# ESTIMATION OF GROUND-WATER DISCHARGE TO STREAMS IN THE CENTRAL SAVANNAH RIVER BASIN OF GEORGIA AND SOUTH CAROLINA

**By J.B. Atkins, Celeste A. Journey, and John S. Clarke**

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**BRUCE BABBITT, Secretary**

**U.S. GEOLOGICAL SURVEY**

**Gordon P. Eaton, Director**

For additional information write to:

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

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## CONVERSION FACTORS AND VERTICAL DATUM

| Multiply | By | To obtain |
|---|---|---|
| inch (in.) | 25.4 | millimeter |
| foot (ft) | 0.3048 | meter |
| mile (mi) | 1.609 | kilometer |
| square mile ($mi^2$) | 2.590 | square kilometer |
| cubic foot per second ($ft^3/s$) | .02832 | cubic meter per second |
| cubic foot per second per square mile [$(ft^3/s)/mi^2$] | .01093 | cubic meter per second per square kilometer |
| gallon per minute (gal/min) | .06308 | liter per second |
| million gallons per minute (Mgal/min) | .04381 | cubic meter per second |

*Temperature*

degree Fahrenheit (° F) C = 5/9 x ° F - 32 degrees Celsius (° C)

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

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## ABSTRACT

Ground-water discharge to streams was estimated in the central Savannah River basin near the U.S. Department of Energy, Savannah River Site, and adjacent parts of Georgia and South Carolina using hydrograph-separation techniques and a drought streamflow analysis. The estimated mean-annual ground-water discharge determined from the hydrograph-separation method indicates a greater ground-water contribution to streamflow for Upper Three Runs than for Butler, Brushy, or Brier Creeks. The unit-area mean-annual ground-water discharge ranges from 1.06 to 1.15 cubic feet per second per square mile for the Upper Three Runs basin; and from 0.39 to 0.69 cubic feet per second per square mile for the Butler, Brushy, and Brier Creek basins. The higher unit-area mean-annual discharges in the Upper Three Runs basin implies greater ground-water contribution from underlying Coastal Plain aquifers in that area.

A drought-period stream discharge analysis indicates that streamflow in the Upper Three Runs basin, S.C., receives a greater contribution of ground-water discharge from the intermediate ground-water flow system than the Georgia streams. During the 1986 drought, Butler, Brushy, and Brier Creeks had unit-area ground-water discharges that ranged from 0.004 to 0.16 cubic feet per second per square mile; and Upper Three Runs had unit-area ground-water discharges that ranged from 0.43 to 0.77 cubic feet per second per square mile. The drought stream discharge (estimated minimum ground-water discharge) was 16 to 23 percent of the estimated mean-annual ground-water discharge for the Brier Creek basin, and 41 to 67 percent for the Upper Three Runs basin.

Contribution of ground-water discharge to the tributaries is considered to be mainly from local and intermediate flow systems. The ground-water contribution from the local flow system in the Upper Three Runs basin ranged from 72 percent of the total ground-water discharge in the upper two-thirds of the basin to 100 percent in the lower part of the basin. Discharge from the local flow system in the Brier Creek basin ranged from 78 percent of the total ground-water discharge in the upper part of the basin to 95 percent of the total ground-water discharge in the central part of the basin.

# INTRODUCTION

The U.S. Department of Energy (DOE), Savannah River Site (SRS), has manufactured nuclear materials for the National defense since the early 1950's. A variety of hazardous materials including radionuclides, volatile organic compounds, and heavy metals, are either disposed of or stored at several locations at the SRS. Ground-water contamination has been detected at several locations within the SRS. Concern has been raised by State of Georgia officials over the possible migration of ground water contaminated with hazardous materials through aquifers underlying the Savannah River into Georgia (trans-river flow).

The U.S. Geological Survey (USGS), in cooperation with the U.S. Department of Energy (DOE) and Georgia Department of Natural Resources (DNR), is conducting a study to describe ground-water flow and quality near the Savannah River (trans-river flow project). The overall objectives of this study are to identify ground-water flow paths, quantitatively describe ground-water flow, and evaluate stream-aquifer relations between the Savannah River and underlying aquifers. Stream-aquifer relations are being evaluated to determine the potential movement beneath or discharge into the Savannah River.

The study area includes the Savannah River Site (SRS) and adjacent parts of Georgia and South Carolina that lie in the central Savannah River basin. The Savannah River drains the northern part of the Coastal Plain physiographic province in the study area and forms the State line between Georgia and South Carolina.

## Purpose and Scope

As a part of the trans-river flow project, ground-water discharge to streams was estimated for selected tributaries in the central Savannah River basin of Georgia and South Carolina. Results presented in this report are being used to help calibrate a regional ground-water flow model to evaluate ground-water flow and stream-aquifer relations in the vicinity of the Savannah River Site. Stream baseflow, estimated using hydrograph-separation techniques, and drought streamflow are an approximation of the quantity of ground water discharged to a stream under a variety of climatic conditions, and can be compared directly to model-simulated values of aquifer discharge.

Mean-annual and drought-period ground-water discharges were estimated for selected tributaries to the Savannah River in the vicinity of the SRS. The mean-annual ground-water discharge was estimated using hydrograph-separation techniques. The minimum ground-water discharge to tributaries was determined by evaluating stream discharge during the 1954 and 1986 drought years. A comparison between streamflow characteristics of each tributary to the computed mean-annual and minimum ground-water discharge was conducted to provide general corroboration.

## Description of Study Area

The study area consists of 4,352 square miles ($mi^2$) that covers adjacent parts of Georgia and South Carolina in the central Savannah River basin, including the Savannah River Site (SRS) (fig. 1). In Georgia, the study area includes all of Richmond County and parts of Burke, Screven, Jenkins, and Jefferson Counties. In South Carolina, the study area includes Aiken, Barnwell, and Allendale Counties. The SRS covers about 300 $mi^2$, or 7 percent of the study area, including parts of Aiken, Barnwell, and Allendale Counties, S.C.

The study area is located in the northern part of the southeastern Coastal Plain Province of Georgia and South Carolina (fig. 1). The Fall Line marks the boundary between the Cretaceous and younger Coastal Plain sediments and the older, crystalline rocks of the Piedmont Province that forms the approximate northern limit of the study area. Relief generally is greatest near the Fall Line and becomes progressively less toward the south and east; the minimum elevation of 150 feet (ft) occurrs south of Augusta, Ga. (Clark and Zisa, 1976). Deeply entrenched streams in the Fall Line region develop characteristic rapids and shoals formed by preferential erosion of poorly consolidated Coastal Plain sediments that exposes the more resistant, crystalline rocks of the Piedmont.

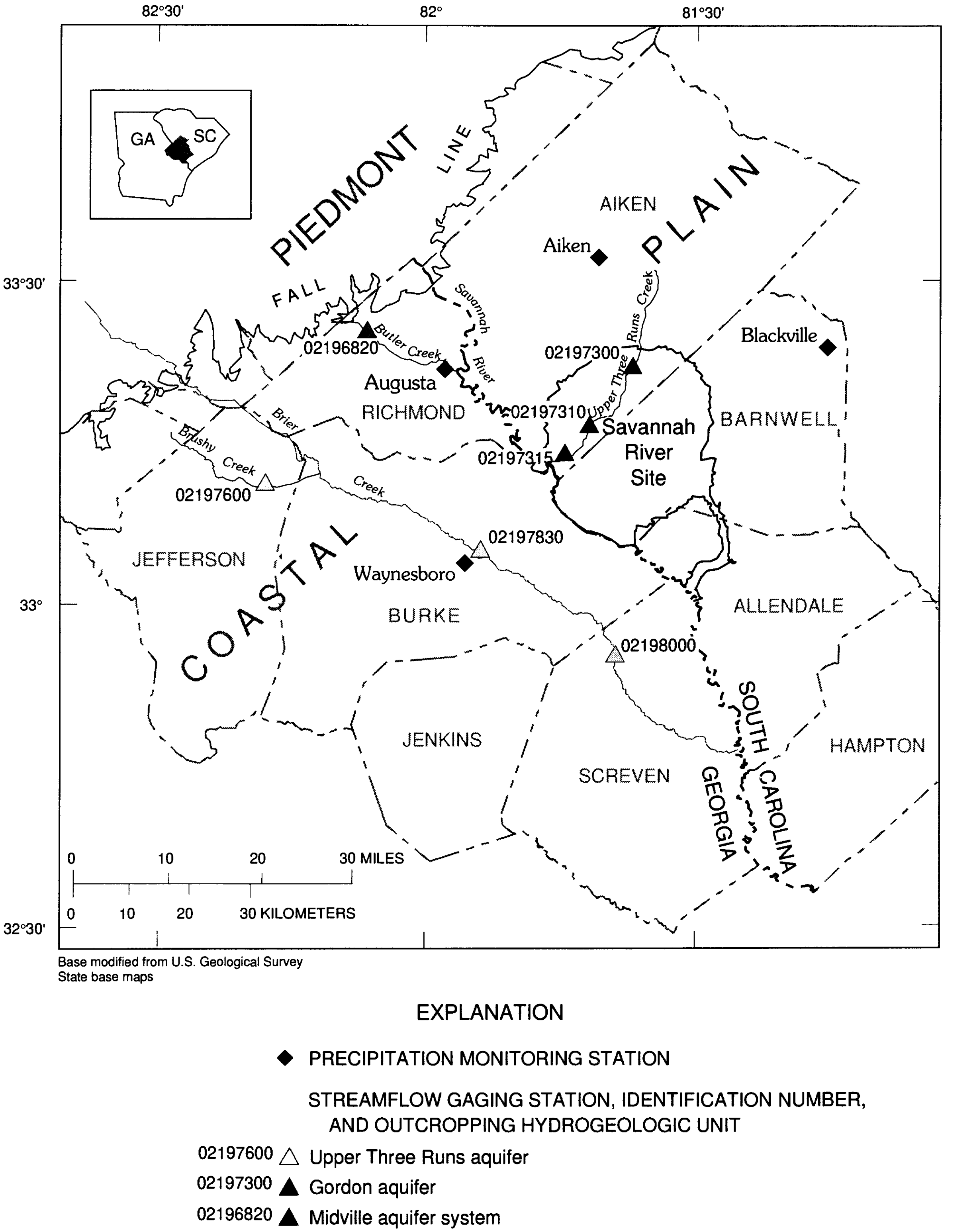



**Figure 1.** Location of study area, streamflow gaging stations, and precipitation monitoring stations.

The Coastal Plain Province is described as a moderately stream-dissected area that has a well-developed dendritic stream pattern. Streams that flow over the younger Coastal Plain sediments develop wider floodplains and meander more than those near the Fall Line (Clark and Zisa, 1976). Floodplains near large rivers, such as the Savannah River, have swamps bordering both sides of the channel. The relief ranges from 100 to 150 ft. Elevations in the district decrease to the southeast from 500 to 100 ft, reflective of the regional dip of Coastal Plain sediments.

In the central Savannah River basin, the sedimentary rocks of the Coastal Plain consist of layers of sand, clay, and minor limestone that range in age from Late Cretaceous through Holocene. The strata dip and progressively thicken from the Fall Line to the southeast, reaching an estimated thickness of 2,700 ft in the southern part of the study area (Wait and Davis, 1986). The strata crop out in discontinuous belts that generally are parallel to the Fall Line. The sedimentary sequence unconformably overlies igneous and metamorphic rocks of Paleozoic age, and consolidated red beds of early Mesozoic age (Chowns and Williams, 1983).

Coastal Plain deposits consist of fluvial, deltaic, and marine coastal and shelf sediments (Prowell and others, 1985). Through time, the axes of deposition of the deltaic systems have changed due to differential tectonism and uplift in the Appalachian region (Prowell, 1988; D.C. Prowell, U.S. Geological Survey, oral commun., 1992). Numerous marine transgressions and regressions have deposited, removed, and redistributed sediments (Colquhoun, 1981). In the updip part of the Coastal Plain in Aiken County, S.C., and Richmond County, Ga., sediments predominantly consist of nonmarine siliciclastic sediments. Marine sediments are more abundant in the southern and southeastern parts of the study area and include carbonate-shelf deposits in some strata of Tertiary age.

