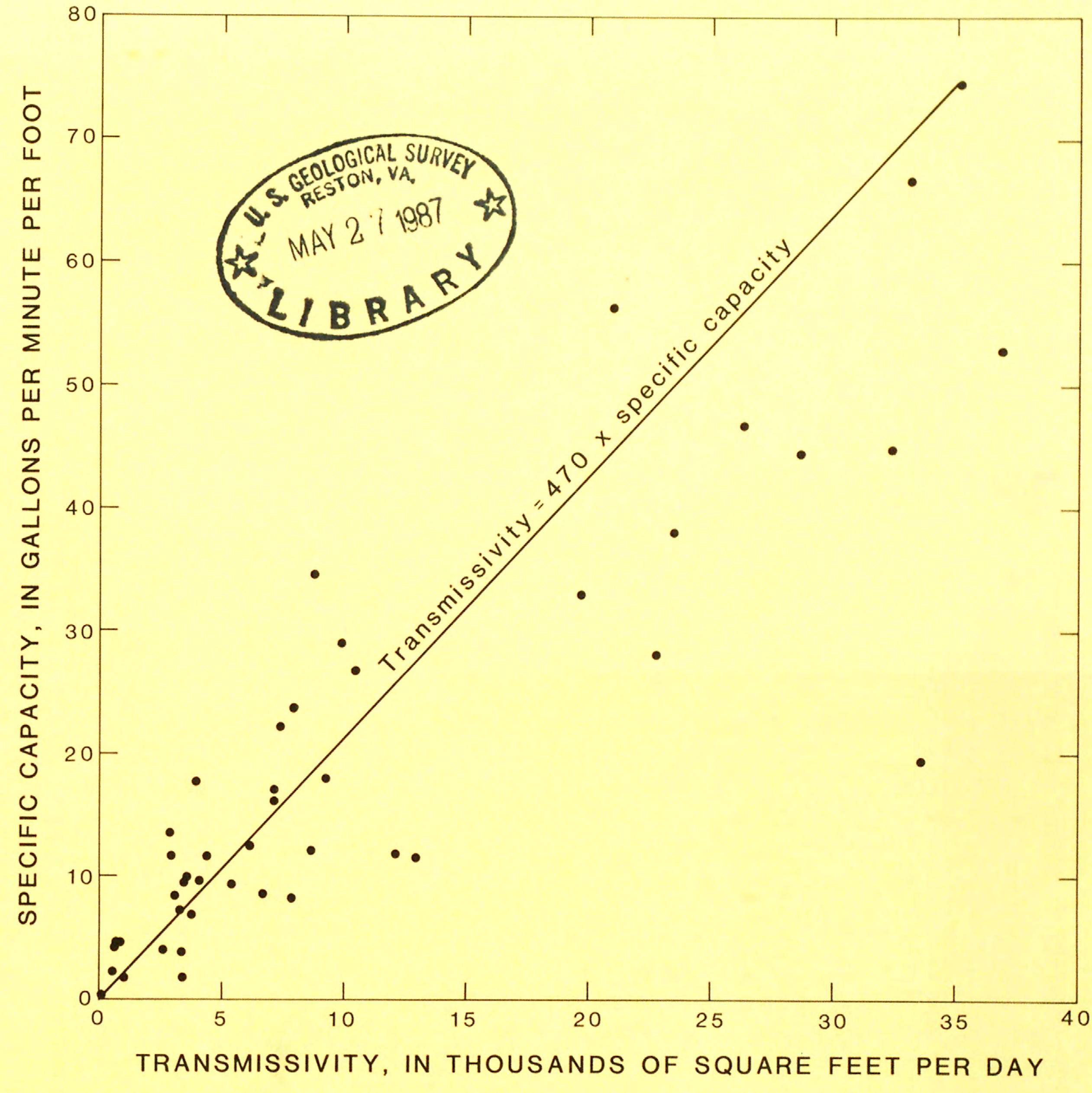
HYDRAULIC CHARACTERISTICS OF UPPER CRETACEOUS AND LOWER TERTIARY CLASTIC AQUIFERS--EASTERN ALABAMA, GEORGIA, AND WESTERN SOUTH CAROLINA



U.S.GEOLOGICAL SURVEY

Water-Resources Investigations Report 86-4210

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By Robert E. Faye and Keith W. McFadden

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Water-Resources Investigations Report 86-4210

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1986

DEPARTMENT OF THE INTERIOR

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DEFINITION OF TERMS

Terms used in this text to describe ground-water flow and hydrology, geology, streamflow characteristics, and watershed morphology are described below. Definitions are listed verbatim or are slightly modified from those reported by Lohman (1972), Lohman and others (1972), Poland and others (1972), Fetter (1980), Bates and Jackson (1980), and Johnson (1981).

ANISOTROPY: The condition under which one or more of the of the hydraulic properties of an aquifer vary according to the direction of flow.

AQUIFER: An aquifer is a formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs.

AQUIFER TEST: A test made by pumping a well for a period of time and observing the change in hydraulic head in the aquifer. An aquifer test may be used to determine the capacity of the well and the hydraulic characteristics of the aquifer; also called pumping test.

CONFINING UNIT: A saturated, but poorly permeable, bed that impedes ground-water movement and does not yield water freely to wells, but which may transmit appreciable water to or from adjacent aquifers and, where sufficiently thick, may constitute an important ground-water storage unit. Confining units are characterized by values of leakance that may range from relatively low to relatively high. Areally extensive confining units of relatively low leakance may function regionally as boundaries of aquifer flow systems; also called confining bed and confining layer.

GROUND WATER, CONFINED: Ground water that is under pressure significantly greater than atmospheric. The upper limit of confined ground water is the bottom of a bed of hydraulic conductivity distinctly lower than that of the material in which confined water occurs.

GROUND WATER, UNCONFINED: Water in an aquifer that has a water table.

HETEROGENEITY: An aquifer is heterogeneous if its hydraulic characteristics are different in different locations. A synonym is nonuniform.

HOMOGENEITY: Synonymous with uniformity. An aquifer is homogenous if its hydraulic properties are identical everywhere. Although no known aquifer is homogenous in detail, models based upon the assumption of homogeneity have been shown empirically to be valuable tools for predicting the approximate relationship between discharge and potential in many aquifers.

HYDRAULIC CONDUCTIVITY, $[LT^{-1}]$: The proportionality factor in Darcy's law as applied to the viscous flow of water in soil, that is, the flux of water per unit gradient of hydraulic potential.

HYDRAULIC GRADIENT [DIMENSIONLESS]: The change in total head with a change in distance in a given direction. The direction is that which yields a maximum rate of decrease in head.

HYDRAULIC HEAD [L]: The elevation in regard to a specified reference level at which water stands in a piezometer connected to the point in question in the soil. Hydraulic head can be determined in soil above the water table if the piezometer is replaced by a tensiometer. The hydraulic head is a potential expressed in terms of the height of a water column.

ISOTROPY: Having the same properties in all directions of flow; that condition in which all significant properties are independent of direction. Although no aquifers are isotropic in detail, models based on the assumption of isotropy have been shown to be valuable tools for predicting the approximate relationship between discharge and potential in many aquifers.

