New Studies of Urban Flood Frequency in the Southeastern United States

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ABSTRACT

Five reports dealing with flood magnitude and frequency in urban areas in the southeastern United States have been published during the past 2 years by the U.S. Geological Survey (USGS). These reports are based on data collected in Tampa and Tallahassee, Florida; Atlanta, Georgia; and several cities in Alabama and Tennessee. Each report contains regression equations useful for estimating flood peaks for selected recurrence intervals at ungauged urban sites in their respective study area. A nationwide study of urban flood characteristics by the USGS published in 1983 contains equations for estimating urban peak discharges for ungauged sites throughout the United States. At the time that the nationwide study was conducted, data from only 35 sites in the southeastern United States were available. The five new reports contain data for 88 additional sites in the southeastern United States. These new data show that the seven-parameter estimating equations developed in the nationwide study are unbiased and have prediction errors less than those described in the nationwide report. On the other hand, the new data indicate that the three-parameter equations are biased and significantly underestimate flood discharge in four of the new study areas. The five new reports on the southeastern United States and the nationwide report provide reliable methods for estimating design discharges.

Rapid expansion and development of urban areas in the United States bring many informational needs. An important one is flood data, which are necessary in the design of stream channels, canals, storm sewers, detention ponds, roadways, bridges, and culverts. Likewise, the magnitude, frequency, and boundaries of floods are required for zoning and insurance purposes. Gauging, or measuring, all streams and locations where data are needed is not feasible. Instead, flood data are collected at a few selected sites, and the information is transferred to ungauged sites by various regionalization procedures. To this end, the U.S. Geological Survey (USGS) has collected urban flood data in many cities throughout the United States during the past 20 to 30 years. These data have been published for public use and analyzed for flood-frequency regionalization studies. Reports have been published describing flood characteristics for individual cities, metropolitan areas, or selected groups of cities. References to and brief abstracts of many of these reports as well as other urban flood-frequency procedures may be found in a literature review by Rawls et al. (1). A nationwide regionalization of urban flood characteristics by Sauer et al. (2) describes techniques for estimating flood magnitude and frequency for cities throughout the United States, including Alaska. That report contains flood data and basin characteristics for 269 urban sites in 56 cities and 31 states. It also has an extensive list of references for both urban and rural flood-frequency procedures.

After analysis of the nationwide regionalization (2), five new urban studies were prepared for cities, metropolitan areas, and states in the southeastern region of the United States. These include a statewide study for Alabama (3); the Atlanta, Georgia, metropolitan area (4); the Leon County, Florida, area, which includes Tallahassee (5); the Tampa Bay, Florida, area, which includes the cities of Tampa, Clearwater, and St. Petersburg (6); and a statewide study for Tennessee (7). These five studies contain useful equations and techniques for estimating urban flood frequency in each study area. In addition, they contain specific flood and basin data for 88 gauged sites. Only three of these sites had been available for inclusion in the nationwide study (2), which used only 35 sites from the southeastern region, so the new data represent a significant increase in available data.

The purpose of this paper is to summarize and briefly describe the new urban studies in the southeastern region of the United States and to compare the new data with estimates based on the nationwide equations (2).

DESCRIPTION OF VARIABLES

Several equations for the five new urban studies and the nationwide study are presented in this paper. Flood characteristics and basin and climatic parameters are symbolized in these equations by abbreviations. In this paper some symbols have been changed from those shown in the original publications in order to present a consistent set of symbols. These are as follows:

A = contributing drainage area (mi^2). In urban areas drainage systems sometimes cross topographic divides. Such drainage changes should be accounted for when computing A.

BDF = 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

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to 12. A value of zero for BDF indicates that the foregoing drainage aspects are not prevalent but does not necessarily mean that the basin is nonurban. A value of 12 indicates full development of the drainage aspects throughout the basin. See the paper by Sauer et al. for details of computing BDF (2).

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

n = number of gauging sites used in error analysis.

RI2 = rainfall intensity (in.) for the 2-hr, 2-year occurrence [determined from Weather Bureau (8)].

RI24 = rainfall intensity (in.) for the 24-hr, 2-year occurrence [determined from Weather Bureau (8)].

RMS = Root-mean-square error (logarithmic units and percent) is considered for this study as an approximation of the standard error of prediction. It is used for comparing new data with existing estimating equations. See text for method of computation.

