SOUTH CAROLINA

WATER RESOURCES COMMISSION

Report No. 8

The Occurrence, Availability, and Chemical Quality of Ground Water, Grand Strand Area and Surrounding Parts of Horry and Georgetown Counties, South Carolina

By
Allen Zack

Prepared by
U. S. Geological Survey, Water Resources Division
in cooperation with
South Carolina Water Resources Commission
Columbia, South Carolina

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CONVERSION FACTORS

English Units	Multiply by	Metric units
ft (feet)	3.048×10^{-1}	m (meters)
ft/day (feet per day)	3.048×10^{-1}	m/day (meters per day)
ft/s (feet per second)	3.048×10^{-1}	m/s (meters per second)
ft^3/s (cubic feet per second)	2.832×10^{-2}	m^3/s (cubic meters per second)
ft^2/s (square feet per day)	9.290×10^{-2}	m^2/day (square meters per day)
gal (gallons)	3.785	L (liters)
gal/min (gallons per minute)	6.309×10^{-2}	L/s (liters per second)
(gal/min)/ft (gallons per minute per foot)	2.070×10^{-1}	(L/s)/m (liters per second per meter)
(gal/min)/in^2 (gallons per minute per square inch)	$9.778 \times 10^{+1}$	(L/s)/m^2 (liters per second per square meter)
in (inches)	2.540	cm (centimeters)
in (inches)	$2.540 \times 10^{+1}$	mm (millimeters)
in^2 (square inches)	6.452×10^{-4}	m^2 (square meters)
mi (miles)	1.609	km (kilometers)
(Mgal)/day (million gallons per day)	4.381×10^{-2}	m^3/s (cubic meters per second)
	Temperature conversion	
°F (degrees Fahrenheit)	5/9(°F-32)	°C (degrees Celsius)
	Hydraulic conversion	
Transmissivity ft^2/day	7.48	Transmissibility (gal/min)/ft
Hydraulic conductivity ft/day	7.48	Permeability (gal/min)/ft^2

THE OCCURRENCE, AVAILABILITY, AND CHEMICAL QUALITY OF GROUND WATER, GRAND STRAND AREA AND SURROUNDING PARTS OF HORRY AND GEORGETOWN COUNTIES, SOUTH CAROLINA

by

Allen Zack

ABSTRACT

An evaluation of developing water-well and water-quality problems in the coastal aquifer systems of Horry and Georgetown Counties was initiated in 1972.

Geologic cross-sections detail the stratigraphic relationships of sand, clay, and calcareous sandstone and also establish formational boundaries between Tertiary formations and the Peedee, Black Creek, and Middendorf Formations. The most prominent structural feature of the area is the Cape Fear Arch. The Black Creek aquifer system is the most satisfactory source of good-quality water in the two-county area. Usually the water is soft, low in chloride, and iron- and sulfate-free. However, fluoride concentrations are excessive, reaching 5.5 milligrams per liter in some areas.

High concentrations of fluoride occur in hard, calcareous sandstone in the upper third of the Black Creek Formation. Low-fluoride ground water is obtained by screening only sandy formations devoid of the calcareous sandstone.

Salty water in the Black Creek aquifer system is a problem in the North Myrtle Beach-Little River area where connate sea water apparently has not been flushed from the flank of the Cape Fear Arch. However, no problems associated with saltwater encroachment have been observed. Improperly designed and abandoned wells are primarily responsible for

saltwater leakage into freshwater sands, which if allowed to continue, will degrade the quality of the freshwater in the aquifers.

Water in the Peedee Formation and Tertiary formations, although low in fluoride and chloride, often contains excessive concentrations of iron, hydrogen sulfide, and sulfate. Treatment would be necessary before this water could be considered for a domestic water supply.

Water in the Middendorf Formation is salty presumably throughout the two-county area.

A typical value of the hydraulic conductivity of Black Creek sand beds is 30 feet per day, but it is less in central and southern Georgetown County. An average value of specific storage of 2.6×10^{-6} per foot has been calculated from pumping tests throughout the area.

Regional water levels are compared with regional water-use totals and show that vast quantities of ground water are added to the Black Creek aquifer system from several possible sources. However, major aquifers in Horry and Georgetown Counties have been shown to be hydraulically independent during short-term pumping tests.

During the study various types of geophysical logs were run and it was discovered that the induction-resistivity geophysical logging tool measures formation resistivities in the project area with more accuracy than the standard electric-logging tool. The induction tool has certain focusing properties that minimize the possibility of obtaining spurious measurements resulting from adjacent thin beds.

Except for widespread high concentrations of fluoride and locally high concentrations of chloride, untreated water from the Black Creek aquifer system is of suitable chemical quality and quantity for present and foreseeable future water supplies. Improperly constructed and abandoned gravel-filter wells and the potential for saltwater encroachment appear to be major threats to the geohydrologic environment.

INTRODUCTION

Location and General Features of the Area

The Grand Strand area of Horry and Georgetown Counties, South Carolina is a narrow strip of land about 5 mi wide and 69 mi long extending from the North Carolina State line southwestward to Winyah Bay. The Grand Strand is bordered by the Atlantic Ocean on the east and the Intracoastal Waterway and Waccamaw River on the west (fig. 1).

Both Horry and Georgetown Counties lie wholly within the Atlantic Coastal Plain, and are within the Pee Dee River basin which slopes southeastward. Principal drainage within the area is provided by several rivers: Pee Dee, Little Pee Dee, Waccamaw, Black, Sampit, and Santee Rivers, and the Intracoastal Waterway. Extensive areas of tidal marshland occur along the coast and extend about 25 mi up the larger rivers.

The area has a humid, subtropical climate with a mean annual temperature of 18.2°C and a mean annual precipitation of 49.25 in (Waccamaw Regional Planning and Development Council, 1974, p. 10).

Miles of white sand beaches on the Grand Strand make tourism the principal industry in the two-county area. Manufacturing is of secondary economic importance, with the greatest concentration occurring near the city of Georgetown. Although the two-county area is 65 percent rural, agriculture is the least important economic activity and is virtually nonexistent on the Grand Strand.

The combined 1970 resident population of Horry and Georgetown Counties was 103,500 with two-thirds of the population residing in Horry County (Waccamaw Regional Planning and Development Council, 1974). The Waccamaw Regional Planning and Development Council

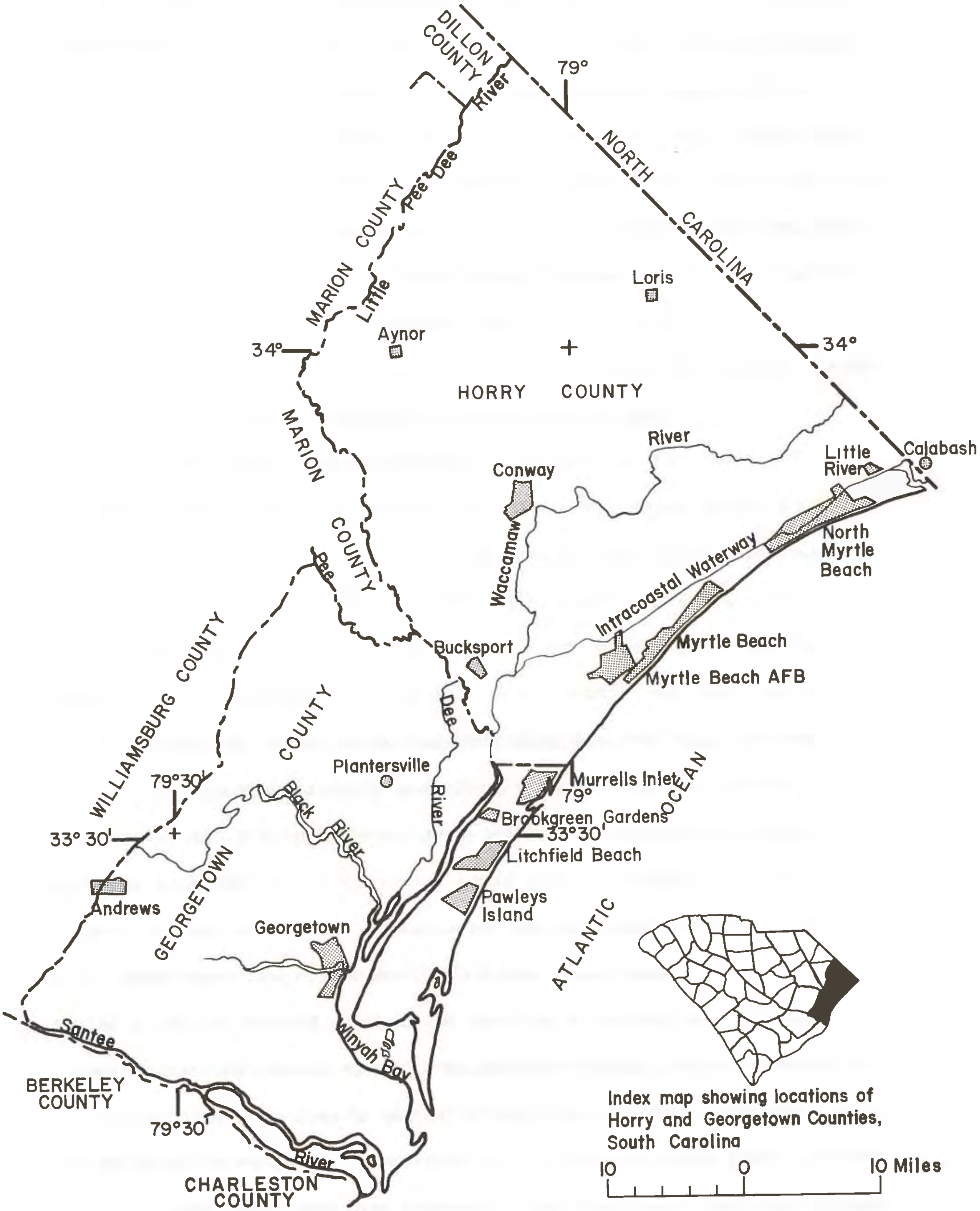

Figure 1. Locations of principal geographic features of Horry and Georgetown Counties, S. C.

estimates that the combined resident population of the area by the year 2000 will be approximately 150,000 (Wyndell Peacock, oral commun. March 4, 1976). Although resident population is evenly distributed on the Grand Strand, the nonresident and tourist population reaches 270,000 or more during the summer, with the preponderance of tourists concentrated at Myrtle Beach. The rest of the population in the two-county area is less evenly distributed and remains the same throughout the year. Principal cities in the two-county area are Georgetown, Myrtle Beach, and Conway.

Purpose and Scope of the Investigation

The study was initiated in 1972 when, acting under the South Carolina Ground Water Use Act of 1969, the Horry County delegation and the Georgetown Board of Commissioners made requests of the SCWRC (South Carolina Water Resources Commission) for a ground-water evaluation of the Grand Strand and the surrounding parts of Horry and Georgetown Counties. These local officials anticipated the development of water-well problems and indicated that development of the ground-water resource was accelerating such that ultimate deterioration of the supply was inevitable unless steps were taken to manage the resource.

The Ground Water Use Act gives authority to the SCWRC to investigate, declare, and delineate capacity-use areas of the State where it finds that the use of ground water requires coordination and regulation for the protection of public or private interests. Because of its interest in national coastal water resources and coastal-zone management, the U. S. Geological Survey participated in all phases of the study on a matching-fund basis as part of its longstanding program of cooperative water-resources investigations with state and local agencies.

The purpose of the investigation was to collect and interpret ground-water data for a preliminary evaluation of the occurrence, availability, and chemical quality of ground water in Horry and Georgetown Counties. The report is a preliminary step to future, more detailed geohydrologic investigations.

As quoted from Section 6 (h) of the Ground Water Use Act these nine items would be considered by the SCWRC before any regulations are adopted:

"(1) The number of persons using an aquifer and the object, extent, and necessity of their respective withdrawals or uses;

(2) The nature and size of the aquifer;

(3) The physical and chemical nature of any impairment of the aquifer adversely affecting its availability or fitness for other water uses (including public use);

(4) The probable severity and duration of such impairment under foreseeable conditions;

(5) The injury to public health, safety, or welfare which result if such impairment were not prevented or abated;

(6) The kinds of businesses or activities to which the various uses are related;

(7) The importance and necessity of the uses claimed by permit applicants (under this section), or of the water uses of the area (under Section 5) and the extent of any injury or detriment caused or expected to be caused to other water uses (including public use);

(8) Diversion from or reduction of flows in other water courses or aquifers; and

(9) Any other relevant factors."

Priorities in data collection were established that would best supply the information required for the stated purpose of the study. The data-collection and monitoring program for the study included:

1. Compilation of geologic information.
2. Compilation of design and hydraulic information on water wells.
3. Collection and interpretation of geophysical logs.
4. Detailing of aquifer continuity.
5. Determination of chemical analyses of ground-water samples.
6. Monitoring of water-level fluctuation in wells.
7. Determination of aquifer characteristics.
8. Determination of aquifer independence.
9. Completion of a water-use inventory.
10. Information on ground-water availability.

During the early phases of the study, it became apparent that existing wells, by themselves, could not provide satisfactory points of data collection. Most large-capacity wells throughout Horry and Georgetown Counties are multiple-screened; that is, they contain several lengths of screen placed opposite the most productive water-bearing zones penetrated by the well. Each one of the screened zones commonly has different water-quality characteristics, different hydraulic head, and different transmissive and storage properties. A water sample from a multiple-screened well represents a combination of the waters from all screened sands, and water-level measurement represents a composite head of all zones screened. Similarly, it is virtually impossible to measure the individual transmissive and storage capabilities of the water-bearing zones screened in such a well. To overcome these problems of data collection, the SCWRC contracted a test-drilling program with the U. S. Army Corps of Engineers to provide a series of test holes and wells constructed in such a way that individual water-bearing zones could be investigated. Partial funding for the program was provided by the Coastal Plains Regional Commission. Eight holes were drilled, and seven were completed as observation wells. The locations and descriptions of all wells mentioned throughout this report are presented in figure 2 and table 1.

Acknowledgments

The author gratefully acknowledges the many individuals who provided assistance and cooperation throughout the project. Foremost assistance in data collection was provided by James Griffith, Larry West, Ivan Roberts, and Dennie Lewis of the SCWRC staff in Conway, S.C. Without their help, this report would have been impossible. B.C. Spigner and Mark Cannon of the SCWRC in Columbia collected and made available all of the data on water use contained in this report. In addition Mr. Spigner reviewed the report and offered many valuable suggestions.

Garland Sydnor of Sydnor Hydrodynamics, Richmond, Va. generously provided many geophysical logs and made available several completed wells from which valuable water-quality data were obtained.

Paleontological identification of formations from borehole samples was provided by Philip M. Brown and Donald L. Brown, U.S. Geological Survey, Raleigh, N.C.

Special assistance and support was given by Donald Duncan, Director, Hydrology Division and Rohinton Tata, District Engineer, of the South Carolina Department of Health and Environmental Control.

The author is indebted to the Coastal Plains Regional Commission for providing a grant to support the test drilling program during the project.

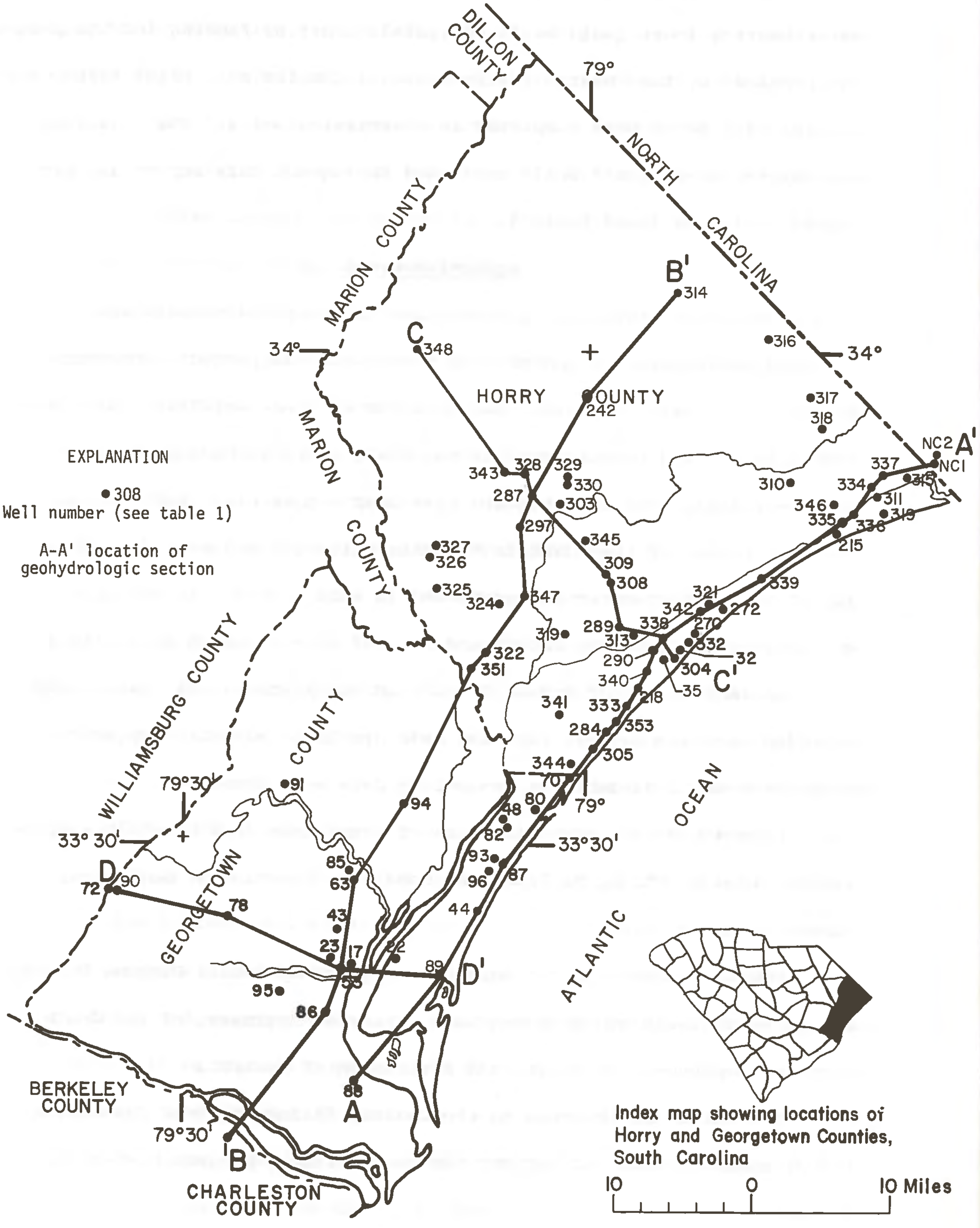

Figure 2. Location of selected wells in Horry and Georgetown Counties and vicinity and location of geohydrologic sections.

Special acknowledgment is due to those who provided basic data throughout the project. The list includes water-well drillers, consulting engineers, water superintendents, and the many persons throughout Horry and Georgetown Counties who have provided records on their wells, property on which to drill, or access to their wells from which data were collected.

GEOLOGIC FRAMEWORK

The geology of Horry and Georgetown Counties is the primary control on the occurrence, availability, and chemical quality of all ground-water resources. For example, the ability to withdraw ground water is related to the texture of the sediments which in turn was determined by the depositional environment and subsequent history. Also, the chemistry of ground water is related at least in part to the mineralogy of the host sediments.

Previous Investigators

Numerous investigators have described the stratigraphy, structure, and mineralogy of Cretaceous and Tertiary sediments of the South Carolina Coastal Plain. Swift and Heron (1969) list some of the more important researchers. Major contributors are listed below.

Edmund Ruffin (1843) originally described and named the Peedee Formation.

Sloan (1908) subdivided Cretaceous sediments and named them the Black Creek and Middendorf "phases" or formations. He also identified the basal Tertiary Black Mingo Formation.

The Peedee Formation was described in detail by Stephenson (1923) who suggested that a disconformity separates the Peedee and Black Creek Formations.

Cooke (1936) renamed the Middendorf the Tuscaloosa Formation after correlating it with the Tuscaloosa Formation in Alabama. However, in recent years the name Middendorf has been reinstated for the rocks in South Carolina. Cooke also recognized the base of the Black Creek Formation as the base of the Tayloran Stage. Cooke first described these sediments in detail.

Siple (1946, 1957, 1959) described the stratigraphy, structure, mineralogy, and geohydrology of Cretaceous and Tertiary sediments in the South Carolina Coastal Plain.

Heron and Wheeler (1959) recognized facies relationships between the Tuscaloosa and Black Creek Formations; and Pusey (1960) suggested interfingering of the two units.

Swift and Heron (1969) described depositional features and facies relationships of Cretaceous sediments in North and South Carolina.

Colquhoun (1962) and Colquhoun and Johnson (1968) described the outcrop areas of various formations in central South Carolina and discussed sea-level changes during Cretaceous and Tertiary time.

Stratigraphy

Table 2 summarizes the stratigraphy and water-bearing properties of sediments in Horry and Georgetown Counties. The nomenclature of geologic formations used throughout this report conforms to the U. S. Geological Survey usage. In the project area, geohydrologic boundaries and the geologic boundaries appear to be the same, but there may be exceptions locally.

Geologic cross sections (figs. 3, 4, 5, and 6) constructed from geophysical logs delineate the geologic formations of the area and detail the stratigraphic relationships of sand, clay, and calcareous sandstone.

Formational boundaries were determined from paleontological examination of geologic samples and from correlation with the known geologic section, and from the ionic make-up of ground-water samples. Facies changes and interfingering of formations obscure formational boundaries when correlations are attempted from geophysical logs. Therefore these boundaries are subject to revision because of disagreement among

Table 2. Tertiary, Upper Cretaceous, and pre-Cretaceous geologic formations and aquifers, Horry and Georgetown Counties.

SYSTEM	SERIES	GEOLOGIC UNIT	DESCRIPTION OF SEDIMENTS	ASSOCIATED AQUIFERS	WATER-BEARING PROPERTIES
Holocene	Pleistocene	Waccamaw Formation	Blue-gray to yellow and brown sandy marl, gray to buff fine loose quartz sand.	Shallow water-table and artesian aquifers primarily in coastal Horry County	Water often hard, having some iron and hydrogen sulfide odor, Fair to large yields. Important in Little River-Calabash area where freshwater from other formations is unobtainable.
Tertiary	Upper Tertiary	Undifferentiated	Sands, silts, marls, and dark clays.	Water table and artesian aquifers. Primarily in inland Horry and Georgetown Counties.	Water usually hard, with hydrogen sulfide odor and iron.
	Middle Eocene	Santee Limestone	Occurs only in inland Georgetown County; fossiliferous and calcareous.	Fractured carbonate-rock aquifer. Water table and artesian conditions.	Hydraulic properties undetermined Supplies water to domestic wells in southwest Georgetown County.
	Lower Eocene and Paleocene	Black Mingo Formation	Greenish-gray glauconitic sands with thick beds of coquina (loose fossiliferous limestone). Occurs primarily in Georgetown County.	Shallow water-table and artesian aquifers primarily in Georgetown County (possible hydraulic connection with Peedee aquifer system locally).	Water quality usually poor but yields are locally high.
Cretaceous	Upper Cretaceous	Peedee Formation (Navarroan and Tayloran Age)	Gray to greenish-black calcareous glauconitic clayey silts and fine-grained sands with thin beds of gray calcareous sand and hard sandy limestone.	Peedee aquifer system	Treatment for iron and sulfate removal required for municipal use. Yields are high.
		Black Creek Formation (Tayloran and Austinian Age).	Gray to greenish montmorillonitic clays and thin beds of gray to white slightly glauconitic sand Thin beds of hard, sandy limestone containing pyrite, lignite, and possibly collophane.	Black Creek aquifer system	Principal aquifer in the two-county area. Contains saline water in northeastern Horry County. Yields as high as 1000 gallons per minute have been obtained in Horry County. Fluoride is usually high.
		Middendorf Formation	Light-colored cross-bedded kaolinitic sands with lenses of white massive kaolin. Lignite and pyrite common. Clays are non-calcareous.	Middendorf aquifer system	Contains salty water throughout area (possible exception along northwestern boundary of area).
Pre-Cretaceous		Basement	Basement rocks (metamorphic crystalline complex).	None	None

References: Adapted from Cooke, 1936; Stringfield, 1966, and Maher, 1971.

researchers. Boundaries chosen from paleontological examination of drill cuttings depend on whether the researchers are making identifications of pollen, foraminifera, or ostracoda. For example, Philip M. Brown, U. S. Geological Survey (oral commun., 1975) places the top of the Black Creek and Middendorf Formations based on faunal assemblages (with emphasis on ostracoda) somewhat deeper than indicated in figures 3, 4, 5, and 6.

Contour maps showing the altitude of the top of the Black Creek and Middendorf Formations, and the basement rocks (figs. 7, 8, and 9 respectively) were prepared from the geologic cross sections and additional geophysical logs. Accordingly, the approximate thickness of Black Creek and Middendorf Formations (figs. 10 and 11) were derived from the preceding maps. Along most of the Grand Strand, Peedee sediments are approximately 300 ft thick. However, an isopach map was not prepared because of the lack of geologic and stratigraphic data.

Upper Cretaceous Formations

The Upper Cretaceous formations in Horry and Georgetown Counties consist of the Middendorf Formation, which rests unconformably on the basement rock, and, in ascending order, the Black Creek Formation, and the Peedee Formation (Table 2). Swift and Heron (1969) concluded that these Cretaceous formations are time-transgressing facies which were deposited in fluvial, estuarine, and open-shelf environments of the transgressing Late Cretaceous sea. The Middendorf-Black Creek contact appears to be an interfingering one, whereas "the Black Creek-Peedee contact is a ravinement or disconformity cut by the transgressing Peedee Sea" (Swift and Heron, 1969, p. 201).