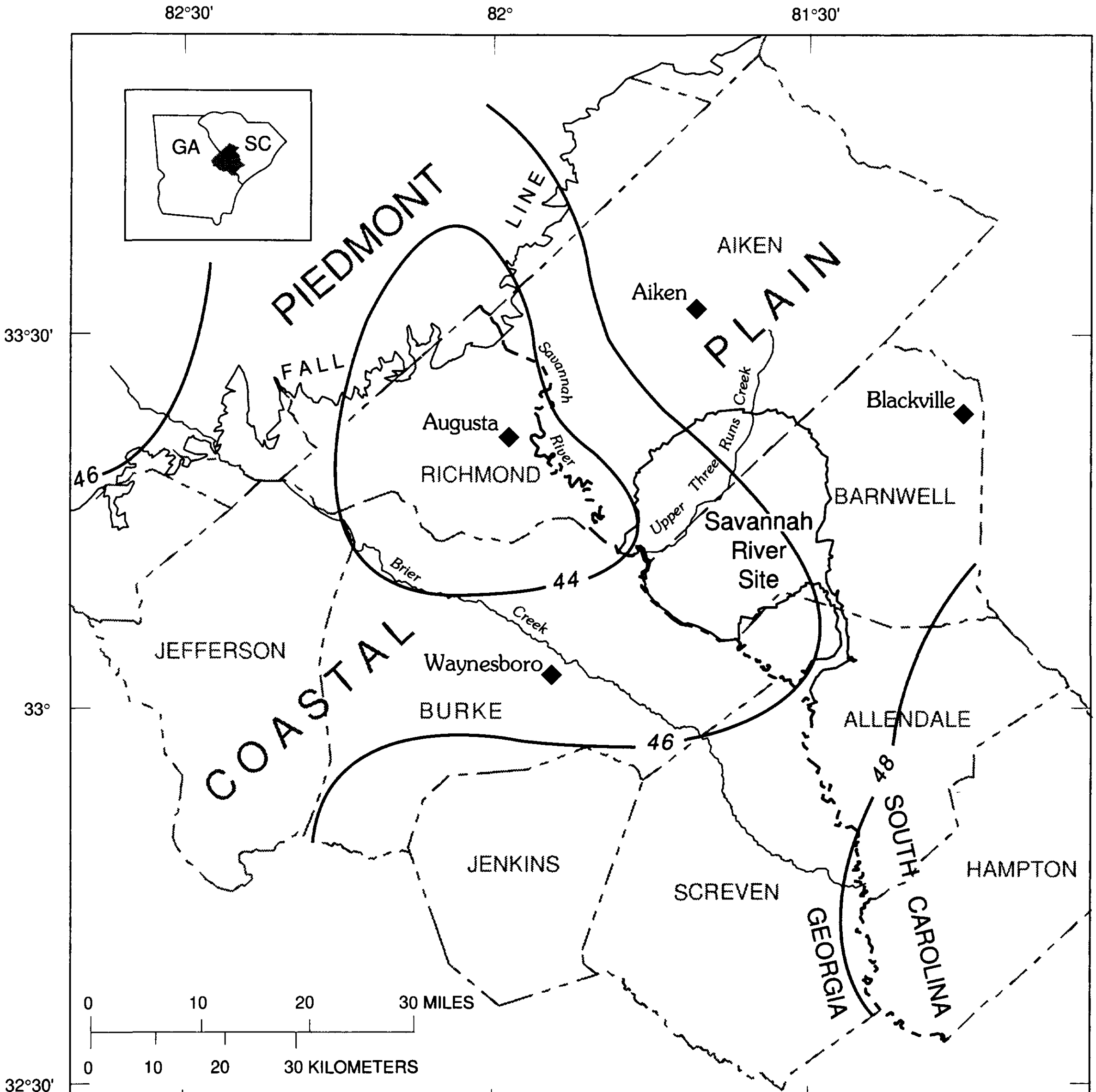
The largest cities in the study area are Augusta, Ga., which had a population of 44,639 in 1990; and Aiken, S.C., which had a population of 19,872 in 1990 (U.S. Department of Commerce, Bureau of the Census, 1991). The cities of Augusta and Aiken serve as manufacturing centers that produce textiles, paper products, lumber, fertilizer, bricks, refractory ceramics, and chemicals.

The predominant land use is agriculture, having soybeans and cotton as major crops; and silviculture, having pine timber as the major crop. Kaolin clay is mined in parts of the study area.

Average annual rainfall in the study area (fig. 2), for the period 1941 to 1970, ranged from 44 inches (in.) in Richmond County, Ga., to 48 in. in southern Screven County, Ga., and Allendale County, S.C. (Faye and Mayer, 1990). During the same period (1941-70), runoff data were available only for Georgia (fig. 3) where the average annual runoff ranged from 0.9 cubic foot per second per square mile [$(ft^3/s)/mi^2$] of drainage area in southern Screven, Jenkins, Burke and Jefferson Counties; and in northern Richmond and Jefferson Counties; to 1.1 $(ft^3/s)/mi^2$ in eastern Richmond and Burke Counties (Faye and Mayer, 1990).

## Previous Investigations

Hydrogeologic investigations in the study area in Georgia include reports by LeGrand and Furcron (1956) that described the geology and ground-water resources of Burke, Columbia, Glascock, Jefferson, McDuffie, Richmond, and Warren Counties; and by Pollard and Vorhis (1980) that defined the hydrogeology of the Cretaceous aquifer system in southern Georgia. Recent reports describe the hydrogeology of specific aquifer systems in Georgia: the Jacksonian aquifer (Vincent, 1982), the Dublin and Midville aquifer systems (Clarke and others, 1985), the Gordon aquifer system (Brooks and others, 1985), and the Coastal Plain aquifer systems in Richmond and northern Burke Counties (Gorday, 1985). The effects of suspected Late Cretaceous and Cenozoic faulting on ground-water flow near the Savannah River in Georgia and South Carolina were evaluated by Faye and Prowell (1982).

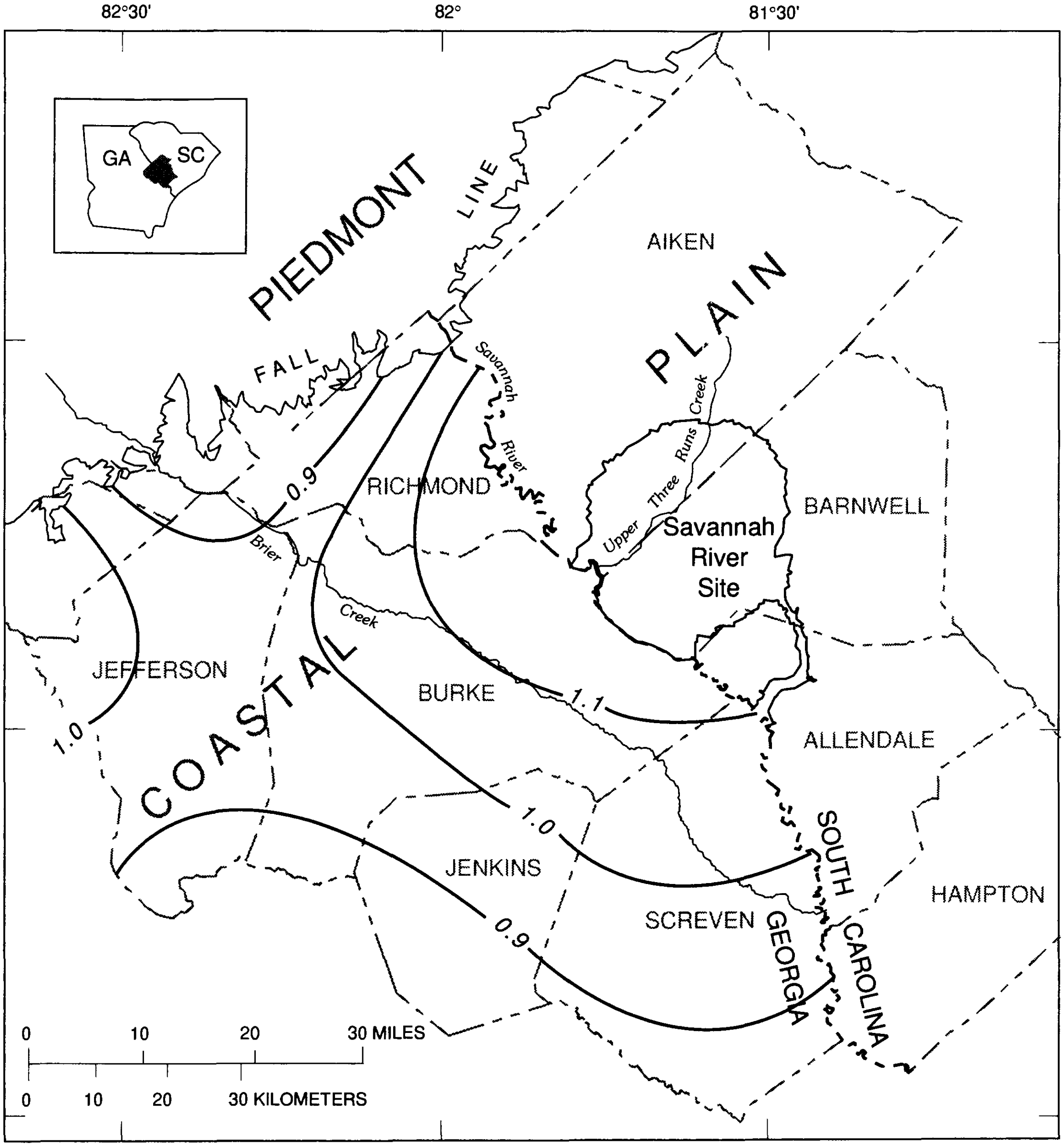



Base modified from U.S. Geological Survey
State base maps

EXPLANATION

—— *44* —— LINE OF EQUAL MEAN-ANNUAL RAINFALL, 1941–70—
Interval 2 inches

**Figure 2.** Mean-annual rainfall in study area, 1941–70 (modified from Faye and Mayer, 1990).




Base modified from U.S. Geological Survey
State base maps

EXPLANATION

—— *1.0* —— LINE OF EQUAL MEAN-ANNUAL RUNOFF, 1941–70—
Contour interval 0.1 cubic foot per square mile of drainage area

**Figure 3.** Mean-annual runoff in Georgia part of study area, 1941–70 (modified from Faye and Mayer, 1990).

Hydrogeologic investigations that describe various parts of the study area in South Carolina include Logan and Euler (1989) who reported on Allendale, Bamberg, and Barnwell Counties; and Aadland and others (1992) who described the hydrostratigraphy of the SRS.

Several investigations provided descriptions of the stream-aquifer relations in the central Savannah River basin. Siple (1967) described the hydrogeology of the SRS area, including a discussion of stream-aquifer relations and potentiometric surface, and also discussed trends and fluctuations in water levels in the study area. LeGrand and Pettyjohn (1981) discussed the influence of river incision on the configuration of the potentiometric surface near the SRS.

Aucott (1987) evaluated the ground-water contribution to streamflow in the South Carolina Coastal Plain (including the SRS area) on the basis of river gains observed over selected stream reaches. Faye and Mayer (1990) evaluated stream-aquifer relations in the Georgia Coastal Plain, including the central Savannah River area, using hydrograph-separation techniques and digital modeling. Clarke and West (1994) discussed the development of water-table and potentiometric-surface maps in the SRS area and described the effects of river incision on the configuration of the potentiometric surfaces.

Several hydrologic investigations reported streamflow during drought conditions in the study area. Thomson and Carter (1955) reported the effects of the 1954 drought on streamflow in Georgia. Siple (1967) described baseflow in streams during the 1951 and 1954 droughts for the study area. Hale and others (1989) reported the effects of the 1986 drought on streamflow in the southeastern United States, including Georgia and South Carolina.

Regional investigations that include the study area were conducted as part of the USGS Regional Aquifer-System Analysis (RASA) program including (1) the description of the configuration, extent, geologic age, and lithic character of the major aquifers and confining units that collectively comprise the southeastern Coastal Plain aquifer system, by Renken and others (1989); (2) a digital-model evaluation of major aquifers in rocks of Late Cretaceous and early Eocene age in eastern Alabama, Georgia, and western South Carolina, by Faye and Mayer (*in press*); and (3) a similar modeling investigation in South Carolina, by Aucott (1988).

### Streamflow Gaging Station Numbering System

Streamflow gaging stations are assigned an 8- to 14-digit station-identification number according to downstream order along the main stream. The first two digits of the station-identification number represent the "Part" number with the remaining digits representing the downstream order number. All stations on a tributary entering upstream from a mainstream station are listed before that station. A station on a tributary that enters between two mainstream stations is listed between them. A similar order is followed in listing stations on first rank, second rank, and other ranks of tributaries. Gaps are left in the series of numbers to allow for new stations that may be established; hence, the numbers are not consecutive.

## APPROACH AND METHODS OF STUDY

This study includes several work elements used to describe the conceptual model of ground-water flow and estimate the ground-water discharge to streams in the Savannah River basin in the vicinity of the SRS. The approach and methods used to accomplish these tasks include:

- compilation of information and data from pertinent literature, including geologic, ground-water, streamflow, and precipitation data;
- separation of streamflow hydrographs to estimate mean-annual ground-water contribution to three tributaries of the Savannah River in the vicinity of the SRS; and
- evaluation of streamflow records and periodic discharge measurements during drought periods to estimate "worst-case" streamflow conditions.

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 and Witherspoon (1966, 1967, 1968), Winter (1976), Faye and Mayer (1990), Heath (1984, 1989), and Miller (1990). These studies suggest that large rivers 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 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 methods of Rorabaugh (1960, 1964) and Daniel (1976); and (2) a drought-flow analysis of streamflow. The hydrograph-separation method was used to estimate the mean-annual discharge (baseflow) of ground water to the basin. The drought-flow analysis was used to estimate the minimum ground-water discharge to the surface-water system during historically significant droughts and the minimum volume of ground water delivered as baseflow to streams in the central Savannah River basin. Stream-discharge measurements listed in this report are stored in the USGS National Water Information System (NWIS).

## Mean-Annual Ground-Water Discharge Analysis

Discharge data from continuous-record gaging stations along three tributaries to the Savannah River were selected for baseflow analysis based on the period of record of unregulated flow (table 1; fig. 1). Streamflow representative of low, average, and high years of stream discharge were evaluated by hydrograph-separation methods to estimate annual ground-water discharge to streams. The mean-annual ground-water discharge to streams then was computed as the average ground-water discharge of the three representative flow years.

The selection process for the most representative year of low, average, and high stream discharge involve objective statistical examination of the discharge data, followed by some subjectivity in the final choice of the selected water year. For each station, boxplots of daily streamflows were prepared for each year of the period of record (fig. 4). The boxplots depict the minimum, maximum, mean, and median daily discharge; and the 25- and 75-percent quartiles for each selected water year. The upper and lower adjacents each extend a distance of 1.5 times the interquartile range beyond the box. The mean-annual stream discharge was computed for the unregulated flow period and used as a reference mean for low-, average-, and high-flow conditions for the selected station.

Hydrographs acceptable for separation are characterized by relatively normal distributions of daily stream discharge, small ranges, and without extremely high, isolated peak stream discharges. The mean- and median-annual stream discharge for water years identified as acceptable were compared to the reference mean. Extremely high discharge during a water year may greatly influence the mean but not the median-annual stream discharge (the median is similar to the geometric mean for positively skewed data sets, such as discharge). Therefore, 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. Hydrographs for these representative water years were examined and analyzed using hydrograph-separation methods. 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.

