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REGIONAL GROUND-WATER DISCHARGE TO LARGE STREAMS IN THE UPPER COASTAL PLAIN OF SOUTH CAROLINA AND PARTS OF NORTH CAROLINA AND GEORGIA

By Walter R. Aucott, Robin S. Meadows, and Glenn G. Patterson

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Columbia, South Carolina

1987

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CONTENTS

ILLUSTRATIONS

TABLES

REGIONAL GROUND-WATER DISCHARGE TO LARGE STREAMS IN THE UPPER COASTAL PLAIN OF SOUTH CAROLINA AND PARTS OF NORTH CAROLINA AND GEORGIA

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ABSTRACT

Computations of base flow were made to estimate discharge from regional aquifers for six large streams in the upper Coastal Plain of South Carolina and parts of North Carolina and Georgia. Aquifers that sustain the base flow of both large and small streams are stratified into shallow and deep flow systems. Base-flow computations were made during dry conditions on main stems of large streams which is assumed to be the discharge from the deep ground-water flow system. Six streams were analyzed: the Savannah, South and North Fork Edisto, Lynches, Pee Dee, and the Lumber Rivers. Computations were made on stream reaches in the upper Coastal Plain because of the relatively large aquifer discharge in these areas in comparison to the lower Coastal Plain.

Estimates of discharge from the deep ground-water flow system to the six large streams averaged 1.8 cubic feet per second per mile of stream and 0.11 cubic feet per second per square mile of surface drainage area. The estimates were made by subtracting all tributary inflows from the discharge gain between two gaging stations on a large stream during an extreme low-flow period. These estimates pertain only to flow in the deep ground-water flow system. Shallow-flow system and total base flow are greater than flow in the deep system.

INTRODUCTION

The regional aspects of ground-water flow in the Coastal Plain aquifers of South Carolina have been studied only in very general terms. Stream-aquifer interactions in particular have been studied regionally from a surface-water perspective (Bloxham, 1976, 1979, and 1981). The stream-aquifer work that has been done from a ground-water perspective (Stricker, 1983) deals only with the total base flow of smaller streams.

The U.S. Geological Survey has been conducting a series of investigations of major aquifers throughout the United States as a part of the Regional Aquifer Systems Analysis (RASA) program. These studies provide a comprehensive understanding of ground-water availability throughout the Nation. The Coastal Plain aquifers in South Carolina are being studied as a part of this program. The objective of this report is to describe a method used to estimate regional ground-water discharge to major rivers in the Coastal Plain of South Carolina and to present these estimates. The scope of this report is limited to evaluating streamflow data collected from 1941 to 1983 and using standard techniques for the estimation of missing streamflow data.

The study area includes the upper Coastal Plain and part of the Piedmont of South Carolina and adjacent parts of North Carolina and Georgia (fig. 1). The Coastal Plain has been subdivided into the upper Coastal Plain and the lower Coastal Plain on the basis of ground-water flow system characteristics and aquifer discharge to streams. The study area is characterized by a humid, temperate climate with hot summers and mild spring, fall, and winter seasons. Precipitation averages 48 inches per year (Snyder and others, 1983).

Throughout much of the upper Coastal Plain, the topography consists of sand hills dissected by large and small streams. This is particularly true in the southwestern and central parts of the study area. The northeastern part of the study area is generally characterized by less topographic relief. Sediments have a higher clay and silt content and thus a lower permeability than sediments to the southwest. Land surface altitudes[1] range from less than 100 feet above NGVD of 1929 in the valleys of the larger rivers to slightly more than 500 feet above NGVD of 1929 in the sand hills of the southwestern part of the study area. The lower Coastal Plain, in contrast, is a low, broad plain ranging in altitude from 0 to 200 feet above NGVD of 1929.

The sediments that underlie the upper Coastal Plain consist of a wedge of sand and clay of late Cretaceous to Holocene. These sediments can be divided into aquifers and intervening confining beds on the basis of relative permeabilities (Aucott and others, 1986). In general, the permeability of the aquifers is relatively high in the upper Coastal Plain because coarse to medium sand is most prevalent in the sediment column. Because the aquifers thin to a featheredge at the Fall Line, transmissivity, which is a function of both the permeability and thickness of sediments, is low near the Fall Line and increases toward the coast.

The Coastal Plain aquifer system of South Carolina consists of the surficial aquifer, Floridan aquifer system, Tertiary sand aquifer, Black Creek aquifer, Middendorf aquifer, and Cape Fear aquifer. These aquifers are generally associated with a particular geologic formation or group of formations as indicated in table 1. This association is general because some geologic formations do not extend throughout the Coastal Plain and because an aquifer may contain parts of several formations. A generalized outcrop map (fig. 2) and generalized geohydrologic sections (figs. 3 and 4) are presented to aid in the understanding of the aquifer framework.

GROUND-WATER FLOW SYSTEM

The ground-water flow system of the Coastal Plain aquifers of South Carolina and adjacent states is best described with the aid of potentiometric maps of the aquifers. Figures 5 and 6 are potentiometric maps with flow lines for the combined Floridan aquifer system/Tertiary sand aquifer, and the Middendorf aquifer, respectively, for the period prior to development. Because of the similarities in the flow systems of the Black Creek and Middendorf aquifers prior to development and the greater areal extent of the Middendorf aquifer, only the potentiometric map for the latter is presented here.

[1]Altitude, as used in this report, refers to distance above or below the National Geodetic Vertical Datum of 1929 (NGVD of 1929).

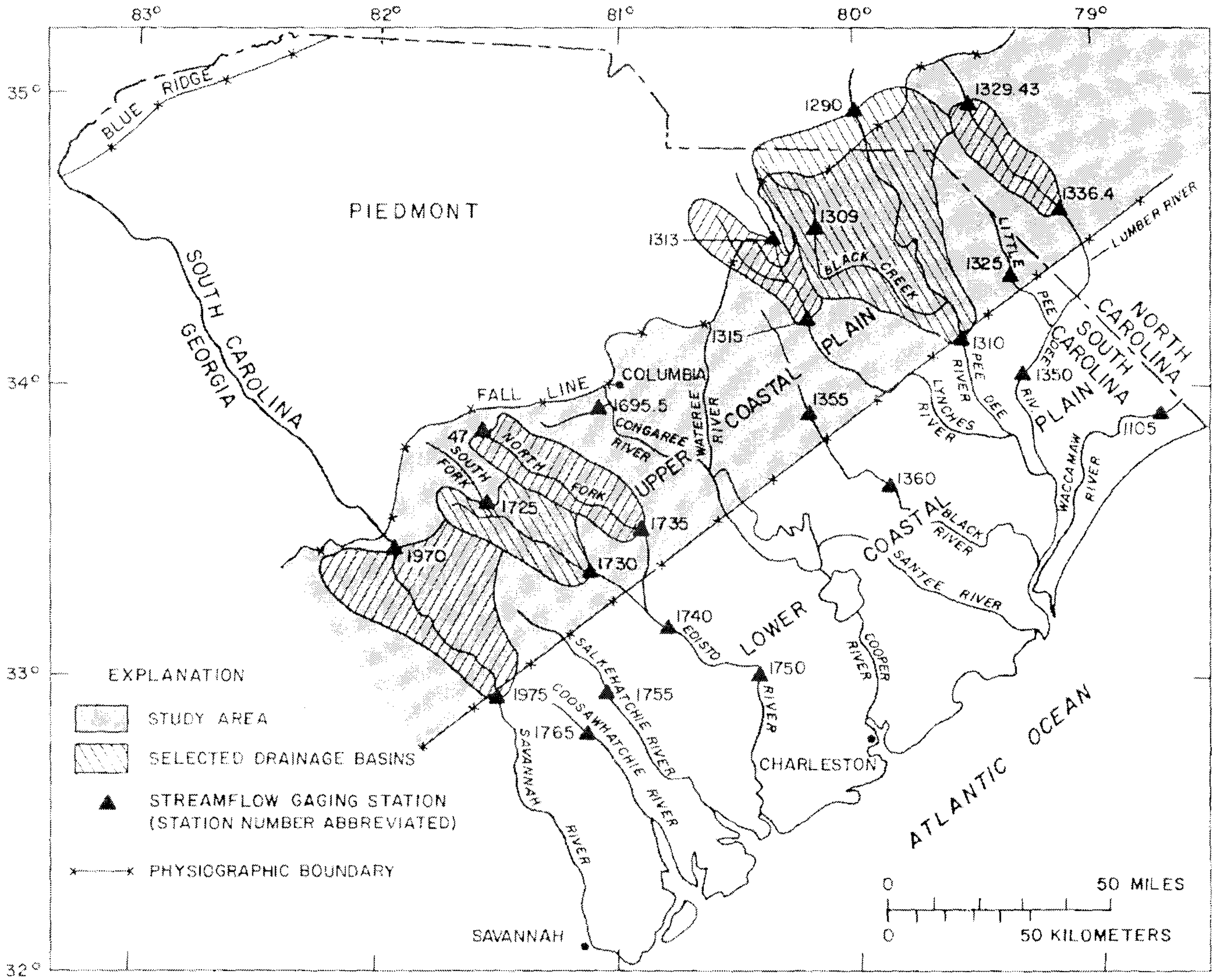

Figure 1.--Location of the study area, drainage basins of selected upper Coastal Plain rivers, and data-collection sites.

