HYDROLOGIC EFFECTS OF THE JUNE 1998 – AUGUST 2002 DROUGHT IN SOUTH CAROLINA

A compilation of hydrographs illustrating the effects of the drought on ground-water levels, lake levels, and streamflows in South Carolina.

STATE OF SOUTH CAROLINA
DEPARTMENT OF NATURAL
RESOURCES

LAND, WATER AND
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WATER RESOURCES
REPORT 34

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STATE OF SOUTH CAROLINA

The Honorable Mark H. Sanford, Governor

South Carolina Department of Natural Resources

Land, Water and Conservation Division

Alfred H. Vang, Deputy Director

A.W. Badr, Ph.D., Chief, Hydrology Section

HYDROLOGIC EFFECTS OF THE JUNE 1998 – AUGUST 2002 DROUGHT IN SOUTH CAROLINA

South Carolina experienced one of its most severe multiyear droughts during the period from June 1998 through August 2002. Ground-water levels, lake levels, and streamflows were at or below record lows in most areas. This report documents the hydrologic conditions of the State's aquifers, lakes, and streams during the drought. It consists of three sections:

GROUND-WATER LEVELS IN SOUTH CAROLINA
DURING THE JUNE 1998 – AUGUST 2002 DROUGHT
by Joseph A. Gellici and Shelly L. Harwell

LAKE LEVELS IN SOUTH CAROLINA
DURING THE JUNE 1998 – AUGUST 2002 DROUGHT
by Joseph A. Gellici and A. W. Badr

STREAMFLOW CONDITIONS IN SOUTH CAROLINA
DURING THE JUNE 1998 – AUGUST 2002 DROUGHT
by Masaaki Kiuchi

Each section consists of hydrographs that illustrate the effects of the drought on the water resources of South Carolina. Data for the report were provided by the U.S. Geological Survey, South Carolina Department of Natural Resources, Duke Power Company, U.S. Army Corps of Engineers, South Carolina Public Service Authority (Santee-Cooper), and the South Carolina Electric and Gas Company.

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GROUND-WATER LEVELS IN SOUTH CAROLINA DURING THE JUNE 1998 – AUGUST 2002 DROUGHT

by
Joseph A. Gellici and Shelly L. Harwell

ABSTRACT

Ground-water levels from 27 wells were compiled and plotted over a period from October 1, 1996, to September 30, 2002, to evaluate ground-water conditions during the 1998-2002 drought. On average, water levels in the 27 wells declined 7.7 ft (feet) during the drought. Coastal Plain and Piedmont wells had average water-level declines of 8.7 and 4.7 ft, respectively. Several wells showed little or no effects from the drought. A well in Beaufort County (BFT-429) had a rise in the water level of 0.4 ft, and a well in Anderson County (AND-326) had no net change in water level during the drought. Above-normal precipitation prior to the onset of the drought raised water levels as much as 13.5 ft over a 5-month period, reducing the impact of the drought on wells and demonstrating that some aquifers are capable of significant recharge over short periods of time.

INTRODUCTION

South Carolina experienced one of its most severe multiyear droughts on record from June 1998 to August 2002. Precipitation was 10-30 percent below normal, and streamflows, lake levels, and ground water levels were at or below record lows in most areas (Kiuchi, 2002). To offset ground water declines, pumps often had to be lowered or, in some cases, wells had to be deepened or replaced to reach the productive aquifer. Domestic wells completed in shallow aquifers were particularly susceptible because, for economic reasons, they were often drilled to a depth just below the water table and because the rate and magnitude of declines are generally greater in shallow aquifers. This section of the report illustrates the impact that the drought had on ground water levels in shallow and deep aquifers of the Coastal Plain and Piedmont physiographic provinces of South Carolina.

AQUIFERS OF SOUTH CAROLINA

Coastal Plain aquifers in South Carolina consist of extensive layers of sand and limestone that are as thick as 300 ft (feet) and as deep as 3,800 ft. Most of the wells studied for this report are completed in confined aquifers, which are bounded above and below by relatively impermeable layers of clay and/or rock. Water in these aquifers is under pressure and will rise above the top of the aquifer in a well. Confined aquifers are the most productive in the State, yielding up to 3,000 gpm (gallons per minute) for municipal, industrial, and agricultural supplies. They are recharged mainly by precipitation in areas where the aquifer is at or near the surface and no confining unit is present. Recharge from adjacent aquifers also takes place where there is hydraulic connection and where the adjacent aquifers have greater pressure.

Several of the Coastal Plain wells used in the study are completed in water-table aquifers, which are open to the atmosphere and contain water under normal atmospheric pressure. Water-table aquifers are critical for sustaining streamflows and wetlands during droughts. They generally do not produce as much water as the thicker and more laterally extensive confined aquifers, but they usually can produce enough water to supply domestic wells. Water-table aquifers are recharged directly by precipitation that seeps into the ground, and they generally recharge at faster rates than confined aquifers.

The Piedmont consists of dense metamorphic and igneous rock overlain by a layer of poorly consolidated sandy clay called saprolite. Wells are drilled through the saprolite and constructed as open holes in the rock. Water is produced where wells intersect fractures; if no significant fractures are encountered the well will produce little water, sometimes less than 1 gpm. There is no known pattern to the occurrence of fractures, and their continuity is of limited areal extent.

Bedrock aquifers are recharged by precipitation that seeps into the saprolite and is transmitted downward wherever the hard rock is fractured. The thickness and permeability of the saprolite affect the rate of decline and recovery of water levels in bedrock wells. Recharge to bedrock aquifers generally takes longer in areas where the saprolite layer is thick or relatively impermeable than it does in areas where the saprolite is thin or is of a higher permeability.

METHODOLOGY

Daily ground water levels for 27 wells (Figure 1 and Table 1) were compiled and plotted over a period from October 1, 1996, to September 30, 2002 (Figures 2-28). The resulting hydrographs depict depth to water level relative to land surface. Twenty of the wells are located in the Coastal Plain province and seven in the Piedmont province. Eight of the Coastal Plain wells are located at one site, C-10, which is near the town of Appleton in Allendale County. Monthly precipitation in Allendale County for the period 1996-2002 is provided in Figure 29, and a composite plot of all eight wells is provided in Figure 30.

Each of the major aquifers is represented by at least two hydrographs. The aquifer nomenclature of Aucott and others (1987) and Aadland and others (1995) are used to identify the aquifer being monitored (Table 1). Well construction for each well is provided in Table 1.

For the purposes of this report, the drought began in June 1998 and ended in August 2002. The first 20 months of each hydrograph represent water levels recorded before the onset of the drought, illustrating how above-normal precipitation affected ground water levels.

Seasonal fluctuations of ground water levels normally occur during the year. Levels are lowest in the fall due to the combined effects of pumping and high rates of evapotranspiration that occur in the summer. Levels are generally highest in the spring due to decreased pumping and reduced rates of evapotranspiration that occur in the winter. Assessing ground water conditions during the length of the drought must take into account these seasonal changes. The period of record for most of the wells was not long enough to establish baseline curves that represent average ground water levels throughout the year. Therefore, in calculating declines that took place during the drought, water levels from the same month and day were compared. Water

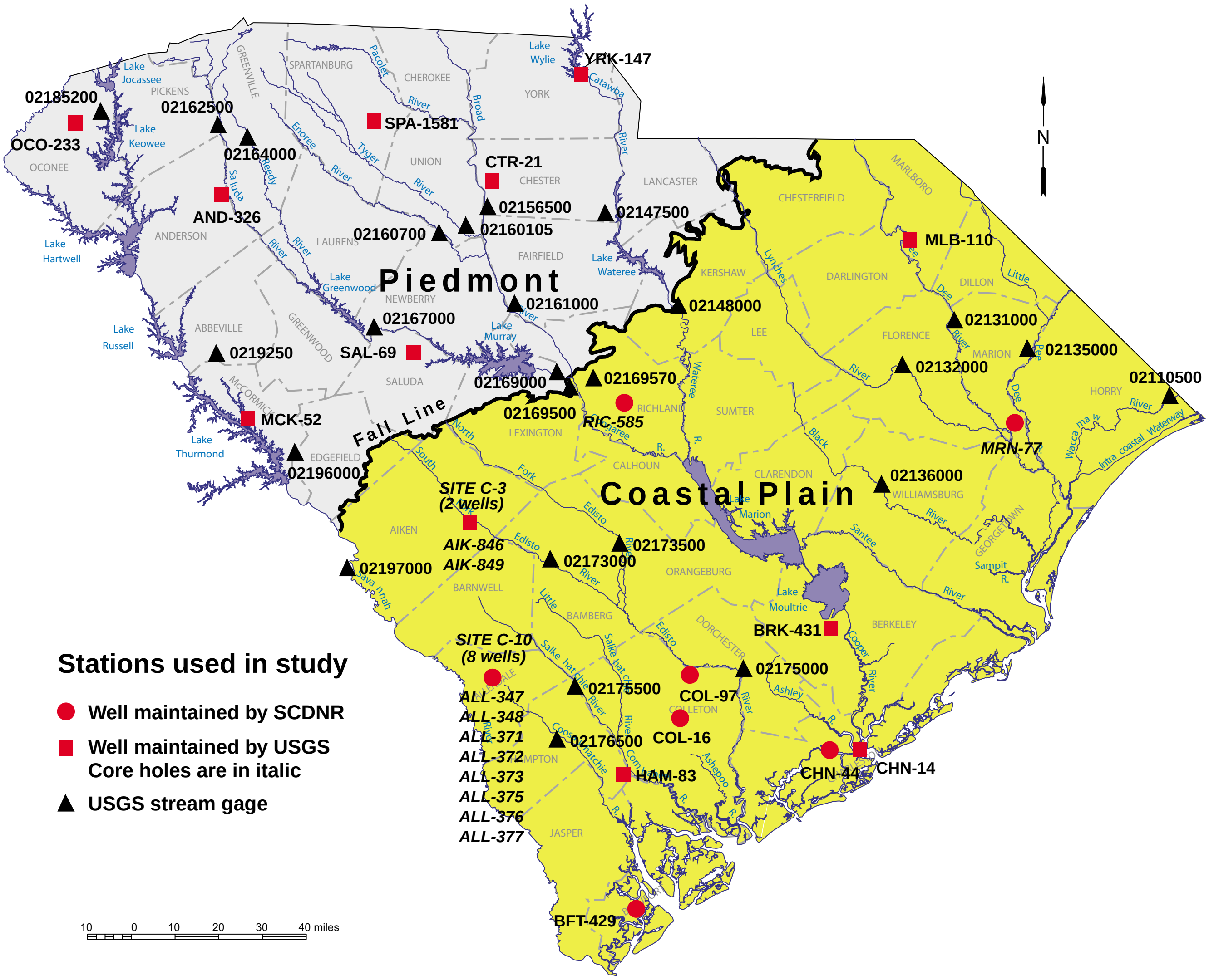


Figure 1. Location of monitor wells and stream gages used in drought study.

Table 1. Well construction data and ground-water declines during the drought

	Well	Latitude Longitude	Well elevation (feet)	Well depth (feet)	Top screen (feet)	Bottom screen (feet)	Decline during drought (feet)	Rate of decline per year (feet)	Unit (from Aadland and others, 1995)	Unit (from Aucott and others, 1987)
Coastal Plain wells	AIK-846[a]	33 32 32.6 81 29 08.2	297.8	255	240	250	4.7	0.9	Crouch Branch	Black Creek
	AIK-849[a]	33 32 32.6 81 29 07.4	301.6	97	82	92	2.4	0.5	Steed Pond	Surficial
	ALL-347	33 01 29.1 81 23 03.1	281.6	1,423	1,408	1,418	7.5	1.5	McQueen Branch	Middendorf
	ALL-348	33 01 29.9 81 23 05.2	280.5	1,605	1,575	1,600	1.4	0.3	Appleton confining unit	Cape Fear
	ALL-371	33 01 29.3 81 23 04.9	282.2	217	192	212	6.9	1.4	Upper Three Runs	Tertiary sand
	ALL-372	33 01 29.2 81 23 04.3	282.0	155	140	150	5.5	1.1	Upper Three Runs	Tertiary sand
	ALL-373[b]	33 01 29.5 81 23 03.2	279.7	372	327	367	6.5	1.3	Middle Floridan	Floridan
	ALL-375	33 01 29.5 81 23 05.7	282.9	583	453	578	9.3	1.9	Gordon	Tertiary sand
	ALL-376	33 01 29.5 81 23 05.3	282.2	994	784	989	13.4	2.7	Crouch Branch	Black Creek
	ALL-377	33 01 29.1 81 23 03.8	281.5	1,199	1,174	1,194	6.8	1.4	McQueen Branch	Middendorf
	BFT-429[b]	32 15 51 80 49 10	22	300	100	300	n/a	n/a	Upper Floridan	Floridan
	BRK-431[a]	33 10 22 80 02 18	67	1,704	1,602	1,607	20.3	4.1	McQueen Branch	Middendorf
	CHN-14[a]	32 47 29 79 55 43	7.5	2,007	1,887	2,007	44.5	8.9	McQueen Branch	Middendorf
	CHN-44[b]	32 47 41 80 04 14	9.4	434	180	425	6.8	1.4	Middle Floridan / Gordon	Floridan
	COL-16[b]	32 53 54 80 39 57	70	528	68	528	7.7	1.5	Middle Floridan / Gordon	Floridan
	COL-97[b]	33 02 51 80 35 52	84	342	134	342	9.0	1.8	Middle Floridan	Floridan
	HAM-83[a,b]	32 41 52 80 51 04	45	113	86	113	6.4	1.3	Upper Floridan	Floridan
	MLB-110[a]	34 29 35 79 43 10	95	115	75	115	5.5	1.1	McQueen Branch	Middendorf
	MRN-77	33 51 43 79 19 50	30	356	325	355	6.2	1.2	McQueen Branch	Middendorf
	RIC-585	33 56 56 80 50 27	320	469	363	393	3.7	0.7	McQueen Branch	Middendorf
Piedmont wells	AND-326[a,b]	34 37 14 82 28 56	785	398	75	398	0.0	0.0	Bedrock	Bedrock
	CTR-21[a,b]	34 40 27 81 24 55	665	98	72	98	7.0	1.4	Bedrock	Bedrock
	MCK-52[a,b]	33 53 36 82 21 46	400	202	54	202	7.6	1.5	Bedrock	Bedrock
	OCO-233[a,b]	34 50 51 83 04 18	1,080	443	24	443	2.2	0.4	Bedrock	Bedrock
	SAL-69[a,b]	34 05 17 81 40 13	445	480	92	480	2.8	0.6	Bedrock	Bedrock
	SPA-1581[a,b]	34 51 45 81 50 29	605	255	54	225	9.4	1.9	Bedrock	Bedrock
	YRK-147[a,b]	35 01 37 81 01 59	600	700	50	700	3.7	0.7	Bedrock	Bedrock

[a] ,Well maintained by the USGS; [b] ,Well constructed as an open hole; n/a, BFT-429 had a net rise in water level.

levels that occurred before the onset of the drought, on September 30, 1997, were compared with those that occurred near the end of the drought, on September 30, 2002. In some cases, data were missing on this day and a slightly different day had to be used.

Each well in the study is fitted with an automated water-level data recorder (ADR), which consists of a casing-mounted, data logger connected to a downhole pressure transducer. Loggers are programmed to record water levels every hour on the hour and are maintained by either the South Carolina Department of Natural Resources or the U.S. Geological Survey (USGS) (Table 1).

DISCUSSION AND HYDROGRPAPHS

During the drought, water levels declined in 26 of the 27 wells analyzed in the study. Declines ranged from 0 to 44.5 ft, averaged 7.7 ft, and had a median value of 6.5 ft during the period from September 30, 1997, to September 30, 2002 (Table 1). Well CHN-14 had the greatest decline, 44.5 ft (Figure 14). This well, however, is almost certainly influenced by ground water pumping at Mount Pleasant and/or Kiawah Island, which has caused water levels to drop several hundred feet from predevelopment levels (see Hockensmith, 2003).

Twenty of the monitor wells are in the Coastal Plain. From September 30, 1997, to September 30, 2002, net water-level declines in these wells ranged from 0 to 44.5 ft, averaged 8.7 ft, and had a median value of 6.6 ft. Omitting well CHN-14 from the analysis indicates an average decline of 6.8 ft for Coastal Plain wells. Seven of the monitor wells are in the Piedmont. Net water-level declines in these wells ranged from 0.0 to 9.4 ft, averaged 4.7 ft, and had a median value of 3.7 ft (Table 1).

Well BFT-429, completed in the Upper Floridan aquifer in Beaufort County, had a net water-level rise of 0.4 ft during the drought (Figure 12). Recent reductions in ground water withdrawals from the aquifer may have contributed to the rise in water level. The drought also had little effect on well AND-326 (Figure 22), which is constructed in bedrock in Anderson County. This well had no net water level change during the drought. Seasonal cycles are present and are very regular, with highs occurring every April and lows every October; however, there was no long-term downward trend during the drought.

Seasonal cycles, like those observed in well AND-326, were not observed in every Piedmont well. Wells CTR-21 and SPA-1581 (Figures 23 and 27), for example, had no seasonal fluctuations during the drought, indicating little or no recharge to the aquifer. This can be attributed to a number of factors, including: depth to water table; thickness and hydraulic conductivity of the saprolite; the number, continuity, or hydraulic conductivity of the fractures; and/or the effects of local discharge or pumping.

Well BRK-431 is completed in the Middendorf aquifer in Berkeley County. A constant downward trend occurred before and during the drought (Figure 13), suggesting that the well is influenced by pumping. A cone of depression centered at Mount Pleasant is probably affecting water levels in this well (Hockensmith, 2003). The drought accelerated the rate of decline from 3.3 ft/year before the drought to 4.1 ft/year during the drought.

During the winter and spring of 1997-98, above-normal precipitation resulted in a high rate of recharge to many of the aquifers. Well ALL-372 (Figure 7) had a water-level rise of 13.5 ft over a 5-month period from January 1998 to May 1998, an average of 2.7 ft/month. Water levels in the well began dropping in June 1998, when the drought began, but it took about 14 months to reach the January 1998 level, declining at a rate of about 1 ft/month. This is evident in several other wells, where the rate of rise before the drought was greater than the rate of decline during the drought.

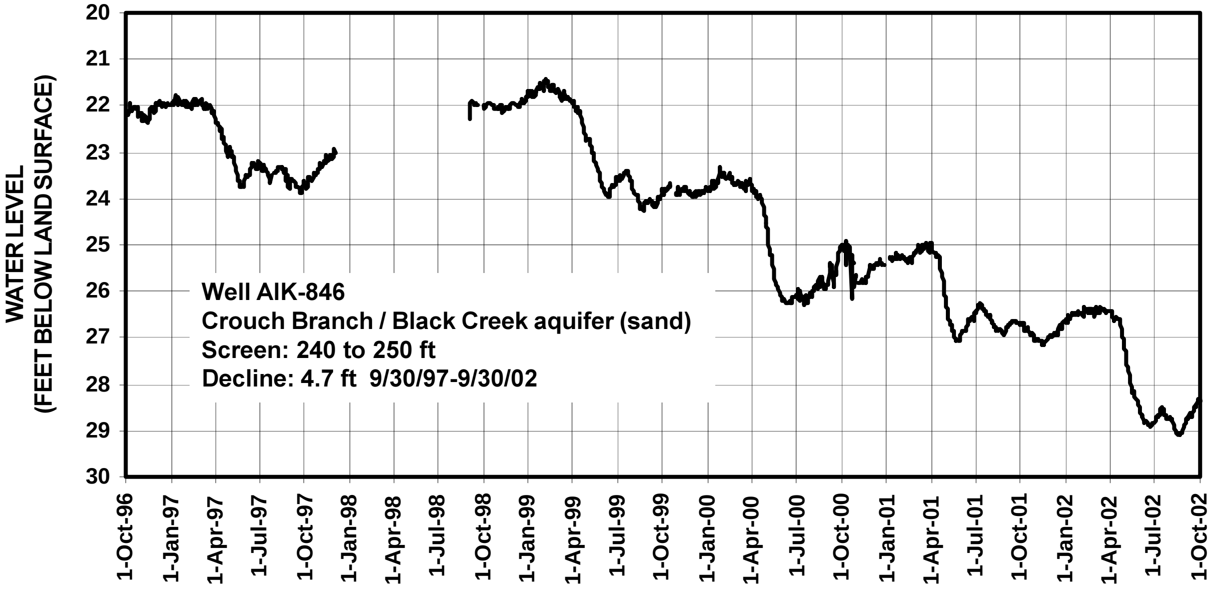


Figure 2. Located at Aiken State Park, the monitor well is screened in the Black Creek aquifer from 240 to 250 ft. Water levels declined 4.7 ft from September 30, 1997, to September 30, 2002, dropping an average of 0.9 ft/year. Seasonal cycles are evident, with 2- to 3-ft declines in April through June of each year and about 1-ft rises during the winter months. Sharp declines in April through June suggest nearby pumping.

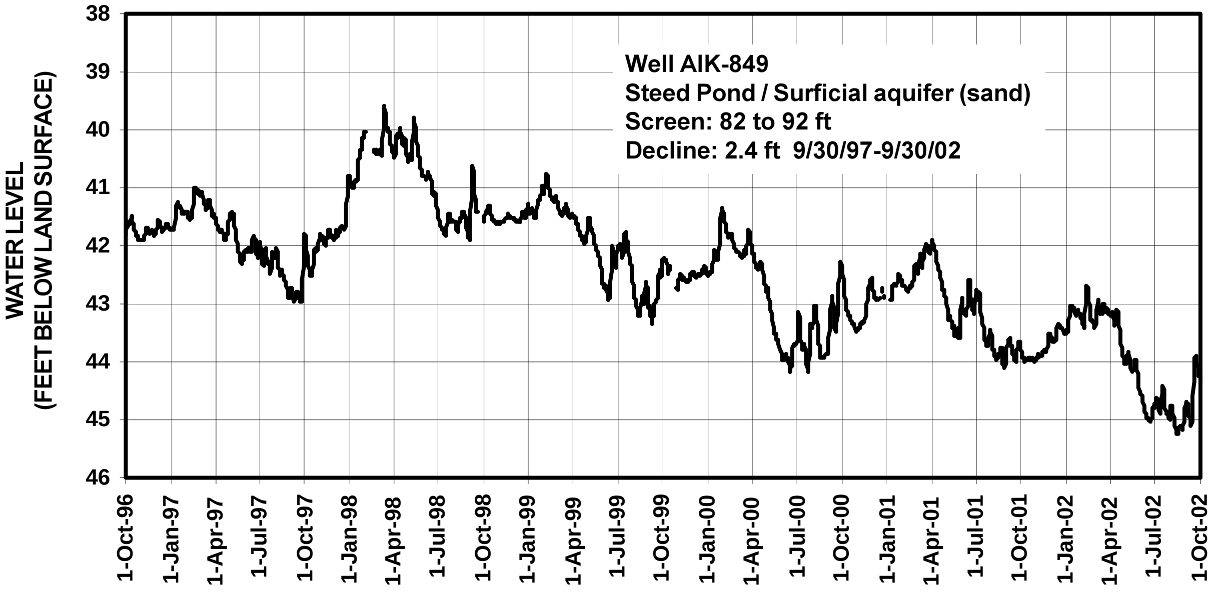


Figure 3. Located at Aiken State Park, the monitor well is screened in the surficial aquifer from 82 to 92 ft. Water levels declined 2.4 ft from September 30, 1997, to September 30, 2002, dropping an average of 0.5 ft/year. High water levels occurred in March and April and low levels in July through October. The aquifer is hydraulically connected with the South Fork of the Edisto River, which is less than 1 mile from the well. Water levels in the well are strongly correlated with the flow rate of the river.

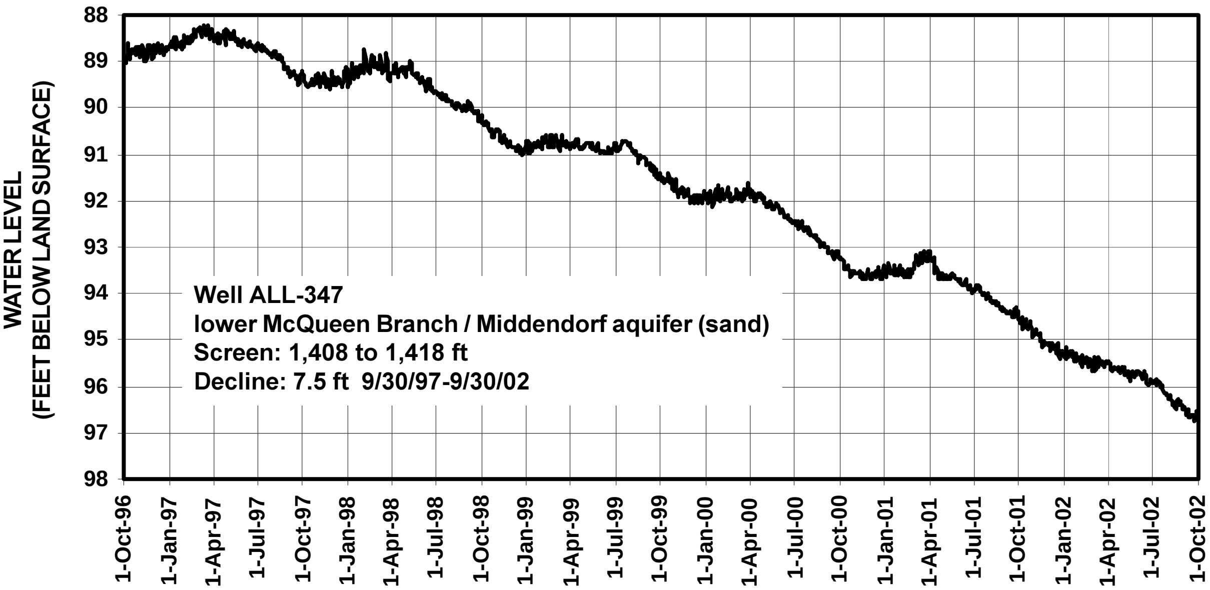


Figure 4. Screened from 1,408 to 1,418 ft in the Middendorf aquifer, the well had a net decline of 7.5 ft from September 30, 1997, to September 30, 2002. This is the third-greatest overall decline of the eight wells that were monitored at the C-10 cluster site, dropping an average of 1.5 ft/year. During the first 3 years of the drought, water levels declined during the summer and fall but leveled off and were generally flat during winter and spring. In the last year of the drought, however, there was a continuous decline throughout the year. Local irrigation wells and several high-capacity wells southwest of Orangeburg may have contributed to the overall water-level decline observed during the drought.

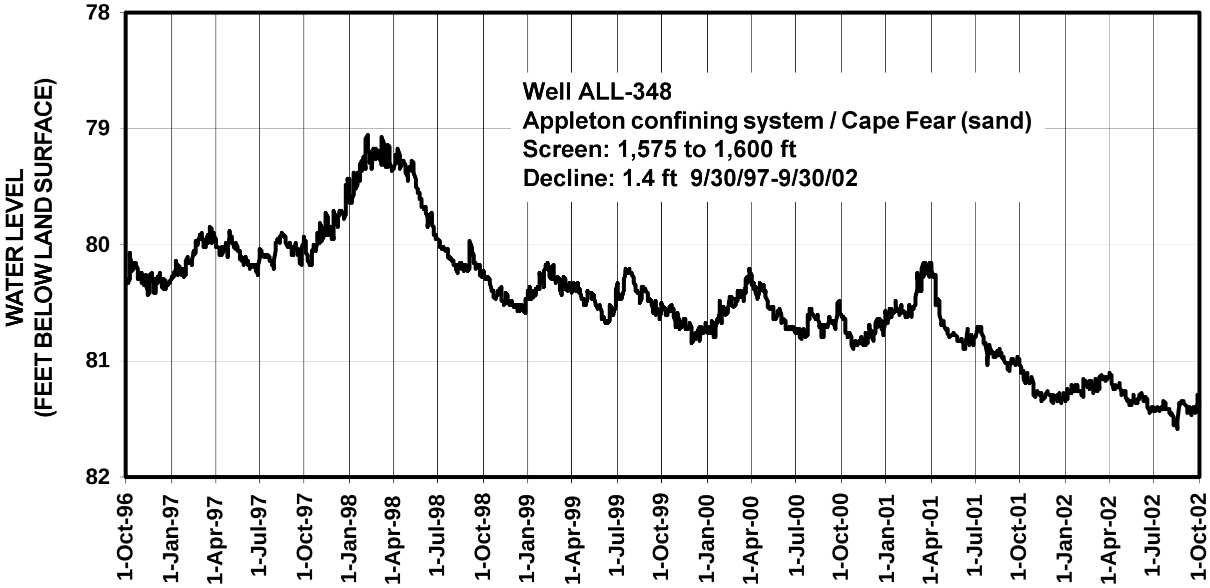


Figure 5. Screened from 1,575 to 1,600 ft in the basal confining unit of the Coastal Plain, the well had a net decline of only 1.4 ft from September 30, 1997, to September 30, 2002. This is the lowest overall decline of the eight wells that were monitored at the C-10 cluster site, dropping an average of 0.3 ft/year. No seasonal cycles are observed on the hydrograph. The Appleton confining system consists of beds of sand, silt, and clay that are weakly cemented with silica. Unconsolidated, permeable sand beds occur in the system but generally do not yield much water. Recharge of the sand beds mainly occurs in updip regions of the Coastal Plain where the system crops out or is thinly mantled by younger deposits.