The Middendorf Formation contains medium to coarse sand and thin

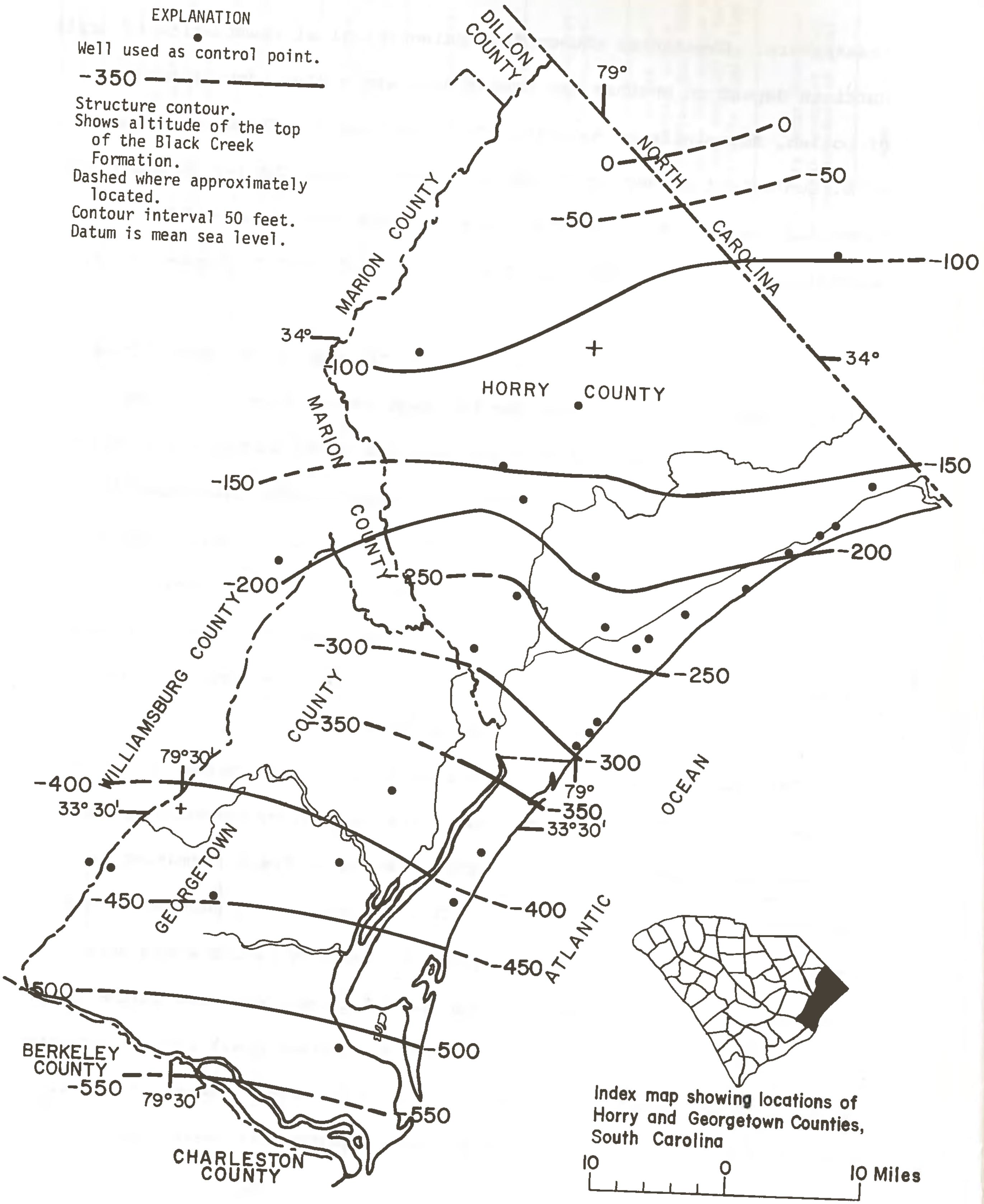

Figure 7. Structure contours on top of the Black Creek Formation.

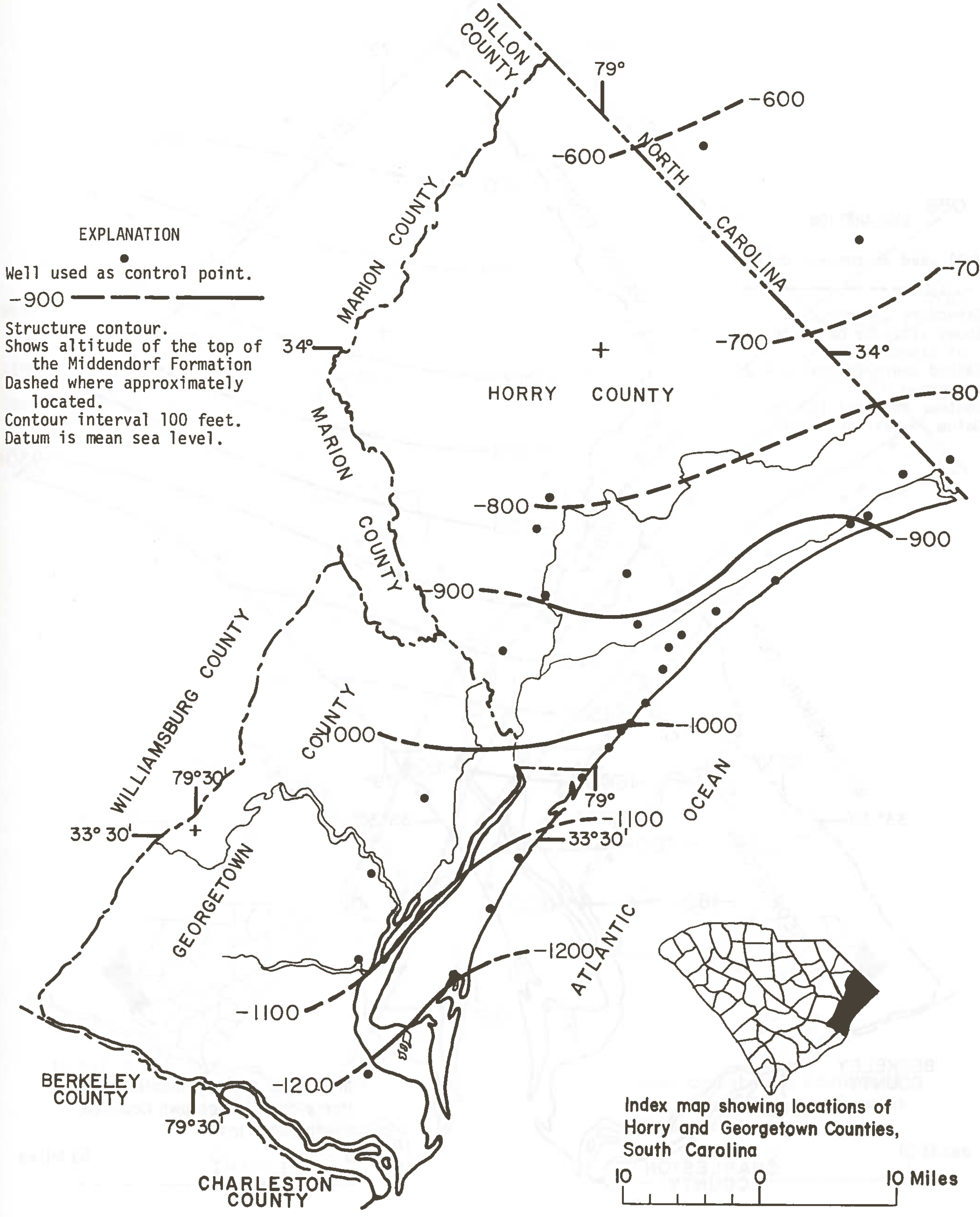

Figure 8. Structure contours on the top of the Middendorf Formation.

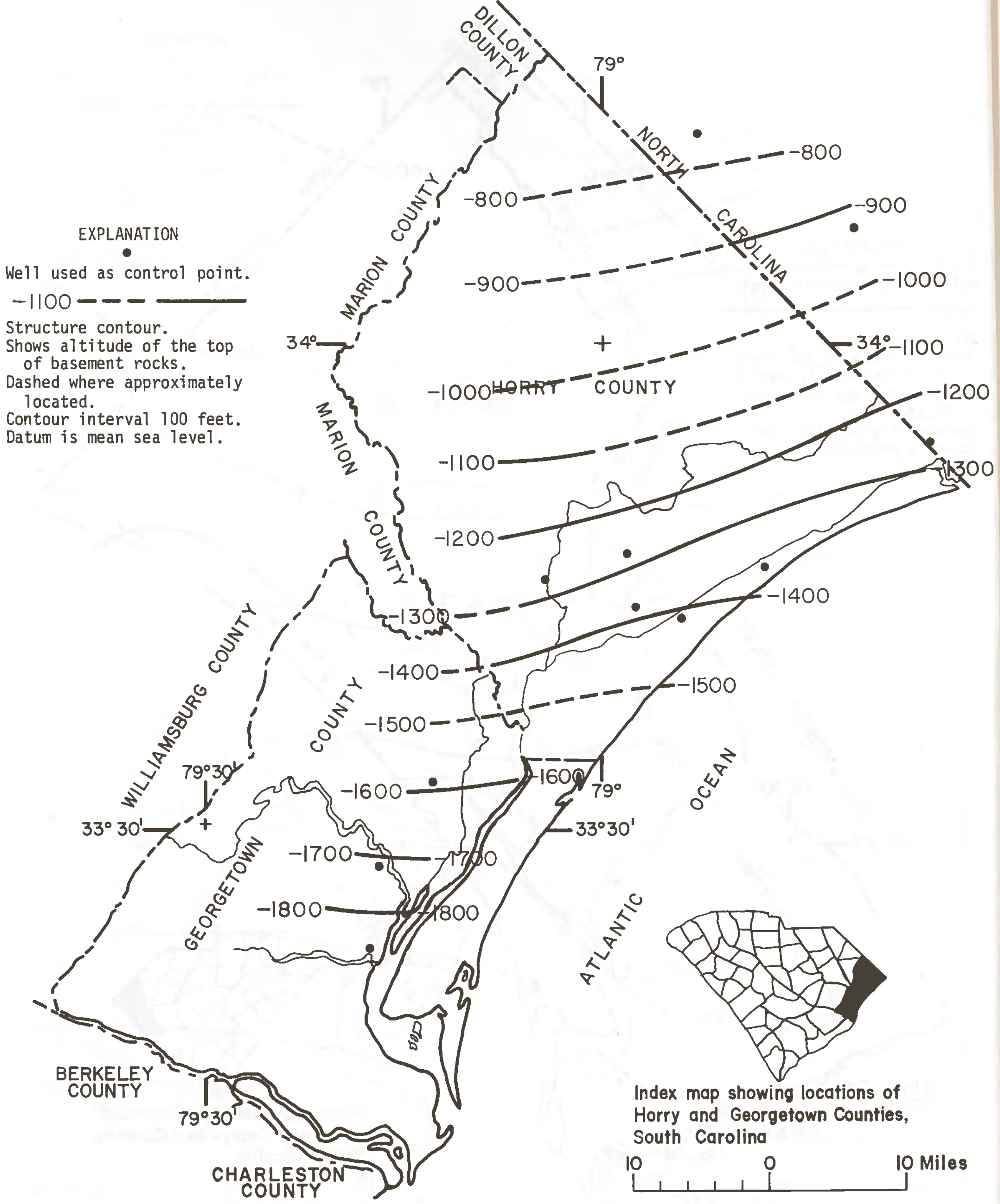

Figure 9. Structure contours on top of basement rocks.

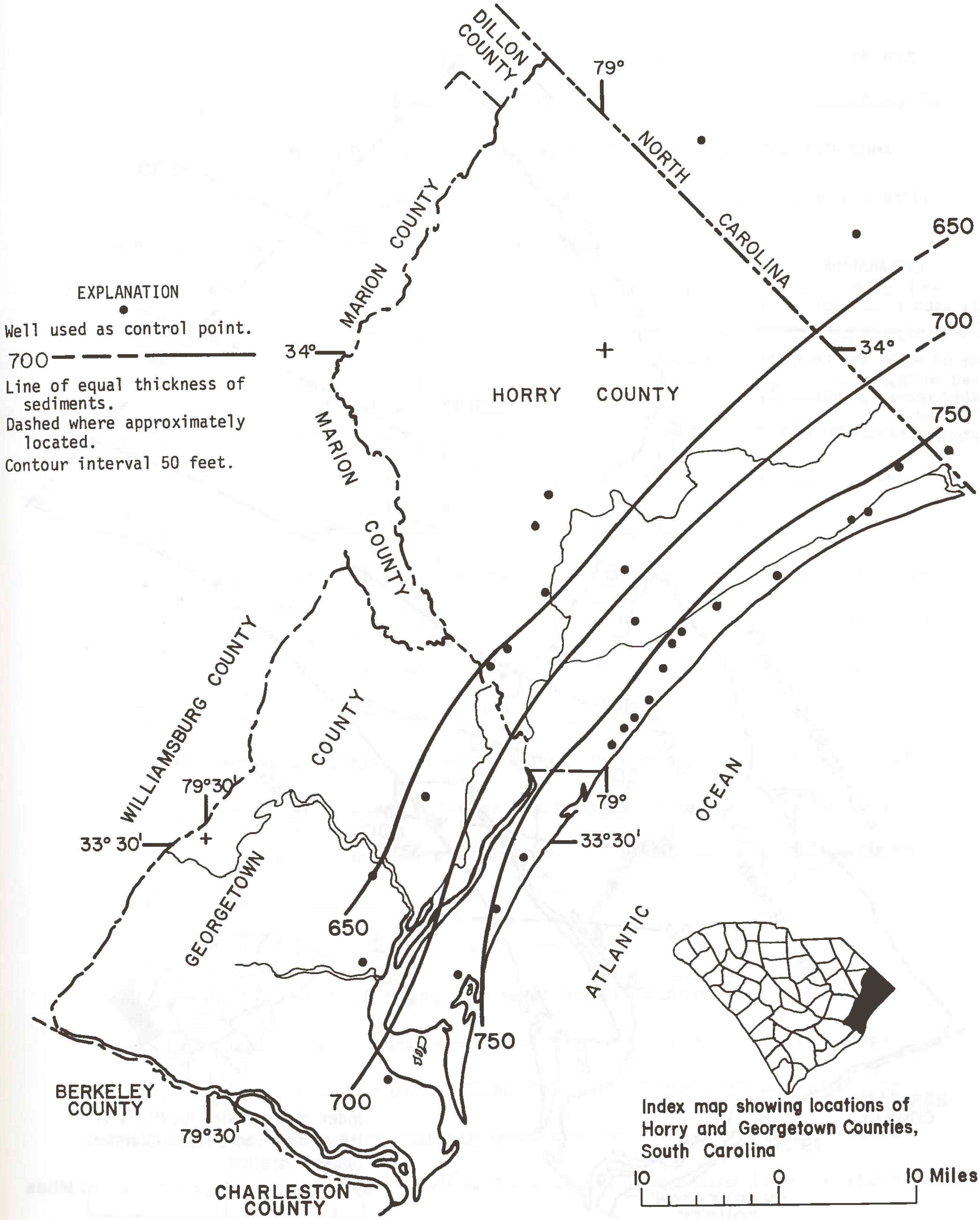

Figure 10. Thickness of the Black Creek Formation

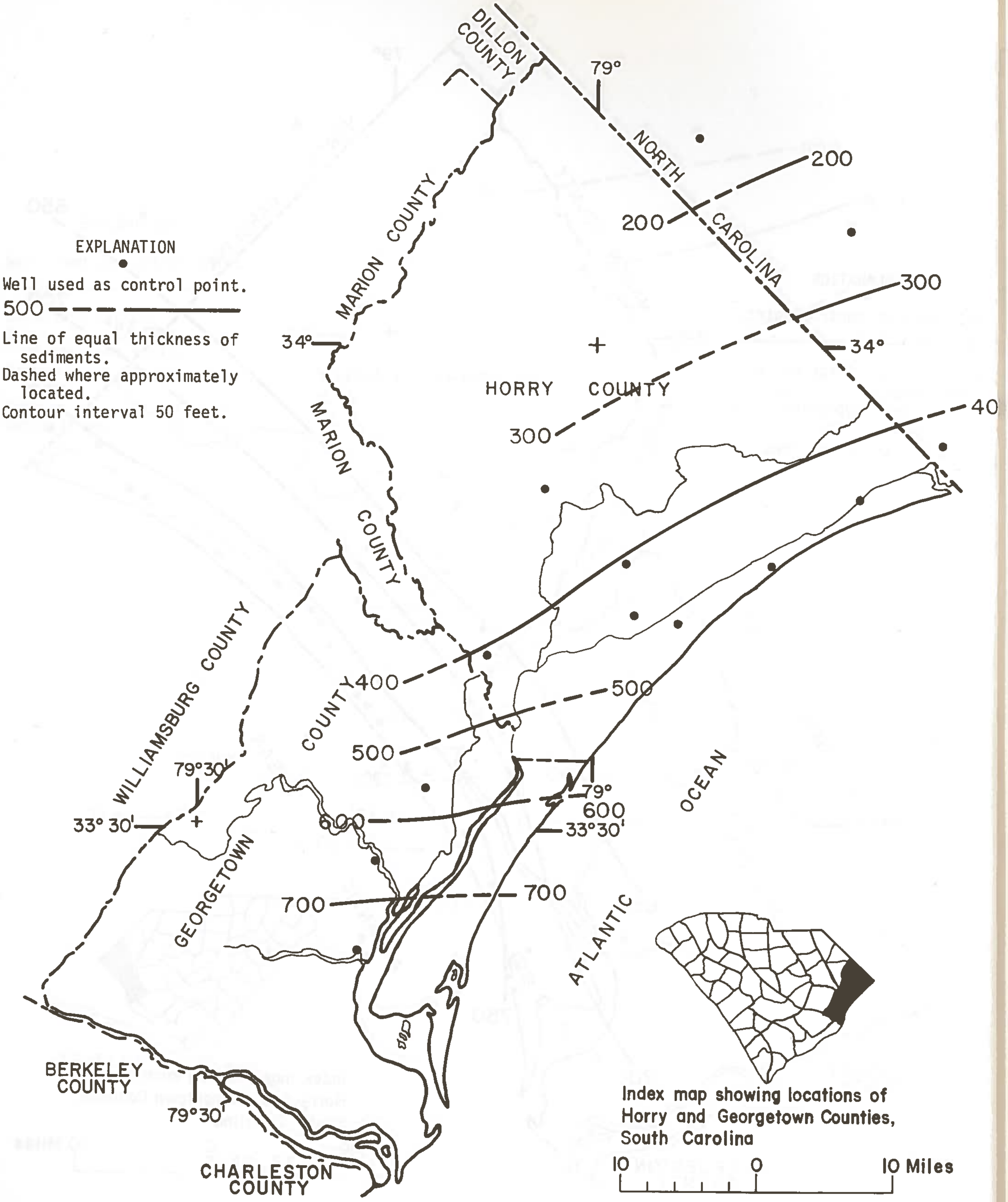

Figure 11. Thickness of the Middendorf Formation.

layers of silty clay. There are, however, well sorted, clean sands within the Middendorf Formation which are thick and continuous. According to Swift and Heron (1969, p. 214) oxidation in the outcrop area (whether depositional or post-depositional) is almost universal with orange, red, and purple clays and yellow-to-orange sands.

The Black Creek Formation consists of laminated, dark-gray clay interbedded with gray to white, fine to very-fine glauconitic, phosphatic, and micaceous quartz sand. Nodules of pyrite and marcasite as well as lignite fragments are common. Thin continuous layers of hard, impervious, calcareous sandstone possibly containing collophane, a calcium-fluorophosphate mineral, are abundant in sands of the upper third of the formation. These layers of hard calcareous sandstone may have as little as 2 percent porosity and make water well drilling very difficult. Minerals causing ion exchange have been shown to be relatively common throughout the Black Creek Formation (Foster, 1942, p. 846).

The Peedee Formation is composed of dark-gray, fine, clayey sand with horizons of very loose, coarse, and shelly limestone or coquina. The thin calcareous sandstones so common in the Black Creek Formation are absent in the Peedee.

Tertiary Formations

Throughout most of Horry and Georgetown Counties, thin beds of fine clayey sand, fine calcareous sand, and coquinas of Tertiary age overlie the Peedee Formation. These Tertiary formations are used for water supplies where they contain good quality water. However, these shallow aquifers were not studied in detail during this investigation.

Structure

The strike of coastal-plain sediments in the two-county area is generally northeast-southwest and the dip is southeast (figs. 7, 8, and 9). The dip has resulted from an accretion of sediments from the landward source in the coastal area as well as by downward flexture of the Coastal Plain. The downwarping is regional and accounts for the numerous facies changes encountered throughout the geologic formations. Eventually erosion exposed the updip limits of the sediments. The outcrops of the Middendorf, Black Creek, and Peedee Formations are shown in figure 12.

All formations thicken toward the coast (figs. 10 and 11) and their structure has been affected by the Cape Fear Arch (fig. 13) in southeastern North Carolina. The Cape Fear Arch is a southeastward plunging basement nose, the axis of which intersects the North Carolina coastline near the South Carolina State line (Maher, 1971, p. 22). The axial plunge increases sharply near the shoreline and gradually diminishes updip toward the Fall Line. Swift and Heron (1969, p. 225) indicate that the Navarroan and Tayloran Stage (Peedee Formation) thickens over the Cape Fear Arch, suggesting that the arch was negative during Navarroan time and has not been a persistently positive feature.

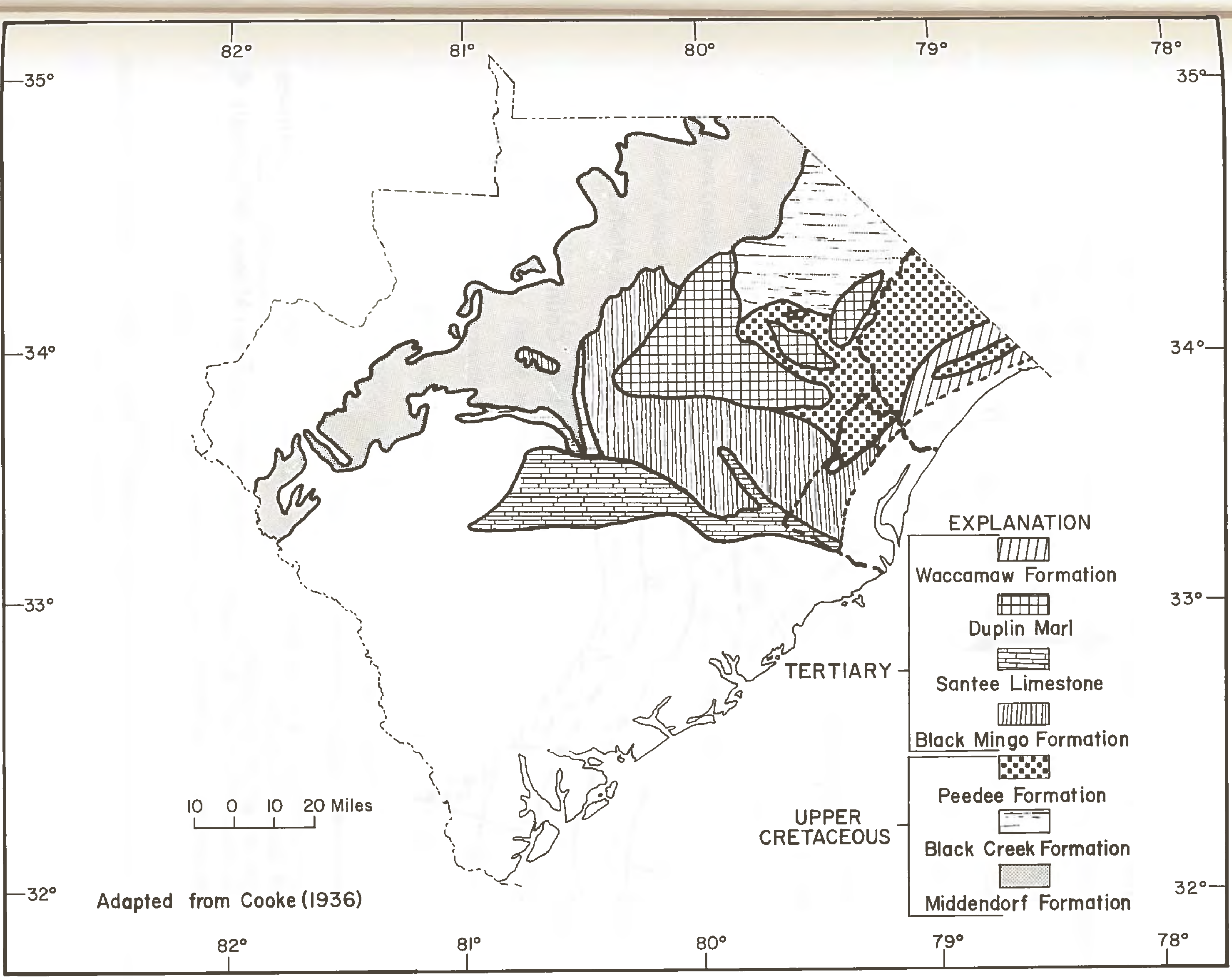

Figure 12. Generalized geologic map of the Coastal Plain showing outcropping Upper Cretaceous and Tertiary sediments which occur in Horry and Georgetown Counties, S. C.

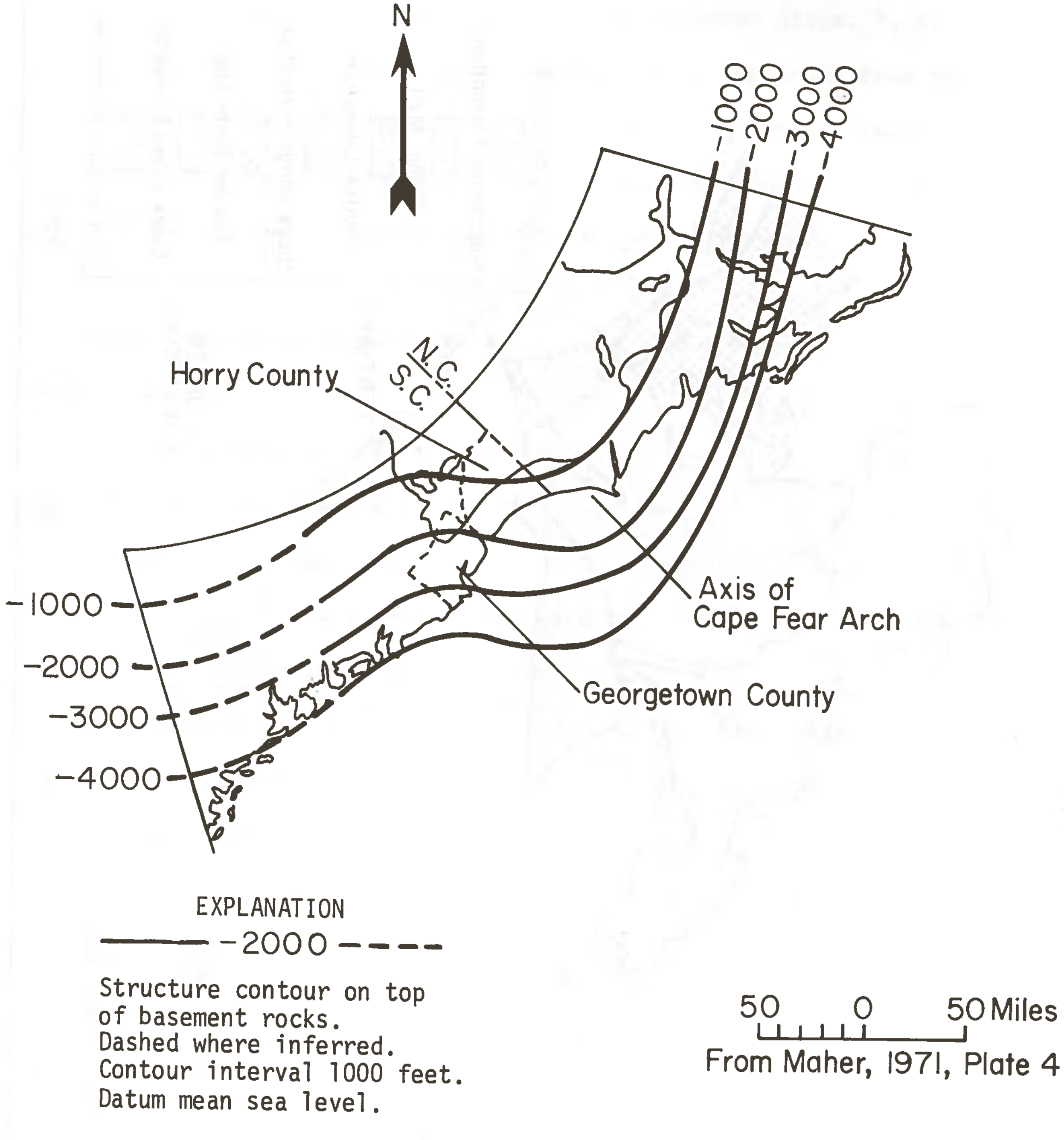

Figure 13. Structure contours on top of basement rocks showing the Cape Fear Arch.