Table 1.--Generalized geohydrologic correlation chart

[Adapted from Siple, 1959]

Aquifer	System	Formation	Description
Surficial	Quaternary	Coastal terrace	Reddish brown, orange, gray and white sand deposits and clay.
Floridan aquifer system (downdip)	Tertiary	Cooper Group (lower part)	Green or brown, grayish sandy phosphatic fossiliferous limestone and marl.
		Ocala Limestone	White to cream-colored calcitized fossiliferous limestone.
		Santee Limestone	White to creamy yellow, fossiliferous, glauconitic limestone with numerous bryozoan interlayered in part with gray to yellow sandstone.
Tertiary sand (updip)	Tertiary	Barnwell Formation	Fine to coarse, red to brown massive sand.
		McBean Formation	Fine, green to yellow glauconitic sand and gray green glauconitic marl.
		Congaree Formation	Yellowish-brown to green, fine to coarse glauconitic quartz sand or sandstone interbedded with dark green to gray clays.
		Black Mingo Formation (upper part)	Gray sand shale and black sand limestone; may be carbonaceous and fossiliferous in places.
Black Creek	Cretaceous	Black Creek Formation	Gray to white, glauconitic, phosphatic, micaceous quartz calcareous sand interbedded with dark gray to black thinly laminated clay containing nodules of pyrite and marcasite and fragments of lignite.
Middendorf	Cretaceous	Middendorf Formation	Light-gray, fine to coarse micaceous, glauconitic and, in part, calcareous sand interbedded with green, purple, and maroon clay and greenish-gray micaceous silt, sandstone and grit.
Cape Fear	Cretaceous	Cape Fear Formation	Reddish brown, gray and greenish clay interbedded with yellow to white, fine to coarse quartz and feldspar sand with some mica.

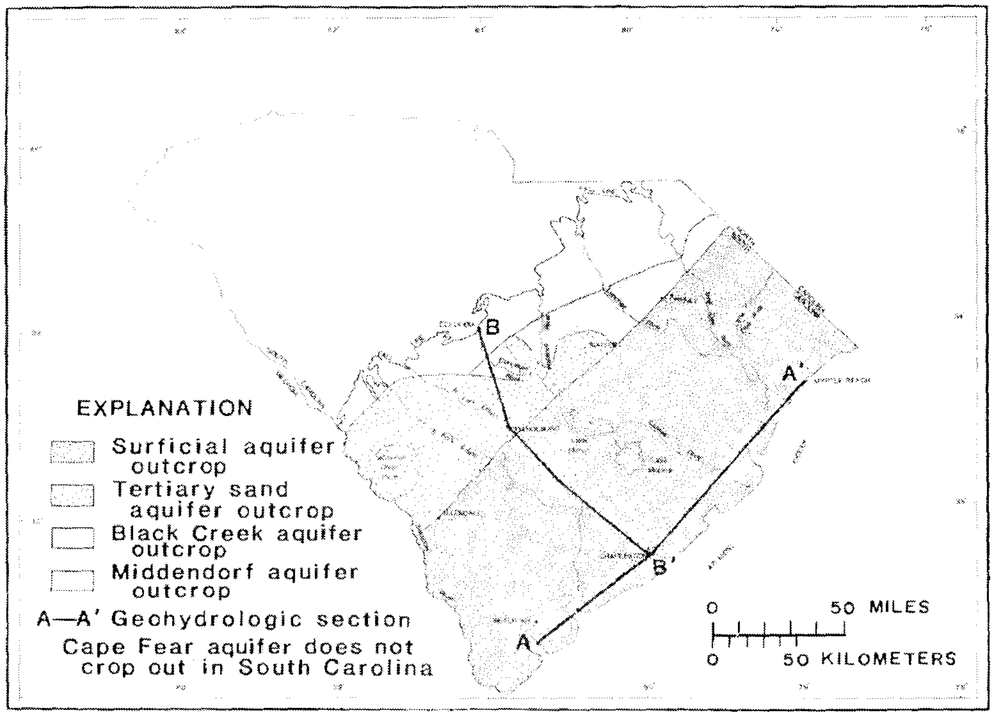

Figure 2.--Generalized Coastal Plain aquifer outcrops and locations of cross sections.

The major source of recharge to the Coastal Plain aquifers is precipitation in their outcrop areas. Recharge in the updip interstream areas results in potentiometric highs such as those in the Tertiary sand aquifer and the Middendorf aquifer near their updip limits.

Discharge from the Tertiary sand, Black Creek, and Middendorf aquifers is primarily to rivers in the vicinity of the aquifer outcrops in the upper Coastal Plain. Upstream bending of the potentiometric contours in the vicinity of the Savannah River and other major rivers (figs. 5 and 6) indicates discharge from the aquifers to the rivers. Discharge to smaller streams has a corresponding effect on the potentiometric surface in the upper Coastal Plain, but is not explicitly shown due to map scale and data density.

Leakage between aquifers through confining units is also an important mechanism for recharge and discharge in the flow system. Downward leakage in the western part of the upper Coastal Plain (for example, in some areas of the Savannah River Plant) provides an important source of recharge to the Black Creek and Middendorf aquifers. This recharge occurs because of the relatively high permeability of the confining units and a downward potentiometric gradient.

The principal discharge from the Cretaceous aquifers in the lower Coastal Plain is through diffuse upward leakage to overlying aquifers. Flow quantities from upward leakage are probably small, especially between the Black Creek aquifer and the overlying combined Floridan aquifer system/ Tertiary sand aquifer. Water discharged by upward leakage eventually discharges to the surficial aquifer or the Atlantic Ocean. If discharged to the surficial aquifer, water eventually leaves the ground-water system by evapotranspiration or discharge to surface-water bodies.

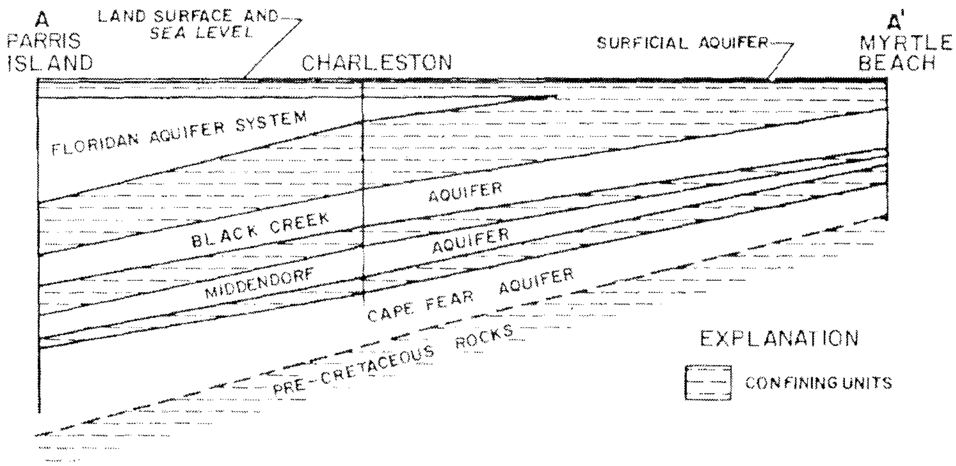

Figure 3.--Generalized geohydrologic section A-A'.

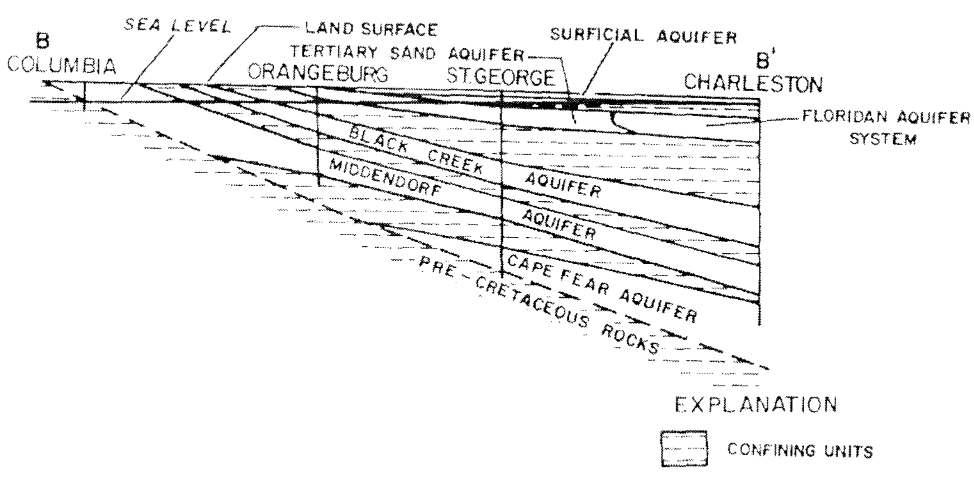

Figure 4.--Generalized geohydrologic section B-B'.

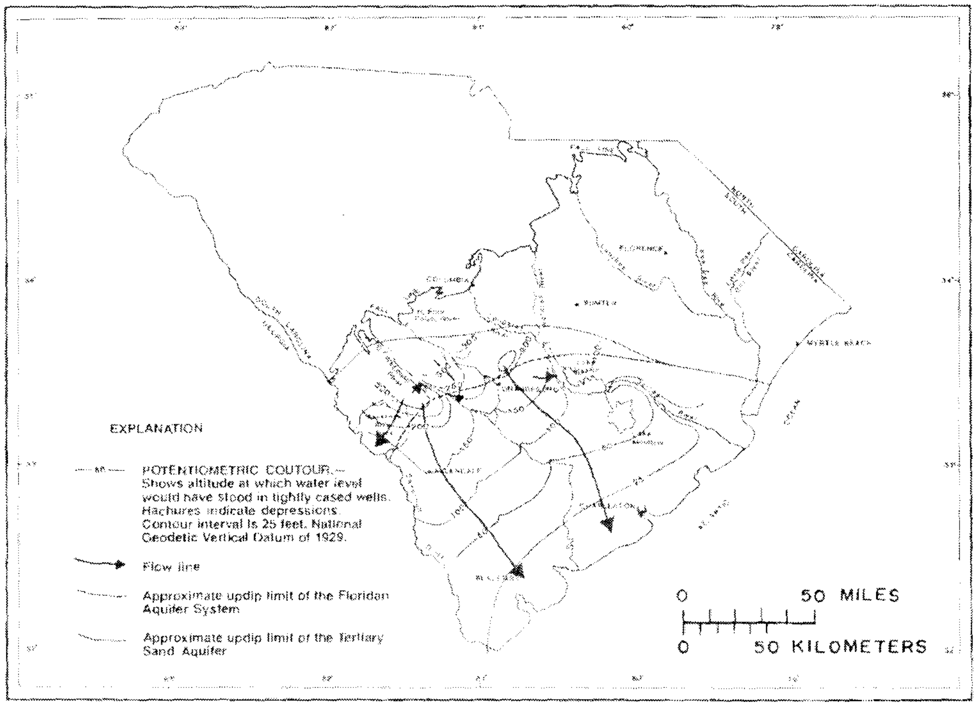

Figure 5.--The potentiometric surface of the Floridan aquifer system and the Tertiary sand aquifer prior to development (adapted from Aucott and Speiran, 1985).

