Prepared in cooperation with the
Georgia Department of Transportation
Preconstruction Division
Office of Bridge Design

Magnitude and Frequency of Floods for Urban and Small Rural Streams in Georgia, 2008

Scientific Investigations Report 2011–5042

U.S. Department of the Interior
U.S. Geological Survey

Cover. Allatoona Creek at Stillesboro Road near Ackworth, Georgia, September 21, 2009.
Photograph by Andrew E. Knaak, U.S. Geological Survey.

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Conversion Factors and Datums

Multiply	By	To obtain
	Length	
inch	2.54	centimeter (cm)
inch	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C = (°F - 32) / 1.8$$

Vertical coordinate information is referenced to North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to North American Datum of 1983 (NAD 83).

Elevation, as used in this report, refers to distance above the vertical datum.

Acronyms Used in this Report

AEP	annual exceedance probability
APS	all possible subsets
ARC	Atlanta Regional Commission
ARIS	Atlanta Region Information System
BDF	basin-development factor
DEMs	digital elevation models
GDOT	Georgia Department of Transportation
GIS	geographic information system
GLS	generalized least square
NED	National Elevation Dataset
NHD	National Hydrography Dataset
NLCD	National Land Cover Dataset
NWIS	National Water Information System
OLS	ordinary least squares
QA/QC	quality assurance and quality control
USGS	U.S. Geological Survey
VIF	variance inflation factor
WREG	weighted-multiple-linear regression

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Abstract

A study was conducted that updated methods for estimating the magnitude and frequency of floods in ungaged urban basins in Georgia that are not substantially affected by regulation or tidal fluctuations. Annual peak-flow data for urban streams from September 2008 were analyzed for 50 streamgaging stations (streamgages) in Georgia and 6 streamgages on adjacent urban streams in Florida and South Carolina having 10 or more years of data. Flood-frequency estimates were computed for the 56 urban streamgages by fitting logarithms of annual peak flows for each streamgage to a Pearson Type III distribution. Additionally, basin characteristics for the streamgages were computed by using a geographical information system and computer algorithms.

Regional regression analysis, using generalized least-squares regression, was used to develop a set of equations for estimating flows with 50-, 20-, 10-, 4-, 2-, 1-, 0.5-, and 0.2-percent annual exceedance probabilities for ungaged urban basins in Georgia. In addition to the 56 urban streamgages, 171 rural streamgages were included in the regression analysis to maintain continuity between flood estimates for urban and rural basins as the basin characteristics pertaining to urbanization approach zero. Because 21 of the rural streamgages have drainage areas less than 1 square mile, the set of equations developed for this study can also be used for estimating small ungaged rural streams in Georgia. Flood-frequency estimates and basin characteristics for 227 streamgages were combined to form the final database used in the regional regression analysis. Four hydrologic regions were developed for Georgia. The final equations are functions of drainage area and percentage of impervious area for three of the regions and drainage area, percentage of developed land, and mean basin slope for the fourth region. Average standard errors of prediction for these regression equations range from 20.0 to 74.5 percent.

Introduction

Reliable estimates of the magnitude and frequency of floods are essential for Flood Insurance Studies, flood-plain management, and the design of transportation and water-conveyance structures, such as roads, bridges, culverts, dams, and levees. Federal, State, regional, and local officials rely on these estimates to effectively plan and manage land use and water resources, protect lives and property in flood-prone areas, and determine flood-insurance rates.

Reliable flood-frequency estimates are particularly important in densely populated urban areas. Urbanization changes a basin's response to precipitation. The most common effects are reduced infiltration and decreased lag time, which significantly increase peak flows (U.S. Department of Agriculture, 1986). Engineers and planners often need to consider the potential effects on peak flow of urban development scenarios in their design and planning efforts. Because urbanization can produce significant changes in flood-frequency characteristics of streams, rural basin flood-frequency relations are not always applicable to urban streams.

Urban flood-frequency equations were developed by Inman (1995) for urban streams in Georgia using simulated peak-flow data from rainfall-runoff modeling. Inman (1997) compared the 50-, 4-, and 1-percent annual exceedance probability (AEP) flows computed from measured data with the urban flood-frequency estimating equations from Inman (1995) and found that peak flows computed by using equations derived from data generated by rainfall-runoff models generally are higher than those computed by using measured data. However, the differences were within the range of standard error of prediction for the statewide regression equations from Inman (1995). Feaster and Guimaraes (2004) found a significant difference in flood-frequency estimates using simulated peak-flow data compared to using only measured peak-flow data. The flood-frequency estimates using simulated data were higher than estimates using only measured data. Because of the bias found in simulated peak-flow data, only measured data collected on urban streams were used in this study. Since the Inman (1995) study, the U.S. Geological Survey (USGS) has collected additional peak-flow data on urban streams, thus reducing the need for simulated peak-flow data.

The understanding of urban flood-frequency in Georgia can be improved in several ways. One way is to expand the database used for estimating the magnitude and frequency of floods on urban streams by continuing to collect streamflow data at existing urban streamgaging stations, hereafter referred to as streamgages. Griffis and Stedinger (2007a) determined that estimates of magnitude and frequency of floods using streamgages with a shorter record of annual peak-flow data have higher standard errors or uncertainties when compared to estimates using streamgages with longer annual peak-flow record. Thus, long-term data collection at streamgages is important in the determination of reliable estimates of the magnitude and frequency of floods. Urban flood-frequency estimates also could be improved with additional streamgages in urban areas where the network is sparse, which not only would improve the geographical coverage in the State but also would increase the number of streamgages and the range of basin characteristics represented in the database. An extended monitoring network and database are likely to provide more accurate flood-frequency equations for use in design and planning.

Purpose and Scope

The purpose of this report is to present methods for estimating the magnitude and frequency of floods on urban streams and on small rural streams in Georgia. Methods were developed using flood-frequency analyses of annual peak-flow data through September 2008 at urban and rural streamgages. The report includes (1) regional equations for estimating the magnitude and frequency of peak flows on ungaged, non-regulated urban streams; (2) estimates of the magnitude of floods at the 50-, 20-, 10-, 4-, 2-, 1-, 0.5-, and 0.2-percent AEP levels for 50 urban streamgages; (3) techniques used to develop regression equations to estimate the magnitude of floods for ungaged urban sites; (4) a discussion of the accuracy and limitations of these equations; and (5) regional equations for estimating the magnitude and frequency of peak flows on small rural, ungaged non-regulated streams in Georgia.

Previous Studies

Many urban flood-frequency studies have been undertaken in Georgia, however, none of the previous urban studies were based on the extensive number of streamgages and the amount of measured data contained in this report. Earlier USGS studies describing urban flood-frequency relations applicable to Georgia include reports completed by Lumb (1975), James and Lumb (1975), Golden (1977), Lichty and Liscum (1978), Price (1979), Inman (1983), Sauer and others (1983), and Inman (1988, 1995, 1996, 1997).

Lumb (1975) explained how a flood-simulation model was used to simulate an annual series of flood peaks and perform a flood-frequency analysis at a selected point. James and Lumb (1975) applied the model to eight watersheds in DeKalb County, Georgia, with limited observed data for verification.

Golden (1977) presented flood-frequency relations for urban streams in Metropolitan Atlanta based on the technique used by Sauer (1974) for Oklahoma, which included rural flood-frequency and rainfall-frequency characteristics of the local area. Sauer (1974) adjusted rural flood-frequency relations to urban conditions by using local rainfall-frequency characteristics, percentage of impervious area in the basin, and percentage of the basin served by street gutters and storm sewers. Price (1979) used the same technique on a statewide basis for Georgia.

Lichty and Liscum (1978) described a procedure for computing estimates of 2- through 100-year floods that incorporates a rainfall information-transfer mechanism in the form of three maps, and a generalized definition of synthetic T-year flood potential as a function of fitted rainfall-runoff model parameters. Impervious area was incorporated in T-year flood equations to account for urban development. This procedure is applicable for most of the Eastern United States.

A method for estimating the magnitude and frequency of floods on small streams in the Atlanta metropolitan area was presented by Inman (1983). This method was based on observed peak-discharge data from 19 streamgages, which were used to calibrate USGS rainfall-runoff models (Dawdy and others, 1972; Alley and Smith, 1982). These models were used to synthesize long-term annual peak discharges for the 19 basins. The 2- to 100-year flood estimates were developed for the 19 basins from these synthetic, long-term peak discharges by fitting a Pearson Type III frequency distribution curve to the logarithms of the annual peak discharges. Multiple-regression analyses were used to define relations between flood-frequency data and certain physical characteristics of the basin, of which drainage area, main-channel slope, and measured total impervious area were found to be statistically significant. These relations were used to estimate the magnitude and frequency of floods at ungaged basins in the Atlanta area.

Regression equations and several other methods of estimating flood frequency for urban watersheds on a nationwide basis were presented by Sauer and others (1983). Five basins in the Atlanta area were used in the analysis.

A method for estimating the magnitude and frequency of floods for urban streams on a statewide basis for Georgia was presented by Inman (1988). This method was based on observed data from 45 streamgages, which were used to calibrate a USGS rainfall-runoff model (Dawdy and others, 1972). This model was used to synthesize long-term peak discharges for the 45 basins. The 2- to 100-year peak discharge estimates were developed for each basin from these synthetic, long-term annual peak discharge records and by fitting a Pearson Type III frequency distribution curve to the logarithms of the annual peak discharges. Multiple-regression analyses were used to define relations between the flood-frequency data and certain physical characteristics of the basin, of which drainage area, equivalent rural discharge, and measured total impervious area were found to be statistically significant. These relations were used to estimate the magnitude and frequency of floods at ungaged basins in urban areas on a statewide basis for Georgia. Inman (1995) updated the previous study (Inman, 1988) by including an additional 20 basins in four urban areas of South Georgia. Subsequently, Inman (1996, 1997) compared the results of the updated study (Inman, 1995) with flood-frequency estimates computed from measured-only data.

Acknowledgments

This report was prepared as part of an ongoing cooperative program of water-resources investigations between the USGS and the Georgia Department of Transportation (GDOT), Preconstruction Division, Office of Bridge Design. The peak-flow data used in the analyses described in this report were collected throughout Georgia and adjoining States at streamgages operated in cooperation with GDOT and a variety of other Federal, State, and local agencies. The authors also acknowledge the dedicated work of the USGS field-office staff in collecting, processing, and storing the peak-flow data necessary for the completion of this study.

Data Compilation

The first step in the regionalization of flood-frequency estimates for urban streams is the compilation of data for all urban streamgages with 10 or more years of annual peak-flow record. It is important for the peak-flow data to be reviewed for quality assurance and quality control (QA/QC) and for the absence of trends in watershed and climatic conditions during the period of record. Once peak-flow records are compiled and reviewed, the basin characteristics must be determined for each of the streamgages.

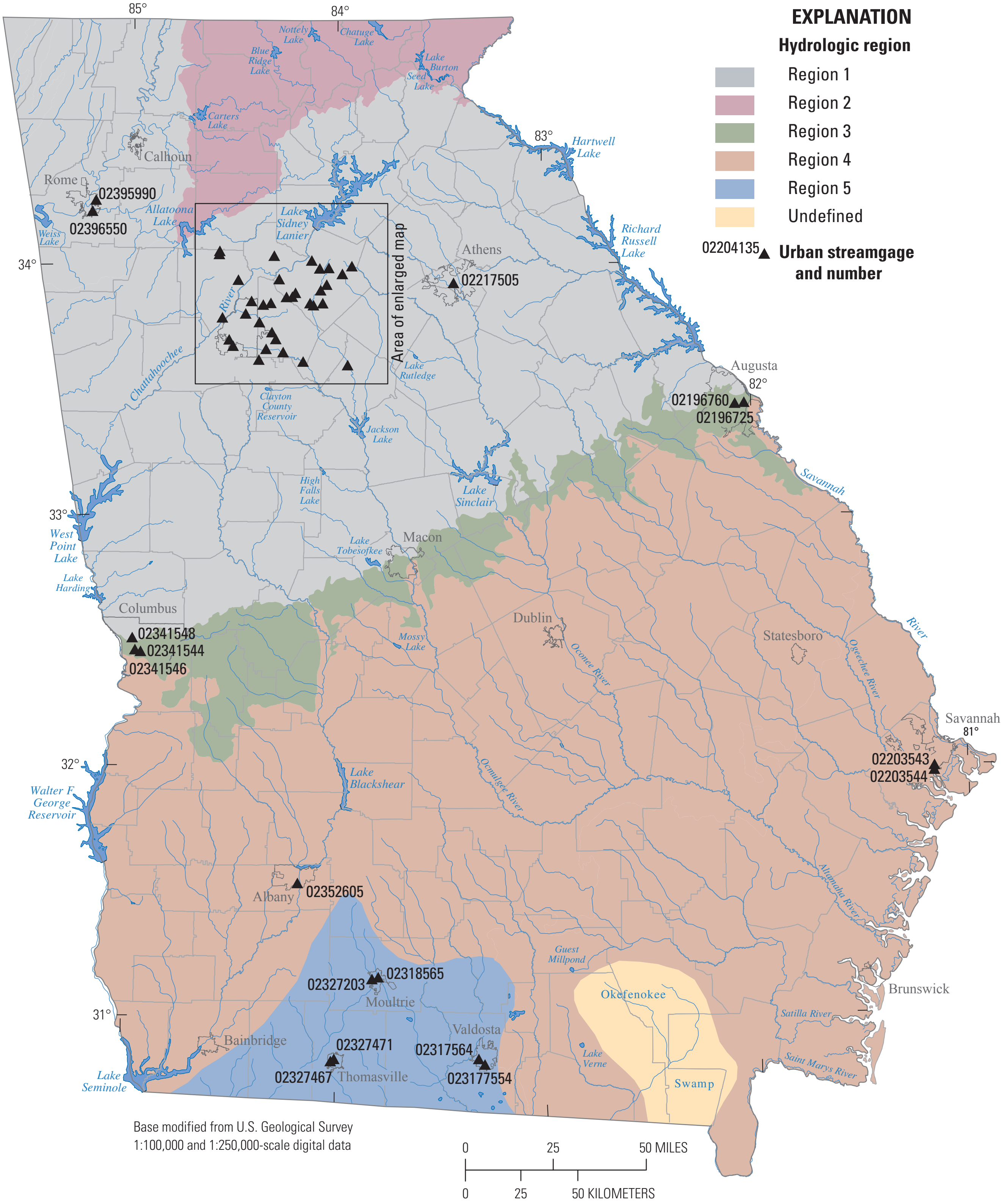
Peak-Flow Data

Streamgages with annual peak-flow record are either continuous-record streamgages or crest-stage gages. At continuous-record streamgages, the water-surface elevation, or stage, of the stream is recorded at fixed intervals, typically 15 minutes. At crest-stage gages, only the crest (highest) stage that occurs between site visits is recorded. Regardless of the type of streamgage, measurements of stage and flow (discharge) are used to develop a relation between stage and discharge for the streamgage. Using this stage-discharge relation, or rating, discharges for all recorded stages at this streamgage are determined. The highest peak discharge that occurs during a given year is the annual peak flow for the year, and the list of annual peak flows forms a time series referred to as the annual peak-flow record. The peak-flow records for streamgages are available from the USGS National Water Information System (NWIS) database at *http://nwis.waterdata.usgs.gov/usa/nwis/peak/*.

Urban streamgages in Georgia were investigated for possible use in this study. The percentage of impervious surface area has long been recognized as an effective indicator of the intensity of urban development and its potential effects on streamflow and the environment (Klein, 1979). The threshold of influence of impervious surface area on streamflow has been reported in previous studies (Brabec and others, 2002) to be between 5 and 21 percent. Landers and others (2007) reported that basin imperviousness had a well-defined influence on streamflow at levels between 12 and 21 percent. For this study, a streamgage is considered urban if the impervious area within the drainage area is 10 percent or greater.

