COMPARISON OF THE 2-, 25-, AND 100-YEAR RECURRENCE INTERVAL FLOODS COMPUTED FROM OBSERVED DATA WITH THE 1995 URBAN FLOOD-FREQUENCY ESTIMATED EQUATIONS FOR GEORGIA

U.S. GEOLOGICAL SURVEY

Prepared in cooperation with the

GEORGIA DEPARTMENT OF TRANSPORTATION
and
FEDERAL HIGHWAY ADMINISTRATION

Water-Resources Investigations Report 97-4118

COMPARISON OF THE 2-, 25-, AND 100-YEAR RECURRENCE INTERVAL FLOODS COMPUTED FROM OBSERVED DATA WITH THE 1995 URBAN FLOOD-FREQUENCY ESTIMATING EQUATIONS FOR GEORGIA

By Ernest J. Inman

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 97-4118

Prepared in cooperation with the

GEORGIA DEPARTMENT OF TRANSPORTATION
and
FEDERAL HIGHWAY ADMINISTRATION

Atlanta, Georgia

1997

U.S. DEPARTMENT OF THE INTERIOR

BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY

Gordon P. Eaton, Director

Any use of trade, product, or firm names is for descriptive purposes only, and does not imply endorsement by the U.S. Government

For additional information,write to:

District Chief
U.S. Geological Survey
Peachtree Business Center
3039 Amwiler Road, Suite 130
Atlanta, GA 30360-2824

Copies of this report can be purchased from:

U.S. Geological Survey
Branch of Information Services
Denver Federal Center
Box 25286
Denver, CO 80225-0286

CONTENTS

ILLUSTRATIONS

TABLES

COMPARISON OF THE 2-, 25-, AND 100-YEAR RECURRENCE INTERVAL FLOODS COMPUTED FROM OBSERVED DATA WITH THE 1995 URBAN FLOOD-FREQUENCY ESTIMATING EQUATIONS FOR GEORGIA

By Ernest J. Inman

ABSTRACT

Flood-frequency relations were computed for 28 urban stations, for 2-, 25-, and 100-year recurrence interval floods and the computations were compared to corresponding recurrence interval floods computed from the estimating equations from a 1995 investigation. Two stations were excluded from further comparisons or analyses because neither station had a significant flood during the period of observed record.

The comparisons, based on the student's t-test statistics at the 0.05 level of significance, indicate that the mean residuals of the 25- and 100-year floods were negatively biased by 26.2 percent and 31.6 percent, respectively, at the 26 stations. However, the mean residuals of the 2-year floods were 2.5 percent lower than the mean of the 2-year floods computed from the equations, and were not significantly biased. The reason for this negative bias is that the period of observed record at the 26 stations was a relatively dry period. At 25 of the 26 stations, the two highest simulated peaks used to develop the estimating equations occurred many years before the observed record began. However, no attempt was made to adjust the estimating equations because higher peaks could occur after the period of observed record and an adjustment to the equations would cause an underestimation of design floods.

INTRODUCTION

A knowledge of flood characteristics of streams is essential for designing roadway drainage structures, establishing flood-insurance rates, and for other uses by urban planners and engineers. Because urbanization can produce significant changes in the flood-frequency characteristics of streams, natural (rural) basin flood-frequency relations are not applicable to urban streams.

Recognizing the need for additional data for comparison or verification of the statewide urban estimating equations presented by Inman (1995), the U.S. Geological Survey (USGS), in cooperation with the Georgia Department of Transportation and the Federal Highway Administration, began a project in 1987 to monitor urban floods in Georgia. The study was expanded to cover the South Georgia areas of Albany, Moultrie, Thomasville, and Valdosta in 1994.

Background

Recognizing the need for reliable urban peak-flood data and improved equations for estimating floods in Georgia, the USGS collected data at 65 rainfall-runoff stations—beginning in 1973 in Metropolitan Atlanta (Inman, 1983); continuing in 1978 in Athens, Augusta, Columbus, Rome, and Savannah (Inman, 1988); and continuing in 1986 in Albany, Moultrie, Thomasville, and Valdosta, Ga. (Inman, 1995) (fig. 1). These data were used to calibrate a USGS rainfall-runoff model (RRM), as described by J.M. Bergmann, E.J. Inman, and A.M. Lumb (U.S. Geological Survey, written commun., 1990).

After the RRM was successfully calibrated for each drainage basin, long-term rainfall and daily pan-evaporation data from nearby National Weather Service stations were used to synthesize about 60 to 90 years of annual peak flows, depending on the length of the long-term rainfall. These synthesized peaks were used to develop flood-frequency relations for each basin. The final step in analyzing these data was to develop regression equations that can be used to estimate the magnitude and frequency of floods at ungaged urban sites in Georgia. Detailed descriptions of the RRM calibration, the long-term simulation, and the regression analyses were given by Inman (1995). The estimating equations for the four flood-frequency regions in Georgia for the 2- through 500-year floods, also given in Inman (1995), are shown in table 1.

