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U.S. GEOLOGICAL SURVEY

Prepared in cooperation with the

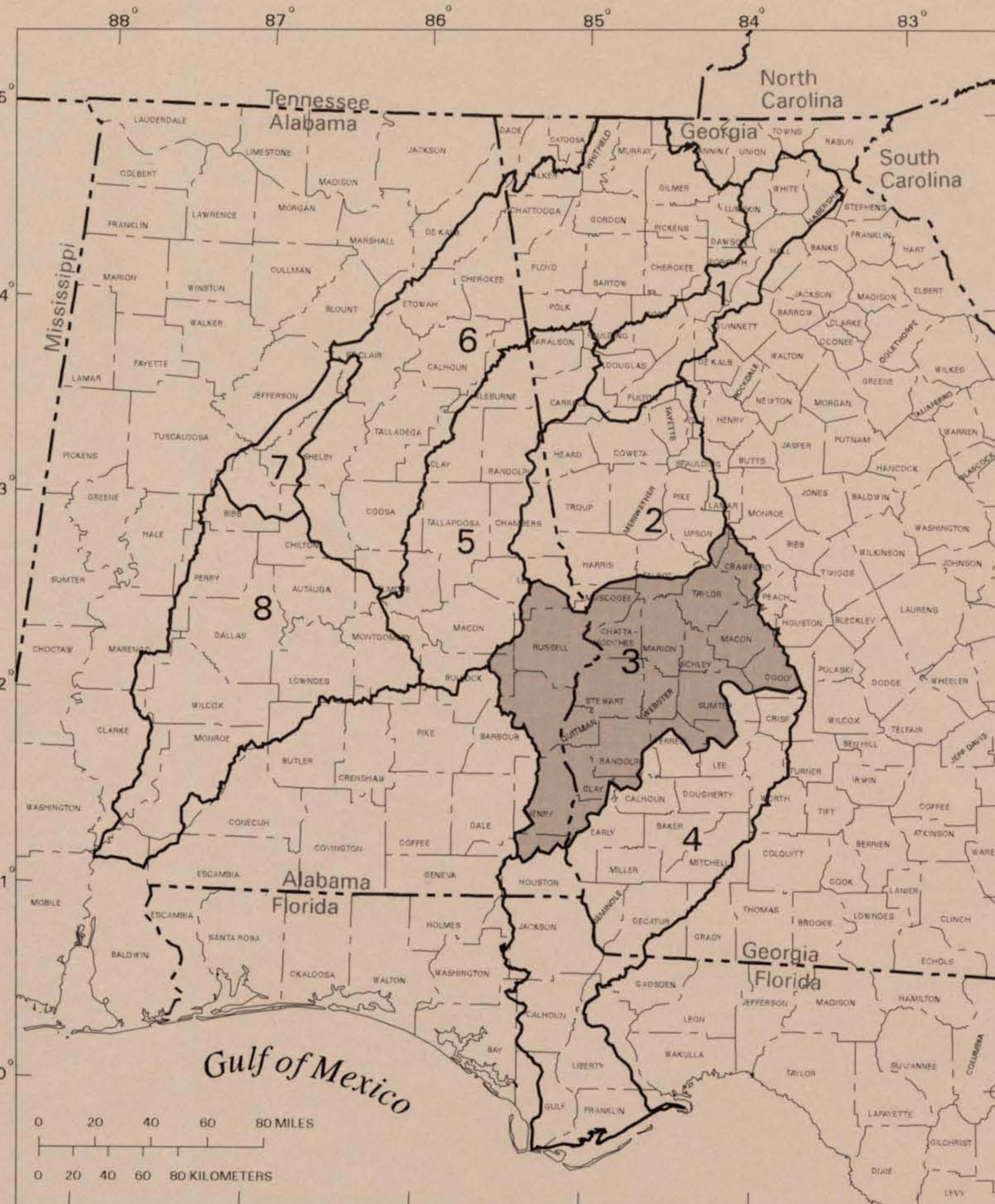
**ALABAMA DEPARTMENT OF ECONOMIC AND COMMUNITY AFFAIRS
OFFICE OF WATER RESOURCES**

**GEORGIA DEPARTMENT OF NATURAL RESOURCES
ENVIRONMENTAL PROTECTION DIVISION**

NORTHWEST FLORIDA WATER MANAGEMENT DISTRICT

**U.S. ARMY CORPS OF ENGINEERS
MOBILE DISTRICT**

Open-File Report 96-492



Base from 1:100000 and 1:250000
USGS Digital Line Graph

Location of subareas in the Apalachicola–Chattahoochee–Flint and Alabama–Coosa–Tallapoosa River basins. Subarea described in this report is shaded.

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NORTHWEST FLORIDA WATER MANAGEMENT DISTRICT

U.S. ARMY CORPS OF ENGINEERS, MOBILE DISTRICT

Atlanta, Georgia

1997

U.S. DEPARTMENT OF THE INTERIOR

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CONVERSION FACTORS

Multiply	by	to obtain
	Length	
inch (in.)	25.4	millimeter
inch per year (in/yr)	25.4	millimeter per year
foot (ft)	0.3048	meter
square foot (ft^2)	0.0929	square meter
mile (mi)	1.609	kilometer
feet per mile (ft/mi)	0.1894	meter per kilometer
	Area	
acre	4,047	square meter
square mile (mi^2)	2.59	square kilometer
	Volumetric rate and volume	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
	448.831	gallon per minute
	0.6463	million gallons per day
cubic foot per second per square mile ($ft^3/s/mi^2$)	0.01093	cubic meter per second per square kilometer
gallon per minute (gal/min)	6.309×10^{-5}	cubic meter per second
	2.228×10^{-3}	cubic foot per second
	0.06308	liter per second
	1,440	gallon per day
gallon per day (gal/d)	3.785×10^{-3}	cubic meters per day
million gallons per day (Mgal/d)	1.547	cubic foot per second
	63.09	cubic meter per second
	694.44	gallons per minute
gallon per minute per foot of drawdown (gal/min/ft)	1.24×10^{-2}	cubic meters per minute per minute per meter of drawdown
acre-foot	325,900	gallon
	Transmissivity	
foot squared per day (ft^2/d)	0.0929	meter squared per day

Temperature

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

C = 5/9 x (° F - 32)

ABBREVIATIONS AND ACRONYMS

7Q2	7-day, 2-year low flow
ACF	Apalachicola-Chattahoochee-Flint River basin
ACT	Alabama-Coosa-Tallapoosa River basin
ADAPS	Automated Data Processing System
Corps	U.S. Army Corps of Engineers
MOA	Memorandum of Agreement
GWSI	Ground Water Site Inventory database
MOVE.1	Maintenance of Variance Extension, Type 1; computer program (Hirsch, 1982)
RORA	Computer program (Rutledge, 1993)
SWGW	Surface Water-Ground Water; computer program (Mayer and Jones, 1996)
USGS	U.S. Geological Survey

VERTICAL DATUM

Sea Level: In this report, “sea level” refers to the National Geodetic Vertical Datum of 1929 (NVGD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

GLOSSARY

7Q2—Minimum average stream discharge for 7 consecutive days for a 2-year recurrence interval.

Alluvium—Sediment transported and deposited by flowing water.

Altitude—As used in this report, refers to the distance above sea level.

Anisotropic—Condition having varying hydraulic properties of an aquifer according to flow direction.

Annual—As used in this report, refers to a water year.

Aquifer—A formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs.

Artesian—Synonymous with confined.

Baseflow—That part of the stream discharge that is not attributable to direct runoff from precipitation or melting snow; it is usually sustained by ground-water discharge.

Bedrock—A general term for the consolidated rock that underlies soils or other unconsolidated surficial material.

Clastics—Rocks composed of fragments of older rocks, for example, sandstone.

Colluvium—Heterogeneous aggregates of rock detritus resulting from the transporting action of gravity.

Cone of depression—A depression of the potentiometric surface, often in the shape of an inverted cone, that develops around a well which is being pumped.

Confined aquifer—An aquifer bounded above and below by impermeable beds or by beds of distinctly lower permeability than that of the aquifer itself; ground water in the aquifer is under pressure significantly greater than that of the atmosphere.

Continuous-record gaging station—Complete records of discharge obtained using a continuous stage-recording device through which either instantaneous or mean-daily discharge may be computed for any time, or any period of time, during the period of record.

Crystalline rock—A general term for igneous and metamorphic rocks.

Darcian flow—Flow that is laminar and in which inertia can be neglected.

Dendritic drainage—A branching stream pattern that resembles the branching of trees.

Drought—There is no accepted definition of drought. As used in this report, a period of deficient rainfall extending long enough to cause streamflow to fall to unusually low levels for the period of record.

Evapotranspiration—The combined evaporation of water from the soil surface and transpiration from plants.

Faults—Fractures in the Earth along which there has been displacement parallel to the fault plane.

Foliation—A planar or layered structure in metamorphic rocks that is caused by parallel orientation of minerals or bands of minerals.

Fluvial—Pertaining to the actions of rivers.

Fracture—Breaks in rocks due to intense folding or faulting.

Geologic contact—The boundary surface between one body of rock or sediment and another.

Ground-water recharge—The process of water addition to the saturated zone or the volume of water added by this process.

Head, static—The height above a standard datum of the surface of a column of water (or other liquid) that can be supported by the static pressure at a given point. The static head is the sum of the elevation head and the pressure head.

Head, total—The total head of a liquid at a given point is the sum of three components:
(a) the elevation head, which is equal to the elevation of the point above a datum, (b) the pressure head, which is the height of a column of static water that can be supported by the static pressure at the point, and (c) the velocity head, which is the height to which the kinetic energy of the liquid is capable of lifting the liquid.

GLOSSARY—Continued

Heterogeneous—Pertaining to a substance having different characteristics in differing locations.

Hydraulic conductivity—The capacity of a rock to transmit water. It is expressed as the volume of water that will move through a medium in a unit of time under a unit hydraulic gradient through a unit area measured perpendicular to the direction of flow.

Hydraulic gradient—A change in the static pressure of ground water, expressed in terms of the height of water above a datum, per unit of distance in a given direction.

Hydrograph separation—Division of the stream hydrograph into components of aquifer discharge and surface runoff.

Igneous rock—Rocks which have solidified or crystallized from a hot fluid mass called magma.

Intergranular porosity—Porosity resulting from space between grains.

Intrusive igneous rocks—Masses of igneous rock formed by magma cooling beneath the surface.

Isotropic—Condition in which hydraulic properties of an aquifer are equal in all directions.

Joints—Fractures in rocks, often across bedding planes, along which little or no movement has taken place.

Mafic—Applied to the ferromagnesian minerals or to igneous rocks relatively rich in such minerals.

Mean annual—As used in this report, refers to the average of the annual values for a specified period of record.

Metamorphic rock—Rocks derived from pre-existing rocks by mineralogical, chemical, and structural alterations due to endogenetic processes.

Partial-record gaging station—Is a particular site where limited streamflow and/or water-quality data are collected systematically over a period of years.

Permeability—The property of a porous medium to transmit fluids under an hydraulic gradient.

Porosity—The amount of pore space and fracture openings, expressed as the ratio of the volume of pores and openings to the volume of rock.

Potentiometric surface—An imaginary surface representing the static head of ground water and defined by the level to which water will rise in a tightly cased well.

Primary porosity—Porosity due to the soil or rock matrix; the original interstices created when a rock was formed.

Recession index—The number of days required for discharge to decline one complete log cycle.

Regolith—Loose, unconsolidated and weathered rock and soil covering bedrock.

Residuum—The material resulting from the decomposition of rocks in place and consisting of the nearly insoluble material left after all the more readily soluble constituents of the rocks have been removed.

Rock—Any naturally formed consolidated material consisting of two or more minerals.

Run-off—Precipitation that flows from the surface of the land and into streams and rivers.

Saprolite—Surficial deposits produced by the decay of rocks and remaining as residuals.

Secondary openings—Voids produced in rocks subsequent to their formation through processes such as solution, weathering, or movement.

Secondary porosity—Porosity due to such phenomena as dissolution or structurally controlled fracturing.

Soil—The layer of unconsolidated material at the land surface that supports plant growth.

Specific capacity—The rate of discharge of water from the well divided by the related drawdown of the water level within the well.

GLOSSARY—Continued

Specific yield—The ratio of the volume of water which the porous medium after being saturated, will yield by gravity to the volume of the porous medium.

Storage coefficient—The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head (virtually equal to the specific yield in an unconfined aquifer).

Stream discharge—The volume of water flowing past a given point in a stream channel in a given period of time.

Transmissivity—The rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of an aquifer under a unit hydraulic gradient. It equals the hydraulic conductivity multiplied by the aquifer thickness.

Trellis drainage—A river system resembling a trellis or rectangular pattern and characteristic of areas of folded sedimentary rocks where tributaries cut channels through less resistant beds.

Unconfined aquifer—An aquifer in which the water table is a free surface at atmospheric pressure.

Unit-area discharge—Stream or ground-water discharge divided by the drainage area.

Water table—Upper surface of a zone of saturation under atmospheric pressure.

Water year—The standard water-year used by the U.S. Geological Survey is from October 1 to September 30 of the second calendar year.

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By Gregory C. Mayer

ABSTRACT

Drought conditions in the 1980's focused attention on the multiple uses of the surface- and ground-water resources in the Apalachicola-Chattahoochee-Flint (ACF) and Alabama-Coosa-Tallapoosa (ACT) River basins in Georgia, Alabama, and Florida. State and Federal agencies also have proposed projects that would require additional water resources and revise operating practices within the river basins. The existing and proposed water projects create conflicting demands for water by the States and emphasize the problem of water-resource allocation. This study was initiated to describe ground-water availability in the lower-middle Chattahoochee River basin of Georgia and Alabama; and middle Flint River basin of Georgia, Subarea 3 of the ACF and ACT River basins, and to estimate the possible effects of increased ground-water use within the basin.

Subarea 3 encompasses about 6,180 square miles (mi^2) of the Coastal Plain Province in southwestern Georgia and southeastern Alabama. About 55 percent of the area is drained by the Chattahoochee River, with the remainder drained by the Flint River. The drainage area of the Chattahoochee River is divided almost equally between Alabama and Georgia.

Subarea 3 is underlain by complexly interbedded sedimentary strata that dip gently to the southeast, underlying the Floridan aquifer system to the south. The strata comprise numerous porous-media aquifers and confining units that crop out in the northern part of Subarea 3 in generally northeast-trending bands.

The conceptual model described for this study qualitatively subdivides the ground-water flow system into local (shallow), intermediate, and regional (deep) flow regimes. Ground-water discharge to tributaries mainly is from local and intermediate flow regimes and varies seasonally. The regional flow regime probably approximates steady-state conditions and discharges chiefly to major drains such as the Chattahoochee River. Ground-water discharge to major drains originates from all flow regimes.

Mean-annual baseflow is about 1,618 cubic feet per second (ft^3/s) in the Chattahoochee River; and about 1,812 ft^3/s in the Flint River. Of the 1,618 ft^3/s baseflow in the Chattahoochee, about 37 percent is discharge from Alabama and 63 percent is discharge from Georgia. Near the end of the drought of 1954, baseflow was about 579 ft^3/s in the Chattahoochee River; and about 963 ft^3/s in the Flint River. Of the 579 ft^3/s drought baseflow in the Chattahoochee River, about 15 percent was from Alabama and 85 percent from Georgia. Baseflow in Subarea 3 during the drought of 1954 was about 45 percent of mean-annual baseflow. Near the end of the drought of 1986, baseflow was about 449 ft^3/s in the Chattahoochee River and about 498 ft^3/s in the Flint River. Of the 449 ft^3/s baseflow in the Chattahoochee River, about 16 percent was discharge from Alabama and 84 percent was discharge from Georgia. Baseflow in Subarea 3 during the 1986 drought was about 28 percent of mean-annual baseflow.

The potential exists for the development of ground-water resources on a regional scale throughout Subarea 3. Estimated ground-water use in 1990 was about 2.2 percent of the estimated mean-annual baseflow, and ranged from about 4.9 to 8.0 percent of baseflows near the end of the droughts of 1954 and 1986, respectively. Because ground-water use in Subarea 3 represents a relatively minor percentage of ground-water recharge, even a large increase in ground-water use in Subarea 3 in one State is likely to have little effect on ground-water and surface-water occurrence in the other. Indications of long-term ground-water level declines were not observed; however, the number and distribution of observation wells having long-term water-level measurements in Subarea 3 are insufficient to draw conclusions.

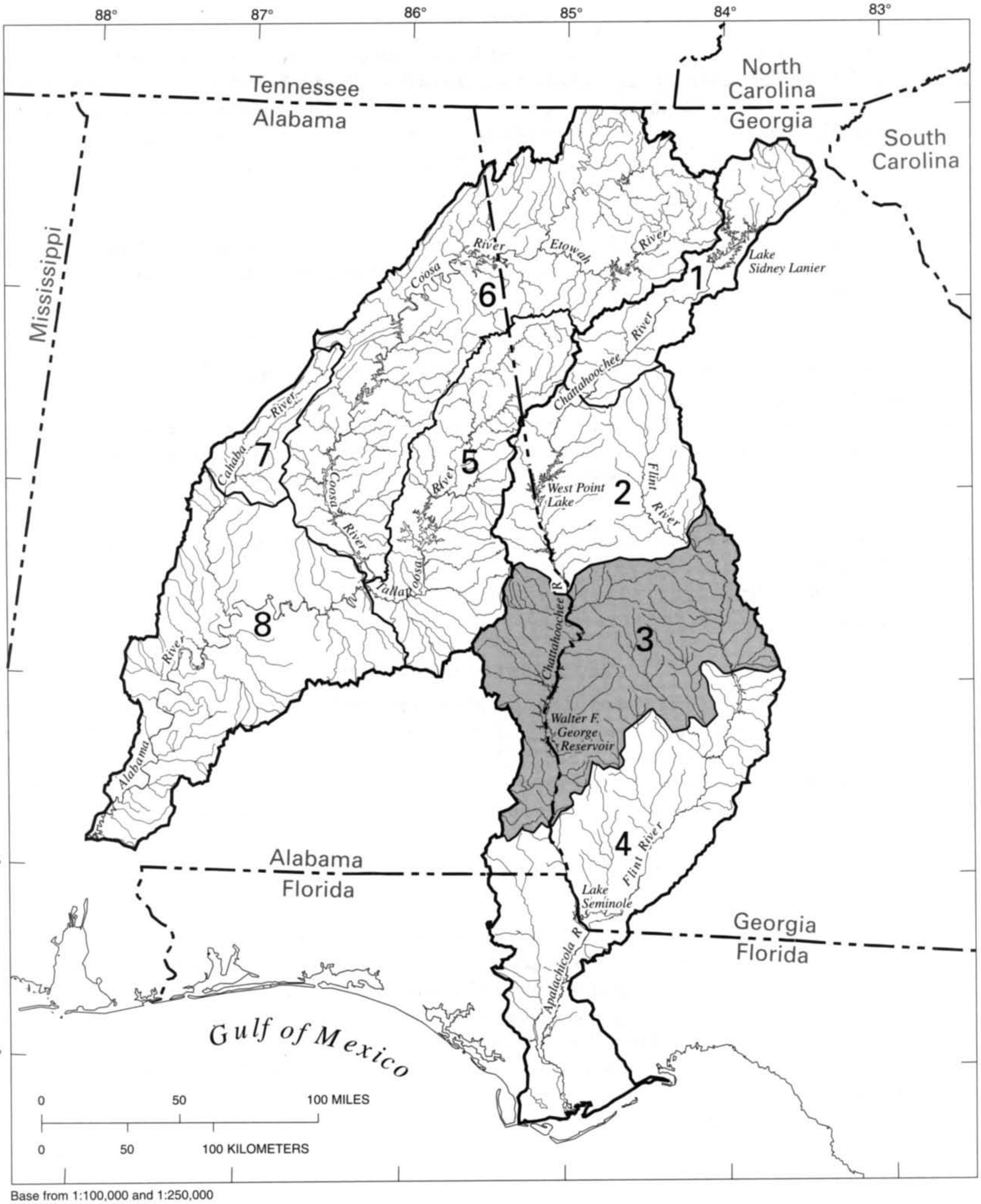
INTRODUCTION

Increased and competing demands for water and the droughts of 1980-81, 1986, and 1988 in the Apalachicola-Chattahoochee-Flint (ACF) and Alabama-Coosa-Tallapoosa (ACT) River basins have focused the attention of water managers and users in Alabama, Florida, and Georgia, on the water resources in the two basins. The ACF-ACT River basins encompass about 42,400 square miles (mi^2) and extend from near the Georgia-Tennessee State line, through most of central and southern Alabama and Georgia and part of the Florida panhandle to the Gulf of Mexico (fig. 1). Ground- and surface-water systems of the ACF-ACT River basins behave as an integrated, dynamic flow system comprised of an interconnected network of aquifers, streams, reservoirs, control structures, floodplains, and estuaries. The degree of hydrologic interaction between ground water and surface water suggests that the water resources be investigated and managed as a single hydrologic entity, to account for the climatic and anthropogenic factors that influence the flow systems.