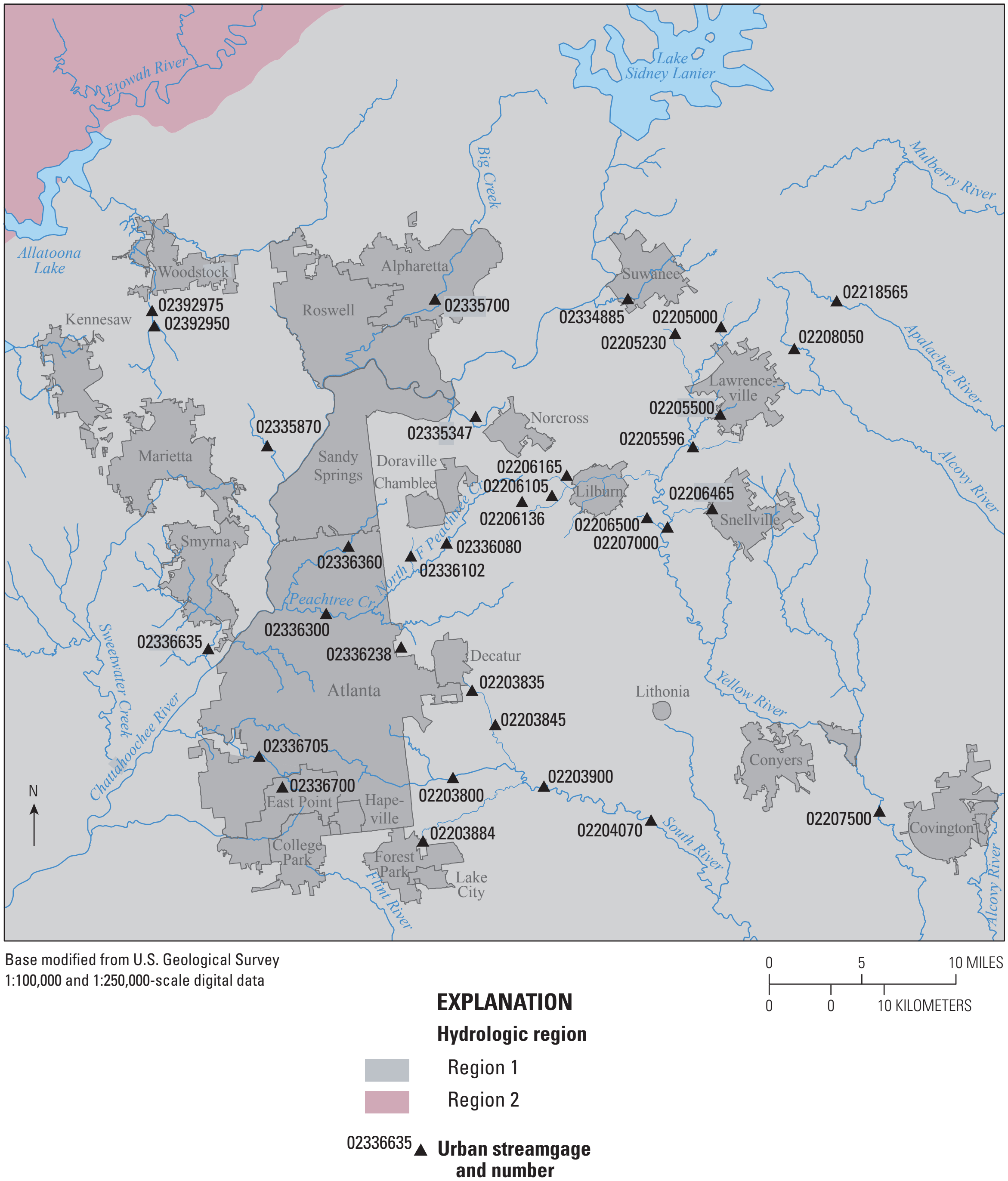
Streamgages were used in the analysis only if 10 or more years of annual peak-flow data were available and if peak flows at the streamgages were not affected substantially by dam regulation, flood-retarding reservoirs, channelization, or tides. The peak-flow record for urban streamgages that meet these criteria then were compiled and reviewed for QA/QC by using the PFReports computer program, as detailed by Ryberg (2008). Kendall’s tau was chosen to assess the significance of time trends in the peak-flow record for each streamgage (Helsel and Hirsch, 1992). If it was determined that a streamgage record was not homogeneous, the entire record for that streamgage was not considered. However, if a significant portion of the record was found to be homogeneous, the homogenous portion of the record was considered for this study if the basin characteristics were representative of this portion of record. Topographic maps and aerial photos were used to help identify if the cause of a positive trend in flood-peak magnitude was a result of increasing urbanization during the gaged period of record in the basin. For the Atlanta area, geographic information system (GIS) coverages of land-use data for 1999, 2001, 2003, 2005, and 2007 were obtained from the Atlanta Regional Commission (ARC; 2008) Atlanta Region Information System (ARIS) at *http://www.atlantaregional.com/info-center/gis-data-maps/gis-data*. These land-use data were used to determine changes in urbanization for the streamgages in the Atlanta metropolitan area. The urban streamgages that were used in the previous Georgia urban flood-frequency study by Inman (1995) are located in older, well-established urban areas outside of the Atlanta metropolitan area, and these basins were considered to be stable.

The QA/QC and trend analyses resulted in the selection of 50 urban gaging stations for use in this study (fig. 1; table 1) from the 101 candidate stations in Georgia. Of the 50 streamgages selected, 10 had a significant positive trend at the 0.05 level in the early part of the record as a result of increasing urbanization. The homogenous portion of the record was used for these 10 streamgages, as noted in table 1.



Base modified from U.S. Geological Survey 1:100,000 and 1:250,000-scale digital data

Figure 1. Locations of streamgages with 10 or more years of record in urban areas of Georgia, 2008.



Base modified from U.S. Geological Survey
1:100,000 and 1:250,000-scale digital data

Figure 1. Locations of streamgages with 10 or more years of record in urban areas of Georgia, 2008.—Continued

Table 1. Summary of urban streamgages in Georgia that were used in the regional regression analysis, 2008.

[USGS, U.S. Geological Survey]

USGS station number	Station name	Drainage area (square miles)	Latitude	Longitude	Hydrologic region	Period of record	Number of systematic peaks
			(degree minute second)				
02196725	Oates Creek at White Road, at Augusta, GA	0.68[a]	33 27 19	82 00 22	3	1979–1989	11
02196760	Rocky Creek tributary at U.S. Highway 78/278 at Augusta, GA	1.35[a]	33 27 07	82 02 56	3	1979–1996	18
02203543	Wilshire Canal at Tibet Avenue at Savannah, GA	1.06[a]	31 59 28	81 08 14	4	1979–1996	18
02203544	Wilshire Canal tributary at Windsor Road at Savannah, GA	0.10[a]	31 58 26	81 08 19	4	1979–1996	18
02203800	South River at Bouldercrest Road at Atlanta, GA	41.5	33 40 46	84 18 30	1	1961–1990[b]	27
02203835	Shoal Creek at Line Street at Atlanta, GA	3.43	33 44 48	84 16 50	1	1973–1996	24
02203845	Shoal Creek tributary at Glendale Drive near Atlanta, GA	0.95[a]	33 43 05	84 15 45	1	1963–1996	26
02203884	Conley Creek at Rock Cut Road near Forest Park, GA	1.88	33 38 08	84 20 37	1	1974–1996	21
02203900	South River at Flakes Mill Road near Atlanta, GA	99.0	33 39 58	84 13 29	1	1961–1991[b]	31
02204070	South River at Klondike Road, near Lithonia, GA	182	33 37 47	84 07 43	1	1984–2008	25
02205000	Wildcat Creek near Lawrenceville, GA	1.28[a]	34 00 07	84 00 18	1	1975–2008[b]	22
02205230	Wolf Creek at Dean Road, near Suwanee, GA	0.33[a]	34 00 04	84 02 57	1	1987–2008	22
02205500	Pew Creek near Lawrenceville, GA	2.43[a]	33 56 05	84 00 60	1	1995–2008[b]	13
02205596	Yellow River tributary at Plantation Road, near Lawrenceville, GA	7.23	33 54 45	84 02 45	1	1997–2008	12
02206105	Jackson Creek at Angels Lane, near Lilburn, GA	0.15[a]	33 53 12	84 12 42	1	1987–2008	20
02206136	Jackson Creek tributary 1 at Williams Road, near Lilburn,GA	0.33	33 53 19	84 10 59	1	1987–2008	17
02206165	Jackson Creek tributary 2 at Worchester Place, near Lilburn, GA	0.10	33 54 09	84 10 01	1	1987–2008	21
02206465	Watson Creek tributary 2 at Tanglewood Drive, at Snellville, GA	0.20	33 51 46	84 02 07	1	1987–2008	22
02206500	Yellow River near Snellville, GA	134	33 51 11	84 04 45	1	1943–2002	60
02207000	Garner Creek near Snellville, GA	5.54	33 51 45	84 05 50	1	1995–2007[b]	13
02207500	Yellow River near Covington, GA	378	33 36 52	83 54 54	1	1976–1999[b]	24
02208050	Alcovy River near Lawrenceville, GA	9.97	33 58 40	83 56 23	1	1995–2008[b]	12
02217505	Brooklyn Creek at Dudley Drive, at Athens, GA	1.44	33 56 32	83 24 07	1	1979–1994	16
02218565	Apalachee River at Fence Road, near Dacula, GA	5.68	34 00 37	83 53 39	1	1994–2008	15
02317564	Dukes Bay Canal at GA Highway 94, at Valdosta, GA	1.64[a]	30 49 14	83 16 20	5	1987–1996	10
023177554	Onemile Branch at Wainwright Drive, at Valdosta, GA	2.84[a]	30 50 35	83 18 04	5	1987–1996	10

Table 1. Summary of urban streamgages in Georgia that were used in the regional regression analysis, 2008.—Continued

[USGS, U.S. Geological Survey]

USGS station number	Station name	Drainage area (square miles)	Latitude (degree minute second)	Longitude (degree minute second)	Hydrologic region	Period of record	Number of systematic peaks
02318565	Okapilco Creek tributary at 10th Street, at Moultrie, GA	0.21[a]	31 10 13	83 46 40	5	1987–1996	10
02327203	Tributary to Ochlockonee River tributary at 4th Street, at Moultrie, GA	0.25[a]	31 09 55	83 47 35	5	1986–1996	11
02327467	Oquina Creek at Wolf Street, at Thomasville, GA	0.94[a]	30 50 13	83 59 38	5	1986–1996	11
02327471	Bruces Branch at North Hansell Street, at Thomasville, GA	0.26[a]	30 50 40	83 58 36	5	1986–1995	10
02334885	Suwanee Creek at Suwanee, GA	47.0	34 01 56	84 05 22	1	1985–2008	24
02335347	Crooked Creek tributary 2, near Norcross, GA	0.19	33 57 24	84 14 43	1	1987–2008	22
02335700	Big Creek near Alpharetta, GA	72.0	34 03 02	84 16 10	1	1961–2008	48
02335870	Sope Creek near Marietta, GA	30.7[a]	33 57 14	84 26 36	1	1985–2008[b]	24
02336080	North Fork Peachtree Creek at Shallowford Road, near Chamblee, GA	19.1	33 51 43	84 17 13	1	1961–1990	22
02336102	North Fork Peachtree Creek tributary at Drew Valley Road, near Atlanta, GA	2.30[a]	33 51 20	84 19 19	1	1973–1996	23
02336238	South Fork Peachtree Creek tributary at East Rock Springs Road, near Atlanta,GA	0.92	33 47 11	84 20 29	1	1974–1996	23
02336300	Peachtree Creek at Atlanta, GA	86.8	33 49 10	84 24 28	1	1970–2008[b]	39
02336360	Nancy Creek at Rickenbacker Drive, at Atlanta, GA	26.6	33 52 09	84 22 44	1	1961–2008	15
02336635	Nickajack Creek at U.S. Highway 78/278, near Mableton, GA	31.5	33 48 12	84 31 17	1	1990–2008[b]	13
02336700	South Utoy Creek tributary at Headland Drive at East Point, GA	0.68[a]	33 41 25	84 28 05	1	1964–1996	32
02336705	South Utoy Creek at Adams Drive, at Atlanta, GA	8.80	33 42 57	84 29 11	1	1961–1983	11
02341544	Mill Branch at Chalbena Road, at Columbus, GA	1.58	32 28 20	84 53 58	3	1977–1996	20
02341546	Bull Creek tributary at Woodland Drive, at Columbus, GA	0.22[a]	32 28 39	84 55 36	3	1977–1996	19
02341548	Lindsey Creek tributary at Canberra Avenue, at Columbus, GA	1.59[a]	32 31 34	84 56 21	1	1978–1996	19
02352605	Emily Avenue Canal at Albany, GA	0.21[a]	31 32 53	84 09 28	4	1987–1996	10
02392950	Noonday Creek at Hawkins Store Road, near Woodstock,GA	25.5[a]	34 03 23	84 32 08	1	1999–2008	10
02392975	Noonday Creek at Shallowford Road, near Woodstock,GA	33.6	34 04 06	84 32 08	1	1999–2008	10
02395990	Etowah River tributary at Atteiram Drive at Rome, GA	0.33[a]	34 16 02	85 08 18	1	1979–1997	19
02396550	Silver Creek tributary 3 at U.S. Highway 27 at Rome, GA	0.25[a]	34 13 26	85 09 14	1	1979–1997	19

[a] Drainage area revised as a result of this study.

[b] Homogenous portion of peak-flow record used in the Bulletin 17B analysis.

Physical and Climatic Basin Characteristics

Peak-flow information can be estimated at ungaged sites by using multiple regression analysis that relates peak-flow characteristics (such as 1-percent AEP flow) to selected physical and climatic basin characteristics for gaged drainage areas. Drainage-basin boundaries are needed for each station to determine basin characteristics. Basin boundaries were generated from National Elevation Dataset (NED) digital elevation models (DEMs) at 30-meter (m) horizontal resolution (or 10-m when available; U.S. Geological Survey, 1999a). To improve boundary delineations, processing was done to make the DEM conform to stream locations defined in the high-resolution National Hydrography Dataset (NHD; U.S. Geological Survey, 1999b).

Basin characteristics were selected for use as potential explanatory variables in the regression analyses on the basis of the theoretical hydrologic relation to flood flows and the ability to measure the basin characteristics using digital datasets and GIS technology. For each of the 50 urban streamgages, the following 17 basin characteristics were determined and considered for this study: drainage area; basin perimeter length; mean basin slope; basin shape factor; main channel length; main channel slope; minimum, maximum, and mean basin elevations; percentage of basin imperviousness; percentage of basin developed; percentage of basin forested; percentage of basin storage; soil drainage index; hydrologic soil index; drainage density; and mean annual precipitation. The names, units of measure, methods of measurement, and source data for the measured basin characteristics that were considered for use in this study are listed in table 2.

The drainage areas that were computed by using GIS were compared to previously published drainage areas for the streamgages as a means of quality assurance. The measured and published drainage areas agreed closely for most stations in Georgia, but the drainage areas for several stations differed by more than 5 percent. In most of these cases, the published drainage areas were determined from older topographic maps with 10-foot (ft) contour intervals. Boundaries determined by the two methods were compared, and those computed by using GIS were considered superior in accuracy to manual delineations. Therefore, the station drainage areas with differences greater than 5 percent were revised using the GIS-measured values. The streamgages with revised drainages areas are noted in table 1.

The methods used in the previous Georgia urban flood-frequency study by Inman (1995) to compute the percentage of impervious area within a drainage area are documented in Cochran (1963). For this study, however, a more current method of computing the percentage of impervious area within a basin was used. The impervious cover dataset developed by the USGS as part of the 2001 National Land Cover Dataset (NLCD; Yang and others, 2003; U.S. Environmental Protection Agency, 2007) was used to compute the percentage of impervious area within a basin. Computing the impervious area by using GIS tools with the NLCD 2001 coverages provided accurate results (Chabaeva and others, 2009) in less time than the previous methods used.

Percentage of developed land is another variable considered in this study to be an indicator of the amount of urbanization in the basin. This variable is computed by dividing the sum of the area of each NLCD land-cover class for developed land by the drainage area of the basin. Table 3 shows the definitions for the four NLCD land-cover classes for developed land. A graph of the relation between the percentage of impervious area and the percentage of developed land for the 50 Georgia urban streamgages with a regression line fit is shown in figure 2. The coefficient of determination, R^2, for the relation is 0.390; thus, these two variables have a poor correlation.

The basin-development factor (BDF) described in Sauer and others (1983) was not included in this study. The BDF computations are labor-intensive field assessments that are subjective and make repeatability difficult. In Feaster and Guimaraes (2004), the inclusion of the BDF reduced the standard error of prediction by only 4 percent for urban streams in the adjacent State of South Carolina. Thus, the effort required to compute the BDF does not appear to provide a substantial benefit for reducing the uncertainty in flood estimates for the Southeastern United States.

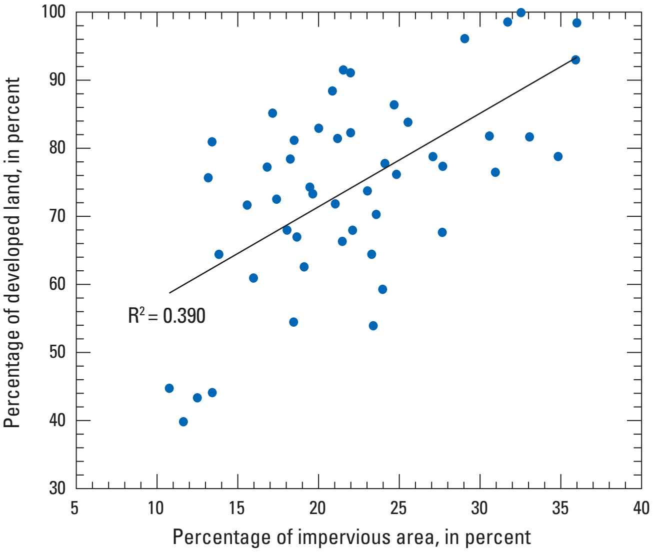


Figure 2. Relation between the percentage of developed land and the percentage of impervious area for the 50 urban streamgages in Georgia used in the regression analysis.

Table 2. Basin characteristics considered for use in the regional regression analysis.

[DEM, digital elevation model; USGS, U.S. Geological Survey; NED, National Elevation Dataset; NHD, National Hydrography Dataset; NLCD, National Land-Cover Dataset; PRISM, Parameter-elevation Regressions on Independent Slopes Model; STATSGO, State Soil Geographic; m, meter; %, percent]

Name	Unit	Method	Source data
Drainage area	Square miles	Area within the watershed boundary, which is represented as a polygon of cells that flow to the streamgage location based on the primary down-slope flow direction of the DEM	USGS NED DEMs at 10- and 30-m resolution (*http://ned.usgs.gov*), conditioned to conform with NHD streams, 1:24,000 scale (*http://nhd.usgs.gov/*)
Main channel length	Miles	Length of the longest flow path in a drainage area based on steepest descent as defined by the flow direction grid	DEM data used to create the watershed boundaries, as defined in the drainage area source data
Basin perimeter	Miles	Length of watershed boundary perimeter	Watershed boundaries, as defined in the drainage area method
Main channel slope	Feet per mile	Difference in the DEM elevation at points corresponding to 10% and 85% of the main channel divided by the main channel length between those two points	DEM data used to create the watershed boundaries, as defined in the drainage area source data Main channel length, as defined in the main channel length method
Mean basin slope	Percent	Mean of the DEM percent slope grid values within the watershed boundary	DEM data used to create the watershed boundaries, as defined in the drainage area source data
Basin shape factor	Dimensionless	Main channel length squared divided by drainage area	Drainage area, as defined in the drainage area method Main channel length, as defined in the main channel length method
Mean basin elevation	Feet	Area-weighted average	DEM data used to create the watershed boundaries, as defined in the drainage area source data
Maximum basin elevation	Feet	Maximum elevation value of the DEM within the watershed boundary	DEM data used to create the watershed boundaries, as defined in the drainage area source data
Minimum basin elevation	Feet	Minimum elevation value of the DEM within the watershed boundary	DEM data used to create the watershed boundaries, as defined in the drainage area source data
Percentage of impervious area	Percent	(Impervious surface area/drainage area)×100	NLCD 2001 impervious surface, 30-meter resolution (*http://www.mrlc.gov/nlcd.php*)
Percentage of developed land	Percent	(Sum of areas of classes 21–24/drainage area)×100, where land-use classes aer defined at *http://www.mrlc.gov/nlcd_definitions.php*	NLCD 2001, 30-meter resolution (*http://www.mrlc.gov/nlcd.php*)
Percentage of forested land	Percent	(Forested area/drainage area)×100	NLCD 2001, 30-meter resolution (*http://www.mrlc.gov/nlcd.php*)
Percentage of storage	Percent	Sum of areas of wetlands and open water/drainage area)×100	NHD, 1:24,000 scale (*http://nhd.usgs.gov*)
Mean annual precipitation	Inches	Area-weighted average	PRISM (*http://prism.oregonstate.edu*)
Soil drainage index	Dimensionless	Area-weighted average	STATSGO data (*http://www.soils.usda.gov/survey/geography/statsgo/*)
Hydrologic soil index	Dimensionless	Area-weighted average	STATSGO data (*http://www.soils.usda.gov/survey/geography/statsgo/*)
Drainage density	Miles per square mile	Total length of all streams divided by drainage area	NHD, 1:24,000 scale (*http://nhd.usgs.gov*)

Table 3. 2001 National Land Cover Dataset (NLCD) class definitions for developed land (*http://www.mrlc.gov/nlcd_definitions.php*).