GEOHYDROLOGY

Occurrence and Availability of Ground Water

Large quantities of ground water occur throughout all of Horry and Georgetown Counties in the saturated sediments above basement rocks. Although many of these sediments (clay, silt, and cemented sandstone) do not readily yield water to wells because of low hydraulic conductivity, large quantities of water occur in the sands and are available to wells. Unfortunately part of this easily recoverable ground water is unacceptable for domestic or industrial purposes because it is heavily mineralized or contains high concentrations of certain ions. In most of the area, however, the ground water contains low concentrations of objectionable ions and, except for fluoride, is highly satisfactory as a water supply.

In the two-county area, water-table and artesian aquifers generally occur in the shallow Tertiary and younger sediments above the Peedee Formation. Locally these aquifers are commonly used as a source of water. Often they are discontinuous, subject to large water-level fluctuations, and are largely reliant on local rainfall for recharge. The chemical quality of water is quite variable and generally inferior to that in the deeper artesian ground water. Close proximity of water-table aquifers to streams and other surface-water bodies (including the ocean) can result in degradation of ground-water quality locally when the aquifers are hydraulically connected to the surface sources and there is a free exchange of water between them.

Below the water-table aquifers and one or more confining clay layers, water occurs under artesian conditions within the Peedee, Black Creek, and Middendorf Formations (figs. 3, 4, 5, and 6). Although large quantities of water are available from the Peedee aquifer system, it is used only locally because of its inferior water quality. The Black Creek aquifer system, which lies stratigraphically below the Peedee Formation, is the most important source of ground water in Horry and Georgetown Counties and is used for municipal, industrial, and domestic water supplies.

Occurring stratigraphically below the Black Creek aquifer system is the hydraulically independent Middendorf aquifer system (within the Middendorf Formation) which contains salty water* in all of the Grand Strand and possibly in all of Horry and Georgetown Counties. It is possible that the Middendorf aquifer system contains freshwater near the western boundaries of the two-county area because freshwater is known to occur in Marion and Williamsburg Counties (Phillip W. Johnson, U. S. Geological Survey, oral commun., 1976). Exploratory drilling would be required to determine the location of the freshwater-saltwater interface within the Middendorf aquifer system.

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*In this report, saltwater is defined as water containing 250 mg/L (milligrams per liter) or more of chloride.

Hydraulic Characteristics of Water-Bearing Sediments

Several aquifer characteristics control the rate and amount of water-level decline when ground-water withdrawals are made. These must be determined in order to properly assess the capability of the Black Creek and other aquifer systems to provide suitable quantities of water for present and future needs.

The amount of water that a material can hold is a direct function of its porosity. Where the pore spaces are large and interconnected, as they are in the sand aquifers of Horry and Georgetown Counties, water is transmitted relatively freely, and the material is said to be permeable. Where the pore spaces are small, as in clay, water is transmitted slowly and the clay is considered relatively impermeable. The thickness of an aquifer (m) multiplied by the hydraulic conductivity (K) of its sediments is termed transmissivity (T). The storage coefficient (S) of an aquifer represents a volume of water released from storage (or taken into storage) per unit surface area of the aquifer per unit change in head. Transmissivity and storage coefficient are the principal hydraulic characteristics of an aquifer used in computations of ground-water flow, and reveal the capability of an aquifer to supply water to a well. Figure 14 shows the effect on drawdown caused by differences in transmissivity or thickness of aquifer screened, where hydraulic conductivity is equal throughout the total thickness.

Data collected from an aquifer test using one or more observation wells are used to calculate transmissivity and storage coefficient. These aquifer characteristics are usually determined by comparing observed response curves with theoretical response curves (Theis, 1935; Wenzel, 1942). The theory of aquifer tests is discussed in detail by

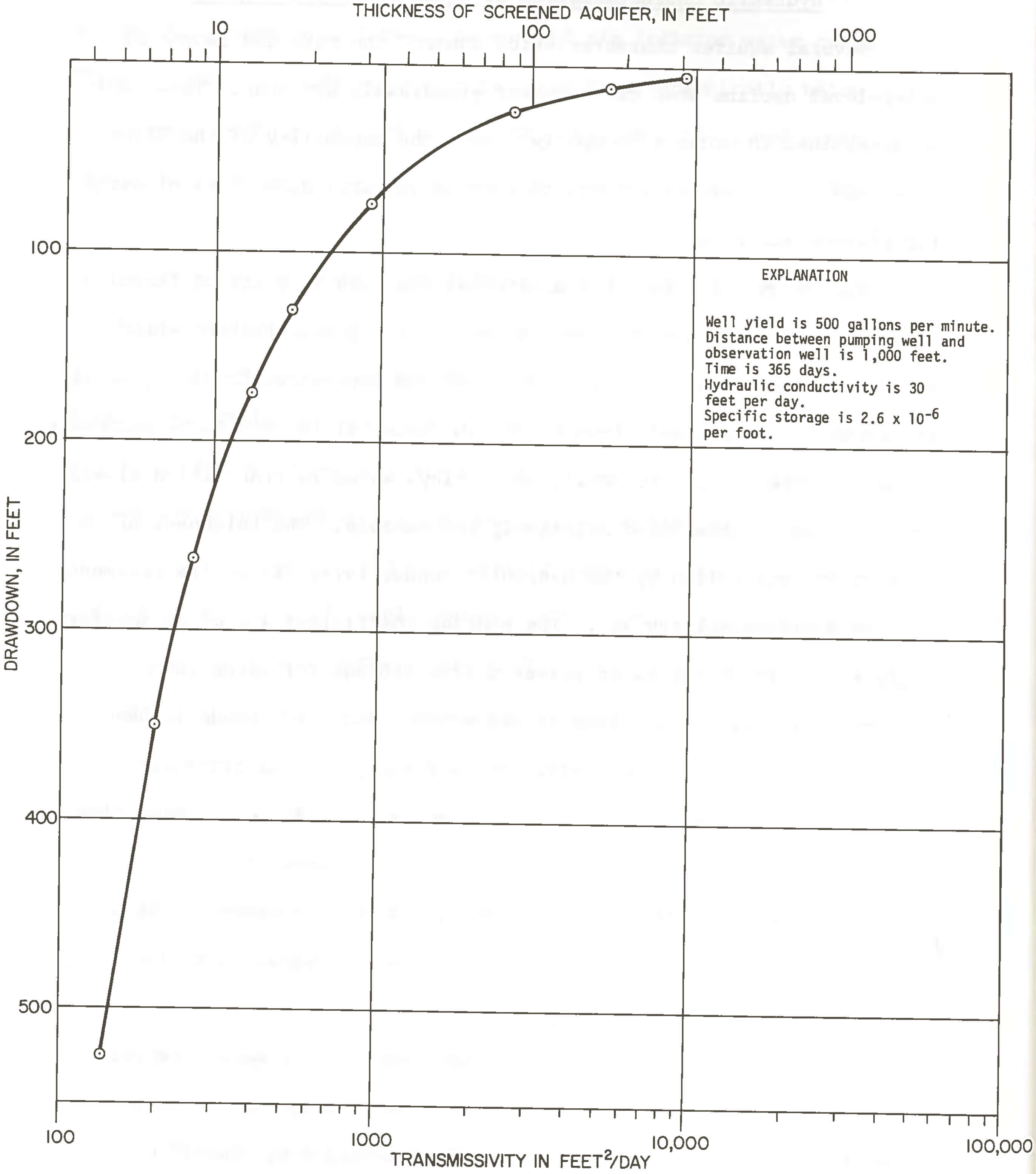


Figure 14. Drawdown in infinite aquifer with different thicknesses or transmissivities.

Ferris and others (1962) and Lohman (1972).

In Horry and Georgetown Counties values of hydraulic conductivity provide a more meaningful measure of an aquifer's ability to transmit water than do values of transmissivity. Because most wells contain several screens that traverse hydraulically independent sands, the value of transmissivity calculated from a short-term aquifer test depends upon the amount of screen in the pumping well since all sands may not be screened. Values of transmissivity derived from tests run on the pumping well alone are further affected by head losses from partial penetration. These losses are difficult to measure and are usually not determined. In the project area, comparing calculated transmissivity values from a pumping well containing 10 ft of screen with a well containing 100 ft of screen is not meaningful. However, the values of hydraulic conductivity derived from each of these calculations would provide meaningful information on aquifer capability at each well site.

Data provided from aquifer tests run primarily on the Grand Strand indicate that the average hydraulic conductivity of the principal water-bearing sands of the Black Creek Formation is 30 ft/day. There is evidence however, that in the vicinity of De Bordieu Colony and Plantersville in central and southern Georgetown County, values of hydraulic conductivity are somewhat smaller. Storage coefficient values for all aquifers tested were similar because of the similar artesian conditions at all sites. An average value of specific storage (S/m) of 2.6×10^{-6} per foot has been calculated from various aquifer tests throughout the area.

The results of aquifer tests at various sites are presented in Table 3, and a typical water-level response curve is shown in figure 15.

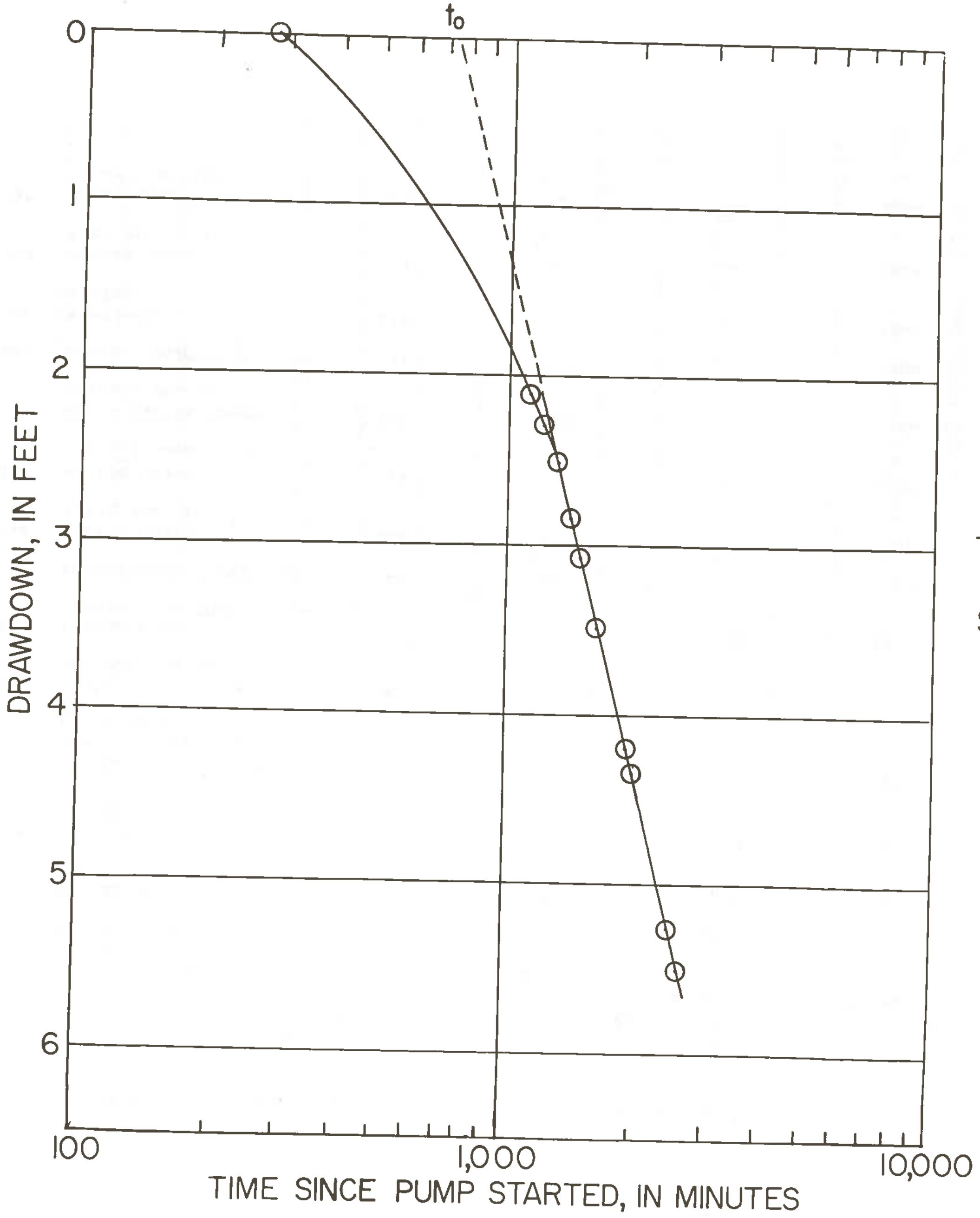
Although the transmissivity of an aquifer can often be estimated by measuring the rate of water-level decline in a pumping well, the determination of storage coefficient is impossible unless an observation well is provided. It has been observed, however, that for most of the tests conducted on pumping wells in Horry and Georgetown Counties there is a fluctuation of the rate of change of water level with time because of improper well development, making it difficult to determine transmissivity values with certainty.

Papadopoulos (1966, p. 4791) states that the determination of transmissivity and storage in a multiple-screened well cannot be made except by asymptotic solutions described in his paper. Although pumping tests have been performed in Horry and Georgetown Counties in multiple-screened wells, asymptotic solutions were not used to obtain values of transmissivity and storage because it was determined that the individual aquifers behaved as a single aquifer.

Plots of drawdown versus the logarithm of time can be used to indicate the presence of hydrologic boundaries. Because of time limitation of the aquifer tests conducted in the project area, effects of hydrologic boundaries (either recharge or barrier) were rarely shown by the drawdown and recovery curves. However, aquifer tests performed at several locations indicate that a small amount of leakage affects water levels. This leakage is derived from nearby unscreened sands and apparently is transmitted through adjacent clays. It is unclear whether this additional water is released from storage in clays or transmitted directly through the clays. Long-term aquifer tests with well pairs placed across confining beds may identify the source of leakage.

Table 3. Results of selected aquifer tests, Horry and Georgetown Counties

Well Number	Well Location	Length of Screen open to aquifer (ft)	Rate of flow during test (gal/min)	Distance of observation well from pumping well (ft)	Duration of pumping test (minutes)	Specific capacity at 24 hrs. [(gal/min)/ft of drawdown]	Transmissivity (ft^2/day)	Hydraulic conductivity (ft/day)	Storage	Measured efficiency of pumping well (percent)
Ho-270	Myrtle Beach (28 Ave.)	100	437	75.5	2815	3.70	2810	28	3.6×10^{-4}	61
Ho-272	Myrtle Beach (Ocean Forest)	100	367	48	2860	3.50	1870	19	4.1×10^{-4}	76
Ho-309	State of S.C. (Perry Rd. West)	15	30	234	1918	1.15	600	40	1.25×10^{-4}	51
Geo-87	Georgetown Water and Sewer District (Litchfield No.3)	65	200	1620	2775	0.60	740	11	3.2×10^{-4}	17
Geo-89	State of S.C. (De Bordieu Beach)	87	124	374	1710	0.69	190	2	1.14×10^{-4}	40
Ho-337	Little River (Eagle Nest Golf Course)	10	30	85	1410	2.39	590	59	1.7×10^{-4}	68
Ho-289	Forestbrook Development	60	360	--	62	--	2140	35	--	--
Ho-332	Myrtle Beach (21st Ave. N.)	116	500	--	1710	10.70	3530	30	--	--
Ho-340	Myrtle Beach (Pine Island)	124	503	--	4320	4.90	2950	24	--	--
Ho-335	North Myrtle Beach (Sydnor No. 1)	195	578	--	210	10.41	2760	14	--	--
Ho-287	Conway (WLAT)	71	517	--	1380	10.10	3500	49	--	--
Ho-344	Windjammer Village	115	200	--	1440	1.50	530	5	--	--
Ho-304	Myrtle Beach (3rd Ave. S.)	11	510	--	2905	5.00	1670	15	--	--
Geo-95	Georgetown Water and Sewer District	60	28	--	1560	0.72	390	6	--	--



EXPLANATION

Pumping rate (Q) = 200 gal/min.

Distance between pumping well and observation well (r) = 1620 ft.

Slope of the time drawdown plot ($\Delta S = 9.55$) expressed as the change in drawdown between any two values of time on the log scale whose ratio is 10. Intercept of the straight line at zero drawdown (t_o) = 730 min.

$$\text{Transmissivity}(T) = \frac{264\,Q}{\Delta S} = \frac{264 \times 200}{9.55 \times 7.48} = 740\ \text{ft}^2/\text{day}$$

$$\text{Storage}(S) = \frac{0.3\,T t_o}{r^2} = \frac{0.3(740)(7.48)(730)}{1440(1620)^2} = 3.2 \times 10^{-4}$$

Figure 15. Drawdown in observation well Geo-93 during aquifer test at Litchfield well No. 3 (Geo-87), September 1975.

Well Efficiency

A discharging well is assumed to be 100 percent efficient if its measured water level during pumping is the same as the theoretical pumping level in the well, calculated from values of transmissivity and storage at the site. Any differences in observed and calculated water levels are the result of either incomplete development, or well-entrance losses due to construction factors such as improper selection of screen slot size. Careful analysis is necessary to determine the efficiency of pumping wells. For this report, well efficiency (table 3) was calculated from values of transmissivity and storage derived from aquifer tests utilizing an observation well.

Specific Capacity

The specific capacity of a well is defined as the rate of discharge divided by the drawdown of water level in a well at a given time since the well began pumping. The specific capacity of a well depends on the transmissivity of the screened formation, the efficiency of the well, and to a lesser degree, the effective diameter of the well. Figure 16 relates specific capacity to transmissivity and efficiency for 10-in and 2-in wells. The figure shows that a low specific capacity measured in a pumping well does not necessarily mean that the well is inefficient. If the screens were inadvertently placed in clay, silt, or other formations of low hydraulic conductivity, the yield of the well per unit of drawdown would be very small, even if the well were 100 percent efficient.

Specific-capacity data can be used to:

1. Compare areal variations in the aquifer's ability to yield water to wells. In the North Myrtle Beach area, where numerous, thick sands are available, typical specific

capacities for wells screened in the Black Creek aquifer system range from 5 to 10 (gal/min)/ft of drawdown whereas in Myrtle Beach the range is 4 to 7 (gal/min)/ft. Near Georgetown some wells have a specific capacity of 2 (gal/min)/ft. This difference indicates the greater ability of wells in the northern part of the project area to yield water, primarily because of the thicker and more numerous water-bearing zones available.

2. Measure the well efficiency (determine the adequacy of well development). On the basis of average values of transmissivity (2700 ft^2/day) for wells in the Myrtle Beach area, figure 16 shows that a 10-in, 100 percent efficient well has a theoretical specific capacity of 10 (gal/min)/ft at the end of one day of continuous pumping. If the observed specific capacity of a similar 10-in well in this area is 5 (gal/min)/ft the estimated efficiency of the well is 50 percent.

3. Determine optimum pumping rates. For any well the pumping rate can increase and retain the same specific capacity up to the rate at which flow through the screen changes from laminar to turbulent conditions. At water velocities greater than approximately 0.1 ft/sec through the screens, specific capacity decreases as the pumping rate increases because of turbulent flow. Therefore, the optimum pumping rate is less than the critical discharge of the well. Figure 17 schematically illustrates the relationship. There has been no opportunity to observe the occurrence of critical dis-

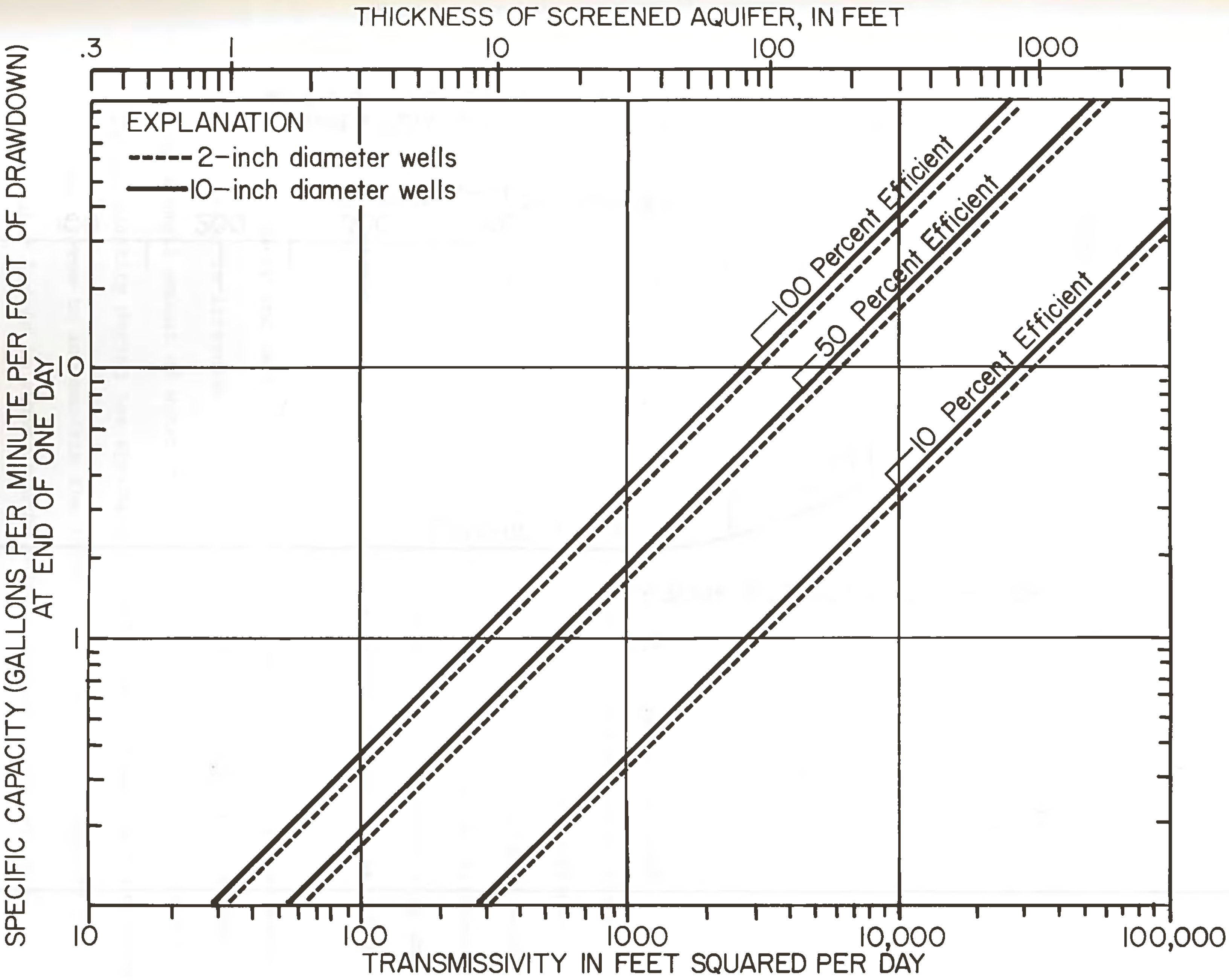


Figure 16. Relationship among transmissivity, specific capacity, well diameter, and well efficiency for pumping wells.

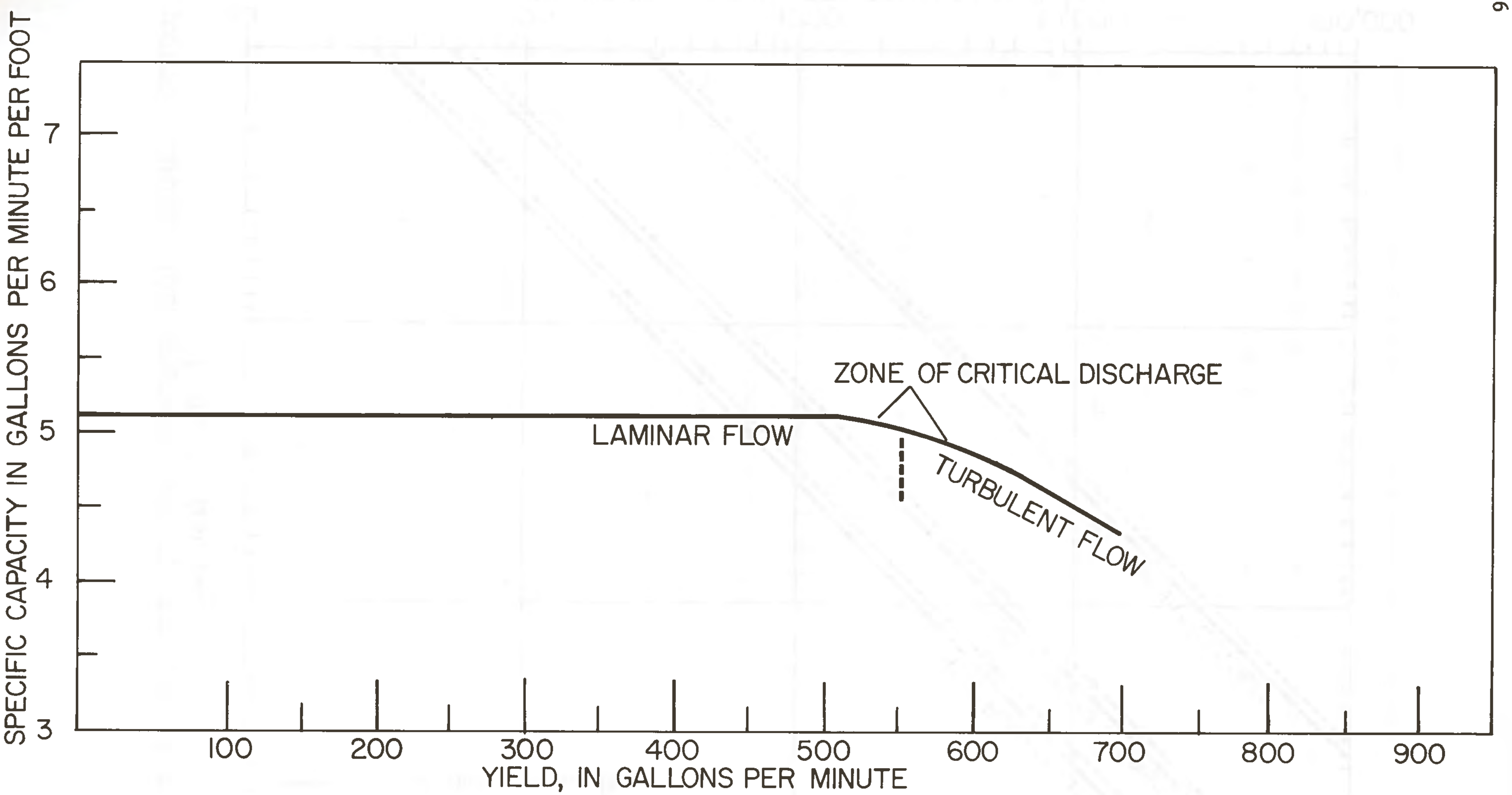


Figure 17. Schematic relationship of specific capacity and yield for a typical well showing zone of critical discharge.

charge in wells in the project area.

