rural peak discharge and basin, urban, and climatic parameters. Each set of equations essentially adjusted the equivalent rural peak discharge to an urban condition. The basin development factor, BDF, which is an index of the drainage improvements, storm drains, and curb-and-gutter streets within the urban basin, was found to be the most important adjustment factor. Impervious area, although significant, played a much lesser role. Other parameters defined the effects of drainage area size, rainfall intensity, permanent basin storage, lagtime, and channel slope. Tests indicated that the equations are not geographically biased. Standard errors of regression for the seven-parameter equations vary from ± 37 percent at the 5-year level to ± 44 percent at the 100-year level.

Estimates of magnitude and frequency of urban peak discharges at ungaged sites throughout the United States can be made by using the seven-parameter or the three-parameter regression equations. Standard errors of prediction for either set of equations will vary from about ±44 percent at small recurrence intervals to about ±50 percent at the 100-year recurrence interval. If sufficient rainfall and hydrograph data are available to estimate lagtime, then the seven-parameter alternate regression equations can be used with an accuracy about equivalent to that of the seven-parameter and three-parameter equations.

The report presents average effects of temporary detention storage for some sites defined in this study. The results indicate that detention storage will reduce peak discharges, with the largest reductions for 10-year or greater floods. Reservoir-routing procedures, which are beyond the scope of this report, are probably the best method of estimating the effect of detention storage. Future studies should attempt to develop more simplified methods of quantifying temporary detention storage.

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APPENDIX I. SELECTED DATA FOR STATIONS USED IN NATIONWIDE URBAN FLOOD-FREQUENCY STUDY

Stations are listed by city.

Most data items are explained in the glossary. Additional explanation is as follows:

N YEARS = Number of years of data

TYPE = Type of data
- O = observed
- S = synthesized
- O,S = both of above

DTS = Detention storage
- N = no
- Y = yes
- U = unknown

. = Data not determined or not available

APPENDIX 1._SELECTED DATA FOR STATIONS USED IN NATIONWIDE URBAN FLOOD-FREQUENCY STUDY (CONTINUED).

GAGING STATION NUMBER AND NAME / N YEARS	TYPE	BDF	DTS	L (MI)	A (SQ MI)	SL (FT/MI)	RI2 (IN)	ST (%)	IA (%)	LT (HRS)	RQ2 / UQ2 (CFS)	RQ5 / UQ5 (CFS)	RQ10 / UQ10 (CFS)	RQ25 / UQ25 (CFS)	RQ50 / UQ50 (CFS)	RQ100 / UQ100 (CFS)	RQ500 / UQ500 (CFS)
ATLANTA GEORGIA																	
02203600 SOUTH RIVER AT EAST POINT, GA											248	420	564	756	916	1080	1550
14	0	6	N	2.00	1.49	76.00	2.20	1.0	40.0	0.85	643	751	817	897	954	1010	1130
02203800 SOUTH RIVER AT ATLANTA, GA											1820	3100	4020	5210	6310	7210	9800
27	0	3	N	7.50	41.50	16.00	2.20	1.0	15.0	9.00	2890	4600	5940	7850	9440	11200	15900
02336250 S. F. PEACHTREE CREEK AT LENOX RD AT ATLANTA, G											1490	2500	3290	4280	5190	5940	8200
9	0	6	N	13.10	29.60	17.00	2.20	1.0	25.0	7.50	2500	3430	4070	4910	5560	6230	7900
02336300 PEACHTREE CREEK AT ATLANTA, GA.											2840	4680	6210	7990	9680	11000	15000
22	0	6	N	18.40	86.80	9.42	2.20	1.0	30.0	12.00	5300	6690	7590	8720	9560	10400	12400
02336700 S UTOY CR TRIB AT HEADLAND DR AT EAST POINT, GA											169	292	388	523	634	754	1050
14	0	6	Y	1.50	0.79	75.90	2.20	0.0	18.0	0.70	317	425	498	593	666	740	923
AUSTIN TEXAS																	
08157000 WALLER CREEK AT 38TH ST AUSTIN TEX											570	1100	1530	2110	2580	3080	4300
13	0	6	N	4.37	2.31	47.50	2.30	0.6	36.0	0.50	712	1040	1260	1530	1730	1930	2390
08157500 WALLER CREEK AT 23RD STREET, AUSTIN, TEX.											790	1580	2220	3110	3830	4600	6300
13	0	7	N	5.23	4.13	47.50	2.30	0.4	38.0	0.70	1410	2170	2680	3340	3840	4340	5520
08158600 WALNUT CREEK AT WEBBERVILLE RD. AUSTIN, TEX.											3000	6400	9370	13600	17100	21000	32000
12	0	1	N	19.30	51.30	19 70	2.30	1.0	13.0	2.00	3630	8150	12200	18600	24100	30400	47900
BALTIMORE MARYLAND																	
01585200 WEST BRANCH HERRING RUN AT IDLEWYLDE, MD.											240	347	435	535	690	890	1400
20	0	8	N	3.10	2.13	97.70	2.00	0.2	20.0	1.60	525	955	1340	1960	2540	3230	5390
01585400 BRIEN RUN AT STEMMERS RUN, MD.											87	157	222	305	450	593	1000
19	0	2	N	2.00	1.97	27.10	2.00	0.1	10.0	2.40	266	469	647	930	1190	1490	2420
01589100 E. BR. HERBERT RUN AT ARBUTUS, MD.											212	372	521	665	900	1110	1900
20	0	4	N	3.30	2.47	92.40	2.00	0.2	15.0	2.30	573	795	957	1180	1360	1550	2050
01589300 GWYNNS FALLS AT VILLA NOVA, MD.											1150	1930	2630	3450	4750	5960	9500
12	0	4	N	13.70	32.50	21.00	2.00	0.0	7.5	3.60	1520	2450	3210	4340	5340	6460	9700
01589330 DEAD RUN AT FRANKLINTOWN, MD.											442	749	1020	1250	1640	1820	2800
12	0	10	N	3.36	5.52	50.40	2.00	0.1	25.0	2.50	1400	2150	2740	3600	4330	5140	7400
01653500 HENSON CREEK AT OXON HILL, MD.											499	863	1210	1680	2250	3620	4100
29	0	7	N	8.50	16.70	22.90	2.00	0.2	15.0	4.90	1170	1940	2590	3580	4460	5470	8440

APPENDIX 1._SELECTED DATA FOR STATIONS USED IN NATIONWIDE URBAN FLOOD-FREQUENCY STUDY (CONTINUED).

GAGING STATION NUMBER AND NAME / N YEARS	TYPE	BDF	DTS	L (MI)	A (SQ MI)	SL (FT/MI)	RI2 (IN)	ST (%)	IA (%)	LT (HRS)	RQ2 / UQ2 (CFS)	RQ5 / UQ5 (CFS)	RQ10 / UQ10 (CFS)	RQ25 / UQ25 (CFS)	RQ50 / UQ50 (CFS)	RQ100 / UQ100 (CFS)	RQ500 / UQ500 (CFS)
BATON ROUGE LOUISIANA																	
07379000 WARD CREEK AT GOVERNMENT STREET, AT BATON ROUGE											359	590	777	1020	1170	1350	1800
13	0	12	N	3.30	4.10	7.20	2.80	7.5	41.0	3.40	1230	1580	1800	2040	2220	2380	2740
BIRMINGHAM ALABAMA																	
02457000 FIVEMILE CREEK AT KETONA, AL											1760	2970	3980	5410	6590	7880	11200
26	0	6	N	10.10	23.90	29.00	2.27	1.0	15.0	4.68	2080	3650	4910	6720	8240	9880	14300
BOSTON MASSACHUSETTS																	
01100600 SHAWSHEEN RIVER NEAR WILMINGTON, MA											422	617	775	1010	1200	1420	1900
14	0	4	N	11.20	36.50	4.76	1.35	7.1	21.8	46.00	515	754	928	1170	1360	1560	2080
01104600 BEAVER BROOK AT BELMONT, MA											94	140	180	242	292	350	480
15	0	6	N	3.80	4.09	21.00	1.35	11.2	30.7	.	130	175	206	247	278	310	389
01105600 OLD SWAMP RIVER NEAR SOUTH WEYMOUTH, MA											98	147	189	250	301	361	490
11	0	6	N	4.60	4.29	14.00	1.35	11.9	19.1	26.00	194	338	457	636	791	967	1470
01107000 DORCHESTER BROOK NEAR BROCKTON, MA											104	156	199	264	318	381	520
12	0,S	6	U	5.80	4.67	33.30	1.36	11.3	11.8	39.00	97	158	207	278	338	404	587
BOULDER COLORADO																	
06728350 GOOSE CREEK AT BOULDER, CO											125	238	359	570	784	1040	1950
8	0,S	6	Y	1.32	0.69	127.00	1.20	0.0	34.0	0.40	84	166	233	328	404	486	703
06728400 BOULDER CREEK TRIB AT BOULDER, CO											35	79	119	180	224	278	440
9	0,S	7	N	0.47	0.20	95.00	1.20	0.0	30.0	0.17	29	55	76	109	137	168	255
BUFFALO NEW YORK																	
04216200 SCAJAQUADA CREEK AT BUFFALO, N Y											734	1230	1610	2160	2620	3130	4450
18	0	6	N	9.20	15.30	9.00	1.25	0.5	10.9	4.70	955	1300	1530	1820	2040	2250	2760
CANTON MISSISSIPPI																	
07289610 BACHELOR CREEK AT CANTON,MS											663	1030	1280	1700	1980	2460	3300
21	0	2	N	3.00	3.85	17.80	2.40	0.0	10.0	.	774	1050	1240	1470	1650	1820	2230
CHARLOTTE NORTH CAROLINA																	
02146300 IRWIN CREEK NR CHARLOTTE, NC											1490	2390	3120	4200	5100	6180	9330
16	0	9	N	11.20	30.50	13.70	1.90	0.0	20.0	2.13	3200	4650	5650	6960	7970	8990	11500

APPENDIX 1._SELECTED DATA FOR STATIONS USED IN NATIONWIDE URBAN FLOOD-FREQUENCY STUDY (CONTINUED).

