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Stream-Aquifer Relations and the Potentiometric Surface of the Upper Floridan Aquifer in the Lower Apalachicola–Chattahoochee–Flint River Basin in parts of Georgia, Florida, and Alabama, 1999–2000

Water-Resources Investigations Report 02-4244

Prepared in cooperation with the
Georgia Department of Natural Resources
Environmental Protection Division
Georgia Geologic Survey

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

Cover photograph: Radium Springs, Albany, Georgia, 1995
Photograph by: Alan M. Cressler, U.S. Geological Survey

"Originally called 'Skywater' by the Creek Indians who held sacred rites on its banks and later referred to as 'Blue Springs' by early Albany residents, 'Radium Springs' got its latest name when developer Baron Collier tested the water and found trace elements of radium, thought to be a healing substance at that time. The largest natural spring in Georgia, Radium is considered one of Georgia's seven natural wonders."

(Albany [Georgia] Area Chamber of Commerce, accessed October 9, 2002, at URL *http://www.albanyga.com/cvb/history1918.html*)

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Atlanta, Georgia
2002

U.S. DEPARTMENT OF THE INTERIOR
GALE A. NORTON, Secretary

U.S. GEOLOGICAL SURVEY
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Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88). Historical data collected and stored as National Geodetic Vertical Datum of 1929 have been converted to NAVD 88 for this publication.

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ABSTRACT

The Upper Floridan aquifer is the principal source of water for domestic and agricultural use in the lower Apalachicola–Chattahoochee–Flint (ACF) River Basin. Recent drought and increased water use have made understanding surface- and ground-water relations a priority for water-resource managers in the region. From July 1999 through August 2000, less than normal precipitation reduced streamflow in the area to less than 12 percent of average mean-daily streamflow and ground-water levels reached record or near-record lows. Effects of drought on stream-aquifer interactions in the basin were evaluated using baseflow estimation, ground-water seepage calculations, and potentiometric-surface maps. Ground-water discharge to streams, or baseflow, was estimated using three methods: field measurements, hydrograph separation, and linear regression analysis. Results were evaluated seasonally—October 1999, April 2000, and August 2000—and for the period of record at four surface-water stations located on Kinchafoonee, Spring, Muckalee, and Turkey Creeks. Estimates of baseflow also were compared annually; ground-water discharge during the drought years, 1999–2000, was compared with ground-water discharge during a relatively wet year, 1994.

Hydrograph separation indicated decreased baseflow of streams as the water level in the Upper Floridan aquifer declined. Mean-annual baseflow for Kinchafoonee, Spring, Muckalee, and Turkey Creeks ranged from 36 to 71 percent of total streamflow during the period of record. In 1994 baseflow accounted for only 37 to 56 percent of total streamflow, in 1999 baseflow comprised from 60 to 73 percent of total streamflow, and in 2000 baseflow comprised from 56 to 76 percent of streamflow. The percentage of total streamflow attributed to ground water increased during the drought, whereas other components of streamflow decreased (overland flow, interflow, and channel precipitation). Even though relative ground-water contributions were increased, the volume of water discharged from the aquifer to streams decreased during the drought as the Upper Floridan aquifer water level declined. Unit-area mean-annual ground-water discharge ranged from 0.60 to 0.79 cubic foot per second per square mile ($[ft^3/s]/mi^2$) in 1994, from 0.24 to 0.58 $(ft^3/s)/mi^2$ in 1999, and from 0.13 to 0.33 $(ft^3/s)/mi^2$ in 2000. Ground-water contributions to streamflow are high in winter, when evaporative demands are low, and low in summer, when evaporative demands are high. Linear regression analysis of stream-aquifer relations in the lower ACF River Basin shows 85- or 90-percent flow durations as reasonable estimates of baseflow.

INTRODUCTION

Increased demand for and multiple uses of the limited ground- and surface-water resources in the lower Apalachicola–Chattahoochee–Flint (ACF) River Basin have become concerns for water managers at both the State and Federal levels. The lower ACF River Basin encompasses nearly 6,800 square miles (mi^2) in southwestern Georgia, northwestern Florida, and southeastern Alabama (fig.1). Previous studies have shown a close hydraulic relation between the ground- and surface-water systems of the basin (Torak and McDowell, 1995; Hicks and others, 1987). Ground-water withdrawals in the basin have lowered the water level in the Upper Floridan aquifer and resulted in reduced baseflow of streams. Downstream users—those who rely on the resource for municipal, agricultural, and industrial uses—are most affected by reductions in streamflow. Although water use in the basin has been a concern for several years, recent drought conditions have exacerbated the already limited ground- and surface-water resources and shown the complexity of stream-aquifer relations in the area. The dry or nearly dry stream conditions that occurred during recent drought conditions have focused water managers' attention on the multiple and competing uses of water resources in the basin, along with potential conflicts among users.

Because ground water is the major water source in the basin, and the potential exists for pumping-induced streamflow reduction to impact downstream users, a quantitative understanding of stream-aquifer relations is essential to effectively manage water resources in the lower ACF River Basin. In response to this need, the Georgia Department of Natural Resources, Environmental Protection Division, Georgia Geologic Survey requested that the U.S. Geological Survey (USGS) conduct an investigation to improve the understanding of stream-aquifer relations in the lower ACF River Basin and evaluate how ground-water pumping and drought conditions affect those relations.

Purpose and Scope

This report describes stream-aquifer relations in the lower ACF River Basin in southwestern Georgia and northwestern Florida by evaluating the effects of drought on the ground-water level of the Upper Floridan aquifer and ground-water discharge to (or baseflow of) streams. This description is part of a larger study to investigate hydrogeologic heterogeneity and to improve the understanding of the effects of ground-water pumping and drought on the water resources of the lower ACF River Basin. This report includes:

- ground-water seepage maps that indicate areas where streams gained or lost water as a result of surface-water interaction with the Upper Floridan aquifer during October 1999 and August 2000;
- a comparison of methods for estimating ground-water discharge (ground-water seepage) to streams; and
- potentiometric-surface maps of the Upper Floridan aquifer for October 1999 and August 2000, based on field measurements taken during those times.

Ground-water levels in wells and stream discharge measured in October 1999 and August 2000 were used to construct potentiometric-surface maps and stream seepage maps. Net gains or losses to streamflow (ground-water seepage) for the two time periods were determined along selected stream reaches to estimate the quantitative interaction between surface water and ground water. Changes in ground-water altitudes and flow directions were compared using potentiometric-surface maps. In addition, hydrograph-separation techniques and linear regression analysis were used to estimate ground-water contribution to streamflow at four streamgaging stations for normal and extreme climatic conditions. Maximum ground-water discharge to streams was estimated using streamflow during a relatively wet year, 1994. Minimum ground-water discharge was estimated using streamflow during the drought year of 1999.

Data utilized as part of this evaluation include: historical and current (1999–2000) water-level data from 324 wells, stream-discharge data from 74 streamgaging stations, ground-water discharge data from 12 springs, current precipitation data from 2 over-water weather stations on Lake Seminole, and precipitation data from the National Climatic Data Center for 2 National Weather Service weather stations located in the lower ACF River Basin.

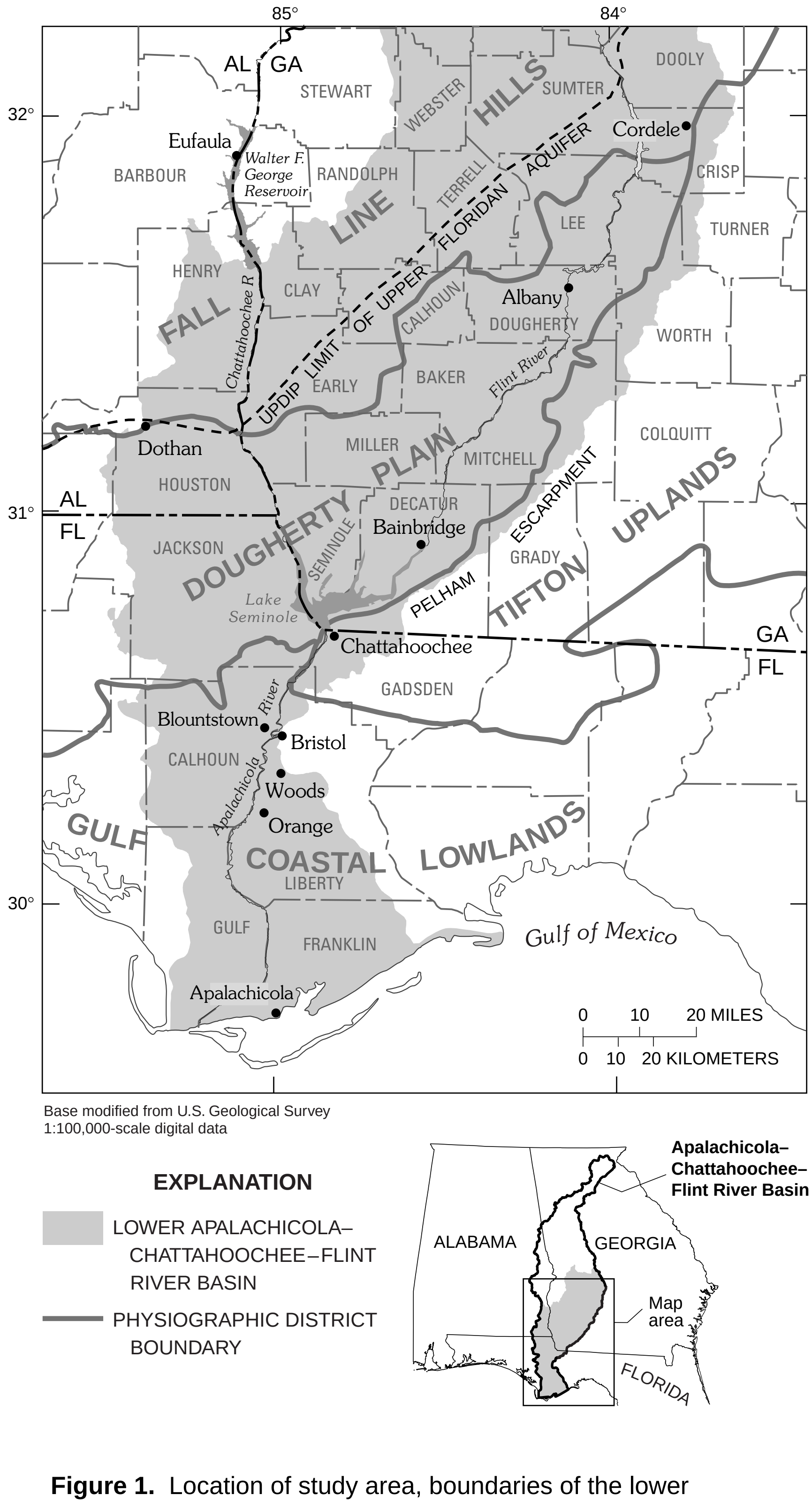


Figure 1. Location of study area, boundaries of the lower Apalachicola–Chattahoochee–Flint River Basin, and physiographic districts of the Coastal Plain Province (modified from Torak and other, 1996).

Description of Study Area

The 6,800-mi^2 study area includes Lake Seminole and the land area that contributes ground- and surface-water flow into and out of the lake (fig.1). In Georgia, the study area includes all or parts of Baker, Calhoun, Crisp, Decatur, Dougherty, Early, Lee, Miller, Mitchell, Randolph, Seminole, Sumter, Terrell, and Worth Counties. In Florida, the study area includes all or parts of Gadsden and Jackson Counties. In Alabama, the study area includes part of Houston County.

Physiography

The lower ACF River Basin lies within the Coastal Plain physiographic province in southwestern Georgia, northwestern Florida, and southeastern Alabama and is drained by the Apalachicola, Chattahoochee, and Flint Rivers and their tributaries (Torak and others, 1996) (fig. 1). The northern extent of the study area is in the Fall Line Hills district near the updip limit of the Ocala Limestone (Clark and Zisa, 1976). The Fall Line Hills district is highly dissected, with steep slopes, and streams that are from about 50 to 250 feet (ft) below adjacent ridges. Relief diminishes gradually where the Fall Line Hills district grades into the Dougherty Plain (Torak and others, 1996).

The Dougherty Plain is a nearly level lowland that ends where the Fall Line Hills district and Tifton Uplands meet (Clark and Zisa, 1976). Formed by erosion, land-surface altitude ranges from about 300 ft at the northern extent of the plain to about 77 ft at Lake Seminole. Relief in the Dougherty Plain rarely exceeds 20 ft, and slopes average about 5 ft per mile (Hicks and others, 1987). Karst topography and solution and erosional features define the landscape of the Dougherty Plain. Continual formation of sinkholes, the bottoms of which are filled with low-permeability sediment and hold water year round, is responsible for the development of the numerous ponds and wetlands characteristic of the region. Underground channels formed from active dissolution of the Ocala Limestone commonly capture surface water; these underground channels account for a significant percentage of drainage in the Dougherty Plain (Hicks and others, 1987).

To the east, a well-defined northwest-facing feature called the “Pelham Escarpment,” which forms a prominent regional boundary between the Tifton Upland and the Dougherty Plain, borders the basin (Hicks and others, 1987). The crest of the Pelham Escarpment forms a topographic and surface-water divide between the Flint River to the west and the Ochlockonee and Withlacoochee Rivers to the east (Torak and others, 1996). In northwestern Florida, the Tifton Uplands are termed the Tallahassee Hills, in which the southern limit of the study area is located. Land-surface altitude in that area ranges from about 330 ft near the Georgia-Florida State line to about 100 ft south of the study area.

Hydrogeologic Setting

Pre-Cretaceous to Quaternary sediments underlie the Coastal Plain physiographic province. In the study area, these sediments consist of alternating sand, clay, dolomite, and limestone, which dip gently and thicken to the southeast (Hicks and others, 1987). The Dougherty Plain is characterized by a highly transmissive ground-water flow system, developed through solutioning and karst processes in the Ocala Limestone, which is the main water-bearing unit of the Upper Floridan aquifer. This flow system is characterized by high rates of direct recharge through sinkholes, indirect recharge by vertical leakage through the overburden, and discharge to surface-water bodies such as the Flint and Chattahoochee Rivers (Torak and others, 1996). The ability of geologic units to function as an aquifer, transmit usable amounts of ground water, or provide leakage of water between aquifers and surface water is determined, in part, by the varying hydrologic characteristics of thickness and hydraulic conductivity.

The vertical and areal distribution of the Upper Floridan aquifer adds complexity to the dynamics of stream-aquifer interactions. The Upper Floridan aquifer ranges in thickness from a few feet at its updip limit to greater than 700 ft in Florida, and generally is exposed along major river reaches where erosion has removed the overburden. Dissolution of limestone by fluctuating ground-water levels and infiltrating rainfall have produced secondary permeability in the Ocala Limestone, making the aquifer extremely productive. Solution conduits between the Pelham Escarpment and the Flint River transmit large amounts of ground water from the Upper Floridan aquifer to springs that discharge along streams. The relative rate at which ground water moves through the aquifer is determined by the hydraulic gradient and the amount of solutioning and connectivity of conduits, which result in aquifer transmissivity of 2,000–300,000 feet squared per day (ft^2/d); transmissivity is lower at the updip limit of the Ocala Limestone, where the aquifer is relatively thin, and increases southward as the aquifer thickens (Hicks and others, 1987).

Throughout much of the study area, the Upper Floridan aquifer is unconfined or semiconfined, and ground-water discharge mainly is by springflow and seepage to surface-water bodies (Johnston and Bush, 1988). Because of the connectivity between the Upper Floridan aquifer and surface-water features, only the Ocala Limestone and younger units were considered important to stream-aquifer relations in the study area. Included are sediments of late Eocene age and younger—which, in ascending order, are the Lisbon Formation, Clinchfield Sand, Ocala Limestone, Suwannee Limestone, Tampa Limestone, Hawthorn Group, Miccosukee Formation, and terrace and undifferentiated deposits (fig. 2). Details about these geologic units are contained in Hayes and others (1983), Miller (1986), Hicks and others (1987), Bush and Johnston (1988), Torak and others (1996), and Torak and McDowell (1995).

Ground-Water Level

The ground-water level in the Upper Floridan aquifer fluctuates seasonally in response to recharge from precipitation, discharge from pumping, evapotranspiration, interaction with surface-water features, and periods of reduced precipitation and drought. Water level is highest during winter and spring and lowest during summer and fall. Generally, recharge begins in early winter, and the water level rises quickly in response to precipitation. During late spring and early summer, the water level declines in response to increased agricultural water use (pumping) and evapotranspiration. These factors also contribute to decreased water-level response to precipitation by reducing infiltration. Seasonal ground-water-level fluctuations range from 2 ft to nearly 30 ft (fig. 3). The ground-water level in the overlying semiconfining units is similarly affected by seasonal fluctuations and also may be affected by changes in river stage.

Although withdrawals from the Upper Floridan aquifer have averaged about 66 million gallons per day (Mgal/d) for more than 30 years, the aquifer has remained in equilibrium; recharge to the aquifer from normal annual precipitation is equal to discharge from both natural and human-induced conditions (Hicks and others, 1987). In areas where the overlying semiconfining unit of the aquifer is thin or absent, the water level in the aquifer responds considerably to climatic conditions, declining rapidly during drought and recovering quickly during wet conditions. During the drought years of 1980–1981, water levels in wells in the Dougherty Plain declined to record or near-record lows; but with the return of normal precipitation, water levels recovered to pre-drought conditions (Hicks and others, 1987). Ground-water levels again declined to record or near-record lows during 1999–2000 in response to drought and pumping (fig. 3).

