GEOLOGIC, HYDROLOGIC, AND WATER-CHEMISTRY DATA FOR A MULTI-AQUIFER SYSTEM IN COASTAL PLAIN SEDIMENTS NEAR GIRARD, BURKE COUNTY, GEORGIA, 1992–95

by

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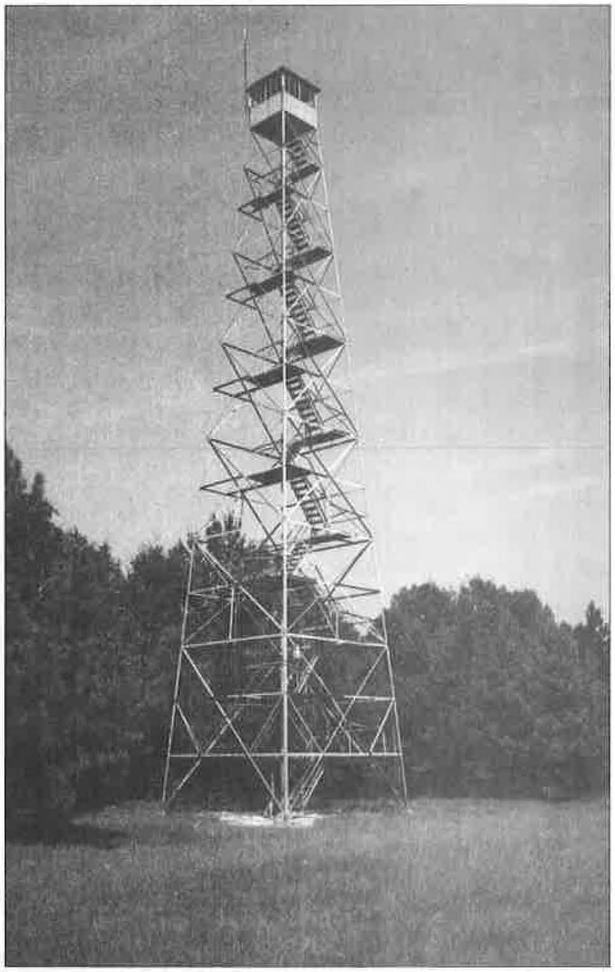

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INFORMATION CIRCULAR 100

Cover photograph: Georgia Forestry Commission fire tower near Girard, Burke County, Georgia.
Photograph by Alan M. Cressler, U.S. Geological Survey.

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GEORGIA DEPARTMENT OF NATURAL RESOURCES
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[Plate is in pocket in back of report]

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CONVERSION FACTORS, ACRONYMS AND DEFINITIONS, AND VERTICAL DATUM

CONVERSION FACTORS

Multiply	by	to obtain
Length		
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
Area		
square mile (mi^2)	2.590	square kilometer
Volume		
gallon (gal)	3.785	liter
Flow		
gallon per minute (gal/min)	0.06309	liter per second
Concentration		
part per million	1	milligrams per liter (mg/L)
	1,000	micrograms per liter (µg/L)
picocurie per liter (pCi/L)	3.19	tritium unit
Specific conductance		
micromho per centimeter at 25 ° Celsius (µmhos/cm at 25 ° C)	1	microsiemens per centimeter at 25 ° Celsius (µS/cm at 25 ° C)

Temperature

Temperature in degrees Fahrenheit (° F) can be converted to degrees Celsius (° C) as follows:

$$°C = 5/9 (°F - 32)$$

ACRONYMS AND ABBREVIATIONS

DIC	Dissolved inorganic carbon
DNR	Georgia Department of Natural Resources
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
EPD	Georgia Environmental Protection Division
SRCC	Spearman's rank correlation coefficient
SRS	Savannah River Site
TOC	Total organic carbon
USGS	U.S. Geological Survey

VERTICAL DATUM

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929--a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called "Sea Level Datum of 1929"

GEOLOGIC, HYDROLOGIC, AND WATER-QUALITY DATA FOR A MULTI-AQUIFER SYSTEM IN COASTAL PLAIN SEDIMENTS NEAR GIRARD, BURKE COUNTY, GEORGIA, 1992-95

By David C. Leeth[1/], William F. Falls[1/], Lucy E. Edwards[1/],
Norman O. Frederiksen[1/], and R. Farley Fleming[1/]

ABSTRACT

The Girard hydrogeologic test site (Girard site), in southeastern Burke County, Ga., was constructed during 1992-95 to better characterize the geologic, hydrogeologic, and water-quality characteristics of a multi-aquifer system in Coastal Plain sediments. Data presented herein include the depth, thickness, geologic properties, hydrologic properties, paleontology, and water quality of the Coastal Plain aquifers at the Girard site. During March and April 1992, continuous, 2-inch diameter core was collected from land surface to a total depth of 1,385 feet using the wire-line coring method. The core penetrated Coastal Plain sediments and bottomed in pre-Cretaceous basement rock.

Paleontologic data provide geologic age, and when combined with lithologic data indicate the environment of deposition for several geologic units at the Girard site. Twenty-five samples were examined for dinoflagellates, pollen, benthic foraminifera, and calcareous nanofossils. Eleven of the samples yielded age-diagnostic assemblages, ranging from middle Eocene to the Late Cretaceous.

Water-bearing units at the Girard site were related to previously defined hydrogeologic units by comparing borehole data collected at this site to interpreted borehole data from nearby sites. This comparison indicates that several equivalent hydrogeologic units are present at the Girard site. In descending order, these are the Upper Three Runs aquifer, Gordon aquifer, Millers Pond aquifer, the upper and lower Dublin aquifers, and the upper and lower Midville aquifers.

Selected core samples were analyzed to determine vertical hydraulic conductivity and porosity. Laboratory analyses indicate that the vertical hydraulic conductivity of confining units is less than 2 x 10^{-9} feet per day.

Three test wells were completed at the Girard site. Clemson University personnel conducted aquifer tests in two of the wells to determine transmissivity, horizontal hydraulic conductivity, and to detect any interaquifer leakage. Horizontal hydraulic conductivity estimated from these tests indicates that the lower Dublin aquifer is much more productive than the lower Midville aquifer and that both aquifers are confined at the Girard site.

Horizontal hydraulic conductivities for several of the aquifers at the Girard site were estimated by applying logarithmic regression models to borehole resistivity data. These values are comparable to those derived fromaquifer pumping tests and are within the range of error reported for the method. Average hydraulic conductivity values from TW-2 ranged from 26.93 feet per day using the logarithmic regression model to 177 feet per day using TW-2 aquifer pumping tests. In addition, average horizontal hydraulic conductivity values for TW-3 ranged from 24.74 feet per day using the logarithmic regression model to a value of 8.9 feet per day using TW-3 aquifer pumping tests.

[1/] U.S. Geological Survey.

Continuous water-level recorders were installed in each test well to monitor water-level fluctuations and trends. Water-level data also were used to determine the vertical distribution of hydraulic head in the water-bearing units. A statistical comparison of ground-water levels, stream stage, and precipitation was performed using Spearman's rank correlation coefficient. Based on this statistical analysis, two significant correlations are apparent. A mass loading water-level response in the lower Dublin aquifer occurs in response to recharge of the Upper Three Runs aquifer. In addition, some interaquifer leakage from pumping of the lower Dublin aquifer may be affecting the water level in the Upper Three Runs aquifer.

Water samples were collected from two of the test wells to determine the physical and chemical characteristics of water from the screened water-bearing zones. Trace-element chemistry shows significant differences in water quality between the lower Midville and lower Dublin aquifers. Of the 11 trace elements tested, barium, iron, and strontium have disparate values between the two aquifers. Values for these elements are significantly higher in the lower Dublin aquifer than in the lower Midville aquifer; the value for iron (1,600 micrograms per liter) exceeds the U.S. Environmental Protection Agency drinking-water standards by 1,300 micrograms per liter. This high value for iron would limit the usefulness of the lower Dublin aquifer to agricultural purposes unless extensive pretreatment is utilized.

INTRODUCTION

The U.S. Department of Energy (DOE), Savannah River Site (SRS) has manufactured nuclear materials for the National defense since the early 1950's. A variety of hazardous materials including, radionuclides, volatile organic compounds, and heavy metals, are either disposed of or stored at several locations at the SRS. Contamination of ground water has been detected at several locations within the SRS. Concern has been raised by State of Georgia officials over the possible migration of ground water contaminated with hazardous materials through aquifers underlying the Savannah River into Georgia (trans-river flow).

The U.S. Geological Survey (USGS), in cooperation with the DOE and the Georgia Department of Natural Resources (DNR), Environmental Protection Division (EPD), Georgia Geologic Survey (GGS), is conducting a study to describe ground-water flow and ground-water quality near the Savannah River. The overall objectives of this study are to identify ground-water flow paths, quantitatively describe ground-water flow, and evaluate stream-aquifer relations between the Savannah River and underlying aquifers.

The geologic, hydrologic, and water-quality characteristics of aquifers and confining units are being characterized to support the analysis. Accordingly, a test-drilling program was initiated to establish the geologic, hydrologic, and water-quality characteristics of Coastal Plain sediments near the Savannah River (fig. 1). Test-well cluster sites are being constructed in major aquifers at several locations along the Savannah River in Georgia (fig. 1).

Purpose and Scope

This report presents geologic, hydrologic, and water-quality data collected at the Girard hydrogeologic test site (Girard site) in southeastern Burke County, Ga. Data include the depth, thickness, geologic properties, hydrologic properties, paleontology, and water chemistry of the Coastal Plain aquifers at the site. These data, presented in graphs, tables, and diagrams, provide correlation of stratigraphy and ground-water flow-system characteristics. Data collected at the site are on file at the U.S. Geological Survey, Atlanta, Ga.

Test-drilling activities were designed to obtain various data. These included:

- recovery of core samples for geologic testing and paleontologic examination;
- acquisition of geophysical logs to aid in the description and definition of the lithology and physical characteristics of the sediments penetrated;
- collection of water-quality samples from discrete water-bearing zones;
- measurement of water levels in selected water-bearing intervals; and
- determination of hydraulic properties of water-bearing zones and confining units.

This is the third in a series of reports that present results of the project test-drilling program. The previous reports described the results of test drilling at the Millers Pond site in northern Burke County, Ga. (Clarke and others, 1994) and at the Millhaven Plantation site in northeastern Screven County, Ga. (Clarke and others, 1996).

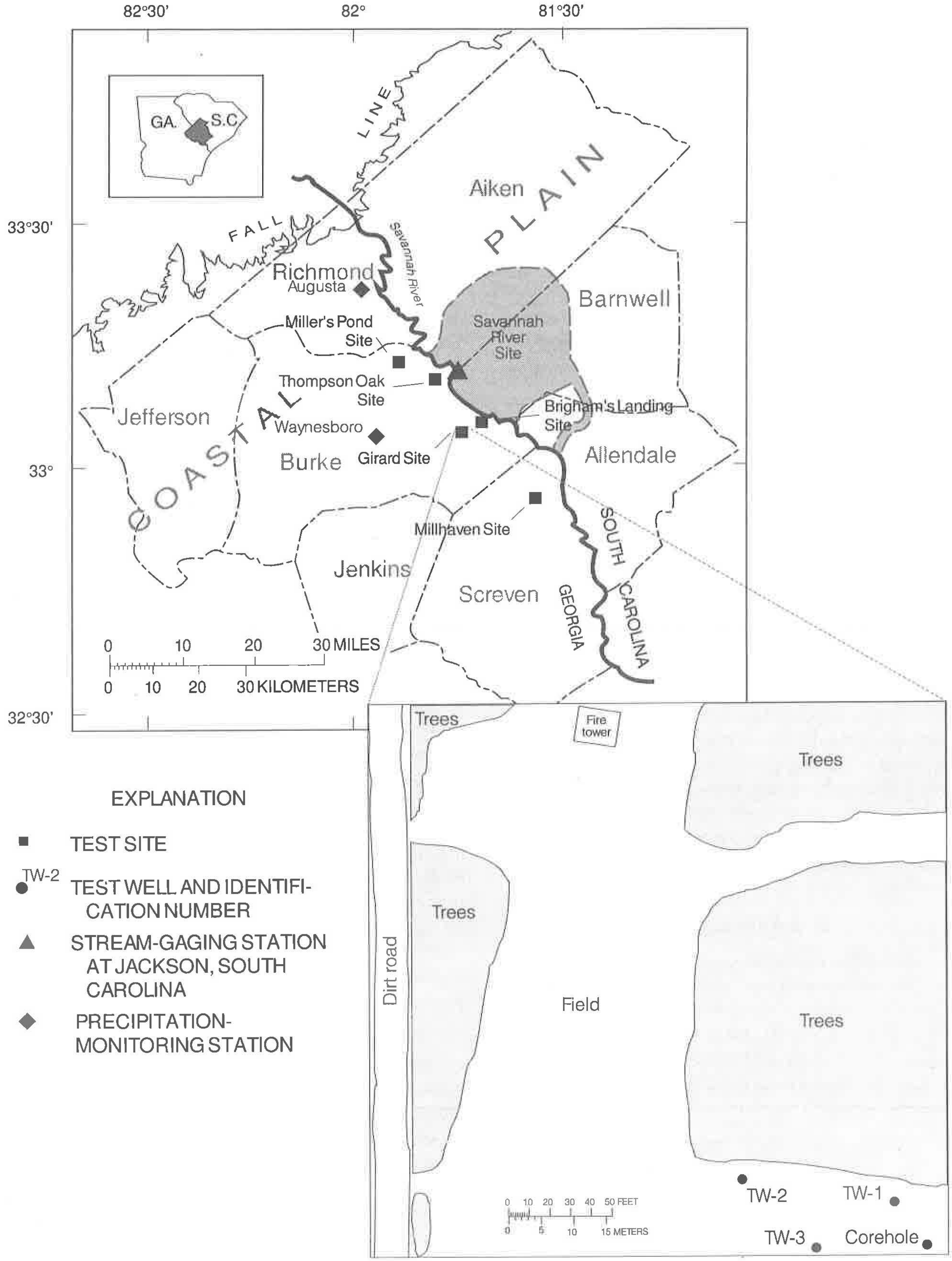


Figure 1. Locations of Savannah River Site, Girard hydrogeologic test site, and test wells.