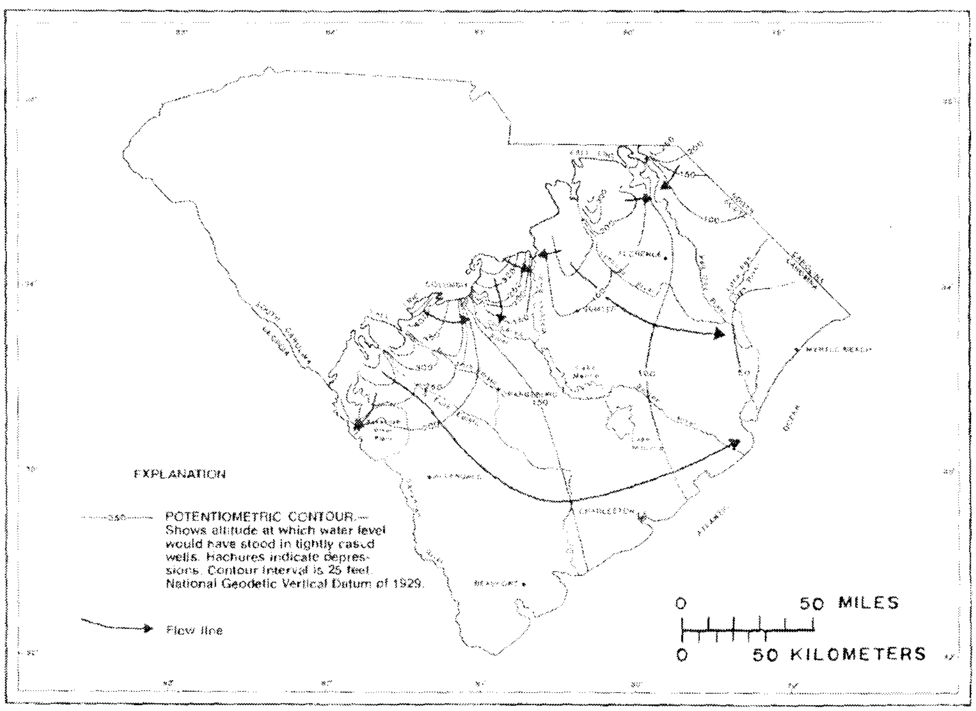

Figure 6.--The potentiometric surface of the Middendorf aquifer prior to development (adapted from Aucott and Speiran, 1985).

The general direction of ground-water flow is from recharge areas to discharge areas. In the upper Coastal Plain, most of the ground water in the Tertiary sand, Black Creek, and Middendorf aquifers flows from inter-stream recharge areas to rivers and small streams where the water is discharged. These flow paths are comparatively short. In the lower Coastal Plain, flow paths within each aquifer are much longer and the horizontal hydraulic gradients are less than those in the upper Coastal Plain. Ground water flows downgradient from the upper Coastal Plain to the lower Coastal Plain, where it is discharged by upward leakage to overlying aquifers.

REGIONAL GROUND-WATER DISCHARGE

A typical ground-water flow system in an area such as the upper Coastal Plain is shown in cross section in figure 7. In this system, water from precipitation enters the aquifer as recharge in areas of potentiometric highs between rivers and lakes, flows down the potentiometric gradient and discharges to rivers, lakes, swamps, and other surface-water features (Aucott and Speiran, 1985). Depending on a number of conditions, including aquifer thickness and transmissivity, a stratified flow system such as that depicted in figure 7 may develop. Stratified ground-water flow systems have been described by Toth (1963), Freeze and Witherspoon (1966), and Winter (1976).

In a flow system that is stratified, a shallow-flow system develops that is characterized by relatively short flow paths from local topographic highs to nearby small streams. Typically, much of the water in the ground-water system flows through the shallow-flow system at relatively high velocities. This system is near the surface and can be relatively thin. Short-term variations in recharge can cause considerable variations in the amount of water flowing through the shallow-flow system and being discharged.

The deep ground-water flow system is more typically characterized by low velocities and long flow paths that originate near regional ground-water divides and extend either to discharge areas at large rivers or downgradient to the lower Coastal Plain. Because the time of travel from areas of recharge to areas of discharge is longer for the deep system than for the shallow system, the deep system tends to be less affected by short-term environmental factors such as variations in recharge. Discharge from the deep flow system, therefore, is more consistent over time than discharge from the shallow-flow system.

Intermediate flow systems probably also occur in the upper Coastal Plain between the shallow- and deep-flow systems (fig. 7). These flow systems have characteristics intermediate between those of the shallow and deep systems, and can be considered either shallow or deep.

Many factors that affect ground-water discharge to streams also determine whether or not the ground-water flow system is stratified. These factors include aquifer transmissivity, specific yield (storage coefficient), and thickness; potentiometric gradient; the quantity and timing of recharge; and factors affecting discharge, such as stream elevation and incisement and streambed hydraulic conductivity. Both deep- and shallow-flow systems occur in the upper Coastal Plain in South Carolina.

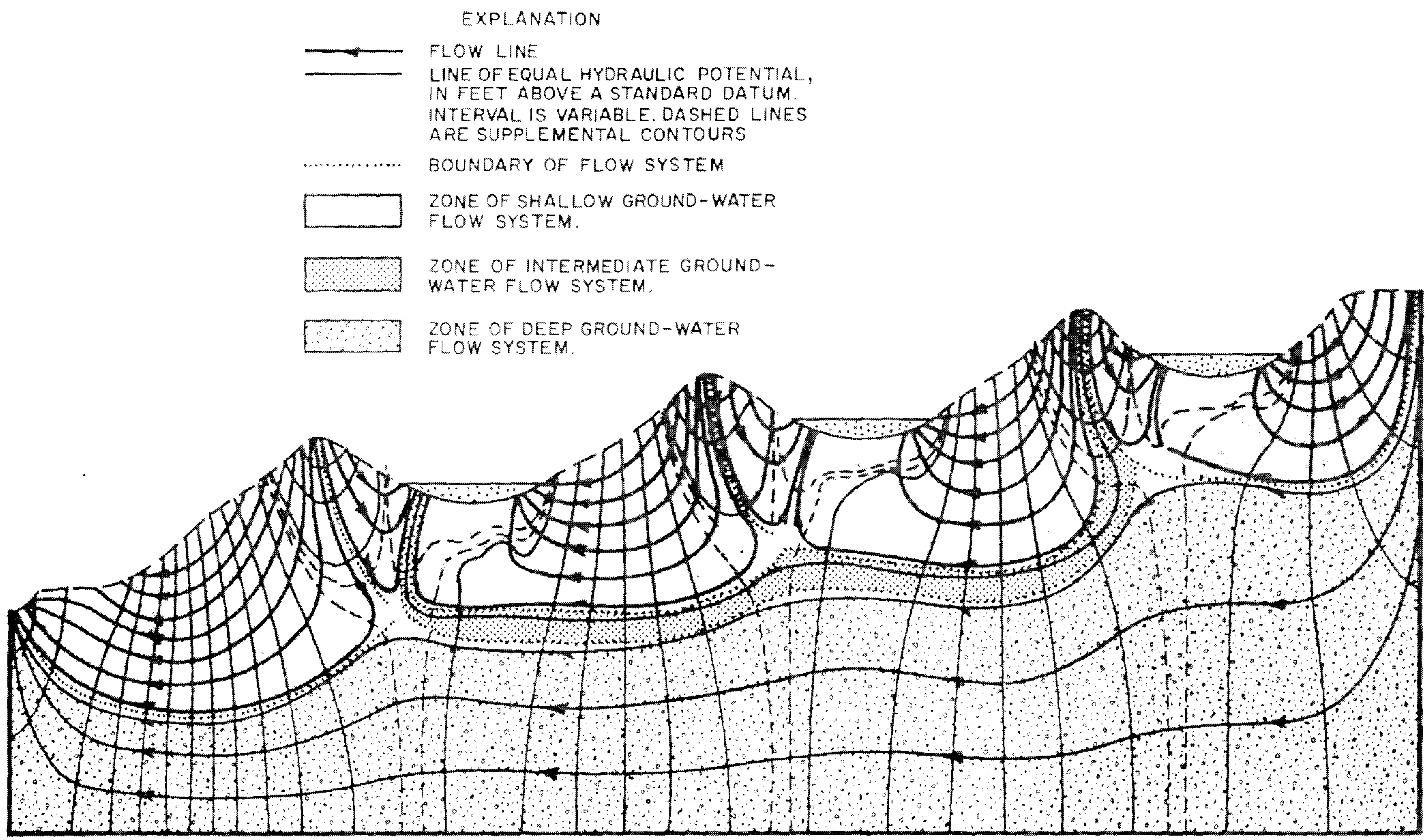

Figure 7.--Generalized depiction of shallow, intermediate, and deep ground-water flow systems (Winter, 1976).

Most traditional methods for estimating the discharge of aquifers to streams use streamflow hydrograph separation techniques to identify surface runoff (flow over the land surface during and immediately following a storm) and total base flow (discharge from the entire ground-water flow system). For example, Stricker (1983), using a hydrograph separation technique (fig. 8), determined total base flow of six small streams in the upper Coastal Plain of South Carolina averaged 12 inches per year [0.9 $(ft^3/s)/mi^2$] which represented discharge of both the shallow- and deep-flow system. This method cannot be used to estimate discharge from only the deep ground-water flow system to the large streams. Therefore, an alternative to hydrograph separation techniques had to be developed.

