GROUND-WATER RESOURCES OF THE UPPER CHATTAHOOCHEE RIVER BASIN IN GEORGIA—*SUBAREA 1* OF THE APALACHICOLA-CHATTAHOOCHEE-FLINT AND ALABAMA-COOSA-TALLAPOOSA RIVER BASINS

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

U.S. DEPARTMENT OF THE INTERIOR
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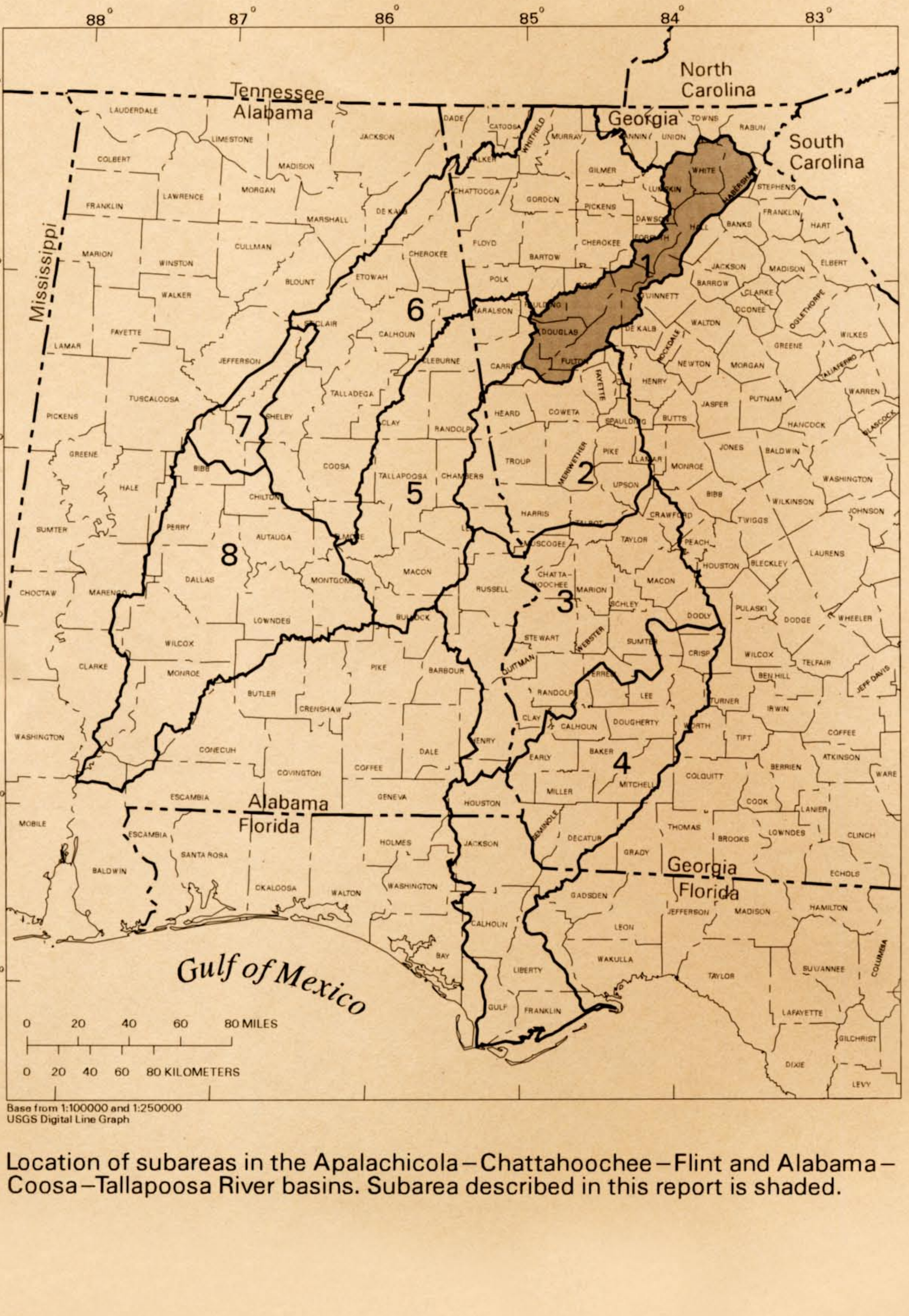

Location of subareas in the Apalachicola–Chattahoochee–Flint and Alabama–Coosa–Tallapoosa River basins. Subarea described in this report is shaded.

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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:

$$°C = 5/9 \times (°F - 32)$$

ABBREVIATIONS AND ACRONYMS

ACF	Apalachicola-Chattahoochee-Flint River basin
ACT	Alabama-Coosa-Tallapoosa River basin
ADAPS	Automated Data Processing System
CMWA	Cobb-Marietta Water Authority
Corps	U.S. Army Corps of Engineers
MOA	Memorandum of Agreement
GWSI	Ground Water Site Inventory database
PGC	Peachtree Golf Club
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

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.

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

GLOSSARY—Continued

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.

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).

GLOSSARY

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 Melinda J. Chapman and Michael F. Peck

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 upper Chattahoochee River basin of Georgia, Subarea 1 of the ACF and ACT River basins, and to estimate the possible effects of increased ground-water use within the basin.

Subarea 1 encompasses about 2,430 square miles in the Piedmont and Blue Ridge physiographic provinces of north-central Georgia. Subarea 1 includes about 28 percent of the total 8,740 square-mile area of the Chattahoochee River basin. The study area is underlain by a two-component aquifer system composed of a fractured, crystalline-rock aquifer characterized by little or no primary porosity or permeability; and the overlying weathered regolith (saprolite), which generally behaves as a porous-media aquifer. In some areas, a transition zone lies between the regolith and unweathered crystalline bedrock.

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 ground-water discharge to streams (baseflow) is considered to approximate the long-term, average recharge to ground water. The mean-annual baseflow was estimated using an automated hydrograph-separation method, and represents discharge from the local, intermediate, and regional flow regimes of the ground-water flow system. Mean-annual baseflow exiting Subarea 1 was estimated to be 2,570 cubic feet per second. Mean-annual baseflow represented about 69 percent of total mean-annual stream discharge for the period of record.

Stream discharge for selected sites on the Chattahoochee River and its tributaries were compiled for the years 1941, 1954, and 1986, during which sustained severe droughts occurred throughout most of the ACF-ACT area. Stream discharge was assumed to be sustained entirely by baseflow during the latter periods of these droughts. Estimated baseflow (unregulated) near the end of the individual droughts (1941 and 1954) averaged about 19.3 percent of the estimated mean-annual baseflow in Subarea 1.

The potential exists for the development of ground-water resources on a regional scale throughout Subarea 1. Estimated ground-water use in 1990 was about 1.1 percent of the estimated mean-annual baseflow; and 5.8 percent of the average drought flow. Because ground-water use in Subarea 1 represents a relatively minor percentage of ground-water recharge, even a large increase in ground-water use in Subarea 1 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 for which long-term water-level measurements are available in Subarea 1 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).

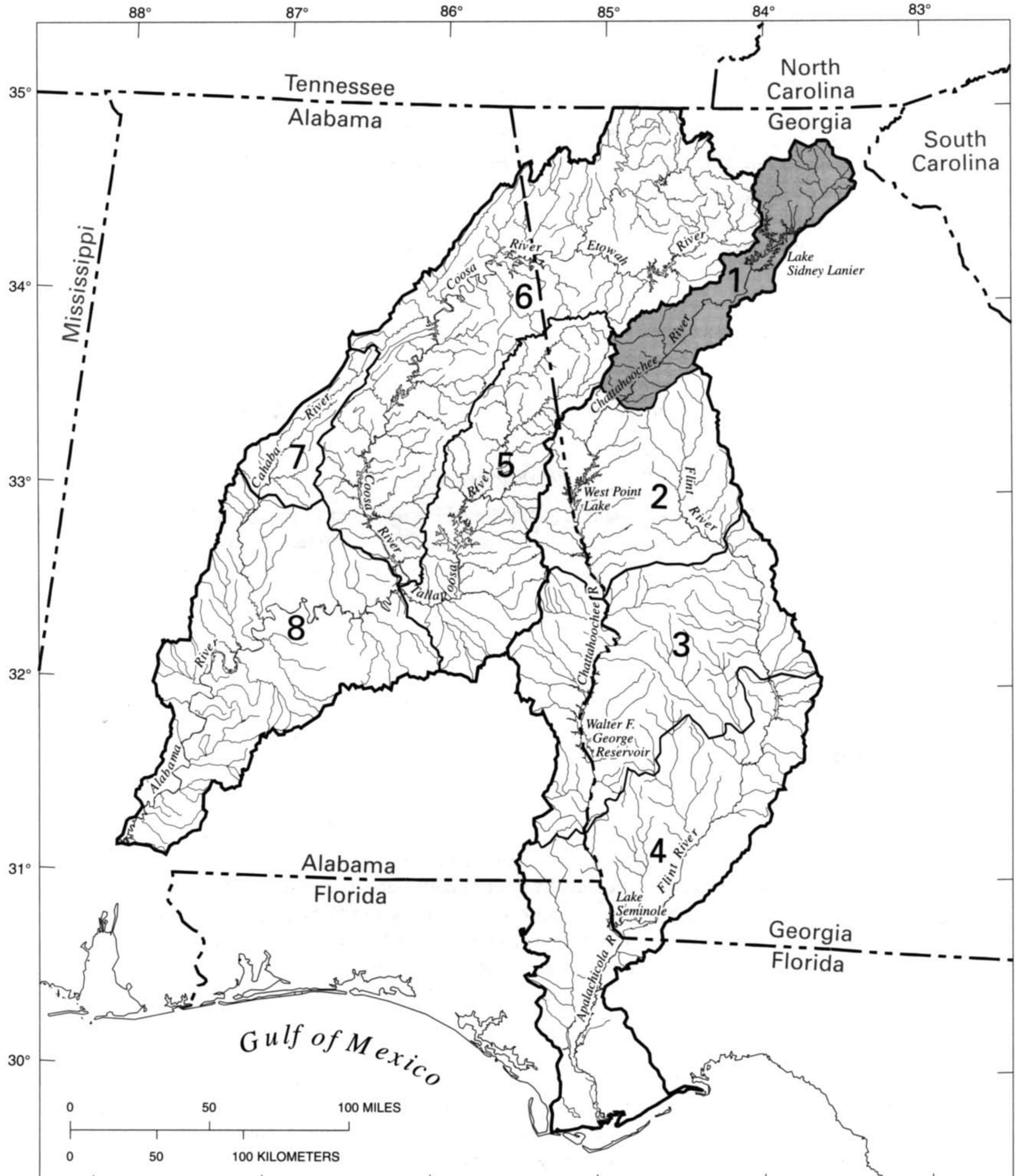
In 1992, the Governors of Alabama, Florida, and Georgia; and the U.S. Army, Assistant Secretary for Civil Works, signed a Memorandum of Agreement (MOA) establishing a partnership to address interstate water-resource issues and promote coordinated systemwide management of water resources. An important 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 ACF-ACT subareas.

Purpose and Scope

This report describes the ground-water resources of the upper Chattahoochee River basin of Georgia—Subarea 1 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 1;
- quantify mean-annual and drought period ground-water contributions to the Chattahoochee River from the headwaters to Whitesburg, Ga., and the ground water exiting Subarea 1; and
- describe and evaluate ground-water utilization and general development potential.



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.

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 State and Federal water 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

The Subarea 1 study area encompasses about 2,430 mi^2 in northern Georgia (fig. 1). The study area is bounded to the northwest by the Tennessee River basin, to the east-northeast by the Savannah River basin, and to the east by the Altamaha River basin. To the west, the study area is bounded by the Coosa River basin (Subarea 6) and Tallapoosa River basin (Subarea 5), and to the south by the middle Chattahoochee and upper Flint River basins (Subarea 2) (fig. 1).

Physiography

Eighty-eight percent of Subarea 1 lies within the Piedmont Province and 12 percent lies with the Blue Ridge Province (fig. 2). Land-surface altitudes in the study area range from about 4,430 feet (ft) above sea level in the northeastern Blue Ridge Province to about 700 ft near the Chattahoochee River at Whitesburg, Ga.; altitude of intermountain plateaus within the province ranges from about 1,600 to 1,700 ft (Brackett and others, 1991). Most streams are characterized by rectangular or trellis drainage patterns. Piedmont topography is characterized by low, rolling hills in the north and a broad rolling upland or plateau in the south (Cressler and others, 1983). The Blue Ridge is distinguished from the Piedmont chiefly by its greater topographic relief (Clark and Zisa, 1976). These two provinces are comprised of metamorphic and igneous rocks and are covered by regolith of varying thickness. The regolith in the study area is composed of semi-consolidated to unconsolidated saprolite (weathered bedrock), soil, and other surficial deposits (Clarke and Peck, 1991).

Climate

The climate in Subarea 1 is moist and temperate. The area receives an average of 58 inches (in.) of precipitation annually, which occurs primarily during the winter and early spring (Cressler and others, 1983; Carter and Stiles, 1983). The Blue Ridge receives substantially more rainfall—about 65 in. because of the orographic effect on the mountains—compared to about 50 in. in the Metropolitan Atlanta area (Miller, 1990). The percentage of rainfall resulting in runoff also is higher in the mountainous areas of northeastern Georgia. The average monthly temperature in the Metropolitan Atlanta area ranges from about 44 to 78 degrees Fahrenheit; and in Cleveland (northeastern Georgia mountains), from 39 to 78 degrees Fahrenheit (U.S. Department of Commerce, 1992).

