Brenda L. Hockensmith and Karen E. Waters

The potentiometric surface of the Middendorf aquifer for November 1996 shows that the generally southeastward ground-water flow is affected by two potentiomentric lows. These two cones of depression have developed because of ground-water pumping in the Florence-Hemingway area and around Mount Pleasant. Comparing the November 1996 data with historical data shows that water levels near the outcrop areas of this aquifer have not changed significantly. In areas influenced by pumping, water levels have declined 47 to 257 feet during various periods of record.

INTRODUCTION

The Middendorf aquifer is the source of water for many public, industrial, and agricultural supplies in much of the Coastal Plain of South Carolina. This important water resource is monitored by regularly measuring the static water levels in wells. The potentiometric surface of an aquifer is defined by the elevations at which water stands in tightly cased wells completed in the aquifer. This map of the potentiometric surface of the aquifer was prepared by the Land, Water and Conservation Division of the South Carolina Department of Natural Resources (SCDNR-LWCD), using data collected during late 1996. For selected wells, trends in the ground-water levels are shown by hydrographs.

METHOD OF INVESTIGATION

Boundaries of the Middendorf aquifer used in this investigation are those defined by Aucott, Davis, and Speiran (1987), who delineated the aquifer on the basis of geologic data (primarily geophysical well logs), water-level data, water-chemistry data, and previous investigations. They acknowledged that the complex deposition of sediments in the Coastal Plain makes aquifer delineation somewhat problematic. This aquifer has been studied extensively by Cooke (1936), Siple (1957), Colquhoun and others (1983), Renken (1984), Aucott and Speiran (1985a, and 1985b), Stringfield and Campbell (1993), and Aucott (1996). The potentiometric map presented here was constructed by using water levels measured in 97 wells from October to December 1996, and supplemented by data from April 1997 (FLO-274) and September 1997 (BFT-10 and 11) (see table). Wells used by Aucott and Speiran (1985a) and Stringfield and Campbell (1993) were used in this study, where possible, to facilitate comparison of the potentiometric maps of this aquifer made in 1982, 1989, and 1996. Data from additional wells also were used.

GEOHYDROLOGIC FRAMEWORK

Survey personnel. Where continuous records are available, lowest monthly water levels were plotted.

The hydrographs were constructed from data collected by SCDNR-LWCD and U.S. Geological

The Coastal Plain formations of South Carolina compose a wedge of sediments that thickens from about 0 ft (feet) at the Fall Line to more than 4,000 ft at Hilton Head Island on the coast. These sediments consist of sand, clay, and limestone of late Cretaceous and younger ages that were deposited on a pre-Cretaceous basement complex of metamorphic, igneous, and consolidated sedimentary rocks. The Middendorf Formation lies between the Black Creek Formation and the Cape Fear Formation, the oldest of the Cretaceous formations in the region. The Middendorf aquifer is composed mostly of permeable sediments of the Middendorf Formation (hence its name), but locally it may include sediments from inderlying or overlying formations. In the updip areas, the aquifer is composed of sand interbedded with clay lenses deposited in an upper delta plain environment. Toward the coast, the aguifer is composed of thin-to thick-bedded sand and clay that was deposited in marginal marine or lower delta plain environments. In general, the Middendorf aquifer has coarser sand and less clay in the western part of the Coastal Plain than in

The Middendorf crops out along the Fall Line from Chesterfield County to Edgefield County, except for some areas in Aiken County where it not exposed. Its outcrop is narrowest in southwestern Edgefield County and widest in Chesterfield County. The aquifer dips southeastward in the updip region near the Fall Line; however, the dip is to the south along the coast. The top of the aquifer is at elevation 100, -700, and -1,700 ft msl (referenced to mean sea level) at Aiken, Little River, and Charleston, respectively. Thickness ranges from 0 at the Fall Line to more than 300 ft in Dorchester County.

