GROUND WATER IN THE PEE DEE REGION OF SOUTH CAROLINA

A PRELIMINARY REPORT

By

Robert E. Curley

South Carolina Water Resources Commission

Open-File Report No. 36

May 1990

STATE
OF
SOUTH CAROLINA

The Honorable Carroll A. Campbell, *Governor*

SOUTH CAROLINA WATER RESOURCES COMMISSION

Appointed Members

Mr. Erick B. Ficken, *Chairman*
Mr. Lynn H. Youmans, Jr., *Vice-Chairman*

Agriculture

Mr. Lynn H.Youmans, Jr.	Furman
Mr. Lewis Walker	Sumter
Mr. Ben M. Gramling, III	Gramling

Industry

Mr. Floyd E. Williams	Fort Mill
Mr. Frank B. Winslow	Hartsville
Mr. Dan E. Jones	Columbia

Municipalities

Mr. Tom W. Dunaway, III	Anderson
Mayor Elsie Rast Stuart	Pelion
Mr. Erick B. Ficken	Myrtle Beach

Saltwater

Mr. Whitemarsh S. Smith	Charleston

Ex Officio Members and Designees

Mr. D. Leslie Tindal
Commissioner
S.C. Department of Agriculture
Desig: Mr. David L. Tompkins

Mr. Michael D. Jarrett, Commissioner
S.C. Department of Health and
Environmental Control
Desig: Mr. R. Lewis Shaw

Mr. Boris Hurlbutt
Chairman
S.C. Forestry Commission
Desig: Mr. Robert J. Gould

Mr. Marion Burnside
Chairman
S.C. Wildlife & Marine
Resources Department
Desig: Mr. Larry D. Cartee

The Honorable L. Edward Bennett
Chairman
S.C. House Agriculture and
Natural Resources Committee
Desig: The Honorable John J. Snow, Jr.

Mr. Glenn C. Alexander
Chairman
S.C. Land Resources
Conservation Commission
Desig: Mr. Cary D. Chamblee

Mr. Richard E. Greer
Chairman
S.C. Development Board
Desig: Mr. O'Neal Laird

Dr. A. Max Lennon
President
Clemson University
Desig: Dr. Paul B. Zielinski

Mr. Joe G. Rideoutte
Commissioner
S.C. Department of Highways
and Public Transportation
Desig: Mr. Robert B. Ferrell

The Honorable John C. Land
Chairman
S.C. Senate Agriculture and
Natural Resources Committee
Desig: vacant

Staff

Alfred H. Vang, Executive Director
Hank W. Stallworth, Deputy Director
Camille Ransom, III, Director, Geology-Hydrology Division

CONTENTS

ILLUSTRATIONS

TABLES

GROUND WATER IN THE PEEDEE REGION OF SOUTH CAROLINA

by
Robert E. Curley

ABSTRACT

The Pee Dee Region of South Carolina is underlain by the Peedee, Black Creek, Middendorf, and Cape Fear Formations of Cretaceous age. All four of these formations consist of clastic sand and clay sediments that strike northeast and dip southeast. Crystalline bedrock underlies the sediments.

The units of major hydrologic importance are the Black Creek, Middendorf, and Cape Fear Formations. The Black Creek, which overlies the Middendorf, is utilized more extensively in the downdip portions of the study area, while the Middendorf and Cape Fear are utilized more in the updip areas.

In general, the transmissivity of the Middendorf aquifers is greater than that of the Black Creek aquifers. Subtle trends of increasing transmissivity toward the southwest were noted in both units. Cones of depression (areas of locally depressed hydraulic head) occur at the cities of Florence, Johnsonville, and Marion.

Chemically, the water in the Black Creek aquifers is different from that in the Middendorf aquifers, the former being of a bicarbonate type and the latter characterized by high percentages of sulfate and chloride. Two water-quality problems affecting the area are locally high iron concentration and increased sodium concentration in the downdip part of the Middendorf. A general trend of increased dissolved solids to the southeast (downdip and down-flowpath) was also noted.

Many of the observed water-quality patterns are related to the environments in which the sediments were deposited, because the chemistry of water in marine sediments differs from that of nonmarine sediments. In the Middendorf Formation alone, three depositional zones, nonmarine, transitional, and marine, have been identified in the study area. Evidence suggests that similar zones may exist in the Black Creek Formation.

Future work in the investigation will include the development and implementation of a computer ground-water flow model, refinement of the water-level monitoring network, implementation of a water-quality monitoring network, further delineation of the hydrogeology through the drilling of additional test holes, and investigation into the degree of hydraulic connection among the various geologic formations.

INTRODUCTION

In response to concerns expressed by local government officials over declining ground-water levels, the South Carolina Water Resources Commission (SCWRC) and the U.S. Geological Survey (USGS) embarked upon a joint study to characterize the hydrology, geology, and water chemistry of the clastic sedimentary aquifers in a five-county area in northeastern South Carolina. Financial support for the project has been supplied, in part, by the cities of Florence, Bennettsville, and Dillon, by Dillon and Darlington Counties, and by Trico Rural Water Company.

Study Area

The counties of Darlington, Dillon, Florence, Marion, and Marlboro constitute the study area for this investigation (Figures 1.1 and 1.2). These counties are located in the northeastern portion of the South Carolina and span parts of the upper, middle, and lower Coastal Plain physiographic province. Topographically, the area is generally flat, with elevations ranging from slightly over +500 ft msl (feet, referred to mean sea level) in western Darlington County to less than +10 ft msl in parts of eastern Marion County. The area is wholly within the Pee Dee River basin, and includes parts of the Pee Dee, Little Pee Dee, Lynches, and Black River sub-basins. The climate is subtropic, with an average annual temperature of 63^{0} F and average annual precipitation of about 47 inches (SCWRC, 1983).

With the exception of Florence County, the study area is predominantly rural. Over half of Florence County's population is classified as urban,

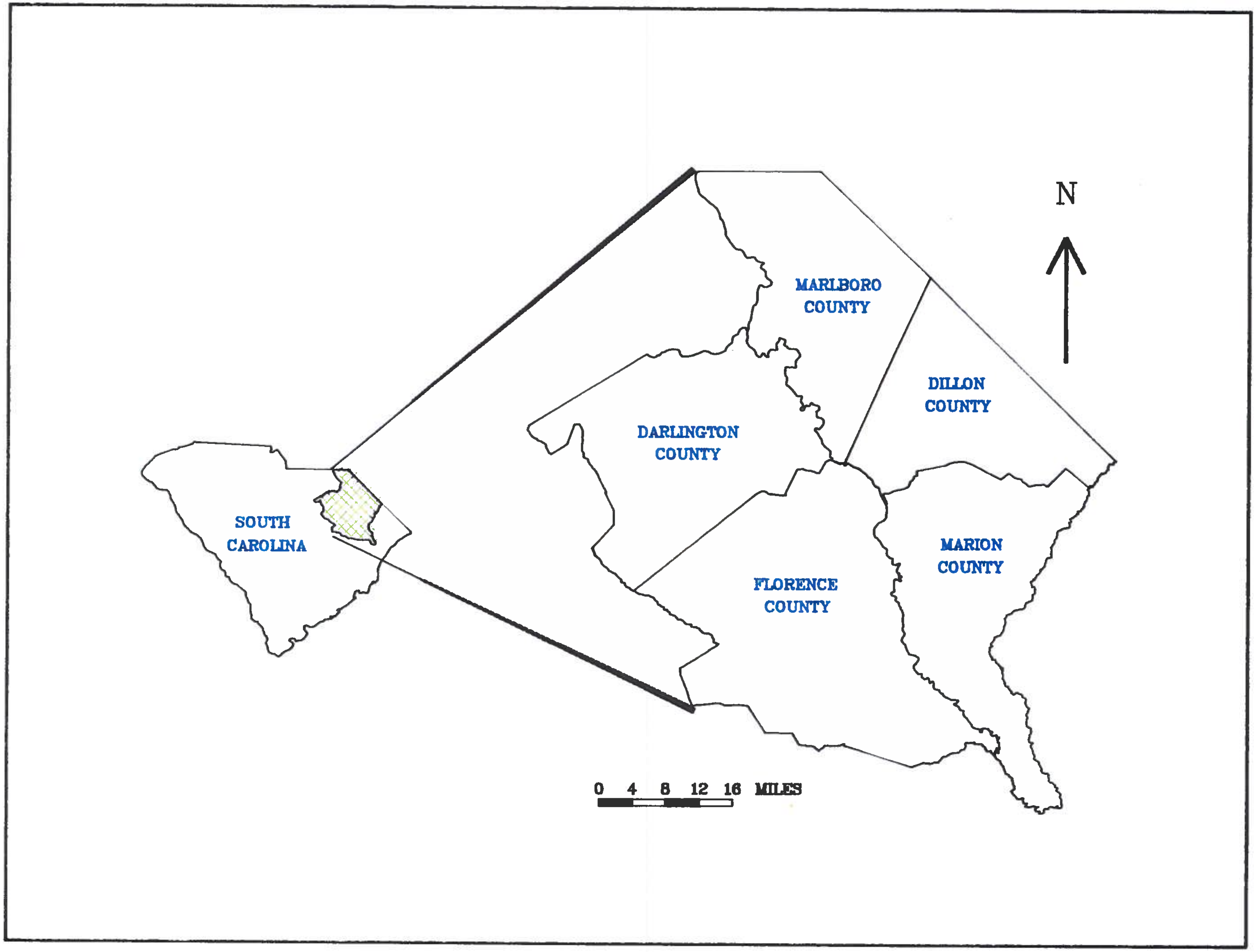


Figure 1.1 Location map of study area.

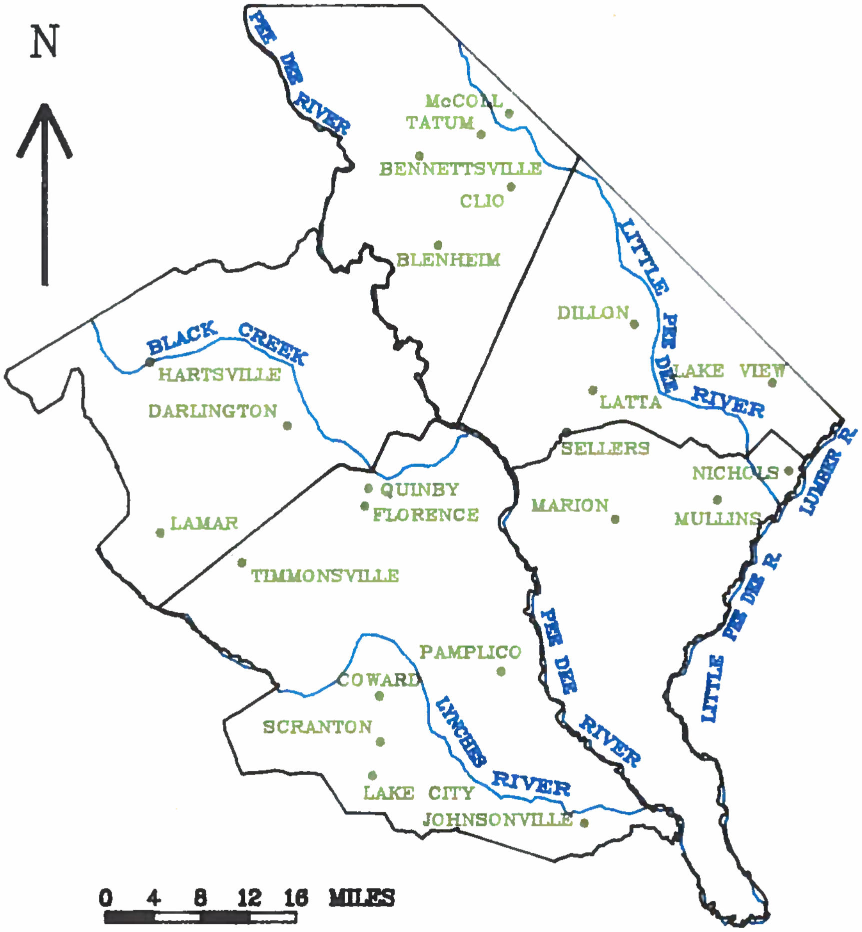


Figure 1.2 Major towns and streams of the Pee Dee region.

largely because of the city of Florence, which is the seventh most populous city in the State (S.C. Statistical Abstract, 1986). Contained within the study area are 10 of the 100 largest public suppliers in South Carolina, including the city of Florence (No. 10), which is the second largest public supplier that relies solely upon ground water, and the city of Darlington (No. 41) (Newcome, 1990).

Previous Investigations

No previous hydrologic, geologic, or water quality reports have been devoted exclusively to this five-county area. Many regional reports, however, include this study area. Park's 1980 report described the ground-water resources of Sumter and Florence Counties. He was preceded in his efforts by C.W. Cooke (1936) and G.E. Siple (1946, 1955, & 1957), both of whom published reports that included well data from the study area. The SCWRC published a statewide assessment of water resources in 1983 that includes geologic and water-quality information in the Pee Dee region. In addition, many reports have been prepared by private consulting firms.

The U.S. Geological Survey has produced several regional reports that include the area, and recently have begun to concentrate efforts in the Florence vicinity. Investigations by Chapelle and Lovley (1990) and other ongoing studies deal with the effects of bacteria on water quality and aquifer porosity.

Purpose and Scope

This report summarizes the results of the data-collection phase of the investigation. This phase, which involved the establishment of a database, can be divided into two parts:

1) collection of existing information; and
2) collection of new information, such as water-level data, lithologic data from a core hole, and borehole geophysical data.

The collection of existing information involved a literature search of pertinent hydrologic, geologic, and water quality reports and the establishment of a well database through well canvassing and field verification.

The collection of new information included the drilling of a continuously cored test hole to basement rock in the city of Florence, macroscopic and microscopic analyses of the core samples from this hole, and the collection of a suite of geophysical logs.

This phase of the investigation served three major purposes:

1) to provide better knowledge of the hydrology, geology, and water quality of the formations in the study area;
2) to identify areas where data are lacking, so that future efforts can be focused in the proper direction; and
3) to provide the framework for developing a ground-water flow computer model.

The ultimate goal of the investigation is the development and implementation of a ground-water management program. A central component of this management program is a computer model of the hydrologic system. The task immediately at hand is to create the proper infrastructure for this model by improving our database, establishing a water-quality monitoring network, and refining our water-level monitoring network.

Well-Numbering System

The SCWRC uses a grid system, based on the latitude and longitude of wells, to assign identification numbers. For this purpose, the State has been divided into major grid blocks, each measuring 5 minutes of latitude by 5 minutes of longitude. These blocks are identified by a number followed by a capital letter and are labeled from east to west and north to south. Each of these major grid blocks has been divided into 25 minor blocks, each being 1-minute square, which have been labeled with the lower-case letters from a to y. Within each minor block the wells are numbered consecutively in the order they are inventoried. For example, the well with the number 13H-p1 was the first well to be located in the minor block "p" of the major block 13H.

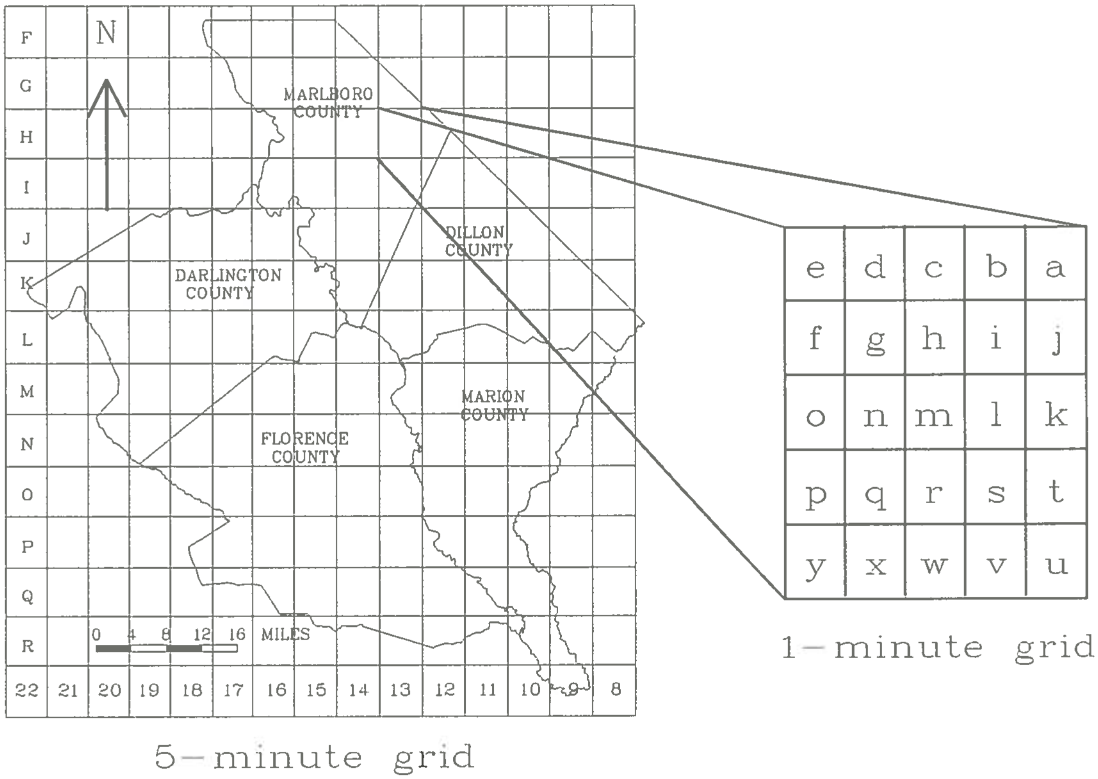


Figure 1.3 SCWRC well-numbering grid.

Acknowledgements

The author gratefully acknowledges the many entities and individuals who have cooperated in this project. Foremost of these are the members of the U.S. Geological Survey, the cities of Florence, Bennettsville, and Dillon, Dillon and Darlington Counties, and the Trico Rural Water Company.

Numerous staff members of the SCWRC are also appreciated for their assistance.

GEOLOGY

The sediments overlying the crystalline bedrock in the five-county area are classified into five major geologic units. They are, in ascending order, the Cape Fear, Middendorf, Black Creek, and Peedee Formations of late Cretaceous age and, in aggregate, the post-Cretaceous units of Pliocene, Pleistocene, and Holocene ages (Table 2.1). Because of their discontinuity and hydrologic insignificance in the study area, the post-Cretaceous units are treated as one for this report.

Two hydrogeologic sections were prepared for this study (Figure 2.1, Plates 1 and 2). Section A-A′ trends roughly along strike from Timmonsville in western Florence County (well 18N-i2) to Lakeview in eastern Dillon County (well 9L-b1). Section B-B′ trends roughly along dip from Hartsville in northwestern Darlington County (well 19K-o2) to Brittons Neck in southern Marion County (10Q-p1). As suggested by these sections, the Cape Fear and Middendorf Formations underlie the entire five-county study area. The Black Creek Formation, which crops out over a large portion of the study area, is absent along a narrow band in northwestern Florence and Marlboro Counties, and along portions of the Pee Dee River. The Peedee Formation is present in the study area only in the southeastern two thirds of Florence County and the Brittons Neck portion of Marion County.