GAGING STATION NUMBER AND NAME / N YEARS	TYPE	BDF	DTS	L (MI)	A (SQ MI)	SL (FT/MI)	RI2 (IN)	ST (%)	IA (%)	LT (HRS)	RQ2 / UQ2 (CFS)	RQ5 / UQ5 (CFS)	RQ10 / UQ10 (CFS)	RQ25 / UQ25 (CFS)	RQ50 / UQ50 (CFS)	RQ100 / UQ100 (CFS)	RQ500 / UQ500 (CFS)
02146500 LITTLE SUGAR CRK NR CHARLOTTE, NC											1830	2930	3810	5110	6180	7460	11200
16	O	9	N	11.00	41.00	13.10	1.90	0.0	22.0	1.97	4360	5950	7000	8330	9330	10300	12700
02146600 MCALPINE CRK AT SARDIS RD NR CHARLOTTE, NC											1740	2800	3640	4880	5910	7140	10700
16	O	7	N	8.72	38.30	12.20	1.90	0.0	10.0	1.84	2700	3880	4700	5760	6560	7390	9380
02146700 MCMULLEN C AT SHARON VW R NR CHARLOTTE, NC											520	870	1160	1590	1960	2410	3790
14	O	9	N	5.20	6.98	20.90	1.90	0.0	12.0	1.60	925	1260	1470	1750	1950	2160	2630
CHICAGO ILLINOIS																	
05528230 INDIAN CREEK AT PRAIRIE VIEW, IL											334	572	738	947	1110	1260	1610
17	O	1	N	11.60	35.70	13.60	1.70	8.0	7.6		486	800	1030	1350	1600	1860	2520
05528500 BUFFALO CREEK NEAR WHEELING, IL											227	394	511	660	776	888	1140
26	O	2	U	10.90	19.60	15.40	1.70	8.7	8.4	7.40	300	528	704	952	1150	1370	1920
05529500 MC DONALD CREEK NEAR MOUNT PROSPECT, IL											108	186	241	310	363	415	534
19	O	3	Y	7.04	7.93	9.66	1.70	4.2	19.6	13.20	210	380	514	706	865	1040	1490
05530000 WELLER CREEK AT DES PLAINES, IL											157	270	349	449	526	601	770
19	O	8	Y	7.34	13.20	10.60	1.70	2.7	36.0	7.40	793	1170	1430	1760	2010	2270	2870
05530700 SILVER CREEK AT MELROSE PARK, IL											117	195	249	316	366	415	526
18	O	9	Y	10.40	11.20	5.02	1.70	0.0	25.2		437	556	630	718	780	840	973
05531000 SALT CREEK NEAR ARLINGTON HEIGHTS, IL											309	530	684	877	1030	1170	1500
17	O	7	Y	11.30	32.10	13.40	1.70	10.8	15.5	20.60	506	780	974	1230	1430	1630	2120
05531080 SPRING BROOK AT BLOOMINGDALE, IL											96	174	229	301	358	413	541
18	O	1	U	5.19	5.08	22.10	1.70	1.0	11.8		181	266	324	399	455	512	647
05531500 SALT CREEK AT WESTERN SPRINGS, IL											516	810	1000	1240	1410	1580	1940
19	O	4	Y	36.40	114.00	2.85	1.70	6.7	16.4	39.10	1110	1440	1640	1890	2060	2230	2610
05532000 ADDISON CREEK AT BELLWOOD, IL											171	286	365	463	538	609	772
19	O	6	Y	8.97	17.90	6.21	1.70	2.6	30.4	9.20	432	560	639	735	803	870	1020
05532500 DES PLAINES RIVER AT RIVERSIDE, IL											1340	1960	2350	2810	3150	3450	4110
19	O	3	N	88.10	630.00	1.06	1.70	9.5	7.7	37.40	3970	5000	5630	6380	6900	7410	8520
05533000 FLAG CREEK NEAR WILLOW SPRINGS, IL											196	341	442	571	670	767	986
19	O	7	Y	9.29	16.50	14.00	1.70	3.5	20.2	8.00	701	1200	1580	2100	2530	2980	4130
05533300 WARDS CREEK NEAR WOODRIDGE, IL											66	118	155	203	241	278	364
15	O	1	N	4.22	3.21	16.90	1.70	5.0	7.2		75	117	147	186	217	249	327

APPENDIX 1._SELECTED DATA FOR STATIONS USED IN NATIONWIDE URBAN FLOOD-FREQUENCY STUDY (CONTINUED).

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05533400 SAWMILL CREEK NEAR LEMONT, IL											159	277	361	468	550	631	814
18	0	2	N	6.31	12.00	14.60	1.70	7.0	10.3	.	530	873	1130	1470	1750	2030	2750
05534500 NORTH BRANCH CHICAGO RIVER AT DEERFIELD, IL											156	254	319	399	460	517	648
19	0	4	N	16.10	19.70	3.24	1.70	3.5	8.5	20.10	282	382	445	524	581	637	765
05535000 SKOKIE RIVER AT LAKE FOREST, IL											133	223	284	361	419	475	603
19	0	3	N	10.30	13.00	5.58	1.70	3.8	15.0	11.50	197	287	348	425	483	541	680
05535500 WEST FK OF N BR CHICAGO RIVER AT NORTHBROOK, IL											111	182	231	291	336	379	478
19	0	5	N	8.37	11.50	3.69	1.70	4.2	11.6	10.00	440	601	705	833	927	1020	1230
05536000 NORTH BRANCH CHICAGO RIVER AT NILES, IL											474	747	927	1150	1310	1460	1800
19	0	6	N	29.10	100.00	2.94	1.70	2.6	17.9	15.70	1120	1430	1610	1830	1980	2130	2460
05536207 THORN CREEK TRIB AT CHICAGO HEIGHTS, IL											69	122	160	208	245	282	366
14	0	3	Y	4.44	3.87	12.30	1.70	8.0	35.1	.	289	487	635	839	1000	1170	1610
05536215 THORN CREEK AT GLENWOOD, IL											268	463	601	775	911	1040	1340
19	0	2	Y	10.50	24.70	15.70	1.70	2.9	23.1	5.70	1010	1490	1830	2260	2580	2910	3700
05536255 BUTTERFIELD CREEK AT FLOSSMOOR, IL											208	346	441	559	649	735	929
19	0	2	U	13.90	23.50	6.34	1.70	1.9	12.4	14.20	572	960	1250	1650	1970	2310	3160
05536275 THORN CREEK AT THORNTON, IL											667	1110	1420	1790	2090	2360	2970
19	0	2	N	15.40	104.00	10.80	1.70	2.5	13.5	19.60	1670	2440	2960	3630	4130	4640	5830
05536310 CALUMET UNION DRAINAGE CANAL NEAR MARKHAM, IL											171	301	392	509	601	690	892
16	0	6	Y	6.20	12.60	17.20	1.70	1.0	19.2	.	297	392	452	525	578	629	746
05536340 MIDLOTHIAN CREEK AT OAK FOREST, IL											144	245	315	403	470	536	684
19	0	2	Y	9.72	12.60	8.33	1.70	3.2	12.6	18.40	238	321	373	438	485	531	637
05536500 TINLEY CREEK NEAR PALOS PARK, IL											143	247	321	413	485	555	713
19	0	1	N	9.56	11.20	11.50	1.70	5.0	7.4	8.70	470	755	962	1240	1460	1690	2250
05536510 NAVAJO CREEK AT PALOS HEIGHTS, IL											50	94	126	169	203	237	315
18	0	2	U	2.00	1.69	35.80	1.70	1.0	16.9	.	239	318	369	431	475	519	619
05536560 MELVINA DITCH NEAR OAK LAWN, IL											74	125	161	205	239	272	348
17	0	9	Y	3.12	5.58	5.60	1.70	1.0	37.2	.	126	209	272	357	425	496	675
05536570 STONY CREEK (WEST) AT WORTH, IL											186	315	404	516	602	685	873
15	0	6	U	6.42	18.00	8.60	1.70	0.0	38.7	.	404	708	942	1270	1540	1830	2570
05536620 MILL CREEK NEAR PALOS PARK, IL											89	153	198	254	298	340	437
17	0	3	N	4.73	6.39	8.19	1.70	11.0	9.3	.	119	184	230	292	339	387	506

APPENDIX 1._SELECTED DATA FOR STATIONS USED IN NATIONWIDE URBAN FLOOD-FREQUENCY STUDY (CONTINUED).

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05539900 WEST BRANCH DU PAGE RIVER NEAR WEST CHICAGO, IL											240	399	508	643	746	845	1070
18	0	5	Y	14.10	28.50	6.58	1.70	2.0	10.0	19.50	407	589	712	869	986	1100	1380
05539950 KLEIN CREEK AT CAROL STREAM, IL											105	177	227	290	338	384	490
18	0	0	Y	5.20	8.81	6.32	1.70	1.0	6.9	.	184	289	364	463	539	619	813
05540060 KRESS CREEK AT WEST CHICAGO, IL											170	283	360	457	530	601	760
18	0	0	U	7.53	18.10	5.84	1.70	2.0	6.9	.	258	368	442	536	605	675	839
06540080 SPRING BROOK AT WHEATON, IL											48	86	113	149	176	203	267
18	0	6	Y	2.78	2.10	15.40	1.70	0.0	30.0	.	154	222	268	326	369	412	515
05540160 EAST BRANCH DU PAGE RIVER NEAR DOWNERS GROVE, I											213	349	442	555	642	724	909
16	0	0	N	10.80	27.20	4.61	1.70	1.0	19.8	.	562	881	1110	1410	1640	1890	2480
05540190 ST. JOSEPH CREEK AT BELMONT, IL											115	198	256	329	386	440	566
17	0	2	Y	5.83	8.80	9.38	1.70	2.0	29.3	.	336	515	641	806	933	1060	1380
05540240 PRENTISS CREEK NEAR LISLE, IL											112	200	264	345	409	472	616
18	0	0	N	5.96	6.48	20.40	1.70	2.0	16.6	.	206	322	405	514	598	685	898
05540500 DU PAGE RIVER AT SHOREWOOD, IL											1190	1870	2320	2860	3270	3650	4480
19	0	0	N	52.60	324.00	4.38	1.70	0.8	6.0	43.30	3050	4720	5900	7450	8650	9880	12900
05549850 FLINT CREEK NEAR FOX RIVER GROVE, IL											302	504	643	816	948	1080	1360
17	0	0	N	14.70	37.00	7.99	1.70	11.0	5.4	.	251	312	349	392	423	452	516
05550430 EAST BRANCH POPLAR CREEK NR PALATINE IL											59	107	141	185	220	255	335
17	0	0	N	3.75	2.63	19.20	1.70	3.0	13.2	.	83	129	162	205	239	273	358
05550470 POPLAR CREEK TRIB NEAR BARTLETT, IL											75	131	170	220	259	297	385
18	0	3	N	4.29	4.55	10.60	1.70	6.0	23.4	.	159	238	292	363	417	471	602
05550500 POPLAR CREEK AT ELGIN, IL											300	505	646	822	958	1090	1380
19	0	0	N	16.40	35.20	9.08	1.70	5.6	8.1	31.40	382	580	718	899	1040	1180	1520
05551530 INDIAN CREEK AT AURORA, IL											182	311	400	513	599	683	873
18	0	1	Y	8.66	16.70	9.82	1.70	2.0	8.3	.	507	645	730	830	902	970	1120
COLUMBUS OHIO																	
03221900 DRY RN AT COLUMBUS OH											174	307	405	544	648	763	1040
13	0	9	N	2.84	1.91	26.00	1.50	0.0	45.0	.	489	651	754	880	970	1060	1260
03226900 FISHINGER AND KENNY C AT UPPER ARLINGTON OH											80	147	197	270	325	386	538
14	0	12	N	0.97	0.45	76.00	1.50	0.0	60.0	0.27	252	322	365	417	454	489	568