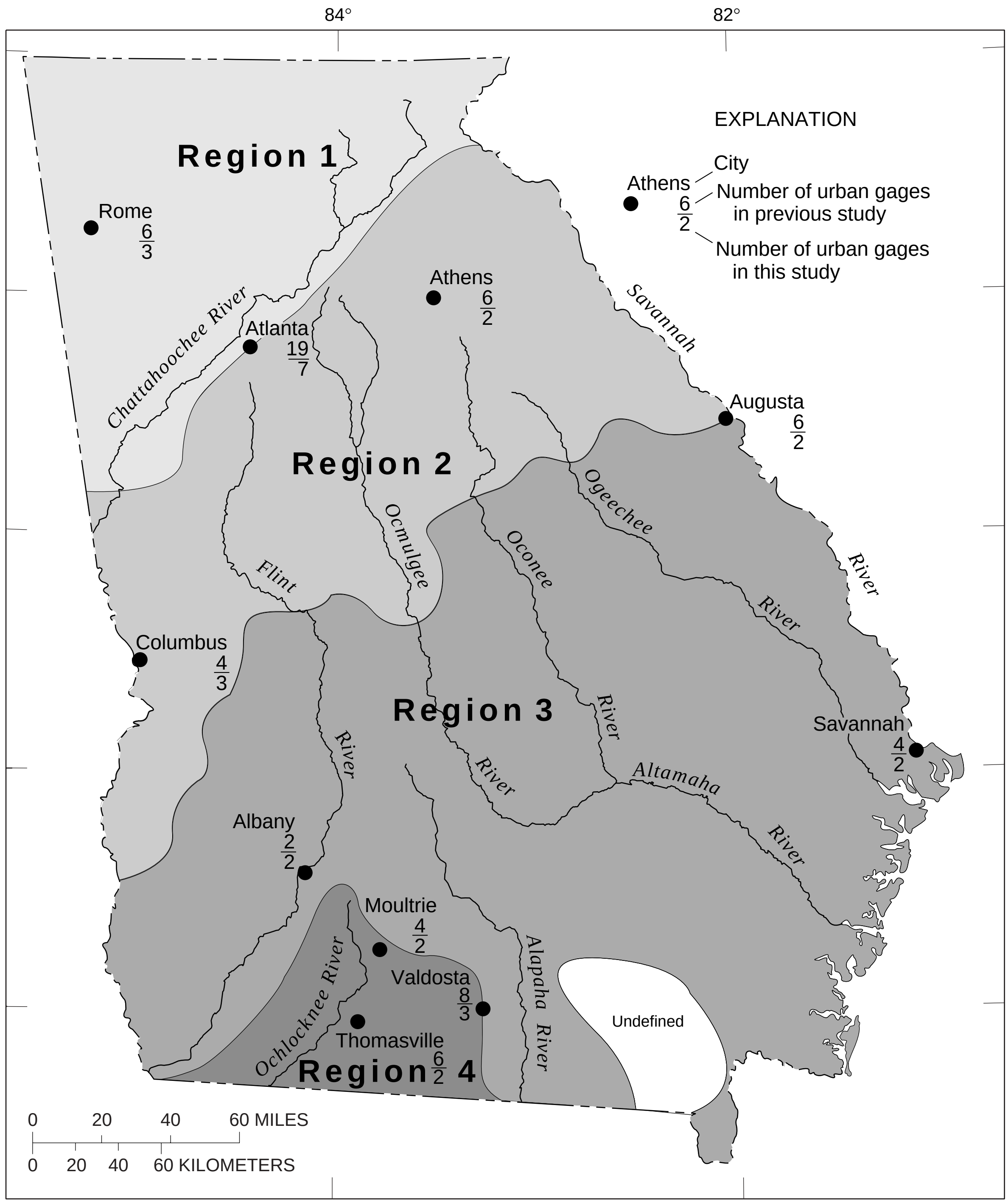
Six to eight years of observed annual peak flows are insufficient for developing reliable flood-frequency estimates. Collection of additional flood data at about 40 percent of the stations used in the statewide report (Inman,1995) would provide a data base of sufficient length for verification or comparison with the flood-frequency data computed using the statewide estimating equations.

Purpose and Scope

This report describes the results of the expanded study to compare the results of the statewide flood-frequency estimating equations presented by Inman (1995) with the flood-frequency data computed from observed data. To accomplish the project objectives, 28 urban stations were selected from previous urban flood-frequency investigations to collect additional data through September 1996, which provides a data base of sufficient length to compare flood frequencies.

At least two urban stations were selected in each of the 10 cities from the previous study (Inman, 1995) (fig. 1, table 2). Stability of the stage-discharge relations at each site was the primary selection criterion; together with range in size of drainage areas, and percent impervious areas.

The U.S. Geological Survey is responsible for the information contained in this report. The report does not necessarily reflect the official view or policy of the Georgia Department of Transportation or the Federal Highway Administration, nor does the report constitute a standard, specification, or regulation.



Base from U.S. Geological Survey digital files

Figure 1. Four flood-frequency regions in Georgia and cities where gaging stations were used in this study and in the previous statewide urban flood-frequency study by Inman (1995).

Table 1. Regional flood-frequency equations for urban stream in Georgia

[UQ_T, peak discharge for an urban drainage basin, in cubic feet per second; A, drainage area, in square miles; TIA, area that is impervious to infiltration of rainfall, in percent; ±, plus-minus; table from Inman (1995)]

UQ_T recurrence interval (years)	Flood-frequency estimating equations (region 1)	Average standard error of prediction (percent)	Flood-frequency estimating equations (Rome, Ga.)	Average standard error of prediction (percent)	Flood-frequency estimating equations (region 2)	Average standard error of prediction (percent)	Flood-frequency estimating equations (region 3)	Average standard error of prediction (percent)	Flood-frequency estimating equations (region 4)	Average standard error of prediction (percent)
2	$167A^{0.73}TIA^{0.31}$	±34	$107A^{0.73}TIA^{0.31}$	±40	$145A^{0.70}TIA^{0.31}$	±35	$54.6A^{0.69}TIA^{0.31}$	±34	$110A^{0.66}TIA^{0.31}$	±34
5	$301A^{0.71}TIA^{0.26}$	±31	$183A^{0.71}TIA^{0.26}$	±36	$258A^{0.69}TIA^{0.26}$	±31	$99.7A^{0.69}TIA^{0.26}$	±31	$237A^{0.66}TIA^{0.26}$	±31
10	$405A^{0.70}TIA^{0.21}$	±31	$249A^{0.70}TIA^{0.21}$	±35	$351A^{0.70}TIA^{0.21}$	±31	$164A^{0.71}TIA^{0.21}$	±32	$350A^{0.68}TIA^{0.21}$	±30
25	$527A^{0.70}TIA^{0.20}$	±29	$316A^{0.70}TIA^{0.20}$	±33	$452A^{0.70}TIA^{0.20}$	±29	$226A^{0.71}TIA^{0.20}$	±30	$478A^{0.69}TIA^{0.20}$	±29
50	$643A^{0.69}TIA^{0.18}$	±28	$379A^{0.69}TIA^{0.18}$	±33	$548A^{0.70}TIA^{0.18}$	±29	$288A^{0.72}TIA^{0.18}$	±30	$596A^{0.70}TIA^{0.18}$	±28
100	$762A^{0.69}TIA^{0.17}$	±28	$440A^{0.69}TIA^{0.17}$	±33	$644A^{0.70}TIA^{0.17}$	±29	$355A^{0.72}TIA^{0.17}$	±30	$717A^{0.70}TIA^{0.17}$	±28
200	$892A^{0.68}TIA^{0.16}$	±28	$505A^{0.68}TIA^{0.16}$	±34	$747A^{0.70}TIA^{0.16}$	±28	$428A^{0.72}TIA^{0.16}$	±30	$843A^{0.70}TIA^{0.16}$	±28
500	$1063A^{0.68}TIA^{0.14}$	±28	$589A^{0.68}TIA^{0.14}$	±34	$888A^{0.70}TIA^{0.14}$	±28	$531A^{0.72}TIA^{0.14}$	±30	$1017A^{0.71}TIA^{0.14}$	±28