Class number	Class name	Class definition
21	Developed, open space	Includes areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20 percent of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.
22	Developed, low intensity	Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20 to 49 percent of total cover. These areas most commonly include single-family housing units.
23	Developed, medium intensity	Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50 to 79 percent of the total cover. These areas most commonly include single-family housing units.
24	Developed, high intensity	Includes highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80 to100 percent of the total cover.

Estimation of Flood Magnitude and Frequency at Urban Streamgages

A frequency analysis of annual peak-flow data at a streamgage provides an estimate of the flood magnitude and frequency at that specific stream site. Flood-frequency flows in previous USGS reports were expressed as T-year floods based on the recurrence interval for the flood quantile (for example, the "100-year flood"). The use of recurrence-interval terminology is now discouraged because it is sometimes confusing to the general public. The term has been interpreted to imply a set time interval between floods of a particular magnitude, when in fact floods are random processes that are best understood by using probabilistic terms. While the T-year recurrence interval flood is statistically expected to occur, on average, once during the T-year period, it may occur multiple times during the period or not at all.

Terminology associated with flood-frequency estimates is shifting away from the T-year recurrence interval flood to the P-percent AEP flood. The use of percent AEP flood is now recommended because it conveys the probability, or odds, of a flood of a given magnitude being equaled or exceeded in any given year. For example, a 1-percent AEP flood (formerly known as the "100-year flood") corresponds to the flow magnitude that has a probability of 0.01 of being equaled or exceeded in any given year. The P-percent is computed as the inverse of the recurrence interval "T" multiplied by 100 (for example, 1/100 × 100). T-year recurrence intervals with corresponding percent AEPs are shown in table 4 (Gotvald and others, 2009).

Table 4. T-year recurrence intervals with corresponding percent annual exceedance probabilities for flood-frequency flow estimates.

T-year recurrence interval	P-percent annual exceedance probability
2	50
5	20
10	10
25	4
50	2
100	1
200	0.5
500	0.2

Flood-frequency estimates for streamgages are computed by fitting the series of annual peak flows to a known statistical distribution. Flood-frequency estimates for this study were computed by fitting logarithms (base 10) of the annual peak flows to a Pearson Type III distribution. This follows the guidelines and computational methods described in Bulletin 17B (Interagency Advisory Committee on Water Data, 1982). Fitting the distribution requires calculating the mean, standard deviation, and skew coefficient of the logarithms of the annual peak-flow record, which describe the mid-point, slope, and curvature of the peak-flow frequency curve, respectively. Estimates of the P-percent AEP flows are computed by inserting the three statistics of the frequency distribution into the equation:

$$\log Q_P = X + KS, \qquad (1)$$

where

Q_P is the P-percent AEP flow, in cubic feet per second (ft^3/s);

X is the mean of the logarithms of the annual peak flows;

K is a factor based on the skew coefficient and the given percent AEP, which can be obtained from appendix 3 in Bulletin 17B; and

S is the standard deviation of the logarithms of the annual peak flows, which is a measure of the degree of variation of the annual values about the mean value.

A series of annual peak flows at a station may include outliers, or annual peak flows that are substantially lower or higher than other peak flows in the series. The station record also may include information about peak flows that occurred outside of the period of regularly collected, or systematic, record. These peak flows are known as historic peaks and usually are peak flows known to have occurred during an extended period of time (longer than the period of collected record). Bulletin 17B (Interagency Advisory Committee on Water Data, 1982) provides guidelines for detecting and interpreting outliers and historic data points and provides computational methods for appropriate corrections to the distribution to account for the presence of outliers and historic information. In some cases, outliers may be excluded from the record; thus, the number of systematic peaks may not be equal to the number of years in the period of record.

In terms of annual peak flows, the period of collected record can be thought of as a sample of the entire record, or population. Statistical measures, such as mean, standard deviation, or skew coefficient, can be described in terms of the sample, or computed measure, and the population, or true measure. Statistical measures computed from the sample record are estimates of what the measure would be if the entire population were known and used to compute the given measure. The accuracy of these estimates depends on the specific statistic and the given sample of the population.

The USGS computer program PeakFQ version 5.2 (U.S. Geological Survey, 2007) was used to compute flood-frequency estimates for the 50 urban streamgages in Georgia considered for this study. PeakFQ software automates many of the analytical procedures recommended in Bulletin 17B (Interagency Advisory Committee on Water Data, 1982), including identifying and adjusting for outliers and historical periods, weighting of station skews with a generalized skew, and fitting a log-Pearson Type III distribution to the annual peak-flow data (Flynn and others, 2006). Bulletin 17B (Interagency Advisory Committee on Water Data, 1982) recommends using a weighted average of the station skew coefficient with a generalized or regional skew coefficient. For urban streamgages, this method is problematic because of the limited number of urban streamgages with 25 years or more of peak-flow record from which to develop a generalized skew. In this study, therefore, each urban streamgage was considered individually, and the flood-frequency estimates were computed using the respective station skew. This is consistent with the methodology used in the previous Georgia urban flood-frequency study (Inman, 1995) and the approach used in the national urban flood-frequency study by Moglen and Shivers (2006). The final flood-frequency estimates from the Bulletin 17B analysis for the 50 urban streamgages in Georgia are listed in table 5.

Table 5. Flood-frequency statistics for urban streamgages in Georgia that were used in the regression equations, 2008.—Continued

[USGS, U.S. Geological Survey]

USGS station number	Annual exceedance flow, in cubic feet per second 50 percent	20 percent	10 percent	4 percent	2 percent	1 percent	0.5 percent	0.2 percent
02196725	147	188	210	234	249	262	274	288
02196760	345	513	647	844	1,010	1,200	1,410	1,730
02203543	254	371	481	665	843	1,060	1,340	1,800
02203544	82.8	101	111	121	128	135	140	147
02203800	3,670	5,250	6,380	7,900	9,110	10,400	11,700	13,600
02203835	715	938	1,150	1,510	1,860	2,280	2,810	3,680
02203845	422	577	669	774	845	910	971	1,050
02203884	672	929	1,100	1,310	1,460	1,610	1,770	1,970
02203900	5,270	7,460	8,930	10,800	12,200	13,500	14,900	16,800
02204070	6,400	9,090	11,000	13,600	15,600	17,700	20,000	23,100

Table 5. Flood-frequency statistics for urban streamgages in Georgia that were used in the regression equations, 2008.—Continued

[USGS, U.S. Geological Survey]

USGS station number	Annual exceedance flow, in cubic feet per second							
	50 percent	20 percent	10 percent	4 percent	2 percent	1 percent	0.5 percent	0.2 percent
02205000	303	539	701	902	1,050	1,180	1,320	1,480
02205230	139	183	211	246	272	297	323	357
02205500	449	868	1,300	2,120	2,980	4,130	5,650	8,460
02205596	648	945	1,140	1,390	1,570	1,740	1,920	2,150
02206105	86.8	118	137	161	178	195	211	232
02206136	130	162	184	213	235	257	280	311
02206165	63.5	90.5	106	123	133	143	152	162
02206465	73	110	137	172	199	227	256	296
02206500	3,680	5,630	7,200	9,520	11,500	13,800	16,300	20,100
02207000	847	1,220	1,440	1,700	1,880	2,040	2,200	2,390
02207500	5,510	9,550	13,900	22,100	31,000	43,200	59,900	91,600
02208050	668	1,030	1,310	1,720	2,070	2,450	2,880	3,510
02217505	506	670	792	962	1,100	1,250	1,410	1,650
02218565	486	713	864	1,060	1,200	1,340	1,480	1,670
02317564	247	305	339	377	402	426	449	477
023177554	717	801	844	887	914	937	957	981
02318565	45.5	63.8	80	106	130	159	194	250
02327203	137	187	223	273	312	354	398	461
02327467	213	277	321	379	423	468	515	580
02327471	86.2	115	141	185	227	278	340	444
02334885	1,730	2,750	3,410	4,210	4,770	5,310	5,830	6,480
02335347	149	204	238	279	309	337	365	400
02335700	1,980	3,470	4,580	6,110	7,320	8,580	9,900	11,700
02335870	3,540	5,370	6,590	8,120	9,240	10,300	11,400	12,900
02336080	2,180	2,480	2,640	2,790	2,890	2,970	3,040	3,130
02336102	726	904	1,010	1,120	1,200	1,280	1,350	1,430
02336238	586	738	844	983	1,090	1,200	1,320	1,480
02336300	6,400	8,160	9,330	10,800	11,900	13,100	14,200	15,800
02336360	2,500	3,330	3,890	4,630	5,190	5,770	6,370	7,200
02336635	2,880	4,680	6,020	7,890	9,400	11,000	12,700	15,100
02336700	301	377	426	490	537	585	634	700
02336705	2,570	2,930	3,130	3,370	3,530	3,680	3,820	3,990
02341544	582	794	931	1,100	1,230	1,350	1,470	1,640
02341546	69	105	136	186	232	286	351	456
02341548	414	571	676	811	913	1,020	1,120	1,260
02352605	46.2	71.7	90.7	117	138	161	185	220
02392950	1,450	2,330	3,340	5,430	7,850	11,400	16,500	26,900
02392975	1,520	2,480	3,540	5,620	7,940	11,200	15,700	24,600
02395990	114	162	190	223	246	266	286	310
02396550	141	171	188	208	222	235	247	262

Estimation of Flood Magnitude and Frequency at Ungaged Urban Sites

A regional regression analysis was used to develop a set of equations for use in estimating the magnitude and frequency of floods for ungaged urban sites in Georgia. These equations relate the 50-, 20-, 10-, 4-, 2-, 1-, 0.5-, and 0.2-percent AEP flows computed from available records for streamgages to measured physical and climatic basin characteristics of the associated drainage areas. All 50 urban streamgages used in the flood-frequency analysis were considered for use in the regional regression analysis (fig. 1; table 1).

Regression Analysis

Ordinary least-squares (OLS) regression techniques were used in the exploratory analysis to determine the best regression models for all combinations of basin characteristics and the development of hydrologic regions that define the study area. OLS regression explores linear relations between the explanatory (basin characteristics) and response (P-percent AEP flows) variables; thus, sometimes variables must be transformed in order to create more linear relations. For example, the relation between arithmetic values of basin drainage area and P-percent AEP flow is typically curvilinear. However, the relation between the logarithms of basin drainage area and the logarithms of P-percent AEP flow typically is linear. Homoscedasticity (a constant variance in the response variable over the range of the explanatory variables) about the regression line and normality of the residuals also are requirements for OLS regression. Log transformation of the P-percent AEP flow and some of the explanatory variables enhance the homoscedasticity of the data about the regression line. Homoscedasticity and normality of residuals were examined in residual plots.

Selection of the explanatory variables for each hydrologic region was based on all-possible-subsets (APS) regression methods (Neter and others, 1985). The final explanatory variables for each hydrologic region were selected on the basis of several factors, including standard error of the estimate, Mallow's *Cp* statistic, statistical significance of the explanatory variables, coefficient of determination (R^2), and ease of measurement of explanatory variables. Multicollinearity in the candidate exploratory variables also was assessed by the variance inflation factor (VIF) and the correlation between explanatory variables.

Generalized least square (GLS) regression methods, as described by Stedinger and Tasker (1985), were used to determine the final regional P-percent AEP flow regression equations with the use of the weighted-multiple-linear regression (WREG) program version 1.01 (U.S. Geological Survey, 2010). Details on this computer program are available in Eng and others (2009). Stedinger and Tasker (1985) found that GLS regression equations are more accurate and provide a better estimate of the accuracy of the equations than OLS regression equations when annual peak flow records at streamgages are of different and widely varying lengths and when concurrent flows at different streamgages are correlated. GLS regression techniques give less weight to streamgages that have shorter periods of record than to streamgages with longer periods of record. Less weight is also given to streamgages where concurrent peak flows are correlated because of the geographic proximity to other streamgages (Hodgkins, 1999).

Regionalization of Flood-Frequency Estimates

Some regional regression analyses for urban streams result in an equation that includes the equivalent rural regression flood flow, which is a flood flow computed by using a rural regression equation for an equivalent rural basin in the same hydrologic region as the urban basin (Sauer and others, 1983; Inman, 1995; Moglen and Shivers, 2006). For this study, many of the urban streamgages have drainage areas less than 1 square mile (mi^2), which is outside the limits of the rural equations from Gotvald and others (2009); thus, the equivalent rural flood flow could not be computed for these streamgages. To maintain continuity between the rural and urban flood estimates as the characteristics related to urbanization approach zero, the estimates based on Bulletin 17B from Gotvald and others (2009) for 280 rural streamgages in Georgia, with drainage areas that are within one hydrologic region, were included in this regional regression analysis (table 6, see back of report). The assumption is that if the same rural streamgages are used in the development of both sets of equations, the urban equations developed in this study will converge with the rural equations from Gotvald and others (2009) as the urbanization characteristics approach zero.

The hydrologic regions defined in Gotvald and others (2009) were used as the initial hydrologic regions for this study (fig. 1). The 50 urban sites and 280 rural streamgages in Georgia were grouped together based on the hydrologic regions. Because of the limited number of urban streamgages in hydrologic regions 2, 3, 4, and 5, urban streamgages from surrounding States were used to supplement the data. A list of the six urban streamgages in surrounding States that were used in this study is given in table 7. No urban streamgages were identified in hydrologic region 2 because of the lack of urban areas in the mountainous terrain of this region, so the effects of urbanization in region 2 are unknown. Only 8 Georgia rural streamgages were identified in region 3, so 11 South Carolina and North Carolina rural streamgages from Gotvald and others (2009) were included in the analysis of region 3 (table 8). Also, a limited number of Georgia rural streamgages are in region 5, so 10 Florida rural streamgages in region 5 from Gotvald and others (2009) were included in the analysis of this region (table 8).

Plots of flood estimates in relation to drainage area, based on Bulletin 17B, for the urban and rural streamgages

Table 7. Summary of urban streamgages in States adjacent to Georgia that were used in the regional regression analysis.

[USGS, U.S. Geological Survey; SC, South Carolina; FL, Florida]

USGS station number	Station name	Latitude (degree minute second)	Longitude (degree minute second)	State	Hydrologic region	Period of record	Number of systematic peaks
02162093	Smith Branch at North Main Street, at Columbia, SC	34 01 38	81 02 31	SC	3	1977–2008	32
02167020	Tributary to Crane Creek at Columbia, SC	34 03 02	81 02 05	SC	3	1986–2008	23
02246497	McCoy Creek at Jacksonville, FL	30 19 35	81 41 56	FL	4	1976–1988	13
02246522	Red Bay Branch tributary at Jacksonville, FL	30 20 40	81 35 22	FL	4	1975–1986	12
02326838	Lafayette Creek at Miccosukee Road, at Tallahassee, FL	30 27 50	84 14 24	FL	5	1979–1995	14
02329180	Megginnis Arm tributary at Tallahassee, FL	30 28 40	84 17 41	FL	5	1972–1982	11

Table 8. Summary of rural streamgages in States adjacent to Georgia that were used in the regional regression analysis.

[USGS, U.S. Geological Survey; NC, North Carolina; SC, South Carolina; FL, Florida]

USGS station number	Station name	Latitude (degree minute second)	Longitude (degree minute second)	State	Hydrologic region	Period of record	Number of systematic peaks
02102908	Flat Creek near Inverness, NC	35 10 58	79 10 39	NC	3	1969–2006	38
02103000	Little River at Manchester, NC	35 11 36	78 59 08	NC	3	1939–2006	15
02103390	South Prong Anderson Creek near Lillington, NC	35 15 32	78 55 26	NC	3	1953–1971	19
02130900	Black Creek near Mcbee, SC	34 30 51	80 10 59	SC	3	1960–2006	46
02133500	Drowning Creek near Hoffman, NC	35 03 40	79 29 38	NC	3	1940–2006	67
02133590	Beaverdam Creek near Aberdeen, NC	35 00 43	79 26 49	NC	3	1953–1971	18
02148090	Swift Creek near Camden, SC	34 11 50	80 28 57	SC	3	1990–2004	12
02148300	Colonels Creek near Leesburg, SC	34 00 26	80 43 57	SC	3	1968–2006	15
02169550	Congaree Creek at Cayce, SC	33 56 16	81 04 39	SC	3	1960–1980	21
02172500	South Fork Edisto River near Montmorenci, SC	33 34 36	81 30 49	SC	3	1940–1993	49
02196689	Little Horse Creek near Graniteville, SC	33 33 49	81 52 26	SC	3	1990–2006	13
02326500	Aucilla River at Lamont, FL	30 22 12	83 48 25	FL	5	1951–2001	40
02326598	Caney Creek near Monticello, FL	30 30 53	83 56 24	FL	5	1969–1981	13
02329000	Ochlockonee River near Havana, FL	30 33 15	84 23 03	FL	5	1926–2006	81
02329490	Willacoochee Creek near Quincy, FL	30 38 14	84 30 02	FL	5	1975–1990	15
02329534	Quincy Creek at Quincy, FL	30 36 01	84 34 50	FL	5	1975–1992	18
02329600	Little River near Midway, FL	30 30 45	84 31 25	FL	5	1965–2006	41
02329700	Rocky Comfort Creek near Quincy, FL	30 32 45	84 38 09	FL	5	1965–1981	17
02329877	Ocklawaha Creek near Wetumpka, FL	30 27 01	84 38 36	FL	5	1975–1990	15
02330050	Telogia Creek near Greensboro, FL	30 33 35	84 43 36	FL	5	1965–1986	22
02330100	Telogia Creek near Bristol, FL	30 25 36	84 55 40	FL	5	1903–2006	53

in hydrologic region 1 are shown in figure 3. The increase in flood magnitude related to urbanization is most evident for higher probability floods that result from moderate rainfall events, as indicated for the 50-percent annual exceedance flow plot (fig. 3). The flood magnitude for urban streamgages appears less distinct from rural streamgages for low AEP floods (larger peak flows), as indicated in figure 3. The influence of impervious area on flood magnitude also decreases as the AEP decreases, as is illustrated in figure 4 for an urban streamgage in hydrologic region 1. As the AEP decreases, the Bulletin 17B estimates for the urban streamgage converge with the equivalent rural regression AEPs from Gotvald and others (2009) for most of the urban streamgages in this region. A possible explanation for this phenomenon is that the soil in this region becomes so saturated during intense rainfall events that infiltration becomes negligible and the entire drainage basin essentially becomes impervious. Thus, the percentage of impervious area resulting from urbanization has little or no effect on the flood magnitude for larger flood events.