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DALLAS TEXAS																	
08055600 JOES CREEK AT DALLAS,TEXAS											2210	3920	5090	6620	7700	8800	12000
10	O,S	11	N	6.42	7.51	31.00	2.30	0.5	35.0	0.80	2100	3070	3720	4550	5170	5790	7430
08055700 BACHMAN BRANCH AT DALLAS, TEX.											2870	5150	6720	8830	10300	11900	16000
10	O,S	6	N	6.32	10.00	31.60	2.30	0.2	30.0	1.10	3630	5700	7160	9040	10500	12000	15400
08056500 TURTLE CREEK AT DALLAS, TEX.											2350	4180	5440	7090	8270	9460	13000
31	O,S	9	N	5.30	7.98	36.30	2.30	1.0	47.0	0.90	3140	5010	6340	8080	9420	10800	14100
08057020 COOMBS CRK AT SYLVAN AVE,DALLAS,TEXAS											1610	2890	3760	4870	5650	6420	8500
13	O,S	8	N	4.58	4.75	45.20	2.30	1.0	43.0	0.60	2360	3530	4330	5360	6140	6930	8580
08057050 CEDAR CR AT BONNIE VIEW RD., DALLAS, TEX.											2790	5020	6570	8630	10100	11600	15000
13	O,S	3	N	6.09	9.42	38.90	2.30	0.5	45.0	0.80	4840	7110	8620	10500	11900	13200	16300
08057140 COTTONWOOD CREEK AT FOREST LANE, DALLAS, TEX											2430	4320	5620	7320	8540	9770	13000
16	O,S	5	N	7.04	8.50	32.10	2.30	1.0	30.0	0.80	3390	6110	8240	11300	13800	16400	23000
08057160 FLOYD BRANCH AT FORREST LANE, DALLAS, TEX.											1400	2480	3210	4130	4770	5400	6800
16	O,S	3	N	4.84	4.17	38.60	2.30	1.0	26.0	0.80	2060	3390	4350	5600	6560	7540	9960
08057200 WHITE ROCK CREEK AT GREENVILLE AVE., DALLAS, TE											11300	20100	26300	35400	42300	49600	67000
16	O,S	3	N	21.90	66.40	12.00	2.30	1.0	10.0	3.20	12100	21200	28300	38200	46300	54800	76700
08057320 ASH CREEK AT HIGHLAND ROAD, DALLAS, TEX.											2240	4050	5290	6930	8100	9270	13000
14	O,S	4	N	4.44	6.92	38.00	2.30	0.2	38.0	0.70	3080	5330	7010	9310	11100	13000	17800
08057420 FIVEMILE CR AT US HWY 77M DALLAS, TEX.											3510	6280	8200	10800	12700	14600	19000
13	O,S	4	N	8.22	13.20	32.10	2.30	1.0	21.0	1.00	4910	8230	10600	13900	16300	18900	24900
08057425 WOODY BRANCH AT US HWY 77, DALLAS, TEX.											3350	6070	7970	10500	12400	14300	19000
13	O,S	2	N	6.12	11.50	40.10	2.30	1.0	13.0	1.00	3990	6010	7440	9280	10700	12100	15700
08061540 ROWLETT CREEK NEAR SACHSE, TEX.											4440	9380	13700	19900	25100	30900	47000
9	O	0	N	26.20	120.00	8.96	2.30	1.0	6.0	10.00	9330	21700	33200	51400	67700	86200	138700
DENVER COLORADO																	
06710200 BIG DRY CREEK TRIB AT LITTLETON, CO											162	318	478	780	1080	1470	2850
10	O,S	5	N	2.42	0.95	90.00	1.20	0.0	29.0	0.47	150	272	371	519	647	789	1170
06711580 HARVARD GULCH TRIB AT ENGLEWOOD, CO											130	248	373	600	818	1090	2050
8	O,S	4	N	1.74	0.72	48.00	1.20	0.0	26.0	0.33	118	248	356	520	655	827	1310

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06711600 SANDERSON GULCH TRIB AT LAKEWOOD,CO											82	146	211	320	429	550	990
10	O,S	6	N	1.04	0.38	79.00	1.20	0.0	40.0	0.35	120	249	364	540	698	853	1260
06714300 CONCOURSE D STM DRN AT STAPLTON AIRPT DENV, CO											42	68	92	133	168	204	330
8	O,S	3	N	0.88	0.12	21.00	1.20	0.0	98.0	0.27	87	179	250	344	408	491	706
06714310 SAND CREEK TRIB AT DENVER, CO											68	118	166	250	327	412	710
8	O,S	11	N	0.65	0.29	32.00	1.20	0.0	43.0	0.19	80	142	189	254	305	365	520
DETROIT MICHIGAN																	
04162900 BIG BEAVER CREEK NEAR WARREN, MICH.											710	1100	1350	1700	1950	2250	2950
24	O	9	U	8.40	23.50	15.30	0.18	0.1	27.0	11.00	513	737	891	1090	1240	1400	1770
04163400 PLUM BROOK AT UTICA, MICH.											284	450	570	730	850	1000	1300
12	O	9	U	9.80	16.50	24.10	0.18	2.1	23.0	12.00	361	583	749	978	1160	1360	1860
DULUTH MINNESOTA																	
04015400 MILLER CREEK AT DULUTH, MN											124	209	277	370	452	529	740
18	O	1	N	3.95	4.92	28.00	1.50	8.0	7.0	.	218	312	376	459	522	587	742
FLAGSTAFF ARIZONA																	
09400700 SWITZER CANYON TRIB AT FLAGSTAFF, ARIZ.																	
10	O	0	Y	2.00	1.20	104.00	0.95	0.0	31.0	.	68	133	189	274	349	433	673
09400740 HARENBERG WASH AT FLAGSTAFF,ARIZ.																	
9	O	1	Y	3.10	2.41	594.00	0.95	0.0	9.0	.	63	121	171	246	312	386	593
FT WORTH TEXAS																	
08047200 WEST CR AT BILGLADE RD AT FORT WORTH, TEX (DISC											209	376	483	602	676	744	910
9	O	9	N	0.85	0.31	119.00	2.20	0.1	48.0	0.25	282	493	651	868	1040	1220	1670
HARRISBURG PENNSYLVANIA																	
01571000 PAXTON CREEK NEAR PENBROOK, PA.											470	930	1340	1940	2480	3120	4900
11	O	2	N	5.00	11.20	36.60	1.65	0.0	4.0	8.00	1170	1610	1890	2250	2520	2780	3420
HARTFORD CONNECTICUT																	
01190200 MILL BK AT NEWINGTON, CT.											82	180	230	335	420	497	750
16	O	6	N	2.60	2.65	25.10	1.60	0.0	56.0	4.50	166	281	382	542	688	860	1390
01191000 NORTH BRANCH PARK R AT HARTFORD, CT											605	1200	1650	2490	3380	4700	8100
27	O	4	N	11.30	25.10	39.20	1.60	0.0	24.0	14.40	1240	2160	2990	4340	5600	7110	11900

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HATTIESBURG MISSISSIPPI																	
02473047 GORDON C AT HATTIESBURG, MS											1170	1900	2440	3200	3850	4430	6000
9	0	4	N	7.30	8.83	21.90	2.70	0.0	21.0	2.50	2210	2890	3290	3740	4040	4320	4910
HILO HAWAII																	
16701400 PALAI STREAM AT HILO, HAWAII, HI																	
11	0	2	N	8.06	5.08	291.00	4.30	0.0	11.0	.	459	621	732	878	989	1100	1390
HONOLULU HAWAII																	
16229300 KALIHI STREAM AT KALIHI, OAHU, HI											1590	3010	4180	5910	7370	8980	13500
16	0	4	N	5.37	5.18	189.00	2.10	0.0	25.0	.	3280	5150	6580	8610	10300	12100	17000
16235400 WAOLANI STREAM AT HONOLULU, OAHU, HI											472	924	1310	1890	2390	2940	4500
19	0	3	N	2.30	1.28	460.00	2.10	0.0	28.0	.	778	1340	1800	2490	3090	3760	5660
16237500 PAUOA STREAM AT HONOLULU, OAHU, HI											439	869	1240	1800	2280	2830	4400
20	0	5	N	3.10	1.43	492.00	2.10	0.0	27.0	.	409	753	1050	1510	1930	2410	3810
16247000 PALOLO STREAM NEAR HONOLULU, OAHU, HI											1190	2270	3170	4500	5630	6880	10500
25	0	5	N	3.90	3.63	233.00	2.00	0.0	21.0	.	1240	2110	2820	3870	4770	5780	8610
16247100 MANOA-PALOLO DR CANAL AT MOILIILI,OAHU, HI											2060	3920	5470	7760	9710	11900	18000
10	0	8	N	5.48	9.35	312.00	2.00	0.0	38.0	.	3540	5550	7100	9300	11100	13100	18400
HOUSTON TEXAS																	
08074150 COLE CREEK AT DEIHL ROAD AT HOUSTON TX											501	692	813	979	1100	1220	1510
14	0,S	3	N	5.50	8.81	5.90	2.80	0.5	4.1	2.00	833	1370	1760	2310	2750	3200	4350
08074200 BRICKHOUSE GULLY AT CLARBLAK ST AT HOUSTON TX											188	251	289	339	375	409	491
13	0,S	7	N	2.60	2.56	4.80	2.80	0.5	3.5	2.00	228	349	435	550	636	728	946
08074250 BRICKHOUSE GULLY AT COSTA RICA AT HOUSTON TX											613	854	1010	1220	1380	1530	1910
13	0,S	8	N	6.10	11.40	7.40	2.80	0.4	10.5	2.00	2270	3670	4720	6180	7340	8560	11600
08074500 WHITEOAK BAYOU AT HOUSTON TX											2820	4150	5050	6330	7340	8340	11000
12	0,S	9	N	21.80	84.70	4.90	2.80	0.2	9.0	2.50	7410	11300	14100	17800	20700	23600	31000
08074800 KEEGANS BAYOU AT ROARK ROAD AT HOUSTON, TX											635	886	1050	1270	1430	1590	1990
13	0,S	6	N	9.90	12.00	3.00	2.80	1.0	2.1	1.60	750	1030	1220	1450	1610	1780	2160
08074850 BINTLIFF DITCH BISSONNET ST HOUSTON TX											281	381	442	524	584	641	781
10	0,S	12	N	3.80	4.29	3.90	2.80	0.2	25.8	0.70	1040	1230	1350	1490	1600	1700	1930

APPENDIX 1._SELECTED DATA FOR STATIONS USED IN NATIONWIDE URBAN FLOOD-FREQUENCY STUDY (CONTINUED).