Recent water projects and resource allocations, and other actions proposed by Federal, State, and local agencies, have resulted in conflicts among the States of Alabama, Florida, and Georgia, and the U.S. Army Corps of Engineers (Corps). The Corps has been given the authority to regulate the Nation’s surface waters through the Rivers and Harbors Act of 1927, in accordance with the U.S. House of Representatives Document Number 308, 69th U.S. Congress. Proposed projects designed to increase development and to re-allocate surface-water supplies in Georgia, based on revised operating practices of control structures for flood control, navigation, and hydropower generation, and a proposal to construct a dam and reservoir have met with opposition from Alabama and Florida. As a result, in 1991, the U.S. Congress authorized the Corps to initiate a Comprehensive Study of the ACF-ACT River basins that would “develop the needed basin and water-resources data and recommend an interstate mechanism for resolving issues” (Draft Plan of Study, Comprehensive Study, Alabama-Coosa-Tallapoosa and Apalachicola-Chattahoochee-Flint River basins, prepared by: The Comprehensive Study Technical Coordination Group, July 1991, U.S. Army Corps of Engineers, Mobile District).

In 1992, the Governors of Alabama, Florida, and Georgia; and the U.S. Army, Assistant Secretary for Civil Works, signed a Memorandum of Agreement establishing a partnership to address interstate water-resource issues and promote coordinated systemwide management of water resources. An important part of this process is the Comprehensive Study of the ACF and ACT River basins. Since this signing, the Study Partners defined scopes of work to develop relevant technical information, strategies, and plans, and to recommend a formal coordination mechanism for the long-term, basinwide management and use of water resources needed to meet environmental, public health, and economic needs (U.S. Army Corps of Engineers, written commun., 1993). The U.S. Geological Survey (USGS) was requested to assist in the development of a scope of work for the ground-water-supply element of the Comprehensive Study, and in June 1993, was asked to conduct that study element.

Eight subareas of the ACF-ACT River basins were identified by the Study Partners and the USGS on the basis of hydrologic and physiographic boundaries. Addressing the study at the smaller, subarea scale within the ACF-ACT River basins facilitated evaluation of the ground-water resources on a more detailed scale. This report is one of a series of eight reports that present results of ground-water studies of the eight ACF-ACT subareas.



Base from 1:100,000 and 1:250,000
USGS Digital Line Graph

Figure 1. Subareas and major streams in the Apalachicola–Chattahoochee–Flint and Alabama–Coosa–Tallapoosa River basins.

Purpose and Scope

This report describes the ground-water resources of the lower-middle Chattahoochee River basin of Georgia and Alabama, and middle Flint River basin of Georgia—Subarea 3 of the ACF-ACT River basins. The report provides an analysis of ground-water resources that can be used to address resource-allocation alternatives created by existing and proposed uses of the water resources in the river basin. Specific objectives of this study were to:

- describe a conceptual model of ground-water flow and stream-aquifer relations;
- describe the hydrologic setting of Subarea 3;
- quantify mean-annual and drought period ground-water contributions to the Chattahoochee and Flint Rivers from Subarea 3, including separate computations of the contributions from Georgia and from Alabama; and
- describe and evaluate ground-water utilization and general development potential.

Findings contained herein are but one component of a multidiscipline assessment of issues related to the basinwide utilization and management of water. This report is not intended to provide definitive answers regarding the acceptability of ground-water-resource utilization or the potential for additional resource development. Such answers are dependent on the synthesis of results from all components of the Comprehensive Study and on subsequent consideration by the Federal, State, and local water-resource managers responsible for decision making within the basin.

The report scope includes literature and data searches and an assessment of existing geologic data. A conceptual model that describes the hydrologic processes governing the ground- and surface-water flow was developed, and an evaluation of ground-water utilization was made by compiling and evaluating existing hydrologic, geologic, climatologic, and water-use data. Field data were not collected during this study.

Physical Setting of Study Area

Subarea 3 encompasses an area of about 6,180 mi^2, about 75 percent of which is in southwestern Georgia, and about 25 percent of which is in southeastern Alabama. The eastern part is drained by the Flint River and the western part is drained by the Chattahoochee River. In Subarea 3, the drainage area of the Flint River is about 2,810 mi^2, and the drainage area of the Chattahoochee River is about 3,370 mi^2. The drainage area of the Chattahoochee River is almost equally divided between the two States encompassing about 1,670 mi^2 in Alabama and 1,700 mi^2 in Georgia. The Flint River basin lies wholly in Georgia. Subarea 3 is bounded to the north by Subarea 2, and to the south by Subarea 4 (fig. 1). The northwestern part of Subarea 3 is bounded by Subarea 5.

Physiography

Subarea 3 lies almost entirely (95 percent) within the Coastal Plain physiographic province (fig. 2), which extends into Subarea 4 to the south. All of the Georgia part of Subarea 3 is bounded to the north by the Piedmont Province, is highly dissected by streams, and has little level land surface other than floodplains (Clark and Zisa, 1976). Average altitude in Subarea 3 ranges from about 500 feet above sea level in the north to about 100 feet in the south. The physiography of Subarea 3 in Alabama has been described by Kidd (1987) and Scott and Cobb (1988). The part of Subarea 3 north of Uchee Creek in Alabama consists mainly of flat to moderately rolling sandy uplands dissected by deeply-entrenched streams (Kidd, 1989). From Uchee Creek south to about Barbour Creek, the physiography is characterized by sandy cuestas characterized by fairly steep north-facing escarpments and gently to moderately rolling backslopes. Farther south to central Henry County, Ala., the area is dissected by southward and southwestward-flowing streams (Kidd, 1989). The southernmost part of Subarea 3 in Alabama, drained by Omussee Creek, is a relatively flat upland that slopes gently southward except where dissected by streams (Scott and Cobb, 1988).

Climate

The climate in Subarea 3 is moist and temperate, and generally is characterized by short mild winters and hot humid summers. Winter temperatures generally are above freezing, but do occasionally drop below 20 ° F. Summer temperatures commonly are above 90 ° F, and temperatures above 100 ° F are common.

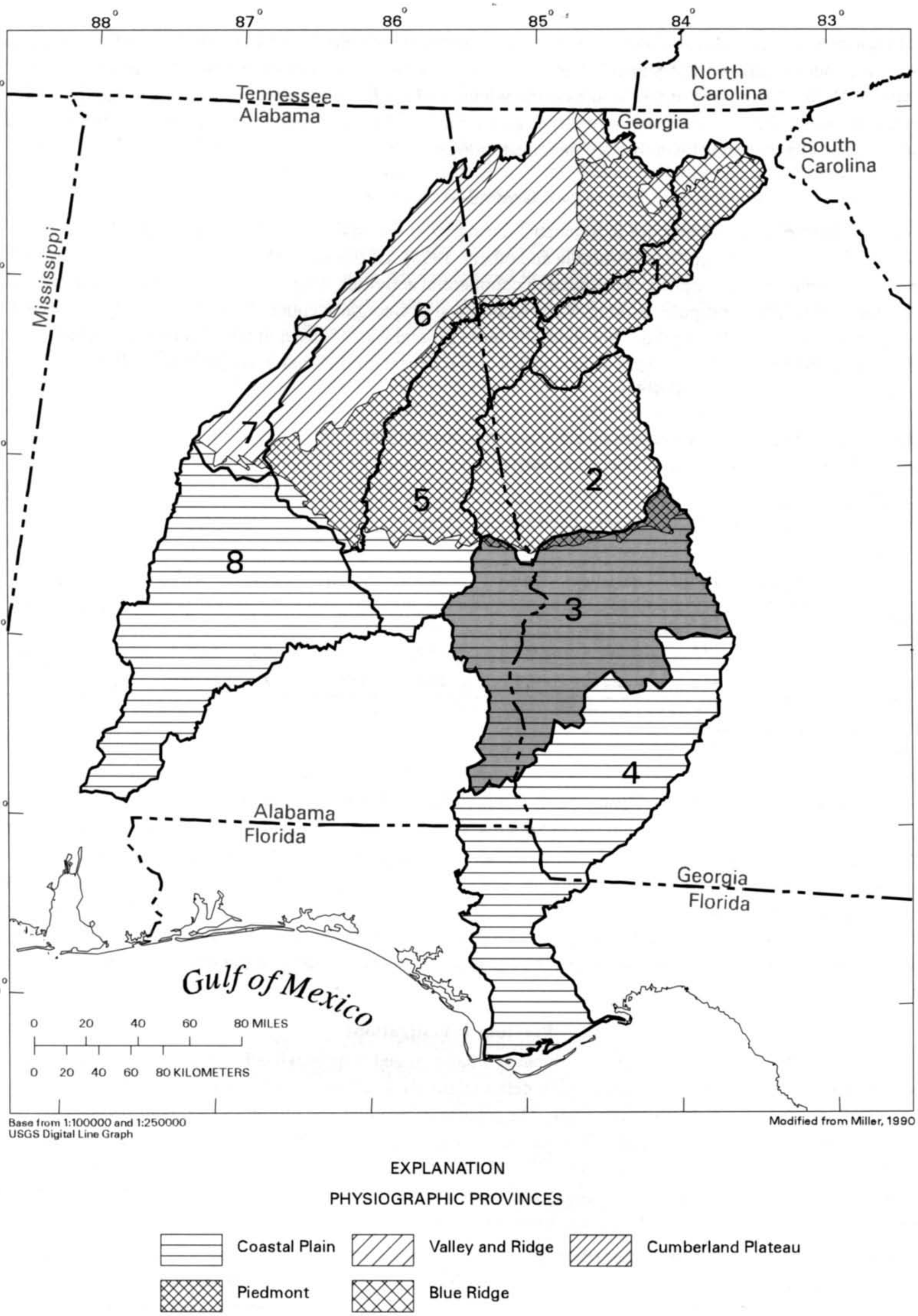


Figure 2. Physiographic provinces and subareas in the Apalachicola–Chattahoochee–Flint and Alabama–Coosa–Tallapoosa River basins.

Precipitation occurs almost completely as rainfall, and ranges from about 48 inches (in.) in the northeastern to 54 in. in the south-central part of Subarea 3. Rainfall generally increases from the northeast to the southwest (Faye and Mayer, 1990). Abundant rainfall occurs during winter, and gradually increases to a seasonal maximum in February or March. Rainfall intensity normally is greatest during July and August as a result of frequent summer thunderstorms. October and November are the driest months of the year.

Ground-Water Use

The estimated ground-water use in Subarea 3 during 1990 was about 56 million gallons per day (Mgal/d) or about 86 cubic feet per second (ft^3/s) (Marella and others, 1993). Of this total, about 40 percent was for public water supply, 13 percent for self-supplied industrial and commercial activities, 40 percent for agricultural use, and about 7 percent for domestic water supply. Ground-water withdrawal in Georgia accounts for approximately 70 percent of the total ground-water use of 56 Mgal/d. Substantially more ground water is used in Georgia than in Alabama, with the exception of public-water supply. Agricultural supply is the largest ground-water use in Georgia. Public water supply is the largest use in Alabama (table 1).

Table 1. Estimated ground-water use, by category, Subarea 3, 1990
[Mgal/d, million gallons per day; ft^3/s, cubic feet per second]

State	Public water supply		Self-supplied industrial and commercial		Agricultural		Domestic		Total	
	(Mgal/d)	(ft^3/s)	(Mgal/d)	(ft^3/s)	(Mgal/d)	(ft^3/s)	(Mgal/d)	(ft^3/s)	(Mgal/d)	(ft^3/s)
Georgia[1/]	9.5	14.7	7.2	11.1	18.7	28.9	3.3	5.1	38.7	59.9
Alabama[2/]	12.6	19.5	0.2	0.3	3.6	5.6	0.5	0.8	16.9	26.1
Subarea total	**22.1**	**34.2**	**7.4**	**11.4**	**22.3**	**34.5**	**3.8**	**5.9**	**55.6**	**86.0**

[1/]Fanning and others (1992).
[2/]Baker and Mooty (1993).

Ground-water use reported by Fanning and others (1992) and Baker and Mooty (1993) is by county; ground-water use in those counties that are partially in Subarea 3 are reported herein for Subarea 3 only. Ground-water use for public water supply, and self-supplied industrial and commercial uses were determined by using site-specific data. Ground-water pumpage for domestic purposes was determined by subtracting the population served by public supply facilities from the total population of the county or hydrologic unit, then multiplying that number by a water-use coefficient of 75 gallons per day (gal/d) per person. Agricultural ground-water use in Subarea 3 was estimated by multiplying the reported county use by the percentage of the land area of the county in the Chattahoochee and Flint River basins.

Previous Investigations

Geologic and hydrogeologic studies of Subarea 3 have ranged from localized to regional investigations. However, most investigations have addressed in detail relatively small areas, such as a few counties. Studies of a reconnaissance nature cover much larger areas. The science of geology and ground-water hydrogeology is evolutionary and recursive in nature, resulting in the advancement of knowledge and understanding. However, the different times that these advancements occurred, and the areas in which they occurred, led to disparities and differences in the interpretations of the geology and hydrogeology of adjoining areas. Resolving these disparities and differences in adjoining areas is well beyond the scope of this study.

Stephenson and Veatch (1915) described the geology of the Coastal Plain in Georgia by formation, including the areal extent, lithology, stratigraphic position, strike and dip of beds, thickness of rock units, paleontology and structure. Cooke (1943) described the general geology of the Coastal Plain in Georgia. Herrick (1961) advanced the knowledge of the geologic framework of the Coastal Plain in Georgia by publishing detailed lithologic logs. Marsalis and Friddell (1975) provided an overall description of the lithologic units exposed in the Chattahoochee River valley, including discussions of facies changes along strike and down dip. Gibson (1982) described six Paleocene and middle Eocene marine units in eastern Alabama and western Georgia that included discussions of composition, fossil assemblage, and nonmarine and marine transitions.

By the early 1950's, the demand for ground water had increased substantially and numerous investigations of ground-water hydrology were undertaken. As in most ground-water studies, investigation of the geology commonly was a substantial part of these efforts. Wait (1960a,b,c,) described the geology and ground-water resources in Calhoun, Clay, and Terrell Counties, Ga. Owen (1963) used available data to describe ground-water conditions in Lee and Sumter Counties, Ga. Stewart (1974) reported the hydraulic characteristics of the Clayton aquifer determined from aquifer tests performed during the design and construction of the Walter F. George Lock and Dam, in the Ft. Gaines, Ga., area. Pollard and Vorhis (1980) described the geohydrology of the Cretaceous aquifer system in Georgia. Ripy and others (1981) described the hydrogeology of the Clayton and Claiborne aquifers in southwest Georgia. Arora (1984) compiled an atlas of aquifers in the Coastal Plain of Georgia that included isopachs, structure contours, potentiometric surface maps, and cross-sections. McFadden and Perriello (1983) conducted a general study of the Clayton and Claiborne aquifers in southwestern Georgia inclusive of water-level trends, ground-water quality, ground-water use, aquifer geometry, lithologic and hydrologic characteristics, and recharge and discharge mechanisms. Clarke and others (1983, 1984) described and evaluated the effects of water use on the Providence and Clayton aquifers, respectively. Davis (1988) described the stratigraphic and hydrogeologic framework of the Cretaceous, Tertiary, and Quaternary Systems in Alabama to aid in delineating aquifers and confining units within the Alabama Coastal Plain. The geohydrology of southeastern Alabama was described in a series of reports produced by the USGS, in cooperation with the Alabama Department of Environmental Management (Kidd, 1987, 1989; and Scott and Cobb, 1988). Long (1989) compiled water-level, water-use, and water-quality information for the Clayton and Claiborne aquifers in Georgia between 1982-86. Ground-water flow and stream-aquifer relations in the outcrop areas of Coastal Plain sediments in Georgia and adjacent parts of Alabama were quantitatively described by Faye and Mayer (1990).

Recent ground-water levels in eastern Alabama were listed by county by Scott (1960, 1962a,b, 1964), Newton and others (1966), Scott and others (1967, 1968), Newton and others (1968), Newton, McCain and Avrett (1968), Shamburger and others (1968), Davis (1980), Scott and others (1984) and Moffett and others (1985). Potentiometric surfaces of the major aquifers in the Alabama Coastal Plain were described by Williams, DeJarnette, and Planert (1986), Williams, Planert and DeJarnette (1986a,b,c), Miller (1992), Mallory (1993), and Planert, Williams, and DeJarnette (1993).

Thompson and Carter (1955) described streamflow in Georgia near the end of the drought of 1954. Hale and others (1989) described streamflow in Alabama, Georgia, North Carolina, South Carolina, Tennessee, and Virginia during the drought of 1986.

Reports describing methods of estimating streamflow and ground-water discharge to streamflow include Bingham (1982), Hirsch (1982), Hoos (1990), Rorabaugh (1960, 1964), Rutledge (1991, 1992, 1993), and Mayer and Jones (1996). Data collected as part of the ongoing surface-water monitoring program of the USGS are published annually in the reports "Water-Resources Data, Alabama" (or Georgia, respectively). Other reports containing information about the surface- and ground-water resources of the ACF-ACT River basin area are listed in the "Selected References" section of this report.

Surface-Water Station Numbering System

The USGS established a standard identification numbering system for all surface-water stations in 1950. Stations are numbered according to downstream order. Stations on a tributary entering upstream of a main-stream station are numbered before and listed before the main-stream station. No distinction is made between continuous-record and partial-record stations. Each station has a unique eight-digit number that includes a two-digit part number (02 refers to natural drainage into the Eastern Gulf of Mexico) and a six digit downstream order number. Gaps are left in the series of numbers to allow for new stations that may be established; hence, the numbers are not consecutive. The complete number for each station includes a two-digit part number "02" plus the downstream-order number, which can be from 6 to 12 digits. All records for a drainage basin, encompassing more than one State, can easily be correlated by part number and arranged in downstream order.

Approach and Methods of Study

This study included several work elements used to appraise the ground-water resources of Subarea 3, including the description of a conceptual model of ground-water flow and stream-aquifer relations, and an assessment of ground-water availability. The approach and methods used to accomplish these tasks included:

- compilation of information and data from pertinent literature, including geologic, ground-water, streamflow, and ground-water use data;
- separation of streamflow hydrographs to estimate mean-annual ground-water contribution to the Chattahoochee and Flint Rivers and their tributaries;
- evaluation of streamflow records and periodic discharge measurements during drought periods to estimate "worst-case" streamflow conditions; and
- comparison of 1990 ground-water use with mean-annual and drought-flow conditions to evaluate ground-water availability.

Literature and data reviews provided information necessary to describe a conceptual model of ground-water/surface-water relations. Much of the conceptual model is based on results of previous investigations by Toth (1962, 1963), Freeze (1966), Freeze and Witherspoon (1966, 1967, 1968), Winter (1976), Faye and Mayer (1990), Heath (1984, 1989), and Miller (1990). These studies suggest that large rivers, such as the Chattahoochee, and their tributaries function as hydraulic drains for ground-water flow, and that during significant droughts, most of the discharge in these streams is contributed by ground water.

Streamflow data were compiled from the USGS Automated Data Processing System (ADAPS) database. Streamflow records from continuous-record and miscellaneous discharge-measurement stations were used for hydrograph-separation analyses and drought streamflow evaluation.

Stream-aquifer relations were quantified using two approaches: (1) the hydrograph-separation method of Rorabaugh (1960, 1964) and Daniel (1976), called the recession-curve-displacement method; and (2) a drought-flow mass-balance analysis of streamflow. The hydrograph-separation method was used to estimate the mean-annual discharge of ground water (baseflow) to the basins. The mean-annual baseflow was used as a base or reference with which to compare and evaluate droughts under "worst-case" conditions. The mass-balance analysis was used to estimate baseflow contributions to the surface-water system during historically significant droughts.

Mean-Annual Baseflow Analysis

Discharge data from continuous-record gaging stations along the Chattahoochee and Flint Rivers and their tributaries were selected for baseflow analysis based on the period of record of unregulated flow. Streamflow representative of low, average, and high years of stream discharge were evaluated by hydrograph-separation methods to estimate annual baseflow. The mean-annual baseflow was then computed as the average baseflow of the three representative flow years.