Description of Study Area

Sediments at the Girard test site in the Coastal Plain physiographic province in Georgia consist of alternating layers of sand, silt, clay, and lesser amounts of limestone that dip southeastward forming a series of aquifers and confining units. Although data in South Carolina are plentiful, limited geologic, hydrologic, and water-quality data are available in Georgia to determine the characteristics of these aquifers and confining units adjacent to the Savannah River.

The Girard hydrogeologic test site is in southeastern Burke County, about 22 miles (mi) south of Augusta, Ga.; about 12 mi southeast of Waynesboro, Ga.; and about 3.8 mi west of the Savannah River on the site of a Georgia Forestry Commission fire tower (fig. 1). The site is about 250 ft above sea level with altitudes varying less than one foot between the wells.

Well-Numbering System

Each of the test wells at the Girard site were numbered according to the order of drilling; that is, test well 1 (TW-1) was the first well completed, TW-2 was the second, and so on. In addition to these project well numbers, wells in Georgia also are numbered according to a system based on the USGS index of topographic maps. Each 7 1/2-minute topographic quadrangle in the State has been given a number and letter designation beginning at the southwest corner of the State. Numbers increase eastward and letters increase alphabetically northward. Quadrangles in the northern part of the area are designated by double letters. The letters "I", "II", "O", and "OO" are omitted. Wells inventoried in each quadrangle are numbered consecutively beginning with 1. Thus, the 17th well numbered on the 30Z quadrangle is designated 30Z017.

Acknowledgments

The authors gratefully acknowledge the cooperation and assistance of the Georgia Forestry Commission, for providing access to the Girard fire tower property. Thanks also is extended to David S. Snipes, Rex Hodges and Peter G. Luetkehans, Clemson University, for conducting and analyzing aquifer tests at the site.

WELL CONSTRUCTION AND CORING

During March and April 1992, a corehole was completed at the Girard site penetrating Coastal Plain sediments and bottoming in pre-Cretaceous basement rock. During drilling of the corehole, surface casing was emplaced to a depth of 140 ft to alleviate problems with caving sand zones. Continuous, 2-in. diameter core samples were collected from land surface to a depth of 1,385 ft using the wire-line coring method. The core samples were used to determine lithology, grain size, sand/clay ratio, and depositional environment.

The paleontology of selected core samples provides age control for the time of deposition. Borehole geophysical logs were collected for the total depth of the corehole to aid correlation of units and determine water-bearing properties of the sediments. Geophysical logs from the corehole are shown on plate 1. After geophysical logging, the corehole was capped.

To characterize the vertical distribution of hydraulic head and water chemistry of Coastal Plain sediments at the Girard site, test wells were installed at three water-bearing intervals at depths ranging from 72 to 1,122 ft, using standard mud-rotary drilling practices. Screened intervals for each well were positioned in layers having relatively high sand content overlain and underlain by clay beds of relatively low permeability, as was determined by examination of core and geophysical logs. Screened intervals were made as large as possible (up to a maximum of 50 ft) to allow adequate pumping rates during aquifer tests. Well-construction diagrams are shown along with geophysical logs and lithology on plate 1.

Test well TW-1, completed in March 1992, originally was constructed as a water-supply well for the corehole. The well is constructed of threaded 2-in. diameter polyvinyl chloride (PVC) casing from a depth of 0.5 to 48 ft, coupled with a 24-ft section of 2-in. diameter, 0.012-in. slotted PVC screen set from 48 to 72 ft. A 5-ft section of PVC was added below the screen as a sediment trap, making the total completed well depth 77 ft. To alleviate problems with caving sand, a 3-in. diameter PVC surface casing was installed to a depth of 48 ft. The well was completed by allowing the formation sand to collapse around the screen and grout was emplaced from the top of the screened interval to approximately 2 ft below land surface (plate 1).

The two other wells (TW-2, TW-3) were constructed using a double-string technique by telescoping a smaller diameter screen and blank casing into a larger diameter outer casing, that was previously grouted into place. A neoprene packer was used to form a seal between the inner and outer casing. Test wells TW-2 and TW-3 were developed using air surging and jetting techniques. Development in each of the wells continued until the return water was free of drilling mud and sand.

Test well TW-2, completed in May 1994, was constructed of a 6-in. diameter threaded-and-coupled low-carbon steel outer casing, emplaced from land surface to a depth of 730 ft. Using a neoprene rubber "K" packer as a seal, a 4-in. diameter string of low-carbon steel inner casing is telescoped into the outer casing from a depth of 720 ft to the top of the screen at 743 ft. Thirty feet of 4-in. diameter, 0.010-in., wire wrapped, continuous slot, type 304 stainless-steel screen continues the inner string down to a depth of 773 ft. The bottom of the well string is completed with a nominal 10 ft, low-carbon steel sump bringing the total depth of the well to about 784 ft (plate 1).

Test well TW-3, completed in December 1995, was constructed of a 6-in. diameter threaded-and-coupled, low-carbon steel outer casing, emplaced from land surface to a depth of 1,000 ft. Using a neoprene rubber "K" packer as a seal, a 4-in. diameter string of low-carbon steel inner casing is telescoped into the outer casing from a depth of 942 ft to the top of the screen at 1,070 ft. Fifty-two feet of 4-in. diameter, 0.016-in., wire wrapped, continuous slot, type 304 stainless-steel screen continues the inner string down to a depth of 1,122 ft bringing the total depth of the well to about 1,142 ft (plate 1).

GEOLOGIC DATA

An understanding of the lithology and micropaleontology of the Girard hydrogeologic test site is necessary to delineate the age and depositional environments of the sediments. Sediments underlying Burke County range in age from Mesozoic to Holocene and consist of units of sand, silt, clay, and minor amounts of limestone. Lithologic and paleontologic evidence from the Girard fire tower core suggests that at least 13 distinct lithologic units (fig. 2) are present in the vicinity of the site. These lithologic units have a total thickness of about 1,385 ft (plate 1). A generalized correlation of units of Late Cretaceous through Eocene age in the southeastern United States is shown in figure 2. These sediments unconformably overlie consolidated red beds of Mesozoic age (Chowns and Williams, 1983).

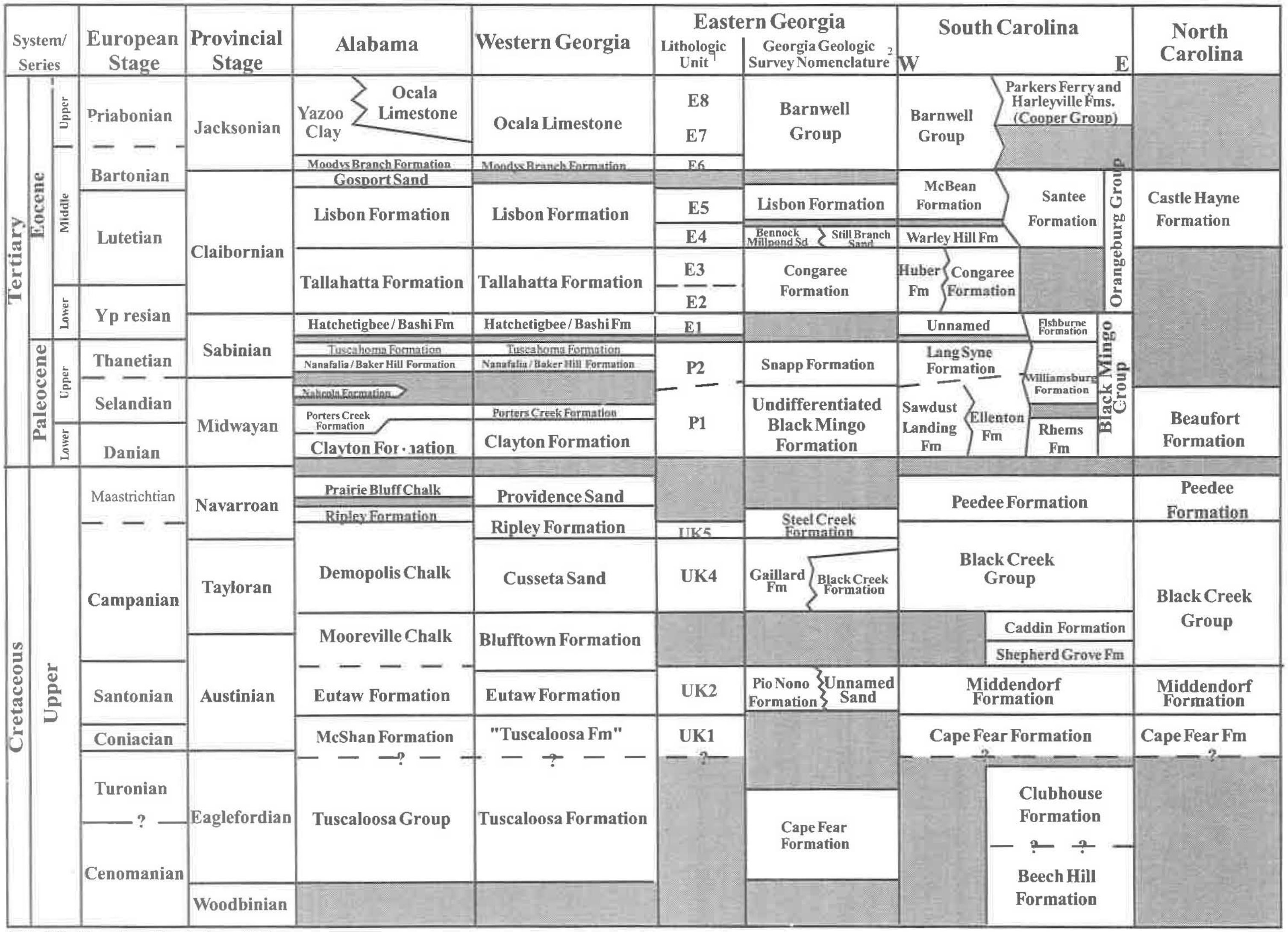
Lithology

The sediments underlying the Girard site consist predominantly of deltaic and marine sand and clay. The lithology and geophysical characteristics of sediments at the Girard site are shown graphically on plate 1. A detailed description of the lithology, grain size and sorting, induration, texture, contact relations, and physical and biogenic sedimentary structure of core collected at the Girard site is listed in the Appendix. Textural classification of siliciclastic sediments shown in the appendix was adapted from a standard grain-size scale (Wentworth, 1922) and includes: clay (less than 0.020 millimeters (mm)), silt (0.020 to 0.065 mm), sand (0.065 to 2.00 mm), granules (2.00 to 4.00 mm), and pebbles (4.00 to 64.00 mm). Sand-size grains are further subdivided into five classes: very fine (0.065 to 0.125 mm), fine (0.125 to 0.250 mm), medium (0.250 to 0.500 mm), coarse (0.500 to 1.000 mm), and very coarse (1.000 to 2.000 mm). Grain-size distribution and sorting of siliciclastic framework grains were based on visual classification of sand grains, granules, and pebbles. In this report, granules and pebbles are considered to be grain-size classes in estimates of sorting.

Categories of sorting are based on the number of grain-size classes observed in a sediment sample and are herein defined as: well sorted (one grain-size class), moderately sorted (two grain-size classes), poorly sorted (three or four grain-size classes), and very-poorly sorted (five or more grain-size classes). The size of heavy minerals, mica grains, clasts, lignite, and carbonate grains, and the abundance of matrix were not considered in sorting estimates.

Categories of induration for siliciclastic sediment depends on the amount of matrix and cement present. Samples from this core are categorized as: loose (grains are not bound by cement or clay matrix); clay-bound (framework grains are bound in a soft clay matrix); and friable (framework grains are bound in a hardened clay matrix and cement).

The textural classification of carbonates is based on the distribution and abundance of carbonate matrix and grains (Dunham, 1962). A mudstone includes less than 10-percent carbonate grains in a matrix-supported texture. A wackestone includes greater than 10-percent carbonate grains in a matrix-supported texture. A packstone has a grain-supported texture with carbonate matrix between the grains. A grainstone consists of carbonate grains without a matrix. In addition to this textural based classification, this report uses the compositional terminology of Folk (1959, 1962) whose four major compositional types are based on allochemical constituents (bioclasts, made of broken and whole skeletal parts; ooids; intraclasts; and fecal pellets). Carbonates in the core are predominantly calcite with some aragonite. Carbonates are described as either loose, partially lithified, or lithified.



1 Modified from Prowell and others, 1985

2 From Huddlestun and Summerour, 1995.

Figure 2. Generalized correlation of units of Late Cretaceous through Eocene age in the southeastern United States. Gray areas indicate missing stratigraphic interval. Abbreviation used: Fm, formation; Modified from Clarke and others, 1994.