GROUND-WATER FLOW SYSTEM

The potentiometric surface of the Middendorf aquifer generally declines toward the coast and defines a southeastward regional ground-water flow. In southwestern Lexington and northern Richland Counties, water levels are the highest, exceeding 350 ft msl. In areas where the aquifer crops out, it is recharged by rainfall. In the upper part of the Coastal Plain where stream valleys are incised into the aquifer, it is drained by those streams. This is shown by the convex curving of contour lines upstream near the Great Pee Dee, Congaree, Wateree, and Savannah Rivers. In the lower part of the Coastal Plain, the aquifer discharges into erlying aquifers or through pumping wells.

Dimpling this surface are cones of depression resulting from ground-water withdrawal. The potentiometric surface has been affected by pumping in Berkeley, Charleston, Colleton, Dorchester, Florence, mter, and Williamsburg Counties. Mount Pleasant has the lowest point on the potentiometric map, with a water level below -130 ft msl.

HISTORICAL TRENDS

Potentiometric levels of the Middendorf aquifer have been observed since 1917 (Cooke, 1936). Aucott and Speiran estimated the potentiometric levels before development (1985b). When they compared their predevelopment surface map with that of November 1982, they noted declines in Berkeley, Charleston, Darlington, Dillon, Dorchester, Florence, Georgetown, Horry, Kershaw, Lexington, Marion, Orangeburg, Sumter, and Williamsburg Counties (Aucott and Speiran, 1985a). Stringfield and Campbell (1993) prepared a potentiometric surface map for November 1989. They also observed continued declines between November 1982 and November 1989 in Berkeley, Charleston, Dorchester, Kershaw, and Williamsburg Counties. The historical water levels of several wells discussed below (denoted by *) are represented in the assembly of

The 1996 data indicate little change in the potentiometric surface near much of the outcrop area in recent years. A comparison of the 1996 surface with the predevelopment surface indicates that little change has occurred in water levels in Chesterfield, Kershaw, Lee, Marlboro, and northern Richland Counties. In Chesterfield County (CTF-46) water levels were 113 ft msl in September 1972 (Aucott and Speiran, 1984) and 117 ft msl in November 1982, November 1989, and November 1996. No change in water level was noted in eastern Kershaw County (KER-82) in 1982, 1989, and 1996. Water levels in Marlboro County (MLB-112*) have remained stable since 1972, averaging 131 ft msl with seasonal fluctuations of 3 ft. On the LEE-23* hydrograph, water levels also have changed little, ranging from 188 to 195 ft msl for the period of record. Sparse data suggest that little decline has occurred in northern Richland County.

Water levels in central Dillon County appear to have declined from predevelopment levels. Near Dillon, water levels were at 115 ft msl in 1917 (DIL-1) (Cooke, 1936) and 69 ft msl in 1996 (DIL-121). In DIL-70, a decline of 20 ft occurred between 1982 and 1996, but in DIL-79*, located in the eastern part of the county, water levels have changed little since 1982. Potentiometric contours in Aiken County and western Barnwell County show ground-water flow

toward the Savannah River in the Middendorf aquifer. This is consistent with previous investigations (Aadland and others, 1995; Aucott and Speran, 1985a and b; Clarke and West, 1997; Siple, 1967; Stringfield and Campbell, 1993). Addland and others (1995) suggested that the Cretaceous-age sediments in this area constitute a single aquifer system and that there is discharge from this aquifer to the Savannah River. Pumping also is influencing the potentiometric surface of the aquifer, since an estimated 10 mgd (million gallons per day) of water is pumped from the Middendorf aquifer in Aiken and Barnwell Counties and adjacent counties in Georgia. Clark and West (1997) indicated that water levels in AIK-817* may respond to both precipitation and pumping. Other wells in this area, such as AIK-430*, may be similarly effected. The extent to which pumping affects water levels is not evident from the 1996 data, owing to the effect of natural discharge to the

In eastern Barnwell County, where the Middendorf is well confined (Aadland and others, 1995), the direction of ground-water flow is to the south or southeast. Wells are more likely to be affected by pumping, and less by precipitation, than those to the west (BRN-349*) (Clark and West, 1997) Where the potentiometric contours point upstream, such as along much of the Congaree and Wateree Rivers, these rivers gain water from the Middendorf aquifer where it forms their beds or banks. In addition, water levels are influenced by industrial pumping exceeding 1.3 mgd in northwestern Calhoun County along the Congaree River and 2.2 mgd in Richland County along the Wateree River (1996 water use data, South Carolina Department of Health and Environmental Control). The extent of pumping effects is not well defined,