The selection process for the most representative year of low, average, and high stream discharge involved objective statistical examination of the discharge data, followed by some subjectivity in the final choice of the water year selected. Hydrographs acceptable for separation were characterized by relatively normal distributions of daily stream discharge, small ranges of discharge, and the absence of extremely high, isolated peak stream discharge. For each station, the mean annual stream discharge was computed for the period of record of unregulated flow and used as a reference mean for low-, average-, and high-flow conditions for that station. The mean- and median-annual stream discharge for those water years identified as acceptable were compared to the reference mean. Because extremely high discharge during a water year could greatly influence the mean but not the median (which is similar to the geometric mean for positively skewed data sets, such as discharge), the process of selecting representative water years for low-, average-, and high-flow conditions considered the position of the mean discharge for the selected year relative to the median and the reference mean. The hydrographs for these representative water years were examined and separated. True subjectivity in the selection process entered only at this point, such that, if acceptable hydrographs were available for several years, one year arbitrarily was chosen over the others.

The separation analyses were conducted using the computer program SWGW (Mayer and Jones, 1996) which is an automated version of the recession-curve-displacement method, often referred to as the Rorabaugh or Rorabaugh-Daniel method. SWGW was applied to a water-year period of streamflow data. SWGW utilizes daily mean discharge data collected at unregulated stream-gaging sites and requires at least 10 years of record to accurately estimate a recession index necessary for hydrograph-separation analysis.

The hydrograph-separation method estimates the ground-water component of total streamflow. In general, the streamflow hydrograph can be separated into two components—surface runoff and baseflow (ground-water discharge to streams). Figure 3 shows the graphical output from the SWGW program. Surface runoff is the quick response (peaks) of stream stage to precipitation and nearby overland flow.

Application of the recession-curve-displacement method requires the use of the streamflow recession index. The streamflow recession index is defined as the number of days required for baseflow to decline one order of magnitude (one log cycle), assuming no other additional recharge to the ground-water system. The streamflow recession index is a complex number that reflects the loss of ground water to evapotranspiration (Daniel, 1976) or leakage, and the influence of geologic heterogeneities in the basin (Horton, 1933; Riggs, 1963). The slope of the streamflow recession is affected by evapotranspiration, such that the streamflow recession index varies from a maximum during the major rise period to a minimum during the major recession period (fig. 3). The major rise period of streamflow generally occurs from November through March or April, when precipitation is greatest and evapotranspiration is least. The major recession period occurs during late spring through fall and coincides with a period of lesser precipitation, higher temperature, and greater evapotranspiration (fig. 3). Two recession indices were estimated for streamflow observed at each continuous-record gaging station used in the mean-annual baseflow analysis; one index for the major rise period and one for the major recession period.

Available ground-water-level data indicate that long-term changes in ground-water storage are minimal in Subarea 3. Because long-term storage changes are minimal, mean-annual ground-water discharge, estimated using the hydrograph-separation method, is considered an estimate of minimum mean-annual recharge. Also, aquifers at a regional scale in Subarea 3 are considered, for purposes of analysis, to respond as homogeneous and isotropic media.

Results of the mean-annual baseflow analysis are based on measured and estimated data, and the analytical methods to which they are applied. Drainage areas were measured using the most accurate maps available at the time of delineation (Novak, 1985), and are reported in units of square miles. Drainage areas are reported to the nearest square mile for areas greater than 100 mi^2; to the nearest tenth of a square mile for areas between 10 and 100 mi^2; and to the nearest hundredth of a square mile for areas less than 10 mi^2, if the maps and methods used justify this degree of accuracy (Novak, 1985). Annual stream discharge, the sum of the daily mean stream discharges for a given water year, is reported in units of cubic feet per second, to the nearest cubic foot per second. Daily mean discharge is reported to the nearest tenth of a cubic foot per second for discharge between 1.0 and 9.9 ft^3/s; to the nearest unit for discharge between 10 and 100 ft^3/s; and is reported using three significant figures for discharge equal to or greater than 100 ft^3/s (Novak, 1985).

The accuracy of stream-discharge records depends primarily on: (1) the stability of the stage-discharge relation or, if the control is unstable, the frequency of discharge measurements; and (2) the accuracy of measurements of stage and discharge, and the interpretation of records. Accuracy of records of streamflow data used in this report can be found in annually published USGS data reports, for example, Stokes and McFarlane (1994). The accuracy attributed to the records is indicated under “REMARKS” in the annual data reports for each station. “Excellent” means that about 95 percent of the daily discharges are within 5 percent of the true discharge; “good,” within 10 percent; and “fair,” within 15 percent. Records that do not meet these criteria are rated “poor.” The accuracy of streamflow records at a station may vary from year to year. In addition, different accuracies may be attributed to different parts of a given record during a single year (Novak, 1985).

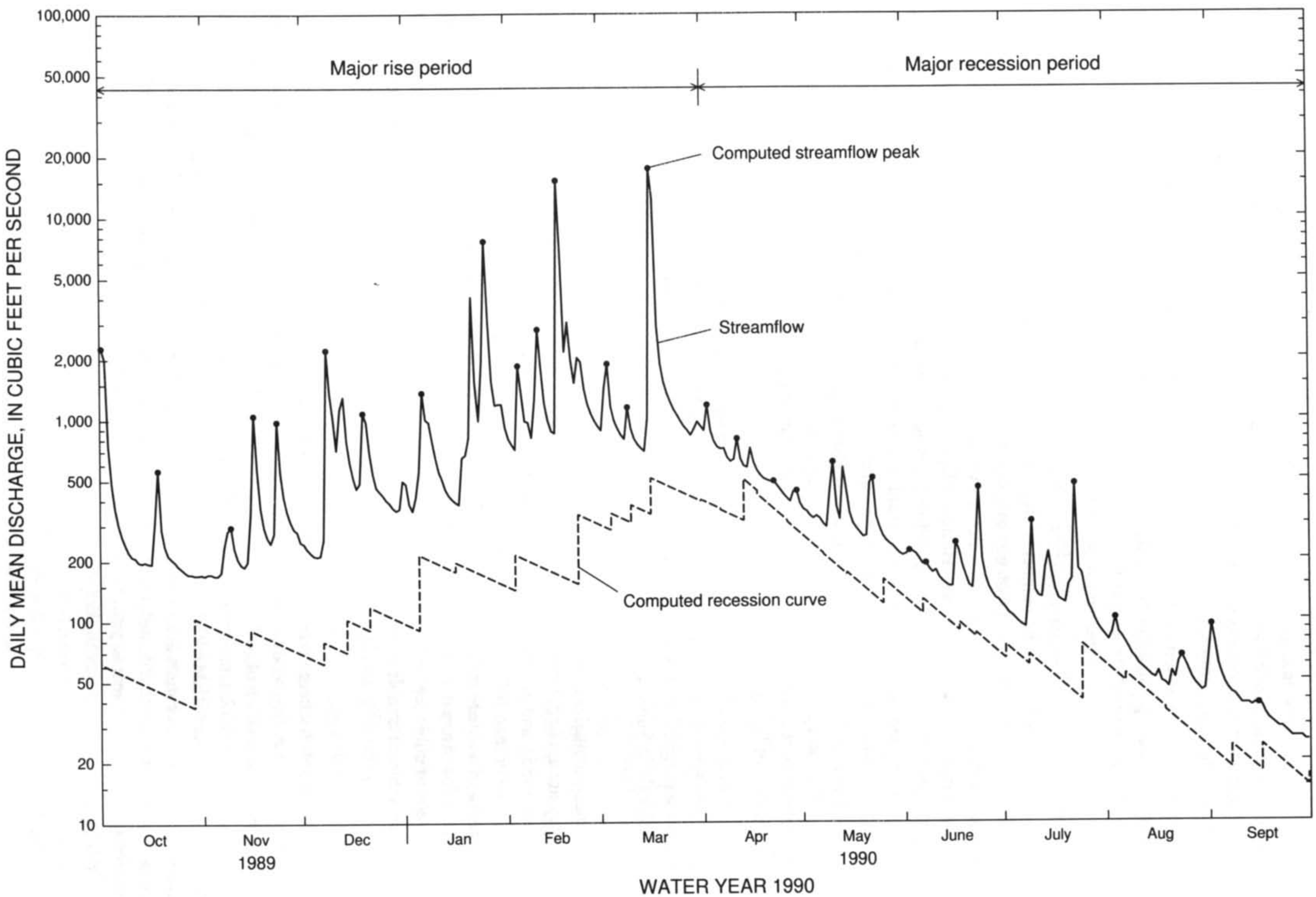


Figure 3. Streamflow hydrograph, separated by program SWGW.

Results of the mean-annual baseflow analyses are inherently uncertain. The hydrograph-separation method of analysis is partly subjective, relying on the input of several user-selected variables. As such, the results of the analyses derived and reported herein, are difficult to independently confirm and are presented as estimates of unknown quality and confidence. However, because the values in this report are used in several water budgets, not only within Subarea 3 but also from subarea to subarea, hydrograph-separation results may be reported to a greater significance than the data and analyses warrant to maintain the numerical balance of the water budget; implication of accuracy to the extent shown is not intended.

Drought-Flow Analysis

Daily mean streamflow data collected at gaging stations during periods of low flow and corresponding periodic measurements of stream discharge collected at partial-record stations were compiled for the drought years 1954 and 1986. These data included nearly concurrent daily measurements of streamflow in the Chattahoochee and Flint Rivers and periodic measurements of tributary discharge.

Standard periods of analyses for drought studies were selected for all ACF-ACT subareas. The period of analysis selected for compiling 1954 drought data was September 15 through November 1, 1954. The selected period for the 1986 drought was July 1 through August 14, 1986. Streamflow during these periods was considered to represent the “worst case” of ground-water storage and availability throughout the ACF-ACT study area. Discharge data for Subarea 3 are sparse during the 1941 drought; therefore, a standard period of analysis was not selected for the entire ACF-ACT study area.

The period of “worst-case” conditions may not include the minimum streamflow that occurred during a drought at a streamflow measurement site. Minimum drought flows typically occur at different times at different stations within large watersheds, such as the Chattahoochee River basin. Rather, the “worst-case” evaluation was designed to describe streamflow during the advanced stages of each drought; thus, providing a near-contemporaneous summary of streamflow conditions during periods of low flow throughout the ACF-ACT study area.

The estimated “worst-case” distribution of Chattahoochee and Flint Rivers streamflow near the end of the 1954 and 1986 drought periods was determined by balancing mass in the stream network in a general downstream direction during a relatively short interval of time. The tributary discharge to the Chattahoochee and Flint Rivers during drought periods was calculated using a unit-area discharge extrapolated to the entire drainage area of the tributary. Unit-area discharges are based on streamflow measurements that generally are inclusive of only part of the tributary drainage, and may not be representative of an average unit-area discharge for the entire tributary drainage.

CONCEPTUAL MODEL OF GROUND-WATER FLOW AND STREAM-AQUIFER RELATIONS

The conceptual model of the ground-water flow and stream-aquifer relations in Subarea 3 is based on previous work done in other areas by Toth (1962, 1963), Freeze (1966), Freeze and Witherspoon (1966, 1967, 1968), Winter (1976), and Faye and Mayer (1990). These studies suggest that recharge originates from precipitation that infiltrates the land surface, chiefly in upland areas, and percolates directly, or leaks downward to the water table. Ground water subsequently flows through the aquifer down the hydraulic gradient and either discharges to a surface-water body or continues downgradient into confined parts of an aquifer. Major elements of this conceptual model include descriptions of flow regimes, stream-aquifer relations, recharge to ground water, and ground-water discharge to streams.

Toth (1963) observed that most ground-water flow systems could be qualitatively subdivided into paths of local (shallow), intermediate, and regional (deep) flow. Local flow regimes are characterized by relatively shallow and short flow paths that extend from a topographic high to an adjacent topographic low. Intermediate flow paths are longer and somewhat deeper than local flow paths and contain at least one local flow path. Regional flow paths (fig. 4) begin at or near the major topographic (drainage) divide and terminate at the regional drain, which is the Chattahoochee River in Subarea 3. Depending on local hydrogeologic conditions, all three flow regimes may not be present everywhere within the subarea.

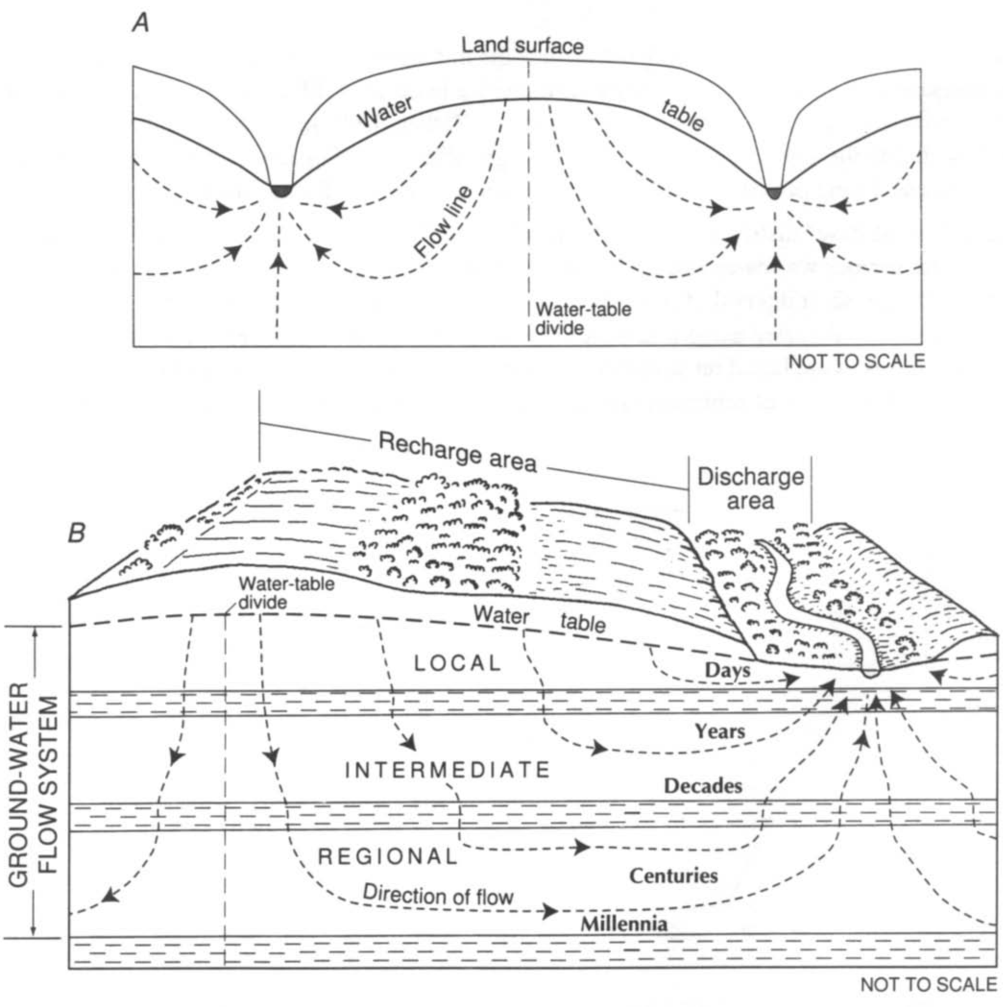


Figure 4. (*A*) Distribution of ground-water flow in an areally extensive, isotropic, homogeneous aquifer system (modified from Hubbert, 1940, and Heath, 1984) and (*B*) example of local, intermediate, and regional ground-water flow (modified from Heath, 1984).

The water table in Subarea 3 probably is a subdued replica of the land-surface topography but generally with less relief. The presence of ground-water flow regimes depends largely on the configuration of the water table, such that recharge occurs in highland areas and discharge occurs in lowland areas. Quantities of recharge to the water table and ground-water discharge to streams are variably distributed throughout the local, intermediate, and regional flow regimes. Local regimes receive the greatest ground-water recharge from the water table and provide the most ground-water discharge to streams. Faye and Mayer (1990) indicated that in the Coastal Plain aquifer system, under natural conditions, as much as 80 percent of the total ground-water recharge, discharges through the local and intermediate ground-water flow regimes to streams tributary to the large drains like the Chattahoochee River. Only about 10 percent of the total recharge discharges through the regional ground-water flow regime directly to the regional drains. The remaining 10 percent discharges to evapotranspiration and to the deeper confined parts of the aquifer system. Ground-water discharge to tributary drainages primarily is from local and intermediate flow regimes; ground-water discharge to regional drains, such as the Chattahoochee River includes contributions from the regional as well as local and intermediate regimes.

Seasonal variation in rainfall affects the local ground-water flow regime most significantly, and affects the regional flow regime least significantly. Generally, regional flow probably approximates steady-state conditions, and long-term recharge to and discharge from this regime will not vary significantly.

HYDROLOGIC SETTING

The hydrologic framework of Subarea 3 contains dynamic hydrologic systems consisting of aquifers, streams, reservoirs, and floodplains. These systems are interconnected and form a single hydrologic entity that is stressed by natural hydrologic and climatic factors and by anthropogenic factors (fig. 5). For this discussion, the hydrologic framework is separated into two systems: the ground-water system and surface-water system.

Ground-Water System

The ground-water system forms as geology and climate interact. Geology primarily determines the aquifer media, as well as the natural quality and quantity of ground water. Climate primarily influences the quantity of ground water.

Geology

A detailed description of the diverse and complex geology of Subarea 3 is beyond the scope of this study; however, a brief description of the geology of the subarea is presented, based on selected published descriptions of various geologic investigations. The “Selected References” section of this report lists selected geologic investigations.

The geologic sequence of Subarea 3 is mainly comprised of older sedimentary units exposed in the northern part of the area that are overlain by younger units that sequentially crop out south of each underlying unit. These geologic units generally dip south-southeastward at about 35 feet per mile from a featheredge at the Fall Line. The Fall Line is a physiographic boundary that generally coincides with the inner margin of Coastal Plain strata, and also approximates the northern boundary of Subarea 3 in Georgia and eastern Alabama.

A small part of Subarea 3 lies within the Piedmont Province (fig. 2) at the northern edge of the study area. The study area was defined this way to accommodate stream-drainage areas and streamflow-measurement sites. The igneous and metamorphic rocks exposed in this small part of the subarea are relatively impermeable and do not comprise a major aquifer in the study area.

The Coastal Plain sediments were deposited during a series of transgressions and regressions of the sea. Accordingly, the rocks represent depositional environments ranging from fluvial to shallow marine, with the exact location of each environment depending upon the relative positions of land masses, shorelines, and streams at a particular point in geologic time. Fluctuating depositional conditions account for the observed variations in sediment lithology in Subarea 3. As such, Coastal Plain sediments are comprised largely of sand and interbedded or lensoidal deposits of clay. Generally, the thickness and areal extent of most clays deposits are relatively small near the inner Coastal Plain margin; also, the distribution of these deposits is local. The thickness and areal extent of laterally continuous deposits of sand and clay progressively increase seaward of the outcrop area (Faye and Mayer, 1990).