LEAKANCE, [T^{-1}]: The ratio of the vertical hydraulic conductivity of a confining unit to its thickness.

POROSITY: The porosity of a rock or soil is its property of containing interstices or voids and may be expressed quantitatively as the ratio of the volume of its interstices to its total volume.

POROSITY, EFFECTIVE: The amount of interconnected pore space available for fluid transmission. Effective porosity is expressed as a percentage of the total volume occupied by the connected interstices and equals the ratio of (1) the volume of the voids of a soil or rock mass that can be drained by gravity to (2) the total volume of the mass.

POROSITY, PRIMARY: Primary porosity comprises the original interstices created when a rock or soil was formed in its present state. In soil and sedimentary rocks the primary interstices are the spaces between grains and pebbles.

POROSITY, SECONDARY: Fractures such as joints, faults, and openings along planes of bedding or schistosity in consolidated rocks having low primary porosity and permeability.

SATURATED ZONE: The zone in which the voids in the rock or soil are filled with water at a pressure greater than atmospheric. The water table is the top of the saturated zone in an unconfined aquifer.

SPECIFIC CAPACITY, [L^2T^{-1}]: The rate of discharge of water from a well divided by the drawdown of the water level within the well. It varies slowly with duration of discharge, which should be stated when known. If the specific capacity is constant except for the time variation, it is roughly proportional to the transmissivity of the aquifer. The relation between discharge and drawdown is affected by energy losses at the well which may occur as a result of the construction of the well, its development, the character of the screen or casing perforation, and the velocity and length of flow up the casing. If the well energy losses are significant, the ratio between discharge and drawdown decreases with increasing discharge; it is generally possible to approximately separate the effects of the aquifer from those of the well using step drawdown tests. In aquifers with large tubular openings, the ratio between discharge and drawdown also may decrease with increasing discharge because of a departure from laminar flow near the well.

SPECIFIC YIELD: The volume of water which the rock or soil, after being saturated, will yield by gravity to the volume of rock or soil. The definition implies that gravity drainage is complete. In the natural environment, specific yield is generally observed as the change that occurs in the amount of water in storage per unit area of an unconfined aquifer as the result of a unit change in head. Such a change in storage is produced by the draining or filling of pore space and is therefore dependent upon particle size, rate of change of the water table, time, and other variables. Hence, specific yield is only an approximate measure of the relation between storage and head in unconfined aquifers. It is equal to porosity minus specific retention.

STORATIVITY [DIMENSIONLESS]: Synonymous with storage coefficient. The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head. In a confined body the water derived from storage with a decline in head comes from expansion of the water and compression of the aquifer; similarly, water added to storage with a rise in head is accommodated partly by compression of the water and partly by expansion of the aquifer. In an unconfined water body, the amount of water derived from or added to the aquifer by these processes generally is negligible compared with that involved in gravity drainage or filling of pores; hence, in an unconfined water body the storativity is virtually equal to the specific yield.

TRANSMISSIVITY, [L^2T^{-1}]: The rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient. However, though spoken of as a property of the aquifer, it embodies also the saturated thickness of the aquifer and the properties of the contained liquid. It is equal to an integration of the hydraulic conductivities across the saturated part of the aquifer perpendicular to the flow paths.

CONVERSION FACTORS

Factors for converting inch-pound units to the International System (SI) of units are given below:

Multiply	By	To obtain
	Length	
inch (in.)	25.40	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (L)
	3.785×10^{-3}	cubic meter (m^3)
	Flow	
gallon per minute (gal/min)	0.06309	liter per second (L/s)
	6.309×10^{-5}	cubic meter per second (m^3/s)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
inch per year (in/yr)	25.40	millimeter per year (mm/yr)
cubic foot per second (ft^3/s)	2.832×10^{-2}	cubic meter per second (m^3/s)
	Transmissivity	
foot squared per day (ft^2/d)	0.09290	meter squared per day (m^2/d)
	Hydraulic conductivity	
foot per day (ft/d)	0.3048	meter per day (m/d)
	Specific capacity	
gallon per minute per foot [(gal/min)/ft]	0.2070	liter per second per meter [(L/s)m]

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ABSTRACT

Transmissivity and storativity data for the clastic sediments of the northern Coastal Plain of eastern Alabama, Georgia, and western South Carolina were compiled and evaluated. Transmissivity values ranged from less than 100 to about 35,000 feet squared per day; storativity ranged from about 1.0×10^{-3} to 2.0×10^{-5}.

Data for lower Tertiary sediments represented by the Clayton and Tallahatta Formations and equivalent Midwayan and Claibornian sediments are listed for 17 sites. Transmissivity values of these sediments range from about 500 to 10,000 feet squared per day.

Transmissivity values for the Cretaceous Providence Sand and Cusseta Sand and equivalent Navarroan-Tayloran sediments are listed for 10 sites and range from about 500 to 34,000 feet squared per day.

Transmissivity values for the Blufftown and Eutaw Formations and equivalent Cretaceous Tayloran-Austinian sediments are listed for 16 sites and range from about 3,000 to 35,000 feet squared per day.

Transmissivity of the Cretaceous Tuscaloosa Formation and equivalent Eaglefordian sediments is listed for 5 sites and ranges from about 30 to 500 feet squared per day.

Estimates of transmissivity based on well specific capacity were computed by using the modified nonequilibrium formula and linear regression analysis. The regression analysis was based on log-transformed paired transmissivity and specific-capacity data at 48 pumping wells. The regression model provided better estimates of transmissivity than the modified nonequilibrium formula.

INTRODUCTION

Hydrologic investigations of clastic aquifers undertaken as part of the U.S. Geological Survey's Southeastern Coastal Plain Regional Aquifer Systems Analysis (RASA; Bennett, 1979) have required the computation and compilation of hydraulic characteristics data for sediments of Late Cretaceous and early Tertiary age within the Coastal Plain of eastern Alabama, Georgia, and western South Carolina. The area of study is generally bounded by the western limit of drainage to the Chattahoochee River in eastern Alabama and the Savannah River-Edisto River divide in western South Carolina. Seaward from the Coastal Plain margin the study area extends a distance of about 200 mi (fig. 1). The RASA subdivision pertinent to this report is the Doraville Subregion.