SERIES	GEORGIA		
	GEOLOGIC UNIT		HYDROLOGIC UNIT
HOLOCENE AND PLEISTOCENE	Terrace and undifferentiated deposits		Semiconfining unit
MIOCENE	Undifferentiated overburden (residuum)	Miccosukee Formation	
		Hawthorn Group	
		Tampa Limestone	Upper Floridan aquifer
		Suwannee Limestone	
EOCENE	Ocala Limestone		
		Clinchfield Sand	
	Lisbon Formation		Lower confining unit

Figure 2. Geologic and hydrologic units in the lower Apalachicola–Chattahoochee–Flint River Basin (from Torak and others, 1996).

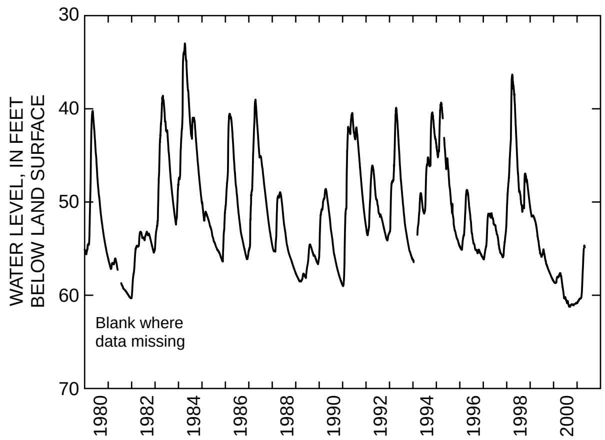


Figure 3. Water-level fluctuations in well 10G313 in the Upper Floridan aquifer, 1980–2001 (see plate 1 for location of well).

Climate

The climate of the study area is humid subtropical. The mean-annual temperature for a 43-year period (1959–2001) at Arlington, Georgia, is about 66.7 degrees Fahrenheit (ºF) (table 1; see plate 1 for location). The coldest months, December and January, average about 51.3ºF; occasional freezing temperatures occur during this time. During the warmest months of July and August, the average temperature is about 81.1ºF; however, temperatures near 100ºF and above are not uncommon. Average annual rainfall at Arlington, is about 53.9 inches; highest monthly rainfall occurs in March; lowest monthly rainfall occurs in October (Georgia Automated Environmental Monitoring Network, 2002).

Previous Investigations

Several hydrogeologic investigations have been conducted in the study area. Sever (1965) described the hydrogeology in Decatur, Grady, and Seminole Counties, Georgia, and the water resources of the area surrounding Lake Seminole. Hayes and others (1983) described the hydrology of the Upper Floridan aquifer in the Dougherty Plain. Miller (1986) delineated the hydrogeologic framework of the Floridan aquifer system in parts of Alabama, Florida, Georgia, and South Carolina. Hicks and others (1987) investigated the hydrogeology, water quality, and availability of water in the Upper Floridan aquifer near Albany, Georgia. Johnston and Bush (1988) summarized the hydrology of the Floridan aquifer system. Bush and Johnston (1988) evaluated the ground-water hydraulics, regional flow, and ground-water development potential of the Floridan aquifer system in parts of Florida, Georgia, Alabama, and South Carolina. Torak and others (1993) evaluated the geohydrology and water-resource potential of the Upper Floridan aquifer in the Albany area, Dougherty County, southwest Georgia. Torak and McDowell (1995) and Torak and others (1996) evaluated the hydrogeology and ground-water resources in the lower ACF River Basin. Stewart and others (1999) also completed an investigation of water quality and hydrogeology of the Upper Floridan aquifer near Albany, Georgia. Results of selected investigations in the study area in Florida include reports by Vernon and others (1958) describing the geology of the area near Lake Seminole and Pratt and others (1996) describing the hydrogeology of the Northwest Florida Water Management District, which includes the study area in Florida. Albertson (2001), Mosner (2001), and Torak (2001) discussed the hydrogeology, water chemistry, and stream-aquifer relations, respectively, in the lower ACF River Basin, near Lake Seminole in southwestern Georgia and northwestern Florida.

Table 1. Climate data for Arlington, Calhoun County, Georgia, 1959–2001
[°F, degrees Fahrenheit; data from Georgia Automated Environmental Monitoring Network (2002)]

Month	Temperature (°F)[a]		Average precipitation (inches)
	Average maximum	Average minimum	
January	61.9	38.1	5.37
February	65.5	40.8	4.92
March	72.5	46.9	6.09
April	80.4	53.8	3.79
May	86.2	60.6	3.65
June	90.7	67.6	5.10
July	92.3	70.3	4.96
August	91.8	69.8	4.80
September	88.5	65.8	3.84
October	80.6	54.7	2.65
November	72.1	46.0	3.15
December	64.9	40.1	5.61
MEAN	**78.9**	**54.5**	**TOTAL 53.9**

a. Mean-annual temperature, 66.7°F.

Well- and Stream-Numbering Systems

In this report, wells are identified in two ways, a numbering system based on USGS topographic maps and a numbering system developed by the Northwest Florida Water Management District. In Georgia, each 7 1/2-minute topographic quadrangle map has been given a number and letter designation beginning at the southwestern corner of the State. Numbers increase eastward through 39 and letters increase alphabetically northward through “Z” and then become double-letter designations “AA” through “PP.” The letters “I,” “O,” “II,” and “OO” are not used. Wells inventoried in each quadrangle are numbered sequentially beginning with “1.” Thus, the third well inventoried in the Chattahoochee quadrangle (map 06D) is designated 06D003. Springs are considered ground-water sites and are identified in the same manner as wells. In Florida, the Northwest Florida Water Management District inventories wells using a numbered identification system; each well is assigned a four-digit identifier, for example 1640. Surface-water stations are identified by a numbering system used for all USGS reports and publications since October 1, 1950. The order of listing stations is in a downstream direction along the main channel. All stations on a tributary entering upstream from each mainstream are listed prior to that station. Each surface-water station is assigned a unique 8- to 14-digit number. Each station number, such as 02351890, begins with the 2-digit identifier “02,” which designates it as being a surface-water station, followed by the downstream-order number, “351890,” which can range from 6 to 12 digits.

Acknowledgments

The author extends appreciation to the many agencies that contributed to the collection of data used in this report, including the Northwest Florida Water Management District and the U.S. Army Corps of Engineers. Gratitude is extended to all landowners and land managers who allowed access to wells and springs to collect water-resource data.

METHODS

Stream-aquifer relations were evaluated using existing hydrogeologic data, measurements of ground-water levels, stream and spring discharge, and climatological data. Field measurements of ground-water levels in wells and stream and spring discharge were collected during October 1999 and April and August 2000. Data were collected from 324 wells (Appendix A), 74 streamgaging stations (Appendix B), and 12 springs (Appendix C) (plate 1). Ground-water levels were measured using a steel tape or an airline in wells so equipped. Streamflow was measured using conventional methods such as stream discharge and stage measurements, and acoustic Doppler current profiling. Land-surface altitude at wells was obtained using two methods, surveying and interpolation by plotting locations from global-positioning-system coordinates on 7 1/2-minute USGS topographic maps. Wells and streamgaging stations located on topographic maps are estimated to be accurate to within 40 ft; land-surface altitudes are estimated to be accurate to within 5 ft. Precipitation data were collected at two over-water weather stations on Lake Seminole and were obtained from the National Climatic Data Center for two National Weather Service weather stations located in Cordele and Bainbridge, Georgia (plate 1). Water-level data collected from wells and stream-stage measurements at streamgaging stations were used to construct water-level-altitude maps of the Upper Floridan aquifer in the lower ACF River Basin for October 1999 and August 2000. Ground-water seepage maps were constructed by calculating the difference in streamflow between streamgaging stations. These maps were used to identify reaches where ground water discharges to streams, or where streams recharge the aquifer. Net stream gains or losses were calculated between streamgaging stations, and losing and gaining stream reaches were identified using these calculations.

Estimation of Ground-Water Seepage

During periods of little or no rainfall, it is assumed that baseflow is composed entirely of ground-water discharge to the stream (ground-water seepage). Therefore, during the study period—October 1999–August 2000—techniques used to estimate baseflow also result in reasonable estimates of ground-water seepage. Three methods of estimating ground-water seepage are compared in this report: field measurements, hydrograph separation, and linear regression analysis. Ground-water level and surface-water discharges measured in October 1999, April 2000, and August 2000 were used to calculate ground-water seepage along stream reaches. These results were compared with quantitative estimates of ground-water seepage from long-term data.

Hydrograph separation was performed to evaluate the seasonality of ground-water seepage. The USGS computer program HYSEP (Sloto and Crouse, 1996), which modifies the methodology described by Pettyjohn and Henning (1979), was used for hydrograph separation. HYSEP uses one of three methods—fixed-interval, sliding-interval, or local-minimum—to perform a separation. Each method employs an algorithm that systematically separates baseflow (ground-water seepage) from runoff by connecting low points on the streamflow hydrograph (Sloto and Crouse, 1996). The duration of surface-water runoff is equivalent to the relation:

$$N=A^{0.2},$$

where N is the number of days for cessation of runoff, and A is drainage area of the basin. All three methods are an algorithm based on the interval 2N*, which is the odd integer between 3 and 11 that is nearest to 2N (Pettyjohn and Henning, 1979).

- For the fixed-interval method, the lowest discharge in the 2N* interval is assigned to each day in that interval.
- For the sliding-interval method, the lowest discharge in the days prior to and after the interval 2N* is assigned, using the relation, 0.5(2N*-1); intervals may overlap using this method.
- For the local-minimum method, the lowest discharge in the days prior to and after the interval 2N* also is assigned using the relation 0.5(2N*-1); however, the intervals do not overlap.

Four sites—Kinchafoonee Creek, Muckalee Creek, Spring Creek, and Turkey Creek (table 2)—were selected to compare results for each method of determining ground-water seepage or baseflow separation. Field measurements at each site were divided by the basin area, yielding estimates of unit-area ground-water discharge, expressed as cubic foot per second per square mile ($[ft^3/s]/mi^2$). Estimates calculated from hydrograph separation and linear regression analysis also were converted to unit-area discharge and compared with field measurements.

Table 2. Streamgaging stations used for hydrograph separation and flow-duration analyses in the lower Apalachicola–Chattahoochee–Flint River Basin

Station number	Station name	Drainage area (square miles)	Period of record analyzed
02349900	Turkey Creek at Byromville, Ga.	45	1959–2000
02350600	Kinchafoonee Creek at Preston, Ga.	197	1905–1913, 1931–2000
02351890	Muckalee Creek at Ga. 195, near Leesburg, Ga.	362	1981–2000
02357000	Spring Creek near Iron City, Ga.	485	1938–2000

A plot showing all three methods of hydrograph separation for the gage at Turkey Creek near Byromville, Georgia, indicates the fixed-interval and sliding-interval methods are biased toward baseflow; thus, overpredict ground-water contribution to streamflow, or baseflow (fig. 4). For this reason, the local-minimum method was used to estimate baseflow, or ground-water seepage. This method determines that if the discharge on a particular day is the lowest discharge in 0.5(2N*-1) days before and after that day, then that discharge is the local minimum. A straight line connects local minima, and baseflow between local minima is linearly interpolated.

Stream reaches that are free of impoundments that regulate surface runoff, lack direct spring discharge, and are characterized by normal streamflow distributions are most acceptable for hydrograph-separation techniques. Since extreme climatic conditions during the short term also may bias baseflow estimation, mean-annual average estimates are more reliable than monthly or daily average estimates.

Linear regression analysis was used to determine the flow duration that best estimates baseflow of streams in the study area. Linear regression analysis, however, is limited to specific hydrogeologic settings, as the setting influences the amount of infiltration and subsequent discharge to streams (White and Sloto, 1990). For instance, baseflow of streams in the glacial till/outwash of Long Island can be estimated from the 50-percent flow duration; whereas in the Cretaceous aquifers of southwest Georgia, baseflow is estimated to be in the 60–65-percent flow-duration range. Mean-annual baseflow for 16 sites in the lower ACF River Basin was compared to flow durations ranging from Q_1 to Q_{99} (that is, streamflows that are equaled or exceeded from 1 percent to 99 percent of the time, respectively) to derive a flow duration that is representative of baseflow. This flow duration then can be applied to all streams in the basin to estimate baseflow for any time interval, even daily.

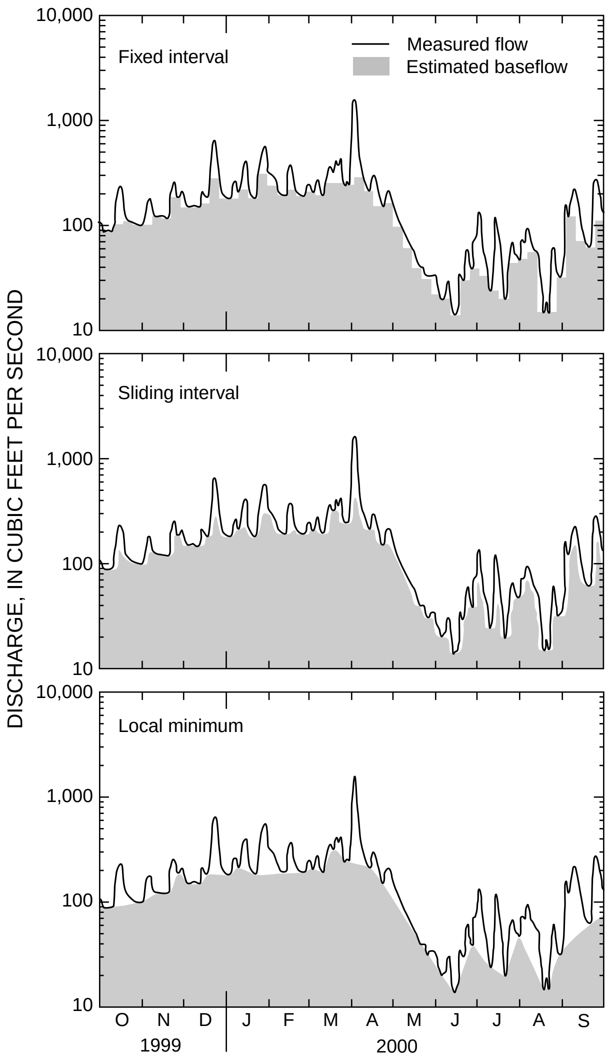


Figure 4. Differences in baseflow separation among the fixed-interval, sliding-interval, and local-minimum methods of HYSEP (from Sloto and Crouse, 1996).

Precipitation Trends

Precipitation data for Cordele and Bainbridge, Georgia, were evaluated to estimate how variations in long-term precipitation affects ground-water recharge, fluctuations in streamflow, and ground-water levels throughout the basin. The cumulative departure from normal monthly precipitation for 1949–1999 was computed by adding successive monthly departures and plotting the result to illustrate seasonality and long-term effects of wet and/or dry conditions (fig. 5). Cordele is located in the extreme northern part of the basin; and Bainbridge is in the southern part of the basin, near Lake Seminole (plate 1). Daily precipitation data for both sites were obtained from the National Climatic Data Center for the period October 1949–September 1999.

The monthly departure from normal rainfall for the period 1949–1999 was used to evaluate precipitation trends (fig. 5). Above-average precipitation is represented graphically by a positive slope, and below-average precipitation by a negative slope (Atkins and others, 1996). During 1949–1999, precipitation at Cordele and Bainbridge was highly variable. Although both sites had a cumulative deficit for most of the period, a relatively wet period in the early 1990s resulted in a surplus of rainfall by 1998. For example, Bainbridge was 23 inches above normal rainfall and Cordele was 8 inches above normal by the end of 1998. The onset of drought in the late 1990s, however, reduced this surplus; and by September 1999, the surplus was eliminated. Although the drought, which began in 1998, is not yet as severe as previous droughts (fig. 5), the spatial extent of the drought throughout the state has led to substantially reduced streamflow in the Dougherty Plain.

STREAM-AQUIFER RELATIONS

During normal conditions, recharge of the Upper Floridan aquifer by rainfall and ground-water discharge to stream channels is in equilibrium (Hicks and others, 1987; Stewart and others, 1999). However, drought conditions during 1999–2000 reduced overland runoff, and stream discharge was derived largely from baseflow (table 3). In addition, the water level in the Upper Floridan aquifer declined in response to decreased recharge and increased pumping. In the northeastern part of the study area, some streams had losing reaches when the water level in the aquifer declined beneath the stream stage and became dry as the water level in the aquifer declined beneath the stream channel. The aquifer is thin in the northeast, and transmissivity is less than 10,000 ft^2/d, retarding vertical ground-water flow between the aquifer and the stream channel (Johnston and Bush, 1988). Conversely, the aquifer is thick and unconfined to the south and east, and the resulting transmissivity ranges from 10,000 to 1,000,000 ft^2/d (Johnston and Bush, 1988). Under these conditions during the study period, streams were gaining, and ground-water discharge was the major component of baseflow. In the southern part of the study area, the potentiometric surface of the aquifer was higher than the altitude of the stream channel and the aquifer continued to discharge water into streams.

Ground-water discharge to streams in the lower ACF River Basin was highly variable during the study period. Ground-water seepage maps illustrate relative gains and losses along stream reaches in response to changes in runoff and ground-water discharge during drought conditions (figs. 6–8). On these maps, losing stream reaches are identified by hachures. Stream sections with a small basin area lost water to the aquifer more often than larger stream sections. In October 1999, several stream reaches with small drainage areas recharged the aquifer; however, a large section of the Flint River, from south of Montezuma to Warwick, Georgia, also lost water to the aquifer (fig. 6). In April and August 2000 only sections of streams in smaller basins recharged the aquifer (figs. 7 and 8, respectively).