Ground-Water Use

The estimated ground-water use in Subarea 1 during 1990 was about 18.6 million gallons per day (Mgal/d) or about 28.8 cubic feet per second (ft^3/s) (Marella and others, 1993). Of this total, about 16 percent was for public water supply, about 53 percent for domestic water supply, 9 percent for self-supplied industrial and commercial activities, and 22 percent for agricultural use. The largest ground-water use in Subarea 1 in Georgia is for domestic water supply (table 1).

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

	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)
Subarea 1 total	3.0	4.6	1.6	2.5	4.2	6.5	9.8	15.2	18.6	28.8

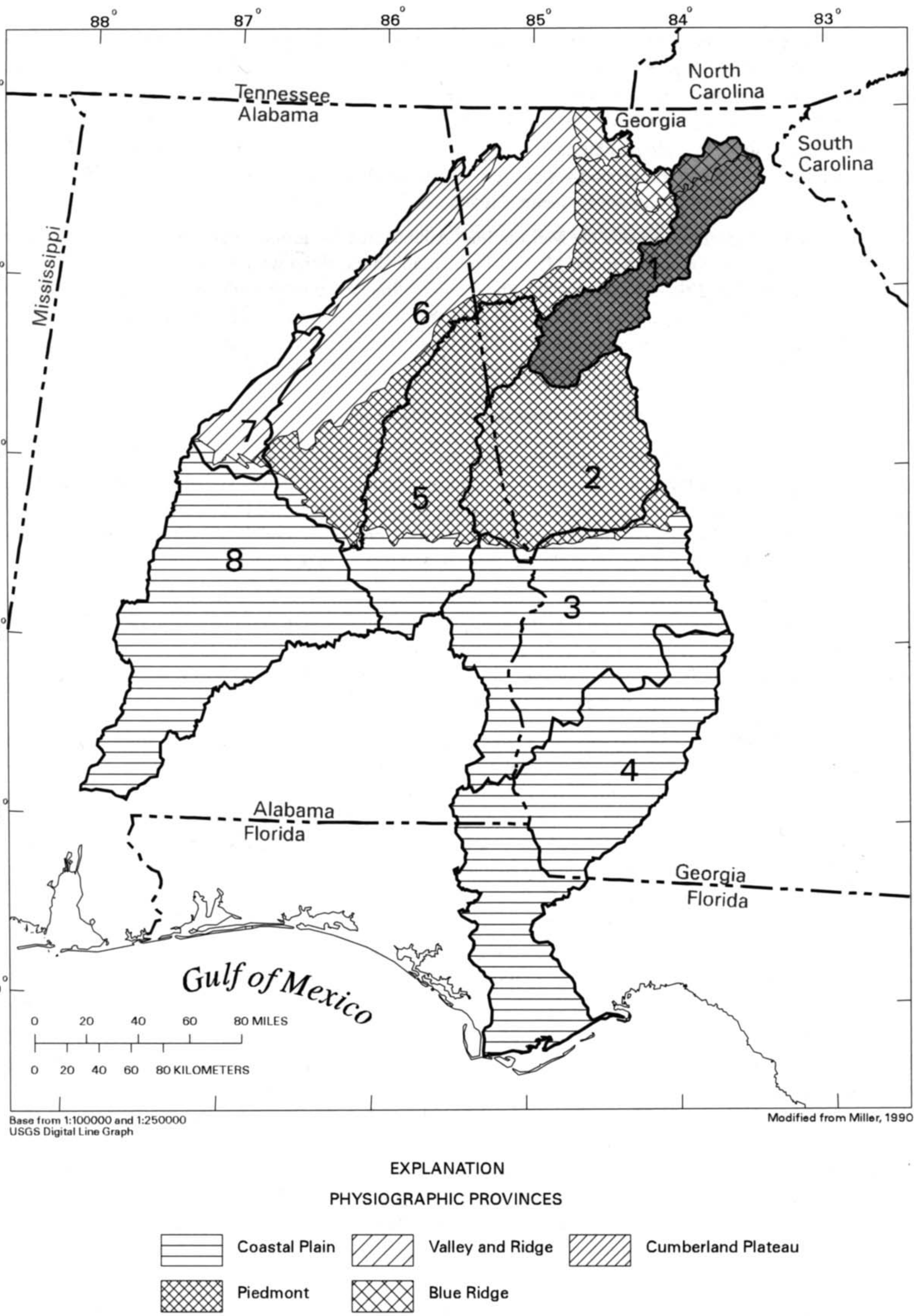


Figure 2. Physiographic provinces and subareas in the Apalachicola–Chattahoochee–Flint and Alabama–Coosa–Tallapoosa River basins.

Ground-water use reported by Marella and others (1993) is by county; ground-water use in those counties that are partially in Subarea 1 are reported herein for Subarea 1 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 was estimated by multiplying the reported county use by the percentage of the land area of the county in Subarea 1.

Many small communities outside the Metropolitan Atlanta area use ground water as their primary water supply. Rapid increases in population in the Metropolitan Atlanta area, along with the variability of surface-water supplies during drought conditions, have caused some municipalities to investigate the possibility of supplementing surface-water supplies with ground water. The Cobb–Marietta Water Authority, Cobb County, Ga., is presently (1996) installing clusters of wells to supplement the water supply during peak demand; and the city of Lawrenceville, Gwinnett County, Ga., also is actively exploring ground water as a supplemental water-supply resource.

Previous Investigations

The results of several regional studies have described ground-water resources in crystalline-rock hydrogeologic settings in the Piedmont Province of the southeastern United States. The major objectives of regional studies were to formulate concepts regarding the availability of ground water and to determine possible controlling factors that affect or control well yield and ground-water quality. Conceptual models of hydrogeologic frameworks of the crystalline-rock aquifers in this region evolve as information increases (Chapman and others, 1993).

Some of the earliest reports describing ground-water resources in the crystalline rocks of the Piedmont were by McCallie (1898, 1908), who concluded that the yield of wells completed in bedrock would be sufficient only for rural use, and would not be a viable source for large cities such as Atlanta and Macon. In urban areas, wells would be susceptible to contamination from “local drainage”; an Atlanta public supply well (2,175 ft deep), apparently was contaminated after only a few years of use (McCallie, 1898).

Herrick and LeGrand (1949) inventoried a large number of wells in the Atlanta region and conducted regional geologic mapping to determine possible factors influencing ground-water availability and quality. They concluded that the occurrence of ground water in the Metropolitan Atlanta area depended largely on factors, such as rock type, structural features, degree of weathering, and topography. Geologic settings considered to be favorable for developing high-yielding wells were discussed for a variety of rock types, geologic structural conditions, and topographic settings. Although the study represented a reconnaissance rather than a detailed evaluation, Herrick and LeGrand (1949) recognized that variations in the rock character and attitude strongly influence the availability of ground water, and distinct differences could be observed within intervals of feet in the Piedmont region. Herrick and LeGrand (1949) also related the quality of ground water to rock type. Ground water from granitic rocks was substantially less mineralized compared to water from amphibolites and hornblende gneisses, which contained elevated concentrations of calcium and magnesium.

Carter and Herrick (1951) evaluated water use and sources of water supply (including surface water) in the Metropolitan Atlanta area and estimated future water-supply needs. Historically, dug wells were the primary sources of water supply in the Atlanta area until the late 1800’s, when surface-water sources were developed to meet increasing water-supply demands. The study examined the relation between ground-water availability and certain geologic factors, such as joints, faults, and other fractures. The investigators evaluated well yield, total depth of wells, and the importance of aquifer tests in assessing sustained yield and potential well interference. The report concluded that the potential for ground-water development in the Atlanta area was considerable, and that wells could serve as sole sources of water supply for rural communities and some industries throughout the Piedmont region. Carter and Herrick (1951) related hardness of ground water to mafic rocks, such as amphibolites and hornblende gneisses, and determined that granitic rocks contained softer water.

Thomson and Carter (1955) presented streamflow data for the 1954 drought throughout Georgia, including the Chattahoochee River in Subarea 1. The authors included a discussion of the lack of rainfall—the rainfall deficit in most areas was at least 15 in. Streamflow was below normal in the Piedmont region by July 1954. Record low flows were recorded during September and early October.

A later report by Thomson and Carter (1963) continued a discussion of the 1954 drought streamflow data for Georgia. The authors state that the 1954 data may be the last available extreme drought streamflow data representing natural flow conditions. For the Chattahoochee River in subarea 1 in the northern part above the Norcross, Ga., gaging station, the 1954 drought was the fourth to sixth most severe in 60 years. The most severe drought for the Norcross station occurred in 1925. The remainder of the Chattahoochee River downstream of the Norcross station, the 1954 drought was the most severe in 61 years.

Stewart and others (1964) and Stewart (1964) conducted an investigation to determine the effects of waste-disposal migration in weathered crystalline rocks at the Georgia Nuclear Laboratory, Dawson, Ga. Infiltration tests were conducted in a saprolite disposal pit to determine the rate and areal extent of possible waste leakage into the shallow ground-water system. The purpose of the study was to determine the feasibility of using infiltration pits constructed in weathered crystalline rocks for the disposal of liquid wastes. The three water-bearing units evaluated were near-surface alluvium, regolith, and unweathered crystalline bedrock. The investigation of regolith material included estimates of saprolite porosity and permeability and ion-exchange capacity from core samples, the measurement of infiltration rates, and shallow aquifer testing. Bedrock wells also were drilled and estimates of transmissivity were made from aquifer-test data. A noticeable increase in ground-water mounding was observed along the strike of schistosity in the regolith. Other fieldwork included surficial geologic mapping and the collection of ground-water quality samples, streamflow data, and continuous ground-water levels in wells. During aquifer testing, the largest drawdowns in the saprolite wells were along the strike of schistosity. Rates of ground-water movement were calculated from hydraulic gradient data and estimates of porosity and permeability in the saprolite.

LeGrand (1967) proposed a rating system, based on topographic setting and soil (regolith) thickness, to assess ground-water conditions in the Piedmont and Blue Ridge Provinces of the southeastern United States. LeGrand (1967) developed the concept of a statistical percentage chance of obtaining a certain yield under various conditions. Actual quantifiable yields were said to be difficult to estimate because well yields were shown to vary substantially within 100 ft of lateral distance. LeGrand (1967) also stated that fractures seemed to diminish with increasing depth, and that the relation between well yield and depth was complex.

Cressler and others (1983) conducted a study of ground-water in the Atlanta area to assess the availability, quality, and quantity of ground water in crystalline rocks and to devise methods for locating sites for high-yielding wells that could serve as alternative or supplemental sources of water supply. Results from that study indicated that the highest well yields in the Atlanta area seemed to be associated with wells tapping contact zones between rocks of contrasting lithology, fault zones, stress-relief (horizontal) fractures, drainage features controlled by local structural characteristics, concentrated jointing within folded rocks, and shear zones. Results of this study indicated that topographic drainage features may or may not be related to underlying water-bearing features in the rocks. From data gathered using borehole geophysical logs of wells, Cressler and others (1983) determined that the size, spacing, and interconnection of water-bearing openings differed greatly from one rock type to another. The range in well yield within an identified water-bearing unit was highly variable, and high-yielding wells were present in each unit. Local features in the rocks were recognized as generally controlling well yield. The authors also noted that water from wells open to mafic rock types contained higher concentrations of iron, magnesium, manganese, dissolved solids, and possibly chloride, than water from wells open to granitic rocks in the Metropolitan Atlanta area. The pH of water samples collected from wells completed in mafic rocks also was relatively high compared to samples collected from wells completed in granitic rocks.

Hale and others (1989) presented streamflow data for the 1986 drought in Alabama, Georgia, North Carolina, South Carolina, Tennessee, and Virginia. Minimum flows occurred in midsummer during 1986, which was several months earlier than the regional droughts of 1954 and 1981. The source of this drought was a rainfall deficit that began in 1985 and persisted until late summer 1986. The range of 7-month precipitation totals was about 30 to 85 percent of normal. The authors reported minimum low flows for 1, 7, 30, 60, and 90 days from April 1, 1986 through March 31, 1987.

Clarke and Peck (1991) conducted a study of a nine-county area south of the Metropolitan Atlanta area. The study consisted of a general evaluation of the existing and possible future development of ground-water resources. Data collection consisted of the compilation of geologic, hydrologic, and water-quality data. An extensive inventory of wells and springs was assembled. The study followed the same method as that used by Cressler and others (1983). Many high-yielding wells were inventoried; reported yields for two of which were 600 and 700 gallons per minute (gal/min). Clarke and Peck (1991) concluded that ground water is a viable resource that had been underutilized in the variety of hydrogeologic settings in the area. Ground-water quality problems included elevated concentrations of iron, manganese, fluoride, and radon.

The most recent investigation of ground-water resources near the study area was by Chapman and others (1993). A study of the relation of geologic controls, well yields, and ground-water quality was conducted in the area of Zebulon, Pike County, Ga. Well yields and potential ground-water quality problems were similar to those indicated by Cressler and others (1983) and Clarke and Peck (1991).

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, Georgia." 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.

Well and Surface-Water Station Numbering Systems

Wells in Georgia are numbered by a system based on U.S. Geological Survey topographic maps. Each 7 1/2-minute topographic quadrangle map in Georgia has been assigned a number and letter designation beginning at the southwest corner of the State. Numbers increase sequentially eastward through 39; letters advance northward through "Z," then double-letter designations "AA" through "PP" are used. The letters "I," "O," "II," and "OO" are not used. Wells and springs inventoried in each quadrangle are numbered sequentially beginning with "1." Thus, the second well inventoried in the Leaf quadrangle (designated 16LL) is designated 16LL02.