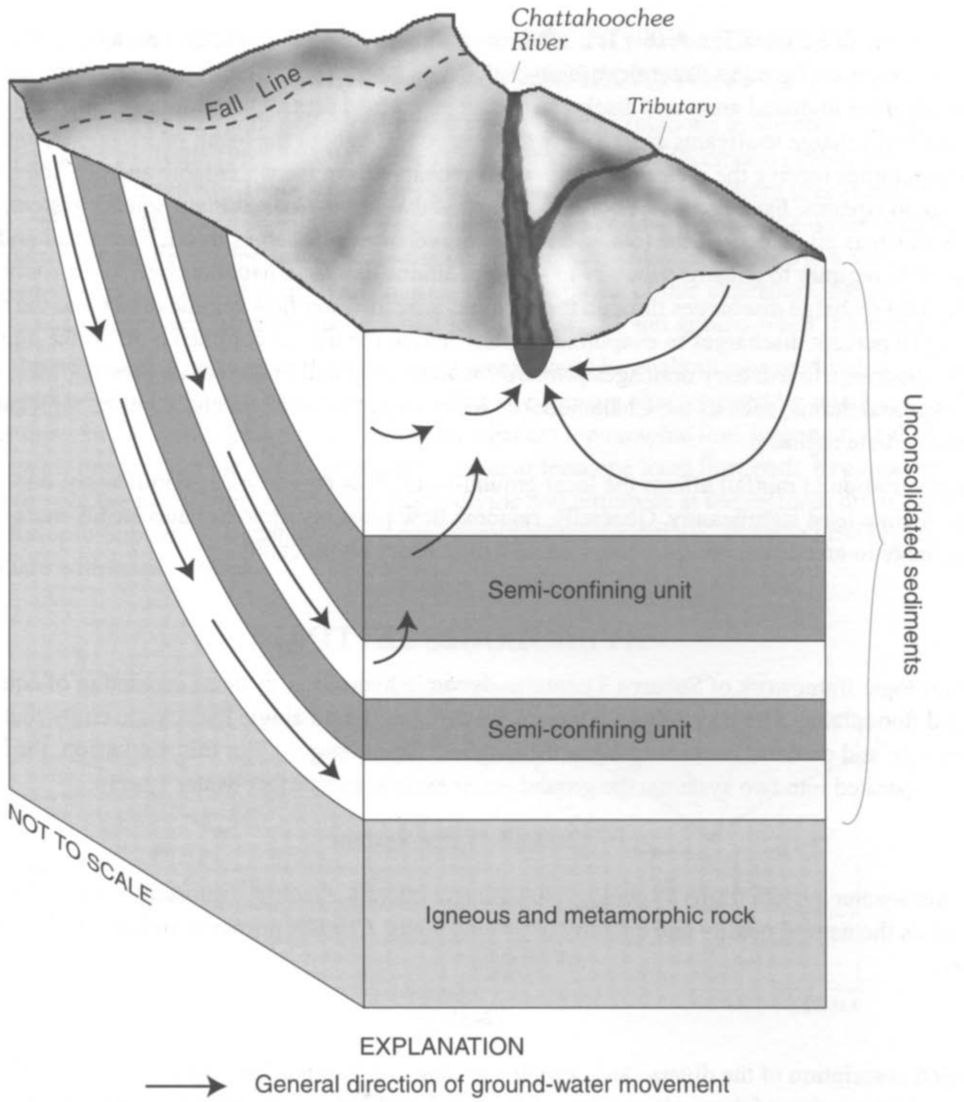


Figure 5. Conceptual ground-water and surface-water systems in Subarea 3: porous-media aquifer in unconsolidated sediments of the Coastal Plain Province.

Discussion of the geology of the western part of Subarea 3 may be found in Monroe (1941), Eargle (1948), Scott (1960, 1962a,b, 1964), Shamberger and others (1968), Newton, Golden, Avrett, and Scott, (1966), Newton, McCain, and Avrett (1968), MacNeil (1946), Toulim and LaMoreaux (1963), Causey and others (1967), and Raymond and Copeland (1987). Discussion of the geology of the eastern part of Subarea 3 may be found in Stephenson and Veatch (1915), Cooke (1943), Herrick (1961), Marsalis and Friddell (1975), Gibson (1982), and Reinhardt and others (1994).

Aquifers

The complexly interbedded Coastal Plain strata that occurs in Subarea 3 contain numerous aquifers and confining units (fig. 6). Much of these strata display significant facies changes, areally and vertically. The facies changes result in a complex physical distribution of hydraulic characteristics. The complexity of this distribution is reflected in the literature, and is also somewhat exacerbated by the area being dissected by a State boundary, which has constrained several rigorous field investigations.

The uppermost aquifer in Subarea 3 is the Floridan aquifer system which occurs in the extreme south-eastern corner. The Floridan aquifer system is thin in this area and is not considered a major aquifer. This boundary of Subarea 3 was selected to incorporate specific streamflow data stations; and consequently, incorporates areas where thin deposits of the Floridan aquifer system occur.

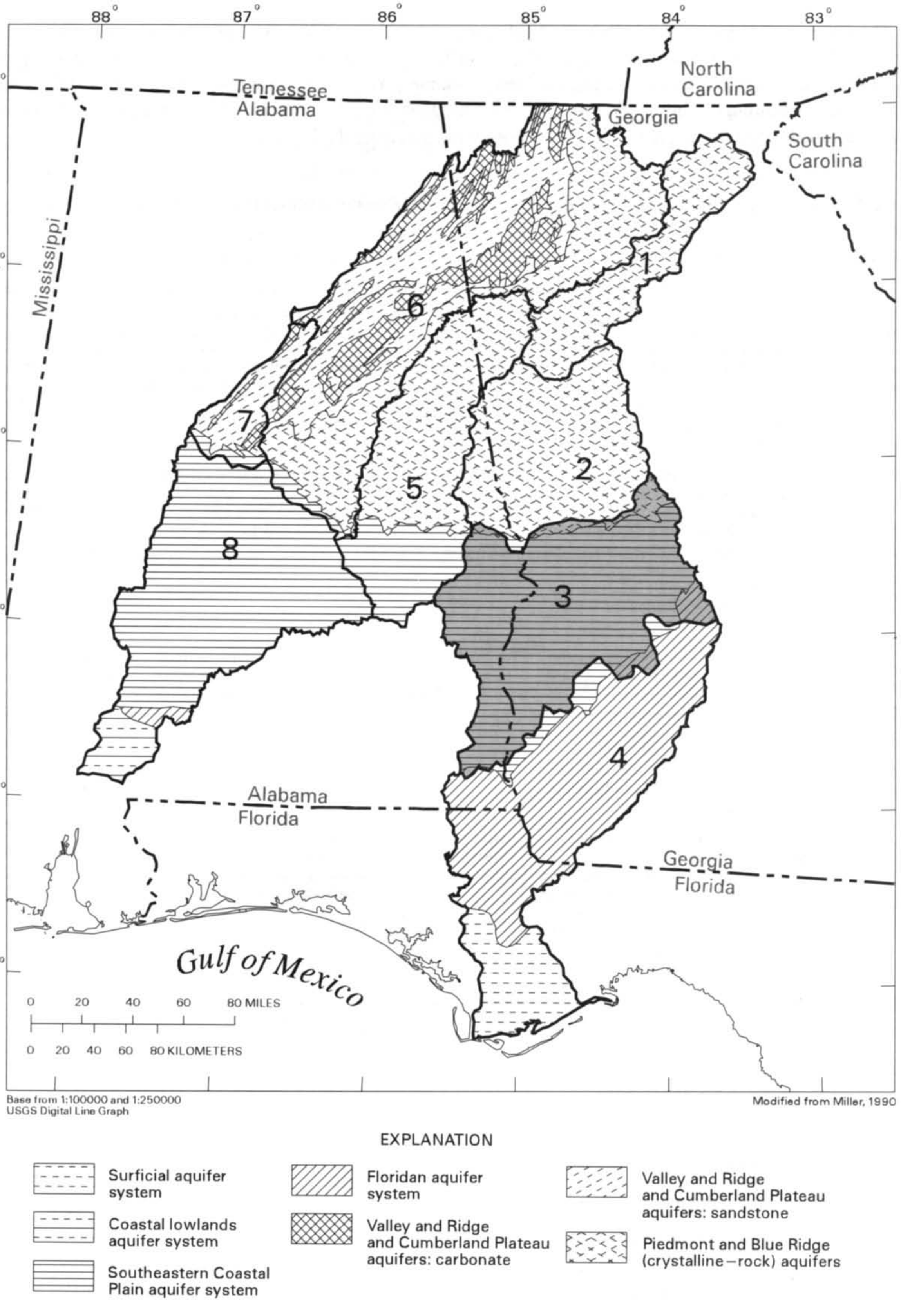


Figure 6. Major aquifers and subareas in the Apalachicola–Chattahoochee–Flint and Alabama–Coosa–Tallapoosa River basins.

The uppermost major aquifer in Subarea 3 is known as the Claiborne aquifer in Georgia (Long, 1989) and the Lisbon aquifer in Alabama (Scott and Cobb, 1988) (table 2). The recharge area generally coincides with the outcrop area, which extends from northern Houston and Henry Counties, Ala., northeast across central Clay and Randolph Counties, Ga., and through southern Webster, Sumter, and Dooly Counties, Ga. The recharge area extends southeast to the approximate edge of Subarea 3 where it is overlain in places by the Floridan aquifer system.

Table 2. Generalized geologic units in Subarea 3, and water-bearing properties, chemical characteristics, and well yields
[—, no available data; >, greater than]

Physiographic province	Geologic age and lithology	Aquifer type	Water-bearing properties and chemical characteristics	Well yield
Coastal Plain	Eocene—calcareous, fossiliferous, glauconitic clayey sands of the Tallahatta Formation and parts of overlying Lisbon and underlying Hatchetigbee Formations	Lisbon aquifer (Alabama); Claiborne aquifer (Georgia); porous media	moderate supply source; calcium bicarbonate type water, generally basic (pH >7) and moderately hard to hard (Long, 1989)	generally less than 100 gallons per minute (DeJarnette, 1989)
Do.	Paleocene—In Alabama, basal part of Tuscahoma Sand, fossiliferous, glauconitic sand zones and sandstone of the underlying Nanafalia Formation; and limestone and calcareous sands of the Clayton Formation; —In Georgia, the middle limestone unit of the Clayton Formation and supra-adjacent sand units.	Nanafalia–Clayton aquifer (Alabama); Clayton aquifer (Georgia); porous media	moderate supply source; calcium bicarbonate type water, moderately hard to hard	about 100 to 700 gallons per minute (Clarke and others, 1984; Scott and Cobb, 1988)
Do.	Upper Cretaceous—In Georgia, very fine to coarse sand of the Providence Sand; —In Alabama, fine-to-coarse grained micaceous, carbonaceous sand and clay layers of the Providence Sand, and sand beds of the Ripley Formation, Cusseta Sand Member; and sand and sandy clay of the Blufftown Formation (Kidd, 1987)	Providence aquifer (Georgia;) Providence–Ripley aquifer (Alabama); porous media	moderate to major supply source; sodium bicarbonate type water, generally soft (Clarke and others, 1983)	generally ranges from 100 to 300 gallons per minute (Clarke and others, 1983; Kidd, 1987)
Do.	Upper Cretaceous—In Georgia, sand, coarse with thinly bedded carbonaceous clay of the Cusseta Sand; —In Alabama, the Cusseta Sand Member is part of the Ripley Formation; and where present, part of the Providence–Ripley aquifer (Raymond and Copeland, 1987)	Cusseta aquifer (Georgia); porous media	moderate supply source; generally sodium bicarbonate type water, possibly slightly acidic (Pollard and Vorhis, 1980)	ranges from 50 to more than 1,000 gallons per minute (Pollard and Vorhis, 1980)
Do.	Upper Cretaceous—In Georgia, medium to coarse quartzite sand of the Blufftown Formation; —In Alabama, sands of the Blufftown Formation comprise the lowest part of the Providence–Ripley aquifer	Blufftown aquifer (Georgia); porous media	marginal supply source, not commonly used alone; sodium bicarbonate type water	—
Do.	Upper Cretaceous—In Georgia and Alabama, fine to very coarse calcareous sand of the Eutaw Formation; —In Georgia, also gravelly, micaceous, arkosic sand of the Tuscaloosa Formation (Pollard and Vorhis, 1980)	Eutaw aquifer; porous media	major source in Alabama; moderate source in Georgia; sodium bicarbonate type water; slightly acidic	range from 250 to more than 600 gallons per minute
Do.	Upper Cretaceous—In Alabama, sand fine-to-very coarse-grained, sandy clay, and sandstone (Kidd, 1987)	Tuscaloosa aquifer; porous media	major source in Alabama	about 150 gallons per minute in Alabama (Kidd, 1987)

Cropping out north of and underlying the Claiborne aquifer is the Clayton aquifer, referred to as the Nanfalia–Clayton aquifer in Alabama. Confining the Clayton aquifer below the Claiborne aquifer is the Wilcox confining unit, which consists of parts of the Hatchetigbee, Tuscahoma, Nanafalia and Clayton Formations in Georgia (Long, 1989), and the clay units in the upper part of the Tuscahoma Sand in Alabama (Scott and Cobb, 1988). The recharge area of the Clayton/Nanafalia–Clayton aquifer generally coincides with the outcrop area, which extends form northern Henry County, Ala., and northwest through Quitman, southern Stewart and Webster Counties, Ga. The recharge area extends southeast to the northwestern edge of sediments of the overlying Claiborne aquifer.

Cropping out north of and underlying the Clayton/Nanafalia–Clayton aquifer is the Providence aquifer (Clarke and others, 1983) and its western equivalent, the Providence-Ripley aquifer (Kidd, 1987). Confining the Providence/Providence–Ripley aquifers below the Clayton/Nanafalia–Clayton aquifer is the Clayton–Providence confining unit, where present (Long, 1989). The recharge area of the Providence/Providence–Ripley aquifers extends from central Barbour County, Ala., northeast through Quitman, central Stewart, southern Marion Counties, Ala., and across northern Macon County, Ga. The recharge area of the Providence/Providence–Ripley aquifers extends in an irregular fashion southwest to the northwest edge of sediments of the overlying Clayton/Nanafalia–Clayton aquifer.

Cropping out north of and underlying the Providence/Providence–Ripley aquifers in Alabama is the Eutaw aquifer, comprised of the Eutaw Formation (Kidd, 1987) which is subsequently underlain by the Tuscaloosa aquifer. In Georgia, these aquifers are present but are difficult to distinguish, and are mapped as one unit (Pollard and Vorhis, 1980). The recharge area of the Eutaw and Tuscaloosa aquifers extends from Russell County Ala., across northern Chattahoochee and Marion Counties, Ga., and northwest across northern Taylor and southern Crawford Counties, Ga.

Surface-Water System

The surface-water system in Subarea 3 includes the Chattahoochee River and its tributaries in Georgia and Alabama and the Flint River and its tributaries in Georgia (fig. 7). The drainage area of the Flint River is about 2,810 mi^2, and the drainage area of the Chattahoochee River is about 3,370 mi^2. The drainage area of the Chattahoochee River is almost equally divided between the two States, encompassing about 1,670 mi^2 in Alabama and 1,700 mi^2 in Georgia. The major tributaries to the Chattahoochee River in Georgia include Bull Creek, Upatoi Creek, Hichitee Creek, Hannahatchee Creek, Pataula Creek, Cemochechobee Creek, and Kolomoki Creek. Major tributaries in Alabama include Uchee Creek, Ihagee Creek, Hatchechubbee Creek, Cowikee Creek, Barbour Creek, and Abbie Creek. Major tributaries to the Flint River include Patsiliga Creek, Whitewater Creek, Buck Creek, Hogcrawl Creek, Turkey Creek, Muckalee Creek, Kinchafoonee Creek, Ichawaynochaway Creek and Pachitla Creek. Stream-gaging station data exists for several, but not all, tributary streams. Stream-gaging stations noted in this study are listed in table 3.

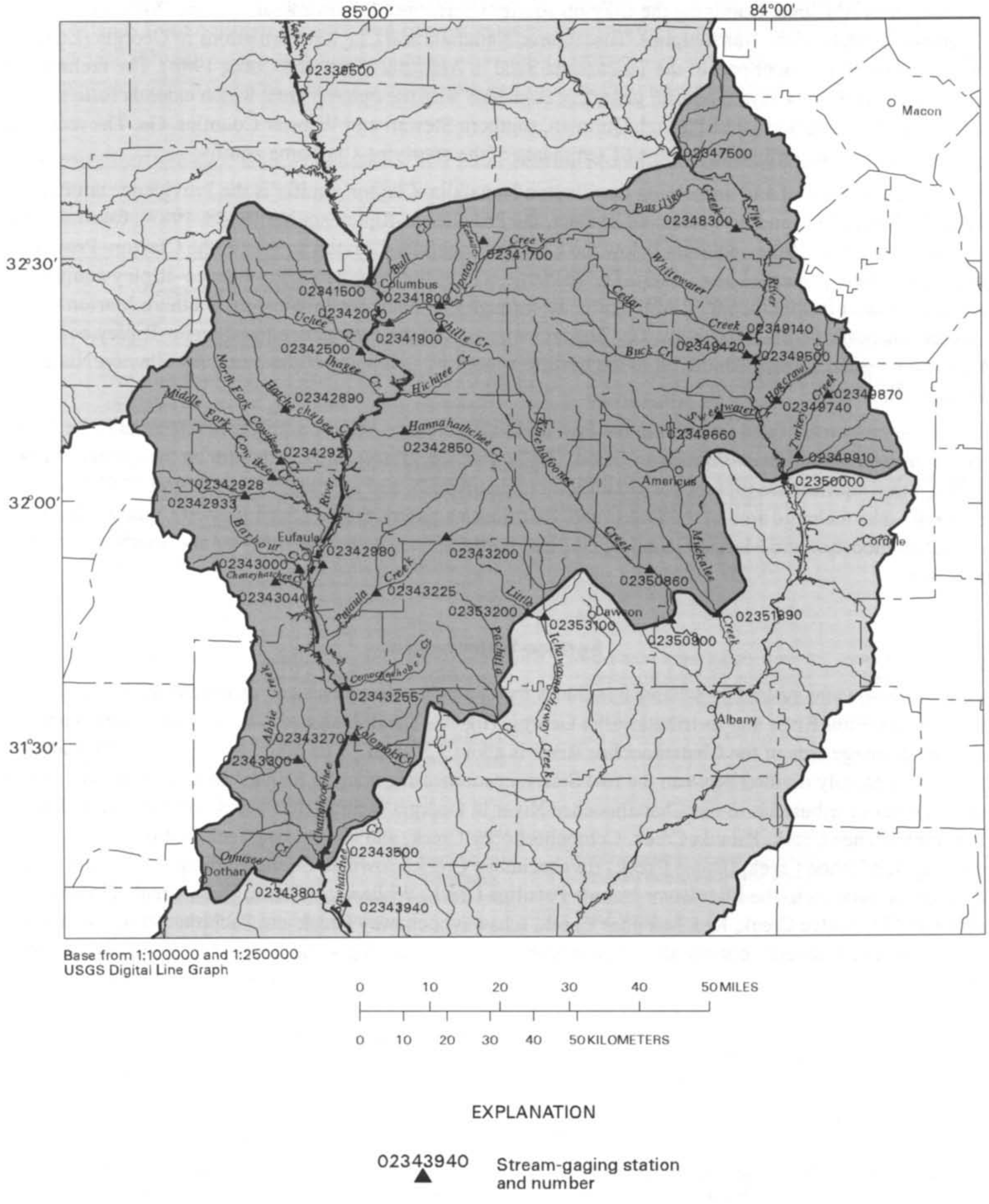


Figure 7. Selected stream-gaging stations, Subarea 3.

Table 3. Selected active and discontinued continuous-record stream-gaging stations in the Chattahoochee and Flint River basins, Subarea 3
[—, not applicable]

Station number	Station name	Drainage area (square miles)	Type of stream	Major aquifer drained	Period of record of unregulated flow	Mean-annual stream discharge (cubic feet per second)
02339500	Chattahoochee River at West Point, Ga.	3,550	regional	Providence	1896-1955	5,625
02341500	Chattahoochee River at Columbus, Ga.	4,670	do.	do.	none	—
02341800	Upatoi Creek near Columbus, Ga.	342	tributary	do.	1969-present	1/451
02342500	Uchee Creek near Fort Mitchell, Ala.	322	do.	do.	1947-present	2/436
02342933	South Fork Cowikee Creek near Batesville, Ala.	112	do.	do.	1964-71, 1975-present	2/120
02343200	Pataula Creek near Lumpkin, Ga.	70.0	do.	do.	1959-71	3/87.8
02343300	Abbie Creek near Haleburg, Ala.	146	do.	do.	1959-71, 1975-92	2/198
02343500	Chattahoochee River at Columbia, Ala.	8,040	regional	do.	none	—
02343801	Chattahoochee River at Andrews Lock and Dam, at Columbia, Ala.	8,210	do.	do.	none	—
02347500	Flint River near Culloden, Ga.	1,850	do.	do.	1912-22, 1929-30, 1938-present	1/2,330
02349000	Whitewater Creek below Rambulette Creek, near Butler, Ga.	93.4	tributary	do.	1952-71	3/164
02349500	Flint River at Montezuma, Ga.	2,900	regional	do.	1905-08, 1912, 1931-present	1/3,542
02349900	Turkey Creek at Byromville, Ga.	45.0	tributary	do.	1959-present	1/45.5
02350600	Kinchafoonee Creek at Preston, Ga.	197	do.	do.	1952-77	4/215
02351890	Muckalee Creek at State Route 195, near Leesburg, Ga.	362	do.	do.	1981-present	1/358

1/Stokes and McFarlane (1994).
2/Pearman and others (1994).
3/U.S. Geological Survey (1972).
4/U.S. Geological Survey (1978).