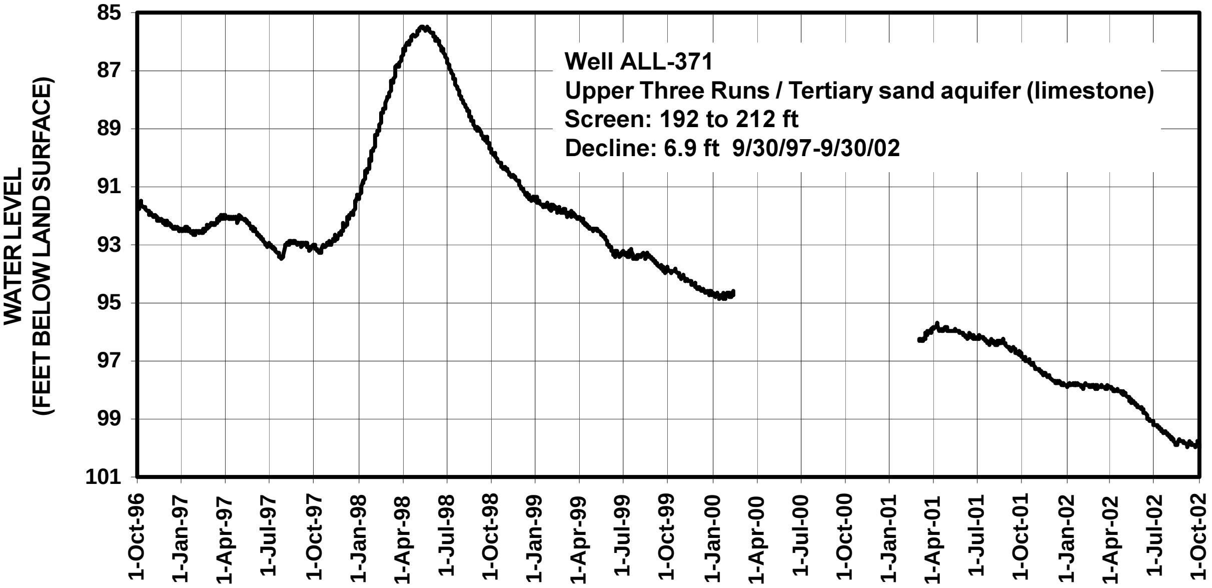


Figure 6. Screened from 192 to 212 ft, the well had a net decline of 6.9 ft from September 30, 1997, to September 30, 2002. This is the fourth-greatest overall decline of the eight wells that were monitored at site C-10, dropping an average of 1.4 ft/year. An absence of seasonal cycles on the hydrograph suggests that discharge exceeded recharge throughout the drought, even during winter and spring months. A sharp rise in water level during the winter and spring of 1997-98, similar to that seen in well ALL-372 (Figure 7), indicates that the aquifer can recharge quickly during the winter and spring. Water levels rose 5.7 ft during a 5-month period from January through May 1998. No large supply wells are completed in the aquifer near site C-10, however, private wells used for residential purposes or for small irrigation systems tap the aquifer. These wells probably did not significantly affect water levels during the drought. The well is completed in a sandy limestone unit that is the age-equivalent of the downdip Upper Floridan aquifer. The limestone is discontinuous in southern Allendale County but thickens and is laterally continuous to the south in Hampton County where it forms the productive Upper Floridan aquifer. Although thin clay beds occur in zones above the limestone, the aquifer is probably recharged by leakage through overlying sediments at site C-10.

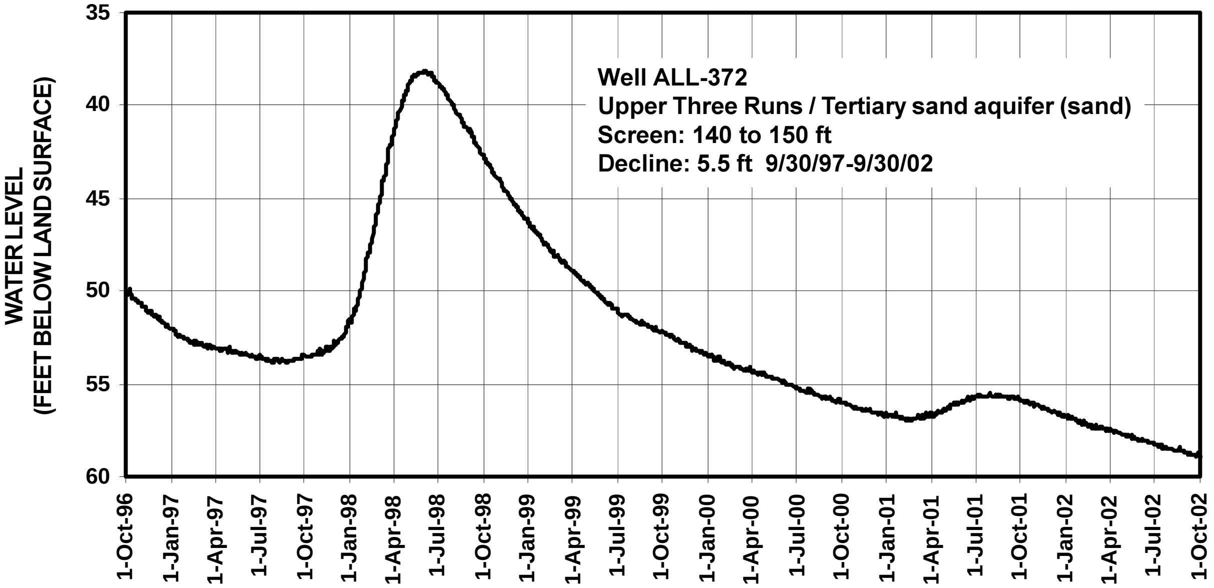


Figure 7. Screened in the shallowest water-bearing zone, from 140 to 150 ft, the well had a net decline of 5.5 ft from September 30, 1997, to September 30, 2002. This is the seventh-greatest overall decline of the eight wells at the C-10 cluster site, dropping an average of 1.1 ft/year. No seasonal cycles in water-level fluctuation are evident in the aquifer, suggesting that discharge to surrounding streams exceeded recharge throughout the drought, even during winter and spring months. A sharp rise in water level during the wet winter and spring of 1997-98 indicates that the aquifer is capable of recharging over a short period of time. Water levels rose 13.5 ft over a 5-month period from January through May 1998. The Upper Three Runs aquifer serves as a domestic supply for residential use; no large production wells are completed in the aquifer. Consequently, local pumping from the aquifer probably had little effect on water-level declines observed in the aquifer during the drought. The aquifer consists of sand, clayey sand, and thin clay beds. No thick confining units overlie the aquifer, and the aquifer is directly recharged by precipitation falling in the general vicinity of the site.

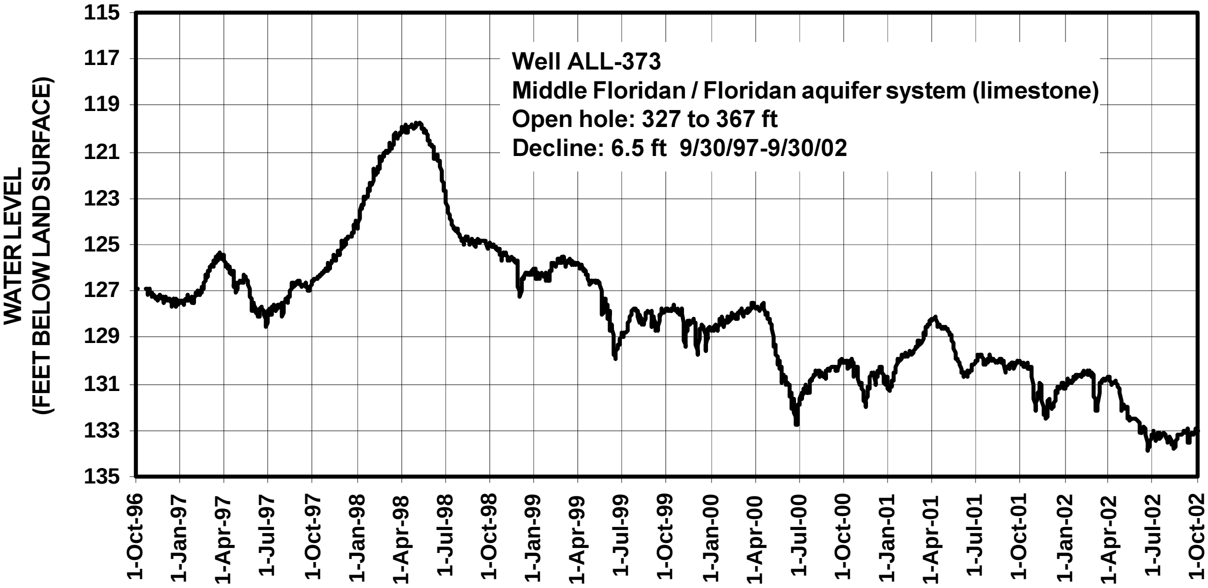


Figure 8. Constructed as an open-hole limestone well from 327 to 367 ft in the Middle Floridan aquifer, the well had a net decline of 6.5 ft from September 30, 1997, to September 30, 2002. This is the sixth-greatest overall decline of the eight wells at C-10, dropping an average of 1.3 ft/year. Poorly defined seasonal cycles are observed on the hydrograph, with water-level highs occurring in April of each year. A sharp rise in water level during the winter and spring of 1997-98, similar to that observed in wells ALL-371 and ALL-372, indicates that the aquifer can be recharged over a relatively short period of time. Water levels rose 3.7 ft during a 5-month period from January through May 1998. Municipal wells in the town of Allendale and in several other smaller towns in the county may have contributed to the overall declines. The town of Allendale has five municipal wells completed in the aquifer and pumps about 0.6 mgd (million gallons per day). The Middle Floridan aquifer consists of consolidated, porous limestone. Overlying the aquifer are confining beds that consist of fine-grained sand and calcareous sediments. The aquifer is recharged updip from site C-10, in the vicinity of the Savannah River Site (SRS). Recharge also occurs by downward leakage through overlying sediments.

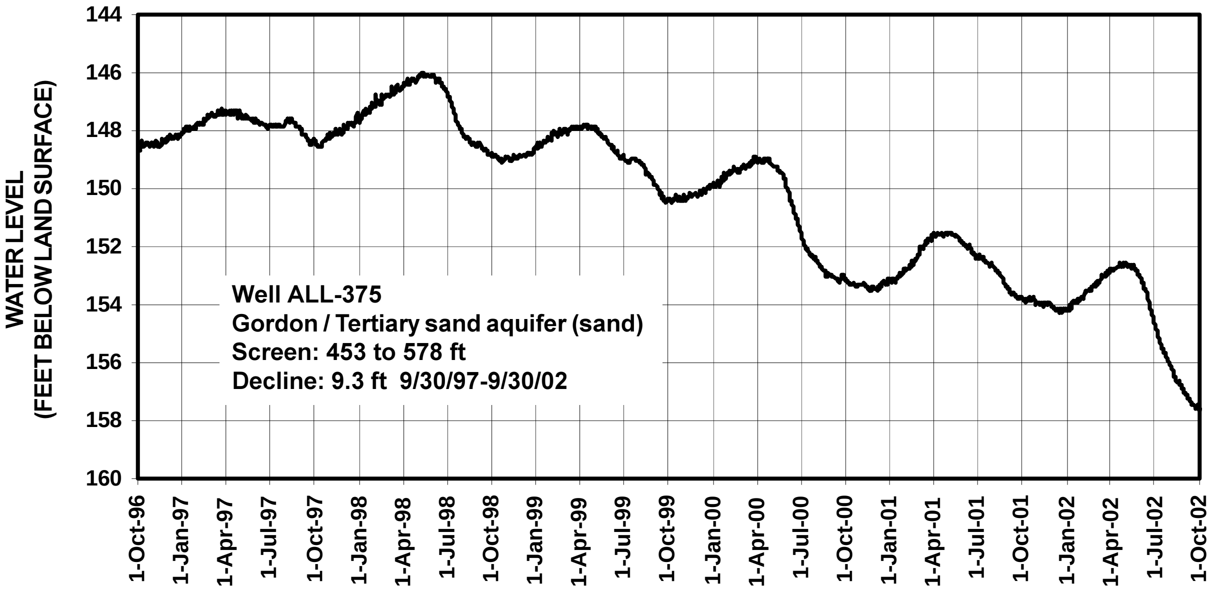


Figure 9. Screened from 453 to 578 ft in the Tertiary sand aquifer, the well had a net decline of 9.3 ft from September 30, 1997, to September 30, 2002. This is the second-greatest overall decline of the eight wells at site C-10, dropping an average of 1.9 ft/year. Well-defined seasonal fluctuations are observed, with lows occurring in October through December and highs in April. The aquifer was recharged during the winter and spring; however, discharge during the summer and fall exceeded recharge, resulting in a net decline. Declines were greatest in 2000 and 2002, when water levels dropped 4.1 and 4.9 ft, respectively, during a 5-month period from April through September. A moderate rise in water level during the wet winter and spring of 1997-98 is recorded. Water levels rose 1.6 ft during a 5-month period from January through May 1998. Eleven municipal wells that supply the town of Barnwell are completed in the aquifer and may have contributed to the overall water-level decline observed during the drought. These wells pump on average 1.5 mgd. The aquifer also supplies several smaller towns in the county. The Tertiary sand aquifer consists of unconsolidated quartz and calcareous sand. The overlying confining unit is about 60 ft thick and is composed of fine-grained limestone. Recharge occurs updip from site C-10 in Aiken County, but it also occurs from leakage across overlying and underlying confining units owing to greater pressure in adjacent aquifers.

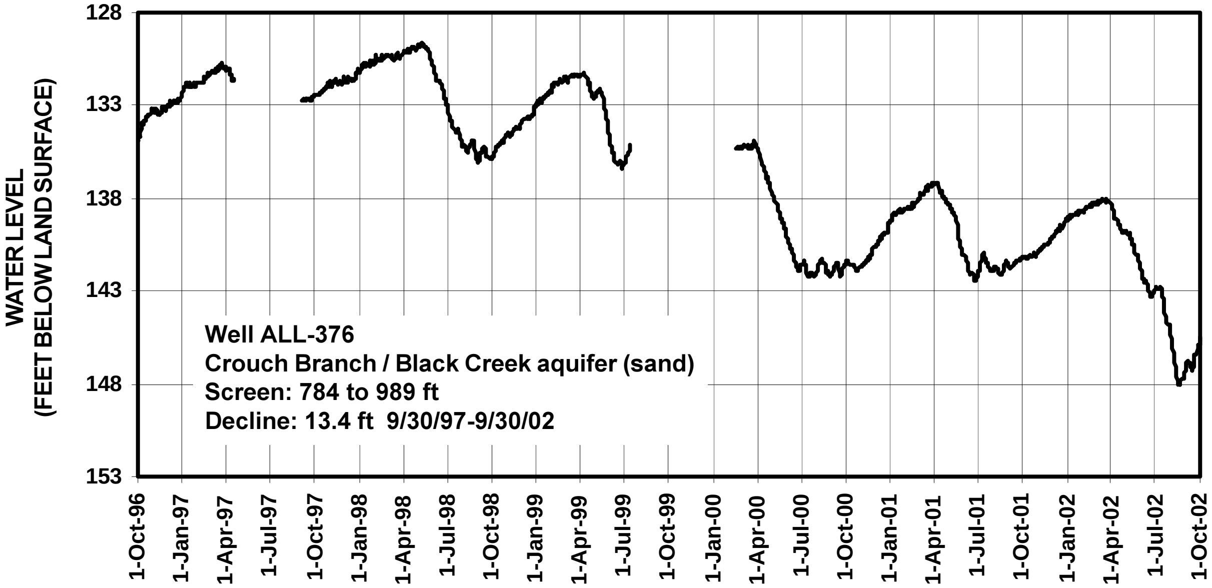


Figure 10. Screened from 784 to 989 ft in the Black Creek aquifer, the well had a net decline of 13.4 ft from September 30, 1997, to September 30, 2002. This is the greatest overall decline of the eight wells that were monitored at site C-10, dropping an average of 2.7 ft/year. Well-defined seasonal cycles are observed, with water-level highs occurring during the winter and spring, and lows during the summer and fall. These cycles indicate that the aquifer was recharged during the winter and spring seasons when evapotranspiration losses were at a minimum. Discharge during the summer and fall exceeded recharge, resulting in a net decline during the drought. Declines were greatest during the summer and fall of 2002, when water levels dropped about 10 ft during a 6-month period from April through September. Local irrigation wells and several high-capacity wells in western Orangeburg County may have contributed to the overall water-level decline observed during the drought. The Black Creek aquifer consists of unconsolidated quartz sand. Overlying the aquifer is a thick (150 ft), regionally extensive confining unit that consists of silt and clay. Recharge of the aquifer is updip from site C-10 in Aiken County, where the confining unit thins and is laterally discontinuous.

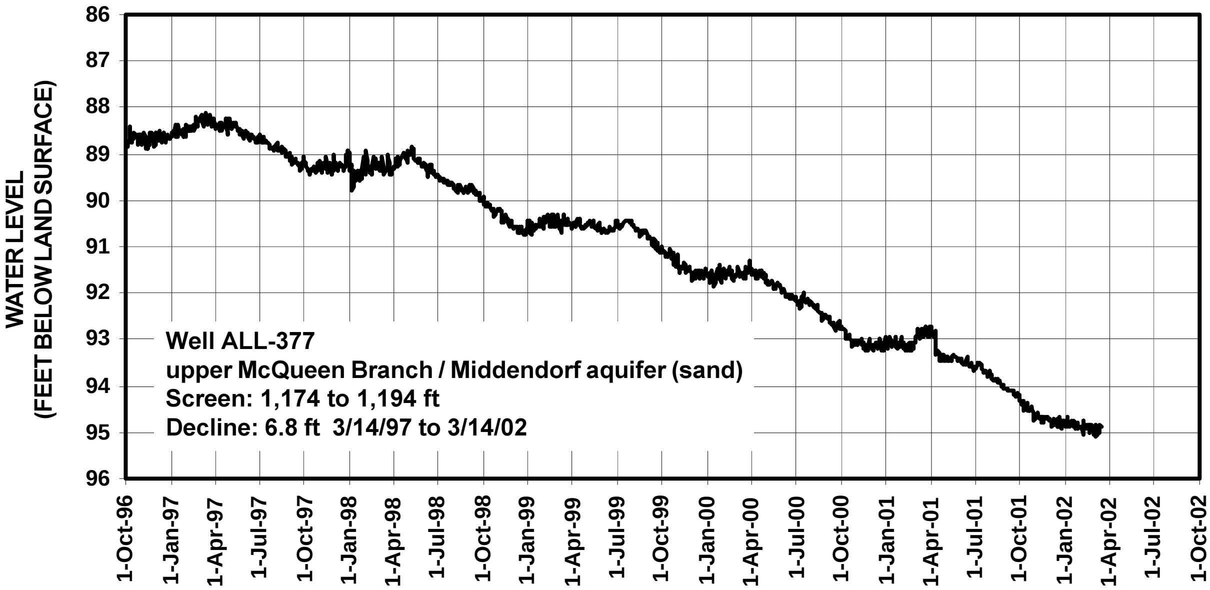


Figure 11. Screened from 1,174 to 1,194 ft in the Middendorf aquifer, the well had a net decline of 6.8 ft from March 14, 1997, to March 14, 2002. (No record is available from March 14, 2002, to September 30, 2002.) This is the fifth-greatest overall decline of the eight wells that were monitored at site C-10, dropping an average of 1.4 ft/year. In general, water levels declined continuously during the summer and fall and leveled off during the winter and spring. These cycles indicate that the aquifer was not being recharged during the winter and spring seasons, as it normally would be. Local irrigation wells and several high-capacity wells in western Orangeburg County may have contributed to the overall water-level decline observed during the drought. The Middendorf aquifer consists of unconsolidated quartz sand. Overlying the aquifer is a thick (170 ft), regionally extensive confining unit that consists of silt and clay. Recharge of the aquifer occurs updip from site C-10 in the central part of SRS and to the north in Aiken County where the confining unit thins and is laterally discontinuous.

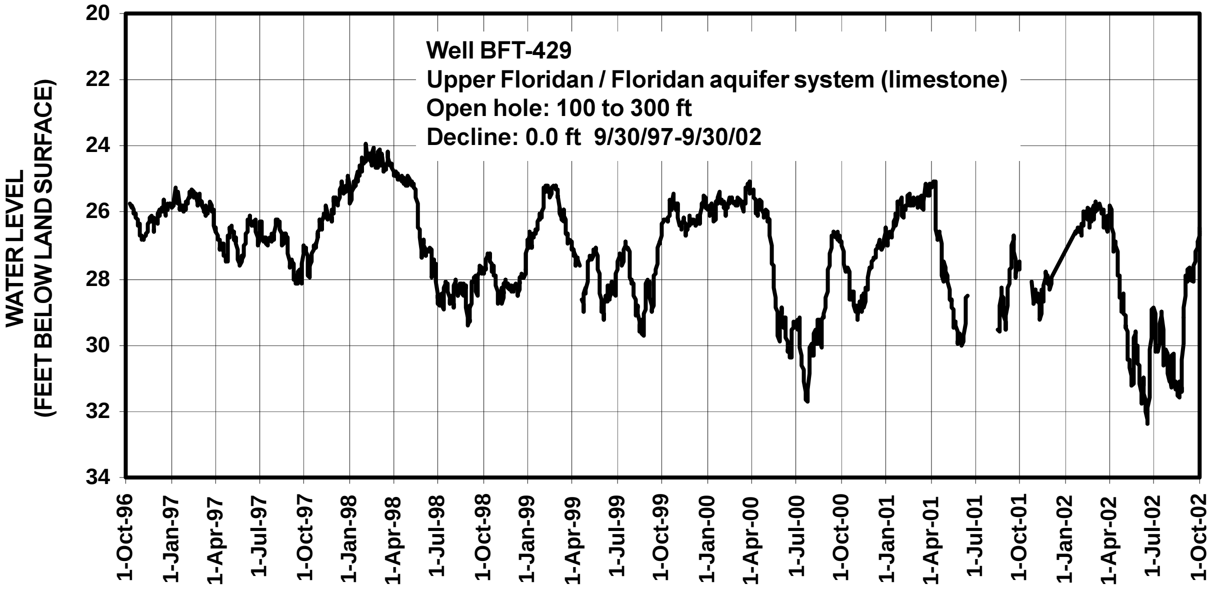


Figure 12. Located at Victoria Bluff Wildlife Management Area in Beaufort County, the monitor well is completed as an open hole in the Upper Floridan aquifer from 100 to 300 ft. No net declines are observed in the well. In fact, the water level rose about 0.4 ft from September 30, 1997, to September 30, 2002. Sharp declines, indicative of nearby pumping, occurred in the spring of each year, but the aquifer recovered fully during the winter months.

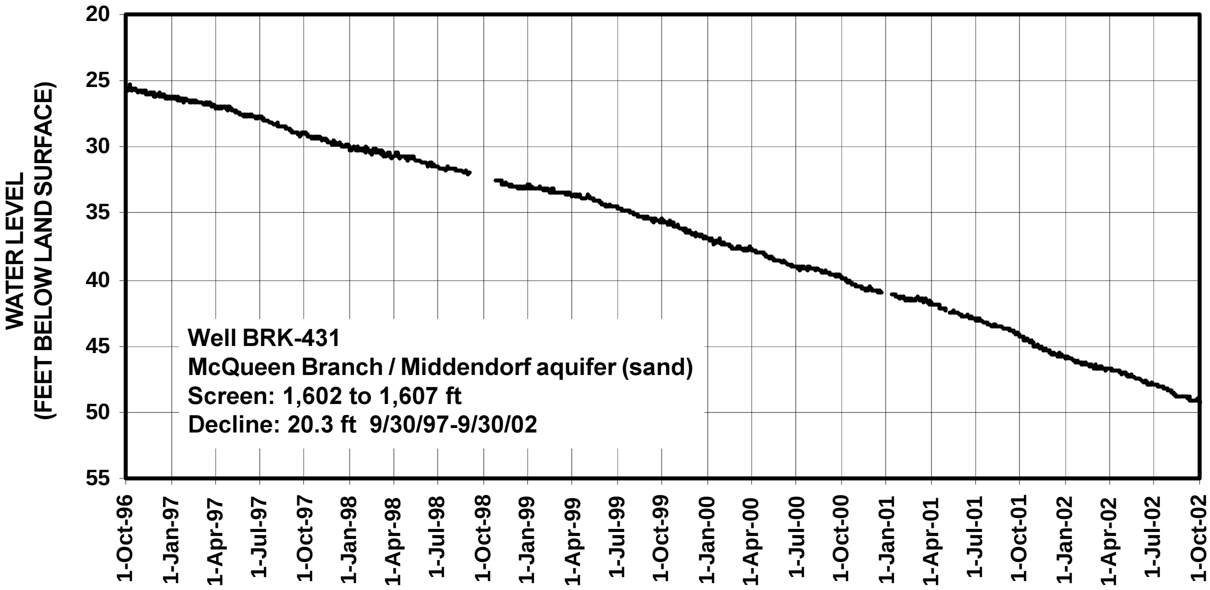


Figure 13. Located near Moncks Corner in the Conifer Hall Subdivision, the monitor well is screened in the Middendorf aquifer from 1,602 to 1,607 ft. Water levels declined 20.3 ft from September 30, 1997, to September 30, 2002, dropping an average of 4.1 ft/year. Seasonal cycles are absent and a steady decline occurred throughout the drought. Declines are also observed before the onset of the drought, indicating that pumping was contributing to the overall water-level decline.

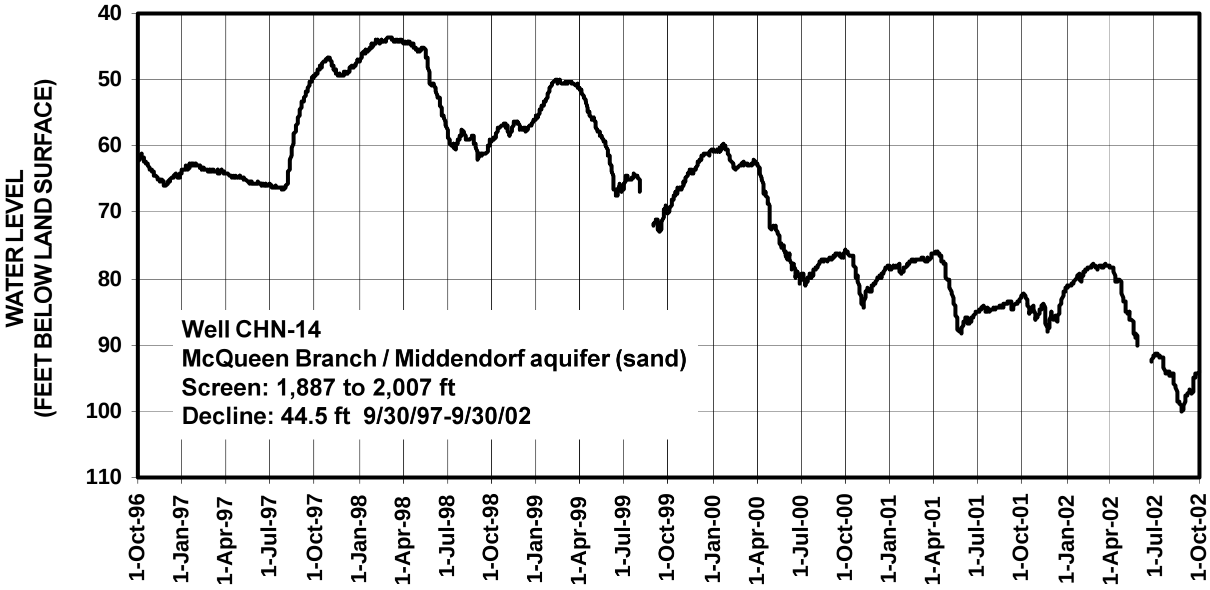


Figure 14. Located in downtown Charleston, the monitor well is screened in the Middendorf aquifer from 1,887 to 2,007 ft. Water levels declined 44.5 ft from September 30, 1997, to September 30, 2002, dropping an average of 8.9 ft/year. Seasonal cycles are evident with highs occurring from January to April and lows in June and July. Pumping from large-capacity wells in the Mount Pleasant area contributed to the overall net decline.