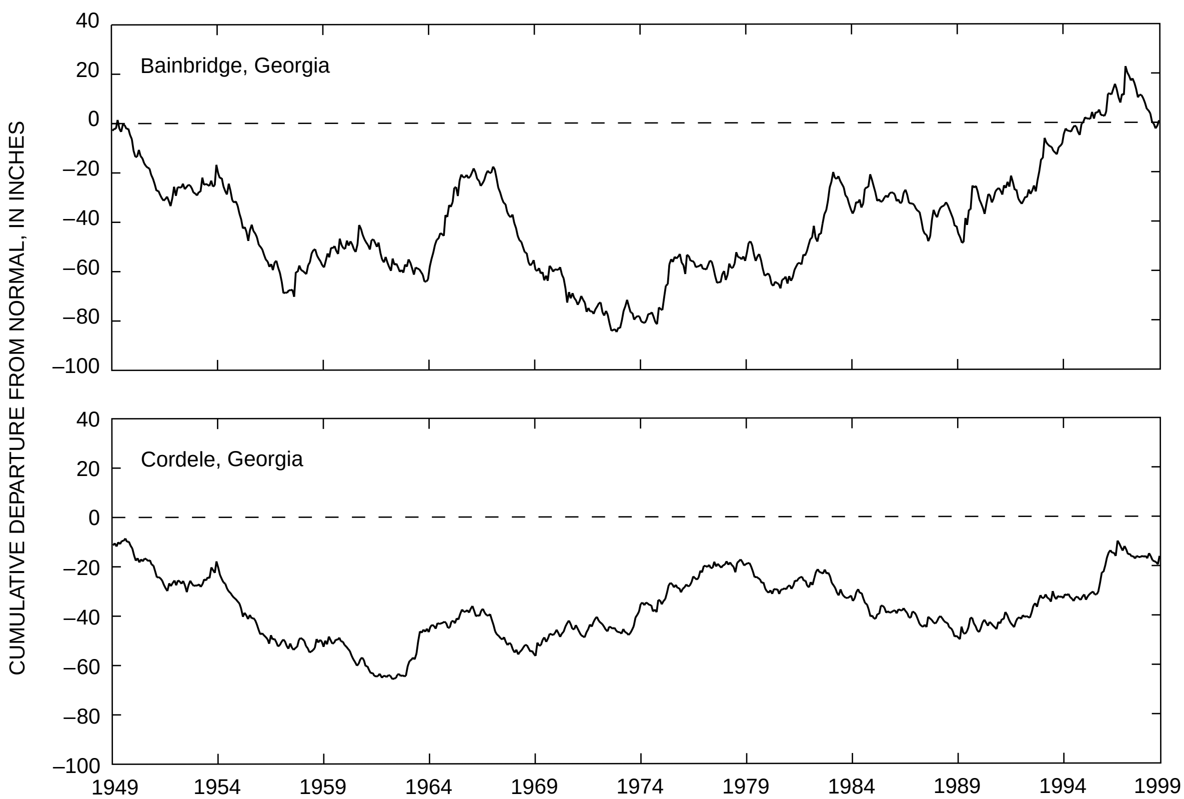


Figure 5. Cumulative departure from normal precipitation for selected sites in the lower Apalachicola–Chattahoochee–Flint River Basin, Bainbridge and Cordele, Georgia, October 1949–September 1999.

Table 3. Mean-annual streamflow and unit-area discharge of selected streams in the lower Apalachicola–Chattahoochee–Flint River Basin for relatively wet conditions of 1994 and drought conditions of 1999 and 2000
[ft^3/s - cubic foot per second; $(ft^3/s)/mi^2$ - cubic foot per second per square mile]

Station name and number	Mean-annual streamflow (ft^3/s)	Mean-annual percent baseflow	1994			1999			2000		
			Discharge (ft^3/s)	Percent as baseflow	Estimated unit-area discharge ($[ft^3/s]/mi^2$)	Discharge (ft^3/s)	Percent as baseflow	Estimated unit-area discharge ($[ft^3/s]/mi^2$)	Discharge (ft^3/s)	Percent as baseflow	Estimated unit-area discharge ($[ft^3/s]/mi^2$)
Turkey Creek at Byromville, Ga. 02349900	23	54	27	37	0.60	11	60	0.24	9	56	0.20
Kinchafoonee Creek at Preston, Ga. 02350600	136	67	144	56	.73	114	70	.58	64	66	.33
Muckalee Creek at Ga. 195, near Leesburg, Ga. 02351890	247	63	287	44	.79	213	73	.58	116	66	.32
Spring Creek near Iron City, Ga. 02357000	313	65	329	48	.68	257	67	.53	62	76	.13

A detailed description of streamflows for sections of Muckalee Creek and Spring Creek during October 1999 and August 2000 shows the variability and effects of drought on streamflows. Muckalee Creek, located in the northeastern part of the study area, lost water to the aquifer during October 1999 and August 2000 (fig. 9). In October 1999, the reach between the gage near State Highway 195 and the gage near Leesburg, Georgia, lost 2 cubic feet per second (ft^3/s) of flow; but farther downstream, between the gage near Leesburg and the gage downstream of Leesburg, the reach lost 23 ft^3/s (fig. 9A). In August 2000, the gage located between State Highway 195 and the Leesburg gage lost 9 ft^3/s to the aquifer (fig. 9B). Spring Creek, between Colquitt and Iron City, Georgia, was a losing reach in October 1999, drying to no flow at the Iron City gage; but farther downstream at Brinson, Georgia, the reach gained 88 ft^3/s from the aquifer (fig. 10A), presumably from springs discharging along the channel and from diffuse ground-water leakage into the channel. As the drought became more severe in August 2000, the same trend was apparent as that observed in October 1999, with Spring Creek losing water between Colquitt and Iron City and gaining between Iron City and Brinson. However, the magnitude of gain or loss was greatly reduced in August 2000 because of drought effects, when compared to the trends exhibited in October 1999. By August 2000, declining water level in the aquifer resulted in 0.22 ft^3/s lost to the aquifer between Colquitt and Brinson (fig. 10B).

Monthly baseflow estimates computed using HYSEP (Sloto and Crouse, 1996) illustrate the effects of drought on the relative contributions of runoff and baseflow to total streamflow (table 4). Estimates of baseflow generally are greater than runoff for the selected sites in the lower ACF River Basin, as indicated by baseflow comprising more than 50 percent of total streamflow (table 4). Occasionally, the flashy nature of streams in the study area combined with the high intensity of rainfall during summer storms will cause runoff to exceed baseflow (table 4; fig. 11).

Drought conditions increase the percentage of baseflow that contributes to total streamflow because surface-water runoff is reduced or absent. As a result, streams require ground-water discharge to maintain flow conditions. As ground-water levels declined to near-record or record lows throughout the lower ACF River Basin during August 2000, the hydraulic gradient to streams decreased, and for some reaches was reversed. This, in turn, reduced discharge to streams and, in some cases, resulted in losing or dry stream reaches.

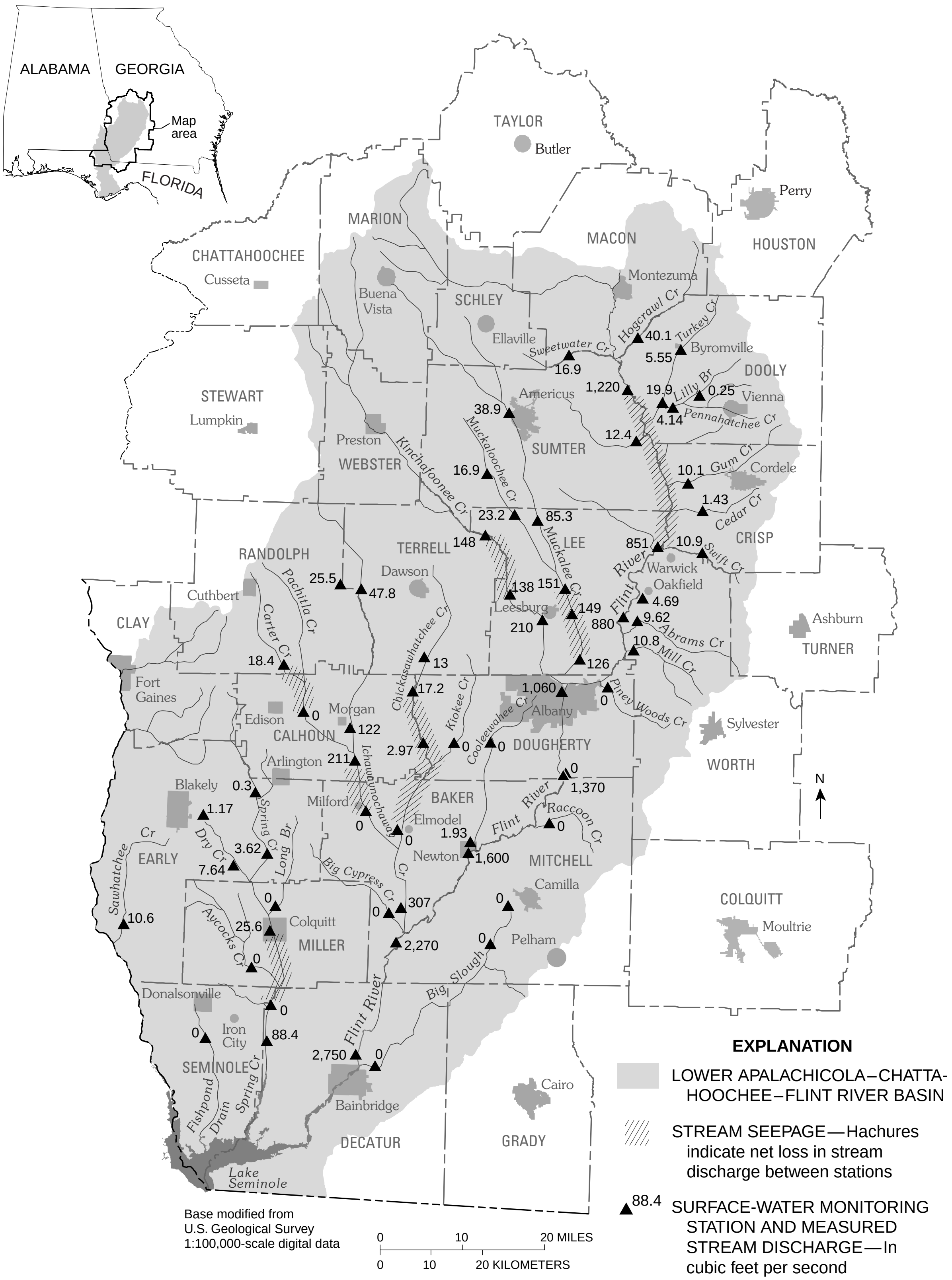


Figure 6. Stream seepage along selected stream reaches in the lower Apalachicola–Chattahoochee–Flint River Basin, October 1999.

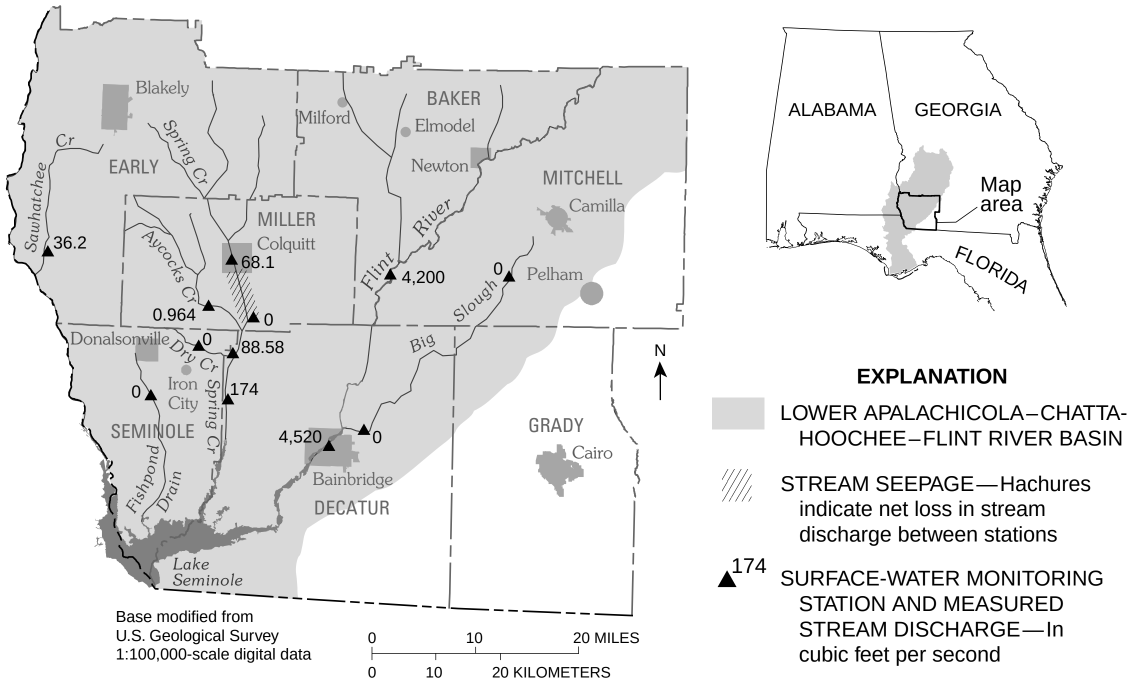


Figure 7. Stream seepage along selected stream reaches in the lower Apalachicola–Chattahoochee–Flint River Basin, April 2000.

Table 4. Mean-annual percentage of total streamflow that is baseflow, by month, in selected streams in the lower Apalachicola–Chattahoochee–Flint River Basin, 1980–2000

Station name and number	Percent of mean-annual streamflow comprised of baseflow											
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep
Spring Creek near Iron City, Ga. 02357000	57	70	66	63	65	61	63	68	68	64	64	64
Muckalee Creek at Ga. 195, near Leesburg, Ga. 02351890	68	70	68	64	60	62	67	59	57	37	60	60
Kinchafoonee Creek at Preston, Ga. 02350600	71	71	64	65	66	62	66	63	68	57	68	65
Turkey Creek at Byromville, Ga. 02349900	64	61	53	55	56	55	54	52	46	36	50	61

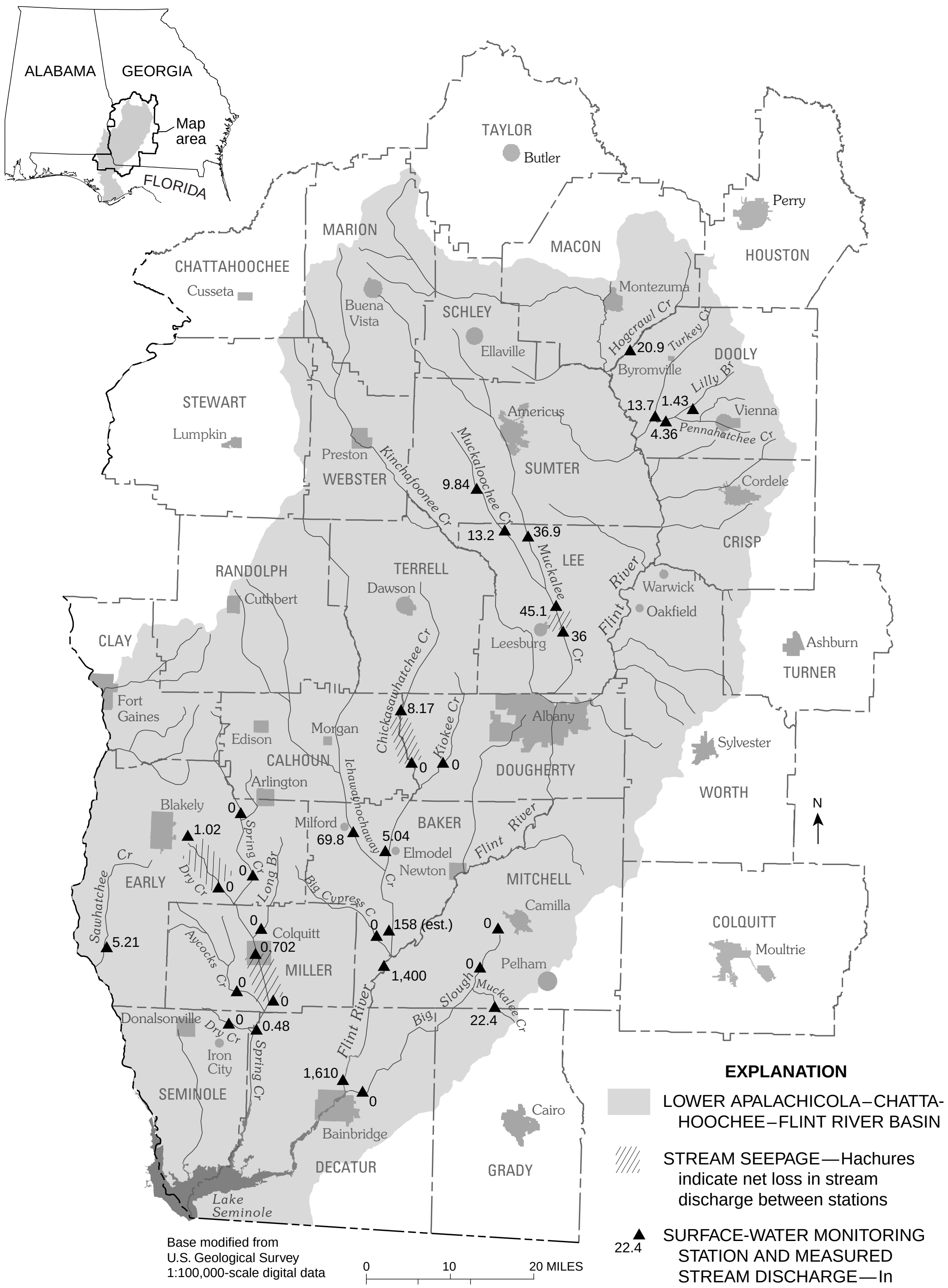


Figure 8. Stream seepage along selected stream reaches in the lower Apalachicola–Chattahoochee–Flint River Basin, August 2000.