RQx = peak discharge (ft^3/sec) 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 USGS regional flood-frequency reports.

s = average standard deviation (logarithmic units and percent) of the errors between observed and estimated discharges. See text.

SEP = average standard error of prediction (logarithmic units and percent) of the regional regression equations for all urban basins, both gauged and ungauged. SEP can be computed either theoretically or from split-sample methods. It is an estimate of how well an equation can predict flood magnitude for a given recurrence interval at any urban site within a designated study area.

SER = average standard error of regression (logarithmic units and percent) of the regional regression equations for the gauged urban basins. It is based only on the data used to derive the regression equations, and it is usually less than the standard error of prediction (SEP).

SL = main channel slope (ft/mi), measured between points that are 10 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 nationwide 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.

STDT = basin storage, the percentage of the drainage basin occupied by lakes, reservoirs, detention basins, and retention basins. This variable is used only in the Tampa Bay area study (6).

UQx = peak discharge (ft^3/sec) for the urban watershed for recurrence interval x. That is, UQ10 = 10-year urban peak discharge, UQ100 = 100-year urban peak discharge.

$\overline{X}$ = mean (logarithmic units and percent) of the errors between observed and estimated discharges. See text.

THE FIVE NEW URBAN STUDIES

The collection of basic data is similar for all five recent southern region urban studies and follows USGS standards. At each gauge site, streamflow and storm rainfall data were measured for 15 or more floods over a period of 2 or more years. These data were used as input for calibration of a rainfall-runoff model, and where sufficient data permitted, split-sample techniques were used to verify the calibration. The models used were either the USGS model (9) or the DR3M model (10). Following a successful calibration at each site, long-term rainfall and evaporation records from a nearby National Weather Service (NWS) station were used to synthesize a flood record of maximum annual peak discharges. In lieu of long-term synthesis, some investigators chose the map-model method (11) to compute flood-frequency data for the site. Flood-frequency analysis of the long-term synthesized annual peaks was done according to log Pearson III procedures (12). For purposes of comparison of the five studies in this paper, only the 10- and 100-year recurrence intervals are presented.

Alabama Urban Study

Olin and Bingham assembled urban flood data for 23 sites from the Alabama cities of Dothan, Alexander City, Montgomery, Homewood, Greenwood, Ketona, Birmingham, Ensley, Adamsville, Tuscaloosa, Mobile, Huntsville, Lily Flagg, and Florence (3). The USGS model was calibrated for each site and a flood-frequency curve was synthesized through application of the map-model method. The synthesized flood-frequency data for the 23 sites were regionalized by relating basin and climatic parameters to urban flood discharge by multiple regression methods. The final equations for the 10- and 100-year urban floods are

$$UQ10 = 266A^{0.69}IA^{0.39} \quad \text{(SER = 24 percent)} \qquad (1)$$

$$UQ100 = 444A^{0.69}IA^{0.39} \quad \text{(SER = 25 percent)} \qquad (2)$$

These equations can be used throughout the state of Alabama.

Atlanta, Georgia, Study

Inman used flood data from 19 sites in the Atlanta, Georgia, metropolitan area to study the effects of urbanization (4). He calibrated both the USGS and the DR3M rainfall-runoff models for each site. A 76-year period of rainfall data from the Atlanta NWS station was used to synthesize two sets of annual flood peaks, one set based on the USGS model and another based on the DR3M model. The primary difference between the results from the two models is that the USGS model calculates flood discharges for an as-is condition of the drainage basin, whereas one feature of the DR3M model allows the user to add or remove storage elements in the basin. For the Atlanta study sites, all significant storage elements, such as detention storage upstream from road embankments, were removed from the model. The flood-frequency results from the DR3M model are therefore essentially storage-free and can be considered a maximum flood potential for the respective basins under their current state of development. The results from the USGS model represent flood potential for existing conditions in the study basins and include the effects of detention storage, which tends

to reduce flood peak discharges. The 10- and 100-year flood-estimating equations are as follows:

Equation based on USGS model (storage included):

$$UQ10 = 15.5A^{0.92}\ (SL - 12)^{0.50}IA^{0.58}$$
(SER = 15 percent; SEP = 25 percent) (3)

$$UQ100 = 30.7A^{0.95}\ (SL - 12)^{0.53}IA^{0.51}$$
(SER = 13 percent; SEP = 25 percent) (4)