Table 2. Gaging stations used in the statewide urban comparison study, by city

Station number[1/]	Station name	Location
	Albany	
02352605	Flint River tributary 1, at Albany	Lat 31°32'52", long 84°09'28", Dougherty County, at culvert on Emily Avenue, at Albany
02352964	Percosin Creek tributary, at Albany	Lat 31°35'47", long 84°14'03", Dougherty County, at culvert on Dean’s Road, at Albany
	Athens	
02217505	Brooklyn Creek, at Athens	Lat 33°56'32", long 83°24'07", Clarke County, at culvert on Dudley Drive, at Athens
02217905	Tanyard Creek, at Athens	Lat 33°57'05", long 83°22'42", Clarke County, at culvert on Baxter Street, at Athens
	Atlanta	
02203835	Shoal Creek, near Atlanta	Lat 33°44'48", long 84°16'50", DeKalb County, at culvert on Line Street, near Atlanta
02203845	Shoal Creek tributary, near Atlanta	Lat 33°43'05", long 84°15'45", DeKalb County, at culvert on Glendale Drive near Atlanta
02203884	Conley Creek, near Forest Park	Lat 33°38'08", long 84°20'38", Clayton County, at culvert on Rock Cut Road, near Forest Park

Table 2. Gaging stations used in the statewide urban comparison study, by city—Continued

Station number[1/]	Station name	Location
02336090	North Fork Peachtree Creek tributary, near Chamblee	Lat 33°50'53", long 84°17'57", DeKalb County, at culvert on Meadowcliff Drive, near Chamblee
02336102	North Fork Peachtree Creek tributary, near Atlanta	Lat 33°51'20", long 84°19'19", DeKalb County, at culvert on Drew Valley Road, near Atlanta
02336238	South Fork Peachtree Creek tributary, near Atlanta	Lat 33°47'11", long 84°20'29", DeKalb County, at culvert on East Rock Springs Road, near Atlanta
02336700	South Utoy Creek tributary, at East Point	Lat 33°41'25", long 84°28'05", Fulton County, at culvert on Headland Drive, at East Point
	Augusta	
02196725	Oates Creek, at Augusta	Lat 33°27'19", long 82°02'23", Richmond County, at culvert on White Road, at Augusta
02196760	Rocky Creek tributary, at Augusta	Lat 33°27'07", long 82°02'57", Richmond County, at culvert on U.S. Highways 78 and 278, at Augusta
	Columbus	
02341544	Mill Branch, at Columbus	Lat 32°28'19", long 84°53'58", Muscogee County, at culvert on Chalbena Road, at Columbus
02341546	Bull Creek tributary, at Columbus	Lat 32°28'38", long 84°55'36", Muscogee County, at culvert on Woodland Drive, at Columbus
02341548	Lindsey Creek tributary, at Columbus	Lat 32°31'33", long 84°56'21", Muscogee County, at culvert on Canberra Avenue, at Columbus
	Moultrie	
02318565	Okapilco Creek tributary, at Moultrie	Lat 31°10'12", long 83°46'40", Colquitt County, at culvert on Southeast 10th Street, at Moultrie
02327203	Tributary to Ochlockonee River tributary, at Moultrie	Lat 31°09'54", long 83°47'35", Colquitt County, at culvert on Southwest 4th Street, at Moultrie
	Rome	
02395990	Etowah River tributary, near Rome	Lat 34°16'02", long 85°08'18", Floyd County, at culvert on Atteiram Road, near Rome
02396510	Silver Creek tributary no. 2 at Lindale Road, near Rome	Lat 34°12'56", long 85°10'09", Floyd County, at culvert on Lindale Road, near Rome
02396550	Silver Creek tributary no. 3, at Rome	Lat 34°13'26", long 85°09'14", Floyd County, at culvert on U.S. Highway 27, 0.4 mile north of U.S. Highway 411 interchange, at Rome
	Savannah	
02203543	Wilshire Canal, near Savannah	Lat 31°59'27", long 81°08'15", Chatham County, at culvert on Tibet Avenue, near Savannah
02203544	Wilshire Canal tributary, near Savannah	Lat 31°58'25", long 81°08'20", Chatham County, at culvert on Windsor Road, near Savannah
	Thomasville	
02327467	Oquina Creek, at Thomasville	Lat 30°50'12", long 83°59'38", Thomas County, at culvert on Wolf Street, at Thomasville
02327471	Bruces Branch, at Thomasville	Lat 30°50'39", long 83°58'36", Thomas County, at culvert on North Hansell Street, at Thomasville
	Valdosta	
02317564	Dukes Bay Canal, at Valdosta	Lat 30°49'13", long 83°16'20", Lowndes County, at culvert on South Patterson Street at intersection with State Route 94, at Valdosta
02317566	Dukes Bay Canal at Industrial Boulevard, at Valdosta	Lat 30°48'34", long 83°15'43", Lowndes County, at culvert on Industrial Boulevard, at Valdosta
023177554	Onemile Branch, at Wainwright Drive at Valdosta	Lat 30°50'34", long 83°18'04", Lowndes County, at culvert on Wainwright Drive, at Valdosta

[1/] U.S. Geological Survey downstream order number.