The cone of depression has expanded in northern Florence County compared to 1989 (Curley, 1990; Stringfield and Campbell, 1993) and 1992 (Rodriguez, Newcome, and Wachob, 1994). In FLO-146, water levels were -35 and -70 ft msl in 1982 and 1996, respectively. Water levels also have declined in FLO-209, from -40 ft msl in 1989 to -74 in 1996. Predevelopment water levels in the Florence area were above 100 ft

Water levels in eastern Florence County (FLO-128*) declined from 61 ft msl in 1959 (Aucott and Speiran, 1984) to a low of 1 ft msl in August 1993; then they recovered somewhat and fluctuated between 20 and 7 ft msl from October 1993 to December 1996. In western Florence County, water levels are less affected by pumping. Cooke (1936) reported a water level elevation of 131 ft msl for a well near Timmonsville in 1917. Water levels in FLO-85*, also located near Timmonsville, average 124 ft msl for the period of record and range from 131 to 120 ft msl. Apart from seasonal variations, there is an overall decline of 0.2 ft per year. The cone of depression centered at Mount Pleasant in Charleston County has deepened since 1989. At CHN-167, the water level was -132 ft msl in November 1996. The water level was -10 ft msl in CHN-185 in 1989 (Stringfield and Campbell, 1993). Predevelopment water levels near Mount Pleasant were above 125 ft msl in 1971 and measured 118 ft msl as recently as 1975 (Aucott and Speiran, 1984). The potentiometric surface in this area has declined by more than 257 feet, for a rate of about 10 ft/yr. Elsewhere in Charleston County, water levels in wells CHN-2, CHN-183, and CHN-186 have declined from 1989 to 1996 by 48, 60, and 69 ft at rates of 7, 9, and 10 ft/yr, respectively. Water levels in CHN-14* show a sharp decline of more than 59 ft since early 1991, with some seasonal variations.

The cone of depression present at Summerville in November 1989 was absent in November 1996. The city of Summerville used an average of 4.3 million gallons per day in the late 1980's from surface water sources and five wells open to the Middendorf aquifer (Newcome, 1990). In 1994, Summerville began receiving water from Lake Moultrie (Newcome, 1995), and discontinued use of the wells. The effects of Summerville's pumping changes are seen in the hydrograph for BRK-431*. In 1983, the water level was above 65 ft msl in this well. Water levels declined from 1989 until January 1995 and recovered to 39 ft msl by November 1996. Water levels in DOR-206 and DOR-221 recovered 53 and 39 ft, respectively, between 198 and 1996. Pumping continued until late 1994, and recovery probably exceeds that reported for DOR-206 and

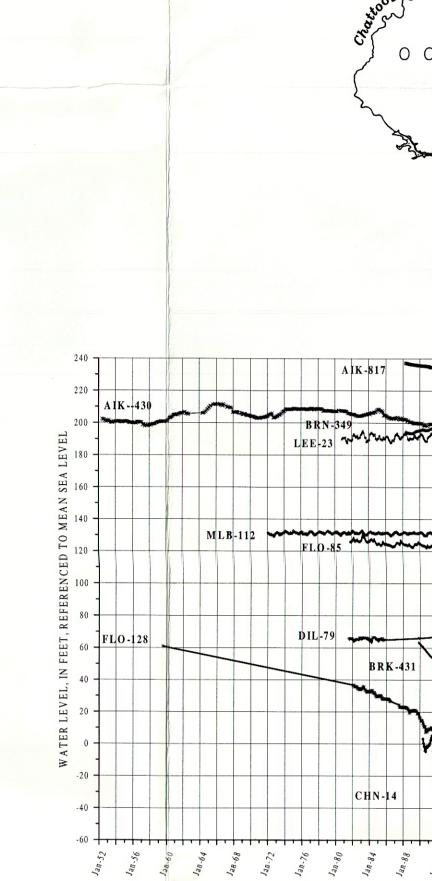
A cone of depression is centered at Herningway, in eastern Williamsburg County. The water level in 1970 was 54 ft msl in WIL-37 (Aucott and Speiran, 1984), but it declined 89 ft (3.4 ft/yr) by 1996. Public-supply and industrial pumpage in western Williamsburg County totals more than 2.6 mgd, part of which is obtained from the Middendorf aquifer, and it is likely that the potentiometric surface has declined in this