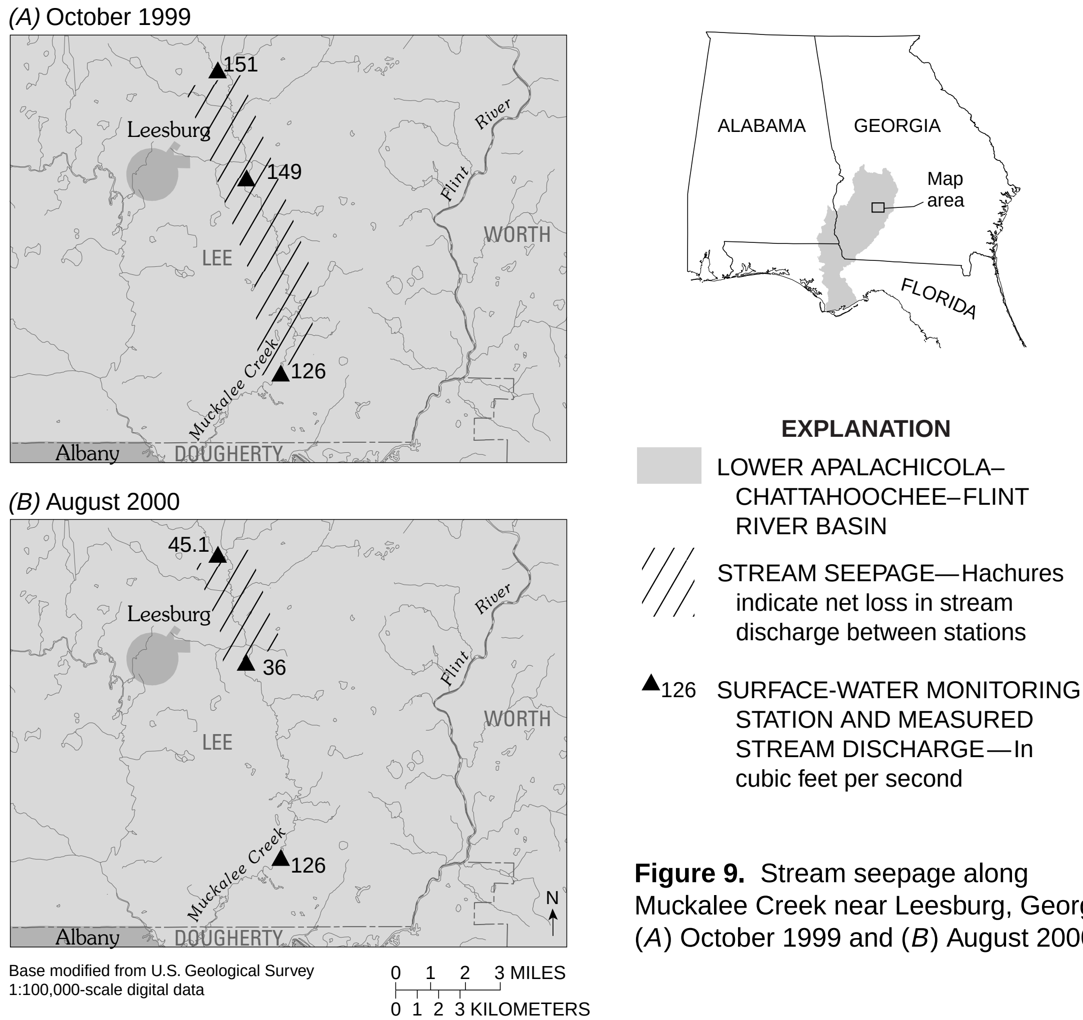
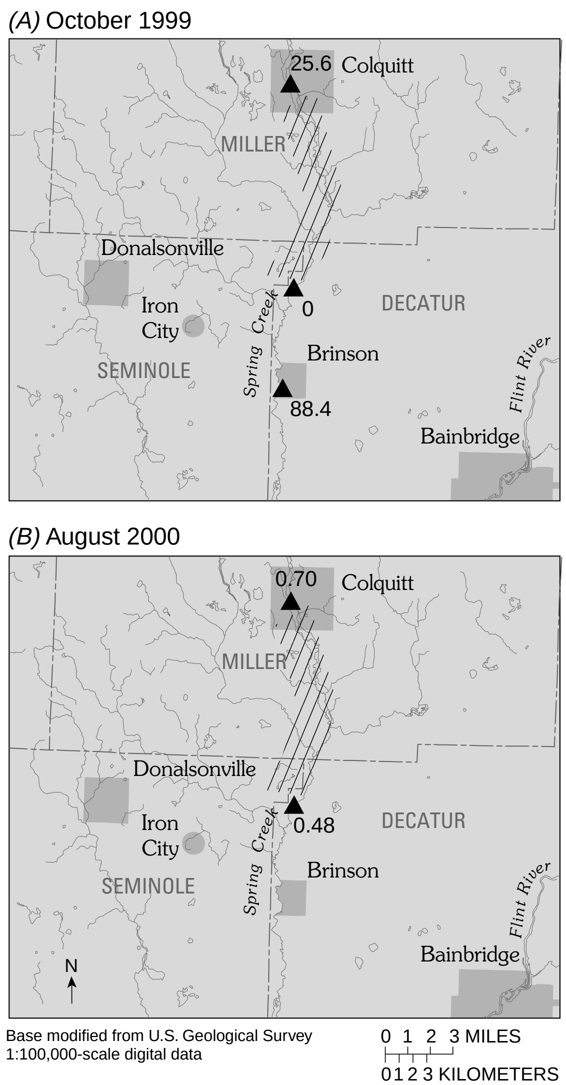


Figure 9. Stream seepage along Muckalee Creek near Leesburg, Georgia, (*A*) October 1999 and (*B*) August 2000.

Conceptual Model of Stream-Aquifer Flow System

The conceptual model of the hydrologic flow system (fig. 12) is based on previous works by Sever (1965), Hayes and others (1983), Miller (1986), Johnston and Bush (1988), Hicks and others (1987), Torak and McDowell (1995), Torak and others (1996), and Stewart and others (1999). These studies suggest that recharge to the Upper Floridan aquifer is mainly by infiltrated precipitation, especially in outcrop areas near the updip limit of the limestone units and in river valleys, where the overburden has been eroded away, leaving the limestone exposed at the land surface. The Upper Floridan aquifer is semiconfined above by an undifferentiated overburden of sand, silt, and clay, which at times can support a water table and slow the flow of water to the Upper Floridan aquifer; but often, flow from the overburden to the aquifer is relatively rapid. Regional ground-water flow is northwest to southeast; and near streams, discharge is toward the stream channel.

Although the lithology of the Upper Floridan aquifer indicates the potential for direct hydraulic connection between the aquifer and surface-water features, sudden changes in river stage do not necessarily correspond to a rise in the ground-water level (Torak and others, 1996). When the ground-water level is higher than that of the stream stage, the Upper Floridan aquifer discharges to the stream. Conversely, when the ground-water level is lower than that of the stream stage, the stream may discharge water to the aquifer. This relation depends on the hydraulic gradient between the aquifer water level and stream stage, and the permeability of the streambed in areas of diffuse discharge (Hicks and others, 1987).



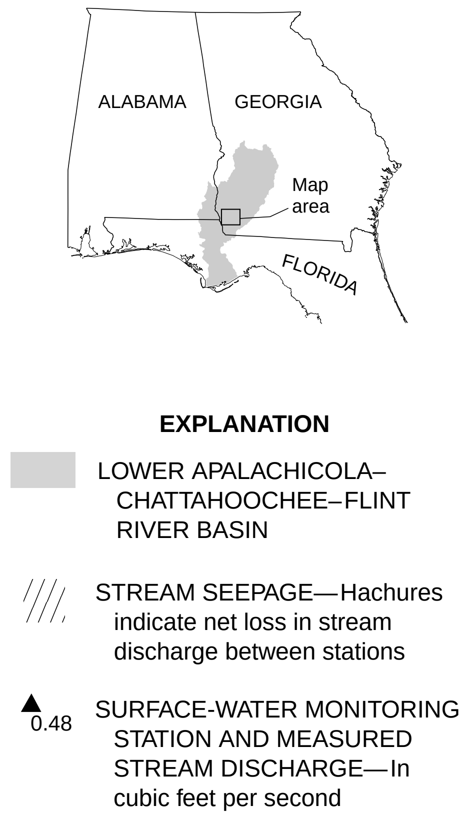


Figure 10. Stream seepage along Spring Creek between Colquitt and Brinson, Georgia, (*A*) October 1999 and (*B*) August 2000.

Ground-Water Contribution to Streamflow (Baseflow)

Baseflow is that part of streamflow contributed solely by ground-water discharge. Baseflow of all streams in the study area is maintained by ground-water discharge from the Upper Floridan aquifer. In winter, the ground-water level in the Upper Floridan aquifer is high and ground water discharges to streams, resulting in high baseflow. As the ground-water level declines during late spring through fall, so does baseflow (fig. 13). During the 1986 drought, streamflow (baseflow) was reduced substantially but recovered quickly with the return of normal precipitation in the early 1990s.

The extended drought of 1998–2000 reduced streamflow to record or near-record lows; in southwest Georgia, streamflow was less than 12 percent of normal (mean-annual) flow (fig. 14A, B). In May 2000, drought conditions continued and streamflow conditions decreased to 12–24 percent of normal streamflow, with some areas as low as 1–12 percent (fig. 14A). By August 2000, streamflow in almost the entire study area decreased to 1–12 percent of normal streamflow (fig. 14B). By April 2001, streamflow had returned to normal conditions throughout much of the State; but drought conditions returned in late spring and early summer 2001, and streamflow was once again below normal flow conditions (U.S. Geological Survey, Georgia Drought Watch, 2002).

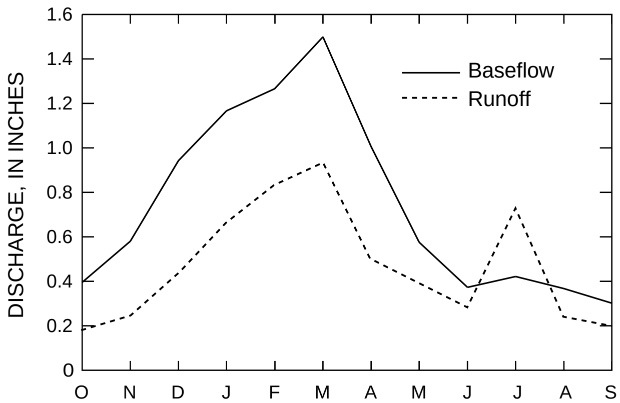


Figure 11. Mean-monthly baseflow and runoff for Muckalee Creek, Georgia, 1980–2000.

The ratio of 1999 mean-annual streamflow to long-term runoff indicates drought conditions as compared with normal streamflow conditions (fig. 14C). Although drought conditions during 1998–2000 had little affect on the long-term runoff of the lower ACF River Basin, streamflows were reduced by as much as 99 percent (fig. 14A, B). When streamflows are reduced, the ratio between streamflow and long-term runoff increases (fig. 14C), and the areas with the greatest reduction in streamflow also showed the highest ratios of long-term runoff to streamflow. A high ratio indicates that to maintain normal streamflow conditions, contributions from sources other than ground-water discharge are present—including direct precipitation and, consequently, runoff. Decreased precipitation and runoff during the drought result in ground-water discharge to streams becoming the principal component of streamflow. During the drought, however, the ground-water level also declined, reducing ground-water discharge to stream channels, which further reduced streamflow.

The distribution of mean-daily streamflow at selected sites in the study area indicates low-flow conditions during most of 1999–2000 (fig. 15). Median streamflow in 2000 was well below mean-annual streamflows at each station, having a record in 2000, and even lower than those during the drought of 1986, with the exception of Kinchafoonee Creek near Preston, Georgia. Box plots were used to illustrate the range of daily values in recent years and identify years that represent high and low daily streamflow conditions (fig. 15). Plotting the October 1999 and April and August 2000 estimated baseflows allows comparison to mean-daily streamflow ranges. Baseflow measurements were below median streamflow in each year of available data (1980–2001) except for the drought year of 2000, during which April streamflows were at or above median streamflows for each streamgaging station, due to precipitation events. August 2000 streamflows were consistently at or near the lower extreme of streamflows for each site (fig. 15).

Three methods were used to estimate ground-water seepage, or baseflow, of streams in the lower ACF River Basin: field measurements, linear regression analysis, and hydrograph separation. Field measurements of baseflow obtained during October 1999, April 2000, and August 2000 were compared to the distribution of mean-daily streamflow at selected reaches (fig. 15), and with estimates from linear regression analysis and hydrograph separation. Baseflow estimates using these methods were compared and evaluated seasonally, as well as climatically, for conditions of drought and normal or above-normal rainfall to determine the best method for estimating baseflow. Unit-area discharge of ground water to stream channels was reduced as the water level in the aquifer declined. In 1994, unit-area discharge ranged from 0.60 $(ft^3/s)/mi^2$ to 0.79 $(ft^3/s)/mi^2$; in 1999 and 2000, unit-area discharge was reduced, ranging from 0.13 $(ft^3/s)/mi^2$ to 0.58 $(ft^3/s)/mi^2$ (table 3).

Studies by Cushing and others (1973), Pettyjohn and Henning (1979), Reynolds (1982), Stricker (1983), and Atkins and others (1996) have shown that a regression relation between mean-annual baseflow and flow duration can be developed to determine the flow duration that best estimates baseflow. Flow-duration curves graphically represent the percent of time mean-daily discharges were equaled or exceeded during a specified period. For example, the Q_{90} flow-duration point is that streamflow rate equaled or exceeded 90 percent of the time. To develop a statistically valid relation between baseflow and flow duration using regression, long-term data are required for a minimum of 10 sites.

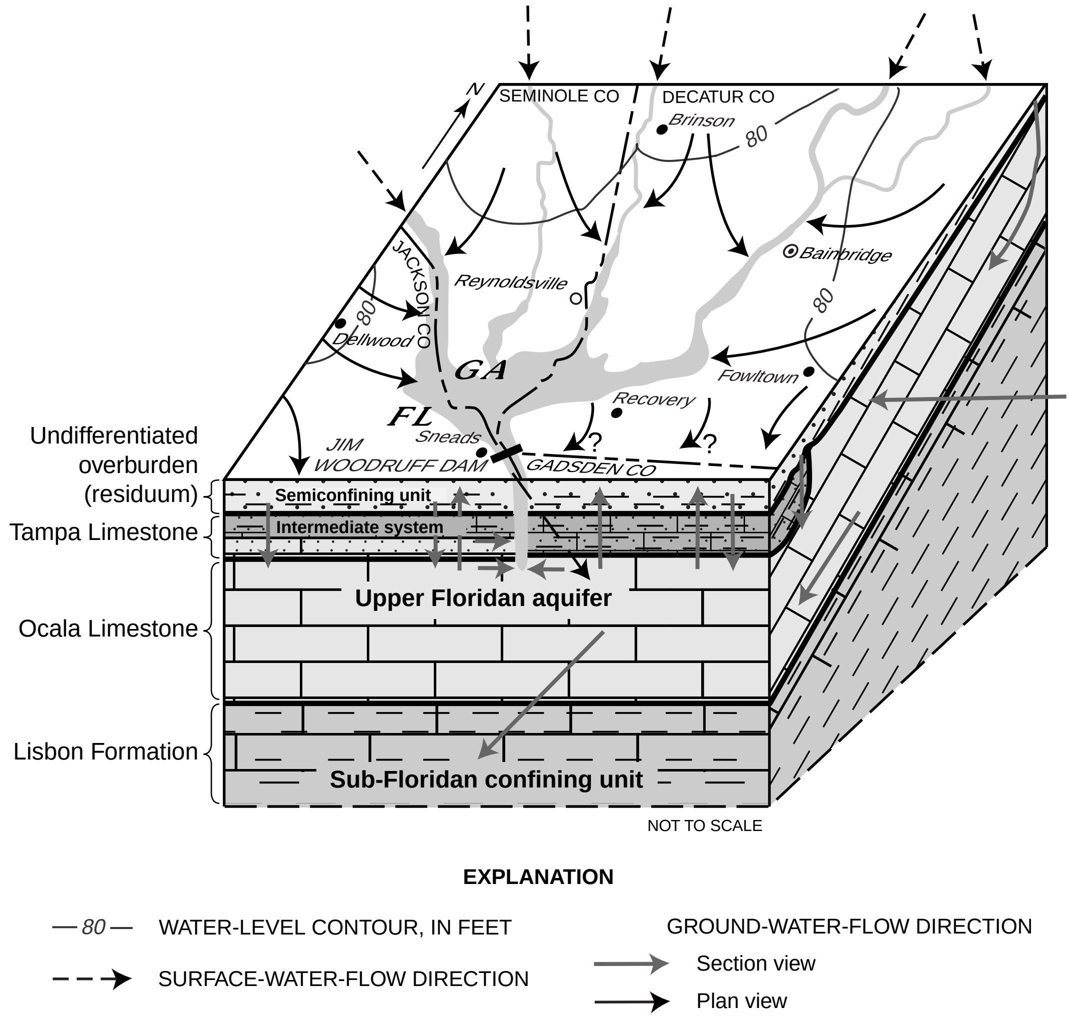


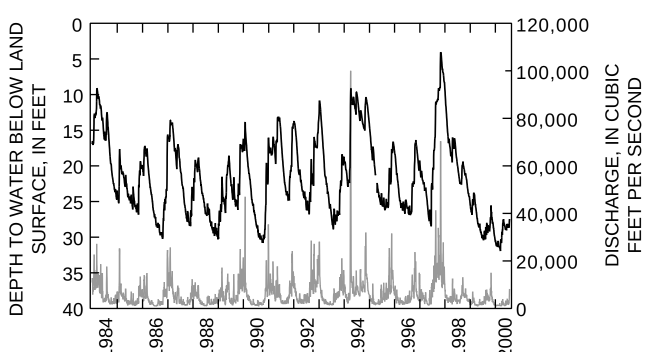
Figure 12. Schematic diagram of the conceptual hydrologic flow system in the lower Apalachicola–Chattahoochee–Flint River Basin (modified from Torak and others, 1993).