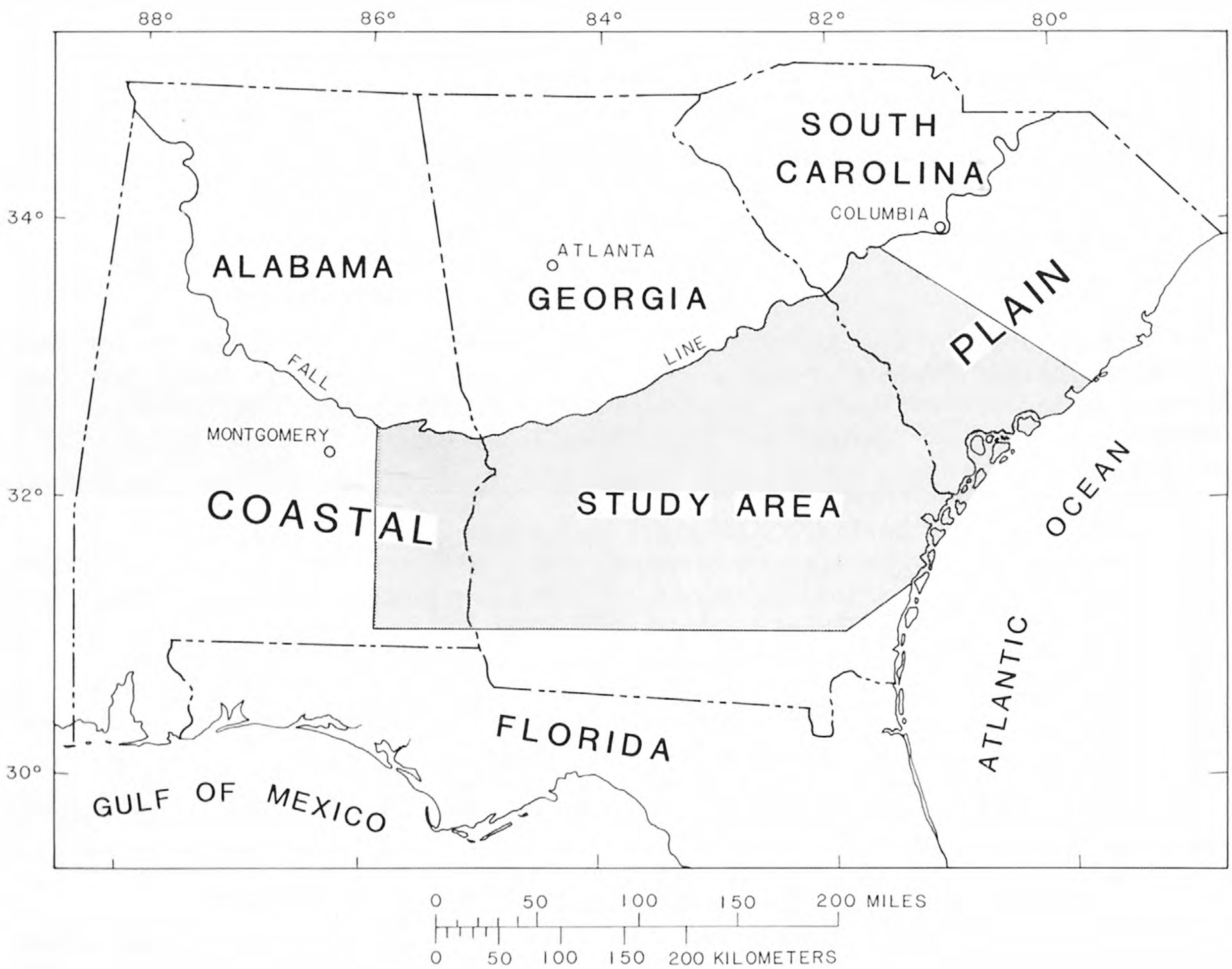

Figure 1.—General area of study.

Aquifer-test data used in this study were collected from the files of the U.S. Geological Survey, industries, drillers, and cooperating State, Federal, and municipal agencies. In addition, reported aquifer-test analyses were examined and, if determined to be accurate, were credited and reported herein. Data for production wells were most commonly available and were used to compute aquifer transmissivity. At selected sites, observation-well data also were available and were used to compute aquifer transmissivity and storativity.

Description of the Problem

RASA investigations include digital model analyses of regional ground-water-flow systems. Part of the data required to successfully use and calibrate such models are aquifer transmissivity and storativity. Until recently, reports of hydrologic investigations of aquifers comprised of clastic sediments of Late Cretaceous and early Tertiary age within the study area were limited in number, and few contained results of aquifer-test analyses (Siple, 1967, Sever, 1969, Scott, 1962, and Stewart, 1973). Although reports of more recent investigations list aquifer-test results (Ripy and others, 1981, Clarke and others, 1983, 1984, 1985, Brooks and others, 1985, and Gorday, 1985), a considerable quantity of aquifer-test data relevant to RASA investigations remained to be analyzed, compiled, and reported.

Study Objectives

The objectives of this study were to:

(1) Evaluate and compile aquifer-test data and reported analyses;

(2) Generally describe the areal distribution of regional aquifer transmissivity; and

(3) Evaluate the accuracy of several methods which use specific-capacity data to estimate aquifer transmissivity.

Data were not sufficiently numerous to develop contour maps showing lines of equal transmissivity.

Well-Numbering System

In this report, wells in Georgia are numbered according to a system based on the index map of U.S. Geological Survey 7 1/2-minute topographic quadrangle maps. Each quadrangle map in the State has been assigned a number and a letter designation according to its location based on a generally Cartesian pattern with its origin at the southwest corner of the State. Numbers increase numerically eastward and letters increase alphabetically northward. Quadrangles in the northern part of the State are designated by double letters. Wells inventoried in each quadrangle are numbered consecutively beginning with "01". Thus, the third well scheduled in the Doverel quadrangle in Randolph County is designated 09M003. Similarly, the thirty-third well inventoried in the Augusta East quadrangle in Richmond County is designated 30BB33.

Well designations in South Carolina are constructed from a county name abbreviation followed by a number indicating the order in which wells were inventoried in the county. County abbreviations used in this report are AK, AL, BFT, BW, and CH, and represent Aiken, Allendale, Beaufort, Barnwell, and Charleston Counties, respectively. Wells at the Savannah River Plant in South Carolina are numbered as designated by the Plant using a variety of prefixes.

The well-numbering system in Alabama is based on the Federal system of subdivision of public lands. Each township is divided into 36 sections numbered from one in the northeast corner to 36 in the southeast corner. Each section is subdivided into equal parts lettered consecutively from "A" through "X", "A" being assigned to the northeastmost equal subdivision of the section and "X" to the southeastmost subdivision. Wells in each subdivision are numbered consecutively such as A-1, A-2.

Acknowledgments

The authors extend their thanks to Robert Massey of Layne-Atlantic Co., Savannah, Ga.; William Foster of Thomas and Hutton Engineering Co., Savannah, Ga.; and Steven McNeil of Heater Well Drilling, Columbia, S.C., for their cooperation and gratefully acknowledge the use of aquifer-test and other data supplied by their firms. Appreciation is also expressed to Mary H. Danhope and Phillip Means for their compilation of data and well information.

AQUIFERS

Nomenclature

Aquifers in this report are designated by the names of geologic formations that include the aquifer or by the names of corresponding provincial stages where formation names have not been assigned. The correlation of geologic and hydrologic units was based on cross sections and structure-contour maps shown in Scott (1962), Siple (1967), Ripy and others (1981), Faye and Prowell (1982), Clarke and others (1983, 1984, 1985), Renken (1984), Brooks and others (1985), and Owens and Gohn (1984). A correlation chart of geologic units used in this study is shown in figure 2. Where a single aquifer is made up of several formations or provincial stages, aquifer designations are formed by combining individual formation or provincial stage names (table 1).

Only aquifers consisting of Eaglefordian through Claibornian sediments are considered in this report. Hydraulic characteristics of aquifers made up of Jacksonian and younger sediments of lower tertiary age are described by Callahan (1964), Sever (1965, 1969), Wait and Gregg (1973), Hicks and others (1981), and Mitchell (1981).