Equation based on DR3M model (storage free):

$$UQ10 = 46.2A^{0.80}\ (SL - 12)^{0.37}IA^{0.50}$$
(SER = 20 percent; SEP = 31 percent) (5)

$$UQ100 = 72.4A^{0.79}\ (SL - 12)^{0.39}IA^{0.54}$$
(SER = 20 percent, SEP = 32 percent) (6)

The difference between the results of the USGS and DR3M model equations can be attributed to the average effects of detention storage in the Atlanta area. Because detention storage will almost always be present, it is likely that the USGS model equations are more suitable for design purposes.

Leon County, Florida, Study

Franklin and Losey (5) used flood data from 15 sites in the Leon County, Florida, area (mainly Tallahassee) to study urban flood frequency. They calibrated the USGS model for each site and computed two sets of long-term synthesized annual peak discharges for each site by using two long-term NWS rain gauges--the Thomasville-Coolidge gauge and the Pensacola gauge. A flood-frequency curve was computed from each of the separate sets of annual peak discharges and averaged by a weighting procedure. Two stations could not be used because model calibrations were poor; therefore, the data set was reduced to 13 stations. In addition, all streams in the Lake Lafayette basin were found to have large amounts of channel and detention storage. The five sites in the Lake Lafayette basin were in the regression analysis but were assigned a qualitative code to distinguish them from sites where storage was not excessive. The resulting regression analysis gives the following equations:

Lake Lafayette Basin:

$$UQ10 = 7.98A^{0.776}IA^{0.867}$$
(SER = 20 percent; SEP = 33 percent) (7)

$$UQ100 = 32.4A^{0.808}IA^{0.687}$$
(SER = 25 percent; SEP = 40 percent) (8)

Other Leon County Sites:

$$UQ10 = 39.1A^{0.776}IA^{0.867}$$
(SER = 20 percent; SEP = 33 percent) (9)

$$UQ100 = 118A^{0.808}IA^{0.687}$$
(SER = 25 percent; SEP = 40 percent) (10)

Tampa Bay Area, Florida, Study

Lopez and Woodham (6) used nine urban sites to study flood frequency in the Tampa Bay area, which included the cities of Tampa, Clearwater, and St. Petersburg. They calibrated the USGS rainfall-runoff model for each site and simulated a 47-year record of annual peak discharges by using long-term climatic records from the NWS station at Tampa. A flood-frequency analysis was made for each site by using the simulated annual peaks. Transferability of the site data to ungauged sites was accomplished through a regional regression analysis and resulted in the following equations:

$$UQ10 = 12.9A^{1.04}BDF^{0.75}SL^{0.83}\ (STDT + 0.01)^{-0.10}$$
(SER = 35 percent) (11)

$$UQ100 = 282A^{1.16}\ (13 - BDF)^{-0.51}SL^{0.76}$$
(SER = 42 percent) (12)

Note that the storage factor (STDT) is not included in the 100-year flood equation, indicating that it is not significant at high flood levels. This logically implies that at high flood levels, storage becomes satisfied and no longer has a reducing effect.

Tennessee Urban Study

Robbins (7) used flood data from 22 urban runoff sites in the Tennessee cities of Gallatin, Donelson, Nashville, Avondale, Franklin, Dickson, Greeneville, Morristown, Alcoa, Cleveland, Fayetteville, Manchester, Paris, Jackson, Humboldt, Covington, Germantown, Memphis, and Chattanooga to study urban flood frequency in Tennessee. He calibrated the USGS rainfall-runoff model for each site and used the calibration results in the map-model method to estimate synthetic flood-frequency data. These data were used in a statewide regression analysis to regionalize the data for use at ungauged sites. The following equations resulted from the regression analysis:

$$UQ10 = 11.8A^{0.75}IA^{0.43}RI24^{2.12}$$
(SER = 27 percent; SEP = 37 percent) (13)

$$UQ100 = 77.0A^{0.75}IA^{0.40}RI24^{1.10}$$
(SER = 25 percent; SEP = 39 percent) (14)

These equations can be used throughout the state of Tennessee.