4. Indicate whether the decline in well yield is caused by well or pump failure. If the well yield declines but the specific capacity remains unchanged, the decline in yield is the result of faulty pumping equipment. If a decline in yield is accompanied by a decrease in specific capacity, the efficiency of the well has declined and there might be a need for redeveloping the well. Occasionally, declining areal water levels will cause well-yield declines with unchanged specific capacity, but this is attributed to the lifting of water from a depth beyond the range in which the pump can operate efficiently.

Ground-Water Withdrawals and Their Effect on Water Levels

As water is withdrawn from a well, the potentiometric or static head in the aquifer screened is reduced and the water level declines both in the pumping well and in nearby wells screened in the same water-bearing zones. The rate and amount of water-level decline at different distances from the pumping well are functions of the transmissivity and storage coefficient of the aquifer and the length of time the well has pumped.

In Horry and Georgetown Counties the time pattern of ground-water withdrawals is irregular. The resort communities on the Grand Strand pump a small amount of water throughout the winter months and a much larger quantity during the spring and summer months from the Black Creek aquifer system to accommodate the tourist industry. This results in lower water levels in summer months with recovered water levels in winter months (fig. 18). Because irrigation is not used to supplement rainfall in the two-county area, dry-season irrigation pumpage does not affect water-level declines of the Black Creek aquifer system.

Water levels in the vicinity of the City of Georgetown react to a different pattern of cyclical ground-water withdrawals than that of the Grand Strand communities. Since October 1974, water for municipal use has been pumped from the Pee Dee River on week days and from wells on weekends.

Data on ground-water use for 1974 for the two-county area are listed in table 4. Monthly ground-water pumpage data for 1975 were incomplete and therefore are not given. Pumpage for January 1975 (near minimum demand) and July 1975 (maximum demand) was synthesized from available data and is illustrated in figures 19 and 20. The potentiometric surfaces, which reflect the pumpage of the previous months of February and August 1975 for the Black Creek aquifer system (figs. 21 and 22), illustrate the response of winter-month and summer-month ground-water withdrawals. Major cones of depression have developed in the Myrtle Beach, North Myrtle Beach and Georgetown areas.

Recharge

Natural recharge to the artesian aquifers in Horry and Georgetown Counties occurs in the outcrop areas shown on figure 12. Water from precipitation and incised streams infiltrates the aquifers where they are at or near the surface and moves slowly downdip toward points of discharge such as wells and springs. This recharge continuously supplies water to the aquifer. Because of the steady increase of ground-water withdrawals, however, water levels in wells have steadily declined. If withdrawals were to remain constant for several years, water levels would be expected to eventually stabilize. This would indicate that

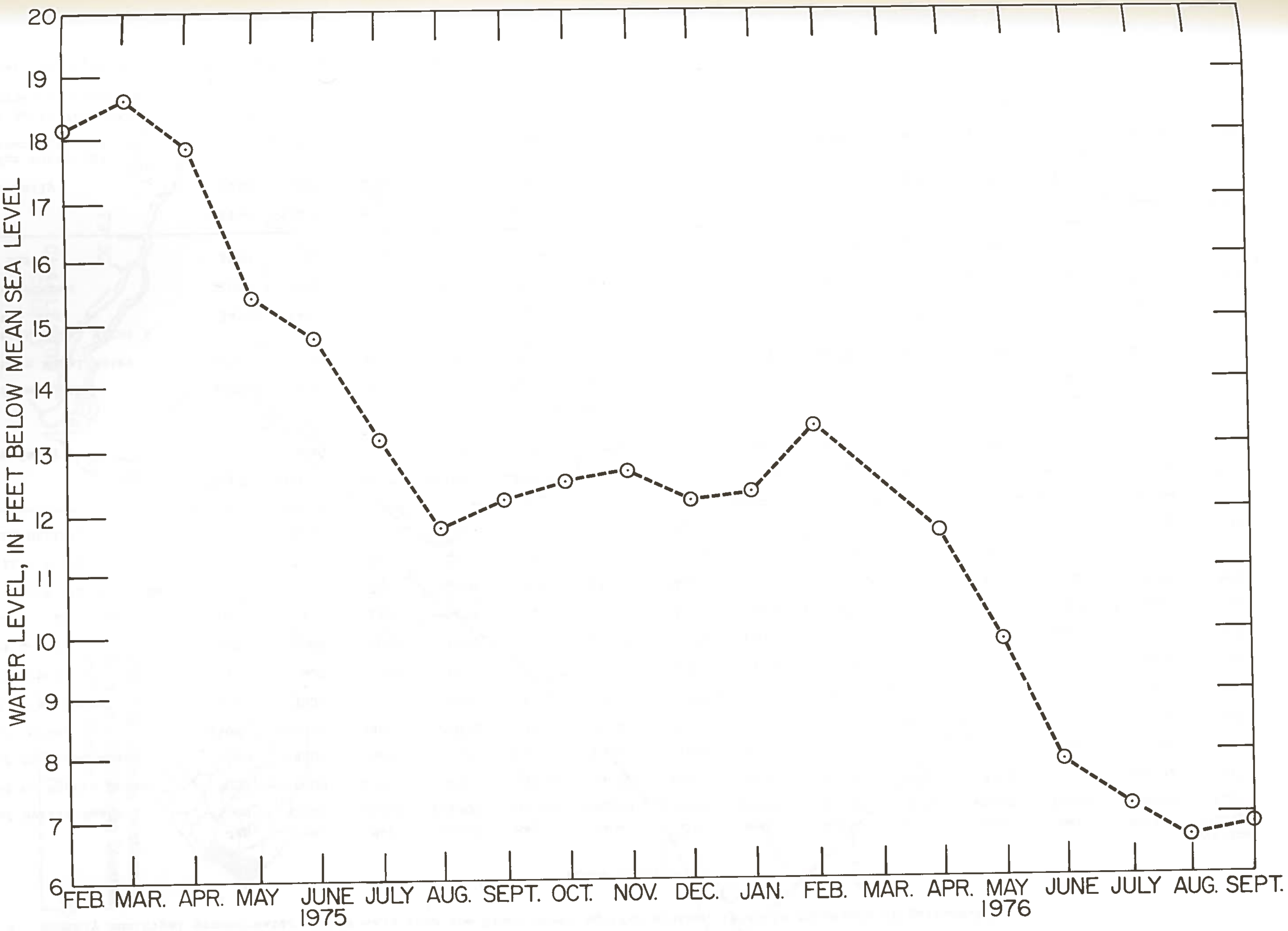


Figure 18. Hydrograph of monthly water level measurements for observation well Ho-311, screened in sands of the Black Creek aquifer system.

Table 4. Monthly municipal ground-water withdrawals from the Black Creek aquifer system, 1974, in thousands of gallons.[1]

HORRY COUNTY

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total	Average Daily
City of Myrtle Beach	75000	65000	88000	124000	136000	198000	236000	207000	145000	118000	80000	76000	1548000	4240
City of N. Myrtle Beach	8000	8000	14000	14000	24000	24000	49000	49000	37000	37000	17000	17000	298000	820
City of Surfside Beach	5000	4000	6000	8000	8000	13000	13000	12000	5000	7000	6000	6000	93000	250
City of Conway	25000	21000	24000	23000	27000	26000	25000	27000	25000	26000	26000	24000	299000	820
Conway Rural Water	8000	7000	7000	6000	5000	7000	7000	10000	9000	10000	12000	8000	96000	260
Town of Aynor	900	800	900	1000	1100	1200	1300	1100	1000	900	900	900	12000	30
Town of Loris	6000	6000	7000	7000	7000	11000	11000	10000	8000	7000	7000	6000	93000	250
Town of Little River	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	16800	50
Myrtle Beach Air Force Base	16000	15000	17000	20000	24000	24000	24000	22000	20000	20000	18000	18000	238000	650
Braircliff Acres	2300	2300	2300	2300	2300	2300	2300	2300	2300	2300	2300	2300	27600	80
Carolina Utilities	5100	5100	5100	5100	5100	5100	5100	5100	5100	5100	5100	5100	61200	170
Total	152700	135600	172700	211800	240900	313000	375100	346900	258800	234700	175700	164700	2782600	7620
Average daily	4930	4840	5570	7060	7770	10440	12100	11190	8630	7570	5860	5310		

GEORGETOWN COUNTY

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total	Average Daily
City of Georgetown	40000	43000	44000	48000	51000	47000	48000	48000	36000	36000	36000	36000	513000	1410
Georgetown Rural Water	12000	7000	6000	7000	14000	10000	20000	15000	14000	15000	8000	8000	136000	370
Georgetown Rural Water & Sewer	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	16800	50
City of Andrews	21000	21000	22000	23000	25000	27000	27000	25000	24000	22000	21000	21000	279000	760
Browns Ferry	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	18000	50
Total	75900	73900	74900	80900	92900	86900	97900	90900	76900	76900	68900	67900	962800	2640
Average daily	2450	2640	2420	2700	3000	2900	3160	2930	2560	2480	2300	2190		
Total for Horry and Georgetown Counties	228600	209500	247600	292700	333800	399900	473000	437800	335700	310600	243600	232600	3745400	10260
Average daily for Horry and Georgetown Counties	7380	7480	7990	9760	10770	13300	15260	14120	11190	10020	8120	7500		

[1] Data supplied by South Carolina Water Resources Commission

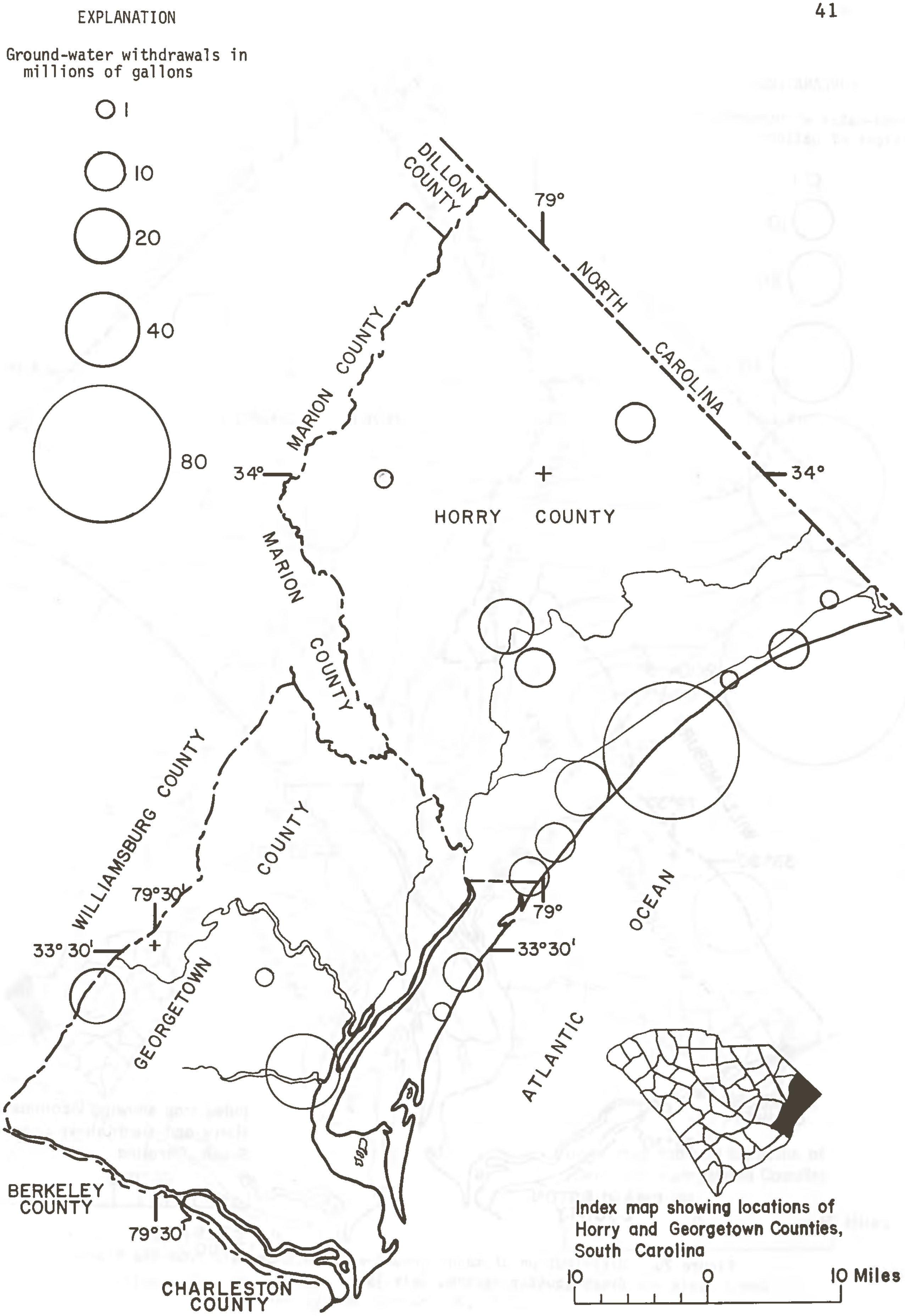


Figure 19. Distribution of major ground-water withdrawals from the Black Creek aquifer system, January 1975.

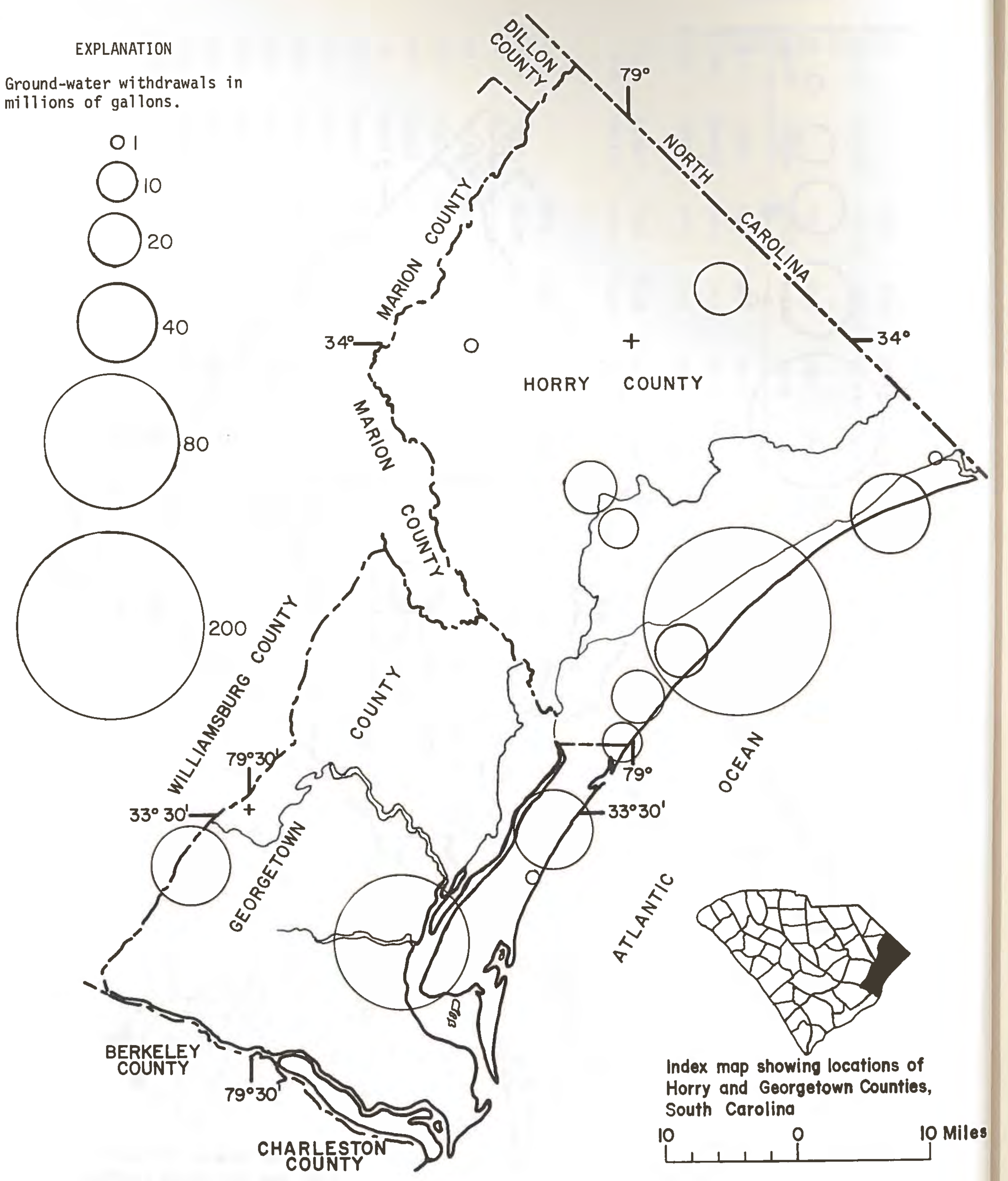


Figure 20. Distribution of major ground-water withdrawals from the Black Creek aquifer system, July 1975.

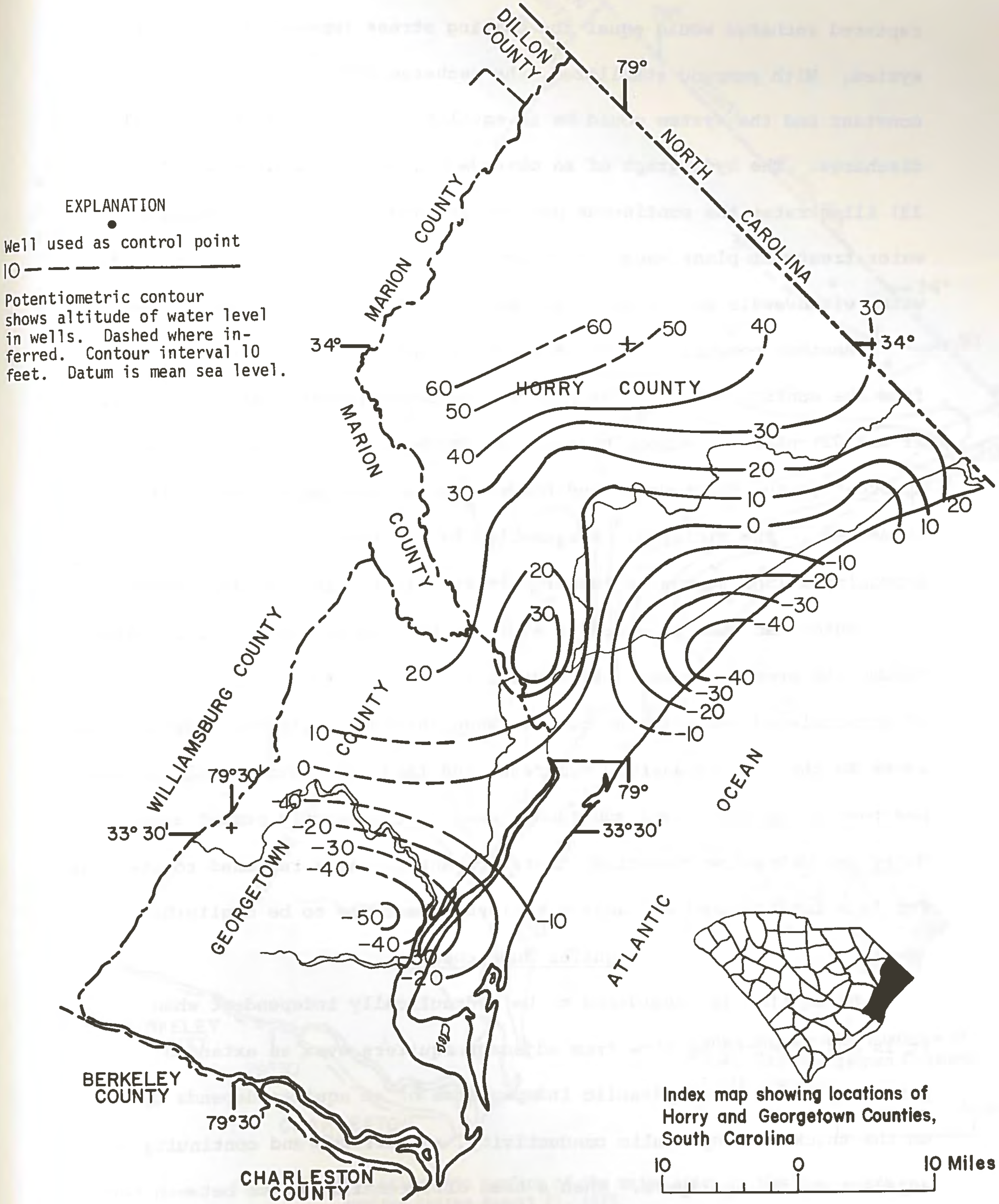


Figure 21. Potentiometric surface of the major sands in the Black Creek aquifer system February 26, 1975.

captured recharge would equal the pumping stress imposed on the aquifer system. With pumping stabilized, the recharge demand would remain constant and the system would be in equilibrium; recharge would equal discharge. The hydrograph of an observation well in Georgetown (fig. 23) illustrates the continuous decline of water levels until the surface-water treatment plant began operation in October 1974 whereupon ground-water withdrawals were reduced and water levels began a rapid recovery.

Another possible source of recharge to Black Creek sands is evident from the configuration of the high in the potentiometric surface (figs. 21 and 22) near the common boundary of Horry and Georgetown Counties. Apparently, the Black Creek and Peedee aquifer systems are hydraulically connected in the vicinity. Presumably the Pee Dee River is indirectly providing a line source of recharge to the Black Creek aquifer system.

Water can also be added to aquifers when ground-water withdrawals reduce the pressure within the aquifer beyond the preconsolidation load of intercalated and adjacent clays. When this occurs, these clays release water to the aquifer as they compress, and land subsidence results. There has been no apparent land subsidence even in the heavily pumped areas of Horry and Georgetown Counties; therefore any recharge released to the aquifer from intercalated and adjacent clays is assumed to be negligible.

Aquifer Independence

An aquifer is considered to be hydraulically independent when it is not affected by flow from adjacent aquifers over an extended period of time. The hydraulic independence of an aquifer depends upon the thickness, hydraulic conductivity, anisotropy, and continuity of adjacent confining layers. When a head differential exists between two aquifers, water will tend to move from the aquifer of higher head to

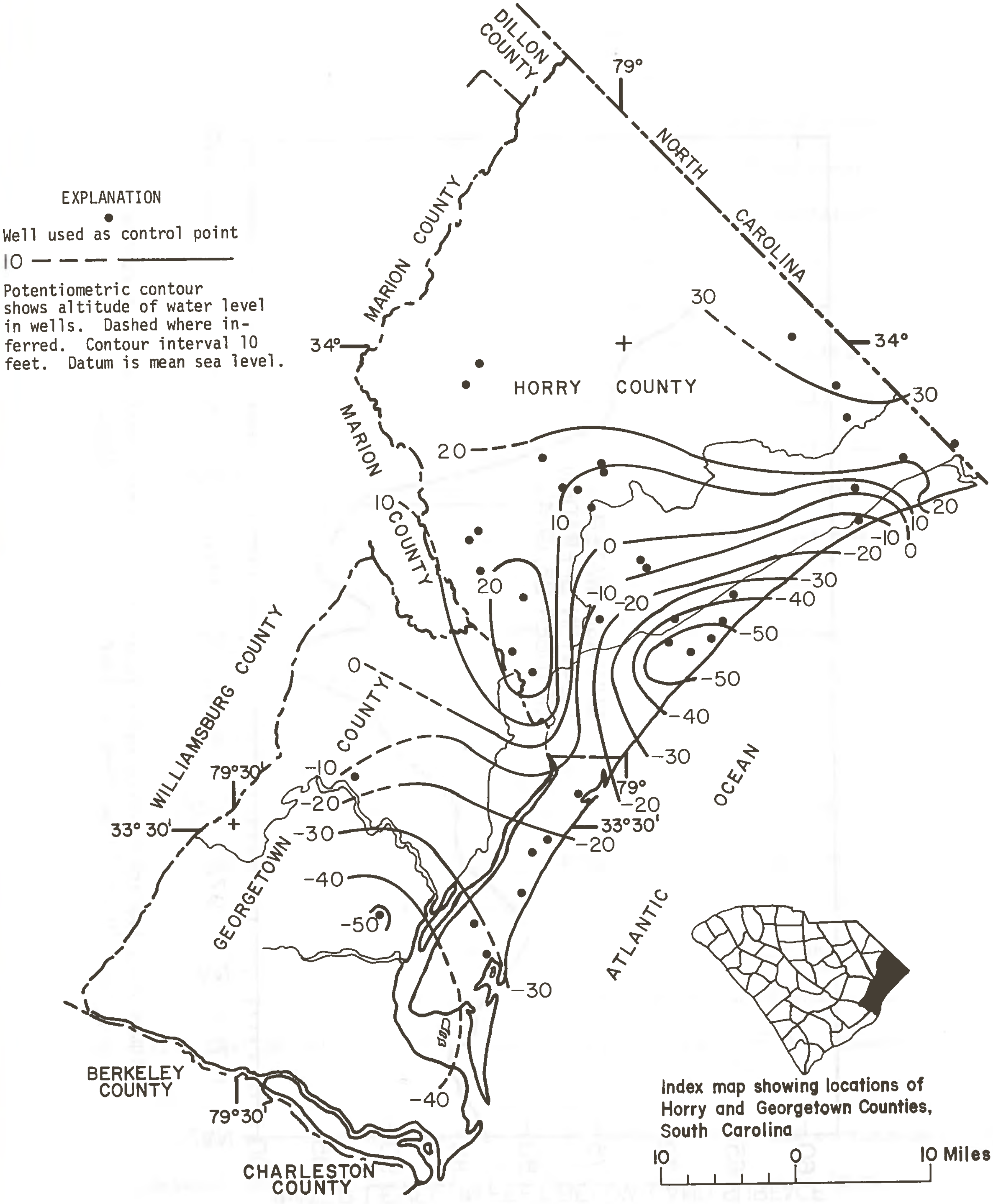


Figure 22. Potentiometric surface of the major sands in the Black Creek aquifer system August 21, 1975.