The most heavily used aquifers on the western side of the study area are those of the Cape Fear and Middendorf Formations, but aquifers of the Black Creek Formation are more commonly tapped in the southeastern part of the study area. The reasons for this are:

Table 2.1 Lithology of Quaternary, Tertiary, Cretaceous, and Pre-Cretaceous formations in the Pee Dee region of South Carolina

SYSTEM	SERIES	GEOLOGIC UNIT	DESCRIPTION OF SEDIMENTS
Quaternary	Holocene and Pleistocene	Surficial deposits	Light-colored medium- to coarse-grainded sand, gravel, and lenses of varicolored clay and sandy clay; locally sandy limestone.
Tertiary	Pliocene	Undifferentiated	Light-colored, fine- to coarse-grained sand, interbedded with dark, sandy calcareous marl; phosphate pebbles locally.
		Duplin Formation	Light-gray, yellow, brown, and buff, fossiliferous, fine- to coarse-grained sand; green and gray clay, marl, and soft fossiliferous limestone.
Cretaceous	Upper Cretaceous	Peedee Formation	Gray, calcareous, fossiliferous clay; gray, glauconitic, calcareous, fine- to medium-grained muddy sand; and coquina.
		Black Creek Formation	Olive-gray, fine- to medium-grained glauconitic, lignitic, phosphatic, and micaceous sand. Dark olive-gray clay with laminae of very fine sand and silt. Occasional beds of sandstone. Traces of pyrite.
		Middendorf Formation	Light to dark olive-gray, medium-grained, lignitic and micaceous sand with massive beds of dark yellowish-brown to dark olive-gray, dense, waxy clay. Clay is mottled in places. Traces of feldspar.
		Cape Fear Formation	Cycles of light to medium yellowish-brown to greenish-gray, medium-grained, feldspathic sand grading to light yellowish-brown and olive-gray, highly mottled clay. Mottled colors include red, yellow, orange, and purple.
Triassic		Unnamed Triassic rocks	Red to reddish brown consolidated claystone, sandstone, shale, and conglomerate; Occurs in narrow Triassic basin west-southwest of city of Florence.
Pre-Cretaceous		Unnamed crystalline rocks	Inferred as gneiss, schist, slate, granite, basalt, and diabase.

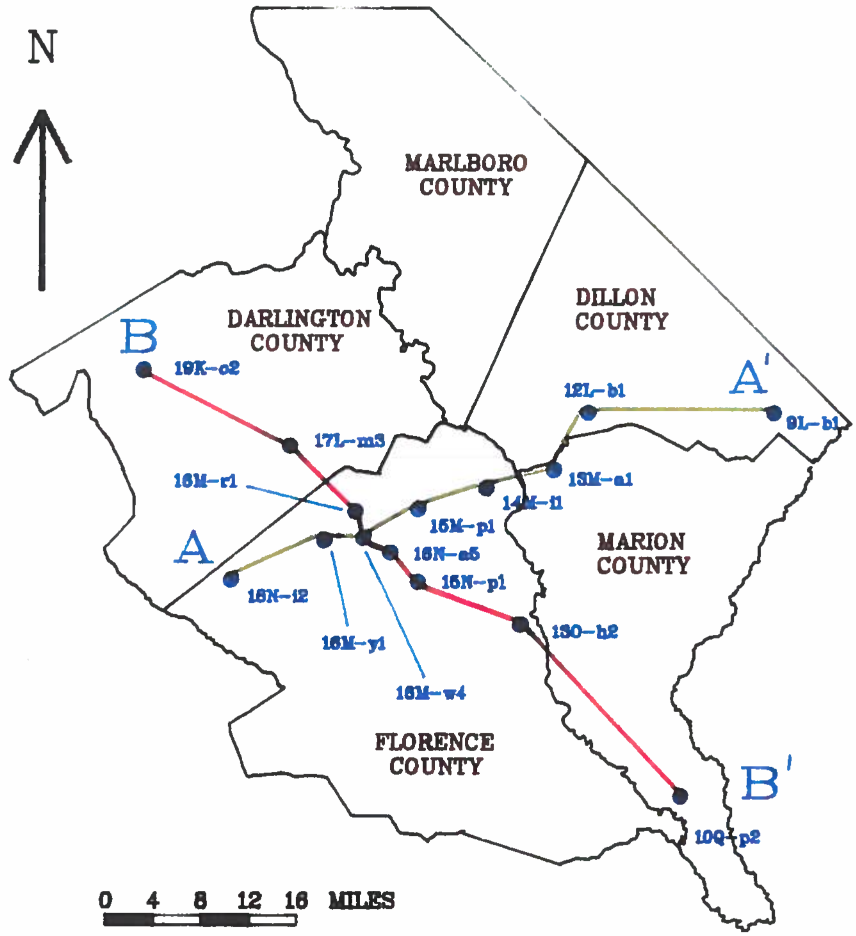


Figure 2.1 Location of hydrogeologic sections A-A' and B-B'.

1) water quality in the Cape Fear and Middendorf aquifers deteriorates toward the southeast; and

2) the depth required to drill into the Cape Fear and Middendorf aquifer increases toward the southeast.

Structural Geology

The Cretaceous formations of the South Carolina Coastal Plain occur as a wedge of sediments that thickens southeastward. The formations strike northeast and dip to the southeast. Two structural features have influenced these formations; the Cape Fear arch and the Florence Triassic basin (Park, 1980).

The Cape Fear arch is a southeastward plunging basement anticline. Its axis runs roughly parallel to a portion of the South Carolina-North Carolina border and is just inside North Carolina. The five-county study area is located along the southwestern flank of this arch.

The Florence Triassic basin is located southwest of the city of Florence and its axis trends east-northeast. On the basis of seismic refraction studies, this basin is thought to be 40 miles long, 13 miles wide, and to contain consolidated sedimentary rocks (Bonini and Woolard, 1960) that underlie the Cretaceous formations.

Pre-Cretaceous Rock

The pre-Cretaceous bedrock underlying the study area is composed of metamorphic and igneous rocks such as gneiss, schist, slate, granite, and basalt. As mentioned, seismic data indicate that portions of Florence

County overlie a narrow basin of Triassic rocks. Because of the relatively few wells that have been drilled to bedrock in this area, it is difficult to characterize the composition of the pre-Cretaceous bedrock throughout the area.

Cape Fear Formation

The Cape Fear Formation is of Late Cretaceous age and unconformably overlies the pre-Cretaceous bedrock. It is characterized by cyclic sequences of sand grading upward to clayey sand and clay. The sand of this formation tends to be light to medium greenish gray, tan, and yellowish brown, fine to coarse grained (medium sized grains are most common), poorly to moderately sorted, and subangular. Clay is generally light colored, yellowish gray, yellowish brown, and olive gray; it is commonly mottled and variegated red and yellow. Orange-and-purple mottling is also evident. Mineralogically, the Cape Fear Formation is noted for its abundant feldspar (ranging from 0 to 30 percent in the Cape Fear section at the Florence test hole).

Along section B-B′, the Cape Fear Formation is present at the most updip well between -15 and -300 ft msl. At the farthest downdip well, it is present between -750 and -1,160 ft msl.

The depositional environment for the Cape Fear Formation is thought to be fluvial or upper delta plain. Evidence for this includes the moderately to poorly sorted sand, the cyclic fining-upward sequences, the abundance of feldspar, and the lack of marine flora and fauna, glauconite, and lignite.

The contact between this formation and the overlying Middendorf Formation is based primarily on the presence of the cyclic fining-upward sequences and the disappearance of lignite. The feldspar content increases significantly below this contact. Mica, although present, is less abundant in the Cape Fear Formation than in the overlying Middendorf.

Middendorf Formation

The Middendorf Formation is of Late Cretaceous age and directly overlies the Cape Fear Formation throughout the study area. This formation contains massive beds of hard, dense, and waxy clay, with thick beds of sand in the lower two thirds of the formation. The sand is light, medium, and dark olive gray and greenish black, medium grained, moderately sorted, and subangular. The clay is dark yellowish brown and light to dark olive gray. In the Florence test hole, the clay is intensively sheared and shows evidence of possible faulting (see Test Hole section). In the upper quarter of the formation, evidence of root veinlets and burrows is common. Some of the clay is mottled red, orange, and green, although this feature is not as prevalent as in the Cape Fear Formation. Lignite, commonly disseminated but also occurring in distinct layers, and mica are prevalent. Pyrite occurs in trace amounts, often associated with the lignite.

Along section B-B′, the Middendorf Formation is present at the most updip well from the surface (at +216 ft msl) to -15 ft msl and at the most downdip well between -570 and -750 ft msl.

In the study area, the depositional environment of the Middendorf Formation varied southeastward from a nonmarine upper-delta plain environment to a proximal marine or marine environment (see Figure 2.2).

This unit differs from the underlying Cape Fear Formation by its abundance of lignite, greater percentage of mica, lack of cyclic upward sequences, and lesser amounts of feldspar. The contact with the overlying Black Creek Formation is irregular and distinguishable by the first massive bed of hard waxy clay and the significant decrease in glauconite and phosphate. Traces of feldspar in sandy units are also typical of the Middendorf Formation.

Black Creek Formation

The Black Creek Formation, like the Cape Fear and Middendorf Formations, is of Late Cretaceous age. The clay of this formation is typically medium to dark olive gray with very thin laminae of light olive gray, very fine sand and silt. Sand units tend to be in light to medium shades of olive gray; are generally fine grained, although they range from very fine to coarse; are poor to well sorted and subrounded to subangular. Sandstone layers are common in this formation; however, only one such layer was encountered in the Florence test hole. Lignite fragments, both disseminated and in distinct layers, are common; as are glauconite, phosphate, and mica. Fine crystals of pyrite are frequently associated with the lignite.

The Black Creek Formation underlies the majority of the study area but is absent in the most updip portions. Downdip the formation thickens to about 500 ft and is present between -95 and -570 ft msl at the Brittons

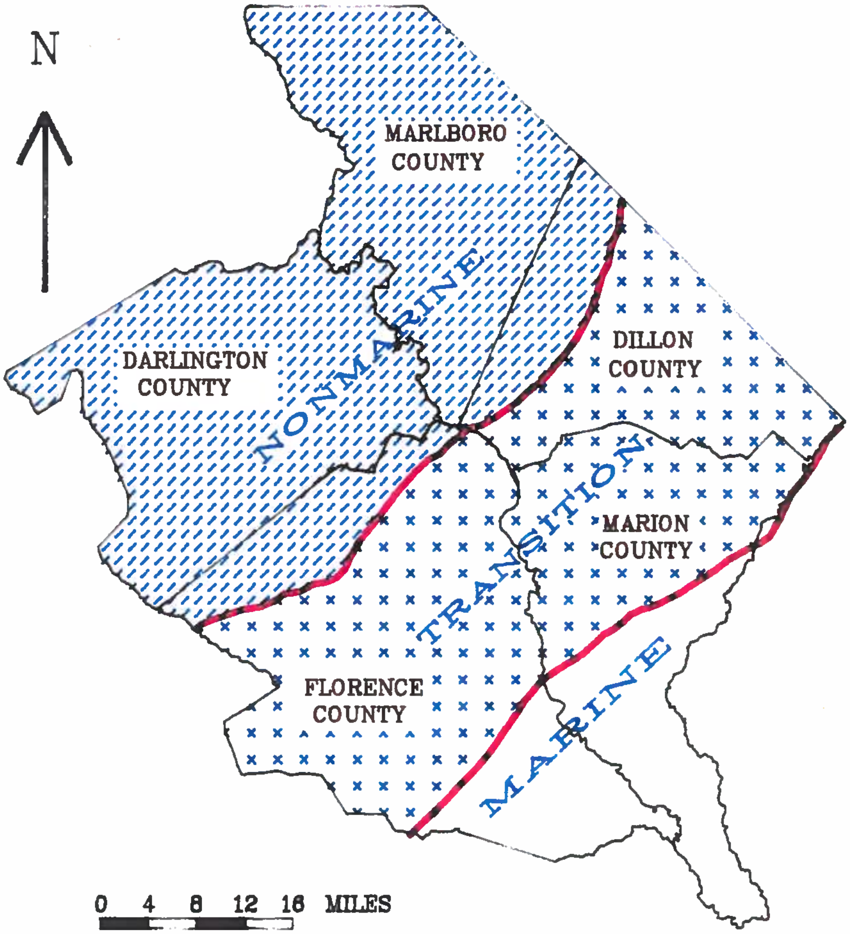


Figure 2.2 Depositional environments of the Middendorf Formation (from Speiran, 1987).

Neck well (10Q-p2).

The depositional environment of the Black Creek Formation is generally thought to be near-shore or estuarine (Pelletier, 1985); however, evidence indicates that, similar to the underlying Middendorf Formation, the depositional environment of the Black Creek may grade from nonmarine updip to more of a marine environment downdip. This is supported by:

1) the far updip sediments of the Black Creek have characteristics of the Tuscaloosa [Middendorf] Formation (Park, 1980); and
2) data from the Florence test hole show little evidence of marine fossils and no sign of shell fragments or calcareous sediment. Downdip, however, in the Brittons Neck test hole, abundant evidence of these marine indicators exist in the Black Creek Formation.

This formation differs from the underlying Middendorf Formation by the characteristic laminae in the clay, the lack of mottling, the lack of feldspar, and the abundance of glauconite and phosphate. Sandstone layers are also diagnostic of the Black Creek.

Peedee Formation

The Peedee Formation is the youngest of the Late Cretaceous formations in the study area. It underlies the area only in parts of Florence and Marion Counties and ranges in thickness from 0 to approximately 200 feet (Park, 1980). This formation consists of dark clayey sand and sandy clay. Downdip from the study area, in coastal Horry County, the Peedee Formation also consists of thin interbeds of sandy limestone and calcareous clay and sandstone, with intermittent lenses of loose shell and coarse sand. The Peedee was deposited in an open-shelf marine environment.

This formation is not present at the site of the Florence test hole. Furthermore, it is of limited hydrologic importance in the study area because of the relatively small yields of the wells that are screened in this formation.

Shallow Deposits

The shallow or post-Cretaceous sediments in the study area consist of the Duplin Formation of Pliocene age, undifferentiated rocks of Pliocene and Pleistocene ages, and Holocene (Recent) alluvial deposits. These units, where present, overlie the Cretaceous formations.

Test Hole

As part of this investigation, a continuously cored test hole was drilled near the Edisto Street public supply well in the city of Florence. Cores 2.4 inches (6 cm) in diameter were obtained to a depth 716 ft below land surface (bls). Crystalline bedrock was encountered at 711 ft bls.

Formation contacts at the test hole are as follows:

Contact	Depth (ft bls)	Elevation (ft msl)
Shallow-Black Creek	15	+ 97
Black Creek-Middendorf	189	- 77
Middendorf-Cape Fear	390	- 278
Cape Fear-bedrock	711	- 599

Data collected from this hole include macroscopic and microscopic analyses of the samples and a suite of geophysical logs (see Plate 3). These logs include:

> caliper, single-point resistance, long-normal and short-normal resistivity, spontaneous-potential, natural gamma ray, density (gamma-gamma), and neutron (porosity).

Using the descriptive data in conjunction with these logs, a geologic description of the core hole was prepared (see Test Hole Lithologic Description).

Having both core data and geophysical logs from the test hole permitted determination of the relationship between the geologic units and their signatures on the geophysical logs. By correlating the geophysical logs from the test hole with those of other wells in the area (see Plates 1 and 2), it was possible to ascertain the geologic nature of the sediments through which the wells were drilled. In making this extrapolation, however, it was noted that the level of confidence in this geologic information decreases as the distance from the core hole increases.

For purposes of geologic investigation, the usefulness of core holes, although they are more time consuming and expensive than conventionally drilled test holes, is evidenced by the undisturbed nature of the sediments that are recovered. Structural and biologic features in unconsolidated sediments, such as cross bedding, shears, burrows, and root markings, are virtually impossible to detect in drill cuttings obtained by conventional drilling methods. Secondly, because conventional drill cuttings are thoroughly inundated with drilling fluid, it is often difficult to determine the lithology. A good example of this occurs with clayey sand, which can frequently be mistaken for clean sand if the lithologic description relies heavily upon drill cuttings.

In the Florence test hole, numerous shears and slickensides in the Middendorf clay beds suggest the possibility that this hole intersects one or more faults. The presence of a relatively large scale fault in this area may explain why certain Middendorf sand layers (particularly those between 150 and 200 ft msl) are present in surrounding wells but absent in the test hole.

Test Hole (16M-w4) Lithologic Description

Depth (ft bls)	Description of material penetrated
5- 9	Sand.
9- 15	Clay, grading downward to micrite; common plant material, mollusk fragments.
15- 20	Clay, olive gray (5Y3/2); increasingly sandy (up to 20 percent) with depth; phosphate pebbles at lower contact; trace glauconite.
20- 22	Sand, dark greenish-gray (5GY4/1); fine- to very fine-grained; 1-5 percent mica.
22- 35	Clay, olive-gray (5Y3/2); frequent interbeds of medium- to fine-grained sand (thickening with depth); some burrows; trace glauconite, mica, and lignite.
35- 39	Sand, olive-gray (5Y3/2) to light olive-gray (5Y5/2); medium-grained; well-sorted; subangular to subrounded; 1-2 cm bands of lignite; 0-1 percent glauconite, trace mica (distinct negative gamma-gamma deflection).
39- 62	Sand, olive-gray (5Y3/2), light olive-gray to dark olive-gray in places; medium-grained; well-sorted; angular to subrounded; stringers of clay at 40, 44, 49 54, and 56 feet. Interbeds of lignite at 43 and 44 ft; 1-5 percent phosphate, 1-3 percent glauconite, 0-3 percent mica.
62- 68	Clay, olive-gray (5Y3/2); frequent laminae of very fine-grained sand and silt (1-5 cm); sparse sand-filled burrows; 1-3 percent mica, 1 percent lignite.
68- 74	Sand, olive-gray (5Y3/2); medium- to coarse-grained; sorting grades from poor to well with depth; subrounded to rounded; disseminated plant material throughout interval (up to 40 percent), 0-5 percent glauconite, 1-2 percent phosphate, trace pyrite.
74- 84	Clay, olive-gray (5Y3/2); laminae of very fine sand common; sand stringer at 80 feet; 1-3 percent phosphate, disseminated lignite at top of interval, trace glauconite.
84- 99	Sand, grades from olive-gray (5Y3/2) to light olive-gray (5Y5/2) with depth; grades from fine- to medium-grained with depth; grades from moderately- to poorly-sorted with depth; subangular; frequent interbeds of lignite; clay stringers between 87 and 90 ft; 0-5 percent glauconite, 0-3 percent mica, 0-1 percent phosphate, trace pyrite.