The plots in figure 3 show the curve for the rural regression equations from Gotvald and others (2009), including an extension of the equations for basins less than 1 mi^2. Evaluation of figure 3 indicates that the rural equations tend to over predict the flood estimates for rural and urban streamgages with drainage areas less than 1 mi^2 for the 4-, 2-, 1-, 0.5-, and 0.2-percent AEPs. The largest drainage area for the urban streamgages in this region is 378 mi^2, so the rural streamgages in this region with drainage areas greater than 400 mi^2 were omitted from further analysis. A total of 144 streamgages were used in the regional regression analysis for this region.

The APS regression methods were conducted on the 144 streamgages in region 1 to determine the candidate explanatory variables for the region. All response variables were transformed to logarithms (base 10) prior to the regression analyses except for the variables with zeros, such as percentage variables. The APS analysis results indicated that drainage area was the most significant variable for all exceedance probabilities. The addition of impervious area reduced the standard error of estimate more than any of the other variables. Adding other variables to drainage area and impervious area did not reduce the standard error of estimate by more than 1 percent. The effect of impervious area is statistically significant at the 0.05 level for the 50-, 20-, 10-, and 4-percent AEPs but is not statistically significant at the 0.05 level for the 2-, 1-, 0.5-, 0.2-percent AEPs.

An OLS analysis was conducted on hydrologic region 1 using the candidate explanatory variables. Figure 5 shows a comparison of the actual P-percent AEP flow and predicted P-percent AEP flow using the regression equation developed from the OLS analysis of all 144 streamgages in region 1. The plot indicates that the regression equation tends to over predict the 1-percent AEP flow for streamgages with smaller drainage areas. This confirms the change in slope in the drainage area and AEP flow relation that is seen in figure 3. To account for this break in the relation, the urban and rural streamgages in region 1 were divided into two groups—streamgages with drainage areas less than 1 mi^2 and streamgages with drainage areas greater than 1 mi^2.

Both groups of streamgages had APS regression methods applied to determine the candidate explanatory variables for the region. For the group of 23 streamgages with drainage areas less than 1 mi^2, APS analysis results indicated that drainage area was the most significant variable for all exceedance probabilities. The addition of impervious area reduced the standard error of estimate more than any of the other variables. Adding other variables to drainage area and impervious area did not reduce the standard error of estimate by more than 1 percent. The effect of impervious area is statistically significant at the 0.05 level for the 50-, 20-, 10-, 4-, and 2-percent AEPs but is not statistically significant at the 0.05 level for the 1-, 0.5-, 0.2-percent AEPs. For the group of 121 streamgages with drainage areas greater than 1 mi^2, the addition of impervious area also was found to result in the highest reduction in standard error, and percentage of impervious area was significant at the 0.05 level for only the 50-, 20-, and 10-percent AEPs. The addition of other variables did not reduce the standard error of estimate by more than 1 percent.

Hydrologic region 3 streamgages were analyzed by using APS regression methods to determine the candidate explanatory variables for the region. The APS analysis results indicated that drainage area was the most significant variable for all exceedance probabilities. The addition of percentage of impervious area reduced the standard error of estimate more than any of the other variables. Adding other variables to drainage area and impervious area did not reduce the standard error of estimate by more than 1 percent. The effect of impervious area is statistically significant at the 0.05 level for all AEPs, which indicates that the sandy soils in this region do not become saturated during intense rainfall; thus, the percentage of impervious area affects the flood magnitude during large flood events.

The same APS regression methods were applied to the streamgages in region 4 to determine the candidate explanatory variables for the region. The largest drainage area is only 1.64 mi^2 for the urban streamgages in this region, so the effects of urbanization on the larger streams in this region are unknown. The APS analysis was performed on 24 urban and rural streamgages in this region with drainage areas less than 1.7 mi^2, and the results indicated that drainage area was the most significant variable for all exceedance probabilities. The addition of mean basin slope was found to be significant at the 0.05 level and reduced the standard error of estimate more than any of the other variables. Adding percentage of developed land as a third explanatory variable was found to be significant and reduced the standard error of estimate by more than 5 percent. The effects of developed land were statistically significant at the 0.05 level for all AEPs. The inclusion of percentage of impervious area instead of percentage of developed land also was found to be significant at the 0.05 level for all AEPs. However, the addition of percentage of developed land

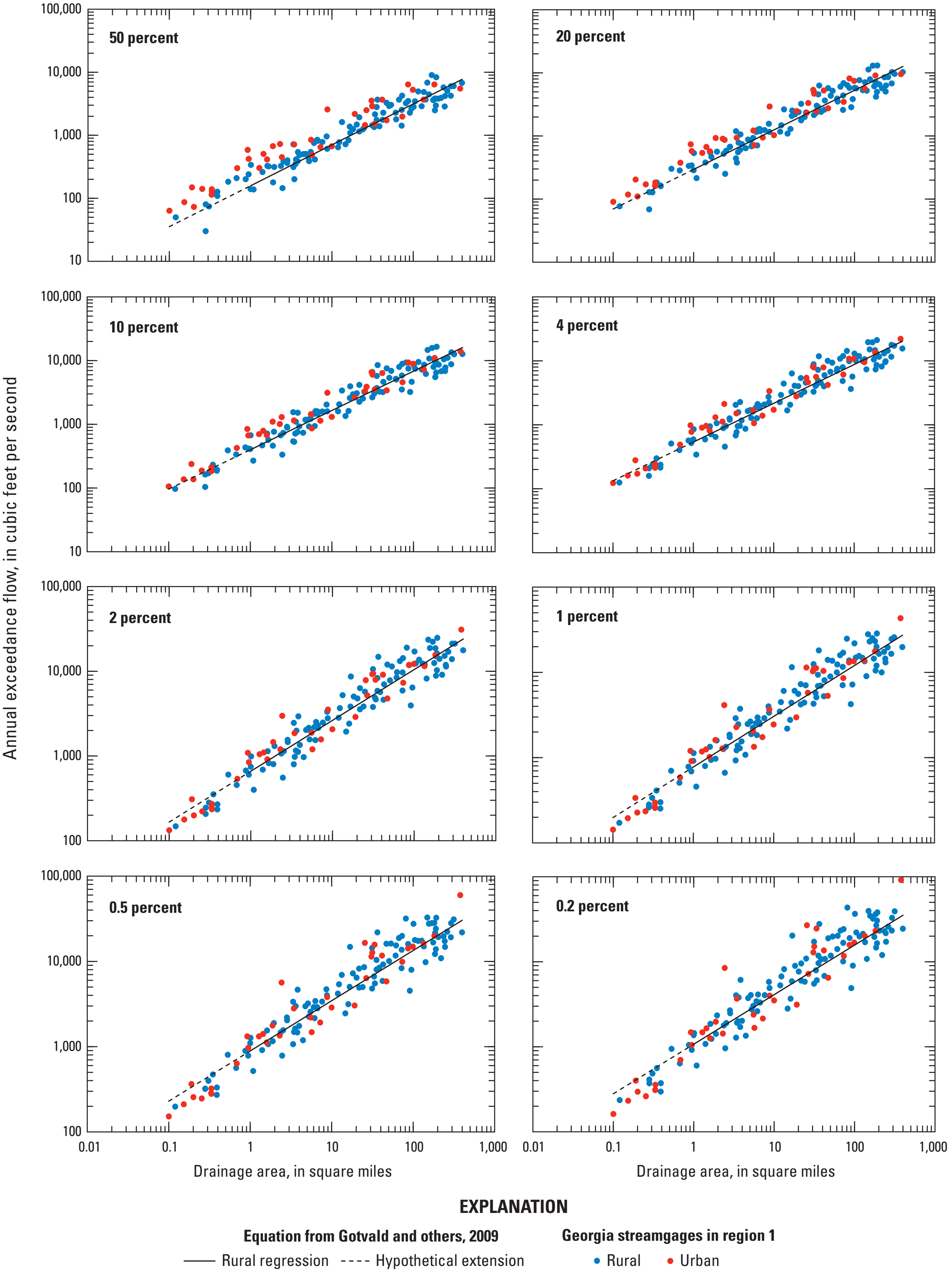


Figure 3. Relation between the annual exceedance probability flows from Bulletin 17B and drainage areas for Georgia streamgages in hydrologic region 1.

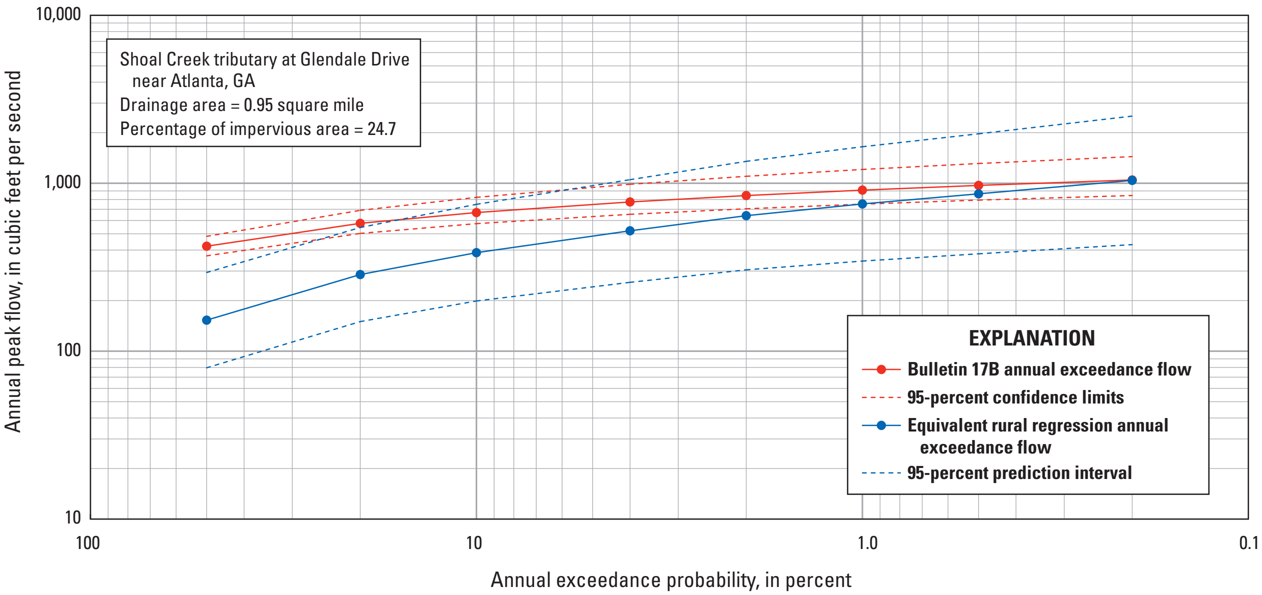


Figure 4. Relation of the annual exceedance flow estimates from Bulletin 17B and the equivalent rural regression annual exceedance estimates for a small urban streamgage in hydrologic region 1 in Georgia.

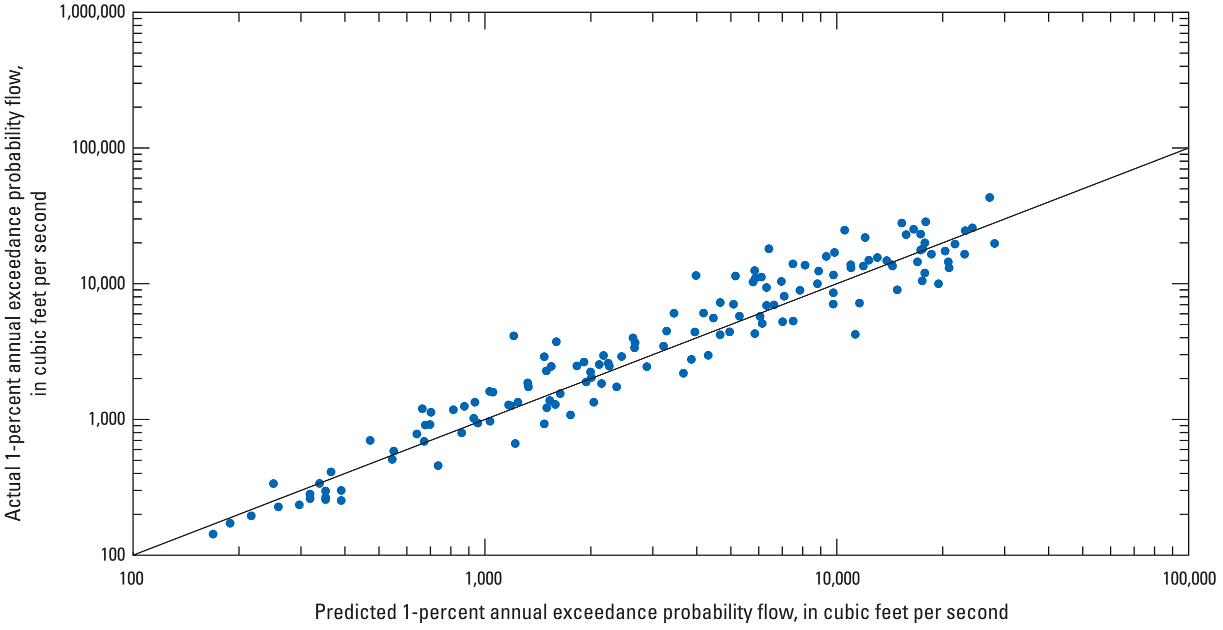


Figure 5. Actual and predicted 1-percent annual exceedance probability flows for urban and rural streamgages in hydrologic region 1 in Georgia, based on 144 streamgages used to develop a regional regression equation to predict 1-percent annual exceedance probability flow.

instead of percentage of impervious area reduced the standard error of estimate an additional 5 to 7 percent for the 50- and 20-percent AEPs (table 9). The significance of the urban basin characteristics indicates that the sandy soils in this region do not become saturated during intense rainfall; thus, urbanization affects the flow magnitudes during larger flood events.

The APS regression methods were applied to streamgages in region 5 to determine the candidate explanatory variables for the region, and the results indicated that drainage area was the most significant variable for all AEPs. Adding additional variables with drainage area did not reduce the standard error of estimate by more than 1 percent. The effect of impervious area is not statistically significant at the 0.05 level in this region for all AEPs. This region is unique in that the flood estimates based on the methods in Bulletin 17B for rural streamgages in this region are higher in relation to drainage area than the rural streamgages in the surrounding region 4 (Gotvald and others, 2009).

An OLS analysis was conducted on each of the hydrologic regions using the candidate explanatory variables. The residuals from the OLS analyses were plotted for each region in order to determine if a geographical bias was present in the urban streamgage estimates within a region. The plots showed no geographical bias, so the hydrologic regions from Gotvald and others (2009) were used in the final GLS analysis.

Table 9. Standard errors of estimate of two candidate models that estimate the annual exceedance probability flows for hydrologic region 4 in Georgia.

Percent annual exceedance probability	Model with drainage area, mean basin slope, and percentage of developed land	Model with drainage area, mean basin slope, and percentage of impervious area
	Standard error of estimate (percent)	
50	44.7	51.0
20	29.4	34.6
10	23.5	27.8
4	20.4	23.2
2	21.1	22.6
1	23.6	24.0
0.5	27.4	26.0
0.2	33.5	31.7

Regional Regression Equations

A GLS analysis was conducted for hydrologic regions 1, 3, 4, and 5 using the final 56 urban and 171 rural streamgages selected for the regional regression analysis to compute the final regional regression equations. The streamgages in region 1 were divided into two groups—drainage area less than 1 mi^2 and drainage area greater than 1 mi^2. The final regional regression equations for the 50- through 0.2-percent AEP flows for regions 1, 3, 4, and 5 are shown in table 10. Although the explanatory variable percentage of impervious area is not significant at the 0.05 level for all AEP flows in region 1, this variable is included in the final equation if the coefficient is positive for consistency and because the coefficients are small positive values, which indicates slightly increased flood magnitudes as a result of impervious area. For region 4, the explanatory variable percentage of developed land was used instead of percentage of impervious area because of the reduction of standard error prediction of more than 5 percent for the 50- and 20-percent AEP flow equations. The explanatory variables for the 50 Georgia urban streamgages used in the regression analysis are shown in table 11.

The transition of the 4-percent AEP urban flow equations to the rural equation from Gotvald and others (2009) can be seen in figure 6 as the effects of urbanization approach zero for region 1. When the percentage of impervious area is zero for the urban equations in this region, the predicted AEP flows are within 15 percent of the flows obtained from the rural regression equation in Gotvald and others (2009), which is within the standard error of prediction. This indicates an adequate transition between the rural and urban equations. Figure 6 also illustrates the small effect that the percentage of impervious area has on urban streamgages with drainage areas greater than 1 mi^2 for the 10- to 0.2-percent AEPs.

Table 10. Regional flood-frequency equations for ungaged urban streams in Georgia.