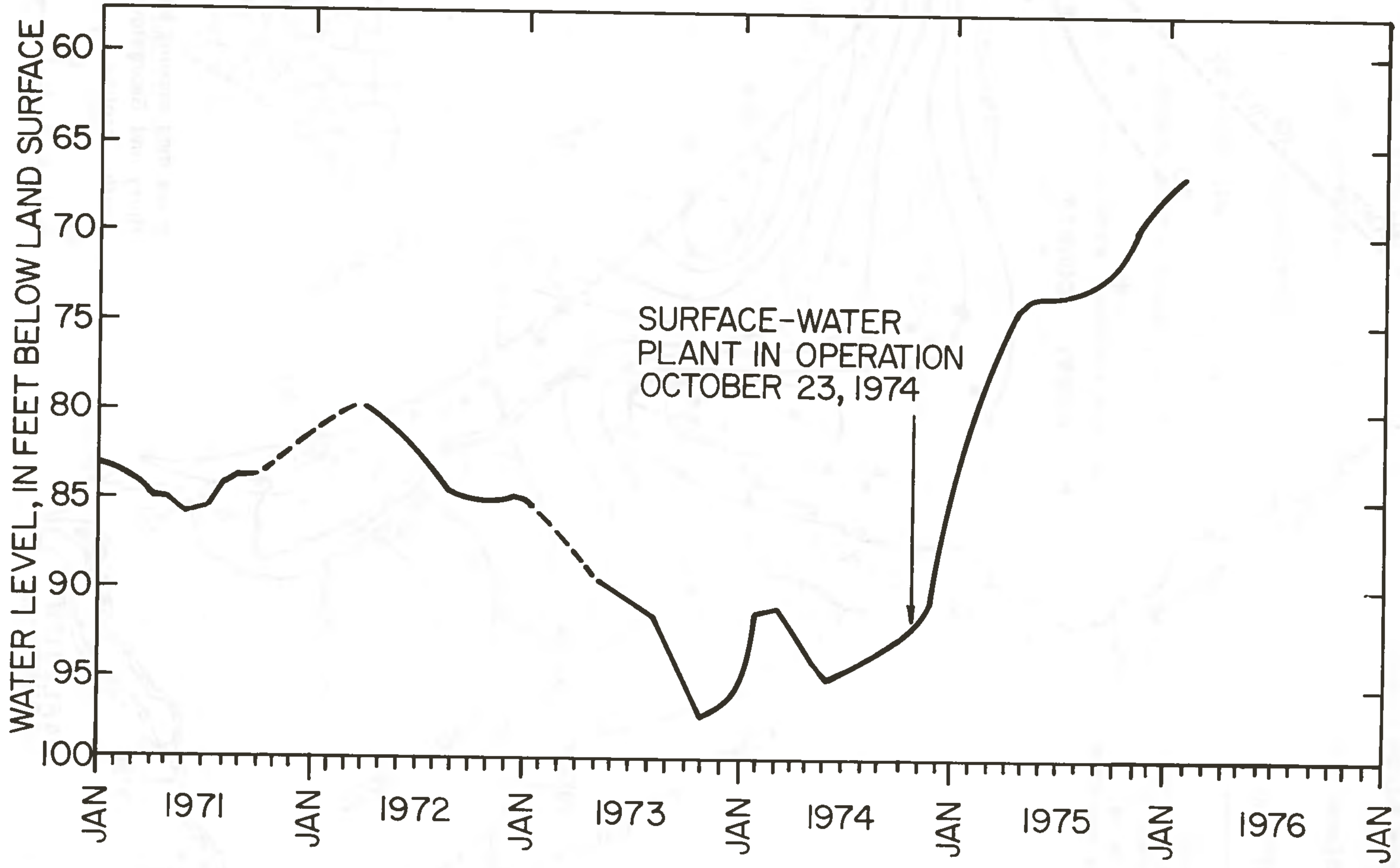


Figure 23. Average monthly water level in observation well Geo-43 screened in the Black Creek aquifer system, Georgetown, S. C.

the aquifer of lower head through the beds that separate them. If these adjacent beds are of relatively high hydraulic conductivity such as sandy silts, the transfer of water and equalization of head occurs relatively rapidly (hydraulically dependent), whereas the transfer of water through a relatively impermeable rock or clay might take an extremely long period of time (hydraulically independent).

The hydraulic independence of one sand or aquifer from another plays a very important role when determinations of transmissivity are made from aquifer tests. Insofar as the tests are concerned, hydraulic independence of sands can be demonstrated over the short term, that is, during the length of an aquifer test. Presumably, however, with the continuation of an aquifer test over weeks and months, the rate of change of water-level decline with time would decrease, eventually reaching zero, indicating water has moved to the screened sands from an outside source. Under these conditions, determination of aquifer transmissivity is no longer a straightforward procedure. One of the major assumptions that must be made in order to determine transmissivity using the Theis nonequilibrium equation (Theis, 1935), is that water is released solely from aquifer storage when wells are pumped. If water is added to the aquifer from an outside source in response to a lowered potentiometric head, the assumption is invalidated and transmissivity must be determined from leaky aquifer analyses or from flownet analyses.

All present information suggests that the impervious and continuous clay between the Black Creek and the Middendorf aquifer systems (figs. 3, 4, 5, and 6) separates the two hydraulically; little if any leakage occurs between these aquifer systems. Except through abandoned wells screened in both aquifer systems, there is apparently no transfer of water from the salty Middendorf aquifer system (of higher potentiometric head) to the Black Creek aquifer system despite the observed large head differences between the two.

Confining clays cause short-term hydraulic independence of the Black Creek from the Peedee aquifer system, of individual sands within the Black Creek, and of the Peedee from overlying Tertiary aquifers (figs. 3, 4, 5, and 6). Water in sands of these three aquifer systems apparently does not move freely across aquifer boundaries when subject to observed short-term pumping stresses.

A comparison of regional monthly water levels to antecedent monthly withdrawals shows that water is moving into the Black Creek aquifer system from an outside source. This is based on a relationship between a series of average monthly weighted water levels for the Grand Strand part of Horry County as determined from potentiometric maps (fig. 24) and the water use for the same area (fig. 25). It appears, however, that the rate of ground-water withdrawals during the yearly pumping cycle is not linearly related to average monthly weighted water levels (fig. 26) as would be expected from the Theis nonequilibrium formula (Theis, 1935). Rather, the average water level is related to withdrawals in an exponential way, in which the rate of decline of the average water level decreases with increased withdrawals. Apparently, vast quantities of water are induced to move into the principal producing sands by a lower potentiometric head. The attenuation rate of water-level decline is evidence of the much greater amount of ground water available to wells than can be calculated from transmissivity and storage values alone. It is probable that this water is not derived from a single source, but is contributed from a combination of sources such as:

1. Capture of water from outcrop areas shown on figure 12;
2. A line source of recharge as indicated by an elongated potentiometric high (figs. 21 and 22);
3. Long-term leakage from overlying Peedee sands; and
4. Removal of water from storage in the vicinity of the saltwater-freshwater interface as it moves inland from the Atlantic Ocean.

The mechanism by which water would move into the Black Creek aquifer system for each of the first three sources listed above is well known. The mechanism involved in the removal of water from storage near the saltwater-freshwater interface is not as obvious.

As potentiometric gradients are developed by withdrawing ground water near the coast, the cones of depression eventually reach the saltwater-freshwater interface causing it to move slightly landward. As the interface moves, saltwater replaces freshwater in storage. The volume of displaced freshwater per unit volume of aquifer material as the interface moves is equal to the effective porosity of the aquifer. The mechanism is similar to that which occurs when the rate of change of water level with time during a pumping test is decreased when the cone of depression reaches an outcrop area where unconfined conditions exist. Only a few hundred feet of interface movement would represent the removal from storage of vast quantities of freshwater from the aquifer system. Thus, the water removed from storage is much larger than that represented by the artesian storage coefficient of the system, and results in a reduced rate of decline of water levels with time. A similar example is presented by Trapp, Pascale, and Foster (1977).

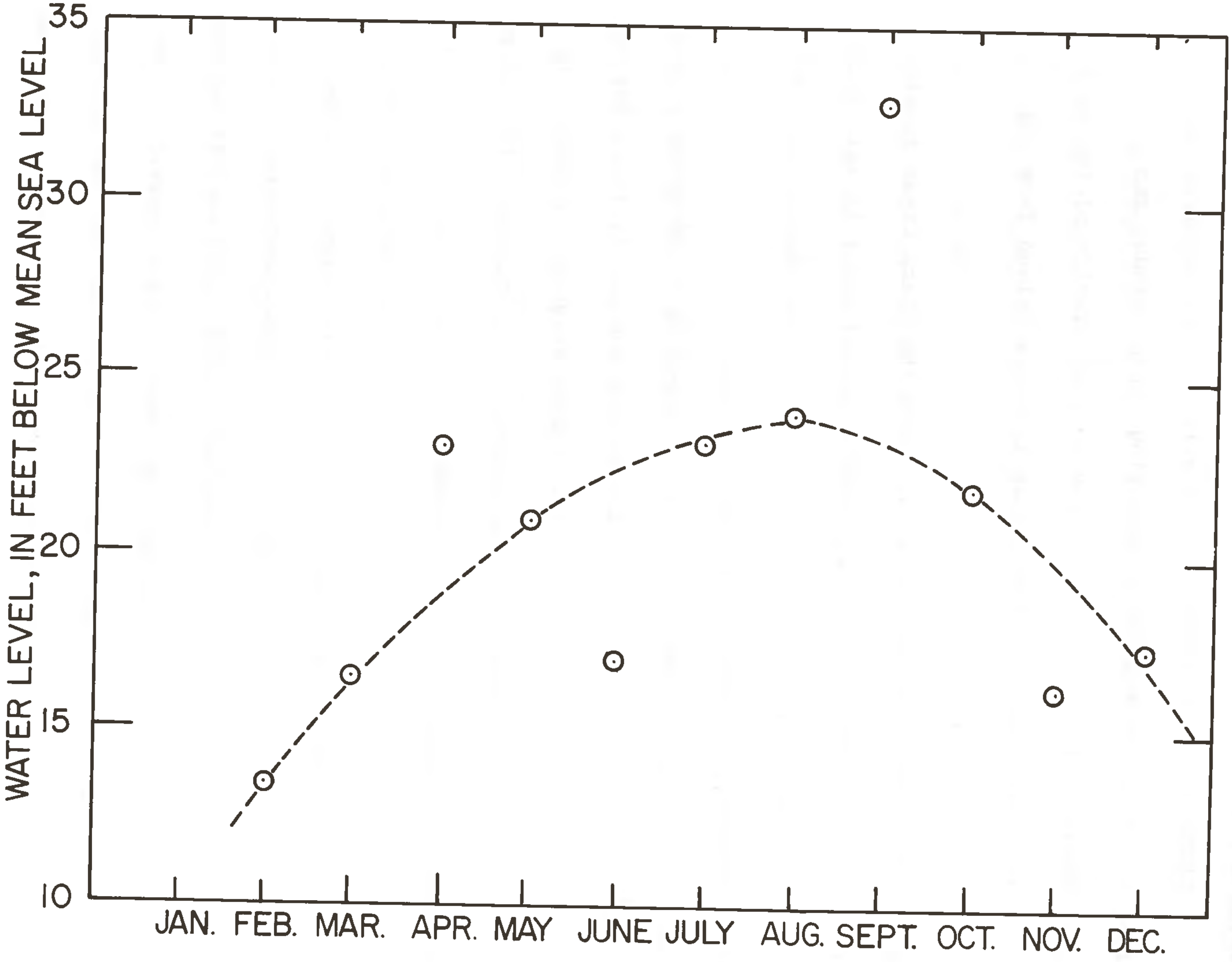


Figure 24. Average monthly weighted water level of the Black Creek aquifer system for the Grand Strand part of Horry County, 1975.

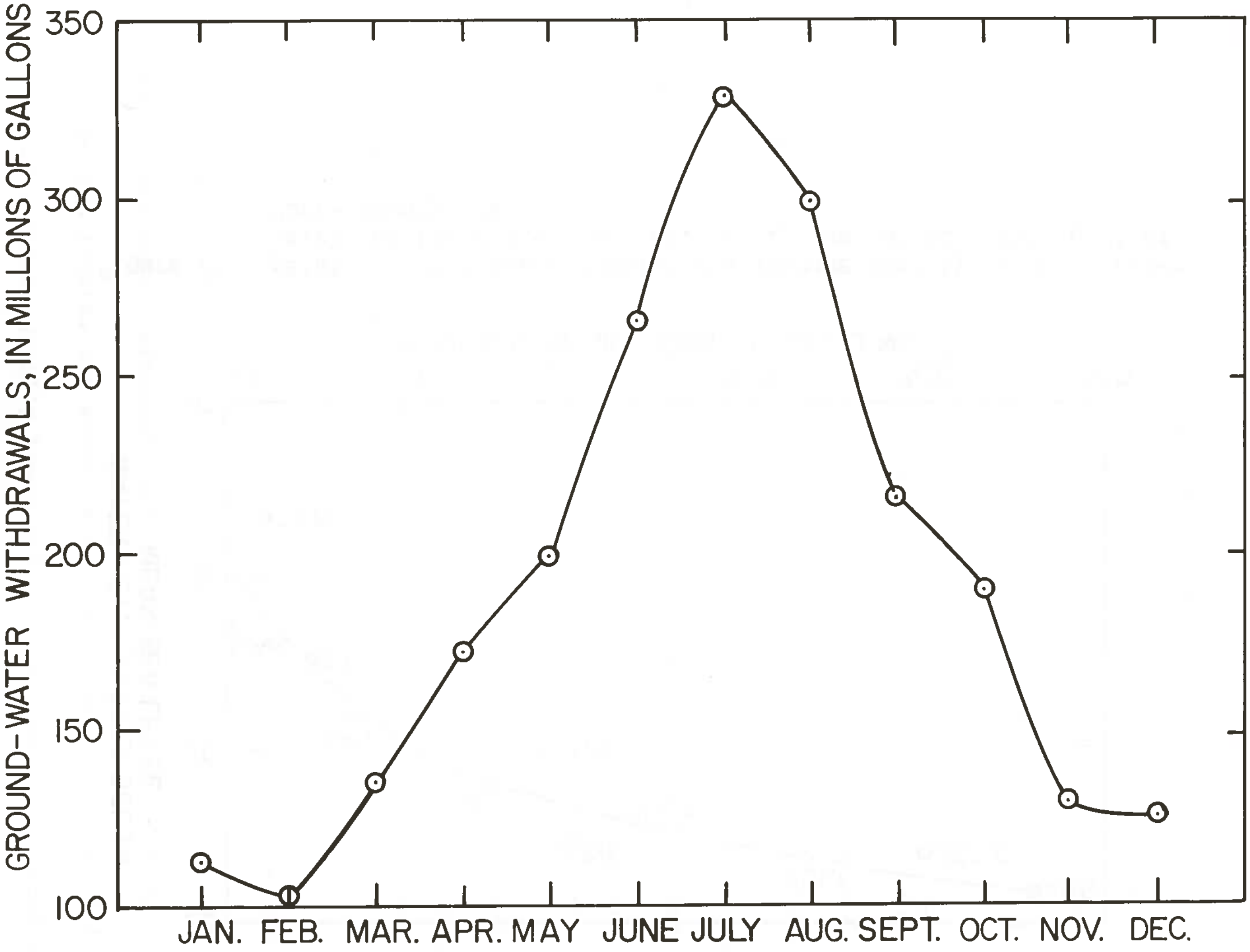


Figure 25. Monthly ground-water withdrawals from the Black Creek aquifer system, Grand Strand part of Horry County, 1975.

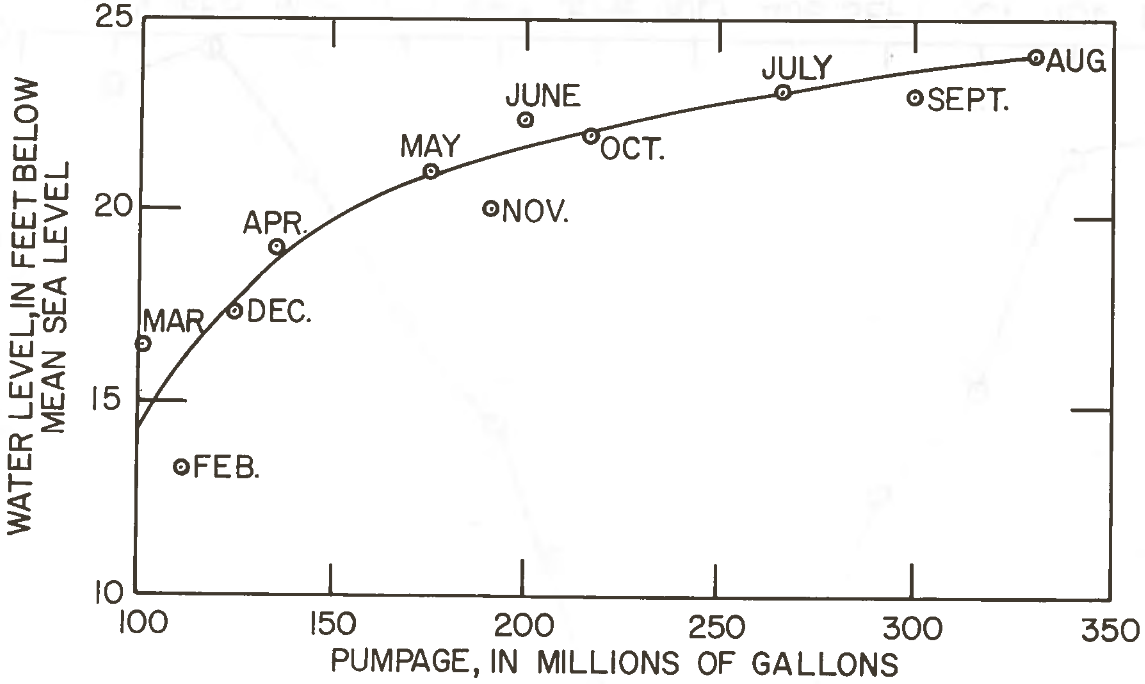


Figure 26. Relationship between pumpage and average monthly weighted water levels of the Black Creek aquifer system, Grand Strand part of Horry County, 1975.

WATER QUALITY

Much of the ionic composition of ground water is derived from the soil and rocks through which the water passes. The degree to which the ground water is mineralized depends on the length of time it has been in transit, the pH of the water, and the solubility of the aquifer material. The presence of zeolites, glauconite, or montmorillonite throughout the geologic section often alters the ionic composition of the ground water by exchanging calcium and magnesium ions with sodium or potassium ions through a natural water-softening process called ion exchange.

Depending on the kinds of ions in the ground water and their concentrations, the water is deemed suitable or unsuitable for drinking water, agriculture, or industry. Chemical analyses of typical groundwater samples from the three major Cretaceous aquifer systems and the EPA (U.S. Environmental Protection Agency) 1975 National Interim Primary Drinking Water Regulations are listed in Table 5.

In Horry and Georgetown Counties it is usually possible to identify the aquifer system from which a water sample is withdrawn from the concentrations of certain ions.

Black Creek Aquifer System

The chemical quality of water withdrawn from sands of the Black Creek aquifer system is the best of any ground water available in the two-county area. Although certain of the ionic constituents often exceed EPA limits, the water is relatively soft, is generally low in chloride, and is usually iron- and sulfate-free. A typical chemical analysis of water from the Black Creek aquifer is given in table 5. Analyses of water from other wells screened in the Black Creek aquifer differ from this analysis primarily in the concentration of dissolved

Table 5. Chemical analyses of typical water samples from the three major aquifer systems in Horry and Georgetown Counties and partial listing of 1975 National Interim Primary Drinking Water Regulations

(Values in milligrams per liter)

	Garden City Point, Geo-70 Black Creek aquifer system	Eagle Nest Golf Course Ho-286 Peedee aquifer system	Myrtle Beach Air Force Base Ho-350 Black Mingo aquifer (?)	U.S. Environmental Protection Agency 1975 National Interim Primary Drinking Water Regulation
Specific conductance, (umho/cm at 25°C)	1260	430	324	No established limits
pH	8.4	7.8	6.9	Do.
Carbon dioxide (CO_2)	4.6	---	36	Do.
Alkalinity as ($CaCO_3$)	593	221	148	Do.
Bicarbonate (HCO_3)	642	270	180	Do.
Dissolved nitrate (NO_3)	0.25	---	---	10 mg/L
Hardness (Ca, Mg)	8	270	140	No established limits
Carbonate (CO_2)	40	0	0	Do.
Dissolved orthophosphate (PO_4)	0.18	0.06	---	Do.
Dissolved phosphorus (P)	0.06	0.02	---	No established limits
Dissolved calcium (Ca)	2.4	100	51	Do.
Dissolved magnesium (Mg)	0.60	4.0	3.1	Do.
Dissolved sodium (Na)	320	8.3	15	Do.
Sodium adsorption ratio	48	---	0.6	Do.

Table 5. (continued)

Percent sodium (Na)	98	6	---	Do.
Dissolved chloride (Cl)	59	14	18	250 mg/L
Dissolved potassium (K)	4.5	0.6	1.5	No established limits
Dissolved sulfate (SO_4)	3.7	2.8	0.4	250 mg/L
Dissolved fluoride (F)	4.0	0	0.2	1.6 mg/L
Dissolved silica (SiO_2)	19	7.3	33	No established limits
Dissolved iron (Fe)	0.1	6.1	10	0.3 mg/L
Dissolved manganese (Mn)	0.02	0	0.1	0.05 mg/L
Dissolved aluminum (Al)	0.1	---	---	No established limits
Dissolved solids	772	276	224	Do.
Iodide (I)	0.06	---	---	Do.
Bromide (Br)	0.60	---	---	Do.

solids, fluoride, and chloride. Occasionally, hydrogen sulfide is of high enough concentration to be noticeable.

Fluoride

Water from many of the sands within the Black Creek Formation contains high concentrations of fluoride (as high as 5.5 mg/L) which "produces objectionable dental fluorosis that increases in a continuum with increasing fluoride concentration above the recommended control limits. In the United States, this is the only harmful effect resulting from fluoride found in drinking water. The fluoride concentrations excessive for a given community depend on climatic conditions because the amount of water (and consequently the amount of fluoride) ingested by children is primarly influenced by air temperature" (U. S. Environmental Protection Agency, 1973). "Based on present Environmental Protection Agency guidance, the Water Supply Division of the South Carolina Department of Health and Environmental Control anticipates the MCL (Maximum Concentration Limit) for fluoride concentrations in public water supplies to be 1.6 ppm for the coastal areas of South Carolina. This MCL will be effective in June 1977 and was determined from MCL fluoride data contained in National Interim Primary Drinking Water Regulations published in the Federal Register on December 24, 1975, and based on an annual average maximum daily air temperature of 73° to 75°F (22.8 to 23.9°C)" (R. Lewis Shaw, written commun., June 1976). Concentrations above 1.6 mg/L would presumably cause dental fluorosis (teeth mottling) in young children. However, there appears to be considerable confusion in the literature concerning individual tolerance to fluoride in causing teeth mottling. Shaw states, "DHEC, The South Carolina Department of Health and Environmental Control, recognizes that many public water supplies in coastal South

Carolina will exceed the MCL for fluoride and that some form of variance or exemption will be available to those systems for an interim period."

Lower concentrations of fluoride have been shown beneficial in helping to prevent tooth decay. "It has been shown epidemiologically that school children using domestic waters containing as little as about one part per million of fluorine [sic] experience only half to a third as much dental decay as comparable groups using fluoride-free waters..." (Dean quoted in Carlston, 1942, p. 9).

Few wells screened in the Black Creek aquifer system yield water containing 1.6 mg/L or less of fluoride. Therein lies the greatest water-quality problem facing engineers and municipal water districts as they attempt to develop ground-water supplies that meet EPA and DHEC standards.

High concentrations of fluoride appear to be related to the occurrence of the hard calcareous sandstones which are very common within sands in the upper third of the Black Creek Formation. This relationship is based on a comparison of the fluoride content of water samples collected in sands where the sandstone was present, with those collected where it was absent. More sampling is necessary to verify the association, but the present evidence seems promising.

The calcareous sandstone possibly contains relatively insoluble collophane, a massive apatite mineral that has the generalized formula $Ca_5(PO_4)_3(F,Cl,OH)$, from which fluoride ions apparently have been dissolved. Gwyne (1934, p. 139-140), as quoted in Stringfield (1966, p. 143) suggested that the breaking down or weathering processes of the less soluble fluoride minerals might be accomplished by action of sulfuric acid formed by decompositon of pyrite. As stated by

LaMoreaux (1948, p. 31) pyrite occurs in many of the aquifers in Tertiary and Cretaceous formations in the Southeastern states. The presence of fluoride-bearing minerals and abundance of pyrite in some of the water-bearing formations seem to support Van Burkalow's theory (1946, p. 187-188) that fluoride in soluble form might be expected where there is an abundance of fluoride minerals and an abundance of pyrite with concentrated organic material, which would facilitate decomposition of the minerals and release of the fluoride. Besides explaining the occurrence of fluoride, Van Burkalow's theory would also explain the occasional occurrence of hydrogen sulfide in water of the Black Creek aquifer system.

Unfortunately, the sands associated with sandstone are the coarsest and most permeable in the Black Creek Formation. They are, therefore, preferred as water sources among water-well drillers and engineers because large volumes of water can be developed from these zones. In addition, it is very easy to misinterpret these impervious sandstones as freshwater-bearing sands from geophysical logs.

Treatment of water supplies for fluoride removal is possible, but high-fluoride ground water can often be avoided by selectively screening only those sands devoid of sandstone. Such selectivity reduces the length of screen needed in a well and therefore reduces the amount of water available to the well. Several municipal wells drilled in the area are screened in sands devoid of sandstone and produce water low in fluoride. A well recently completed for the Georgetown County Rural Water and Sewer District on Penny Royal Road south of Georgetown (Geo-95) was screened in such a way to avoid as many of these sandstone lenses as possible. Yields were low (specific capacity of 0.7 (gal/min)/ft but the fluoride concentration was 0.9 mg/L.

Chloride

The areal and depth distribution of saline water in the Black Creek aquifer system is determined by geologic events during and since the time the sediments were deposited. Initially, sea water was trapped within the marine sediments. Where erosion has exposed the updip reaches of the sediments northwest of the project area (fig. 12), freshwater is added to the aquifer system by recharge from rainfall and by streams which incise the aquifers. This freshwater percolates downdip by gravity and flushes the connate sea water southeastward. The former saltwater sands, flushed with freshwater from the recharge area in recent geologic time, form the extensive Black Creek aquifer system. In the vicinity of Myrtle Beach, the basal sand of the Black Creek aquifer has been flushed of its saline water only as far southeastward as the Waccamaw River. On the Grand Strand this sand contains salty water (up to 900 mg/L chloride in Ho-338) but freshens abruptly updip, beyond the freshwater-saltwater interface (fig. 3). The remainder of the sands within the Black Creek Formation contain freshwater throughout the Grand Strand, with the Little River area the only exception.