Water levels also are declining in the Middendorf aquifer at Walterboro. Data from COL-50 indicate a 1996 water-level elevation of 103 ft msl. Previous investigations noted water levels of 126 and 136 ft msl in 1989 and 1982, respectively. In 1980, a water level of 150 ft msl was measured in a well north of Walterboro (Aucott and Speiran, 1985b). These data suggest that a decline of about 47 ft may have occurred in this area

A cone of depression in Sumter County is a result of pumping in and around the city of Sumter. Average ground-water pumpage in 1994 exceeded 12 million gallons per day for the city and nearby Shaw Air Force Base, located about 7 miles to the northwest (Newcome, 1995). In 1996, the pumpage neared 15 mgd (South Carolina Department of Health and Environmental Control). Although the proportion of these supplies that is withdrawn from the Middendorf aquifer is not known, and water-level data are sparse, it is apparent that

a cone of depression is centered at the city of Sumter. The scarcity of data makes conclusions problematic in Horry and Georgetown Counties, Lake Marion from 1996 are near Little River; however, the Middendorf aquifer is not used there as a source of water supply. BRW-1865 (Brunswick County, N.C.) had a minimum water level of 52 ft msl in 1996 and, reportedly, 70 ft msl in 1992. The water level in HOR-315 was reported at 5, -17 and -5 ft msl, for 1982, 1989, and 1996. respectively. Records indicate that this well has two screened intervals, and one may be in the Middendorf aguifer; however, the upper section is open to the Black Creek aguifer. Therefore, the water levels in this well are more likely to reflect pumping from the Black Creek rather than Middendorf. Well GEO-88, south of Georgetown, believed to be open to the Middendorf, had a water level of 84 ft msl in 1992. Located in Myrtle Beach, HOR-973 is a multiscreened well, open to both the Middendorf and Cape Fear aquifers, that had a water level of 103 ft msl in 1992. During its construction in 1988, the use of weighted mud was necessary below the Black Creek aquifer to prevent flowing. Previous investigations have proposed a cone of depression in coastal Horry and Georgetown Counties. In light of the recently observed heads at wells BRW-1865, GEO-38, and HOR-973 and the absence of known withdrawals from the Middendorf aquifer in this region, no such

cone is shown on the 1996 map.



Little information is available in the Lake Marion vicinity. To the west, ORG-79 had a water level above 180 ft msl in 1964 (predevelopment) and at 170 ft msl in 1996. Water levels near Orangeburg were at about 175 ft msl in 1982 and 1989, and levels seem to be declining slowly. In Clarendon County, CLA-3 and CLA-20 both were measured at 93 ft msl in 1996. Between 1982 and 1989, these wells declined about 10 ft, but no change occurred between 1989 and 1996. Southeast of Lake Marion, water levels have been more active, as noted previously. The potentiometric contours in this region, therefore, are interpolated among these

Hydrographs of wells AIK-817, AIK-430, BRN-349, LEE-23, MLB-112,

FLO-85, DIL-79, BRK-431, FLO-128 and CHN-14

Southern South Carolina also has few Middendorf observation wells. ALL-347 and JAS-426 have been added to the network in this area in recent years and indicate that ground water probably flows southeastward between these wells. Near Beaufort, BFT-10 and BFT-11 had water levels of 150 and 135 ft msl, respectively, in 1996. The discrepancy between the two wells may be a result of the difference in well construction (BFT-10 is screened in a deeper zone) or proximity to pumping on Fripp Island (BFT-11 is nearer Fripp Island). Wells BFT-454 (open to both the Middendorf and Cape Fear aquifers) and BFT-2055 (open only to the Cape Fear) on Hilton Head Island both had water levels at 168 ft msl in 1996. In view of these data, the 150-ft potentiometric contour is drawn near Beaufort. This would indicate that ground-water flow becomes easterly or northeasterly in Jasper and Beaufort Counties.