Figure 13. Comparison of water level in well 12L028 to streamflow at gage 02353000 on the Flint River at Newton, Georgia, 1984–2000.

EXPLANATION

WELL 12L028 (Depth to water)

GAGE 02353000 (Discharge)



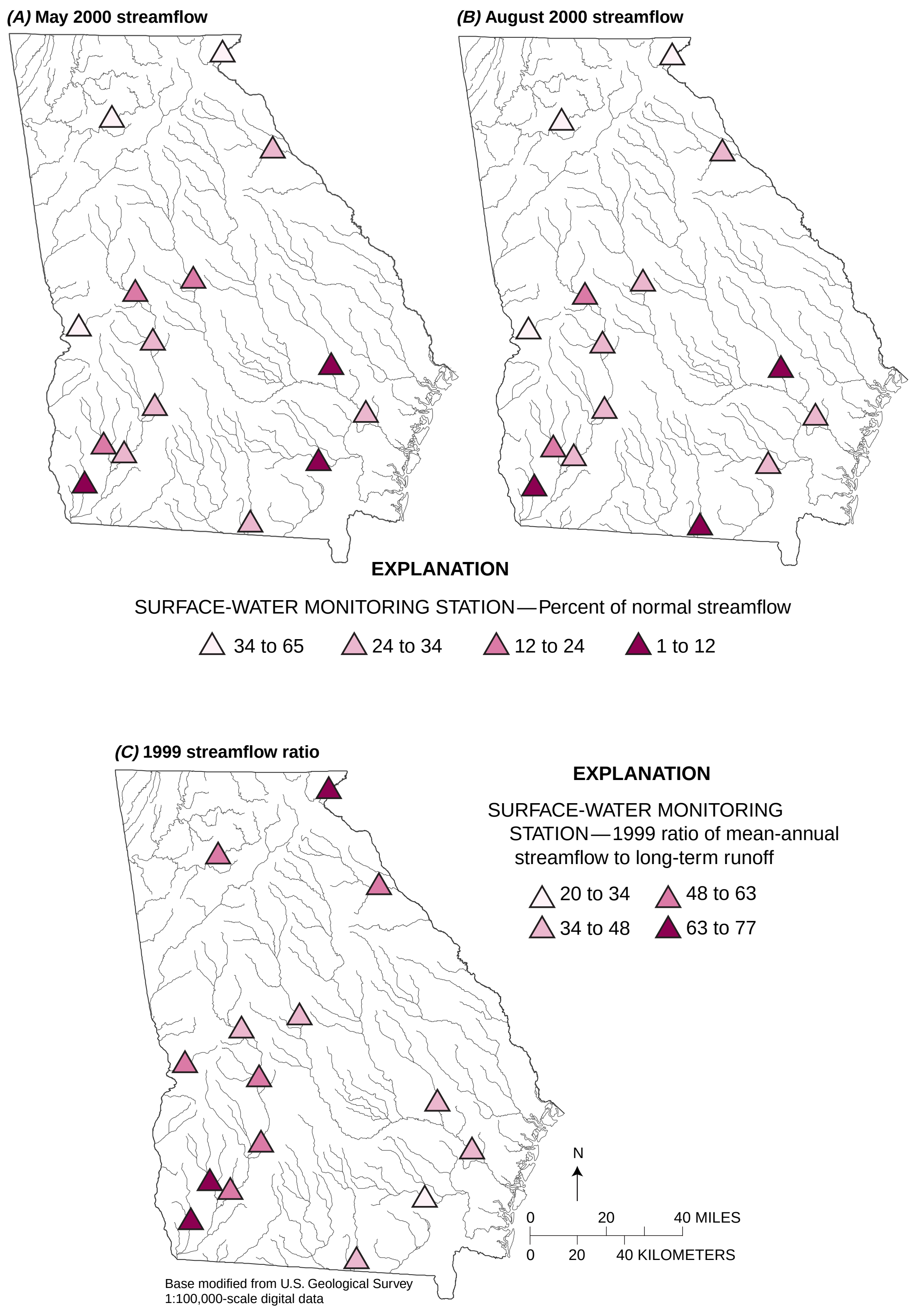
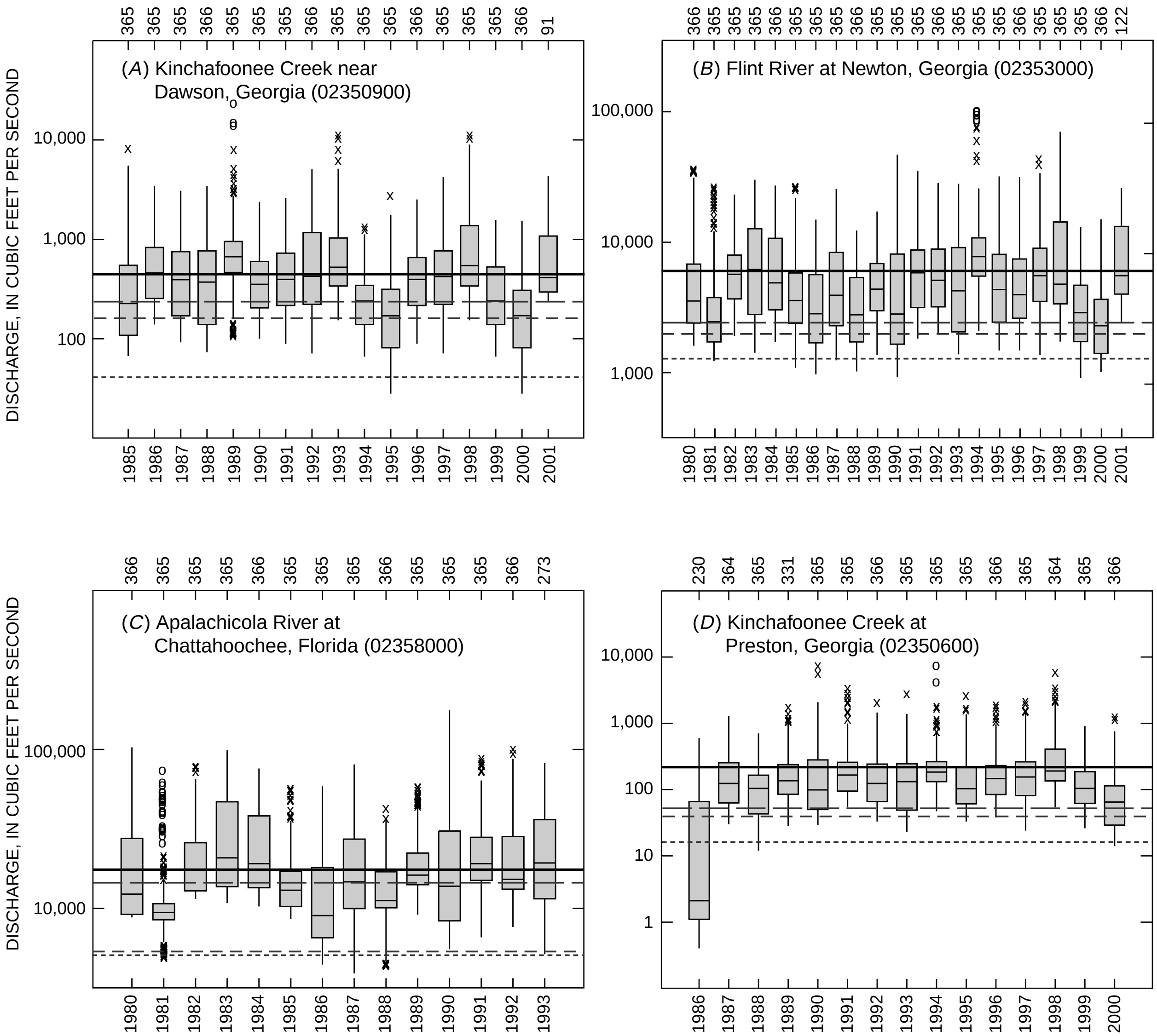


Figure 14. Statewide distribution of percent of normal streamflow for (*A*) May 2000 and (*B*) August 2000; and (*C*) the ratio of 1999 mean-annual streamflow to long-term runoff.



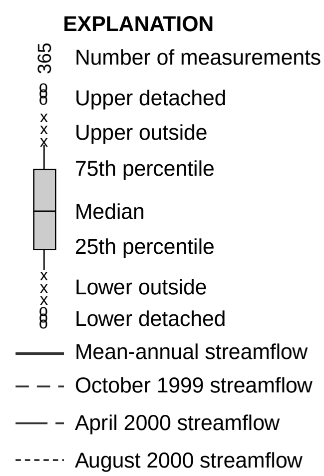


Figure 15. Distribution of mean-daily streamflow for (*A*) Kinchafoonee Creek near Dawson, Georgia; (*B*) Flint River at Newton, Georgia; (*C*) Apalachicola River at Chattahoochee, Florida; and (*D*) Kinchafoonee Creek at Preston, Georgia. Daily discharge during each measurement period shown in relation to mean-annual streamflow (see plate 1 for location).

Linear Regression Analysis

A linear regression analysis, similar to that performed by Stricker (1983), was used to develop a relation between mean-annual baseflow and flow duration for streams located in the lower ACF River Basin. Stricker (1983) developed a relation between flow duration and baseflow for streams in the outcrop areas of Cretaceous aquifers north of the study area, and showed that flow-duration curves having little slope indicate a uniform ground-water contribution to baseflow. Further, steeply sloped curves indicate that runoff is necessary to produce streamflow, with little or no baseflow (Stricker, 1983).

The shape of a flow-duration curve can be described by the index:

$$\sqrt{\frac{Q_{25}}{Q_{75}}}\ , \qquad (1)$$

where, Q_{25} is the streamflow at the 25th percentile and Q_{75} is the streamflow at the 75th percentile; the smaller the index, the greater the portion of baseflow from ground water (Stricker, 1983). Whitewater Creek and Pataula Creek were shown to have index values of 1.13 and 1.48, respectively, indicating a large baseflow component of streamflow (Stricker, 1983). Index values for sites hydraulically connected to the Upper Floridan aquifer range from 1.58 to 4.38 (table 5), higher than index values for sites hydraulically connected to Cretaceous aquifers. The relatively high index values for streams draining the Upper Floridan aquifer indicate a smaller percentage of total streamflow contributed by ground water than streams draining Cretaceous aquifers north of the study area. This is further evidenced by comparing flow-duration curves for the two site types (figs. 16 and 17). Turkey, Kinchafoonee, Muckalee, and Spring Creeks have relatively steeper curves (fig. 16) and higher index values than Whitewater and Pataula Creeks (fig 17), which are hydraulically connected to the Cretaceous aquifers.

Stricker (1983) reported that for streams interacting with Cretaceous aquifers north of the study area, the Q_{60} or Q_{65} discharges provided a reasonable estimate of baseflow. This can be seen graphically on the flow-duration curve where the slope of the line is relatively small at or near Q_{60} or Q_{65} discharges (fig. 17). The variability of hydrologic properties of the Upper Floridan aquifer and the clayey residuum overlying it, the presence of springs in stream channels, and the direct connectivity of streams to the aquifer in areas where the residuum has been eroded, cause streamflow to be flashy, making the Q_{60} or Q_{65} discharges unreliable as estimates of baseflow.

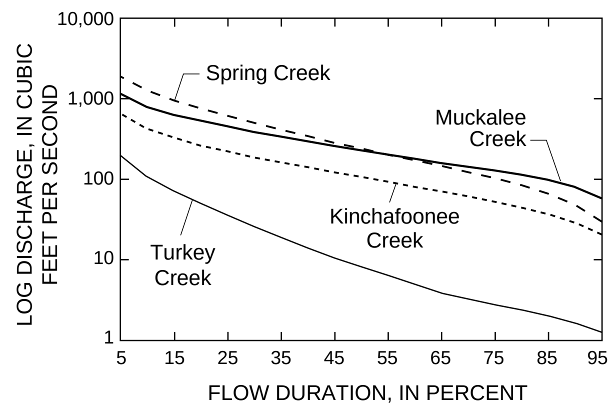


Figure 16. Duration of mean-daily streamflow for selected sites in the lower Apalachicola-Chattahoochee-Flint River Basin that have a direct hydraulic connection to the Upper Floridan aquifer.

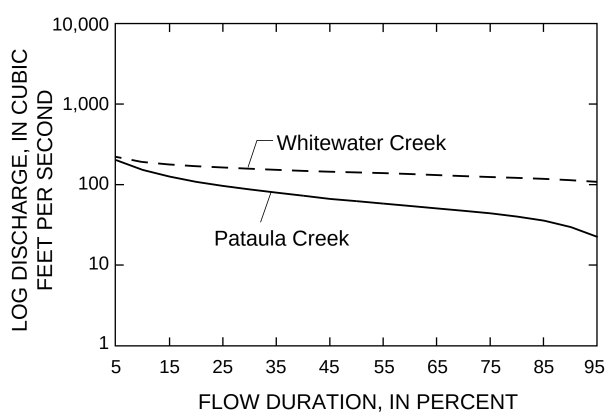


Figure 17. Duration of mean-daily streamflow for selected sites that have a hydraulic connection to the Cretaceous aquifers (from Stricker, 1983).

Table 5. Flow-duration index for selected streams in the lower Apalachicola–Chattahoochee–Flint River Basin
[ft^3/s, cubic foot per second]

Site number	Station name	Index value[a] (ft^3/s)	Mean-annual baseflow (ft^3/s)	Mean-annual discharge (ft^3/s)	Discharge composed of baseflow (percent)
02343200	Pataula Creek near Lumpkin, Ga.[b]	1.48	62	87	71
02343801	Chattahoochee River near Columbia, Ala.	1.75	3,844	10,755	36
02349000	Whitewater Creek below Rambulette Creek near Butler, Ga.[b]	1.13	147	163	90
02349500	Flint River at Montezuma, Ga.	1.68	2,206	3,394	65
02349900	Turkey Creek at Byromville, Ga.	2.58	23	46	50
02350512	Flint River at Ga. 32, near Oakfield, Ga.	1.71	2,230	4,360	51
02350600	Kinchafoonee Creek at Preston, Ga.	1.75	136	210	64
02350900	Kinchafoonee Creek near Dawson, Ga.	1.92	348	532	65
02351890	Muckalee Creek at Ga. 195, near Leesburg, Ga.	1.88	247	392	63
02352500	Flint River at Albany, Ga.	1.70	3,464	6,151	56
02353000	Flint River at Newton, Ga.	1.67	4,064	6,451	63
02353400	Pachitla Creek near Edison, Ga.	1.58	160	248	65
02353500	Ichawaynochaway Creek at Milford, Ga.	1.65	525	761	69
02354500	Chickasawhatchee Creek at Elmodel, Ga.	4.38	161	260	62
02354800	Ichawaynochaway Creek near Elmodel, Ga.	1.77	646	968	67
02355350	Ichawaynochaway Creek below Newton, Ga.	1.69	723	990	73
02357000	Spring Creek near Iron City, Ga.	2.53	313	505	62

a. Index values are computed as $(Q_{25} / Q_{75})^{0.5}$, where Q_{25} is the 25-percent flow duration and Q_{75} is the 75-percent flow duration.
b. Stream having interaction with Cretaceous aquifers, north of the study area (Stricker, 1983).

Linear regression analysis of flow-duration data from selected sites in the study area shows that the Q_{85} or Q_{90} flow duration (fig. 18) is the most reliable estimator of baseflow for the Upper Floridan aquifer (table 6). However, flows of Q_{85} or Q_{90} rarely occur during drought conditions; more typically, flows only reach Q_{95} or Q_{99} levels, which indicates a decrease in normal baseflow during drought conditions. Because the liner regression analysis is a comparison of mean-annual baseflow and flow duration for several sites during many years, baseflow estimation by flow duration probably is representative of average climatic conditions. That is, the flow duration that satisfies the linear regression analysis may not represent baseflow or flow durations that occur during extreme climatic events such as drought.

Hydrograph Separation

Hydrograph separation was performed on streamflow data using HYSEP, a computer program that utilizes mathematical techniques to separate baseflow from streamflow (Sloto and Crouse, 1996). The mathematical formulation of HYSEP does not consider the geology of the basin; therefore, it can be used on a site-by-site basis in any hydrogeologic setting. The flexibility to apply HYSEP to any hydrogeologic setting, however, creates a limitation on its use, as it bases hydrograph separation only on basin area and streamflow hydrograph characteristics.

Estimates of baseflow using HYSEP were used to compare relative changes in baseflow contributions to streamflow on a seasonal and long-term basis.

Baseflow estimates are influenced by hydrologic properties, basin area, presence of impoundments, changing climate, antecedent conditions, and evapotranspiration. Seasonally, baseflow represented a higher percentage of total streamflow during fall and winter, when rainfall and runoff amounts are reduced, than during spring and summer, when rainfall is greater and surface runoff increases (table 4). Drought conditions during 1999 and 2000 increased the percentage of streamflow as baseflow (table 3). During 1994, baseflow contributed from 37 to 56 percent of streamflow; during 1999 and 2000, baseflow ranged from 56 to 76 percent. Median baseflow contributions to the streams for the entire period of record at each site ranged from 54 to 67 percent. When used in this manner, hydrograph separation can illustrate the overall effect of drought on stream-aquifer relations. In general, less precipitation results in a reduction in runoff, causing baseflow to become a larger contributor to streamflow during drought.