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 to analyze streamflow data

**Table 1.** Selected streamflow gaging stations used for hydrograph-separation analysis in the central Savannah River basin of Georgia and South Carolina

| Station number | Station name | Outcropping hydrogeologic unit | Drainage area (square miles) | Period of record analyzed (water years)[1/] |
|---|---|---|---|---|
| 02196820 | Butler Creek at Fort Gordon, Ga. | Midville | 7.5 | 1969-90 |
| 02197300 | Upper Three Runs near New Ellenton, S.C. | Gordon | 87 | 1967-93 |
| 02197310 | Upper Three Runs above Road C at Savannah River Site, S.C. | do. | 176 | 1975-93 |
| 02197315 | Upper Three Runs at Road A at Savannah River Site, S.C. | do. | 203 | 1975-93 |
| 02197600 | Brushy Creek near Wrens, Ga. | Upper Three Runs | 28 | 1959-93 |
| 02197830 | Brier Creek near Waynesboro, Ga. | do. | 473 | 1970-93 |
| 02198000 | Brier Creek at Millhaven, Ga. | do. | 646 | 1938-93 |

[1/]A water year extends from October of a given year through September of the following year.

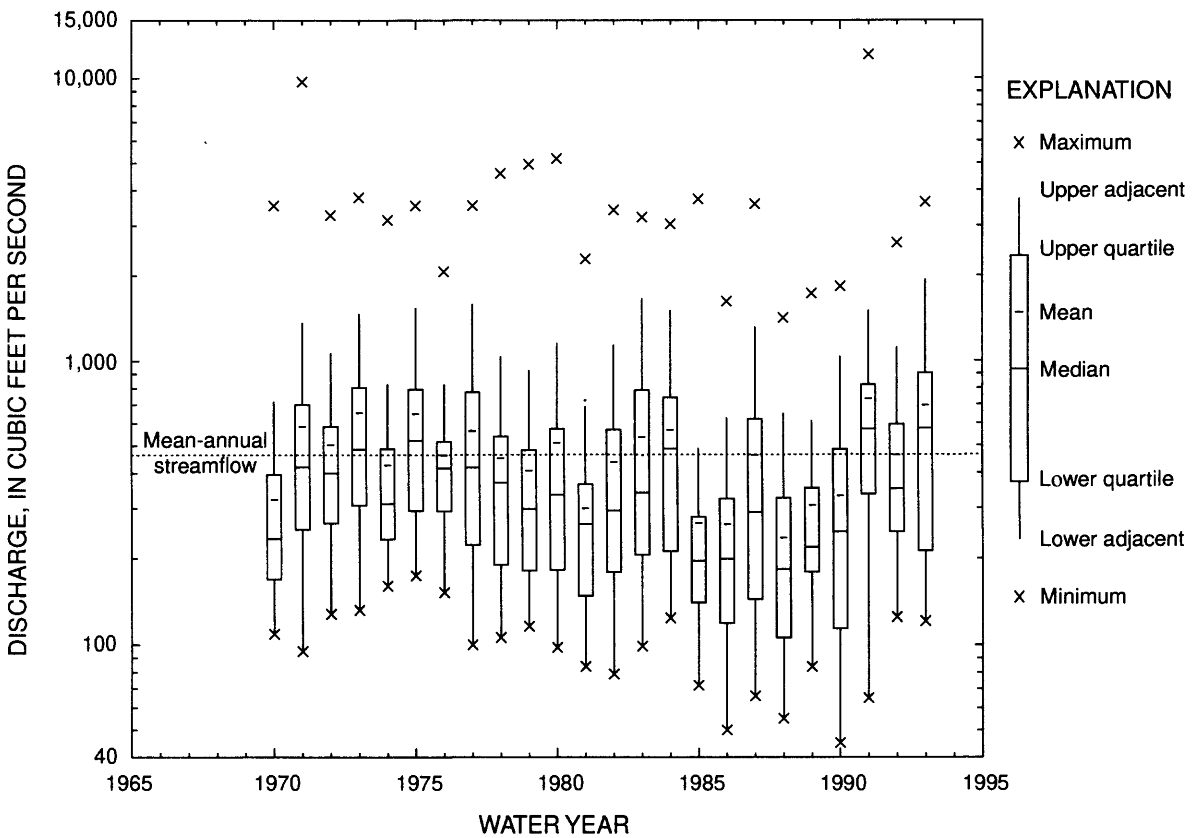



**Figure 4.** Distribution of daily streamflow for Brier Creek near Waynesboro, Georgia.

influenced by riparian evapotranspiration. SWGW utilizes daily mean discharge data collected at unregulated stream-gaging sites and requires at least 10 years of record to estimate long-term average baseflow.

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). Surface runoff is the quick response (peaks) of stream stage to precipitation and nearby overland flow. Figure 5 shows an example of the graphical output from the SWGW program.

Application of the Rorabaugh method requires the use of the streamflow recession index. The streamflow recession index is defined as the number of days required for ground-water discharge 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 from evapotranspiration (Daniel, 1976) or leakage, and the influence of geologic heterogeneities in the basin (Horton, 1933; Riggs, 1963). The slope of the 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. 5). The major rise period of streamflow usually occurs from November through March or April when precipitation is greatest and evapotranspiration lowest. The major recession period usually occurs during late spring though fall and coincides with a period of lesser precipitation and higher temperature, thus producing greater evapotranspiration losses (fig. 5). Two recession indices were estimated for streamflow observed at each continuous-record gaging station used in the mean-annual ground-water discharge analysis—one index for the major rise period and one index for the major recession period.

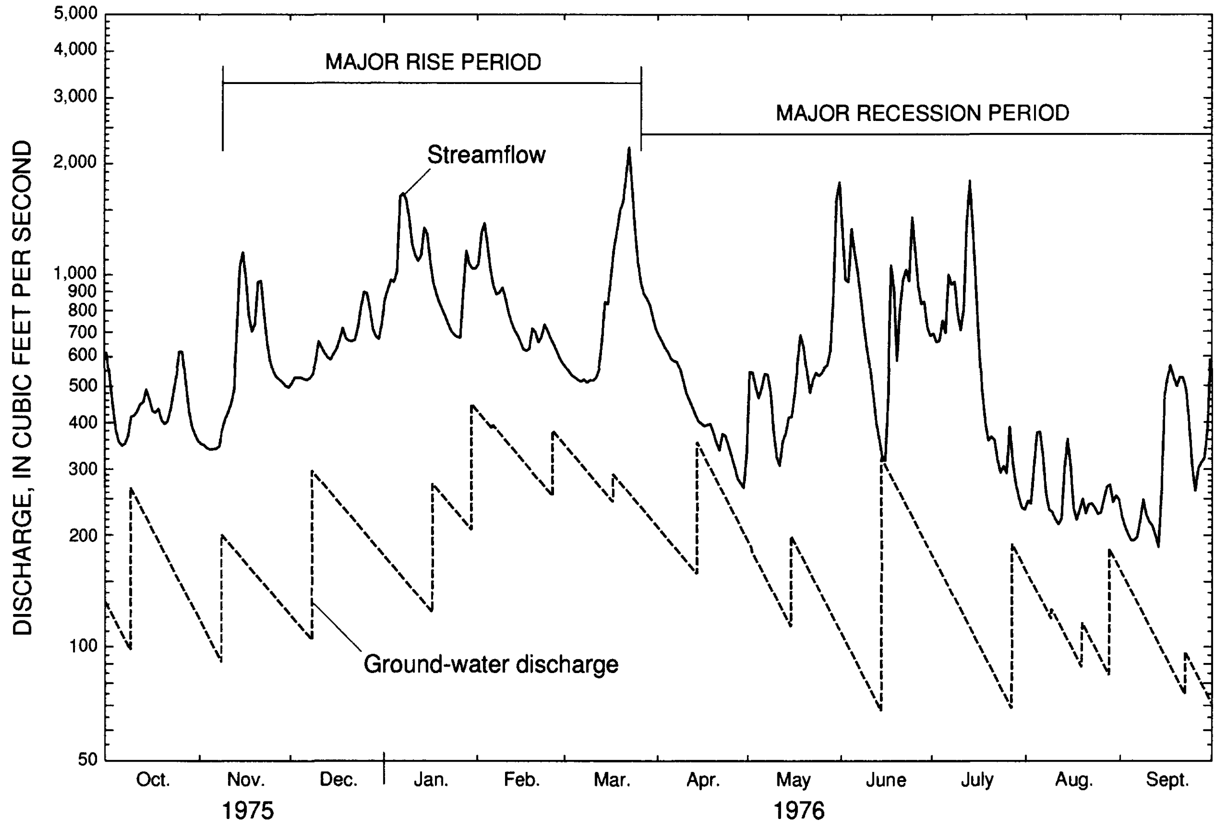



**Figure 5.** Separated streamflow and ground-water discharge hydrograph for Brier Creek near Millhaven, Georgia, water year 1976.

## Drought Streamflow Analysis

Daily mean streamflow data collected at gaging stations during periods of low flow and corresponding periodic measurements of stream discharge collected at partial-record stations were compiled for the drought years 1954 and 1986. These data include nearly concurrent daily measurements of streamflow in the Savannah River basin and periodic measurements of tributary discharge in nearby basins.

Standard periods of analysis for the two droughts were selected. The period of analysis selected for compiling 1954 drought data was July 15 through October 15, 1954. The selected period for the 1986 drought was July 1 through July 31, 1986. Drought conditions during these periods were considered to represent the "worst-case" conditions of ground-water storage and availability. Therefore, the drought streamflow represents a quantitative estimate of minimum ground-water discharge to streams.

# STREAM-AQUIFER RELATIONS

The hydrologic framework of the central Savannah River basin 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. The relation among the ground-water system, surface-water system, and precipitation will be described.

## Ground Water

Previous investigators in Georgia (Miller, 1986; Brooks and others, 1985; Clarke and others, 1985) and in South Carolina (Logan and Euler, 1989; Bledsoe and others, 1990; Aadland and others, 1992) defined three principal aquifer systems near SRS. The aquifer systems (fig. 6) in the study area are, in descending order: (1) the Floridan aquifer system (Miller, 1986), comprised largely of calcareous sand and limestone of Eocene age; (2) the Dublin aquifer system (Clarke and others, 1985) comprised of sand of Paleocene and Late Cretaceous age; and (3) the Midville aquifer system (Clarke and others, 1985) comprised of sand of Late Cretaceous age. Although this subdivision of geologic strata was suitable for most regional-scale hydrologic studies, greater subdivision of units was required to define vertical hydraulic heterogeneity for detailed ground-water modeling investigations in the vicinity of the Savannah River.

| GEOLOGIC AGE | HYDROGEOLOGIC UNITS | | |
|---|---|---|---|
| | Georgia | This study | South Carolina[1] |
| EOCENE | Jacksonian aquifer[2]/ Upper Floridan aquifer[3] | Upper Three Runs aquifer | Upper Three Runs aquifer |
| | Confining unit | Gordon confining unit | Gordon confining unit |
| | Gordon aquifer system[4] | Gordon aquifer | Gordon aquifer |
| PALEOCENE | Confining unit | Millers Pond confining unit | Crouch Branch confining unit |
| | Dublin aquifer system[5] | Millers Pond aquifer | |
| | | Upper Dublin confining unit | |
| LATE CRETACEOUS | | Upper Dublin aquifer | Crouch Branch aquifer |
| | | Lower Dublin confining unit | |
| | | Lower Dublin aquifer | |
| | Confining unit | Upper Midville confining unit | McQueen Branch confining unit |
| | Midville aquifer system[5] | Upper Midville aquifer | McQueen Branch aquifer |
| | | Lower Midville confining unit | |
| | | Lower Midville aquifer | |
| | Confining unit | Basal confining unit | Appleton confining system |

[1] Aadland and others, 1992
[2] Vincent, 1982
[3] Miller, 1986
[4] Brooks and others, 1985
[5] Clarke and others, 1985

**Figure 6**. Hydrogeologic units in the vicinity of the Savannah River Site (from Clarke and others, 1996).

To delineate the vertical variation in hydraulic conductivity, the Floridan aquifer system was divided into the Upper Three Runs aquifer (Aadland and others, 1992) and the Gordon aquifer (Brooks and others, 1985; Aadland and others, 1992); the Dublin aquifer system was subdivided into the Millers Pond, upper Dublin, and lower Dublin aquifers; and the Midville aquifer system was subdivided into the upper Midville and lower Midville aquifers (Clarke and others, 1996).

The aquifers are confined by layers of clay and silt that are progressively sandier in updip areas. Where the confining units are more sandy, they do not have lateral continuity and the aquifer systems coalesce. Clarke and others (1985, 1994) described the coalescence of the Dublin and Midville aquifer systems in the northern part of the study area (Dublin-Midville aquifer system), and suggested that the Gordon aquifer system might also coalesce with these units in updip areas. Similar coalescence of aquifer units at SRS was identified by Aadland and Bledsoe (1990) and Faye and Mayer (*in press*).

Water-level fluctuations in wells are indicators of possible fluctuations in the quantities of ground-water discharge to streams. When ground-water levels are high, ground-water discharge may be relatively greater; and when low, ground-water discharge may be relatively less. Ground-water levels in wells fluctuate in response to natural and artificial processes, such as natural recharge and discharge and ground-water withdrawal. These fluctuations indicate changes in the amount of water in storage in an aquifer. Ground-water levels in wells may represent differing degrees of aquifer confinement.

To determine the magnitude of seasonal water-level fluctuations in aquifers in the study area, water-level measurements were made in 272 wells during the high (May) and low (October) recharge periods in 1992. Measurements indicate that throughout most of the study area, the magnitude of water level fluctuations was low, generally ± 2 ft.

Long-term fluctuations were evaluated by determining the amount of water-level fluctuation in wells having 10 or more years of record prior to 1993. Data from 279 wells indicates that the water-level fluctuation generally was less than ± 15 ft in most of the study area since the early 1950's. Larger fluctuations were recorded at isolated pumping centers such as SRS and the Augusta, Ga., areas.

## Surface Water

The Savannah River is the major surface-water drain in the study area (fig. 1). The river drains an area of about 10,580 $mi^2$ and discharges into the Atlantic Ocean near Savannah, Ga. The Thurmond Lake storage reservoir upstream of Augusta, Ga., was impounded in December 1951 and regulates flow that affects the Savannah River in the study area.