99-132	Clay, olive-gray (5Y3/2); stringers of medium- and fine-grained sand at 107, 110, 119, 123 and 127 feet; abundant lignite (up to 20 percent); 0-15 percent glauconite, 0-10 percent mica, 0-8 percent phosphate, trace pyrite.
132-189	Sand, olive-gray (5Y3/2); fine- to coarse-grained; grades from well to poorly sorted with depth; subangular to subrounded; stringers of clay at 162 ft, 167 ft, 173 ft, and 173 ft; frequent lignite interbeds between 156-158 ft; sandstone stringer at 146 ft; 0-15 percent glauconite, generally increasing with depth, 0-5 percent mica, 0-1 percent phosphate; trace pyrite.
189-221	Clay, grades from olive-gray (5Y3/2) to light olive-gray (5Y5/2) to medium gray (N5) with depth; common burrows; sparsely disseminated plant material; possible root structures toward top; mottling toward bottom of unit; 2-10 percent silt and fine-grained sand, 0-1 percent mica, 0-1 percent phosphate.
221-228	Sand, yellow (5Y7/6) to dark yellowish-brown (10YR4/2); coarse-grained; poorly- to moderately-sorted; subangular; trace plant material; cross-bedding; possible horizontal bedding; 0-1 percent pyrite, trace glauconite, possible traces feldspar, lignite and phosphate.
228-323	Clay, dark yellowish-brown (10YR4/2), varies to olive-brown (5Y4/4) and olive-gray (5Y4/1), variegated reddish-yellow from 248 ft to 256 ft; sheering, fracturing and slickensides are common; root structures toward top of unit; sand stringer at 321 ft, interbed of lignite at 322 ft; 0-10 percent lignite, 0-5 percent mica, trace phosphate.
323-326	Sand, light olive-gray (5Y5/2); very fine-grained; poorly-sorted; subangular; 5 percent mica, 5 percent lignite, trace glauconite.
326-331	Clay, dark yellowish-brown (10YR4/2); very fine-grained sand laminae; 1-10 percent lignite, 1-2 percent mica, trace glauconite.
331-334	Sand, greenish-black (5GY2/1); fine- to very fine-grained; poorly-sorted; angular; large interbed of lignite at 333-334; 5-10 percent lignite, 1-3 percent mica, trace glauconite.
334-349	Clay, dark yellowish-brown (10YR4/2); very fine-grained sand laminae; 1-3 percent lignite, 0-1 percent mica, trace pyrite, glauconite and phosphate.
349-377	Sand, light olive-gray (5Y5/2); medium- to fine-grained, moderate- to well-sorted, except at lower contact where it is poorly-sorted; subangular; sporadic thin clay interbeds; lignite interbeds (2"-3" thick) at 349 and 364 feet; 1-10 percent mica, increasing with depth, 0-3 percent disseminated lignite, possible trace feldspar.

377-390	Clay, dark olive-gray (5Y3/2); thin, medium-grained sand laminae; 1-2 percent disseminated lignite, 1-2 percent mica, trace pyrite and glauconite.
390-408	Sand, grading from medium yellowish-gray (5Y8/1) to light olive-gray (5Y6/1) with depth; fine- to very coarse-grained (generally coarsening downward); moderately-sorted; subangular; 0-3 percent disseminated lignite, 1-2" lignite interbed at 407, 0-1 percent mica, 2 percent feldspar at bottom contact.
408-421	Clay, light olive-gray (5Y5/2) to dark olive-gray (5Y3/2), mottled red, yellow, green and purple; irregular vein structures noted; trace lignite, mica, glauconite, and phosphate.
421-427	Clayey sand grading downward to sand, dark yellowish-brown (10YR4/2) to light olive-gray (5Y5/2), variegated orange in places; medium- to coarse-grained; poorly sorted; subangular; 0-3 percent phosphate, trace mica.
427-433	Clay to sandy clay, light yellowish-brown (10YR6/2) to olive-gray 5Y4/1), mottled red, purple and yellow; sand fraction is medium, subangular to angular; 1 percent mica, trace phosphate.
433-438	Sand, olive-gray (5Y4/1); medium- to coarse-grained; subangular; poorly sorted; trace mica and phosphate.
438-459	Clay, light olive-gray (5Y5/2) to dark yellowish-brown (10YR4/2) to light yellowish-brown (10YR6/2), variegated red and orange in places; distinct vertical and reticular vein structures; 0-1 percent mica, trace of lignite, pyrite, and phosphate.
459-462	Sand, light yellowish-brown (10YR6/2); fine-grained; angular to subangular; poorly-sorted; cross-bedding present; 1 percent phosphate.
462-472	Clay, light yellowish-brown (10YR6/2) to dark yellowish-brown (10YR4/2), variegated red, yellow, and purple; sand-filled mud crack at top contact; polygonal structures present; trace pyrite and phosphate.
472-477	Sand, light yellowish-gray (5Y7/2); medium-grained; poorly-sorted; subangular; possible roots or burrows; trace of phosphate.
477-491	Clay, light yellowish-gray (5Y7/2); mottle red to purple; increasing sand content (up to 20 percent) with depth.
491-500	Sand, light yellowish-gray (5Y7/2), mottled in places; very coarse-grained; poorly-sorted; subangular; possible burrows; trace phosphate.
500-515	Sandy clay grading downward to clay, light olive-brown (5Y6/1) to dark yellowish-gray, mottled red in places; 0-1 percent mica, trace phosphate.

515-564	Sand with clay interbeds at: 520-523, 538-542, 549-551, color varies from medium yellowish-brown (10YR5/4) to light yellowish-gray (5Y7/2) to light olive-gray (5Y5/2), variegated red and yellow in places; medium- to coarse-grained; poorly-sorted; subangular to subrounded; occasional gravel and cross-bedding; 0-1 percent mica, 0-1 percent phosphate, 10 percent feldspar at 543 ft.
564-568	Clay, generally becoming sandier (up to 45 percent) with depth, light olive-gray (5Y5/2) to medium yellowish-brown (10YR5/4); trace feldspar, mica, and phosphate.
568-583	Sand with minor clay interbeds, clay content increasing toward bottom, light olive-gray (5Y5/2) to light olive-brown (5Y5/6) to medium yellow (5Y5/7), variegated red in places; coarse- to very coarse-grained; moderately- to poorly-sorted; subangular to subrounded; occasional gravel zones; possible root or burrow structures; 0-5 percent feldspar, 0-2 percent phosphate.
583-586	Clay with minor fine-grained sand, (determined from geophysical log, most of core was missing).
586-607	Clay interbedded with sand, light yellowish-gray (5Y7/2) to dark yellowish-brown (10YR4/2), variegated red in places; sand is fine- to coarse-grained (coarsening downward); moderately- to poorly-sorted; subangular; occasional mud cracks and cross-bedding; reticular vein structures in places; 1-4 percent mica, 0-1 percent feldspar, 0-1 percent phosphate.
607-618	Clayey sand (with 15 percent to 30 percent clay content), light olive-gray (5Y5/2) to medium yellow (5Y7/6); medium- to very coarse-grained, generally coarsening with depth; poorly-sorted, subangular to subrounded; 0-1 percent feldspar, trace mica and phosphate.
618-623	Clay, medium yellowish-brown (10YR5/4), mottled red in places; 20 percent subangular sand and granules; trace feldspar and mica.
623-636	Repeating sequences of clay grading downward to sand, light olive-gray (5Y5/2) to light yellowish-gray (5Y7/2); sand ranges from coarse- to very coarse-grained; poorly-sorted; subangular; pebbles and cobbles noted at 636 ft; occasional cross-bedding; 0-10 percent feldspar, trace mica and phosphate.
636-643	Clay, becoming increasingly sandy with depth (up to 25 percent), light olive-brown (5Y5/6); sand is very fine-grained; poorly-sorted; subangular to angular; occasional interbedded sand; rootlet structures and polygonal cracks noted; 0-5 percent mica, 0-2 percent phosphate.

643-661	Repeating sequences of clay grading downward to sand to cobbles, sequences become increasingly sandy with depth, medium yellowish-gray (5Y7/2) to light olive-gray (5Y5/2); sand is generally coarse-grained; poorly- to moderately-sorted; subangular to subrounded; occasional cross bedding; 0-1 percent feldspar, 0-1 percent mica.
661-666	Clay, medium grayish-olive (10Y4/2), mottled red in places; polygonal cracks noted, trace phosphate.
666-691	Repeating sequences of clay grading downward to sand to cobbles, sequences become increasingly sandy with depth, medium olive-brown (5Y4/4) to light yellowish-gray (5Y7/2) to light yellowish-brown (10YR6/2); sand generally coarsens downward from very fine- to very coarse-grained; poorly-sorted, angular to subrounded; occasional cross bedding; in general, this unit is less sandy than the 643-661 unit; 0-10 percent feldspar, 1 percent mica.
691-711	Saprolite, dark reddish-brown (10R3/4) to light olive (10Y5/4), mottled olive-gray and medium yellow; less than 1 percent sand, 1 percent unidentified heavy mineral.
711-716	Gabbro, grayish-black (N2); well indurated; phaneritic texture; quartz and biotite are present, additional unidentified mafic minerals also present.

HYDROLOGY

The major aquifers of the study area are the clastic sedimentary sand beds of the Cape Fear, Middendorf, and Black Creek Formations. Generally, these aquifers exist under confined conditions, although there are places in the study area where the Black Creek and Middendorf aquifers are unconfined. Historically, these sand beds have been grouped into aquifer systems coinciding with the geologic formations within which they are contained.

Nomenclature of the aquifer systems and geologic formations tends to vary from report to report, as shown below:

SCWRC 1990	USGS 1980's	Other
Black Creek	A3A2	Black Creek
Middendorf	A3A3	Middendorf or Tuscaloosa
Cape Fear	A4	

Many former works did not differentiate between the Cape Fear and Middendorf Formations. Additionally, the resulting composite has been variably referred to as both the Middendorf and Tuscaloosa Formation. Usage of the name "Tuscaloosa" in reference to the Middendorf and Cape Fear Formations is still common, as is the grouping of the Cape Fear and Middendorf Formations (and aquifer systems) as one.

On the basis of geologic evidence, it is concluded here that the Middendorf and Cape Fear Formations are distinct and that both are present in the study area. The issue of whether the aquifers of the Cape Fear and Middendorf are hydraulically independent, however, is arguable. It is the writer's opinion that present evidence is inconclusive as to whether they should be classified into one or two aquifer systems.

Because of the lack of differentiation in historical data and of evidence to suggest otherwise, the aquifers of the Cape Fear and Middendorf Formations are treated as one aquifer system in this report. Collectively, they are called the Middendorf aquifers.

Recharge to both the Middendorf and Black Creek aquifers occurs directly from precipitation in the updip areas of the respective formations where they crop out or subcrop beneath the Tertiary or Quaternary deposits (Park, 1980). For the Black Creek aquifers, a large portion of this area coincides with the study area. For the Middendorf aquifers, the recharge area is predominantly northwest of the study area (see Figure 3.1). Leakage between aquifer systems is also thought to be a significant source of recharge. Prior to development of these aquifers, leakage, because of overall greater hydraulic heads in the Middendorf aquifers, was from the Middendorf to the Black Creek aquifers. Presently, however, because development has caused the hydraulic head in the Middendorf aquifers to drop below that of the Black Creek aquifers in many portions of the study area, this trend may be locally reversed.

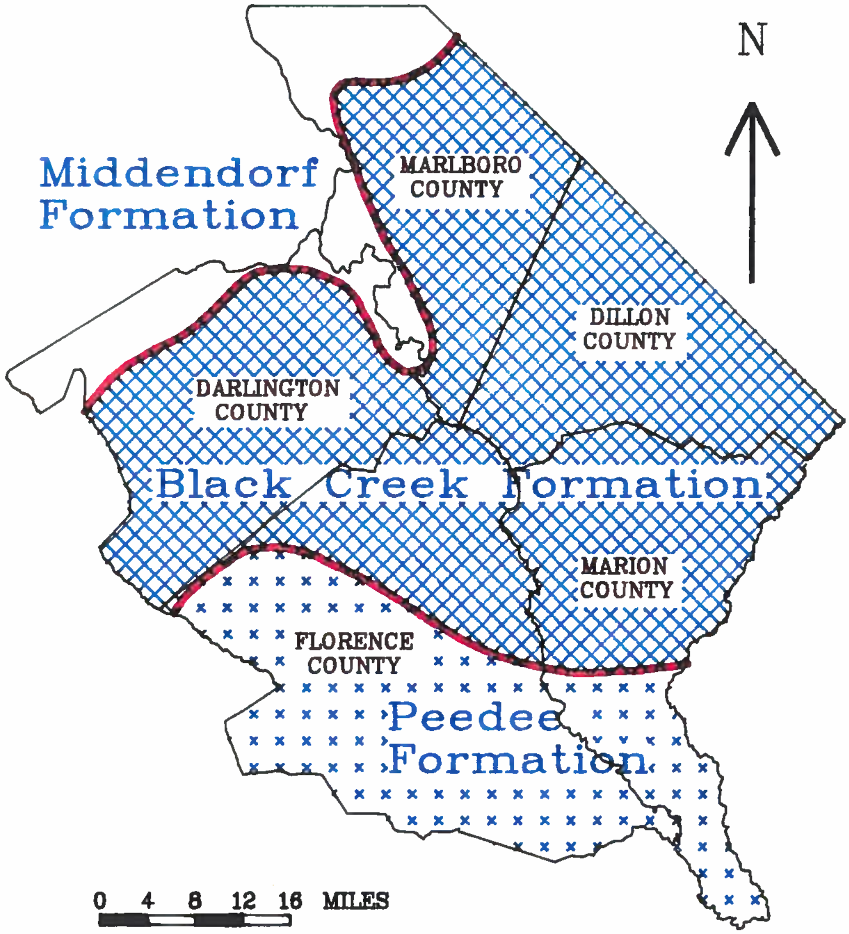


Figure 3.1 Outcrop-subcrop map of Cretaceous formations (from Colquhoun, 1983).

Hydrographs

Water-level data from four observation wells located in the study area are depicted in Figure 3.2. Two of these wells are screened in Middendorf aquifers (18N-i1 and 15J-d2) and two in Black Creek aquifers (15M-o2 and 10Q-p1). Several observations can be made by looking at these hydrographs:

1) Long-term trends of declining water levels can be seen in all four wells.

2) Seasonal water-level variations seem to occur in all four wells. These variations are probably the result of both seasonal recharge and water-use patterns.

3) The magnitude of seasonal variation is greater in the wells that tap the Middendorf aquifers. This is probably a result of the proximity of these wells to population centers, which magnifies the effect of seasonal water use patterns. This trend, therefore, should not be generalized to include all parts of the Middendorf aquifers in the study area.

4) Despite the different locations and aquifers, the hydrographs for all four of these wells show a similar character. Although not conclusive, this suggests that recharge by leakage from one aquifer system to another (as mentioned by previous authors) plays a large role in the Pee Dee region because the aquifers appear interconnected.

Potentiometric Surfaces

Predevelopment potentiometric surfaces in the Middendorf and Black Creek aquifers are shown in Figures 3.3 and 3.4. Prior to development, the direction of ground-water flow in the Middendorf aquifers was generally downdip toward the coast; however, a significant component of this flow was toward the Pee Dee River. Within the study area, potentiometric levels ranged from just over +250 ft msl in the most updip region, to less than +50 ft msl in the most downdip region. The pattern

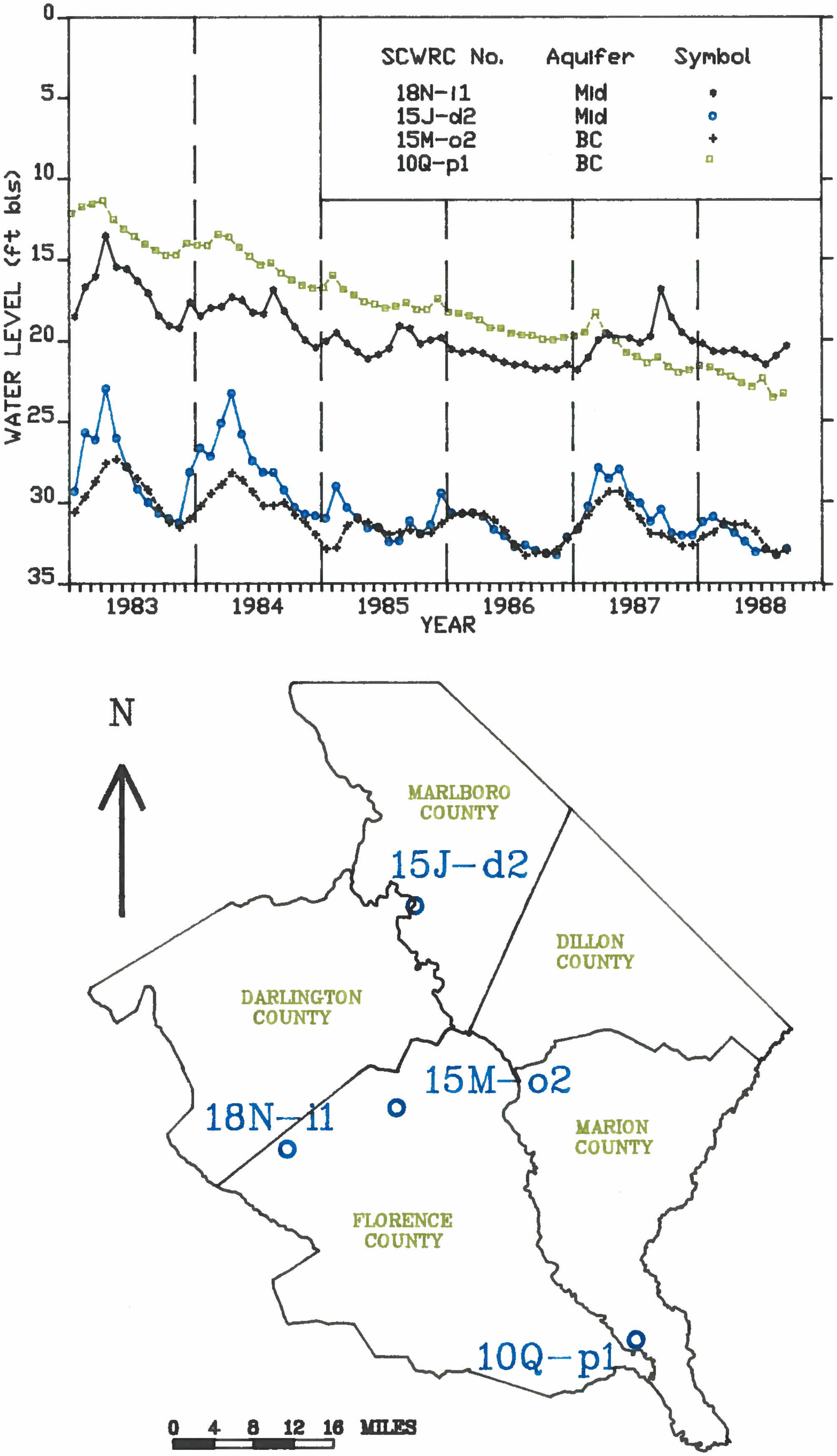
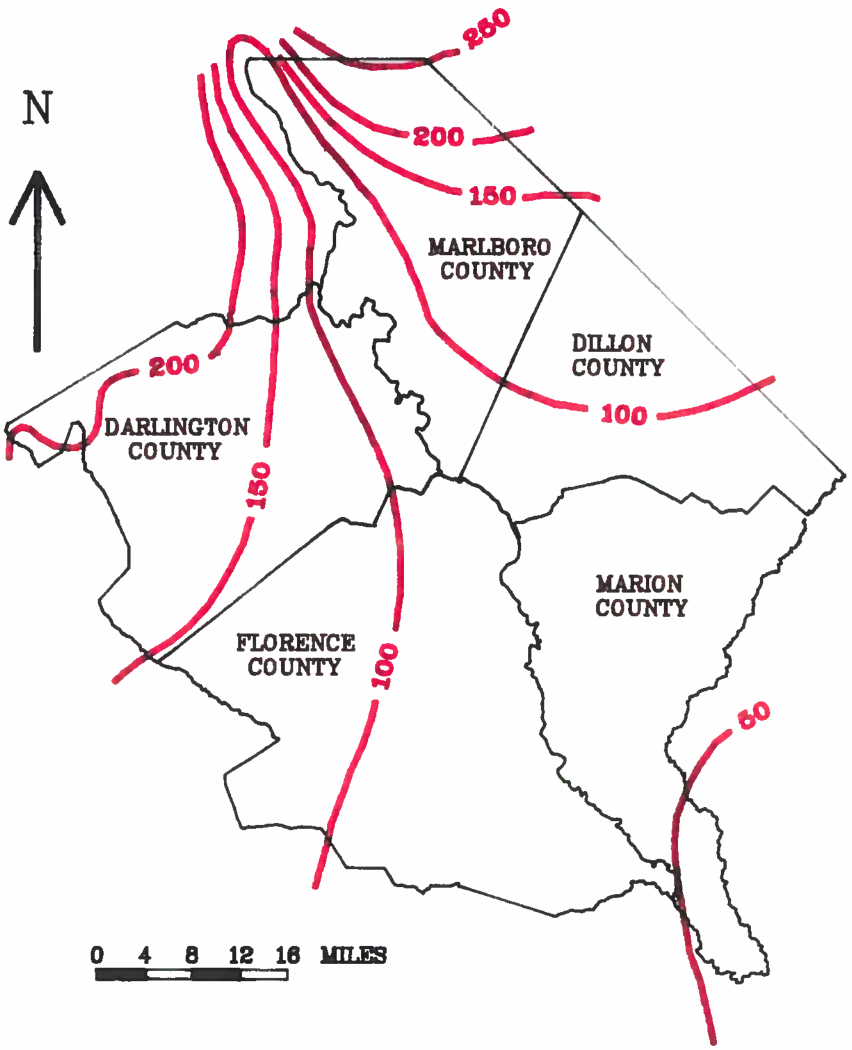
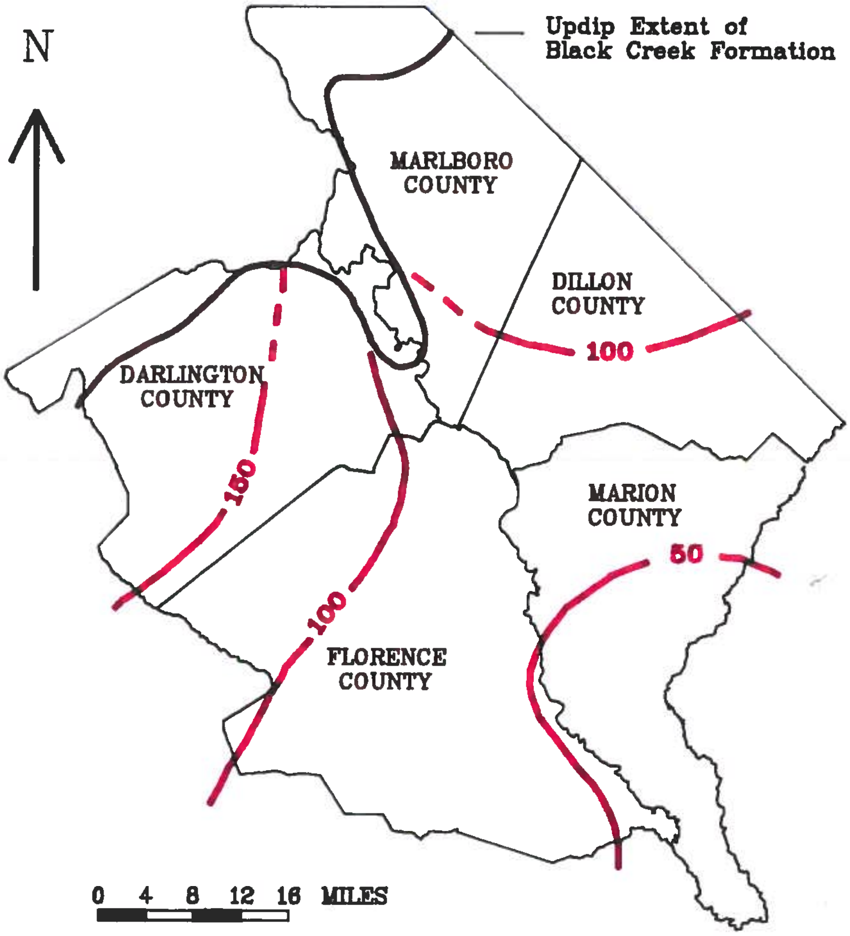