Analysis of Baseflow Estimation Methods and Discussion of Error

Results of baseflow estimations by field measurements, linear regression analysis, and hydrograph separation were compared for each of the four selected streamgaging stations (table 7). Linear regression estimations tend to have higher error relative to HYSEP. In some instances, linear regression analysis proved to be an adequate method; but more often than not, baseflow estimations differed from field measurements by more than 30 percent (table 7). The hydrogeology of the lower ACF River Basin makes the errors associated with the linear regression analysis too large to prove useful. Hydrograph separation proved to be more useful in estimating relative differences between seasonal variations in ground-water discharge to streams than in providing accurate estimates of baseflow for any one period in time. Ground-water discharge, hence baseflow, is greatest during winter when evaporative demands and pumping needs are reduced. However, rainfall of long duration and moderate intensity infiltrates to recharge the aquifer, and eventually discharges to stream channels more in winter than in summer, when runoff is high from short-duration, high-intensity storms. Runoff accounts for a greater part of streamflow in summer than in winter (fig. 11). During the recent drought, however, there was little runoff, and streamflow comprised a higher proportion of ground-water discharge (table 3), which also was reduced as aquifer water level dropped. In comparison to field measurements, HYSEP adequately estimated baseflow; errors generally were less than 25 percent; but in a few instances, errors were larger than 40 percent (table 7). There was no trend in terms of accumulation of error in a downstream direction, distance from recharge (outcrop) area, or magnitude of streamflow, although sites having smaller basin areas were more accurately estimated than those having larger basin areas.

Table 6. Coefficient of determination (r^2) and residual standard error for flow durations evaluated as indicators of baseflow for selected sites in the lower Apalachicola–Chattahoochee–Flint River Basin

[P-value = less than 0.001, number of measurements = 16]

Flow duration	r-squared	Residual standard error
Q_1	0.95	350.1
Q_5	.91	452.4
Q_{10}	.92	437.8
Q_{15}	.89	504.6
Q_{20}	.90	476.2
Q_{25}	.90	482.0
Q_{30}	.89	494.1
Q_{35}	.89	509.9
Q_{40}	.88	526.8
Q_{45}	.87	545.9
Q_{50}	.86	564.2
Q_{55}	.86	568.9
Q_{60}	.86	567.7
Q_{65}	.87	552.4
Q_{70}	.90	487.6
Q_{75}	.93	414.7
Q_{80}	.95	331.3
Q_{85}	.98[a]	205.4[a]
Q_{90}	.99[a]	137.7[a]
Q_{95}	.97	251.9
Q_{99}	.97	285.6

a. Best estimate of baseflow.

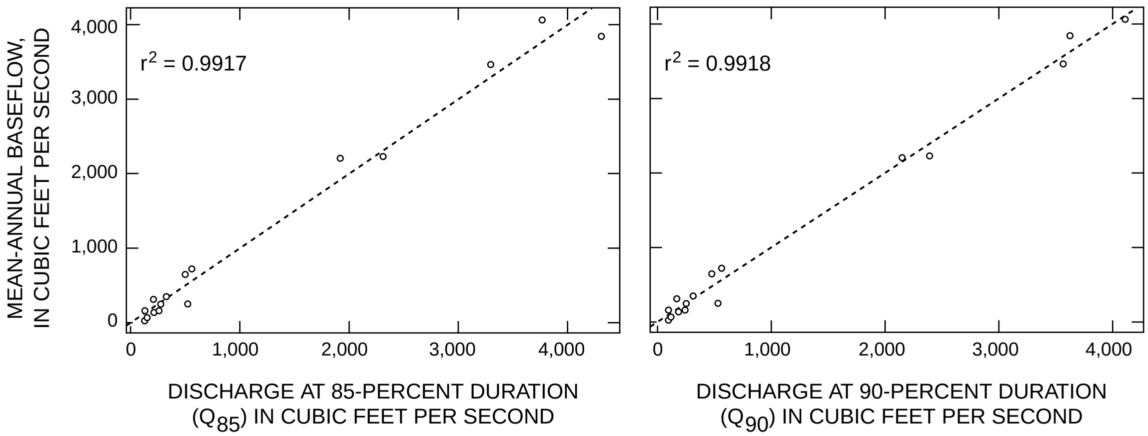


Figure 18. Comparison of mean-annual baseflow and discharge at the 85- and 90-percent duration points.

POTENTIOMETRIC SURFACE

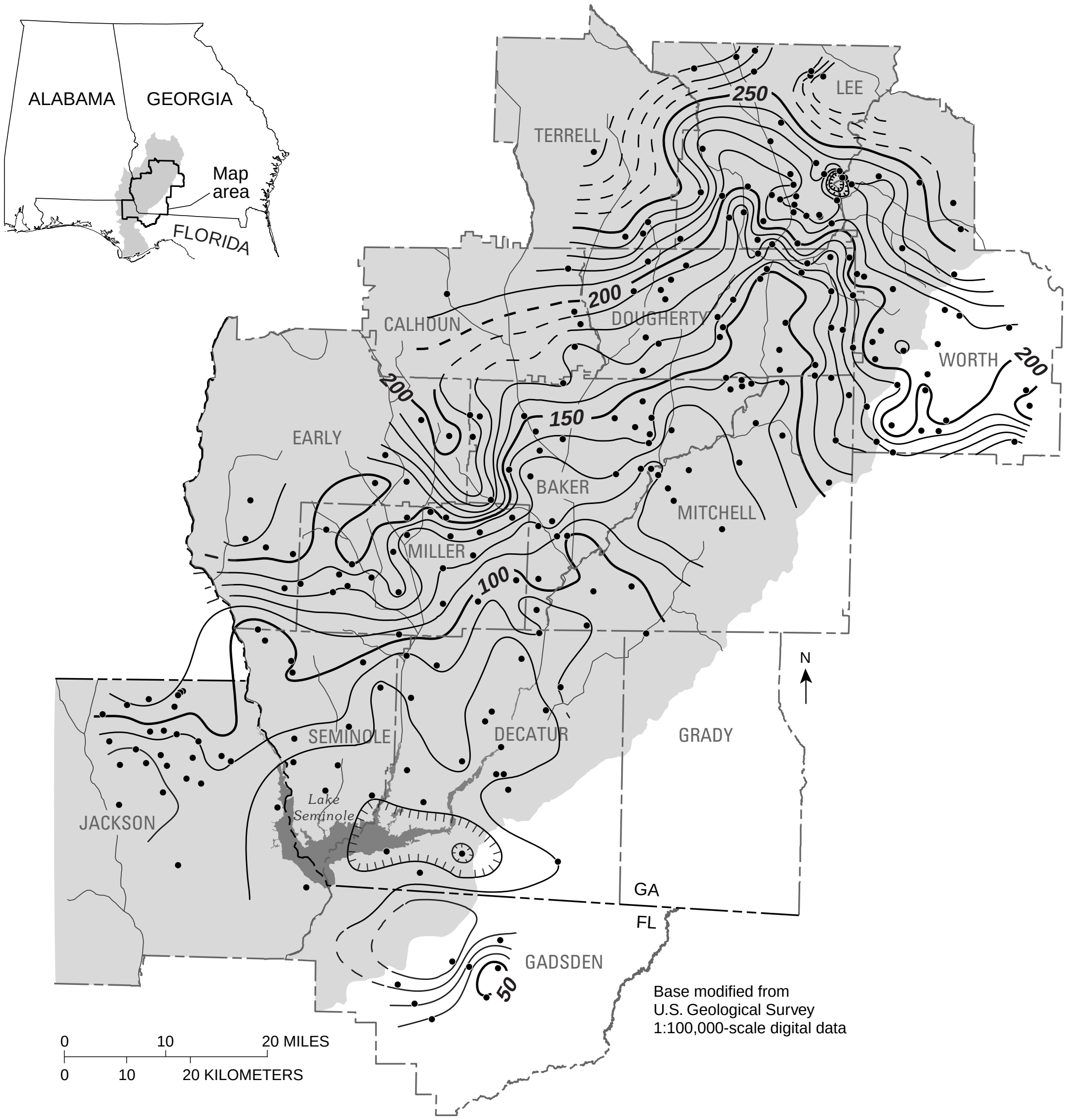
Potentiometric-surface maps for October 1999 and August 2000 illustrate the general direction of ground-water flow in the lower ACF River Basin (figs. 19 and 20, respectively). Distances between contour lines can be used to estimate the hydraulic gradients in a basin. Changes in the hydraulic gradients affect the rate and volume of ground-water contributions to streams and are indicated by the slope of the contour lines. Contour lines that are closely spaced indicate a steeply-sloping potentiometric surface, and therefore, a relatively rapid flow of ground water perpendicular to the contours. More widely spaced contour lines indicate a flatter potentiometric surface. In this case, ground water still moves in a direction perpendicular to the contour; however, the rate of ground-water flow is less than that for a steeply-sloping potentiometric surface. During each measurement period, the regional hydraulic gradient sloped from northwest to southeast except in the vicinity of streams, where local hydraulic gradients allowed ground water to discharge to stream channels independent of regional flow gradients.

Under normal conditions, hydraulic gradients in the lower ACF River Basin are steepest near stream channels and become flatter farther away from the streams. An example is shown on the May 1998 potentiometric-surface map of Peck and others (1999) (fig. 21). The slope of the contour lines is steepest near stream channels; but south and east of the Flint River, the contour lines are more widely spaced, indicating a lower hydraulic gradient and a gentler slope. Drought conditions can also decrease these gradients and affect the rate at which ground water discharges to streams. During October 1999 and August 2000, water-level altitudes in the Upper Floridan aquifer declined, resulting in a lower regional hydraulic gradient and reduced baseflow to streams compared to that occurring during normal or wet periods (figs. 19 and 20). In areas where the water level in the Upper Floridan aquifer fell below a stream channel, hydraulic gradients were established from the stream to the aquifer and streams lost water to the aquifer through streambed leakage. Although some stream reaches discharged water to the aquifer, throughout most of the study area, ground water continued to discharge to streams; that is, hydraulic gradients caused ground water to flow from the aquifer to the stream channel.

Table 7. Comparison of unit-area ground-water discharge estimates using field measurements of baseflow, hydrograph separation, and regression techniques for selected streams in the lower Apalachicola–Chattahoochee–Flint River Basin, October 1999 and April and August 2000

[$(ft^3/s)/mi^2$ - cubic foot per second per square mile]

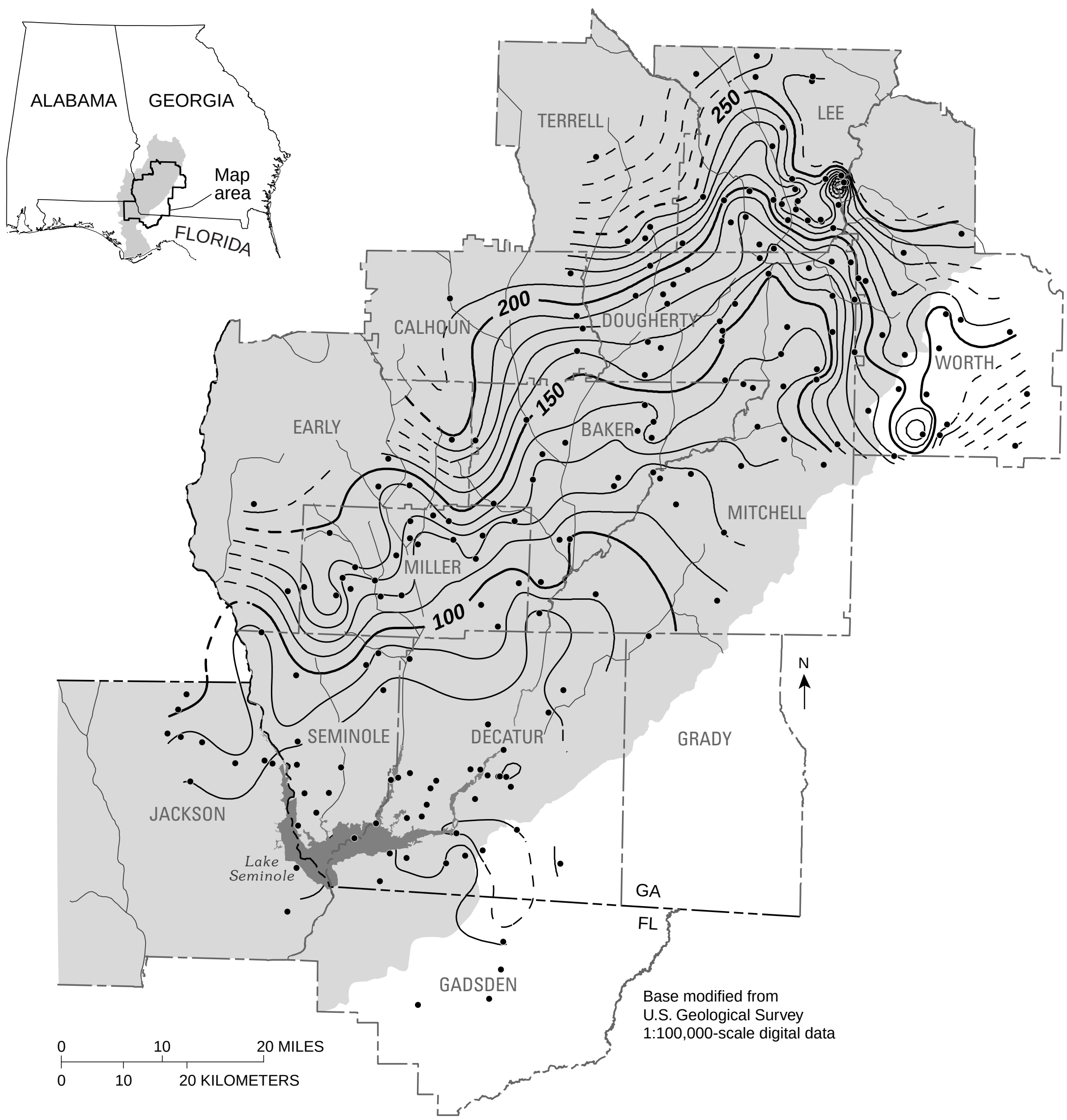
Station name and number	Month year	Field measurement of baseflow ($[ft^3/s]/mi^2$)	HYSEP ($[ft^3/s]/mi^2$)	Q_{85} ($[ft^3/s]/mi^2$)	Q_{90} ($[ft^3/s]/mi^2$)	Error in HYSEP estimation	Error in Q_{85} estimation	Error in Q_{90} estimation	Percent error in HYSEP estimation	Percent error in Q_{85} estimation	Percent error in Q_{90} estimation
Turkey Creek near	October 1999	0.13	0.09	0.12	0.10	-0.04	-0.01	-0.03	-30.77	-5.98	-21.37
Byromville, Ga.	April 2000	.31	.38	.12	.10	.07	-.19	-.21	22.58	-60.57	-67.03
02349900	August 2000	.08	.07	.12	.10	-.01	.04	.02	-12.50	52.78	27.78
Kinchafoonee Creek	October 1999	.34	.24	.30	.25	-.1	-.04	-.09	-29.41	-10.42	-26.84
near Preston, Ga.	April 2000	.39	.49	.30	.25	.1	-.09	-.14	25.64	-21.91	-36.22
02350600	August 2000	.12	.1	.30	.25	-.02	.18	.13	-16.67	153.81	107.28
Muckalee Creek at Ga.	October 1999	.43	.25	.28	.23	-.18	-.15	-.20	-41.86	-35.76	-47.32
195, near Leesburg,	April 2000	.45	.52	.28	.23	.07	-.17	-.22	15.56	-38.61	-49.66
Ga. 02351890	August 2000	.15	.07	.28	.23	-.08	.13	.08	-53.33	84.16	51.01
Spring Creek near	October 1999	.08	.07	.15	.08	-.01	.07	.00	-12.50	85.57	5.67
Iron City Ga.	April 2000	.17	.26	.15	.08	.09	-.02	-.09	52.94	-12.67	-50.27
02357000	August 2000	.001	.00	.15	.08	-.001	.15	.08	-100.00	14,745.36	8,353.61



EXPLANATION

(shaded)	LOWER APALACHICOLA–CHATTAHOOCHEE–FLINT RIVER BASIN
— 100 – –	POTENTIOMETRIC CONTOUR—Shows altitude at which water level would have stood in tightly cased wells completed in the Upper Floridan aquifer during October 1999. Dashed where approximately located. Contour interval 10 feet. Hachures indicate depression. Datum is NAVD 88
•	MONITORING WELL, UPPER FLORIDAN AQUIFER

Figure 19. Generalized potentiometric surface of the Upper Florida aquifer in the lower Apalachicola–Chattahoochee–Flint River Basin, October 1999.