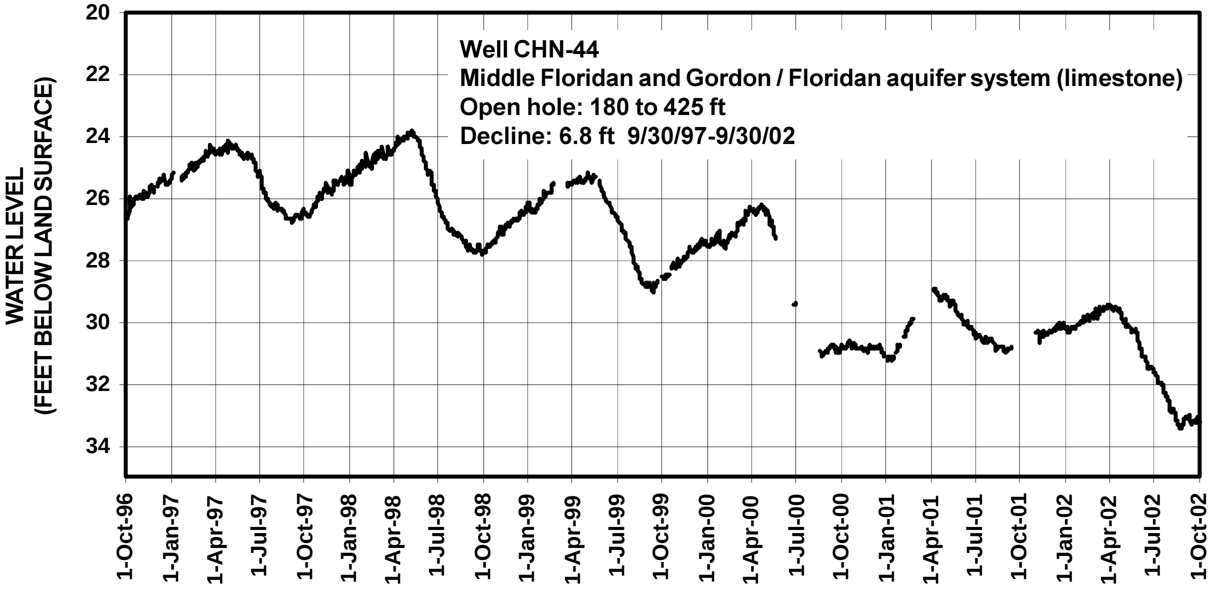


Figure 15. Located on property of the U.S. Department of Agriculture in Charleston, the monitor well is open to the Floridan aquifer system. Water levels declined 6.8 ft from September 30, 1997, to September 30, 2002, dropping an average of 1.4 ft/year. Seasonal cycles are clearly present, with highs occurring from April to June and lows in September and October.

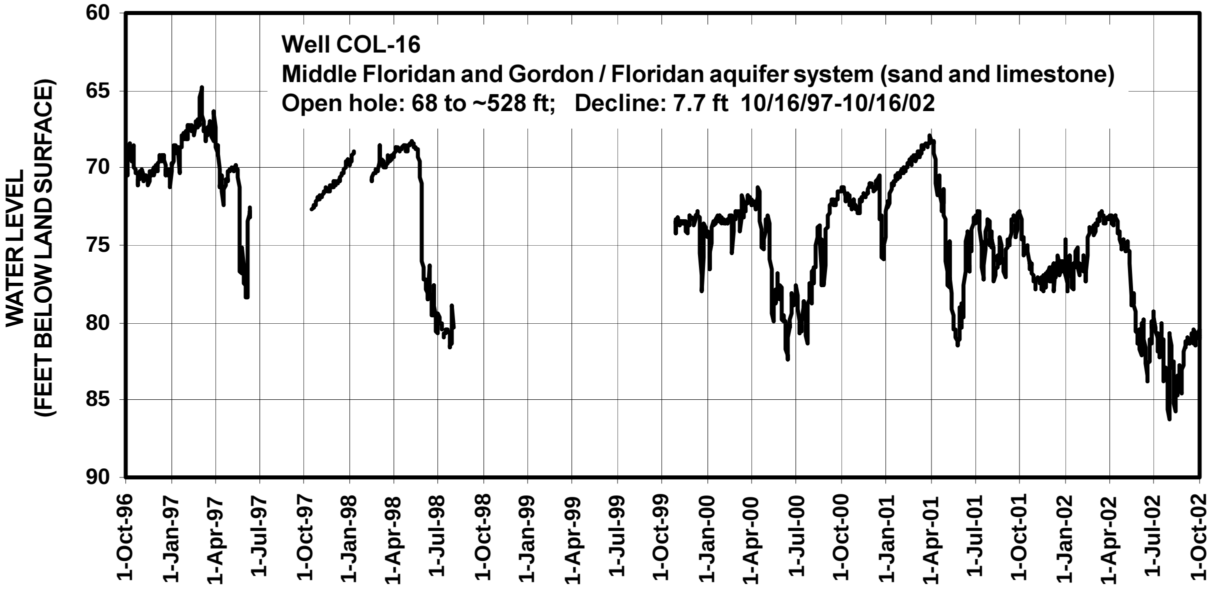


Figure 16. Located in the city of Walterboro, the monitor well is completed as an open hole from 68 to about 528 ft in the Floridan aquifer system. Water levels declined 7.7 ft from October 16, 1997, to October 16, 2002, dropping an average of 1.5 ft/year. Water-level highs occurred in April. Sharp declines in May and June may reflect nearby pumping.

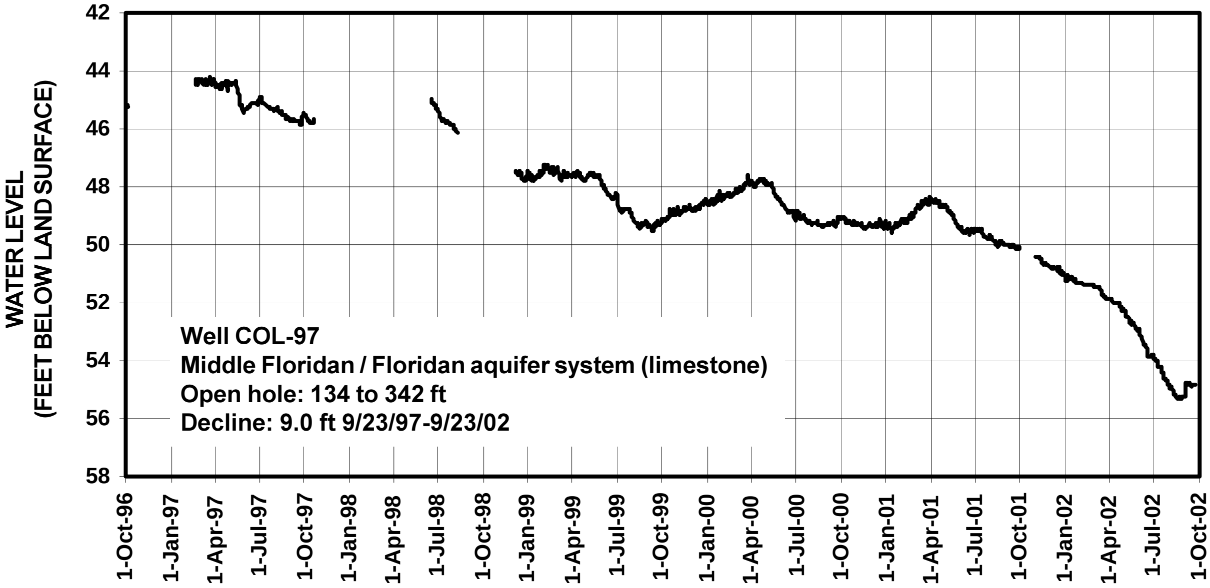


Figure 17. Located several miles south of Colleton State Park in Colleton County, the monitor well is completed as an open hole from 134 to 342 ft in the Floridan aquifer system. Water levels declined 9.0 ft from September 23, 1997, to September 23, 2002, dropping an average of 1.8 ft/year. Recharge occurred during the first 3 years of the drought, during the winter and spring months; however, during the last year of the drought the aquifer was not recharged.

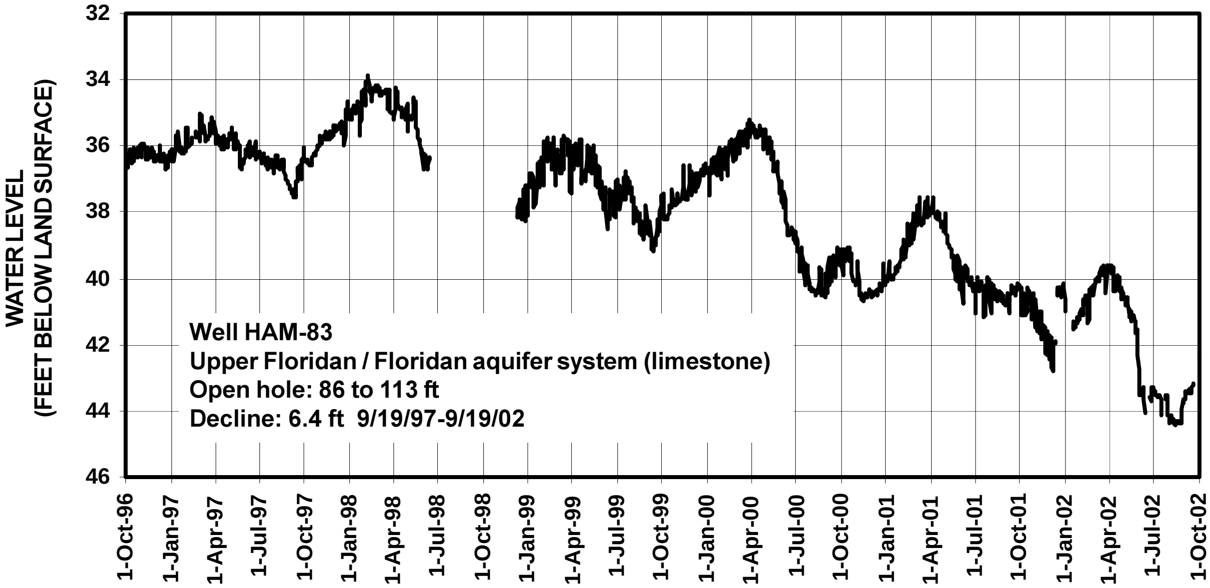


Figure 18. Located in the town of Yemassee in Colleton County, the monitor well is completed as an open hole from 86 to 113 ft in the Upper Floridan aquifer. Water levels declined 6.4 ft from September 19, 1997, to September 19, 2002, dropping an average of 1.3 ft/year. Water-level highs occurred in April of each year and lows in October through January. Pumping from irrigation wells may have contributed to the declines observed in the well.

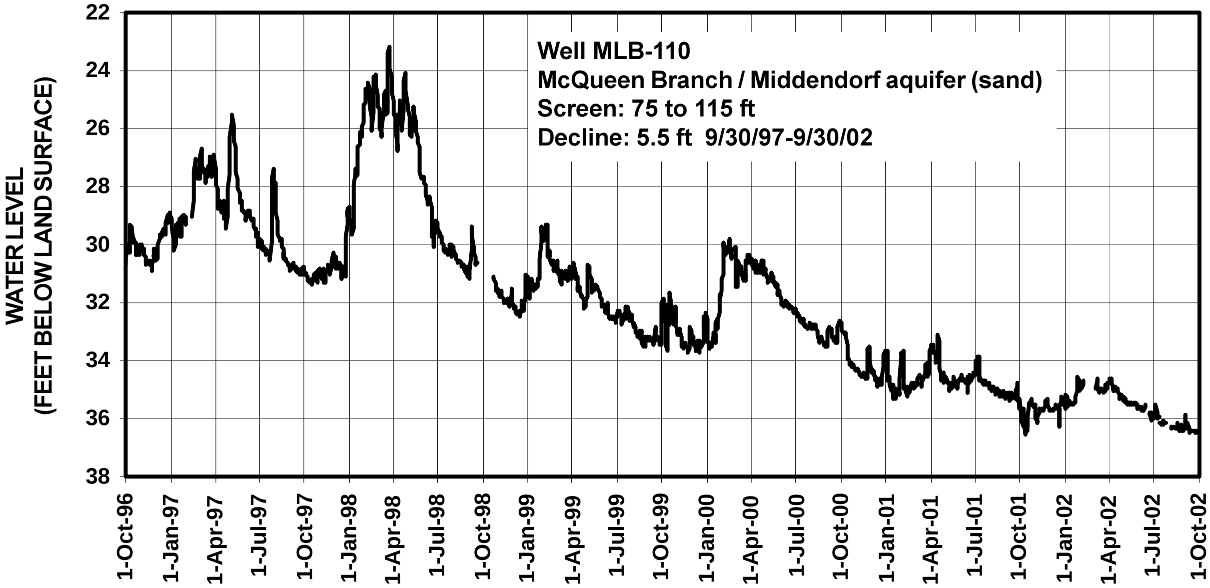


Figure 19. Located at Oak River Mills in the town of Bennettsville in Marlboro County, the monitor well is screened from 75 to 115 ft in the Middendorf aquifer. Water levels declined 5.5 ft from September 30, 1997, to September 30, 2002, dropping an average of 1.1 ft/year. Seasonal cycles indicate water levels were highest in February through April and lowest in December and January.

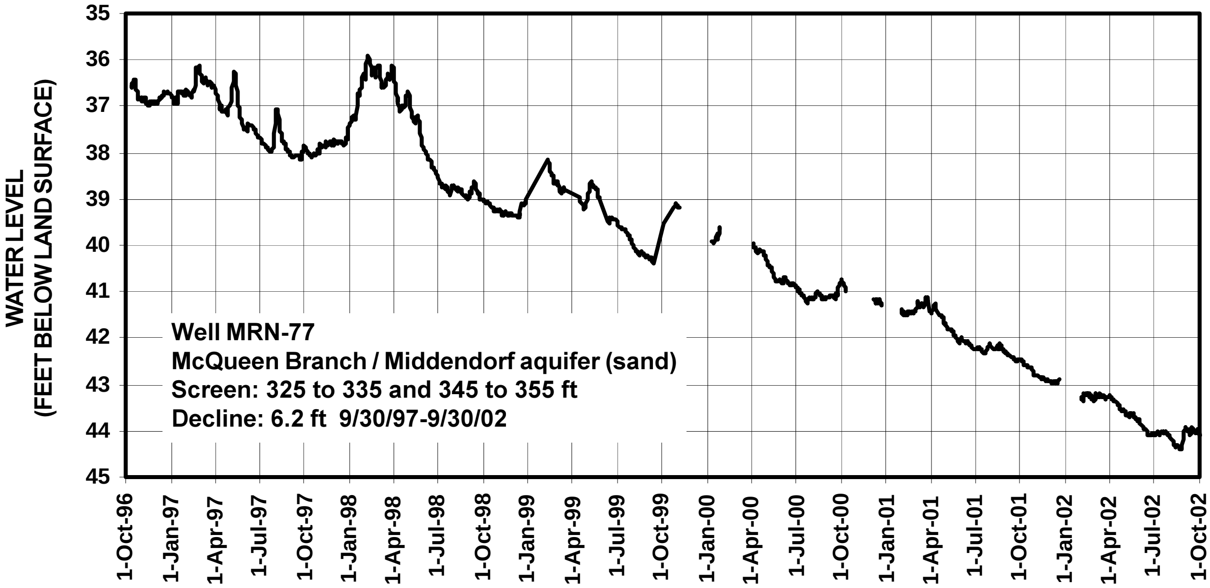


Figure 20. Located about 4 miles south of Brittons Neck in Marion County, the monitor well is screened from 325 to 335 ft and 345 to 355 ft in the Middendorf aquifer. Water levels declined 6.2 ft from September 30, 1997, to September 30, 2002, dropping an average of 1.2 ft/year. Seasonal cycles are generally absent, and a steady decline occurred throughout most of the drought.

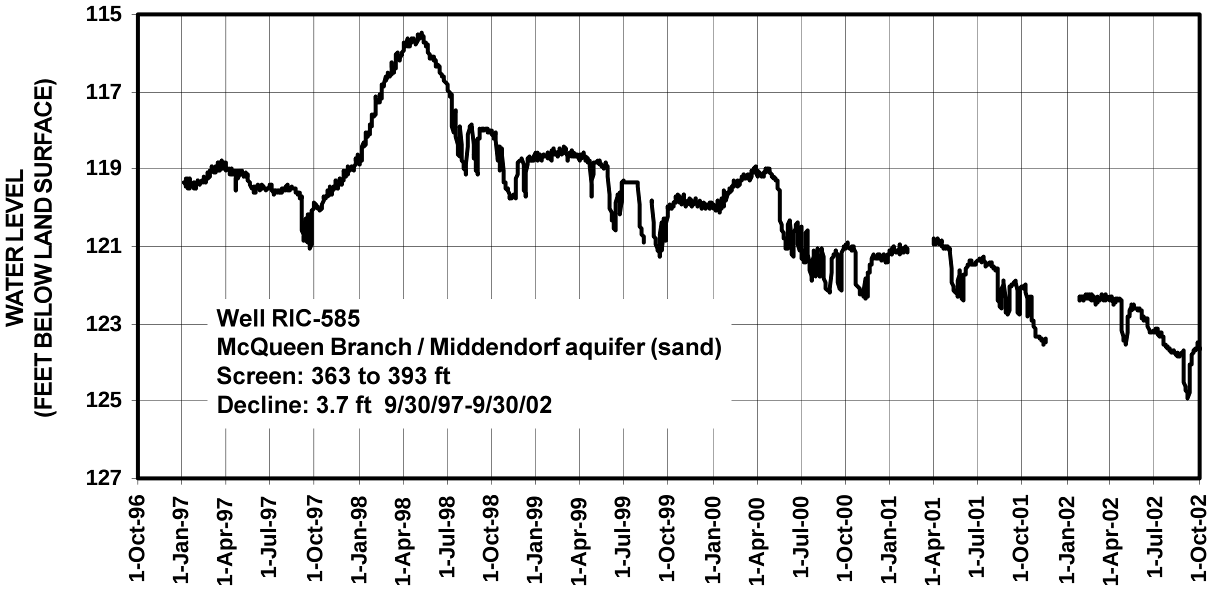


Figure 21. Located at Horrell Hill Elementary School in Richland County, the monitor well is screened from 363 to 393 ft in the Middendorf aquifer. Water levels declined 3.7 ft from September 30, 1997, to September 30, 2002, dropping an average of 0.7 ft/year. Poorly defined seasonal cycles are present, with the highest water levels occurring in April and the lowest in October through January.

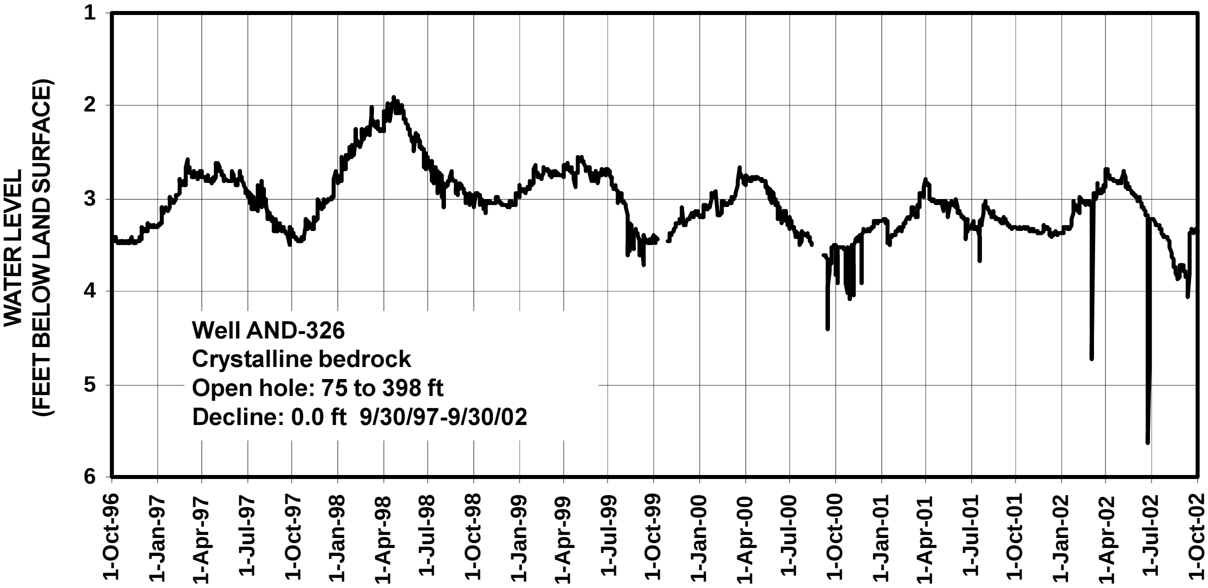


Figure 22. Located in the city of Williamston in Anderson County, the monitor well is completed as an open hole in bedrock from 75 to 398 ft. There was no net water-level decline from September 30, 1997, to September 30, 2002. Seasonal cycles are present on the graph, with water-level lows occurring in September and October and highs in April and May.

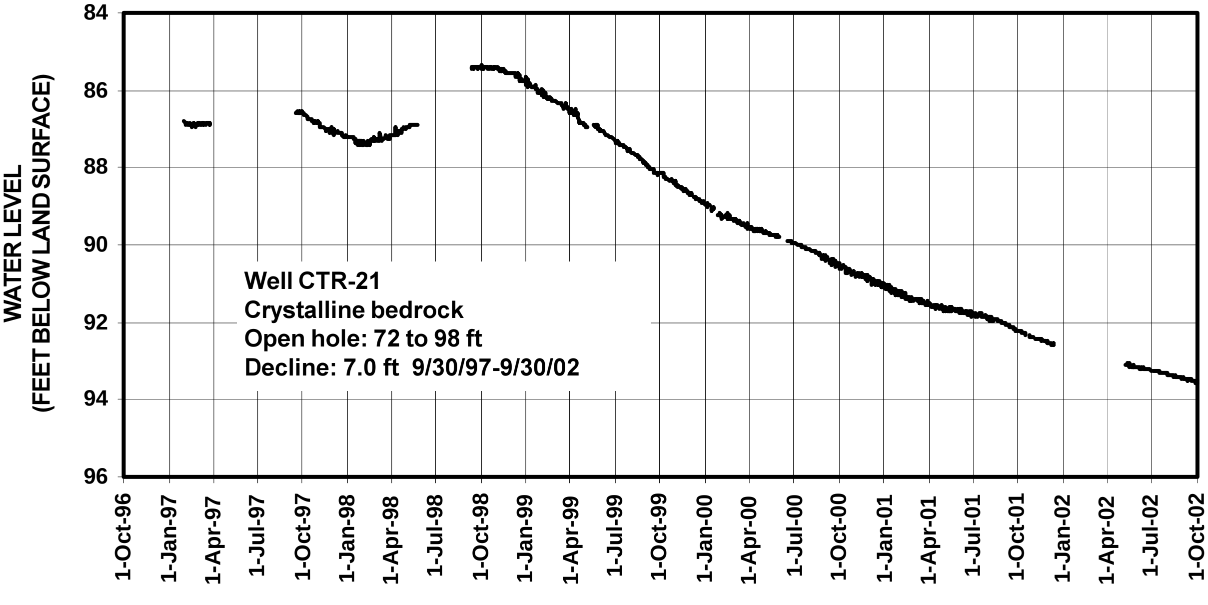


Figure 23. Located at the Leeds Fire Tower several miles northeast of the town of Leeds in Chester County, the monitor well is completed as an open hole in bedrock from 72 to 98 ft. Water levels declined 7.0 ft from September 30, 1997, to September 30, 2002, dropping an average of 1.4 ft/year. Water levels declined continuously throughout the drought.

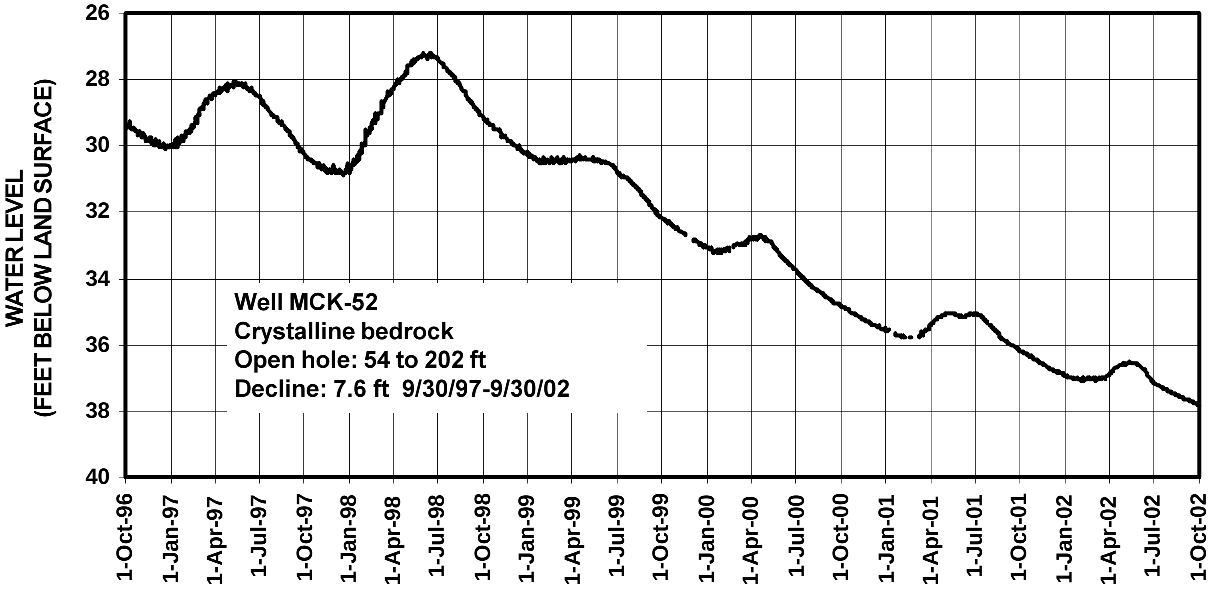


Figure 24. Located at Baker Creek State Park in McCormick County, the monitor well is completed as an open hole in bedrock from 54 to 202 ft. Water levels declined 7.6 ft from September 30, 1997, to September 30, 2002, dropping an average of 1.5 ft/year. Seasonal cycles indicate that the highest water levels occurred in May and June and the lowest in February and March.

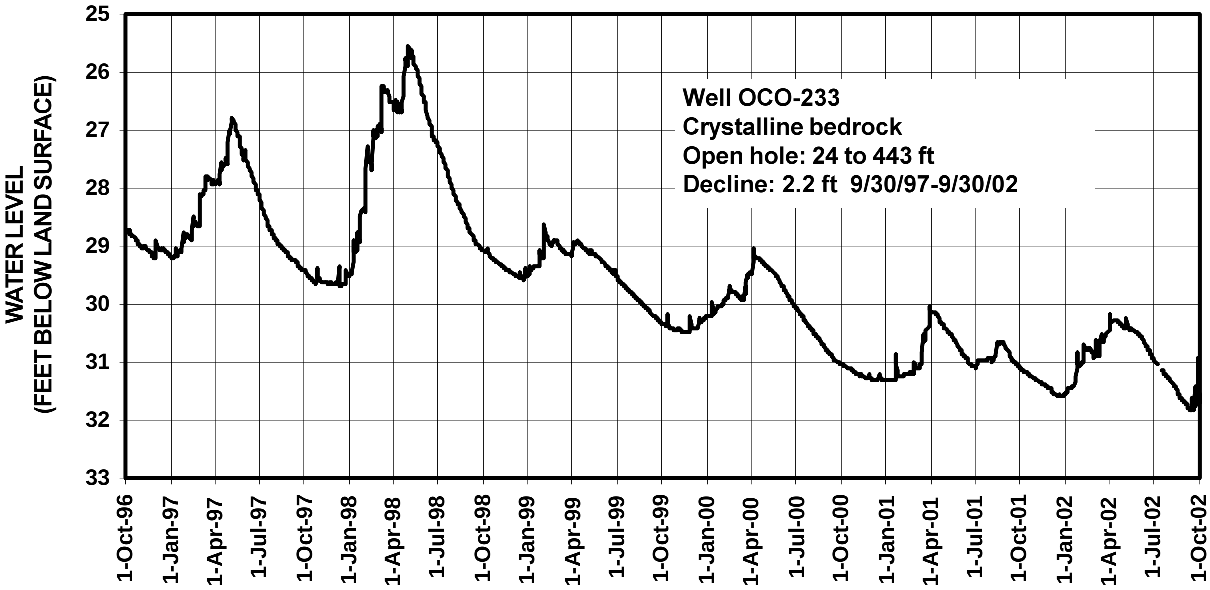


Figure 25. Located at Oconee Station in Oconee County, the monitor well is completed as an open hole in bedrock from 24 to 443 ft. Water levels declined 2.2 ft from September 30, 1997, to September 30, 2002, dropping an average of 0.4 ft/year. Distinct seasonal cycles are present, with high water levels occurring in April and low levels in January.