Two major tributaries to the Savannah River drain the study area—Upper Three Runs in South Carolina, and Brier Creek and its tributary Brushy Creek, in Georgia. Streamflow record from three continuous-record streamflow gaging stations along each of the two tributaries to the Savannah River were used in the investigation (table 1; fig. 1). One continuous-record station on Butler Creek, located near the Fall Line at the northern limit of the study area, also was used (table 1; fig. 1).

## Precipitation Trends

Precipitation data from two Georgia and two South Carolina sites were evaluated to determine long-term trends that could affect ground-water recharge and associated water-level fluctuations and trends. The sites are located at Augusta and Waynesboro, Ga., and Aiken and Blackville, S.C. (fig. 1). The Augusta and Aiken sites are near the recharge areas for the Gordon aquifer and the Dublin and Midville aquifer systems; whereas, the Waynesboro and Blackville sites are near the recharge area for the Upper Three Runs aquifer.

Cumulative departure is a term used to describe the long-term surplus or deficit of precipitation over a designated period of time. It is derived by adding successive monthly values of departures from normal precipitation. Normal precipitation for a given month is defined as the average of total monthly precipitation during a specified period. For this report, the period 1948-92 was used to determine normals for computation of cumulative departure. Values for Aiken and Blackville, S.C., and Augusta and Waynesboro, Ga., are shown graphically for the period July 1948 through December 1992 in figure 7. Periods of above-normal precipitation are indicated by upward or positive slopes on the graph; periods of below-normal precipitation are indicated by downward or negative slopes on the graph.

Precipitation trends were variable at the four sites during 1948-92. Precipitation throughout the SRS area was below normal from 1948 through much of the 1950's, a period during which one of the most severe droughts of the 20th century occurred in 1954.

In South Carolina, precipitation at Aiken and Blackville was below normal during 1948-57, followed by a general above-normal trend during 1958-80. During 1981-92, however, the precipitation trend was generally below normal at

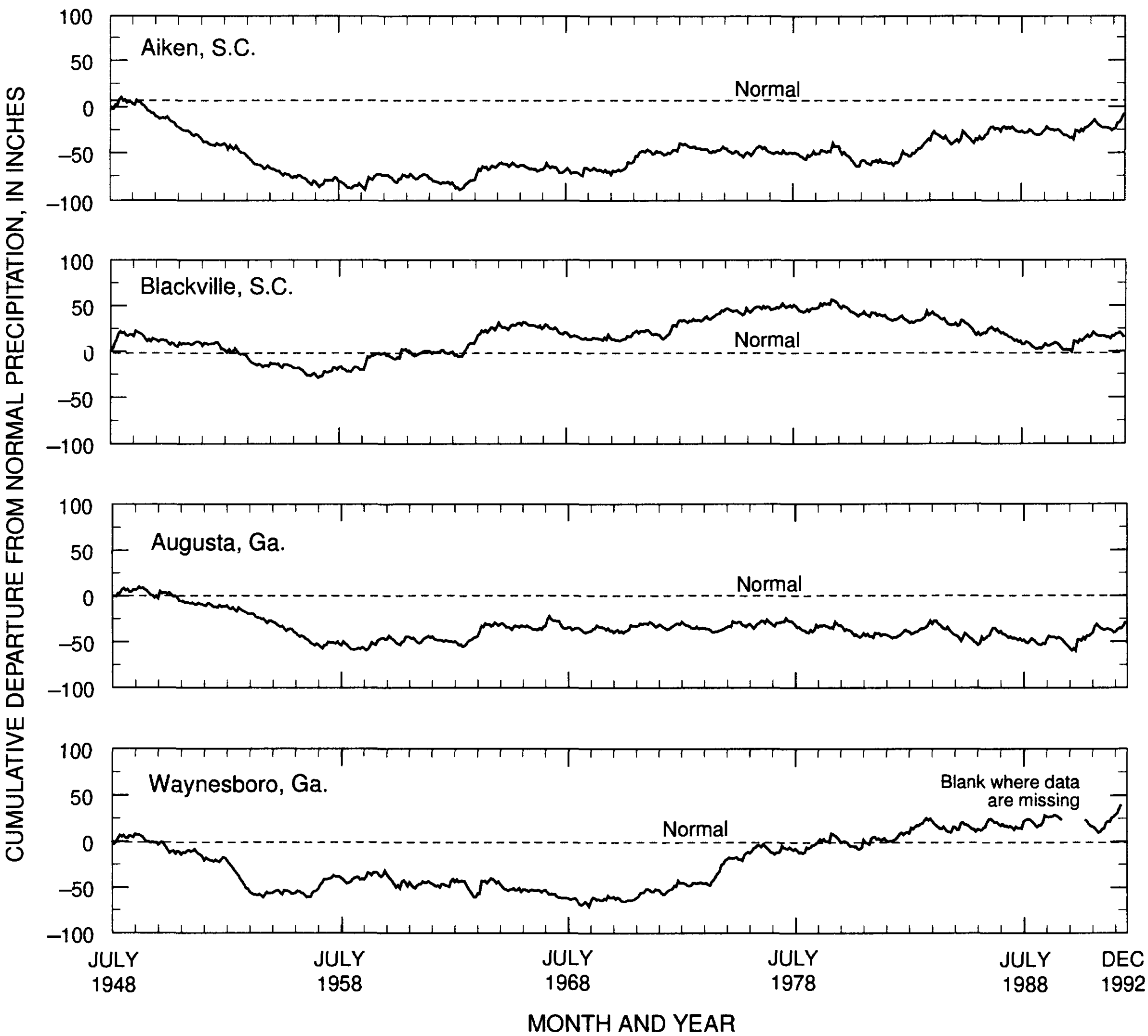



**Figure 7.** Cumulative departure from normal (1948–92) precipitation for selected sites in South Carolina and Georgia, July 1948 through December 1992.

Blackville and above normal at Aiken. By the end of 1992, the long-term cumulative departure was +11.5 in. at Blackville, and -1.2 in. at Aiken.

Precipitation at the Augusta and Waynesboro, Ga., sites also was below normal during 1948-57. At Augusta, precipitation was near normal during most of the period 1958 through 1984, followed by a below-normal trend during 1985-90, and an above-normal trend during 1991-92. At Waynesboro, precipitation was below normal during much of 1958-69, above normal during 1970-84, near normal during 1984-91, and above normal during 1992. By the end of 1992, the long-term cumulative departure was -30.4 in. at Augusta and +40.7 in. at Waynesboro.

## Conceptual Model of Hydrologic Flow System

The conceptual model of the hydrologic flow system in the central Savannah River basin is based on previous work in other areas by Toth (1962, 1963), Freeze and Witherspoon (1966, 1967), 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. 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 systems, 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 (fig. 8). Local flow systems 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 system. Regional flow paths begin at or near the major topographic (drainage) divide and terminate at regional drains, such as the Savannah River. Depending on local hydrogeologic conditions, all three flow systems may not be present.

The water table of the ground-water flow system is a subdued replica of the land-surface topography and generally has less relief. The development of ground-water flow systems depends largely on the configuration of the water table, such that net recharge occurs in highland areas and discharge occurs in lowland areas. Quantities of net recharge to aquifers and net ground-water discharge to streams are variably distributed throughout the local, intermediate, and regional flow systems. The depth of influence of the water table on ground-water flow is limited largely to the local flow system; however, in the absence of areally extensive confining units, the influence may extend to the intermediate and regional flow systems. Local systems receive the greatest net ground-water recharge to the water table and provide the most net ground-water discharge to streams. Ground-water discharge to tributary drainages primarily is from local and intermediate flow systems; and ground-water discharge to regional drains, such as the Savannah River, includes contributions from the regional, local, and intermediate systems.

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

In the study area, the ground-water and surface-water systems interact dynamically throughout the year, varying seasonally. Ground-water discharges to (and at time, sustains) streams by the amount equal to ground-water recharge under steady-state conditions. The frontal precipitation events and low evapotranspiration in winter and spring months provide the greatest recharge to the ground-water system, and isolated storm events and high evapotranspiration in summer and fall provide less net recharge.

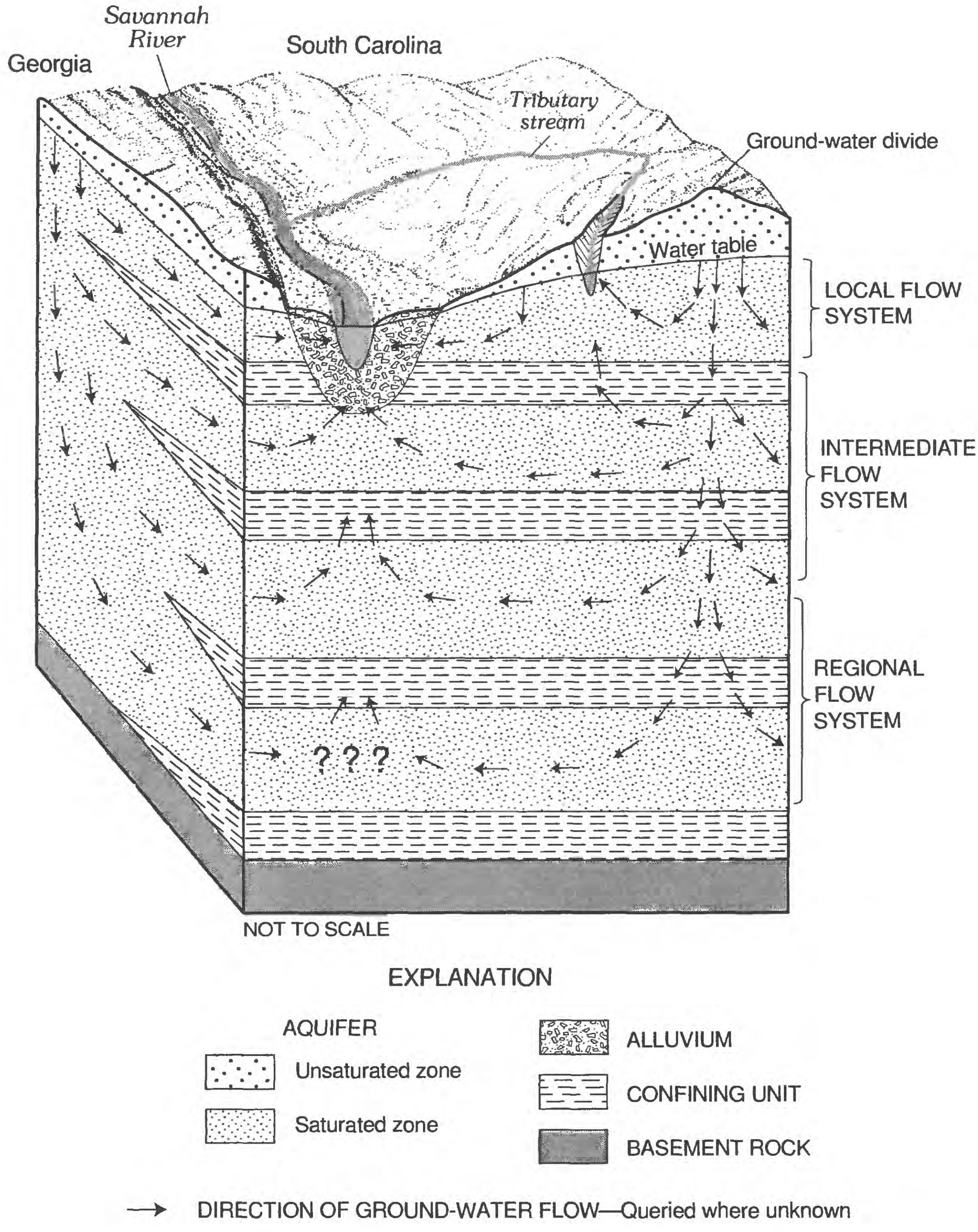



**Figure 8.** Schematic diagram of the conceptual hydrologic flow system in the central Savannah River basin of Georgia and South Carolina.

Recharge to the hydrologic system of the central Savannah River basin is provided by rainfall that ranges from 44 to 48 inches per year (in/yr) (Faye and Mayer, 1990). The Savannah River serves as the major drain for the hydrologic system. The flow mechanisms of the surface-water and ground-water systems are vastly different—having streams that exhibit swift open-channel flow and aquifers that exhibit slow porous-media flow. However, the systems can be studied as one complete hydrologic system because of interaction between the two.

The ground-water system of the central Savannah River basin is complex. The Coastal Plain Province contains several complex interbedded, mostly clastic geologic units in Georgia and South Carolina that form seven aquifers in the study area (fig. 6). Confining units between aquifers affect the degree of interaction between ground-water and surface-water systems. The variation of sediment lithology within and between units is reflected in variation in the hydraulic conductivity of the aquifers.

Throughout much of the area, the Upper Three Runs aquifer is at or near land surface and is mostly under water-table conditions. The other aquifers are more deeply buried and are mostly under confined conditions. Contribution of ground-water discharge by the regional flow system to tributaries to the Savannah River was considered negligible. During drought-streamflow periods, the ground-water discharge to streams from local flow systems is small or none and the flow largely represents the contribution by the intermediate flow system.

Potentiometric surface maps indicate that a large component of ground-water recharge is captured by streams that incise aquifer sediments. Specifically, the Savannah River is deeply incised into the aquifers and is a major ground-water discharge area in the northern part of the study area. Butler Creek, near the Fall Line, incises and receives discharge from the Midville aquifer system. Below the Fall Line, Brier Creek and its tributary, Brushy Creek, incise and receive discharge from the Upper Three Runs aquifer. Upper Three Runs incises and receives discharge from both the Upper Three Runs aquifer and the underlying confined Gordon aquifer.

## GROUND-WATER DISCHARGE TO STREAMS

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

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

In relation to the conceptual model, baseflow in streams is comprised of contributions from the local, intermediate, or regional ground-water flow systems. 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, well pumpage, or downgradient ground-water flow into other aquifers beyond the topographic boundary defining the study area. Streamflow is assumed to be sustained entirely by baseflow during extended periods of drought. Local flow systems likely are the most affected by droughts. Discharge measured in streams and rivers near the end of a drought should be relatively steady and composed largely of baseflow.