Figure 3.2 Hydrograph of selected wells and location map.



Explanation: Contour lines show elevation of potentiometric surface in feet above sea level.

Figure 3.3 Potentiometric map of Middendorf aquifers before development (modified from Aucott, 1988).



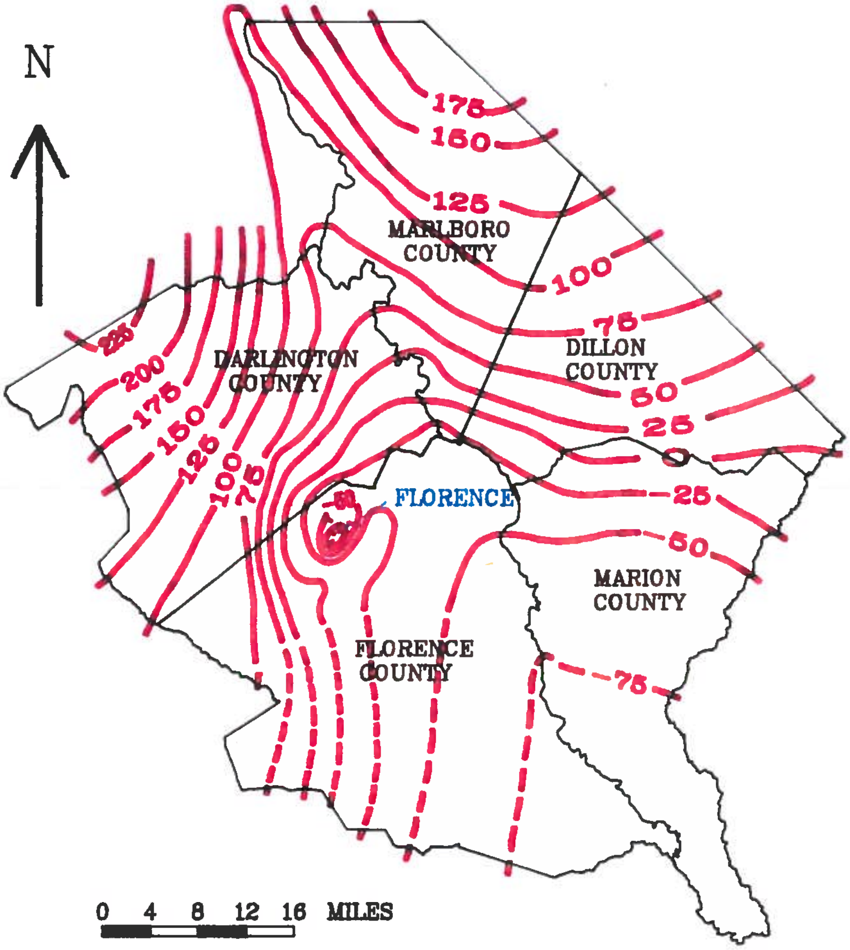
Explanation: Contour lines show elevation of potentiometric surface in feet above sea level. Lines dashed where approximate.

Figure 3.4 Potentiometric map of Black Creek aquifers before development (modified from Aucott, 1988).

of flow in the Black Creek aquifers was similar to this; generally toward the coast with a component toward the Pee Dee River. Because the recharge area of the Black Creek aquifers has a lower elevation than the recharge area of the Middendorf aquifers, however, the potentiometric surface ranged from less than +200 ft msl in the updip areas to less than +50 ft msl in the downdip areas. The lesser hydraulic heads in the predevelopment Black Creek aquifers are the reason it is generally thought that recharge occurred through leakage into these aquifers from the underlying Middendorf aquifers

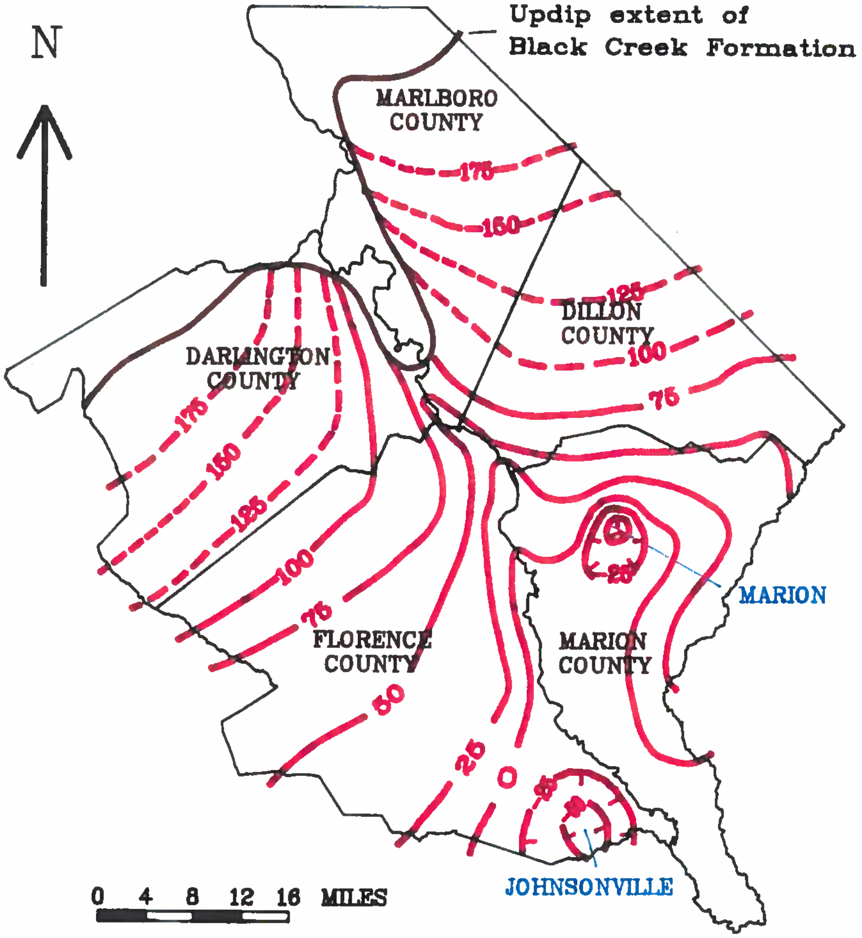
Figures 3.5 and 3.6 depict the potentiometric surfaces of the Middendorf and Black Creek aquifers in the fall of 1989. In the Middendorf aquifers, potentiometric surfaces now range from slightly higher than +225 ft msl in northern Darlington County to lower than -75 ft msl in the city of Florence. This latter point represents the center of a cone of depression that surrounds the city of Florence and has affected the direction of ground-water flow in many parts of the study area. With a few minor exceptions (which are possibly the result of sampling error), the potentiometric surface of the Middendorf aquifers has declined throughout the study area since predevelopment, particularly in Marion and Florence Counties, where drops of 50 to 100 ft are common.

Potentiometric surfaces in the Black Creek aquifers now range from +100 ft msl updip to lower than -50 ft msl in cones of depression that surround the cities of Johnsonville and Marion. As in the Middendorf aquifers, flow paths have been affected by the two cones of depression and a general decline in the potentiometric surface has occurred since predevelopment.



Explanation: Contour lines show elevation of potentiometric surface in feet above sea level. Lines dashed where approximate.

Figure 3.5 Potentiometric map of Middendorf aquifers, November 1989.



Explanation: Contour lines show elevation of potentiometric surface in feet above sea level. Lines dashed where approximate.

Figure 3.6 Potentiometric map of Black Creek aquifers, November 1989.

Hydraulic Properties

Transmissivity (T) is a measure of an aquifers capacity to transmit water and is usually calculated from aquifer test data. Specific capacity (Q/s) is the ratio of discharge to drawdown in a given well, typically over a 24-hour period, and is a function of the transmissivity of the formation in which a well is screened and the well efficiency. In a well that is 100-percent efficient (no loss in head as water flows through the screen), the following equations can be used to give a reasonable estimate of transmissivity:

$$T = Q/s \times 2{,}000 \text{ for confined aquifers}$$
$$T = Q/s \times 1{,}500 \text{ for unconfined aquifers}$$

for T in gallons per day per foot
and Q/s in gallons per minute per foot of drawdown.

Table 3.1 lists values of transmissivity at various wells in the study area. As noted, most transmissivity values were calculated from specific-capacity values and, therefore, reflect inaccuracies caused by well inefficiency. The remaining values were obtained from single-well aquifer tests. The transmissivities derived from specific-capacity values are presented because aquifer tests are scarce in the study area and because the estimated transmissivity provides a value that can be used until reliable data are obtained.

Table 3.1 Transmissivity data

SCWRC No.	County	Aquifer	Discharge (gpm)	Transmissivity (gpd/ft)
16L-q1	DAR	CF	600	6,700
16L-x1	DAR	Mid/CF	951	9,700
17I-v3	DAR	Mid	250	5,400 *
17I-v5	DAR	Mid	240	12,000 *
17L-m1	DAR	Mid	465	36,000 *
17L-m2	DAR	Mid	800	58,000 *
19K-f1	DAR	Mid	530	30,000 *
19K-g1	DAR	Mid	278	28,000 *
19K-g3	DAR	Mid	375	18,000 *
19K-o2	DAR	Mid	1,022	38,000
19M-y1	DAR	Mid	626	16,000 *
20K-r1	DAR	Mid	1,430	78,000 *
20K-t1	DAR	Mid	800	84,000 *
09L-b1	DIL	Mid	500	8,400 *
11J-j2	DIL	Mid	360	28,000 *
11J-j5	DIL	Mid	521	18,000 *
11J-k6	DIL	Mid	525	24,000 *
11J-v1	DIL	Mid	703	20,000 *
11J-w	DIL	Mid	780	22,000 *
12K-v1	DIL	Mid	650	17,000 *
12R-b2	FLO	Mid	668	28,000 *
12R-b3	FLO	BC	500	19,000 *
12R-b4	FLO	BC	350	11,000 *
12R-g1	FLO	BC	408	11,000
13N-d2	FLO	BC	115	3,400 #
13N-d3	FLO	BC	118	18,000
13P-d1	FLO	BC	536	22,000
13P-e1	FLO	BC	100	2,600 *
14M-p2	FLO	Mid	302	12,000 *
14M-p5	FLO	Mid/CF	1,107	7,900
15M-p1	FLO	Mid	1,000	22,000 *
15Q-e2	FLO	BC	912	28,000 *
15Q-e3	FLO	BC	700	20,000 *
15Q-p3	FLO	BC/Mid	751	30,000 *
15Q-q2	FLO	BC/Mid	754	13,000 *
16M-d3	FLO	Mid	340	13,000 *
16M-l1	FLO	Mid	1,150	28,000 *
16M-r1	FLO	Mid/CF	1,469	28,000 *
16M-s1	FLO	Mid/CF	520	27,500
16M-s3	FLO	Mid	700	24,000 *
16M-t1	FLO	Mid/CF	1,180	22,000 *

* Calculated from specific-capacity value. Confined conditions assumed.
\# Calculated from specific-capacity value. Unconfined conditions assumed

Table 3.1 Transmissivity data (continued)

SCWRC No.	County	Aquifer	Discharge (gpm)	Transmissivity (gpd/ft)
16M-t3	FLO	BC	475	54,000
16M-w	FLO	BC	450	6,300 #
16M-w1	FLO	Mid	1,400	20,000
16M-w2	FLO	BC/Mid	600	22,000
16M-x1	FLO	Mid/CF	1,250	19,000 *
16N-b2	FLO	Mid/CF	855	11,000
16O-m2	FLO	BC	87	29,000
16Q-i2	FLO	BC/Mid	751	20,000 *
16Q-k1	FLO	BC	1,250	24,000 *
16Q-k2	FLO	BC	250	5,000 *
16Q-t2	FLO	BC/Mid	750	24,000 *
17M-t1	FLO	Mid	1,300	13,000 *
18N-i2	FLO	Mid	517	12,000 *
18N-i3	FLO	BC	234	9,300 #
18N-i5	FLO	Mid	580	7,400 *
18N-i6	FLO	BC	488	13,000 #
18P-s1	FLO	BC	450	13,000 *
18P-v1	FLO	BC	300	6,600 *
09M-p1	MRN	BC	602	12,000
09M-p2	MRN	BC	570	21,000
10M-k2	MRN	BC	514	12,000 #
10M-k3	MRN	BC	372	6,700
10M-l1	MRN	BC	400	5,700 #
10M-q1	MRN	BC	402	10,000 #
10N-g1	MRN	BC	87	5,400 #
11M-q1	MRN	BC/Mid	400	20,000 *
11M-r1	MRN	BC/Mid	955	14,000 *
11M-x1	MRN	BC/Mid	525	18,000 *
11N-c1	MRN	BC	339	9,600 #
13G-w	MLB	Mid	340	10,000 *
13H-c2	MLB	Mid	403	4,200 *
14G-l1	MLB	Mid	151	11,000 *
14K-b1	MLB	Mid	1,002	60,000
15H-j2	MLB	Mid	351	12,000 *
15H-l2	MLB	CF	200	4,000 *
15H-r1	MLB	Mid	200	24,000 *
15H-s3	MLB	Mid/CF	350	6,600 *
15H-t4	MLB	Mid	500	20,000 *
15H-t5	MLB	Mid/CF	800	11,200 *
15I-a1	MLB	Mid	350	36,000 *
15I-i1	MLB	Mid	560	9,200 *
15J-d1	MLB	Mid	508	30,000 *
15J-d2	MLB	Mid	325	32,000 *
15J-d3	MLB	Mid	362	37,000

* Calculated from specific-capacity value. Confined conditions assumed.

\# Calculated from specific-capacity value. Unconfined conditions assumed

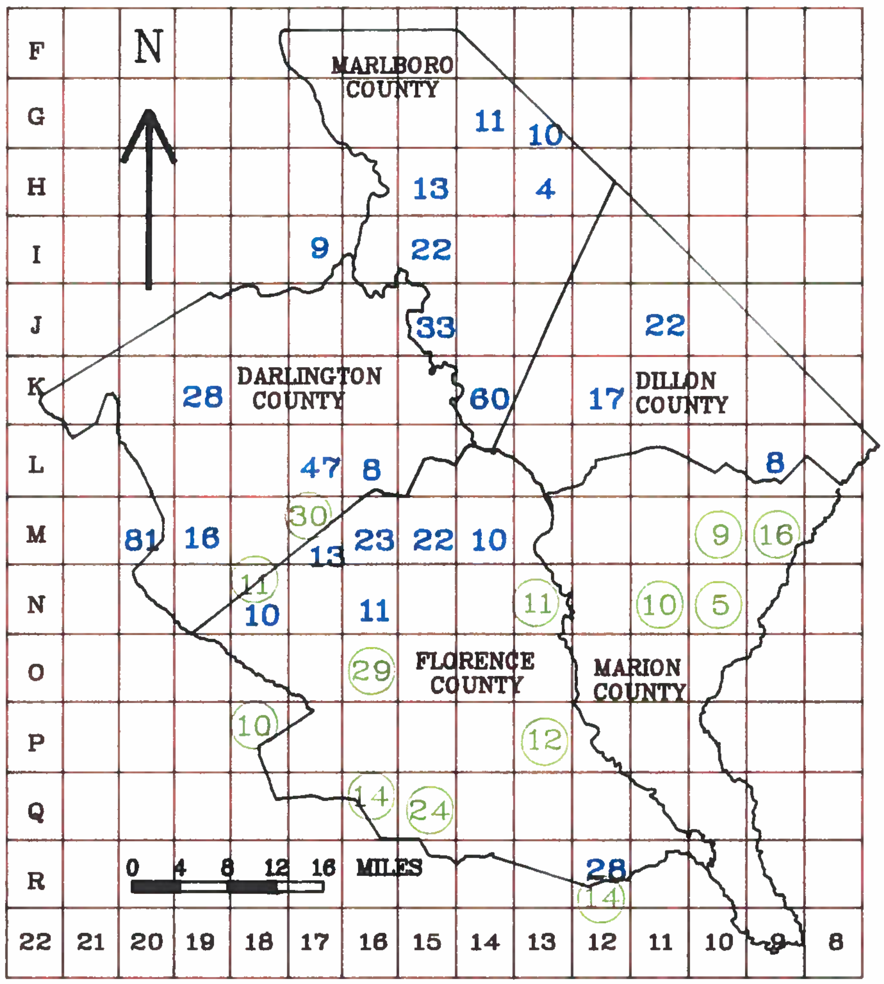
The information presented below summarizes the data from Table 3.1. As shown, the mean transmissivity value calculated from wells tapping the Middendorf aquifers is the greatest, while the mean value from wells tapping the Black Creek aquifers is the least. Predictably, the mean value calculated from wells that tap both aquifer systems falls between these other two values.