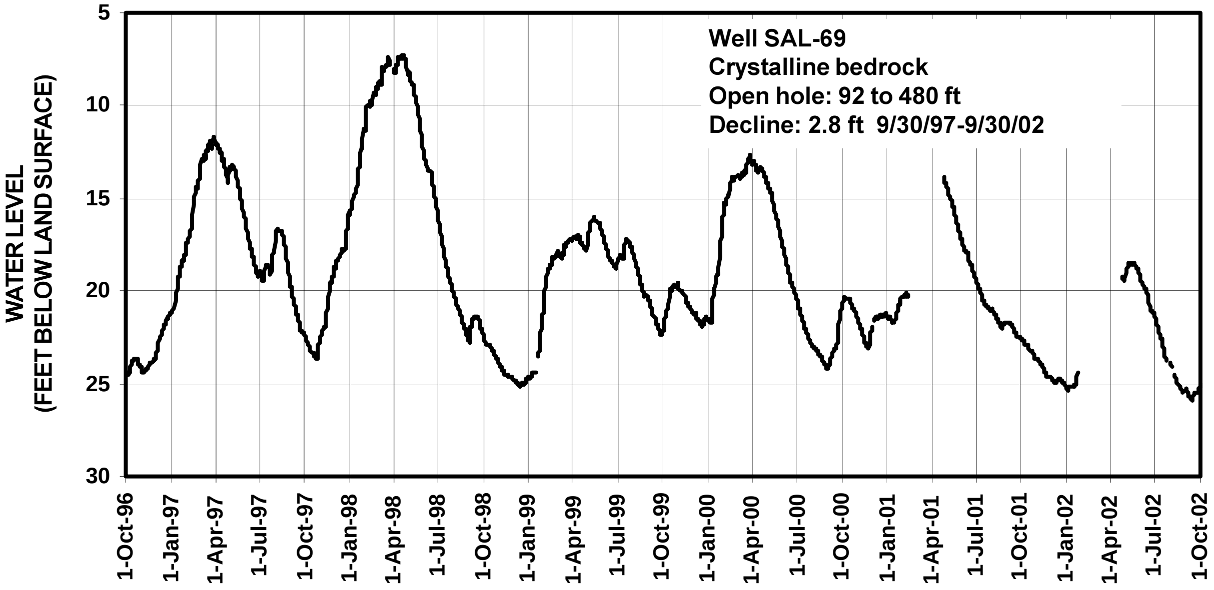


Figure 26. Located at Hollywood Elementary School northeast of Saluda, the monitor well is completed as an open hole in bedrock from 92 to 480 ft. Water levels declined 2.8 ft from September 30, 1997, to September 30, 2002, dropping an average of 0.6 ft/year. Distinct cycles are present, with high water levels occurring in April and low levels generally occurring in January. Fluctuations up to 15 ft occur in a single year.

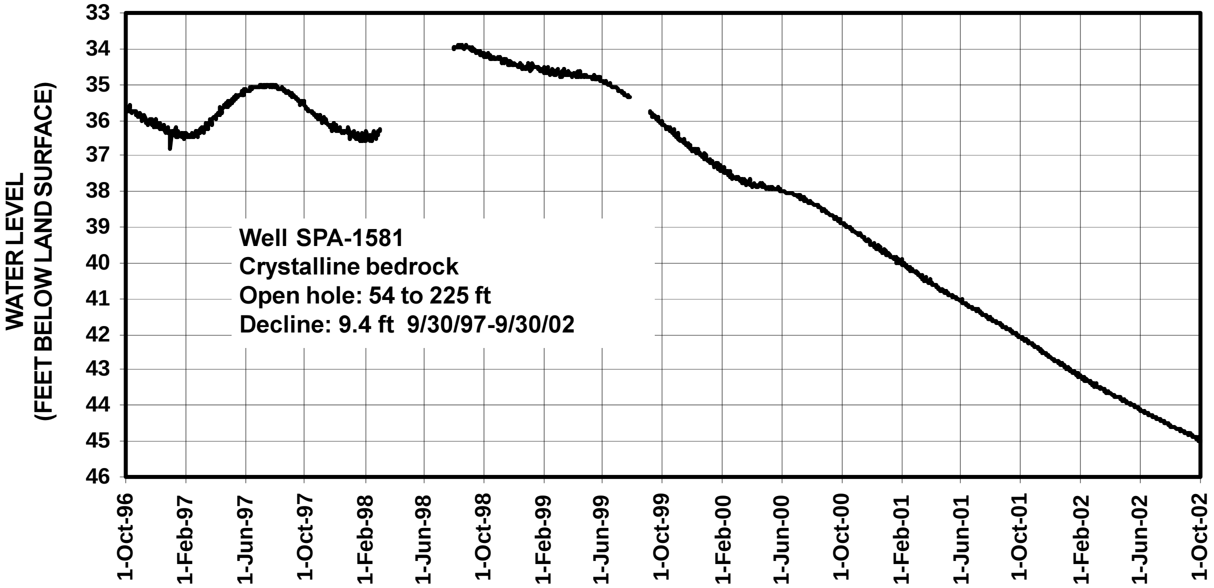


Figure 27. Located at Croft State Park in Spartanburg County, the monitor well is completed as an open hole in bedrock from 54 to 225 ft. Water levels declined 9.4 ft from September 30, 1997, to September 30, 2002, dropping an average of 1.9 ft/year. Seasonal cycles are clearly absent on the hydrograph, as water levels continuously and steadily declined during the drought.

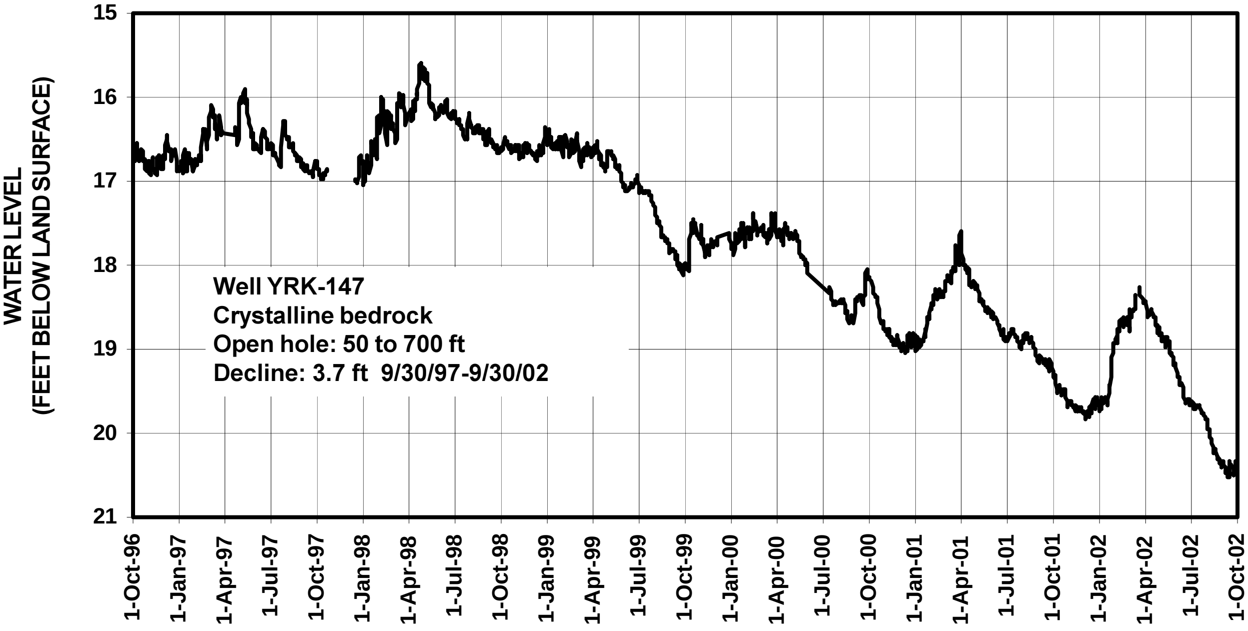
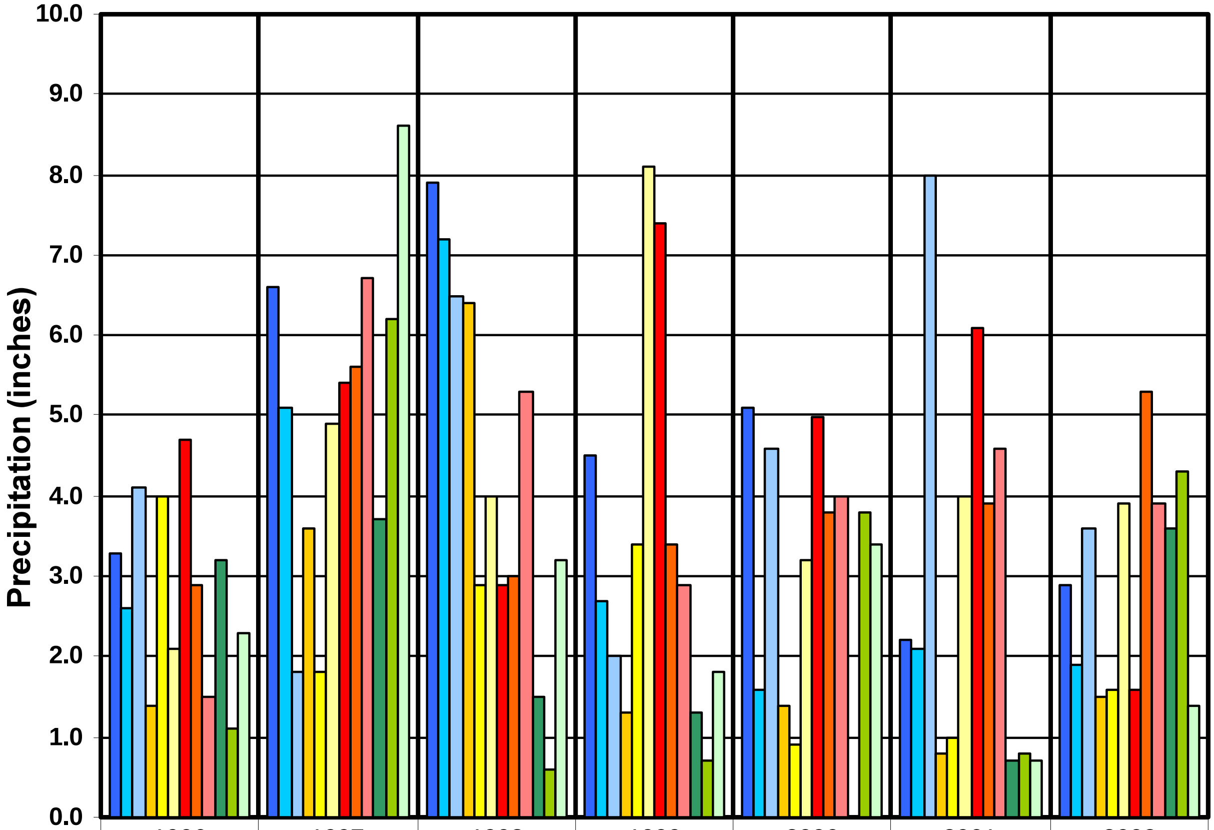


Figure 28. Located near Fort Mill on Lake Wylie in York County, the monitor well is completed as an open hole in bedrock from 50 to 700 ft. Water levels declined 3.7 ft from September 30, 1997, to September 30, 2002, dropping an average of 0.7 ft/year. Seasonal cycles can be discerned with highs occurring in April and lows in October through January.



	1996	1997	1998	1999	2000	2001	2002	Long-term monthly average (inches)
🟦 Jan	3.3	6.6	7.9	4.5	5.1	2.2	2.9	4.7
🟦 Feb	2.6	5.1	7.2	2.7	1.6	2.1	1.9	3.5
🟦 Mar	4.1	1.8	6.5	2.0	4.6	8.0	3.6	4.2
🟧 Apr	1.4	3.6	6.4	1.3	1.4	0.8	1.5	3.0
🟨 May	4.0	1.8	2.9	3.4	0.9	1.0	1.6	3.5
🟨 Jun	2.1	4.9	4.0	8.1	3.2	4.0	3.9	5.6
🟥 Jul	4.7	5.4	2.9	7.4	5.0	6.1	1.6	4.8
🟧 Aug	2.9	5.6	3.0	3.4	3.8	3.9	5.3	5.2
🟥 Sep	1.5	6.7	5.3	2.9	4.0	4.6	3.9	3.5
🟩 Oct	3.2	3.7	1.5	1.3	0.0	0.7	3.6	2.5
🟩 Nov	1.1	6.2	0.6	0.7	3.8	0.8	4.3	2.7
🟩 Dec	2.3	8.6	3.2	1.8	3.4	0.7	1.4	3.4

Figure 29. Monthly precipitation in Allendale County, 1996-2002 (station #70126).

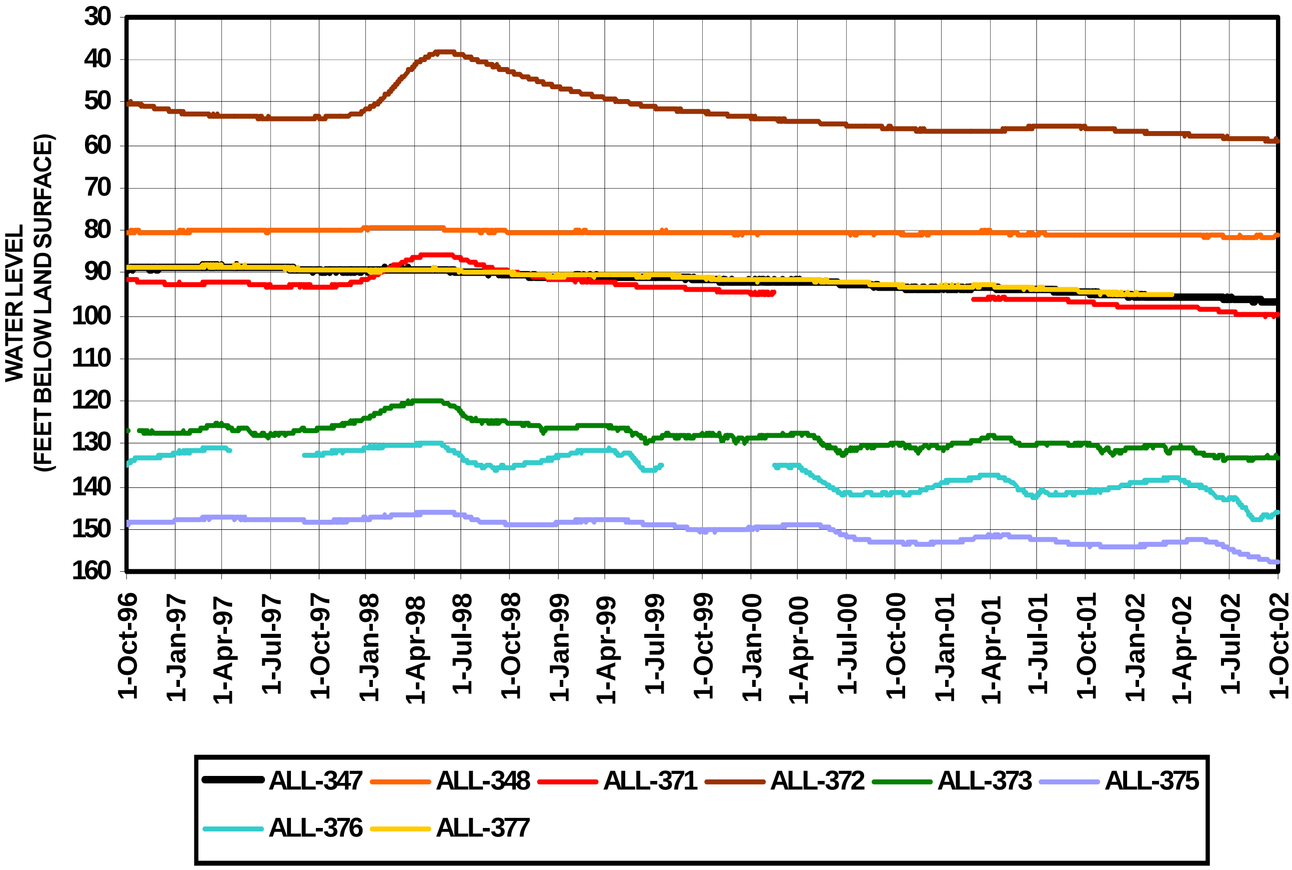


Figure 30. Composite plot of eight wells at site C-10, Allendale County.

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Aadland, R.K., Gellici, J.A., and Thayer, P.A., 1995, Hydrogeologic framework of west-central South Carolina: South Carolina Department of Natural Resources, Water Resources Report 5.

Aucott, W.R., Davis, M.E., and Speiran, G.K., 1987, Geohydrologic framework of the Coastal Plain aquifers of South Carolina: U.S. Geological Survey Water-Resources Investigations Report 85-4271.

Hockensmith, B.L., 2003, Potentiometric surface of the Middendorf aquifer in South Carolina, November, 2001: S.C. Department of Natural Resources, Water Resources Report 28.

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LAKE LEVELS IN SOUTH CAROLINA DURING THE JUNE 1998 – AUGUST 2002 DROUGHT

by
Joseph A. Gellici and A. W. Badr

ABSTRACT

Water levels for nine lakes were compiled and plotted over a period from October 1, 1996, to September 30, 2002, to evaluate lake conditions during the 1998-2002 drought. Water levels were low in the lakes, with the exceptions of Lakes Greenwood, Murray, and Wateree that were maintained at or near desired operating levels throughout most of the drought. Most lakes were at their lowest levels in the last year of the drought (2002). Lake Jocassee was 24.9 feet below desired operating levels in September 2002. Lakes Hartwell and Thurmond were more than 14 feet below desired levels in September 2002, and Lakes Marion, Moultrie, and Keowee were about 5 feet below desired levels during the last few months of the drought.

INTRODUCTION

Most of the large lakes in South Carolina were originally built to provide hydroelectric power and to control floods. Over the years, however, the lakes have become an important source of water for municipalities and industries, and they are increasingly used for recreation. Lakes, however, are managed not only to satisfy the demands of lake users, they are also managed to ensure that adequate downstream flows are maintained for the protection of fish and wildlife habitat and water quality and to provide water for navigation, water supply, and recreation. During years of normal precipitation, there is sufficient water to meet these demands. During droughts, however, and especially during several consecutive years of drought, lake levels can decline to a point where demands cannot be met. When this occurs, the limited amount of water must be shared among competing interests to lessen the impact of the drought. Each user of the resource bears the burden of having less water than is needed, and each shares the responsibility of protecting the environment.

The recent drought that lasted from June 1998 to August 2002 was one of the most severe on record. Water levels in several lakes dropped to dangerously low levels, disrupting lake and downstream users and threatening water-supply intakes and water quality. This section of the report illustrates, with a series of hydrographs, the effects that the drought had on lake levels in the State.

METHODOLOGY

Daily water levels of nine lakes were compiled and plotted over a period from October 1, 1996, to September 30, 2002, to evaluate lake conditions during the drought (Figures 31-39). Lake levels on each hydrograph are referenced to mean sea level (msl) and are shown in black.

Superimposed on each graph is the lake's "rule curve", which represents the desired operating level of the lake. Ideally, lakes should be maintained at levels indicated by the rule curve. When levels drop below this curve it indicates that there is a shortage of water in the lake; when levels rise above this curve it indicates that there is a surplus of water.

One of the ways that lakes are managed to control flooding is by increasing the volume of flood storage in the fall and winter in expectation of heavy rains and flooding that ordinarily occur during the spring. Consequently, lakes are intentionally lowered in the fall and winter months, to increase storage, and are raised in the spring and summer months. These changes in lake levels are reflected on the rule curve of each lake.

DISCUSSION AND HYDROGRAPHS

The lowest lake levels occurred during the last several months of the drought. Lake Jocassee, for example, was 24.9 ft (feet) below desired operating levels in September 2002 (Figure 33) and Lakes Hartwell and Thurmond were more than 14 ft below desired operating levels in September 2002 (Figures 32 and 38). Lake levels in Keowee, Marion, and Moultrie were about 5 ft below desired levels during the last few months of the drought (Figures 34, 35, and 36). Levels in Lakes Greenwood, Murray, and Wateree were generally maintained to within several feet of their rule curves throughout the drought (Figures 31, 37, and 39).

Toward the end of the drought, levels in Lake Thurmond dropped to within 4 ft of the base of the conservation pool. The conservation pool refers to the amount of usable water in a lake—water that can be used to meet authorized demands, such as water for public-supply systems. Releases from the lake were reduced from 4,500 cfs (cubic feet per second) to 3,600 cfs in accord with the lake's drought contingency plan. To maintain this minimum-flow requirement, water had to be released from Lake Hartwell, causing further declines in Lake Hartwell. If the drought had continued for several more months, it is estimated that levels in Lake Thurmond would have reached the base of the conservation pool and discharge to the river would have been reduced to an amount equal to the lake's inflow. This would have threatened water-supply intakes, diminished water quality for fish and wildlife, and caused saltwater to migrate upstream.

The effects of the drought were also felt in the Yadkin–Pee Dee basin. Streamflows in the Pee Dee River historically average about 8,000 cfs. During the drought, however, flow rates were reduced to about 300 cfs. These low flows were threatening the operations of industries that rely on the river to assimilate their effluent. In coastal areas, low flows were causing saltwater to move upstream, threatening water-supply intakes in the Grand Strand area.

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Flow rates of the Pee Dee River are controlled by a series of six lakes in North Carolina. Severe rainfall deficits in North Carolina caused inflow rates to decline substantially. Computer flow models developed by the U.S. Geological Survey indicated that a minimum flow of 900 cfs is required to keep industries operating and to keep saltwater from contaminating supply intakes. Negotiations between the States resulted in an agreement to discharge 900 cfs to the Pee Dee River by releasing additional water from the North Carolina lakes.

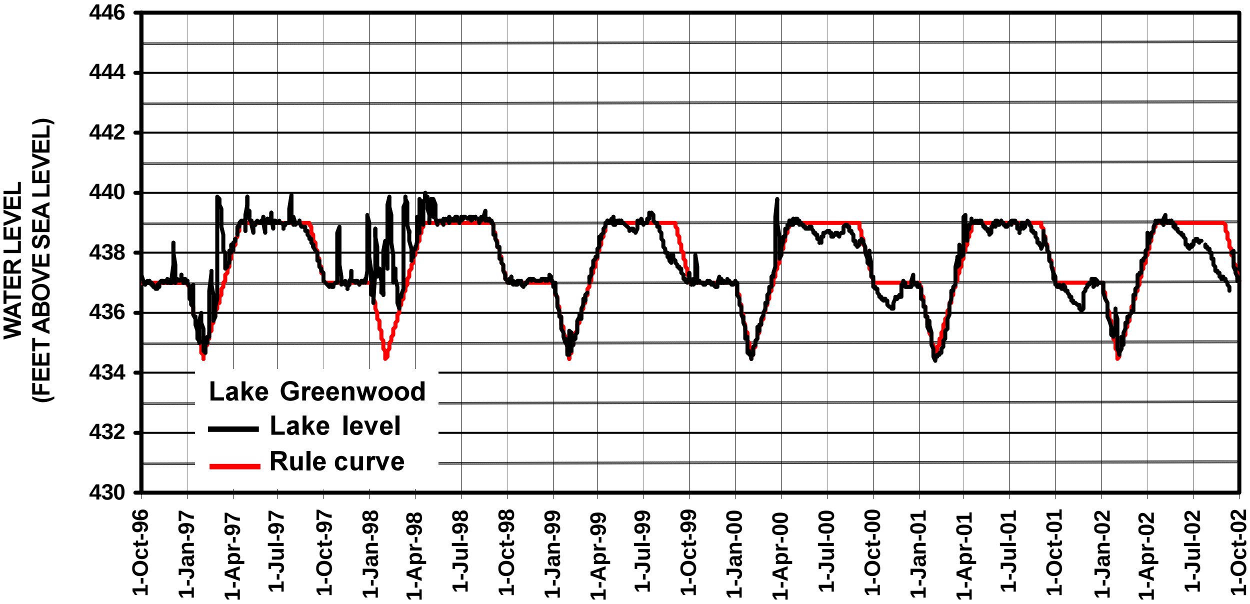

Figure 31. Completed in 1940 for the production of hydropower, Lake Greenwood is owned by Greenwood County and is operated by Duke Power Company (Buzzards Roost hydroelectric plant). In addition to supplying hydropower, the lake is also used as a source for supply systems and for recreation. Impounding the Saluda River, the lake has a surface area of 11,400 acres, a volume of 270,000 acre-feet, and a drainage area of about 1,170 mi^2 (square miles). During the drought, lake levels were maintained at desired operating levels by regulating releases. On average, the lake was only 0.1 ft below desired levels during the period from June 1, 1998, to September 30, 2002. Lake levels were at their lowest during the summer of 2002, dropping to 1.8 ft below the rule curve on September 1, 2002.

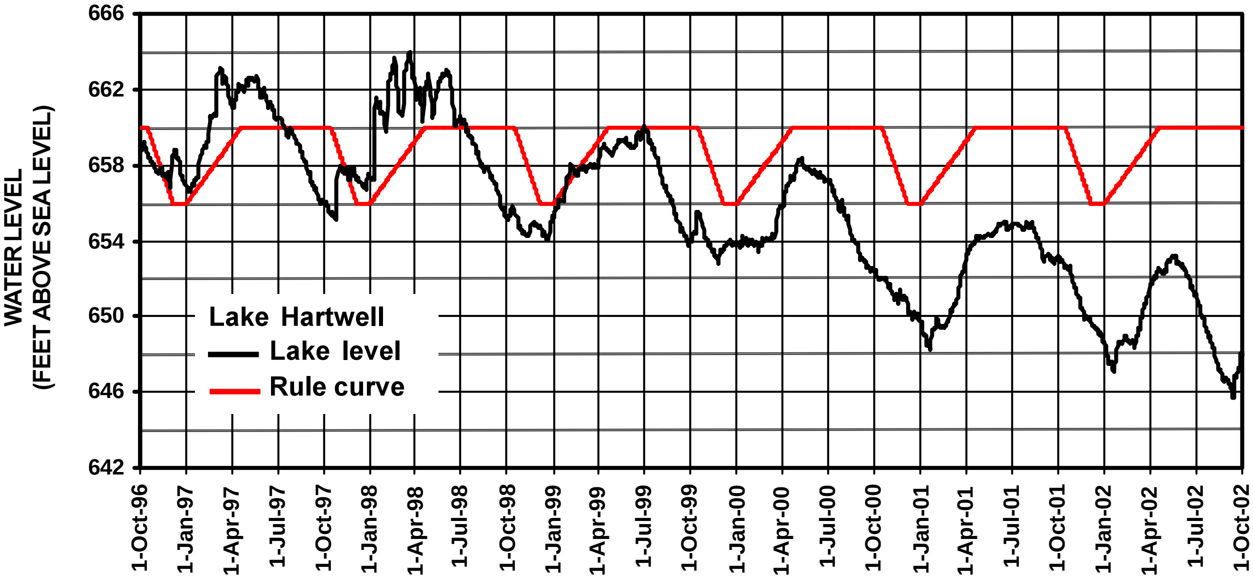

Figure 32. Completed in 1962, Lake Hartwell is used for hydropower production, flood control, recreation, and water supply. The lake is owned and operated by the U.S. Army Corps of Engineers. Impounding the Savannah River, the lake has a surface area of 56,000 acres, a volume of 2,549,000 acre-feet, and a drainage area of 2,088 mi^2. Lake levels progressively declined during each year of the drought. On average, the lake was 4.9 ft below desired operating levels during the period from June 1, 1998, to September 30, 2002. Lake levels were at their lowest during the summer of 2002, dropping to 14.3 ft below the rule curve on September 13, 2002.