[mi², square mile; DRNAREA, drainage area, in mi²; IMPNLCD01, percentage of impervious area from the 2001 National Land Cover Dataset, in percent; BSLDEM, mean basin slope from digital elevation model, in percent; DEVNLCD01, percentage of developed land from the 2001 National Land Cover Dataset, in percent]

Percent annual exceedance probability	Hydrologic region (shown in fig. 1)		
	1		2
	$0.10\ \mathrm{mi}^2 < \mathrm{DRNAREA} < 1\ \mathrm{mi}^2$	$1\ \mathrm{mi}^2 < \mathrm{DRNAREA} < 400\ \mathrm{mi}^2$	
50	$190(\mathrm{DRNAREA})^{0.751}10^{(0.0116\mathrm{IMPNLCD01})}$	$208(\mathrm{DRNAREA})^{0.578}10^{(0.00854\mathrm{IMPNLCD01})}$	unknown
20	$309(\mathrm{DRNAREA})^{0.760}10^{(0.00866\mathrm{IMPNLCD01})}$	$361(\mathrm{DRNAREA})^{0.573}10^{(0.00578\mathrm{IMPNLCD01})}$	unknown
10	$399(\mathrm{DRNAREA})^{0.767}10^{(0.00710\mathrm{IMPNLCD01})}$	$475(\mathrm{DRNAREA})^{0.571}10^{(0.00448\mathrm{IMPNLCD01})}$	unknown
4	$526(\mathrm{DRNAREA})^{0.773}10^{(0.00539\mathrm{IMPNLCD01})}$	$627(\mathrm{DRNAREA})^{0.569}10^{(0.00307\mathrm{IMPNLCD01})}$	unknown
2	$630(\mathrm{DRNAREA})^{0.778}10^{(0.00427\mathrm{IMPNLCD01})}$	$741(\mathrm{DRNAREA})^{0.569}10^{(0.00215\mathrm{IMPNLCD01})}$	unknown
1	$738(\mathrm{DRNAREA})^{0.781}10^{(0.00328\mathrm{IMPNLCD01})}$	$859(\mathrm{DRNAREA})^{0.569}10^{(0.00133\mathrm{IMPNLCD01})}$	unknown
0.5	$853(\mathrm{DRNAREA})^{0.785}10^{(0.00237\mathrm{IMPNLCD01})}$	$982(\mathrm{DRNAREA})^{0.569}10^{(0.00056\mathrm{IMPNLCD01})}$	unknown
0.2	$1{,}010(\mathrm{DRNAREA})^{0.790}10^{(0.00125\mathrm{IMPNLCD01})}$	$1{,}130(\mathrm{DRNAREA})^{0.573}$	unknown

Percent annual exceedance probability	Hydrologic region (shown in fig. 1)		
	3	4	5
	$0.20\ \mathrm{mi}^2 < \mathrm{DRNAREA} < 5.5\ \mathrm{mi}^2$	$0.10\ \mathrm{mi}^2 < \mathrm{DRNAREA} < 1.7\ \mathrm{mi}^2$	$0.20\ \mathrm{mi}^2 < \mathrm{DRNAREA} < 10\ \mathrm{mi}^2$
50	$35.2(\mathrm{DRNAREA})^{0.632}10^{(0.0297\mathrm{IMPNLCD01})}$	$54.6(\mathrm{DRNAREA})^{0.541}(\mathrm{BSLDEM})^{0.339}10^{(0.00726\mathrm{DEVNLCD01})}$	$165(\mathrm{DRNAREA})^{0.537}$
20	$56.1(\mathrm{DRNAREA})^{0.634}10^{(0.0270\mathrm{IMPNLCD01})}$	$97.5(\mathrm{DRNAREA})^{0.521}(\mathrm{BSLDEM})^{0.418}10^{(0.00633\mathrm{DEVNLCD01})}$	$265(\mathrm{DRNAREA})^{0.583}$
10	$72.1(\mathrm{DRNAREA})^{0.636}10^{(0.0257\mathrm{IMPNLCD01})}$	$135(\mathrm{DRNAREA})^{0.517}(\mathrm{BSLDEM})^{0.461}10^{(0.00578\mathrm{DEVNLCD01})}$	$349(\mathrm{DRNAREA})^{0.600}$
4	$94.6(\mathrm{DRNAREA})^{0.637}10^{(0.0243\mathrm{IMPNLCD01})}$	$190(\mathrm{DRNAREA})^{0.518}(\mathrm{BSLDEM})^{0.500}10^{(0.00512\mathrm{DEVNLCD01})}$	$473(\mathrm{DRNAREA})^{0.615}$
2	$113(\mathrm{DRNAREA})^{0.639}10^{(0.0234\mathrm{IMPNLCD01})}$	$236(\mathrm{DRNAREA})^{0.519}(\mathrm{BSLDEM})^{0.522}10^{(0.00469\mathrm{DEVNLCD01})}$	$574(\mathrm{DRNAREA})^{0.624}$
1	$132(\mathrm{DRNAREA})^{0.639}10^{(0.0227\mathrm{IMPNLCD01})}$	$284(\mathrm{DRNAREA})^{0.516}(\mathrm{BSLDEM})^{0.540}10^{(0.00433\mathrm{DEVNLCD01})}$	$684(\mathrm{DRNAREA})^{0.632}$
0.5	$153(\mathrm{DRNAREA})^{0.641}10^{(0.0220\mathrm{IMPNLCD01})}$	$337(\mathrm{DRNAREA})^{0.515}(\mathrm{BSLDEM})^{0.557}10^{(0.00404\mathrm{DEVNLCD01})}$	$804(\mathrm{DRNAREA})^{0.639}$
0.2	$184(\mathrm{DRNAREA})^{0.642}10^{(0.0212\mathrm{IMPNLCD01})}$	$411(\mathrm{DRNAREA})^{0.512}(\mathrm{BSLDEM})^{0.578}10^{(0.00376\mathrm{DEVNLCD01})}$	$971(\mathrm{DRNAREA})^{0.649}$

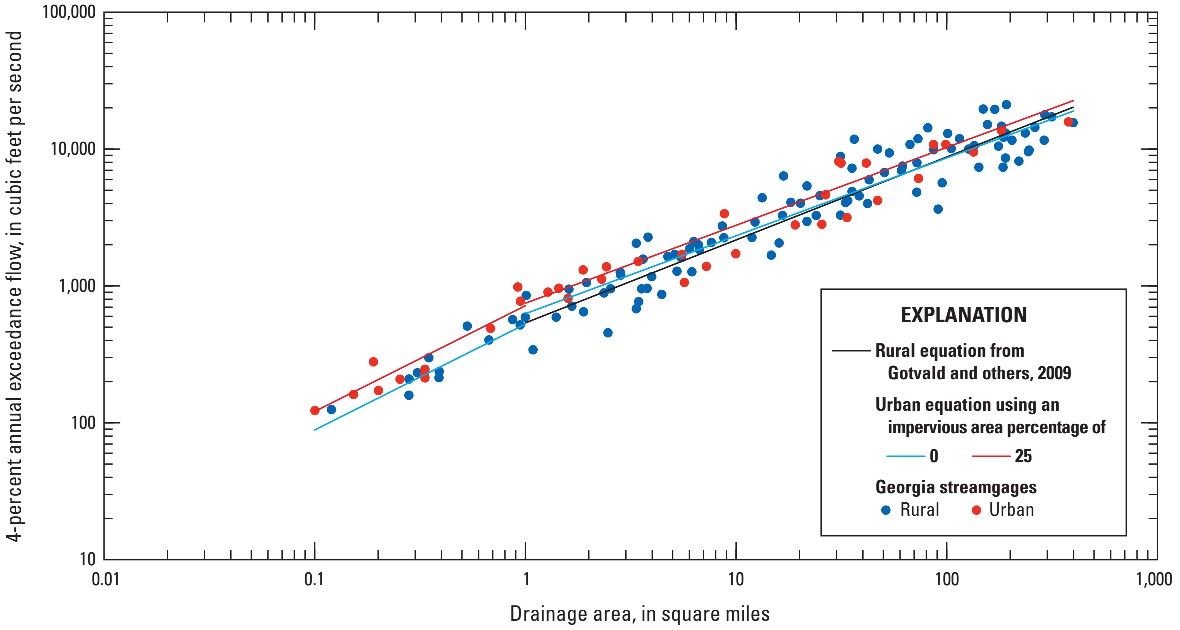


Figure 6. 4-percent annual exceedance probability relations for urban streams for hydrologic region 1.

Table 11. Explanatory variables that were used in the regional regression equations for urban streamgages in Georgia.

[USGS, U.S. Geological Survey; mi², square mile]

USGS station number	Drainage area (mi²)	Mean basin slope (percent)	Percentage of impervious area (percent)	Percentage of developed land (percent)
02196725	0.68	4.38	35.9	93.0
02196760	1.35	6.29	25.5	83.8
02203543	1.06	1.02	20.0	82.9
02203544	0.10	0.67	13.4	80.9
02203800	41.5	5.43	30.9	76.5
02203835	3.43	5.09	16.8	77.2
02203845	0.95	4.79	24.7	86.4
02203884	1.88	4.80	27.7	77.3
02203900	99.0	5.40	23.6	70.3
02204070	182	5.51	19.1	62.6
02205000	1.28	5.59	21.2	81.4
02205230	0.33	5.26	15.6	71.7
02205500	2.43	4.54	24.8	76.2
02205596	7.23	5.71	16.0	60.9
02206105	0.15	4.87	24.1	77.8
02206136	0.33	5.43	23.0	73.7
02206165	0.10	5.80	22.0	91.1
02206465	0.20	6.57	34.8	78.8
02206500	134	6.20	22.1	68.0
02207000	5.54	5.63	13.8	64.4
02207500	378	6.46	12.5	43.3
02208050	9.97	4.91	18.5	54.5
02217505	1.44	4.81	29.1	96.1
02218565	5.68	6.55	10.8	44.7
02317564	1.64	0.88	23.4	53.9
023177554	2.84	1.31	21.5	91.5
02318565	0.21	2.64	18.5	81.2
02327203	0.25	2.33	17.4	72.5
02327467	0.94	1.22	27.7	67.6
02327471	0.26	2.23	36.0	98.4
02334885	47.0	7.36	13.4	44.1
02335347	0.19	7.53	31.7	98.6
02335700	72.0	7.06	11.6	39.8
02335870	30.7	6.74	19.5	74.3
02336080	19.1	6.05	33.1	81.7
02336102	2.30	5.36	22.0	82.3
02336238	0.92	6.32	20.9	88.4
02336300	86.8	5.55	30.6	81.8
02336360	26.6	6.99	27.1	78.8
02336635	31.5	6.43	18.0	68.0
02336700	0.68	5.13	17.2	85.2
02336705	8.80	5.72	19.6	73.3
02341544	1.58	6.78	18.3	78.4
02341546	0.22	3.69	18.7	67.0
02341548	1.59	4.41	21.0	71.8
02352605	0.21	0.52	32.5	99.9
02392950	25.5	6.61	23.3	64.4
02392975	33.6	6.43	21.5	66.3
02395990	0.33	5.84	13.2	75.7
02396550	0.25	14.05	24.0	59.3

Accuracy and Limitations

When applying regression equations, users are advised against interpreting the empirical results as exact. Regression equations are statistical models that need to be interpreted and applied within the limits of the data and with the understanding that the results are best-fit estimates with an associated scatter or variance. The development and use of a regression equation raises questions about how well the predicted values represent true values. Errors in the model (that is, differences between predicted and observed values) can be examined to determine parameters that describe the accuracy of a regression equation, which depends on both the model and sampling error. Model error measures the ability of a set of explanatory variables to estimate the values of peak-flow characteristics calculated from the station records that were used to develop the equation. The model error depends on the number and predictive power of the explanatory variables in a regression equation. Sampling error measures the ability of a finite number of stations with a finite number of recorded annual peak flows to describe the true peak-flow characteristics for a station. The sampling error depends on the number and record length of stations used in the analysis and decreases as either the number of stations or length of record increases.

A measure of the uncertainty in a regression equation estimate for a site, *i*, is the variance of prediction, $V_{p,i}$. The $V_{p,i}$ is the sum of the model error variance and sampling error variance and is computed using the following equation:

$$V_{p,i} = \gamma^2 + MSE_{s,i} , \tag{2}$$

where

γ^2 is the model error variance; and

$MSE_{s,i}$ is the sampling mean square error for site *i*.

Assuming that the explanatory variables for the streamgages in a regression analysis are representative of all stations in the region, the average accuracy of prediction for a regression equation can be determined by computing the average variance of prediction, *AVP*, for *n* number of stations:

$$AVP = \gamma^2 + \left(\frac{1}{n}\right)\sum_{i=1}^{n} MSE_{s,i} \ . \tag{3}$$

A more traditional measure of the accuracy of P-percent AEP flow regression equations is the standard error of prediction, S_p, which is simply the square root of the variance of prediction. The average standard error of prediction for a regression equation can be computed in error percentage by using *AVP*, in log units, and the following transformation formula:

$$S_{p,ave} = 100\left[10^{2.3026(AVP)} - 1\right]^{0.5} , \tag{4}$$

where

$S_{p,ave}$ is the average standard error of prediction, in percent.

Approximately two-thirds of the estimates obtained from a regression equation for ungaged sites will have errors less than the standard error of prediction (Gotvald and others, 2009).

A measure of the proportion of the variation in the dependent variable explained by the independent variables in OLS regressions is the coefficient of determination, R^2 (Montgomery and others, 2001). For GLS regressions, a more appropriate performance metric than R^2 is R^2_{pseudo} described by Griffis and Stedinger (2007b). Unlike the R^2 metric, R^2_{pseudo} is based on the variability in the dependent variable explained by the regression after removing the effect of the time-sampling error. The R^2_{pseudo} is computed by using the following formula:

$$R^2_{pseudo} = 1 - \frac{\gamma^2(k)}{\gamma^2(0)} \ , \tag{5}$$

where

$\gamma^2(k)$ is the model error variance from a GLS regression with *k* independent variables; and

$\gamma^2(0)$ is the model error variance from a GLS regression with no independent variables.

The average variance of prediction, average standard error of prediction, and R^2_{pseudo} for the final set of regional regression equations are shown in table 12.

The number of streamgages used in each hydrologic region in the development of the equations for this study is shown in figure 7. Hydrologic regions 3, 4, and 5 have a small number of streamgages that are located in urban areas. The small sample of urban streamgage data increases the uncertainty of flood estimates for these regions. Adding more streamgages in urban areas in these regions likely would provide a better understanding of the effects of urbanization in the regions as well as provide more accurate flood-frequency estimates for urban streams within these regions.

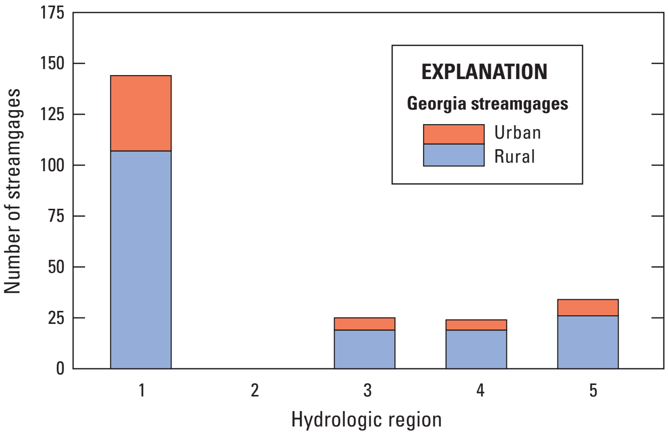


Figure 7. Number of rural and urban streamgages that were used in each hydrologic region in the development of the regional regression equations.

Table 12. Average variance of prediction, average standard error of prediction, and pseudo coefficient of determination for the urban regional regression equations.

[*AVP*, average variance of prediction; $S_{p,ave}$, average standard error of prediction; R_{pseudo}^2, pseudo coefficient of determination]

Percent annual exceedance probability	Hydrologic region (shown in fig. 1)														
	1						3			4			5		
	0.10 mi² < DRNAREA < 1 mi²			1 mi² < DRNAREA < 400 mi²			0.20 mi² < DRNAREA < 5.5 mi²			0.10 mi² < DRNAREA < 1.7 mi²			0.20 mi² < DRNAREA < 10 mi²		
	AVP (log units)	$S_{p,ave}$ (percent)	R_{pseudo}^2	*AVP* (log units)	$S_{p,ave}$ (percent)	R_{pseudo}^2	*AVP* (log units)	$S_{p,ave}$ (percent)	R_{pseudo}^2	*AVP* (log units)	$S_{p,ave}$ (percent)	R_{pseudo}^2	*AVP* (log units)	$S_{p,ave}$ (percent)	R_{pseudo}^2
50	0.022	34.8	80.6	0.019	32.3	91.4	0.048	54.0	81.9	0.042	49.8	66.8	0.030	41.8	91.9
20	0.012	25.8	88.5	0.016	29.3	92.8	0.052	56.6	80.9	0.020	33.5	80.4	0.021	34.2	95.3
10	0.010	22.9	91.2	0.015	29.0	93.1	0.056	58.8	80.2	0.014	27.8	86.4	0.020	33.9	95.8
4	0.008	20.6	93.4	0.016	29.8	92.8	0.061	61.6	79.2	0.012	25.4	89.6	0.022	35.6	95.8
2	0.007	20.1	94.1	0.017	31.2	92.3	0.065	64.3	78.2	0.013	26.6	89.3	0.025	37.8	95.6
1	0.007	20.0	94.6	0.020	33.0	91.6	0.070	67.0	77.2	0.016	29.5	87.6	0.029	41.0	95.1
0.5	0.007	20.1	94.9	0.022	35.0	90.9	0.076	70.3	76.0	0.020	33.8	84.6	0.033	44.1	94.6
0.2	0.008	21.3	94.6	0.025	37.3	89.9	0.083	74.5	74.5	0.029	40.6	79.9	0.041	49.5	93.6

Users of the regression models may be interested in a measure of uncertainty at a particular site as opposed to the uncertainty statistics based on station data used to generate the regression models. One such measure of uncertainty at a particular ungaged site is the confidence interval of a prediction, or prediction interval. Prediction interval is the area between minimum and maximum values in which a stated probability that the true value of the response variable occurs. Tasker and Driver (1988) determined that a 100 (1−α) prediction interval for the true value of a streamflow statistic for an ungaged site from the regression equation can be computed as follows:

$$Q/C<Q<CQ\,, \tag{6}$$

where

Q is the streamflow characteristic for the ungaged site; and

C is computed as

$$C = 10^{t_{(\alpha/2,\,n-p)}\,S_{p,i}}\ , \tag{7}$$

where

$t_{(\alpha/2,\,n-p)}$ is the critical value from the student's t-distribution at a particular alpha-level (α) and degrees of freedom ($n-p$) and is equal to 2.040, 1.980, 2.074, 2.086, and 2.040 for hydrologic regions 1 (drainage area less than 1 mi^2), 1 (drainage area greater than 1 mi^2), 3, 4, and 5, respectively, for a prediction interval of 95 percent ($\alpha=0.05$); and

$S_{p,i}$ is the standard error of prediction for site i, and is computed as

$$S_{p,i} = \left[\gamma^2 + \boldsymbol{x_i U x_i'}\right]^{0.5}\ , \tag{8}$$

where

γ^2 is the model error variance;

$\boldsymbol{x_i}$ is a row vector of the explanatory variables for site i, augmented by a 1 as the first element;

$\boldsymbol{U}$ is the covariance matrix for the regression coefficients; and

$\boldsymbol{x_i'}$ is the transpose of $\boldsymbol{x_i}$ (Ludwig and Tasker, 1993).