NATIONWIDE URBAN FLOOD-FREQUENCY STUDY

Sauer et al. (2) used urban flood data from 199 of the 269 urban sites listed in their report to develop regression equations for use at ungauged sites throughout the United States. The seven-parameter equations are

$$UQ10 = 2.99A^{0.32}SL^{0.15}\ (RI2 + 3)^{1.75}\ (ST + 8)^{-0.57}\ (13 - BDF)^{-0.30}IA^{0.09}RQ10^{0.58}$$
(SER = 38 percent; SEP = 45 percent) (15)

$$UQ100 = 2.50A^{0.29}SL^{0.15}\ (RI2 + 3)^{1.76}\ (ST + 8)^{-0.32}\ (13 - BDF)^{-0.28}IA^{0.06}RQ100^{0.63}$$
(SER = 44 percent; SEP = 53 percent) (16)

The basin development factor (BDF) proved to be highly effective in these equations for explaining the effects of urbanization on flood peaks. The equations include an estimate of the equivalent rural discharge (RQx) for a similar basin in the same hydrologic area. This serves as a regional or geographic factor, thus allowing use of the equations throughout the United States. The equations essentially adjust the equivalent rural peak to the urban condition. The equations do not include an adjustment for detention or temporary in-channel storage. Therefore, they should not be used if detention storage is highly significant in the basin--such as in the Lake Lafayette basin in Leon County,

Florida. Slope (SL) is limited to a maximum value of 70 ft/mi and 70 ft/mi should be used for any basin in which SL exceeds this amount.

The seven-parameter equations were simplified by eliminating the less significant variables and recalibrating the regression constants and coefficients. The following three-parameter equations resulted:

$$UQ10 = 9.51A^{0.16}\ (13 - BDF)^{-0.36} RQ10^{0.79}$$
(SER = 41 percent; SEP = 43 percent) (17)

$$UQ100 = 7.70A^{0.15}\ (13 - BDF)^{-0.32} RQ100^{0.82}$$
(SER = 46 percent; SEP = 49 percent) (18)

COMPARISONS OF URBAN ESTIMATING EQUATIONS

Each of the five new urban studies was carried out by the USGS using similar techniques. One would logically expect that the results would be similar. Rainfall-runoff modeling was similar for each study, synthesization was similar, and regionalization was made by regression analysis in all cases. Each investigator explored numerous basin and climatic variables for explaining the variation in urban flood characteristics, and only those that were statistically significant were used. These are compared in Table 1, which also includes parameters from the nationwide study. For the five new studies, drainage area size and an index of urbanization, either impervious area or the basin development factor, are significant in all. Slope is significant in only two, Atlanta and Tampa. The rainfall index used in the Tennessee study accounts for statewide variations in rainfall, which probably reflect variations in flood potential across the state.

The three- and seven-parameter nationwide equations were used to estimate the 10- and 100-year discharges for 78 of the 88 sites for which data are available from the five new urban studies. Three sites were not used because they were in the original nationwide analysis; two sites from the Leon County, Florida, study could not be used because of poor calibrations; and the five Lake Lafayette basin sites in the Leon County study were not used because of the large amounts of detention storage. Average error ($\bar{X}$) and standard deviation of the errors (s) were computed for each study for both the three- and seven-parameter equations. The root-mean-square (RMS) error was computed as follows:

$$RMS = (\bar{X}^2 + s^2)^{1/2} \quad (19)$$

The RMS error is considered an approximation of the standard error of prediction and was used for comparison with the standard errors reported for each study. All error analysis was performed by transforming the discharge data to logarithmic units and computing the logarithmic residual between the estimated discharge and the observed discharge. The final logarithmic values of $\bar{X}$, s, and RMS of the residuals were then converted to percentages.

The mean error ($\bar{X}$) is an indication of the bias present in the equations. Student's t-test was used to determine whether any $\bar{X}$-values were significantly different from zero. The results of the error analyses are shown in Tables 2 and 3. These comparisons show that the three-parameter nationwide equations have a negative average error for the 10- and 100-year floods for each of the new study areas. Student's t-test, at the 0.01 level of significance, indicates that these negative errors are statistically significant for both return levels for the Alabama, Atlanta, and Leon County studies and for the 10-year floods in the Tampa study. The 10- and 100-year floods in the Tennessee study and 100-year floods in the Tampa study show no significant bias, but overall the new data appear to indicate that the three-parameter nationwide equations are biased, at least in parts of the southeastern United States. Data from the original 35 sites were reexamined and found not to show the same bias. Tests are now being made in an attempt to explain the reason for the bias in the new data.