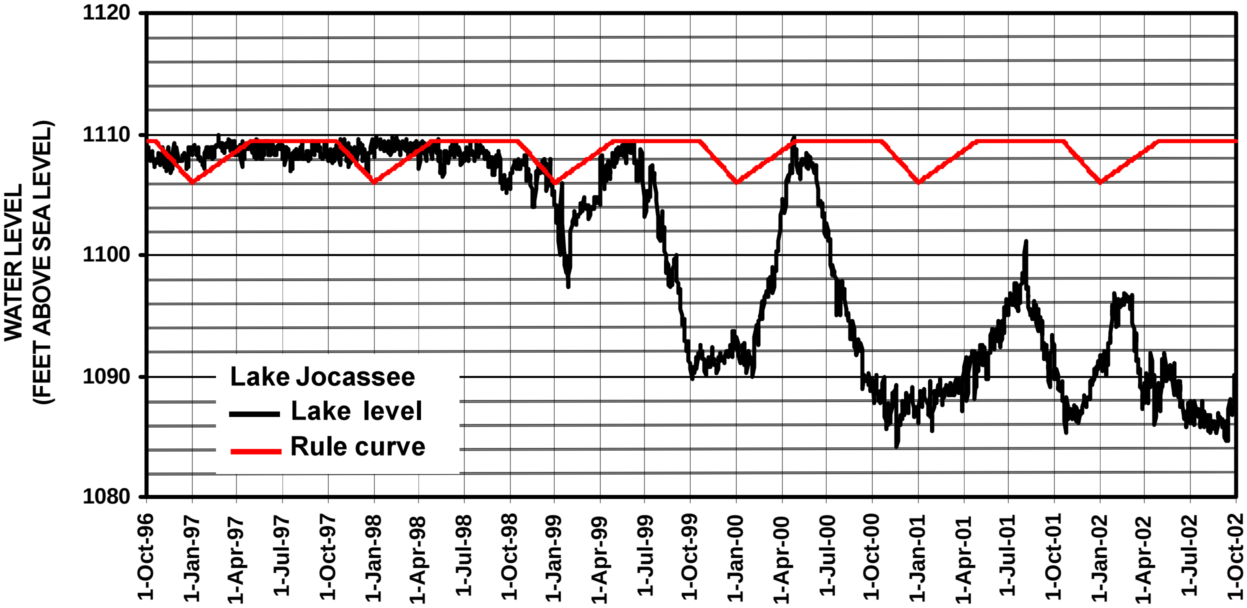

Figure 33. Completed in 1974, Lake Jocassee is used for hydropower generation and recreation. The lake is owned and operated by Duke Power Company. Supplied by the Keowee, Toxaway, and Whitewater Rivers, the lake has a surface area of 7,565 acres and a volume of 1,185,000 acre-feet. During the drought, lake levels declined sharply each summer. On average, the lake was 12.4 ft below desired operating levels during the period from June 1, 1998, to September 30, 2002. The lake level dropped to 24.9 ft below the rule curve on September 10, 2002.

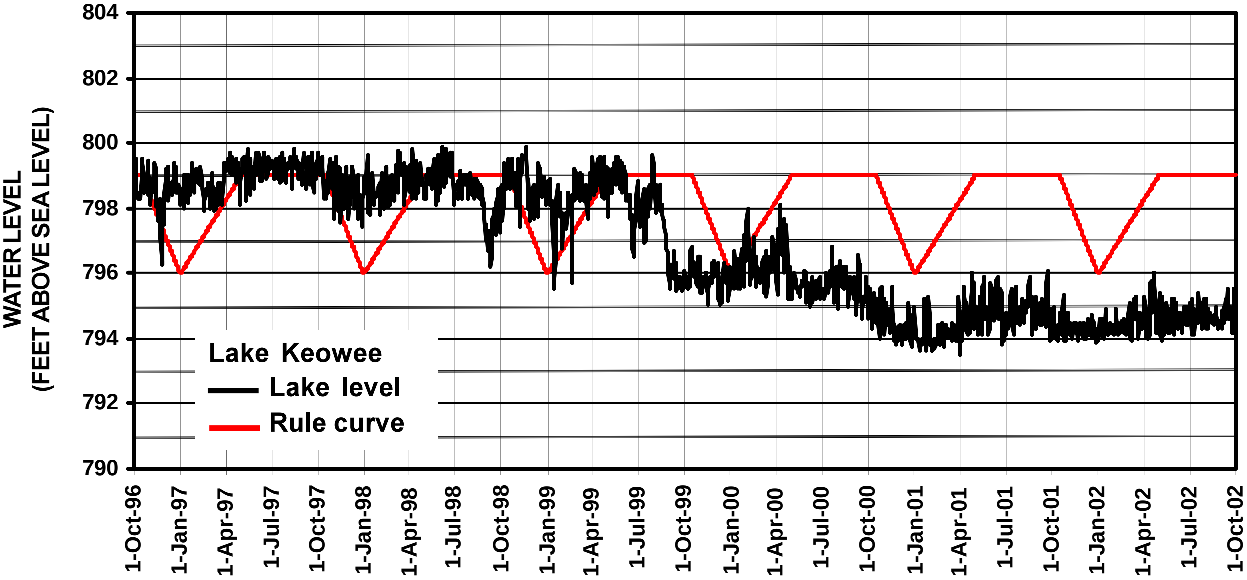

Figure 34. Completed in 1971, Lake Keowee is used for hydropower generation, recreation, cooling water for Oconee Nuclear Station, and for the pumped-storage facility at Lake Jocassee. The lake is owned and operated by Duke Power Company. Created by damming of adjacent rivers, the Keowee and the Little, the lake has a surface area of 18,372 acres and a volume of 1,000,000 acre-feet. During the first year of the drought, lake levels were maintained at desired operating levels. Thereafter, lake levels declined and were below desired levels for the remainder of the drought. On average, the lake was 2.2 ft below desired levels during the period from June 1, 1998, to September 30, 2002. Lake levels dropped to 5.2 ft below the rule curve on June 25, 2001.

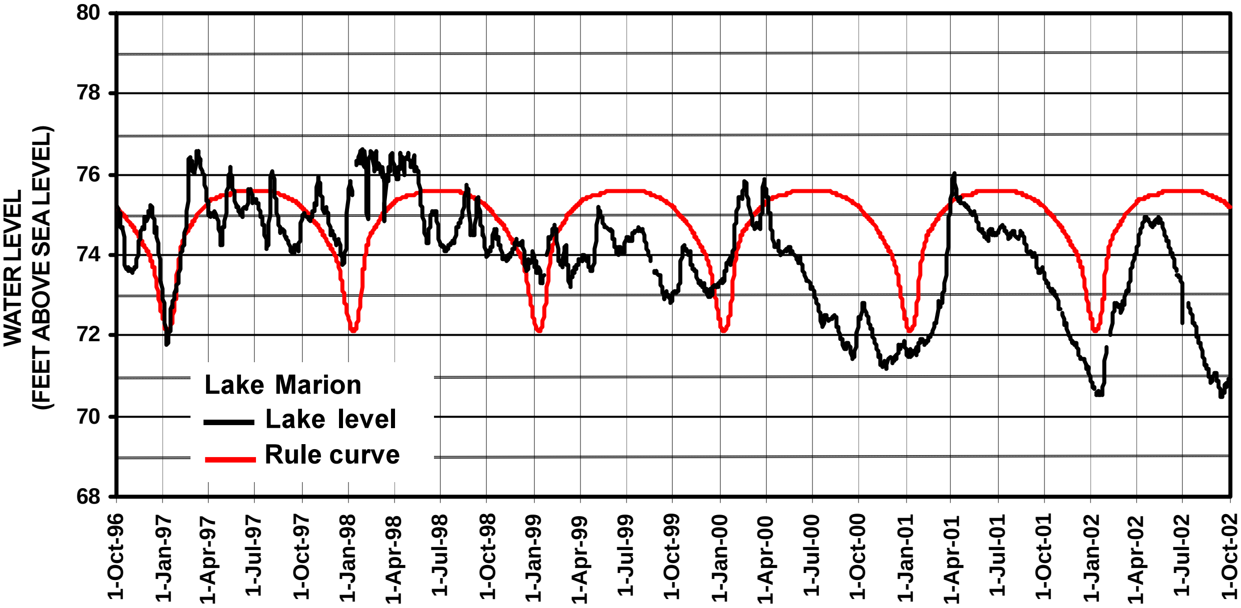

Figure 35. Completed in 1941, Lake Marion is used for hydropower production, flood control, and recreation. The lake is owned and operated by Santee-Cooper. Impounding the Santee River, the lake has a surface area of 110,600 acres, a volume of 1,400,000 acre-feet, and a drainage area of about 14,300 mi^2. Significant declines began occurring in the summer of 2000 when lake levels were 2-4 ft below desired operating levels. On average, the lake was 1.4 ft below desired levels during the period from June 1, 1998, to September 30, 2002. Lake levels dropped to 4.9 ft below the rule curve on September 13, 2002.

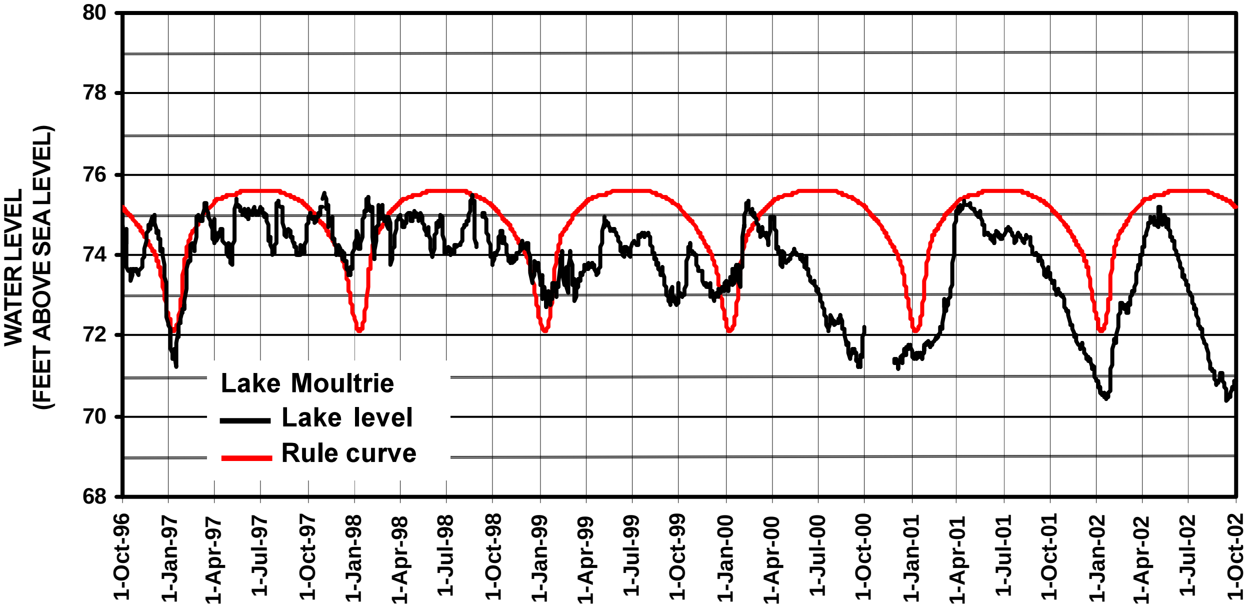

Figure 36. Completed in 1941, Lake Moultrie is used for hydropower production, recreation, and water supply. The lake is owned and operated by Santee-Cooper. Supplied by a diversion canal from Lake Marion, the lake has a surface area of 60,400 acres and a volume of 1,200,000 acre-feet. Significant declines began occurring in the summer of 2000 when lake levels were 2-4 feet below desired operating levels. On average, the lake was 1.5 ft below desired levels during the period from June 1, 1998, to September 30, 2002. Lake levels were at their lowest during the summer of 2002, dropping to 5.0 ft below the rule curve on September 13, 2002.

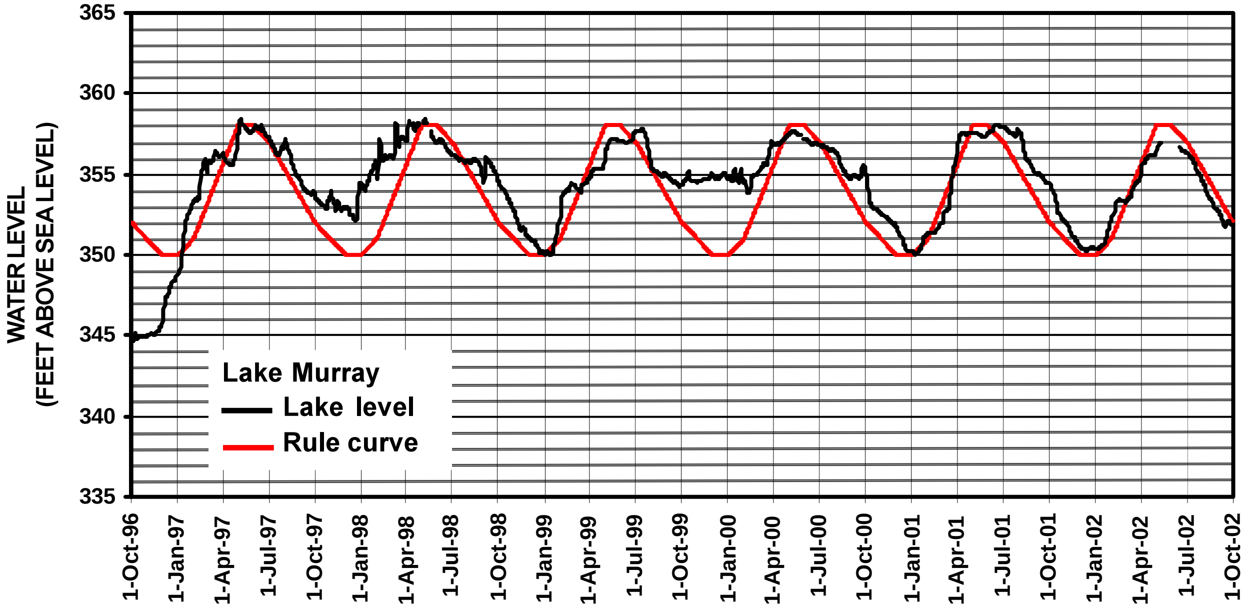

Figure 37. Completed in 1930, Lake Murray is used for hydropower generation, recreation, and water supply. The lake is owned and operated by S.C. Electric and Gas Company. Created by damming the Saluda River, the lake has a surface area of 51,000 acres, a volume of 2,114,000 acre-feet, and a drainage area of about 2,420 mi^2. Lake levels were maintained at desired operating levels throughout the drought. On average, the lake was 0.8 ft above desired levels during the period from June 1, 1998, to September 30, 2002. A maximum decline of 2.3 ft below the rule curve was measured on April 27, 1999.

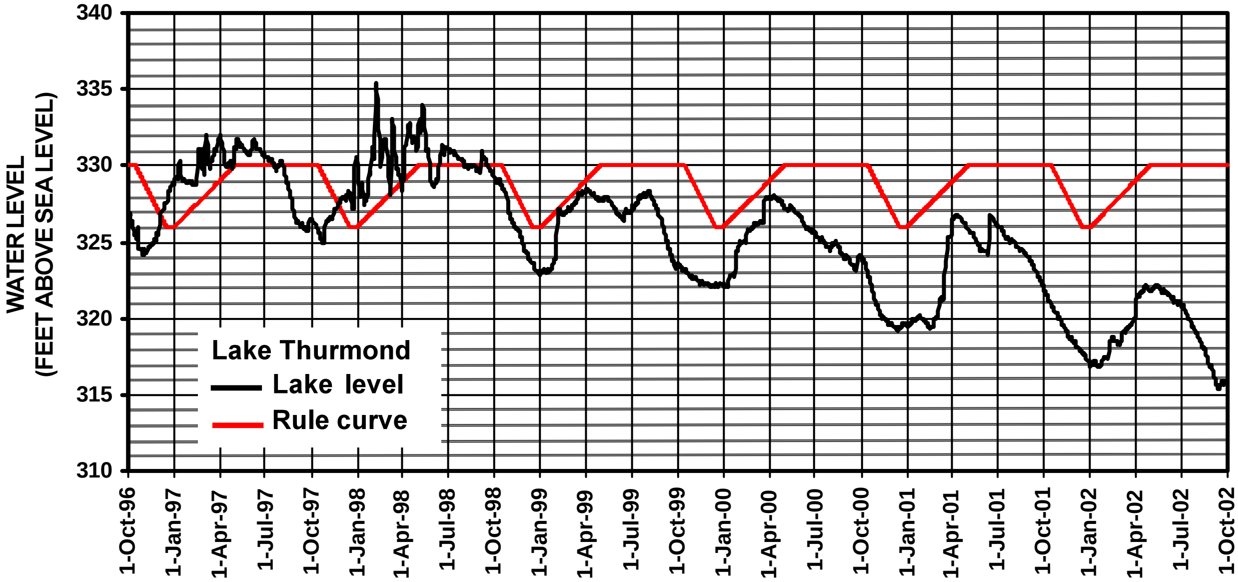

Figure 38. Completed in 1952, Lake Thurmond is used for hydropower generation, flood control, water supply, recreation, and as a supply for the pumped-storage facility at Lake Russell. The lake is owned and operated by the U.S. Army Corps of Engineers. Impounding the Savannah River, the lake has a surface area of 70,000 acres, a volume of 2,510,000 acre-feet, and a drainage area of about 6,150 mi^2. Lake levels declined each year during the drought. On average, the lake was 5.0 ft below desired operating levels during the period from June 1, 1998, to September 30, 2002. Lake levels were at their lowest during the summer of 2002, dropping to 14.7 ft below the rule curve on September 14, 2002.

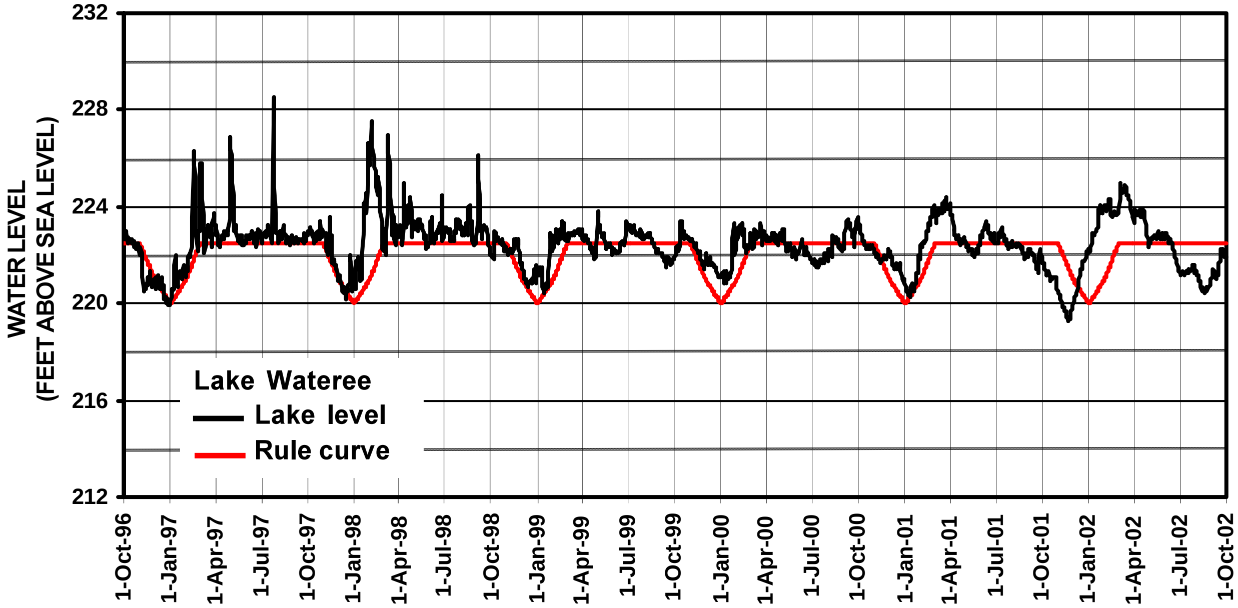

Figure 39. Completed in 1919, Lake Wateree is used for hydropower generation, water supply, and recreation. The lake is owned and operated by Duke Power Company. Created by damming the Wateree River, the lake has a surface area of 13,710 acres and a volume of 310,000 acre-feet. Lake levels were maintained at or above the desired operating level throughout the drought. On average, the lake was 0.3 ft above desired levels during the period from June 1, 1998, to September 30, 2002. The maximum decline from the rule curve was 2.2 ft, which occurred on November 20, 2001.

STREAMFLOW CONDITIONS IN SOUTH CAROLINA DURING THE JUNE 1998 – AUGUST 2002 DROUGHT

by
Masaaki Kiuchi

INTRODUCTION

South Carolina was in a continuous drought from June 1998 to August 2002. Successive tropical storms and other rain events from late summer through the end of the year in 2002 finally relieved the drought conditions. As a result of the large precipitation deficit, especially during the normal recharge period of late winter and spring, streamflow throughout the State declined each year. This report presents the impact of the multiyear drought on both unregulated (no impoundment) and regulated streams.

UNREGULATED STREAMS

Unregulated streams depend on rain and ground-water discharge to sustain flow. As the severity of drought worsened, they depended more on ground-water discharge to sustain flow; however, the shortage of rain during the recharge period in late winter and spring for 4 years caused ground-water levels to remain low. As a result, many unregulated streams recorded new historical low flows in 2003 (Table 2). Of 14 unregulated streams with their duration of record 30 years or longer, 8 broke previous low-flow records.

Streamflow data for a total of 17 unregulated streams were compiled and plotted (hydrographs) over a period from October 1, 1996, to September 30, 2002, to evaluate streamflow conditions during the drought (Figures 40-56). It is clear from these hydrographs that the multiyear drought impacted streamflow significantly, owing to the reduced base flow (ground-water discharge) as the drought progressed. Each hydrograph contains actual (measured) daily average flows (cubic feet per second, cfs) in blue; statistical daily average flows in red, which were derived from the measured daily average flows for the period of record; and the historical lowest flow in orange. Data from October 1, 2001, to September 30, 2002, are provisional and are subject to change. Locations of stream gages used in this report are provided in Figure 1.

A summary of lowest flows is given in Table 2. The lowest flows for 14 unregulated streams with a record of 30 years or longer are given for each decade, as well as for years 2000, 2001, and 2002 (as of September 30). The historical lowest flow for each stream is highlighted in yellow. The records for 2002 are based on provisional data and are subject to change.

REGULATED STREAMS

Unlike unregulated streams, flow in regulated streams was largely sustained by releases from the reservoirs during very low flow periods. Although the release of water from these reservoirs also decreased incrementally following drought contingency plans implemented as the multiyear drought progressed, flow in these regulated streams fared better than in the unregulated streams, owing to a constant rate of water release, especially in streams with large reservoirs.

Hydrographs for regulated streams (Figures 57-65) were constructed in the same way as those for unregulated streams. Pee Dee River at Peedee broke its historical low-flow record in October 2001. Broad River near Alston also broke its record (lowest flow recorded before regulation).

Table 2. Analysis of low flow for 14 unregulated (no impoundment) streams in South Carolina. This table shows the lowest flow for each decade and for calendar years 2000, 2001, and 2002. The historical lowest flow for each stream is highlighted in yellow. For the year 2002, data are provisional and subject to change.

	1950's	1960's	1970's	1980's	1990's	2000	2001	2002
Waccamaw River, Longs Horry County	1.0 10/14/54	6.6 10/25/63	14 11/09/78	2.8 10/21/83	13 06/02/95	35 06/10/00	7.3 11/21/01	7.3 06/17/02
Black Creek, McBee Chesterfield County	167 12/03/59	22 08/31/68	27 07/04/70	17 06/29/81	17 08/04/90	29 08/22/00	17 08/27/01	9.5 08/14/02
Lynches River, Effingham Florence County	95 10/09/54	147 10/06/68	141 07/10/70	110 07/26/86	144 08/17/99	147 08/24/00	100 11/01/01	69 08/16/02
Little Pee Dee River, Galivants Ferry Horry-Marion Counties	158 10/12/54	158 10/06/68	386 10/29/78	290 09/07/80	180 07/13/90	524 05/25/00	271 11/17/01	76 08/18/02
Black River, Kingstree Williamsburg County	2.0 09/12/54	11 10/13/68	20 07/26/77	7.2 07/27/86	7.0 09/13/99	10 07/17/00	12 10/29/01	2.7 08/24/02
Rocky Creek, Great Falls Chester County	0.04 10/06/54	5.9 09/11/66	9.1 10/10/70	4.9 08/27/88	1.3 09/03/99	0.69 08/21/00	2.8 08/23/01	0.0 08/11/02
Reedy River, Greenville Greenville County	8 10/04/54	18 07/25/66	22 07/12/70	10 06/29/88	5.3 08/19/99	10 09/16/00	11 08/21/01	8.1 09/12/02
South Fork Edisto River, Denmark Bamberg-Orangeburg Counties	156 08/11/56	261 08/19/63	268 07/05/70	148 07/14/86	133 07/13/90	176 06/04/00	200 08/29/01	114 08/15/02
North Fork Edisto River, Orangeburg Orangeburg County	190 09/13/54	328 10/06/68	327 08/08/70	200 07/21/86	222 08/13/99	194 06/04/00	199 08/29/01	128 08/15/02
Edisto River, Givhans Dorchester County	292 08/16/56	600 09/12/63	563 07/22/77	268 07/21/88	252 07/13/90	323 06/17/00	412 10/30/01	145 08/18/02
Salkehatchie River, Miley Hampton County	18 09/13/54	47 07/30/68	49 07/08/70	26 07/08/86	18 07/09/90	12 07/21/00	31 05/20/01	9.9 06/17/02
Coosawhatchie River, Hampton Hampton County	0.0 08/31/51	0.0 07/30/68	0.46 10/07/70	0.0 07/29/80	0.0 07/05/90	0.0 05/08/00	0.0 05/11/01	0.0 05/08/02
Little River, Mt. Carmel Abbeville County	1.0 10/08/54	24 09/05/62	26 07/20/70	1.0 08/31/88	12 09/19/99	6.7 07/12/00	13 09/17/01	2.2 09/13/02
Stevens Creek, Modoc Edgefield County	0.0 09/14/54	0.9 11/07/62	6.5 10/25/77	1.3 11/02/87	3.1 09/13/93	2.1 08/29/00	0.11 11/12/01	0.21 08/24/02

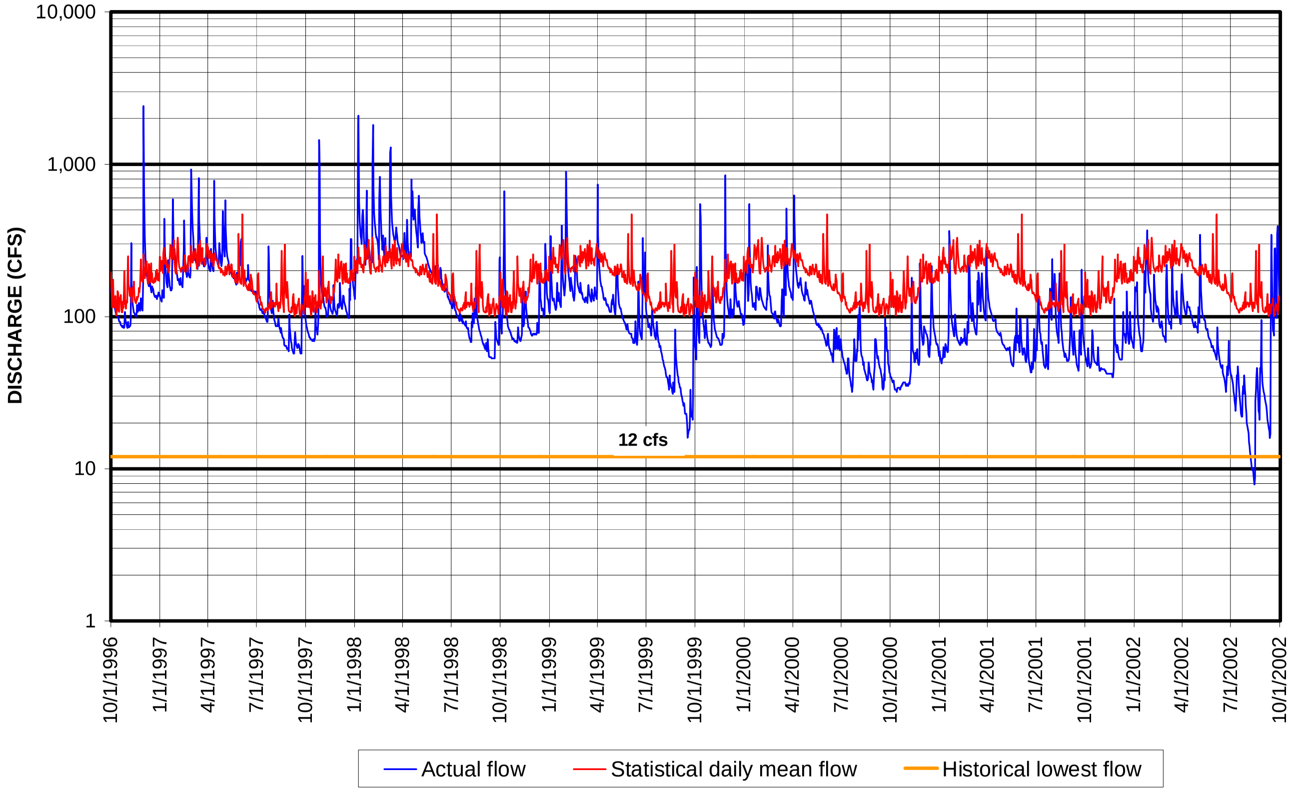

Figure 40. Little River near Walhalla, Oconee County (station 02185200).