The values for γ^2 and $\boldsymbol{U}$ are presented in table 13.

The procedure required to obtain the prediction intervals for P-percent annual exceedance flow estimates is explained in the following example computation of the 2-percent annual exceedance flow for a hypothetical ungaged site on Indian Creek near Big City, Georgia, in hydrologic region 1:

1. Obtain the drainage area and percentage of impervious area for the ungaged site ($DA=0.50$ mi^2, $IMPNLCD01=30.0$);
2. Compute $Q_{2\%}$ using the equation in table 10 for drainage area less than 1 mi^2 in hydrologic region 1 ($Q_{2\%}=630\times(0.50)^{0.778}10^{(0.00427*30.0)}=493$ ft^3/s);
3. Determine the $\boldsymbol{x_i}$ vector ($\boldsymbol{x_i}$ = {1, $\log_{10}$(0.50), 30.0});
4. Compute the standard error of prediction using equation 8 with γ^2 and $\boldsymbol{U}$ for the 2-percent annual exceedance flow from table 13; $S_{p,i}=(0.0054+0.001715)^{0.5}=0.08435$;
5. Compute C using equation (7); $C=10^{(2.040*0.08435)}=1.486$; and

Compute the 95-percent prediction interval using equation (6); $(493/1.486)<Q_{2\%}<(493\times1.486)$, or 332 ft^3/s$<Q_{2\%}<$733 ft^3/s.

The example may not be clear to readers unfamiliar with the matrix algebra computations necessary for solution. To aid users who wish to compute the 95-percent prediction intervals at an ungaged site, a spreadsheet program has been developed and posted at *http://pubs.usgs.gov/sir/2011/5042/*. Instructions for proper application of the program are self-explanatory and are embedded within the spreadsheet.

The following limitations need to be recognized when using the final regional regression equations:

1. The ranges of explanatory variables used to develop the urban regional regression equations are shown in table 14. Applying the equations to sites on streams having explanatory variables outside the ranges of those used in this study may result in prediction errors that are considerably greater than those indicated by the standard error of prediction percentages listed in table 12. If the impervious area is less than 10 percent and the drainage area is 1 mi^2 or greater, the equations from Gotvald and others (2009) should be used.
2. The equations were developed using percentage of impervious area from NLCD 2001 (U.S. Environmental Protection Agency, 2007). The equations should not be used with percentages of impervious area calculated using NLCD 1992 or other methods, such as the method documented in Cochran (1963). However, future NLCD updates, such as NLCD 2006, can be used to compute the percentage of impervious area for use in the equations for this study.
3. The methods are not appropriate (or applicable) for sites where the peak-flow magnitudes are affected substantially by regulation from impoundments, channelization, levees, or other manmade structures.
4. The methods do not apply where flooding is influenced by extreme ocean storm surge or tidal events.

Table 13. Values needed to determine prediction intervals for the regression equations.

[γ^2, the regression model error variance used in equation 8; *U*, the covariance matrix used in equation 8]

Percent annual exceedance probability	Hydrologic region (shown in fig. 1)							
	1							
	$0.10\ \text{mi}^2 < \text{DRNAREA} < 1\ \text{mi}^2$				$1\ \text{mi}^2 < \text{DRNAREA} < 400\ \text{mi}^2$			
	γ^2	*U*			γ^2	*U*		
50	0.019	2.51E-3	1.06E-3	–8.16E-3	0.018	1.84E-3	–6.45E-4	–3.57E-3
		1.06E-3	4.93E-3	1.63E-3		–6.45E-4	3.93E-4	7.19E-4
		–8.16E-3	1.63E-3	6.18E-2		–3.57E-3	7.19E-4	2.87E-2
20	0.010	2.05E-3	7.80E-4	–6.09E-3	0.014	1.82E-3	–6.00E-4	–3.38E-3
		7.80E-4	3.08E-3	4.54E-4		–6.00E-4	3.59E-4	7.02E-4
		–6.09E-3	4.54E-4	4.11E-2		–3.38E-3	7.02E-4	2.71E-2
10	0.008	2.08E-3	7.37E-4	–5.85E-3	0.014	1.98E-3	–6.38E-4	–3.64E-3
		7.37E-4	2.69E-3	1.54E-4		–6.38E-4	3.78E-4	7.51E-4
		–5.85E-3	1.54E-4	3.71E-2		–3.64E-3	7.51E-4	2.90E-2
4	0.006	2.25E-3	7.36E-4	–5.97E-3	0.015	2.30E-3	–7.30E-4	–4.22E-3
		7.36E-4	2.51E-3	–3.29E-5		–7.30E-4	4.31E-4	8.58E-4
		–5.97E-3	–3.29E-5	3.54E-2		–4.22E-3	8.58E-4	3.34E-2
2	0.005	2.46E-3	7.79E-4	–6.38E-3	0.016	2.60E-3	–8.24E-4	–4.79E-3
		7.79E-4	2.58E-3	–8.59E-5		–8.24E-4	4.86E-4	9.67E-4
		–6.38E-3	–8.59E-5	3.67E-2		–4.79E-3	9.67E-4	3.78E-2
1	0.005	2.70E-3	8.32E-4	–6.87E-3	0.018	2.96E-3	–9.40E-4	–5.46E-3
		8.32E-4	2.70E-3	–1.22E-4		–9.40E-4	5.56E-4	1.10E-3
		–6.87E-3	–1.22E-4	3.86E-2		–5.46E-3	1.10E-3	4.32E-2
0.5	0.005	2.96E-3	8.99E-4	–7.47E-3	0.020	3.33E-3	–1.06E-3	–6.16E-3
		8.99E-4	2.88E-3	–1.40E-4		–1.06E-3	6.28E-4	1.25E-3
		–7.47E-3	–1.40E-4	4.12E-2		–6.16E-3	1.25E-3	4.89E-2
0.2	0.006	3.38E-3	1.03E-3	–8.55E-3	0.023	3.10E-3	–1.09E-3	
		1.03E-3	3.28E-3	–1.24E-4		–1.09E-3	7.05E-4	
		–8.55E-3	–1.24E-4	4.70E-2				

Table 13. Values needed to determine prediction intervals for the regression equations.—Continued

[γ^2, the regression model error variance used in equation 8; U, the covariance matrix used in equation 8]

Hydrologic region (shown in fig. 1)											
3				4					5		
0.20 mi^2 < DRNAREA < 5.5 mi^2				0.10 mi^2 < DRNAREA < 1.7 mi^2					0.20 mi^2 < DRNAREA < 10 mi^2		
γ^2	U			γ^2	U				γ^2	U	
0.043	1.14E-2	–5.59E-3	–3.76E-2	0.034	5.64E-3	1.75E-3	–5.79E-3	–6.67E-3	0.028	2.62E-3	–8.95E-4
	–5.59E-3	3.62E-3	1.80E-2		1.75E-3	1.15E-2	–8.35E-4	2.05E-3		–8.95E-4	8.46E-4
	–3.76E-2	1.80E-2	2.06E-1		–5.79E-3	–8.35E-4	2.14E-2	9.59E-3			
					–6.67E-3	2.05E-3	9.59E-3	1.87E-2			
0.046	1.26E-2	–6.17E-3	–4.15E-2	0.016	3.58E-3	1.02E-3	–2.83E-3	–3.81E-3	0.018	2.49E-3	–7.02E-4
	–6.17E-3	3.98E-3	1.98E-2		1.02E-3	5.88E-3	–6.33E-4	8.77E-4		–7.02E-4	6.46E-4
	–4.15E-2	1.98E-2	2.26E-1		–2.83E-3	–6.33E-4	1.14E-2	4.87E-3			
					–3.81E-3	8.77E-4	4.87E-3	1.03E-2			
0.049	1.38E-2	–6.70E-3	–4.51E-2	0.010	3.17E-3	8.55E-4	–2.09E-3	–3.14E-3	0.018	2.89E-3	–7.77E-4
	–6.70E-3	4.32E-3	2.14E-2		8.55E-4	4.48E-3	–6.29E-4	6.17E-4		–7.77E-4	6.95E-4
	–4.51E-2	2.14E-2	2.45E-1		–2.09E-3	–6.29E-4	9.12E-3	3.77E-3			
					–3.14E-3	6.17E-4	3.77E-3	8.41E-3			
0.053	1.54E-2	–7.45E-3	–5.01E-2	0.008	3.30E-3	8.49E-4	–1.92E-3	–3.13E-3	0.019	3.57E-3	–9.49E-4
	–7.45E-3	4.78E-3	2.37E-2		8.49E-4	4.16E-3	–7.04E-4	5.87E-4		–9.49E-4	8.36E-4
	–5.01E-2	2.37E-2	2.71E-1		–1.92E-3	–7.04E-4	9.04E-3	3.64E-3			
					–3.13E-3	5.87E-4	3.64E-3	8.42E-3			
0.057	1.69E-2	–8.13E-3	–5.47E-2	0.008	3.77E-3	9.79E-4	–2.21E-3	–3.60E-3	0.021	4.17E-3	–1.12E-3
	–8.13E-3	5.21E-3	2.58E-2		9.79E-4	4.74E-3	–8.22E-4	6.97E-4		–1.12E-3	9.77E-4
	–5.47E-2	2.58E-2	2.96E-1		–2.21E-3	–8.22E-4	1.04E-2	4.20E-3			
					–3.60E-3	6.97E-4	4.20E-3	9.73E-3			
0.061	1.84E-2	–8.83E-3	–5.95E-2	0.010	4.49E-3	1.20E-3	–2.75E-3	–4.37E-3	0.025	4.90E-3	–1.33E-3
	–8.83E-3	5.65E-3	2.79E-2		1.20E-3	5.83E-3	–9.93E-4	8.74E-4		–1.33E-3	1.16E-3
	–5.95E-2	2.79E-2	3.21E-1		–2.75E-3	–9.93E-4	1.27E-2	5.17E-3			
					–4.37E-3	8.74E-4	5.17E-3	1.19E-2			
0.066	2.02E-2	–9.66E-3	–6.50E-2	0.014	5.47E-3	1.52E-3	–3.57E-3	–5.44E-3	0.028	5.65E-3	–1.56E-3
	–9.66E-3	6.17E-3	3.04E-2		1.52E-3	7.46E-3	–1.21E-3	1.17E-3		–1.56E-3	1.35E-3
	–6.50E-2	3.04E-2	3.51E-1		–3.57E-3	–1.21E-3	1.59E-2	6.59E-3			
					–5.44E-3	1.17E-3	6.59E-3	1.49E-2			
0.072	2.25E-2	–1.07E-2	–7.23E-2	0.020	7.04E-3	2.04E-3	–4.96E-3	–7.20E-3	0.035	6.86E-3	–1.94E-3
	–1.07E-2	6.85E-3	3.37E-2		2.04E-3	1.02E-2	–1.55E-3	1.66E-3		–1.94E-3	1.67E-3
	–7.23E-2	3.37E-2	3.91E-1		–4.96E-3	–1.55E-3	2.12E-2	8.97E-3			
					–7.20E-3	1.66E-3	8.97E-3	2.00E-2			

Table 14. Ranges of explanatory variables used to develop the urban regional regression equations for Georgia.

[mi^2, square mile; —, not applicable]

Basin characteristic	Hydrologic region (shown in fig. 1)							
	1		3		4		5	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
Drainage area (mi^2)	0.1	400	0.2	5.5	0.1	1.7	0.2	10
Percentage of impervious area (percent)	0.0	35.0	0.0	40.0	—	—	0.0	36.0
Percentage of developed land (percent)	—	—	—	—	0.0	100	—	—
Mean basin slope (percent)	—	—	—	—	0.4	5.5	—	—

Estimation of Flood Magnitude and Frequency at Small Rural Ungaged Sites

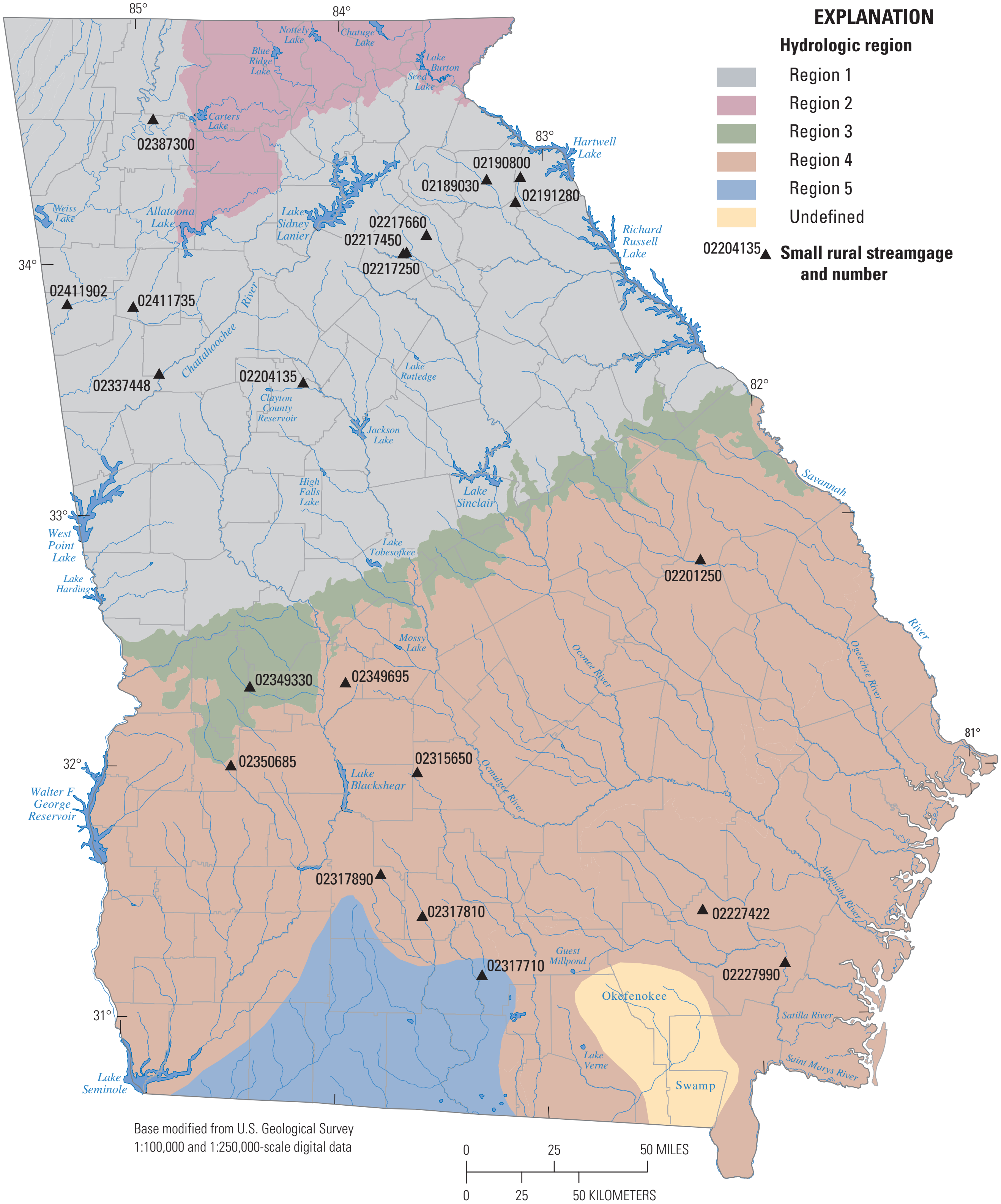
The rural regression equations from Gotvald and others (2009) are limited to rural streamgages that have drainage areas greater than or equal to 1 mi^2. In this study, 21 rural streamgages with drainage areas less than 1 mi^2 were used to develop the equations (fig. 8). Thus, the equations in table 10 can be used to estimate the AEP flows for rural ungaged sites that are less than 1 mi^2. The equations are limited to small rural streams that are not affected by regulation, channelization, or tides, and the equations also are limited to the minimum drainage areas shown in table 13. The average variance of prediction, average standard error of prediction, and pseudo coefficient of determination for these equations are shown in table 12.

Summary and Conclusions

This report presents methods for determining flood magnitude and frequency at urban streamgages and ungaged urban sites and at small rural streamgages and small rural ungaged sites in Georgia. The regional regression analyses for this study included 56 urban streamgages that are in or near Georgia, have 10 years or more of peak-flow record, and are not significantly affected by regulation, tidal fluctuations, or channelization. The analyses also included 171 rural streamgages to maintain continuity between urban and rural flood estimates as the basin characteristics pertaining to urbanization approach zero.