Circulation of freshwater has been such that connate sea water has not been completely flushed from the Black Creek aquifer system on the flanks and summit of the Cape Fear Arch. Freshwater moving toward the coast has been diverted around the arch, leaving water with high concentrations of chloride. Therefore, the locations and production of low-chloride ground water from water-bearing zones on the flanks of the Cape Fear Arch has been and will continue to be

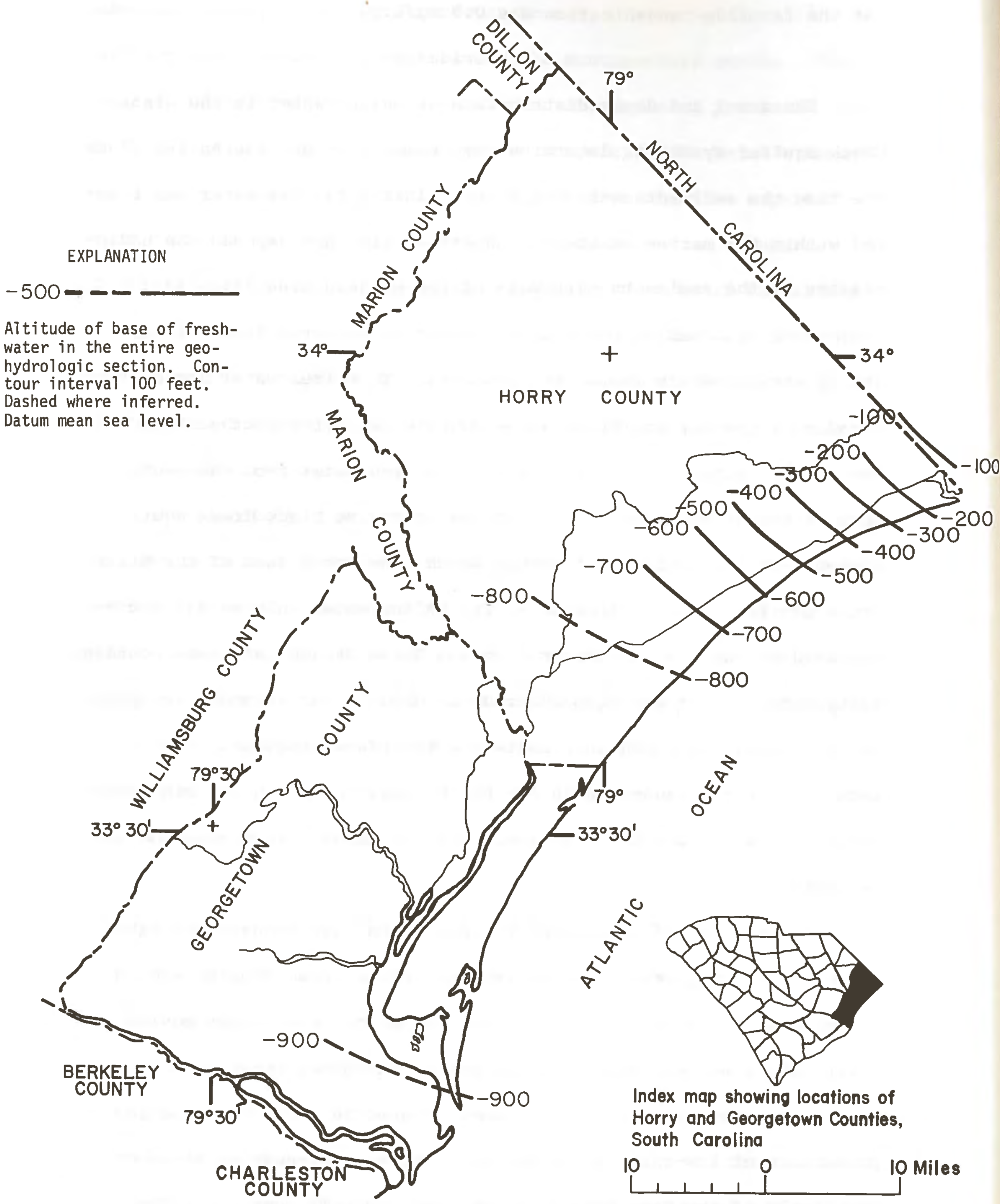


Figure 27. Approximate altitude of the base of freshwater for all aquifer systems.

difficult.

The change from freshwater to salty water within individual sands of the Black Creek aquifer system occurs abruptly between the northern end of the city of Myrtle Beach and the North Carolina State line. The freshwater-saltwater interface, in plan view, is very narrow in each of the sands, unlike the wide zone of diffusion and dispersion usually encountered in coastal aquifers. The location of each interface is incompletely known and is difficult to determine because of the scarcity of wells, particularly in strategic areas along the interface. The few existing wells are usually multiple-screened and any water sample collected represents a composite of the various sands screened. The approximate locations of these fronts based on limited data are placed on the geohydrologic sections (figs. 3, 4, 5, and 6). Much more information is required to refine these locations, and a plan view of the distribution was not attempted. The base of freshwater (as presently known) for all aquifer systems is presented in figure 27.

The saltwater-monitoring program in the North Myrtle Beach-Little River area shows no evidence that the saltwater interfaces have responded to ground-water withdrawals by moving toward the producing wells. Many wells continue to produce relatively fresh water in the vicinity of the interfaces with no changes in chemical quality being evident.

It is very difficult to measure slow rates of interface movement even in ideally placed wells. The effects of dispersion and shape of the interface are not observed simply by withdrawing water samples from wells, even if the program is carefully controlled. In addition, the location of the interface under the Atlantic Ocean, southeast of the Myrtle Beach and Georgetown cones of depression, is not known and its rate of movement cannot be measured. As previously discussed, the possibility exists that the saltwater-freshwater interface has moved inland in response to withdrawals.

Peedee Aquifer System

Water from the Peedee aquifer system is generally of poor quality and is rarely used except locally for irrigation. Throughout most of the area, water from this aquifer system contains low concentrations of chloride and fluoride, but unfortunately contains relatively high concentrations of iron, calcium, magnesium, and hydrogen sulfide (table 5). Fluoride concentrations appear to be acceptable throughout the Peedee Formation because the calcareous sandstones so common in the Black Creek Formation are absent in the Peedee. The Peedee aquifer system would be satisfactory as a municipal water supply with treatment for removal of iron, sulfate, and hydrogen sulfide.

Tertiary Aquifers

Locally, shallow artesian aquifers occurring in what appears to be Tertiary sands yield extremely high-quality water, even in areas where saltwater is a problem in all other aquifers. Information concerning the occurrence of high-quality water in these sands is scarce, but it has been established that many shallow domestic wells (100 ft or less in depth) throughout the area have yielded relatively large quantities of highly acceptable water, (Kenneth Stevens, oral commun. July, 1977). The water in the shallow artesian aquifers is relatively soft, having 100 mg/L or less of hardness, with fluoride and chloride occurring in very small concentrations. Concentrations of iron, sulfate, and hydrogen sulfide are negligible.

The water in the shallow Tertiary sands has a relatively poor chemical quality where the confining clays above the aquifer are very thin or absent, causing a merger with the overlying water-table aquifer. Because the water-table aquifer contains very high concentrations of iron and is in other ways objectionable as a water supply (table 5), the shallow Tertiary aquifer should only be considered as a water supply where it is isolated from the overlying water-table aquifer by confining layers.

Middendorf Aquifer System

As has previously been discussed, the Middendorf aquifer system presumably contains saline water throughout Horry and Georgetown Counties, and is therefore unacceptable as a water supply. It probably contains diluted connate sea water as far inland as the western boundaries of Horry and Georgetown Counties.

GEOPHYSICAL LOGS

During the course of this investigation geophysical logs have been used to correlate both geologic and water-quality information. It is beyond the scope of this report to discuss the theory and applications of geophysical logging. Several excellent publications, including those by Keys and MacCary (1971), Schlumberger (1974), and Brown (1971), are available that detail borehole exploration for ground water and discuss the interpretation of the logs. Only those aspects of geophysical logging that have helped in assessing the ground-water resources of Horry and Georgetown Counties will be discussed in this report.

Collection of Geologic Data

Electric logs, both single-point and standard, were used for making stratigraphic correlations and isopach maps for the project area. Gamma logs were helpful for stratigraphic correlation where marker beds were recognized. Precise thicknesses of strata were determined from microcontact resistivity logs, and the high-density sandstones were best recognized on the gamma-gamma and neutron logs.

Collection of Water-Quality Data

The standard, normal-arrangement electric log is widely used by geohydrologists to estimate the quality of water within the aquifer because the electrical resistivity of undisturbed aquifer fluid is measured away from the borehole and beyond the mud-invaded zone. The capability of estimating ground-water quality (and specifically chloride) within a particular aquifer without actually withdrawing a water sample is very important in terms of time and economics. From such estimates, sands containing highly mineralized water can be recognized and avoided during screening.

It was discovered that the standard electric log has only limited application for water-quality determinations in Horry and Georgetown Counties because of local peculiarities of lithology and stratigraphy. Many of the important Black Creek sands are too thin to allow the true resistivity to be measured accurately by the long-normal electrode of the standard electric-logging tool. Adjusting the measured resistivity for thin-bed effects has not proved satisfactory in all instances. Also, where the sands are thicker, they are usually interbedded with the impervious sandstone beds described earlier, which cause anomalous resistivity measurements in overlying and underlying sands (adjacent-bed effects). Even in very saline sands, adjacent, highly resistive sandstone causes the resistivity measurements of the sand to be inordinately high. Thus, on the basis of resistivity measurements using the long-normal electrode, freshwater may be thought to occur whereas only saltwater is present. There are very few places where sands in the project area are thick enough (10 ft or greater) and devoid of sandstone to allow true resistivities to be measured in the borehole.

During the course of the project, it was discovered that the induction-resistivity logging tool apparently measured formation resistivities more accurately than the standard electric logging tool because the induction tool has certain focusing properties that minimize the effects of the adjacent sandstone beds and allow resistivities of beds as thin as 6 ft to be measured accurately. Generally the induction-resistivity log has a very limited application for ground-water exploration in areas where formation resistivities normally range from 20 to 2000 Ω -m^2/m (ohm-meters squared per meter) for freshwater sands.

The induction-resistivity log is accurate, however, where formation resistivities are 50Ω $-m^2/m$ or less (Keys and MacCary, 1971) as they are in the project area.

The value of the induction-resistivity log was first demonstrated for a municipal well at Myrtle Beach - 3rd Ave. S. well (Ho-304). The focusing properties of the induction tool permit a more representative measure of resistivity in thin sands (note the "plateaus" opposite sands in fig. 28), whereas the resistivity trace of the long-normal curve is affected by the adjacent rocks. The measurement of resistivity values with the induction log has been tested further at Georgetown (Geo-95) and Plantersville (Geo-94), and its application for obtaining true resistivities throughout the project area seems promising. It is possible that other focused electric logs would accurately measure formation resistivities, but the induction tool was the only focusing device available.

PROBLEMS RELATED TO GROUND-WATER AVAILABILITY

Ground-water availability problems result from local overdevelopment of the ground-water resource as well as from the design and construction of natural- and gravel-filter wells. In addition, local aquifer contamination through abandoned wells is a problem affecting future availability of potable ground water.

Overdevelopment

In the project area, local well-field overdevelopment has led to misconceptions concerning the availability of ground water. For example, where the intakes of well pumps are too shallow to accommodate the prevailing water level in wells during pumping, the water levels are quickly lowered to the level of the intakes, and the wells appear to "go dry." The problem can usually be remedied by lowering the intakes of the pumps to accommodate the greater decline.

Additive drawdown effects have occurred when pumping wells screened in the same aquifer are closely spaced, causing the individual cones of depression to coalesce. During the summer months of 1975 several domestic and industrial wells near the Intracoastal Waterway at Myrtle Beach experienced water-level declines that caused the wells to "go dry." All of the wells were very closely spaced and were completed in the shallow Black Creek sand, 300 to 400 ft in depth. Also, several large municipal wells in the vicinity (approximately 1 mi away) were screened in this sand. The additive drawdown effects of the pumping wells lowered the water levels to or below the pump intake at some wells.

The difficulties encountered in this area are not the result of a diminishing ground-water supply, as has mistakenly been considered, but is a problem concerning well design, where one water-bearing zone of the aquifer has been overdeveloped. Proper spacing of wells and utilization of other sands for future water supplies would help alleviate the strain imposed on the heavily-pumped, shallow Black Creek sand and would provide shallower water levels.

Design and Construction of Natural-Filter and Gravel-Filter Wells

The potential for developing ground-water resources for water supplies in Horry and Georgetown Counties is often obscured by the inordinately high percentage of low-capacity and inefficient wells identified during the study. These wells are not discussed in this report because of the limited amount of geohydrologic information that they provide. Problems associated with these inefficient wells are not attributable to ground-water conditions but rather to problems with the design and construction of both gravel-filter and natural-filter wells. A description of the design and construction features of natural- and gravel-filter wells is required to understand these problems.

The basic difference between the natural-filter well and the gravel-filter well is in the method of retaining the aquifer sand so that the sand will not enter the well through the screens when the well is pumped. The natural-filter well depends upon the well screen to retain the aquifer material whereas the gravel-filter well depends upon a carefully sized and graded gravel or coarse sand filter placed between the screens and the borehole. If the sieve analysis (fig. 29) indicates that a small screen-slot size is required to retain the aquifer sand, and it is determined that excessive well-entrance losses would develop when the well is pumped at the required rate, a gravel-filter well should be considered so that a larger screen-slot size (designed to retain the gravel) can be used. The larger openings in the well screen are accompanied by a decrease of well-entrance losses, a higher well efficiency, and a higher specific capacity. Although aquifer sands are very fine grained in Horry and Georgetown Counties, the yields from most wells are such that well-entrance losses are not measurably affected by the screen-slot size -- whether the openings are designed to retain the gravel-filter media or the aquifer sand.

In order to achieve and maintain maximum well efficiency, the screen-entrance velocity for any kind of well should never exceed 0.1 ft/s (Johnson Division, Universal Oil Products Co. 1966, p. 193). At velocities over 0.1 ft/s, critical discharge is exceeded in the vicinity of the well screens (fig. 17) and laminar flow gives way to turbulent flow. The entrance velocity is calculated by dividing the expected yield of the well by the total area of openings in the screen. For example, one hundred feet of a typical wire-wound 10-in screen with 0.020 in slot size (commonly used for the Grand Strand) has 6,500 in^2 of openings. If 500 gal/min is expected from the well, there will be 500/6,500 or 0.077 (gal/min)/in^2 or 0.025 ft/s of screen-entrance velocity in the well. This is less than the 0.1 ft/s required for critical discharge. Theoretically, the screen is of sufficient slot size to produce a 100 percent efficient well, and a gravel filter in such a well is not required. For all types of well screen the total area of openings would have to be calculated; velocities may or may not fall within the critical discharge limits.

The relationship between yield, a typical wire-wound screen length, and slot size is presented graphically in figures 30 and 31 for 6-in and 10-in diameter wells respectively. The lines on the upper half of each graph represent the smallest slot size that can be used for a selected yield and screen length to assure a well entrance velocity of 0.1 ft/s

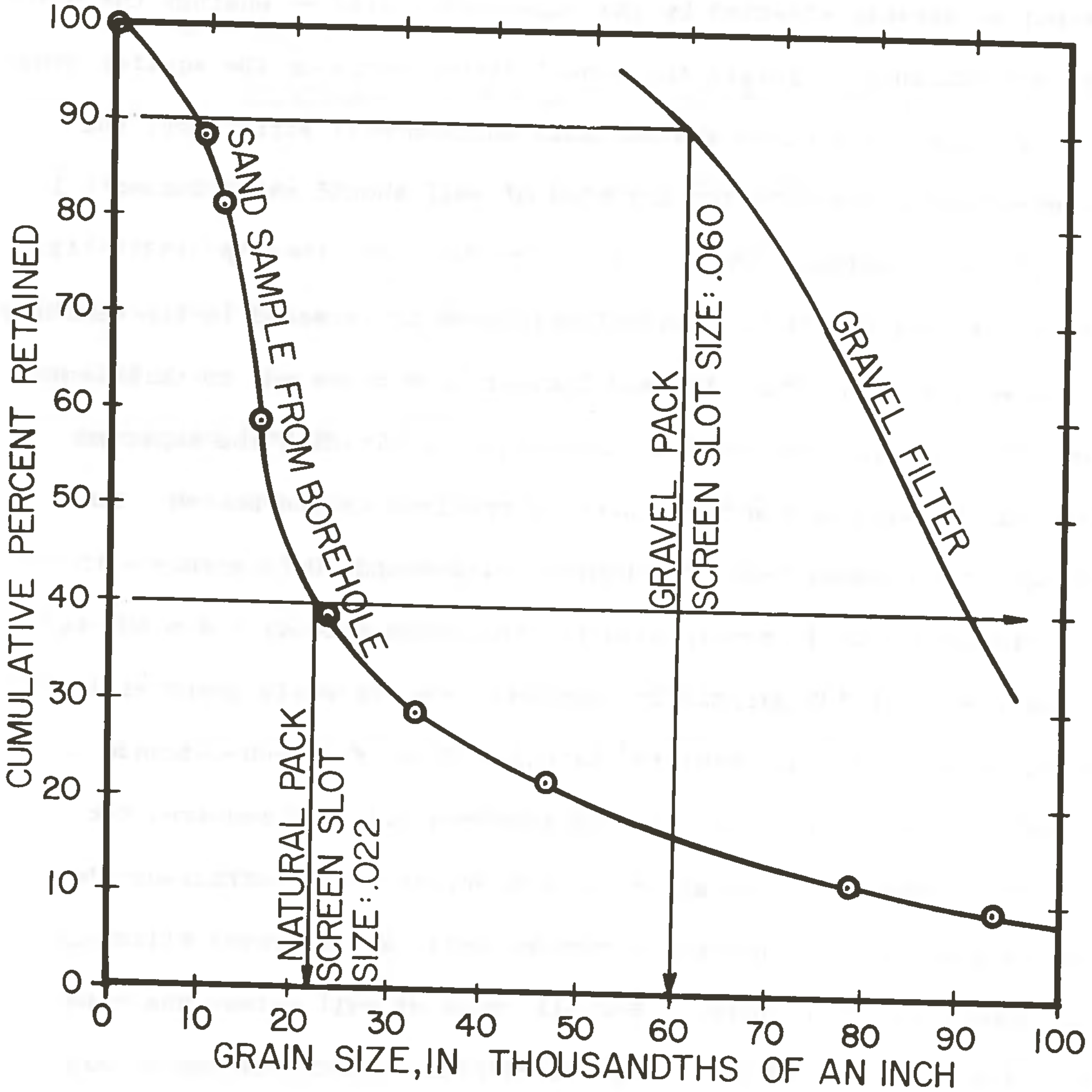


Figure 29. Sieve analyses for borehole sample collected at Myrtle Beach, 10th Ave. Well (Ho-338) from depth 462-484 feet and for a correctly designed gravel filter.

assuming that all of the screen is admitting water to the well. For example, from figure 31, 50 ft of 10-in wire-wound screen will permit as much as 500 gal/min through 0.008 in slot-size screens with 0.1 ft/s or less of entrance velocity. In the project area, natural-filter wells usually require a slot size of 0.010 to 0.022 in. If a screen slot size selected on the basis of a natural-filter well is smaller than 0.010 in, the gravel-filter alternative should be considered if high yields are desired.

The lower half of each of the graphs (figs. 30 and 31) relate yield, aquifer thickness, and transmissivity to drawdown, and well efficiency expected after 24 hours of continuous pumping. The relationship is based on the Theis nonequilibrium formula and values of hydraulic conductivity and specific storage typical in the project area. In the above example, the 500 gal/min that is being admitted through 50 ft of 10-in wire-wound screen would theoretically cause a drawdown of 94 ft in a 100 percent efficient well at the end of one day of continuous pumping from an aquifer 50 ft thick. If less than the full thickness of aquifer is screened, head losses from partial penetration will contribute to hydraulic inefficiency. The calculated specific capacity is 5.3 (gal/min)/ft of drawdown, which is all that could be expected from the aquifer. However, it is more reasonable to assume that the well will be about 70 percent efficient upon completion, resulting in a specific capacity of 5.3x0.70 or about 3.7 (gal/min)/ft. The recalculated yield reasonably expected at the prevailing 94 ft of drawdown would be 94x3.7 or approximately 350 gal/min. Accordingly, even though a particular length of screen may be capable of admitting a certain amount of water at a screen-entrance velocity less than 0.1 ft/s, the aquifer might be incapable of providing this amount at a reasonable pumping level.

The graphs, therefore, must be used with caution because they represent theoretical relationships. In actual field situations, aquifer characteristics and design aspects might deviate substantially from the norm upon which these relationships are based, yielding unanticipated results. In addition, unless most or all of the screen in a well is admitting water, the relationships are invalid. The two figures do serve to illustrate the often unnecessary use of large screen slot sizes permitted by placing a gravel filter in a well when the slot sizes required for a natural-filter well usually suffice in admitting water at velocities of 0.1 ft/s or less. The graphs can also be used as a guide for selecting screen lengths based on the sieve analysis and desired yield for natural-filter wells.

Occasionally wells are drilled that are relatively efficient and yet have very small yields and small specific capacities. Although relatively permeable sands are usually available at the well site, at times screens are inadvertently placed opposite clays and other formations of low hydraulic conductivity making it appear that little ground water is available at the well site. The most effective guides the engineer and water-well contractor have in locating and assessing water-bearing formations are geophysicals logs. Although it is often helpful to have an accurate driller's log to confirm screen setting, geophysical logs, when properly used, can reliably determine most borehole characteristics.

Although gravel-filter wells have generally proven satisfactory in supplying large quantities (as much as 500 gal/min) of ground water for municipalities and other public water supplies in the project area, there are several problems associated with gravel-filter wells that can be avoided with lower capacity natural-filter wells.

Sand Pumpage

Wells in Horry and Georgetown Counties frequently pump sand because of a ruptured or deteriorated screen. Often, sand entry into wells is the result of incorrectly chosen screen-slot size, gravel-filter media, or both. When the sand of an aquifer is to be screened for a natural-filter well, the determination of screen-slot size must be based on the sieve analysis of representative sand samples collected during drilling (fig. 29). For a gravel-filter well, the sieve analysis of the water-bearing material determines the size of the gravel-filter media to be used in the well, and the size of the gravel filter determines the screen-slot size. Correct design of the gravel filter and choice of screen-slot size will provide minimum entrance losses of sand-free water into the well. Occasionally, a gravel-filter well will pump sand if the gravel filter fails to properly encase the screens. This can occur either by gravel bridging or by screens being in direct contact with the sides of the borehole where centralizers were not used.

Well Development

During drilling, proper mud control allows the formation of a mud cake on the borehole walls. This minimizes invasion of the drilling mud into sandy formations and protects against hole collapse and erosion. Where aquifer sands are very fine, as they are throughout the project area, great difficulty may be encountered when the drilling fluids are to be recovered from the aquifer during development. Inefficient wells result when drilling fluids cannot be removed.

Excessive enlargement of the borehole by underreaming to make room for a gravel filter often causes serious difficulties in developing a well. The resulting thicker gravel filter hampers the flushing of drilling fluids from the filter and nearby aquifer material during development. Laboratory tests have shown that a properly designed gravel filter with a thickness of only a fraction of an inch successfully retains the formation particles regardless of the well-entrance velocity (Johnson Division, Universal Oil Products Co., 1966, p. 201). Although this publication states that the upper limit of gravel-filter thickness should be about 8 in, common sense dictates that because of the very fine sands encountered in the Black Creek aquifer system throughout Horry and Georgetown Counties, the gravel-filter thickness should be as thin as possible, perhaps no greater than 4 in. As filter thickness is increased, greater difficulty will be experienced with well development.

In order to facilitate development of a gravel-filter well, placement of a thin gravel filter under pressure would help scour the borehole sides of the mud cake. It is desirable to clear drilling fluids from the gravel filter immediately after gravel implacement so that the drilling fluid can be flushed from less permeable zones. A very effective method of cleaning the gravel filter is by pumping large quantities of clear water through a short jetting swab. The clear water is forced through the screen at the bottom of the well into the gravel filter, and, because of the nature of the hydraulic gradients that are created, flows back into the well, through the screen (but above the swab), carrying the drilling fluids to the surface. By cleaning the gravel filter and swabbing before water is pumped from the well, a higher degree of well development can be obtained. Simple pumping of the well without cleaning and swabbing often allows only the most permeable of the screened sands to be developed, greatly reducing the potential of the well.

Development of natural-filter wells is usually a straightforward process of (1) backwashing through a foot valve, (2) high-velocity water jetting with easy pumping, and finally (3) air lifting. Occasionally, surging is necessary. In a natural-filter well the absence of a gravel filter allows the aquifer sands to be more easily developed, and a greater amount of drilling fluid usually can be removed from the water-bearing zones.

The drilling and development of natural-filter wells can be accomplished in a much shorter time than gravel-filter wells, because they are simpler to construct and mud viscosities can be more carefully controlled, minimizing mud invasion. It has been observed that loss of mud control during long delays in drilling and development of a gravel-filter well often reduce the efficiency of the well. Although time delays hamper development in natural-filter wells, they are more critical in gravel-filter wells. The faster a well is drilled and developed, the less chance the drilling mud has to disperse, change viscosities, or cake.

Highly efficient wells have been obtained using an organic polymer drilling mud which remains viscous during the drilling of the well but can be thinned by pumping chlorine and water into the borehole. A chemical reaction breaks down the mud and vastly simplifies the development procedures.

It follows that because natural-filter wells can usually be developed more completely, they often have greater specific capacities than gravel-filter wells (if transmissivities are equal) because they are more efficient.

Well and Aquifer Contamination

Occasionally, salty water is pumped from wells in Horry and Georgetown Counties which have, in the past, produced freshwater. Often this new occurrence of saline water has erroneously been attributed to saltwater encroachment. Generally, the greatest concentration of salty water is withdrawn initially from these wells, with the concentration decreasing as pumping continues. This is the opposite of what would be expected if saltwater encroachment or coning had occurred. It has been shown that these wells leak salty (or poor quality) water from a source of higher head when the wells are idle. The poor-quality water is brought in through a gravel filter that extends beyond the well screens or by the inadvertent screening of sands containing the poor-quality water.

Before ground water was used in the study area, potentiometric heads were presumably in equilibrium in all aquifers. As ground water was developed, certain sands were preferred because of water quality, and head differentials were created within the Black Creek aquifer system and between aquifers. The greatest amount of water is withdrawn from the shallower Black Creek sands for economic reasons and because chloride concentrations are relatively low (this is particularly true in the northeast corner of Horry County). Heads, therefore, are lowest in the upper sands of the Black Creek aquifer system and highest in those sands containing salty or poor-quality water. These differences in head that have developed because of pumping selected formations can have a deleterious effect on the geohydrologic environment if hydraulic continuity is established between fresh and poor-quality water within a well.

In natural-filter wells, the saltwater usually enters the well from a saltwater-bearing zone that has been inadvertently screened. In a gravel-filter well, saltwater will enter either through a screened saltwater zone or by infiltrating the gravel filter. While the well is idle, saltwater will move through the well and out into the freshwater zones of lower head. When the well is pumped, the saltwater is eventually flushed from the freshwater zones. During pumping, saltwater will continue to enter the well but its presence is obscured by freshwater inflow.