Geology and Hydrology

Formations that make up the regional aquifers are located within the Coastal Plain physiographic province of Georgia, Alabama, and South Carolina (fig. 1). These units generally dip and thicken seaward of the Coastal Plain margin and increase in the number of individual formations and beds downdip.

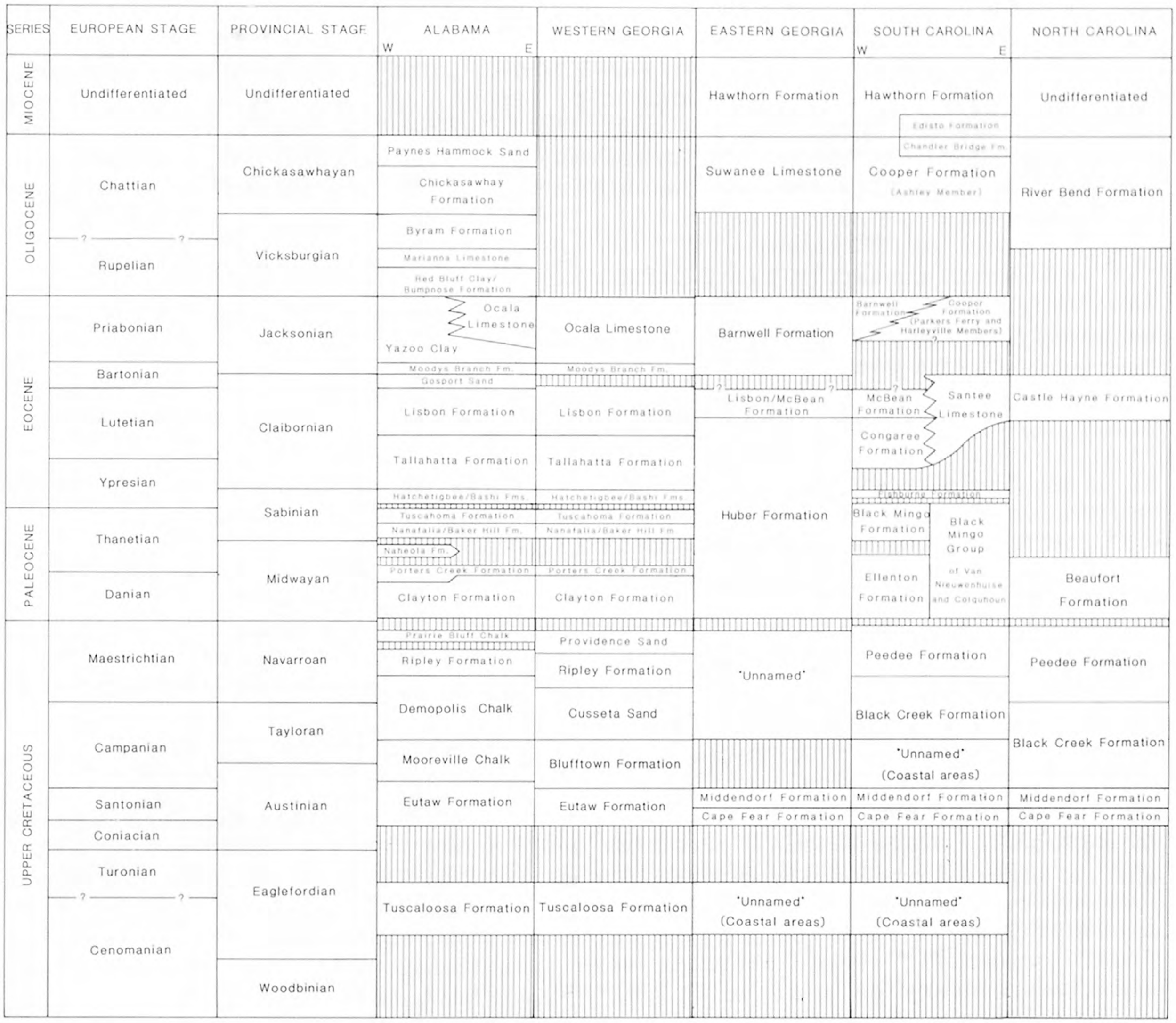

Figure 2.—Correlation of chronostratigraphic and formation units.

Sediments of Eaglefordian through Claibornian age in the study area generally are clastic and consist of sand and gravel interbedded with clay, marl, and limestone. An exception, the Clayton Formation of Midwayan age, consists mainly of limestone. The lithologies of the aquifers reflect depositional environments, which are largely marine and marginal marine. Consequently, lithofacies within aquifers show considerable areal variation.

Within outcrop areas, aquifers contain lensiodal clay deposits and alternating lenticular beds of sand and clay of varying thickness and hydraulic conductivity. Water moves upward and downward through the permeable sediments and mostly around poorly permeable clay lenses and beds. Clay deposits are discontinuous and generally are not areally extensive from a regional viewpoint and aquifers in outcrop areas may be locally confined. In general, aquifer confinement increases and becomes areally more extensive seaward of outcrop areas.

Hydraulic conductivity of clastic aquifers is largely the result of primary effective porosity. Hydraulic conductivity of the Clayton Formation generally is the result of secondary porosity.

AQUIFER TESTS

Results of aquifer-test analyses are summarized in table 1. Aquifer-test values are listed as well as formation name(s) or provincial stage(s) and descriptions of well location, identification, and construction. Published sources of data and methods of analyses also are noted. Aquifer-test locations are shown on plate 1. Most locations occur within or near the outcrop areas of aquifer sediments, about 10 to 50 mi seaward of the inner Coastal Plain margin.

Methods and Qualifications

Methods of aquifer-test analysis varied depending on the type and quality of test data. Time-variable drawdown and recovery data at observation wells were analyzed by using the nonequilibrium formula and checked using the modified nonequilibrium formula (Ferris and others, 1962). Corresponding data at pumping wells were analyzed by using the modified nonequilibrium formula. Aquifer hydraulic characteristics were computed by using both time-drawdown and time-recovery data at wells where dual data sets were available. The characteristics listed in table 1 are considered the best of these alternatives tives and are related to data type (time drawdown or time recovery) by footnote.

Regardless of method, all aquifer-test analyses summarized in this report are based on the following assumptions (U.S. Bureau of Reclamation, 1977):

(1) The aquifer is confined, homogeneous, isotropic, and of uniform thickness and infinite areal extent;

(2) The production well penetrates and receives water from the entire thickness of the aquifer and is of infinitesimal diamater;

(3) Flow toward the well is radial, horizontal, and laminar;

(4) All water produced is derived from aquifer storage within the area of influence of the well and is released instantaneously from storage as aquifer potentiometric head declines; and

(5) Aquifer transmissivity and storativity are spatially and temporally constant.

Several or all of these assumptions are violated to some degree during most aquifer tests and the tests summarized in this report are no exception. Regardless, the methods referenced previously have been applied successfully with apparently valid results to many studies and problems related to ground-water flow and are considered equally valid herein.

Wells listed in table 1 generally do not penetrate the entire aquifer, and where penetration is complete, wells are screened through only part of the total aquifer thickness. Consequently, transmissivity values listed in table 1 can be considerably less than total aquifer transmissivity at the well site and are henceforth termed observed transmissivities. Comparisons of well penetration to total aquifer thickness at individul well sites are made where such combinations of data are available.