Micropaleontology

Paleontologic data provide geologic age for several geologic units at the Girard site. Paleontologic samples were examined for dinoflagellates, pollen, benthic foraminifera, and calcareous nanofossils. Eleven of the paleontologic samples yielded age-diagnostic assemblages for Tertiary sediments. The locations of all samples are shown on plate 1 as small triangles adjacent to the lithologic column.

Paleocene palynomorphs were taken from four paleontologic samples ranging in depths from 484.3 to 532.7 ft. The sample from 532.5 to 532.7 ft contains a nondiagnostic dinoflora consisting of small peridiniacean cysts, *Spiniferites* spp., and a few specimens of the *Areoligera* group. The sample from 521.0 to 521.2 ft contains lower Paleocene, Midwayan dinocysts, including *Carpatella cornuta* Grigorovich and a new species of *Alterbidinium*. The assemblage is dominated by small peridiniacean cysts. Pollen in this paleontologic sample included *Pseudoplicapollis serenus* Tschudy, *Caryapollenites prodromus* group of Frederiksen (1991), and an unnamed species of *Sparganiaceaepollenites* in addition to long-ranging forms. *Osculapollis*? *colporatus* Frederiksen was also tentatively identified in the sample. The overlap of age ranges represented by this assemblage suggests a late Paleocene age with reworked material of early Paleocene age. The sample from 514.0 to 514.3 ft contains a sparse dinoflora. The paleontologic sample from 484.1 to 484.3 ft contains a typical late Paleocene (late Midwayan or early Sabinian) dinoflora, again dominated by small peridiniacean cysts and containing *Damassadinium californicum* (Drugg) Fensome *et al.* and *Phelodinium* sp. of Edwards.

Paleontologic samples examined between 327 and 415 ft indicate a range in age from early Eocene to the early part of the middle Eocene. The age of the sample at 423 ft is Eocene, but attempts to determine whether the age is early or middle Eocene were inconclusive. A paleontologic sample at 415 ft recovered a single specimen of *Wetzeliella* or *Dracodinium*. A second sample from 415.2 to 415.5 ft, tentatively identified; *Homotryblium tenuispinosum* of Davey and Williams. This paleontologic sample contains very few pollen grains, but two of the specimens were of *Platycaryapollenites* sp. cf. *P. swasticoidus*; and therefore, are of Eocene age, (probably early Eocene or possibly early middle Eocene age). The next productive paleontologic sample was from 362 to 362.3 ft and contained a variety of dinocysts suggesting correlation to the lower part of the Lisbon Formation in Alabama. Important species include *Pentadinium favatum* Edwards, *Cerebrocysta bartonensis* Bujak, *Phthanoperidinium echinatum* Eaton, *Samlandia chlamydophora* Eisenack, *Wetzeliella articulata* Eisenack, *Glaphyrocysta*? *vicina* (Eaton) Stover and Evitt and a new species of *Eocladopyxis*. The paleontologic sample from 327.3 to 327.5 ft contains a similar dinocyst assemblage.

Paleontologic samples examined between 258 ft and 322 ft indicate that these sediments are characteristic of the upper part of the middle Eocene (correlative to the upper Lisbon and Gosport Formations). The paleontologic sample at 322.3 to 322.5 ft contains a very sparse and relatively nondiagnostic dinocyst assemblage, but includes *Pentadinium goniferum* Edwards. The paleontologic sample from 321.4 to 321.6 contains the lowest occurrence of *Cordosphaeridium cantharellus* (Brosius) Gocht. The paleontologic sample from 257.8 to 258 ft contains a well preserved, diverse dinocyst assemblage which includes *Pentadinium polypodum* Edwards, *Samlandia* sp. and *Enneadocysta arcuata* (Eaton) Stover and Williams.

The paleontologic sample from 211.1 to 211.3 ft contains the species *Rhombodinium perforatum* (Jan du Chêne & Châteauneuf) Lentin & Williams and *Dapsilidinium pseudocolligerum* (Stover) Bujak *et al.* These species suggest a late Eocene age, but are not wholly diagnostic. The paleontologic sample at 146.7 ft contains a very sparse and nondiagnostic dinocyst assemblage. Samples at 64 and 104 ft were barren of dinocysts.

HYDROLOGIC DATA

Hydrologic data are presented for 1992-95 and include the hydrogeologic units encountered, aquifer properties, and ground-water levels at the Girard site. Hydrogeologic units are correlated to other named units. Aquifer-property data include core analyses, resistivity estimates, and aquifer-test results. Ground-water levels were collected on a continuous basis from each test well upon completion of construction and development.

Hydrogeologic Units

Hydrogeologic units at the Girard site were related to previously named hydrogeologic units by comparing core and geophysical data collected at the site to interpreted borehole data from nearby sites reported by Miller (1986); Clarke and others (1985, 1994, 1996); Brooks and others (1985); and Aadland and others (1992). This comparison indicates that several equivalents to hydrogeologic units described in previous reports also are present at the Girard site. A generalized correlation chart of hydrogeologic and time-stratigraphic units in the study area is shown in figure 3. Based on the nomenclature of Clarke and others (1996), they are, in descending order:

- loosely consolidated sand and calcareous sand of Eocene age of the Upper Three Runs aquifer of Aadland and others (1992);
- the Gordon aquifer of Brooks and others (1985); and Aadland and others (1992);
- the Dublin aquifer system (Clarke and others, 1985)—comprised of the upper Paleocene clay of the Millers Pond confining unit; and the predominantly sand, upper Paleocene Millers Pond aquifer (Clarke and others, 1996); the lower Paleocene calcareous sand and clay of the upper Dublin confining unit combined with the Upper Cretaceous sand of the upper Dublin aquifer; and the Upper Cretaceous clay of the lower Dublin confining unit and the sand of the lower Dublin aquifer (Clarke and others, 1996); and
- the Midville aquifer system (Clarke and others, 1985, 1996)—comprised of the interbedded sand and clay of the upper Midville confining unit that overlies the clayey sand of the upper Midville aquifer; this, in turn, overlies the Upper Cretaceous clayey sand and clay of the lower Midville confining unit and the predominantly sand lower Midville aquifer.

At the Girard site, TW-1 is screened in the Upper Three Runs aquifer and is used only to monitor water levels. Wells TW-2 and TW-3 are screened, respectively, in the lower Dublin and lower Midville aquifers and were selected because of the sparsity of hydrologic data for these two aquifers in the study area.

Hydraulic Properties

Hydraulic properties described for the Girard site include horizontal hydraulic conductivity in aquifers and vertical hydraulic conductivity in confining units. Clemson University, Clemson, S.C., personnel conducted aquifer tests in wells TW-2 and TW-3 to determine transmissivity, horizontal hydraulic conductivity and to detect any interaquifer leakage. Selected low-permeability core samples were analyzed in the laboratory, by Core Laboratories Inc., to determine vertical hydraulic conductivity and porosity. Horizontal hydraulic conductivity for the upper Midville and upper Dublin aquifers also was estimated from borehole formation resistivity logs using the method described by Faye and Smith (1994).

Hydraulic Conductivity Estimated from Aquifer Tests

Horizontal hydraulic conductivity, estimated from aquifer pumping tests for the lower Midville and lower Dublin aquifers, indicates that the lower Dublin aquifer is much more productive than the lower Midville at the Girard site. During December 1994 and January 1995, aquifer tests were conducted and analyzed by Clemson University at two of the three test wells at the Girard Site (Luetkehans, 1995a,b). The Jacob straight-line method (Cooper and Jacob, 1946) was used to estimate transmissivity values for TW-2 and TW-3 test wells. Aquifer-test results at the Girard site are listed in table 1.

Barometric efficiency was determined by calculating the ratio of change in hydraulic head in a well (because of atmospheric changes) to the actual change in atmospheric pressure. A barometric efficiency of 1 indicates that 100 percent of the atmospheric pressure changes have been transmitted to an aquifer; whereas, a barometric efficiency of zero indicates atmospheric pressure changes have not been transmitted to an aquifer. Prior to computation of hydraulic properties, water-level readings were corrected for barometric fluctuations by subtracting atmospheric pressure changes multiplied by the barometric efficiency (Luetkehans, 1995a,b).

Well-efficiency was determined by dividing the theoretical drawdown by the actual drawdown after 24 hours of pumping (Luetkehans, 1995a,b). Partial penetration of both of the aquifers was not considered in these estimates, so actual well efficiencies could be higher than those reported by Leutkehans (1995a,b). The lower Dublin well (TW-2) had a well efficiency of 26 percent and the lower Midville well (TW-3) had a well efficiency of 49 percent. The horizontal hydraulic conductivity of 177 ft per day (ft/d) for the lower Dublin aquifer was almost 20 times that of 8.9 ft/d for the lower Midville aquifer. In addition, the transmissivity of 5,300 ft^2/day for the lower Dublin aquifer is almost five times greater than the 1,130 ft^2/day of the lower Midville aquifer. Finally, the specific capacity of 3.52 gallons per minute per foot (gal/min/ft) in the lower Dublin aquifer is almost twice the 1.85 gal/min/ft of the lower Midville aquifer.

TIME-STRATIGRAPHIC UNIT	HYDROGEOLOGIC UNIT		
SERIES	Georgia	This Study	South Carolina[1]
EOCENE	JACKSONIAN[2]/ UPPER FLORIDAN[3] AQUIFER	UPPER THREE RUNS AQUIFER	UPPER THREE RUNS AQUIFER
	CONFINING UNIT	GORDON CONFINING UNIT	GORDON CONFINING UNIT
	GORDON AQUIFER SYSTEM[4]	GORDON AQUIFER	GORDON AQUIFER
PALEOCENE	CONFINING	MILLERS POND CONFINING UNIT[6]	CROUCH BRANCH CONFINING UNIT
	DUBLIN AQUIFER SYSTEM[5]	MILLERS POND AQUIFER[6]	
		UPPER DUBLIN CONFINING UNIT	
UPPER CRETACEOUS		UPPER DUBLIN AQUIFER	CROUCH BRANCH AQUIFER
		LOWER DUBLIN CONFINING UNIT	
		LOWER DUBLIN AQUIFER	
	CONFINING UNIT	UPPER MIDVILLE CONFINING UNIT	MCQUEENS BRANCH CONFINING UNIT
	MIDVILLE AQUIFER SYSTEM[5]	UPPER MIDVILLE AQUIFER	MCQUEENS BRANCH AQUIFER
		LOWER MIDVILLE CONFINING UNIT	
		LOWER MIDVILLE AQUIFER	
	CONFINING UNIT	BASAL CONFINING UNIT	APPLETON CONFINING SYSTEM

1 Aadland and others, 1992.
2 Vincent, 1982.
3 Miller, 1986.
4 Brooks and others, 1985.
5 Clarke and others, 1985.
6 Clarke and others, 1996.

Figure 3. Correlation of hydrogeologic units in the vicinity of the Girard hydrogeologic test site, Girard, Georgia.

Table 1. Summary of aquifer-test analyses at the Girard hydrogeologic test site, January 1994 and December 1995
[Analyses by Clemson University (Luetkehans, 1995a,b)]

Well number	Water-bearing unit	Dates of test	Pumping period (hours)	Average discharge (gallons per minute)	Maximum drawdown (feet)	Specific capacity (gallons per minute per foot)	Well efficiency (percent)	Barometric efficiency (percent)	Transmissivity (feet squared per day)	Horizontal hydraulic conductivity (feet per day)
TW-2	lower Dublin	12/27/94 to 01/4/95	72	77.67	22.01	3.52	26	58	5,300	177
TW-3	lower Midville	01/14/95 to 01/21/95	72	76.50	41.30	1.85	49	55	1,130	8.9

Extended pumping during each of the two aquifer tests did not induce leakage between the two aquifers, indicating that these aquifers are hydraulically separated at the Girard test site. However, this lack of response also could be because of the large vertical distance (297 ft) between the screens in wells TW-2 and TW-3—an interval that includes the upper Midville and lower Midville confining units—and does not necessarily reflect the competency of the confining units.

Hydraulic Conductivity of Core Samples

Laboratory analyses indicate that the vertical hydraulic conductivity of confining units is low, with all values less than 9.07 x 10^{-5} ft/day. Laboratory analyses were performed on selected low permeability core samples (table 1, plate 1) by Core Laboratories, Inc., New Orleans, La., to determine vertical hydraulic conductivity and porosity. Vertical hydraulic conductivity was determined using a flexible wall permeameter, following American Society for Testing and Materials (ASTM) standard D-5084-90 (ASTM, 1990). Porosity was determined using procedures described in ASTM standard D-2216-80 (ASTM, 1980).

Eight core samples were collected at depths ranging from 305.5 to 850.3 ft (plate 1). The two deepest samples collected from depths of 800.3 and 850.3 ft were unusable because of fracturing. A third, fractured sample, collected from the upper Dublin confining unit at 518.5 ft, yielded vertical hydraulic conductivity and porosity values that appear reasonable but may be suspect because of fracturing.

The first core sample, with a reported vertical hydraulic conductivity of 3.34 x 10^{-4} ft/d and a reported porosity of 43.7 percent, was collected from within the Gordon confining unit from a layer of yellow green, calcareous, sandy clay at a depth of 305.5 ft. Both values fall within expected ranges as reported by Heath (1983) for vertical hydraulic conductivity and Freeze and Cherry (1979) for porosity.