### Mean-Annual Ground-Water Discharge

Mean-annual ground-water discharge was estimated for the major tributaries to the Savannah River in the vicinity of the SRS. Streamflow data used to estimate the mean-annual ground-water discharge at continuous-record gaging stations were selected according to periods of record when flow was unregulated. At each station, three representative water years were selected that had mean streamflow that reflected low, average, and high flow conditions as compared to the mean-annual streamflow for the station's period of record (table 2).

**Table 2.** Estimated mean-annual stream discharge, annual ground-water discharge, and unit-area mean-annual ground-water discharge for selected sites in the central Savannah River basin for the period of record

[$mi^2$, square miles; $ft^3/s$, cubic feet per second; $(ft^3/s)/mi^2$, cubic feet per second per square mile]

| Station number | Station name | Drainage area ($mi^2$) | Recession index, winter/summer, (in days) | Water year | Flow condition | Mean-annual stream discharge ($ft^3/s$) | Annual ground-water discharge[1/] ($ft^3/s$) | Mean-annual ground-water discharge[2/] ($ft^3/s$) | Unit-area mean-annual ground-water discharge[3/] [$(ft^3/s)/mi^2$] |
|---|---|---|---|---|---|---|---|---|---|
| 02196820 | Butler Creek at Fort Gordon, Ga. | 7.5 | 71/35 | 1988 | Low | 5.0 | 1.8 | | |
| | | | | 1982 | Average | 7.4 | 2.4 | 2.9 | 0.39 |
| | | | | 1973 | High | 11 | 4.5 | | |
| 02197300 | Upper Three Runs near New Ellenton, S.C. | 87.0 | 155/135 | 1983 | Low | 83 | 79 | 100 | 1.15 |
| | | | | 1968 | Average | 103 | 101 | | |
| | | | | 1977 | High | 120 | 119 | | |
| 02197310 | Upper Three Runs above Road C at the Savannah River Site, S.C. | 176 | 158/137 | 1986 | Low | 169 | 160 | | |
| | | | | 1987 | Average | 210 | 192 | 194 | 1.10 |
| | | | | 1991 | High | 263 | 229 | | |
| 02197315 | Upper Three Runs at Road A at the Savannah River Site, S.C. | 203 | 115/104 | 1989 | Low | 179 | 160 | | |
| | | | | 1987 | Average | 239 | 216 | 215 | 1.06 |
| | | | | 1977 | High | 287 | 270 | | |
| 02197600 | Brushy Creek near Wrens, Ga. | 28.0 | 92/67 | 1986 | Low | 14 | 11 | | |
| | | | | 1983 | Average | 27 | 19 | 19 | .68 |
| | | | | 1965 | High | 47 | 27 | | |
| 02197830 | Brier Creek near Waynesboro, Ga. | 473 | 114/62 | 1986 | Low | 264 | 216 | | |
| | | | | 1992 | Average | 462 | 275 | 321 | .68 |
| | | | | 1973 | High | 654 | 471 | | |
| 02198000 | Brier Creek at Millhaven, Ga. | 646 | 105/64 | 1990 | Low | 403 | 266 | | |
| | | | | 1976 | Average | 627 | 377 | 447 | .69 |
| | | | | 1964 | High | 1,160 | 697 | | |

[1/]Annual ground-water discharge estimated using the automated Rorabaugh-Daniel method of hydrograph separation (Mayer and Jones, 1996).
[2/]Mean annual ground-water discharge estimated by computing the average streamflow for low, average, and high flow years for the period of unregulated record.
[3/]Unit-area discharge computed using mean-annual ground-water discharge and drainage area.

The modified hydrograph-separation method SWGW (Mayer and Jones, 1996) was applied to data from seven continuous-record stations in the Savannah River basin, three stations in South Carolina and four stations in Georgia. For each gaging station, two recession indices are listed in table 2; one was used for streamflow recession during winter, the other during summer. Some variables supplied by the user to SWGW for each hydrograph separation are not listed either in table 2 or table 3, but are listed in the Appendix. 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 ground-water discharge, in cubic feet per second, and the unit-area mean-annual ground-water discharge (the mean-annual ground-water discharge divided by the station's drainage area), in cubic feet per second per square mile, were computed for each tributary station. The computed mean-annual ground-water discharge represents an estimate of the discharge from the local and intermediate flow systems to streamflow. Unit-area mean-annual ground-water discharges estimated for three stations in South Carolina (Upper Three Runs basin) represented discharge from the Gordon aquifer; for three stations in Georgia (Brier Creek basin), the Upper Three Runs aquifer; and for one station in Georgia (Butler Creek) the Midville aquifer system (table 1; fig. 1).

The Upper Three Runs basin (Gordon aquifer) had the highest ground-water discharge from the local and intermediate flow systems when compared to the Brier Creek (Upper Three Runs aquifer) and Butler Creek (Midville aquifer system) basins. The estimated unit-area mean-annual ground-water discharge (fig. 1):

- ranged from 1.06 to 1.15 $(ft^3/s)/mi^2$ for three sites in the Upper Three Runs basin (average of 1.10 $(ft^3/s)/mi^2$ for the basin), representing discharge from the Gordon aquifer;
- was 0.39 $(ft^3/s)/mi^2$ for one site at Butler Creek, representing discharge from the Midville aquifer system; and
- ranged from 0.68 to 0.69 $(ft^3/s)/mi^2$ for three sites in the Brier Creek basin (an average of 0.68 $(ft^3/s)/mi^2$ for the basin), representing discharge from the Upper Three Runs aquifer.

Comparison of the average unit-area mean-annual ground-water discharges indicates that unit-area mean-annual ground-water discharge for the Upper Three Runs basin was 62 percent higher than the Brier Creek basin and 182 percent higher than the Butler Creek basin.

Mean-annual ground-water discharge also was estimated for each of the stations (table 3) for the period 1987-92, which was a period when conditions were considered to be at steady state. The mean-annual ground-water discharge at each station during 1987-92 was computed as the arithmetic average of annual ground-water discharges estimated by hydrograph separation.

The estimated unit-area discharge during 1987-92 ranged from 0.99 to 1.10 $(ft^3/s)/mi^2$ for the Upper Three Runs basin in South Carolina and from 0.19 to 0.49 $(ft^3/s)/mi^2$ for the stations in Georgia (fig. 1). The unit-area ground-water discharge for Butler Creek (0.19 $(ft^3/s)/mi^2$) may be lower than expected because data for the 1991-92 water years were not available. Comparisons with other basins indicate that discharge for the 1991 and 1992 water years at Butler Creek probably was higher than during the 1987-90 water years. Thus, the average discharge for 1987-92 probably would be higher than the average discharge for 1987-90.

**Table 3.** Estimated mean-annual ground-water discharge at selected gaged streams and total stream discharge in the central Savannah River basin, 1987-92

[$mi^2$, square miles; $ft^3/s$, cubic feet per second; $(ft^3/s)/mi^2$, cubic feet per second per square mile]

| Station number | Station name | Drainage area ($mi^2$) | Water year | Mean-annual streamflow ($ft^3/s$) | Annual ground-water discharge ($ft^3/s$)[1/] | Mean-annual ground-water discharge ($ft^3/s$) | Unit-area mean-annual ground-water discharge [$(ft^3/s)/mi^2$] |
|---|---|---|---|---|---|---|---|
| 02196820 | Butler Creek at Fort Gordon, Ga. | 7.5 | 1987 | 7.5 | 1.5 | | |
| | | | 1988 | 5.0 | 1.8 | 1.4 | 0.19 |
| | | | 1989 | 7.2 | 1.6 | | |
| | | | 1990 | 5.8 | .8 | | |
| 02197300 | Upper Three Runs near New Ellenton, S.C. | 87 | 1987 | 99 | 98 | | |
| | | | 1988 | 91 | 89 | | |
| | | | 1989 | 93 | 90 | | |
| | | | 1990 | 77 | 79 | 96 | 1.10 |
| | | | 1991 | 105 | 109 | | |
| | | | 1992 | 108 | 109 | | |
| 02197310 | Upper Three Runs above Road C at the Savannah River Site, S.C. | 176 | 1987 | 210 | 192 | | |
| | | | 1988 | 161 | 151 | | |
| | | | 1989 | 161 | 143 | | |
| | | | 1990 | 154 | 140 | 178 | 1.01 |
| | | | 1991 | 263 | 229 | | |
| | | | 1992 | 232 | 210 | | |
| 02197315 | Upper Three Runs at Road A at the Savannah River Site, S.C. | 203 | 1987 | 239 | 216 | | |
| | | | 1988 | 177 | 167 | | |
| | | | 1989 | 179 | 160 | | |
| | | | 1990 | 172 | 162 | 200 | .99 |
| | | | 1991 | 289 | 253 | | |
| | | | 1992 | 256 | 240 | | |
| 02197600 | Brushy Creek near Wrens, Ga. | 28 | 1987 | 25 | 17 | | |
| | | | 1988 | 12 | 9 | | |
| | | | 1989 | 15 | 10 | | |
| | | | 1990 | 15 | 11 | 14 | .50 |
| | | | 1991 | 50 | 22 | | |
| | | | 1992 | 24 | 15 | | |
| 02197830 | Brier Creek near Waynesboro, Ga. | 473 | 1987 | 461 | 217 | | |
| | | | 1988 | 236 | 160 | | |
| | | | 1989 | 307 | 197 | | |
| | | | 1990 | 331 | 192 | 234 | .49 |
| | | | 1991 | 733 | 360 | | |
| | | | 1992 | 462 | 275 | | |
| 02198000 | Brier Creek at Millhaven, Ga. | 646 | 1987 | 601 | 390 | | |
| | | | 1988 | 301 | 189 | | |
| | | | 1989 | 364 | 171 | | |
| | | | 1990 | 403 | 266 | 309 | .48 |
| | | | 1991 | 966 | 469 | | |
| | | | 1992 | 596 | 371 | | |

[1/]Annual ground-water discharge estimated using the SWGW program (Mayer and Jones, 1996).

## Comparison of Ground-Water Discharge to Streamflow Characteristics

Ground-water discharge to a stream sustains the streamflow during periods without runoff; whereby, the greater the ground-water discharge to a stream, the higher the sustained streamflow. Streamflow frequency at a station can be estimated by constructing the flow-duration curve for the stream. By definition, the flow-duration curve is a cumulative frequency curve that shows the percent of time a specific streamflow is equaled or exceeded during a given period. The shape of a flow-duration curve is a reflection of the hydrologic and geologic characteristics of the stream's drainage basin and is used, at times, to study the effects of these characteristics on the ground-water discharge to streams (Searcy, 1959). A flow-duration curve that has a steep slope is indicative of a stream having highly variable flow that largely is from direct runoff (little or no ground-water contribution); whereas, a curve that has a flat slope is indicative of a stream having equalized flow due to contributions from surface- or ground-water storage.

Many studies have compared ground-water discharge to streams with flow-duration characteristics of streamflow. Cushing and others (1973) showed that the ground-water discharge on the Delmarva Peninsula was approximately the 50-percent flow duration. Reynolds (1982) reported that ground-water discharge on Long Island, N.Y., was approximately equal to the 55-percent flow duration. Pettyjohn and Henning (1979) indicated that ground-water discharge in Ohio was between the 60- to 90-percent flow durations, depending on the hydrogeologic characteristics of the basin. Stricker (1983) demonstrated that streams in the outcrop area of the sand aquifer system of the Southeastern Coastal Plain of the United States receiving ground-water discharge greater than 10 $ft^3/s$ were related to the 60- and 65-percent flow durations.

For this investigation, the estimated mean-annual unit-area ground-water discharge for Butler Creek, Upper Three Runs, and Brier Creek basins (table 2) was compared to unit-area flow-duration streamflow of the same magnitude (table 4) to help corroborate the ground-water discharge to streams in the study area. The unit-area ground-water discharge estimated for the Upper Three Runs and Brier Creek basins ranges from 40- to 53-percent flow duration that corresponds to a mean-flow duration of 48 percent (table 4). The 50-percent flow duration rather than the 48-percent flow duration was selected for reasons of simplicity.

The 50-percent flow duration was computed for all three basins; the average unit-area 50-percent flow duration for the Upper Three Runs basin was 1.09 $(ft^3/s)/mi^2$; whereas, the average unit-area 50-percent flow duration for the Brier Creek basin was 0.67 $(ft^3/s)/mi^2$. A comparison of the average unit-area 50-percent flow duration for these two basins indicates that the average unit-area 50-percent flow duration for the Upper Three Runs basin was 63 percent higher than the average unit-area 50-percent flow duration for the Brier Creek basin; and was similar to the ratio of the average unit-area mean-annual ground-water discharge (62 percent) estimated for the two basins in the "Mean-Annual Ground-Water Discharge" section of this report.

Although the unit-area 50-percent flow duration for Butler Creek was equal to the average unit-area 50-percent flow duration for the Brier Creek basin, the unit-area mean-annual ground-water discharge for Butler Creek was equal to a flow duration of 69 percent, indicating that there is less ground-water contribution to the streamflow in the Butler Creek basin when compared to the other basins in the study area (fig. 9). The flow-duration curves in figure 9 were averaged for the gaging stations in the Upper Three Runs and Brier Creek basins to represent average flow-duration curves for the two basins. This comparison helps to corroborate that the variation of ground-water discharge to streams between the basins (as estimated by the hydrograph-separation method) generally was consistent with the variations of flow durations that are indicators of the stream-aquifer relations in the study area.

**Table 4**. Comparison of unit-area mean-annual ground-water discharge to flow durations
[(ft$^3$/s)/mi$^2$, cubic feet per second per square mile]

| Station number | Station name | Unit-area mean-annual ground-water discharge[1/] [(ft$^3$/s)/mi$^2$] | Corresponding flow-duration (percent) | Unit-area 50-percent flow-duration stream discharge [(ft$^3$/s)/mi$^2$] |
|---|---|---|---|---|
| 02196820 | Butler Creek at Fort Gordon, Ga. | 0.39 | 69 | 0.67 |
| 02197300 | Upper Three Runs near New Ellenton, S.C. | 1.15 | 50 | 1.15 |
| 02197310 | Upper Three Runs above Road C at the Savannah River Site, S.C. | 1.10 | 40 | 1.03 |
| 02197315 | Upper Three Runs at Road A at the Savannah River Site, S.C. | 1.06 | 53 | 1.09 |
| 02197600 | Brushy Creek near Wrens, Ga. | .68 | 44 | .61 |
| 02197830 | Brier Creek near Waynesboro, Ga. | .68 | 52 | .70 |
| 02198000 | Brier Creek at Millhaven, Ga. | .69 | 52 | .71 |

[1/]From table 2.