Aquifers near the land surface are the usual source of saltwater in gravel-filter wells. Although these surface sands are not necessarily screened, they are traversed by the gravel filter outside of the screens and casing. The high hydraulic conductivity of the gravel filter plus the high potentiometric head of the surficial aquifers allow free movement of saltwater into the freshwater sands when the well is idle and when the well is pumping. The contamination continues at a rate dependent on the hydraulic conductivity of the filter media and head difference. Most new gravel-filter wells are constructed with the gravel extending several feet above the shallowest screen. After development and settling of the gravel, cement grout is pumped on top of the gravel to the surface between the open hole and the casing. This provides an impermeable seal between surficial sands containing salty or poor-quality water and the producing aquifers.

The inadvertent screening of saltwater sands, even within the same aquifer system, can also cause contamination. An excellent example is provided by a well at the northern end of the city of North Myrtle Beach (Ho-335). The well is screened between 308 and 700 ft by 12 sections of screen totalling 195 ft that traverse 9 different sands within the Black Creek aquifer system (fig. 32). Brine-injection and flowmeter studies indicate that when the well is idle, water from the lower sands of high head travels up the well and infiltrates into sands of lower head. Because the deeper screened sands between 675 and 700 ft contain salty water having 440 mg/L chloride, the upper sands in the vicinity of the well become saltier when the well is idle. With pumping, the infiltrated salty water is flushed from the sands, but again accumulates when the pump is turned off. If this well is ever abandoned, poor-quality water will infiltrate the fresh sands at a continuous rate, depending primarily on head differentials. Even if the well is plugged by pumping cement into the well, the leakage will continue through the continuous gravel filter placed from 258 to 750 ft. Cement collars placed within the gravel filter and between screened sands would provide impermeable seals between the aquifers and therefore would protect freshwater sands from contamination if the wells are eventually abandoned and plugged. Collars are not usually necessary in natural-filter wells to protect against contamination after abandonment and plugging.

There are many unplugged abandoned wells in the two-county area that continually seep salty or poor-quality water into the freshwater sands of the Black Creek aquifer system. The seeping will continue until heads equalize across all of the sands in the vicinity of the wells, or until the wells and gravel filters are plugged and sealed. It is virtually impossible to determine the number of abandoned wells in Horry and Georgetown Counties that have been improperly plugged. The worst of those that have been identified are located on the northern Grand Strand, where freshwater is a precious commodity. If abandoned wells are not located and properly plugged, and if steps are not taken to ensure that all wells abandoned in the future are plugged, the longevity of the ground-water resource in these areas will be threatened.

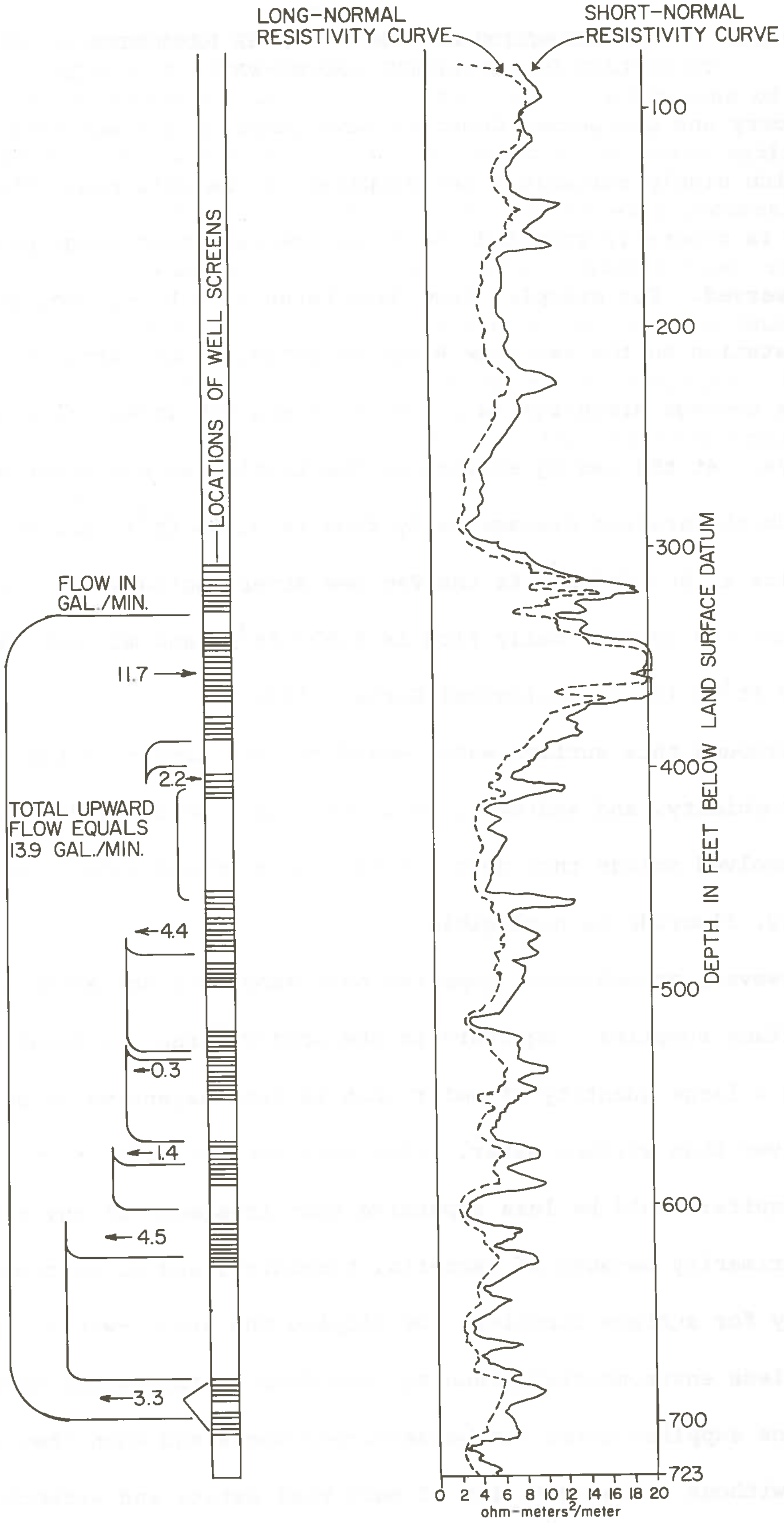


Figure 32. Internal flow within well Ho-335 when not pumping.

CONSIDERATION OF SURFACE-WATER RESOURCES TO REPLACE OR SUPPLEMENT GROUND-WATER RESOURCES

Horry and Georgetown Counties have numerous surface-water resources from which highly suitable water supplies can be obtained. The water quality is generally good and the flows are such that large populations can be served. For example, flow data taken at a U. S. Geological Survey gaging station on the Waccamaw River at Longs, South Carolina indicate that the average discharge is 1,214 ft^3/s and the lowest flow on record is 121 ft^3/s. At the gaging station on the Little Pee Dee River at Galivants Ferry, South Carolina average daily flow is 3,265 ft^3/s and the lowest daily flow is 803 ft^3/s. At the Pee Dee River gaging station at Pee Dee, South Carolina average daily flow is 9,657 ft^3/s and minimum daily flow is 2,280 ft^3/s (U. S. Geological Survey, 1976).

Although this surface water would require treatment for removal of color, turbidity, and sediment, it is generally softer and contains much less dissolved solids than does the available ground water. Most importantly, fluoride is negligible.

However, ground-water supplies have many inherent advantages over surface supplies. Aquifers in the project area are capable of yielding a large quantity of water that is less expensive to develop and deliver than surface water. Even treatment of water from the Peedee aquifer would be less expensive than treatment of any surface supply primarily because of bacteria, turbidity, and color removal necessary for surface supplies. Developing the ground-water resource entails less environmental planning than does surface-water development. Subsurface supplies often can be developed where and when they are needed, without the acquisition of much real estate and without the lengthy time period required for a surface supply to be established if reservoirs are needed. Aquifers are naturally insulated from the atmosphere, thus preventing any major temperature fluctuations of the ground water throughout the year. The isolation of artesian aquifers from the land surface also provides the ground water with protection against accidental industrial spills, biological contamination, radioactive fallout, and other influences which may affect quality changes in surface-water and water-table aquifer ground-water supplies. Furthermore, ground-water supplies are more dependable than surface supplies during droughts.

ASSESSMENT OF GROUND-WATER RESOURCES, BLACK CREEK AQUIFER SYSTEM

Excessive concentrations of fluoride and chloride in ground-water supplies of Horry and Georgetown Counties are the major factors determining the continued development of the Black Creek aquifer system. High concentrations of chloride are a problem only in the North Myrtle Beach and Little River areas, but high concentrations of fluoride are widespread throughout the two-county area. Except for these problems, untreated water from the Black Creek aquifer system is of suitable chemical quality for present and future water supplies. The high concentrations of fluoride probably can be reduced by selective screening of wells. Although there have been difficulties with saltwater on the Grand Strand, there has been no observed saltwater encroachment anywhere in the two-county area.

Throughout Horry and Georgetown Counties, the amount of recoverable water within the Black Creek aquifer system can sustain present withdrawals and can accommodate vastly greater withdrawals than are presently being made. Depending on the amount of screen placed in a well and the prevailing hydraulic conductivity of the screened sands, highly efficient wells have been completed that produce 1000 gal/min with a specific capacity of 10 (gal/min)/ft of drawdown (Ho-335) but wells of this capacity are exceptional. Lower yields and smaller specific capacities encountered at various locations are due in part to local hydraulic characteristics within the Black Creek aquifer system.

The effects of ground-water withdrawal from the Black Creek aquifer system can be predicted if ground-water leakage, future salt-water encroachment, water treatment, and economic considerations can be anticipated. For example, although accurate values of transmissivity and storage can be determined from aquifer tests, calculations of water-level decline after several years of pumping using these values alone would certainly be erroneous. Leakage to the major Black Creek sands has not been determined and might supply greater quantities of water than would be provided by natural recharge alone. Therefore, water level decline would not be nearly as great as the aquifer test results would suggest. Based on typical values of aquifer parameters of $T = 2{,}700\ \text{ft}^2/\text{day}$ and $S = 2.3\text{x}10^{-4}$, 123 wells spaced on a 4 mi center grid system could be "fitted" into Horry and Georgetown Counties. If each well were to pump 190 gal/min for 10 years, water levels throughout the area would be drawn down approximately 400 ft, the average depth to the top of the Black Creek aquifer. This would amount to 23,000 gal/min or an average of 34 Mgal/d for the area, 3.3 times the present daily usage. However, the data presented in figure 26 indicate that a large quantity of water is added to the aquifer when regional water levels are lowered during the seasonal pumping cycle. Although it is impossible to calculate the quantity of water from these data, and thereby obtain realistic drawdowns, an upper limit of ground-water availability can be approximated from figure 26.

By replotting the data presented in figure 26 on semi-logarithmic paper and extrapolating (fig.33), average monthly water levels can be predicted from projected ground-water withdrawals. Assuming that water will continue to be added to the aquifer to maintain the extrapolated curve in figure 33, the pumping of 33,000 Mgal of water from the Black Creek aquifer of the Horry County part of the Grand Strand during the course of one month (100 times the July 1975 pumpage) would result in an average weighted water level of 42 ft below mean sea level. The accuracy of these predicted water levels is questionable because the plotted points from which the extrapolation is made are based on generalized and

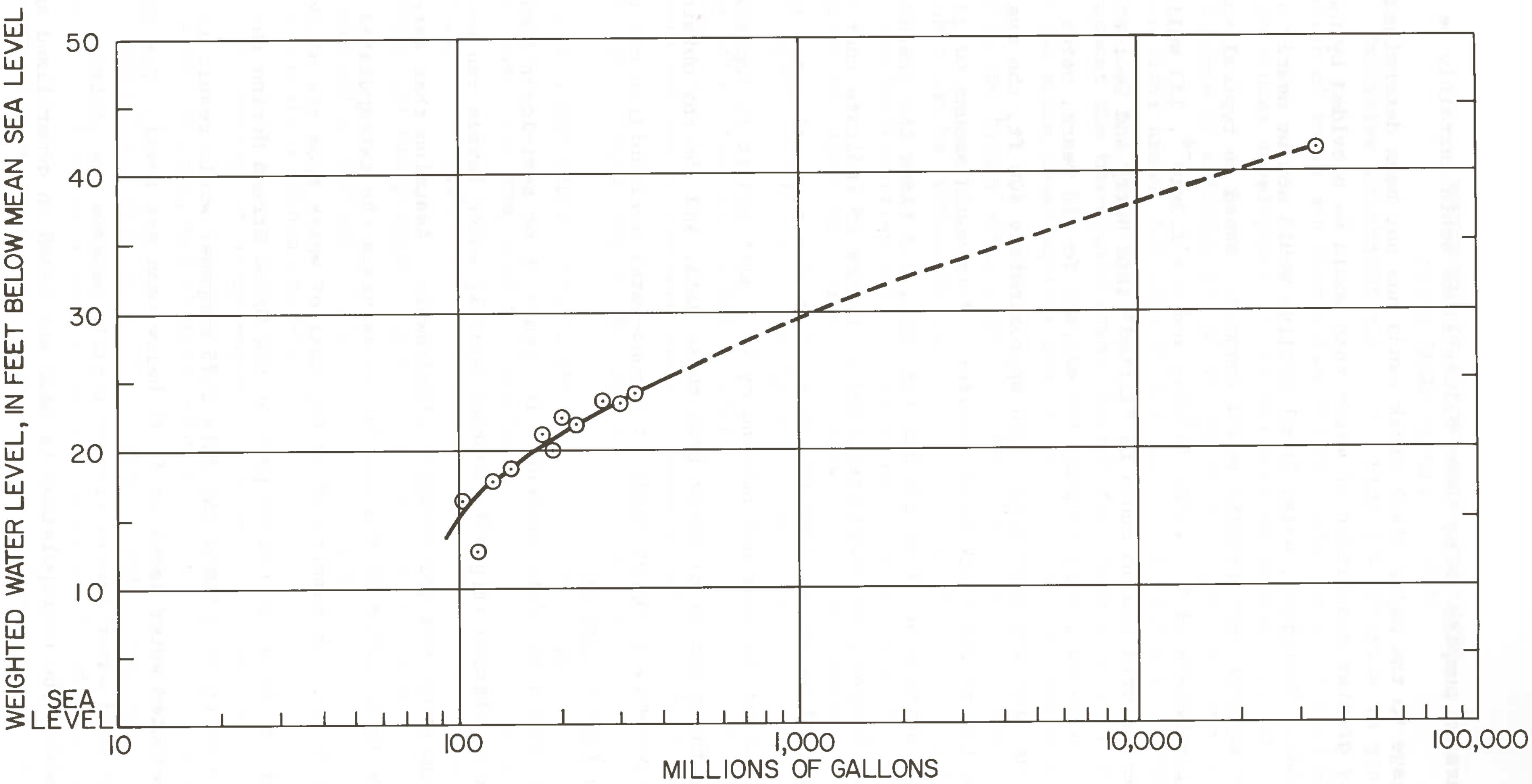


Figure 33. Extrapolation of water level and pumpage data from figure 26 to include a withdrawal equal to 100 times the July, 1975 pumpage from the Black Creek aquifer system of the Grand Strand part of Horry County.

simplified data. Also, as previously discussed, the mechanism by which the additional water is provided to the system is not presently known. The configuration of the water-level surface from which the average monthly weighted water level is calculated would have an important effect on the extrapolation that cannot be measured. However, the important addition of this water to the Black Creek aquifer system has been observed and it may eventually be measured.

A complex constraint on the system is the effect saltwater encroachment would have on future ground-water withdrawals. Although it has not been possible to measure the movement of the saltwater interface under present conditions, it is possible that its movement will be observed when water levels are greatly lowered. Any future movement of salty water will affect the distribution and pumping pattern of wells.

The amount of ground water available would be greater if development of the Peedee aquifer system were considered. This water would generally have to be treated to remove iron and hydrogen sulfide, but would otherwise be acceptable as a water supply because water from this aquifer is very low in chloride and fluoride. Very little hydraulic information is available on the Peedee aquifer system because of a scarcity of wells, but it is suspected that Peedee sands have much greater hydraulic conductivity than Black Creek sands. It is possible that there is at least as much water available from the Peedee as from the Black Creek aquifer system. Wells completed in Peedee sands would be shallower, making a very attractive alternative or supplement, even with treatment, to pumpage from the Black Creek aquifer system.

Economic considerations would also affect the future availability of ground water. For example, before it can be determined whether or not freshwater occurs in the Middendorf aquifer system near the western boundaries of the project area, exploration wells and geophysical logs will be required. Also, if saltwater encroachment were to threaten wells, it would be necessary to: (1) construct scavenger or barrier wells to curb the movement of the saltwater; (2) import water from distant wells; (3) increase well spacing; or (4) abandon the wells and develop a surface-water supply.

GROUND-WATER PLANNING AND MANAGEMENT CONSIDERATIONS

In contemplating ground-water planning and management, it is important to understand how ground-water withdrawals affect hydrologic changes which cause a variety of problems if such changes are neglected. These problems include: (1) depleted ground-water supply, manifested in terms of excessively lowered water levels in wells; (2) deteriorated water quality, and (3) land subsidence. Because each of these problems could be considered an adverse environmental effect, and could jeopardize the supply, responsible agencies should exercise vigilance over the ground-water resource.

Potentially dangerous situations exist in Horry and Georgetown Counties where the ground-water quality is threatened by improperly constructed and abandoned wells which provide a vehicle for saltwater contamination of fresh ground-water supplies. A potentially dangerous situation also exists where water levels are lowered excessively near centers of ground-water withdrawal. In such a situation it may be uneconomical locally to continue pumping ground water.

In addition, wells throughout the project area are often inefficient and deliver water of less desirable quality than could be obtained with improved methods of well design, construction, and development.

This report documents that in spite of numerous problems, large quantities of undeveloped ground water are available. However, the life of the Black Creek aquifer system and other aquifers are dependent upon sound management and conservation practices. Sensible long-range planning would anticipate future withdrawals and their cumulative drawdown effects as well as environmental considerations. Changes in water rights and water laws, and the importance of the supply in terms of future economic conditions also would be anticipated.

Long-range planning would entail the assimilation and analysis of countless data. These difficult and time-consuming operations can often be accomplished satisfactorily with the aid of a model of the aquifer systems.

Computer models of aquifer systems have become increasingly useful in ground-water planning. They are extremely helpful in analyzing cause-and-effect relationships in those aquifer systems that are very complex and for which large quantities of data are available. Models are expensive and can be difficult to build; but experience has shown that, in terms of time and energy saved, they can become an invaluable tool of the ground-water hydrologist for attacking ground-water problems scientifically.

A model of the Black Creek aquifer system could be used as a management decision tool to analyze the effects of hydrologic stresses on the aquifer system and to predict water levels. It could be used to plan the redistribution of wells, to locate favorable areas for new wells, to anticipate changes in ground-water quality, to measure the potential for saltwater intrusion, and to determine the effects of hydrologic continuity between aquifers. A model could help measure the practicability of artificial recharge for prolonging the useful life of the aquifer as well as the effect of scavenger-well networks in curbing saltwater intrusion.

The rapid expansion of the science of ground-water hydrology in the past decade now provides the water planner, engineer, and hydrologist with techniques for managing and utilizing the ground-water resource so that its quality and quantity can be maintained.

Table 1. Description of wells in Horry and Georgetown Counties (and vicinity) discussed in report

Well Number	Owner	Coordinates		Depth of well (in feet)	Screened intervals (in feet)
		Latitude	Longitude		
Ho-1	Conway (Collins Park)	33°50'55"	79°03'39"	443	Unknown
Ho-32	Myrtle Beach (Depot St)	33°41'52"	78°53'32"	548	Unknown
Ho-35	Myrtle Beach (Federal Observation Well)	33°41'57"	78°53'35"	483	104-483
Ho-215	North Myrtle Beach (Cresent Beach)	33°48'27"	78°42'14"	613	192-264
Ho-218	Myrtle Beach (Air Force Base No. 4)	33°39'27"	78°56'32"	990	553-558 697-702 563-578 744-774 642-646 782-787
Ho-270	Myrtle Beach (28th Avenue North)	33°42'33"	78°52'00"	803	380-388 432-436 562-566 636-640 396-400 440-448 570-578 654-658 410-414 530-542 618-622 664-672 420-428 550-558 626-630 698-704
Ho-272	Myrtle Beach (Ocean Forest)	33°43'32"	78°50'30"	814	340-360 660-680 492-512 723-743 530-550
Ho-284	Town of Surfside (Poplar Drive & 2nd Avenue)	33°36'36"	78°58'43"	799	419-469 596-616

Table 1. (continued)

Ho-286	Eagle Nest Golf Course	33°53'25"	78°36'40"	132	Unknown	
Ho-287	Conway (WLAT)	33°51'01"	79°04'08"	1150	611-622	667-72
Ho-289	Forestbrook Development	33°43'28"	78°57'27"	682	365-380 390-410	628-638 660-675
Ho-290	Myrtle Beach Air Force Base (Engineers' Office)	33°40'30"	78°51'45"	416	Unknown	
Ho-292	United Merchants (Adrian Mill)	33°57'07"	79°00'23"	521	421-471	
Ho-297	Earl Lewis	33°49'28"	79°04'54"	381	Unknown	
Ho-303	Burroughs & Collins Co. (Old Mill Site)	33°50'07"	79°02'29"	173	Unknown	
Ho-304	Myrtle Beach (3rd Avenue South)	33°41'31"	78°53'58"	800	342-354 364-383 391-407	416-426 519-534 612-620
Ho-305	Pirate Cove Trailer Park	33°35'04"	79°00'32"	728	588-597 604-614	632-654 666-716
Ho-308	State of South Carolina Perry Road (East)	33°45'05"	78°58'04"	482	360-375 472-482	
Ho-309	State of South Carolina Perry Road (West)	33°45'05"	78°58'04"	375	360-375	
Ho-310	Lloyd Chestnut	33°51'21"	78°47'15"	Unknown	Unknown	
Ho-311	Dr. Nixon	33°51'13"	78°39'24"	600+	Unknown	

Table 1. (continued)

Ho-312	Town of Surfside	33°36'28"	78°58'31"	621	110-123 259-284 382-402 521-545 156-177 300-320 420-459 199-218 341-362 479-497
Ho-313	Van Smith	33°42'46"	78°55'33"	512	462-512
Ho-314	Town of Loris	34°04'03"	78°54'14"	460	280-320 371-391 335-345
Ho-315	Town of Little River	33°52'14"	78°38'07"	692	500-520 660-690
Ho-316	E.W. Prince	34°00'38"	78°46'56"	Unknown	Unknown
Ho-317	Leon Butler	33°56'57"	78°43'54"	105+	Unknown
Ho-318	Unknown	33°55'00"	78°43'12"	238	Unknown
Ho-319	Jay Straight	33°42'45"	79°01'39"	570	530-570
Ho-321	Myrtlewood Golf Course	33°44'32"	78°50'54"	435	425-435
Ho-322	Bucksport No. 1	33°41'31"	79°07'15"	840	99-101 192-194 268-270 352-354 421-423 115-117 219-221 298-300 384-386 361-463 181-183 247-249 320-322 396-398 533-535
Ho-323	Edgar Collins	33°38'48"	79°06'40"	286	Unknown
Ho-324	Lonnie Causey	33°44'14"	79°07'27"	320	310-320
Ho-325	Pawley Swamp Church	33°45'35"	79°11'07"	290	280-290
Ho-326	Mack James	33°48'01"	79°10'43"	236	Unknown
Ho-327	Charles Martin	33°48'35"	79°10'03"	248	Unknown

Table 1. (continued)

Ho-328	Teddy Henry	33°52'35"	79°04'47"	Unknown	Unknown			
Ho-329	Burroughs & Collins Co. (Long Farm, North)	33°52'12"	79°01'40"	Unknown	Unknown			
Ho-330	Burroughs & Collins Co. (Long Farm, South)	33°52'12"	79°01'40"	Unknown	Unknown			
Ho-332	Myrtle Beach (21st Avenue North)	33°42'48"	78°53'10"	801	316-324	428-448	561-565	
					345-350	514-518	576-584	
					378-390	532-540	603-607	
					398-408	544-554	656-664	
Ho-333	Myrtle Beach (Pirateland)	33°38'42"	78°56'18"	801	308-324	400-405	556-566	654-658
					330-338	425-430	572-578	
					354-358	450-460	608-612	
					385-390	476-484	630-638	
Ho-334	Little River (Bay Tree Golf Course)	33°52'09"	78°39'28"	539	460-500			
Ho-335	North Myrtle Beach (Sydnor No. 1)	33°50'20"	78°40'57"	760	308-328	453-463	568-588	
					338-368	467-482	604-624	
					376-386	488-498	675-685	
					402-412	518-548	690-700	
Ho-336	North Myrtle Beach (Sydnor No. 2)	33°50'25"	78°40'03"	757	300-315	435-455	516-526	
					324-349	472-482	530-560	
					360-375	497-512	570-580	
Ho-337	State of South Carolina (Eagle Nest Golf Course)	33°52'33"	78°39'06"	700	344-354			

Table 1. (continued)

Ho-339	Myrtle Beach (Dogwood Neck)	33°47'13"	78°46'12"	816	588-598 610-625	640-690	
Ho-340	Myrtle Beach (Pine Island)	33°42'04"	78°54'44"	804	403-437 449-465	549-561 611-644	648-661 691-707
Ho-341	State of South Carolina (Burgess)	33°37'52"	78°52'41"	766	Test hole		
Ho-342	Myrtlewood Golf Course	33°41'01"	78°52'41"	780	280-300 308-318 352-362	393-403 412-427 430-450	524-539 590-620 735-750
Ho-343	Aynor - Conway Career Center	33°52'40"	79°06'00"	230	210-230		
Ho-344	Windjammer Village	33°35'02"	79°01'22"	706	374-384 392-402	454-534 573-588	
Ho-345	Conway Rural (Pearce, Young, Angel)	33°48'27"	79°00'26"	800	495-520 650-660	670-690 716-726	740-765 770-780
Ho-346	State of South Carolina (Wampee)	33°50'55"	78°42'23"	340	316-326		
Ho-347	Bucksport No. 2	33°44'26"	74°04'35"	598	300-320 330-340 392-402	408-443 448-453 463-473	492-502
Ho-348	Town of Aynor	34°00'05"	79°12'09"	717	300-350		
Ho-349	North Myrtle Beach (Cherry Grove)	33°50'00"	78°38'18"	607	Unknown		

Table 1. (continued)

Ho-350	Myrtle Beach Air Force Base (Bldg. No. 514)	33°40'54"	78°56'38"	42	32-42
Ho-351	Fannie Collins	33°41'04"	79°07'32"	1419	Test hole
Ho-352	Jerome Walker	33°49'38"	78°39'38"	320	106-126
Ho-353	Ocean Lakes Campground	33°37'26"	78°57'17"	644	406-416 442-482
Geo-17	Georgetown (Hospital)	33°21'26"	79°17'05"	990	703-713 874-884
Geo-22	Arcadia Plantation	33°22'53"	79°13'30"	532	Unknown
Geo-23	Georgetown (Cherry Hill Park)	33°22'51"	79°17'48"	840	500-517 600-630 750-755 550-560 680-700
Geo-30	Georgetown (Maryville No. 1)	33°19'58"	79°18'13"	840	618-633 713-743
Geo-43	Georgetown Water and Sewer Dist. (Federal Observation Well)	33°23'25"	79°17'36"	759	530-610 710-750 650-670
Geo-44	Pelican Inn	33°25'06"	79°07'30"	529	Unknown
Geo-48	State of South Carolina (Brookgreen Gardens)	33°31'18"	79°05'27"	110	80-110
Geo-53	Georgetown (Test)	33°22'05"	79°17'22"	1848	Test hole
Geo-63	Georgetown Rural Water (Firetower)	33°26'56"	79°16'53"	820	504-514 546-551 648-668 526-536 560-590

Table 1. (continued)

Geo-70	Carolina Utilities (Garden City Point)	33° 30'56"	79° 05'38"	803	422-442 555-565	675-685 695-715
Geo-72	City of Andrews (No. 5)	33° 27'21"	79° 34'45"	839	598-613 696-741	785-792
Geo-78	International Paper Co.	33°25'26"	79°26'48"	800	360-380 520-530	550-580
Geo-80	Arden Stevens	33° 31'53"	79° 03'25"	500	490-500	
Geo-82	State of South Carolina (Brookgreen Gardens)	33° 31'00"	79° 05'27"	Unknown	Unknown	
Geo-85	Holt Drew	33° 28'25"	79° 16'28"	400	390-400	
Geo-86	Georgetown (Maryville No. 2)	33°_9'42"	79° 18'37"	804	612-647 670-680	766-776 795-800
Geo-87	Georgetown Water and Sewer Dist. (Litchfield No. 3)	33° 29'05"	79° 05'50"	555	439-454 486-526	545-555
Geo-88	State of South Carolina (Estherville Plantation)	33° 15'08"	79° 16'24"	1837	1270-1295	
Geo-89	State of South Carolina (De Bordieu Colony)	33° 21'50"	79° 10'05"	665	570-580 620-635	
Geo-90	City of Andrews (No. 4)	33° 26'42"	79° 31'45"	817	750-810	
Geo-91	West Virginia Paper Co.	33° 33'58"	79° 22'39"	450	Unknown	

Table 1. (continued)

Geo-93	Georgetown Water and Sewer Dist. (Litchfield No. 4)	33°28'57"	79°06'02"	706	497-547 568-588
Geo-94	Georgetown Water and Sewer Dist. (Plantersville)	33°31'42"	79°12'54"	817	486-496 540-580
Geo-95	Georgetown Water and Sewer Dist. (Penny Royal Rd)	33°20'17"	79°21'43"	810	620-680
Geo-96	Billy Andrews	33°28'20"	79°07'02"	430	418-428
NC-1	State of North Carolina (Calabash)	33°53'35"	78°35'20"	1340	1040-1052
NC-2	State of North Carolina (Calabash)	33°53'35"	78°35'20"	358	338-348
Chas-1	State of South Carolina (Hampton Plantation)	33°12'00"	79°25'53"	721	680-720

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Figure 3. Geohydrologic section A-A' from Estherville Plantation to Calabash, N.C., showing Tertiary and Upper Cretaceous rocks as well as approximate locations of freshwater-saltwater interfaces.