Because the aquifers are neither homogeneous nor isotropic, transmissivity changes with direction laterally away from a well site and vertically with depth. Although lateral changes probably are relatively gradual across a large percentage of total aquifer thickness, changes in transmissivity with depth can be radical and observed transmissivity (table 1) should be considered an average value across the total length of designated open interval.

Well Construction

Water-supply wells that penetrate clastic aquifers generally are screened through water-bearing sands and gravels and most are gravel packed. Energy losses across screens and artificial packs occur during pumping and must be considered when specific capacity is used to determine transmissivity.

Wells that penetrate limestone aquifers generally are cased to a depth slightly below the top of the limestone. The remainder of the well is uncased and water moves freely into the open borehole when the well is pumped. Energy losses in such wells probably are negligable compared to screened wells unless excessive turbulence occurs in the borehole during pumping.

OBSERVED TRANSMISSIVITY AND STORATIVITY

Athough aquifer-test data are not available for the entire study area, data for several regional aquifers are sufficient in parts of the study area to generally describe hydraulic characteristics and their areal variability (table 1; pl. 1). Data for sediments of Tayloran-Austinian age are the most numerous and best distributed. Aquifer tests describing the hydraulic properties of Navarroan-Tayloran and Claibornian sediments also are relatively numerous and well-distributed. Descriptions of the hydraulic properties of Midwayan sediments are limited in number and almost exclusively pertain to the carbonate facies of the Clayton Formation in southwest Georgia. Aquifer-test data are least numerous for sediments of Eaglefordian age, which are limited to three test sites in the northernmost part of the Alabama and Georgia Coastal Plain and to two drill-stem tests in southernmost Georgia (pl. 1).

Claibornian Sediments

Claibornian sediments in the western part of the study area are largely included in the Tallahatta Formation. Observed transmissivity of the Tallahatta Formation ranges from about 130 ft^2/d at well 5J003 in Early County, Ga., near the Chattahoochee River to about 6,600 ft^2/d at well 16S002 in northeast Dooly County, Ga., east of the Flint River (pl. 1). The transmissivity at the Early County site probably is representative of only a small section of the total water-bearing thickness of the aquifer. Observed transmissivities of the Tallahatta Formation near the city of Albany in Dougherty County, Ga., range from about 3,400 to 6,100 ft^2/d.

East of the Ocmulgee River in Georgia, Claibornian sediments largely comprise the upper part of the Huber Formation and the Gordon aquifer (Brooks and others, 1985). Observed transmissivities in this part of the study area are relatively high and range from about 3,500 ft^2/d at well 33X037 in Screven County, Ga., near the Savannah River to about 9,800 ft^2/d at well 18S012 in Pulaski County, Ga., near the Ocmulgee River. Such differences in observed transmissivity within the Gordon aquifer probably are largely due to variations in aquifer thickness and lithology rather than to a general eastward trend of decreasing transmissivity. Note that the observed transmissivity of a 10-foot section of Claibornian age sand at well AL-27 in Allendale County, S.C., just east of the Savannah River, is about 1,100 ft^2/d.

Storativity values for Claibornian sediments are limited to the Tallahatta Formation in Early and Dougherty Counties, southwest Georgia, and range from about 1.0×10^{-4} to 1.0×10^{-3}.

Midwayan Sediments

Data for Midwayan sediments are limited almost exclusively to the carbonate facies of the Clayton Formation in southwest Georgia. Observed transmissivity of the Clayton Formation ranges from about 2,400 ft^2/d at well 09M003 in Randolph County, Ga., to about 6,700 ft^2/d at well 05M005 in Clay County, Ga., near the Chattahoochee River (pl. 1). Although data are limited, this range of values probably is representative of most of the carbonate facies of the Clayton Formation. Transmissivity data for the Clayton Formation are available at other well sites in southeastern Randolph County, Ga., and in southernmost Lee County, Ga. (table 1).

Storativity within the Clayton Formation was observed only at the Clay County, Ga., site (well 05M005) and equals about 3.1×10^{-3}. This site is within the outcrop area of the Clayton Formation and the observed storativity probably is large with respect to most of the formation within the study area.

Scott and others (1984) describe the results of an aquifer test at Fort Rucker, Ala., just west of the study area, which included a clastic facies of the Clayton Formation and overlying units of the Nanafalia and Tuscahoma Formations of Sabinian age. Reported transmissivity at the test site is 7,800 ft^2/d. Storativity is 3.0×10^{-4}.

Navarroan and Navarroan-Tayloran Sediments

A single aquifer test in the Providence Sand of Navarroan age is recorded for the Providence Sand at well 05L007 in Clay County, Ga., near the Chattahoochee River (pl. 1; table 1). Observed transmissivity at this site is about 930 ft^2/d. Elsewhere in the study area, aquifer-test data are available only for wells that penetrate sediments of Navarroan age and underlying sediments of Tayloran age. In the northern part of the Coastal Plain, generally east of the Ocmulgee River, the middle and lower parts of Navarroan sediments and the upper part of Tayloran sediments are lithologically similar and comprise a single aquifer designated the Dublin aquifer by Clarke and others (1985).

Observed transmissivity of two 10-foot sand layers at well AL-27 in Allendale County, S.C., ranges from about 210 to 260 ft^2/d. Elsewhere observed transmissivity is much higher. In Houston County, Ga., transmissivity of Navarroan-Tayloran sediments ranges from about 7,800 ft^2/d at well 17U008 to about 32,000 ft^2/d at well 16T002. East of these sites, in Twiggs County, Ga. (pl. 1), observed transmissivity at several wells within quadrangle 18V equals or exceeds 30,000 ft^2/d. At well AL-66 in Allendale County, S.C., the open interval is largely within Navarroan-Tayloran sediments and transmissivity equals about 7,100 ft^2/d.

Storativity of Navarroan-Tayloran sediments was determined for the Twiggs County, Ga., site and ranged from about 1.0×10^{-4} to 8.0×10^{-4}.

Tayloran-Austinian Sediments

Aquifer-test data for Tayloran-Austinian sediments are relatively numerous and widely distributed across the northern part of the study area. In the vicinity and east of the Ocmulgee River, sediments of Tayloran and Austinian age generally make up a single regional aquifer described by Clarke and others (1985) as the Midville aquifer. In western Georgia and eastern Alabama, Tayloran-Austinian sediments consist in descending order of parts of the Cusseta Sand, Blufftown Formation, and Eutaw Formation.

Observed transmissivity of the Blufftown Formation at well 11U001 in Taylor County, southwest Georgia, is about 6,200 ft^2/d. At well 16V002 in Bibb County, Ga., observed transmissivity of the Blufftown Formation near the Ocmulgee River is about 4,100 ft^2/d. The Blufftown Formation at this well is reported (Herrick, 1961) to consist of at least 230 ft of fine to coarse sand. Well 16V002 is screened through less than 20 percent of this thickness (table 1) and total aquifer transmissivity probably is considerably larger than observed transmissivity at this well.