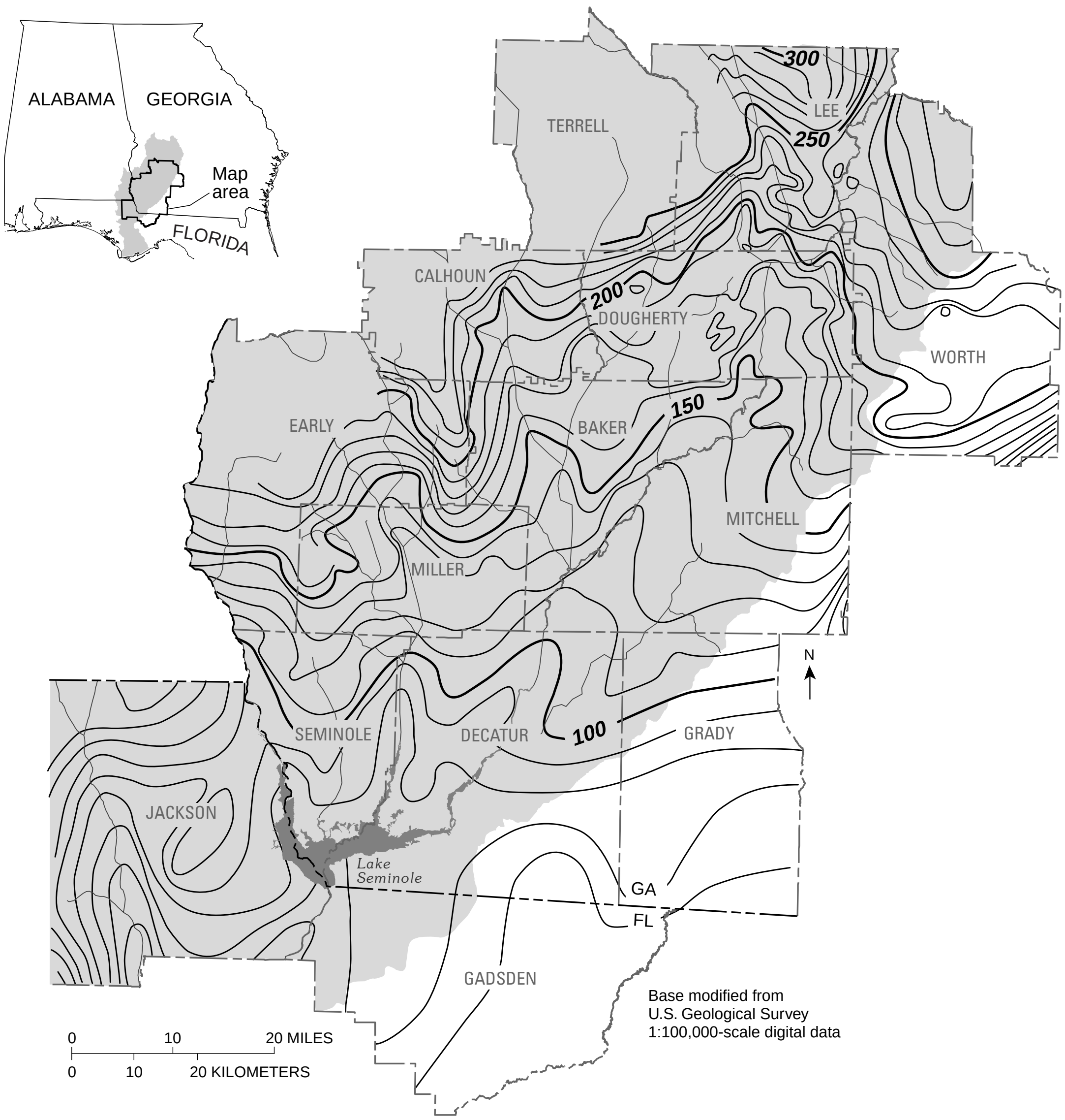
EXPLANATION

LOWER APALACHICOLA–CHATTAHOOCHEE–FLINT RIVER BASIN

100 POTENTIOMETRIC CONTOUR—Shows altitude at which water level would have stood in tightly cased wells completed in the Upper Floridan aquifer during August 2000. Dashed where approximately located. Contour interval 10 feet. Datum is NAVD 88

• MONITORING WELL, UPPER FLORIDAN AQUIFER

Figure 20. Generalized potentiometric surface of the Upper Floridan aquifer in the lower Apalachicola–Chattahoochee–Flint River Basin, August 2000.



EXPLANATION

LOWER APALACHICOLA–CHATTAHOOCHEE–FLINT RIVER BASIN

100 APPROXIMATE POTENTIOMETRIC CONTOUR—Shows approximate altitude at which water level would have stood in tightly cased wells during May–June 1998. Contour interval 10 feet. Datum is NAVD 88

Figure 21. Potentiometric surface of the Upper Floridan aquifer in the lower Apalachicola–Chattahoochee–Flint River Basin, May 1998 (modified from Peck and others, 1999).

SUMMARY

Stream-aquifer relations in the lower ACF River Basin were evaluated during drought conditions of 1999–2000 to estimate rates of ground-water discharge. Ground-water discharge to selected streams was estimated using three methods: (1) field measurements of baseflow; (2) HYSEP, an automated hydrograph-separation computer program; and (3) a comparison of mean-annual baseflow and flow-duration data using a simple linear regression analysis. HYSEP provided estimates of mean-annual baseflow, runoff, and flow duration for four tributaries of the Flint River in the study area. Although accurately estimating baseflow is difficult, HYSEP is useful for comparing seasonal differences in baseflow as well as long-term trends. Typically during winter, ground-water discharge is the largest component of streamflow; in summer, runoff becomes more important with the increased intensity and short duration of precipitation. Drought conditions changed the relative magnitudes of streamflow components by reducing ground-water levels (and baseflow) and limiting the amount of runoff due to the lack of precipitation. During 1999–2000, ground water was the largest component of streamflow, in some instances comprising as much as 76 percent of total streamflow.

The complex hydrogeology of the lower ACF River Basin results in many unique problems in assessing stream-aquifer relations. Commonly, the streambed is in direct connection with the Upper Floridan aquifer in areas where the residuum has been eroded. Clay layers, if present in the lower part of the residuum, retard the vertical leakage of water that recharges the Upper Floridan aquifer and reduce discharge to stream channels. However, evaluation of mean-annual baseflow and flow duration shows that, under normal conditions, streams in the study area are not entirely dependent on ground-water discharge for streamflow. In addition, flow-duration indices tended to be high, suggesting that streamflow in the study area is composed more of runoff than baseflow. Flow-duration curves for selected sites in the study area are steeply sloped, suggesting that runoff constitutes a large percentage of streamflow under normal conditions; this is typical of sites having a clayey lithology. Linear regression analysis of streamflow data shows that baseflow can be estimated by flow duration at the 85- and 90-percent levels (Q_{85} or Q_{90}). However, linear regression analysis proves to be less useful in the lower ACF River Basin than in other areas, especially where streams intersect the Upper Floridan aquifer. The unique hydrogeology of the basin provides too many problems for linear regression analysis to estimate baseflow accurately. The unconfined nature of the aquifer, large variation in aquifer thickness and hydraulic conductivity, abundance of springs discharging to streams, and the variability of aquifer water level in response to pumping and drought cause large errors in baseflow estimates in linear regression analysis.

Drought conditions reduced not only runoff contributing to streamflow, but also the contribution from ground-water discharge. Changes to ground-water levels on potentiometric-surface maps illustrate declining hydraulic gradients from the Upper Floridan aquifer to streams for May 1998 through August 2000. As the ground-water level declined, the volume of water discharging to stream channels decreased. Unit-area discharge to stream channels decreased to such low levels that, in some reaches, streams went dry; but more often than not, record-low streamflow occurred. In selected streams under normal precipitation conditions (1994), unit-area discharge ranged from 0.60–0.79 $(ft^3/s)/mi^2$; in 1999, unit-area discharge declined to 0.24–0.58 $(ft^3/s)/mi^2$; and, by 2000, unit-area discharge had been reduced to 0.13–0.33 $(ft^3/s)/mi^2$. Runoff also decreased due to lack of precipitation, increasing the contribution of baseflow to total streamflow. In selected streams, baseflow estimates increased from 37 percent to 56 percent under normal conditions (1994), from 60 percent to 73 percent in 1999, and from 56 percent to 76 percent in 2000. This increased dependence of streamflow on ground-water contributions and the subsequent reduction of ground-water level and ground-water discharge reduced streamflows to record or near-record lows throughout the lower ACF River Basin.

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APPENDIX A.—WELLS MEASURED IN THE LOWER APALACHICOLA–CHATTAHOOCHEE–FLINT RIVER BASIN, 1999–2000

Appendix A. Wells measured in the lower Apalachicola–Chattahoochee–Flint River Basin, 1999–2000

[—, no data]

USGS site name	Latitude (North)	Longitude (West)	Well depth[a]	Land surface altitude[a]	USGS site name	Latitude (North)	Longitude (West)	Well depth[a]	Land surface altitude[b]
05H008	31°12'09"	85°00'33"	145	199	07F002	30°56'16"	84°49'58"	160	118
05J007	31°15'26"	85°00'08"	100	208	07F004	30°59'38"	84°46'53"	—	113
06E001	30°49'05"	84°53'26"	180	127	07F006	30°52'58"	84°51'02"	—	100
06E019	30°50'44"	84°54'38"	250	120	07G005	31°02'50"	84°47'27"	200	130
06E020	30°50'12"	84°53'25"	130	110	07G006	31°01'46"	84°48'39"	200	155
06E023	30°47'58"	84°55'13"	220	80	07G007	31°00'10"	84°49'48"	260	156
06F005	30°55'09"	84°55'23"	200	156	07G008	31°04'11"	84°45'06"	—	152
06F007	30°53'09"	84°55'26"	250	162	07H005	31°07'47"	84°45'12"	—	145
06F084	30°56'57"	84°55'48"	250	148	07H006	31°07'39"	84°47'17"	—	140
06G006	31°04'27"	84°59'11"	123	152	07H007	31°09'01"	84°47'54"	—	169
06G007	31°00'29"	84°59'18"	195	135	07H008	31°08'16"	84°50'18"	—	175
06G008	31°03'31"	84°58'28"	140	132	07H009	31°07'43"	84°51'46"	—	180
06G009	31°01'48"	84°55'47"	140	148	07H011	31°13'02"	84°52'29"	—	181
06G012	31°00'48"	84°55'39"	170	190	07H012	31°11'13"	84°45'46"	—	174
06H003	31°08'23"	84°54'59"	180	198	07H014	31°09'14"	84°51'09"	—	172
06H006	31°08'14"	84°56'11"	—	189	07J012	31°19'29"	84°46'42"	—	187
06H008	31°10'55"	84°55'47"	—	207	07J013	31°17'04"	84°47'40"	—	180
06H009	31°11'08"	84°56'43"	160	202	08D001	30°44'50"	84°44'27"	140	255
06H012	31°11'28"	84°58'30"	205	192	08D002	30°44'15"	84°43'48"	340	285
06H013	31°08'00"	84°56'36"	150	185	08D003	30°44'08"	84°44'47"	300	250
07D001	30°44'20"	84°50'00"	—	179	08D005	30°43'53"	84°42'42"	—	276
07D002	30°44'54"	84°48'30"	200	182	08D006	30°42'47"	84°40'20"	380	290
07D004	30°43'57"	84°47′57"	120	127	08D007	30°44'56"	84°40'02"	300	300
07D005	30°43'56"	84°47'59"	150	159	08D090	30°44'54"	84°40'24"	340	293
07D006	30°43'16"	84°46'59"	340	272	08E002	30°51'17"	84°42'04"	—	118
07E001	30°45'39"	84°46'03"	154	170	08E003	30°49'54"	84°42'26"	—	100
07E003	30°45'08"	84°47'06"	174	189	08E005	30°49'28"	84°40'40"	—	83
07E006	30°50'47"	84°52'13"	170	91	08E019	30°46'13"	84°43'43"	147	90
07E007	30°50'24"	84°47'35"	130	105	08E020	30°46'23"	84°43'38"	88	82
07E008	30°45'50"	84°45'45"	145	130	08E021	30°46'16"	84°43'12"	125	85
07E009	30°45'32"	84°45'08"	135	170	08E022	30°46'14"	84°43'14"	85	85
07E044	30°52'10"	84°45'19"	83	89	08E023	30°45'17"	84°43'32"	280	260
07E045	30°46'56"	84°49'35"	100	90	08E024	30°45'36"	84°43'41"	216	165
07E046	30°48'15"	84°47'26"	44	90	08E025	30°45'33"	84°38'32"	300	135
07E047	30°51'59"	84°46'02"	123	110	08E026	30°45'18"	84°44'22"	294	255

Appendix A. Wells measured in the lower Apalachicola–Chattahoochee–Flint River Basin, 1999–2000—Continued

USGS site name	Latitude (North)	Longitude (West)	Well depth[a]	Land surface altitude[a]
08E027	30°45'56"	84°42'16"	—	205
08E031	30°47'53"	84°38'51"	240	192
08E032	30°50'27"	84°37'35"	119	95
08E034	30°48'58"	84°42'47"	—	107
08E035	30°48'36"	84°44'22"	115	90
08E037	30°51'57"	84°41'29"	97	125
08F006	30°58'48"	84°43'48"	—	120
08F009	30°53'26"	84°38'38"	—	118
08F012	30°55'20"	84°39'15"	—	115
08F018	30°52'36"	84°44'07"	125	118
08F499	30°52'58"	84°38'05"	120	100
08G005	31°01'36"	84°41'17"	—	130
08G006	31°00'25"	84°43'28"	—	122
08H003	31°12'41"	84°44'25"	—	148
08H005	31°14'10"	84°44'26"	165	175
08H006	31°12'36"	84°40'04"	—	172
08H007	31°14'41"	84°42'07"	200	190
08H008	31°12'11"	84°43'37"	—	160
08H009	31°14'11"	84°40'33"	—	193
08H010	31°09'52"	84°40'48"	210	172
08J004	31°21'07"	84°37'59"	—	220
08J005	31°21'11"	84°40'21"	100	230
08J015	31°17'13"	84°44'32"	160	176
08K013	31°22'57"	84°38'17"	155	218
08K016	31°22'31"	84°43'08"	260	232
09E003	30°52'23"	84°35'17"	75	115
09E004	30°52'23"	84°35'13"	75	115
09E005	30°52'22"	84°34'30"	80	120
09E006	30°51'32"	84°34'03"	225	110
09E007	30°51'04"	84°34'02"	225	138
09E008	30°48'23"	84°33'30"	320	292
09E009	30°47'50"	84°33'22"	360	300
09E521	30°46'03"	84°36'47"	294	280
09E522	30°52'28"	84°36'21"	105	100
09F004	30°57'53"	84°30'22"	—	119

USGS site name	Latitude (North)	Longitude (West)	Well depth[a]	Land surface altitude[b]
09F005	30°56'51"	84°36'24"	—	130
09F520	30°57'42"	84°35'46"	251	128
09F522	30°52'58"	84°37'05"	86	90
09G004	31°06'24"	84°31'23"	—	138
09G005	31°05'12"	84°35'31"	—	152
09G006	31°07'04"	84°37'14"	220	158
09G007	31°02'15"	84°32'52"	—	142
09G010	31°02'50"	84°34'21"	230	145
09H001	31°09'05"	84°31'14"	—	152
09H007	31°13'00"	84°37'09"	—	189
09H009	31°14'16"	84°33'57"	—	166
09H011	31°12'36"	84°35'43"	195	175
09H012	31°08'57"	84°33'27"	205	150
09H014	31°13'35"	84°31'19"	200	152
09J004	31°18'22"	84°34'18"	245	204
09J008	31°20'01"	84°31'14"	—	157
09J009	31°15'45"	84°36'04"	—	193
09J010	31°17'49"	84°32'09"	—	175
09J012	31°21'38"	84°31'40"	—	158
09K010	31°22'51"	84°37'17"	—	195
10D015	30°44'57"	84°29'01"	—	315
10F001	30°59'50"	84°28'54"	—	140
10G313	31°05'07"	84°26'22"	206	145
10H004	31°12'42"	84°29'25"	—	152
10H006	31°08'04"	84°25'44"	200	158
10J002	31°16'21"	84°23'45"	—	158
10J003	31°18'05"	84°23'36"	—	173
10J004	31°18'43"	84°24'45"	140	180
10K004	31°22'51"	84°23'47"	—	189
10K006	31°25'46"	84°28'58"	100	183
10L003	31°30'49"	84°27'19"	—	222
10L004	31°35'32"	84°28'35"	—	234
10L016	31°31'52"	84°27'56"	—	229
10L018	31°31'53"	84°24'32"	—	207
10M003	31°38'18"	84°22'52"	176	268

Appendix A. Wells measured in the lower Apalachicola–Chattahoochee–Flint River Basin, 1999–2000—Continued

USGS site name	Latitude (North)	Longitude (West)	Well depth[a]	Land surface altitude[a]
10N012	31°45'30"	84°26'08"	103	333
11G002	31°04'31"	84°20'25"	250	140
11G003	31°01'58"	84°18'16"	—	182
11H003	31°08'30"	84°21'55"	—	149
11J003	31°21'30"	84°20'16"	—	169
11J004	31°22'05"	84°21'43"	—	170
11J005	31°18'32"	84°21'07"	—	168
11J012	31°18'02"	84°19'23"	225	165
11J014	31°20'45"	84°20'19"	—	174
11J016	31°18'27"	84°16'18"	206	155
11J018	31°15'50"	84°17'47"	200	158
11J019	31°16'53"	84°18'24"	225	158
11J020	31°21'52"	84°18'05"	196	150
11K011	31°22'53"	84°20'05"	—	173
11K016	31°24'18"	84°21'00"	—	170
11K028	31°29'44"	84°20'45"	155	201
11K033	31°26'54"	84°21'01"	77	183
11K043	31°29'13"	84°19'26"	170	193
11L019	31°30'10"	84°18'49"	—	179
11L020	31°33'00"	84°18'49"	150	207
11L077	31°33'48"	84°19'16"	130	210
11L111	31°33'40"	84°22'00"	125	220
11L112	31°36'14"	84°20'34"	180	232
11L115	31°35'54"	84°16'46"	150	220
11L116	31°34'40"	84°18'14"	150	209
11M007	31°39'34"	84°20'36"	95	260
11M010	31°38'11"	84°17'20"	120	263
11M017	31°42'10"	84°15'19"	—	264
11M025	31°38'36"	84°21'04"	120	260
11M027	31°38'35"	84°21'06"	—	259
11P006	31°52'41"	84°16'06"	319	300
12H008	31°13'27"	84°12'56"	341	165
12J002	31°19'09"	84°11'15"	200	174
12K001	31°22'32"	84°09'38"	270	170
12K008	31°25'22"	84°12'13"	195	193