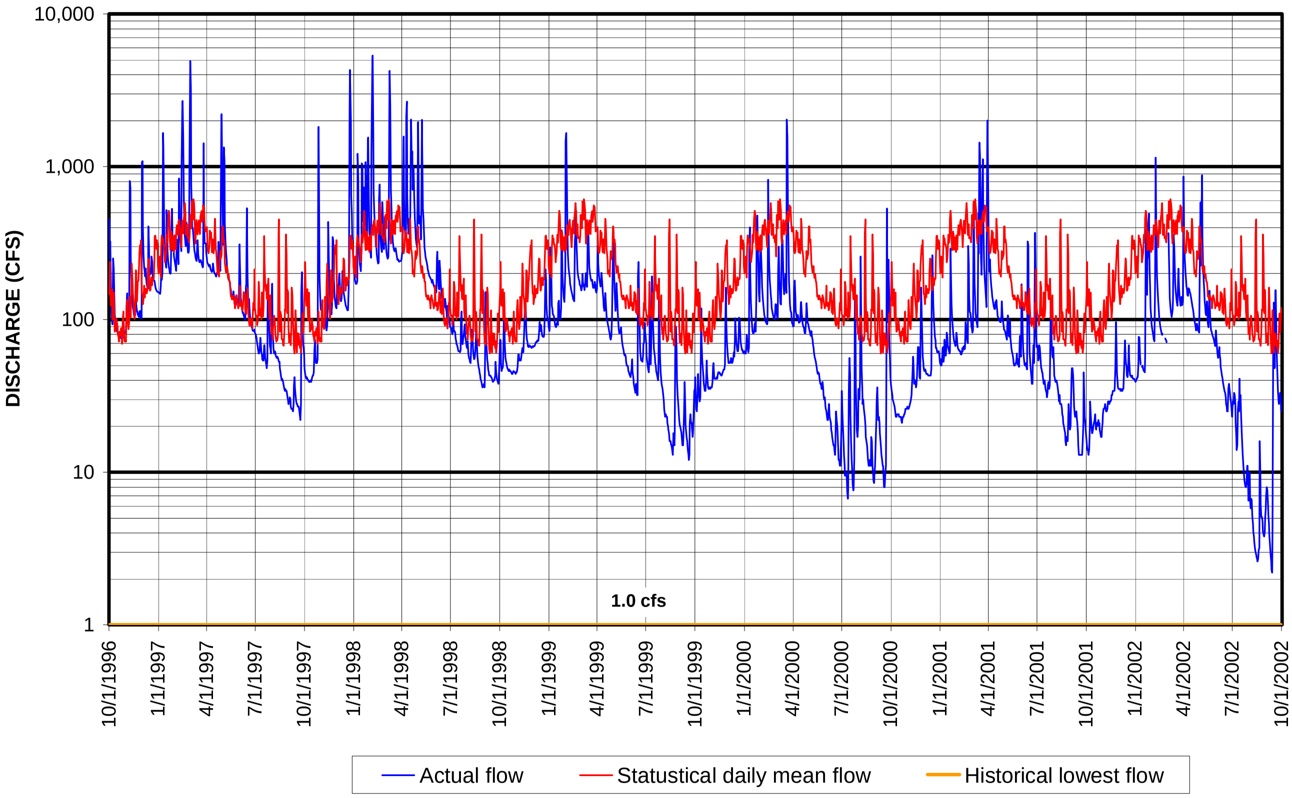

Figure 41. Little River near Mt.Carmel, Abbeville County (station 02192500).

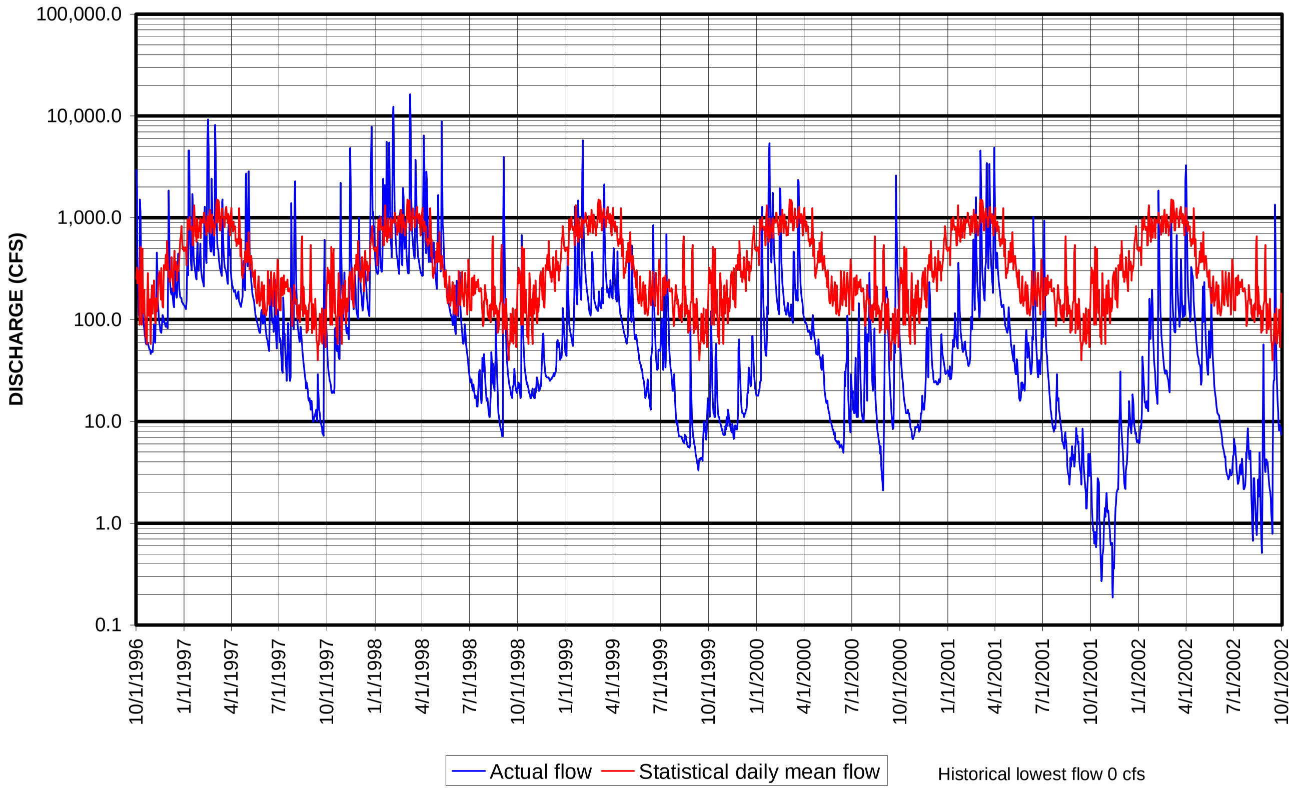

Figure 42. Stevens Creek near Modoc, Edgefield County (station 02196000).

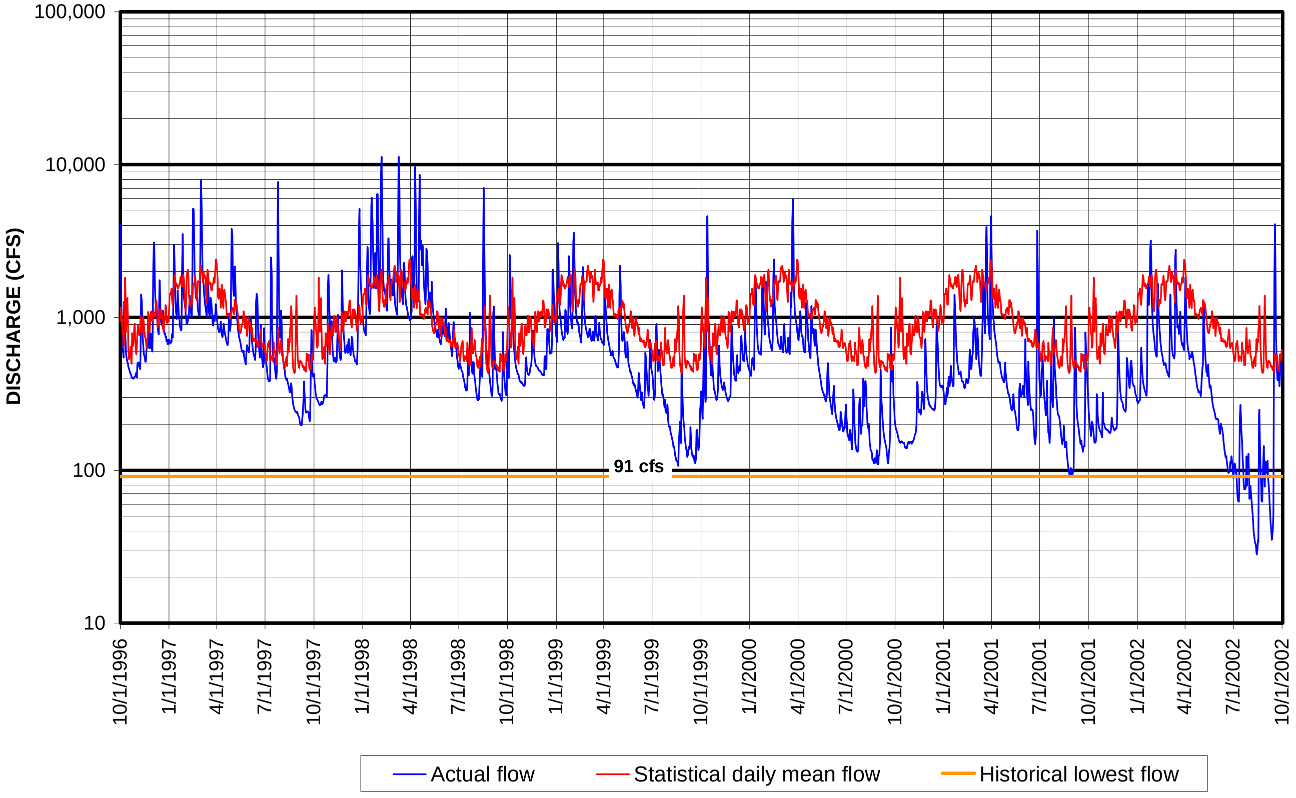

Figure 43. Tyger River near Delta, Union County (station 02160105).

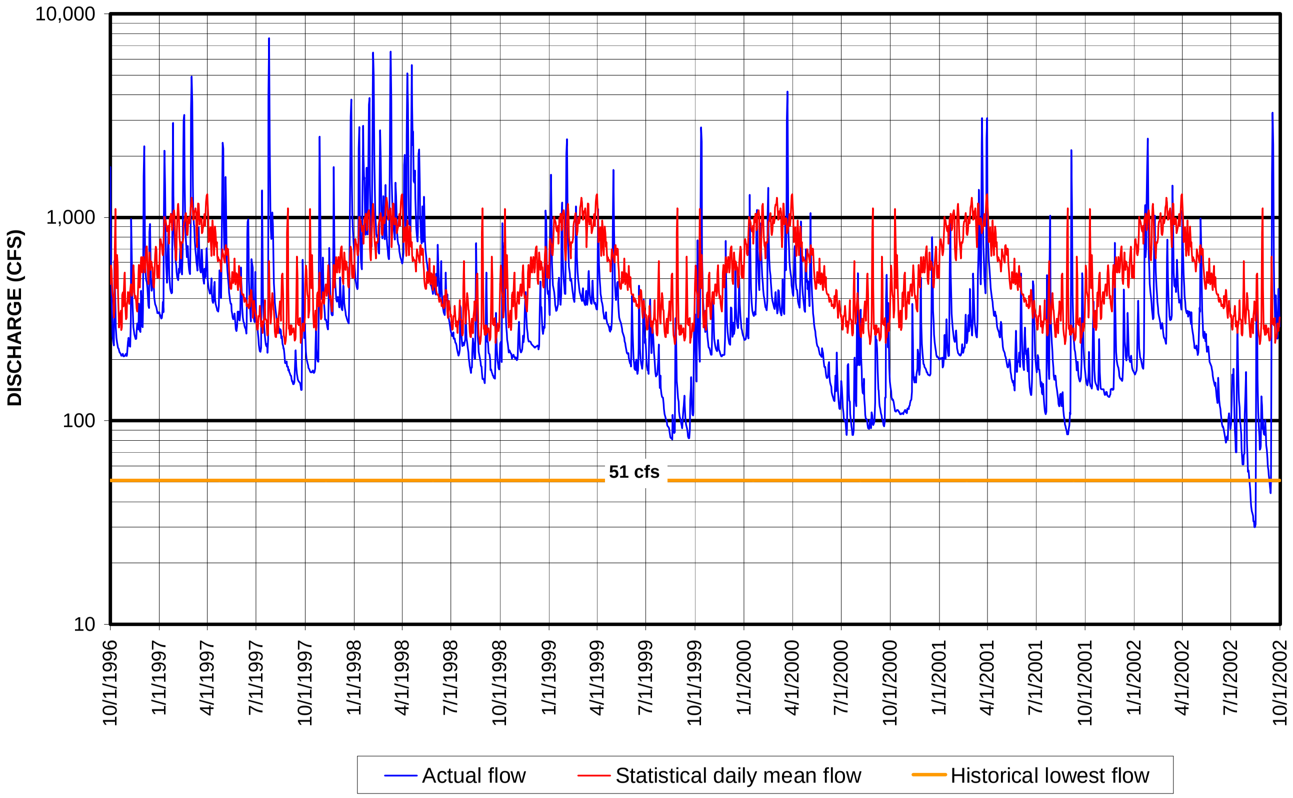

Figure 44. Enoree River at Whitmire, Union-Newberry County Line (station 02160700).

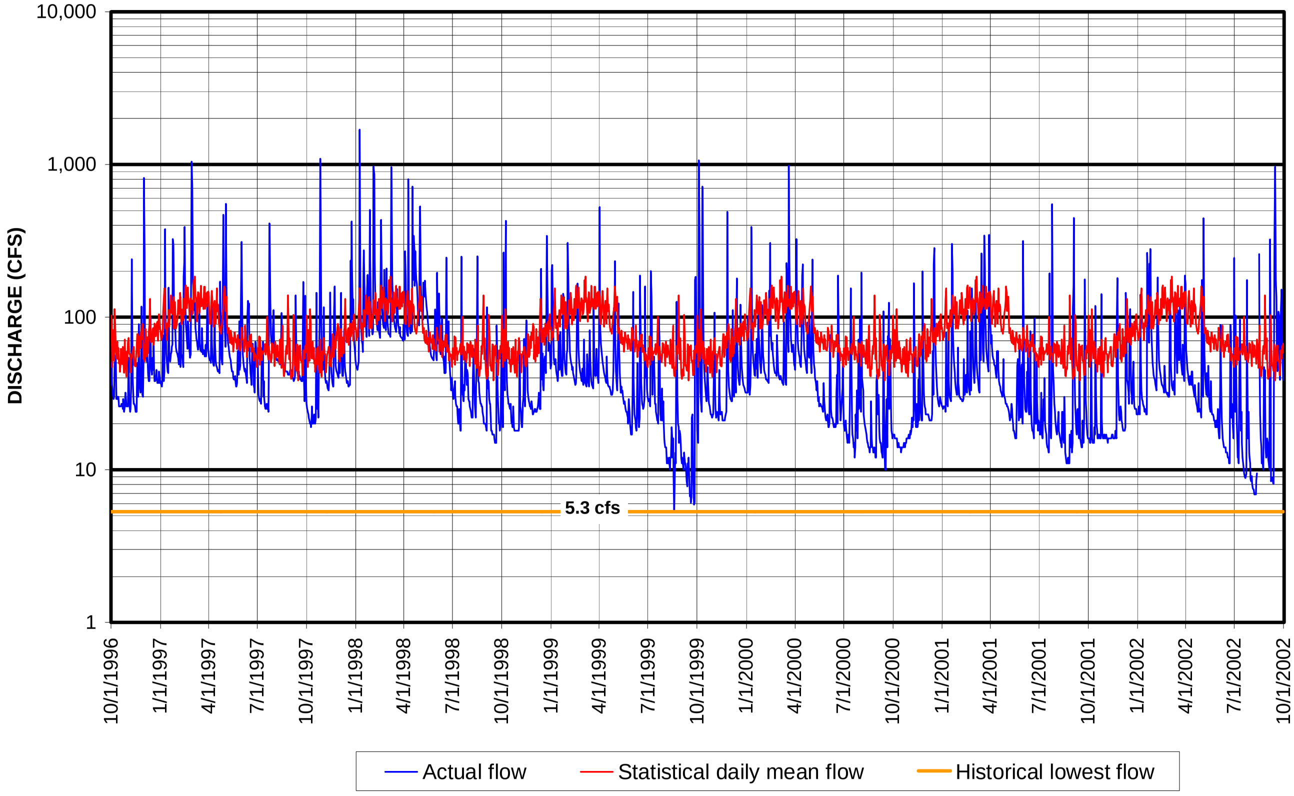

Figure 45. Reedy River near Greenville, Greenville County (station 02164000).

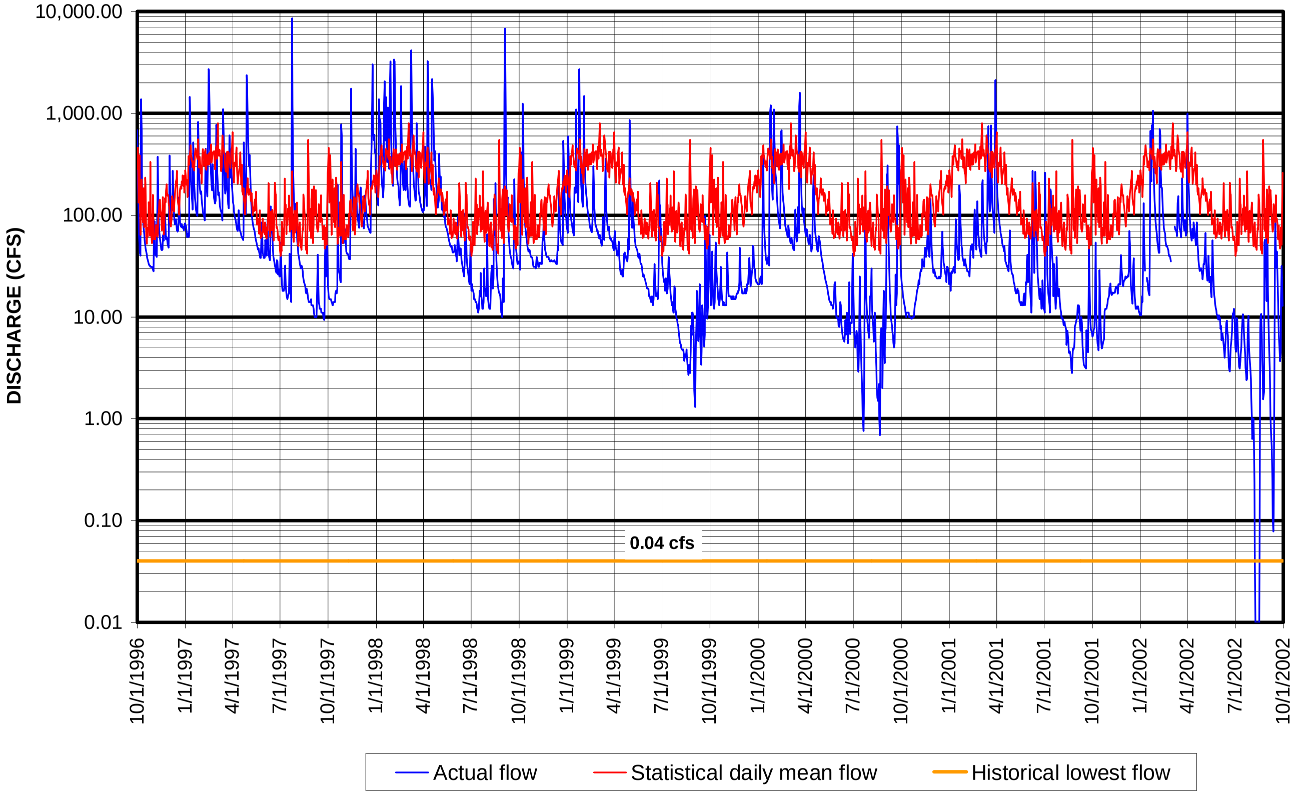

Figure 46. Rocky Creek at Great Falls, Chester County (station 02147500).

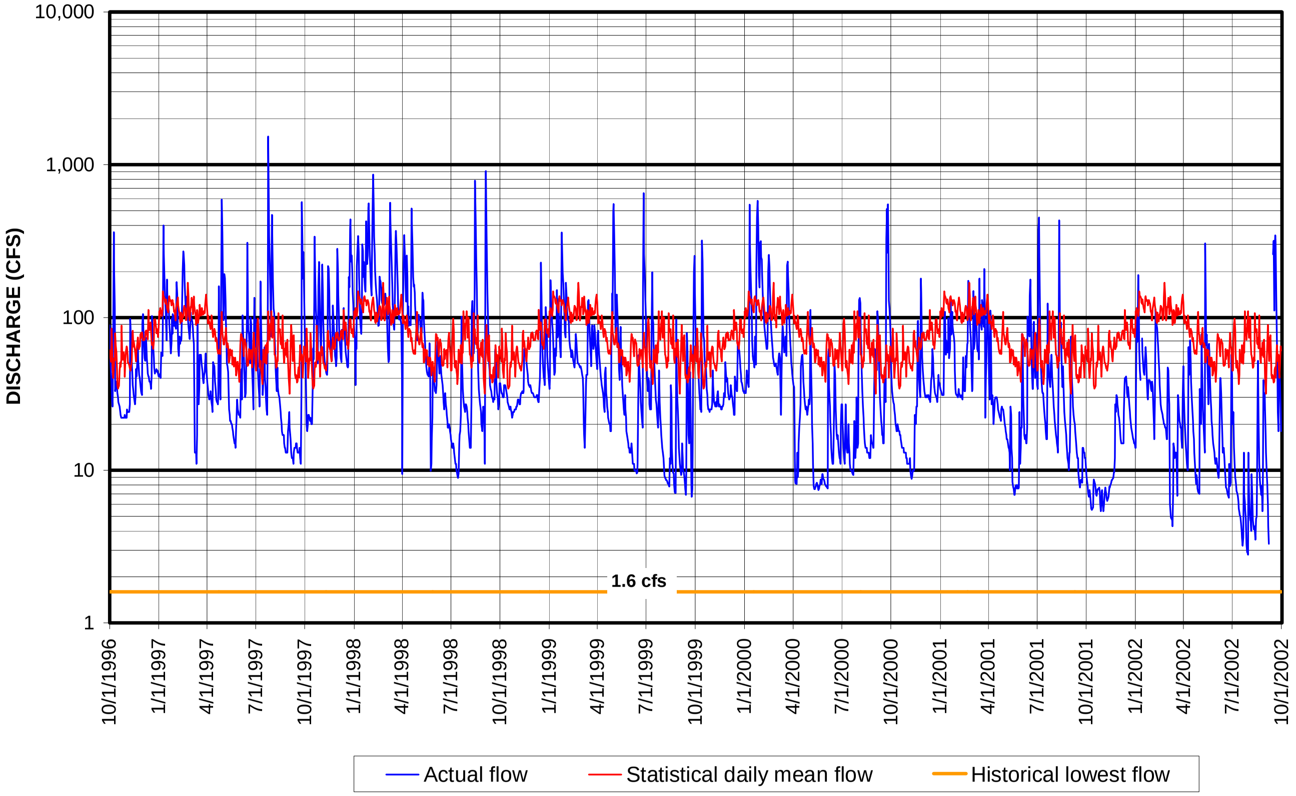

Figure 47. Gills Creek at Columbia, Richland County (station 02169570).

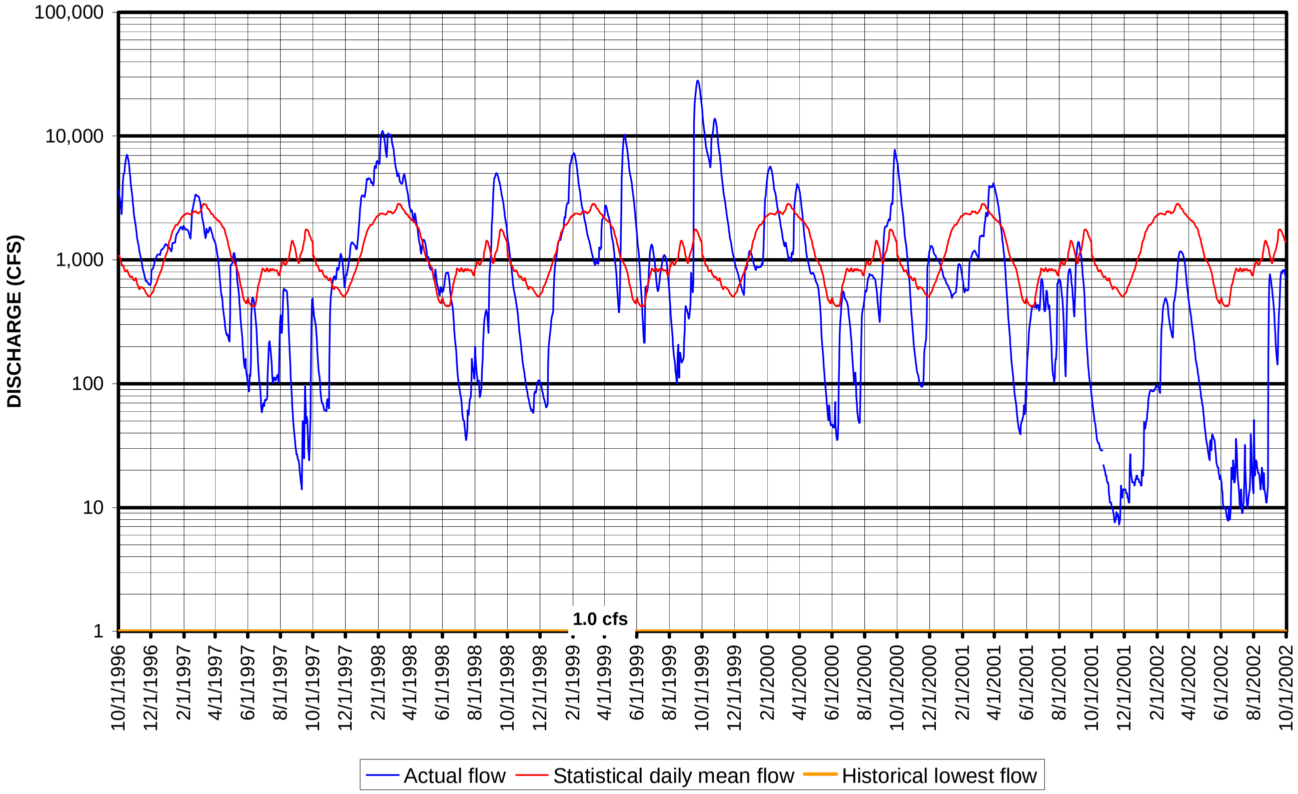

Figure 48. Waccamaw River near Longs, Horry County (station 02110500).