At wells 13S012 and 13S015 in Macon County, Ga., observed transmissivity is about 3,000 ft^2/d within the upper part of the Blufftown Formation. The apparent southeastward reduction in observed transmissivity from Taylor County to Macon County possibly is caused by partial penetration of the aquifer by wells 13S012 and 13S015 and a change in lithofacies that may include greater quantities of silt and clay.

South of Bibb County in Houston County, Ga., observed transmissivity of Tayloran-Austinian sediments increases rapidly to about 29,000 ft^2/d at well 16U011. Much of this increase probably is caused by lithofacies changes within the aquifer that result in sediments of greater hydraulic conductivity at well 16U011 than at well 16V002. Similar rapid increases in the observed transmissivity of Tayloran-Austinian sediments occur southwestward from Bibb County where observed transmissivity of the Blufftown Formation at wells 14U002 and 14U003 in Peach County exceeds 30,000 ft^2/d.

Wells in east-central Georgia that penetrate Tayloran-Austinian sediments are in the northern parts of Twiggs, Wilkinson, and Washington Counties, generally within or near outcrop areas of the aquifer. Observed transmissivity at these wells ranges from about 3,300 ft^2/d at well 19W004 in northern Wilkinson County to about 8,700 ft^2/d at well 17V004 in northern Twiggs County, and is consistent with values noted previously at similarly located wells in Taylor County and Bibb County.

In eastern Georgia and western South Carolina, wells that penetrate Tayloran-Austinian sediments are located near the Savannah River and extend seaward from near the Coastal Plain margin to the southern parts of Burke County, Ga., and Barnwell County, S.C. (pl. 1). Observed transmissivity ranges from about 3,100 ft^2/d at well 29BB03 in northern Richmond County, Ga., to about 34,000 ft^2/d at well 24-F near the southern boundary of Aiken County, S.C. Wells in the northern part of Richmond County, Ga., and Aiken County, S.C., are within or proximate to outcrop areas of the aquifer. Observed transmissivity at these wells ranges from about 3,000 to 12,000 ft^2/d, which is consistent with observed values at similarly located wells in central and southwest Georgia. The observed transmissivity of 12,200 ft^2/d at well

AK-440 in northern Aiken County, S.C., may indicate an eastward lithofacies change toward sediments of greater hydraulic conductivity. Similar lithofacies changes probably account for the rapid southeastward increase in transmissivity indicated between wells 30AA12-30AA14 and wells 31Z002-31Z008 in Richmond and Burke Counties Ga., and between wells AK-440 and LA-24 in Aiken County, S.C.

Transmissivity data for basal Austinian sediments are available at well Ch-186 at Kiawah Island in Charleston County, S.C. (pl. 1; table 1). Observed transmissivity is about 3,400 ft^2/d. The open interval of the well is nearly 120 ft, from a depth of 2,018 to 2,210 ft, and includes most of the permeable thickness of the aquifer.

Hydraulic conductivities based on permeameter data (C. E. Nuzman, Layne-Atlantic Co., written commun., 1974) at well BFT-457 at Fripp Island in Beaufort County, S.C., indicate that the transmissivity of basal Austinian sediments is similar to that observed to the northeast in Charleston County. The results of constant-head permeameter tests applied to core samples at various depth intervals are listed in table 2. The listed hydraulic conductivities are averages of several conductivities at various pressures for the given interval. Transmissivities listed in table 2 were computed as the product of depth-interval length and hydraulic conductivity. Total computed transmissivity of the selected intervals exceeds 2,000 ft^2/d.

Table 2.--Summary of permeameter test data--basal Austinian sediments at well BFT 457 at Fripp Island, Beaufort County, South Carolina

Test interval (ft)	Sediment description	Measured horizontal hydraulic conductivity (ft/d)	Computed transmissivity (ft^2/d)
2707-2757	Sand, fine to medium	19.4	970
2927-2967	Sand, fine to medium	26.2	1,050
2,987-3,017	Sand, fine	13.6	410

Eaglefordian Sediments

Aquifer tests for Eaglefordian sediments are few and are limited to the outcrop and adjacent areas of the Tuscaloosa Formation in southwest Georgia and southeast Alabama and to two oil-test-well sites in Seminole and Wayne Counties, Ga. (pl. 1; table 1). Observed transmissivity within the outcrop area of the Tuscaloosa Formation seems to be somewhat consistent, ranging from about 500 to 700 ft^2/d based on three aquifer-test sites. In southernmost Georgia, drill-stem-test data (Humble Oil and Refining Co., written commun., June 25, 1970) at oil-test wells in Seminole and Wayne Counties indicate average sediment hydraulic conductivities across a given depth interval. These data and the corresponding computed transmissivities are listed in table 3. The observed transmissivities of 63 and 30 ft^2/d were measured in relatively small open intervals compared to total aquifer thickness. Thus, transmissivity of the corresponding aquifer at these sites probably is an order of magnitude or more larger than the values listed in table 3.

Table 3.--Summary of hydraulilc conductivity data--Eaglefordian sediments, Seminole and Wayne Counties, Georgia

Borehole identification	Test interval (ft)	Observed hydraulic conductivity (millidarcies)	Observed hydraulic conductivity (ft/day)	Transmissivity (ft^2/d)
06E013, J. R. Sealy 1, GGS 654, Seminole County, Ga.	3397-3432	656	1.8	63
32L014, Union Bag and Paper Co., 1, GGS 651, Wayne County, Ga.	4167-4178	986	2.7	30

Note that at sites near the drill-stem-tests in Wayne and Seminole Counties (table 3), Applin and Applin (1964, 1967) assigned stratigraphically equivalent sediments to the lower Atkinson Formation. Recently, Owens and Gohn (1985) have tentively redefined the age of the upper part of the lower Atkinson Formation as Eaglefordian. Similarly the age of the upper Atkinson Formation which had formerly been defined as Eaglefordian by Applin and Applin (1964, 1967), was redefined by Owens and Gohn (1985) as Austinian. The age conventions of Owens and Gohn (1985) are followed in this report.

SEDIMENT ANISOTROPY

Horizontal

Data to analyze the directional properties of aquifer transmissivity, according to the method of Papadopaulous (1965), are few in the study area. Sufficient aquifer-test data are available, however, at well sites 19W001-19W004 (table 1) in western Wilkinson County, Ga. (LaMoreaux & Associates, 1969). A scale site plan showing the distribution and location of observation and pumping wells within an arbitrarily applied grid system is shown in figure 3. Transmissivity along the major and minor axes of anisotropy is about 15,900 ft^2/d and 9,040 ft^2/d, respectively. Thus, the anisotropy ratio is about 1.76:1. Storativity is about 6.6×10^{-4} and the major axis of anisotropy is oriented about 9 degrees west of true north (M. L. Maslia, U.S. Geological Survey, written commun., 1984). Results of the anisotropy analysis with respect to values of transmissivity and storativity are well within the ranges of values for Tayloran-Austinian age sediments observed elsewehere within the study area and indicate that sediment anisotropy at the test site is not pronounced.

Vertical

Measurements of vertical anisotropy ratios, that is, ratios of vertical to horizontal hydraulic conductivity within the study area, also are few and are based on laboratory permeameter analyses of sediment cores (Core Laboratories, Inc., written commun., Aug. 13, 1980; Christl, 1964; Marine, 1979). Sediments considered in these analyses are of Tayloran-Austinian and Clai-bornian age and were obtained in Aiken County, S.C., and Washington County, in east-central Georgia. Reported vertical anisotropy ratios range from 10^{-1} to 10^{-3}.