METHOD OF ANALYSIS

The method used to compute discharge from the deep ground-water flow system to large regional streams was modified from a method first proposed by R. E. Faye and G. C. Mayer (written commun., 1983). The first step in the modified method was to determine the streamflow gain between two stations on the main stems of each of six large streams for a series of low-flow periods. The two stations were, as nearly as possible, located at the upstream and downstream boundaries of the upper Coastal Plain, that is, at the Fall Line and the boundary with the lower Coastal Plain. Tributary inflow, which is surface inflow to the large streams, was summed and the sum subtracted from the streamflow gain between the two main-stem stations of the six large streams. The result, the net discharge, represents discharge from the ground-water flow system to the main stem during a particular low-flow event. A graph of net discharges versus streamflow at the downstream station for each large stream was then developed.

The next step was to determine the net discharge that represents only discharge from the deep flow system with no significant contribution from the shallow-flow system. The slopes of the daily flow-duration curves for the large, unregulated streams in the upper Coastal Plain of South Carolina were examined and a change in slope noted at the low-flow end of the curve (fig. 9). Because the shallow-flow system is much less resistant to drought

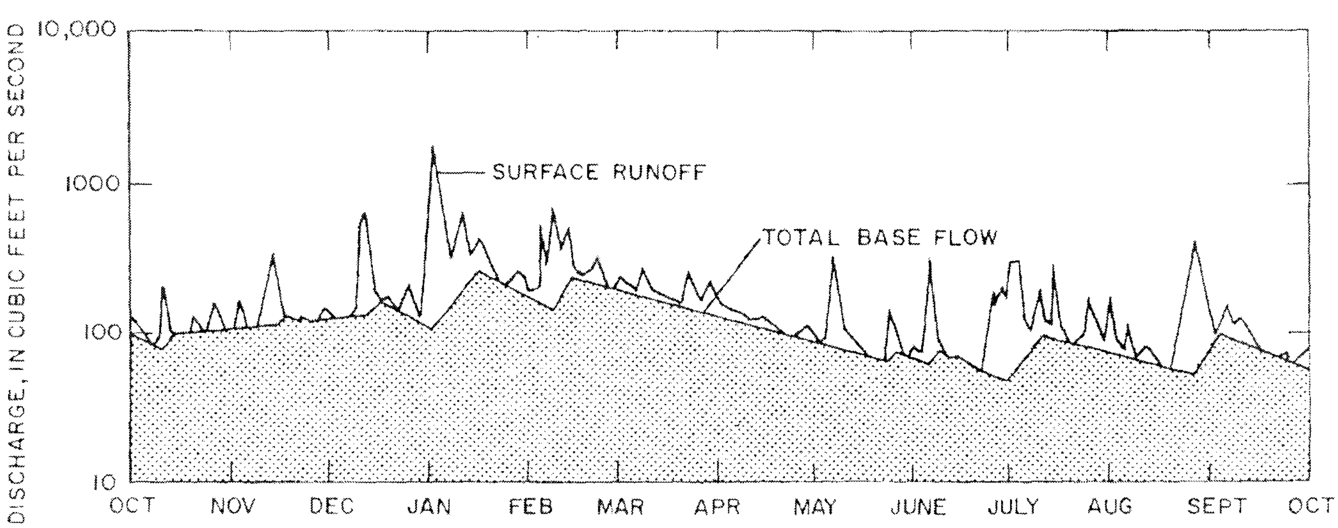

Figure 8.--Hydrograph separation for station 02350600, Kinchafonee Creek at Preston, Georgia, 1967 water year, into surface runoff and total base flow components (Stricker, 1983).

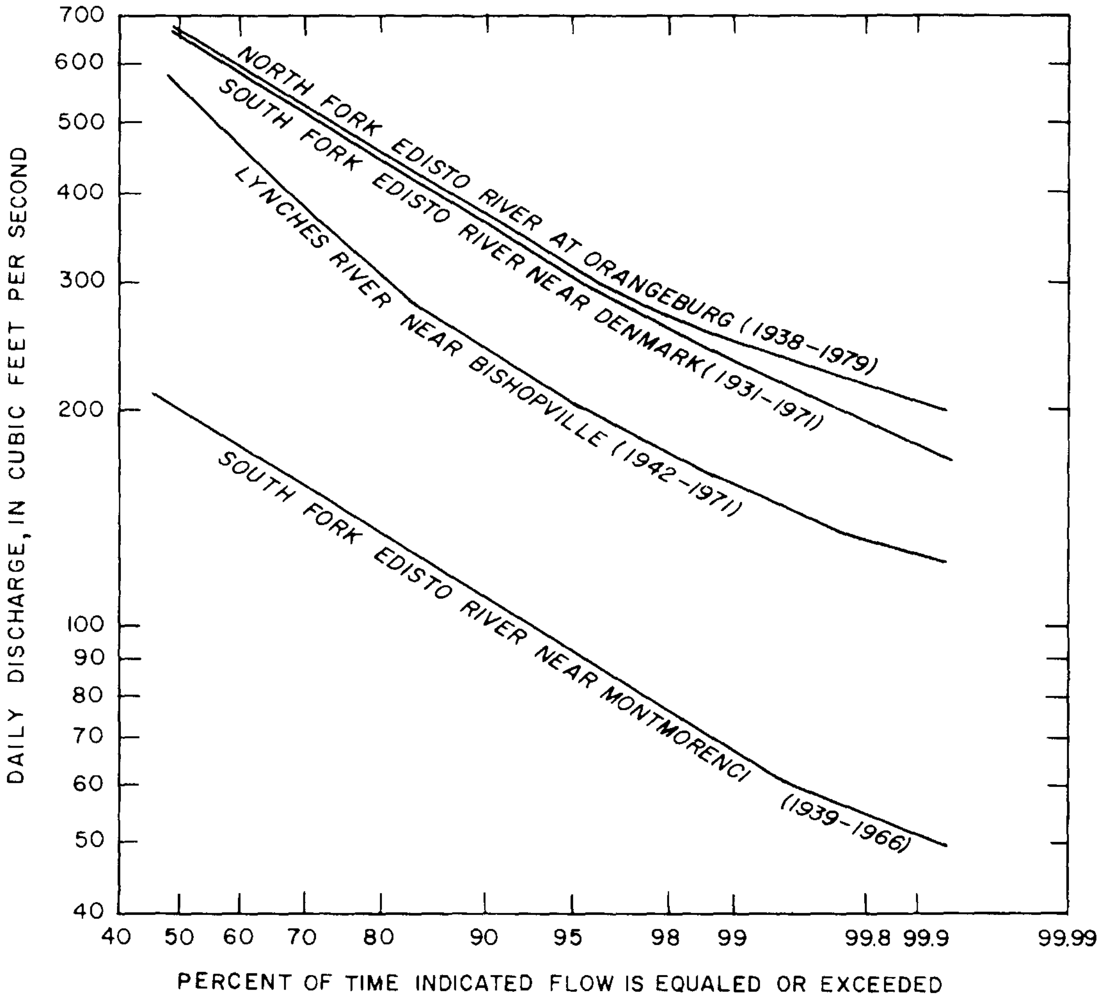

Figure 9.--Daily flow-duration curves for large, unregulated upper Coastal Plain streams (from Bloxham, 1979).

than is the deep-flow system, the part of the curve above the slope change can be assumed to represent flow in both the shallow and deep system whereas that below the slope change represents primarily flow in the deep system. This is also supported by the fact that this slope change occurs in a similar part of the flow-duration curves for a number of different streamflow sites. Flow at the change in slope of the flow-duration curve was used with the net discharge versus streamflow graph to estimate the net discharge where shallow flow becomes insignificant. The net discharge that corresponds to the streamflow at the break in slope of the flow-duration curve represented the best estimate of discharge from the deep-flow system to the large stream reach in question.

One check on the validity of this method was provided by comparing the computed net discharge with area-weighted minimum streamflows for the entire period of record for basins that lie wholly in the upper Coastal Plain. These record low flows represented basinwide discharge from the ground-water flow system to both tributaries and main stems during periods when contributions from the shallow-flow system were probably minimal. The low streamflows for five gaging stations (table 2) ranged from 0.16 to 0.28 $ft^3/s/mi^2$ which compared favorably with the range of 0.08 to 0.25 $ft^3/s/mi^2$ for the main-stem net discharges computed herein.

Table 2.--Record low flows for five upper Coastal Plain gaging stations

[Data are from Bennett and others, 1984]

Station		Period of record (years)	Drainage area (mi^2)	Minimum flow (ft^3/s)	Date	Area-weighted flow ($(ft^3/s)/mi^2$)
1309	Black Creek near McBee	25	108	17	6/29/81	0.16
1309.1	Black Creek near Hartsville	24	173	32	7/2,3/81	.18
1730	S. Fork Edisto River near Denmark	44	720	146	8/12/56	.20
1735	N. Fork Edisto River at Orangeburg	46	683	190	9/13,14/54	.28
1740	Edisto River near Branchville	39	1,720	323	8/14/56	.19

COMPUTATIONS OF NET DISCHARGE

A computation of regional ground-water discharge to the North Fork Edisto River between Steedman and Orangeburg (station 1735) for September 1968 is presented in table 3. Mean daily streamflow at Orangeburg was obtained from the 1969 annual report (U.S. Geological Survey, 1969), whereas the mean daily streamflow at Steedman was obtained from Bloxham (1976). The difference between the streamflows at these stations for September 25-26, 1968, was 314 ft^3/s which represents the gain between the stations.