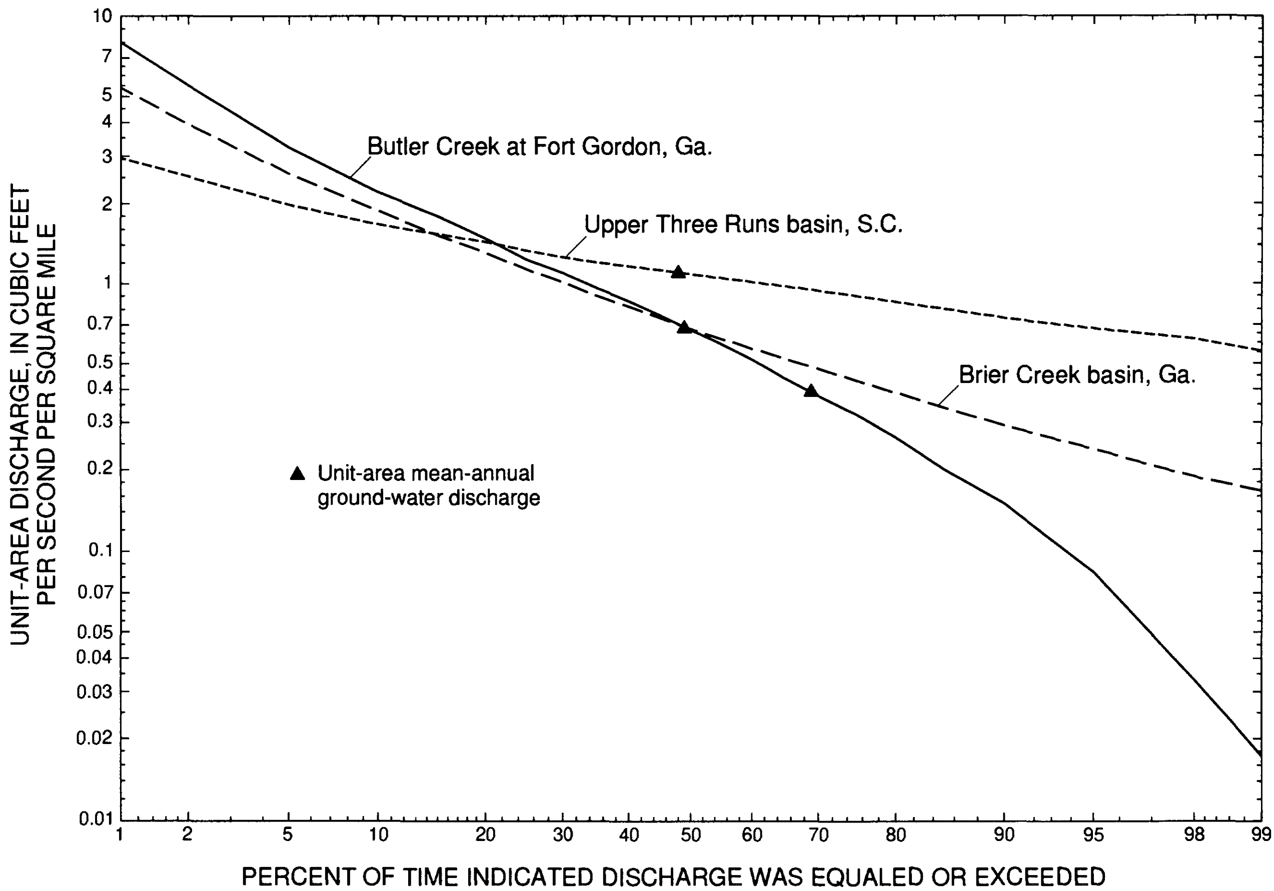



**Figure 9.** Flow-duration curves for Butler Creek at Fort Gordon, Georgia, Upper Three Runs basin, South Carolina, and Brier Creek basin, Georgia.

## Drought Streamflow for 1954 and 1986

Regional drought periods of 1950-63 and 1984-88 were marked by severe droughts in 1954 and 1986 in the study area. Near concurrent discharge measurements at partial-record stations or daily mean streamflow at continuous-record gaging stations during these "dry" periods were assumed to provide a quantitative estimate of minimum ground-water discharge throughout the study area. During drought-flow periods, the contribution of ground water from local flow systems to streamflow is negligible; thereby, streamflow during steady-state conditions and without surface runoff probably is the result of ground-water discharge from the intermediate and regional flow systems (Faye and Mayer, 1990). Because the ground-water contribution to tributary streamflow from the regional flow system is considered negligible, stream discharge during drought periods probably is from the intermediate flow system.

Measured streamflow for selected sites were compiled for the 1954 and 1986 drought-flow years (tables 5, 6) as listed in Thomson and Carter (1955), Stallings (1967), and Hale and others (1989). Because available streamflow data for 1954 are limited, 1954 drought streamflows for some sites outside the study area in the Edisto and Ogeechee River basins are listed to help "bracket" the extreme low-flow conditions in the study area (table 5). Unit-area discharge in 1954 ranged from zero to 0.68 $(ft^3/s)/mi^2$ in Georgia; whereas, unit-area discharge ranged from 0.25 to 0.40 $(ft^3/s)/mi^2$ in South Carolina (table 5; fig. 10). Unit-area discharge in 1986 ranged from zero to 0.77 $(ft^3/s)/mi^2$ in Georgia and 0.02 to 0.77 $(ft^3/s)/mi^2$ in South Carolina (table 6; fig. 11).

Unit-area discharge during the 1954 drought period ranged from 25 to 38 percent of the unit-area mean-annual ground-water discharge for the Brier Creek basin (table 2). Unit-area discharge during the 1986 drought period was 8 percent of the unit-area mean-annual ground-water discharge for Butler Creek; ranged from 16 to 23 percent of the unit-area mean-annual ground-water discharge for the Brier Creek basin; and ranged from 41 to 67 percent for the Upper Three Runs basin.

## Contributions of Local and Intermediate Flow Systems to Tributary Streamflow

The mean-annual ground-water discharge computed by the hydrograph-separation method (Mayer and Jones, 1996) represents the total ground-water contribution (combined discharge from the local and intermediate flow systems) to the tributaries (table 2). Net gain in ground-water discharge was determined for Upper Three Runs and Brier Creek (table 7). The unit-area mean-annual ground-water discharge for Brushy Creek near Wrens and Brier Creek near Waynesboro (0.68 $(ft^3/s)/mi^2$) were used to estimate the mean-annual ground-water discharge for the intermediate drainage area (about 418 $mi^2$) between the Fall Line and Brier Creek near Waynesboro

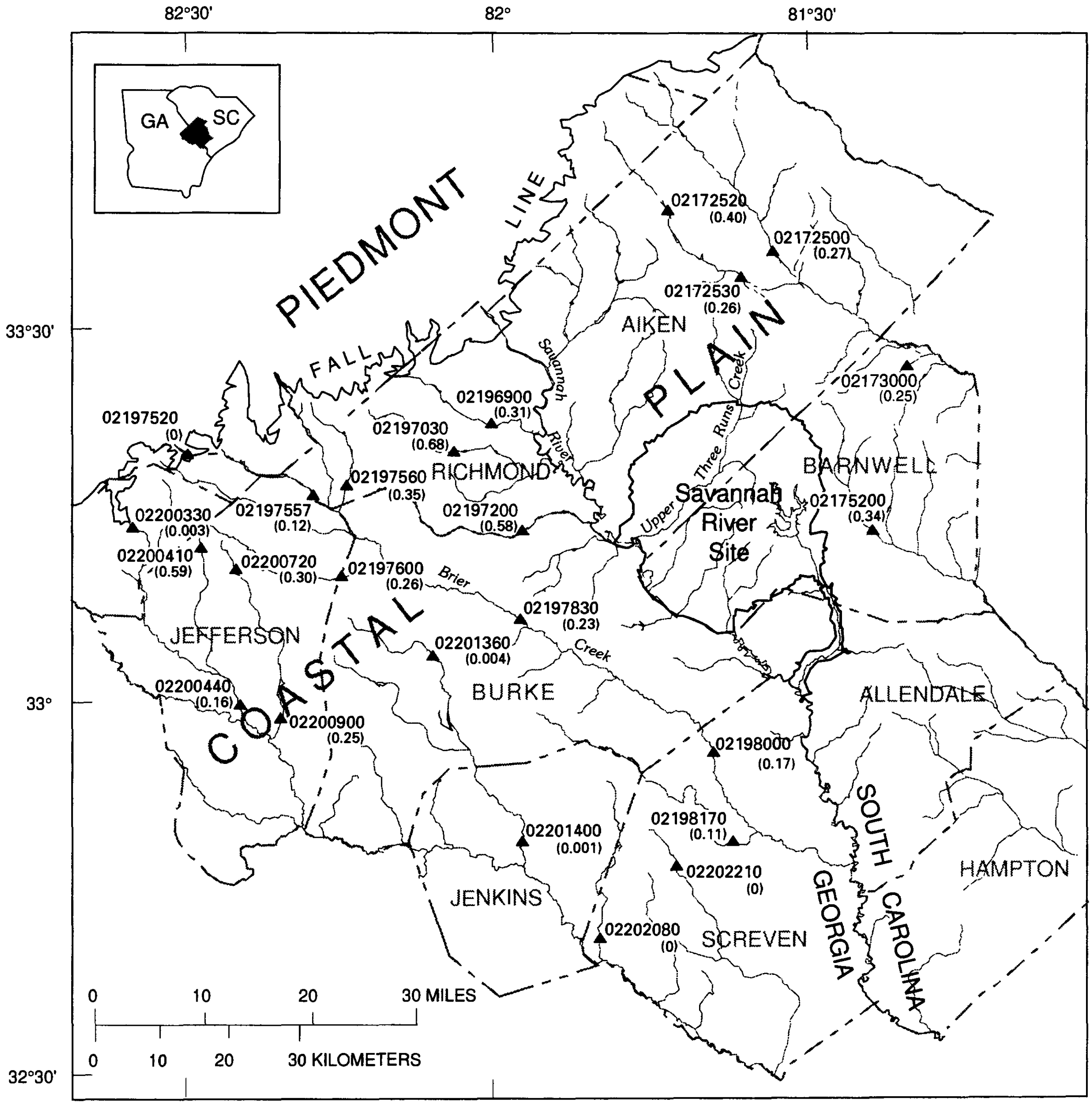
The ground-water discharge to streams during drought-flow periods is considered to be from the intermediate ground-water flow system. Net gain in streamflow during the 1954 drought period was determined for Brier Creek in the Savannah River basin and the South Fork Edisto River, which is adjacent to the Upper Three Runs basin to the northeast of the study area (table 8); and for the 1986 drought period for Butler Creek, Upper Three Runs, and Brier Creek (table 9). The 1986 drought flows generally were less than the 1954 drought flows (table 8) and can be considered indicative of the minimum ground-water discharge to streams from the intermediate ground-water flow system.

In general, the ground-water contribution to streamflow from the intermediate flow system decreased in a downstream direction in the Upper Three Runs and Brier Creek basins. During the 1954 drought period, the ground-water contribution from the intermediate system decreased from an average of 0.23 $(ft^3/s)/mi^2$ upstream from Brier Creek at Waynesboro, to zero at Brier Creek near Millhaven (table 8). For the 1986 drought, the ground-water contribution from the intermediate flow system decreased from 0.29 $(ft^3/s)/mi^2$ to zero in the Upper Three Runs basin, and from 0.16 to 0.03 $(ft^3/s)/mi^2$ in the Brier Creek basin (table 9).

**Table 5.** Measured stream discharge at selected sites during the drought of 1954
[mi$^2$, square miles; ft$^3$/s, cubic feet per second; (ft$^3$/s)/mi$^2$, cubic feet per second per square mile]

| Station number (fig. 10) | Station name | Drainage area (mi$^2$) | Date of measurement | Stream discharge (ft$^3$/s) | Unit-area discharge [(ft$^3$/s)/mi$^2$] |
|---|---|---|---|---|---|
| | **Edisto River basin** | | | | |
| 02172500 | South Fork Edisto River near Montmorenci, S.C. | 198 | 09/10/54 | [1/]53 | 0.27 |
| 02172520 | Shaw Creek near Eureka, S.C. | 50.0 | 09/10/54 | [2/]19.8 | .40 |
| 02172530 | Shaw Creek near Montmorenci, S.C. | 103 | 09/10/54 | [2/]27.2 | .26 |
| 02173000 | South Fork Edisto River near Denmark, S.C. | 720 | 09/10/54 | [1/]182 | .25 |
| 02175200 | Salkehatchie River near Barnwell, S.C. | 64.6 | 08/30/54 | [2/]22.1 | .34 |
| | **Savannah River basin** | | | | |
| 02196900 | Butler Creek near Augusta, Ga. | 29.7 | 10/06/54 | [2/]9.3 | .31 |
| 02197030 | Spirit Creek near Hephzibah, Ga. | 49.3 | 10/05/54 | [2/]33.7 | .68 |
| 02197200 | McBean Creek at McBean, Ga. | 71.4 | 10/04/54 | [2/]41.1 | .58 |
| 02197520 | Brier Creek near Thomson, Ga. | 55.0 | 10/14/54 | [2/].01 | 0 |
| 02197557 | Brier Creek at U.S. Highway 1 near Wrens, Ga. | 171 | 10/05/54 | [2/]20.8 | .12 |
| 02197560 | Sandy Run Creek near Blythe, Ga. | 31.4 | 10/06/54 | [2/]11.1 | .35 |
| 02197640 | Brushy Creek at Middle Ground Road near Keysville, Ga. | 40.7 | 10/05/54 | [2/]10.5 | .26 |
| 02197830 | Brier Creek near Waynesboro, Ga. | 473 | 10/04/54 | [2/]107 | .23 |
| 02198000 | Brier Creek near Millhaven, Ga. | 646 | 10/06/54 | [1/]107 | .17 |
| 02198170 | Beaverdam Creek near Sylvania, Ga. | 116 | 07/20/54 | [2/]13.1 | .11 |
| | **Ogeechee River basin** | | | | |
| 02200330 | Rocky Comfort Creek north of Gibson, Ga. | 94.0 | 10/13/54 | [2/].30 | .003 |
| 02200410 | Duhart Creek at Stapleton, Ga. | 3.17 | 10/06/54 | [2/]1.86 | .59 |
| 02200440 | Rocky Comfort Creek at Louisville, Ga. | 286 | 10/13/54 | [2/]46.7 | .16 |
| 02200720 | Big Creek near Wrens, Ga. | 8.1 | 10/06/54 | [2/]2.4 | .30 |
| 02200900 | Big Creek near Louisville, Ga. | 95.8 | 10/13/54 | [2]23.6 | .25 |
| 02201350 | Buckhead Creek near Waynesboro, Ga. | 63.7 | 10/05/54 | [2/]0 | 0 |
| 02201360 | Rocky Creek at Ga. Highway 24 near Waynesboro, Ga. | 31.7 | 10/05/54 | [2/].12 | .004 |
| 02201400 | Little Buckhead Creek near Millen, Ga. | 29.7 | 09/10/54 | [2/].02 | .001 |
| 02202080 | Horse Creek near Rocky Ford, Ga. | 74.8 | 09/09/54 | [2/]0 | 0 |
| 02202210 | Ogeechee Creek near Sylvania, Ga. | 14.0 | 09/09/54 | [2/]0 | 0 |

[1/]Daily mean discharge.
[2/]Discharge measurement.