SUMMARY AND CONCLUSIONS

wells measured during late 1996, shows that the generally southeastward ground-water flow is affected by several potentiometric lows. These potentiometric lows have developed because of ground-water pumping around Florence, Hemingway, and Mount Pleasant. Historical data show that water levels are stable nearest the aquifer's outcrop area; however,

fluctuations have occurred in areas influenced by pumping. The greatest water level change has occurred at Mount Pleasant, where water levels have declined nearly 260 ft from the estimated predevelopment level. Water-level declines also have been recorded at Florence, Hemingway, and Walterboro. Following a period of decline at Summerville, water levels have recovered at least 53 ft as a result of discontinuing the use of

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 Division Report 5,

Aucott, W.R., 1996, Hydrology of the southeastern Coastal Plain aquifer system in South Carolina and parts of Georgia and North Carolina: U.S. Geological Survey Professional Paper 1410-E, 83 p. 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-

Aucott, W.R., and Speiran, G.K., 1985a, Potentiometric surfaces of November 1982 and declines in the potentiometric surfaces between the period prior to development and November 1982 for the oastal Plain aquifers of South Carolina: U.S. Geological Survey Water-Resources Investigations

Aucott, W.R., and Speiran, G.K., 1985b, Potentiometric surfaces of the Coastal Plain aquifers of South Carolina prior to development: U.S. Geological Survey Water-Resources Investigations Report

Aucott, W.R., and Speiran, G.K., 1984, Water-level measurements for the Coastal Plain aquifers of South Carolina prior to development: U.S. Geological Survey Open-File Report 84-803, 36 p, 1 sheet. Clark, J.S. and West, C.T., 1997, Ground-water levels, predevelopment ground-water flow, and streamaquifer relations in the vicinity of the Savannah River Site, Georgia and South Carolina: U.S. Geological Survey Water-Resources Investigations Report 97-4197, 120 p, 1 sheet.

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: Columbia, S.C., University of South Carolina, Department of

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

Curley, R.E., 1990 Ground water in the Pee Dee Region of South Carolina, a preliminary report: South Carolina Water Resources Commission Open-File Report 36.

Newcome, Roy, Jr. 1990, The 100 largest public water supplies in South Carolina: South Carolina Water Newcome, Roy, Jr., 1995, The 100 largest public water supplies in South Carolina - 1995: South Carolina Department of Natural Resources, Water Resources Division Report 3, 42 p.