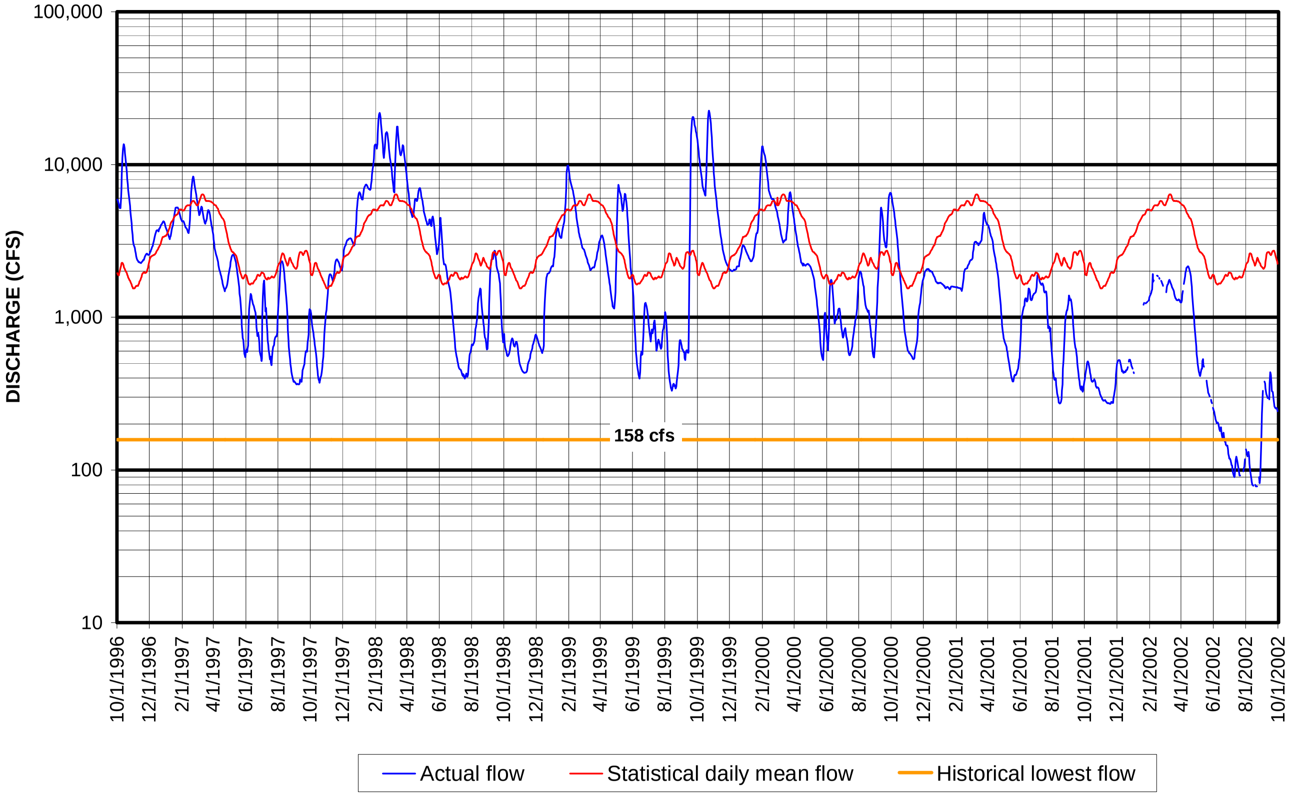

Figure 49. Little Pee Dee River at Galivants Ferry, Horry-Marion County Line (station 02135000).

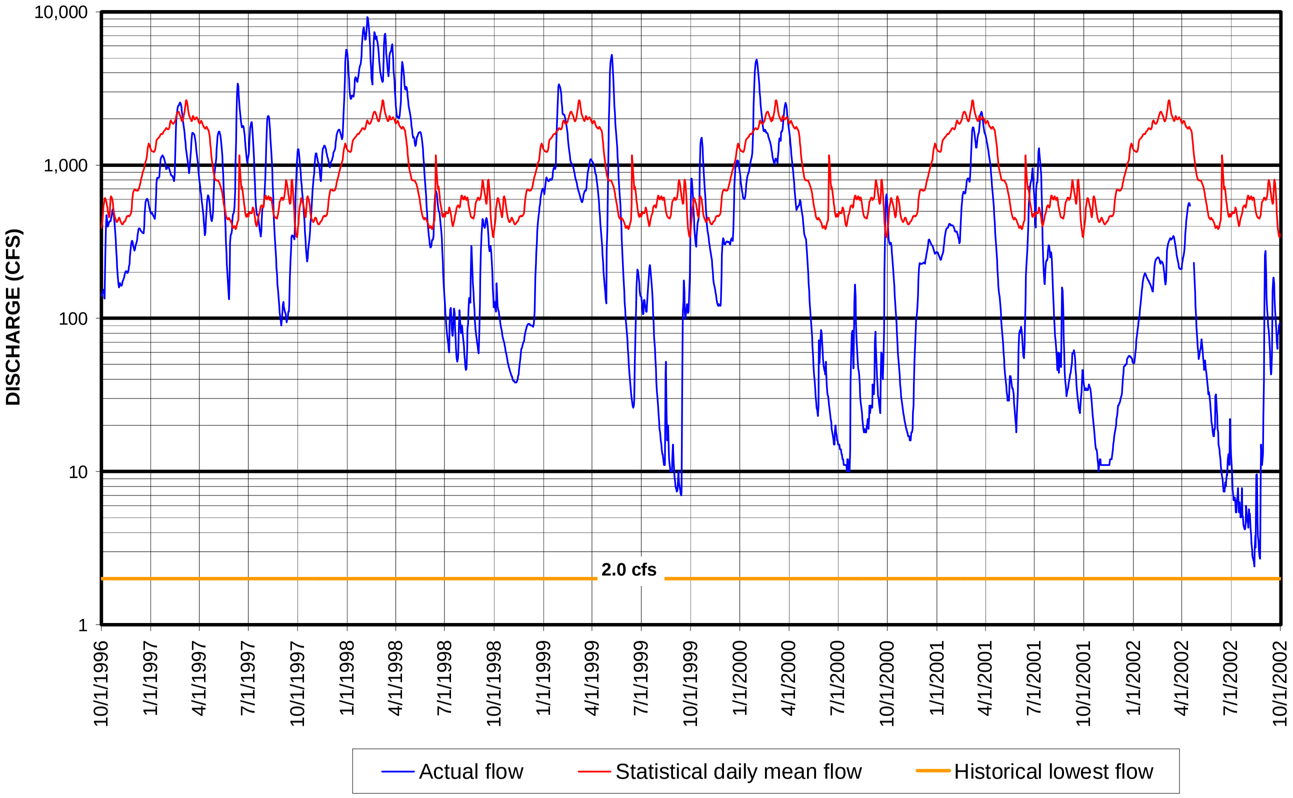

Figure 50. Black River at Kingstree, Williamsburg County (station 02136000).

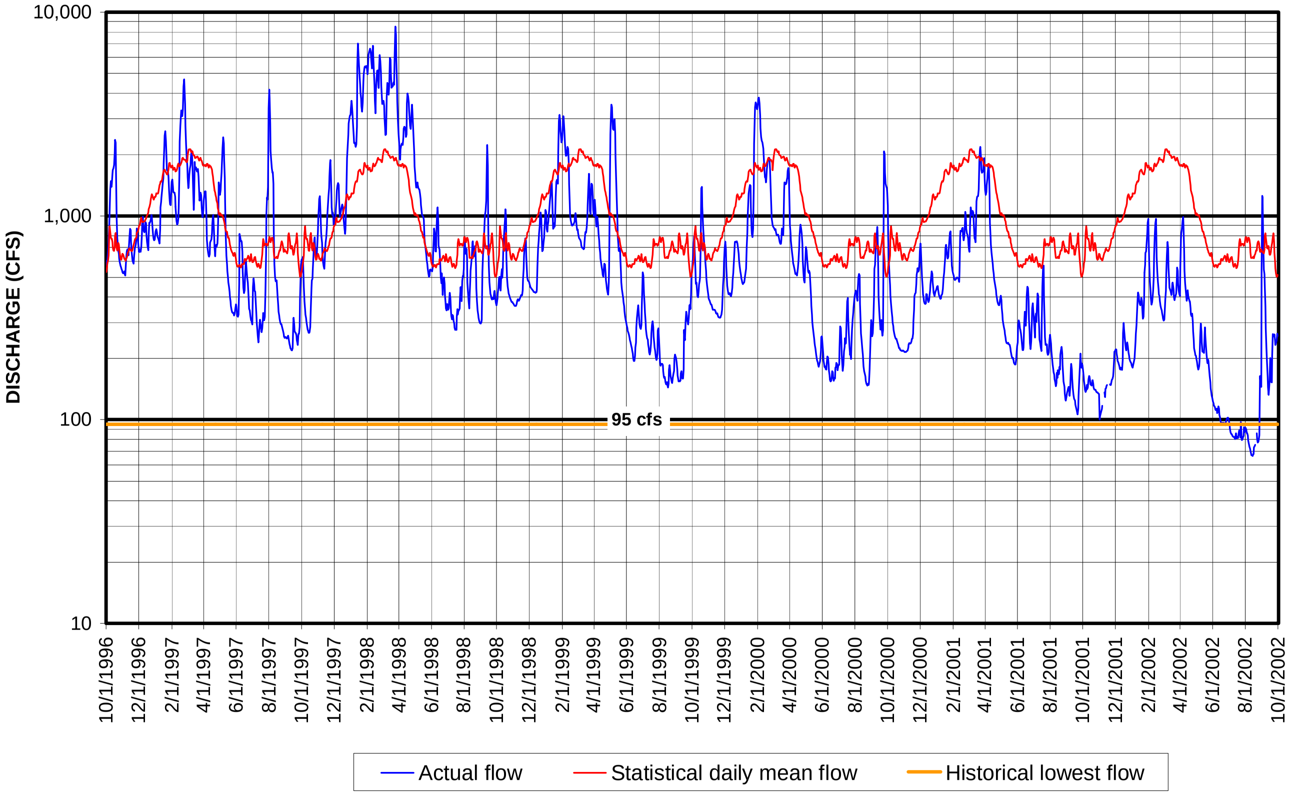

Figure 51. Lynches River at Effingham, Florence County (station 02132000).

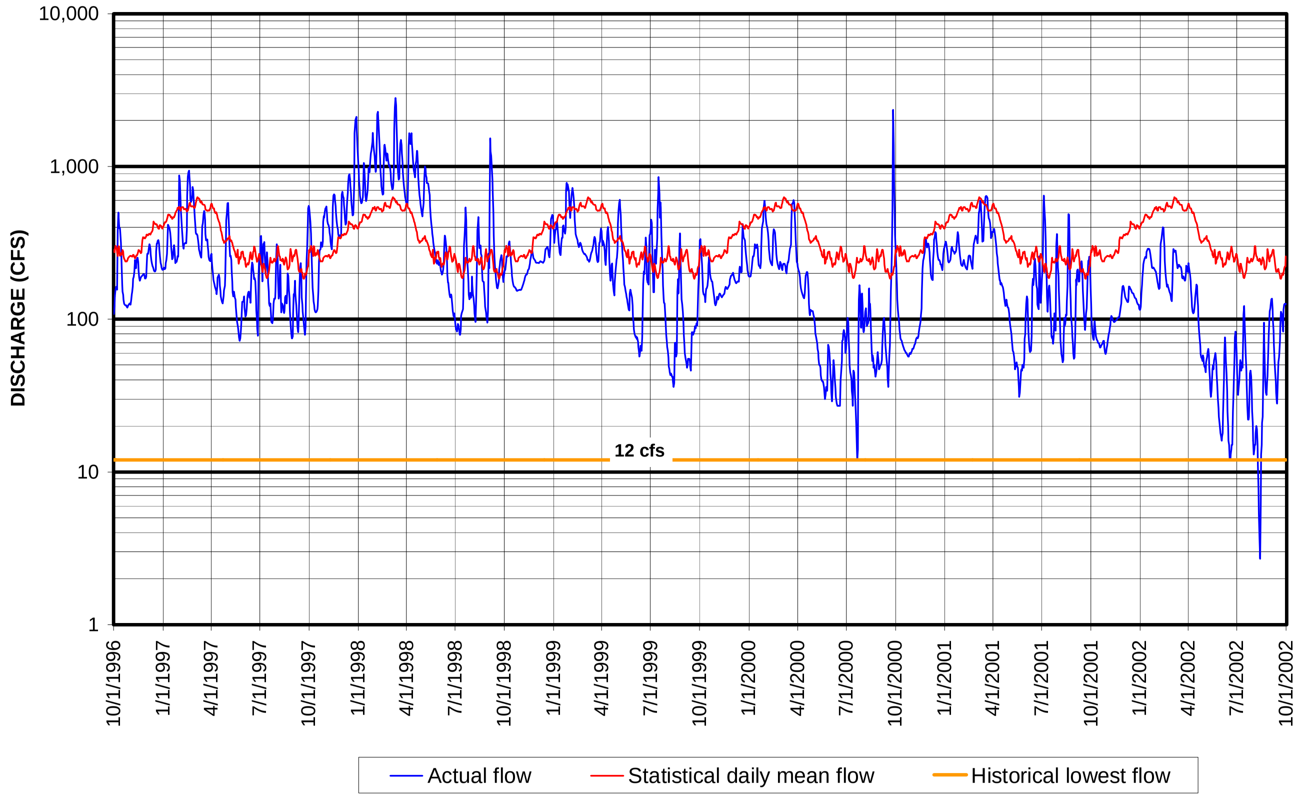

Figure 52. Salkehatchie River near Miley, Hampton County (station 02175500).

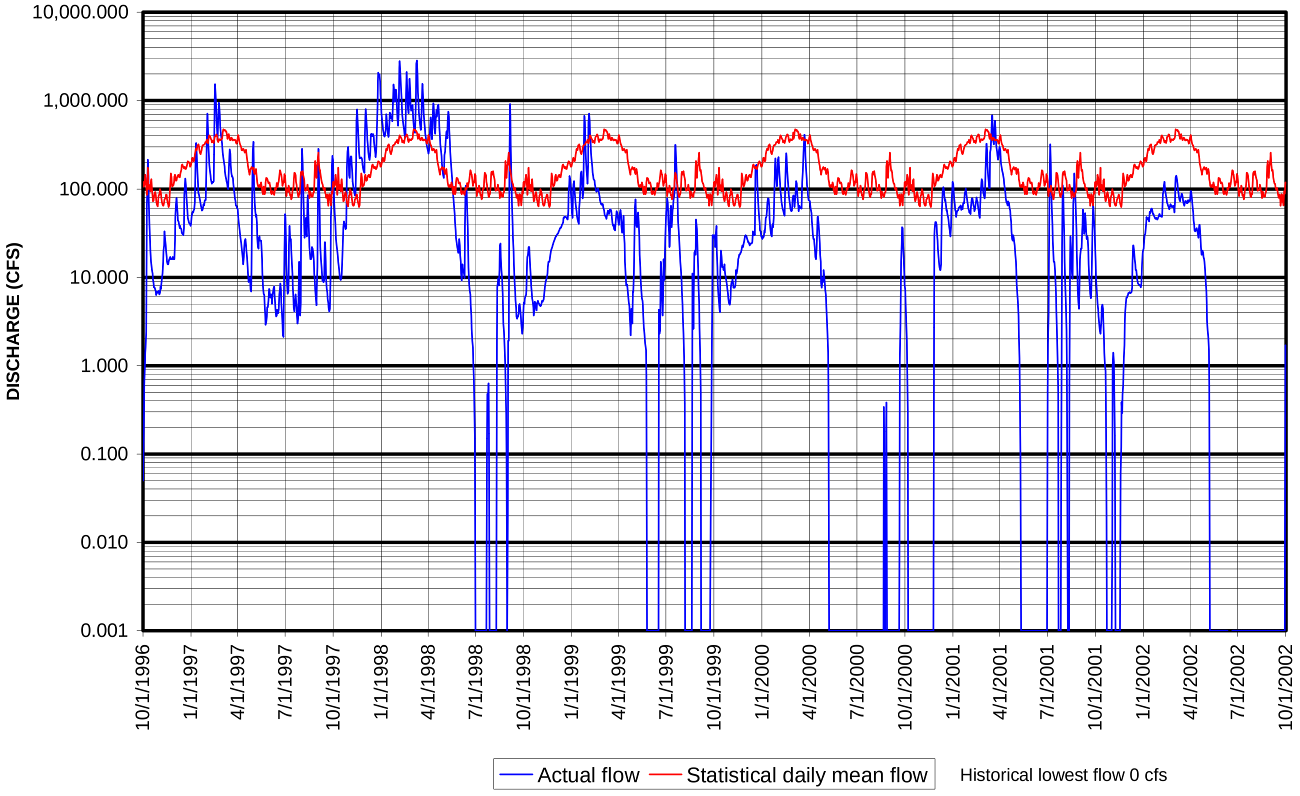

Figure 53. Coosawhatchie River near Hampton, Hampton County (02176500).

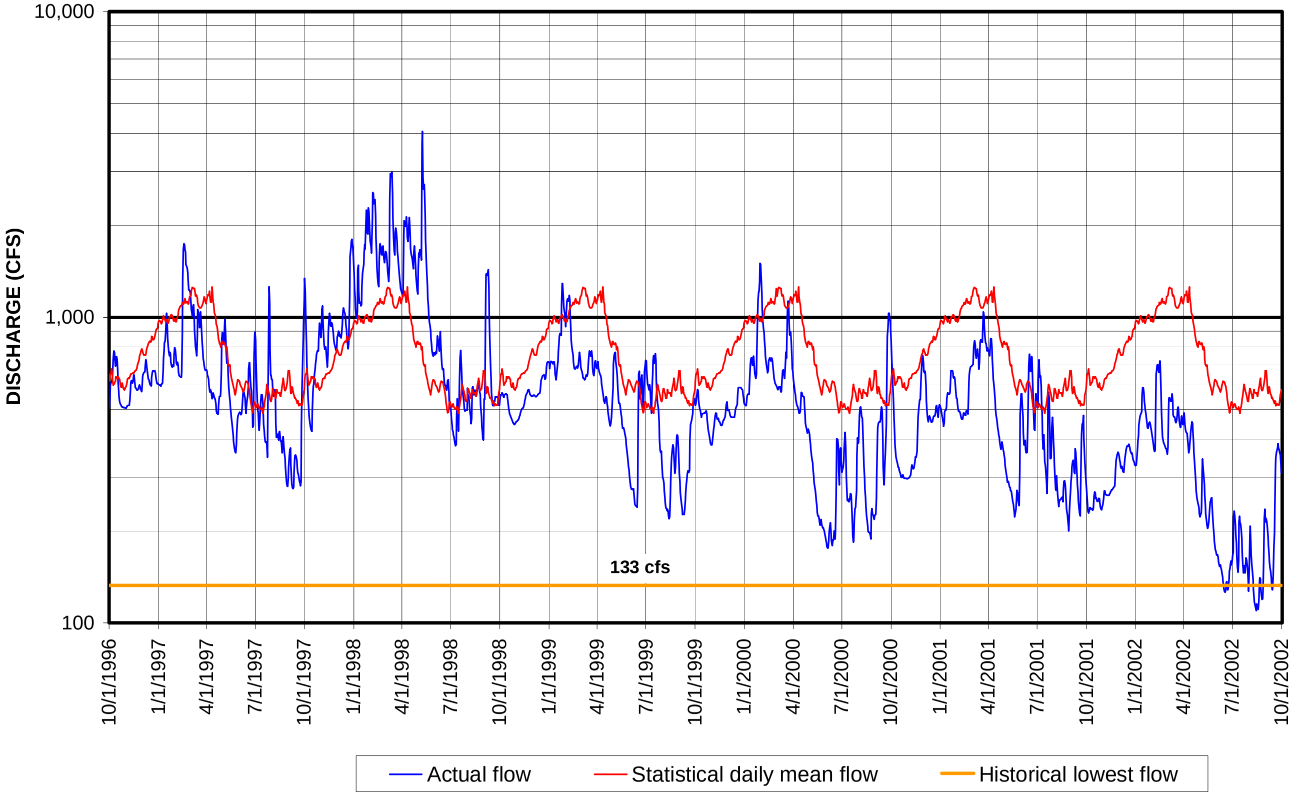

Figure 54. South Fork Edisto River near Denmark, Bamberg-Orangeburg County Line (station 02173000)

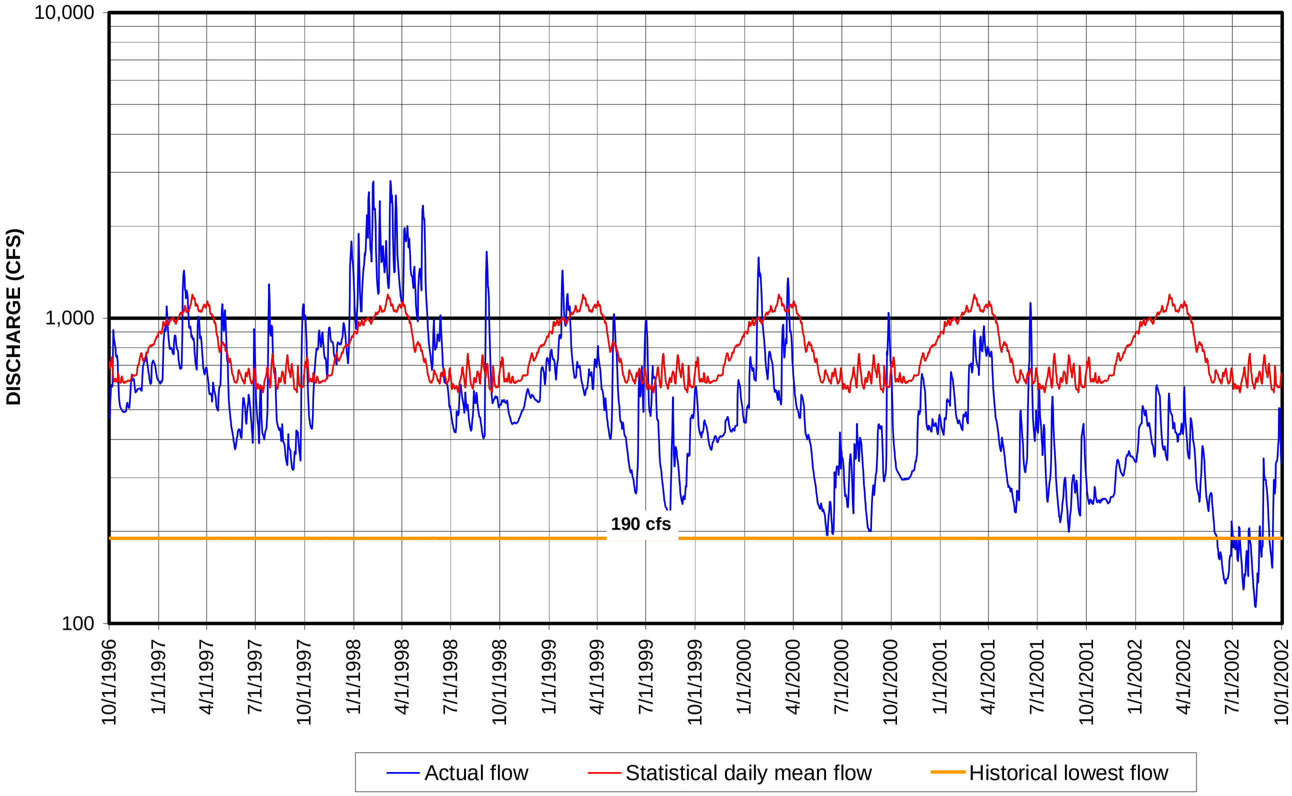

Figure 55. North Fork Edisto River at Orangeburg, Orangeburg County (station 02173500).

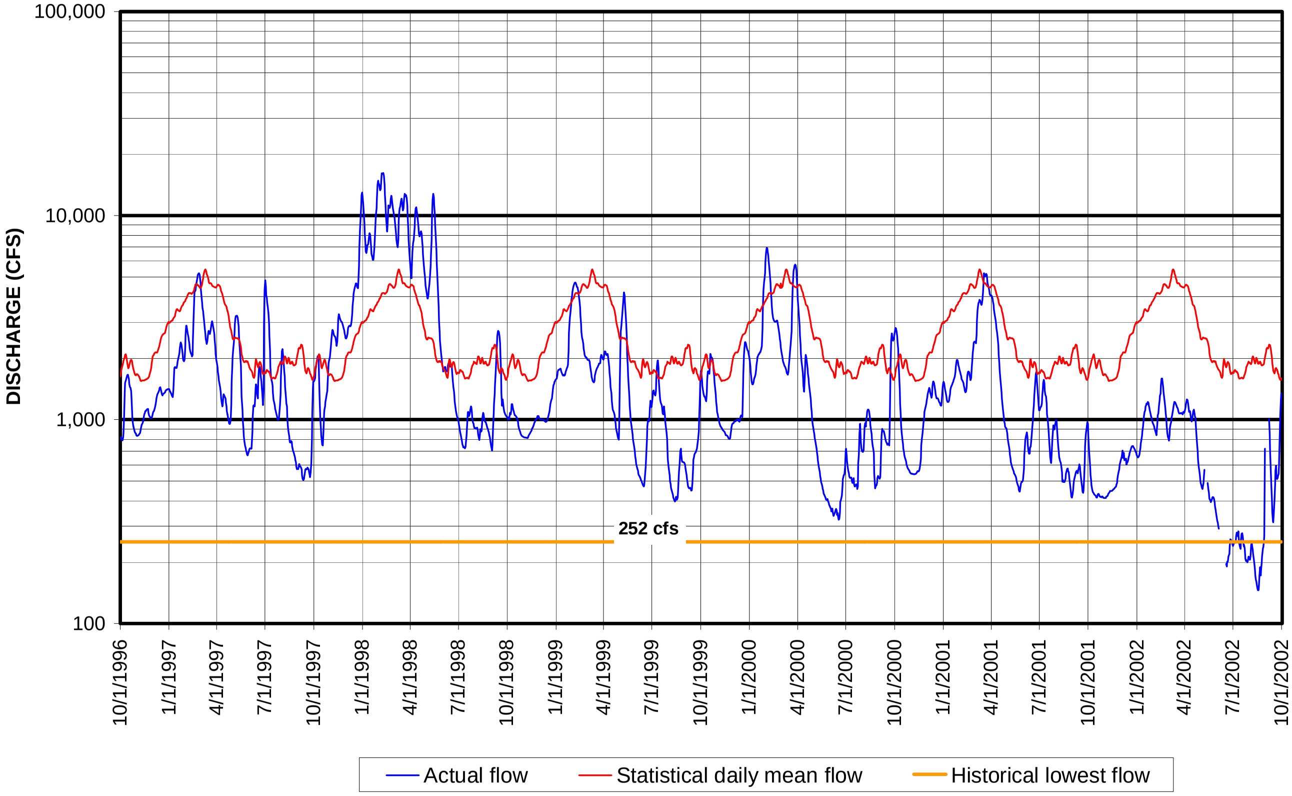

Figure 56. Edisto River near Givhans, Dorchester County (station 02175000).

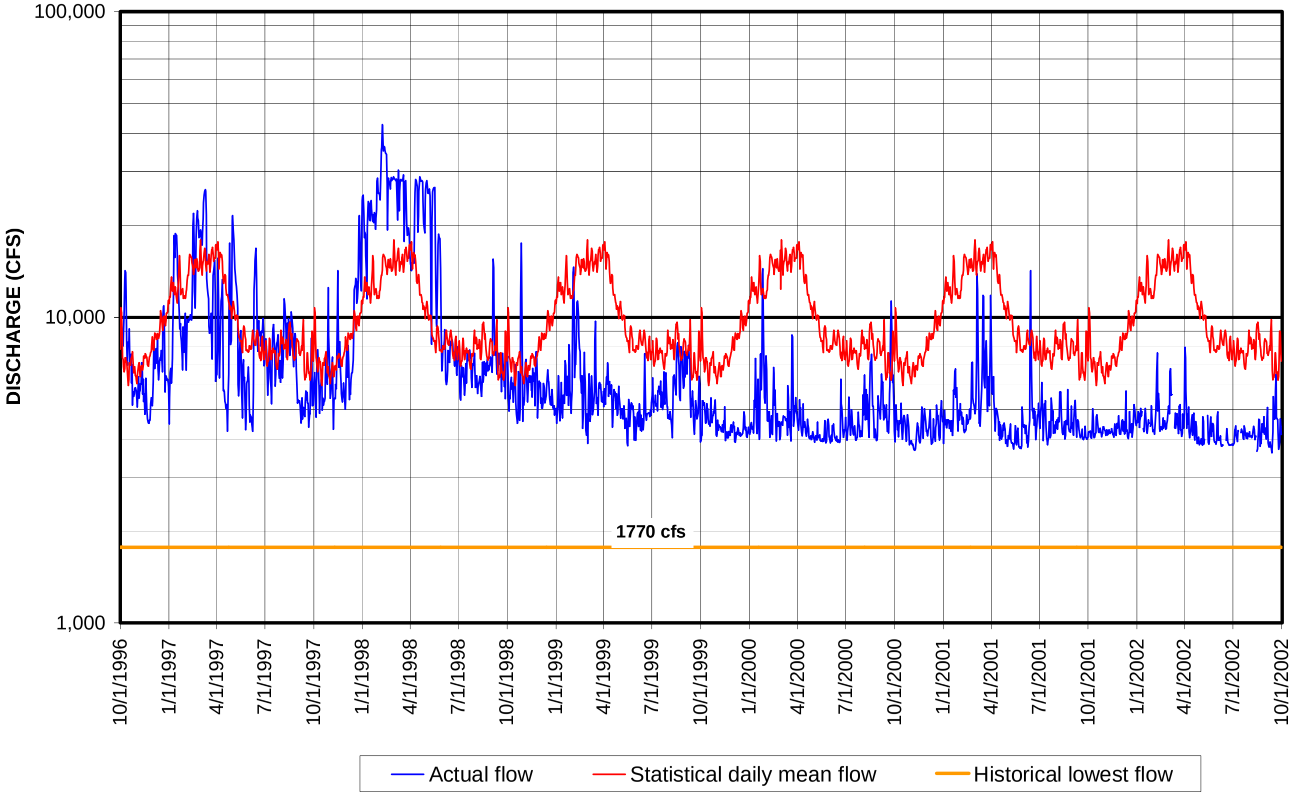

Figure 57. Savannah River at Augusta, Richmond County, Georgia (station 02197000).