Base modified from U.S. Geological Survey
State base maps

EXPLANATION

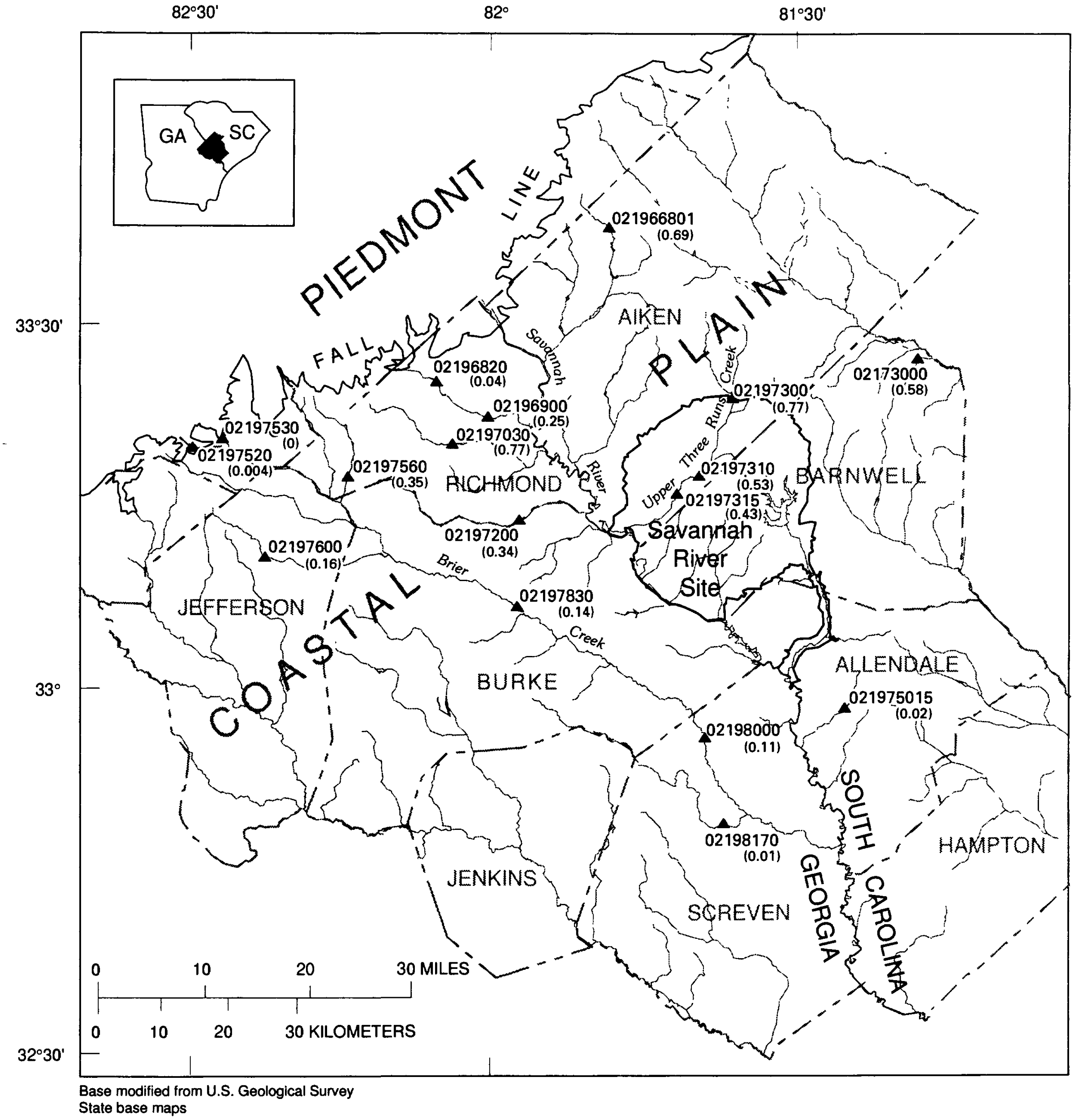
▲02202080 (0) STREAMFLOW GAGING STATION AND IDENTIFICATION NUMBER (UNIT-AREA DISCHARGE, IN CUBIC FEET PER SECOND PER SQUARE MILE—Value represents stream discharge divided by drainage-basin area)

**Figure 10.** Selected streamflow gaging stations monitored during the 1954 drought period and corresponding unit-area discharge (see table 5).

**Table 6.** Measured stream discharge at selected sites during the drought of 1986
[$mi^2$, square miles; $ft^3/s$, cubic feet per second; $(ft^3/s)/mi^2$, cubic feet per second per square mile]

| Station number (fig. 11) | Station name | Drainage area ($mi^2$) | Date of measurement | Stream discharge ($ft^3/s$) | Unit-area discharge [$(ft^3/s)/mi^2$] |
|---|---|---|---|---|---|
| | **Edisto River basin** | | | | |
| 02173000 | South Fork Edisto River near Denmark, S.C. | 720 | 07/15/86 | 1/157 | 0.22 |
| | **Savannah River basin** | | | | |
| 021966801 | Little Horse Creek near Vaucluse, S.C. | 9.8 | 07/24/86 | 2/6.8 | .69 |
| 02196820 | Butler Creek at Fort Gordon, Ga. | 7.5 | 07/24/86 | 1/.28 | .04 |
| 02196900 | Butler Creek near Augusta, Ga. | 29.7 | 07/24/86 | 2/7.3 | .25 |
| 02197030 | Spirit Creek near Hephzibah, Ga. | 49.3 | 07/23/86 | 2/38 | .77 |
| 02197200 | McBean Creek at McBean, Ga. | 71.4 | 07/24/86 | 2/24 | .34 |
| 02197300 | Upper Three Runs near New Ellenton, S.C. | 87.0 | 07/20/86 | 1/67 | .77 |
| 02197310 | Upper Three Runs above Road C at the Savannah River Site, S.C. | 176 | 07/20/86 | 1/93 | .53 |
| 02197315 | Upper Three Runs at Road A at the Savannah River Site, S.C. | 203 | 07/20/86 | 1/88 | .43 |
| 021975015 | Brier Creek near Allendale, S.C. | 15.2 | 07/22/86 | 2/.23 | .02 |
| 02197520 | Brier Creek near Thomson, Ga. | 55.0 | 07/24/86 | 1/.23 | .004 |
| 02197530 | Sweetwater Creek near Bonesville, Ga. | 7.5 | 07/23/86 | 2/0 | 0 |
| 02197560 | Sandy Run Creek near Blythe, Ga. | 31.4 | 07/23/86 | 2/11 | .35 |
| 02197600 | Brushy Creek near Wrens, Ga. | 28.0 | 07/24/86 | 1/4.6 | .16 |
| 02197830 | Brier Creek near Waynesboro, Ga. | 473 | 07/24/86 | 1/67 | .14 |
| 02198000 | Brier Creek near Millhaven, Ga. | 646 | 07/24/86 | 1/73 | .11 |
| 02198170 | Beaverdam Creek near Sylvania, Ga. | 116 | 07/24/86 | 2/.80 | .01 |

1/Daily mean discharge.
2/Discharge measurement.




EXPLANATION

▲ 02198170 (0.01) STREAMFLOW GAGING STATION AND IDENTIFICATION NUMBER (UNIT-AREA DISCHARGE, IN CUBIC FEET PER SECOND PER SQUARE MILE—Value represents stream discharge divided by drainage-basin area)

**Figure 11.** Selected streamflow gaging stations monitored during the 1986 drought period and corresponding unit-area discharge (see table 6).

**Table 7.** Mean-annual ground-water discharge based on hydrograph separation
[—, not applicable; mi², square miles; ft³/s, cubic feet per second; (ft³/s)/mi², cubic feet per second per square mile]

| Station number | Station name | Intermediate drainage area (mi²) | Mean-annual ground-water discharge[1] (ft³/s) | Mean-annual gain in ground-water discharge (ft³/s) | Mean-annual gain in unit-area discharge[2] [(ft³/s)/mi²] |
|---|---|---|---|---|---|
| | **Upper Three Runs basin** | | | | |
| 02197300 | Upper Three Runs near New Ellenton, S.C. | — | 100 | — | — |
| — | intermediate area between Upper Three Runs near New Ellenton and above Road C at the Savannah River Site, S.C. | 89 | — | 94 | 1.06 |
| 02197310 | Upper Three Runs above Road C at Savannah River Site, S.C. | — | 194 | — | — |
| — | intermediate area between Upper Three Runs above Road C and at Road A at the Savannah River Site, S.C. | 27 | — | 21 | .78 |
| 02197315 | Upper Three Runs at Road A at the Savannah River Site, S.C. | — | 215 | — | — |
| | **Brier Creek basin below the Fall Line** | | | | |
| — | intermediate area between the Fall Line and Brier Creek near Waynesboro, Ga. | 418 | — | [3]284 | [4].68 |
| 02197830 | Brier Creek near Waynesboro, Ga. | — | 321 | — | — |
| — | intermediate area between Brier Creek near Waynesboro, Ga., and near Millhaven, Ga. | 173 | — | 126 | .73 |
| 02198000 | Brier Creek near Millhaven, Ga. | — | 447 | — | — |

[1]From table 2.
[2]Unit-area discharge computed using streamflow and drainage area.
[3]Mean-annual gain computed by multiplying the intermediate drainage area times the unit-area mean-annual discharge for Brushy Creek near Wrens, Ga., and Brier Creek near Waynesboro, Ga.
[4] Unit-area mean-annual ground-water discharge for Brushy Creek near Wrens, Ga., and Brier Creek near Waynesboro, Ga.

**Table 8.** Stream discharge from intermediate flow system during the drought of 1954 in the central Savannah River basin of Georgia and South Carolina
[—, not applicable; mi², square mile; ft³/s, cubic feet per second; (ft³/s)/mi², cubic feet per second per square mile]

| Station number | Station name | Intermediate drainage area (mi²) | Date | Stream discharge[1] (ft³/s) | Net gain in stream discharge (ft³/s) | Unit-area discharge [(ft³/s)/mi²] |
|---|---|---|---|---|---|---|
| | **Edisto River basin** | | | | | |
| 02172500 | South Fork Edisto River near Montmorenci, S.C. | — | 09/10/54 | 53 | — | — |
| — | intermediate area between South Fork Edisto River near Montmorenci and Denmark, S.C. | 522 | — | — | 129 | 0.25 |
| 02173000 | South Fork Edisto River near Denmark, S.C. | — | 09/10/54 | 182 | — | — |
| | **Brier Creek basin below the Fall Line** | | | | | |
| 02197520 | Brier Creek near Thomson, Ga. | — | 10/14/54 | .01 | — | — |
| — | intermediate area between Brier Creek near Thomson and at Georgia Highway 4 near Blythe, Ga. | 116 | — | — | 20.8 | .18 |
| 02197557 | Brier Creek at Georgia Highway 4 near Blythe, Ga. | — | 10/05/54 | 20.8 | — | — |
| — | intermediate area between Brier Creek near Blythe and near Waynesboro, Ga. | 302 | — | — | 86.2 | .28 |
| 02197830 | Brier Creek near Waynesboro, Ga. | — | 10/04/54 | 107 | — | — |
| — | intermediate area between Brier Creek near Waynesboro and Brier Creek near Millhaven, Ga. | 173 | — | — | 0 | 0 |
| 02198000 | Brier Creek near Millhaven, Ga. | — | 10/06/54 | 107 | — | — |

[1]From table 5.