Wells in the USGS Ground-Water Site Inventory (GWSI) data base are assigned a 15-digit identification number based on the latitude and longitude grid system. The first six digits denote the degrees, minutes, and seconds of latitude. The next seven digits the degrees, minutes, and seconds of longitude. The last two digits (assigned sequentially) identify wells within a one-second grid.

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 1, 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 River and its 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), Heath (1984, 1989), Faye and Mayer (1990), 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 basin. The mean-annual baseflow was used as a base or reference with which to compare and evaluate droughts under “worst-case” conditions. An estimate also was made of the mean-annual volume of ground water discharged from Subarea 1 to Subarea 2 as baseflow in the Chattahoochee River. The mass-balance analysis was used to estimate the baseflow contributions to the surface-water system during historically significant droughts and the ground water delivered as baseflow from Subarea 1 to Subarea 2 near the end of these droughts.

Mean-Annual Baseflow Analysis

Discharge data from continuous-record gaging stations along the Chattahoochee River and its 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. The SWGW program 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

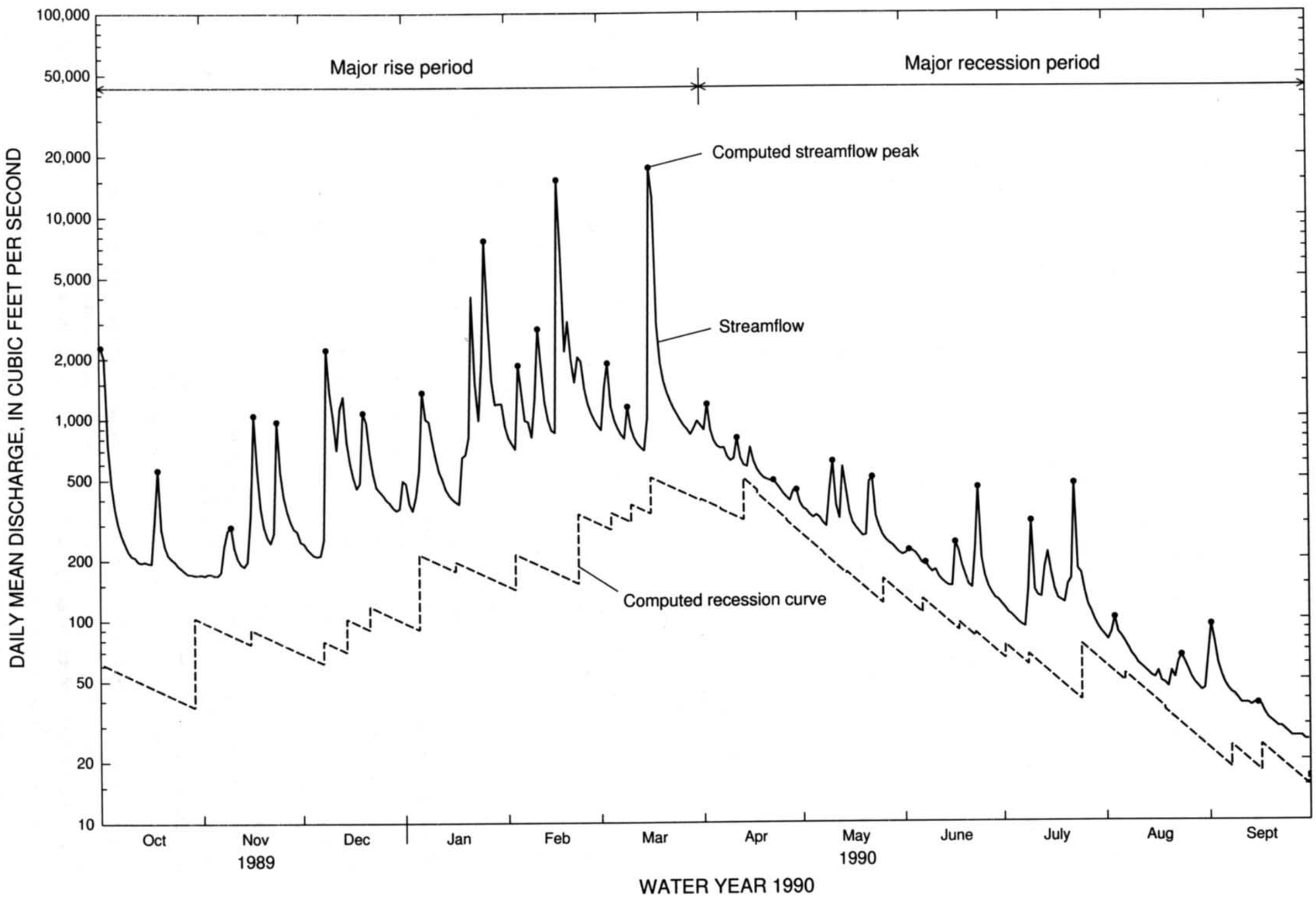


Figure 3. Streamflow hydrograph, separated by program SWGW.

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 temperatures, 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 1. 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 1 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 foot per second (ft^3/s), 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.” Different accuracies may be attributed to different parts of a given record (Novak, 1985).

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 1 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 1941, 1954, and 1986. These data included nearly concurrent daily measurements of streamflow in the Chattahoochee River 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 were 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 River streamflow near the end of the 1941, 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 River 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. Therefore, most unit-area discharges used to estimate discharge at ungaged and unmeasured tributaries were based on streamflow data measured near the mouths of tributaries to better represent the entire tributary contributing area.

Acknowledgments

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

The conceptual model of the ground-water flow and stream-aquifer relations in Subarea 1 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 regional drains, which is the Chattahoochee River in Subarea 1. Depending on local hydrogeologic conditions, all three flow regimes may not be present everywhere within the subarea.

The water table in Subarea 1 probably is a subdued replica of the land-surface topography but generally has 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. 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.

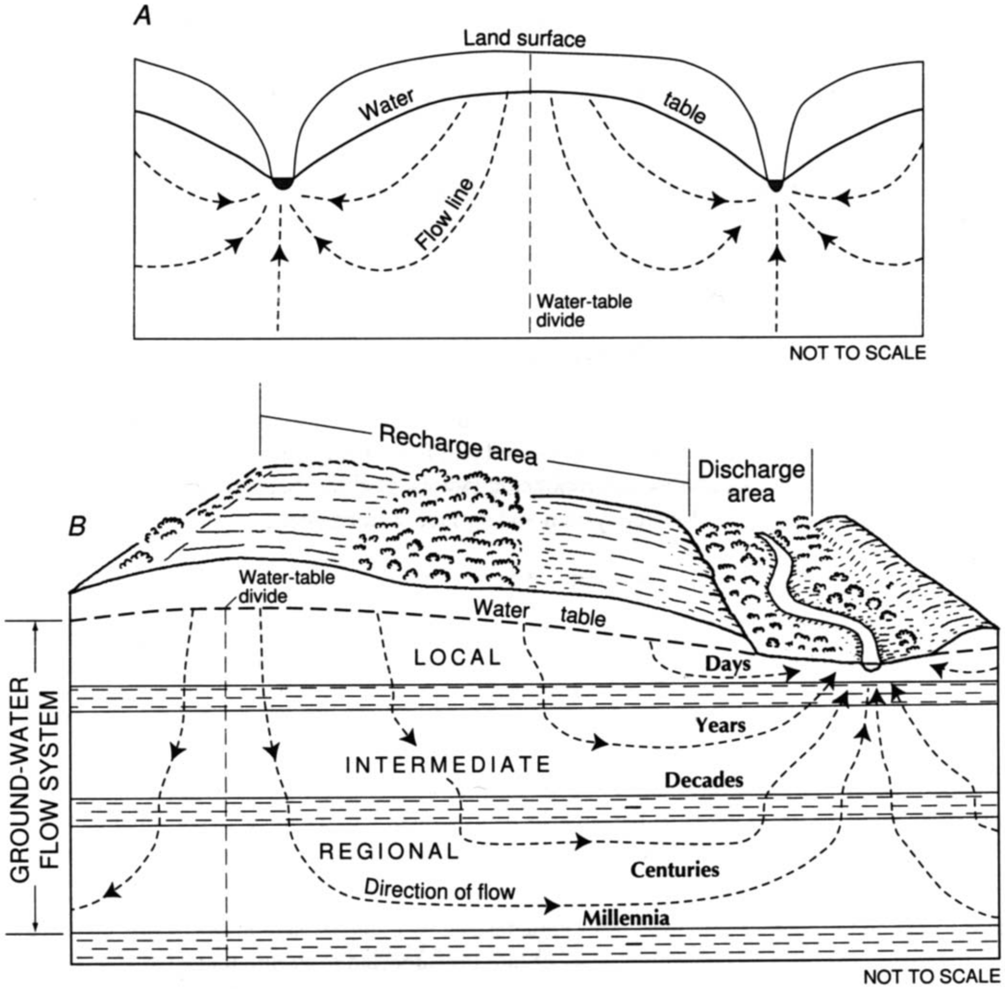

Figure 4. (*A*) Distribution of ground-water flow in an areally extensive, isotropic, homogeneous aquifer system (modified from Hubbert, 1940, and Heath, 1984) and (*B*) example of local, intermediate, and regional ground-water flow (modified from Heath, 1984).

Continuum methods of analysis of ground-water flow, such as hydrograph separation, are based on assumptions of laminar flow through a medium characterized by systematic changes in primary porosity and permeability. Such media generally are classified as porous media. Ground-water flow through porous media is commonly termed Darcian flow. Fractured rock media in the Blue Ridge and Piedmont Provinces contain virtually no primary porosity or permeability and virtually all ground-water flow occurs through secondary openings. For purposes of analysis, continuum methods based on assumptions of Darcian flow are applied to ground-water flow through fractured rock media. Such approaches commonly are justified on a regional scale because fracture systems typically are ubiquitous and intersecting.

Results of smaller-scale studies also demonstrate the continuity of ground-water flow through fractured media. For example, long-term ground-water pumping operations near Ridgeway, S.C., began in the fall of 1988 to dewater fractured Piedmont rocks to accommodate open-pit mining of gold-bearing ore (Glenn and others, 1989). Detailed ground-water monitoring around and within the mined areas indicated that after less than one year of pumping, drawdown extended in an oblong distribution for more than 1 mi beyond the center of pumping. Drawdown decreased uniformly with distance from pumped wells. Nelson (1989) used water-level data from numerous monitoring wells at a 120-acre study site constructed in fractured Piedmont rocks to describe stream-aquifer relations (non-pumping conditions) near the Rocky River in North Carolina. Nelson (1989) concluded that the Rocky River was a drain for ground water discharged from Piedmont rocks, and that observed hydraulic relations between the fractured-rock aquifer and the river and within the aquifer at various depths, were consistent with porous media concepts of ground-water flow, as described by Toth (1962, 1963). Under pumping conditions, drawdown can extend across surface-water drainage divides in a fractured-rock aquifer, similar to drawdown conditions observed in porous media. As part of an ongoing ground-water-resources investigation in the Lawrenceville, Ga., area (in the Piedmont Province), drawdown across drainage divides was observed at a distance of about 0.9 mi during a 96-hour constant-discharge aquifer test (U.S. Geological Survey, unpublished data from 1995). A study of 18 bedrock wells in the Piedmont Province in Virginia showed the influence of a pumping well across drainage-basin divides, where significant drawdown was observed in a nonpumping well located 1,900 ft from a pumping well in an adjacent drainage basin (Tinkham and others, 1989).

HYDROLOGIC SETTING

The hydrologic framework of Subarea 1 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. 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 types present, 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 1 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 Blue Ridge and Piedmont Provinces are characterized by complex sequences of igneous rocks of Precambrian to Paleozoic age, and metamorphic rocks of late Precambrian to Permian age (Miller, 1990); in the Piedmont, isolated igneous rocks of Mesozoic age also are present (D.C. Prowell, U.S. Geological Survey, oral commun., 1996). Collectively, these rocks are called crystalline rocks. The metamorphic rocks originally were sedimentary, volcanic, and volcaniclastic rocks that have been altered by several stages of regional metamorphism to slate, phyllite, schist, gneiss, quartzite, and marble; a variety of cataclastic rocks also are present. The metamorphic rocks are extensively folded and faulted. The intrusive igneous rocks, dominantly granites and lesser amounts of diorite and gabbro, occur as widespread plutons. The rocks are characterized by a complex outcrop and subsurface distribution pattern, as shown on geologic maps of various scales (Szabo and others, 1988). Because rock characteristics can vary significantly on the scale of a few tens of feet within the same lithologic unit, detailed geologic-unit differentiation can be accomplished only on the scale of a topographic quadrangle, or larger. The Piedmont contains major fault zones that generally trend northeast-southwest and form the boundaries between major rock groups (Georgia Geologic Survey, 1976). One such fault is the Brevard Zone of Cataclasis, which extends from Cornelia in northwestern Georgia, through the Metropolitan Atlanta area; and to Whitesburg, near the boundary with Subarea 2 (Georgia Geologic Survey, 1976). The Chattahoochee River generally is within or parallel to the Brevard Zone of Cataclasis in Subarea 1. The trellised and rectangular drainage patterns of the river reflect geologic control.

The crystalline igneous and metamorphic rocks largely are covered by a layer of weathered rock and soil known as regolith. The regolith ranges in thickness from a few to more than 150 ft, depending upon the type of parent rock, topography, and hydrogeologic history. From the land surface, the regolith consists of a porous and permeable soil zone that grades downward into a clay-rich, relatively impermeable zone that overlies and grades into porous and permeable saprolite, generally referred to as a transition zone (Heath, 1989). The transition zone grades downward into unweathered bedrock. Regolith thickness generally is less in the Blue Ridge Province than in the Piedmont because of the steeper slopes (Schmitt and others, 1989; Brackett and others, 1991). In general, the massive granite and gabbro rocks are poorly fractured and are characterized by a thin soil cover; in contrast, the schists and gneisses are moderately to highly fractured. The weathering of the rocks is erratic and usually deep; remnants of the original texture and foliation are retained in the saprolite in many places (Clarke, 1963).