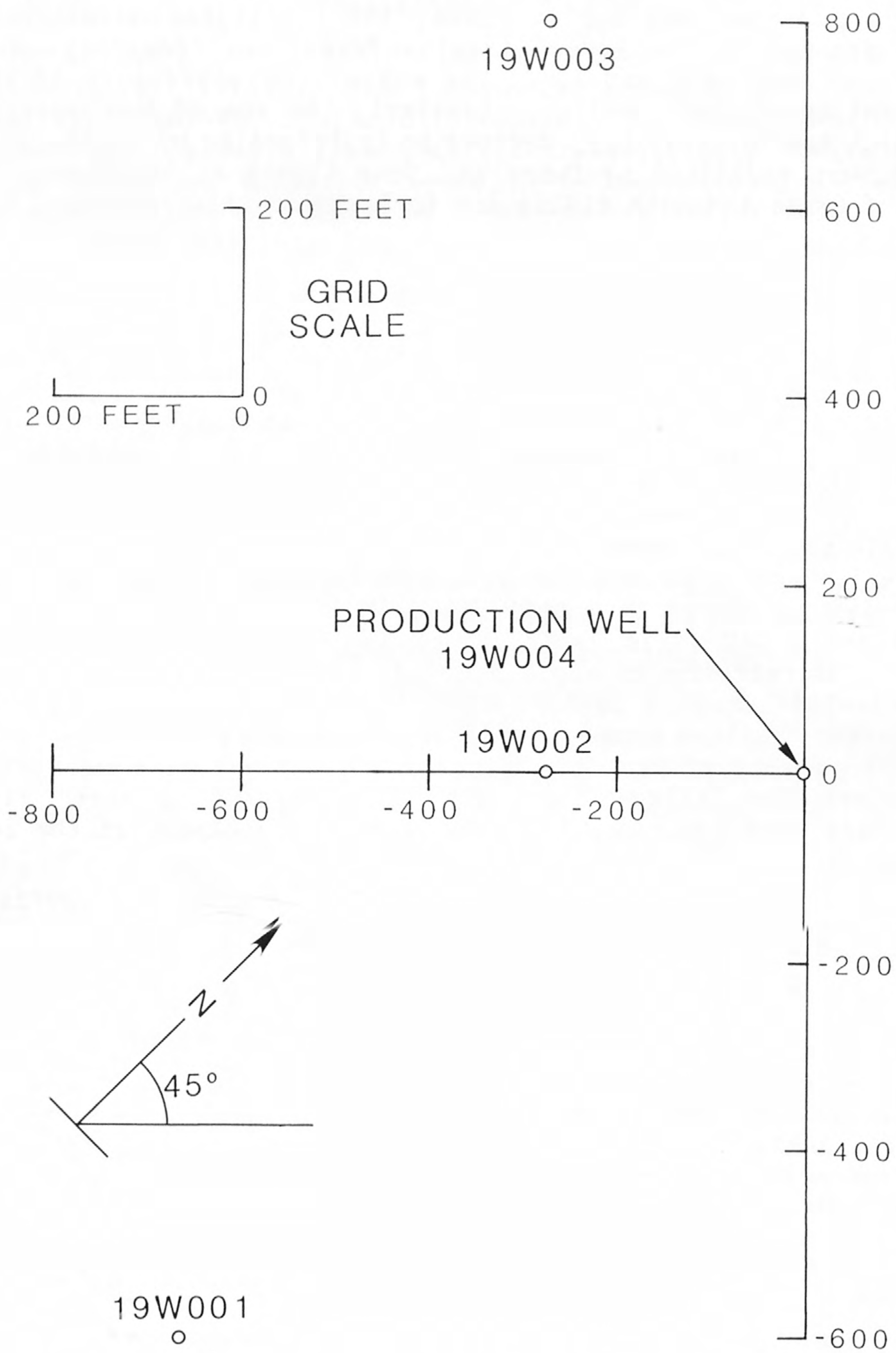

Figure 3.—Site plan showing distribution and orientation of wells 19W001–19W004, Wilkinson County, Georgia.

ESTIMATING TRANSMISSIVITY--METHODS OF APPROXIMATION

Modified Nonequilibrium Formula

Estimates of transmissivity traditionally have been based on specific capacity using a form of the modified nonequilibrium formula (Ferris and others, 1962, p. 98) listed below:

$$T = \frac{Q}{4\pi s} \ln \frac{2.25Tt}{r^2 S} , \qquad (1)$$

where T = aquifer transmissivity, in L^2T^{-1},

Q = well discharge, in L^3T^{-1},

s = observed total drawdown in the pumping well, in L,

t = length of aquifer test, in T,

r = effective radius of pumping well, in L,

and

S = aquifer storativity.

For this study, specific-capacity data listed in table 1 were applied to equation (1). Solution of the equation was exact using a storativity value of 5.0×10^{-4} and assuming that the effective radius equals the actual well radius. The value of storativity is considered to be representative of clastic aquifers in the study area. Where well diameter was unknown (table 1), a diameter of 8 in. was assumed. Because of the logarithmic function which contains radius and storativity, relatively large changes in radius and storativity result in correspondingly small changes in computed transmissivity. Results of these computations are shown in table 1. Percent-difference values listed in table 1 were computed by taking the difference between the estimated and the observed value of transmissivity and dividing by the observed value. Positive differences indicate that estimated values are larger than observed values; negative differences indicate that estimated values are smaller.

Comparison of observed transmissivities computed by using time-drawdown or time-recovery water-level data with transmissivity estimated by using equation (1) indicates that estimated transmissivities generally are lower than observed transmissivities by absolute differences ranging from about 1 to 90 percent. These lower values are to be expected because drawdown at the pumped well is caused, in part, by energy losses in the well bore and in the aquifer, whereas observed transmissivities are based on the slope of a time-drawdown or time-recovery relation. As a consequence, observed transmissivities relate only to head changes within the aquifer. At 11 of the well sites where specific-capacity data are listed in table 1, estimated transmissivity exceeds observed transmissivity, commonly by a significant percentage. This difference may be due to the effective radius which occurred during the test being significantly greater than the well radius actually used in equation (1). However, no rationale, either from the viewpoint of data quality or aquifer lithology, could be developed to specifically explain the positive estimated values.

Regression Analysis

Paired observed transmissivity and specific-capacity data at 48 sites listed in table 1 and log transformations of these data were correlated by using a simple linear regression. All paired data except those for the Clayton Formation were used in this analysis. Based on comparisons of the coefficients of determination and the standard errors of estimate, the regression model based on log-transformed data explained the variability of the transmissivity data significantly better than did the model based on normal data. Consequently, the log-transformed model is used in this report and is presented below. Log transformations are to the base 10.

$$\text{Log transmissivity} = 1.00 \text{ (log specific capacity)} + 2.672,$$

$$\text{or transmissivity} = 470 \times \text{specific capacity.}$$

Results of the analysis are summarized in table 1. The quality of the regression is excellent and with a "t" statistic of 15.8 and an "F" statistic of 250, predictions are well within a 99-percent level of confidence. The correlation coefficient of this model is 91.7 percent and the standard errors of estimate from the regression line are 74 and -42 percent. A graph of the regression line and related observed data is shown in figure 4. Note that six of the nine poorest predictions by the regression model, based on absolute percent difference (table 1), correspond to observed transmissivity values of less than 1,000 ft^2/d and that values predicted using the regression model within this group of data generally are significantly larger than observed values (fig. 4). Such bias should be taken into account when applying the regression model. Similar bias relative to other groups of sample data was not noted. The regression model should not be used with specific capacities significantly smaller that the smallest specific capacity (0.29 [(gal/min)/ft]) shown in table 1.