Conversely, the seven-parameter nationwide equations show both negative and positive mean errors, and in no case are these significantly different from zero. These equations are not biased and can be used for estimating urban floods in all of the new study areas.

The RMS errors for the 100-year three-parameter nationwide equations are less than the nationwide standard error of prediction when those equations are applied to the new data in Alabama, Atlanta, and Tennessee, in spite of the fact that the equations are biased in Alabama and Atlanta. In both Florida studies, the equations have large RMS errors. The RMS error for all the data combined is ±47 percent as compared with the nationwide SEP of ±49 percent. Except for Tennessee, the three-parameter equation RMS error is larger than the SEP for the individual regionalized equations of the five new studies.

The RMS errors for the 10- and 100-year seven-parameter nationwide equations are less than the nationwide standard error of prediction for those equations when applied to the data from each of the five new studies. This, plus the fact that the equations are not biased, shows them to be good estimating equations throughout the southeastern United States. The RMS error for both the 10- and 100-year equations is ±35 percent for the combined data set of 78 sites. This is significantly better than the

TABLE 1 Comparison of Variables Used in Urban Flood-Frequency Estimating Equations

	Equation Variable								
Study Area	A	SL	RI2	RI24	ST	STDT	BDF	IA	RQx
Alabama	X							X	
Atlanta, Georgia	X	X						X	
Leon County, Florida	X							X	
Tampa Bay, Florida	X	X				X[a]	X		
Tennessee	X			X				X	
Nationwide									
Three parameters	X						X		X
Seven parameters	X	X	X		X		X	X	X

Note: X = variable is significant.

[a]Storage of 10 yr or less.

TABLE 2 Comparison of Errors for Nationwide Equations and Five Southeastern Studies

Study Area	n	Nationwide Three Parameters (log units/%)			Nationwide Seven Parameters (log units/%)			Reported Study Error (%)	
		X	s	RMS	X	s	RMS	SER	SEP
10-Year Floods[a]									
Alabama	22	−0.1462/−29	0.1450/±34	0.2059/±49	−0.0897/−19	0.1547/±36	0.1788/±42	±24	(±37)
Atlanta	18	−0.1325/−26	0.1262/±29	0.1830/±43	−0.0091/−2	0.1085/±25	0.1089/±25	±15	±25
Leon County	8	−0.3015/−50	0.1331/±31	0.3296/±83	−0.1157/−23	0.1394/±33	0.1811/±43	±20	±33
Tampa	9	−0.2160/−39	0.1779/±42	0.2798/±69	−0.0417/−9	0.1624/±38	0.1677/±40	±35	(±48)
Tennessee	21	−0.0381/−8	0.1530/±36	0.1577/±37	−0.0093/1	0.1418/±33	0.1419/±33	±27	±37
Total	78	−0.1379/−27	0.1627/±38	0.2133/±51	−0.0430/−9	0.1446/±34	0.1508/±35	–	–
100-Year Floods[b]									
Alabama	22	−0.1284/−26	0.1263/±29	0.1801/±43	−0.0589/−13	0.1392/±33	0.1512/±35	±25	(±38)
Atlanta	18	−0.1100/−22	0.1205/±28	0.1632/±38	−0.0417/3	0.1039/±24	0.1049/±24	±13	±25
Leon County	8	−0.2478/−43	0.1576/±37	0.2937/±73	−0.0703/−15	0.1753/±41	0.1888/±45	±25	±40
Tampa	9	−0.1903/−35	0.2215/±53	0.2921/±72	−0.0412/−9	0.2101/±50	0.2141/±51	±42	(±54)
Tennessee	21	−0.0428/−9	0.1512/±36	0.1571/±37	−0.0182/4	0.1405/±33	0.1417/±33	±25	±39
Total	78	−0.1205/−24	0.1575/±37	0.1983/47	−0.0203/−5	0.1470/±34	0.1484/±35	–	–

Note: Values in parentheses were estimated for this paper only.

[a]Nationwide values for SER and SEP (n = 199) are as follows. Three parameters: ±41 percent and ±43 percent; seven parameters: ±38 percent and ±45 percent.