The second core sample, with a reported vertical hydraulic conductivity of 1.54 x 10^{-3} ft/d and a porosity of 36.2 percent was collected from near the top of the upper Dublin confining unit from a black, non-calcareous silty clay at a depth of 487.5 ft. The value for the vertical hydraulic conductivity lies at the upper end of the range of vertical hydraulic conductivities of clay reported by Heath (1983); although the porosity value lies at the lower end of the range for porosity of silt reported by Freeze and Cherry (1979). These values (high vertical hydraulic conductivity and low porosity) likely are explained by the 10-percent silt and sand content reported by Core Laboratories, Inc.

The third core sample, with a reported vertical hydraulic conductivity of 9.41 x 10^{-2} ft/d and a porosity of 34.9 percent, was collected from a black, laminated clay at the bottom of the upper Dublin confining unit at a depth of 518.5 ft. This value is suspect because of fracturing during sample collection; however, the value is reported here to provide additional data.

The fourth core sample, with a reported vertical hydraulic conductivity of 9.07 x 10^{-5} and a porosity of 25.4 percent, was collected from a yellow to light gray, sandy clay at a depth of 628.0 ft. This clay lies near the bottom of the upper Dublin confining unit. The value for the vertical hydraulic conductivity lies in the middle of the range of vertical hydraulic conductivity of clay reported by Heath (1983); but the porosity value also lies at the lower end of the porosity values of sand reported by Freeze and Cherry (1979). The porosity value is anomalous and can only partially be explained by the presence of up to 15-percent sand intercalated throughout the sample, but may be due partially to the presence of fine-sand-size mica.

The fifth core sample, with a reported vertical hydraulic conductivity of 1.82 x 10^{-4} ft/day and a porosity of 25.7 percent, was collected from a medium gray, micaceous, silty, laminated, clay within the lower

Dublin aquifer at a depth of 737.5 ft. The value for the vertical hydraulic conductivity lies in the upper range of vertical hydraulic conductivity value for clay as reported by Heath (1983); whereas the porosity value lies at the lower end of the porosity values of sand reported by Freeze and Cherry (1979). As was the case in the fourth core sample, the porosity value is anomalous and can only partially be explained by the presence of up to 20-percent silt intercalated throughout the sample, but may also be due partially to the presence of fine-sand-size mica, and fine-sand laminations.

The sixth core sample, with a reported vertical hydraulic conductivity of 3.43 x 10^{-5} ft/d and a porosity of 35.4 percent, was collected at a depth of 781.5 ft from a gray black, clay with thin beds (0.05 to 0.2 in.) of very fine to fine micaceous sand that lies at the top of the upper Midville confining unit. The value for the vertical hydraulic conductivity is in the middle range for clay as reported by Heath (1983); however, the porosity value is at the lower end of the values for silt as reported by Freeze and Cherry (1979). The low porosity can be attributed to the thin-bedded sand in the unit.

Hydraulic Conductivity Estimated from Borehole Resistivity

Horizontal hydraulic conductivity was estimated for several of the aquifers at the Girard site by applying logarithmic regression models developed by Faye and Smith (1994) to borehole resistivity data. Faye and Smith (1994) developed regression models describing the relation between hydraulic conductivity (as determined by aquifer tests) to aquifer bulk resistivity (as determined from borehole geophysical logs) for clastic aquifers. Using data from boreholes throughout the Coastal Plain of the southeastern United States, Faye and Smith (1994) developed regression models based on the age of sediments that comprise aquifers:

Late Cretaceous

$$K_h = 3.2R_o 0.48 \qquad (1)$$

Paleocene and early Eocene

$$K_h = 0.57R_o 1.0 \qquad (2)$$

middle Eocene

$$K_h = 3.8R_o 0.67 \qquad (3)$$

where:

K_h, is the horizontal hydraulic conductivity in ft/d; and

R_o, is bulk resistivity in ohm-meters.

At the Girard site, bulk resistivity was determined using the long-normal (64-in.) resistivity log (Joan S. Baum, U.S. Geological Survey, written commun., 1995). The maximum, minimum, and mean bulk resistivity for a contributing interval was determined from digital resistivity data collected from the borehole. Estimates were not computed either for the Upper Three Runs aquifer or the Gordon aquifer because the estimates do not fall within one of the age ranges evaluated by Faye and Smith (1994). However, estimates were computed for the Millers Pond, upper Dublin, lower Dublin, upper Midville, and lower Midville aquifers (table 2).

The mean horizontal hydraulic conductivity estimate for the lower Dublin aquifer using the Faye and Smith (1994) method (table 2) was compared to the horizontal hydraulic conductivity determined from aquifer testing in TW-2 (table 1), completed in the lower Dublin aquifer. Estimated mean hydraulic conductivity of 26.9 ft/d computed using the Faye and Smith (1994) method was about 85 percent lower than the value of 177 ft/d determined from the TW-2 aquifer test. The disparity between these values lies well within the range of absolute error reported by Faye and Smith (1994).

Table 2. Estimates of horizontal hydraulic conductivity determined from formation resistivity logs at the Girard hydrogeologic test site

[Estimated using methodology of Faye and Smith (1994); analyses by Joan S. Baum, U.S. Geological Survey, written commun., 1995]

Aquifer	Lithology	Age of sediments	Permeable thickness (feet)	Estimated horizontal hydraulic conductivity		
				Minimum (feet per day)	Maximum (feet per day)	Mean (feet per day)
Gordon	fine to very coarse bioclastic sand	early Eocene	38.8	52.2	94.5	55.2
Millers Pond	fine to very coarse sand and gravel	Paleocene	11.8	18.8	48.5	38.0
Upper Dublin	fine to very coarse sand	Late Cretaceous	5.8	16.1	23.4	19.0
Lower Dublin	fine to very coarse sand	Late Cretaceous	33.6	16.4	33.7	26.9
Upper Midville	fine to very coarse sand	Late Cretaceous	12.8	14.7	29.2	23.3
Lower Midville	very fine to coarse sand	Late Cretaceous	37.0	14.1	31.0	24.7

For the lower Midville aquifer, the mean horizontal hydraulic conductivity, using the Faye and Smith (1994) method, was compared to the horizontal hydraulic conductivity determined from the TW-3 aquifer test. The estimated mean hydraulic conductivity of 24.74 ft/d computed using the Faye and Smith (1994) method was about 278 percent higher than the value of 8.9 ft/d determined from the TW-3 aquifer test. The disparity between these values also lies within the range of absolute error reported by Faye and Smith (1994), but may be enhanced by a low well efficiency (nearing 50 percent).

Ground-Water Levels

Following well completion and development, continuous water-level recorders were installed in the three test wells to monitor water-level fluctuations and trends. Water-level data were used to determine the vertical distribution of hydraulic head in the water-bearing units (plate 1).

Vertical distribution of hydraulic head gives an indication of the potential for vertical ground-water movement and interconnection between adjacent aquifers. Under unstressed conditions, upward gradients occur in discharge areas; downward gradients occur in recharge areas; and minimal vertical gradient exists in areas dominated by lateral flow.

Water levels were measured in the three wells on March 13, 1995, yielding head measurements of 34.98 ft below land surface for TW-1; 89.85 ft for TW-2; and 74.93 ft for TW-3. These values, when corrected for altitude differences between wells, indicate that there is an upward hydraulic gradient from well TW-3 to TW-2; thus, indicating a potential for discharge from the Midville aquifer system into the Dublin aquifer system.

Hydrographs showing relations between ground-water levels at the Girard site, stream stage of the Savannah River near Jackson, S.C., and precipitation at the city of Waynesboro, Ga., are shown in figure 4. Locations of the stream gage and precipitation-monitoring station are shown in figure 1.

Because of the relatively short period of record available for the three wells, few trends are evident in the data. The period of record for TW-1 is somewhat longer than the period of record for TW-1 and TW-2; however, and a few conclusions may be drawn. It is apparent that there is no instantaneous response to rainfall in TW-1 (Upper Three Runs aquifer) and TW-2 (lower Dublin aquifer); and there is no apparent connection to the Savannah River during the period of record. The 4-ft water-level decline observed in well TW-1 between late 1993 and early 1995 is incongruous and not readily explained. Because the Upper Three Runs aquifer is shallow, this decline could be the result of microclimatic changes, such as less localized precipitation or an increase in evapotranspiration because of localized temperature fluctuations that are not recorded by the existing precipitation monitoring network. A change in local agricultural crop type also could increase evapo-transpiration that could, in turn, cause an increase in localized agricultural pumping for irrigation. It is unlikely that evapotranspiration is the causative factor because there should be a relatively strong correlation between evapotranspiration and the summer months; however, this is not the case. In addition to these localized factors, the possibility of long-term deficits in rainfall, causing a general decline for the year, is real and would not be evident from inspection of the short period of record. For the remaining two wells (TW-2 and TW-3), insufficient data prevent a visual assessment of water-level fluctuations; however, a statistical treatment of the data may be useful.

A statistical comparison of stream stage, ground-water levels, and precipitation was performed using Spearman's rank correlation coefficient (SRCC) (Iman and Conover, 1983). The SRCC measures the strength of monotonic correlation between two variables. If the two variables increase together, the variables have a positive correlation; however, if one variable increases, while the other decreases, the variables are said to have a negative correlation. The closer the SRCC is to either +1 (a positive correlation) or -1 (a negative correlation), the stronger the relation is between the two variables. Ground-water-level data from the three test wells were compared to stage data from the stream gage at Jackson, S.C., and precipitation data from Waynesboro, Ga. (Raymond Brown, National Oceanic and Atmospheric Administration, Southeastern Region Climatic Data Center, oral commun., 1995) (table 3).

Two strong correlative relations are apparent based on the SRCC of 0.683 between water levels in TW-1 and TW-2 may be caused by mass loading in the upper Dublin aquifer in response to recharge of the Upper Three Runs aquifer. Also, interaquifer leakage induced by pumping the lower Dublin aquifer may be affecting the water level in the Upper Three Runs aquifer. These are possibilities, but other explanations may be plausible but undetected given the short period of record.

The SRCC of 0.703 between water levels in the deeper TW-2 and TW-3 wells (table 3), indicates that water-level fluctuations for these wells also are correlative based on the SRCC. The underlying causal factor (or factors) for this correlation is uncertain. However, given the correlation of all three wells with precipitation, mass loading from precipitation, is likely a major causative factor.

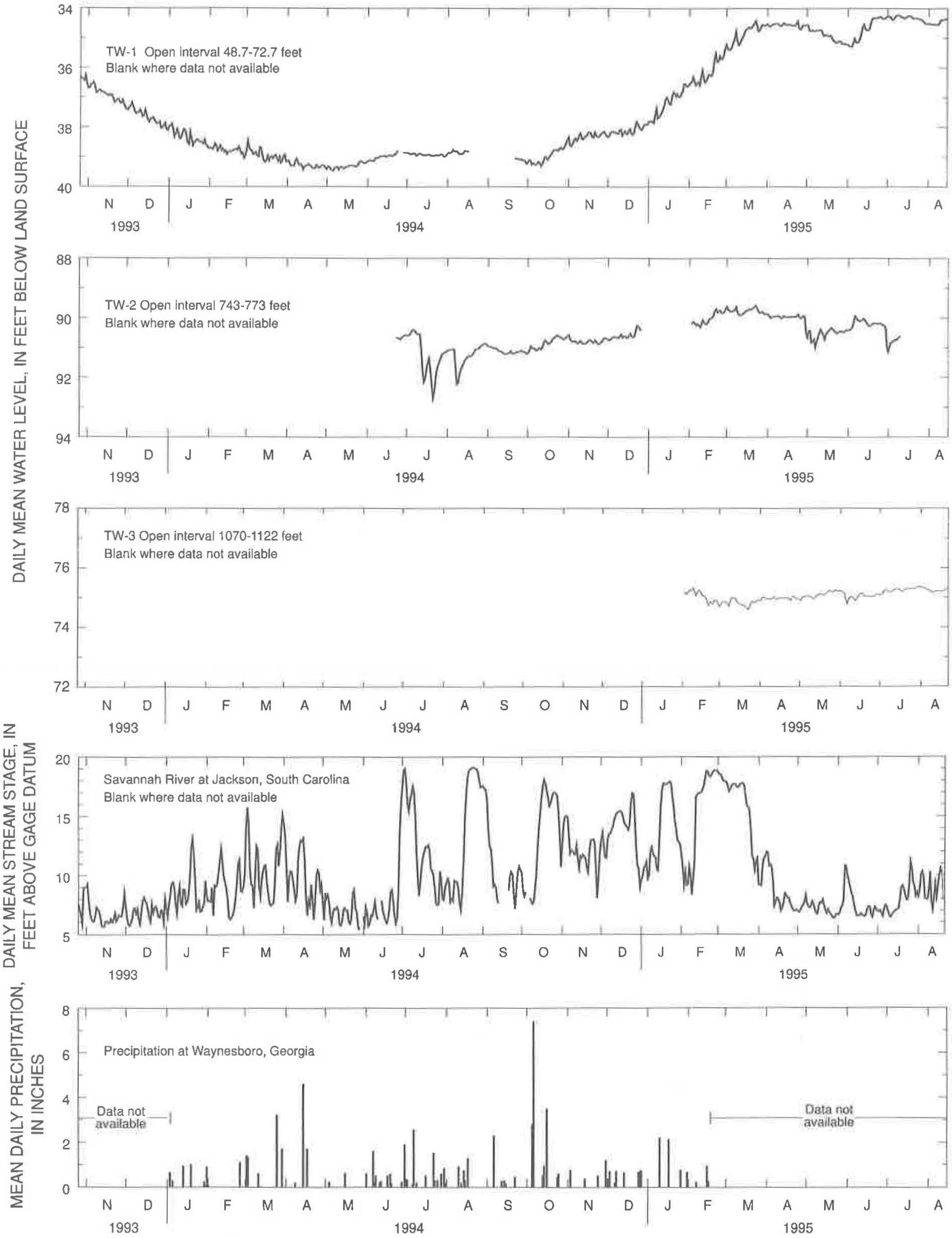


Figure 4. Daily mean ground-water levels in Girard test wells TW-1, TW-2, and TW-3; daily mean stream stage, Savannah River at Jackson, South Carolina; and precipitation at Waynesboro, Georgia.