The Chattahoochee River flows south into the subarea from the Piedmont Province to the north. Within Subarea 3, the Chattahoochee River defines the boundary between the States of Alabama and Georgia. The river flows south across the successively exposed recharge areas of the aquifers, which trend east to west. Streamflow of the Chattahoochee River in Subarea 3 has been influenced by regulation upstream at Lake Harding since 1926, at Lake Sidney Lanier since 1955, and at West Point Lake since 1975 (Stokes and others, 1992). The Flint River also flows south into Subarea 3 from the Piedmont Province to the north, crossing the exposed recharge areas of the aquifers. Walter F. George Reservoir near Ft. Gaines, Ga., is the only major impoundment in Subarea 3 (table 4). Reservoir filling began in May 1962 and the reservoir became operational for navigational and power-generation purposes in March 1963. Lake Sidney Lanier is an upstream impoundment in Subarea 1 and Lake Harding is an upstream impoundment in adjacent Subarea 2 near the boundary of Subareas 2–3.

Table 4. Major impoundment in the Chattahoochee River basin, Subarea 3

Impoundment structure	Station number	Location	Installation date	Major uses	Total storage capacity (acre-feet)
Walter F. George Dam	02343240	Clay County, Ga.	1963	navigation and power generation	1/934,400

1/Stokes and McFarlane (1994).

For this report, the mean-annual stream discharge of a surface-water drainage measured at a gaging station is defined as the arithmetic average of all reported annual discharges for the selected period of record. Note that, by definition, the stream discharge includes both surface runoff and baseflow.

GROUND-WATER DISCHARGE TO STREAMS

Streamflow is comprised of two major components—a typical hydrograph integrates these components as:

- overland or surface runoff, represented by peaks, indicating rapid response to precipitation; and
- baseflow, represented by the slope of streamflow recession, indicating ground-water discharge to the stream.

In relation to the conceptual model, baseflow in streams is comprised of contributions from the local, intermediate, or regional ground-water flow regimes. Estimates of recharge to the ground-water system are minimum estimates because the budgets were developed as ground-water discharge to streams, and do not include ground water discharged as evapotranspiration, to wells, or ground water that flows downgradient into other aquifers beyond the topographic boundary defining Subarea 3. Local flow regimes likely are the most affected by droughts. Discharge measured in unregulated streams and rivers near the end of a drought should be relatively steady and composed largely of baseflow.

Mean-Annual Baseflow

Mean-annual baseflow was determined by averaging results of streamflow hydrograph-separation analyses for discrete water years representative of low-, mean-, and high-flow conditions in the Chattahoochee and Flint Rivers and their major tributaries. Streamflow data used to determine mean-annual baseflow at continuous-record gaging stations were selected according to periods of record when flow was unregulated. The hydrograph-separation program SWGW (Mayer and Jones, 1996) was applied to estimate mean-annual baseflow at eight continuous-record gaging stations in the Chattahoochee River basin and at three continuous-record gaging stations in the Flint River basin (table 5). For each gaging station, two recession indices are listed in table 5; one represents the rate of streamflow recession during the major rise period, generally in winter, and the other major recession period, generally in summer. Some variables that are supplied by the user to SWGW for each hydrograph separation are not listed in table 5, but can be obtained from the U.S. Geological Survey, Georgia District Office, Atlanta, Ga. These variables include the time-base (in days) from the peak to the cessation of surface runoff, the time period (the beginning and ending months) for application of the summer recession index, and the adjustment factor for the displacement of the recession curve. See Rutledge (1993) for a discussion of time-base, and Mayer and Jones (1996) for a discussion of the other user-supplied variables.

The mean-annual baseflow, in cubic feet per second; and the related unit-area baseflow, in cubic feet per second per square mile ($ft^3/s/mi^2$), were computed for each station. The station Chattahoochee River at Columbus, Ga. (02341500), is located at the northern edge of Subarea 3 and has been regulated by Lake Harding since 1926; thus, preventing use of hydrograph-separation methodology. Mean-annual baseflow at the Chattahoochee River at Columbus, Ga., therefore, was estimated from the upstream station at Chattahoochee at West Point, Ga. (02339500) (table 5). Faye and Mayer (1990, fig. 7) demonstrate the comparability of streamflow at these two stations, and the use of West Point gage data as an estimator of streamflow at the Columbus gage. Likewise, streamflow records for Kinchafoonee Creek at the southern boundary of the area were unavailable, and mean-annual baseflow was estimated using daily streamflow data at the station at nearby Muckalee Creek at State Route 195 near Leesburg, Ga. (02351890) (table 2).

Baseflow in the Chattahoochee River

The reach of the Chattahoochee River that transects Subarea 3 is bounded on the north by station 02341500, at Columbus, Ga., and to the south by station 02343500, at Columbia, Ala. (fig. 7). Through this reach, the river defines the boundary between the States of Alabama and Georgia. The mean-annual baseflow at these stations was estimated to be about 4,640 cubic feet per second (ft^3/s) and 7,460 ft^3/s, respectively (table 5). The difference in these values, 2,820 ft^3/s represents the sum of the baseflow from the intervening area between the gages under average conditions. This approximation utilizes none of the available tributary streamflow data and is considered to be of low confidence. Tributary streamflow data provide a more detailed analysis of the ground- and surface-water relation.

Table 5. Mean-annual stream discharge, estimated annual and mean-annual baseflow, and unit-area mean-annual baseflow at selected gaged streams in the Chattahoochee and Flint River basins, Subarea 3

[P, porous media; —, not available or not applicable]

Station number	Station name	Type of stream	Drainage area (square miles)	Major aquifer type	Recession index: Winter (days)	Recession index: Summer (days)	Water year	Flow conditions	Mean-annual stream discharge[1] (cubic feet per second)	Annual baseflow[2,3] (cubic feet per second)	Mean-annual baseflow[3,4] (cubic feet per second)	Unit-area mean-annual baseflow[3,5] (cubic feet per second per square mile)
	CHATTAHOOCHEE RIVER BASIN											
	Georgia Contributing Area											
02339500	Chattahoochee River at West Point, Ga.	regional	3,550	P	140	100	1941	Low	3,018	1,960		
							1929	High	9,839	4,970	3,530	0.994
							1929	High	9,839	4,970		
02341500	Chattahoochee River at Columbus, Ga	regional	4,670	P	—	—	—	—	—	—	[6]4,640	—
—	intermediate drainage area upstream of Bull Creek at mouth at Columbus, Ga.	—	2	P	—	—	—	—	—	—	[7]**1**	—
—	Bull Creek at mouth at Columbus, Ga.	tributary	74	P	—	—	—	—	—	—	[7]**52**	—
—	intermediate drainage area between mouths of Bull Creek and Upatoi Creek near Columbus, Ga.	—	14	P	—	—	—	—	—	—	[7]**9.9**	—
02341800	Upatoi Creek near Columbus, Ga.	tributary	342	P	100	50	1988	Low	253	179		
							1982	Average	473	257	251	.734
							1973	High	601	317		
02342000	Upatoi Creek at Fort Benning, Ga.	do.	447	P	109	38	1945	Low	588	246		
							1946	Average	626	310	316	.707
							1947	High	726	391		
—	Upatoi Creek at mouth at Fort Benning, Ga.	do.	455	P	—	—	—	—	—	—	[7]**322**	—
—	intermediate drainage area between mouths of Upatoi and Hichitie Creeks, Ga.	—	66	P	—	—	—	—	—	—	[7] **47**	—
—	Hichitee Creek at mouth near Ft. Benning, Ga.	do.	55	P	—	—	—	—	—	—	[8]**20**	—
—	intermediate drainage area between mouths of Hichitee Creek and Hannahatchee Creek at Union, Ga	—	14	P	—	—	—	—	—	—	8/ **5**	—
02342850	Hannahatchee Creek at Union, Ga.	tributary	121	P	—	—	—	—	—	—	[9]44	.364

Table 5. Mean-annual stream discharge, estimated annual and mean-annual baseflow, and unit-area mean-annual baseflow at selected gaged streams in the Chattahoochee and Flint River basins, Subarea 3—Continued

[P, porous media; —, not available or not applicable]

Station number	Station name	Type of stream	Drainage area (square miles)	Major aquifer type	Recession index		Water year	Flow conditions	Mean-annual stream discharge[1/] (cubic feet per second)	Annual baseflow[2/],[3/] (cubic feet per second)	Mean-annual baseflow[3/],[4/] (cubic feet per second)	Unit-area mean-annual baseflow[3/],[5/] (cubic feet per second per square mile)
					Winter (days)	Summer (days)						
—	Hannahatchee Creek at mouth near Omaha, Ga.	do.	146	P	—	—	—	—	—	—	[8/] **53**	—
—	intermediate drainage area between mouths of Hannahatchee Creek and Pataula Creek near Lumpkin, Ga.	—	164	P	—	—	—	—	—	—	[10/] **92**	—
02343200	Pataula Creek near Lumpkin, Ga.	tributary	70	P	75	50	1968	Low	40	34		
							1961	Average	84	47	53	.757
							1964	High	153	77		
—	Pataula Creek at mouth near Fort Gaines, Ga.	do.	394	P	—	—	—	—	—	—	[11/]**298**	—
—	intermediate drainage area between mouths of Pataula Creek and Cemochechobee Creek, Ga.	—	41	P	—	—	—	—	—	—	[12/]**16**	—
02343255	Cemochechobee Creek at Fort Gaines, Ga.	do.	103	P	—	—	—	—	—	—	[9/]39	.379
—	Cemochechobee Creek at mouth near Fort Gaines, Ga.	tributary	106	P	—	—	—	—	—	—	[12/]**40**	—
—	intermediate drainage area between mouths of Cemochechobee and Kolomoki Creeks, Ga.	—	19	P	—	—	—	—	—	—	[12/]**7.2**	—
—	Kolomoki Creek at mouth, Ga.	tributary	102	P	—	—	—	—	—	—	[12/]**39**	—
—	intermediate drainage area below mouth of Kolomoki Creek, Ga.	—	67	P	—	—	—	—	—	—	[12/]**25**	—
					Alabama Contributing Area							
—	intermediate drainage area upstream of Uchee Creek at mouth at Fort Mitchell, Ala.	—	30	P	—	—	—	—	—	—	[13/]**12**	—
02342500	Uchee Creek near Fort Mitchell, Ala.	tributary	322	P	109	38	1985	Low	185	67		
							1959	Average	447	130	130	.404
							1964	High	910	192		
—	Uchee Creek at mouth at Fort Mitchell, Ala.	tributary	334	P	—	—	—	—	—	—	13/**135**	—

Table 5. Mean-annual stream discharge, estimated annual and mean-annual baseflow, and unit-area mean-annual baseflow at selected gaged streams in the Chattahoochee and Flint River basins, Subarea 3—Continued

[P, porous media; —, not available or not applicable]

Station number	Station name	Type of stream	Drainage area (square miles)	Major aquifer type	Recession index		Water year	Flow conditions	Mean-annual stream discharge[1/] (cubic feet per second)	Annual baseflow[2/],[3/] (cubic feet per second)	Mean-annual baseflow[3/],[4/] (cubic feet per second)	Unit-area mean-annual baseflow[3/],[5/] (cubic feet per second per square mile)
					Winter (days)	Summer (days)						
—	intermediate drainage area between mouths of Uchee and Ihagee Creeks, Ala.	—	11	P	—	—	—	—	—	—	[13/]**4.4**	—
—	Ihagee Creek at mouth near Holy Trinity, Ala.	tributary	34	P	—	—	—	—	—	—	[13/]**14**	—
—	intermediate drainage area between mouths of Ihagee and Hatchechubbee Creeks, Ala.	—	25	P	—	—	—	—	—	—	[13/]**10**	—
02342890	Hatchechubbee Creek near Pittsview, Ala.	tributary	51	P	—	—	—	—	—	—	[9/]7.3	.143
—	Hatchechubbee Creek at mouth near Eufaula, Ala.	tributary	151	P	—	—	—	—	—	—	[14/]**22**	—
—	intermediate drainage area between mouths of Hatchechubbee Creek and South Fork Cowikee Creek near Batesville, Ala.	—	56	P	—	—	—	—	—	—	[15/]**8.0**	—
02342933	South Fork Cowikee Creek near Batesville, Ala.	tributary	112	P	79	40	1969	Low	77	16		
							1977	Average	106	26	23	.205
							1978	High	158	28		
02343940	Cowikee Creek at mouth near Eufaula, Ala.	tributary	464	P	—	—	—	—	—	—	[16/]**65**	.140
—	intermediate drainage area between mouths of Cowikee and Barbour Creeks, Ala.	—	49	P	—	—	—	—	—	—	[17/]**9.1**	—
02343000	Barbour Creek at mouth near Eufaula, Ala.	tributary	95	P	—	—	—	—	—	—	[18/]**22**	.232
—	intermediate drainage area between mouths of Barbour Creek and Cheneyhatchee Creek near Eufaula, Ala.	—	4	P	—	—	—	—	—	—	[19/]**1.6**	—
02343040	Cheneyhatchee Creek near Eufaula, Ala.	tributary	28	P	—	—	—	—	—	—	[16/]16	.571
—	Cheneyhatchee Creek at mouth, Ala.	tributary	54	P	—	—	—	—	—	—	[20/]**31**	—
—	intermediate drainage area between mouths of Cheneyhatchee Creek and Abbie Creek near Haleburg, Ala.	—	136	P	—	—	—	—	—	—	[21/]**89**	—

Table 5. Mean-annual stream discharge, estimated annual and mean-annual baseflow, and unit-area mean-annual baseflow at selected gaged streams in the Chattahoochee and Flint River basins, Subarea 3—Continued

[P, porous media; —, not available or not applicable]

Station number	Station name	Type of stream	Drainage area (square miles)	Major aquifer type	Recession index: Winter (days)	Recession index: Summer (days)	Water year	Flow conditions	Mean-annual stream discharge[1/] (cubic feet per second)	Annual baseflow[2/],[3/] (cubic feet per second)	Mean-annual baseflow[3/],[4/] (cubic feet per second)	Unit-area mean-annual baseflow[3/],[5/] (cubic feet per second per square mile)
02343300	Abbie Creek near Haleburg, Ala.	tributary	146	P	81	48	1988	Low	120	72		
							1980	Average	207	113	108	.740
							1983	High	272	140		
—	Abbie Creek at mouth.	do.	196	P	—	—	—	—	—	—	[22/]**145**	—
—	intermediate drainage area downstream of Abbie Creek at mouth	—	31	P	—	—	—	—	—	—	[22/]**23**	—
02343500	Chattahoochee River at Columbia, Ala.	regional	8,043	P	222	111	1941	Low	5,860	3,030		
							1952	Average	9,590	6,550	7,460	.928
							1949	High	14,800	12,800		
	FLINT RIVER BASIN											
02347500	Flint River near Culloden, Ga.	regional	1,850	P	85	55	1941	Low	1,220	654		
							1941	Low	1,220	654	1,160	.628
							1949	High	2,370	1,480		
02349500	Flint River near Montezuma, Ga.	do.	2,900	P	113	54	1941	Low	2,260	1,680		
							1957	Average	3,760	1,740	2,000	.690
							1949	High	4,200	2,590		
02350000	Flint River near Vienna, Ga.	do.	3,390	P	—	—	—	—	—	—	[23/]2,340	—
02351890	Muckalee Creek at State Route 195 near Leesburg, Ga.	tributary	362	P	85	55	1988	Low	210	132		
							1985	Average	315	157	**183**	.506
							1984	High	453	260		
02350900	Kinchafoonee Creek near Dawson, Ga.	do.	527	P	—	—	—	—	—	—	[24/]**267**	—
02353100	Ichawaynochaway Creek near Graves, Ga.	do.	118	P	—	—	—	—	—	—	[24/]**60**	—
02353200	Little Ichawaynochaway Creek near Shellman, Ga.	do.	52	P	—	—	—	—	—	—	[24/]**26**	—

Table 5. Mean-annual stream discharge, estimated annual and mean-annual baseflow, and unit-area mean-annual baseflow at selected gaged streams in the Chattahoochee and Flint River basins, Subarea 3—Continued

[P, porous media; —, not available or not applicable]

Station number	Station name	Type of stream	Drainage area (square miles)	Major aquifer type	Recession index		Water year	Flow conditions	Mean-annual stream discharge[1/] (cubic feet per second)	Annual baseflow[2/,3/] (cubic feet per second)	Mean-annual baseflow[3/,4/] (cubic feet per second)	Unit-area mean-annual baseflow[3/,5/] (cubic feet per second per square mile)
					Winter (days)	Summer (days)						
02353400	Pachitla Creek (at subarea boundary) near Edison, Ga.	do.	190	P	—	—	—	—	—	—	[24/]**96**	—

[1/]From annually published U.S. Geological Survey data reports; for example, Pearman and others (1994) or Stokes and McFarlane (1994).
[2/]Estimated using the SWGW program (Mayer and Jones, 1996).
[3/]Values are reported to three significant digits to maintain the numerical balance of the water budget; implication of accuracy to the degree shown is not intended.
[4/]Estimated by averaging discharges for low, average, and high flow years for the period of unregulated flow.
[5/]Discharge divided by drainage area.
[6/]Estimate based on unit-area discharge at Chattahoochee River at West Point, Ga.
[7/]Estimate based on unit-area discharge at Upatoi Creek at Fort Benning, Ga.
[8/]Estimate based on unit-area discharge at Hannahatchee Creek at Union, Ga.
[9/]Estimate based on MOVE.1 (Hirsch, 1982) statistical correlation with a continuous-record station.
[10/]Estimate based on mean of unit-area discharges at Hannahatchee Creek at Union, Ga., and at Pataula Creek near Lumpkin, Ga. [(0.364 + 0.757   2 = 0.560 cubic feet per second per square mile)].
[11/]Estimate based on unit-area discharge at Pataula Creek near Lumpkin, Ga.
[12/]Estimate based on unit-area discharge at Cemochechobee Creek at Fort Gaines, Ga.
[13/]Estimate based on unit-area discharge at Uchee Creek near Fort Mitchell, Ala.
[14/]Estimate based on unit-area discharge at Hatchechubbee Creek near Pittsview, Ala.
[15/]Estimate based on mean of unit-area discharge at Hatchechubbee Creek at Pittsview, Ala., and Cowikee Creek at mouth near Eufaula, Ala. [(0.143 + 0.140   2 = 0.142 cubic feet per second per square mile)].
[16/]Estimate based on graphical correlation with a continuous-record station.
[17/]Estimate based on mean of unit-area discharge at Cowikee Creek at mouth near Eufaula, Ala., and Barbour Creek at mouth near Eufaula, Ala. [(0.140 + 0.232   2 = 0.186)].
[18/]Estimate developed by computation of 60-percent flow duration of five years of streamflow record, which could not be analyzed by hydrograph-separation methodology.
[19/]Estimate based on mean of unit-area discharge at Barbour Creek at mouth near Eufaula, Ala., and Cheneyhatchee Creek near Eufaula, Ala. [(0.232 + 0.571   2 = 0.402 cubic feet per second per square mile)].
[20/]Estimate based on unit-area discharge at Cheneyhatchee Creek near Eufaula, Ala.
[21/]Estimate based on mean of unit-area discharges at Cheneyhatchee Creek near Eufaula, Ala., and Abbie Creek near Haleburg, Ala. [(0.571 + 0.740   2 = 0.656 cubic feet per second per square mile)].
[22/]Estimate based on unit-area discharge at Abbie Creek near Haleburg, Ala.
[23/]Estimate based on unit-area discharge at Flint River near Montezuma, Ga.
[24/]Estimate based on unit-area discharge at Muckalee Creek at State Route 195 near Leesburg, Ga.

To estimate the contribution to mean-annual baseflow from Alabama and Georgia separately, a gain analysis was performed using the tributary streams and intermediate drainage areas of each State. This analysis was performed using the hydrograph-separation method to estimate mean-annual baseflow at five continuous-record stations and, subsequently, in conjunction with estimation methods, estimate mean-annual baseflow for the tributary streams that have limited or no streamflow data. The discrete estimates of each State then were summed.

Streamflow data are available from continuous-record stations on Upatoi Creek, Ga. (0234200); Uchee Creek, Ala. (02342500); South Fork Cowikee Creek, Ala. (02342933); Pataula Creek, Ga. (02343200); and Abbie Creek, Ala. (02343300). These streams drain about one-third of the Subarea and are unevenly distributed over the area (fig. 7). The mean-annual baseflow at these five stations was estimated using the SWGW hydrograph-separation methodology, and are listed in table 2, along with respective unit-area discharges.