USGS site name	Latitude (North)	Longitude (West)	Well depth[a]	Land surface altitude[b]
12K009	31°25'38"	84°11'03"	160	180
12K113	31°25'52"	84°10'08"	—	170
12K115	31°28'48"	84°09'41"	—	171
12K120	31°29'04"	84°13'50"	—	192
12K130	31°26'21"	84°12'39"	94	185
12K134	31°26'38"	84°10'26"	—	184
12K136	31°26'44"	84°12'37"	215	194
12L028	31°33'02"	84°12'00"	100	190
12L045	31°36'58"	84°09'32"	—	191
12L310	31°31'32"	84°13'32"	250	206
12M010	31°39'44"	84°09'01"	185	246
12M011	31°42'41"	84°10'37"	197	234
12M012	31°41'58"	84°08'12"	135	239
12M013	31°40'00"	84°12'28"	158	230
12M017	31°38'08"	84°09'36"	181	224
12M022	31°37'47"	84°08'07"	164	191
12M024	31°40'29"	84°11'00"	—	232
12M027	31°41'53"	84°13'11"	—	243
12N004	31°52'28"	84°10'05"	200	289
12P010	31°54'16"	84°10'00"	185	300
13J001	31°17'29"	84°02'18"	431	375
13J004	31°21'29"	84°06'57"	208	194
13J006	31°19'18"	84°02'58"	206	247
13J008	31°21'05"	84°01'37"	—	234
13K011	31°27'30"	84°03'43"	430	230
13K017	31°26'36"	84°03'46"	132	241
13K019	31°28'46"	84°07'19"	—	195
13K021	31°26'26"	84°02'06"	310	311
13K023	31°24'56"	84°00'19"	386	332
13K091	31°26'01"	84°07'04"	—	198
13L028	31°30'42"	84°02'09"	300	219
13L047	31°36'40"	84°00'21"	256	256
13L052	31°36'09"	84°04'35"	105	204
13L054	31°36'43"	84°02'17"	—	206
13L057	31°33'47"	84°02'11"	150	227

Appendix A. Wells measured in the lower Apalachicola–Chattahoochee–Flint River Basin, 1999–2000—Continued

USGS site name	Latitude (North)	Longitude (West)	Well depth[a]	Land surface altitude[a]
13M006	31°43'30"	84°00'51"	123	237
13M011	31°40'08"	84°03'18"	160	260
13M013	31°37'51"	84°05'36"	170	240
13M027	31°42'52"	84°06'01"	—	246
13M046	31°40'30"	84°06'00"	105	211
13M049	31°40'15"	84°06'44"	110	241
13M050	31°41'36"	84°07'22"	—	254
13M051	31°42'56"	84°00'11"	245	244
13M055	31°39'35"	84°02'10"	150	223
13M056	31°41'34"	84°01'38"	173	254
13M060	31°43'46"	84°02'56"	165	267
13M062	31°40'12"	84°04'43"	160	249
13M065	31°41'53"	84°05'45"	140	244
13M066	31°43'45"	84°06'19"	120	259
13M070	31°41'09"	84°05'55"	—	247
13M080	31°40'18"	84°03'25"	160	261
13M084	31°44'04"	84°01'22"	110	221
13M086	31°44'42"	84°03'45"	160	279
13N003	31°48'09"	84°07'19"	160	289
13N007	31°52'09"	84°04'24"	160	313
13N009	31°52'05"	84°03'05"	115	299
13P005	31°52'32"	84°04'19"	240	315
14J018	31°21'00"	83°57'34"	—	389
14J019	31°21'57"	83°53'03"	—	389
14J021	31°20'05"	83°55'53"	—	375
14J022	31°22'23"	83°56'03"	—	417
14K006	31°29'30"	83°58'01"	—	321
14K008	31°23'58"	83°58'32"	—	408
14K009	31°28'59"	83°59'57"	—	311
14K011	31°28'02"	83°57'43"	—	289
14K012	31°28'46"	83°54'52"	—	399
14K013	31°25'50"	83°55'29"	—	432
14K015	31°25'23"	83°52'41"	—	417
14L005	31°35'17"	83°59'36"	—	256
14L006	31°34'00"	83°55'58"	235	331

USGS site name	Latitude (North)	Longitude (West)	Well depth[a]	Land surface altitude[b]
14L011	31°35'03"	83°58'52"	—	257
14L013	31°30'27"	83°57'09"	—	279
14L014	31°37'29"	83°55'03"	—	283
14L048	31°33'28"	83°59'58"	135	238
14M006	31°43'36"	83°57'28"	—	260
14M008	31°43'06"	83°53'20"	102	288
14P012	31°57'36"	83°59'14"	—	294
14Q005	32°02'27"	83°56'45"	63	279
14Q006	32°01'57"	83°56'29"	175	277
14Q009	32°02'37"	83°53'22"	—	320
15J015	31°21'54"	83°51'19"	—	399
15K006	31°22'49"	83°50'35"	305	411
15K009	31°26'45"	83°52'28"	—	409
15K010	31°29'20"	83°51'26"	—	389
15L007	31°30'40"	83°46'12"	—	369
15L020	31°31'46"	83°49'16"	450	419
15L021	31°32'15"	83°50'45"	536	379
15L022	31°35'17"	83°49'49"	—	435
15M004	31°41'23"	83°49'58"	—	341
15M005	31°39'09"	83°49'12"	—	322
15Q012	32°03'04"	83°51'56"	165	321
16J011	31°21'01"	83°43'44"	570	300
16K011	31°24'05"	83°42'14"	620	358
16K013	31°25'26"	83°42'35"	610	373
16L019	31°30'45"	83°44'18"	—	379
16M008	31°39'18"	83°38'07"	375	388
1370	30°44'31"	84°59'02"	—	—
1640	30°53'13"	84°57'52"	—	—
3339	30°31'09"	84°27'54"	96	201
3340	30°31'09"	84°27'54"	356	200
3341	30°31'09"	84°27'54"	27	199
3342	30°31'09"	84°27'54"	435	200
3375	30°31'24"	84°41'18"	432	248
3558	30°32'43"	84°43'03"	803	250
3636	30°33'11"	84°42'34"	460	265

Appendix A. Wells measured in the lower Apalachicola–Chattahoochee–Flint River Basin, 1999–2000—Continued

USGS site name	Latitude (North)	Longitude (West)	Well depth[a]	Land surface altitude[a]	USGS site name	Latitude (North)	Longitude (West)	Well depth[a]	Land surface altitude[b]
3653	30°33'19"	84°35'57"	396	225	5341	30°52'41"	85°07'59"	157	143
3692	30°33'37"	84°37'41"	250	230	5342	30°52'41"	85°12'42"	137	129
3785	30°34'18"	84°44'47"	420	275	5352	30°52'53"	85°10'05"	117	121
4026	30°35'49"	84°34'50"	701	151	5374	30°53'13"	85°01'36"	113	—
4040	30°35'54"	84°37'41"	660	279	5378	30°53'26"	85°05'26"	105	131
4102	30°36'20"	84°39'21"	467	289	5391	30°53'35"	85°02'35"	110	119
4318	30°38'13"	84°34'37"	460	265	5393	30°53'36"	85°08'39"	118	139
4421	30°39'19"	84°49'11"	—	—	5408	30°53'09"	85°01'39"	152	123
4541	30°40'33"	84°56'09"	122	—	5424	30°54'03"	85°11'07"	64	122
4566	30°40'55"	84°50'25"	214	121	5450	30°54'42"	85°13'48"	137	137
4577	30°41'05"	84°42'09"	469	—	5460	30°54'50"	85°04'54"	65	126
4607	30°53'30"	84°58'40"	105	100	5490	30°55'23"	85°07'05"	98	141
4647	30°42'04"	84°48'18"	355	—	5508	30°55'36"	85°09'45"	117	129
4677	30°42'30"	84°52'53"	210	—	5511	30°55'41"	85°08'21"	157	147
4681	30°42'29"	84°53'58"	101	99	5574	30°56'58"	85°14'30"	150	124
4795	30°44'12"	85°06'43"	210	167	5635	30°57'43"	85°07'22"	120	141
5062	30°47'45"	85°22'32"	280	134	5640	30°57'48"	85°12'06"	177	142
5147	30°49'18"	84°56'56"	200	100	5671	30°58'22"	85°09'56"	117	146
5151	30°49'18"	85°12'42"	152	107	5697	30°58'45"	85°07'03"	123	156
5226	30°50'25"	85°08'21"	118	129	5704	30°58'57"	85°06'48"	123	137
5266	30°51'12"	85°04'36"	158	128	5718	30°59'04"	85°06'33"	123	147
5288	30°51'37"	85°06'02"	80	123	6363	30°44'21"	84°56'09"	120	179

a. Well depth in feet below land surface.
b. Land surface altitude in feet above NAVD 88.

APPENDIX B.—STREAMGAGING STATIONS MEASURED IN THE LOWER APALACHICOLA–CHATTAHOOCHEE–FLINT RIVER BASIN, 1999–2000

Appendix B. Streamgaging stations measured in the lower Apalachicola–Chattahoochee–Flint River Basin, 1999–2000

Station number	Station name	Latitude (North)	Longitude (West)
2343200	Pataula Creek near Lumpkin, Ga.	31°56'04"	84°48'12"
2343801	Chattahoochee River near Columbia, Ala.	31°15'34"	85°06'37"
2343940	Sawhatchee Creek at Cedar Springs, Ga.	31°10'41"	85°02'37"
2349000	Whitewater Creek below Rambulette Creek near Butler, Ga.	32°28'01"	84°15'58"
2349500	Flint River at Montezuma, Ga.	32°17'54"	84°02'38"
2349660	Sweetwater Creek at Andersonville, Ga.	32°11'10"	84°08'03"
2349740	Hogcrawl Creek (S-533) near Montezuma, Ga.	32°13'03"	83°59'30"
2349800	Flint River near Methvins, Ga.	32°07'29"	84°00'43"
2349900	Turkey Creek at Byromville, Ga	32°11'45"	83°54'03"
2349910	Turkey Creek (County Road) near Drayton, Georgia	32°06'14"	83°56'23"
2349960	Little Pennahatchee Creek near Lilly, Ga.	32°07'01"	83°51'44"
2349980	Pennahatchee Creek (County Road) near Drayton, Ga.	32°05'44"	83°55'04"
2350080	Lime Creek near Cobb, Ga	32°02'07"	83°59'33"
2350220	Gum Creek (U.S. Hwy. 280) at Coney, Ga.	31°57'41"	83°53'05"
2350300	Cedar Creek near Cordele, Ga.	31°54'46"	83°51'18"
2350360	Swift Creek near Warwick, Ga.	31°50'21"	83°51'18"
2350405	Flint River near Warwick, Ga.	31°50'57"	83°56'50"
2350509	Jones Creek near Oakfield, Ga.	31°45'34"	83°58'42"
2350512	Flint River at Ga. 32, near Oakfield, Ga.	31°43'31"	84°01'07"
2350524	Abrams Creek near Oakfield, Ga.	31°43'08"	83°59'19"
2350527	Mill Creek near Albany, Ga.	31°40'05"	83°59'48"
2350543	Piney Woods Creek above Albany, Ga.	31°36'09"	84°02'58"
2350600	Kinchafoonee Creek at Preston, Ga	32°03'10"	84°32'54"
2350860	Kinchafoonee Creek (Ga. 118) near Smithville, Ga.	31°52'07"	84°18'18"
2350900	Kinchafoonee Creek near Dawson, Ga.	31°45'53"	84°15'12"
2351000	Kinchafoonee Creek (Ga. Hwy. 32) near Leesburg, Ga.	31°43'11"	84°11'08"
2351500	Muckalee Creek near Americus, Ga.	32°05'00"	84°15'29"
2351700	Muckalee Creek near Smithville, Ga.	31°53'44"	84°11'52"
2351780	Muckaloochee Creek near Americus, Ga.	31°58'38"	84°18'12"
2351800	Muckaloochee Creek at Smithville, Ga.	31°54'20"	84°14'44"
2351890	Muckalee Creek at Ga. 195, near Leesburg, Ga.	31°46'35"	84°08'22"
2351900	Muckalee Creek near Leesburg, Ga.	31°43'56"	84°07'30"
2351930	Muckalee Creek below Leesburg, Ga.	31°39'06"	84°06'27"
2352500	Flint River at Albany, Ga.	31°35'40"	84°08'39"
2352760	Dry Creek near Putney, Ga.	31°27'05"	84°08'07"
2352790	Flint River (Putney Intake) near Putney, Ga.	31°26'40"	84°08'16"
2352920	Raccoon Creek at Ga. Hwy. 3 near Baconton, Ga.	31°21'49"	84°10'04"
2352970	Cooleewahee Creek near Albany, Ga.	31°30'14"	84°17'28"
2352980	Cooleewahee Creek near Newton, Ga.	31°19'49"	84°19'50"

Appendix B. Streamgaging stations measured in the lower Apalachicola–Chattahoochee–Flint River Basin, 1999–2000—Continued

Station number	Station name	Latitude (North)	Longitude (West)
2353000	Flint River at Newton, Ga.	31°18'25"	84°20'19"
2353100	Ichawaynochaway C (U.S. Hwy. 82) near Graves, Ga.	31°46'17"	84°33'44"
2353200	Little Ichawaynochaway Creek near Shellman, Ga.	31°46'46"	84°36'13"
2353265	Ichawaynochaway Creek at Ga. 37, Near Morgan, Ga.	31°31'38"	84°34'58"
2353350	Carter Creek near Carnegie, Ga.	31°38'13"	84°43'14"
2353400	Pachitla Creek near Edison, Ga.	31°33'18"	84°40'43"
2353460	Ichawaynochaway Creek at State Rt. 62 near Leary, Ga.	31°28'10"	84°34'15"
2353500	Ichawaynochaway Creek at Milford, Ga.	31°22'59"	84°32'52"
2354300	Chickasawhatchee Creek near Dawson, Ga.	31°39'11"	84°25'46"
2354350	Chickasawhatchee Creek near Albany, Ga.	31°35'38"	84°27'12"
2354410	Chickasawhatchee Creek near Leary, Ga.	31°30'14"	84°25'50"
2354440	Kiokee Creek near Pretoria, Ga.	31°30'14"	84°22'01"
2354500	Chickasawhatchee Creek at Elmodel, Ga.	31°21'03"	84°28'57"
2354800	Ichawaynochaway Creek near Elmodel, Ga.	31°17'43"	84°29'17"
2355350	Ichawaynochaway Creek below Newton, Ga.	31°12'49"	84°28'24"
2355600	Big Cypress Creek near Newton, Ga.	31°12'15"	84°29'53"
2355660	Flint River near Camilla, Ga.	31°09'09"	84°28'57"
2355700	Flint River (Aux.) above Bainbridge, Ga.	30°57'16"	84°33'47"
2355785	Big Slough (SR 97) near Camilla, Ga.	31°13'07"	84°15'08"
2355830	Big Slough (SR 65) below Camilla, Ga.	31°09'03"	84°17'19"
2355880	Big Slough at Ga. 179 near Pelham, Ga.	31°05'25"	84°19'32"
2355950	Big Slough at Ga. Hwy. 97 near Bainbridge, Ga.	30°56'06"	84°31'23"
2356100	Spring Creek near Arlington, Ga.	31°24'48"	84°46'33"
2356220	Spring Creek at State Route 200 at Damascus, Ga.	31°18'21"	84°44'59"
2356290	Dry Creek near Blakely, Ga.	31°22'23"	84°52'59"
2356460	Dry Creek at Hentown, Ga.	31°17'03"	84°49'10"
2356600	Long Branch near Colquitt, Ga.	31°12'50"	84°43'54"
2356640	Spring Creek at U.S. 27, at Colquitt, Ga	31°10'15"	84°44'34"
2356970	Aycocks Creek below Colquitt, Ga.	31°06'20"	84°46'46"
2357000	Spring Creek near Iron City, Ga.	31°02'24"	84°44'18"
2357050	Spring Creek (U.S. Hwy. 84) at Brinson, Ga.	30°58'31"	84°44'44"
2357310	Fishpond Drain near Donalsonville, Ga.	30°58'45"	84°52'17"
2358000	Apalachicola River at Chattahoochee, Fla.	30°42'04"	84°51'33"
2358500	North Mosquito Creek at Chattahoochee, Fla.	30°42'09"	84°49'35"
2358519	Mosquito Creek at Chattahoochee, Fla.	30°41'20"	84°50'30"

APPENDIX C.—SPRINGS MEASURED IN THE LOWER APALACHICOLA–CHATTAHOOCHEE–FLINT RIVER BASIN, 1999–2000

Appendix C. Springs measured in the lower Apalachicola–Chattahoochee–Flint River Basin,1999–2000

Spring Name	Latitude (North)	Longitude (West)
Abrams Blue Hole	31°40'59"	83°55'41"
Blow Hole	31°32'47"	84°08'36"
Cow Pasture Spring	31°06'10"	84°30'28"
Crystal Cove Spring	31°25'42"	84°08'44"
Heli Hole	31°08'15"	84°28'59"
Hog Parlor	31°01'59"	84°30'43"
Mercer Mill Spring	31°41'03"	83°59'26"
New Hole	31°07'44"	84°29'15"
Punks Ramp Spring	31°23'24"	84°08'31"
Radium Spring	31°31'35"	84°08'12"
Vine Spring	31°24'43"	84°10'26"
Wall Spring	31°25'54"	84°08'35"