Table 3. Statistical comparison of precipitation and stream-stage data to ground-water levels at the Girard hydrogeologic test site

[SRCC, Spearman rank correlation coefficient (Rho); <, less than; —, either not applicable or appropriate]

Factor	Water-bearing unit, test well, and correlation statistics					
	Upper Three Runs aquifer		lower Dublin aquifer		lower Midville aquifer	
	TW-1		TW-2		TW-3	
	SRCC	P-value	SRCC	P-value	SRCC	P-value
Savannah River stage at Jackson, South Carolina	0.590	0.1454	-0.113	0.0392	-0.362	<0.0001
Precipitation at Waynesboro, Georgia	.472	<.0001	.461	<.0001	.500	<.0001
Ground-water levels in TW-1	—	—	.683	<.0001	—	—
Ground-water levels in TW-2	.683	<.0001	—	—	.703	<.0001
Ground-water levels in TW-3	—	—	.703	<.0001	—	—

WATER-QUALITY DATA

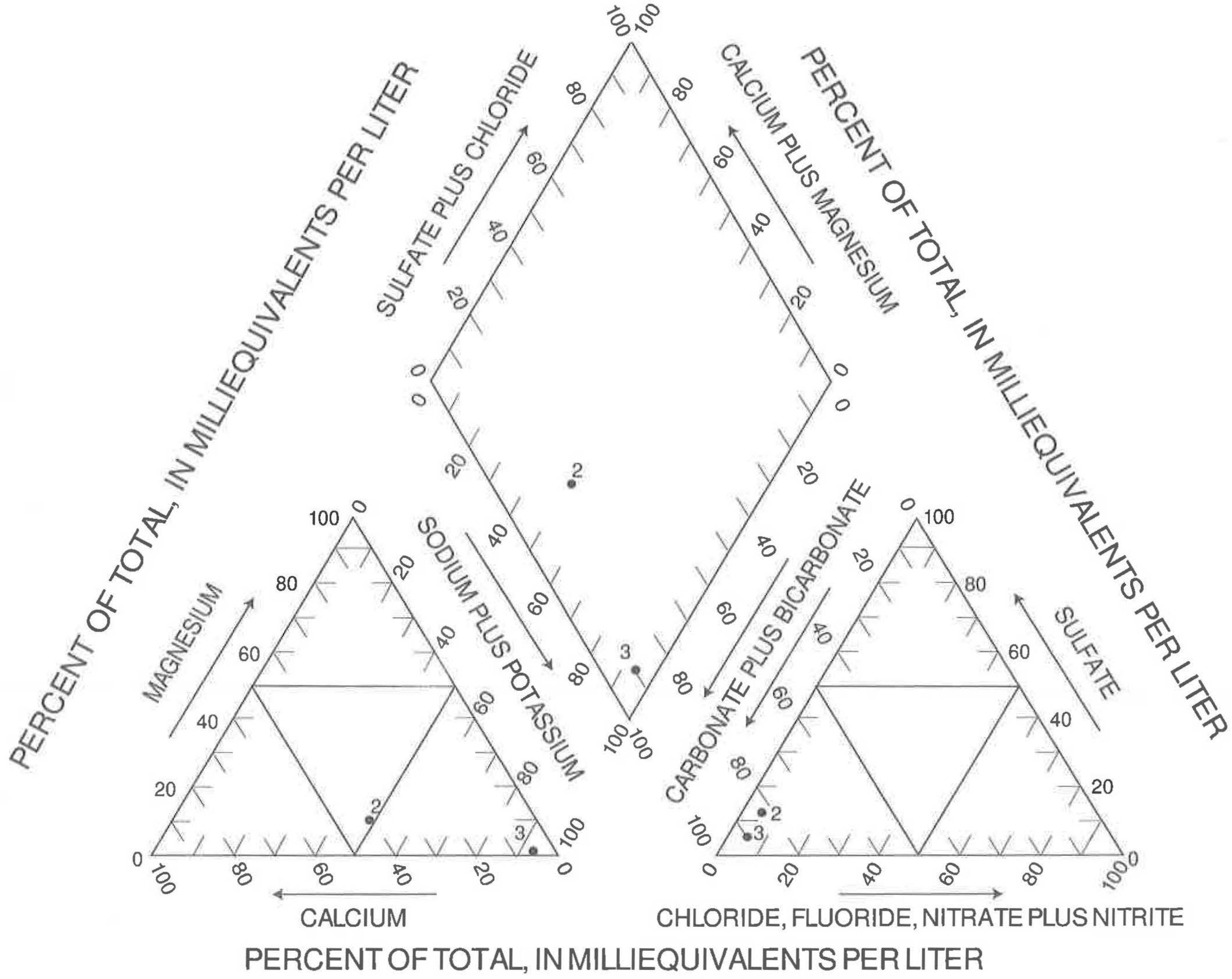
Water-quality data were used to describe the chemical variability of the water between the lower Dublin and lower Midville aquifers at the Girard hydrogeologic test site. Water samples were collected from wells TW-2 (lower Dublin aquifer) and TW-3 (lower Midville aquifer) following well development and a subsequent pumping period of at least 24 hours to determine the chemical characteristics of water from the screened water-bearing zones. Water samples were analyzed for dissolved concentrations of inorganic constituents and selected trace elements (table 4). Alkalinity, dissolved oxygen, pH, specific conductance, and water temperature were measured at the well head prior to the collection of water samples.

Constituents in water of the lower Dublin and lower Midville aquifer are very similar with a few exceptions. The hardness as $CaCO_3$ in water is less than 32 millgrams per liter (mg/L) from both aquifers and is classified as soft. Dissolved oxygen was not present in ground water from either TW-2 or TW-3, which is similar to the water chemistry observed in wells at the Millers Pond and Millhaven test sites (Clarke and others, 1994; 1996). This lack of dissolved oxygen probably is a function of the wells being located a significant distance from the outcrop area. The alkalinity of water in the two aquifers is somewhat less than that of rainwater, but the lower alkalinity is likely a function of this strongly reducing environment. The pH of the water in the two aquifers is basic, with the Dublin aquifer very near to neutral. Dissolved solids; and therefore, the spcific conductance of the water in both aquifers is relatively low.

All inorganic-constituents in water from wells TW-2 and TW-3 are within a similar range of such values for wells completed in the same aquifers in the area (Clarke and others, 1994; 1996). Also, comparison of the values between the two wells indicates that the inorganic constituents in water from the two aquifers are similar.

Significant differences in water quality between the two aquifers are apparent in the trace-element water chemistry. Of the 11 trace elements tested, barium, iron, and strontium proved to have disparate values between the two aquifers (table 4). All three values were significantly higher in TW-2 than in TW-3, with the 1,600 µg/L value for iron in TW-2 exceeding the U.S. Environmental Protection Agency (1990a,b) secondary drinking-water standards by 1,300 micrograms per liter (µg/L). The high iron value would limit the usefulness of the aquifer to agricultural purposes without extensive pretreatment. A trilinear plot of percentage composition (in milliequivalents per liter) of major ions was used to differentiate water quality in the two aquifers (fig. 5). This type of plot demonstrates that the percentage composition of the major ionic constituents in water of the two aquifers is different; therefore, the likelihood that the aquifers are hydraulically interconnected is small.

The reason(s) for these differences in trace-element chemistry are uncertain, but may be related to the original depositional environment of carbonate aquifer material. Limestone, the predominant carbonate sediment of the Georgia Coastal Plain, consists essentially of calcite; however, calcium carbonate also may be deposited biotically in the form of aragonitic shells. This could have significant impact on the water chemistry of an aquifer because aragonite permits ready substitution of larger cations like strontium and iron (Mason and Moore, 1982). Hence, the minor elements in a shelly marine sediment and the water that passes through that sediment probably differ in kind and amount according to the nature of the calcium carbonate in the original sediment.



EXPLANATION

● 2 TEST WELL AND IDENTIFICATION NUMBER

Figure 5. Percentage composition of major ionic constituents in ground water at the Girard hydrogeologic test site, January 23-27, 1995.

Table 4. Physical and chemical characteristics of ground-water samples collected at the Girard hydrogeologic test site [Analyses by U.S. Geological Survey; Units: mg/L, milligrams per liter; µS/cm, microSiemens per centimeter; µg/L, micrograms per liter; pCi/L, picocuries per liter; —, no data available; <, less than]

Property or constituent and units	TW-2	TW-3
Screened interval, in feet below land surface	743-773	1,070-1,122
Water-bearing unit (aquifer)	lower Dublin	lower Midville
Date sampled	01-26-95	01-23-95
Properties		
Alkalinity, as calcium carbonate, mg/L	58	84
Hardness as calcium carbonate, mg/L	[1/]31.5	[1/]5.31
Oxygen, dissolved, mg/L	<0.1	<0.1
pH, standard units	7.2	8.6
Specific conductance, in µS/cm	135	180
Water temperature, degrees Celsius	22.5	23.0
Dissolved solids		
Sum of constituents, mg/L	88	111
Inorganic constituents		
Bromide, dissolved, mg/L	.20	.10
Calcium, dissolved, mg/L	10.0	1.8
Chloride, dissolved, mg/L	1.7	2.2
Fluoride, dissolved, mg/L	.2	.4
Magnesium, dissolved, mg/L	1.7	.2
Nitrogen, ammonia dissolved, mg/L	.06	.08
Nitrogen, nitrite dissolved, mg/L	<.01	<.01
Nitrogen, ammonia and organic dissolved, mg/L	<.2	<.2
Nitrogen, nitrate and nitrite, dissolved, mg/L	<.02	<.02
Orthophosphate phosphorus, dissolved, as phosphorus, mg/L	.04	.03
Phosphorus, dissolved, mg/L	.06	<.02
Potassium, dissolved, mg/L	3.6	1.4
Sulfide, total, mg/L	–	<1.0
Sodium, dissolved, mg/L	12	38
Sulfate, dissolved, mg/L	8.9	4.2
Silica, dissolved, mg/L	13	12
Trace elements		
Aluminum, dissolved, µg/L	<20	50
Barium, dissolved, µg/L	92	9
Beryllium, dissolved, µg/L	1	1
Cadmium, dissolved, µg/L	<1	<1
Chromium, dissolved, µg/L	<5	<5
Cobalt, dissolved, µg/L	<3	<3
Copper, dissolved, µg/L	<10	<10
Iron, dissolved, µg/L	1,600	190
Lead, dissolved, µg/L	<10	<10
Lithium, dissolved, µg/L	<4	<4
Manganese, dissolved, µg/L	66	11
Molybdenum, dissolved, µg/L	<10	<10
Nickel, dissolved, µg/L	<10	<10
Silver, dissolved, µg/L	<1	<1
Strontium, dissolved, µg/L	130	30
Vanadium, dissolved, µg/L	<6	<6
Zinc, dissolved, µ/g/L	<4	<4

[1/] Estimated value from calcium carbonate.

SUMMARY AND CONCLUSIONS

This report presents geologic, hydrologic, and water-quality data collected at the Girard hydrogeologic test site (Girard site) in southeastern Burke County, Ga. Data collected include the depth, thickness, geologic properties, paleontology, hydrologic properties, and water chemistry of the Coastal Plain aquifers at the site.

During March and April 1992, continuous, 2-in.-diameter core was collected from land surface to a total depth of 1,385 feet (ft) using the wire-line coring method. The core penetrated through Eocene, Paleocene, and Cretaceous Coastal Plain sediments and bottomed in pre-Cretaceous basement rock at a depth of 1,385 ft.

To characterize the vertical distribution of hydraulic head and water quality of Coastal Plain sediments at the Girard site, test wells were installed at three water-bearing intervals at depths ranging from 72 to 1,122 ft. The shallowest well was completed in the unconfined Upper Three Runs aquifer, and the other two wells were completed in the confined lower Dublin and lower Midville aquifers.

Lithologic and paleontologic evidence from the Girard core suggests that at least 13 distinct lithologic units of Late Cretaceous and Tertiary age are present in the vicinity of the site, with a total thickness of 1,374 ft. These sediments unconformably overlie consolidated red beds of Mesozoic age. Microfossils were examined for dinoflagellates, pollen, benthic foraminifera, and calcareous nanofossils. Eleven of the samples yielded age-diagnostic assemblages. Paleocene palynomorphs from the Girard core were taken from four samples ranging in depths from 484.3 to 532.5 ft; samples between 327 and 415 ft range in age from the early Eocene to the early part of the middle Eocene; samples between 258 and 322 ft are characteristic of the late part of the middle Eocene, and the sample at 211.1 to 211.3 ft contains species that suggest a late Eocene age, but are not wholly diagnostic.