Aquifer	Number of Values	Transmissivity (gpd/ft) Maximum	Minimum	Mean
Black Creek	26	54,000	2,600	14,500
Black Creek/Middendorf	8	30,000	13,000	20,100
Middendorf	51	84,000	4,000	22,700

A further breakdown of transmissivity values is illustrated in Figures 3.7 and 3.8. It is difficult to identify trends in these data, although the Middendorf transmissivities tend to be higher than those for the Black Creek, and the Black Creek aquifers become more transmissive away from the Cape Fear arch. Park noted that the transmissivities of the Middendorf aquifers in Sumter County (west of Florence County) are generally greater than those in Florence County.

Storage coefficient is a measure of how much water an aquifer yields per unit surface area under a unit decline of head. For a confined aquifer, these values range from 0.001 to 0.00001 (Driscoll, 1986). Determination of these values requires water-level monitoring in one or more unpumped observation wells during an aquifer test, something that is infrequently done. Consequently, known storage coefficients across the study area are rare.

A pumping test conducted in the Middendorf aquifers east of the city of Florence in 1989 yielded a storage coefficient of 0.00023, well within the range of values expected for confined aquifers.



Explanation: Transmissivity in thousands of gallons per day per foot.

Circled values are for the Black Creek Formation.

Uncircled values are for the Middendorf formation.

Figure 3.7 Average transmissivity per 5-minute grid.

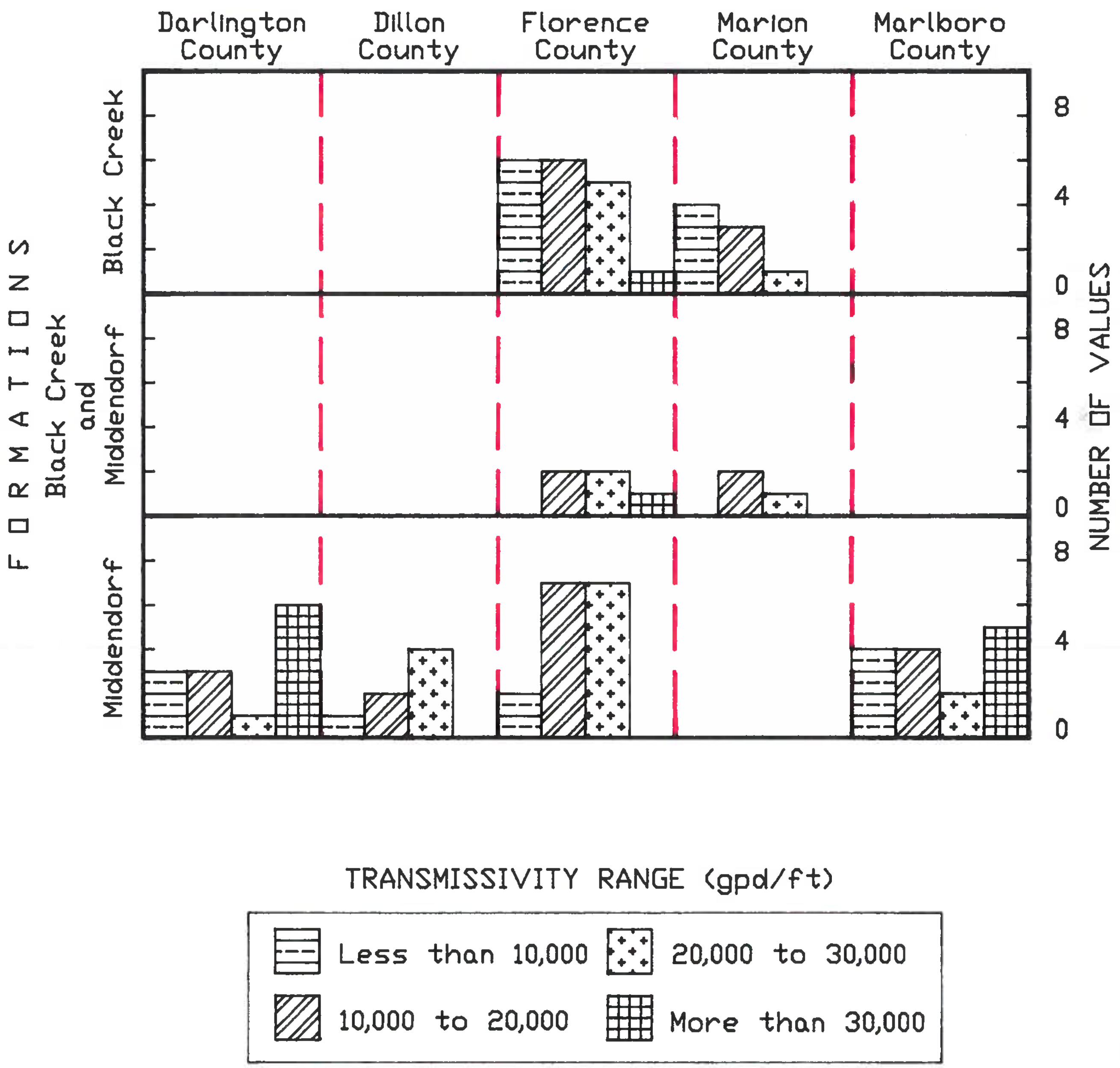


Figure 3.8 Bar chart of transmissivity data.

GROUND-WATER QUALITY

Ground-water quality data used in this study consist of water-quality analyses made at the SCWRC laboratory, dating back to 1984, and data presented by Park (1980). Because some data in the latter source were obtained as long ago as the 1950's, and analyses were performed by a variety of laboratories, the data obtained from 1984 to present were relied upon more heavily. Other water-quality data, particularly those used by Speiran (1987), are reproduced in graphical form in this report. Speiran made use of several historical data sets and noted the shortcomings inherent in using such a variety of data.

Ground-water quality in the Pee Dee region is variable, depending largely upon the aquifer and the location from which it is drawn. Although generally acceptable, concentrations of iron, calcium, magnesium, and fluoride in excess of recommended water-quality standards occur locally (Park, 1980). Additionally, elevated concentrations of sodium are a concern in the eastern part of the study area (Patterson and Speiran, 1988).

A useful tool in characterizing the chemical makeup of ground water is a Piper diagram (see Figure 4.1). By plotting milliequivalents per liter as percentages of specified cations and anions from a given water sample, it can be seen that water from the Black Creek aquifers tends to plot in the lower corner of the diamond and that water from the Middendorf aquifers tends to plot to the left of and slightly above the righthand corner of the diamond. This signifies that the water from the Black Creek aquifers tends to be of a bicarbonate type and that water from the Middendorf aquifers tends to be of a chloride type. Both have high

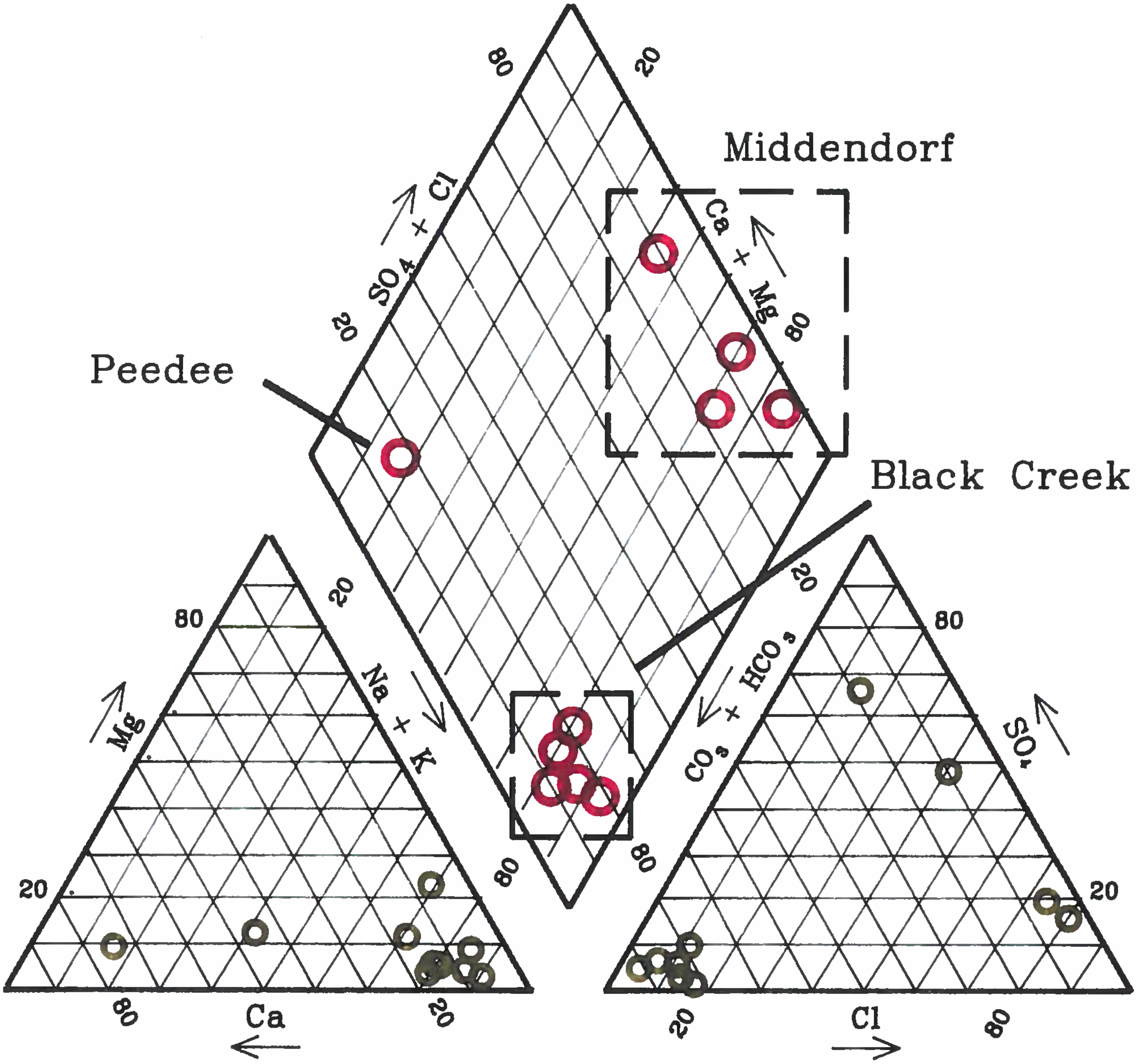


Figure 4.1 Piper diagram of ground-water quality analyses in the Pee Dee region.

percentages of sodium.

Another application of this diagram is that water can be classified as Black Creek or Middendorf simply by looking at the analytical data. The importance of this is twofold: 1) reliable well construction information is often lacking and there is no easy way to determine which aquifer a given well may tap; and 2) many wells are screened in two or more aquifer systems. Using this diagram, we are able to determine which aquifer system is providing the most water to a given well.

Figure 4.2 shows, by Stiff diagrams, much of the same type of information as the Piper diagram but also allows for the identification of areal variations in water quality. Again, the high percentages of sodium and potassium are evident in the Middendorf water; however, the percentage of anions tends to vary. The lone Black Creek analysis plotted in this diagram is consistent with the Black Creek analyses plotted on the Piper diagram; it has high percentages of bicarbonate and sodium.

Much of the identification of areal trends in the water quality data is taken from Speiran (1987), who reported on the aqueous geochemistry of the Middendorf aquifers across the entire Coastal Plain of South Carolina. As seen in Figure 4.3, there is a definite trend of increasing dissolved solids downgradient from the recharge area. This trend is also seen with pH and concentrations of bicarbonate, sodium, chloride, and fluoride (See Figures 4.4, 4.5, 4.6, 4.7, and 4.8).

The trend of increasing dissolved solids downgradient from the recharge area is predictable; the dissolution of minerals into ground water is partly a function of the time the ground water has been in contact with the host material (sediment). The downgradient distance from the recharge area provides a good indication of the relative age of the

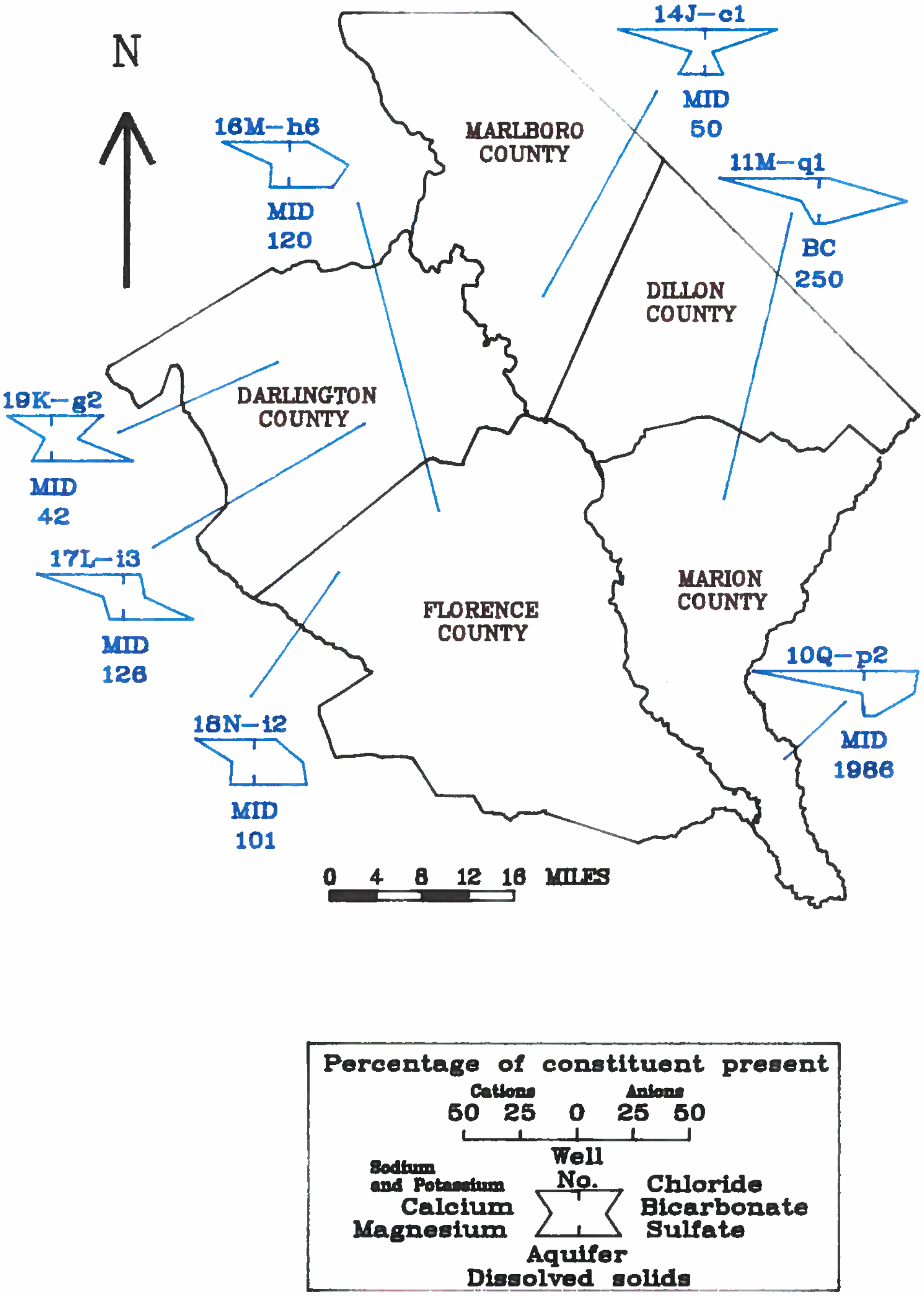
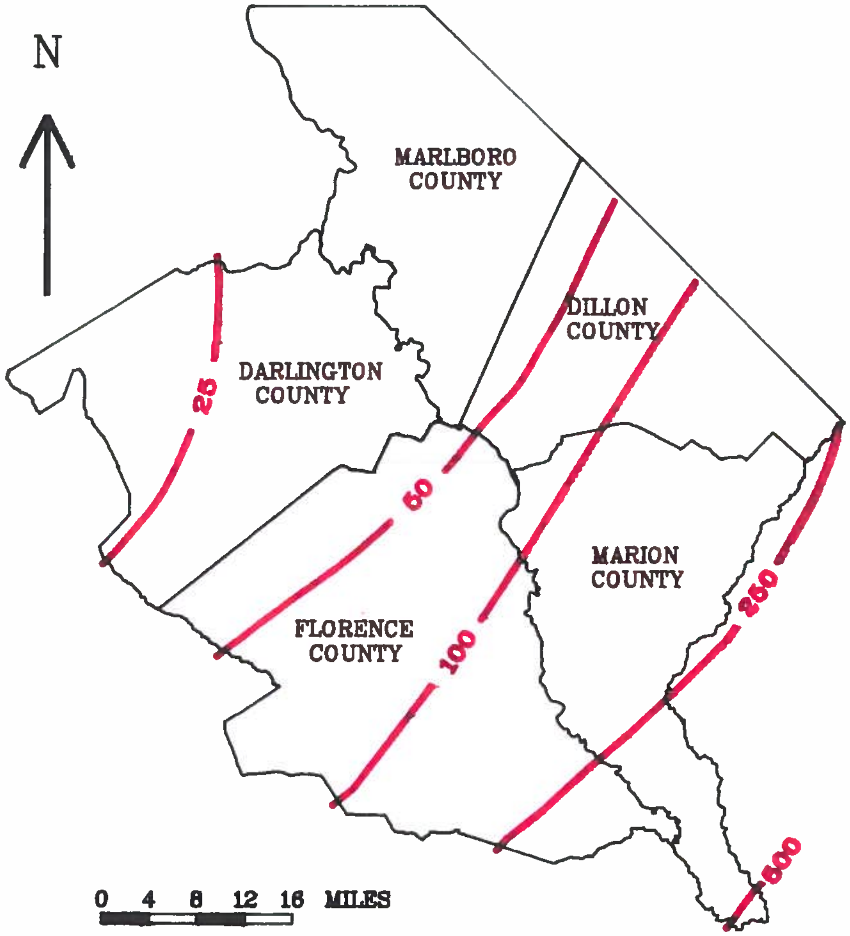
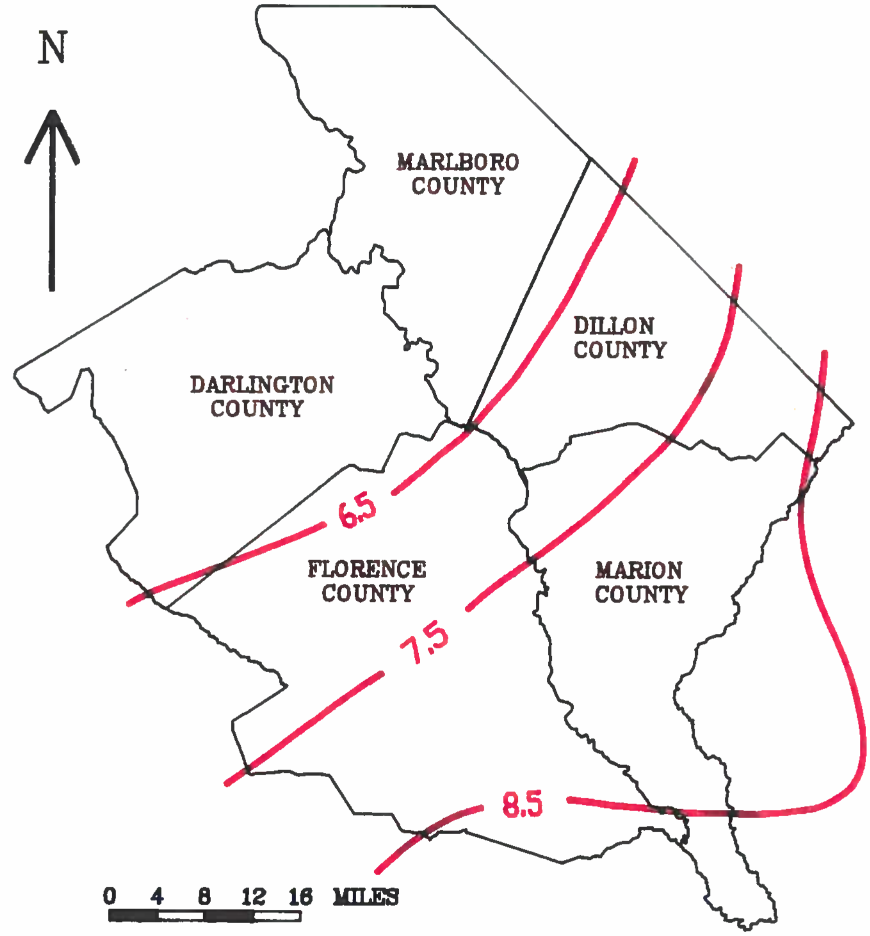


Figure 4.2 Stiff diagram of ground-water quality analyses in the Pee Dee region.