Comparison of Methods

The predictive accuracy of the two methods which correlate specific capacity and observed transmissivity can be compared by using percentage-error data. Absolute mean error of estimated transmissivity based on the modified nonequilibrium formula is 45 percent and the standard deviation of the absolute errors is 23.6. Corresponding mean and standard deviation of absolute error based on residuals of the regression analysis are 48 percent and 46.4 percent, respectively. Absolute error relative to the modified nonequilibrium formula ranges from about 1 to 90 percent whereas corresponding values for the regression model range from about 1 to 210 percent.

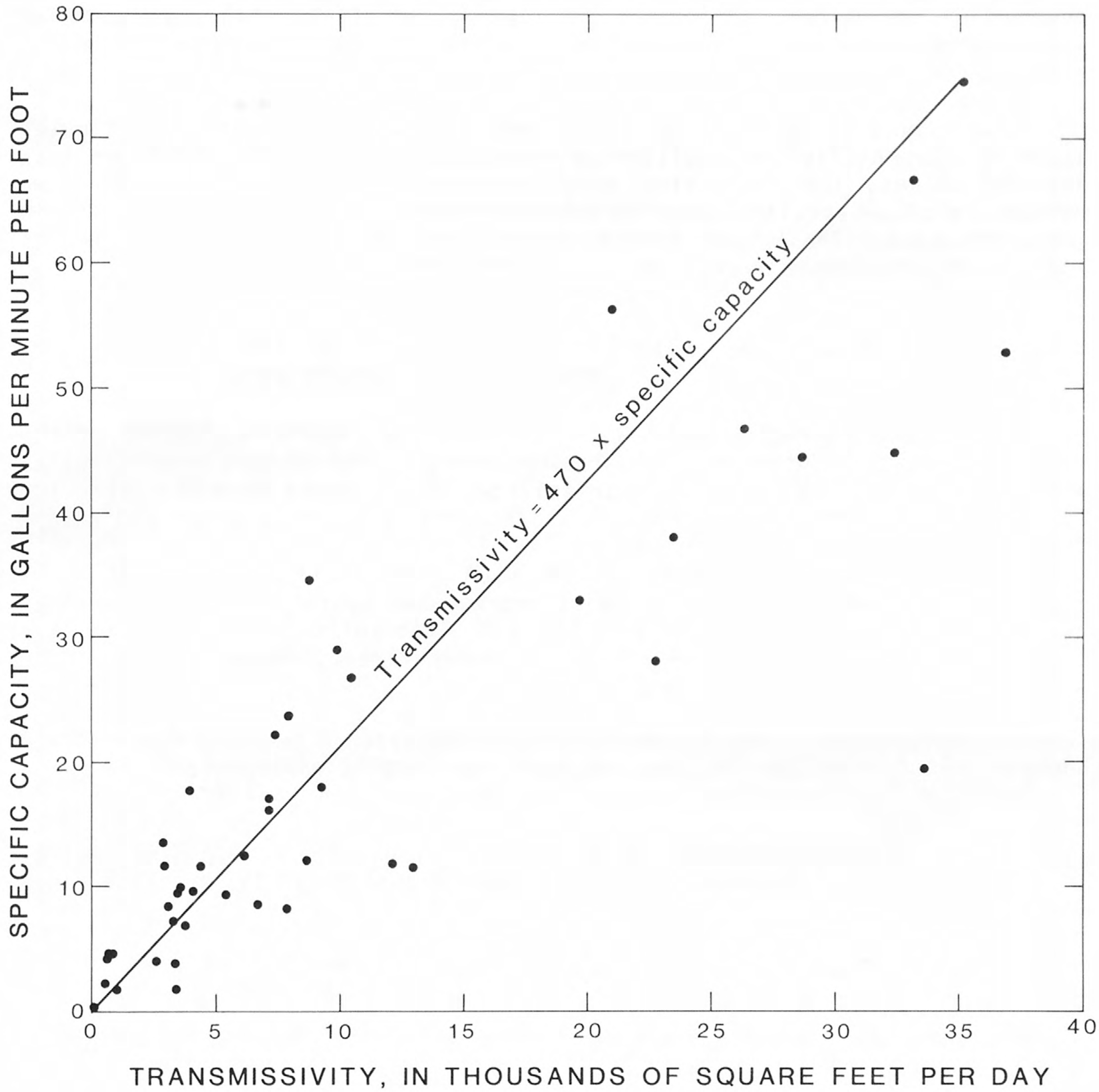

Figure 4.—Regression line and observation data.

Alternatively, the regression model predicted the observed transmissivity with greater accuracy than the modified nonequilibrium formula at 30 of the 48 sites. In addition, estimates of transmissivity based on the regression model were within 50 percent of observed values at 34 of the 48 sites and were within 25 percent of observed values at 15 sites. The corresponding number of predictions by the modified nonequilibrium formula were 30 and 14, respectively.

Given these comparisons and the tendency for transmissivity estimates based on the modified nonequilibrium formula to be consistently lower than observed values, the regression model appears to be the best of the two methods that use specific-capacity data for estimating transmissivity within the study area. The regression model also can be improved and updated as additional data become available.

SUMMARY

Transmissivity and storativity data for the clastic sediments of the northern Coastal Plain of eastern Alabama, Georgia, and western South Carolina were compiled and evaluated. Transmissivity values ranged from less than 100 to about 35,000 feet squared per day; storativity ranged from about 1.0×10^{-3} to 2.0×10^{-5}.

Data for lower Tertiary sediments represented by the Clayton and Tallahatta Formations and equivalent Midwayan and Clairbornian sediments are listed for 17 sites. Transmissivity values of these sediments range from about 500 to 10,000 feet squared per day.

Transmissivity values for the Cretaceous Providence Sand and Cusseta Sand and equivalent Navarroan-Tayloran sediments are listed for 10 sites and range from about 500 to 34,000 feet squared per day.

Transmissivity values for the Blufftown and Eutaw Formations and equivalent Cretaceous Tayloran-Austinian sediments are listed for 16 sites and range from about 3,000 to 35,000 feet squared per day.

Transmissivity of the Cretaceous Tuscaloosa Formation and equivalent Eaglefordian sediments is listed for 5 sites and ranges from about 30 to 500 feet squared per day.

Estimates of transmissivity based on well specific capacity were computed by using the modified nonequilibrium formula and linear regression analysis. The regression analysis was based on log-transformed paired transmissivity and specific-capacity data at 48 pumping wells. The regression model provided better estimates of transmissivity than the modified nonequilibrium formula.

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5 ITEMS