Regional regression analysis, using generalized-least-square regression, was used to develop a set of predictive equations for estimating the 50-, 20-, 10-, 4-, 2-, 1-, 0.5-, and 0.2-percent annual exceedance probability (AEP) flows for ungaged urban sites in Georgia. Four hydrologic regions were developed for Georgia. The final predictive equations for three of the regions are functions of drainage area and percentage of impervious area, and for the fourth region are functions of drainage area, percentage of developed land, and average basin slope. The average standard errors of prediction for these regression equations range from 20.0 to 74.5 percent. Since the equations were developed using small rural streamgages in Georgia, the equations also can be used to estimate the AEP flow for rural ungaged sites in Georgia that have drainage areas less than 1 square mile.

Three of the four hydrologic regions developed for this study have a sparse number of streamgages that are located in urban areas. This lack of urban streamgage data leads to higher standard errors, or uncertainties, in the flood estimates for these regions. Additional urban streamgages likely would provide a better understanding of the effects of urbanization and more accurate flood-frequency estimates for urban streams in these regions.



Base modified from U.S. Geological Survey
1:100,000 and 1:250,000-scale digital data

Figure 8. Locations of small rural streamgages in Georgia that were used to develop the regional regression equations.

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Table 6

Table 6. Summary of rural streamgaging stations in Georgia that were considered for use in the regional regression analysis.

[USGS, U.S. Geological Survey; mi^2, square mile]

USGS station number	Station name	Latitude	Longitude	Drainage area (mi^2)	Hydrologic region	Period of record	Number of systematic peaks
		(degree minute second)					
02177000[a]	Chattooga River near Clayton, GA	34 48 50	83 18 22	207	2	1915–2006	81
02178400[a]	Tallulah River near Clayton, GA	34 53 25	83 31 50	56.5	2	1965–2006	42
02188500	Beaverdam Creek at Dewy Rose, GA	34 10 52	82 56 38	38.4	1	1943–1977	35
02188600	Beaverdam Creek above Elberton, GA	34 10 07	82 53 48	72.0	1	1987–2006	12
02189020	Indian Creek near Carnesville, GA	34 21 19	83 17 16	7.63	1	1964–1976	13
02189030	Stephens Creek tributary at Carnesville, GA	34 21 51	83 13 16	0.39	1	1964–1976	13
02189600	Bear Creek near Mize, GA	34 29 07	83 18 38	3.62	1	1957–1969	13
02190100	Toms Creek near Eastanollee, GA	34 29 01	83 14 02	4.75	1	1957–1969	13
02190200	Toms Creek tributary near Avalon, GA	34 29 35	83 13 23	1.01	1	1955–1969	14
02190800	Double Branch at Bowersville, GA	34 22 51	83 05 28	0.53	1	1960–1975	16
02191200	Hudson River at Homer, GA	34 20 15	83 29 17	60.9	1	1951–1979	29
02191270	Scull Shoal Creek near Danielsville, GA	34 09 30	83 09 51	8.75	1	1964–1975	12
02191280	Mill Shoal Creek near Royston, GA	34 16 13	83 06 08	0.39	1	1964–1987	24
02191300[a]	Broad River above Carlton, GA	34 04 24	83 00 12	760	1	1898–2006	108
02191600	Double Branch near Danielsville, GA	34 06 06	83 14 11	5.12	1	1964–1976	13
02191750	Fork Creek at Carlton, GA	34 02 55	83 01 16	16.0	1	1964–1975	12
02191890	Brooks Creek near Lexington, GA	33 50 30	83 05 22	12.3	1	1964–1975	12
02191910	Trouble Creek at Lexington, GA	33 52 24	83 05 60	2.47	1	1959–1978	18
02191930	Buffalo Creek near Lexington, GA	33 46 40	83 03 01	5.24	1	1964–2006	43
02191960	Macks Creek near Lexington, GA	33 55 24	82 58 30	3.45	1	1959–1975	17
02191970	Little Macks Creek near Lexington, GA	33 56 09	82 57 41	1.89	1	1959–1985	27
02192000[a]	Broad River near Bell, GA	33 58 27	82 46 12	1,430	1	1927–2006	75
02192400	Anderson Mill Creek near Danburg, GA	33 48 35	82 41 35	5.49	1	1964–1975	12
02192420	Anderson Mill Creek tributary near Danburg, GA	33 49 42	82 41 12	1.00	1	1964–1975	12
02193300	Stephens Creek near Crawfordville, GA	33 36 05	82 55 28	6.30	1	1961–1975	13
02193340	Kettle Creek near Washington, GA	33 40 57	82 51 29	33.9	1	1987–2006	20
02193400	Harden Creek near Sharon, GA	33 33 10	82 50 15	3.98	1	1964–1975	12
02193500	Little River near Washington, GA	33 36 46	82 44 33	292	1	1950–2006	39
02197600[a]	Brushy Creek near Wrens, GA	33 10 38	82 18 20	28.0	4	1959–2005	46
02197810[a]	Walnut Branch near Waynesboro, GA	33 08 12	82 02 09	13.1	4	1965–1974	10
02198100[a]	Beaverdam Creek near Sardis, GA	32 56 16	81 48 55	30.8	4	1987–2006	19
02198690[a]	Ebenezer Creek at Springfield, GA	32 21 57	81 17 50	162	4	1990–2006	17
02199700	South Fork Ogeechee River near Crawfordville, GA	33 31 00	82 54 22	31.3	1	1951–1969	19
02200900[a]	Big Creek near Louisville, GA	32 59 01	82 21 22	95.8	4	1951–1976	26
02200930[a]	Spring Creek near Louisville, GA	32 55 21	82 18 48	14.2	4	1965–2006	42
02201110[a]	Nails Creek near Bartow, GA	32 52 26	82 26 33	8.36	4	1965–1974	10
02201160[a]	Boggy Gut Creek near Wadley, GA	32 53 43	82 24 01	7.49	4	1965–1974	10

Table 6. Summary of rural streamgaging stations in Georgia that were considered for use in the regional regression analysis. —Continued

[USGS, U.S. Geological Survey; mi^2, square mile]

USGS station number	Station name	Latitude	Longitude	Drainage area (mi^2)	Hydrologic region	Period of record	Number of systematic peaks
		(degree minute second)					
02201250	Seals Creek tributary near Midville, GA	32 51 05	82 13 57	0.65	4	1964–1974	11
02201350[a]	Buckhead Creek near Waynesboro, GA	32 58 22	82 07 14	50.5	4	1963–1983	21
02201800[a]	Richardson Creek near Millen, GA	32 43 24	81 58 34	35.2	4	1963–1983	21
02201830[a]	Sculls Creek near Millen, GA	32 39 35	81 59 28	4.38	4	1965–1975	11
02202300[a]	Mill Creek near Statesboro, GA	32 28 29	81 45 16	39.0	4	1963–1974	12
02202600[a]	Black Creek near Blitchton, GA	32 10 05	81 29 17	232	4	1980–2006	27
02202605[a]	Mill Creek near Pembroke, GA	32 09 40	81 36 14	3.53	4	1979–1996	18
02202800[a]	Canoochee Creek near Swainsboro, GA	32 36 20	82 15 20	46.0	4	1951–1976	26
02202810[a]	Hughes Prong near Swainsboro, GA	32 37 30	82 19 03	5.05	4	1965–1975	11
02202820[a]	Reedy Creek near Twin City, GA	32 35 41	82 12 22	8.99	4	1965–1974	10
02202850[a]	Reedy Branch near Metter, GA	32 28 44	82 07 44	3.41	4	1965–1974	10
02202865[a]	Canoochee River near Metter, GA	32 21 21	82 05 24	202	4	1970–1986	17
02202900[a]	Fifteenmile Creek near Metter, GA	32 23 34	82 00 54	137	4	1963–1983	21
02202910	Tenmile Creek tributary at Pulaski, GA	32 23 19	81 58 16	1.14	4	1965–1987	23
02202950	Cypress Flat Creek near Collins, GA	32 13 10	82 07 13	1.25	4	1965–1974	10
02203000[a]	Canoochee River near Claxton, GA	32 11 06	81 53 19	555	4	1938–2006	69
02203559[a]	Peacock Creek at Mcintosh, GA	31 48 50	81 31 12	36.8	4	1967–1977	11
02204135	Camp Creek tributary near Stockbridge, GA	33 34 35	84 08 51	0.28	1	1977–2006	30
02208200	Beaverdam Creek tributary at Bold Springs, GA	33 53 59	83 47 36	1.09	1	1965–1975	11
02208450	Alcovy River above Covington, GA	33 38 24	83 46 45	185	1	1973–2006	33
02209000	Alcovy River below Covington, GA	33 30 21	83 49 30	244	1	1929–1965	25
02211300	Towaliga River near Jackson, GA	33 15 50	84 04 17	105	1	1961–1983	23
02211459	Big Towaliga Creek near Barnesville, GA	33 04 20	84 11 04	2.36	1	1969–1981	13
02211500	Towaliga River near Forsyth, GA	33 07 17	83 56 36	315	1	1929–1966	25
02212600	Falling Creek near Juliette, GA	33 05 59	83 43 25	72.2	1	1965–2006	42
02213050	Walnut Creek near Gray, GA	32 58 20	83 37 08	31.3	1	1962–1994	33
02213350	Tobesofkee Creek below Forsyth, GA	32 59 37	83 56 41	53.4	1	1963–1987	24
02213400	Little Tobesofkee Creek near Forsyth, GA	32 57 10	84 02 33	16.8	1	1951–1961	11
02213470	Tobesofkee Creek above Macon, GA	32 52 02	83 50 24	156	1	1967–1978	12
02214280[a]	Savage Creek near Bullard, GA	32 35 34	83 28 11	33.0	4	1979–2006	28
02214500[a]	Big Indian Creek at Perry, GA	32 27 21	83 44 21	102	4	1944–1977	34
02215100[a]	Tucsawhatchee Creek near Hawkinsville, GA	32 14 22	83 30 06	163	4	1984–2006	23
02215220[a]	Ocmulgee River tributary near Abbeville, GA	32 06 54	83 24 12	1.83	4	1965–1975	11
02215230[a]	Cedar Creek near Pineview, GA	32 05 35	83 30 12	7.33	4	1965–1975	11
02215245	Folsom Creek tributary near Rochelle, GA	32 00 20	83 26 07	1.26	4	1964–2006	43

Table 6. Summary of rural streamgaging stations in Georgia that were considered for use in the regional regression analysis.—Continued

[USGS, U.S. Geological Survey; mi^2, square mile]

USGS station number	Station name	Latitude	Longitude	Drainage area (mi^2)	Hydrologic region	Period of record	Number of systematic peaks
		(degree minute second)					
02215280[a]	Ball Creek tributary near Rochelle, GA	31 49 58	83 22 05	2.45	4	1960–1977	18
02215800[a]	Gum Swamp Creek near Chauncey, GA	32 07 28	83 03 37	221	4	1984–2006	23
02216000[a]	Little Ocmulgee River at Towns, GA	32 00 29	82 45 10	351	4	1938–1978	39
02216100[a]	Alligator Creek near Alamo, GA	32 01 36	82 41 43	242	4	1951–1966	16
02216180[a]	Turnpike Creek near Mcrae, GA	31 59 29	82 55 19	49.2	4	1983–2006	24
02216610[a]	Tillman Mill Creek near Lumber City, GA	31 58 54	82 38 31	2.71	4	1966–1985	20
02217000	Allen Creek at Talmo, GA	34 11 34	83 43 11	18.2	1	1952–1974	23
02217200	Middle Oconee River near Jefferson, GA	34 05 46	83 36 23	135	1	1951–1965	15
02217250	Buffalo Creek tributary near Jefferson, GA	34 05 00	83 38 01	0.35	1	1964–1976	13
02217380	Mulberry River near Winder, GA	34 03 08	83 39 49	142	1	1983–2006	23
02217400	Mulberry River tributary near Winder, GA	34 03 53	83 39 45	2.54	1	1965–2006	42
02217450	Mulberry River tributary near Jefferson, GA	34 04 38	83 38 53	0.67	1	1965–1974	10
02217500	Middle Oconee River near Athens, GA	33 56 48	83 25 22	398	1	1929–2006	71
02217660	Little Curry Creek near Jefferson, GA	34 08 25	83 32 09	0.87	1	1964–1976	13
02217900	North Oconee River at Athens, GA	33 56 55	83 22 04	290	1	1929–1972	31
02218100	Porters Creek at Watkinsville, GA	33 50 56	83 23 42	1.95	1	1964–1975	12
02218450	Town Creek near Greensboro, GA	33 38 29	83 13 36	11.9	1	1964–1987	24
02218500[a]	Oconee River near Greensboro, GA	33 34 52	83 16 22	1,090	1	1904–1991	83
02219000	Apalachee River near Bostwick, GA	33 47 17	83 28 27	176	1	1945–2006	33
02219500[a]	Apalachee River near Buckhead, GA	33 36 31	83 20 58	436	1	1901–1978	49
02220550	Whitten Creek near Sparta, GA	33 23 12	83 01 34	16.6	1	1961–1986	26
02220900	Little River near Eatonton, GA	33 18 50	83 26 14	262	1	1971–2006	36
02221000	Murder Creek near Monticello, GA	33 24 56	83 39 43	24.0	1	1952–1976	25
02221525	Murder Creek below Eatonton, GA	33 15 08	83 28 53	190	1	1978–2006	29
02223300	Big Sandy Creek near Jeffersonville, GA	32 48 16	83 25 04	33.5	3	1959–1971	13
02223700[a]	Indian Branch tributary near Scott, GA	32 33 23	82 44 32	1.99	4	1965–1975	11
02224000[a]	Rocky Creek near Dudley, GA	32 29 39	83 08 49	62.9	4	1952–1976	25
02224100[a]	Turkey Creek near Dublin, GA	32 27 22	82 56 32	316	4	1984–2006	23
02224200[a]	Mercer Creek near Soperton, GA	32 26 39	82 41 29	16.1	4	1965–1975	11
02224400[a]	Cypress Creek near Tarrytown, GA	32 16 50	82 35 44	6.77	4	1965–1975	11
02224650[a]	Peterson Creek at Glenwood, GA	32 10 09	82 40 00	5.16	4	1965–1974	10
02224800	Oconee River tributary near Glenwood, GA	32 03 17	82 39 08	1.18	4	1965–1974	10
02225100[a]	Cobb Creek near Lyons, GA	32 02 07	82 22 46	73.2	4	1951–1966	16
02225150[a]	Ohoopee River near Wrightsville, GA	32 42 51	82 45 19	64.4	4	1963–1983	21

Table 6. Summary of rural streamgaging stations in Georgia that were considered for use in the regional regression analysis. —Continued

[USGS, U.S. Geological Survey; mi^2, square mile]

USGS station number	Station name	Latitude	Longitude	Drainage area (mi^2)	Hydrologic region	Period of record	Number of systematic peaks
		(degree minute second)					
02225180[a]	Mulepen Creek near Adrian, GA	32 32 59	82 31 25	13.8	4	1965–1974	10
02225200[a]	Little Ohoopee River near Wrightsville, GA	32 47 21	82 33 01	63.0	4	1951–1976	26
02225210[a]	Hurricane Branch near Wrightsville, GA	32 47 01	82 34 41	3.53	4	1965–1974	10
02225240[a]	Crooked Creek near Kite, GA	32 40 23	82 26 42	7.22	4	1965–1974	10
02225250[a]	Little Ohoopee River near Swainsboro, GA	32 33 45	82 28 02	216	4	1970–2006	29
02225300[a]	Ohoopee River near Oak Park, GA	32 23 30	82 18 48	620	4	1951–1986	22
02225330[a]	Beaver Creek near Cobbtown, GA	32 16 53	82 11 26	9.58	4	1965–2006	41
02225350	Reedy Creek tributary near Soperton, GA	32 25 36	82 29 51	1.68	4	1965–1988	24
02225500[a]	Ohoopee River near Reidsville, GA	32 04 43	82 10 38	1,110	4	1904–2006	73
02225850[a]	Beards Creek near Glennville, GA	31 55 27	81 52 57	74.4	4	1966–1987	22
02226030[a]	Doctors Creek near Ludowici, GA	31 44 08	81 42 07	31.1	4	1966–1987	22
02226100[a]	Penholoway Creek near Jesup, GA	31 34 01	81 50 17	180	4	1959–2000	42
02226190[a]	Little Creek near Willacoochee, GA	31 27 25	83 03 02	6.38	4	1965–1987	23
02226200[a]	Satilla River near Douglas, GA	31 24 50	82 51 02	222	4	1951–1976	26
02226465[a]	Dryden Creek near Dixie Union, GA	31 20 24	82 28 42	13.7	4	1978–1988	11
02226500[a]	Satilla River near Waycross, GA	31 14 18	82 19 28	1,200	4	1937–2006	70
02226580[a]	Big Creek near Hoboken, GA	31 10 29	82 11 16	53.2	4	1966–1987	22
02227000[a]	Hurricane Creek near Alma, GA	31 34 04	82 27 50	139	4	1952–1987	35
02227100[a]	Little Hurricane Creek near Alma, GA	31 29 45	82 31 40	52.6	4	1948–1962	15
02227200[a]	Little Hurricane Creek below Alma, GA	31 25 26	82 25 58	94.2	4	1948–1978	31
02227290[a]	Alabaha River near Blackshear, GA	31 21 05	82 14 15	414	4	1953–1987	21
02227400[a]	Big Satilla Creek near Alma, GA	31 39 29	82 25 56	112	4	1948–1978	31
02227422	Crooked Creek tributary near Bristol, GA	31 26 26	82 15 02	0.38	4	1976–2006	31
02227430[a]	Little Satilla Creek at Odum, GA	31 40 05	82 02 26	61.9	4	1949–1978	30
02227470[a]	Little Satilla Creek near Jesup, GA	31 33 49	81 59 10	99	4	1949–1965	17
02227500[a]	Little Satilla River near Offerman, GA	31 27 05	82 03 16	646	4	1951–2006	56
02227990	Satilla River tributary at Atkinson, GA	31 13 33	81 51 09	0.59	4	1977–2006	29
02228000[a]	Satilla River at Atkinson, GA	31 13 14	81 51 56	2,790	4	1931–2006	76
02228050[a]	Buffalo Creek at Hickox, GA	31 09 22	81 59 28	71.1	4	1966–1987	22
02228055[a]	Satilla River tributary near Winokur, GA	30 59 60	81 57 29	1.91	4	1980–1989	10
02314500[a]	Suwannee River at Fargo, GA	30 40 50	82 33 38	1,130	4	1928–2006	73
02314600[a]	Suwannoochee Creek at Dupont, GA	30 59 10	82 52 50	93.7	4	1952–1976	25
02314700[a]	Suwannoochee Creek near Thelma, FL	30 49 19	82 50 27	195	4	1963–1987	25
02315650	Alapaha River tributary near Pitts, GA	32 00 21	83 33 27	0.11	4	1965–1975	11
02315670[a]	Alapaha River tributary near Rochelle, GA	31 56 41	83 30 52	2.87	4	1965–1975	10
02315700[a]	Alapaha River at Rebecca, GA	31 48 56	83 28 26	112	4	1951–1977	27
02315900[a]	Deep Creek near Ashburn, GA	31 43 50	83 34 60	135	4	1951–1976	26