Water-bearing units at the Girard site were related to previously named hydrogeologic units by comparing core and geophysical data collected at the site to interpreted borehole data from nearby sites. This comparison indicates that several equivalents to hydrogeologic units from the literature are present at the Girard site and include the Upper Three Runs aquifer in upper Eocene sediments, the Gordon aquifer in middle Eocene sediments, the Millers Pond aquifer in upper Paleocene sediments, the Dublin aquifer system in lower Paleocene and Upper Cretaceous sediments, and the Midville aquifer system in Upper Cretaceous sediments.

Laboratory analyses to determine vertical hydraulic conductivity and porosity were performed on selected low permeability core samples. Values of horizontal hydraulic conductivity ranged from 3.43×10^{-5} ft/d to 9.41×10^{-2} ft/d. The lowest values were measured in a clay near the top of the upper Midville confining unit.

During December 1994 and January 1995, aquifer tests were conducted and analyzed by Clemson University, Clemson, S.C., personnel at two of the three test wells located at the Girard site. Aquifer-test data indicate that at the Girard site the lower Dublin aquifer is much more productive than is the lower Midville. The horizontal hydraulic conductivity of 177 ft/d calculated for the lower Dublin is almost 20 times that of 8.9 ft/d for the lower Midville. In addition, the transmissivity of 5,300 ft^2/d for the lower Dublin is almost 5 times greater than the 1,130 ft^2/d of the lower Midville, and finally the specific capacity of 3.52 gal/min/ft in the lower Dublin is almost twice the 1.85 gal/min/ft value of the lower Midville. Extended pumping does not indicate interaquifer leakage between the lower Midville and lower Dublin aquifers. This lack of response, however, may be due to the large vertical distance (297 ft) between the two screened intervals—an interval that includes the upper Midville and lower Midville confining units—and does not necessarily reflect the competency of the confining units.

Horizontal hydraulic conductivity for several of the aquifers at the Girard site was estimated by applying logarithmic regression models to borehole resistivity data. The mean horizontal hydraulic conductivity estimate for the lower Dublin aquifer was compared to the horizontal hydraulic conductivity value determined from aquifer testing in well TW-2 completed in the lower Dublin aquifer. The estimated mean hydraulic conductivity of 26.93 ft/d was about 85 percent lower than the value determined from the TW-2 aquifer test of 177 ft/d. A comparison of the mean vertical hydraulic conductivity based on resistivity estimates and the vertical hydraulic conductivity from the aquifer test on TW-3 was also completed For the lower Midville aquifer. The estimated mean hydraulic conductivity of 24.74 ft/d was about 278 percent higher than the value of 8.9 ft/d determined from the TW-3 aquifer test. These disparate conductivity values seem large; however, given the precision of the methodologies, they are in relative agreement.

Following well completion and development, water-level recorders were installed in each well to continuously monitor water-level fluctuations and trends in water-bearing units. Water levels were measured on March 13, 1995, in the three wells at the site yielding head measurements of 34.98 ft for TW-1, 89.85 ft for TW-2, and 74.93 ft for TW-3. These values, when corrected for altitude differences between wells, show an upward gradient between the wells TW-2 and TW-3, indicating a potential for discharge from the lower Midville aquifer into the lower Dublin aquifer.

Hydrographs show relations between ground-water levels at the Girard test site; stream stage of the Savannah River near Jackson, S.C.; and precipitation at the city of Waynesboro, Ga. Because of the relatively short period of record available for the three wells, few trends are evident in the data. The period of record for TW-1 is somewhat longer, however, allowing a few conclusions. It is clear that there neither is instantaneous response to rainfall in the TW-1 nor loading from the Savannah River for the period of record. The 4-ft water-level decline in well TW-1 between 1994 and 1995 is incongruous and not readily explained. This could be the result of micro-climatic changes, such as less localized precipitation or an increase in evapotranspiration due to localized temperature increases or a change in local agricultural crop type.

A statistical comparison of stream stage, ground-water levels, and precipitation was performed using Spearman's rank correlation coefficient. Based on the SRCC, two clearly significant correlations are apparent. The SRCC of 0.683 between water levels in TW-1 and TW-2 may be caused by mass loading in the upper Dublin aquifer that is in response to recharge of the Upper Three Runs aquifer. In addition, some interaquifer leakage induced by pumping of the lower Dublin aquifer may be affecting the water level in the Upper Three Runs aquifer. These are possibilities, but other explanations could be plausible given the short period of record. The SRCC of 0.703 for the two deeper wells, TW-2 and TW-3, indicates that the fluctuations in water levels for these two wells also is correlative based on the Spearman's rank correlation coefficient. The underlying causal factor (or factors) for this correlation is uncertain. However, the data suggest that this may be caused by mass loading from precipitation.

Water samples were collected from TW-2 (lower Dublin aquifer) and TW-3 (lower Midville aquifer) to determine the chemical character of the screened water-bearing zones. The water quality in the lower Dublin and lower Midville aquifers is very similar with a few exceptions. The hardness value of both aquifers is less than 6; and are therefore, considered soft. The dissolved oxygen content in both aquifers is 0.0 mg/L, a value similar to most other wells in the area. The alkalinity of the two aquifers is somewhat less than the average for rainwater, but this likely is a function of the strongly reducing environment. The pH of the two aquifers is basic, with the Dublin aquifer very near to neutral. The dissolved solids, and therefore the specific conductance, is very low. Inorganic constituents in the two wells are similar to other wells completed in the same aquifers in the area.

Although concentrations of most constituents in ground water from the lower Dublin and lower Midville are similar, trace-element chemistry shows some significant differences in water quality between the two aquifers. Of the 11 trace elements tested, barium, iron, and strontium proved to have disparate values between the two aquifers. The values for barium, iron, and strontium were significantly higher in the lower Dublin aquifer than in the lower Midville aquifer, with the 1,600 micrograms per liter (μg/L) value in TW-2 for iron exceeding the U.S. Environmental Protection Agency drinking-water standards by 1,300 μg/L. This type of high iron value limits the usefulness of the aquifer for agricultural purposes unless extensive pretreatment is utilized. A trilinear plot indicates that the percentage compositions of major ions is different in the lower Dublin and lower Midville aquifers, indicating that the units are probably hydraulically separated.

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APPENDIX

Lithologic description of Girard hydrogeologic test site, Burke County, Georgia

Lithology	Depth below land surface (in feet)
Moderately to well-sorted sand and clayey sand with a few thin beds of sandy clay. Sand is fine to coarse with clay matrix (5 to 30 percent) and is mostly yellowish gray with some red and purple staining.	0-58
Moderately to poorly sorted sand with granules and pebbles (5 to 10 percent) interbedded with clayey sand. Sand is medium to very coarse and is yellowish gray. Clayey sand is very fine to fine with clay matrix (10 to 20 percent) and is pale red to purple.	58-72
Moderately to well-sorted sand and clayey sand. Sand is very fine to coarse and is yellowish orange with very fine lignite and thin beds of pale olive clay from 81 to 86 ft.	72-91
Moderately to poorly sorted clayey sand. Sand is fine to coarse with clay matrix (10 to 35 percent) and is yellowish gray.	91-104
Moderately to well-sorted calcareous sand and sandy carbonate. Sand is fine to coarse and light olive gray to white with carbonate grains and matrix (20 to 60 percent). Carbonate grains include gastropods, pelecypods and bryozoans. Shark teeth, phosphatic grains, and glauconite observed from 120 to 125 ft and from 133 to 135 ft.	104-139
Well-sorted calcareous, clayey sand. Sand is very fine to fine with a matrix of carbonate (20 to 35 percent) and clay (20 to 25 percent) and varies from grayish yellow to medium light gray. Clay laminae are abundant from 172 to 183 ft. Pelecypods and glauconite are present.	139-183
Lithified carbonate wackestone to grainstone with very fine to medium sand (30 to 40 percent). Interval is greenish gray with pelecypods, large oyster fragments (10 to 25 percent), and glauconite (1 percent).	183-193
Moderately to well-sorted calcareous sand. Sand is very fine to fine with clay laminae from 209 to 211 ft and grades down to medium-to-coarse with pelecypods (10 to 25 percent) and glauconite (1 percent). Matrix is carbonate (10-25 percent) and clay (5-10 percent). Interval is light olive gray to grayish green.	193-233
Lithified carbonate wackestone to packstone with pelecypods and bryozoans, and fine to coarse sand (10 to 25 percent), glauconite (5-20 percent), and clay matrix (5 percent). Interval is partially silicified and phosphatized with pelecypod moldic porosity (5 to 25 percent) and is grayish green.	233-244
Laminated clay with thin laminae and beds of very fine sand and sand-filled burrows. Clay is calcareous (10 to 20 percent) with glauconite (5 percent) and is grayish green. Laminae of lignitic (5 percent) sand at 252 ft.	244-255
Well-sorted, calcareous, clayey sand to sandy calcareous clay with sandy carbonate nodules. Sand is very fine to fine with matrix of clay (20 to 30 percent) and carbonate (10 to 25 percent). Pelecypods (5 to 15 percent), glauconite (1 to 10 percent) and lignite (1 to 2 percent) are observed. Interval is wavy-laminated to burrow-mottled and is dusky yellow green.	255-322
Partially lithified to lithified, sandy carbonate wackestone to packstone with pelecypods, bryozoans, gastropods, and glauconite (5 to 8 percent). Sand is fine to coarse (10 to 40 percent). Hydrocarbon smell and staining, pelecypod- and gastropod-moldic porosity (5 to 40 percent), pyrite (2 to 5 percent) and glauconite (8 percent) observed at top of interval. Interval is light olive gray.	322-341

Lithologic description of Girard hydrogeologic test site, Burke County, Georgia—Continued

Lithology	Depth below land surface (in feet)
Moderately sorted calcareous sand. Sand is fine to medium with carbonate matrix (5 to 10 percent) and grains (10 to 25 percent), including pelecypods and oysters. Shark teeth and bone fragments are present from 360 to 365 ft. Interval contains glauconite (1 percent) and lignite (1 percent), and is light olive gray.	341-380
Moderately to poorly sorted sand. Sand is medium to very coarse with minor clay matrix (5 to 10 percent), clay laminae (5 to 10 percent) and clay-lined burrows (1-2 percent). Interval is slightly calcareous (1 to 2 percent) and varies from light olive gray to yellowish gray.	380-423
Massively bedded clay with pyrite (10 to 20 percent) along vertical fractures from 423 to 428 ft and patchy staining of iron oxide from 431 to 435 ft. Interval is white with yellow iron staining.	423-436
Moderately to very poorly sorted sand with granules (5 percent) and pebbles (1 to 2 percent) disseminated in sand, lags of granules (10 to 30 percent) at 457, 477 and 481 ft. Sand is fine to very coarse and generally is finer towards the top of the interval. Interval contains clay matrix (less than 10 percent) and mica (1 to 2 percent). A few large clay clasts are observed at 477 and 481 ft.	436-481
Laminated clay with lenses of glauconitic sand and sand-filled burrows. The interval contains mica and pyrite on bedding planes and is black.	481-490
Poorly to well-sorted calcareous sand and sandy carbonate. Sand is fine to very coarse with carbonate matrix and grains (5 to 20 percent), glauconite (2 to 5 percent), and clay matrix (5 to 15 percent). Carbonate wackestone to packstone contains pelecypods, oysters, sand (10 to 25 percent), and glauconite (2-10 percent), and includes clay clasts (25 percent) and moldic porosity (5 to 10 percent) from 504 to 509 ft. Sand from 517 to 518 ft includes glauconite (20 percent) and shark teeth. Interval is unlithified to partially lithified and is greenish gray to light olive gray.	490-518
Laminated black clay interbedded and interlaminated with very fine to coarse clayey sand. Interval includes glauconite (1 to percent) and mica (1 to 2 percent). Sand from 533 to 542 is poorly sorted and medium to very coarse with granules (10 to 20 percent), clay matrix (10-20 percent) and pyrite (2 to 5 percent), and is light olive gray.	518-542
Moderately to poorly sorted clayey sand interbedded with sandy clay. Sand is fine to very coarse with granules (5 to 15 percent), pebbles (1 to 5 percent), mica (2 to 3 percent) and clay matrix (5 to 15 percent), and is very light gray. Clay includes sand (10 to 35 percent) and is stained with yellow and red iron oxides. Smoky quartz granules and pebbles are common. Granule lag present at 600 ft.	542-600
Clay with very fine to coarse sand (10 to 25 percent). Clay is very light gray and is stained with yellow and red iron oxide along root pattern near top of interval and in large patchy pattern. Interval grades into underlying sand.	600-635
Moderate to very poorly sorted sand. Sand is fine to very coarse grained with granules (5 to 15 percent) of clear and smoky quartz, clay matrix (2 to 10 percent), and mica (1 to 3 percent). Abundant granules and heavy minerals present at 642 and 679 ft. Interval is cross-bedded and is very light gray to white.	635-679
Clay with very fine to medium sand (10 to 20 percent). Coloration is very light gray with patchy staining of red iron oxide.	679-690

Lithologic description of Girard hydrogeologic test site, Burke County, Georgia—Continued