GAGING STATION NUMBER AND NAME / N YEARS	TYPE	BDF	DTS	L (MI)	A (SQ MI)	SL (FT/MI)	RI2 (IN)	ST (%)	IA (%)	LT (HRS)	RQ2 / UQ2 (CFS)	RQ5 / UQ5 (CFS)	RQ10 / UQ10 (CFS)	RQ25 / UQ25 (CFS)	RQ50 / UQ50 (CFS)	RQ100 / UQ100 (CFS)	RQ500 / UQ500 (CFS)
08075000 BRAYS BAYOU AT HOUSTON, TEX.											3030	4470	5440	6850	7950	9040	11900
13	O,S	11	N	19.50	94.90	3.18	2.80	0.5	15.0	2.00	11500	17600	21900	27500	31900	36400	47400
08075400 SIMS BAYOU AT HIRAM CLARKE ST AT HOUSTON TX											951	1350	1600	1960	2230	2490	3150
12	O,S	5	N	7.10	20.20	5.20	2.80	1.0	5.3	2.70	2070	2980	3600	4410	5020	5640	7160
08075500 SIMS BAYOU AT HOUSTON TX											2260	3300	4000	4990	5760	6530	8520
13	O,S	9	N	15.30	64.00	3.20	2.80	0.6	11.0	4.40	4340	6940	8840	11400	13400	15600	21000
08075550 BERRY BAYOU AT GILPIN ST AT HOUSTON TX											206	277	319	376	416	455	548
11	O,S	6	N	2.00	2.87	3.90	2.80	0.5	12.0	1.10	456	590	672	770	838	905	1050
08075650 BERRY BAYOU AT FOREST OAKS ST. AT HOUSTON, TEX.											558	775	913	1100	1240	1380	1710
14	O,S	8	N	4.60	10.10	8.50	2.80	0.4	14.5	1.60	1840	2930	3720	4780	5610	6460	8550
08075730 VINCE BAYOU AT PASADENA,TX											474	654	768	923	1040	1150	1420
	S	9	N	5.70	8.21	4.60	2.80	0.1	35.5	0.70	2170	2920	3420	4050	4530	5000	6130
08075760 HUNTING BAYOU FALLS ST HOUSTON TX											199	266	307	361	400	437	525
13	O,S	4	N	1.40	2.75	8.80	2.80	0.2	21.0	1.50	491	666	779	923	1030	1130	1380
08075770 HUNTING BAYOU AT I-H 610 AT HOUSTON, TX											743	1040	1230	1500	1700	1890	2370
14	O,S	6	N	5.00	14.70	3.20	2.80	0.2	14.8	3.00	1250	2150	2850	3850	4660	5520	7750
08075780 GREENS BAYOU AT CUTTEN ROAD AT HOUSTON TX											336	456	531	634	710	784	969
12	O,S	1	N	4.80	8.73	5.10	2.80	0.2	1.9	3.70	314	465	572	716	832	952	1260
08075900 GREENS BAYOU AT US HWY 75 AT HOUSTON TX											1460	2090	2510	3100	3550	4000	5140
11	O,S	2	N	12.50	36.10	4.80	2.80	1.0	3.0	4.40	1900	2670	3210	3950	4530	5150	6750
08076000 GREENS BAYOU NEAR HOUSTON, TEX.											2420	3530	4280	5360	6190	7020	9180
13	O,S	3	N	17.30	69.60	4.40	2.80	0.8	3.0	8.00	3380	4850	5860	7180	8200	9240	11900
08076200 HALLS BAYOU AT DEERTRAIL ST AT HOUSTON TX											495	684	804	967	1090	1200	1490
12	O,S	1	N	4.70	8.69	6.80	2.80	0.2	3.6	2.30	638	865	1020	1210	1340	1480	1830
08076500 HALLS BAYOU AT HOUSTON, TEX.											1230	1750	2090	2570	2940	3300	4220
17	O,S	6	N	19.00	28.30	4.41	2.80	0.2	7.0	4.80	2060	2750	3190	3750	4170	4600	5610
08076700 GREENS BAYOU AT LEY RD AT HOUSTON TX											5060	7590	9340	11900	13900	16000	21400
	S	6	N	33.50	182.00	3.60	2.80	1.0	5.0	15.00	5760	8710	10900	14000	16600	19300	26600
08077100 CLEAR CREEK TRIB AT HALL ROAD, HOUSTON, TEX											120	158	180	209	229	248	294
13	O,S	7	N	1.70	1.33	5.00	2.80	0.1	8.5	1.50	246	336	393	466	517	570	687
INDIANA PENNSYLVANIA																	
03042170 STONEY RUN AT INDIANA, PA.											258	415	538	708	850	1000	1400
13	O	6	Y	2.60	4.39	38.50	1.43	0.0	19.0		294	392	456	536	594	653	789

APPENDIX 1._SELECTED DATA FOR STATIONS USED IN NATIONWIDE URBAN FLOOD-FREQUENCY STUDY (CONTINUED).

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INDIANAPOLIS INDIANA																	
03352000 LAWRENCE CREEK AT F BENJAMIN HARRISON, IND.											327	583	788	1060	1330	1640	2400
18	0	5	N	2.40	2.74	5.00	1.70	0.0	15.0	2.05	546	944	1240	1620	1920	2220	2960
03353160 PLEASANT RN AT BROOKVILLE RD AT INDPLS, IND.											712	1190	1570	2030	2490	2960	4100
18	0	6	Y	7.30	10.10	15.80	1.70	0.0	15.5	3.72	1160	1640	1930	2290	2550	2800	3340
IOWA CITY IOWA																	
05455010 SOUTH BRANCH RALSTON CREEK AT IOWA CITY, IOWA											390	766	1060	1460	1780	2090	2910
16	0	5	N	3.80	2.94	23.10	1.84	0.0	15.0	.	420	748	985	1300	1530	1770	2330
JACKSON MISSISSIPPI																	
02485800 EUBANKS CREEK AT JACKSON, MISS.											752	1190	1490	1950	2290	2720	3700
19	0	4	Y	3.50	3.91	23.90	2.50	0.0	33.0	1.50	2180	2610	2850	3110	3280	3430	3740
02485950 TOWN CREEK AT JACKSON, MS.											1340	2170	2780	3720	4450	5340	7400
25	0	4	Y	6.70	11.40	14.20	2.50	0.0	29.0	3.00	2800	3430	3780	4170	4420	4650	5120
02486100 LYNCH CREEK AT JACKSON, MISS.											1450	2380	3050	4080	4880	5830	8100
25	0	4	Y	6.50	12.00	15.50	2.50	0.0	27.0	2.50	3670	5050	5880	6850	7520	8140	9470
02486115 THREE MILE CREEK AT JACKSON, MS											349	524	642	807	939	1070	1400
16	0	0	Y	1.78	1.12	44.40	2.50	0.0	29.0	0.80	1230	1510	1660	1840	1950	2050	2270
KANEOHE HAWAII																	
16274499 KEAAHALA STR AT KAMEHAMEHA HWY KANEOHE, OAHU,HI											430	921	1370	2070	2700	3430	5500
19	0	7	N	1.95	0.62	212.00	2.70	0.0	29.0	.	474	1150	1870	3190	4530	6260	12200
LENOIR NORTH CAROLINA																	
02141150 LOWER CREEK AT MULBERRY ST AT LENOIR, N. C.											1530	2460	3210	4320	5240	6340	9100
11	0	4	U	9.40	31.80	17.70	1.90	0.0	13.0	2.42	1390	2090	2630	3410	4070	4790	6780
LOUISVILLE KENTUCKY																	
03292500 SOUTH FORK BEARGRASS CREEK AT LOUISVILLE, KY.											1010	1610	2030	2580	2990	3420	4380
38	0	6	N	8.90	17.00	19.40	1.70	0.1	25.0	3.00	1070	2020	2870	4210	5440	6880	11200
03292785 MIDDLE FORK BEARGRASS AT ST MATHEWS											516	841	1070	1370	1590	1830	2360
24	0	2	Y	5.10	6.59	29.00	1.70	0.0	10.0	3.00	803	1360	1820	2530	3140	3840	5870
03293000 MIDDLE FORK BEARGRASS CR AT LOUISVILLE,KY.											1060	1690	2130	2710	3140	3850	4590
33	0	4	N	9.60	18.30	18.50	1.70	0.0	15.0	3.00	1370	2110	2700	3550	4260	5050	7240

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03302000 POND CREEK NEAR LOUISVILLE, KY.											2550	3990	4980	6250	7200	8180	10400
33	O	6	N	15.40	64.00	11.70	1.70	0.6	12.0	3.00	2510	3730	4640	5930	6990	8130	11200
NASHVILLE TENNESSEE																	
03430400 MILL CREEK AT NOLENSVILLE, TN											1970	3100	3920	5000	5850	6720	8780
13	O,S	0	N	4.34	12.00	30.60	1.88	0.1	3.0	1.70	3640	5350	6620	8360	9720	11100	14100
03431000 MILL CREEK NEAR ANTIOCH, TN											6730	10400	13200	16700	19500	22400	29400
24	O,S	1	N	17.00	64.00	11.40	1.88	0.0	4.2	5.40	6390	10100	13000	17100	20100	23100	30800
03431080 SIMS BRANCH AT ELM HILL PIKE NEAR DONELSON,TN											868	1380	1750	2240	2610	3000	3910
	S	1	N	3.03	3.92	57.80	1.87	0.5	22.4	1.10	766	1320	1710	2180	2520	2850	3420
03431120 W F BROWNS C AT GEN BATES DR, AT NASHVILLE, TEN											765	1220	1540	1970	2310	2650	3450
13	O,S	0	N	3.35	3.30	77.00	1.87	0.0	22.3	0.90	915	1620	2220	3100	3810	4510	6380
03431240 E F BROWNS C AT BAIRD-WARD P CO, NASHVILLE, TEN											446	713	906	1160	1360	1560	2030
13	O,S	6	Y	2.36	1.58	65.60	1.87	0.0	37.3	1.10	217	320	405	546	689	864	1230
03431340 BROWNS CREEK AT FACTORY STREET AT NASHVILLE TEN											2110	3320	4200	5360	6260	7190	9400
13	O,S	7	N	6.51	13.20	42.60	1.87	0.0	31.5	1.90	1900	2640	3230	4180	5110	6230	8410
03431520 CLAYLICK CREEK AT LICKTON, TN											902	1430	1820	2320	2710	3120	4060
13	O,S	0	N	3.40	4.13	69.30	1.85	0.1	8.2	1.50	796	1470	2030	2850	3480	4090	6210
03431580 EWING CREEK AT KNIGHT ROAD, NEAR BORDEAUX, TENN											2130	3340	4230	5390	6300	7230	9460
13	O,S	2	N	4.50	13.30	46.70	1.86	0.3	14.2	2.00	3020	4230	5140	6500	7680	8950	11100
03431600 WHITES CRK AT TUCKER ROAD NR BORDEAUX,TN											5740	8930	11300	14300	16700	19200	25200
11	O,S	1	N	11.10	51.60	21.50	1.86	0.1	8.0	3.50	4970	8000	10500	14300	17600	20900	27000
03431630 RICHLAND C AT LYNNWOOD BLVD AT BELLE MEADE, TEN											570	910	1150	1480	1730	1990	2580
9	O,S	0	N	2.20	2.21	119.00	1.88	0.0	11.7	1.30	302	545	752	1070	1340	1610	2200
03431650 VAUGHNS GAP BR AT PERCY WARNER BELLE MEADE, TEN											653	1040	1320	1690	1980	2270	2950
11	O,S	4	N	2.38	2.66	83.30	1.87	0.2	14.9	0.70	543	878	1170	1640	2080	2580	3450
03431700 RICHLAND C AT CHARLOTTE AVE., AT NASHVILLE, TEN											3310	5170	6540	8310	9720	11200	14600
13	O,S	3	N	7.90	24.30	33.00	1.87	0.0	21.3	2.40	2860	4610	5990	7990	9580	11200	14700
NATCHEZ MISSISSIPPI																	
07290910 SPANISH BAYOU AT NATCHEZ, MS											503	781	975	1260	1490	1730	2300
11	O	4	N	3.70	2.46	27.90	2.60	0.0	27.0	1.20	1140	1560	1830	2150	2380	2600	3100