FLOOD-FREQUENCY ANALYSES

A log-Pearson Type III frequency distribution was fitted to the logarithms of the annual peak discharges at each of the 28 urban stations in accordance with "Guidelines for Determining Flood Flow Frequency," Bulletin 17B (Interagency Advisory Committee on Water Data, 1982) recommendations. These recommendations include the proper handling of low and high outliers. Skew coefficients were computed directly from the observed data. No attempt was made to adjust the skew coefficients of the frequency curves based on regionalized skews because the data did not meet the criteria specified in the Interagency Advisory Committee on Water Data (1982). The generalized skew-coefficient map in Interagency Advisory Committee on Water Data (1982), was used in the adjustment computations only for rural watersheds and is not applicable to urban flood peaks.

Frequency curves for the observed annual flood peaks of the 28 urban stations represent an "as is" storage condition that may be present at upstream roadway embankments with culverts of limited capacity, or minor floodplain storage. The annual peaks for the frequency curves in the earlier study were simulated with the RRM using the same storage conditions of the observed peaks. Therefore, any difference in flood frequency is due to temporal climatological differences. At least 10 years of record were available at the 28 urban stations as recommended in the Interagency Advisory Committee on Water Data (1982). Eighteen of the urban stations had 18 or more years of record and one station in Atlanta had 33 years. Flood-frequency data from the log-Pearson Type III frequency analysis for selected recurrence intervals at the 28 urban stations are shown in table 3.

Statistical Methods Used for Flood-Frequency Comparisons

The statistical analyses and computations for the flood-frequency comparisons were conducted using procedures defined by the SAS Institute, Inc. (1989). All peak-discharge data were transformed to logarithmic units before conducting the statistical analysis and computations. The logarithmic residual, x, of the estimated discharges minus the observed discharges for each series of differences for the 2-, 25-, and 100-year floods were analyzed using the student's t-test at the 0.05 level of significance, to determine if the mean, $\bar{x}$, was significantly different from zero. A mean residual ($\bar{x}$) significantly different from zero indicates possible bias in the flood-frequency estimating equations, or a bias of the observed discharge due to the time of the sampling period. The SAS univariate procedure was used for all mean-bias testing and to determine if all distributions were normal according to the Shapiro-Wilk statistic (SAS Institute, Inc.,1989).

In order to determine if a bias exists and if the bias varies with the magnitude of discharge, logarithms of observed discharges are regressed against logarithms of discharges estimated from regional regression equations. Then, if the slopes of the regression lines are significantly different from an equal yield line, a bias may exist. In particular, if the slopes are significantly different from 1.0, the bias is a function of magnitude of flow. The student's t-test at the 0.05 significance level is used to determine if the slopes of the regressions is different from 1.0 and if the intercepts are different from zero. Iman and Conover's (1983) methodology of using the student's t-test determines if the slopes or intercepts are biased. Plots of these comparisons are shown in figures 2, 3, and 4.

Data from the 26 urban stations were analyzed as one group, rather than dividing the stations into regions, because some regions had only five or six stations. Groups having five or six stations are too small to make reliable statistical analyses of basins.

Comparison of Flood-Frequency Data

Flood-frequency data are used to determine if significant differences exist between the flood frequency of observed discharges from the 28 selected urban stations and the discharges computed from the estimating equations for the four urban flood-frequency regions (Inman, 1995). Flood-frequency data for the 2-, 25-, and 100-year floods from the 28 urban stations with observed data, from the estimating equations, and from the most recent (latest) 20 years of simulated data at each of the 28 urban stations are shown in table 4. Stations 02196725 in Augusta and 02318565 in Moultrie were deleted from further comparisons, because neither station had as much as a 2-year flood during the period of observed record.

Table 3. Flood-frequency data for the urban stations used in this study

Station number	Flood-frequency region	Drainage area (in square miles)	Period of record	Stream statistical data			Recurrence interval flood (in cubic feet per second)		
				Mean (log)	Standard deviation (log)	Skew of logarithms	2-year	25-year	100-year
				Albany					
02352605	3	0.16	1987-96	1.622	0.296	-0.528	44	121	156
02352964	3	0.05	1987-96	0.691	.282	1.035	4	19	36
				Athens					
02217505	2	1.44	1979-96	2.722	.131	0.605	512	948	1,210
02217905	2	0.42	1979-96	2.617	.163	0.272	407	826	1,070
				Atlanta					
02203835	2	3.43	1973-96	2.876	.164	0.453	731	1,540	2,050
02203845	2	0.84	1973-96	2.613	.176	-0.427	422	782	925
02203884	2	1.88	1974-96	2.826	.168	-0.073	672	1,310	1,610
02336090	1	0.32	1973-96	2.062	.301	0.206	113	406	640
02336102	1	2.19	1973-96	2.855	.118	-0.281	726	1,120	1,280
02336238	1	0.90	1974-96	2.777	.112	0.512	586	983	1,200
02336700	1	0.79	1964-96	2.481	.117	0.122	301	491	581
				Augusta					
02196725	3	1.44	1979-88	2.155	.139	-0.585	147	234	262
02196760	3	1.56	1979-96	2.554	.194	0.530	345	844	1,200
				Columbus					
02341544	2	1.58	1977-96	2.763	.162	-0.077	582	1,100	1,350
02341546	2	0.26	1977-96	1.870	.196	0.941	69	186	286
02341548	2	1.42	1977-96	2.618	.166	0.025	414	813	1,020
				Moultrie					
02318565	4	0.27	1986-96	1.697	.151	1.221	46	103	149
02327203	4	0.38	1986-96	2.147	.153	0.425	137	273	354
				Rome					
02395990	1	0.37	1979-96	1.975	.265	-0.867	103	224	263
02396510	1	0.04	1979-96	1.278	.232	0.008	19	48	66
02396550	1	0.19	1979-96	2.153	.100	-0.288	144	208	232
				Savannah					
02203543	3	0.95	1979-96	2.416	.130	0.586	253	465	593
02203544	3	0.18	1979-96	1.911	.108	-0.409	83	121	134
				Thomasville					
02327467	4	1.07	1986-96	2.335	.131	0.320	213	379	468
02327471	4	0.21	1986-95	1.974	.134	1.836	86	185	278
				Valdosta					
02317564	3	1.27	1986-96	2.368	.143	-0.992	246	366	395
02317566	3	3.81	1986-96	2.539	.156	0.463	336	685	901
023177554	4	2.66	1987-96	2.860	.074	-0.262	730	963	1,040