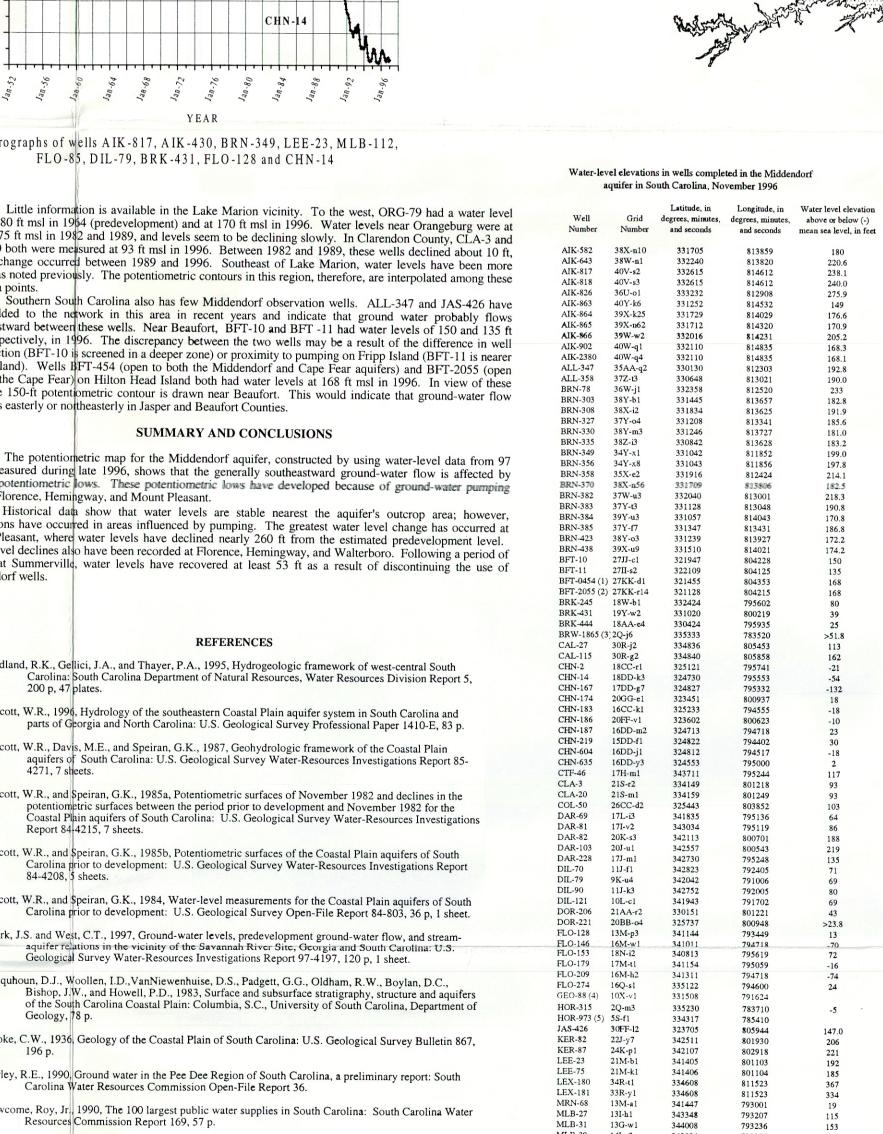
Renken, R.A., 1984, The hydrologic framework for the sand aquifer of the Southeastern United States Coastal Plain: U.S. Geological Survey Water-Resources Investigations Report 84-4243, 30 p., 8 Rodriguez, J.A., Newcome, Roy, Jr., and Wachob, Andrew, 1994, Ground-water resources of Darlington,

Florence, Marion, and Marlboro Counties, South Carolina: South Carolina Department of Natural

Resources, Water Resources Division Report 1, 119 p. Siple, G.E., 1967, Geology and ground water of the Savannah River Plant and vicinity, South Carolina: U.S. Geological Survey Water Supply Paper 1841, 113.

Siple, G.E., 1957, Ground water in the South Carolina Coastal Plain: Journal of the American Water Works Assoc., v. 49, no. 3, p. 283-300.

Stringfield, W.J., and Campbell, B.G., 1993, Potentiometric surfaces of November 1989 and declines in the potentiometric surfaces between November 1982 and November 1989 for the Black Creek and Middendorf aquifers in South Carolina: U.S. Geological Survey Water-Resources Investigations