[b]Nationwide values for SER and SEP (n = 199) are as follows. Three parameters: ±46 percent and ±49 percent; seven parameters: ±44 percent and ±53 percent.

TABLE 3 Nationwide Urban Equation Bias Based on Student's t-Test

Study Area	Three-Parameter Equation		Seven-Parameter Equation	
	10 Yr	100 Yr	10 Yr	100 Yr
Alabama	Yes	Yes	No	No
Atlanta	Yes	Yes	No	No
Leon County	Yes	Yes	No	No
Tampa	Yes	No	No	No
Tennessee	No	No	No	No
Total	Yes	Yes	No	No

Note: Level of significance = 0.01.

±44 percent (10-year) and ±53 percent (100-year) reported SEP for the nationwide equations. For each new study area, the seven-parameter RMS error is approximately the same as the prediction errors reported for the individual study regional equations.

SUMMARY AND CONCLUSIONS

During the past 2 years, significant new urban flood data have become available in the southeastern United States. Five new studies have been published by the USGS in Alabama, Georgia, Florida, and Tennessee. In each study, regional equations were developed for estimating urban flood magnitude and frequency. A comparison shows the regional equations to be similar, using drainage area size and an index of urbanization as primary estimating parameters. Standard errors of prediction are generally less than 40 percent.

A comparison with the nationwide urban equations published by Sauer et al. shows their three-parameter equations to significantly underestimate urban floods in four of the new study areas (2). Only for Tennessee and the 100-year flood levels in the Tampa Bay area are the equations unbiased. On the other hand, the nationwide seven-parameter equations are unbiased in all new study areas and show standard errors of prediction less than those published for the nationwide equations.

In conclusion, the individual study regional equations can be used within their specific region and parameter limits. The seven-parameter nationwide equations can be considered good estimating equations throughout the southeastern United States.

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Simulation of Flood Hydrographs for Georgia Streams

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ABSTRACT

Flood hydrographs are needed for the design of many highway drainage structures and embankments. A method for simulating these flood hydrographs at urban and rural ungauged sites in Georgia is presented. The O'Donnell method was used to compute unit hydrographs from 355 flood events from 80 stations. An average unit hydrograph and an average lag time were computed for each station. These average unit hydrographs were transformed to unit hydrographs having durations of one-fourth, one-third, one-half, and three-fourths lag time and then reduced to dimensionless terms by dividing the time by lag time and the discharge by peak discharge. Hydrographs were simulated for these 355 flood events and their widths were compared with the widths of the observed hydrographs at 50 and 75 percent of peak flow. The dimensionless hydrograph based on one-half lag-time duration provided the best fit of the observed data. Multiple-regression analysis was used to define relations between lag time and certain physical basin characteristics, of which drainage area and slope were significant for the rural equations, with impervious area being added for the Atlanta urban equation. A hydrograph can be simulated from the dimensionless hydrograph, peak discharge of a specific recurrence interval, and lag time obtained from regression equations for any site of less than 500 mi^2 in Georgia. For simulating hydrographs at sites larger than 500 mi^2, the U.S. Geological Survey computer model CONROUT can be used. CONROUT produces a simulated outflow discharge hydrograph with a peak discharge of a specific recurrence interval. The diffusion analogy routing method with single linearization was used in this study.

The design of many highway drainage structures and embankments requires an evaluation of the flood-related risk to the structures and to the surrounding property. Risk analyses of alternative designs are necessary to determine the design with the least total expected cost. In order to fully evaluate these risks, a runoff hydrograph with a peak discharge of specific recurrence interval may be necessary to estimate the length of time of inundation of specific features, for example, roads and bridges. For ungauged streams, this information is difficult to obtain; therefore, there is a need for a method based on Georgia hydrologic data to estimate the flood hydrograph associated with a design discharge. The objective of this study was to define techniques for simulating flood hydrographs for specific design discharges at ungauged sites in Georgia. The scope of this study was statewide for rural basins and the Atlanta metropolitan area for urban basins up to 25 mi^2.

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HYDROGRAPH SIMULATION PROCEDURE

Several traditional methods for simulating a hydrograph for a flood of selected recurrence interval at an ungauged watershed were considered for this study. However, a new procedure based on observed streamflow data was developed for this study and is presented in this section.

Basins Less Than 500 mi^2

A dimensionless hydrograph was developed for use in basins up to 500 mi^2. Peak discharge of a selected