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NEW YORK NEW YORK																	
01376500 SAW MILL RIVER AT YONKERS, N Y											729	1100	1390	1830	2190	2590	3600
31	O	6	Y	21.50	25.60	13.70	1.70	1.8	8.3	12.30	434	573	670	797	896	999	1260
NEWARK NEW JERSEY																	
01392500 SECOND R AT BELLEVILLE NJ											416	663	943	1310	1650	2100	3560
41	O	12	N	6.20	11.60	47.80	1.80	0.9	30.0		1950	2840	3510	4430	5190	6000	8160
01393500 ELIZABETH R AT ELIZABETH NJ											776	1210	1700	2320	2900	3680	6180
57	O	10	N	8.20	18.00	23.60	1.80	0.1	35.0	9.00	1520	2330	2910	3680	4280	4890	6400
01395000 RAHWAY R AT RAHWAY NJ											984	1520	2120	2860	3600	4530	7590
57	O	7	Y	19.20	40.90	9.90	1.80	0.5	20.0	19.00	1250	2060	2730	3760	4680	5720	8790
01396000 ROBINSONS BRANCH RAHWAY RIVER AT RAHWAY NJ											252	403	571	793	1020	1290	2200
39	O	7	N	7.10	21.60	11.40	1.80	5.6	20.0	12.00	1020	1550	1950	2530	3020	3540	4970
OKLAHOMA CITY OKLAHOMA																	
07159450 BLUFF CREEK AT OKC, OK											220	460	660	970	1260	1560	2400
.	S	8	Y	2.10	1.64	65.70	2.10	7.0	40.0	1.02	551	893	1140	1480	1750	2030	2720
07242200 DEEP FORK AT PORTLAND AV AT OKC, OK											397	808	1200	1740	2190	2780	4190
.	S	12	N	3.00	2.93	44.00	2.10	1.0	46.0	0.95	1760	2580	3130	3820	4320	4820	5980
07242220 DEEP FORK AT EASTERN AV AT OKC OK											1480	3010	4480	6610	8290	10500	16100
.	S	9	N	12.20	28.20	19.90	2.10	1.0	31.0	3.48	5410	8470	10700	13700	16100	18600	24800
ORANGE COUNTY CALIFORNIA																	
11048500 SAN DIEGO CREEK AT JEFFERY RD NR IRVINE CALIF											144	590	1180	2610	4100	5830	11000
13	O	1	Y	11.30	40.30	90.50	0.80	0.3	6.3	.	1270	2410	3360	4800	6040	7420	11300
PATERSON-CLIF-PASS NEW JERSEY																	
01377475 MUSQUAPSINK BK NR WESTWOOD NJ											67	111	160	231	296	384	676
14	O	6	N	2.80	2.12	72.70	1.70	3.0	25.0	.	389	691	951	1360	1720	2150	3410
01378350 TENAKILL BK AT CRESSKILL NJ											120	187	261	369	475	615	1080
14	O	6	Y	2.20	3.01	9.40	1.80	0.0	40.0	.	167	195	214	236	252	267	304
01378590 METZLER BK AT ENGLEWOOD NJ											90	144	203	292	373	485	855
14	O	8	N	3.10	1.54	33.20	1.80	0.0	50.0	.	218	291	342	409	461	515	649

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01378615 WOLF C AT RIDGEFIELD NJ											101	165	236	340	430	562	979
14	0	11	Y	1.90	1.18	137.00	1.80	0.0	40.0	.	341	486	592	738	856	981	1310
01389900 FLEISCHER BK AT MARKET ST AT ELMWOOD PARK NJ											64	102	143	206	266	347	617
12	0	6	Y	2.70	1.37	19.00	1.80	0.0	55.0	.	178	245	292	357	407	460	595
01390450 SADDLE R AT UPPER SADDLE RIVER NJ											305	497	717	1000	1260	1610	2740
13	0	6	N	4.20	10.90	91.10	1.70	3.0	10.0	.	1420	2680	3800	5630	7320	9330	15500
01391000 HOHOKUS BK AT HOHOKUS NJ											254	411	589	822	1050	1330	2280
25	0	4	Y	8.50	16.40	30.20	1.70	5.5	15.0	6.00	958	1610	2140	2950	3650	4450	6740
01391500 SADDLE R AT LODI NJ											766	1210	1730	2350	2960	3720	6230
55	0	6	N	17.30	54.60	19.30	1.80	4.0	10.0	10.00	1280	2090	2750	3720	4550	5490	8100
01392000 WEASEL BK AT CLIFTON NJ											269	429	611	861	1080	1390	2380
29	0	12	Y	2.90	3.92	93.00	1.80	0.4	40.0	.	468	666	812	1010	1170	1350	1800
PEARL CITY HAWAII																	
16216500 WAIMANO FLOOD CHANNEL AT PEARL CITY, OAHU, HI											351	726	1060	1580	2050	2580	4000
12	0	5	N	5.10	2.63	152.00	2.00	0.0	21.0	.	256	570	883	1420	1960	2160	4770
PHILADELPHIA PENNSYLVANIA																	
01465770 POQUESSING CREEK AT TREVOSE ROAD, PHILA., PA.											600	1200	1740	2550	3320	4240	6700
13	0	6	N	2.30	5.08	42.60	1.85	0.0	16.7	2.28	721	945	1090	1280	1420	1550	1880
01467043 STREAM 'A' AT PHILADELPHIA, PA.											190	380	543	786	1020	1290	2100
13	0	6	N	2.01	1.20	67.60	1.85	0.0	17.0	0.40	261	457	615	849	1050	1270	1880
01467045 PENNYPACK CREEK BELOW VEREE ROAD AT PHILA., PA.											2300	4000	5260	7030	8550	10200	14500
13	0	4	N	14.00	42.80	17.10	1.85	0.0	16.3	.	2830	4020	4860	5950	6790	7670	9820
01474000 WISSAHICKON CREEK AT MOUTH, PHILADELPHIA, PA.											3100	5300	6980	9310	11300	13500	19000
12	0	6	N	24.70	64.00	13.60	1.85	0.0	20.3	.	3640	4400	4860	5420	5820	6210	7100
01475510 DARBY CREEK NEAR DARBY, PA.											2100	3600	4790	6400	7780	9320	13000
13	0	4	N	17.80	37.40	20.90	1.85	0.0	14.0	3.50	3110	4540	5550	6900	7950	9050	11800
01475530 COBBS CR AT U.S. HGHWY NO. 1 AT PHILA., PA.											560	1150	1650	2430	3160	4040	6300
13	0	6	N	4.27	4.78	62.50	1.85	0.0	23.0	2.00	837	1570	2200	3170	4020	4990	7780
01475550 COBBS CREEK AT DARBY, PA.											1500	2500	3300	4420	5380	6450	9100
13	0	8	N	11.10	22.00	31.40	1.85	0.0	33.0	3.20	2770	4000	4860	6000	6890	7800	10100

APPENDIX 1._SELECTED DATA FOR STATIONS USED IN NATIONWIDE URBAN FLOOD-FREQUENCY STUDY (CONTINUED).

GAGING STATION NUMBER AND NAME / N YEARS	TYPE	BDF	DTS	L (MI)	A (SQ MI)	SL (FT/MI)	RI2 (IN)	ST (%)	IA (%)	LT (HRS)	RQ2 / UQ2 (CFS)	RQ5 / UQ5 (CFS)	RQ10 / UQ10 (CFS)	RQ25 / UQ25 (CFS)	RQ50 / UQ50 (CFS)	RQ100 / UQ100 (CFS)	RQ500 / UQ500 (CFS)
PITTSBURG PENNSYLVANIA																	
03084000 ABERS CREEK NEAR MURRYSVILLE, PA.											210	360	478	640	783	928	1300
10	O	1	N	3.55	4.39	73.80	1.42	0.2	7.2	3.40	524	760	923	1140	1300	1460	1870
PORTLAND-VANCOUVER OREGON																	
14142580 KELLY CR AT KANE RD NR GRESHAM ORE											177	270	339	435	513	596	799
.	S	5	N	4.70	4.16	48.00	0.80	0.1	9.0	4.96	272	430	551	720	859	1010	1400
14144690 VANCOUVER SEWER OUTFALL AT VANCOUVER WA											39	61	77	100	120	140	192
.	S	12	N	2.20	1.00	108.00	0.60	0.0	49.0	0.35	126	206	260	330	381	432	547
14206320 BEAVERTON CR AT BEAVERTON ORE											187	294	383	501	597	701	966
.	S	6	Y	5.70	6.63	150.00	0.52	2.0	23.0	14.00	325	477	575	694	779	862	1050
14206330 BEAVERTON CR TRIB AT BEAVERTON ORE											9	15	18	24	29	34	46
.	S	8	N	0.62	0.21	180.00	0.52	1.1	19.0	0.43	12	19	24	33	42	51	81
14206470 BUTTERNUT CR AT ALOHA ORE											30	48	61	80	95	112	153
.	S	3	N	2.40	0.82	240.00	0.52	0.3	8.0	3.00	52	76	93	113	128	144	179
14206900 FANNO CR AT PORTLAND ORE											82	128	165	215	256	300	409
.	S	7	N	2.50	2.37	200.00	0.57	0.0	32.0	1.87	213	308	374	460	526	592	750
14207800 SINGER CR AT OREGON CITY ORE											16	24	30	38	46	53	71
.	S	2	Y	0.77	0.28	310.00	0.62	3.7	28.0	4.20	14	22	27	35	41	48	65
14211110 WILLAMETTE RIVER TRIB AT ROBINWOOD ORE											46	70	89	115	136	159	215
.	S	1	N	2.10	1.03	400.00	0.57	0.0	10.0	4.35	59	84	102	125	143	161	200
14211120 WILLAMETTE RIVER TRIB AT OAK GROVE ORE											34	53	67	86	102	119	161
.	S	3	N	1.80	0.74	160.00	0.57	0.3	36.0	2.12	36	58	75	100	121	145	191
14211130 KELLOGG CR AT MILWAUKIE ORE											96	148	189	244	289	337	456
.	S	2	Y	2.70	2.42	16.00	0.57	7.0	22.0	10.70	90	129	157	195	227	260	350
14211301 TRYON CR TRIB AT PORTLAND ORE											17	26	33	43	51	60	82
.	S	5	N	0.88	0.36	210.00	0.57	0.6	32.0	0.93	35	49	61	77	90	105	145
14211450 JOHNSON CR TRIB AT GRESHAM,ORE											12	19	23	30	35	41	55
.	S	2	N	1.10	0.21	95.00	0.67	0.0	16.0	1.88	27	35	39	44	46	48	52
14211500 JOHNSON CREEK AT SYCAMORE OREG											876	1380	1730	2220	2620	3040	4100
37	O,S	2	Y	13.80	26.50	32.00	0.75	0.3	7.0	25.00	1210	1810	2230	2820	3240	3740	4220

APPENDIX 1._SELECTED DATA FOR STATIONS USED IN NATIONWIDE URBAN FLOOD-FREQUENCY STUDY (CONTINUED).

GAGING STATION NUMBER AND NAME / N YEARS	TYPE	BDF	DTS	L (MI)	A (SQ MI)	SL (FT/MI)	RI2 (IN)	ST (%)	IA (%)	LT (HRS)	RQ2 / UQ2 (CFS)	RQ5 / UQ5 (CFS)	RQ10 / UQ10 (CFS)	RQ25 / UQ25 (CFS)	RQ50 / UQ50 (CFS)	RQ100 / UQ100 (CFS)	RQ500 / UQ500 (CFS)
14211604 EVERETT SEWER AT PORTLAND,OR											75	117	149	194	230	269	366
.	S	10	N	3.40	1.98	230.00	0.57	0.0	36.0	0.75	244	354	436	548	638	735	990
14211610 MADISON SEWER AT PORTLAND,OR											64	99	126	163	193	225	305
.	S	12	N	2.30	1.53	66.00	0.57	0.0	39.0	0.51	232	342	424	538	631	730	990
14211614 FLINT SEWER AT PORTLAND,OR											58	90	114	147	174	203	275
.	S	12	N	2.80	1.36	58.00	0.57	0.0	43.0	0.56	221	340	434	573	691	822	1190
14211617 KILPATRICK SEWER AT PORTLAND,OR											42	66	83	107	127	148	200
.	S	6	N	1.60	0.95	92.00	0.57	0.0	44.0	0.32	94	141	175	220	256	293	385
14211618 OWR&N SEWER AT PORTLAND,OR											17	27	34	43	51	60	81
.	S	11	N	1.50	0.34	107.00	0.57	0.0	46.0	0.28	51	89	118	158	191	227	317
14211625 BYBEE SEWER AT PORTLAND,OR											36	55	69	89	106	123	167
.	S	12	N	1.20	0.77	166.00	0.57	0.0	26.0	0.28	158	246	306	384	443	502	640
14211630 BELMONT SEWER AT PORTLAND,OR											26	40	50	65	77	90	122
.	S	12	N	1.20	0.54	42.00	0.57	0.0	35.0	0.28	102	167	216	283	337	394	540
14211950 VANCOUVER LAKE TRIB NR VANCOUVER WA											13	22	28	38	46	54	76
.	S	11	N	1.10	0.44	40.00	0.56	2.2	30.0	0.28	16	25	31	40	47	55	73
14213040 COUGAR CR AT VANCOUVER WA											71	115	150	199	239	282	396
.	S	4	N	4.00	2.88	50.00	0.60	3.8	25.0	3.83	82	140	190	270	343	428	690
PROVIDENCE RHODE ISLAND																	
01114000 MOSHASSUCK RIVER AT PROVIDENCE, RI											381	592	776	1060	1330	1690	2500
14	O	7	N	9.80	23.10	20.50	1.39	2.9	30.8	6.00	961	1400	1730	2200	2590	3010	4160
ROCHESTER NEW YORK																	
04232050 ALLEN CREEK NEAR ROCHESTER, N. Y.											990	1570	2010	2620	3130	3660	5000
18	O	4	N	9.30	30.10	33.70	1.30	2.1	12.1	7.20	847	1320	1660	2120	2490	2870	3840
ROCKLAND COUNTY NEW YORK																	
01377200 PASCACK B TR AT SPRING VALLEY NY											208	319	408	542	658	788	1080
18	O	2	Y	4.90	4.58	55.50	1.70	3.3	4.6	.	219	338	430	562	672	793	1120
SACRAMENTO CALIFORNIA																	
11336580 MORRISON CREEK NEAR SACRAMENTO, CALIF.											.	.	.	.	.	.	.
18	O	9	Y	22.40	53.40	10.80	0.60	0.0	11.0	.	658	1190	1620	2250	2780	3370	4960

APPENDIX 1._SELECTED DATA FOR STATIONS USED IN NATIONWIDE URBAN FLOOD-FREQUENCY STUDY (CONTINUED).