The flow duration of the mean-annual baseflow at these five continuous-record stations (0234200, 02342500, 02342933, 02343200, and 02343300) range from 57 to 67 percent, and averaged 62 percent. Therefore, a flow duration of 60 percent was chosen as approximately representative of mean-annual baseflow conditions. This indicates that the mean-annual baseflow component of streamflow is equaled or exceeded 60 percent of the time. Consequently, baseflow at several partial record gaging stations in Alabama and Georgia was estimated using the discharge computed at 60-percent flow duration. These estimates of mean-annual baseflow were converted to unit-area discharges and used to estimate baseflow from intermediate drainage areas and adjacent or nearby tributary streams. Estimates of mean-annual baseflow of ungaged streams and intermediate areas also were based on the unit-area mean-annual baseflow computed at one of the five continuous-record stations. All estimates of mean-annual baseflow using a surrogate unit-area discharge are identified in boldface type in table 5.

Estimated mean-annual baseflow from areas in Alabama and Georgia to the Chattahoochee River were computed by summation of the discrete discharges estimated for the tributary streams and intermediate drainage areas between the tributaries (table 5). The total mean-annual baseflow computed by summing the baseflow estimated from tributary streams and intermediate drainage areas is 1,618 ft^3/s (table 5). Of this, about one-third (591 ft^3/s) is from Alabama, and the remainder (1,027 ft^3/s) is from Georgia.

An approximate check of this tributary stream gain, 1,618 ft^3/s, is the net gain computed between the Chattahoochee River gages at Columbus, Ga., and Columbia, Ala., which bracket the reach of the tributary streams. The tributary stream gain is about 60 percent of the 2,820 ft^3/s net gain computed between the Chattahoochee River gages. The difference between the two computations of mean-annual baseflow to the Chattahoochee River may be the result of possible erroneous fundamental assumptions implicit to the tributary gain analysis, and to inaccuracies inherent in the applied estimation methods. The tributary gain analysis is based on the assumption that ground-water flow divides are coincident with surface-water topographic divides. Faye and Mayer (1990) postulated that this is not the case for the lower part of the Chattahoochee River (in Subarea 3)—that ground-water flow divides extend beyond the topographic divides that define the watershed draining to the lower part of the Chattahoochee River. Scott (1984) and Williams and others (1986a,b) clearly depict this condition on maps of the 1982 potentiometric surfaces of several Alabama aquifers in the southwestern corner of Subarea 3. Regional ground-water flow divides positioned beyond the surface-water divides would result in ground-water discharge to the Chattahoochee River from a contributing area substantially larger than the intervening area between the gages at Columbus, Ga., and Columbia, Ala. (table 5). Consequently, the Chattahoochee River net-gain analysis probably is an overestimate of mean-annual baseflow from the specified drainage area of Subarea 3.

Unknown error possibly was introduced in the Chattahoochee River net-gain analysis through the extrapolation of hydrograph-separation results from the station at West Point, Ga. (02339500), to the downstream station at Columbus, Ga. (02341500). Faye and Mayer (1990; fig. 7) demonstrated reasonable streamflow comparability but did not discuss the possible error inherent in the method. Any error or variability introduced in the unit-area discharge extrapolation is magnified by the 25-percent increase in drainage area between the stations at West Point and Columbus, Ga. Also, streamflow at the downstream station used in the net-gain analysis—Chattahoochee River at Columbia, Ala.—has been affected by the upstream control of streamflow at Lake Harding through the entire period-of-record of the station. Although far downstream, the effect of upstream control upon streamflow and, consequently, upon hydrograph-separation results at Columbia, Ala., is unknown, but possibly significant.

Unknown error in the estimates of mean-annual baseflow at both the Columbus, Ga., and Columbia, Ala., stations may also significantly affect the results of the Chattahoochee River net-gain analysis. A hypothetical error in streamflow measurement of plus or minus 5 percent at both stations results in a possible range of error in the reported net gain of more than plus or minus 20 percent. A hypothetical error of plus or minus 10 percent at both stations results in a range of net gain larger than the 1,618 ft^3/s computed from the tributary stream gain.

The estimates used to compute the tributary stream gain were made using deliberately conservative judgment and interpretation. Unit-area mean-annual baseflows were computed at gaging stations or partial record stations and then used to estimate baseflow downstream at the mouth of the tributary. Unit-area baseflow increases downstream in a basin of consistent hydrogeologic properties (Faye and Mayer, 1990) because more of the ground-water flow system is intersected with proximity of the tributary drain to the large regional drains, such as the Chattahoochee River (figs. 4, 5). This downstream increase in unit-area ground-water discharge is unaccounted for in the tributary stream analyses because unit-area tributary discharge frequently accounted for only part of the tributary drainage. Subjective adjustment of the discharge rates would add additional uncertainty to the analysis and was not attempted.

Although the magnitude and distribution of “unaccounted for” baseflow in the tributary stream-gain analysis is unknown, the distribution is assumed to be constant in time and uniform in space. The total and intermediate tributary drainage areas of the two States are about equal; therefore, any error that may result from the unit-area estimation method probably is evenly distributed between the States. Because all estimation methods were applied consistently and with disregard to location, any error in baseflow estimates also is considered evenly distributed between the States. Although the accuracy of the results in table 5 is unknown, the relative values are considered representative of the true baseflow.

Baseflow in the Flint River

In the eastern and south-central parts of Subarea 3, the Flint River is the major surface-water feature, functioning as the hydraulic sink for both surface and ground-water flow systems. Tributary streams (Muckalee Creek, Kinchafoonee Creek, Ichawaynochaway Creek, and Pachitla Creek) flow south out of Subarea 3 and then into the Flint River. Mean-annual baseflow in this part of Subarea 3 was computed from the mean-annual baseflow analysis of continuous streamflow data for three stations. Mean-annual baseflow in the Flint River where it enters Subarea 3 was computed for the gaging station 02347500, near Culloden, Ga. (table 5, fig. 7) using streamflow hydrograph separation. Similarly, mean-annual baseflow was computed farther downstream on the Flint River at gage 02349500, at Montezuma, Ga., (table 5, fig. 7). Mean-annual baseflow at station 02350000, Flint River near Vienna, Ga., was estimated using the mean-annual unit-area baseflow computed for the upstream gage 02349500, Flint River at Montezuma (table 5). Subsequently, mean-annual baseflow directly into the Flint River within Subarea 3 was computed by net-gain analysis between the stations at Culloden and Vienna, Ga. This net gain was about 1,180 ft^3/s. Mean-annual baseflow to Muckalee Creek was computed for station 02351890 (fig. 7) by streamflow-hydrograph separation. The resulting mean-annual unit-area baseflow was used to estimate mean-annual baseflow for the streams that flow south out of Subarea 3 and then into the Flint River (table 5, fig. 7). Results of these analyses are shown in boldface type in table 5. Summation of these values indicate that about 1,812 ft^3/s discharges from the ground-water flow system into the Flint River in Subarea 3 under mean-annual flow conditions (table 5).

Drought Flow for 1954 and 1986

Regional drought periods of 1938-45, 1950-63, and 1984-88 were marked by severe droughts in the years of 1941, 1954, and 1986 in the ACF and ACT River basins. Typically, the lowest mean-annual streamflow for the period of record occurred during one of these years. Streamflow probably was sustained entirely by baseflow near the end of these droughts. Near-synchronous discharge measurements at partial-record gaging stations or daily mean streamflow at continuous-record gaging stations near the end of these droughts were considered a quantitative estimate of near-minimum baseflow.

A significant base of streamflow data exists that describes the areal distribution of streamflow in Subarea 3 during the droughts of 1954 and 1986. Similar data for the 1941 drought for Subarea 3 are not comprehensive and were not applied to a mass-balance analysis. As noted previously, much of the areal streamflow data for the 1954 and 1986 droughts were collected during short periods of time, often only a few days. Studies describing these droughts (Thomson and Carter, 1955; Hale and others, 1989) indicated that many small tributary streams were dry, and that streamflow of the larger streams was diminishing near the end of the droughts. These observations are the basis for the assumption that the streamflow occurring in these streams during the 1954 and 1986 droughts was ground-water discharge (baseflow), and that overland runoff was nonexistent. Measured and estimated streamflows during the 1954 and 1986 droughts are listed in tables 6 and 7, respectively.

Table 6. Stream discharge during the drought of 1954, Subarea 3
[—, not applicable]

Station number	Station name	Type of stream	Drainage area, (square miles)	Date	Stream discharge (cubic feet per second)	Unit-area discharge[1/] (cubic feet per second per square mile)
	CHATTAHOOCHEE RIVER BASIN					
	Georgia Contributing Area					
02341500	Chattahoochee River at Columbus, Ga.	regional	4,670	10-03-54	[2/]679	0.145
—	intermediate drainage area upstream of Bull Creek at mouth, Georgia	—	2	—	[3/]**.15**	—
02341529	Bull Creek at Georgia Highway 22 near Upatoi, Ga.	tributary	12.2	10-14-54	[4/].90	.074
[5/]	Bull Creek at mouth at Columbus, Ga.	do.	74	—	[3/]**5.5**	—
—	intermediate drainage area between mouths of Bull and Upatoi Creeks, Georgia	—	14	—	[6/]**3.8**	—
02342000	Upatoi Creek at Ft. Benning, Ga.	tributary	447	10-12-54	[7/]121	.271
[5/]278	Upatoi Creek at mouth at Ft. Benning, Ga.	do.	455	—	[6/]**123**	—
—	intermediate drainage area between mouths of Upatoi and Hichitee Creeks, Georgia	—	66	—	[6/]**18**	—
02342680	Hichitee Creek near Louvale, Ga.	tributary	39	10-26-54	[4/]7.9	.203
[5/]284A	Hichitee Creek at mouth near Ft. Benning, Ga.	do.	55	—	[8/]**11**	—
—	intermediate drainage area between mouths of Hichitee and Hannahatchee Creeks, Georgia	—	14	—	[9/]**1.9**	—
[5/]287	Hannahatchee Creek near Julia, Ga.	tributary	132	10-26-54	[4/]18	.136
[5/]287A	Hannahatchee Creek at mouth near Omaha, Ga.	do.	146	—	[9/]**20**	—
—	intermediate drainage area between mouths of Hannahatchee and Pataula Creeks, Georgia	—	164	—	[10/]**36**	—
02343225	Pataula Creek near Georgetown, Ga.	tributary	295	09-27-54	[4/]91	.308
[5/]296A	Pataula Creek at mouth near Fort Gaines, Ga.	do.	394	—	[11/]**121**	—
—	intermediate drainage area between mouths of Pataula and Cemochechobee Creeks, Georgia	—	41	—	[12/]**13**	—
02343255	Cemochechobee Creek at Fort Gaines, Ga.	tributary	103	10-21-54	[4/]32	.311
[5/]299C	Cemochechobee Creek at mouth near Fort Gaines, Ga.	do.	106	—	[12/]**33**	—
—	intermediate drainage area between mouths of Cemochechobee and Kolomoki Creeks, Georgia	—	19	—	[13/]**8.4**	—
02343260	Chattahoochee River at Fort Gaines, Ga.	regional	7,570	10-05-54	[4/]955	.126
02343270	Kolomoki Creek near Fort Gaines, Ga.	tributary	97	10-21-54	[4/]56	.577
[5/]103	Kolomoki Creek at mouth, Georgia	do.	102	—	[14/]**59**	—
—	intermediate drainage area downstream of mouth of Kolomoki Creek, Georgia	—	67	—	[14/]**39**	—

Table 6. Stream discharge during the drought of 1954, Subarea 3—Continued
[—, not applicable]

Station number	Station name	Type of stream	Drainage area, (square miles)	Date	Stream discharge (cubic feet per second)	Unit-area discharge[1] (cubic feet per second per square mile)
	Alabama Contributing Area					
—	intermediate drainage area upstream of Uchee Creek at mouth, Alabama	—	30	—	[15] **.72**	—
02342500	Uchee Creek near Ft. Mitchell, Ala.	tributary	325	10-05-54	[7] 7.9	.024
[16] 18	Uchee Creek at mouth at Ft. Mitchell, Ala.	do.	334	—	[15] **8.0**	—
—	intermediate drainage area between mouths of Uchee and Ihagee Creeks, Alabama	—	11	—	[15] **.26**	—
[16] 19	Ihagee Creek at mouth near Holy Trinity, Ala.	tributary	34	—	[15] **.82**	—
—	intermediate drainage area between mouths of Ihagee and Hatchechubbee Creeks, Alabama	—	25	—	[15] **.60**	—
[16] 22	Hatchechubbee Creek at mouth near Eufaula, Ala.	tributary	151	—	[17] **5.1**	—
—	intermediate drainage area between mouths of Hatchechubbee and Cowikee Creeks, Alabama	—	56	—	[17] **1.9**	—
02342940	Cowikee Creek near Eufaula, Ala.	tributary	464	—	[17] **16**	—
—	intermediate drainage area between mouths of Cowikee and Barbour Creeks, Alabama	—	49	—	[17] **1.7**	—
02342960	Chattahoochee River at Eufaula, Ala.	regional	6,730	10-05-54	[4] 877	[18] 0.130
02343000	Barbour Creek near Eufaula, Ala.	tributary	93	10-05-54	[7] 3.2	.034
[16] 32	Barbour Creek at mouth near Eufaula, Ala.	do.	97	—	[17] **3.3**	—
—	intermediate drainage area between mouths of Barbour and Cheneyhatchee Creeks, Alabama	—	4	—	[17] **.14**	—
—	Cheneyhatchee Creek at mouth, Alabama	tributary	54	—	[17] **1.8**	—
—	intermediate drainage area between mouths of Cheneyhatchee and Abbie Creeks, Alabama	—	136	—	[19] **13**	—
02343300	Abbie Creek near Haleburg, Ala.	tributary	144	10-01-54	[4] 22	.153
[16] 37	Abbie Creek at mouth	do.	196	—	[20] **30**	—
—	intermediate drainage area downstream of Abbie Creek at mouth, Alabama	—	31	—	[20] **4.7**	—
02343500	Chattahoochee River at Columbia, Ala.	regional	8,040	10-06-54	[7] 1,210	.150
	FLINT RIVER BASIN					
02347500	Flint River near Culloden, Ga.	regional	1,850	10-19-54	[7] 97	.052
02348300	Patsiliga Creek at Reynolds, Ga.	tributary	139	10-22-54	[4] 32	.230
[5] 108A	Patsiliga Creek at mouth near Reynolds, Ga.	do.	142	—	[21] **33**	—
—	Beaver Creek at mouth near Reynolds, Ga.	do.	27	—	[21] **6.2**	—
02348400	Horse Creek at Ga. Highway 128, near Marshallville, Ga.	do.	30	10-21-54	[4] 31	1.03
—	Horse Creek at mouth near Marshallville, Ga.	do.	37	—	[22] **38**	—
02349000	Whitewater Creek below Rambulette Creek near Butler, Ga.	do.	93.4	10-21-54	[7] 132	1.41
[5] 117A	Whitewater Creek at mouth near Oglethorpe, Ga.	do.	242	—	[23] **341**	—
02349350	Buck Creek near Ellaville, Ga.	do.	146	10-19-54	[4] 90	.616
[5] 121A	Buck Creek at mouth near Oglethorpe, Ga.	do.	232	—	[24] **143**	—
02349500	Flint River at Montezuma, Ga.	regional	2,900	10-19-54	[7] 618	.213
—	Camp Creek at mouth near Andersonville, Ga.	tributary	61	—	[25] **14**	—
02349660	Sweetwater Creek at Andersonville, Ga.	do.	30	07-01-54	[7] 12	.400

Table 6. Stream discharge during the drought of 1954, Subarea 3—Continued
[—, not applicable]

Station number	Station name	Type of stream	Drainage area, (square miles)	Date	Stream discharge (cubic feet per second)	Unit-area discharge[1/] (cubic feet per second per square mile)
—	Sweetwater Creek at mouth near Andersonville, Ga.	do.	42	—	[26/]**17**	—
02349730	Hogcrawl Creek near Montezuma, Ga.	do.	73.4	09-22-54	[4/]17	.232
—	Hogcrawl Creek at mouth near Andersonville, Ga.	do.	97	—	[25/]**22**	—
02349900	Turkey Creek near Byromville, Ga.	do.	45	09-20-54	[4/]4.6	.102
—	Turkey Creek at mouth near Cobb, Ga.	tributary	186	—	[27/]**19**	—
02350900	Kinchafoonee Creek near Dawson, Ga.	do.	527	10-21-54	[4/]**117**	.222
02351700	Muckalee Creek near Smithville, Ga.	do.	265	09-22-54	[4/]62	.234
02351800	Muckaloochee Creek at Smithville, Ga.	do.	47	09-22-54	[4/]25	.532
02351890	Muckalee Creek at State Highway 195 near Leesburg, Ga.	do.	362	—	[28/]**101**	—
02353100	Ichawaynochaway Creek near Graves, Ga.	do.	118	09-27-54	[4/]**25**	.212
02353200	Little Ichawaynochaway Creek near Shellman, Ga.	do.	52	09-27-54	[4/]**25**	.481
02353400	Pachitla Creek (at subarea boundary) near Edison, Ga.	do.	188	10-26-54	[4/]**62**	.330

[1/]Unit-area discharge computed using streamflow and drainage area.
[2/]Estimated unregulated discharge (Chapman and Peck, 1996b).
[3/]Estimate based on unit-area discharge at Bull Creek at Georgia Highway 22.
[4/]Miscellaneous discharge measurement.
[5/]Carter (1959).
[6/]Estimate based on unit-area discharge at Upatoi Creek at Ft. Benning, Ga.
[7/]Daily mean discharge.
[8/]Estimate based on unit-area discharge at Hichitee Creek near Louvale, Ga.
[9/]Estimate based on unit-area discharge at Hannahatchee Creek near Julia, Ga.
[10/]Estimate based on mean of unit-area discharge at Hannahatchee Creek near Julia, Ga., and Pataula Creek near Georgetown, Ga.
[11/]Estimate based on unit-area discharge at Pataula Creek near Georgetown, Ga.
[12/]Estimate based on unit-area discharge at Cemochechobee Creek at Fort Gaines, Ga.
[13/]Estimate based on mean of unit-area discharge at Cemochechobee Creek at Fort Gaines, Ga., and Kolomoki Creek near Fort Gaines, Ga.
[14/]Estimate based on unit-area discharge at Kolomoki Creek near Fort Gaines, Ga.
[15/]Estimate based on unit-area discharge at Uchee Creek near Ft. Mitchell, Ala.
[16/]Stallings and Pierce (1957).
[17/]Estimate based on unit-area discharge at Barbour Creek near Eufaula, Ala.
[18/]Unit-area discharge computed for intermediate drainage area using discharge measurements and drainage areas at Chattahoochee River stations at Columbus, Ga., and Eufaula, Ala.
[19/]Estimate based on mean of unit-area discharge at Barbour Creek near Eufaula, Ala., and Abbie Creek near Haleburg, Ala.
[20/]Estimate based on unit-area discharge at Abbie Creek near Haleburg, Ala.
[21/]Estimate based on unit-area discharge at Patsiliga Creek at Reynolds, Ga.
[22/]Estimate based on unit-area discharge at Horse Creek at Georgia Highway 128 near Marshallville, Ga.
[23/]Estimate based on unit-area discharge at Whitewater Creek below Rambulette Creek near Butler, Ga.
[24/]Estimate based on unit-area discharge at Buck Creek near Ellaville, Ga.
[25/]Estimate based on unit-area discharge at Hogcrawl Creek near Montezuma, Ga.
[26/]Estimate based on unit-area discharge at Sweetwater Creek at Andersonville, Ga.
[27/]Estimate based on unit-area discharge at Turkey Creek near Byromville, Ga.
[28/]Estimate based on area weighted average of unit-area discharges at Muckalee Creek near Smithville, Ga., and Muckaloochee Creek at Smithville, Ga.