The flows of the large tributaries to the North Fork Edisto River between Steedman and Orangeburg were obtained from Bloxham (1976), except the flow for Caw Caw Swamp (station 59) which was estimated. This estimation was made using the average flow of two nearby stations, Caw Caw Swamp (station 53), in the headwaters of the same basin as station 59, and Limestone Creek which is adjacent to station 59 (Bloxham, 1976). The average streamflow in cubic feet per second per square mile for the nearby basins was computed for the same time period and multiplied by the drainage area of station 59. The measurements and flow estimates for all the large tributaries were summed to obtain the total tributary inflow, which, for this period, equaled 163 ft^3/s. Tributaries smaller than Limestone Creek and Hollow Creek were not considered because their flows were insignificant. The net discharge of 151 ft^3/s, which is the difference between the main-stem streamflow gain and the total tributary inflow, represents the regional ground-water discharge for this reach of the North Fork Edisto River. The net discharge can be expressed per mile of main-stem stream or per square mile of intervening drainage area between the main-stem stations. For the 48.2-mile reach of the North Fork Edisto, these values are 3.1 $ft^3/s/mi$ and 0.25 $ft^3/s/mi^2$.

Table 3.--Stream-reach data and computations of net discharge to the North Fork Edisto River for September 25-26, 1968

Station No.	Main-stem station	Tributary to main stem	Main-stem station drainage area (mi^2)	Tributary station drainage area (mi^2)	Main-stem station streamflow (ft^3/s)	Tributary station streamflow (ft^3/s)	Date	Remarks
47[a]	North Fork Edisto River near Steedman		82.5	--	20.5	--	09/25/68	
48[a]		Black Creek	--	61.3	--	75.2	09/26/68	
49[a]		Cedar Creek	--	36.6	--	18.8	09/26/68	
50[a]		Hollow Creek	--	17.7	--	6.72	09/26/68	
51[a]		Bull Swamp Creek	--	96.4	--	37.8	09/27/68	
52[a]		Limestone Creek	--	18.9	--	4.72	09/27/68	
59[a]		Caw Caw Swamp	--	77.1	--	20.	09/26/68	Estimated[b]
1735	North Fork Edisto River near Orangeburg		683.	--	335	--	09/26/68	

Net main-stem drainage area	=	600 square miles
Tributary drainage area	=	51 percent of total
Main-stem streamflow gain	=	314 cubic feet per second
Total tributary inflow	=	163 cubic feet per second
Net discharge	=	151 cubic feet per second
Net discharge	=	0.25 cubic foot per second per square mile of drainage area

[a]From Bloxham, 1976.

[b]Estimated from average streamflow in cubic feet per second per square mile of Limestone Creek and Caw Caw Swamp (station 53[a], drainage area = 45.8 mi^2).

Similar calculations were made for five other large streams in the upper Coastal Plain for September 1968 (tables 4, 5, 6, 7, and 8). Data from September 1968 were used because it was a period of extremely low flow with a generally good set of streamflow measurements on the main stem and tributaries of the six selected streams. One stream, the Lumber River, is located entirely in North Carolina and another, the Savannah River, is partly in Georgia and partly in South Carolina.

Table 4.--Stream-reach data and computations of net discharge to the Savannah River for September 24 to October 7, 1968

Station No.	Main-stem station	Tributary to main-stem	Main-stem station drainage area (mi^2)	Tributary station drainage area (mi^2)	Main-stem station streamflow (ft^3/s)[a]	Tributary station streamflow (ft^3/s)	Date	Remarks
1970	Savannah River at Augusta, Ga.		7,508	--	6,721[a]	--	--	
1969		Butler Creek	--	29.4		14.5	08/30/68	
--		Spirit Creek	--	106		42.	08/30/68	Estimated[b]
1971		Hollow Creek	--	87		69.9	09/26/68	
1972		McBean Creek	--	70		27.	09/26/68	Estimated[c]
--		Upper Three Runs	--	203		167.	09/26/68	Estimated[d]
1973.44		Four Mile Branch	--	22.0		9.	09/25/68	Estimated[e]
1973.48		Pen Branch	--	21.2		8.	09/25/68	Estimated[e]
1973.59		Steel Creek	--	34.4		13.	09/25/68	Estimated[e]
1974		Lower Three Runs	--	59.3		23.	09/25/68	Estimated[e]
1975	Savannah River near Millhaven, Ga.		8,650		7,317[a]	--	--	

Net main-stem drainage area	=	1,142 square miles
Tributary drainage area	=	55 percent of total
Main-stem streamflow gain	=	596 cubic feet per second
Total tributary inflow	=	373 cubic feet per second
Net discharge	=	223 cubic feet per second
Net discharge	=	0.20 cubic foot per second per square mile of drainage area

[a] Main-stem streamflow computed by taking the difference of the 14-day averages for the period 09/24/68 to 10/07/68 for Savannah River at Augusta, Ga. and Savannah River near Millhaven, Ga.

[b] Estimated from average streamflow in cubic feet per second per square mile of Sandy Run Creek near Blythe and Butler Creek.

[c] Estimated from correlation with Brushy Creek near Wrens, correlation coefficient = 0.807.

[d] Estimated from average streamflow in cubic feet per second per square mile of Upper Three Runs at New Ellenton (drainage area = 87 mi^2) and Hollow Creek.

[e] Estimated from average streamflow in cubic feet per second per square mile of Turkey Creek (station 54[f]), Toby Creek (station 55[f]), and Salkehatchie River near Barnwell.

[f] From Bloxham, 1976.

Table 5.--Stream-reach data and computations of net discharge to the South Fork Edisto River for September 26, 1968

Station No.	Main-stem station	Tributary to main-stem	Main-stem station drainage area (mi^2)	Tributary station drainage area (mi^2)	Main-stem station streamflow (ft^3/s)	Tributary station streamflow (ft^3/s)	Date	Remarks
1725	South Fork Edisto River near Montmorenci		198	--	91	--	09/26/68	Estimated[a]
40[b]		Shaw Creek	--	103	--	61.9	09/27/68	
41[b]		Yarrow Branch	--	16.6	--	6.4	09/26/68	
42[b]		Spur Branch	--	18.9	--	0.65	09/26/68	
43[b]		Dean Swamp Creek	--	49.2	--	34.2	09/26/68	
44[b]		Goodland Creek	--	36.9	--	15.8	09/26/68	
45[b]		Willow Swamp	--	14.9	--	1.07	09/26/68	
1730	South Fork Edisto River near Denmark		720	--	279	--	09/26/68	

Net main-stem drainage area	=	522 square miles
Tributary drainage area	=	46 percent of total
Main-stem streamflow gain	=	188 cubic feet per second
Total tributary inflow	=	120 cubic feet per second
Net discharge	=	68 cubic feet per second
Net discharge	=	0.13 cubic foot per second per square mile of drainage area

[a]Estimated from correlation with South Fork Edisto River near Denmark, correlation coefficient = 0.961.

[b]From Bloxham, 1976.

Table 6.--Stream-reach data and computations of net discharge to the Lynches River for September 26-27, 1968

Station No.	Main-stem station	Tributary to main-stem	Main-stem station drainage area (mi^2)	Tributary station drainage area (mi^2)	Main-stem station streamflow (ft^3/s)	Tributary station streamflow (ft^3/s)	Date
1313	Lynches River at Jefferson		170	--	4.42	--	09/26/68
12[a]		Little Fork Creek	--	15.0	--	1.46	09/26/68
13[a]		Buffalo Creek	--	18.2	--	2.23	09/27/68
1314.8		Little Lynches River	--	163	--	29.3	09/27/68
1315	Lynches River at Bishopville		675	--	183	--	09/27/68

Net main-stem drainage area = 505 square miles
Tributary drainage area = 39 percent of total
Main-stem streamflow gain = 179 cubic feet per second
Total tributary inflow = 33 cubic feet per second
Net discharge = 146 cubic feet per second
Net discharge = 0.29 cubic foot per second per square mile of drainage area

[a] From Bloxham, 1976.

Table 7.--Stream-reach data and computations of net discharge to the Pee Dee River for September 23 to October 6, 1968

Station No.	Main-stem station	Tributary to main-stem	Main-stem station drainage area (mi^2)	Tributary station drainage area (mi^2)	Main-stem station streamflow (ft^3s)[a]	Tributary station streamflow (ft^3/s)	Date	Remarks
1290	Pee Dee River near Rockingham, N.C.		6,870	--	1,918[a]	--	--	
1293.31		Hitchcock Creek	--	131		14.	09/10/68	Estimated[b]
1295.28		Jones Creek	--	98		0	10/04/68	Estimated[c]
1295.38		Mill Creek	--	17		0.01	10/04/68	
1295.7		Marks Creek	--	29		5.71	10/04/68	
--		Thompson Creek	--	182		15.	09/25/68	Estimated[d]
1[e]		Big Westfield Creek	--	22.6		0	09/25/68	
2[e]		Whites Creek	--	28		2.68	09/26/68	
1305		Juniper Creek	--	64		5.62	09/25/68	
4[e]		Naked Creek	--	12		2.25	09/26/68	
5[e]		Crooked Creek	--	30		10.2	09/28/68	
1306		Cedar Creek	--	55		8.85	09/25/68	
6[e]		Three Creeks	--	76		0	08/26/68	See note[f]
9[e]		Black Creek	--	270		57.	09/26/68	Estimated[g]
1310	Pee Dee River at Peedee		8,830	--	2,186[a]	--	--	

Net main-stem drainage area = 1,960 square miles
Tributary drainage area = 52 percent of total
Main-stem streamflow gain = 268 cubic feet per second
Total tributary inflow = 121 cubic feet per second
Net discharge = 147 cubic feet per second
Net discharge = 0.08 cubic feet per second per square mile of drainage area

[a] Main-stem streamflow computed by taking the difference of the 14-day averages for the period 09/23/68 to 10/06/68 for Pee Dee River near Rockingham, N.C. and Pee Dee River at Peedee.

[b] Estimated from correlation with Drowning Creek at Hoffman, correlation coefficient = 0.987.

[c] Estimated from average streamflow in cubic feet per second per square mile of South Fork Jones Creek near Morven (drainage area = 34 mi^2), North Fork Jones Creek near Wadesboro (drainage area = 9.43 mi^2), and Mill Creek.

[d] Estimated from average streamflow in cubic feet per second per square mile of Juniper Creek, Black Creek near McBee, Big Westfield Creek, and Lynches River near Jefferson.