GAGING STATION NUMBER AND NAME											RQ2	RQ5	RQ10	RQ25	RQ50	RQ100	RQ500
N YEARS	TYPE	BDF	DTS	L (MI)	A (SQ MI)	SL (FT/MI)	RI2 (IN)	ST (%)	IA (%)	LT (HRS)	UQ2 (CFS)	UQ5 (CFS)	UQ10 (CFS)	UQ25 (CFS)	UQ50 (CFS)	UQ100 (CFS)	UQ500 (CFS)
SAN ANTONIO TEXAS																	
08177600 OLMOS C TRIB AT FR 1535, SHAVANO PARK, TEX.											189	339	448	596	711	830	1100
9	0	0	N	1.10	0.33	55.40	2.30	1.0	7.0	0.60	45	123	193	298	385	477	702
08177700 OLMOS CR AT DRESDEN DRIVE, SAN ANTONIO, TEX.											1860	3860	5550	7940	9920	12100	18000
9	0	6	N	11.00	21.20	24.60	2.30	2.0	20.0	2.10	1800	4200	6170	8920	11100	13300	18500
08178300 ALAZAN C AT ST. CLOUD ST, SAN ANTONIO, TEX.											715	1440	2030	2850	3510	4220	6100
9	0	8	N	3.45	3.26	63.70	2.30	1.0	34.0	0.50	1750	2850	3560	4400	4980	5530	6690
08181400 HELOTES CREEK AT HELOTES, TEXAS											1660	3540	5160	7440	9330	11400	17000
9	0	0	N	9.35	15.00	49.50	2.30	1.0	3.6	2.00	1080	3560	6120	10300	14000	18000	28600
08181450 LEON CREEK TRIB AT KELLY AIR FORCE BASE, TEX.											327	571	747	989	1180	1370	1800
9	0	9	N	2.10	1.19	12.50	2.30	0.1	8.0	0.90	323	490	592	710	790	864	1020
SAN FRANCISCO CALIFORNIA																	
11162720 COLMA CREEK AT SOUTH SAN FRANCISCO CALIF											157	465	773	1260	1720	2230	3500
10	0	8	Y	4.20	10.80	55.00	0.70	0.0	13.7	.	1190	1680	1980	2330	2580	2810	3300
11162800 REDWOOD CREEK AT REDWOOD CITY, CALIF.											16	57	105	189	274	378	650
10	0	8	N	2.80	1.82	164.00	1.00	0.0	11.0	.	184	371	519	726	891	1060	1480
11166000 MATADERO C AT PALO ALTO CALIF											67	223	396	692	991	1330	2400
15	0	7	N	6.50	7.24	89.00	1.00	0.0	7.7	.	361	688	935	1270	1530	1800	2440
11181400 WILDCAT CREEK AT RICHMOND, CALIF.											51	188	354	656	977	1360	2600
11	0	4	Y	10.50	8.69	108.00	0.80	0.0	4.6	.	476	629	719	821	890	955	1090
11182030 RHEEM CREEK AT SAN PABLO, CALIF.											6	25	49	95	144	207	400
17	0	12	N	2.80	1.09	85.00	0.80	0.0	18.8	.	271	369	428	495	542	585	677
11183000 SAN RAMON CREEK AT WALNUT CREEK, CALIF.											432	1370	2360	3970	5620	7340	13000
10	0	4	Y	17.50	47.90	47.40	1.00	0.1	4.6	.	1420	3650	5720	8970	11800	14900	23300
11183600 WALNUT CREEK AT CONCORD, CALIF.											734	2820	3960	6620	9360	12200	21000
9	0	4	Y	23.00	85.10	43.60	1.00	0.0	7.2	.	2900	6470	9480	13900	17500	21400	31300
11460100 ARROYO CORTE MADERA D PRES AT MILL VALLEY CALIF											360	540	710	900	1100	1200	1700
12	0	5	Y	3.30	4.69	181.00	1.10	0.0	8.5	.	410	829	1160	1620	1990	2370	3310
SEATTLE-TACOMA WASHINGTON																	
12091100 FLETT CREEK AT TACOMA, WASH.											48	70	85	104	120	136	172
18	0	6	Y	5.60	8.01	8.30	0.35	0.0	24.0	4.00	48	71	87	108	124	141	182

APPENDIX 1._SELECTED DATA FOR STATIONS USED IN NATIONWIDE URBAN FLOOD-FREQUENCY STUDY (CONTINUED).

GAGING STATION NUMBER AND NAME / N YEARS	TYPE	BDF	DTS	L (MI)	A (SQ MI)	SL (FT/MI)	RI2 (IN)	ST (%)	IA (%)	LT (HRS)	RQ2 / UQ2 (CFS)	RQ5 / UQ5 (CFS)	RQ10 / UQ10 (CFS)	RQ25 / UQ25 (CFS)	RQ50 / UQ50 (CFS)	RQ100 / UQ100 (CFS)	RQ500 / UQ500 (CFS)
12102200 SWAN CREEK NEAR TACOMA, WASH.											25	34	41	49	56	63	77
21	O	0	N	3.20	2.15	10.00	0.35	0.0	5.0	.	112	149	173	202	223	245	294
12119800 VALLEY (NO BRANCH MERCER) CR NR BELLEVUE, WASH.											47	69	80	96	112	126	158
8	O	0	N	2.60	3.05	95.00	0.23	0.0	3.0	.	59	76	87	100	109	118	139
12120000 MERCER CREEK NEAR BELLEVUE, WASH.											134	195	222	269	316	355	445
10	O	4	N	3.90	12.00	65.00	0.23	0.0	8.0	8.00	252	316	356	403	438	471	547
12120500 JUANITA CREEK NEAR KIRKLAND, WASH.											70	102	117	141	165	185	230
10	O	2	N	3.60	6.43	83.00	0.23	0.0	6.0	4.00	138	185	216	254	283	311	376
12127100 SWAMP CREEK AT KENMORE, WASH.											203	295	333	403	476	533	670
10	O	3	N	13.50	23.10	43.00	0.23	0.2	6.0	9.00	382	471	525	590	637	681	781
ST LOUIS MISSOURI																	
06935800 SHOTWELL CREEK AT HWY.340 NR. ELLISVILLE											389	634	821	1080	1250	1430	1850
18	O,S	5	N	1.10	0.81	84.80	1.90	1.5	22.0	0.53	464	728	963	1290	1510	1730	2300
06935830 CAULKS CREEK AT HWY 340 (ST LOUIS)											2050	3570	4800	6660	8310	10100	15600
.	S	3	N	7.71	17.10	33.60	1.90	1.0	5.0	2.63	3060	5170	6910	9510	11800	14300	21500
06935880 SMITH CREEK AT MASON RD (ST LOUIS)											984	1660	2200	2980	3600	4270	6080
.	S	4	N	3.21	4.44	53.50	1.90	0.5	18.0	1.88	1240	1950	2510	3310	3980	4720	6730
06935890 CREVE COEUR CREEK AT HWY 340 (ST LOUIS)											2360	4120	5560	7750	9720	11900	18600
.	S	5	N	8.13	22.00	16.40	1.90	3.0	15.0	4.85	2340	3900	5200	7170	8900	10900	16500
06935955 FEE FEE CREEK AT MC KELVEY RD (ST LOUIS)											1670	2880	3860	5310	6570	7950	12000
.	S	9	N	4.70	11.70	29.40	1.90	0.0	25.0	2.26	2280	3680	4840	6590	8120	9870	14900
06935980 COWMIRE CREEK AT KERCHNER INC (ST LOUIS)											891	1500	1980	2670	3220	3800	5350
.	S	9	Y	2.56	3.70	32.10	1.90	0.0	20.0	1.41	1240	1950	2520	3370	4110	4930	7260
06936185 COLDWATER CR AT ST LOUIS INT ARPT (ST LOUIS)											1310	2230	2970	4060	4980	5960	8740
.	S	9	N	4.65	7.47	30.10	1.90	0.0	32.0	1.46	1900	2940	3790	5040	6130	7360	10900
06936380 PADDOCK CR AT LINDBERGH BLVD (ST LOUIS)											741	1240	1630	2180	2610	3060	4220
.	S	9	N	2.56	2.64	29.30	1.90	0.0	32.0	0.90	1560	2290	2790	3430	3920	4410	5570
06936460 COLDWATER CR AT OLD HALLS FY RD (ST LOUIS)											3220	5690	7730	10900	13800	17200	27800
.	S	9	N	14.40	38.90	8.67	1.90	0.0	25.0	3.64	5950	9460	12300	16600	20400	24600	36700
07002000 WATKINS CREEK AT COAL BANK RD (ST LOUIS)											1180	2000	2660	3620	4420	5270	7650
.	S	7	N	5.30	6.17	24.70	1.90	0.0	10.0	1.40	1210	2170	2980	4180	5230	6390	9670

APPENDIX 1._SELECTED DATA FOR STATIONS USED IN NATIONWIDE URBAN FLOOD-FREQUENCY STUDY (CONTINUED).