Table 7. Stream discharge during the drought of 1986, Subarea 3
[—, not applicable]

Station number	Station name	Type of stream	Drainage area, (square miles)	Date	Stream discharge (cubic feet per second)	Unit-area discharge[1/] (cubic feet per second per square mile)
	CHATTAHOOCHEE RIVER BASIN					
	Georgia Contributing Area					
02341500	Chattahoochee River at Columbus, Ga.	regional	4,670	—	[2/]888	0.190
—	intermediate drainage area upstream of Bull Creek at mouth, Georgia	—	2	—	[3/]**.39**	—
[4/]241A	Bull Creek at mouth at Columbus, Ga.	tributary	74	—	[3/]**15**	—
—	intermediate drainage area between mouths of Bull and Upatoi Creeks, Georgia	—	14	—	[3/]**2.8**	—
02342000	Upatoi Creek at Ft. Benning, Ga.	tributary	447	07-09-86	[5/]88	.197
[4/]278	Upatoi Creek at mouth at Ft. Benning, Ga.	do.	455	—	[3/]**90**	—
—	intermediate drainage area between Upatoi and Hichitee Creeks, Georgia	—	66	—	[3/]**13**	—
[4/]284A	Hichitee Creek at mouth near Ft. Benning, Ga.	tributary	55	—	[6/]**4.6**	—
—	intermediate drainage area between mouths of Hichitee and Hannahatchee Creeks, Georgia	—	14	—	[6/]**1.2**	—
02342850	Hannahatchee Creek at Union, Ga.	tributary	121	07-09-86	[5/]10	.083
[4/]287A	Hannahatchee Creek at mouth near Omaha, Ga.	do.	146	—	[6/]**12**	—
—	intermediate drainage area between mouths of Hannahatchee and Pataula Creeks, Georgia	—	164	—	[7/]**26**	—
02343225	Pataula Creek near Georgetown, Ga.	tributary	295	07-08-86	[5/]70	.237
[4/]296A	Pataula Creek at mouth near Fort Gaines, Ga.	do.	394	—	[8/]**93**	—
—	intermediate drainage area between mouths of Pataula and Cemochechobee Creeks, Georgia	—	41	—	[9/]**10**	—
02343255	Cemochechobee Creek at Fort Gaines, Ga.	tributary	103	07-08-86	[5/]26	.252
[4/]299C	Cemochechobee Creek at mouth near Fort Gaines, Ga.	do.	106	—	[9/]**27**	—
—	intermediate drainage area between mouths of Cemochechobee and Kolomoki Creeks, Georgia	—	19	—	[10/]**6.5**	—
02343270	Kolomoki Creek near Fort Gaines, Ga.	tributary	98	07-08-86	[5/]42	.429
[4/]103	Kolomoki Creek at mouth, Ga.	do.	102	—	[11/]**44**	—
—	intermediate drainage area downstream of Kolomoki Creek, Georgia	—	67	—	[11/]**29**	—
	Alabama Contributing Area					
—	intermediate drainage area upstream of Uchee Creek, Alabama	—	30	—	[12/]**.51**	—
02342500	Uchee Creek near Ft. Mitchell, Ala.	tributary	325	07-12-86	[13/]5.6	.017
[14/]18	Uchee Creek at mouth at Ft. Mitchell, Ala.	do.	334	—	[12/]**5.7**	—
—	intermediate drainage area between mouths of Uchee and Ihagee Creeks, Alabama	—	11	—	[12/]**1.9**	—
[14/]19	Ihagee Creek at mouth near Holy Trinity, Ala.	do.	34	—	[12/]**.58**	—
—	intermediate drainage area between mouths of Ihagee and Hatchechubbee Creeks, Alabama	—	25	—	[12/]**.42**	

Table 7. Stream discharge during the drought of 1986, Subarea 3—Continued
—, not applicable]

Station number	Station name	Type of stream	Drainage area, (square miles)	Date	Stream discharge (cubic feet per second)	Unit-area discharge[1/] (cubic feet per second per square mile)
02342890	Hatchechubbee Creek near Pittsview, Ala.	tributary	51	07-09-86	[5/].62	.012
[14/]22	Hatchechubbee Creek at mouth near Eufaula, Ala.	do.	151	—	[15/]**1.8**	—
—	intermediate drainage area between mouths of Hatchechubbee and Cowikee Creeks, Alabama	—	56	—	[15/]**0.67**	—
02342920	North Fork Cowikee Creek near Glenville, Ala.	tributary	114	07-10-86	[5/].09	.001
02342928	Middle Fork Cowikee Creek near Hawkinsville, Ala.	do.	168	07-10-86	[5/]1.0	.006
02342933	South Fork Cowikee Creek near Batesville, Ala.	do.	112	07-15-86	[13/].34	.003
[14/]29	Cowikee Creek at mouth near Eufaula, Ala.	do.	464	—	[16/]**1.7**	—
—	intermediate drainage area between mouths of Cowikee and Barbour Creeks, Alabama	—	49	—	[17/]**5.6**	—
02342980	Barbour Creek at White Oak, Ala.	tributary	20	07-10-86	[5/]2.3	.115
[14/]32	Barbour Creek at mouth near Eufaula, Ala.	do.	97	—	[17/]**11**	—
—	intermediate drainage area between mouths of Barbour and Cheneyhatchee Creeks, Alabama	—	4	—	[17/]**.46**	—
02343040	Cheneyhatchee Creek near Eufaula, Ala.	tributary	28	07-10-86	[5/]1.6	.057
—	Cheneyhatchee Creek at mouth, Ala.	do.	54	—	[18/]**3.1**	—
—	intermediate drainage area between mouths of Cheneyhatchee and Abbie Creeks, Alabama	—	136	—	[19/]**16**	—
02343300	Abbie Creek near Haleburg, Ala.	tributary	146	07-15-86	[13/]17	.116
[14/]37	Abbie Creek at mouth, Ala.	do.	196	—	[20/]**23**	—
—	intermediate drainage area downstream of Abbie Creek at mouth, Alabama	—	31	—	[20/]**3.6**	—
02343801	Chattahoochee River near Columbia, Ala.	regional	8,210	07-13-86	[13/]761	.093
	FLINT RIVER BASIN					
02347500	Flint River near Culloden, Ga.	regional	1,850	07-15-86	[13/]107	.058
02348300	Patsiliga Creek at Reynolds, Ga.	tributary	139	07-08-86	[5/]21	.151
[4/]108A	Patsiliga Creek at mouth near Reynolds, Ga.	do.	142	—	[21/]**21**	—
—	Beaver Creek at mouth near Reynolds, Ga.	do.	27	—	[21/]**4.1**	—
—	Horse Creek at mouth near Marshallville, Ga.	do.	37	—	[21/]**5.6**	—
02349140	Whitewater Creek near Oglethorpe, Ga.	do.	240	07-07-86	[5/]172	.717
[4/]117A	Whitewater Creek at mouth near Oglethorpe, Ga.	do.	242	—	[22/]**174**	—
02349420	Buck Creek at Oglethorpe, Ga.	do.	224	07-07-86	[5/]49	.219
[4/]121A	Buck Creek at mouth near Oglethorpe, Ga.	do.	232	—	[23/]**51**	—
02349500	Flint River at Montezuma, Ga.	regional	2,900	07-15-86	[13/]523	.180
—	Camp Creek at mouth near Andersonville, Ga.	tributary	61	—	[24/]**12**	—
—	Sweetwater Creek at mouth near Andersonville, Ga.	do.	42	—	[24/]**8.1**	—
02349740	Hogcrawl Creek near Montezuma, Ga.	do.	83	07-07-86	[5/]16	.193
—	Hogcrawl Creek at mouth near Andersonville, Ga.	do.	97.0	—	[24/]**19**	—

Table 7. Stream discharge during the drought of 1986, Subarea 3—Continued
—, not applicable]

Station number	Station name	Type of stream	Drainage area, (square miles)	Date	Stream discharge (cubic feet per second)	Unit-area discharge[1/] (cubic feet per second per square mile)
02349910	Turkey Creek near Drayton, Ga.	do.	76	07-07-86	[5/]15	.197
—	Turkey Creek at mouth near Cobb, Ga.	do.	186	—	[25/]**37**	—
02351890	Muckalee Creek at State Route 195 near Leesburg, Ga.	do.	362	07-14-86	[13/]**18**	0.050
02350900	Kinchafoonee Creek near Dawson, Ga.	do.	527	07-15-86	[13/]**39**	.074
02353100	Ichawaynochaway Creek near Dawson, Ga.	do.	118	—	[26/]**45**	—
02353200	Little Ichawaynochaway Creek near Shellman, Ga.	do.	52	07-07-86	[5/]**20**	.385
02353400	Pachitla Creek (at subarea boundary) near Edison, Ga.	do.	188	—	[5/]**44**	—

[1/]Unit-area discharge computed using streamflow and drainage area.
[2/]Estimated unregulated discharge (Chapman and Peck, 1996b).
[3/]Estimate based on unit-area discharge at Upatoi Creek at Ft. Benning, Ga.
[4/]Carter (1959).
[5/]Miscellaneous discharge measurement.
[6/]Estimate based on unit-area discharge at Hannahatchee Creek at Union, Ga.
[7/]Estimate based on mean of unit-area discharge at Hannahatchee Creek at Union, Ga., and Pataula Creek near Georgetown, Ga.
[8/]Estimate based on unit-area discharge at Pataula Creek near Georgetown, Ga.
[9/]Estimate based on unit-area discharge at Cemochechobee Creek at Fort Gaines, Ga.
[10/]Estimate based on mean of unit-area discharge at Cemochechobee Creek at Fort Gaines, Ga., and Kolomoki Creek near Fort Gaines, Ga.
[11/]Estimate based on unit-area discharge at Kolomoki Creek near Fort Gaines, Ga.
[12/]Estimate based on unit-area discharge at Uchee Creek near Ft. Mitchell, Ala.
[13/]Daily mean discharge.
[14/]Stallings and Pierce (1957).
[15/]Estimate based on unit-are discharge at Hatchechubbee Creek near Pittsview, Ala.
[16/]Estimate based on area weighted average of unit-area discharges at North Fork Cowikkee Creek near Glenville, Ala., Middle Fork Cowikee Creek near Hawkinsville, Ala. and South Fork Cowikee Creek near Batesville, Ala.
[17/]Estimate based on unit-area discharge at Barbour Creek at White Oak, Ala.
[18/]Estimate based on unit-area discharge at Cheneyhatchee Creek near Eufaula, Ala.
[19/]Estimate based on mean of unit-area discharge at Barbour Creek at White Oak, Ala., and Abbie Creek near Haleburg, Ala.
[20/]Estimate based on unit-area discharge at Abbie Creek near Haleburg, Ala.
[21/]Estimate based on unit-area discharge at Patsiliga Creek near Reynolds, Ga.
[22/]Estimate based on unit-area discharge at Whitewater Creek near Oglethorpe, Ga.
[23/]Estimate based on unit-area discharge at Buck Creek at Oglethorpe, Ga.
[24/]Estimate based on unit-area discharge at Hogcrawl Creek near Montezuma, Ga.
[25/]Estimate based on unit-area discharge at Turkey Creek near Drayton, Ga.
[26/]Estimate based on unit-area discharge at Little Ichawaynochaway Creek near Shellman, Ga.

During October 1954, estimates of drought flow at the confluence of tributary streams and the Chattahoochee River, and intermediate drainage areas were based largely on a unit-area discharge conversion. These estimates are presented in bold typeface in table 6. The 1954 drought baseflow in the Chattahoochee River was computed by summing estimates of the tributary contributions (table 8). The estimated contributions from the States of Alabama and Georgia to the Chattahoochee River are shown in table 8.

Table 8. Relation between estimated mean-annual baseflow and drought flow in the Chattahoochee and Flint River basins, Subarea 3

River name, by state	Contributing drainage area (square miles)	Stream discharge, in cubic feet per second		
		Estimated mean-annual baseflow[1/]	Drought of 1954[2/]	Drought of 1986[3/]
Chattahoochee				
Georgia	1,720	1,027	492	375
Alabama	1,670	**591**	**87**	74
Chattahoochee–Georgia and Alabama	**3,390**	**1,618**	**579**	**449**
Flint				
Georgia	**2,810**	**1,812**	**963**	**498**
CHATTAHOOCHEE AND FLINT–GEORGIA AND ALABAMA	**6,200**	**3,430**	**1,542**	**947**

[1/]From tables 5 and 6.
[2/]From table 6.
[3/]From table 7.

Baseflow near the end of the 1954 drought in Subarea 3 had decreased to 1,540 ft^3/s, or about 45 percent of the mean-annual baseflow (table 5). Baseflow in the Chattahoochee River during the drought of 1954 was approximately 579 ft^3/s or 36 percent of mean-annual baseflow; baseflow in the Flint River was 963 ft^3/s or about 53 percent of mean-annual baseflow (table 5). These results indicate that the 1954 drought influenced baseflow and the ground-water flow system related to the Chattahoochee River to a greater degree than those of the Flint River. Of the 579 ft^3/s (table 8) discharged to the Chattahoochee River, about 492 ft^3/s, or 85 percent was from Georgia and 87 ft^3/s, or 15 percent was from Alabama.

The streamflow measurements and estimates based on unit-area discharges of the 1986 drought are listed in table 7. These estimates were computed in the same manner as that of the 1954 drought. The drought of 1986 was more severe than the 1954 drought, especially for the Flint River.

Baseflow in the Chattahoochee River during the drought of 1986 was about 449 ft^3/s, or approximately 28 percent of mean-annual baseflow; baseflow in the Flint River was about 498 ft^3/s, or 27 percent of mean-annual baseflow (table 8). Of the 449 ft^3/s discharged to the Chattahoochee River, about 16 percent, or 74 ft^3/s, was from Alabama and 84 percent, or 375 ft^3/s, was from Georgia (table 8).

Although the 1986 drought was more severe than the 1954 drought, with respect to baseflow, the relative distribution of baseflow in the Chattahoochee River is quite similar (table 8). According to table 8, Alabama contributed about 15 percent of the total baseflow in the Chattahoochee River for both droughts; and Georgia contributed about 85 percent. Apparently, as ground-water flow conditions decline from mean conditions to extreme low-flow conditions, the relative contribution from Alabama decreases, while the relative contribution from Georgia increases (table 8).

Baseflow in the Chattahoochee River under mean-annual and drought-flow conditions increases with increasing contributing drainage area (fig. 8). Although different in magnitude, the droughts affected the baseflow from contributing areas similarly. Tributaries contributed relatively more to mean-annual baseflow in the Chattahoochee River than to drought flow.

Baseflow in the Flint River under mean-annual and drought-flow conditions also increases with increasing contributing drainage area (fig. 9). Apparently, both the 1954 and 1986 droughts substantially affected baseflow in the upper part of the basin, as shown by the marginal increase in downstream discharge.

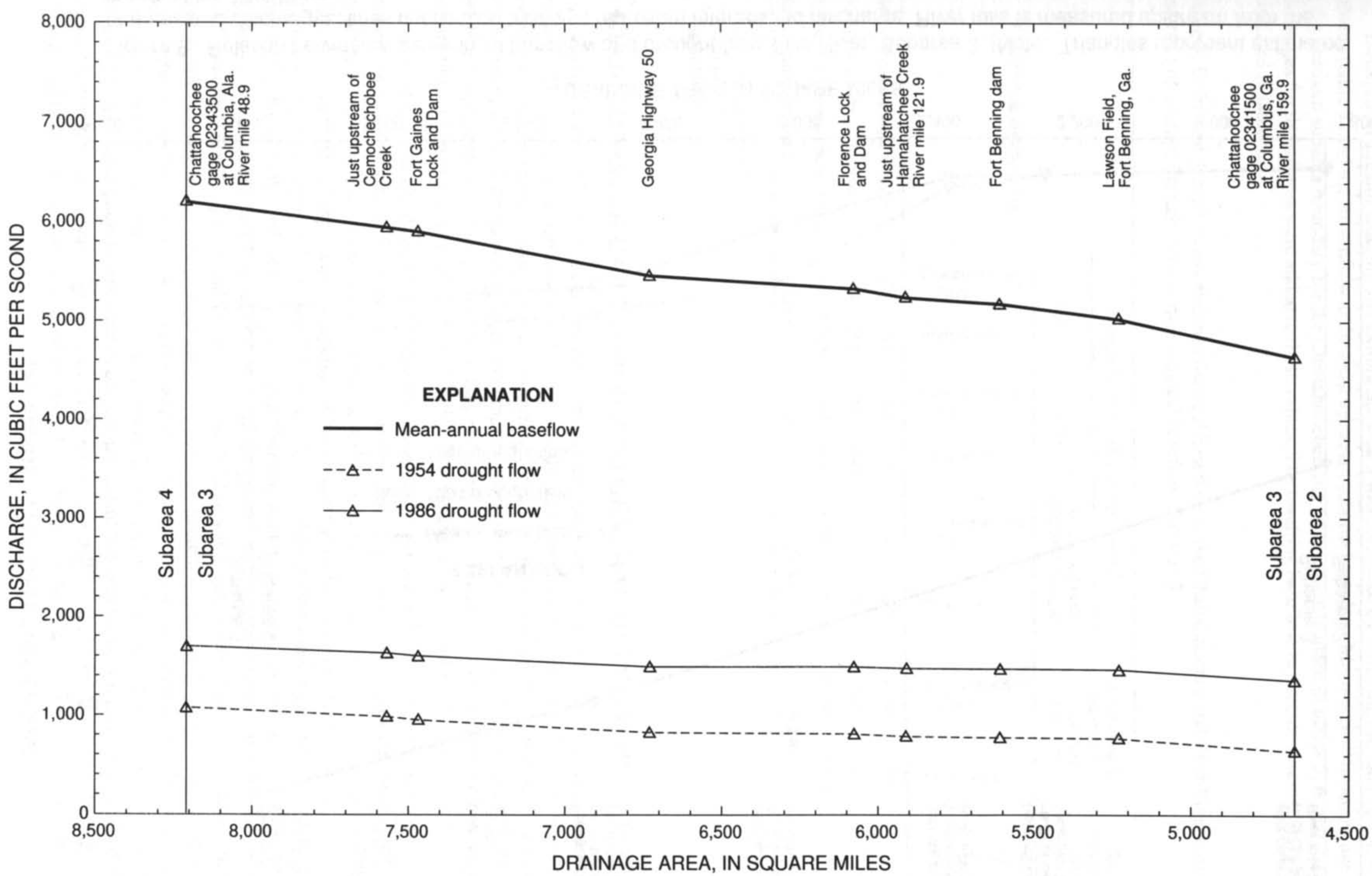


Figure 8. Relation between mean-annual baseflow and drought flow, Chattahoochee River, Subarea 3. [Note: Triangles represent estimated or measured discharges; lines connecting triangles represent interpolated discharge. River mile is measured upstream from the mouth of the Chattahoochee River.]

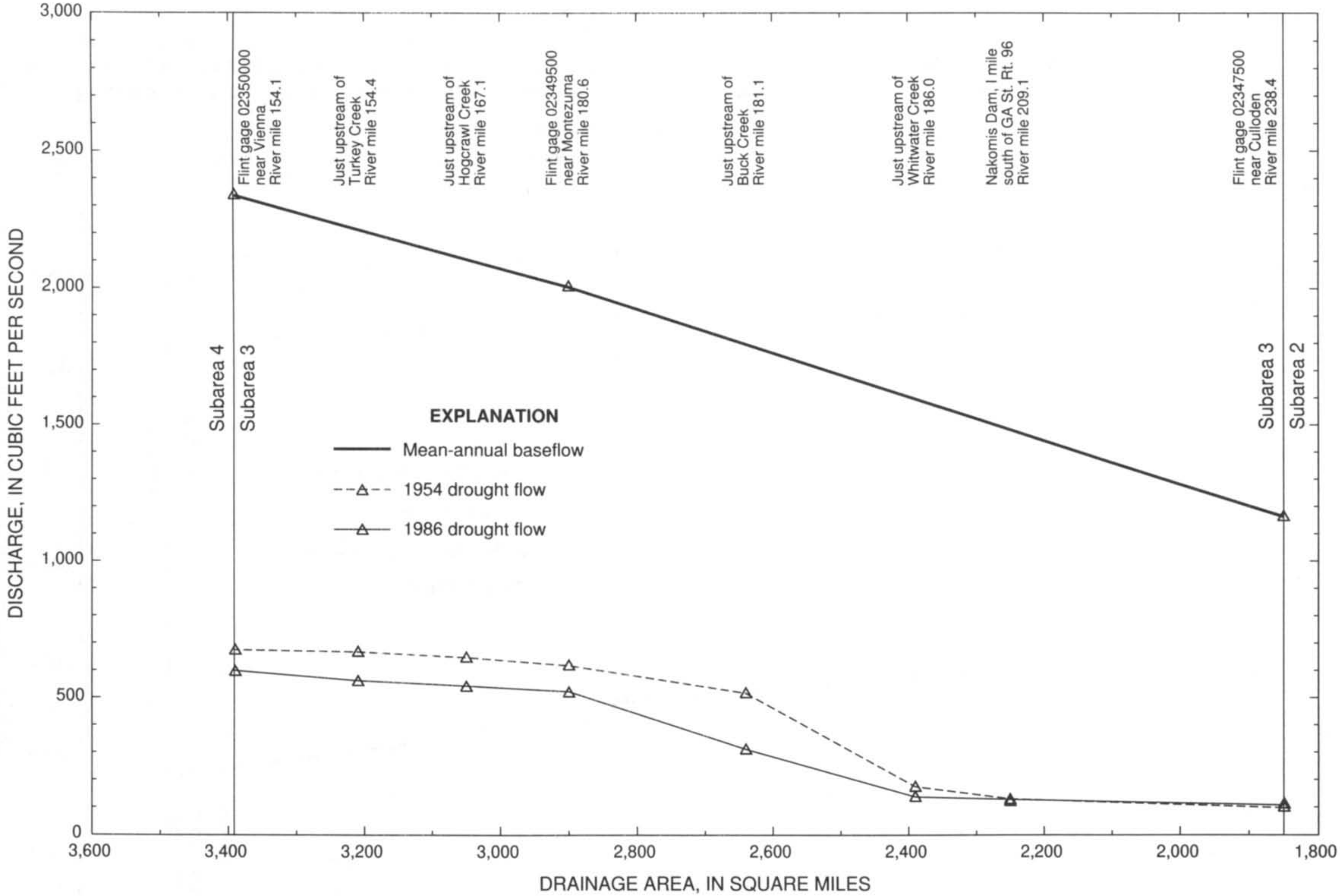


Figure 9. Relation between mean-annual baseflow and drought flow, Flint River, Subarea 3. [Note: Triangles represent estimated or measured discharges; lines connecting triangles represent interpolated discharge. River mile is measured upstream from the mouth of the Flint River.]