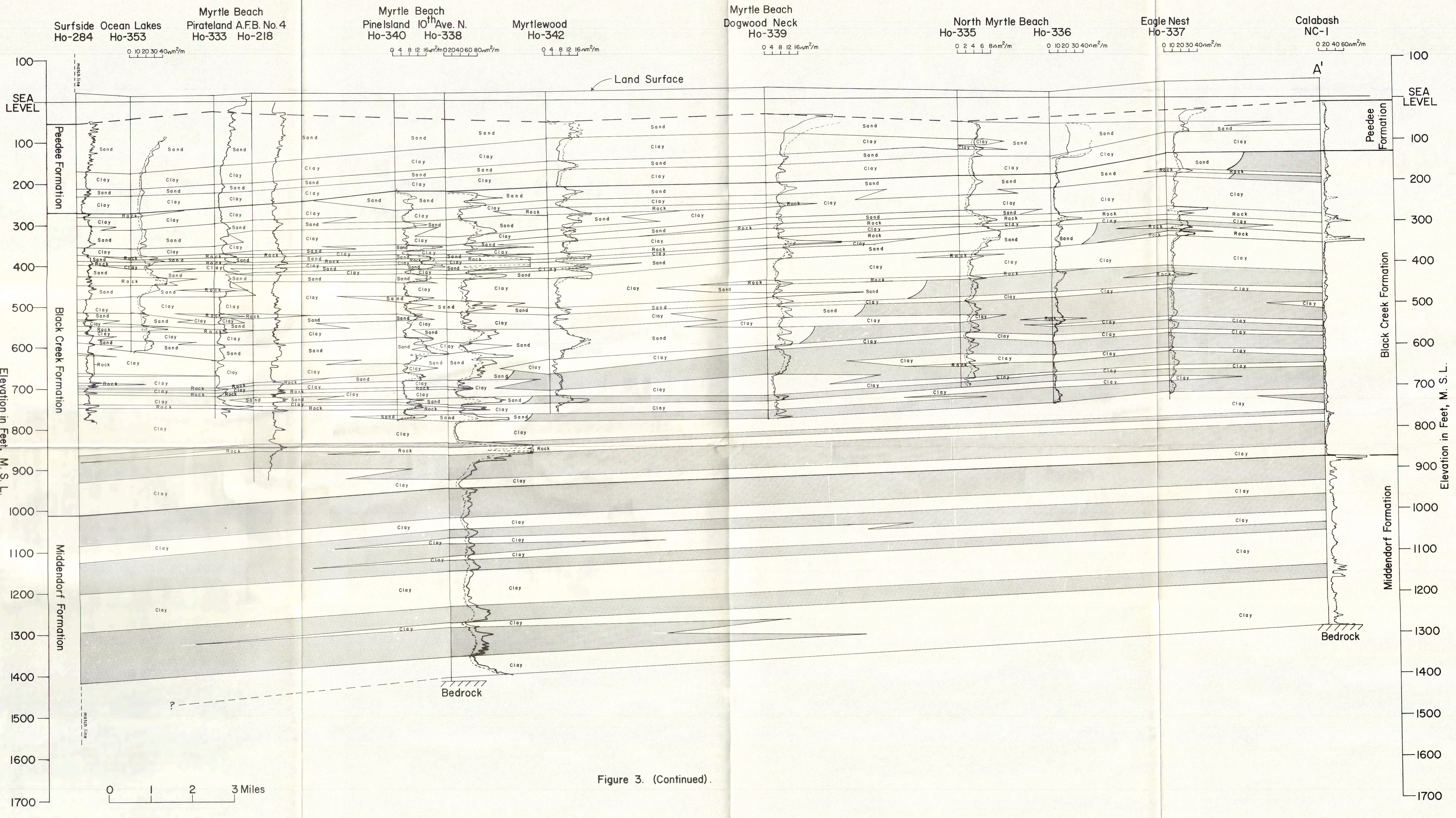

Figure 3. (Continued).

Figure 4. Geohydrologic section B-B' from Hampton Plantation to Loris, showing Tertiary and Upper Cretaceous rocks as well as approximate locations of freshwater-saltwater interfaces.

Figure 4. (Continued).

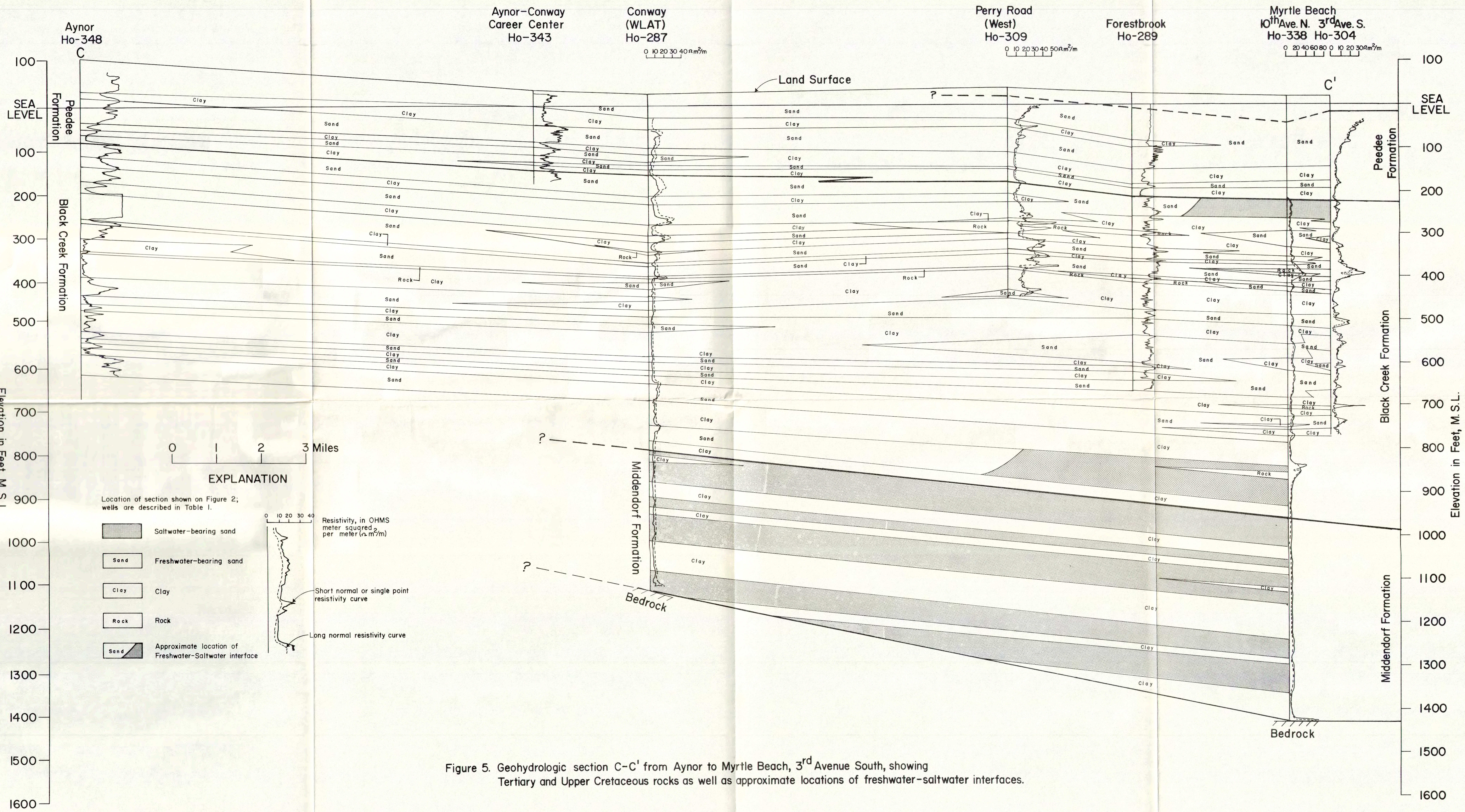

Figure 5. Geohydrologic section C-C' from Aynor to Myrtle Beach, 3rd Avenue South, showing Tertiary and Upper Cretaceous rocks as well as approximate locations of freshwater-saltwater interfaces.

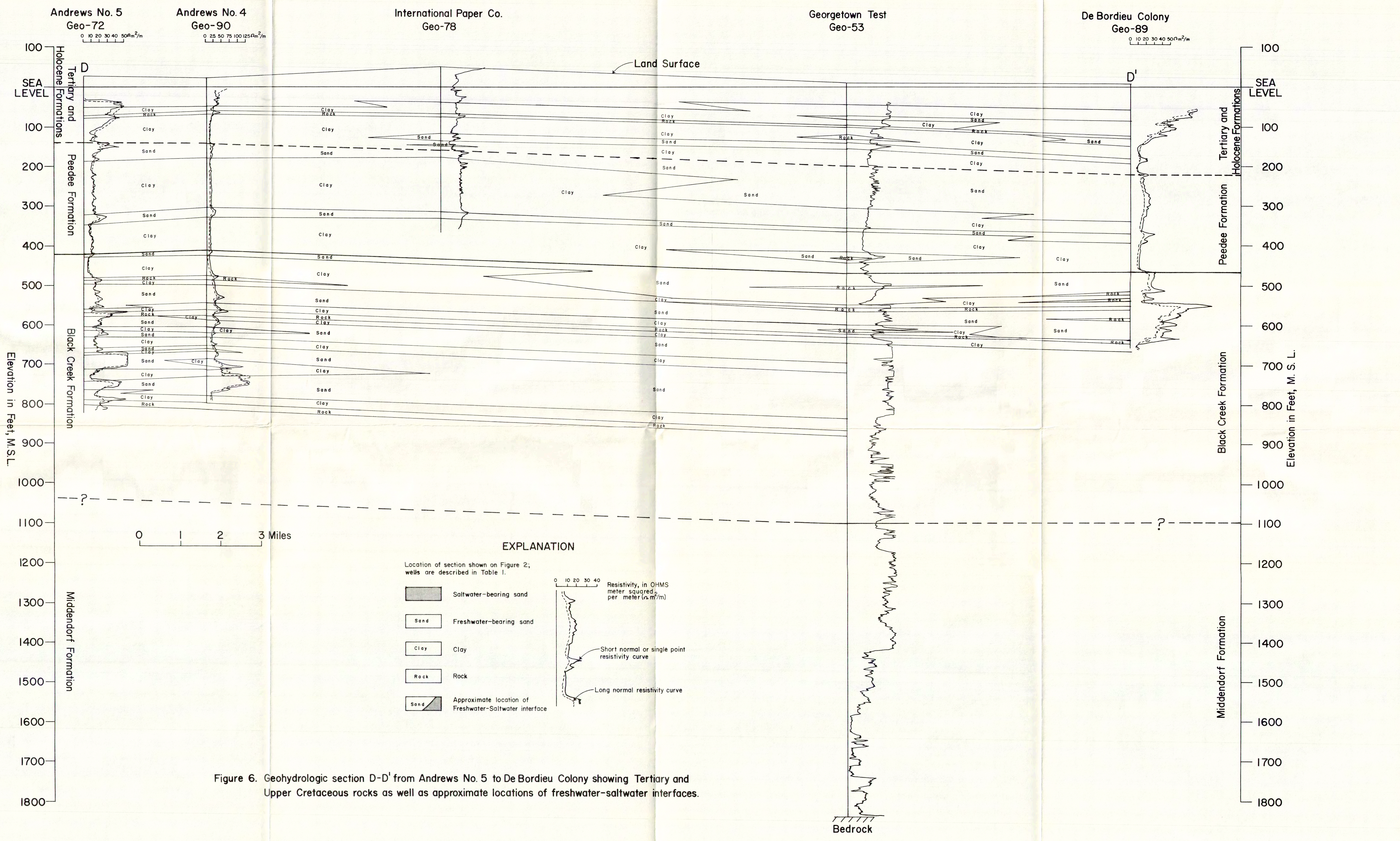

Figure 6. Geohydrologic section D-D' from Andrews No. 5 to De Bordieu Colony showing Tertiary and Upper Cretaceous rocks as well as approximate locations of freshwater-saltwater interfaces.

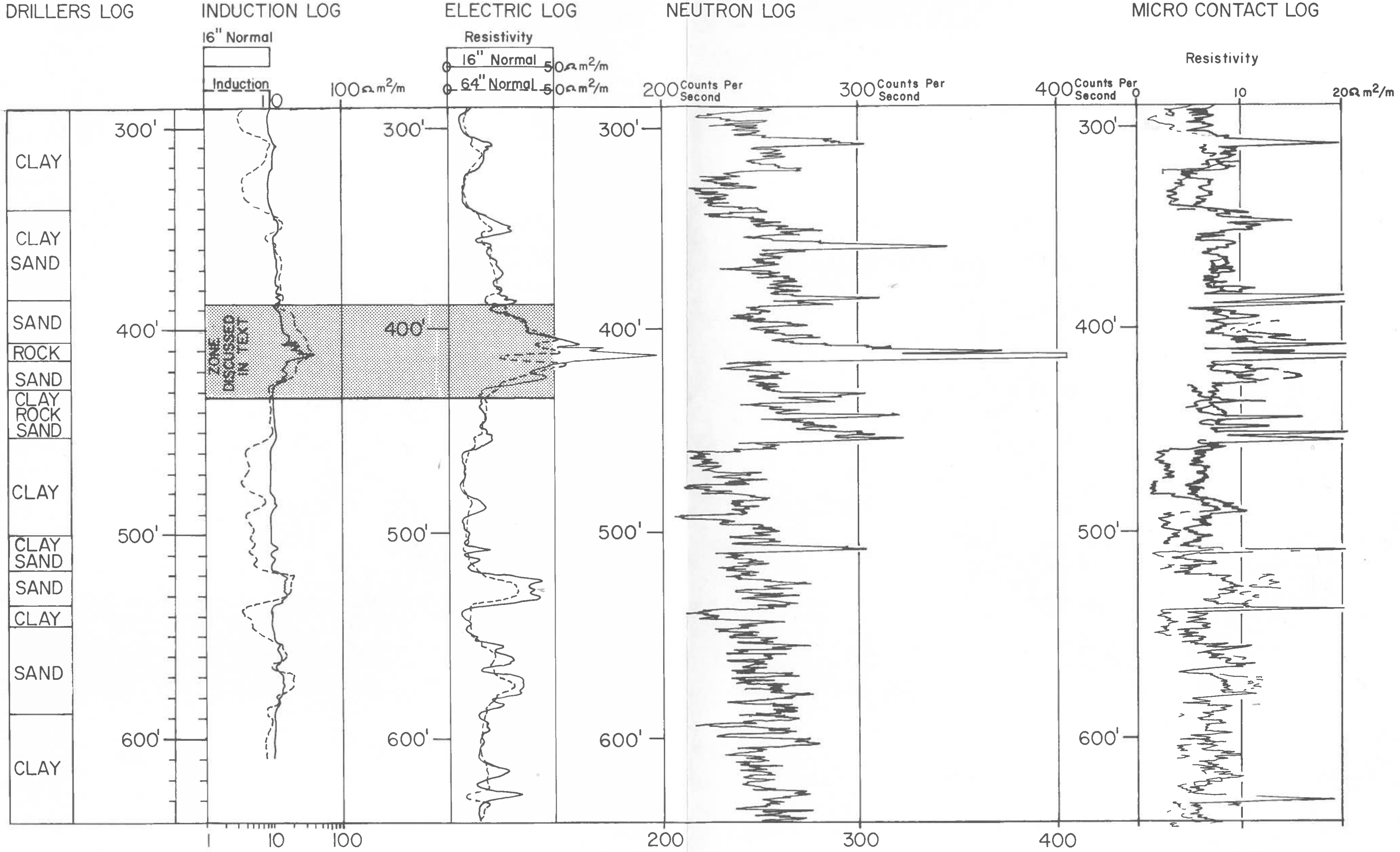

Figure 28. Geophysical logs, 3rd. Ave. S. well, Myrtle Beach, S. C. (Ho-304) showing the effect of impervious calcareous sandstone at 410 feet below land surface.

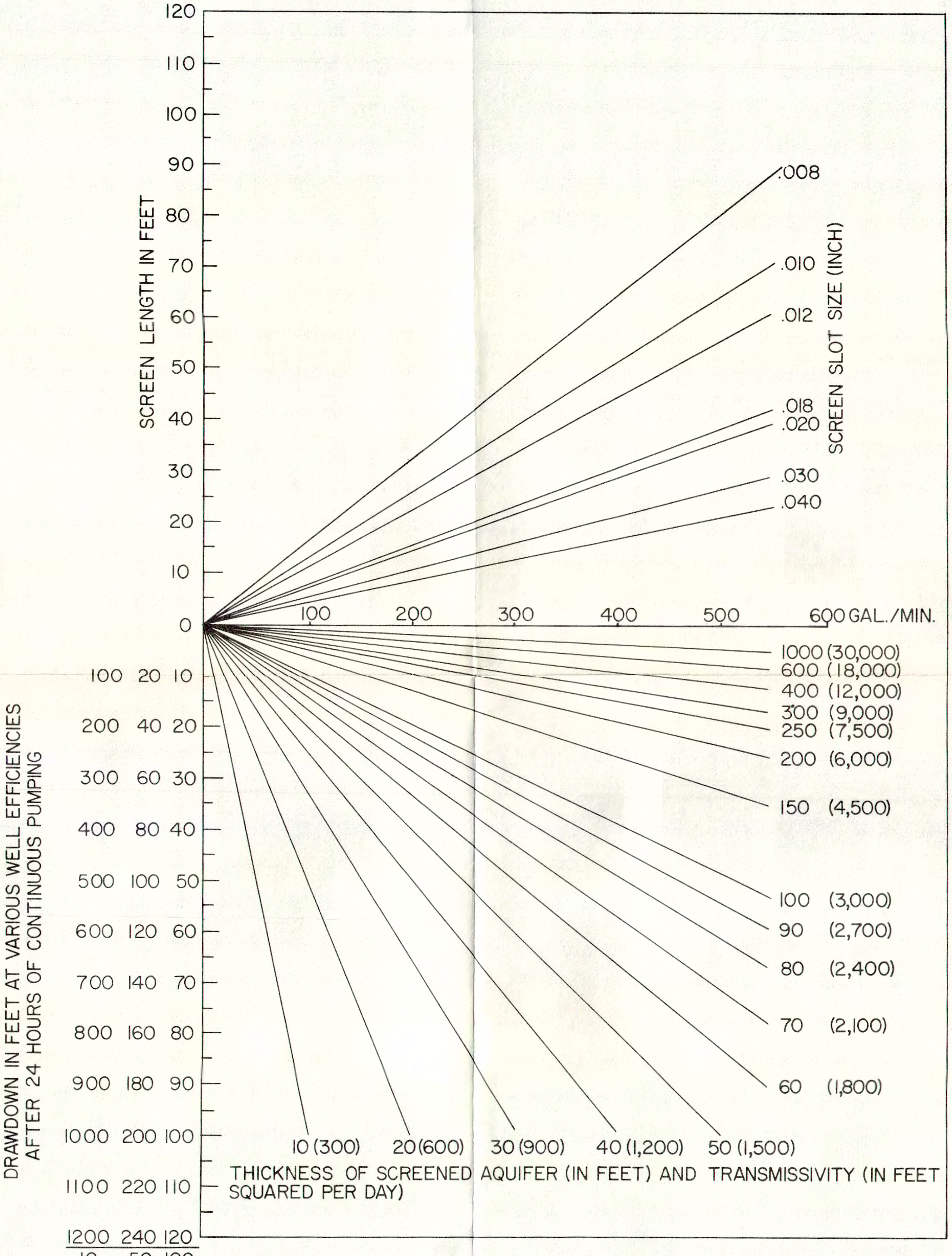

Figure 30. Nomograph relating the yield of a 6 inch well to (1) screen length and slot size (of a typical wire-wound screen) and to (2) the thickness and transmissivity of aquifer material and drawdown after 24 hours of continuous pumping.

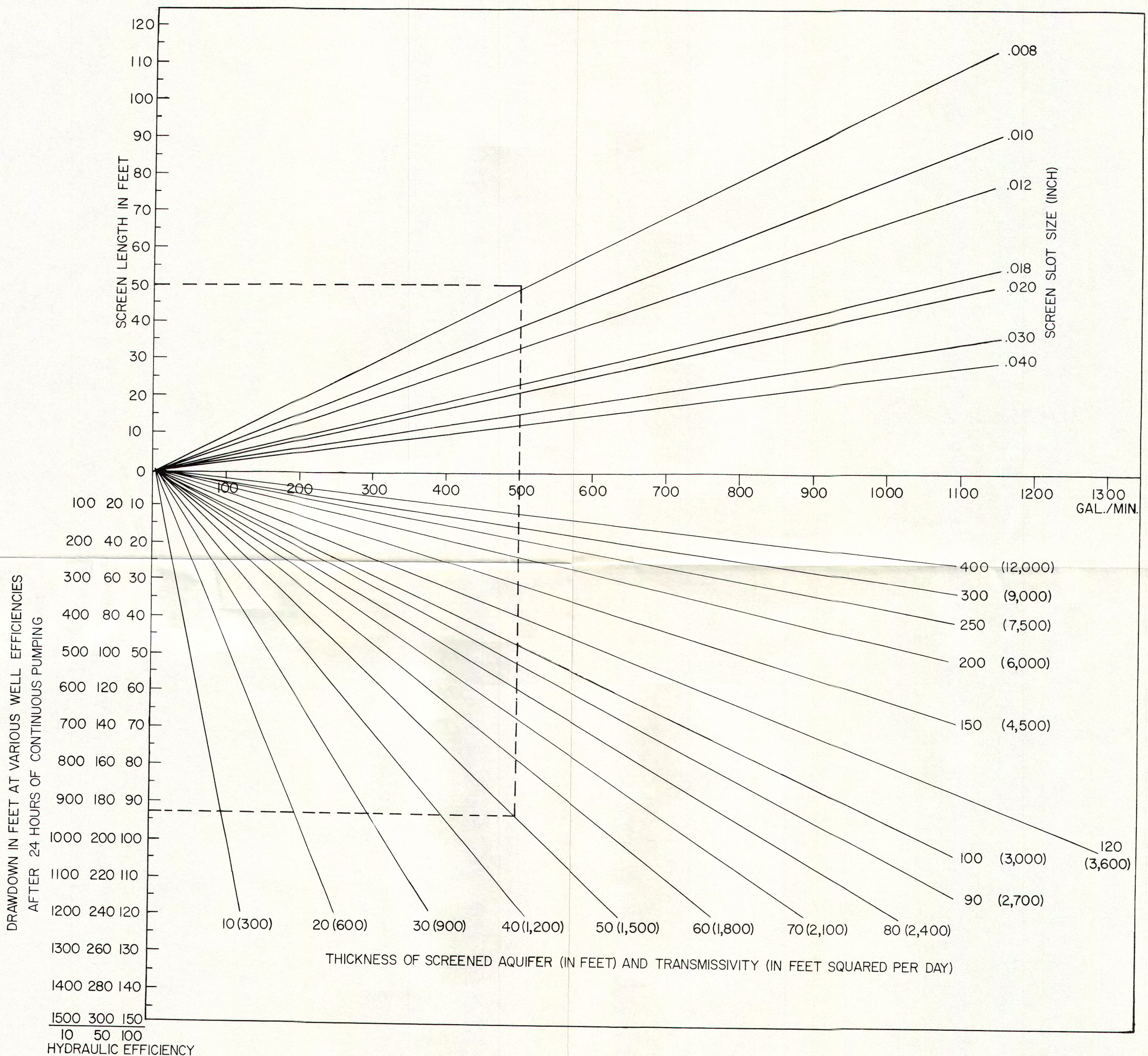

Figure 31. Nomograph relating the yield of a 10 inch well to (1) screen length and slot size (of a typical wire-wound screen) and to (2) the thickness and transmissivity of aquifer material and drawdown after 24 hours of continuous pumping.