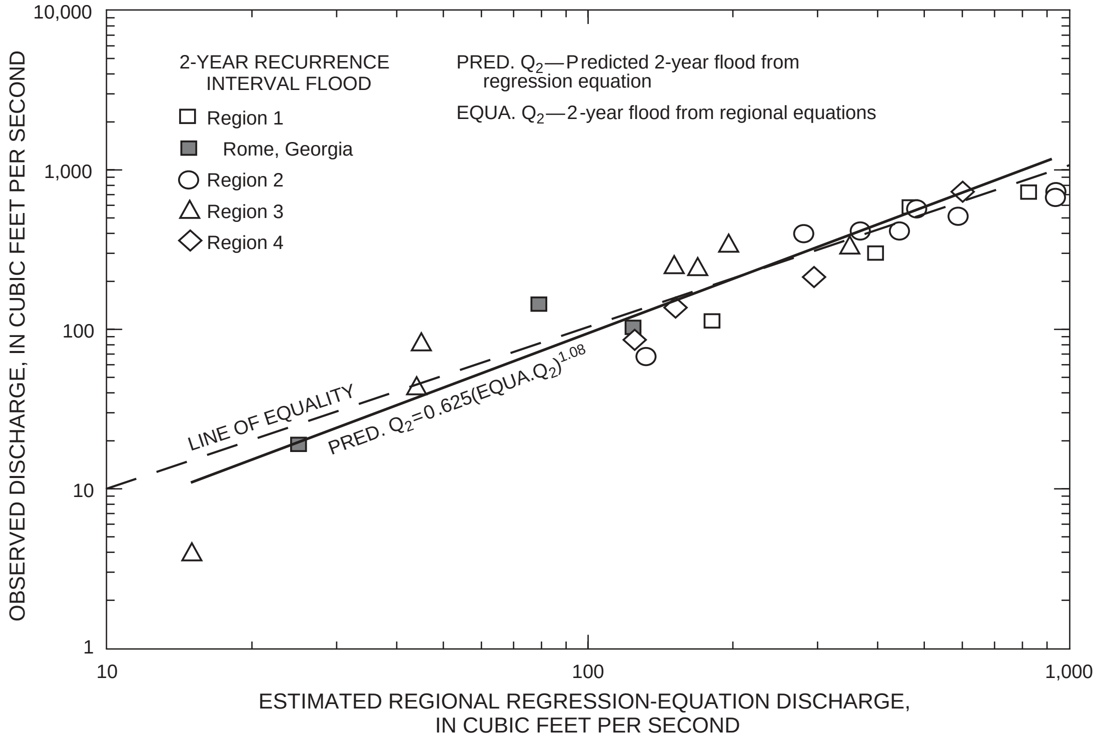


Figure 2. Comparison of 2-year recurrence interval floods from observed data and estimates from regional regression equations for the 26 urban stations used in this study, and the regression equation of the best-fit line of these discharges, with the line of equality.