Table 6. Summary of rural streamgaging stations in Georgia that were considered for use in the regional regression analysis.—Continued

[USGS, U.S. Geological Survey; mi^2, square mile]

USGS station number	Station name	Latitude (degree minute second)	Longitude (degree minute second)	Drainage area (mi^2)	Hydrologic region	Period of record	Number of systematic peaks
02315980	Jacks Creek near Ocilla, GA	31 33 39	83 21 28	1.21	4	1960–1975	16
02316000[a]	Alapaha River near Alapaha, GA	31 23 04	83 11 33	663	4	1938–2006	43
02316200[a]	Willacoochee River near Ocilla, GA	31 30 07	83 09 43	90	4	1950–1977	28
02316220	Little Brushy Creek near Ocilla, GA	31 36 31	83 13 56	1.65	4	1966–1975	10
02316260[a]	Alapaha River tributary near Willacoochee, GA	31 16 51	83 03 45	3.19	4	1965–1975	11
02317500[a]	Alapaha River at Statenville, GA	30 42 15	83 01 60	1,400	4	1928–2006	79
02317600[a]	Alapahoochee River near Statenville, GA	30 42 14	83 07 18	239	4	1984–2006	23
02317710	Withlacoochee River tributary near Nashville, GA	31 11 55	83 17 17	0.63	5	1960–1987	28
02317730	New River tributary near Nashville, GA	31 17 19	83 20 36	1.16	4	1960–1975	16
02317760[a]	Little River near Ashburn, GA	31 41 33	83 42 08	8.54	4	1965–1975	11
02317765	Newell Branch near Worth, GA	31 44 21	83 43 30	1.15	4	1965–1975	11
02317770[a]	Newell Branch near Ashburn, GA	31 41 47	83 41 51	6.48	4	1965–1975	11
02317775	Daniels Creek near Ashburn, GA	31 40 41	83 45 06	1.11	4	1965–1987	23
02317780[a]	Lime Sink Creek near Sycamore, GA	31 36 21	83 40 31	2.59	4	1965–1984	20
02317795[a]	Mill Creek near Tifton, GA	31 29 37	83 34 04	6.21	4	1965–1975	11
02317800[a]	Little River near Tifton, GA	31 26 22	83 33 38	145	4	1951–1973	23
02317810	Arnold Creek tributary near Tifton, GA	31 25 31	83 34 23	0.16	4	1965–2002	37
02317830[a]	Little River near Lenox, GA	31 15 16	83 30 32	208	4	1968–1978	11
02317840[a]	Warrior Creek near Sylvester, GA	31 33 11	83 48 53	8.23	4	1965–1975	11
02317845	Warrior Creek tributary near Sylvester, GA	31 32 55	83 49 11	1.64	4	1965–1975	11
02317870[a]	Warrior Creek near Sumner, GA	31 21 46	83 46 11	109	4	1966–1987	22
02317890	Little Creek near Sylvester, GA	31 36 49	83 45 29	0.31	4	1965–1975	11
02317900[a]	Ty Ty Creek at Ty Ty, GA	31 28 23	83 39 47	47.0	4	1951–1978	28
02317905[a]	Little Creek near Omega, GA	31 23 36	83 37 60	4.22	4	1965–1975	11
02317910[a]	Ty Ty Creek tributary at Crosland, GA	31 19 18	83 37 24	1.86	4	1960–1974	15
02318015	Bull Creek near Norman Park, GA	31 13 14	83 37 20	1.45	5	1965–1975	11
02318020[a]	Bull Creek tributary near Ellenton, GA	31 09 20	83 37 06	0.11	5	1960–1975	16
02318600	Okapilco Creek near Berlin, GA	31 02 49	83 37 02	108	5	1963–1984	22
02318700	Okapilco Creek near Quitman, GA	30 49 32	83 33 45	269	5	1980–2006	27
02326200	Aucilla River near Boston, GA	30 46 45	83 48 12	86.5	5	1962–1984	23
02327200	Ochlockonee River at Moultrie, GA	31 10 59	83 48 32	89.9	5	1951–1977	27
02327350	Ochlockonee River tributary near Coolidge, GA	31 01 25	83 57 35	1.98	5	1965–2006	42
02327355	Ochlockonee River near Coolidge, GA	31 00 08	83 56 21	260	5	1981–2006	26
02327400	Sallys Branch tributary near Sale City, GA	31 14 47	84 01 40	3.31	5	1966–1975	10
02327415	Little Ochlockonee River near Moultrie, GA	31 07 02	83 58 42	44.8	5	1981–2006	24

Table 6. Summary of rural streamgaging stations in Georgia that were considered for use in the regional regression analysis.—Continued

[USGS, U.S. Geological Survey; mi^2, square mile]

USGS station number	Station name	Latitude	Longitude	Drainage area (mi^2)	Hydrologic region	Period of record	Number of systematic peaks
		(degree minute second)					
02327500	Ochlockonee River near Thomasville, GA	30 52 33	84 02 44	550	5	1937–2006	51
02327550	Barnetts Creek near Meigs, GA	31 01 33	84 08 14	15.0	5	1965–1987	21
02327700	Barnetts Creek near Thomasville, GA	30 54 19	84 04 34	104	5	1951–1977	27
02327860	Popple Branch near Whigham, GA	30 55 36	84 20 18	1.71	5	1977–2002	26
02327900	Wolf Creek near Whigham, GA	30 53 37	84 17 26	19.0	5	1951–1977	27
02328000	Tired Creek near Cairo, GA	30 51 55	84 15 46	60.0	5	1944–1979	36
02337000	Sweetwater Creek near Austell, GA	33 46 22	84 36 53	246	1	1904–2006	72
02337400	Dog River near Douglasville, GA	33 39 36	84 51 41	47.0	1	1951–1977	27
02337448	Hurricane Creek tributary near Fairplay, GA	33 35 03	84 50 54	0.31	1	1977–2006	30
02337500	Snake Creek near Whitesburg, GA	33 31 46	84 55 42	35.5	1	1955–2001	47
02338660	New River near Corinth, GA	33 14 07	84 59 16	127	1	1979–2006	28
02338840	Yellowjacket Creek below Hogansville, GA	33 08 22	84 58 31	91.0	1	1979–2006	13
02339000	Yellowjacket Creek near La Grange, GA	33 05 27	85 03 40	182	1	1951–1971	21
02340250	Flat Shoal Creek near West Point, GA	32 52 53	85 04 41	204	1	1948–2006	29
02340500	Mountain Oak Creek near Hamilton, GA	32 44 28	85 04 08	61.7	1	1944–1973	30
02341220	Mulberry Creek near Mulberry Grove, GA	32 42 11	84 57 29	190	1	1984–2006	22
02341600	Juniper Creek near Geneva, GA	32 31 42	84 34 14	47.4	3	1963–2006	44
02341723	Pine Knot Creek near Juniper, GA	32 26 15	84 39 25	31.4	3	1979–2006	27
02343200[a]	Pataula Creek near Lumpkin, GA	31 56 04	84 48 12	70.0	4	1949–1978	30
02343219[a]	Bluff Springs Branch near Lumpkin, GA	32 01 53	84 53 18	2.98	4	1977–2006	30
02343225[a]	Pataula Creek near Georgetown, GA	31 49 07	84 58 26	295	4	1951–1978	28
02343244[a]	Cemochechobee Creek near Coleman, GA	31 39 12	84 53 02	15.3	4	1984–2006	22
02343267[a]	Temple Creek near Blakely, GA	31 26 35	84 58 60	2.64	4	1978–2006	28
02344700	Line Creek near Senoia, GA	33 19 09	84 31 20	101	1	1965–2006	42
02346180[a]	Flint River near Thomaston, GA	32 50 20	84 25 27	1,220	1	1900–1994	73
02346193	Scott Creek near Talbotton, GA	32 39 48	84 36 06	3.36	1	1969–1987	19
02346195	Lazer Creek near Talbotton, GA	32 44 33	84 33 20	81.3	1	1981–2006	24
02346210	Kimbrough Creek near Talbotton, GA	32 41 19	84 30 48	6.62	1	1969–1987	19
02346217	Coleoatchee Creek near Manchester, GA	32 49 20	84 36 16	2.82	1	1969–2006	37
02346500	Potato Creek near Thomaston, GA	32 54 15	84 21 45	186	1	1938–1973	36
02348485	Whitewater Creek near Butler, GA	32 30 15	84 20 03	17.3	3	1979–2002	22
02349000	Whitewater Creek near Butler, GA	32 28 01	84 15 58	82.2	3	1944–1977	34
02349030	Cedar Creek near Rupert, GA	32 23 22	84 17 49	41.1	3	1979–2005	27
02349330	Buck Creek tributary near Tazewell, GA	32 20 50	84 22 26	0.40	3	1977–2006	30
02349350	Buck Creek near Ellaville, GA	32 18 36	84 17 36	146		1979–2006	28

Table 6. Summary of rural streamgaging stations in Georgia that were considered for use in the regional regression analysis. —Continued

[USGS, U.S. Geological Survey; mi^2, square mile]

USGS station number	Station name	Latitude	Longitude	Drainage area (mi^2)	Hydrologic region	Period of record	Number of systematic peaks
		(degree minute second)					
02349695	Horsehead Creek near Montezuma, GA	32 21 28	83 56 12	0.72	4	1977–2006	30
02349900[a]	Turkey Creek at Byromville, GA	32 11 44	83 54 08	45.0	4	1951–2006	56
02350520[a]	Abrams Creek tributary near Doles, GA	31 40 47	83 48 04	3.77	4	1965–1975	11
02350685	Choctahatchee Creek tributary near Plains, GA	32 02 03	84 26 01	0.30	4	1977–2006	29
02351800[a]	Muckaloochee Creek at Smithville, GA	31 54 20	84 14 44	47.0	4	1948–1978	29
02353100[a]	Ichawaynochaway Creek near Graves, GA	31 46 17	84 33 44	118	4	1963–1990	22
02353200[a]	Little Ichawaynochaway Creek near Shellman, GA	31 46 46	84 36 13	48.8	4	1951–1962	12
02353400[a]	Pachitla Creek near Edison, GA	31 33 18	84 40 51	188	4	1948–2006	49
02353500[a]	Ichawaynochaway Creek at Milford, GA	31 22 58	84 32 47	620	4	1906–2006	69
02354500[a]	Chickasawhatchee Creek at Elmodel, GA	31 21 02	84 28 57	320	4	1940–2006	49
02354800[a]	Ichawaynochaway Creek near Elmodel, GA	31 17 38	84 29 31	1,000	4	1996–2006	11
02355000[a]	Ichawaynochaway Creek near Newton, GA	31 16 21	84 29 19	1,020	4	1938–1947	10
02356100[a]	Spring Creek near Arlington, GA	31 24 48	84 46 33	49.0	4	1951–1980	25
02356640[a]	Spring Creek at Colquitt, GA	31 10 16	84 44 31	281	4	1981–2006	24
02357000[a]	Spring Creek near Iron City, GA	31 02 25	84 44 24	485	4	1938–2006	65
02379500[a]	Cartecay River near Ellijay, GA	34 41 03	84 27 31	134	2	1938–1986	48
02380000[a]	Ellijay River at Ellijay, GA	34 41 33	84 28 45	87.7	2	1919–1972	22
02380500[a]	Coosawattee River near Ellijay, GA	34 40 30	84 30 31	236	2	1939–2006	64
02381100[a]	Mountaintown Creek tributary near Ellijay, GA	34 42 04	84 31 54	2.41	2	1965–1974	10
02381300[a]	Fir Creek near Ellijay, GA	34 41 06	84 37 23	1.40	2	1966–1987	22
02381600[a]	Fausett Creek near Talking Rock, GA	34 34 13	84 28 08	9.99	2	1966–2006	41
02381900[a]	Ball Creek near Talking Rock, GA	34 31 52	84 34 11	3.50	2	1965–1974	10
02382200[a]	Talking Rock Creek near Hinton, GA	34 31 22	84 36 40	119	2	1964–2006	42
02383000	Rock Creek near Fairmount, GA	34 21 32	84 46 46	6.17	1	1952–1974	23
02383200	Redbud Creek near Ranger, GA	34 31 57	84 43 39	1.61	1	1964–1974	11
02384540[a]	Mill Creek near Crandall, GA	34 52 19	84 43 17	7.68	2	1985–2006	22
02384600	Pinhook Creek near Eton, GA	34 49 34	84 48 54	3.78	1	1964–2006	43
02385000	Coahulla Creek near Varnell, GA	34 53 43	84 55 15	86.7	1	1940–1962	16
02387100	Polecat Creek near Spring Place, GA	34 39 08	84 50 33	1.40	1	1964–1974	11
02387200	Beamer Creek near Spring Place, GA	34 38 03	84 51 52	1.66	1	1964–1974	11
02387300	Dead Mans Branch near Resaca, GA	34 35 44	84 52 11	0.28	1	1965–1987	23
02387560	Oothkalooga Creek tributary at Adairsville, GA	34 21 34	84 55 20	3.56	1	1965–1974	10
02387570	Oothkalooga Creek at Adairsville, GA	34 22 40	84 56 34	21.7	1	1964–1974	11
02387700	Rocky Creek at Curryville, GA	34 26 44	85 05 12	8.61	1	1965–1974	10

Table 6. Summary of rural streamgaging stations in Georgia that were considered for use in the regional regression analysis.—Continued

[USGS, U.S. Geological Survey; mi^2, square mile]

USGS station number	Station name	Latitude	Longitude	Drainage area (mi^2)	Hydrologic region	Period of record	Number of systematic peaks
		(degree minute second)					
02387800	Bailey Creek near Villanow, GA	34 40 10	85 05 40	3.82	1	1965–1974	10
02388000	West Armuchee Creek near Subligna, GA	34 34 04	85 09 37	36.4	1	1961–1981	21
02388200	Storey Mill Creek near Summerville, GA	34 25 14	85 16 35	6.02	1	1966–1987	22
02388300	Heath Creek near Rome, GA	34 21 57	85 16 17	14.7	1	1969–1990	22
02388400	Dozier Creek near Shannon, GA	34 18 53	85 05 47	2.84	1	1965–1974	10
02389300	Shoal Creek near Dawsonville, GA	34 25 13	84 08 47	21.7	1	1959–1974	16
02394400	Pumpkinvine Creek below Dallas, GA	33 54 59	84 52 41	42.8	1	1951–1977	27
02394820	Euharlee Creek at Rockmart, GA	33 59 55	85 03 09	42.1	1	1984–2006	23
02394950	Hills Creek near Taylorsville, GA	34 04 32	84 57 02	25.0	1	1960–1974	15
02395120	Two Run Creek near Kingston, GA	34 14 34	84 53 23	33.1	1	1981–2006	26
02397410	Cedar Creek at Cedartown, GA	33 59 45	85 15 53	66.9	1	1949–1997	27
02397500	Cedar Creek near Cedartown, GA	34 03 41	85 18 47	115	1	1943–2006	36
02397750	Duck Creek above Lafayette, GA	34 42 16	85 19 51	6.70	1	1965–1974	10
02397830	Harrisburg Creek near Hawkins, GA	34 36 02	85 23 21	13.3	1	1980–2006	27
02398000	Chattooga River at Summerville, GA	34 27 59	85 20 10	192	1	1938–2006	69
02411735	Mcclendon Creek tributary near Dallas, GA	33 50 58	84 57 20	0.94	1	1977–2006	29
02411800	Little River near Buchanan, GA	33 47 51	85 07 03	20.2	1	1960–1985	26
02411900	Tallapoosa River at Tallapoosa, GA	33 46 27	85 17 60	236	1	1951–1977	27
02411902	Mann Creek tributary near Tallapoosa, GA	33 51 16	85 17 28	0.12	1	1977–2006	29
02413000	Little Tallapoosa River at Carrollton, GA	33 35 50	85 04 49	95.1	1	1936–1965	29
02413200	Little Tallapoosa River near Bowden, GA	33 30 46	85 14 03	220	1	1949–1977	29
03544947[a]	Brier Creek near Hiawassee, GA	34 50 05	83 42 34	1.67	2	1984–2006	23
03545000[a]	Hiwassee River at Presley, GA	34 54 17	83 43 01	45.5	2	1942–2001	60
03550500[a]	Nottely River near Blairsville, GA	34 50 28	83 56 10	74.8	2	1943–2000	58
03558000[a]	Toccoa River near Dial, GA	34 47 24	84 14 24	177	2	1913–1996	84
03560000[a]	Fightingtown Creek at Mccaysville, GA	34 58 53	84 23 12	70.9	2	1943–1973	31
03566660	Sugar Creek near Ringgold, GA	34 58 14	85 01 29	4.44	1	1965–1974	10
03566685	Little Chickamauga Creek near Ringgold, GA	34 50 32	85 08 28	35.5	1	1964–1975	12
03566687	Little Chickamauga Creek tributary near Ringgold, GA	34 51 36	85 08 40	3.36	1	1965–1974	10
03566700	South Chickamauga Creek at Ringgold, GA	34 55 07	85 07 32	169	1	1949–1965	17
03567200	West Chickamauga Creek near Kensington, GA	34 48 10	85 20 52	73.0	1	1950–1976	27
03568500	Chattanooga Creek near Flintstone, GA	34 58 20	85 19 40	50.6	1	1951–1974	24
03568933	Lookout Creek near New England, GA	34 53 51	85 27 47	149	1	1980–2006	27

[a] Station not used in regression analysis.

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