Lithology	Depth below land surface (in feet)
Moderately to poorly sorted sand. Sand is fine to very coarse with clay matrix (2 to 10 percent) and mica (1 to 3 percent) and is cross-bedded and very light gray. Granules (10 to 25 percent) and lignite (2 to 5 percent) are present at 710 and 732 ft. Laminated, very fine to fine medium gray sand with clay matrix (20 to 30 percent), lignite (5 percent) and mica (5 to 8 percent) is present from 720 to 722 ft.	690-732
Clay interbedded with sand. Clay is silty (10 to 15 percent), laminated and black. Sand is very fine to medium and is very light gray. Mica (5 to 10 percent) is present.	732-752
Moderately to well-sorted sand. Sand is fine to coarse and is light olive gray with medium gray clay laminae (5 to 10 percent). Lignite (2 to 3 percent) is present in laminae from 771 to 780 ft.	752-780
Moderately to well-sorted sand interbedded and interlaminated with clay. Sand is very fine to medium with clay matrix (5 to 10 percent), mica (1 to 5 percent), lignite (1 to 2 percent), and glauconite (1 percent), and is laminated and burrowed. Sand is light olive gray to olive gray. Clay is wavy-laminated and black, and contains mica (2 to 3 percent) and thin laminae and lenses of sand. Shark teeth present at 830, 852, and 866 ft. Lag of pebbles and granules present at 828 and 875 ft.	780-875
Clay with pyritic, sand-filled burrows. Interval is light to medium gray.	875-884
Moderately to well-sorted sand with thin beds of clay. Sand is very fine to coarse with clay matrix (5 to 10 percent), lignite (1 to 2 percent) and mica (1 to 2 percent), and is light olive gray. Clay is medium gray. Interval from 889 to 908 ft was not recovered.	884-910
Clay is silty (10 to 20 percent) and sandy (5 to 15 percent), and is light olive gray with yellow staining of iron oxide along root traces and as patches.	910-920
Well-sorted sand. Sand is very fine to fine with clay matrix (0 to 5 percent), black clay laminae (5 percent) and mica (1 to 2 percent). Sand is light olive gray and is laminated to cross-bedded with lignite (2 to 5 percent) along laminae.	920-940
Moderately to poorly sorted sand. Sand is medium to very coarse with granules (5 to 10 percent) and pebbles (0 to 5 percent), and is white. Interval is cross-bedded.	940-958
Poorly to well-sorted sand and clayey sand interbedded with clay. Grain size is highly variable. Sand is either fine to very coarse with granules (5 to 15 percent) and clay matrix (10 to 20 percent), or very fine to fine with mica (2 to 10 percent) and lignite (2 to 5 percent). Clay beds are 3- to 5-ft thick and silty (5 to 15 percent), and are medium light gray with red and yellow patches of iron oxide. Crossbeds observed in coarse sands.	958-1,002
Poorly to well-sorted sand. Grain size is highly variable. Sand is fine to very coarse and generally has very little clay matrix (0 to 5 percent). Portions of interval are lignitic (2 to 5 percent) with pyrite (1 to 2 percent). Granules (10 to 35 percent) and pebbles (15 to 20 percent) are present at 1,013 and 1,039 ft, and from 1,056 to 1,062 ft. Interval is very light gray.	1,002-1,062
Clay with silt (20 to 30 percent); very light gray.	1,062-1,070
Poorly to well-sorted sand. Grain size is highly variable. Sand is fine to very coarse with clay matrix (5 to 10 percent) and mica (1 to 2 percent). Granules (5 to 25 percent) and pebbles (0 to 5 percent) are present at 1,083; 1,106; 1,123; and 1,138 ft. Crossbeds and thin beds of gray clay observed.	1,070-1,139
No recovery.	1,139-1,168

Lithologic description of Girard hydrogeologic test site, Burke County, Georgia—Continued

Lithology	Depth below land surface (in feet)
Moderately to very poorly sorted clayey sand and sandy clay. Grain size is variable with beds of fine to medium sand, and beds of fine to very coarse sand with granules (5 to 25 percent), pebbles (5 percent), and clay clasts (1 percent). Sand generally has a silty clay matrix (5 to 25 percent). Clay is sandy (10 to 30 percent). Cristobalite is present in the clay matrix and partially lithifies both sand and clay beds. Interval is greenish gray to pale olive. Clay is partially stained with reddish brown iron oxide.	1,168-1,265
Moderately to very poorly sorted clayey sand and sandy clay. Grain size is highly variable with beds of very fine to fine sand and beds of fine to very coarse sand. Granules (10 to 50 percent) and pebbles (0 to 10 percent) are present at 1,284; 1,296; 1,311; and 1,317 ft, and in a thick interval from 1,369 to 1,375 ft. Sand generally has a silty clay matrix (5 to 25 percent). Clay is sandy (10 to 30 percent). Cristobalite is present in the clay matrix and partially lithifies both sand and clay beds. Interval is greenish gray to pale olive. Clay is partially stained with reddish brown iron oxide. Red siltstone clasts present at 1,362 and 1,374 ft.	1,265-1,375
Siltstone and silty, clayey sand. Siltstone contains very fine sand (5 to 10 percent) and is moderate reddish brown and light greenish gray. Sand is fine to very coarse with clay matrix (5 to 10 percent), and contains large clasts (5 percent) of crystalline rock and slate.	1,375-1,385

GEORGIA DEPARTMENT OF NATURAL RESOURCES
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GEORGIA GEOLOGIC SURVEY

Prepared in cooperation with the
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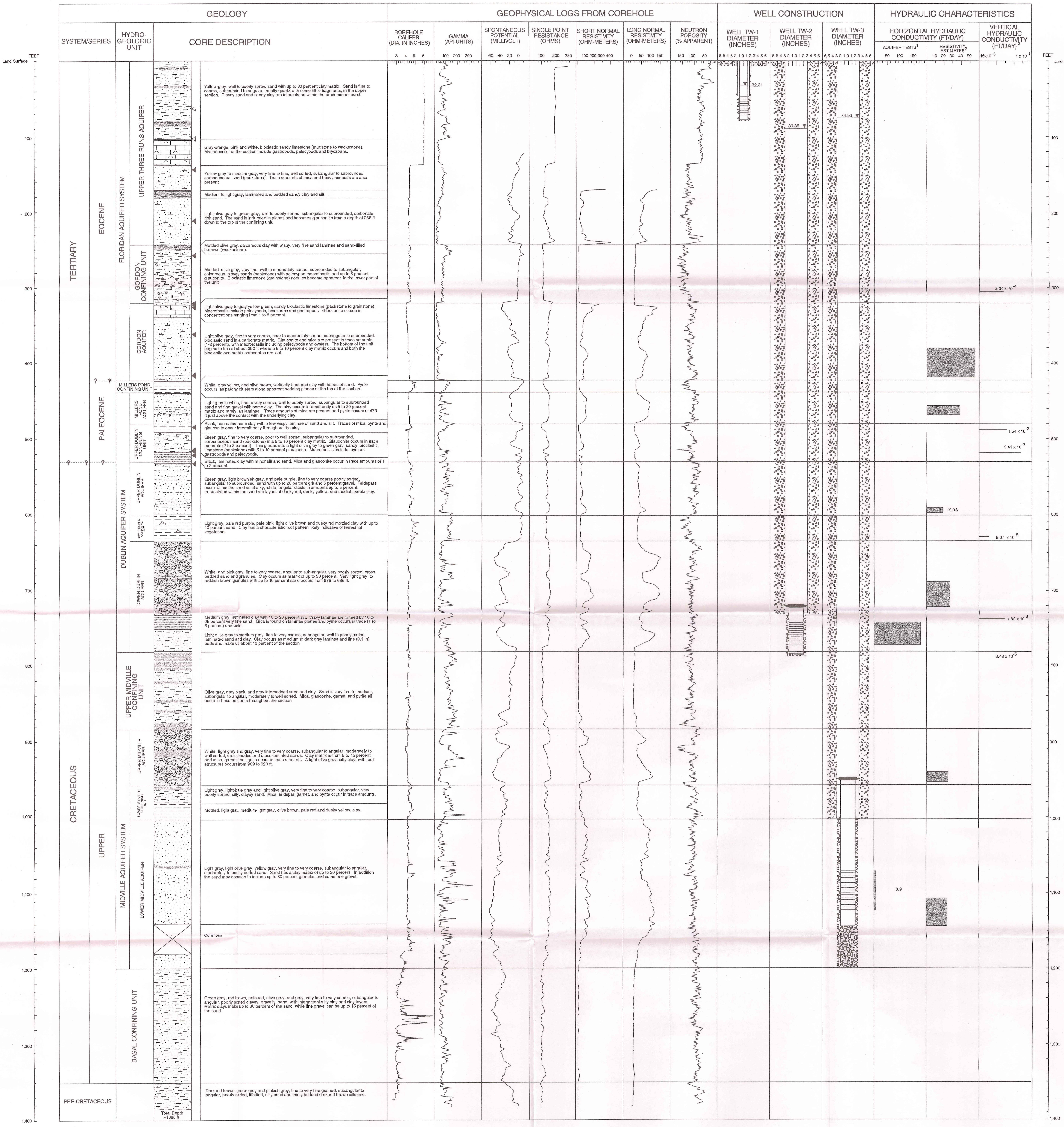
U.S. GEOLOGICAL SURVEY
AND
U.S. DEPARTMENT OF ENERGY

INFORMATION CIRCULAR 100
PLATE 1



Yellow-gray, well to poorly sorted sand with up to 30 percent clay matrix. Sand is fine to coarse, subrounded to angular, mostly quartz with some lithic fragments, in the upper section. Clayey sand and sandy clay are intercalated within the predominant sand.

Gray-orange, pink and white, bioclastic sandy limestone (mudstone to wackestone). Macrofossils for the section include gastropods, pelecypods and bryozoans.

Yellow gray to medium gray, very fine to fine, well sorted, subangular to subrounded carbonaceous sand (packstone). Trace amounts of mica and heavy minerals are also present.

Medium to light gray, laminated and bedded sandy clay and silt.

Light olive gray to green gray, well to poorly sorted, subangular to subrounded, carbonate rich sand. The sand is indurated in places and becomes glauconitic from a depth of 238 ft down to the top of the confining unit.

Mottled olive gray, calcareous clay with wispy, very fine sand laminae and sand-filled burrows (wackestone).

Mottled, olive gray, very fine, well to moderately sorted, subrounded to subangular, calcareous, clayey sands (packstone) with pelecypod macrofossils and up to 5 percent glauconite. Bioclastic limestone (grainstone) nodules become apparent in the lower part of the unit.

Light olive gray to gray yellow green, sandy bioclastic limestone (packstone to grainstone). Macrofossils include pelecypods, bryozoans and gastropods. Glauconite occurs in concentrations ranging from 1 to 8 percent.

Light olive gray, fine to very coarse, poor to moderately sorted, subangular to subrounded, bioclastic sand in a carbonate matrix. Glauconite and mica are present in trace amounts (1-2 percent), with macrofossils including pelecypods and oysters. The bottom of the unit begins to fine at about 390 ft where a 5 to 10 percent clay matrix occurs and both the bioclastic and matrix carbonates are lost.

White, gray yellow, and olive brown, vertically fractured clay with traces of sand. Pyrite occurs as patchy clusters along apparent bedding planes at the top of the section.

Light gray to white, fine to very coarse, well to poorly sorted, subangular to subrounded sand and fine gravel with some clay. The clay occurs intermittently as 5 to 30 percent matrix and rarely, as laminae. Trace amounts of mica are present and pyrite occurs at 479 ft just above the contact with the underlying clay.

Black, non-calcareous clay with a few wispy laminae of sand and silt. Traces of mica, pyrite and glauconite occur intermittently throughout the clay.

Green gray, fine to very coarse, poor to well sorted, subangular to subrounded, carbonaceous sand (packstone) in a 5 to 10 percent clay matrix. Glauconite occurs in trace amounts (2 to 3 percent). This grades into a light olive gray to green gray, sandy, bioclastic, limestone (packstone) with 5 to 10 percent glauconite. Macrofossils include, oysters, gastropods and pelecypods.

Black, laminated clay with minor silt and sand. Mica and glauconite occur in trace amounts of 1 to 2 percent.

Green gray, light brownish gray, and pale purple, fine to very coarse poorly sorted, subangular to subrounded, sand with up to 20 percent grit and 5 percent gravel. Feldspars occur within the sand as chalky, white, angular clasts in amounts up to 5 percent. Intercalated within the sand are layers of dusky red, dusky yellow, and reddish purple clay.

Light gray, pale red purple, pale pink, light olive brown and dusky red mottled clay with up to 10 percent sand. Clay has a characteristic root pattern likely indicative of terrestrial vegetation.

White, and pink gray, fine to very coarse, angular to sub-angular, very poorly sorted, cross bedded sand and granules. Clay occurs as matrix of up to 30 percent. Very light gray to reddish brown granules with up to 10 percent sand occurs from 679 to 685 ft.

Medium gray, laminated clay with 10 to 20 percent silt. Wavy laminae are formed by 10 to 25 percent very fine sand. Mica is found on laminae planes and pyrite occurs in trace (1 to 5 percent) amounts.

Light olive gray to medium gray, fine to very coarse, subangular, well to poorly sorted, laminated sand and clay. Clay occurs as medium to dark gray laminae and fine (0.1 in) beds and make up about 10 percent of the section.

Olive gray, gray black, and gray interbedded sand and clay. Sand is very fine to medium, subangular to angular, moderately to well sorted. Mica, glauconite, garnet, and pyrite all occur in trace amounts throughout the section.