GAGING STATION NUMBER AND NAME / N YEARS	TYPE	BDF	DTS	L (MI)	A (SQ MI)	SL (FT/MI)	RI2 (IN)	ST (%)	IA (%)	LT (HRS)	RQ2 / UQ2 (CFS)	RQ5 / UQ5 (CFS)	RQ10 / UQ10 (CFS)	RQ25 / UQ25 (CFS)	RQ50 / UQ50 (CFS)	RQ100 / UQ100 (CFS)	RQ500 / UQ500 (CFS)
07004100 MALINE CR AT BERMUDA AVE (ST LOUIS)											1460	2510	3350	4590	5650	6800	10100
.	S	9	N	4.40	9.16	29.40	1.90	0.0	20.0	1.40	2040	3410	4560	6320	7880	9670	14900
07005000 MALINE CR AT BELLEFONTAINE RD (ST LOUIS)											2480	4340	5860	8180	10300	12700	19900
.	S	9	N	8.94	24.10	16.40	1.90	0.0	25.0	2.42	4780	7720	10200	14000	17400	21300	32800
07010016 RIVER DES PERES AT HAFNER PLACE (ST LOUIS)											1120	1900	2530	3430	4180	4980	7180
.	S	10	N	4.30	5.64	34.40	1.90	0.0	25.0	0.96	2170	3480	4570	6210	7660	9310	14100
07010026 RIVER DES PERES AT PENNSYLVANIA AVE (ST LOUIS)											1500	2580	3450	4730	5830	7030	10500
.	S	11	N	6.60	9.65	25.30	1.90	0.0	30.0	1.28	2780	4460	5890	8140	10200	12600	19800
07010044 DEER CRK AT WARSON ROAD (ST LOUIS)											1410	2420	3220	4410	5430	6520	9640
.	S	9	N	4.25	8.59	29.70	1.90	0.0	25.0	1.34	2690	4310	5670	7730	9570	11700	17900
07010061 TWO MILE CR AT TRENT DR (ST LOUIS)											1200	2050	2720	3710	4530	5410	7860
.	S	9	N	5.24	6.42	32.10	1.90	0.0	25.0	1.20	2280	3650	4760	6420	7860	9480	14100
07010086 DEER CR AT BIG BEND BLVD (ST LOUIS)											3110	5490	7450	10500	13300	16500	26500
.	S	9	N	10.40	36.50	15.90	1.90	0.0	25.0	2.92	5010	7690	9910	13300	16300	19800	29900
07010155 GRAVOIS CREEK AT TESSON FY RD (ST LOUIS)											1700	2940	3930	5420	6710	8130	12300
.	S	9	N	6.06	12.10	31.10	1.90	0.0	32.0	1.45	3160	5020	6600	9100	11400	14000	22100
07010185 GRAVOIS CR AT BAYLESS AVE (ST LOUIS)											2370	4150	5600	7810	9800	12000	18800
.	S	9	N	11.10	22.30	20.00	1.90	0.0	32.0	3.83	3230	5070	6640	9120	11400	14000	22100
07019100 FISHPOT CR AT OLD BALLWIN RD (ST LOUIS)											703	1170	1540	2060	2460	2880	3950
.	S	7	N	2.80	2.40	57.70	1.90	0.0	27.0	1.25	1000	1510	1880	2400	2810	3250	4400
07019117 FISHPOT CR TRIB AT SULPHUR SPRGS RD (ST LOUIS)											703	1170	1540	2060	2460	2880	3950
.	S	6	N	2.83	2.40	69.80	1.90	0.0	17.0	1.17	1160	1700	2080	2640	3070	3520	4690
07019120 FISHPOT CR AT HANNA RD (ST LOUIS)											1500	2570	3440	4720	5810	7010	10400
.	S	7	N	7.78	9.60	37.00	1.90	0.0	20.0	1.80	2480	3950	5090	6720	8060	9530	13500
07019145 GRAND GLAIZE CRK AT HWY 141 (ST LOUIS)											915	1540	2040	2750	3320	3920	5540
.	S	9	N	3.50	3.89	43.20	1.90	0.0	20.0	1.10	1750	2670	3300	4180	4850	5520	7180
07019180 GRAND GLAIZE CRK AT DOUGHTERTY FY RD (ST LOUIS)											2230	3880	5230	7270	9100	11200	17300
.	S	9	N	6.81	19.80	27.20	1.90	0.0	22.0	3.23	3030	4900	6480	8910	11100	13600	21100
07019320 MATTESE CRK AT YAEGER RD (ST LOUIS)											1450	2480	3310	4540	5590	6730	9970
.	S	7	Y	5.95	9.01	38.80	1.90	0.0	25.0	1.87	2340	3680	4720	6180	7400	8720	12200
SYRACUSE NEW YORK																	
04240100 HARBOR BROOK AT SYRACUSE, N.Y.											425	697	908	1210	1460	1720	2400
18	O	6	N	5.60	9.60	113.00	1.30	1.9	5.0	5.50	279	420	519	651	754	860	1120

APPENDIX 1._SELECTED DATA FOR STATIONS USED IN NATIONWIDE URBAN FLOOD-FREQUENCY STUDY (CONTINUED).

GAGING STATION NUMBER AND NAME / N YEARS	TYPE	BDF	DTS	L (MI)	A (SQ MI)	SL (FT/MI)	RI2 (IN)	ST (%)	IA (%)	LT (HRS)	RQ2 / UQ2 (CFS)	RQ5 / UQ5 (CFS)	RQ10 / UQ10 (CFS)	RQ25 / UQ25 (CFS)	RQ50 / UQ50 (CFS)	RQ100 / UQ100 (CFS)	RQ500 / UQ500 (CFS)
TRENTON NEW JERSEY																	
01464000 ASSUNPINK C AT TRENTON NJ											1010	1560	2190	2930	3720	4650	7780
55	0	3	N	21.10	89.40	4.84	1.80	2.6	15.0	15.00	1510	2220	2730	3430	3980	4560	6030
TUCSON ARIZONA																	
09483000 TUCSON ARROYO AT VINE AVE, AT TUCSON, AZ.											600	1100	1600	2600	3700	4800	9000
23	0	3	N	5.50	8.20	37.00	0.90	0.0	37.0	1.00	822	1590	2240	3240	4100	5080	7830
09483010 HIGH SCHOOL WASH AT TUCSON, ARIZ.											190	330	480	750	1020	1400	2700
11	0	3	N	1.30	0.95	45.00	0.90	0.0	40.0	0.45	274	476	636	866	1060	1270	1820
09483042 CEMETERY WASH AT TUCSON, ARIZ.											210	310	530	850	1200	1600	2900
13	0	7	N	2.20	1.17	41.30	0.90	0.0	30.0	.	290	467	598	780	925	1080	1470
09485550 ARCADIA WASH AT TUCSON, ARIZ.											370	680	1000	1600	2300	3100	6200
13	0	4	N	4.10	3.10	36.50	0.90	0.0	37.0	0.67	375	697	964	1360	1700	2080	3130
URBANA ILLINOIS																	
03337000 BONEYARD CREEK AT URBANA, IL											275	476	620	802	946	1090	1500
18	0	7	Y	2.31	3.58	12.50	1.40	0.0	44.1	1.30	500	571	608	648	673	696	741
WASHINGTON D.C.																	
01646200 SCOTT RUN NEAR MCLEAN VA											346	658	954	1490	2020	2590	4350
13	0	5	N	4.10	4.69	55.30	2.00	1.0	5.0	1.60	1100	2220	3280	5050	6750	8830	15500
01646550 LITTLE FALLS BRANCH NEAR BETHESDA, MD.											327	561	776	940	1210	1430	2100
33	0	9	N	2.90	4.10	63.20	2.00	0.0	20.0	2.30	1040	1640	2100	2760	3310	3920	5560
01648000 ROCK CREEK AT SHERRILL DRIVE, WASHINGTON, D. C.											1770	2930	3950	5100	7100	9270	15000
36	0	4	Y	24.50	62.20	12.60	2.00	0.1	7.5	6.90	1470	2460	3290	4540	5640	6900	10600
01649500 N.E. BR. ANACOSTIA RIVER AT RIVERDALE, MD.											2010	3350	4630	6830	9300	10700	17000
39	0	5	N	15.70	72.80	27.20	2.00	1.5	7.5	4.90	2710	4390	5750	7760	9500	11500	17000
01651000 NORTHWEST BRANCH ANACOSTIA RIVER NEAR HYATTSVIL											1330	2230	3070	4520	5800	7010	11000
39	0	6	N	19.10	49.40	19.70	2.00	0.1	10.0	3.90	2670	4500	6100	8630	10900	13600	22000
01652400 LONG BRANCH AT ARLINGTON, VA											101	201	300	482	672	874	1600
15	0	9	N	2.10	0.94	81.20	2.00	1.0	30.0	0.50	692	915	1070	1270	1430	1590	1990
01652500 FOURMILE RUN AT ALEXANDRIA VA											839	1550	2200	3350	4450	5670	10000
26	0	12	N	7.80	14.40	42.50	2.00	1.0	20.0	1.30	2830	6100	9350	15000	20700	27700	51300

APPENDIX 1._SELECTED DATA FOR STATIONS USED IN NATIONWIDE URBAN FLOOD-FREQUENCY STUDY (CONTINUED).

GAGING STATION NUMBER AND NAME N YEARS	TYPE	BDF	DTS	L (MI)	A (SQ MI)	SL (FT/MI)	RI2 (IN)	ST (%)	IA (%)	LT (HRS)	RQ2 UQ2 (CFS)	RQ5 UQ5 (CFS)	RQ10 UQ10 (CFS)	RQ25 UQ25 (CFS)	RQ50 UQ50 (CFS)	RQ100 UQ100 (CFS)	RQ500 UQ500 (CFS)
01652610 HOLMES RUN NR ANNANDALE, VA											442	833	1200	1870	2520	3240	5700
13	0	6	N	6.00	7.10	36.80	2.00	2.0	12.0	3.50	796	1510	2150	3200	4170	5330	8900
01652620 TRIPPS RUN AT FALLS CHURCH, VA											171	333	491	778	1070	1390	2600
9	0	12	N	2.30	1.78	79.20	2.00	1.0	25.0	0.43	664	1110	1470	2020	2490	3030	4570
01652650 TRIPPS RUN NR FALLS CHURCH, VA											334	636	924	1440	1960	2520	4500
8	0	12	N	4.00	4.55	52.00	2.00	1.0	25.0	0.78	1060	2020	2900	4330	5660	7250	12200
01653000 CAMERON RUN AT ALEXANDRIA, VA.											1560	2810	3950	5940	7780	9860	16500
19	0	12	Y	10.90	33.70	32.90	2.00	1.0	15.0	4.10	3680	6980	9960	14800	19300	24600	41200
01654000 ACCOTINK CREEK NEAR ANNANDALE, VA.											1010	1850	2620	4000	5300	6780	11500
31	0	5	N	10.50	23.50	19.30	2.00	1.0	8.0	6.80	1880	3660	5310	8050	10600	13800	23800
WILMINGTON DELAWARE																	
01477800 SHELLPOT CREEK AT WILMINGTON, DEL.											678	1180	1640	2230	3180	4090	7200
32	0	6	N	5.70	7.46	67.10	1.90	0.3	20.0	2.20	1390	2330	3070	4160	5090	6110	8910

APPENDIX II. LIST OF REPORTS FOR ESTIMATING EQUIVALENT RURAL DISCHARGES FOR URBAN WATERSHEDS

Alabama:

Hains, C. F., 1973, Floods in Alabama, magnitude and frequency: Alabama Highway Department, 174 p.

Olin, D. A., and Bingham, R. H., 1977, Flood frequency of small streams in Alabama: Alabama Highway Department HPR Report No. 83, Research Project 930-087.

Alaska:

Lamke, R. D., 1978, Flood characteristics of Alaskan streams: U.S. Geological Survey Water-Resources Investigations 78-129.

Arizona:

Roeske, R. H., 1978, Methods for estimating the magnitude and frequency of floods in Arizona: Arizona Department of Transportation RS-15(121), 82 p.

Arkansas:

Patterson, J. L., 1971, Floods in Arkansas, magnitude and frequency characteristics through 1968: Arkansas Geological Commission, Water Resources Summary No. 11.

California:

Waananen, A. O., and Crippen, J. R., 1977, Magnitude and frequency of floods in California: U.S. Geological Survey Water-Resources Investigations 77-21 (PB-272 510/AS).

Colorado:

Hedman, E. R., Moore, D. O., and Livingston, R. K., 1972, Selected streamflow characteristics as related to channel geometery of perennial streams in Colorado: U.S. Geological Survey open-file report.