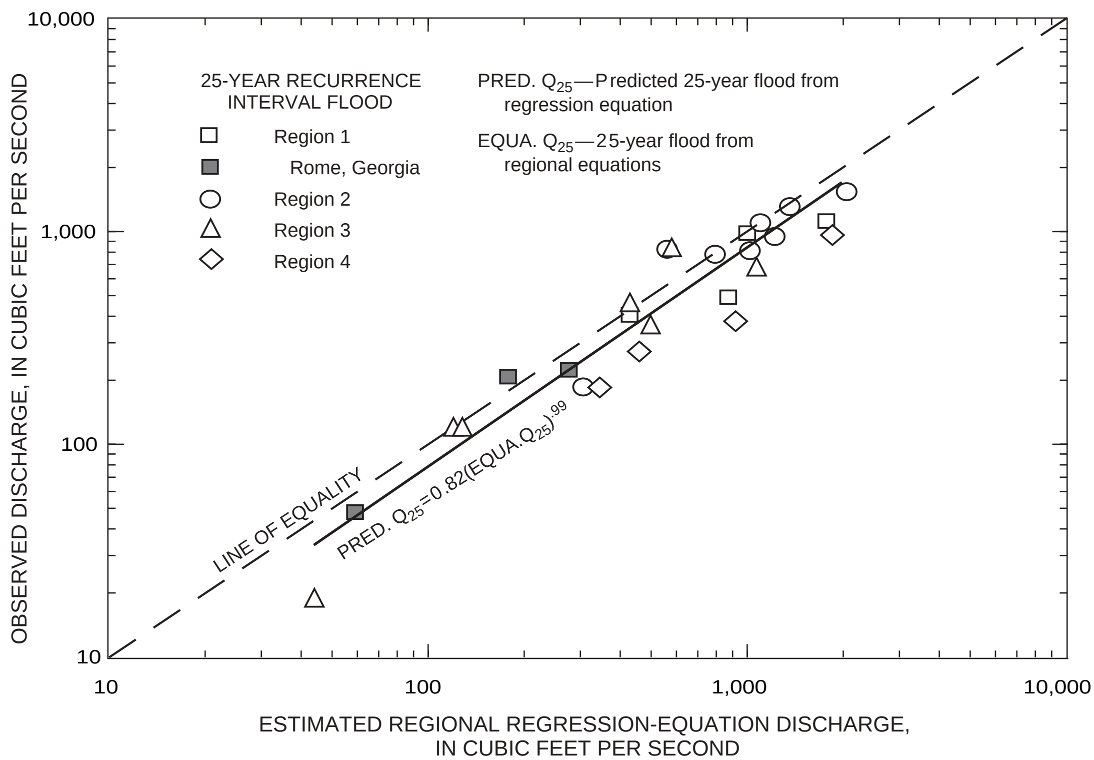


Figure 3. Comparison of 25-year recurrence interval floods from observed data and estimates from regional regression equations for the 26 urban stations used in this study, and the regression equation of the best-fit line of these discharges, with the line of equality.

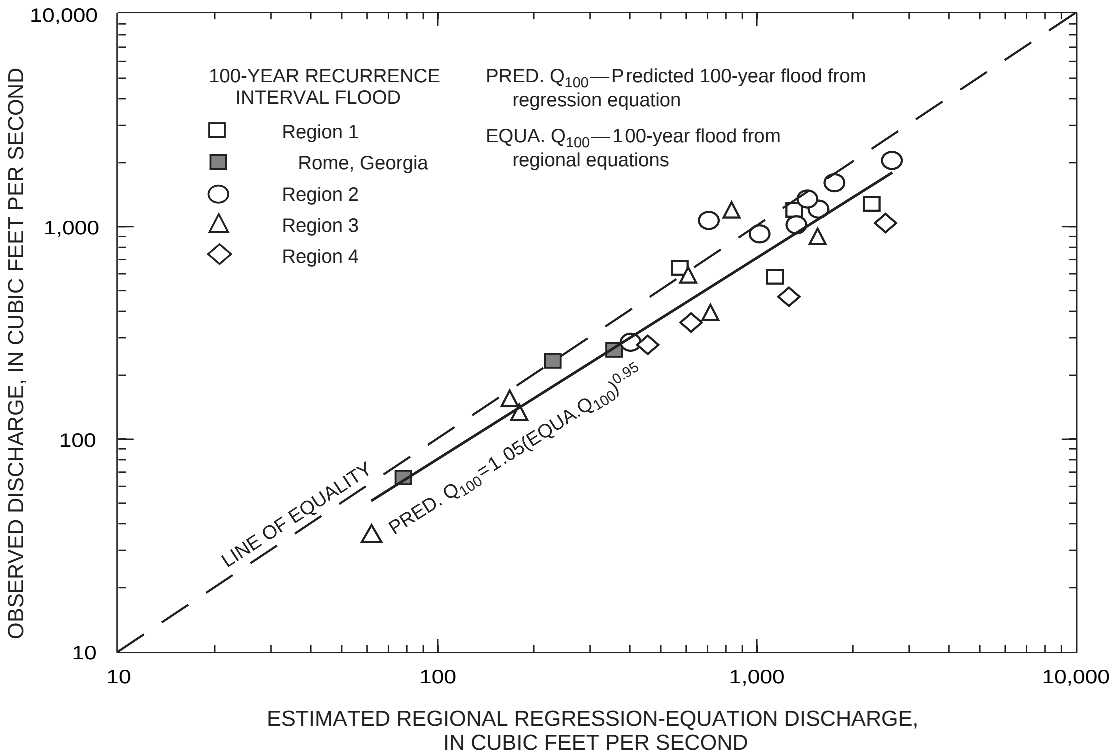


Figure 4. Comparison of 100-year recurrence interval floods from observed data and estimates from regional regression equations for the 26 urban stations used in this study, and the regression equation of the best-fit line of these discharges, with the line of equality.

The flood-frequency data computed from the statewide regression equations are higher than the flood-frequency data computed from observed data for the 2-year flood at 15 urban stations and are equal at one urban station; higher for the 25-year flood at 20 stations and equal at one station; and higher for the 100-year flood at 22 stations (see table 4). Therefore, the peak flows computed with the statewide estimating equations generally are higher than those computed using the observed data. The two highest simulated floods used in developing the estimating equations occurred before the observed record began; thus, indicating a relatively dry period of observed record at 25 of the 26 urban stations. The dates and peak discharges of the two highest observed and simulated floods are shown in table 5. Further evidence that a relatively dry period of record occurred can be observed in table 4 by comparing the results of the log-Pearson flood-frequency analysis of the simulated annual peaks for the most recent (latest) 20 years of record for each urban station with the flood-frequency data from the estimating equations. The magnitudes of the 2-, 25-, and 100-year floods computed from the statewide regression equations, were higher than the corresponding 2-, 25-, and 100-year floods computed from the latest 20 years of record at 20 urban stations. Data in Savannah do not indicate this trend, because the highest simulated annual peaks occurred in Savannah in 1971.

Even though Georgia experienced one of the largest floods of record on the Flint and Ocmulgee Rivers in the southwestern part of Georgia in July 1994, following Tropical Storm Alberto, the very heavy rainfall accompanying this flood did not occur in any of the 10 cities in which the observed record was collected. The city of Albany had extensive flooding caused by very heavy rainfall upstream of the city. Albany had 6.75 inches of rainfall over a five-day period (U.S. Department of Commerce, National Weather Service, 1994). The 1994 annual peak flow for the two Albany urban stations occurred in August.