The ground-water system in the crystalline rocks of the Piedmont and Blue Ridge Provinces of Georgia is controlled largely by geology. Various textural and structural properties in the rocks control permeability characteristics; however, hydraulic head gradients and recharge may be influenced by topography and climatic factors.

Aquifers

The principal aquifers in Subarea 1 are fracture-conduit aquifers in igneous and metamorphic rocks of the Blue Ridge and Piedmont Provinces (fig. 5); the general physical characteristics of these aquifers are given in table 2. As a result of intense heat and pressure during metamorphism and structural deformation, bedrock aquifers of the Piedmont Province contain little or no primary porosity (less than two percent), and are poorly permeable. In the bedrock, water-bearing zones occur in areas where differential weathering along geologic features produces openings that enhance permeability and enable the storage and flow of ground water (Chapman and others, 1993). Geologic features favorable for the development of secondary openings include lithologic contacts, foliation, joints, fractures, faults, folds, quartz veins, and pegmatites.

Table 2. Generalized geologic units in Subarea 1, and water-bearing properties, chemical characteristics, and well yields
[—, no available data]

Physiographic province	Geologic age and lithology	Aquifer type	Water-bearing properties and chemical characteristics	Well yield
Piedmont and Blue Ridge	regolith: soil, alluvium, colluvium, and saprolite derived from various-aged rocks	porous-media; and preferential flow	generally suitable for domestic use only	—
	Precambrian to Paleozoic bedrock: quartzite, slate, gneiss, schist, marble, phyllite, granite, amphibolite	fracture-conduit	local, discontinuous properties, well yields variable, water quality generally good	1 to 25 gallons per minute typical; may exceed 700 gallons per minute (Kidd, 1989; Clarke and Peck, 1991)

Fracture-conduit aquifers in the Piedmont and Blue Ridge Provinces consist of two water-bearing zones—a shallow, regolith zone and a deeper, bedrock zone (fig. 6). The regolith may consist of soil, alluvium, colluvium, and saprolite (weathered bedrock retaining geologic structural characteristics). In general, the regolith consists of a porous, permeable soil at land surface, grading downward into a highly weathered, clay-rich relatively impermeable zone that overlies a less-weathered and more permeable transition zone (Heath, 1989). In some instances, ground water in the regolith is similar to that in porous media, where intergranular porosity is present in the soil or alluvium, or where rocks have been deeply weathered, and retain little structural characteristics. Porosity of the regolith can range from 20 to 30 percent (Heath, 1984). The transition zone between the saprolite and bedrock contains weathered material and boulders, and along structural features, such as foliation and jointing, generally is more permeable than the saprolite. Ground-water flow can be preferential in saprolite, where weathered rock retains relict structural features (Stewart, 1964; Stewart and others, 1964).

The fracture-conduit aquifers are anisotropic and heterogeneous because of the highly complex and locally variable geologic characteristics controlling the presence of the water-bearing units in the bedrock and regolith. Rock type, structural features, and regolith thickness vary locally and affect the storage capacity and hydraulic conductivity of an aquifer (LeGrand, 1967, 1089; Daniel, 1987; Guthrie and DeJarnette, 1989; Schmitt and others, 1989; Chapman and others, 1993; Guthrie and others, 1994).

Recent studies have shown that a thorough evaluation of hydrogeologic settings in areas characterized by fracture-conduit aquifers can lead to an increased likelihood of successful development of ground-water resources. Most municipal, industrial, and commercial ground-water exploration plans now include consultation with hydrogeologists, who evaluate surficial geology, including structural features, topographic relation to geologic features, existing well information, and land use. Surface and borehole geophysical surveys also may be conducted to delineate subsurface features that indicate the sources of water to wells and the water-bearing properties of the rocks.

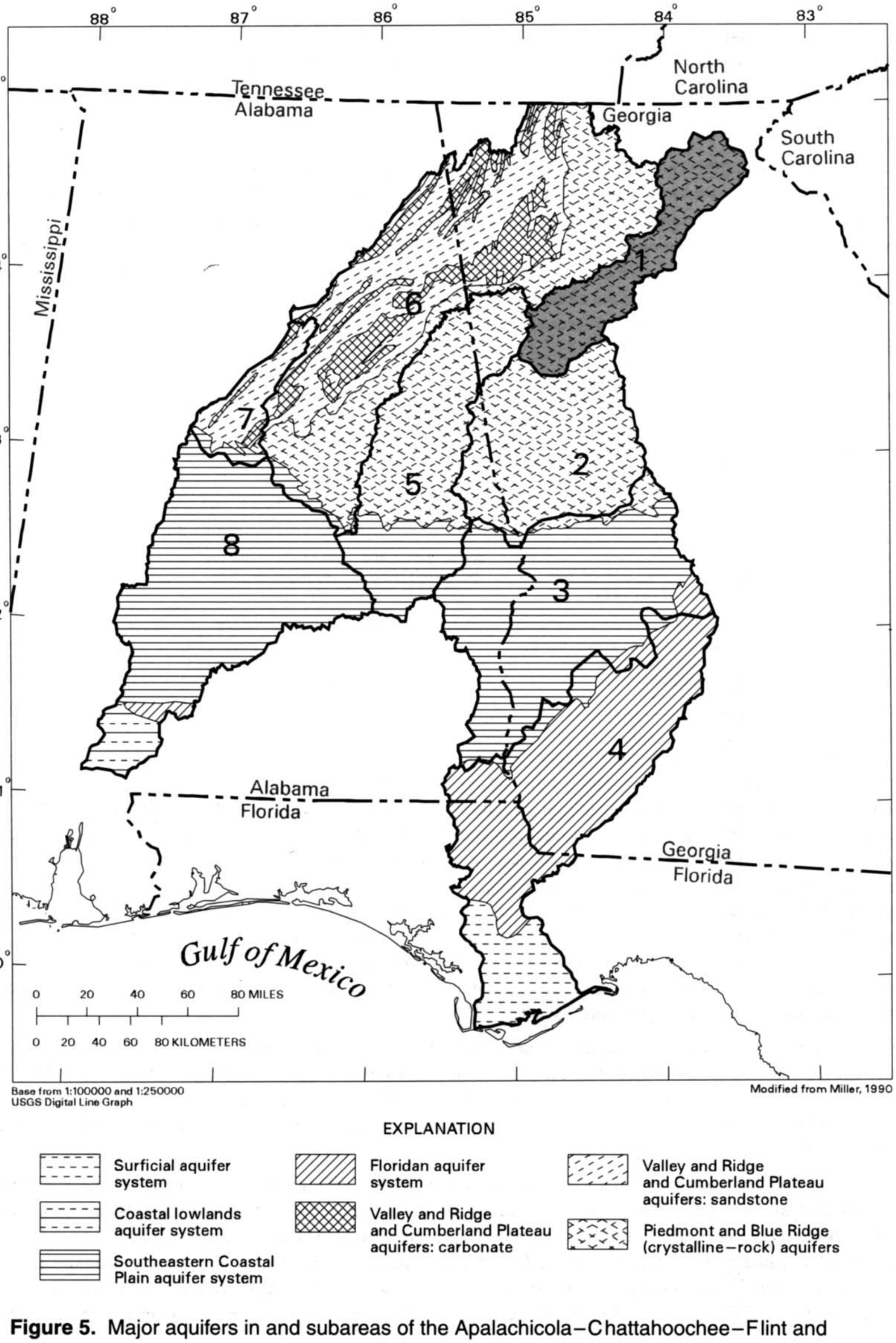

Figure 5. Major aquifers in and subareas of the Apalachicola–Chattahoochee–Flint and Alabama–Coosa–Tallapoosa River basins.

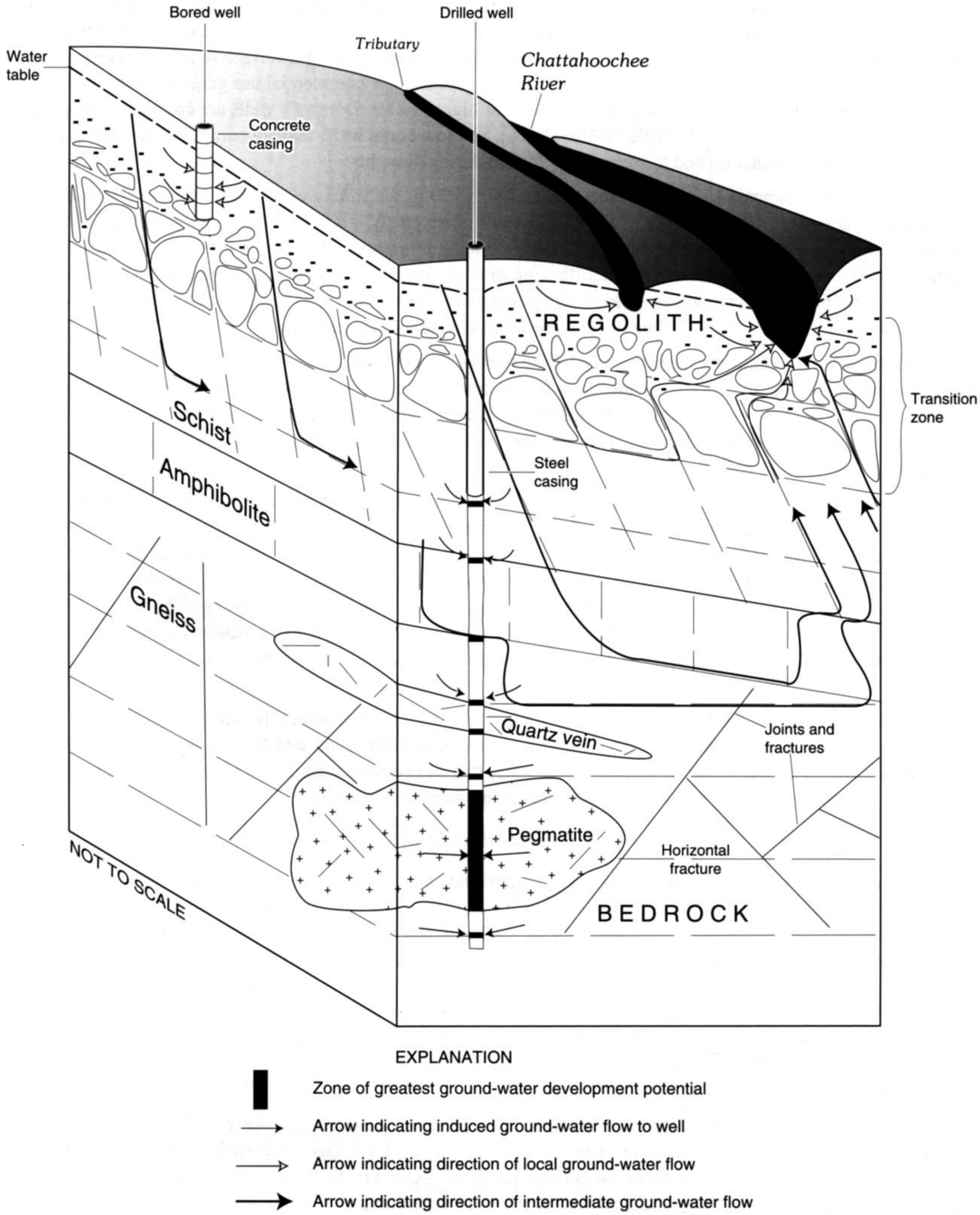

Figure 6. Conceptual ground-water and surface-water systems in Subarea 1: fracture-conduit aquifer in the igneous and metamorphic rocks of the Blue Ridge and Piedmont Provinces.

Ground water in the study area is obtained from either shallow, bored wells that are completed in the regolith, or deeper, drilled wells that are completed in the bedrock. Public supply wells are completed in the bedrock and casing is grouted about 5 ft into the bedrock to avoid possible contamination from surface runoff and direct infiltration through the weathered regolith. Wells drilled for industrial or commercial use generally also are completed in the bedrock primarily due to the potential for higher yields. Domestic wells are completed in both the regolith (bored wells) and bedrock (drilled wells) (fig. 6). Shallow bored wells that are completed in the regolith can be susceptible to contamination and to water-level decline during droughts.

Well depth in Subarea 1 generally ranges from 100 to 700 ft. Wells may yield water from several fractures throughout a borehole, or from a single productive fracture. Conversely, a borehole may not intersect a fracture, or the fracture may not be water bearing, and thus, may yield little or no water. Because of the complex nature of the secondary permeability in fracture-conduit aquifers, production zones generally are of limited extent. Quantitative estimates of aquifer properties such as transmissivity, hydraulic conductivity, and storage coefficient are difficult to assess because of the highly localized geologic controls on secondary permeability.

Fracture-conduit aquifers formed in crystalline rocks may yield quantities of water suitable for public or industrial supply. Yields from wells completed in the fractured crystalline-rock aquifers of Subarea 1 are highly variable. A high-yielding wells produces 100 gal/min or greater and yields of as much as 550 gal/min have been reported in Subarea 1; typical well yields, however, are 1 to 25 gal/min (table 2). Bedrock wells often are more able to sustain yields during droughts.