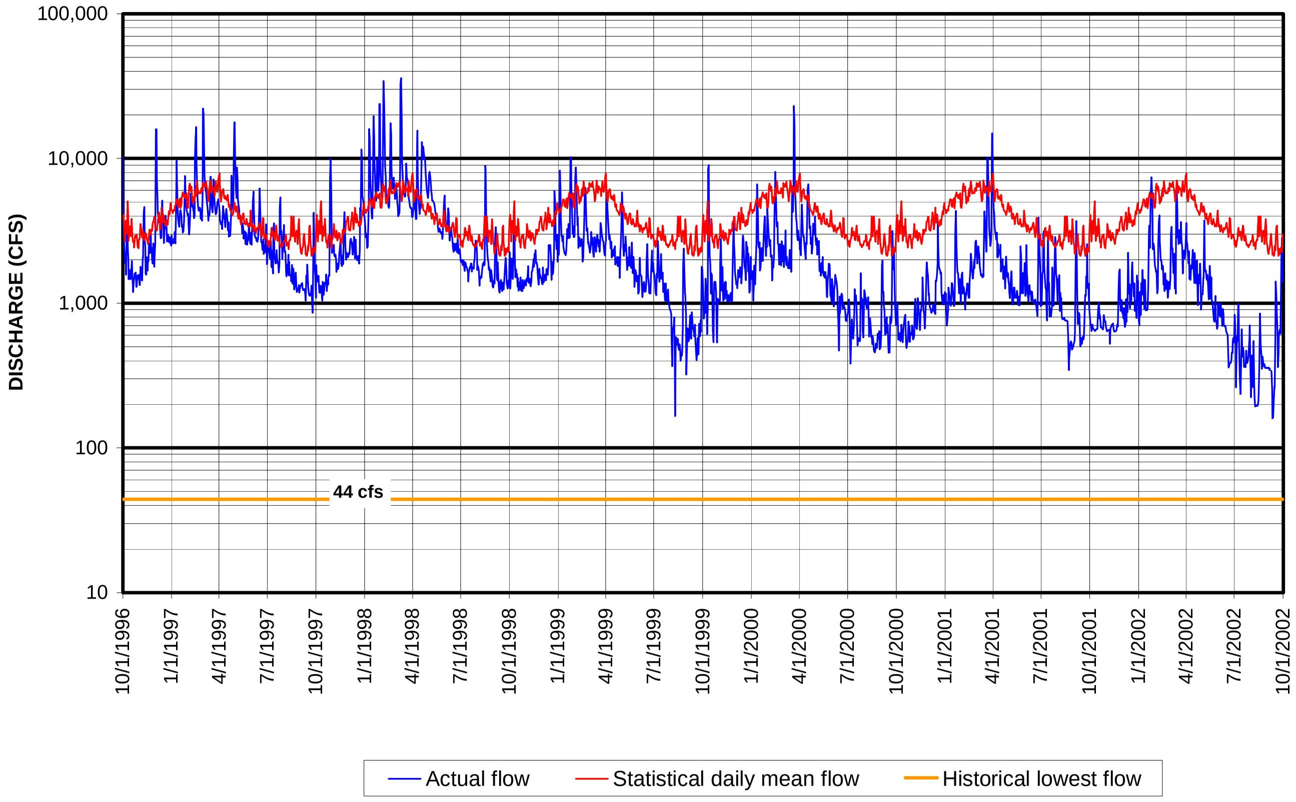

Figure 58. Broad River near Carlisle, Union County (station 02156500).

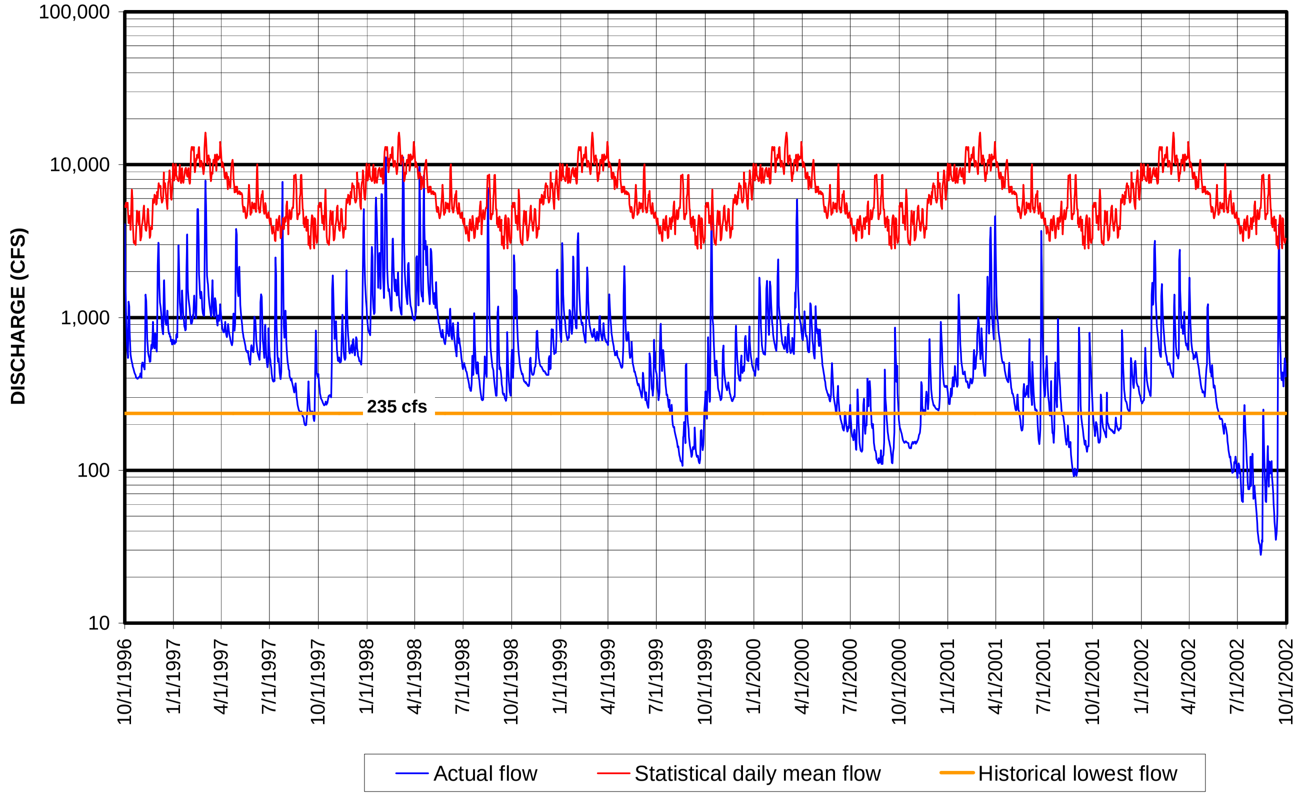

Figure 59. Broad River at Alston, Fairfield County (station 02161000).

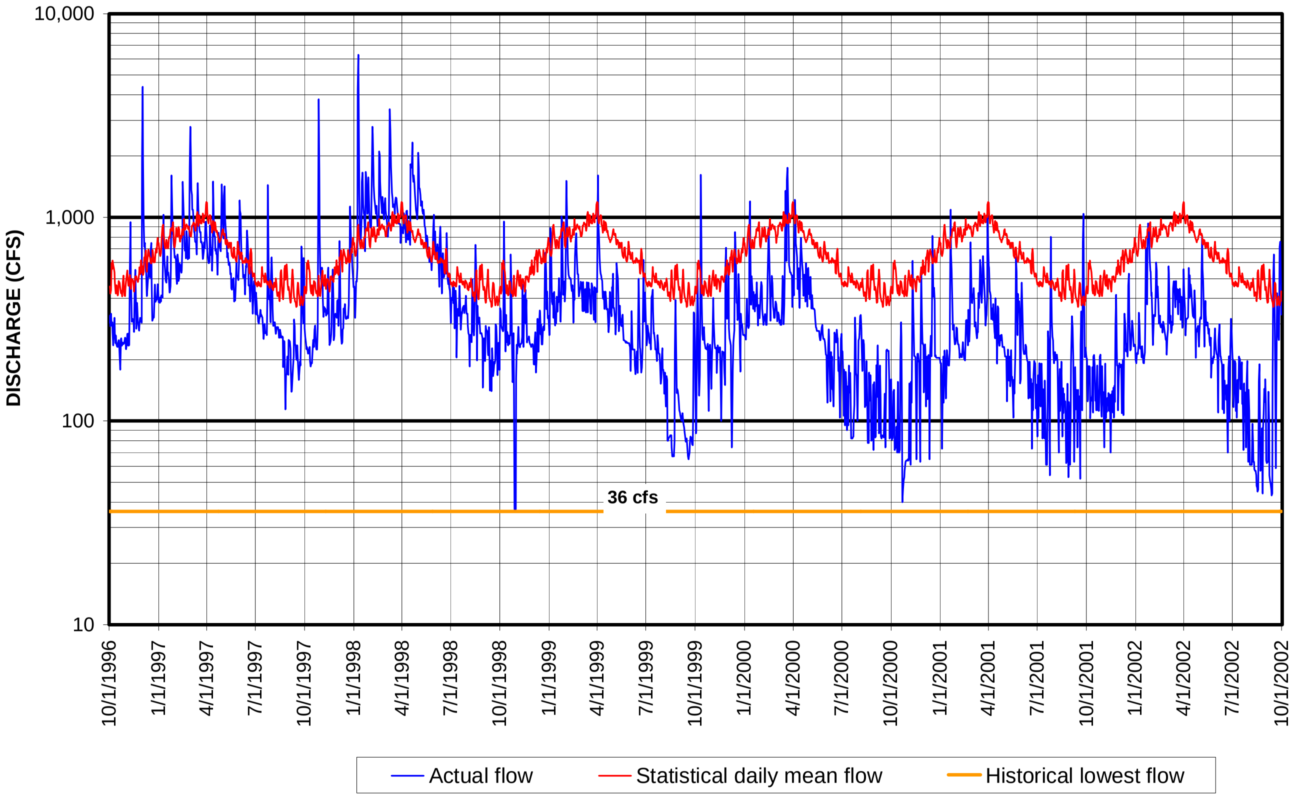

Figure 60. Saluda River near Greenville, Pickens County (station 02162500).

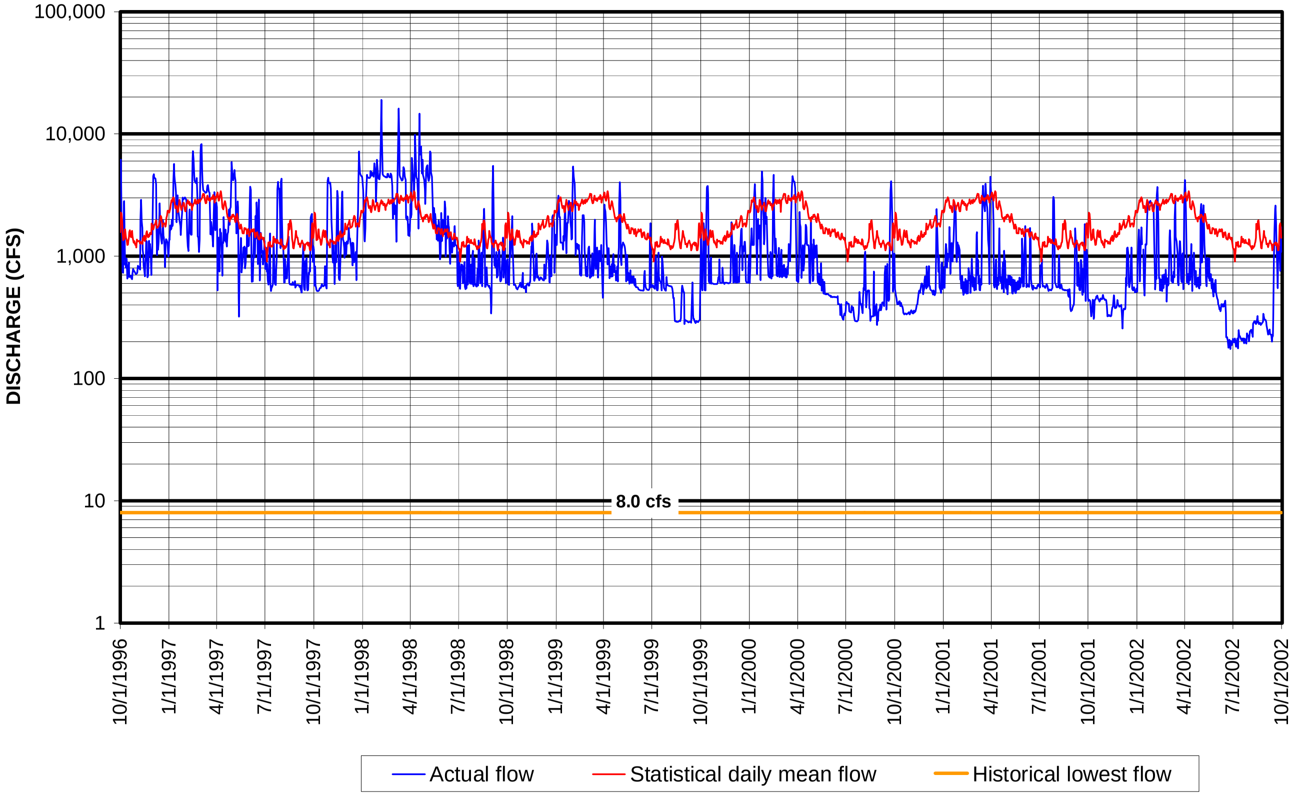

Figure 61. Saluda River at Chappells, Newberry County (station 02167000).

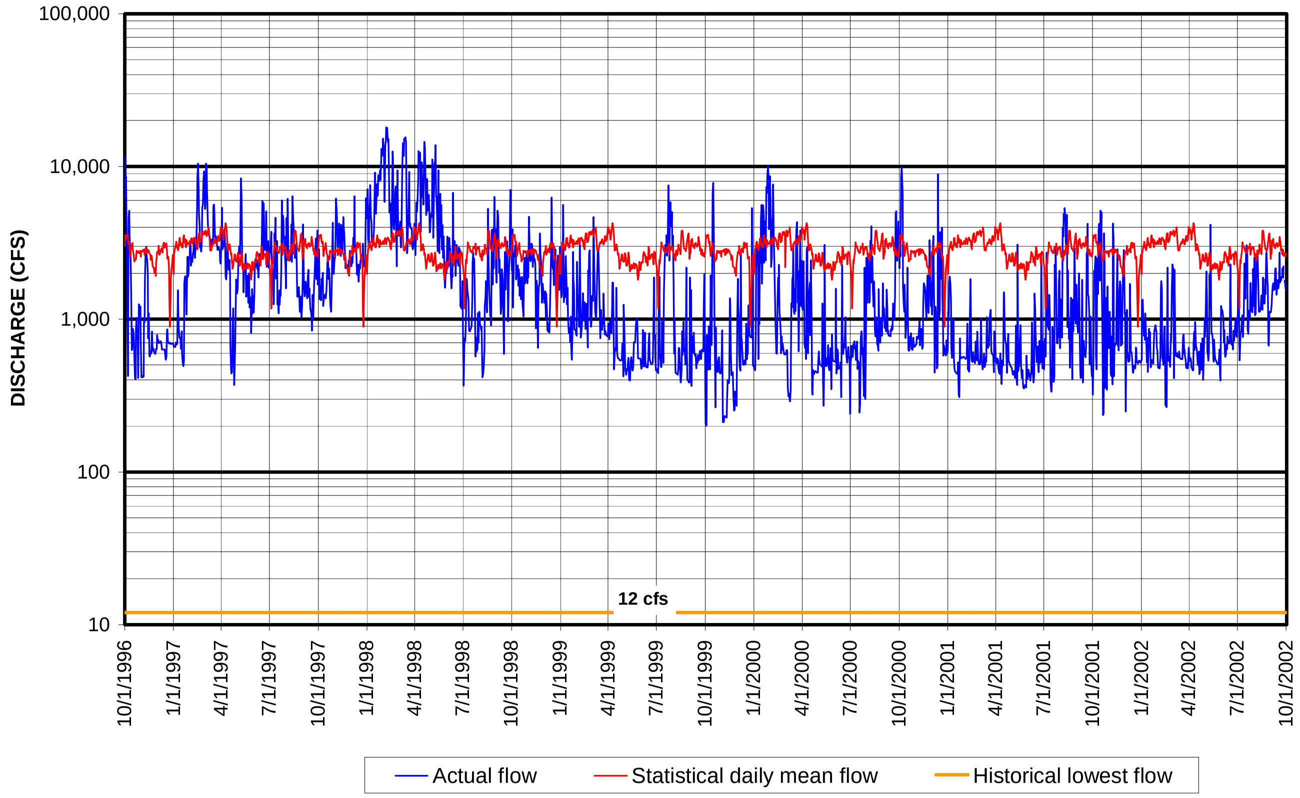

Figure 62. Saluda River near Columbia, Richland County (station 02169000).

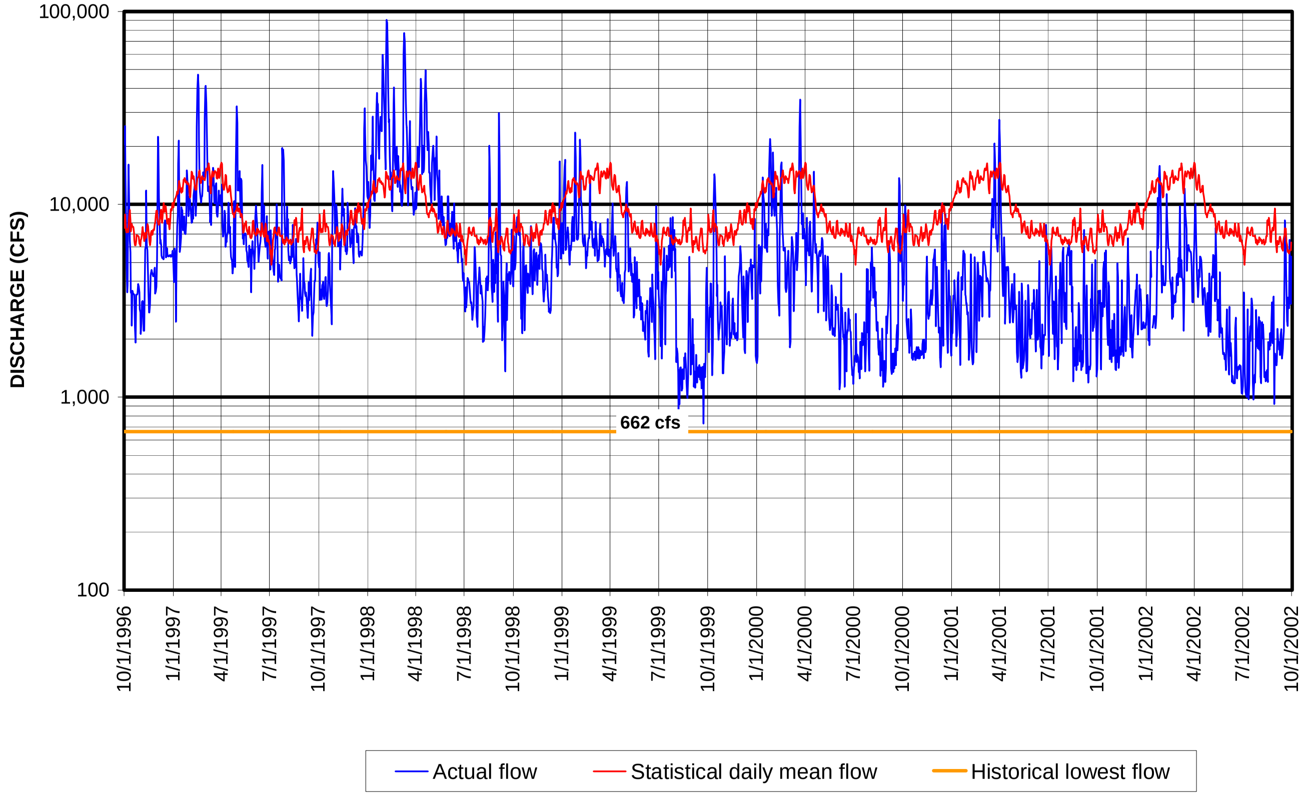

Figure 63. Congaree River at Columbia, Lexington County (station 02169500).

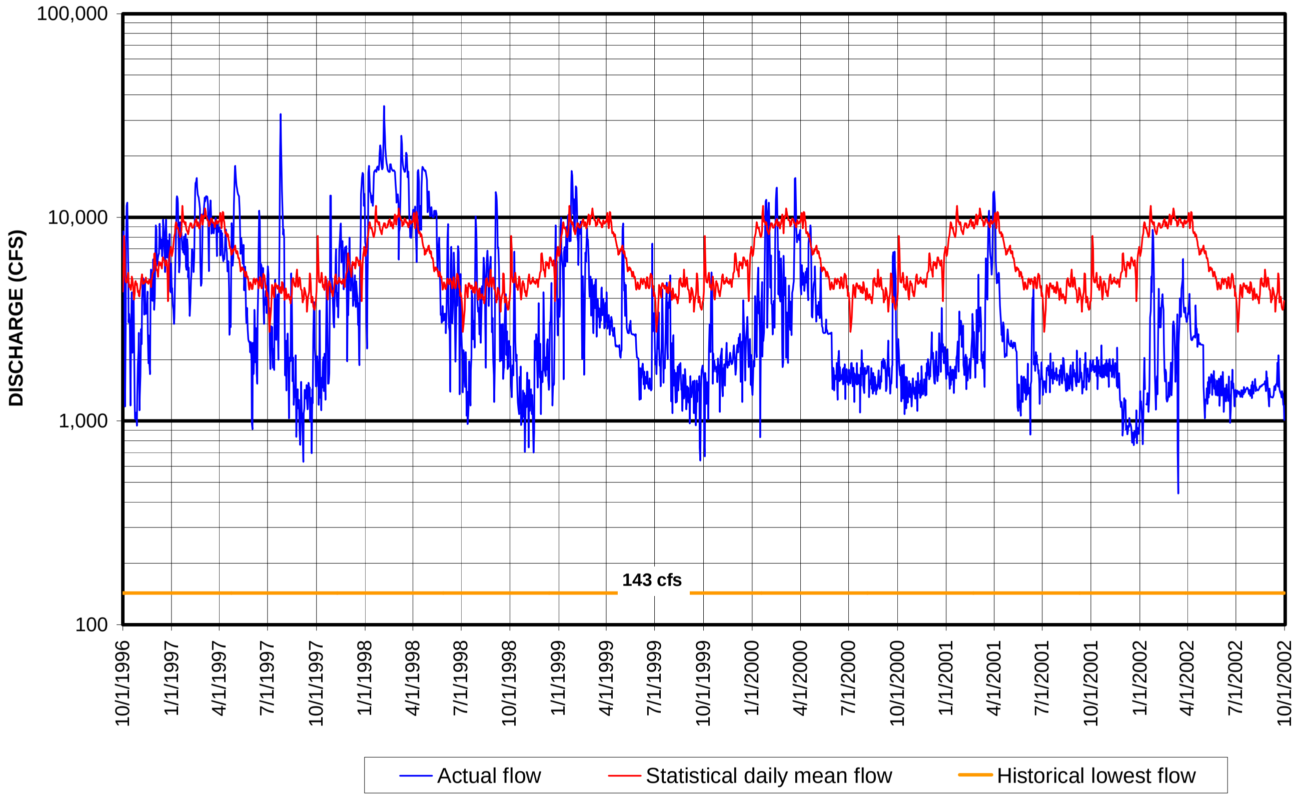

Figure 64. Wateree River near Camden, Kershaw County (station 02148000).

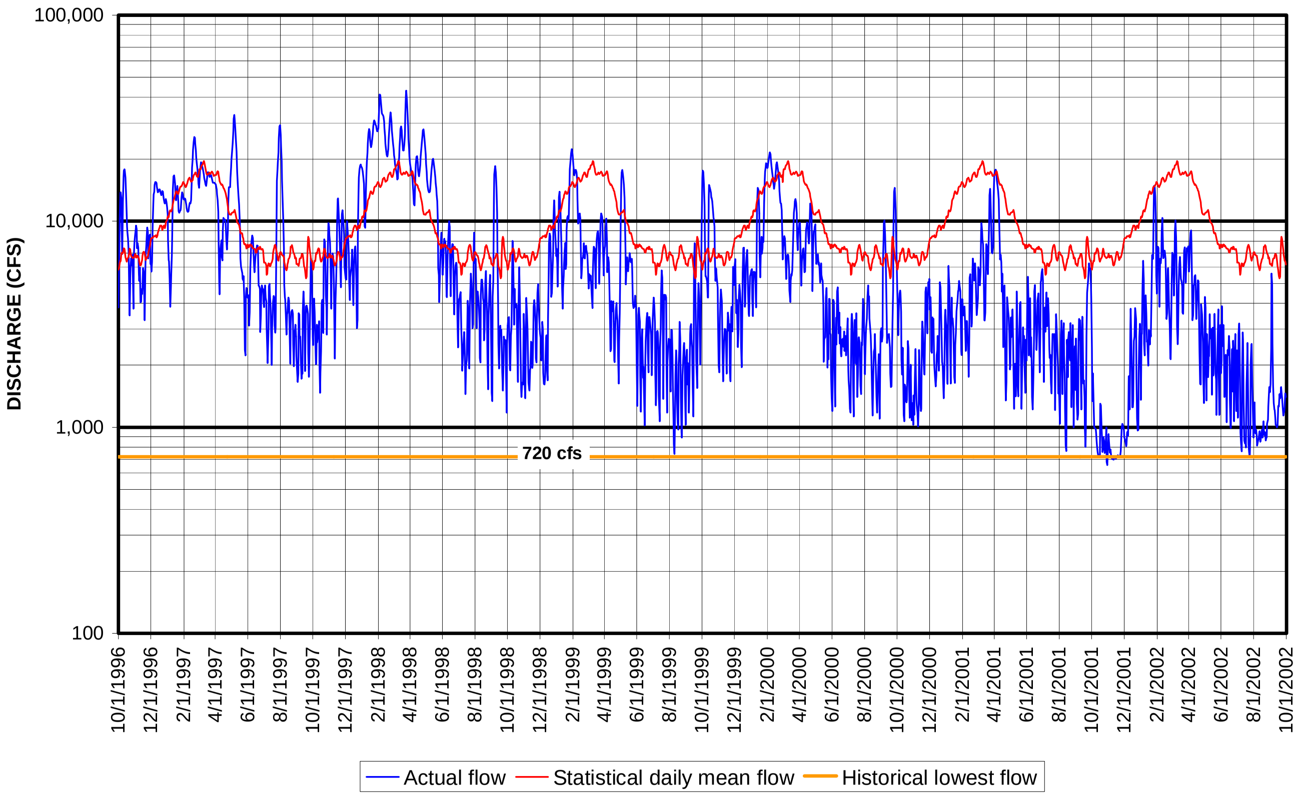

Figure 65. Pee Dee River at Peedee, Marion County (station 02131000).