Table 4. Flood-frequency data for the 2-, 25-, and 100-year floods from urban stations with observed data, from the statewide flood-frequency estimating equations, and from the most recent (latest) 20 years of simulated data from the urban stations

Station number	Flood-frequency observed data (in cubic feet per second)			Flood-frequency regression equation data (in cubic feet per second)			Flood-frequency simulated data, using latest 20 years (in cubic feet per second)		
	2-year	25-year	100-year	2-year	25-year	100-year	2-year	25-year	100-year
Albany									
02352605	44	121	156	44	120	168	33	77	102
02352964	4	19	36	15	44	62	6	20	29
Athens									
02217505	512	948	1,210	588	1,220	1,560	480	1,080	1,400
02217905	407	826	1,070	283	561	707	311	658	862
Atlanta									
02203835	731	1,540	2,050	939	2,050	2,650	749	1,920	2,580
02203845	423	782	925	371	793	1,020	321	800	1,050
02203884	672	1,310	1,610	937	1,360	1,750	523	1,300	1,720
02336090	113	406	640	181	428	573	120	335	461
02336102	726	1,120	1,280	824	1,770	2,290	472	1,200	1,590
02336238	586	983	1,200	467	1,000	1,310	325	933	1,320
02336700	301	491	581	396	872	1,140	254	601	769
Augusta									
02196725	147	234	262	224	619	873	145	359	488
02196760	345	844	1,200	196	580	833	315	894	1,230
Columbus									
02341544	582	1,100	1,350	486	1,100	1,440	594	1,160	1,310
02341546	69	186	286	133	306	402	92	204	255
02341548	414	813	1,020	444	1,020	1,330	418	954	1,190
Moultrie									
02318565	46	103	149	123	363	489	68	147	187
02327203	137	273	354	152	459	622	160	310	372
Rome									
02395990	103	224	263	124	276	357	93	215	275
02396510	19	48	66	25	59	78	22	49	63
02396550	144	208	232	79	178	230	69	160	221
Savannah									
02203543	253	465	593	151	429	609	173	614	967
02203544	83	121	134	45	128	180	92	248	326
Thomasville									
02327467	213	379	468	295	920	1,260	250	510	622
02327471	86	185	278	125	345	455	102	181	219
Valdosta									
02317564	246	366	395	169	498	715	156	381	505
02317566	336	685	901	350	1,070	1,550	326	726	931
023177554	730	963	1,040	601	1,850	2,530	521	1,050	1,290

Table 5. Peak discharges and water years of the two highest flood events, from observed and simulated records for urban stations used in this study

Station number	Peak discharges, in cubic feet per second			
	Observed data	Water year[1/]	Simulated data	Water year
Albany				
02352605	112	1994	108	1909
	79	1995	99	1930
02352964	20	1995	31	1930
	8	1991	27	1909
Athens[2/]				
			(Atlanta 0.5)	
02217505	1,040	1994	1,390	1926
	796	1992	1,380	1912
			(Augusta 0.5)	
			1,540	1903
			1,380	1950
			(Atlanta 0.5)	
02217905	821	1996	942	1908
	715	1991	762	1926
			(Augusta 0.5)	
			832	1903
			800	1927
Atlanta				
02203835	2,140	1980	3,180	1912
	1,390	1983	2,680	1898
02203845	797	1994	1,090	1926
	751	1983	988	1914
02203884	1,230	1978	1,890	1912
	1,070	1992	1,620	1898
02336090	608	1991	410	1908
	343	1980	383	1912
02336102	1,110	1975	1,960	1912
	1,070	1991	1,570	1980
02336238	1,140	1975	1,300	1908
	945	1992	1,140	1912
02336700	533	1971	792	1912
	498	1992	776	1908
Augusta				
02196725	219	1983	713	1930
	201	1986	419	1906
02196760	1,110	1991	1,350	1930
	557	1996	1,020	1967
Columbus				
02341544	1,390	1990	2,770	1923
	858	1994	1640	1957
02341546	244	1990	421	1923
	134	1977	230	1957
02341548	871	1991	2,200	1923
	725	1981	1,160	1916

Table 5. Peak discharges and water years of the two highest flood events, from observed and simulated records for urban stations used in this study—Continued

Station number	Peak discharges, in cubic feet per second			
	Observed data	Water year[1/]	Simulated data	Water year
		Moultrie		
02318565	114	1993	230	1930
	58	1994	198	1909
02327203	298	1993	563	1909
	174	1995	410	1930
		Rome[3/]		
			(Atlanta 0.6)	
02395990	193	1986	344	1912
	190	1979	280	1926
			(Chattanooga 0.4)	
			306	1912
			262	1949
			(Atlanta 0.6)	
02396510	44	1989	60	1914
	41	1990	58	1926
			(Chattanooga 0.4)	
			55	1912
			55	1969
			(Atlanta 0.6)	
02396550	198	1992	343	1908
	189	1982	290	1926
			(Chattanooga 0.4)	
			316	1912
			282	1950
		Savannah		
02203543	550	1995	815	1971
	355	1991	570	1945
02203544	127	1996	297	1971
	118	1995	210	1950
		Thomasville		
02327467	366	1995	911	1909
	284	1994	770	1930
02327471	201	1994	280	1909
	112	1993	272	1948
		Valdosta		
02317564	383	1995	562	1909
	296	1994	535	1930
02317566	668	1995	1,030	1926
	586	1991	1,030	1930
023177554	889	1987	2,660	1909
	889	1991	1,920	1930

[1/]Water year is the 12-month period beginning October 1 and ending September 30, and is designated in the calendar year in which it ends.

[2/]ATLANTA and AUGUSTA long-term rainfall data were used for ATHENS stations with 50 percent weights applied to their simulated flood frequencies.

[3/]ATLANTA and CHATTANOOGA long-term rainfall data were used for ROME stations with 60 percent and 40 percent weights, respectively, applied to their simulated flood frequencies.