Ground-water movement in fracture-conduit aquifers mainly is through secondary openings, such as fractures and joints, or other enhanced openings along lithologic contacts. Secondary porosity is created by faulting and fracturing and is enhanced by weathering along these openings. The bedrock below the weathered zone and laterally beyond fractures typically has little or no matrix porosity or primary permeability. Ground-water storage primarily is in the overlying weathered rock (regolith or saprolite, which behaves like a porous-media aquifer). The volume of water in storage in the regolith is controlled by the porosity and thickness. To a lesser degree, the volume of water in storage in the bedrock is controlled by the degree of fracturing. Because of the limited storage in fractures, water levels in fracture-conduit aquifers typically respond rapidly to pumping.

Ground water pumped from fracture-conduit aquifers in Subarea 1 generally is suitable for drinking. However, elevated concentrations of iron, manganese, sulfate, dissolved solids, and nitrates are known to occur in some areas. Other potential problems include acidic water that can corrode copper water lines, and the presence of radon gas in the water from the natural radioactive decay of uranium in the rocks.

Ground-Water Levels

Ground-water levels fluctuate in response to natural and anthropogenic processes, such as seasonal changes in rainfall, interaction with the surface-water system, and ground-water withdrawal. These fluctuations indicate changes in the amount of water in storage in an aquifer. In the Piedmont and Blue Ridge Provinces, ground-water levels in wells may represent differing degrees of confinement. Because of their shallow depth, wells completed in the regolith are highly influenced by climatic changes, such as variations in evapotranspiration and precipitation. During droughts, shallow bored wells temporarily may go dry when the water table falls. Water-level changes in bedrock wells may exhibit both semiconfined and confined behavior; the former responding most directly to recharge. Flowing bedrock wells, however, exhibit more confined conditions and related yields probably are less influenced by climatic variability.

As part of the evaluation of ground-water levels, observation well data were analyzed for wells completed in the fractured bedrock water-bearing zones. Long-term ground-water-level data are available for only a few bedrock wells in Subarea 1. Figure 7 shows water levels in well 11FF04, located in the Piedmont Province in DeKalb County, Ga. Continuous ground-water level data are not available for wells completed in the regolith in Subarea 1.

Well 11FF04 is located along an unnamed tributary of Nancy Creek which flows into the Chattahoochee River (fig. 8). This well was drilled as part of an investigation by Cressler and others (1983) and water-level data are available from 1980 to 1995 (fig. 7). The well was completed in a schist and granitic gneiss and the casing was set at 36 ft (C.J. Thurmond, U.S. Geological Survey, written commun., 1980). Before the casing was set, the regolith zone produced about 25 gal/min, but after completion of the well, the yield was estimated to be 7.5 gal/min. Most of the water was obtained at depths of 525 to 528 ft in a biotite schist.

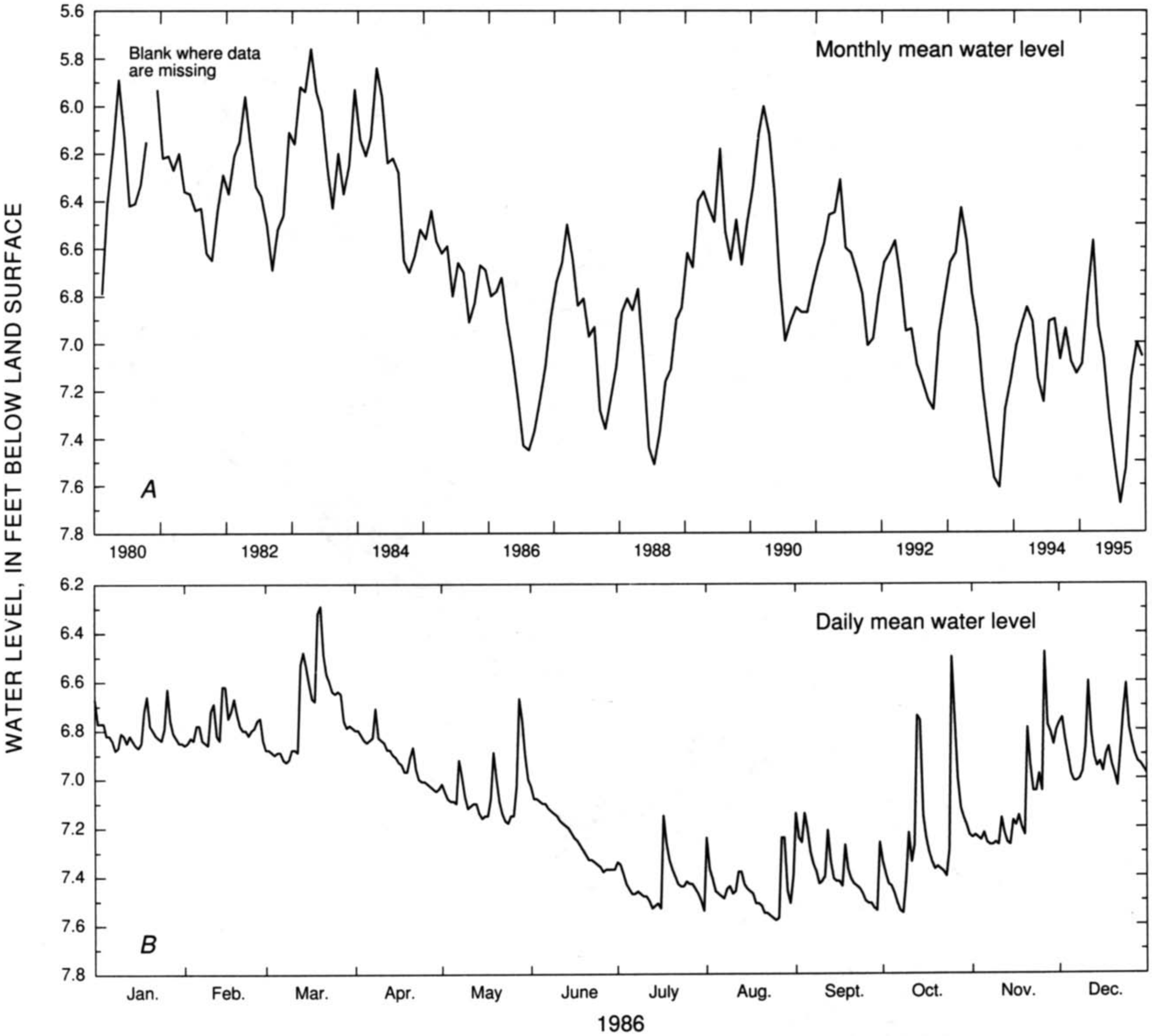

Figure 7. Water-level fluctuations in regolith well 11FF04, DeKalb County, Georgia, during (*A*) 1980–95; and (*B*) the drought of 1986.

Water levels in well 11FF04 ranged from about 5.7 to 7.7 ft below land surface for the period of record. During the 1986 and 1988 droughts, the water level decreased about 1 ft from the average water level for the period of record (fig. 7). The annual hydrograph shows sharp peaks, probably related to precipitation and stage variations in the stream, which is located about 5 ft from the well. The effects of evapotranspiration are observed from the hydrograph of 1986, when ground-water levels exhibited a steady decline from mid-March through mid-August. The water level in bedrock well 11FF04 only declined about 1.2 ft during the drought of 1986.

Surface-Water System

The surface-water system in Subarea 1 includes the upper Chattahoochee River and its tributaries. The drainage area of the Chattahoochee River basin also encompasses about 2,600 mi^2 in Alabama (not in Subarea 1) (U.S. Army Corps of Engineers, 1985a,b) and about 5,940 mi^2 in Georgia, of which 2,430 mi^2 is in Subarea 1. The river serves as water supply for much of the Metropolitan Atlanta area. The Chattahoochee originates near Helen, Ga. (fig. 8), in the Blue Ridge Province (fig. 2). The boundary with Subarea 2 along the river is located near Whitesburg, Ga. Major tributaries to the upper Chattahoochee River include the Soque River, Chestatee River, Suwanee Creek, Big Creek, Sope Creek, Nancy Creek, Peachtree Creek, Sweetwater Creek, and Snake Creek (fig. 8).

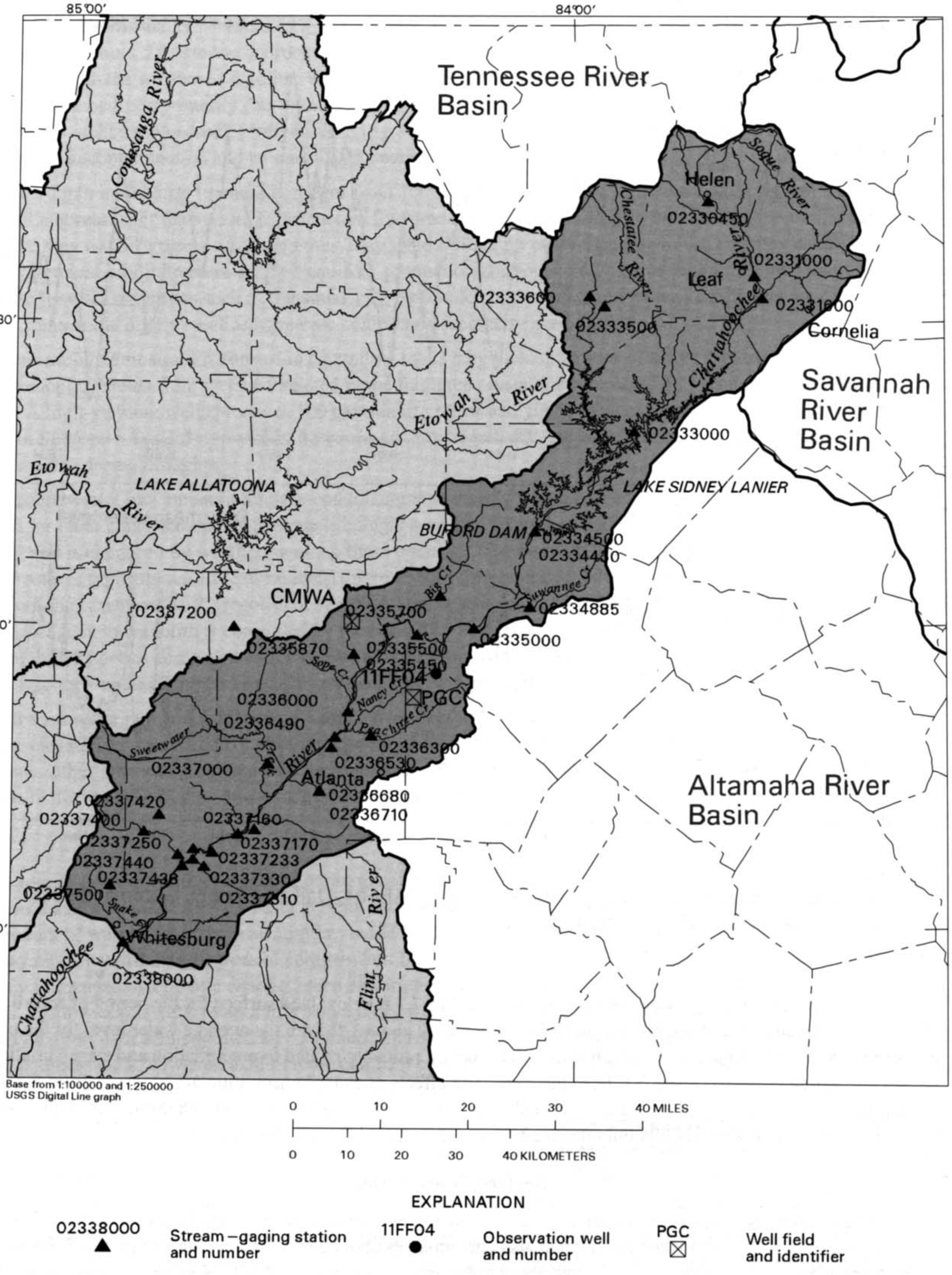

Figure 8. Selected stream-gaging stations, well fields, and observation well 11FF04, Subarea 1.

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 period of record. Note that, by definition, the stream discharge includes both surface runoff and baseflow. The estimated mean-annual stream discharge of the Chattahoochee River from Subarea 1 to Subarea 2 is about 3,740 ft^3/s (table 3), using values based on data from the continuous-record stream-gaging station—Chattahoochee River near Whitesburg, Ga. (02338000) (table 3; fig. 8).

Table 3. Selected active and discontinued continuous-record stream-gaging stations in the upper Chattahoochee River basin, Subarea 1

[I, fracture-conduit aquifer in igneous or metamorphic rock; —, not applicable]

Station number	Station name	Drainage area (square miles)	Type of stream	Major aquifer drained	Period of record of unregulated flow (water years)	Mean-annual stream discharge[1/] (cubic feet per second)
02330450	Chattahoochee River at Helen, Ga.	44.7	regional	I	1982-present	134
02331000	Chattahoochee River near Leaf, Ga.	150	do.	do.	1940-71	[2/]402
02331600	Chattahoochee River near Cornelia, Ga.	315	regional	do.	1958-present	828
02333000	Chattahoochee River near Gainesville, Ga.	559	do.	do.	1902-03 1938-55	[3/]1,240
02333500	Chestatee River near Dahlonega, Ga.	153	tributary	do.	1929-32 1940-present	367
02334430	Chattahoochee River at Buford Dam, near Buford, Ga.	1,040	regional	do.	—	—
02334885	Suwanee Creek near Suwanee, Ga.	46.8	tributary	do.	1985-present	61.7
02334500	Chattahoochee River near Buford, Ga.	1,060	regional	do.	1943-55	2,173
02335000	Chattahoochee River near Norcross, Ga.	1,170	do.	do.	1902-46	2,265
02335500	Chattahoochee River near Roswell, Ga.	1,230	do.	do.	1942-55	2,329
02335700	Big Creek near Alpharetta	72.0	tributary	do.	1961-present	114
02335870	Sope Creek near Marietta	29.2	do.	do.	1985-present	48.8
02336000	Chattahoochee River at Atlanta, Ga.	1,450	regional	do.	1929-31 1937-55	2,567
02336300	Peachtree Creek at Atlanta, Ga.	85.4	tributary	do.	1959-present	137
02337000	Sweetwater Creek near Austell, Ga.	246	tributary	do.	1905 1938-present	337
02337170	Chattahoochee River near Fairburn, Ga.	2,060	regional	do.	—	—
02337500	Snake Creek near Whitesburg, Ga.	35.5	tributary	do.	1955-present	56.3
02338000	Chattahoochee River near Whitesburg, Ga.	2,430	regional	do.	1939-53	3,740

[1/]Stokes and McFarlane (1994).
[2/]U.S. Geological Survey (1971).
[3/]U.S. Geological Survey (1963).