[e] From Bloxham, 1976.

[f] Late September 1968 data unavailable. For those stations in the area which have late August 1968 data, all have greater streamflow for late August 1968 than for late September 1968. It can be inferred that if the streamflow for this station is zero in late August 1968 that it is also zero for late Spetember 1968.

[g] Estimated from average streamflow in cubic feet per second per square mile of Black Creek near McBee (drainage area = 108 mi^2), Cedar Creek, and Lynches River at Bishopville.

Table 8.--Stream-reach data and computations of net discharge to the Lumber River for September 3-4, 1968

Station No.	Main-stem station	Tributary to main-stem	Main-stem station drainage area (mi^2)	Tributary station drainage area (mi^2)	Main-stem station streamflow (ft^3/s)	Tributary station streamflow (ft^3/s)	Date	Remarks
1329.43	Drowning Creek near Derby		81.7	--	5.42	--	09/04/68	
1329.8		Naked Creek	--	38.2	--	4.52	09/04/68	
1334.04		Horse Creek	--	41.3	--	16.0	09/04/68	
1335.9		Beaver Dam Creek	--	4.66	--	2.33	09/04/68	
1335.95		Quewhiffle Creek	--	17.8	--	7.62	09/04/68	
1336.04		Mountain Creek	--	9.97	--	1.33	09/04/68	
1336.06		Hills Creek	--	6.26	--	2.10	09/04/68	
1336.11		Buffalo Creek	--	10.5	--	1	09/04/68	Estimated[a]
1336.32		Gum Swamp	--	35	--	0	09/03/68	
1336.4	Lumber River near Pembroke		420	--	82.6	--	09/03/68	

Net main-stem drainage area	=	338.3 square miles
Tributary drainage area	=	48 percent of total
Main-stem streamflow gain	=	77 cubic feet per second
Total tributary inflow	=	35 cubic feet per second
Net discharge	=	42 cubic feet per second
Net discharge	=	0.12 cubic foot per second per square mile of drainage area

[a]Estimated from correlation with Mountain Creek, correlation coefficient = 0.857.

Other Coastal Plain streams were not analyzed because they either were too small, had inadequate flow measurements on the main stem, or the aquifer-stream discharge was small. Only the larger streams were of interest in this investigation. The Congaree and Wateree Rivers, which are large streams, do not have adequate historical flow measurements. Lower Coastal Plain streams were not analyzed because aquifer-stream discharge is relatively small in the lower Coastal Plain in comparison to discharge to upper Coastal Plain streams. Table 9, which contains data for all streamflow stations with drainage basin areas greater than 100 square miles in South Carolina (Bloxham, 1979), clearly indicates that streamflow during low-flow periods is significantly greater for upper Coastal Plain streams versus lower Coastal Plain streams. This is a direct indication that aquifer-stream discharge is relatively small in the lower Coastal Plain.

Table 9.--Low-flow characteristics of selected streams in South Carolina

[Bloxham, 1979]

Station name[1]	Station No.	Drainage area (mi^2)	Mean annual discharge [(ft^3/s)/mi^2]	70% duration discharge [(ft^3/s)/mi^2]	90% duration discharge [(ft^3/s)/mi^2]	99% duration discharge [(ft^3/s)/mi^2]
	Upper Coastal Plain					
Edisto River near Branchville	02174000	1,720	1.18	0.70	0.46	0.28
S. Fork Edisto River near Denmark	02173000	720	1.11	.71	.50	.32
N. Fork Edisto River at Orangeburg	02173500	683	1.17	.76	.53	.36
Little Pee Dee River near Dillon	02132500	524	1.10	.52	.30	.11
S. Fork Edisto River near Montmorenci	02172500	198	1.22	.76	.56	.34
Congaree Creek at Cayce	02169550	122	1.87	1.39	1.21	1.05
Black Creek near McBee	02130900	108	1.62	1.02	.52	.27
	Upper and Lower Coastal Plain					
Little Pee Dee River at Galivants Ferry	02135000	2,790	1.17	.47	.25	.10
Edisto River near Givans	02175000	2,730	.99	.44	.27	.15
Salkahatchie River near Miley	02175500	341	1.02	.50	.28	.13
	Lower Coastal Plain					
Black River near Kingstree	02136000	1,252	.75	.14	.03	.01
Waccamaw River near Longs	02110500	1,110	1.09	.23	.04	.01
Black River near Gable	02135500	401	1.00	.39	.09	0
Coosawhatchie River near Hampton	02176500	203	.94	.13	.02	0

[1]See figure 1 for location of gaging stations.

Adequate data are not available to make all of the necessary computations; therefore, some streamflow estimates had to be made. These include estimates of main-stem streamflow, particularly for regulated streams such as the Pee Dee and the Savannah Rivers, and estimates of tributary flow. Estimates of tributary flows were made using correlations of past record with similar stations or using streamflow in cubic feet per second per square mile of similar basins for which measurements during the period of interest were available.

Estimates of main-stem streamflow gain for regulated streams were made by analyzing differences of weekly, biweekly, monthly, and bimonthly averages of streamflow between the upstream and downstream stations. This method provided relatively consistent minimum main-stem streamflow gain for a number of low-flow periods for the Pee Dee and the Savannah Rivers. Figures 10 and 11 show comparisons of the Savannah River main-stem streamflow gain between Augusta (station 1970) and Millhaven (station 1975) for the low-flow periods of 1941-42 (before regulation) and 1968 (after regulation) using bimonthly and biweekly average streamflows. The bimonthly graph is needed to observe the general streamflow trend, while the biweekly graph is needed to select the actual streamflow values to be used.

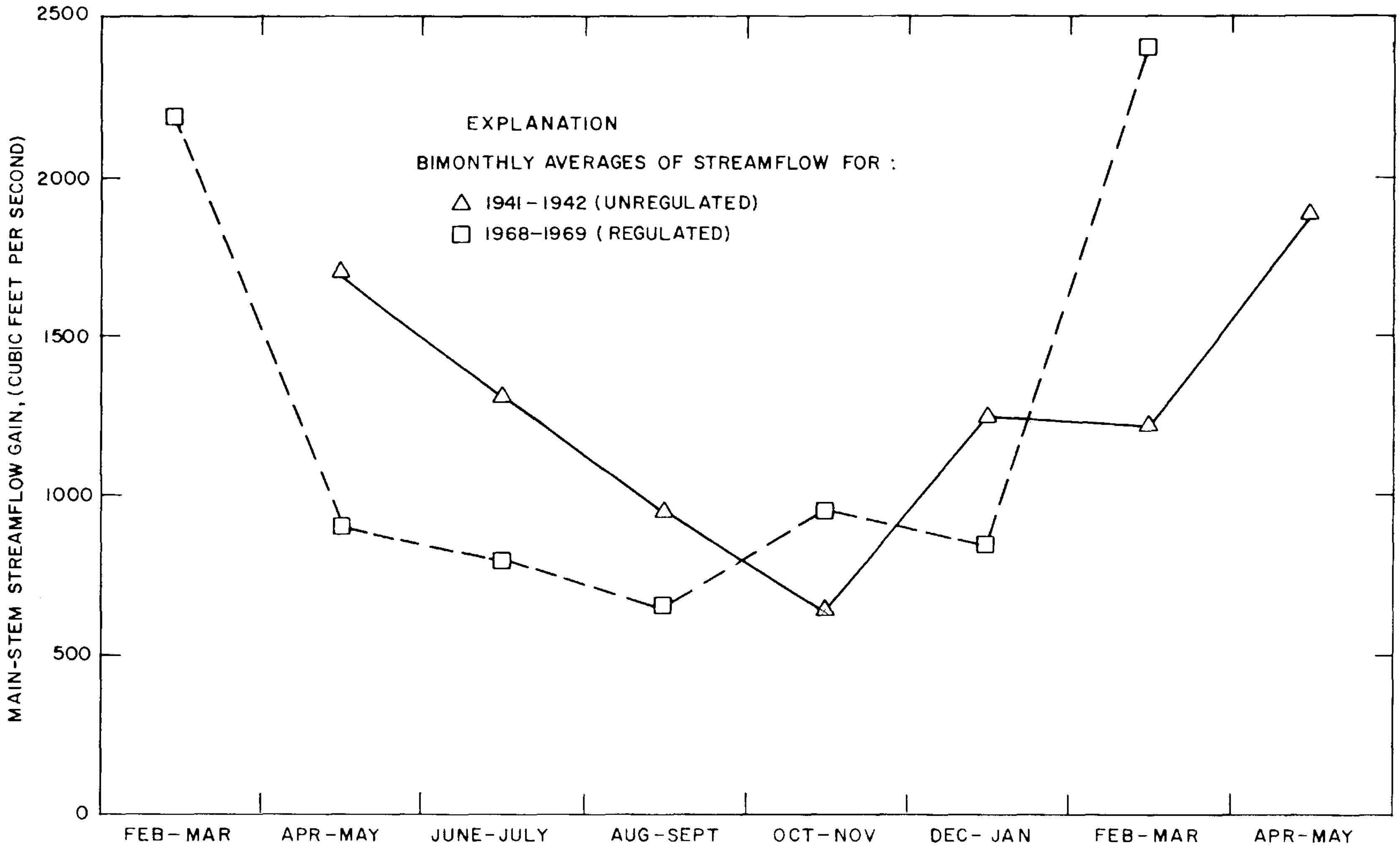

Figure 10.--Differences in mean bimonthly Savannah River streamflow between Augusta and Millhaven before and after regulation for selected low-flow periods.