804210

802816

802811

792706

335504 334406 334417

335458

5 Well is open to both the Middendorf and Cape Fear aquifers; see text

1 Well is open to both the Middendorf and Cape Fear aquifers

Well in open to the Cape Fear aquifer

4 Well was not measured in November 1996; see text

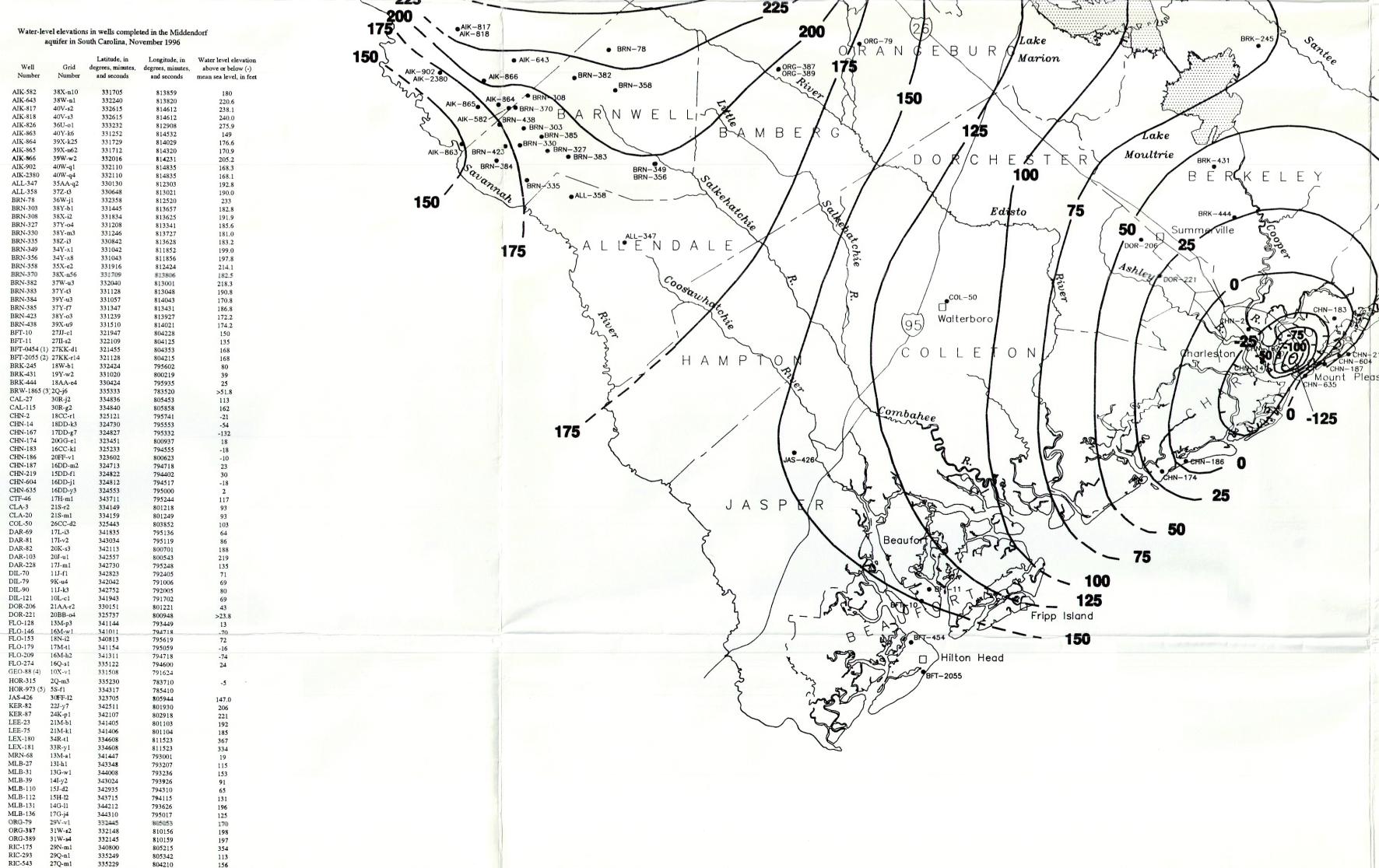
3 Well is located in North Carolina

SUM-119 22P-y2 SUM-151 24S-d1

SUM-161 22Q-e2 WIL-37 12S-c1

WIL-176 12S-h1

LAURENS



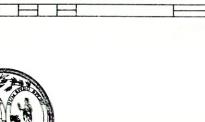
YORK

ANCASTE

SUMTER

Fishing Creek

EXPLANATION POTENTIOMETRIC CONTOUR - shows elevation at which water would have stood in tightly cased wells. Dashed where approximated. Hachures indicate depressions. Contour interval is 20 feet. Datum is mean sea level. CONTROL POINT - Well in which water level or artesian pressure was measured in November MIDDENDORF OUTCROP AREA





State of South Carolina David M. Beasley, Governor

South Carolina Department of Natural Resources

Paul A. Sandifer, Ph.D., Director Land, Water and Conservation Division Alfred H. Vang, Deputy Director