Livingston, R. K., 1980, Rainfall-runoff modeling and preliminary regional flood characteristics of small rural watersheds in the Arkansas River Basin in Colorado: U.S. Geological Survey Water-Resources Investigations 80-112.

McCain, J. R., and Jarrett, R. D., 1976, manual for estimating flood characteristics of natural-flow streams in Colorado: Colorado Water Conservation Board, Technical Manual no. 1.

Connecticut:

Weiss, L. A., 1975, Floodflow formulas for urbanized and non-urbanized areas of Connecticut: in Proceedings of Watershed Management Symposium, American Society of Civil Engineers, Irrigation and Drainage Division, p. 658-675, August 11-13, 1975.

Delaware:

Simmons, R. H., and Carpenter, D. H., 1978, Technique for estimating the magnitude and frequency of floods in Delaware: U.S. Geological Survey Water-Resources Investigations Open-File Report 78-93, 69 p.

Florida:

Seijo, M. A., Giovannelli, R. F., and Turner, J. F., Jr., 1979, Regional flood-frequency relations for west-central Florida: U.S. Geological Survey Open-File Report 79-1293.

Georgia:

Price, McGlone, 1979, Floods in Georgia, magnitude and frequency: U.S. Geological Survey Water-Resources Investigations 78-137 (PB-80 146 244).

Hawaii:

Nakahara, R. H., 1980, An analysis of the magnitude and frequency of floods on Oahu, Hawaii: U.S. Geological Survey Water-Resources Investigation 80-45 (PB-81 109 902).

Idaho:

Harenberg, W. A., 1980, Using channel geometry to estimate flood flows at ungaged sites in Idaho: U.S. Geological Survey Water-Resources Investigations 80-32 (PB-81 153 736).

Kjelstrom, L. C., and Moffatt, R. L., 1981, Method of estimating flood-frequency parameters for streams in Idaho: U.S. Geological Survey Open-File Report 81-909.

Thomas, C. A., Harenburg, W. A., and Anderson, J. M., 1973, Magnitude and frequency of floods in small drainage basins in Idaho: U.S. Geological Survey Water-Resources Investigations 7-73 (PB-222 409).

Illinois:

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 (PB-299 065/AS).

Curtis, G. W., 1977, Technique for estimating magnitude and frequency of floods in Illinois: U.S. Geological Survey Water-Resources Investigations 77-117 (PB-277 255/AS).

Indiana:

Davis, L. G., 1974, Floods in Indiana: Technical manual for estimating their magnitude and frequency: U.S. Geological Survey Circular 710.

Gold, R. L., 1980, Flood magnitude and frequency of streams in Indiana—Preliminary estimating equations: U.S. Geological Survey Open-File Report 80-759.

Iowa:

Lara, O. G., 1973, Floods in iowa: Technical manual for estimating their magnitude and frequency: Iowa Natural Resources Council Bulletin no. 11.

Kansas:

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

Hedman, E. R., Kastner, W. M., and Hejl, H. R., 1973, Selected streamflow characteristics as related to active-channel geometry of streams in Kansas: Kansas Water Resources Board Technical Report no. 10.

Kentucky:

Hannum, C. H., 1976, Technique for estimating magnitude and frequency of floods in Kentucky: U.S. Geological Survey Water-Resources Investigations 76-62 (PB-263 762/AS).

Louisiana:

Lowe, A. S., 1979, Magnitude and frequency of floods

for small watersheds in Louisiana: Louisiana Department of Transportation and Development, Office of Highways, Research Study No. 65-2H.

Neely, B. L., Jr., 1976, Floods in Louisiana, magnitude and frequency, 3d ed., 1976: Louisiana Department of Highways.

Maine:

Morrill, R. A., 1975, A technique for estimating the magnitude and frequency of floods in Maine: U.S. Geological Survey open-file report.

Carpenter, D. H., 1980, Technique for estimating magnitude and frequency of floods in Maryland: U.S. Geological Survey Water-Resources Investigations Open-File Report 80-1016.

Massachusetts:

Wandle, S. W., 1981, Estimating peak discharges of small rural streams in Massachusetts: U.S. Geological Survey Open-File Report 80-676.

Michigan:

Bent, P. C., 1970, A proposed streamflow data program for Michigan: U.S. Geological Survey open-file report.

Minnesota:

Guetzkow, L. C., 1977, Techniques for estimating magnitude and frequency of floods in Minnesota: U.S. Geological Survey Water-Resources Investigations 77-31 (PB-272 509/AS).

Mississippi:

Colson, B. E., and Hudson, J. W., 1976, Flood frequency of Mississippi streams: Mississippi State Highway Department.

Missouri:

Hauth, L. D., 1974, A technique for estimating the magnitude and frequency of Missouri floods: U.S. Geological Survey open-file report.

Spencer, D. W., and Alexander, T. W., 1978, Technique for estimating the magnitude and frequency of floods in St. Louis County, Missouri: U.S. Geological Survey Water-Resources Investigations 78-139 (PB-298 245/AS).

Montana:

Parrett, Charles, and Omang, R. J., 1981, Revised techniques for estimating magnitude and frequency of floods in Montana: U.S. Geological Survey Open-File Report 81-917.

Nebraska:

Beckman, E. W., 1976, Magnitude and frequency of floods in Nebraska: U.S. Geological Survey Water-Resources Investigations 76-109 (PB-260 842/AS).

Nevada:

Moore, D. O., 1974, Estimating flood discharges in Nevada using channel-geometry measurements: Nevada State Highway Department Hydrologic Report no. 1.

———, 1976, Estimating peak discharges from small drainages in Nevada according to basin areas within elevation zones: Nevada State Highway Department Hydrologic Report no. 3.

New Hampshire:

LeBlanc, D. R., 1978, Progress report on hydrologic investigations of small drainage areas in New Hampshire—Preliminary relations for estimating peak discharges on rural, unregulated streams: U.S. Geological Survey Water-Resources Investigations 78-47 (PB-284 127/AS).

New Jersey:

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

New Mexico:

Scott, A. G., 1971, Preliminary flood-frequency relations and summary of maximum discharges in New Mexico—A progress report: U.S. Geological Survey open-file report.

Scott, A. G., and Kunkler, J. L., 1976, Flood discharges of streams in New Mexico as related to channel geometry: U.S. Geological Survey open-file report.

New York:

Zembrzuski, T. J., and Dunn, Bernard, 1979, Techniques for estimating magnitude and frequency of floods on rural unregulated streams in New York excluding Long Island: U.S. Geological Survey Water-Resources Investigations 79-83 (PB-80 201 148).

North Carolina:

Jackson, N. M., Jr., 1976, Magnitude and frequency of floods in North Carolina: U.S. Geological Survey Water-Resources Investigations 76-17 (PB-254 411/AS).

North Dakota:

Crosby, O. A., 1975, Magnitude and frequency of floods in small drainage basins in North Dakota: U.S. Geological Survey Water-Resources Investigations 19-75 (PB-248 480/AS).

Ohio:

Webber, E. E., and Bartlett, W. P., Jr., 1977, Floods in Ohio magnitude and frequency: State of Ohio, Department of Natural Resources, Division of Water, Bulletin 45.

Oklahoma:

Thomas, W. O., Jr., and Carley, R. K., 1977, Techniques for estimating flood discharges for Oklahoma streams: U.S. Geological Survye Water-Resources Investigations 77-54 (PB-273 402/AS).

Oregon:

Harris, D. D., Hubbard, L. L., and Hubbard, L. E., 1979, Magnitude and frequency of floods in western Oregon: U.S. Geological Survey Open-File Report 79-553.

Laenen, Antonius, 1980, Storm runoff as related to urbanization in the Portland, Oregon-Vancouver, Washington, area: U.S. Geological Survey Water-Resources Investigations Open-File Report 80-689.

Pennsylvania:

Flippo, H. N., Jr., 1977, Floods in Pennsylvania: A manual for estimation of their magnitude and frequency: Pennsylvania Department of Environmental Resources Bulletin no. 13, 59 p.

Puerto Rico:

Lopez, M. A., Colon-Dieppa, E., and Cobb, E. D., 1978, Floods in Puerto Rico, magnitude and frequency: U.S. Geological Survey Water-Resources Investigations 78-141 (PB-300 855/AS).

Rhode Island:

Johnson, C. G., and Laraway, G. A., 1976, Flood magnitude and frequency of small Rhode Island streams—Preliminary estimating relations: U.S. Geological Survey open-file report.

South Carolina:

Whetstone, B. H., 1982, Floods in South Carolina—Techniques for estimating magnitude and frequency of floods with compilation of flood data: U.S. Geological Survey Water-Resources Investigations 82-1 [78 pages].

South Dakota:

Becker, L. D., 1974, A method for estimating the magnitude and frequency of floods in South Dakota: U.S. Geological Survey Water-Resources Investigations 35-74 (PB-239 831/AS).

________, 1980, Techniques for estimating flood peaks, volumes, and hydrographs on small streams in South Dakota: U.S. Geological Survey Water-Resources Investigations 80-80 (PB-81 136 145).

Tennessee:

Randolph, W. J., and Gamble, C. R., 1976, Technique for estimating magnitude and frequency of floods in Tennessee: Tennessee Department of Transportation.

Texas:

Dempster, G. R., Jr., 1974, Effects of urbanization on floods in the Dallas Texas, metropolitan area: U.S. Geological Survey Water-Resources Investigations 60-73 (PB-230 188/AS).

Liscum, Fred, and Massey, B. C., 1980, Technique for estimating the magnitude and frequency of floods in the Houston, Texas, metropolitan area: U.S. Geological Survey Water-Resources Investigations 80-17 (ADA-089 495).

Schroeder, E. E., and Massey , B. C., 1977, Techniques for estimating the magnitude and frequency of floods in Texas: U.S. Geological Survey Water-Resources Investigations Open-File Report 77-110.

Utah:

Butler, Elmer, and Cruff, R. W., 1971, Floods of Utah, magnitude and frequency characteristics through 1969: U.S. Geological Survey open-file report.

Vermont:

Johnson, C. G., and Tasker, G. D., 1974, Flood magnitude and frequency of Vermont streams: U.S. Geological Survey Open-File Report 74-130.

Virginia:

Miller, E. M., 1978, Technique for estimating magnitude and frequency of floods in Virginia: U.S. Geological Survey Water-Resources Investigations Open-File Report 78-5.

Washington:

Cummans, J. E., Collings, M. R., and Nassar, E. G., 1975, Magnitude and frequency of floods in Washington: U.S. Geological Survey Open-File Report 74-336.

West Virginia:

Runner, G. S., 1980, Technique for estimating magnitude and frequency of floods in West Virginia: U.S. Geological Survey Open-File Report 80-1218.

Wisconsin:

Conger, D. H., 1980, Techniques for estimating magnitude and frequency of floods for Wisconsin streams: U.S. Geological Survey Water-Resources Investigations Open-File Report 80-1214.

Wyoming:

Lowham, H. W., 1976, Techniques for estimating flow characteristics of Wyoming streams: U.S. Geological Survey Water-Resources Investigations 76-112 (PB-264 224/AS).

Factors for Converting Inch-Pound Units to International System (SI) Units

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

Multiply inch-pound	By	To obtain SI units
	LENGTH	
inches (in)	25.4	millimeters (mm)
	0.0254	meters (m)
feet (ft)	0.3048	meters (m)
miles (mi)	1.609	kilometers (km)
	AREA	
square miles (mi^2)	2.590	square kilometers (km^2)
	FLOW	
cubic feet per second (ft^3/s)	0.02832	cubic meters per second (m^3/s)