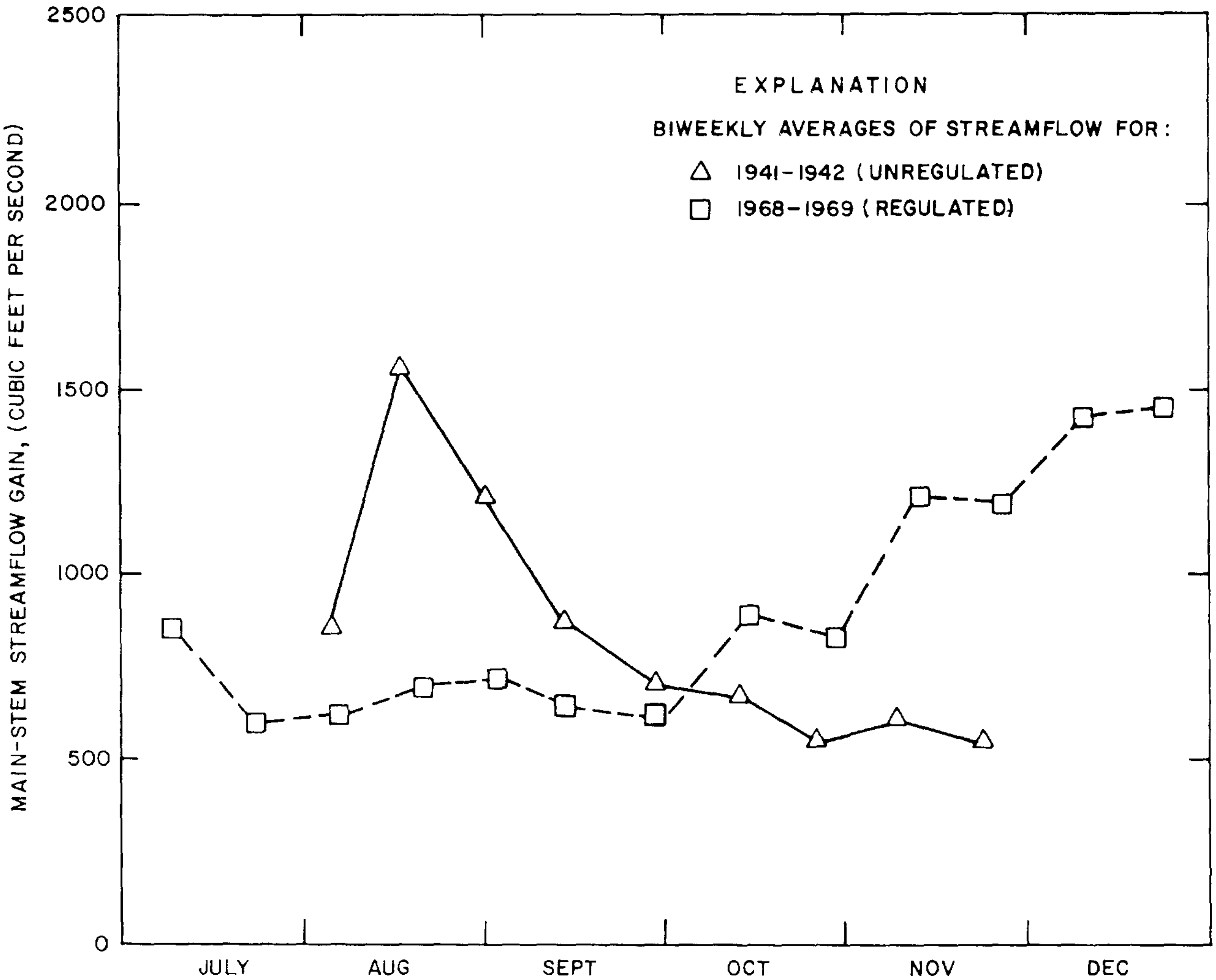

Figure 11.--Differences in mean biweekly Savannah River streamflow between Augusta and Millhaven before and after regulation for selected low-flow periods.

The effects of regulation during the low-flow periods examined on computations of main-stem streamflow gain do not appear to be severe. This is demonstrated by two factors. First, both curves in figure 10 are "U" shaped indicating decreased main-stem streamflow gains during the late summer and fall low-flow period. Second, both curves in figure 11 show similar magnitudes for the main-stem streamflow gain, about 600 ft^3/s near the end of the recession in late September. The main-stem streamflow gain is, of course, highly dependent on the drought severity of the low-flow periods analyzed. The low-flow periods analyzed were all from significant drought periods.

ANALYSIS OF BASE FLOW

As noted previously from daily flow-duration curves (fig. 9), there appears to be a certain drought severity beyond which shallow flow is either nonexistent or of much less importance with respect to discharge from the deep ground-water flow system. The changes of slope on the four flow-duration curves in figure 9 corresponding to the drought severity at which shallow flow becomes insignificant is represented by flows that are exceeded 97 to 99.5 percent of the time. The flows for these same stations during the September 1968 period analyzed are exceeded 93 to 96.5 percent of the time. Because the September 1968 main-stem flows were greater than the duration-curve changes in slope that indicate the drying up of the shallow-flow system, and because the magnitude of tributary flows was so large during September 1968, it is probable that the computations for September 1968 include some flow from the shallow-flow system. Although lower flow periods exist in South Carolina, September 1968 was the most severe drought period on record in the upper Coastal Plain region of South Carolina for which a large number of measurements were made on the tributary streams.

A number of computations, similar to those performed on the September 1968 data, were made for other periods for the three unregulated river reaches in South Carolina (North Fork Edisto, South Fork Edisto, and Lynches Rivers). The results were tabulated (table 10) and the net discharge was plotted as a function of the streamflow of the downstream station (fig. 12). If the 99-percent duration of the downstream station streamflow, being the average of the slope changes indicating the drought severity at which shallow flow becomes insignificant, is entered on figure 12 as indicated by the arrows, a corresponding net discharge can be found. The percent duration at the slope break was used because it yielded the greatest net discharge that contained no shallow flow and because flow in the deep system can be expected to be relatively constant. Table 11 indicates the net discharges that relate to the 99-percent duration of the downstream station flows and their relation to the computed values for September 1968.

Net discharges that relate to the 99-percent duration downstream station streamflow will be used to represent the discharge from the deep flow system for the three stations for which these computations could be made. Discharge from the deep-flow system for the other three stations (Savannah, Pee Dee, and Lumber Rivers) are computed using the average ratio of the 99 percent duration streamflow to the computed September 1968 net discharge for the North and South Forks Edisto River and the Lynches River (0.69) multiplied by the computed September 1968 net discharge for each station. The resultant values to be used to represent flow in the deep ground-water system are listed in table 12.

Table 10.--Summary of net discharges for upper Coastal Plain streams

River	Date	Total drainage area (mi^2)	Main-stem streamflow gain (ft^3/s)	Total tributary inflow (ft^3/s)	Tributary drainage area, % of total	Net discharge (ft^3/s)
Savannah Station 1970 to Station 1975	Sept. 1968	1,142	596	373	55	223
South Fork Edisto Station 1725 to Station 1730	June 1952	522	378	140	46	238
	July 1954	522	147	107	46	40
	Sept. 1954	522	122	77	46	45
	Sept. 1957	522	119	66	46	53
	Sept. 1968	522	188	120.0	46	68
	Oct. 1969	522	290	147	46	143
	July 1970	522	211	145	46	66
	May 1981	522	246	159	43	87
	Sept. 1981	522	227	160	43	67
	May 1982	522	245	150	43	95
	Sept. 1982	522	210	159	43	51
	Sept. 1983	522	322	199	43	123
North Fork Edisto Station 47[a] to Station 1735	Oct. 1954	600	223	118	51	105
	Sept. 1968	600	314	163	51	151
	Oct. 1969	600	362	219	51	143
	July 1970	600	330	165	51	165
	May 1981	600	368	148	53	220
	Sept. 1981	600	325	149	53	176
	May 1982	600	394	181	53	213
	May 1983	600	530	185	49	345
Lynches Station 1313 to Station 1315	Sept. 1954	505	182	11	39	171
	Nov. 1955	505	230	36	39	194
	Sept. 1957	505	122	33	39	89
	Oct. 1960	505	396	104	39	292
	Oct. 1961	505	320	68	39	252
	Apr. 1962	505	566	134	39	432
	Aug. 1963	505	156	38	39	118
	Oct. 1963	505	224	58	39	166
	Sept. 1968	505	179	33	39	146
	May 1969	505	528	134	39	394
	July 1970	505	163	31	39	132
Pee Dee Station 1290 to Station 1310	Sept. 1968	1,960	268	121	52	147
Lumber Station 1329.43 to Station 1336.4	Sept. 1968	338	77	35	48	42

[a] From Bloxham, 1976.