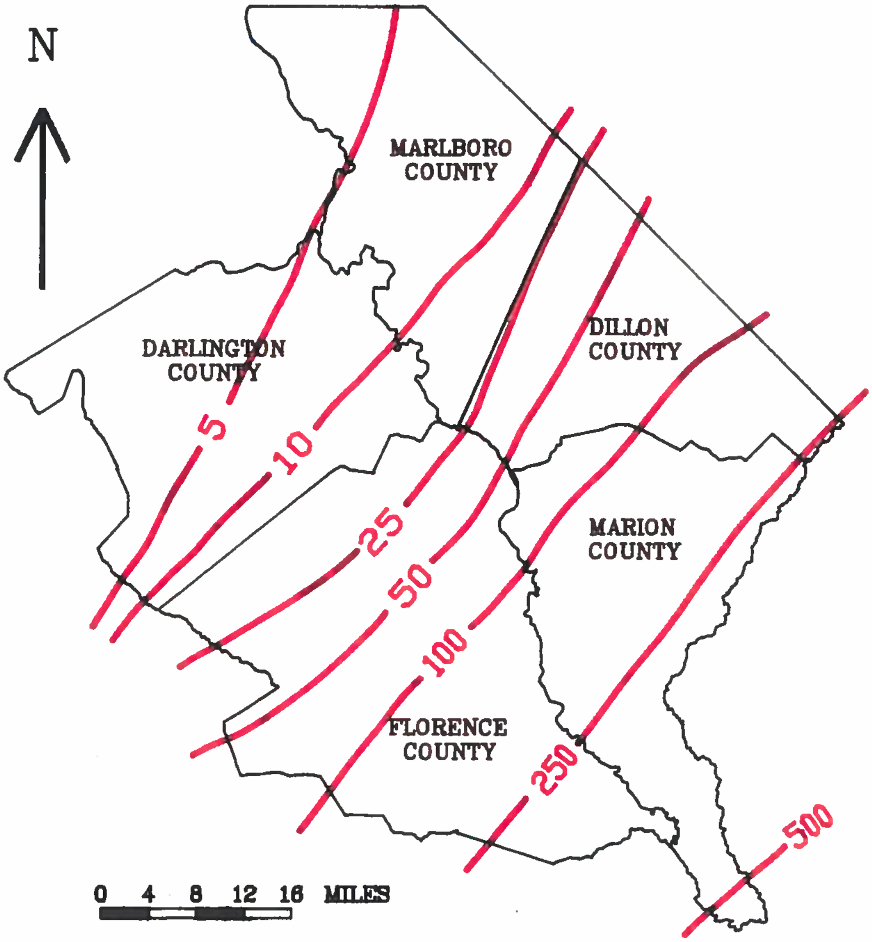
Explanation: Lines of equal concentration of dissolved solids, in milligrams per liter.

Figure 4.3 Areal variation in dissolved-solids concentration in Middendorf aquifers (from Speiran, 1987).



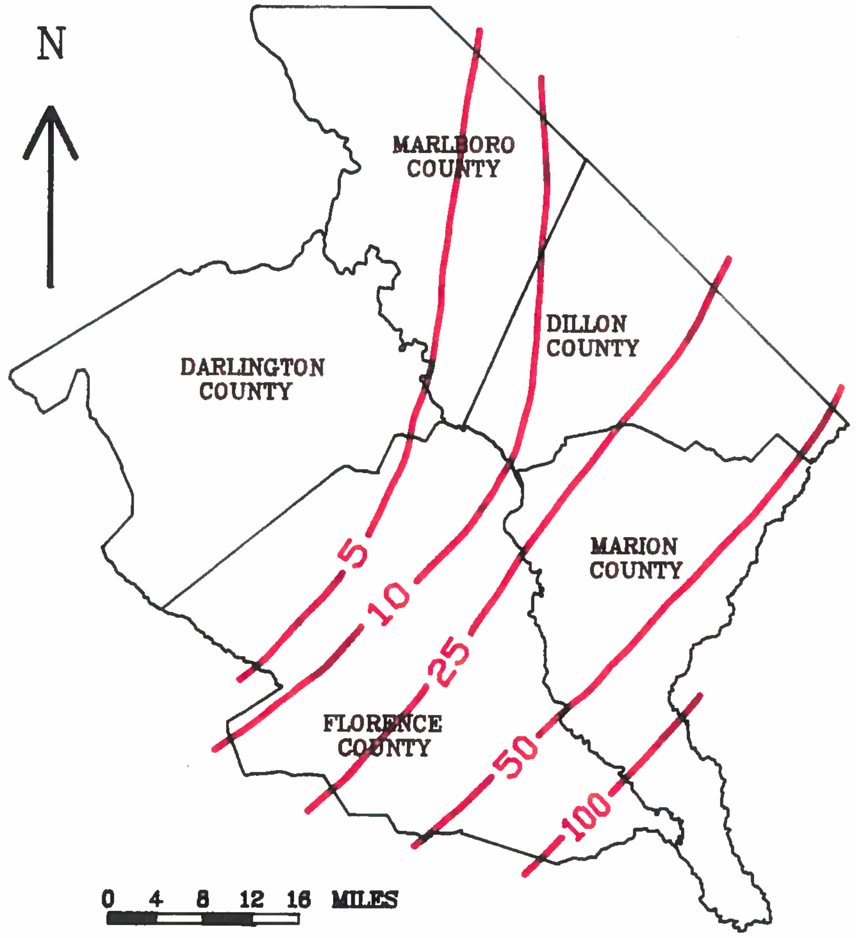
Explanation: Lines of equal pH, in standard pH units.

Figure 4.4 Areal variation in pH in Middendorf aquifers (from Speiran, 1987).



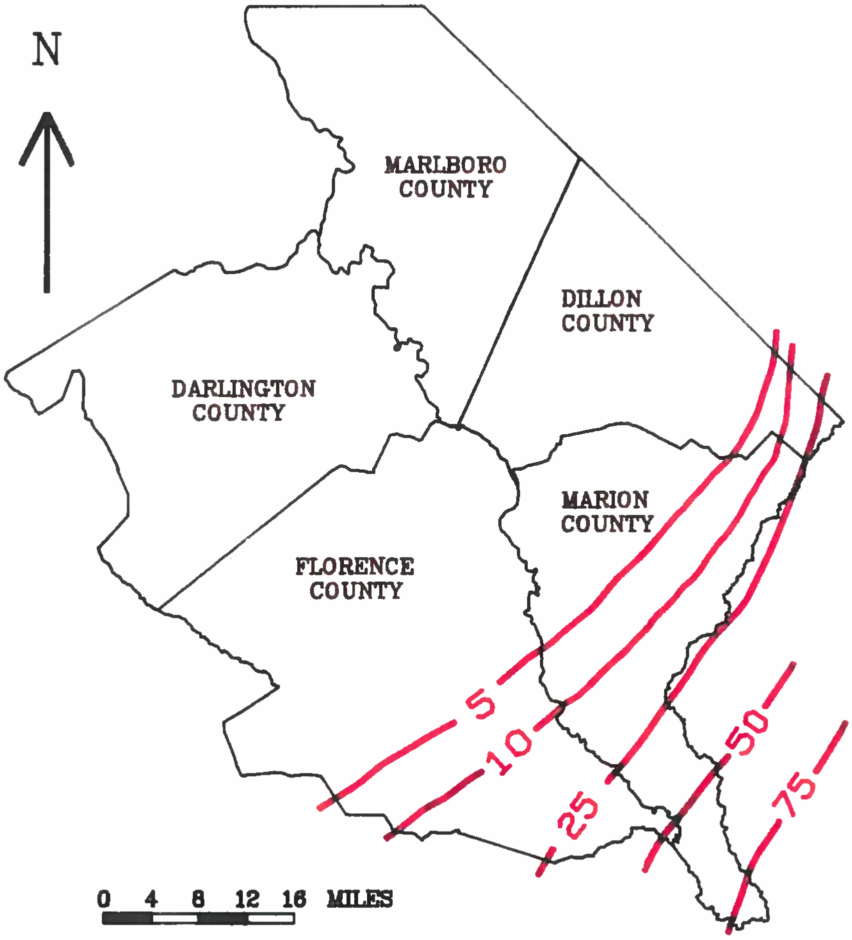
Explanation: Lines of equal concentration of bicarbonate, in miligrams per liter.

Figure 4.5 Areal variation in bicarbonate concentration in Middendorf aquifers (from Speiran, 1987).



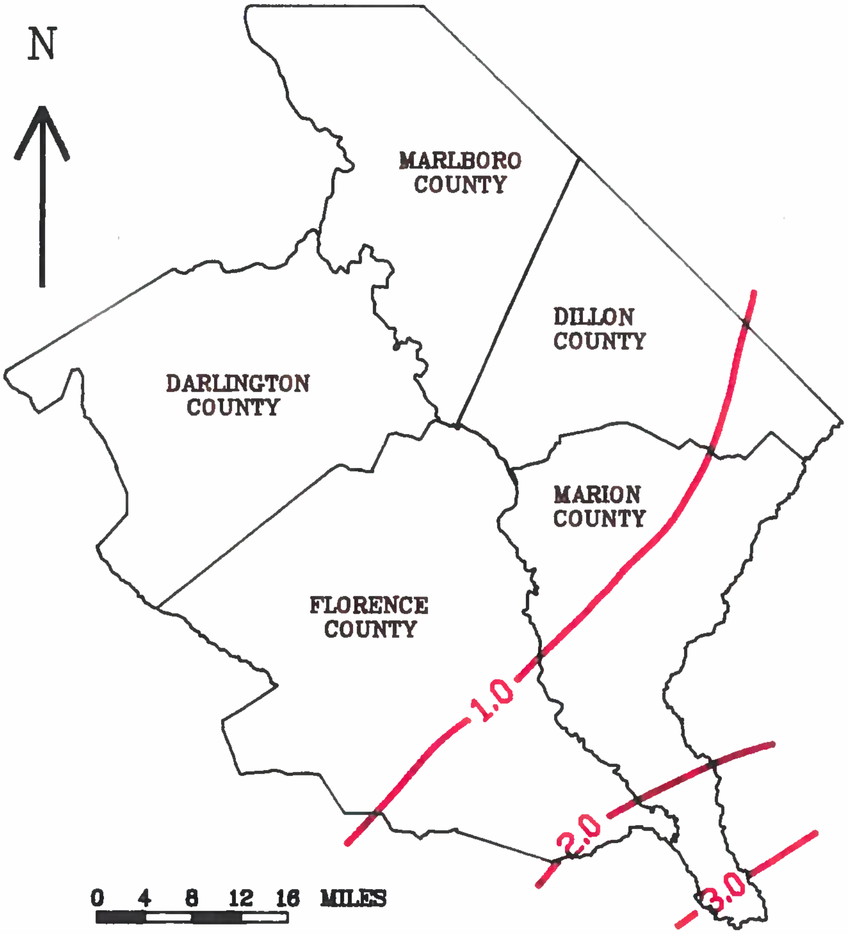
Explanation: Lines of equal concentration of sodium, in miligrams per liter.

Figure 4.6 Areal variation in sodium concentration in Middendorf aquifers (from Speiran, 1987).



Explanation: Lines of equal concentration of chloride, in miligrams per liter.

Figure 4.7 Areal variation in chloride concentration in Middendorf aquifers (from Speiran, 1987).



Explanation: Lines of equal concentration of fluoride, in miligrams per liter.

Figure 4.8 Areal variation in fluoride concentration in Middendorf aquifers (from Speiran, 1987).

ground water, hence downgradient ground water should be expected to have elevated mineralization.

Speiran (1987) suggested an additional reason for the trend of increasing mineralization downgradient from the recharge area, one related to the depositional environment of the Middendorf sediments. He noted three such environments in which sediments of the Middendorf Formation were deposited, all of which are present in the study area (see Figure 2.1). They are a nonmarine environment, a transitional environment, and a marginal marine environment. The significance of this is that sediments deposited in nonmarine environments characteristically have low solubilities and react slowly with water, whereas sediments deposited in marine and marginal marine environments characteristically have high solubilities and react quickly with water. Given this, it is predictable that ground water in the marine sediments would have a higher concentration of minerals than water in the nonmarine sediments.

The differences in mineralogy between the nonmarine and marine sediments are also a major cause for the downgradient increasing trends in concentrations of bicarbonate, sodium, and fluoride. A similar trend observed with the chloride concentrations, however, is attributed more to the mixing with incompletely flushed saltwater than with the differing mineralogies of the nonmarine and marine sediments. High concentrations of chloride are generally not a problem in the study area, but do plague the coastal portions of Horry and Georgetown Counties.

The most likely water-quality issue in the study area is the high concentration of iron that predominates in an approximately 20-mile wide band that trends roughly parallel to the recharge area (Chapelle and Lovley, [in press]) (see Figures 4.9 & 4.10). Although the elevated concentrations of iron found in this band are not thought to pose a health problem, water with high iron tastes bad and causes staining of clothes and plumbing fixtures; therefore, expensive treatment facilities are necessary. When precipitated, high concentrations of iron can also cause severe clogging of well screens, resulting in declining well efficiencies and greater pumping costs.

In the past, several theories have been offered to explain reasons for iron problems in the ground water:

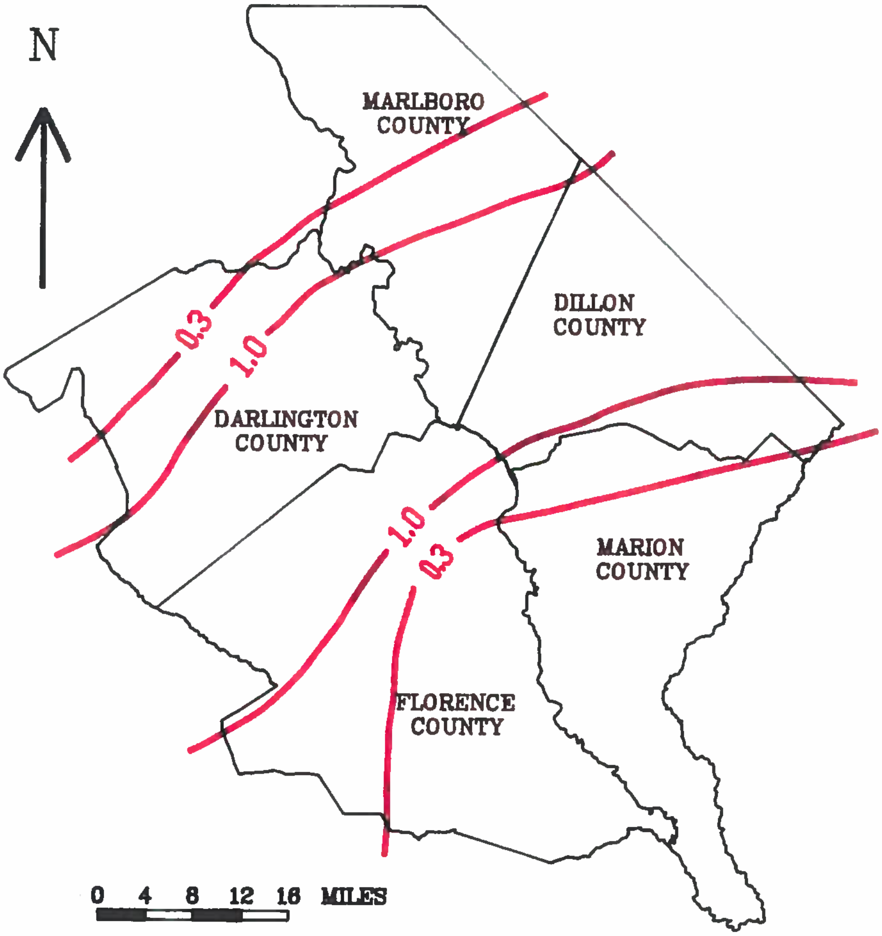
1) mixing of water from different aquifers, specifically from the Black Creek and Middendorf aquifers, resulting in the precipitation of iron;

2) leakage of high-iron water through confining beds. This theory is offered mainly to explain the deterioration of water quality (with respect to iron) over time. As potentiometric surfaces are lowered in the source aquifer, leakage from overlying or underlying aquifers is induced;

3) well drilling and well construction practices, which may introduce iron-fixing bacteria into the aquifer or some agent that enhances the proliferation of such bacteria. This theory is commonly limited to the discussions of precipitation of iron by aerobic bacteria; however, Chapelle and Lovley believe this also may apply to the dissolution of iron by anaeroboic bacteria.

4) dissolution of iron-bearing minerals, such as pyrite, that occur naturally in the sediments.

The reason for the areal pattern of iron concentration in the study area is not readily apparent. Unlike dissolved solids and several of the ions (bicarbonate, sodium, fluoride, and chloride), iron does not consistently increase downgradient from the recharge area; rather, its concentrations peak inside a 20-mile band adjacent to the recharge area and then decrease abruptly downgradient from this band before leveling off. Although the aforementioned theories all have merit, none of them really addresses the observed pattern of iron distribution in this study area.