**Table 9.** Stream discharge from intermediate flow system during the drought of 1986 in the central Savannah River basin of Georgia and South Carolina

[$mi^2$, square miles; $ft^3/s$, cubic feet per second; $(ft^3/s)/mi^2$, cubic feet per second per square mile]

| Station number | Station name | Intermediate drainage area ($mi^2$) | Date | Stream discharge ($ft^3/s$) | Net gain in stream discharge ($ft^3/s$) | Unit-area discharge[1/] [$(ft^3/s)/mi^2$] |
|---|---|---|---|---|---|---|
| | **Butler Creek basin** | | | | | |
| 02196820 | Butler Creek at Fort Gordon, Ga. | — | 07/24/86 | [2]0.28 | — | — |
| — | intermediate area between Butler Creek at Fort Gordon and near Augusta, Ga. | 22.2 | — | — | 7.0 | 0.32 |
| 02196900 | Butler Creek near Augusta, Ga. | — | 07/24/86 | [3]7.3 | — | — |
| | **Upper Three Runs basin** | | | | | |
| 02197300 | Upper Three Runs near New Ellenton, S.C. | — | 07/20/86 | [2/]67 | — | — |
| — | intermediate area between Upper Three Runs near New Ellenton and above Road C at the Savannah River Site, S.C. | 89.0 | — | — | 26 | .29 |
| 02197310 | Upper Three Runs above Road C at the Savannah River Site, S.C. | — | 07/20/86 | [2]93 | — | — |
| — | intermediate area between Upper Three Runs above Roads C and A at the Savannah River Site, S.C. | 27 | — | — | 0 | 0 |
| 02197315 | Upper Three Runs at Road A at the Savannah River Site, S.C. | — | 07/20/86 | [2]88 | — | — |
| | **Brier Creek basin below the Fall Line** | | | | | |
| 02197520 | Brier Creek near Thomson, Ga. | — | 07/24/86 | [2].23 | — | — |
| — | intermediate area between Brier Creek near Thomson and near Waynesboro, Ga. | 418 | — | | 66.8 | .16 |
| 02197830 | Brier Creek near Waynesboro, Ga. | — | 07/24/86 | [2]67 | — | — |
| — | intermediate area between Brier Creek near Waynesboro and near Millhaven, Ga. | 173 | — | — | 6.0 | .03 |
| 02198000 | Brier Creek near Millhaven, Ga. | — | 07/24/86 | [2]73 | — | — |

[1/]Unit-area discharge computed using streamflow and drainage area.
[2/]From table 6.

Ground-water discharge from the local flow system should equal the difference between the total ground-water discharge and the ground-water discharge from the intermediate flow system. The ground-water discharge from the local system for Brier Creek and Upper Three Runs is determined by subtracting the intermediate ground-water flow system discharge (table 9) from the mean-annual ground-water discharge (table 7). The 1986 drought flows are used because they were less than 1954 drought flows. The estimates for these two basins are listed in table 10.

The ground-water contribution from the local flow system in the Upper Three Runs basin ranged from 72 percent of the total ground-water discharge in the upper two-thirds of the basin to 100 percent in the lower part of the basin. Discharge from the local flow system in the Brier Creek basin ranged from 78 percent of the total ground-water discharge in the upper part of the basin to 95 percent of the total ground-water discharge in the central part of the basin.

**Table 10.** Summary of ground-water discharge to streams from local ground-water flow system in the central Savannah River basin of Georgia and South Carolina
[$mi^2$, square miles; $ft^3/s$, cubic feet per second; $(ft^3/s)/mi^2$, cubic feet per second per square mile; —, not applicable]

| Station number | Station name | Intermediate drainage area ($mi^2$) | Total mean-annual gain in ground-water discharge[1/] ($ft^3/s$) | Estimated mean-annual discharge gain from intermediate flow system[2/] ($ft^3/s$) | Estimated mean-annual gain from local flow system[3/] ($ft^3/s$) | Unit-area mean-annual discharge from local flow system[4/] [$(ft^3/s)/mi^2$] |
|---|---|---|---|---|---|---|
| | **Upper Three Runs basin** | | | | | |
| 02197300 | Upper Three Runs near New Ellenton, S.C. | — | — | — | — | — |
| — | intermediate area between Upper Three Runs near New Ellenton and above Road C at the Savannah River Site, S.C. | 89 | 94 | 26 | 68 | 0.76 |
| 02197310 | Upper Three Runs above Road C at the Savannah River Site, S.C. | — | — | — | — | — |
| — | intermediate area between Upper Three Runs above Road C and at Road A at the Savannah River Site, S.C. | 27 | 21 | 0 | 21 | .78 |
| 02197315 | Upper Three Runs at Road A at the Savannah River Site, S.C. | — | — | — | — | — |
| | **Brier Creek basin below the Fall Line** | | | | | |
| 02197520 | Brier Creek near Thomson, Ga. | — | — | — | — | — |
| — | intermediate area between Brier Creek near Thomson and near Waynesboro, Ga. | 418 | 284 | 66.8 | 217 | .52 |
| 02197830 | Brier Creek near Waynesboro, Ga. | — | | | | |
| — | intermediate area between Brier Creek near Waynesboro and near Millhaven, Ga. | 173 | 126 | 6.0 | 120 | .69 |
| 02198000 | Brier Creek near Millhaven, Ga. | — | — | — | — | — |

[1/]From table 7.
[2/]From table 9.
[3/]Estimated mean-annual gain from local system is the difference between the total mean-annual gain (column 4) and the mean-annual gain from intermediate flow system (column 5).
[4/]Unit-area discharge computed using streamflow and drainage area.

## SUMMARY

Ground-water discharge to selected streams was estimated for the central Savannah River basin of Georgia and South Carolina. The study area consists of 4,352 square miles that cover adjacent parts of Georgia and South Carolina, including the U.S. Department of Energy, Savannah River Site, that lies in the central Savannah River basin. The Savannah River drains the northern part of the Coastal Plain Province in the study area and forms the State line between Georgia and South Carolina. The Fall Line marks the boundary between the Coastal Plain and Piedmont Provinces and forms the approximate northern limit of the study area.

Ground-water discharge to streams were estimated using two approaches: (1) an automated hydrograph-separation method and (2) a drought-streamflow analysis. The hydrograph-separation analysis provides an estimate of the mean-annual ground-water discharge to tributaries of the Savannah River in the study area. Analyses were conducted at the continuous-record stations on Brier Creek (two sites), Brushy Creek (one site), and Butler Creek (one site) in Georgia, and on Upper Three Runs (three sites) in South Carolina. The analysis of drought streamflow provides an estimate of the minimum ground-water discharge to tributary streamflow.

The Coastal Plain physiographic province in the Savannah River basin contains several complex, interbedded, mostly clastic, geologic units that form seven aquifers in the study area. Confining units between aquifers affect the degree of interaction between ground water and surface-water systems. The variation of sediment lithology within and between units is reflected in variation in the hydraulic conductivity of the aquifers. Over much of the area, the Upper Three Runs aquifer is at or near land surface and mostly is under water-table conditions. Six other aquifers are deeply buried over most of the study area and are mostly under confined conditions. Potentiometric-surface maps indicate that a large component of ground-water recharge is captured by streams that incise aquifer sediments. Butler Creek, near the Fall Line, incises and receives discharge from the Midville aquifer system. Below the Fall Line, Brier Creek and its tributary, Brushy Creek, incise and receive discharge from the Upper Three Runs aquifer. Upper Three Runs incises and receives discharge from both the Upper Three Runs aquifer and the underlying confined Gordon aquifer.

The conceptual model of ground-water flow and stream-aquifer relations divides the ground-water flow system into local (shallow), intermediate, and regional (deep) flow systems. The regional flow system approximates steady-state conditions. Ground-water discharge to tributaries mainly is from the local and intermediate flow systems. Ground water that discharges to regional drains, such as the Savannah River, mainly is from the regional flow system. Mean-annual ground-water discharge to streams (baseflow) is considered to approximate the long-term average recharge to ground water.

Contribution of ground-water discharge to tributaries by the regional flow system was considered to be negligible. During drought-flow periods, the contribution of ground water from the local flow system to streamflow is negligible because the ground-water discharge to tributaries represents the contribution by the intermediate flow system.

The Upper Three Runs basin (Gordon aquifer) has the greatest discharge contribution from the local and intermediate flow systems (an average unit-area discharge of 1.10 $(ft^3/s)/mi^2$) compared to Butler Creek (Midville aquifer and a unit-area discharge of 0.39 $(ft^3/s)/mi^2$) and the Brier Creek basin (Upper Three Runs aquifer and an average unit-area discharge of 0.68 $(ft^3/s)/mi^2$). The average estimated unit-area mean-annual ground-water discharge for the Upper Three Runs basin was 57 percent higher than for the Brier Creek basin. When compared with unit-area flow-duration curves, the average unit-area ground-water discharge estimated for the two basins is related to a 50-percent flow duration. Similarly, the average unit-area 50-percent flow duration for the Upper Three Runs basin was 64 percent greater than for the Brier Creek basin. This comparison helps to corroborate that the variation of ground-water discharge between the basins estimated by the hydrograph-separation method generally were consistent with the variations of flow duration that are indicators of the stream-aquifer relations in the study area.

Estimated and measured streamflow for selected sites in and near the study area was compiled for historic 1954 and 1986 drought years throughout the study area. Streamflow was assumed to be sustained entirely by ground-water discharge during the latter periods of these droughts. Drought streamflow had unit-area discharge in 1954 that ranged from zero to 0.68 $(ft^3/s)/mi^2$ in Georgia; whereas, unit-area discharge ranged from 0.26 to 0.40 $(ft^3/s)/mi^2$ in South Carolina. Unit-area discharge in 1986 ranged from zero to 0.77 $(ft^3/s)/mi^2$ in Georgia and 0.02 to 0.77 $(ft^3/s)/mi^2$ in South Carolina.

Unit-area discharge during the 1954 drought ranged from 25 to 38 percent of the mean-annual unit-area ground-water discharge for the Brier Creek basin. Unit-area discharge during the 1986 drought ranged from 16 to 23 percent of the mean-annual unit-area ground-water discharge for the Brier Creek basin in Georgia and 41 to 67 percent for the Upper Three Runs basin in South Carolina.

In general, the ground-water contribution to streamflow from the intermediate flow system decreased in a downstream direction in the Upper Three Runs and Brier Creek basins. During the 1954 drought, the ground-water contribution from the intermediate system decreased from an average of 0.23 $(ft^3/s)/mi^2$ upstream from Brier Creek at Waynesboro to zero at Brier Creek near Millhaven. For the 1986 drought, the ground-water contribution from the intermediate flow system decreased from 0.29 $(ft^3/s)/mi^2$ to zero in the Upper Three Runs basin and from 0.16 to 0.03 $(ft^3/s)/mi^2$ in the Brier Creek basin.

The ground-water contribution from the local flow system in the Upper Three Runs basin ranges from 72 percent of the total ground-water discharge in the upper two-thirds of the basin to 100 percent in the lower part of the basin. Discharge from the local flow system in the central part of Brier Creek basin was 95 percent of the total ground-water discharge.

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# APPENDIX

Variables used in the SWGW program for estimating the mean-annual ground-water discharge for the period of record (table 2) and for the period 1987-92 (table 3)
[—, not available]

| Station number | Station name | Recession index, in days | | Water year | [1]Flow condition | Variables used in SWGW program | |
|---|---|---|---|---|---|---|---|
| | | Winter | Summer | | | Time base, in days | Adjustment factor |
| 02196820 | Butler Creek at Fort Gordon, Ga. | 71 | 35 | 1973 | High | 4 | 0.600 |
| | | | | 1982 | Average | 4 | .500 |
| | | | | 1987 | — | 4 | .276 |
| | | | | 1988 | Low | 4 | .500 |
| | | | | 1989 | — | 4 | .300 |
| | | | | 1990 | — | 4 | .200 |
| 02197300 | Upper Three Runs near New Ellenton, S.C. | 155 | 135 | 1968 | Average | 3 | 1.000 |
| | | | | 1977 | High | 3 | 1.000 |
| | | | | 1983 | Low | 3 | 1.000 |
| | | | | 1987 | — | 3 | 1.000 |
| | | | | 1988 | — | 3 | 1.000 |
| | | | | 1989 | — | 3 | 1.000 |
| | | | | 1990 | — | 3 | 1.000 |
| | | | | 1991 | — | 3 | 1.000 |
| | | | | 1992 | — | 4 | 1.000 |
| 02197310 | Upper Three Runs above Road C at the Savannah River Site, S.C. | 158 | 137 | 1986 | Low | 3 | 1.000 |
| | | | | 1987 | Average | 3 | 1.000 |
| | | | | 1988 | — | 3 | 1.000 |
| | | | | 1989 | — | 3 | 1.000 |
| | | | | 1990 | — | 3 | 1.000 |
| | | | | 1991 | High | 3 | 1.000 |
| | | | | 1992 | — | 3 | .966 |
| 02197315 | Upper Three Runs at Road A at the Savannah River Site, S.C. | 115 | 104 | 1977 | High | 3 | 1.000 |
| | | | | 1987 | Average | 3 | 1.000 |
| | | | | 1988 | — | 3 | 1.000 |
| | | | | 1989 | Low | 3 | 1.000 |
| | | | | 1990 | — | 3 | 1.000 |
| | | | | 1991 | — | 3 | 1.000 |
| | | | | 1992 | — | 3 | 1.000 |
| 02197600 | Brushy Creek near Wrens, Ga. | 92 | 67 | 1965 | High | 5 | .798 |
| | | | | 1983 | Average | 5 | .975 |
| | | | | 1986 | Low | 5 | .960 |
| | | | | 1987 | — | 5 | .910 |
| | | | | 1988 | — | 5 | .915 |
| | | | | 1989 | — | 5 | .820 |
| | | | | 1990 | — | 5 | .853 |
| | | | | 1991 | — | 5 | .850 |
| | | | | 1992 | — | 5 | .885 |
| 02197830 | Brier Creek near Waynesboro, Ga. | 114 | 62 | 1973 | High | 5 | 0.939 |
| | | | | 1986 | Low | 5 | .936 |
| | | | | 1987 | — | 5 | .575 |
| | | | | 1988 | — | 5 | .817 |
| | | | | 1989 | — | 5 | .804 |
| | | | | 1990 | Average | 5 | .727 |
| | | | | 1991 | — | 5 | .727 |
| | | | | 1992 | — | 5 | .764 |
| 02198000 | Brier Creek near Millhaven, Ga. | 105 | 64 | 1964 | High | 5 | .773 |
| | | | | 1976 | Average | 5 | .750 |
| | | | | 1987 | — | 5 | .793 |
| | | | | 1988 | — | 5 | .813 |
| | | | | 1989 | — | 5 | .592 |
| | | | | 1990 | Low | 5 | .780 |
| | | | | 1991 | — | 5 | .707 |
| | | | | 1992 | — | 5 | .774 |

[1]Representative flow condition from table 2.



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