White, light gray and gray, very fine to very coarse, subangular to angular, moderately to well sorted, crossbedded and cross-laminted sands. Clay matrix is from 5 to 15 percent, and mica, garnet and lignite occur in trace amounts. A light olive gray, silty clay, with root structures occurs from 909 to 920 ft.

Light gray, light-blue gray and light olive gray, very fine to very coarse, subangular, very poorly sorted, silty, clayey sand. Mica, feldspar, garnet, and pyrite occur in trace amounts.

Mottled, light gray, medium-light gray, olive brown, pale red and dusky yellow, clay.

Light gray, light olive gray, yellow gray, very fine to very coarse, subangular to angular, moderately to poorly sorted sand. Sand has a clay matrix of up to 30 percent. In addition the sand may coarsen to include up to 30 percent granules and some fine gravel.

Core loss

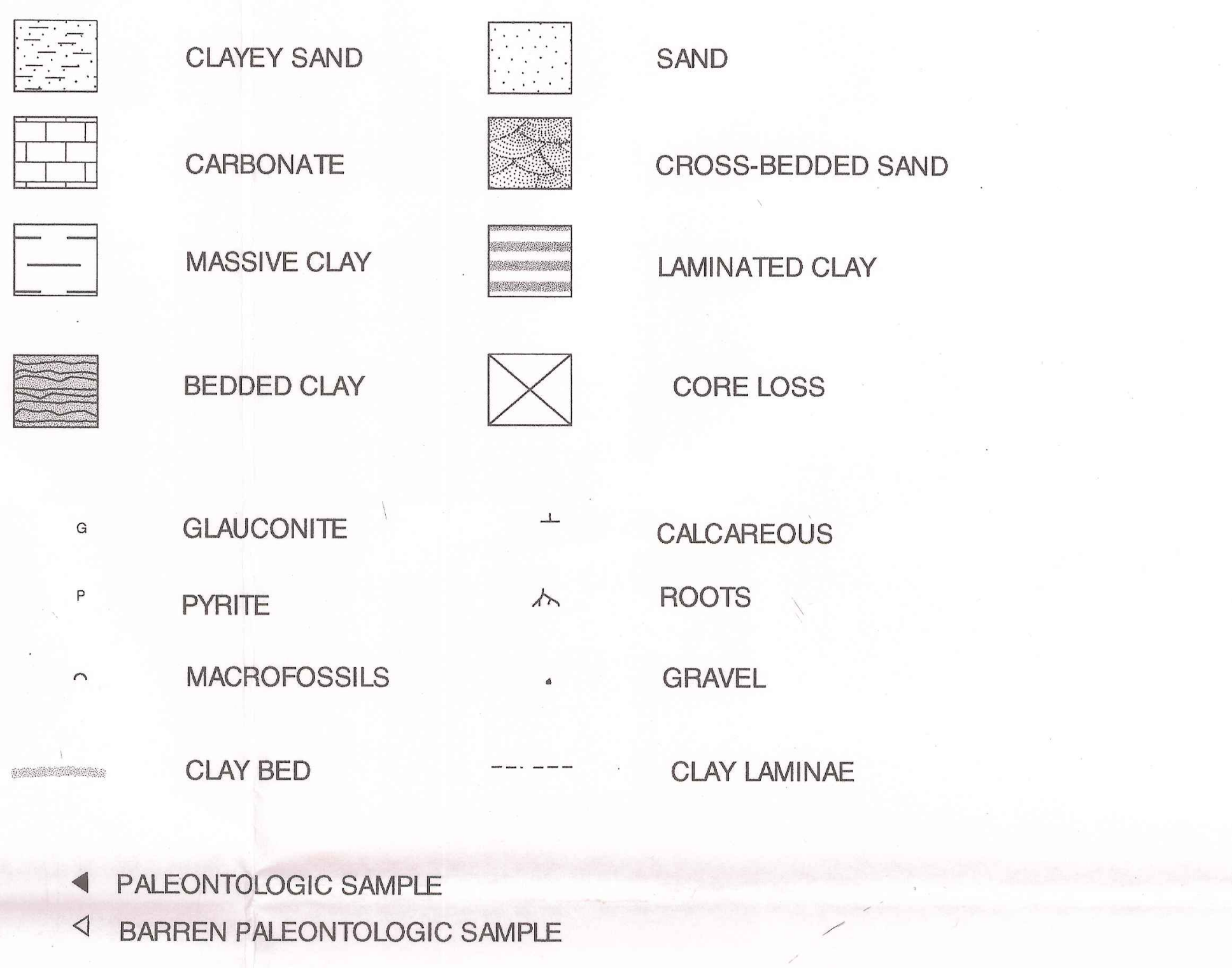
Green gray, red brown, pale red, olive gray, and gray, very fine to very coarse, subangular to angular, poorly sorted clayey, gravelly, sand, with intermittent silty clay and clay layers. Matrix clays make up to 30 percent of the sand, while fine gravel can be up to 15 percent of the sand.

Dark red brown, green gray and pinkish gray, fine to very fine grained, subangular to angular, poorly sorted, lithified, silty sand and thinly bedded dark red brown siltstone.

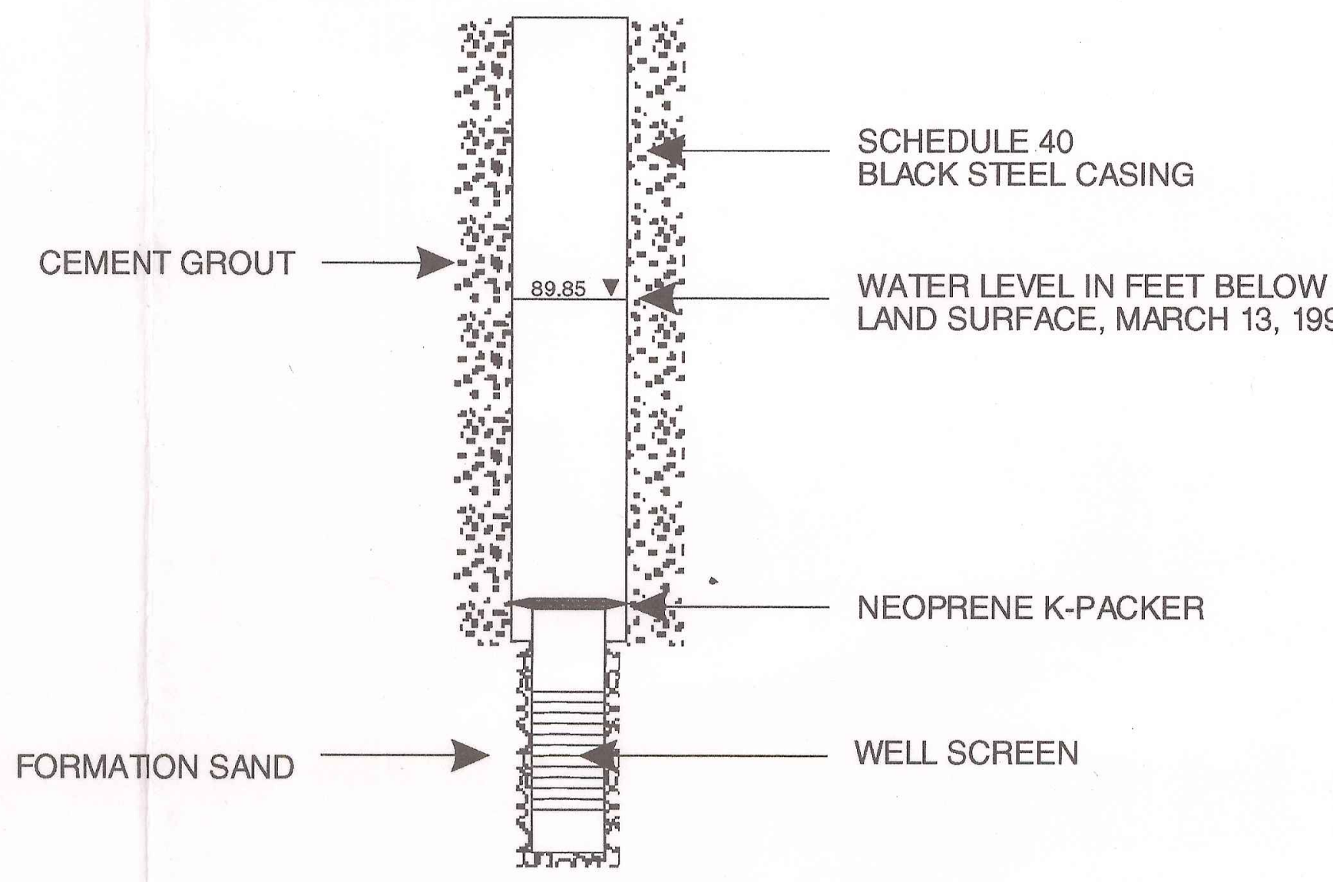
EXPLANATION

LITHOLOGY AND PALEONTOLOGY

(See Appendix for detailed lithologic description)



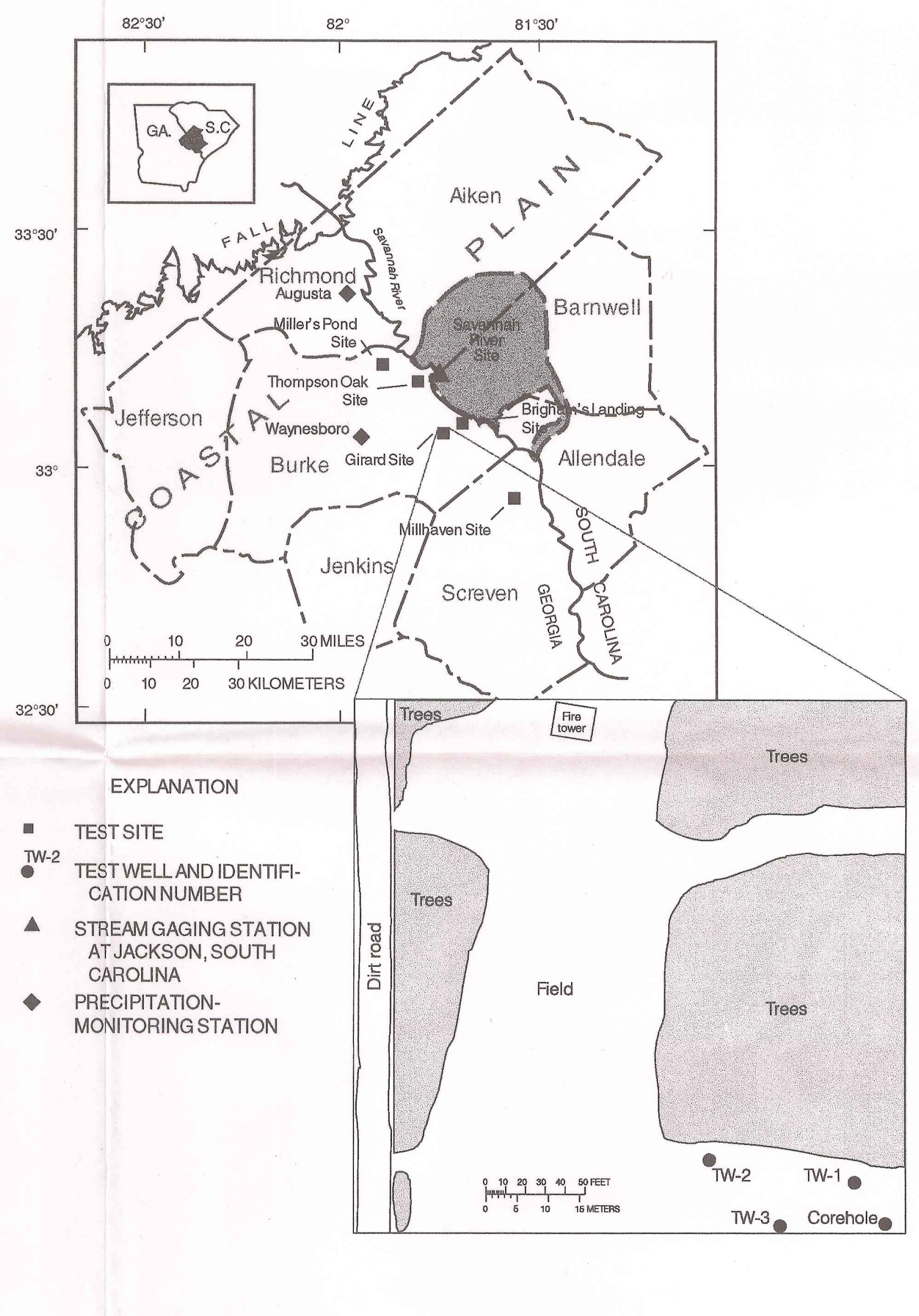
WELL CONSTRUCTION AND WATER LEVEL



HYDRAULIC CHARACTERISTICS

1. Determined from aquifer test (Leutkehans and Hodges, 1995a, b).
2. Estimated from formation resistivity logs (Baum, 1995).
3. Determined from hydraulic analysis of core (Core Laboratories Inc., New Orleans, La.)

LOCATION OF GIRARD HYDROGEOLOGIC TEST SITE TEST WELLS DRILLED AT THE SITE, AND OTHER TEST SITES



HYDROGEOLOGIC UNITS, LITHOLOGY, GEOPHYSICAL LOGS, WELL CONSTRUCTION AND HYDRAULIC CHARACTERISTICS AT THE GIRARD HYDROGEOLOGIC TEST SITE, BURKE COUNTY, GEORGIA.

Editor: Carolyn Casteel