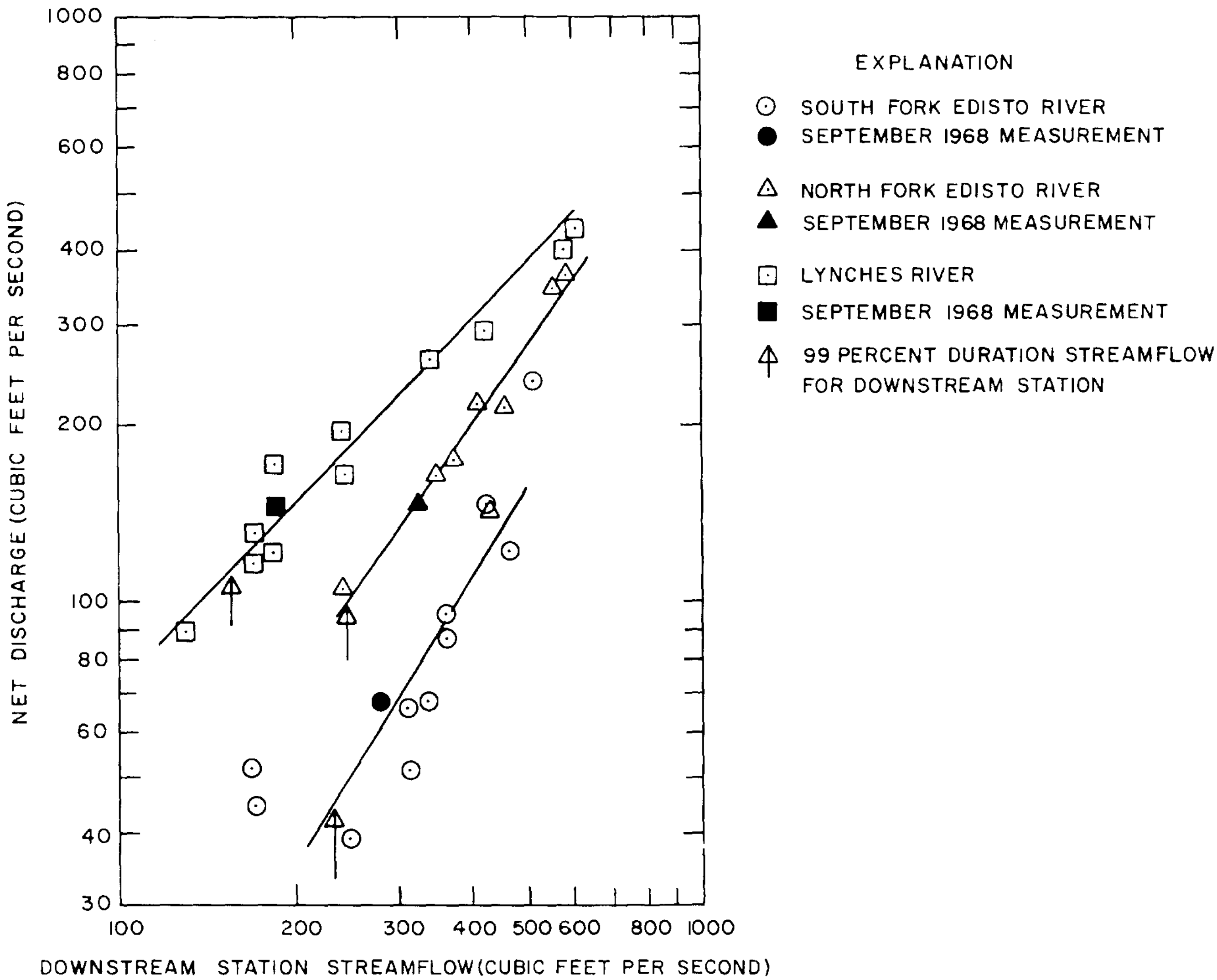

Figure 12.--Net discharge of selected rivers as a function of streamflow at the respective downstream station for selected low-flow periods.

Table 11.--Computed net discharge for September 1968 and net discharge relating to 99-percent duration downstream station streamflow

River	Computed net discharge September 1968	Net discharge relating to 99% duration streamflow of downstream station	Ratio of 99% duration to computed net discharge September 1968
North Fork Edisto	151	100	0.66
South Fork Edisto	68	45	.66
Lynches	146	110	.75
		Average	0.69

Table 12.--Discharge from the deep ground-water flow system to selected streams in the upper Coastal Plain

River Reach	River length (mi)	Drainage area (mi^2)	Discharge from the deep ground-water flow system: ft^3/sec	$(ft^3/sec)/mi$	$(ft^3/sec)/mi^2$
Savannah River Station 1970 to 1975	58.2	1,142	154	2.6	0.13
South Fork Edisto River Station 1725 to 1730	30.7	522	45	1.5	.086
North Fork Edisto River Station 47[a] to 1735	48.2	600	100	2.1	.17
Lynches River Station 1313 to 1315	36.1	505	110	3.0	.22
Pee Dee River Station 1290 to 1310	92	1,960	101	1.1	.052
Lumber River Station 1329.43 to 1336.4	55	338	29	.53	.086
			Average	1.8	0.11

[a]From Bloxham, 1976.

The values used to represent flow in the deep system are probably overestimates because the tributary flow, which was subtracted from main-stem streamflow gain to obtain net discharge, did not include flow from all the small tributaries. Although these estimates are somewhat subjective, they are still useful for estimating flow in the deep ground-water flow system.

The estimates presented here represent the base flow component from the deep ground-water flow system only. If estimates of total base flow, including contributions from both the deep- and shallow-flow system, are desired, a number of methods, including hydrograph separation techniques, are available (Rorabaugh, 1960; Stricker, 1983).

SUMMARY AND CONCLUSIONS

Estimates of base flow of large streams were made for six streams located in the Coastal Plain of South Carolina, North Carolina, and Georgia. Base flow of large streams was defined in this report to be the deep flow system component of ground-water discharge in a stratified flow system that is discharging to the large regional streams. The method used to estimate base flow of large streams requires that the streamflow gain be computed between two stations on the main stem of the large stream during an extreme low-flow period. Intervening tributary inflow was summed and that sum subtracted from the main-stem streamflow gain. The result, called the net discharge, was used as an estimate of flow in the deep ground-water system. Estimates of discharge from the deep ground-water flow system to large streams were made for the Savannah, South and North Fork Edisto, Lynches, Pee Dee, and the Lumber Rivers. Computations were made on reaches near the Fall Line because of the high base flow of streams in the area. Discharge from the deep ground-water flow system to large streams was calculated to range from 0.53 to 3.0 $ft^3/s/mi$, with an average of 1.8 $ft^3/s/mi$, and 0.05 to 0.22 $ft^3/s/mi^2$, with an average of 0.11 $ft^3/s/mi^2$. This compares with 0.9 $ft^3/s/mi^2$ computed as an average total base flow for six small streams in the upper Coastal Plain of South Carolina by Stricker (1983).

Reported values of discharge from the deep ground-water flow system probably are overestimated. Although the estimates are somewhat subjective, they are still valuable in establishing flow in the deep flow system. Estimates of total base flow, including both the deep- and shallow-flow system, could be made using a number of methods, including hydrograph separation techniques.

SELECTED REFERENCES

Aucott, W. R., Davis, M. E., and Speiran, G. K., 1986, Geohydrologic framework for the Coastal Plain aquifers of South Carolina: U.S. Geological Survey Water-Resources Investigations Report 85-4271.

Aucott, W. R., and Speiran, G. K., 1985, Ground-water flow in the Coastal Plain aquifers of South Carolina: Ground Water, v. 23, no. 6, p. 736-745.

Bennett, C. S., Hayes, R. D., Gissendanner, J. W., and Jones, K. H., 1984, Water resources data for South Carolina, water year 1984: U.S. Geological Survey Water-Data Report SC-84-1, 392 p.

Bloxham, W. M., 1976, Low-flow characteristics of streams in the Inner Coastal Plain of South Carolina: South Carolina Water Resources Commission Report No. 5, 28 p.

----- 1979, Low-flow frequency and flow duration of South Carolina streams: South Carolina Water Resources Commission Report No. 11, 90 p.

----- 1981, Low-flow characteristics of ungaged streams in the Piedmont and Lower Coastal Plain of South Carolina: South Carolina Water Resources Commission Report No. 14, 48 p.

Colquhoun, D. J., Woollen, I. D., Van Niewenhuise, D. S., Padgett, G. G., Oldham, R. W., Boylan, D. C., Bishop, J. W., and Howell, P. D., 1983, Surface and subsurface stratigraphy, structure and aquifers of the South Carolina Coastal Plain: University of South Carolina, Department of Geology, 78 p.

Cooke, C. W., 1936, Geology of the Coastal Plain of South Carolina: U.S. Geological Survey Bulletin 867, 196 p.

Freeze, R. A., 1972, Role of subsurface flow in generating surface runoff: 1. base flow contributions to channel flow: Water Resources Research, v. 8, no. 3, p. 609-623.

Freeze, R. A., and Cherry, J. A., 1979, Groundwater: Englewood Cliffs, N.J., Prentice-Hall, 604 p.

Freeze, R. A., and Witherspoon, P. A., 1966, Theoretical analysis of regional groundwater flow: 1. analytical and numerical solutions to the mathematical model: Water Resources Research, v. 2, no. 4, p. 641-656.

Rorabaugh, M. I., 1960, Use of water levels in estimating aquifer constants in a finite aquifer: International Association of Scientific Hydrology Publication 52, p. 314-323.

Siple, G. E., 1959, Guidebook for the South Carolina Coastal Plain field trip of the Carolina Geological Society, Nov. 16-17, 1957: South Carolina State Development Board, Division of Geology Bulletin No. 24, 27 p.

----- 1960, Piezometric levels in the Cretaceous sand aquifer of the Savannah River Basin: Georgia Mineral Newsletter v. XIII, no. 4, p. 163-166.

Snyder, H. S., and others, 1983, South Carolina State water assessment: South Carolina Water Resources Commission Report No. 140, 367 p.

Stallings, J. S., 1967, South Carolina streamflow characteristics, low-flow frequency, and flow duration: U.S. Geological Survey Open-File Report, 83 p.

Stricker, V. A., 1983, Base flow of streams in the outcrop area of the Southeastern Sand Aquifer: South Carolina, Georgia, Alabama, and Mississippi: U.S. Geological Survey Water-Resources Investigations Report 83-4106, 17 p.

Thomson, M. T., and Carter, R. F., 1955, Surface water resources of Georgia during the drought of 1954, Part 1--Streamflow: State of Georgia, Division of Conservation, Department of Mines, Mining and Geology, Information Circular No. 17, 79 p.

Toth, J., 1963, A theoretical analysis of groundwater flow in small drainage basins: Journal of Geophysical Research, v. 68, no. 16, p. 4795-4812.

U.S. Geological Survey, 1942-71, Water resources data for South Carolina, 1941-70 -- Part 1. Surface water records: U.S. Geological Survey Water-Data Reports (published annually).

----- 1982-83, Water resources data for South Carolina, 1981-82: U.S. Geological Survey Water-Data Reports SC-81-1 to SC-82-1 (published annually).

----- 1974, Hydrologic unit map--1974, State of South Carolina, 1 sheet.

Winter, T. C., 1976, Numerical simulation analysis of the interaction of lakes and ground water: U.S. Geological Survey Professional Paper 1001, 45 p.

Yonts, W. L., 1971, Low-flow measurements of North Carolina streams: State of North Carolina, Board of Water and Air Resources, Department of Water and Air Resources, 236 p.