Explanation: Lines of equal concentration of iron, in miligrams per liter.

Figure 4.9 Areal variation in iron concentration in Middendorf aquifers (from Speiran, 1987).

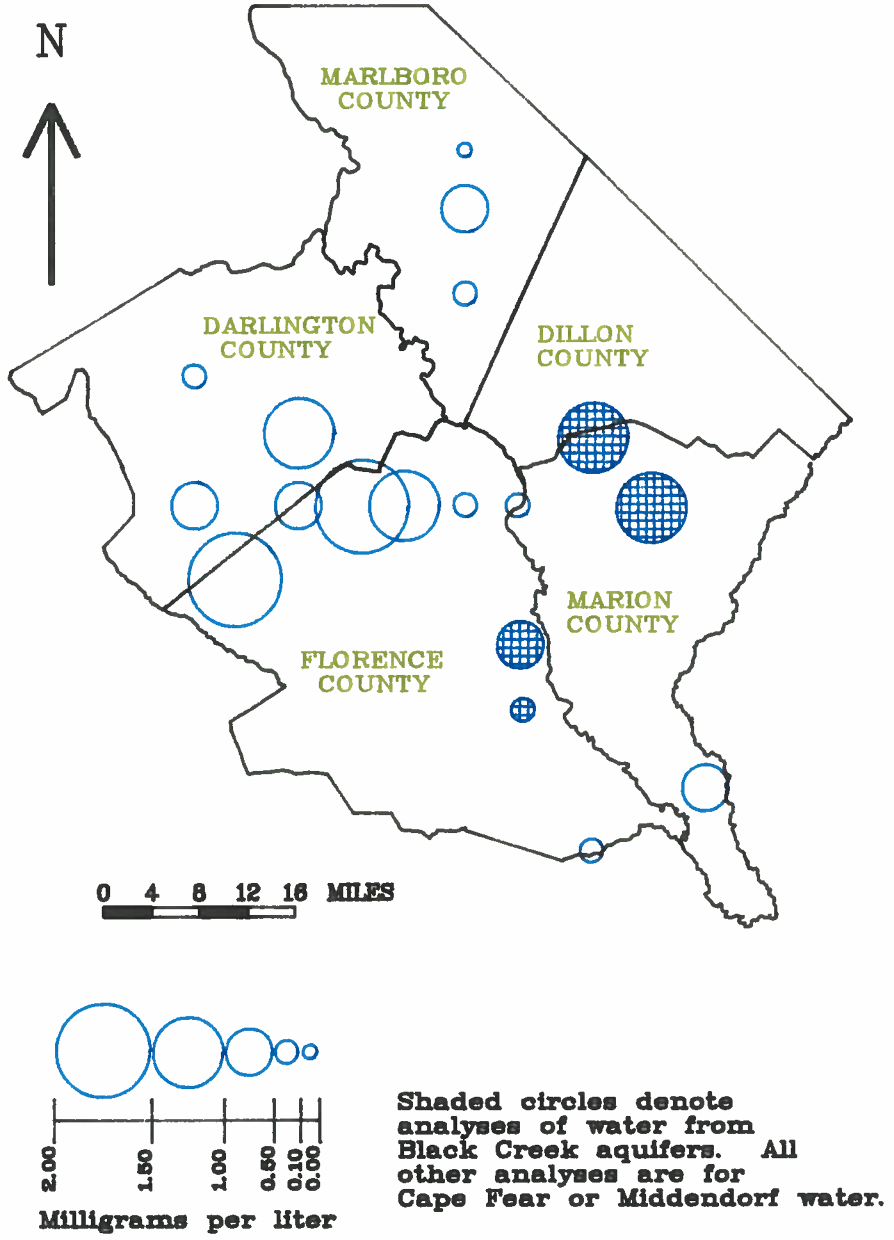


Figure 4.10 Bubble diagram of iron concentration.

Current research by Chapelle and Lovley suggests a cause for the elevated iron concentrations in the previously mentioned 20-mile wide band. They theorize that it has to do with both iron reducing bacteria and the mineralogical makeup and depositional environment of the aquifer. In the nonmarine zone of the Middendorf Formation, sediments coated with highly insoluble Fe(III) oxyhydroxide are quite common. In the presence of iron-reducing bacteria, these insoluble Fe(III) coatings are readily reduced to the much more soluble Fe(II), resulting in elevated concentrations of iron in the ground water.

Downgradient from the high-iron band, in the marine sediments of the Middendorf Formation, high concentrations of Fe(III) are generally lacking. Two other factors actually contribute to the reduction of iron in the ground water: 1) the capacity of Fe(II) ions to exchange with other cations on clay surfaces; and 2) the increased downgradient concentrations of sulfide, which reacts with Fe(II) to precipitate pyrite.

The recharge zone of the Middendorf aquifers, like the zone of high iron concentration, is composed of nonmarine sediments. Iron concentrations in this part of the aquifer, however, are relatively low. Chapelle and Lovley attribute this not to the lack of Fe(III), for this portion of the aquifer is mineralogically similar to the high-iron band, but to the presence of dissolved oxygen in the ground water, which inhibits the growth of the anaerobic iron-reducing bacteria. Dissolved oxygen is commonly present in ground water in or near recharge areas; however, as the water flows downgradient the dissolved oxygen is consumed by aerobic bacteria.

Recognized limitations of this section include the relatively few records available (31 from the 1984-1990 database and 42 from the Park report), the uneven distribution of analyses over the study area, the relatively few analytical records from aquifers other than the Middendorf Formation, and the lack of standardized quality control in both analytical and sampling procedures.

To remedy this situation, the subsequent phase of this investigation will involve the establishment of a water-quality well network. This will allow for the collection of periodic ground-water quality data throughout the five-county study area by trained personnel. To the extent possible, this network will represent aquifers of the Black Creek and Cape Fear Formations, as well as the Middendorf Formation. Furthermore, water quality analyses will be confined to a single laboratory , thereby presumably strengthening the consistency of the analytical data. Periodic duplicate analyses at a second laboratory will be conducted to assure quality control.

SUMMARY AND CONCLUSIONS

The preliminary phase of the Pee Dee hydrologic, geologic, and water-quality investigation has been completed. Work accomplished during this phase includes:

1) literature search for pertinent hydrologic, geologic, and water-quality reports;
2) establishment of a well database;
3) continuous coring of a test hole to basement rock;
4) macroscopic and microscopic analyses of the core;
5) construction of hydrogeologic sections;
6) collection of water-level data and preparation of potentiometric maps.

The geologic formations of major hydrologic importance in the study area are the Cape Fear, Middendorf, and Black Creek. These formations strike roughly northeast, dip to the southeast, and are composed predominantly of sand, which constitutes the aquifers, and clay, which constitutes the confining beds. At the Florence test-hole site, the formations are present in the following intervals:

Formation	Depth (ft bls)
Black Creek	15 - 189
Middendorf	189 - 390
Cape Fear	390 - 711

Continuous coring of the test hole provided the opportunity for comparing the signatures of the geophysical logs directly with the undisturbed core samples. By correlating the geophysical logs of this hole with those of nearby wells, the geologic information was extrapolated beyond the vicinity of the test hole. The validity of this extrapolation, however, decreases with distance.

The Middendorf and Cape Fear Formations underlie the entire study area. It is uncertain, however, whether these two formations act as a single hydraulic unit or are hydraulically independent of each other. Much of this uncertainty may be on account of the "newness" of the Cape Fear Formation; the existence of this formation as a separate entity from the overlying Middendorf Formation has only recently been established and recognized in this area. The Black Creek Formation underlies most of the study area and either crops out or subcrops over more than half the study area. Hydrographs from wells in this formation and the underlying Middendorf are similar in character, perhaps suggesting a higher degree of hydraulic interconnection than previously thought.

Water levels in wells tapping the Black Creek Formation and the Middendorf Formation continue to decline. The potentiometric data indicate three areas where this decline is most pronounced; namely the cities of Florence, Marion, and Johnsonville. In Florence, the potentiometric surface of the Middendorf aquifers has declined more than 175 feet since development began. In Marion and Johnsonville, the potentiometric surface of the Black Creek aquifers has declined approximately 100 ft.

Hydrograph data suggest that leakage from one aquifer system to another occurs in the study area, although quantifying this is very difficult with available data. The direction of this leakage, upward from the Middendorf to the Black Creek aquifers, or downward from the Black Creek to Middendorf aquifers, is dependent upon which aquifer system locally has the greater hydraulic head.

From the available data, it appears that transmissivity values in the Middendorf aquifers are greater than those in the Black Creak aquifers, although the Middendorf data are concentrated in the updip parts of the study area and the Black Creek data are concentrated in the downdip part. There also appears to be a subtle trend of increasing transmissivity toward the southwest edge of the study area, although this trend is more apparent with the Black Creek data than with the Middendorf data.

The distinct chemical makeup of water from the Black Creek aquifers versus water from the Middendorf aquifers is accentuated by plotting the analytical data on a Piper diagram. Black Creek water is typically bicarbonate with a high percentage of sodium, whereas Middendorf water tends to have a high percentage of chloride in addition to a high percentage of sodium.

Previous works have divided the Middendorf Formation across the study area into three identifiable depositional zones; nonmarine, transitional, and marine. Although the Black Creek Formation is normally considered a marine formation, information collected at the Florence test hole suggests that it also may grade from nonmarine updip to marine downdip.

In the Middendorf aquifers, high iron concentrations in a band immediately downdip from the recharge area and elevated sodium concentrations in the eastern parts of the study area are of major concern. In general, the concentration of most ions in the water increases downdip. This is attributed to two factors: 1) the direction of flow is downdip and ion concentrations tend to increase with distance along the flowpath, and 2) as a result of changing depositional environments, the mineralogic makeup of the Middendorf Formation changes downdip from insoluble minerals common to nonmarine environments to soluble minerals common to marine environments.

The reason for the observed pattern of high iron concentration is also partly a result of the deposition-related mineralogy; however, it is also related to the presence of anaerobic iron-reducing bacteria and the absence of dissolved oxygen.

On the basis of preliminary findings, the following recommendations are offered:

1) To define better the subsurface geology in the study area, it is recommended that two additional test holes be cored to basement rock. The suggested location for these test holes is southern Florence County and in Darlington or Marlboro Counties;

2) The quality of information collected in establishing a well database from historical records is highly variable. To improve upon this in the future, it is recommended that the following types of information be collected in the construction of all new public-supply wells and high-capacity irrigation and industrial wells: driller's or engineer's logs, drill cuttings, construction diagrams, geophysical logs, and 24-hour pumping tests with recovery measurements;

3) With respect to iron concentrations, Chapelle and Lovley (1990) have noted that certain types of organic based drilling fluids may provide an enhanced environment for unwanted iron-reducing bacteria, resulting in increased iron concentrations in the ground water. To remedy this situation, they suggest that conventional bentonite based drilling fluids be used instead of organic based fluids;

4) In areas where a particular aquifer is highly stressed, investigation of alternative aquifers for the purpose of supplementation is recommended. The spacing of wells is also a critical factor. Although short-term savings may be realized by drilling new wells close to existing wells and distribution lines, often these savings are negated by increased pumping costs on account of declining water levels and by the need to drill additional wells to compensate for diminished yields.

Future activity in this investigation will be directed at:

1) creation and implementation of a computer (finite-difference) ground-water flow model for the entire Pee Dee region;

2) refinement of the water-level monitoring network and creation of a water-quality network;

3) further delineation of the subsurface geology; and

4) further investigation into the degree of hydraulic connection among the different geologic formations.

REFERENCES CITED

Aucott, W.R., 1988, The predevelopment ground-water flow system and hydrologic characteristics of the Coastal Plain aquifers of South Carolina: U. S. Geological Survey Water-Resources Investigation Report 86-4347, 66 p.

Aucott, W.R., and Newcome, Roy, 1986, Selected aquifer-text informaton for the Coastal Plain aquifers of South Carolina: U.S. Geological Survey Water-Resources Investigations Report 86-4159, 30 p.

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.

Bennett, C.S., and others, 1983, Water resources data, South Carolina, water year 1983, U.S Geological Survey Water-Data Report SC-83-1, 342 p.

_________________________, 1984, Water resources data, South Carolina, water year 1984, U.S Geological Survey Water-Data Report SC-84-1, 396 p.

_________________________, 1985, Water resources data, South Carolina, water year 1985, U.S Geological Survey Water-Data Report SC-85-1, 412 p.

_________________________, 1986, Water resources data, South Carolina, water year 1986, U.S Geological Survey Water-Data Report SC-86-1, 384 p.

_________________________, 1987, Water resources data, South Carolina, water year 1987, U.S Geological Survey Water-Data Report SC-87-1, 486 p.

_________________________, 1988, Water resources data, South Carolina, water year 1988, U.S Geological Survey Water-Data Report SC-88-1, 480 p.

Bonini, W.E., and Woolard, G.P., 1960, Subsurface geology of the North Carolina-South Carolina Coastal Plain from seismic data: Am. Assoc. Petroleum Geologists Bulletin., v. 44, no. 3, p. 298-315.

Chapelle, F.H., and Lovley, D.R., 1990, Microbial Fe(III)-reduction coupled to organic material oxidation: A mechanism for the development of high iron concentrations in ground water, The Journal of Ground Water (in press), 28 p.

Colquhoun, D.J., Woolen, 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, Dapartment of Geology, 78 p.

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

Driscoll, Fletcher, 1986, Groundwater and wells (2d ed.): Johnson Division, St. Paul, Minn., 1,108 p.

Newcome, Roy, Jr., 1990, The 100 largest public water supplies in South Carolina: S.C. Water Resources Commission Report No. 169, 57 p.

Park, A.D., 1980, The ground-water resources of Sumter and Florence Counties, South Carolina: S.C. Water Resources Commission Report No. 133, 58 p.

Pelletier, A.M., 1985, Ground-water conditions and water-supply alternatives in the Waccamaw Capacity Use Area, South Carolina: S.C. Water Resources Commission Report No. 144, 32 p.

Reid, M.S., et. al., 1986, Hydrologic and geologic analysis of two wells in Marion County, South Carolia: U.S. Geological Survey Water Resources Investigations Report 86-4102, 20 p.

Siple, G.E., 1946, Progress report on ground-water investigations in South Carolina: S. C. State Development Board Bulletin No. 15, 116 p.

Siple, G.E., 1955, Geology and ground-water conditions in Florence County, S. C.: U. S. Geological Survey open-file report.

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

South Carolina Division of Research and Statistical Services, 1986, South Carolina statistical abstract, 1986, 476 p.

South Carolina Water Resources Commission, 1983, South Carolina state water assessment: S.C. Water Resources Commission Report No. 140, 367 p.

Speiran, G.K., 1987, Relation of aqueous geochemistry to sediment depositional environment, Middendorf aquifer, South Carolina: American Water Resources Association Monograph series no. 9, 17 p.

Speiran, G.K., and Patterson, G.G., 1988, An evaluation of the hydraulic properties, geology, water quality, and water levels of ground-water aquifers under Florence, South Carolina and surrounding counties: U.S. Geological Survey Water Resources Division Project Proposal SC-88f, 11 p.

Zack, Allen, 1977, The occurrence, availability, and chemical quality of ground water, Grand Strand and surrounding parts of Horry and Georgetown Counties, South Carolina: S.C. Water Resources Comission Report No. 8, 100 p.

APPENDIX A

CONSTRUCTION DATA FOR WELLS AND TEST HOLES USED IN HYDROGEOLOGIC SECTIONS

SCWRC No.	County No.	Owner	Use	Date drilled	Depth drilled (ft bls)	Screen * settings (ft bls)	Screen diameter (in)	Rated capacity (gpm)
9L-b1	DIL-088	Town of Lake View	PS	08-76	604	214- 290	8	?
10Q-p2	MRM-078	U.S. Geological Survey	TH	01-82	1228	1008-1028	4	NA
12L-b1	DIL-102	Trico Water Supply	PS	11-84	640	230- 426	10	?
13O-h2	FLO-152	J.P. Stevens Co.	IN	05-66	518	117- 210	10	250
13M-a1	MRN-068	Marco Rural Water Co.	PS	06-74	438	180- 414	?	?
14M-i1	FLO-226	Phillip Britton	IR	03-82	450	152- 396	?	1100
15N-p1	FLO-264	City of Florence	PS	11-88	628	?	?	?
15M-p1	FLO-125	City of Florence	PS	12-58	740	260- 495	12	830
16M-r1	FLO-154	City of Florence	PS	11-67	825	303- 706	12,16	1400
16M-w4	FLO-268	City of Florence	TH	06-89	716	None	NA	NA
16M-y1	FLO-265	City of Florence	PS	02-89	672	302- 657	12	1140
16N-a5	FLO-096	Florence Co. Recreation	IR	11-89	386	156- 291	6	163
17L-m3	DAR-209	City of Darlington	PS	05-84	480	204- 430	10	?
18N-i2	FLO-153	City of Timmonsville	PS	01-67	600	355- 475	8	360
19K-o2	DAR-094	City of Hartsville	PS	07-76	400	214- 306	10	1020

PS - Public Supply
TH - Test Hole
IN - Industry
IR - Irrigation

* These values represent the depths of the top of the topmost screen and the bottom of the bottommost screen. Most of these wells are screened through multiple intervals.