The most upstream major storage impoundment on the Chattahoochee River system is Lake Sidney Lanier (table 4, fig. 8), which provides 65 percent of total usable storage capacity for flow regulation in federally operated reservoirs—Lake Sidney Lanier, West Point, Walter F. George, and Lake Seminole—in the Chattahoochee-Flint River basin (Comprehensive Study Newsletter, written commun., Fall 1993; Apalachicola Basin Reservoir Regulation Manual, U.S. Army Corps of Engineers, 1991). Lake Sidney Lanier provides hydroelectric power, recreation, water supply for much of the Metropolitan Atlanta area, and support for downstream navigation. Withdrawal and return flow also affects streamflow at various locations along the river's corridor.

Table 4. Major impoundment in the upper Chattahoochee River basin, Subarea 1

Impoundment structure	Station number	Location	Installation date	Major uses	Total storage capacity (acre-feet)
Lake Sidney Lanier (Buford Dam)	02334400	Gwinnett–Forsyth Counties	1959	power generation, water supply, flood control, recreation	[1/]2,554,000

[1/]Stokes and McFarlane (1994).

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 the 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 1. 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 estimating mean-annual ground-water discharge to the Chattahoochee River and selected major tributaries. Streamflow data used to determine mean-annual ground-water discharge 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 six continuous-record gaging stations in the upper Chattahoochee 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, the 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. Mean unit-area baseflow estimated for six stations representing discharge from igneous and metamorphic rocks along the Chattahoochee River in Subarea 1 ranged from 1.06 to 2.19 $ft^3/s/mi^2$ (table 5).

Data for gaging stations located downstream of Lake Sidney Lanier on the Chattahoochee River in Subarea 1 (fig. 8) were evaluated for the period prior to its impoundment by Buford Dam in 1956. Where possible, data for the same years were used for the hydrograph-separation analyses for each station throughout the study area. In general, in the upper Chattahoochee River basin, the lowest streamflow occurred during the drought of 1941; the highest streamflow occurred in 1949. The average flow year selected for analysis varied for each station with regard to the available period of record for unregulated flow.

In general, estimated mean unit-area baseflow decreases downstream; those near the Blue Ridge Province are higher. Mean unit-area baseflow generally is greater than 1 $ft^3/s/mi^2$. Estimated mean-annual baseflow in the Chattahoochee River ranges from about 69 to 82 percent of mean-annual stream discharge in Subarea 1. The contribution of mean-annual baseflow to streamflow from Subarea 1 to Subarea 2 was estimated using data from the Whitesburg, Ga., gaging station (fig. 8; table 3). This discharge to the Chattahoochee River at the Subarea 1–2 boundary near Whitesburg was estimated to be about 2,570 ft^3/s. The mean-annual baseflow represents about 69 percent of the mean-annual stream discharge at the Subarea 1–Subarea 2 boundary.

Table 5. Mean-annual stream discharge, estimated annual and mean-annual baseflow, and unit-area mean-annual baseflow at selected gaged streams in the upper Chattahoochee River basin, Subarea 1

[I, fracture-conduit aquifer in igneous and metamorphic rocks]

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)						
02330450	Chattahoochee River at Helen, Ga.	regional	44.7	I	150	100	1986	Low	68.2	59.3		
							1987	Average	110	78.0	91.8	2.05
							1983	High	180	138		
02331000	Chattahoochee River near Leaf, Ga.	do.	150	do.	120	100	1941	Low	210	159		
							1959	Average	340	271	328	2.19
							1949	High	649	554		
02333000	Chattahoochee River near Gainesville, Ga.	do.	559	do.	150	120	1941	Low	697	564		
							1952	Average	1,397	857	982	1.76
							1949	High	2,015	1,524		
02334500	Chattahoochee River near Buford, Ga.	do.	1,060	do.	150	130	1951	Low	1,568	1,270		
							1944	Average	2,200	1,660	1,790	1.69
							1949	High	3,432	2,440		
02336000	Chattahoochee River at Atlanta, Ga.	do.	1,450	do.	150	120	1941	Low	1,454	1,190		
							1953	Average	2,368	1,550	1,970	1.36
							1949	High	4,406	3,180		
02338000	Chattahoochee River near Whitesburg, Ga.	do.	2,420	do.	130	100	1941	Low	2,166	1,370		
							1952	Average	4,170	2,460	2,570	1.06
							1949	High	6,221	3,890		
Drainage area and mean-annual baseflow exiting Subarea 1			**2,420**								**2,570**	

[1/]From annually published U.S. Geological Survey data reports, for example: Stokes and McFarlane (1994).

[2/]Estimated using SWGW (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.

Drought Flow for 1941, 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 was assumed to be 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 during these periods were assumed to provide a quantitative estimate of near minimum baseflow from Subarea 1 into Subarea 2. Where available, streamflow data for an interval of a few days were compiled; and where not available, streamflow was estimated using various techniques—discussed below.

Estimated and measured streamflow near the end of the 1941, 1954, and 1986 drought years at selected sites on the upper Chattahoochee River and its tributaries are shown in tables 6, 7, and 8, respectively, and summarized in table 9. Most of the data presented represent minimum daily mean streamflow from continuous-record gaging stations. Some miscellaneous streamflow measurements were used for the analyses.

Historical streamflow data are available throughout the upper Chattahoochee River basin during the 1941 and 1954 drought years, except for 1954 drought data for the Chattahoochee River near Whitesburg; the Whitesburg gage was discontinued in June 1954 and reinstalled in 1965. An attempt was made to estimate the flow for the period analyzed in Subarea 1 by balancing mass in the stream network downstream from the Chattahoochee River at Atlanta. The tributary discharges to the Chattahoochee River were estimated using the unit-area discharge computed at a measurement site extrapolated to the entire tributary drainage. These unit-area discharges also were applied to the intermediate areas on the Chattahoochee River not accounted for by the measured tributaries. Streamflow data for the 1954 drought are presented in detail by Thomson and Carter (1955; 1963). Minimum daily streamflow data were similar for most gaging stations during the historical droughts of 1941 and 1954 (tables 6 and 7). For example, streamflow at the Leaf station was 72 and 82 ft^3/s for 1941 and 1954, respectively; Gainesville was 242 and 282 ft^3/s, respectively; and at Roswell was 389 and 350 ft^3/s, respectively.

Data from 1986 drought year measured at stations on the Chattahoochee River downstream from Buford Dam (02334430) indicate higher streamflow due to releases upstream at Lake Sidney Lanier (Hale and others, 1989); and therefore, could not be used in the drought flow analysis. An estimate of the unregulated flow was computed using the procedure described above downstream from the Chattahoochee River near Cornelia, the last unregulated gaged site.

Table 6. Stream discharge during the month of October of the drought of 1941, Subarea 1
[—, not applicable]

Station number	Station name	Type of stream	Drainage area (square miles)	Date	Stream discharge[1/] (cubic feet per second)	Unit-area discharge[2/] (cubic feet per second per square mile)
02331000	Chattahoochee River near Leaf, Ga.	regional	150	10-26-41	72	0.480
02333000	Chattahoochee River near Gainesville, Ga.	do.	559	10-26-41	242	.433
02335000	Chattahoochee River near Norcross, Ga.	do.	1,170	10-26-41	382	.326
02335500	Chattahoochee River near Roswell, Ga.	do.	1,230	10-26-41	389	.316
02336000	Chattahoochee River at Atlanta, Ga.	do.	1,450	10-26-41	422	.291
02338000	Chattahoochee River near Whitesburg, Ga.	do.	[3/]2,420	10-26-41	468	.193
Drainage area and stream discharge exiting Subarea 1[4/]			**2,420**		**468**	

[1/]Daily mean discharge.
[2/]Discharge divided by the drainage area.
[3/]Carter and others (1989).
[4/]Represents entire Chattahoochee River basin in Subarea 1.

Table 7. Stream discharge during the months of September and October of the drought of 1954, Subarea 1

[—, not applicable]

Station number	Station name	Type of stream	Drainage area[1/] (square miles)	Date	Stream discharge[2/] (cubic feet per second)	Unit-area discharge[3/] (cubic feet per second per square mile)
02330350	Chattahoochee River at Helen	regional	44.7	10/15/54	[4/]24.4	.546
02331000	Chattahoochee River near Leaf	do.	150	09/28/54	82	.547
02333000	Chattahoochee River near Gainesville	do.	559	09/28/54	282	.504
02334500	Chattahoochee River near Buford	do.	1,060	09/28/54	381	.359
02335000	Chattahoochee River near Norcross	do.	1,170	09/14/54 10/12/54	[4/]471	.403
02335500	Chattahoochee River near Roswell	do.	1,230	09/28/54	350	.285
02336000	Chattahoochee River at Atlanta	do.	1,450	09/28/54	346	.239
—	intermediate-area contribution between 02336000 and Chattahoochee River above mouth of Peachtree Creek	—	6	—	[5/]0.2	—
02336300	Peachtree Creek at Atlanta	tributary	85.4	09/30/54	[4/]2.31	.027
—	Peachtree Creek at mouth	do.	131	—	[6/]3.5	—
—	intermediate-area contribution between mouths of Peachtree Creek and Proctor Creek	—	6	—	[5/].4	—
02336530	Proctor Creek at Bolton Road at Atlanta	do.	15.9	09/30/54	[4/].95	.060
—	Proctor Creek at mouth	do.	16.4	—	[6/]1.0	—
—	intermediate-area contribution between Proctor Creek and Utoy Creek	—	55	—	[5/]2.5	—
02336680	North Utoy Creek at Freeborn near Ben Hill	tributary	8.9	09/30/54	[4/].31	.035
02336710	South Utoy Creek at Freeborn Road near Ben Hill	do.	13.2	09/30/54	[4/].70	.053
—	confluence of South Utoy Creek and North Utoy Creek	do.	22.1	—	[7/]1.0	.045
—	Utoy Creek at mouth	do.	34.2	—	[8/]1.5	—
—	intermediate-area contribution between Utoy Creek and Sweetwater Creek	—	8	—	[5/].1	—
02337000	Sweetwater Creek near Austell	tributary	246	09/27/54	3.3	.013
—	Sweetwater Creek at mouth	do.	264	—	[6/]3.4	—
—	intermediate-area contribution between Sweetwater Creek and Deep Creek	—	55	—	[5/]3.0	—
02337160	Deep Creek at State Route 154 near Tell	tributary	29.5	09/27/54	[4/]1.62	.055
—	Deep Creek at mouth	do.	29.9	—	[6/]1.6	—
—	intermediate-area contribution between Deep Creek and Pea Creek	—	44	—	[5/]1.9	—
02337233	Pea Creek at State Route 154 near Palmetto	tributary	13.5	09/27/54	[4/].60	.044
—	Pea Creek at mouth	do.	14.5	—	[6/].6	—
—	intermediate-area contribution between Pea Creek and Bear Creek	—	2	—	[5/].4	—
02337250	Bear Creek from right at State Route 166 near Douglasville	tributary	16.8	09/29/54	[4/]3.18	.189
—	Bear Creek at mouth	do.	17.3	—	[6/]3.3	—
—	intermediate-area contribution between right side of Bear Creek and left side of Bear Creek	—	1	—	[5/]0	—
02337310	Bear Creek from left at Woodruff Road near Palmetto	tributary	26.8	09/27/54	[4/].04	.001

Table 7. Stream discharge during the months of September and October of the drought of 1954, Subarea 1—Continued

Station number	Station name	Type of stream	Drainage area[1/] (square miles)	Date	Stream discharge[2/] (cubic feet per second)	Unit-area discharge[3/] (cubic feet per second per square mile)
02337330	Bear Creek at mouth near Rico	tributary	29.0	—	[6/]0	—
—	intermediate-area contribution between Bear Creek from left and Dog River	intermediate	4	—	[9/]0.1	—
02337400	Dog River at Post Road near Douglasville	tributary	46.9	09/29/54	[4/].72	.015
—	Dog River above Mobley Creek	do.	49.7	—	[6/].7	—
02337420	Mobley Creek at Pool Road near Douglasville	do.	10.2	09/29/54	[4/].38	.037
—	Mobley Creek at mouth	do.	16.0	—	[6/].6	—
—	Dog River below Mobley Creek	do.	65.7	—	[10/]1.3	.020
02337440	Dog River at mouth	do.	78.5	—	[11/]1.6	—
—	intermediate-area contribution between Dog River and Snake Creek	intermediate	66	—	[5/]5.0	—
02337500	Snake Creek near Whitesburg	tributary	35.5	09/28/54	2.7	.076
—	Snake Creek at mouth	do.	49.2	—	[6/]3.7	—
—	intermediate-area contribution between Snake Creek and 02338000	intermediate	56	—	[12/]4.3	—
02338000	Chattahoochee River near Whitesburg	regional	2,420	—	[13/]384	.159
Drainage area and stream discharge exiting Subarea 1			**2,420**		**384**	

[1/]Carter and others (1989).
[2/]Daily mean discharge.
[3/]Discharge divided by the drainage area.
[4/]Miscellaneous discharge measurement.
[5/]Estimated by multiplying drainage area of the intermediate area by unit-area discharge that was computed using the discharge at the next downstream miscellaneous measurement site or daily mean-discharge site.
[6/]Estimated by multiplying the drainage area at the tributary mouth by the unit-area discharge that was computed using the discharge at that tributary's miscellaneous measurement site or daily mean-discharge site.
[7/]Sum of the flows in North and South Utoy Creeks and corresponding unit-area discharge.
[8/]Estimated by multiplying the drainage area at the mouth of Utoy Creek by the unit-area discharge at the confluence of North and South Utoy Creeks.
[9/]Computed by multiplying drainage area by estimated unit-area discharge at the mouth of Dog River.
[10/]Estimated by summing the estimated discharges of Dog River above Mobley Creek and of Mobley Creek at mouth.
[11/]Estimated by multiplying the drainage area by the estimated unit-area discharge of Dog River below Mobley Creek.
[12/]Estimated by multiplying intermediate drainage area by Snake Creek unit-area discharge.
[13/]Computed by adding the discharge at station 02326000 to the sum of all estimates of intermediate-area discharges and discharges at tributary mouths downstream from station 02338000, except for Mobley Creek, which is a tributary to Dog River.