RESULTS OF COMPARISONS

Mean residuals, computed as the logarithms of observed discharges subtracted from logarithms of discharges estimated by statewide regional regression equations, are higher for the 2-, 25-, and 100-year recurrence interval floods at the 26 urban stations used in this study. The mean residuals for the 2-year flood is 2.5 percent higher than the observed mean residuals; however, the t-test indicates that the differences are not significant at the 0.05 level of significance. The mean regional regression equation discharge for the 25-year and 100-year floods are higher than the mean observed discharge for the 25-year and 100-year floods by 26.2 percent and 31.6 percent, respectively. The t-tests indicate that both differences are significant at the 0.05 level of significance, but the percentages are within the range or close to the range of the standard error of prediction for the statewide regression equations (Inman, 1995).The slopes of the regression lines are not significantly different from 1.0, for the three recurrence intervals; therefore, the bias is not a function of discharge, and the bias computed by the mean residuals is assumed to apply over the whole range of discharges. The significance or non-significance of the intercept is not a valid indicator of bias because the y-intercept is too far removed from most of the data. Regression equations are computed from normal distributions, as demonstrated by the Shapiro-Wilk statistic from the SAS univariate procedure (SAS Institute, Inc., 1989) (table 6). No attempt was made to adjust the estimating equations because higher peaks can occur after a period of observed record, and an adjustment may cause an underestimation of design floods.

Comparison of mean residuals of the 2-, 25-, and 100-year floods computed using the latest 20 years of record and the mean residuals of the same floods estimated using the regional regression equations, show similar results as previous comparisons of the observed data with the same floods estimated from the regional regression equations. The mean residuals of the 2-, 25-, and 100-year floods estimated from the regional regression equations are 13.5 percent, 19.9 percent, and 22.4 percent higher, respectively, than the mean residuals of the corresponding floods computed from the 20 years of simulated annual peak flows. The t-tests indicate that the differences are significant in all cases; however, the differences are within the range of the standard error of prediction for the statewide regression equations (Inman, 1995). These 20-year-period comparisons eliminate model error as the cause of the regression-equation discharges being higher than observed discharges, because both the 20-year-period annual peak flows and the annual peak flows used for developing the regression equations were simulated with the same model.

Table 6. Results of comparison testing of flood-frequency data based on student's t-test at 0.05 level of significance and statistical analysis of regression results for the final 26 urban stations used in this study
[>, greater than]

Recurrence interval, in years	Mean residual ($\bar{x}$) biased	Percent equation mean greater than observed mean	Normal distribution	Slope biased	Constant biased
2	no	2.5	yes	no	no
25	yes	26.2	yes	no	no
100	yes	31.6	yes	no	no

SUMMARY

The U.S. Geological Survey, in cooperation with the Georgia Department of Transportation, began a study in 1987 to monitor small urban streams in Georgia to verify the accuracy of the urban flood-frequency estimating equations previously published in 1995. Data collection for the monitoring study consisted of obtaining additional annual peak-flow data at 28 selected gaging stations in 10 cities, all of which were part of the previous study. These additional data provided an adequate data base for computing flood-frequency relations with observed data at the selected stations.

Flood-frequency relations were computed for the 28 urban stations and the 2-, 25-, and 100-year recurrence interval floods were compared to the 2-, 25-, and 100-year recurrence interval floods computed from the regional regression equations from the previous study. Two stations were deleted from further comparisons, or analyses, because neither station had as much as a 2-year recurrence interval flood during the period of observed record.

Comparisons at the 26 remaining stations were based on the student's t-test statistics at the 0.05 level of significance. The mean $(\bar{x})$ residual of the 2-year recurrence interval floods computed from observed data was about 2.5 percent lower than the mean $(\bar{x})$ residual of the 2-year recurrence interval floods computed from the regional regression equations; however, the t-test indicated that the bias was not significant at the 0.05 level of significance. The mean $(\bar{x})$ residuals of the 25- and 100-year recurrence interval floods computed from observed data were 26.2 and 31.6 percent lower than the mean residuals of the 25- and 100-year recurrence interval floods computed from the regional regression equations; both floods were significantly biased according to the t-test at the 0.05 level of significance, but were within or close to the limits of the standard error of prediction for the statewide equations. A comparison also was made by regressing logarithms of the 2-, 25-, and 100-year recurrence interval floods computed from observed discharges against logarithms of the 2-, 25- and 100-year recurrence interval floods estimated from the regional regression equations. This regression "best-fit" line was compared to a line of equality and results of the student's t-test indicated that the slope of the regression line was not significantly different from 1.0 at the 0.05 significance level. Therefore, the bias did not vary with discharge.

The primary reason that the mean $(\bar{x})$ of the observed 25- and 100-year floods were biased (less than) the mean $(\bar{x})$ of the 25- and 100-year floods computed from the regional regression equations is because the observed period of record was a relatively dry period. At 25 of the 26 stations, the two highest simulated peaks used in developing the estimating equations occurred before the observed record began. However, no attempt was made to adjust the estimating equations because higher peaks could occur after the period of observed record, and an adjustment could cause an underestimation of design floods.

REFERENCES CITED

Iman, R.L., and Conover, W.J. 1983, A modern approach to statistics: New York, John Wiley, 497 p.

Inman, E.J., 1983, Flood-frequency relations for urban streams in Metropolitan Atlanta, Georgia: U.S. Geological Survey Water-Resources Investigations Report 83-4204, 38 p.

———1988, Flood-frequency relations for urban streams in Georgia: U.S. Geological Survey Water-Resources Investigations Report 88-4085, 36 p.

———1995, Flood-frequency relations for urban streams in Georgia—1994 update: U.S. Geological Survey Water-Resources Investigations Report 95-4017, 27 p.

Interagency Advisory Committee on Water Data, 1982, Guidelines for determining flood-flow frequency, revised 1981: Washington, D.C., Bulletin 17B, 183 p.

SAS Institute, Inc., 1989, SAS user's guide: Statistics, 583 p.

U.S. Department of Commerce, 1948-94, Climatological data, monthly publications for Georgia: Asheville, N.C., National Oceanic and Atmospheric Administration, National Climatic Data Center, variously paged.