APPENDIX B

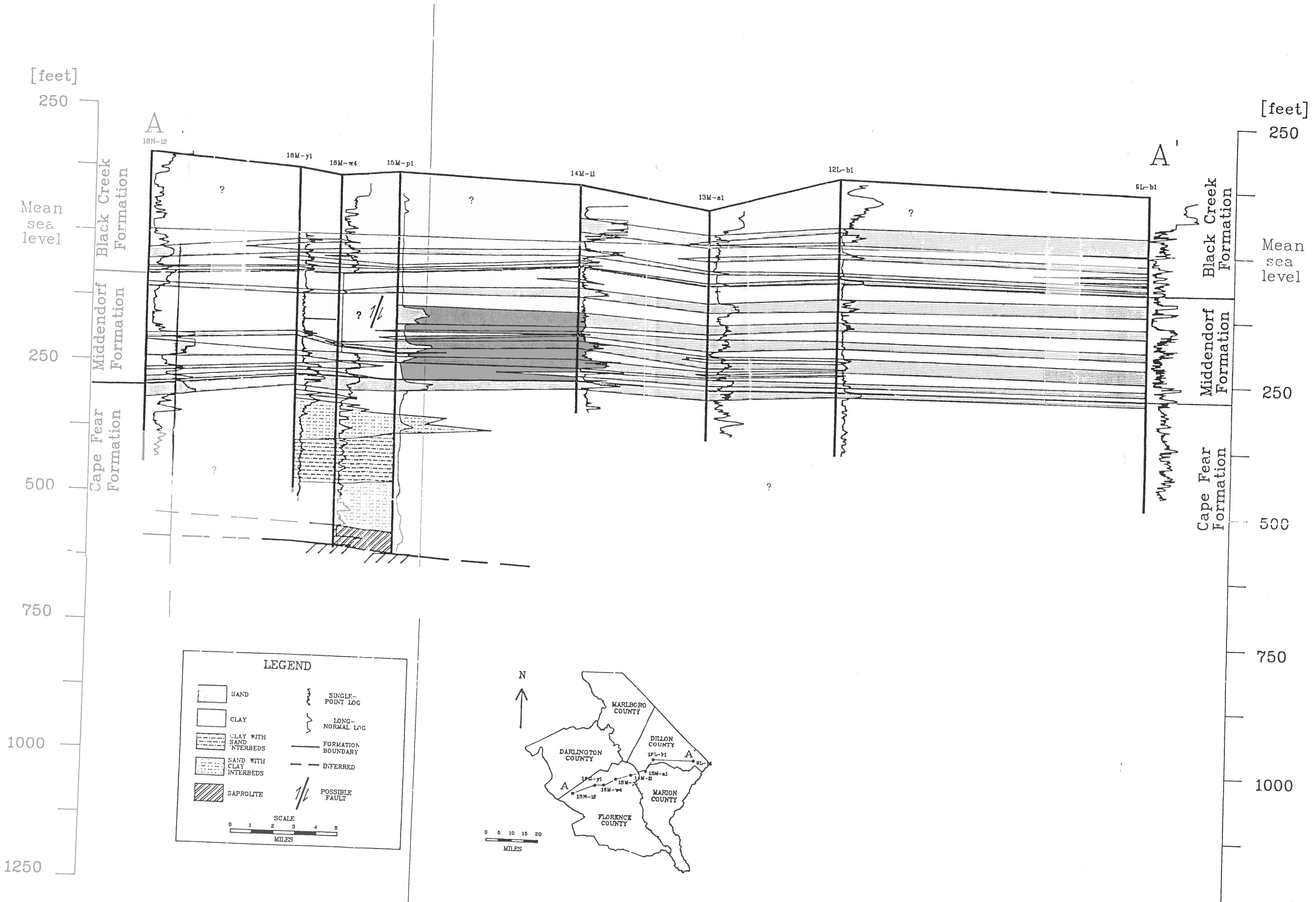
GROUND-WATER QUALITY DATA

SCWRC number	Lab *	Sample date	Sample depths	Alk.	Cl	F	Hard	Field pH	DS	SO_4	Field temp	Ca	Fe	Mg	Mn	K	SiO_2	Na
10N-y1	WRC	3-84	299	438.0	67.4	1.70	49.0	7.95	697	8.8	20.0	12.0	--	3.00	0.01	10.59	28.04	207.0
10Q-p2	WRC	1-88	1028	694.5	517.0	1.10	27.0	8.80	1986	135.0	7.8	7.2	0.69	2.39	0.06	9.69	44.70	686.0
11M-q1	WRC	3-84	450	105.0	8.3	0.92	42.0	7.60	250	7.0	14.5	9.2	0.12	1.20	0.01	2.82	34.90	53.2
11M-q2	WRC	3-84	735	108.0	7.5	0.67	33.0	7.70	264	7.3	20.5	8.5	0.11	1.30	0.01	2.97	34.78	53.0
11M-y1	WRC	3-84	744	118.0	12.1	0.65	34.0	7.80	283	13.9	21.0	10.5	0.11	1.70	0.01	2.84	35.76	65.6
12L-y1	WRC	3-84	360	93.0	3.6	3.60	25.0	7.40	209	3.4	19.0	5.9	0.13	1.30	0.01	4.92	33.47	37.8
12R-b2	COM	4-68	789-870	253.0	33.0	1.50	--	8.50	360	10.0	--	2.8	0.17	0.00	0.00	--	--	--
13M-p1	COM	5-59	242-695	--	5.0	--	--	7.60	--	--	--	--	0.00	--	--	--	--	--
13M-p2	COM	4-59	264-290	--	8.0	--	--	7.60	--	--	--	--	0.40	--	--	--	--	--
13M-p2	COM	4-59	264-292	--	6.0	--	--	7.60	--	--	--	--	0.40	--	--	--	--	--
13M-p2	COM	4-59	327-333	--	8.0	--	--	7.60	--	--	--	--	0.40	--	--	--	--	--
13M-p2	COM	4-59	375-381	--	6.0	--	--	7.60	--	--	--	--	0.40	--	--	--	--	--
13M-p2	COM	4-59	678-690	--	6.0	--	--	7.60	--	--	--	--	0.60	--	--	--	--	--
13O-h1	COM	1-67	131-210	70.0	8.0	--	--	8.60	208	7.0	--	9.0	0.24	2.00	0.00	--	32.00	76.0
13O-h2	COM	1-67	117-210	--	7.0	--	4.0	8.70	110	7.0	--	3.0	--	1.00	0.00	--	32.00	64.0
13O-h2	COM	4-66	299	--	14.0	--	11.0	8.70	--	50.0	--	7.4	1.75	3.60	--	--	35.00	--
13O-h2	COM	4-66	273	--	16.4	--	10.8	8.50	--	40.0	--	8.0	1.25	2.80	--	--	35.00	--
13O-h2	COM	4-66	252	--	17.0	--	9.8	8.50	--	45.0	--	8.0	0.75	1.80	--	--	35.00	--
13O-h2	COM	4-66	231	--	16.0	--	8.4	8.70	--	43.0	--	6.8	0.75	1.60	--	--	40.00	--
13O-h2	COM	4-66	210	--	12.0	--	9.0	8.10	--	36.0	--	7.3	0.37	1.60	--	--	40.00	--
13O-h2	COM	4-66	176	--	16.0	--	53.0	8.10	--	--	--	45.1	0.75	8.10	--	--	20.00	--
13O-h2	COM	4-66	147	--	15.0	--	77.0	7.70	--	62.0	--	74.3	1.25	2.70	--	--	15.00	--
13O-h2	COM	4-66	126	--	14.0	--	51.0	8.60	--	56.0	--	43.0	0.15	8.00	--	--	15.00	--
13P-d1	SLU	4-73	210-300	75.0	4.0	--	--	8.30	98	--	--	0.2	0.10	--	0.10	--	--	32.8
14H-v1	WRC	5-84	--	1.0	17.7	--	7.0	4.70	66	3.8	18.0	1.1	0.02	0.88	0.00	0.69	8.02	16.1
14H-v2	WRC	5-84	105	--	16.1	--	12.0	4.50	46	3.8	20.0	1.4	0.07	1.89	0.01	1.77	7.14	11.6
14I-a1	WRC	5-84	--	6.0	2.1	--	5.0	5.40	25	5.6	19.0	1.1	0.89	0.31	0.01	2.35	14.13	2.2
14J-c1	WRC	5-84	120	2.0	14.1	-	11.0	4.90	50	4.8	19.0	1.4	0.26	1.85	0.04	2.32	9.49	9.6

All concentrations in milligrams per liter

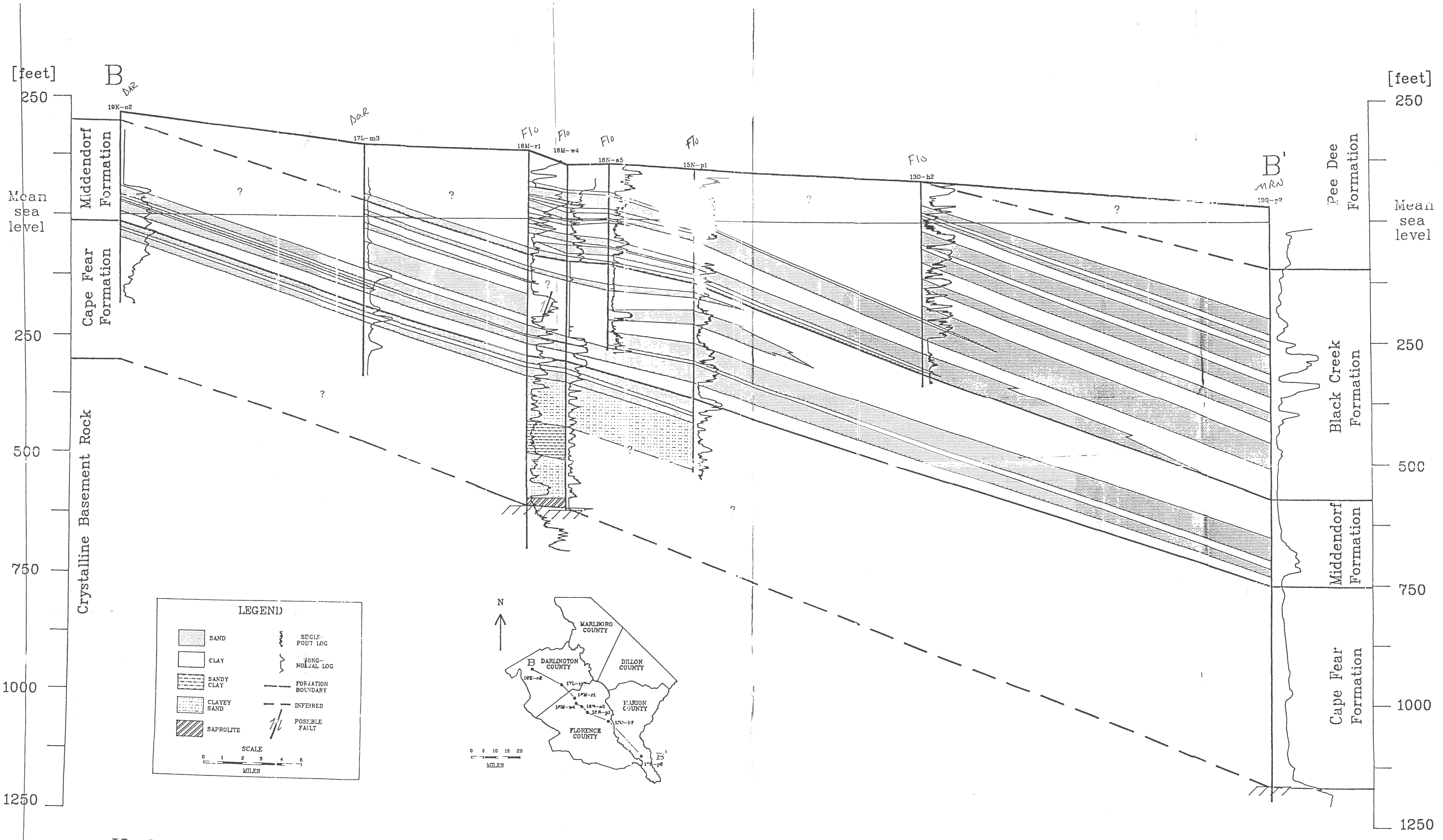
* COM - Commercial
  WRC - Water Resources Commission
  SLU - State Laboratory, Unspecified Agency
  USG - U.S. Geological Survey

SCWRC number	Lab	Sample date	Sample depths	Alk.	Cl	F	Hard	Field pH	DS	SO_4	Field temp	Ca	Fe	Mg	Mn	K	SiO_2	Na
14M-t1	COM	4-59	260-691	--	8.0	--	--	7.60	--	--	--	--	0.20	--	--	--	--	--
14M-t1	COM	4-59	427-439	--	6.0	--	--	7.50	--	--	--	--	0.40	--	--	--	--	--
14M-t1	COM	4-59	472-478	--	6.0	--	--	7.50	--	--	--	--	0.40	--	--	--	--	--
14M-t1	COM	4-59	679-691	--	5.0	--	--	7.60	--	--	--	--	0.40	--	--	--	--	--
15M-p1	COM	4-65	260-495	19.0	5.0	--	--	6.50	--	--	--	1.6	1.20	1.00	--	--	50.00	--
16M-h6	WRC	1-84	--	12.0	2.5	0.13	8.0	--	120	8.4	--	1.4	0.52	1.00	0.01	3.96	15.60	3.9
16M-r1	COM	10-75	303-706	--	8.0	--	--	6.40	--	18.0	--	6.0	1.60	14.00	0.03	--	19.00	22.0
16M-r2	COM	5-55	385-705	20.0	14.0	--	--	5.90	--	--	--	6.0	2.20	14.00	--	--	20.00	--
16M-s1	USG	4-54	320-630	--	5.0	0.20	--	6.60	69	11.0	--	3.2	5.10	2.20	--	--	20.00	12.0
16M-s3	COM	4-65	309-495	30.0	12.0	--	--	6.70	--	12.0	--	2.0	1.00	1.50	--	--	--	--
16M-s5	USG	12-51	208-724	--	20.0	0.30	--	5.80	96	9.8	--	7.6	3.40	2.60	--	--	31.00	12.0
16M-L1	USG	4-54	325-648	--	21.0	0.30	--	6.70	117	20.0	--	3.3	1.60	2.80	0.04	--	17.00	31.0
16M-t2	COM	4-65	--	33.0	21.0	--	--	6.60	88	--	--	3.2	1.00	1.70	--	--	--	--
16M-t3	COM	7-57	150-378	24.0	--	--	--	6.30	86	--	--	--	0.35	--	--	--	--	--
16M-t4	COM	10-75	450-765	--	0.7	--	--	7.30	--	17.0	--	8.0	0.50	14.00	0.04	--	17.00	136.0
16M-v1	COM	10-75	344-680	--	3.0	--	--	6.20	--	11.0	--	6.0	0.98	6.00	0.03	--	16.00	15.0
16M-w1	COM	4-65	354-660	26.0	--	--	--	6.60	54	--	--	5.2	0.80	1.00	--	--	--	0.0
16Q-k1	SLU	10-77	152-426	--	--	--	--	8.00	--	--	--	2.9	1.40	0.54	0.17	3.55	--	32.1
16Q-k2	COM	-	451-481	--	--	--	--	7.80	--	--	--	0.8	0.10	0.12	0.02	1.72	--	28.9
16Q-t2	SLU	10-77	160-556	--	--	--	--	8.00	--	--	--	1.6	0.08	0.18	0.01	2.18	--	33.2
17L-h5	WRC	4-84	305	--	1.8	--	6.0	4.80	127	6.6	17.0	1.3	0.58	0.46	0.01	1.24	9.81	2.0
17L-i3	WRC	4-84	190	3.0	1.8	--	6.0	5.80	126	10.5	19.0	1.3	1.24	0.49	0.01	1.54	11.60	5.2
17L-u1	WRC	1-84	-	5.0	4.0	0.08	8.0	--	82	27.1	18.0	0.9	1.13	1.12	0.01	2.85	14.50	2.1
17L-u2	WRC	1-84	272	9.0	1.7	0.10	11.0	--	103	10.2	18.5	1.7	1.82	1.71	0.01	3.00	14.80	3.5
17M-t1	COM	7-77	306-578	10.0	3.0	--	--	6.10	28	12.0	--	2.8	0.50	1.00	--	--	--	3.3
18N-i2	SLU	10-77	355-475	--	--	--	--	6.25	--	--	--	1.6	2.45	1.00	0.03	2.71	--	2.7
18N-i5	WRC	1-84	476	9.0	3.0	0.07	10.0	--	103	7.3	18.0	1.9	0.69	1.10	0.01	4.00	14.70	3.2
19K-f1	WRC	1-84	236	1.0	2.5	0.02	1.0	--	63	3.3	17.5	0.1	0.63	0.20	0.00	0.44	8.50	2.0
19K-f2	WRC	1-84	181	1.0	2.0	0.02	1.0	--	55	3.3	17.5	0.1	--	0.20	--	0.30	6.80	1.1
19K-g2	WRC	1-84	198	1.0	1.5	0.02	1.0	--	42	3.3	17.5	0.1	0.02	0.20	--	0.26	8.30	0.7
19K-n1	WRC	1-84	150	2.0	4.5	0.03	13.0	--	78	10.9	18.0	3.9	0.32	0.55	0.01	0.37	10.50	4.1
19M-y1	WRC	1-84	476	--	2.0	0.02	4.0	5.50	42	7.4	17.0	0.6	0.60	0.40	0.01	0.85	10.40	2.0



Hydrogeologic section A–A from Timmonsville, Florence Co., to Lakeview, Dillon Co., S.C.

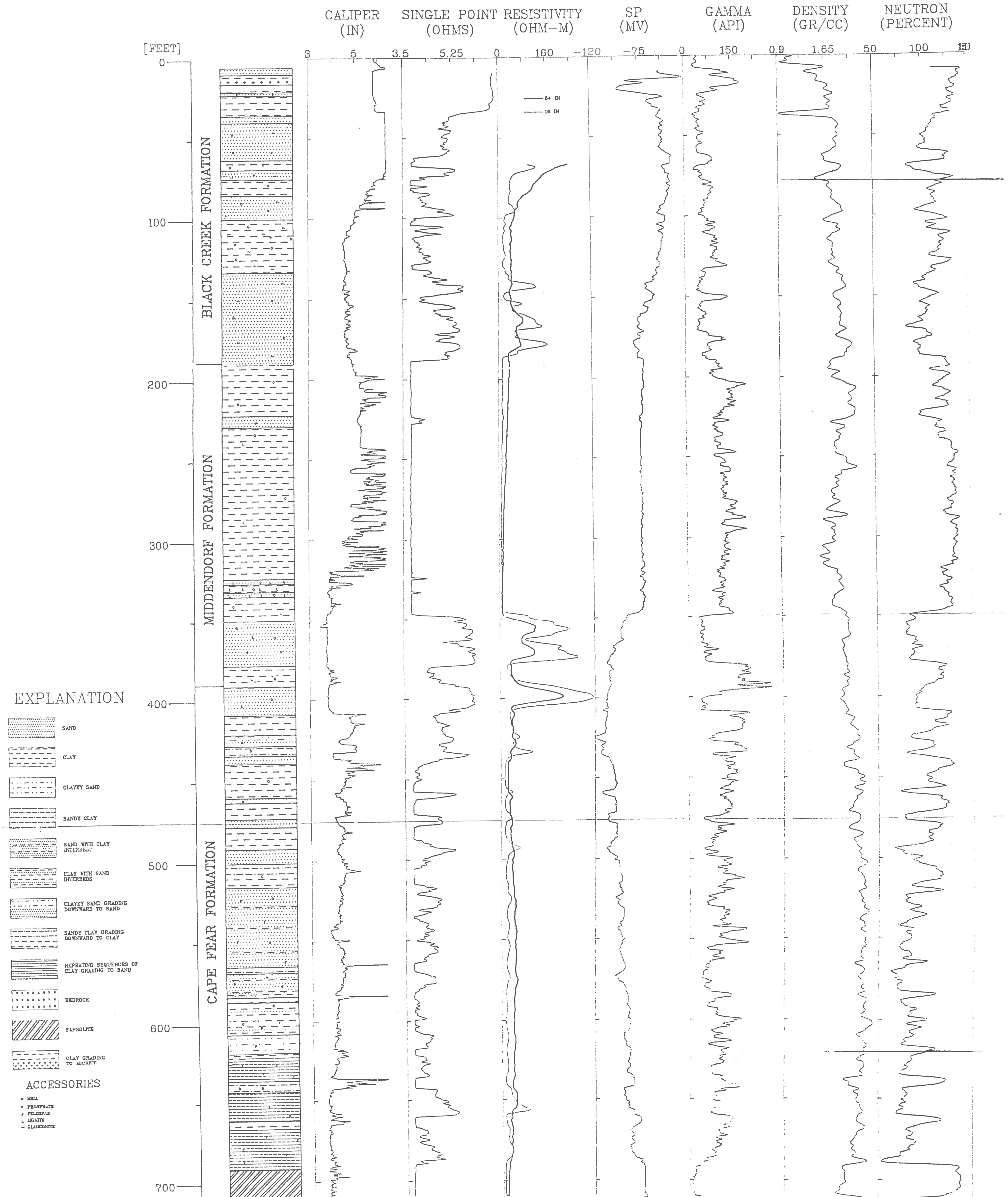
Plate 1



Hydrogeologic section B–B from Hartsville, Darlington Co., to Britton's Neck, Marion Co., S.C.

Plate 2

GEOPHYSICAL AND LITHIC LOGS FOR 16M-W4



SOUTH CAROLINA WATER RESOURCES COMMISSION
PLATE 3