Table 8. Stream discharge during the month of July of the drought of 1986, Subarea 1
[—, not applicable]

Station number	Station name	Type of stream	Drainage area[1/] (square miles)	Date	Stream discharge (cubic feet per second)[2/]	Unit-area discharge (cubic feet per second per square mile)[3/]
02330450	Chattahoochee River at Helen	regional	44.7	07/07/86	29	0.649
02331600	Chattahoochee River near Cornelia	do.	315	07/08/86	162	.514
—	Chattahoochee River above mouth of Chestatee River	do.	576	—	[4/]296	—
02333500	Chestatee River near Dahlonega	tributary	153	07/08/86	54	.353
—	Chestatee River above Yahoo Creek	do.	155	—	[5/]55	—
02333600	Yahoola Creek at Dahlonega	do.	31.3	07/08/86	[6/]8.2	.262
—	Yahoola Creek at mouth	do.	34.4	—	[7/]9.0	—
—	Chestatee River below Yahoola Creek	do.	189	—	[8/]64	.339
—	Chestatee River at mouth	do.	318	—	[9/]108	—
—	Chattahoochee River below Chestatee River	regional	894	—	[10/]404	.452
02334430	Chattahoochee River at Buford Dam near Buford	—	1,040	—	[11/]470	—
—	intermediate-area contribution between station 02334430 and Chattahoochee River above mouth of Suwanee Creek	—	65	—	[12/]4.0	—
02334885	Suwanee Creek near Suwanee	tributary	46.8	07/09/86	2.9	.062
—	Suwanee Creek at mouth	do.	51.2	—	[7/]32	—
—	intermediate-area contribution between Suwanee Creek and Big Creek	—	77	—	[12/]6.6	—
02335700	Big Creek near Alpharetta	tributary	72	07/09/86	6.2	.086
—	Big Creek at mouth	do.	103	—	[7/]8.9	—
—	intermediate-area contribution between Big Creek and Sope Creek	—	42	—	[12/]5.5	—
02335870	Sope Creek near Marietta	tributary	29.2	07/09/86	3.8	.130
—	Sope Creek at mouth	do.	35.4	—	[7/]4.6	—
—	intermediate-area contribution between Sope Creek and station 02336000	—	39	—	[13/]5.1	—
02336000	Chattahoochee River at Atlanta	regional	1,450	—	[14/]508	.350
—	intermediate-area contribution between station 02336000 and Peachtree Creek	—	6	—	[12/].8	—
02336300	Peachtree Creek at Atlanta	tributary	86.8	07/09/86	12	.138
—	Peachtree Creek at mouth	do.	131	—	[7/]18.1	—
—	intermediate-area contribution between Peachtree Creek and Sweetwater Creek	—	119	—	[12/]6.8	—
02337000	Sweetwater Creek near Austell	tributary	246	07/09/86	14	.057
—	Sweetwater Creek at mouth	do.	264	—	[7/]15	—
—	intermediate-area contribution between Sweetwater and Annewakee	—	87	—	[12/]18.8	—
02337200	Annewakee Creek near Douglasville	tributary	29	07/07/86	6.3	.217
—	Annewakee Creek at mouth	do.	29.9	—	[7/]6.5	—
—	intermediate-area contribution between Annewakee and Dog River	—	79	—	[12/]11.4	—

Table 8. Stream discharge during the month of July of the drought of 1986, Subarea 1—Continued
[—, not applicable]

Station number	Station name	Type of stream	Drainage area[1] (square miles)	Date	Stream discharge (cubic feet per second)[2]	Unit-area discharge (cubic feet per second per square mile)[3]
02337438	Dog River near Fairplay	tributary	76.4	07/07/86	[6]11	.144
—	Dog River at mouth	do.	78.5	—	[7]11.3	—
—	intermediate-area contribution between Dog River and Snake Creek	—	66	—	[12]15.6	—
02337500	Snake Creek near Whitesburg	tributary	35.5	07/09/86	8.4	0.237
—	Snake Creek at mouth	do.	49.2	—	[7]11.7	—
—	intermediate-area contribution between Snake Creek and station 02338000	—	56	—	[13]13.3	—
02338000	Chattahoochee River near Whitesburg	regional	2,420	—	[15]637	.263

[1]Carter and others (1989).
[2]Daily mean discharge.
[3]Discharge divided by the drainage area.
[4]Estimated by multiplying unit-area discharge for station 02331600 by drainage area of listed site.
[5]Estimated by multiplying unit-area discharge for station 02333500 by drainage area of listed site.
[6]Miscellaneous discharge measurement.
[7]Estimated by multiplying the drainage area at the tributary mouth by the unit-area discharge that was computed using the discharge at that tributary's miscellaneous measurement site or daily mean-discharge site.
[8]Sum of estimated discharges for the Chestatee River above Yahoola Creek and Yahoola Creek at mouth.
[9]Estimated by multiplying drainage area by unit-area discharge for Chestatee River below Yahoola Creek.
[10]Sum of estimated discharges for the Chattahoochee River above mouth of Chestatee River and Chestatee River at mouth.
[11]Estimated unregulated discharge computed by multiplying drainage area by unit-area discharge of Chattahoochee River below Chestatee River.
[12]Estimated by multiplying drainage area of the intermediate area by unit-area discharge that was computed using the discharge at the next downstream miscellaneous measurement site or daily mean-discharge site.
[13]Estimated by multiplying drainage area by the unit-area discharge that was computed using the discharge at the nearest upstream tributary daily mean-discharge site.
[14]Estimated unregulated discharge at station 02334430, added to the tributary mouth discharges, and intermediate area discharges downstream to station 02336000.
[15]Estimated unregulated discharge at station 02336000, added to the tributary mouth discharges, and intermediate area discharges downstream to station 02338000.

Table 9. Relations among mean-annual stream discharge, and estimated mean-annual baseflow and drought flow in the Chattahoochee River, Subarea 1

[Mean-annual stream discharge is mean for the period of record; —, not applicable or no available data]

Station number or estimation site	Station name	Drainage area (square miles)	Stream discharge, in cubic feet per second				
			Mean-annual stream discharge[1/]	Estimated mean-annual baseflow[2/]	Drought of 1941[3/]	Drought of 1954[4/]	Drought of 1986[5/]
02330450	Chattahoochee River at Helen, Ga.	44.7	134	91.8	—	24.4	29
02331000	Chattahoochee near Leaf, Ga.	150	402	328	72	82	—
02331600	Chattahoochee River near Cornelia, Ga.	315	828	—	—	—	162
02333000	Chattahoochee River near Gainesville, Ga.	559	1,240	982	242	282	—
02334430	Chattahoochee River at Buford Dam, near Buford, Ga.	1,040	—	—	—	—	470
02334500	Chattahoochee River near Buford, Ga.	1,060	2,173	1,790	—	381	—
02335000	Chattahoochee River near Norcross, Ga.	1,170	2,265	—	382	471	—
02335450	Chattahoochee River above Roswell, Ga.	1,220	—	—	—	—	—
02335500	Chattahoochee River near Roswell, Ga.	1,230	2,329	—	389	350	—
02336000	Chattahoochee River at Atlanta, Ga.	1,450	2,567	1,970	422	346	[7/]508
02336490	Chattahoochee River at State Highway 280, near Atlanta, Ga.	1,590	—	—	—	—	—
02337170	Chattahoochee River near Fairburn, Ga.	2,060	—	—	—	—	—
02338000	Chattahoochee River near Whitesburg, Ga.[6/]	2,420	3,740	2,570	468	384	637
Drainage area, mean-annual stream discharge, mean-annual baseflow, and drought flows exiting Subarea 1			**3,740**	**2,570**	**468**	**384**	**[7/]637**

[1/]From table 3.

[2/]From table 5; 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.

[3/]From table 6.

[4/]From table 7.

[5/]From table 8.

[6/]Represents entire Chattahoochee River basin in Subarea 1.

Baseflow during the later parts of the droughts of 1941, 1954, and 1986 averaged about 19.3 percent of the estimated mean-annual baseflow to the surface-water system (table 10). Ground-water contribution to streamflow during the drought periods at the Subarea 1-2 boundary was estimated using data from the Whitesburg, Ga., gage along the Chattahoochee River. Historical drought flows (prior to upstream storage in Lake Sidney Lanier) for 1941 and 1954 were 468 and 384 ft^3/s, respectively (table 10). Streamflow for the 1986 drought was estimated to be 637 ft^3/s. In relation to the conceptual model of ground-water flow and stream-aquifer relations, baseflow during droughts represents greatly reduced contributions from the local and intermediate flow regimes. Downstream baseflow in the upper Chattahoochee River basin near the end of the 1941, 1954, and 1986 droughts is related to drainage area in figure 9 and summarized in tables 9 and 10.

Table 10. Estimated drought flows and mean-annual baseflow in the upper Chattahoochee River basin; and ratio of average drought flow to mean-annual baseflow, Subarea 1

	Drought flow, in cubic feet per second				Mean-annual baseflow[1/,2/] (in cubic feet per second)	Ratio of average drought flow to mean-annual baseflow[5/] (in percent)
	1941[3/]	1954[4/]	1986[5/]	Average drought flow		
Flow exiting Subarea 1	468	384	637	496	2,570	19.3

[1/]From table 5.

[2/]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.

[3/]From table 6.

[4/]From table 7.

[5/]From table 8.

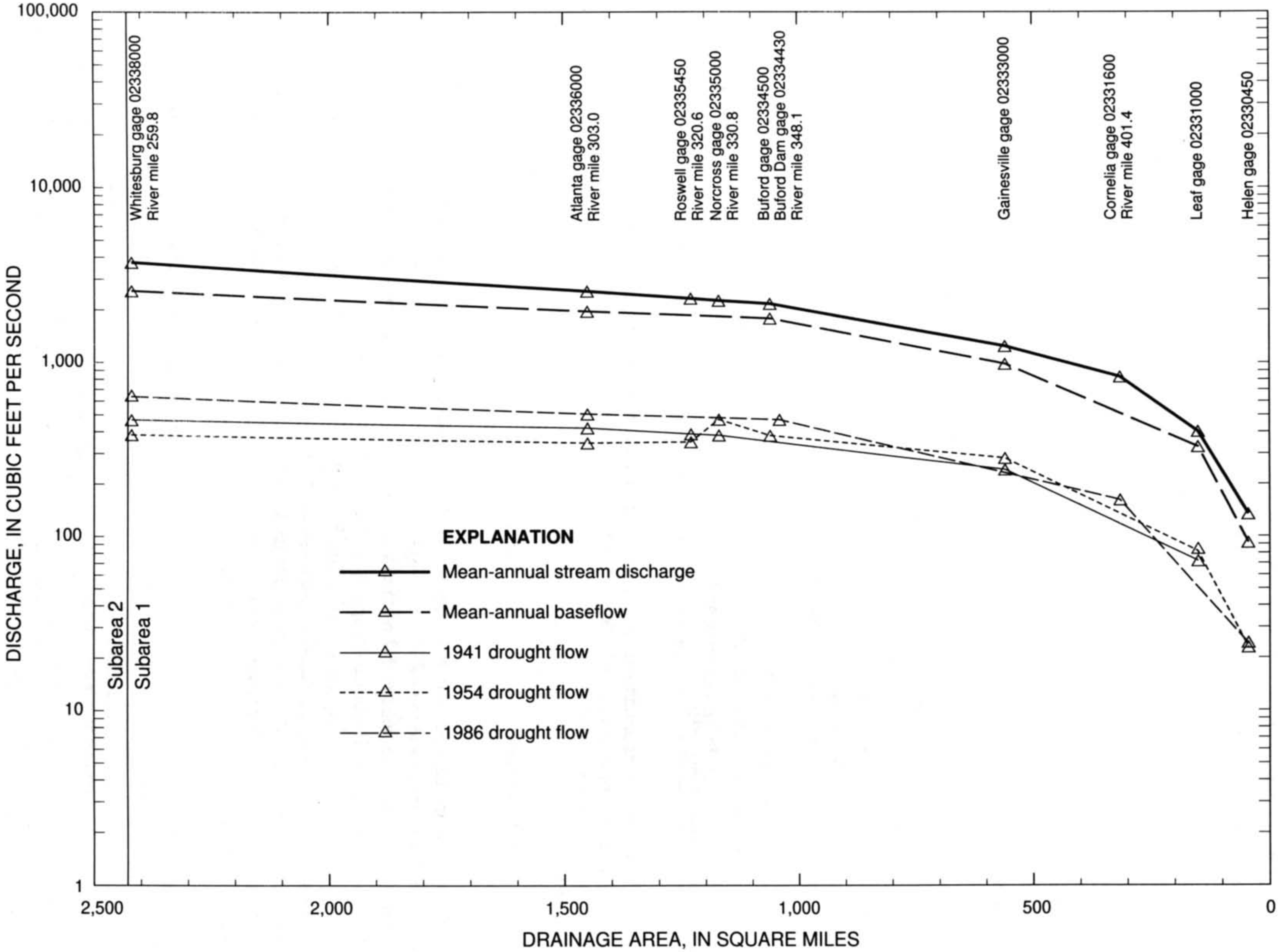

Figure 9. Relations among mean-annual stream discharge, mean-annual baseflow, and drought flow, Chattahoochee River, Subarea 1. [Note: Triangles represent estimated or measured discharges; lines connecting triangles represent interpolated discharge. River mile is measured upstream from the mouth of the Chattahoochee River.]