Baseflow in streams entering and exiting Subarea 3 was computed by summing the total baseflow for the subarea (table 8) and the streamflow at the most upstream subarea boundary. Mean-annual baseflow and drought flow at the northern subarea boundary for the Chattahoochee and Flint Rivers is listed in tables 5, 6, and 7. Ground-water discharges for the subarea were added to these values. The resulting baseflow to streams entering and exiting Subarea 3 is listed in table 9.

Table 9. Estimated drought flows and mean-annual baseflow in the Chattahoochee and Flint Rivers and tributaries; and ratio of average drought flow to mean-annual baseflow, Subarea 3

Contributing drainage area	Drought flows, in cubic feet per second						Mean-annual baseflow,[1/] (cubic feet per second)		Ratio of average drought flow to mean-annual baseflow, (percent)	
	[2/]1954		[3/]1986		Average of 1954 and 1986 droughts					
	Chattahoochee River	Flint River	Chattahoochee River	Flint River	Chattahoochee River	Flint River	Chattahoochee River	Flint River	Chattahoochee River	Flint River
Flow entering subarea, by river	679	97	888	107	784	102	4,640	1,160	17	9
Flow gain in subarea, by river	579	963	449	498	514	730	1,618	1,812	32	40
Flow exiting drainage basin, by river	1,258	1,060	1,337	605	1,298	832	6,258	2,972	21	28
Flow exiting Subarea 3	**2,318**		**1,942**		**2,130**		**9,230**			

[1/]From tables 6 and 7.
[2/]From table 6.
[3/]From table 7.

GROUND-WATER UTILIZATION AND GENERAL DEVELOPMENT POTENTIAL

Ground-water utilization is defined as the ratio of ground-water use in 1990 to mean-annual ground-water recharge. The degree of ground-water utilization is scale dependent. For example, local ground-water pumping may result in substantial storage change and water-level declines near a center of pumping; whereas, such pumping relative to the entire Subarea would be small compared to mean-annual recharge. Because ground-water use in Subarea 3 represents a relatively minor percentage of ground-water recharge, even a large increase in ground-water use in Subarea 3 in one State is likely to have little effect on ground-water and surface-water occurrence in the other.

The 1990 water-use data in table 1 represent estimated water use in Subarea 3, without regard to the effects of ground-water withdrawal at the boundary of the subarea. For the purposes of comparison, these data have been modified to represent only the ground-water withdrawal that affect ground-water flow in Subarea 3. The value of 12.6 Mgal/d shown in table 1 represents total public ground-water use in the Alabama part of Subarea 3, including the total ground-water public supply of 7.92 Mgal/d for the city of Dothan in Houston County in the extreme southwestern corner of Subarea 3 (W.S. Mooty, U.S. Geological Survey, written commun., 1995). The location of Dothan relative to the boundaries of Subarea 3 indicates that not all the ground water pumped is contributed from within Subarea 3. Scott and others (1984, figs. 13 and 14) show a cone of depression around Dothan in 1982, and estimate the contributing recharge area. Of that estimated area, about 20 percent represents the area contributing ground water to the Chattahoochee River in Subarea 3 under natural conditions. Ground water contributed from the remaining area flows to the west and south of Subarea 3. The area of the 1982 cone of depression is considered equal to that produced by 1990 pumpage. Consequently, only 20 percent of the total public-supply pumpage at Dothan (1.58 Mgal/d) is attributed to Subarea 3; thus, the total ground-water public supply for Alabama used in this report is 6.27 Mgal/d, and total ground-water use for Alabama is 10.62 Mgal/d or 16 ft^3/s.

Ground-water use of about 76 ft^3/s in 1990 in Subarea 3 represented about 2.2 percent of the mean-annual baseflow and 4.9 to 8.0 percent of drought flow near the end of the droughts of 1954 and 1986, respectively (table 10). Ground-water withdrawal of 55 ft^3/s in the Flint River basin is about 3 percent of the mean-annual baseflow, and about 5.7 percent of the 1954 drought flow, and about 11.0 percent of the 1986 drought flow (table 10).

Table 10. Relation between 1990 ground-water use and ground-water discharge during mean-annual baseflow and 1954 and 1986 drought flows, Subarea 3

Contributing area	Principal river	Ground-water use, 1990, (cubic feet per second)	Baseflow to the Chattahoochee and lint Rivers and their tributaries (cubic feet per second)			Ratio of ground-water use to baseflow (percent)		
			Mean-annual baseflow	1954 drought baseflow	1986 drought baseflow	Mean-annual baseflow	1954 drought baseflow	1986 drought baseflow
Alabama	Chattahoochee River	16	591	87	74	2.7	18.4	**21.6**
Georgia	Chattahoochee River	5	1,027	492	375	0.5	1.0	**1.3**
Alabama and Georgia	Chattahoochee River	21	1,618	579	449	1.3	3.6	**4.7**
Georgia	Flint River	55	1,812	963	498	3.0	5.7	**11.0**
Total, Subarea 3		**76**	**3,430**	**1,542**	**947**	**2.2**	**4.9**	**8.0**

Comparison of 1990 water-use to baseflow for the Chattahoochee River basin indicates an areally variable relation. The 1990 ground-water use of the Chattahoochee River basin, adjusted for the estimate of pumpage at Dothan, is about 21 ft^3/s, or about 1.3 percent of the estimated 1,618 ft^3/s mean annual baseflow (table 9). The 1990 ground-water use equals about 3.6 percent of the 1954 drought baseflow, and about 4.7 percent of the 1986 drought baseflow (table 9).

Alabama ground-water withdrawal (16 ft^3/s) is about 76 percent of the Chattahoochee River basin area total (21 ft^3/s), and accounts for about 2.7 percent of the mean-annual baseflow contributed from Alabama, 18 percent of the 1954 baseflow from Alabama, and 22 percent of the 1986 baseflow from Alabama (table 10).

Georgia ground-water withdrawal is about 24 percent of the Chattahoochee River basin area total. This ground-water use represents about 0.5 percent of the mean-annual baseflow contributed from Georgia, 1.0 percent of the 1954 baseflow from Georgia, and 1.3 percent of the 1986 baseflow from Georgia (table 10).

Several depressions occur in the potentiometric surfaces of various aquifers that underlie Subarea 3, indicating a relatively substantial withdrawal of ground water and interruption of natural flow paths. In the southern part of the subarea, a small cone of depression in the Nanafalia-Clayton aquifer has formed around the city of Dothan in Houston County, Ala. (Williams and others, 1986c). In the south-central part of the subarea, a larger cone of depression occurs in the Providence aquifer in northern Terrell County, Ga., caused by pumping at Albany in Dougherty County, Ga., just south of Subarea 3 (Clarke and others, 1983). This cone extends marginally into Subarea 3. A small cone of depression in the Providence aquifer is centered around Americus in Sumter County, Ga. (Clarke and others, 1983). A small cone of depression also has been identified in the Tuscaloosa aquifer near Eufaula, Barbour County, Ala. (Kidd, 1987). An areally extensive cone of depression that extends from northwest Early County to Sumter County, Ga., has formed in the Clayton aquifer and is attributed to irrigation pumping (Long, 1989).

Comparisons of the ground-water budgets, water-use data, and potentiometric surfaces indicate that the ground-water resources of Subarea 3 are not significantly impaired by ground-water use. Comparison of the ground-water withdrawal to mean-annual baseflow, indicates that 1990 ground-water withdrawal is less than 3 percent of average baseflow. Ground-water withdrawal during 1990 in Subarea 3 is about 9 percent of mean-annual baseflow, although for the Chattahoochee River basin, the baseflow and pumpage are not evenly distributed between the contributing areas in Georgia and Alabama. Most measurable cones of depression are small and are comparatively far removed from the recharge areas of contributing aquifers. These pumping centers probably affect intermediate and regional flow regimes most substantially and capture ground water that normally would discharge farther downgradient or to major tributaries or regional drains.

A general assessment of ground-water development potential in Subarea 3 would reflect, in part, the cumulative effects of current and anticipated future hydrologic stresses imposed on the ground-water resources, and to a lesser extent, the current availability of surface-water supplies. The nature of such an assessment is necessarily limited by a lack of knowledge of current hydrologic conditions and the lack of agreed upon standards by which Federal, State, or local water-resources managers evaluate the effects of additional stress and future development. Current pumpage and streamflow conditions might be unknown in some areas, making the results of an evaluation of development potential highly uncertain. Future stresses also might be linked to water-management practices that have yet to be formulated, or to water-management decisions that have yet to be made. Therefore, an assessment of ground-water development potential provides insight into only one aspect of the broader question of how water-management decisions affect ground-water availability; specifically, whether or not existing hydrologic data document flow-system behavior adequately to allow the potential effects of future development on the flow system to be adequately evaluated and understood. Further, an assessment of ground-water development potential does not account for the suitability of existing ground-water resource management approaches or the effects of future approaches on further resource development. Such answers partly are dependent on the synthesis of results from the various Comprehensive Study components and subsequent consideration by the Federal, State, or local water managers responsible for decision-making within the basin. The identification of areas that could be developed for ground-water supply to replace or supplement surface-water sources could not be determined from data available for Subarea 3.

SUMMARY

Drought conditions in the 1980’s have focused attention on the multiple uses of the surface- and ground-water resources in the Apalachicola-Chattahoochee-Flint (ACF) and Alabama-Coosa-Tallapoosa (ACT) River basins in Alabama, Florida, and Georgia. Federal, State, and local agencies also have proposed projects that are likely to result in additional water use and revisions of reservoir operating practices within the river basins. The existing and proposed water projects have created conflicting demands for water and emphasized the problem of allocation of the resource. This study was initiated to describe ground-water availability in the lower-middle Chattahoochee River basin in Georgia and Alabama; and middle Flint River basin in Georgia, Subarea 3 of the ACF-ACT River basins, and to estimate the possible effects of increased ground-water use in the basin.

Subarea 3 encompasses about 4,510 square miles (mi^2) in southwestern Georgia and about 1,670 mi^2 in southeastern Alabama. Almost all the Subarea lies within the Coastal Plain physiographic province. The Chattahoochee and Flint Rivers are the major rivers of the Subarea, both entering the Subarea from the north and flowing generally southward into Subarea 4. The Chattahoochee River drains the western 3,370 mi^2 of the Subarea, while the Flint River drains the eastern 2,810 mi^2. Streamflow in the Chattahoochee River has been influenced by regulation upstream of Subarea 3 by Lake Harding since 1926, West Point Lake since 1975, and Lake Sidney Lanier since 1955; and within the Subarea by Walter F. George Reservoir since 1963. Most regulation occurs at Buford and West Point Dams. Tributary stream discharge to the Chattahoochee River is unregulated. There are no streamflow control structures on the Flint River upstream of or within the Subarea.

The hydrologic system is comprised of the aquifers and the rivers and streams. The aquifers are composed of sedimentary rock sequences that dip and thicken to the south. The outcrop area of the sediments functions as the recharge area of the aquifers, receiving precipitation that infiltrates down to the saturated zone. Recharge areas of the aquifers generally occur in east-west trending bands, and areas of outcrop of the older and deeper units that occur farther north are sequentially overlapped to the south by the overlying units. The Chattahoochee and Flint Rivers flow south, crossing the aquifers in an approximate orthogonal fashion.

The conceptual model of the hydrologic flow system is based upon work by several previous investigators. Ground water originates in the recharge areas of the aquifers, and subsequently flows downgradient to discharge to evapotranspiration, a pumping well, a river or stream, or flows farther downgradient into the confined part of the aquifer. Most of the water that enters the aquifers as recharge is discharged to nearby streams or rivers.

The conceptual model of ground-water flow and stream-aquifer relations subdivide the ground-water flow system into local (shallow), intermediate, and regional (deep) flow regimes. The regional flow regime probably approximates steady-state conditions and water from this regime discharges chiefly to the Chattahoochee River and Flint River. Ground-water discharge to tributaries primarily is from the local and intermediate flow regimes. Ground water that discharges to regional drains includes contributions from local, intermediate, and regional flow regimes. Mean-annual ground-water discharge to streams (baseflow) is considered to approximate the long-term, average recharge to ground water.

Estimates of ground-water discharge to the Chattahoochee and Flint Rivers were computed for mean-annual and extreme drought conditions. Under mean-annual conditions, about 1,618 ft^3/s is discharged from the ground-water flow system to the Chattahoochee River. Of this discharge, about 63 percent originates in Georgia and 37 percent in Alabama. Under mean-annual conditions, ground-water discharge to the Flint River is 1,812 ft^3/s. Near the end of drought of 1954, baseflow in the Chattahoochee River was about 579 ft^3/s; with 85 percent contributed from Georgia and 15 percent contributed from Alabama. Nearly contemporaneous discharge to the Flint River was 963 ft^3/s. Near the end of the drought of 1986, baseflow in the Chattahoochee River was about 449 ft^3/s; with 84 percent contributed from Georgia and 16 percent contributed from Alabama. Near contemporaneous baseflow in the Flint River was about 498 ft^3/s.

Ground-water resources were evaluated by comparing the ground-water budgets to 1990 ground-water withdrawal in the Subarea. Total 1990 ground-water withdrawal in the Chattahoochee River basin was about 1.5 percent of the mean-annual baseflow. Of this total 1990 ground-water use, about 25 percent occurred in Georgia and 75 percent in Alabama. Total 1990 ground-water withdrawal in the Chattahoochee River basin was about 4 percent of the 1954 drought baseflow, and about 5 percent of the 1986 drought baseflow. Total 1990 ground-water withdrawal in the Flint River basin was about 3 percent of the mean-annual baseflow, 6 percent of 1954 drought baseflow and 11 percent of the 1986 drought baseflow. Several cones of depression occur in the potentiometric surfaces of aquifers in Subarea 3. Although several of these cones represent substantial reductions in predevelopment water levels, none are extensive enough, or near enough to recharge areas, to greatly affect surface-water resources in Subarea 3.

Because ground-water use in Subarea 3 represents a relatively minor percentage of ground-water recharge, even a large increase in ground-water use in Subarea 3 in one State is likely to have little effect on ground-water and surface-water occurrence in the other.

The limited scope, lack of field-data collection, and the short duration of the ACF-ACT River basin study has resulted in incomplete descriptions of ground- and surface-water-flow systems. For example, the extent and continuity of local and regional flow systems largely are unknown. Similarly, quantitative descriptions of stream-aquifer relations, ground-water flow across State lines, water quality, drought flows, and ground-water withdrawal and subsequent effects on the flow systems (the availability and utilization issue) are highly interpretive; therefore, the descriptions and evaluations should be used accordingly.

A significant data base exists describing well-construction and yield data and hydraulic characteristics of aquifers in Subarea 3. Water-quality information and historic and recent ground-water withdrawal data, both areally and by aquifer, also are available. However, precise information describing the relation between ground water and surface water is lacking. Seepage runs (detailed streamflow measurements of drainage systems made concurrently during baseflow conditions) can be used to identify individual ground-water flow systems and to study stream-aquifer relations. Once identified, a flow system can be studied in detail to define its extent, recharge and discharge areas, movement of water, chemical quality, and the amount of water that can be withdrawn with inconsequential or minimal effects. These detailed studies might employ test drilling, borehole geophysical logging, surface geophysics, aquifer tests, a thorough water-withdrawal inventory, and chemical analyses of ground water to delineate the extent of the ground-water-flow system and evaluate its potential as a water supply. Evaluation of several such flow systems would greatly improve the understanding of ground-water resources throughout the Subarea.

Estimates of water use and ground-water discharge to streams are dependent on methodologies employed during data collection, computation, and analyses. Results reported herein are limited by a lack of recent data and the non-contemporaneity of all data. Analyses using limited data may not adequately describe stream-aquifer relations. Most importantly, analyses in this report describe only two hydrologic conditions—(1) mean-annual baseflow and (2) drought-flow conditions during 1954 and 1986. Results derived from extrapolation of information provided herein to other hydrologic conditions, such as much longer drought periods or increased ground-water withdrawal, should be used with caution. Special concern should be directed to changes in streamflow that may be caused by increased post-1990 withdrawal on ground-water discharge to streams in Subarea 3.

SUGGESTIONS FOR FURTHER STUDY

This report presents a discussion of ground-water resources and interaction of ground- and surface-water systems in the lower-middle Chattahoochee and middle Flint River basins, Subarea 3, of the ACF-ACT River basins. In Subarea 3, ground-water availability is addressed only from a regional perspective using historical data. Data collection was not a part of this study; therefore, lack of streamflow and ground-water data necessitated that estimation methods be used extensively to describe stream-aquifer relations. Additional data, particularly data describing surface- and ground-water conditions on a local scale, are needed to further refine and quantify the descriptions of ground- and surface-water relations in the Subarea. Analyses of these data possibly could better describe ground-water availability and development potential.

Although the overall objectives of this study were to evaluate the ground-water resources and supply, the data used to accomplish these objectives were stream-discharge data. Stream-discharge data were sufficient to meet study objectives; however, such data either were not totally adequate or were not available at critical sites. Future stream-discharge data collection to support resource management should emphasize (1) continuous-record data at critical hydrologic and political boundaries for a period of years; and (2) concurrent stream-discharge measurements at critical sites during drought periods.

Continuous stream-discharge data collected over a period of years at critical locations provide the basic information essential to basinwide water-resource planning and management. Current data coverage is incomplete. For example, stream-gaging stations located on major tributary streams would have eliminated or reduced the need to extrapolate and interpolate data from stations distant from these boundaries, and consequently, would have improved the accuracy of estimates of ground-water contributions.

The collection of drought-flow data obviously is contingent on the occurrence of a drought; thus, collection of drought data is not routine and is not easily planned. A contingency plan to collect drought data should be in place. The plan could consider, but not be limited to, logistics, manpower needs, and the preselection of stream data-collection locations. For more rigorous planning, field reconnaissance of preselected stream sites could be conducted.

Development of a ground-water flow model capable of simulating various ground-water management strategies would provide a powerful tool to water-resources managers. Aquifer-optimization management models, such as AQMAN3D (Puig and Rolon-Collazo, 1996), could be used to optimize development of the ground-water resource. Optimization models incorporate an existing ground-water flow model. The quality and reliability of the incorporated ground-water flow model can be enhanced greatly through the use of a parameter estimation code, such as MODFLOWP (Hill, 1992). The purpose of the parameter-estimation approach is to provide a measurement of reliability and hypotheses testing not found in ground-water flow models calibrated by trial-and-error. Such testing is important to effectively model ground-water flow in complex and dynamic systems, such as those of the southeastern Coastal Plain. The aquifer-optimization management model evaluates management strategies, to plan for optimal distributions of ground-water supply to wells and also for ground water to the streams and rivers within a set of specified constraints.

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