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 1 represents a relatively minor percentage of ground-water recharge, even a large increase in ground-water use in Subarea 1 in one State is likely to have little effect on ground-water and surface-water occurrence in the other.

Ground-water use of about 28.8 ft^3/s in 1990 in Subarea 1 represented 1.1 percent of the mean-annual baseflow in the surface-water system and 5.8 percent of the average drought flow. Local problems of ground-water overuse were not identified. However, the number and distribution of wells having long-term water-level data in Subarea 1 are insufficient to draw conclusions regarding regional water-level declines or storage change.

Table 11. Relation between 1990 ground-water use and ground-water discharge during mean-annual baseflow, average drought flow, and minimum drought flow, Subarea 1

Ground-water use, 1990 (cubic feet per second)	Baseflow to the Chattahoochee River and tributaries (cubic feet per second0			Ratio of ground-water use to baseflow (percent)		
	Mean-annual baseflow	Average drought flow	Minimum drought flow	Mean-annual baseflow	Average drought flow	Minimum drought flow
[1/]28.8	2,570	496	384	1.1	5.8	7.5

[1/]From Marella and others (1993).

In general, ground-water resources are underutilized throughout the study area. The rural population relies on ground water as their principal source of water supply; whereas, more densely populated areas rely on surface-water resources. However, wells supplied water to many communities prior to the development of large surface-water reservoirs. In recent years, suburban communities have developed ground-water supplies in response to curtailed surface-water resources.

Ground-water exploration in the Blue Ridge and Piedmont Provinces of Georgia historically has been “difficult” and its success “unpredictable.” The crystalline-rock aquifers of this region are characterized by little or no primary porosity and complex development of secondary permeability. The yield of bedrock wells depends on the presence and characteristics of the water-bearing zones penetrated by the open borehole in the bedrock. The aquifers in the Piedmont are extremely anisotropic and heterogeneous due to complex geologic controls in the crystalline bedrock (fig. 6). Depth to water-bearing zones is highly variable. Wells may yield water from several fractures throughout a borehole, or from a single productive fracture. Conversely, a borehole may not intersect an opening; and thus, may yield little or no water.

A general assessment of ground-water development potential in Subarea 1 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, current availability of surface-water resources. The nature of such an assessment is necessarily limited in its scope and range of application by knowledge of current hydrologic conditions and the acceptance of these conditions by Federal, State, or local water-resource managers as standards upon which the effects of additional stress and future development are evaluated. Current stresses and hydrologic 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 only into one aspect of the broader question of how water-management decisions affect ground-water availability; specifically, whether existing hydrologic data document flow-system behavior adequately to allow quantification of the potential effects of future development on the flow system. Further, an assessment of 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 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 rather than surface-water sources could not be determined from available data for Subarea 1. Because geologic controls affecting ground-water availability are highly variable, even on a local scale, regional evaluations are inherently difficult. Ground-water availability may be a constraint in areas underlain by Piedmont and Blue Ridge crystalline-rock terranes more because of the difficulty in locating water-bearing voids in the rocks, rather than because of a lack of water. Ground-water resources probably could provide supplemental supply during peak demand periods throughout most suburban areas of the Subarea 1. In more rural areas, ground-water supplies could serve as a primary resource depending upon demands. Generally, wells need only supply about 5 gal/min for domestic users, and may not be drilled to a depth that taps the available ground-water supply at a site. Most municipal or industrial users generally require well yields of at least 50 to 100 gal/min or more, and wells for such supplies likely are drilled to a depth sufficient to intersect as many water-bearing zones as feasible. Municipal and industrial users also tend to drill multiple wells to obtain the required ground-water supply.

Ground-Water Exploration-Program Examples

An example of a successful ground water exploration program in Subarea 1 is in Cobb County, Ga. The Cobb-Marietta Water Authority (CMWA) began an evaluation of the ground water resources of the county in 1988 to develop supplemental sources of drinking water. The CMWA supplied about 75 Mgal/d for public supply in 1990 (Fanning and others, 1992). Population projections for the area to the year 2040 indicate that the demand for water will be about 330 Mgal/d (Brown and Caldwell, Consulting Engineers, Inc., written commun., 1988). Presently (1996), all the drinking water is obtained from two surface-water sources—the Chattahoochee River and Lake Allatoona on the Etowah River (fig. 8). The CMWA plans to develop well fields throughout Cobb County to supplement the drinking water supply during periods of peak demand.

Two CMWA studies were conducted in 1993 and 1994 using different methodologies to locate areas favorable for drilling high-yielding wells. The first study used only existing data; no field work was conducted other than the drilling and monitoring of one well. The drilling area was selected using a geographic information systems and computer-aided design to map and analyze geologic, hydrologic, water use, land use, potential threats to ground water, and water distribution network data. Once the drilling site was selected, a local-scale geologic map was constructed to further refine the site selection. The test well was drilled in a biotite gneiss/amphibolite to a depth of 603 ft. Aquifer tests indicated that the well could be pumped at about 100 to 150 gal/min. Borehole geophysical logs also were used to evaluate water-bearing characteristics. Approximately 75 percent of the water was obtained at depths of less than 400 ft from several fractures. The quality of the water, however, was not suitable for drinking because of the high concentration of sulfate, and would require treatment before use for public supply (Law Environmental Inc., written commun., 1993).

The second CMWA study involved detailed geologic mapping throughout the county (Emery and Garrett Groundwater, Inc., written commun., 1994). The mapping was combined with photolineament analyses, collection of background well information, topography, soils data, watershed geomorphology, and assessment of contamination potential. Two clusters of three wells each were drilled and preliminary aquifer tests were performed. One of the sites was selected for future development. All the wells at this site were drilled in a north-south line about 0.1 mi apart. Estimated yields of the wells range from 180 to 300 gal/min. The northern-most well had the lowest yield and an elevated sulfate concentration of 1,800 milligrams per liter (mg/L). The two southern-most wells flowed naturally at about 7 to 12 gal/min. The southern-most well was airlift tested at 550 gal/min. Chemical analysis of the water indicated no sulfate present, and the water was suitable for public supply (J.J. Brady, Emery and Garrett Groundwater, Inc., oral commun., 1993).

In December 1988, a hydrogeologic investigation was conducted at the Peachtree Golf Club (PGC) in DeKalb County, Ga., to evaluate the potential for the use of ground water as a source for irrigation. Surficial geologic mapping was conducted and correlated with topographic lineaments in the selection of drilling sites. The dominant rock type at the PGC site is a fine-grained granitic gneiss. Discontinuous layers of hornblende gneiss are present within the granitic gneiss. Scattered pegmatites and quartz veins also were mapped. The fine-grained texture is a result of shearing granulation under high, confining pressure; thus, the rock has very low primary permeability. Depth of weathering is shallow, and outcrops are present along creek bottoms.

Four drilling sites were selected. Initial test-well production estimates were highly variable, and ranged from 1 to 200 gal/min. Three of the four test sites are located in stream-valley bottoms, and the other site is located at a higher hillside location along a stream drainage. As with yield, depths to water-bearing zones and types of water-bearing zones were highly variable. One well which produced more than 200 gal/min, yielded most of the water from a "bottom-hole" zone (terminology and definition from Cressler and others, 1983) at a depth of 455 to 465 ft. The zone apparently was a deeply weathered feldspathic zone having numerous fractured quartz veins. Two other wells derive water from various zones throughout the open-hole interval, penetrating rocks having abundant chlorite, which creates greater differential weathering along foliation planes. The fourth well tapped quartz-rich rocks and yielded only a very small amount of water.

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 upper Chattahoochee River basin in Georgia, Subarea 1 of the ACF-ACT River basins, and to estimate the possible effects of increased ground-water use in the basin.

Subarea 1 encompasses about 2,430 square miles in the Piedmont and Blue Ridge physiographic provinces of north-central Georgia, which covers about 28 percent of the total 8,740 square-mile area of the Chattahoochee River basin. The basin also includes about 2,600 square miles in Alabama; however, that part of the basin is not in the study area. Subarea 1 is bounded to the northwest by the Tennessee River basin, to the east by the Savannah River basin and the Altamaha River basin. To the west, the study area is bounded by the Coosa River basin (Subarea 6) and Tallapoosa River basin (Subarea 5) and to the south by the middle Chattahoochee and upper Flint River basins (Subarea 2).

The Piedmont and Blue Ridge Provinces are characterized by a two-component aquifer system composed of a fractured crystalline-rock aquifer characterized by little or no primary porosity or permeability. The overlying weathered regolith (saprolite) behaves as a porous-media aquifer. In some areas, a transition zone lies between the regolith and unweathered crystalline bedrock.

The conceptual model of ground-water flow and stream-aquifer relations subdivides 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 discharges chiefly to the Chattahoochee River. Ground-water discharge to tributaries primarily is from the local and intermediate flow regimes. Ground water that discharges to regional drains is composed of 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.

Mean-annual baseflow in Subarea 1 was estimated using an automated hydrograph-separation method. Total mean-annual baseflow to the upper Chattahoochee River and tributaries was estimated to be about 2,570 cubic feet per second in Georgia (from the headwaters to Subarea 1–Subarea 2 boundary). Mean-annual baseflow represents about 69 percent of the mean-annual stream discharge at the Subarea 1–Subarea 2 boundary.

Stream discharges for selected sites on the Chattahoochee River and tributaries were compiled for the years 1941, 1954, and 1986, during which historically significant droughts occurred throughout most of the ACF-ACT River basins. Stream discharge was assumed to be sustained entirely by baseflow during the latter periods of these droughts. Estimated baseflow (unregulated) near the end of the individual droughts averaged about 19.3 percent of the estimated mean-annual baseflow in Subarea 1.

The limited scope, lack of field-data collection and short duration of the ACF-ACT River basin study has resulted in incomplete descriptions of ground- and surface-water-flow systems, which may affect the future management of water resources in the basins. For example, the extent and continuity of local and regional flow systems and their relation to geology largely is 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 should be used accordingly.

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 1941, 1954, and 1986. Analyses derived from extrapolation to other hydrologic conditions, such as much longer drought periods or increased ground-water withdrawal, should be used with caution. Special concern also should be directed to the effects of increased post-1990 withdrawal on ground-water discharge to streams in Subarea 1.

The potential exists for the development of ground-water resources on a regional scale throughout Subarea 1. Ground-water use in 1990 represented about 1.1 percent of the estimated mean-annual baseflow and 5.8 percent of the average drought flow. Because ground-water use in Subarea 1 represents a relatively minor percentage of ground-water recharge, even a large increase in ground-water use in Subarea 1 in one State probably would have little effect on the quantity of ground-water and surface-water occurrence in the other. Long-term ground-water level declines were not observed; however, long-term water-level data at wells in Subarea 1 are few in number and poorly distributed areally, and conclusions regarding regional water-level declines or storage changes cannot be reasonably drawn.

SUGGESTIONS FOR FURTHER STUDY

This report presents a discussion of ground-water resources and interaction of ground- and surface-water systems in the upper Chattahoochee River basin, Subarea 1, of the ACF-ACT River basins. In Subarea 1, 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 interaction of ground- and surface-water systems in the Subarea. Analyses of these data could better describe stream-aquifer relations, as well as ground-water availability and development potential in Subarea 1.

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-stage 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 to these boundaries, and consequently, would have improved the accuracy of estimates of ground-water contributions from subarea to subarea.

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 preselected of stream data-collection locations. For more rigorous planning, field reconnaissance of preselected stream sites could be conducted.

Data-base development also is critical to resource management. Data elements, such as well construction and yield; hydraulic characteristics of aquifers; water quality; and ground-water withdrawals—both areally and by aquifer—are particularly important. Seepage runs (detailed streamflow measurements of drainage systems made concurrently during baseflow conditions) can be used to identify individual ground-water flow systems and improve the understanding of stream-aquifer relations, especially in crystalline and mixed-rock terranes. 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 include test drilling, borehole geophysical logging, applications of surface geophysics, aquifer testing, 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. Because aquifer properties vary substantially on a local scale and data are sparse, field studies are needed to obtain quantitative definitions of the hydraulic interactions of aquifers and streams in Subarea 1.

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