Relations of Borehole Resistivity to the Horizontal Hydraulic Conductivity and Dissolved-Solids Concentration in Water of Clastic Coastal Plain Aquifers in the Southeastern United States

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By ROBERT E. FAYE and WINSTON G. SMITH

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CONTENTS

FIGURES

TABLES

CONVERSION FACTORS

Multiply	By	To obtain
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
square foot per day (ft^2/d)	0.09290	square meter per day (m^2/d)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per second per square mile ($m^3/s/km^2$)	0.01093	cubic meter per second per square kilometer [$(ft^3/s)/mi^2$]
million gallons per day (Mgal/d)	0.04381	cubic meters per second (m^3/s)

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

$$°F=1.8(°C)+32$$

Transmissivity is reported in the standard unit cubic foot per day per square foot times foot of aquifer thickness [$(ft^3/d)/ft^2$] ft. For convenience, the mathematically reduced form ft^2/d is used in this report.

Relations of Borehole Resistivity to the Horizontal Hydraulic Conductivity and Dissolved-Solids Concentration in Water of Clastic Coastal Plain Aquifers in the Southeastern United States

By Robert E. Faye *and* Winston G. Smith

Abstract

Aquifer bulk resistivity and grain-surface resistivity (inverse of grain-surface conductance) were tested as geoelectrical analogs to the horizontal hydraulic conductivity of clastic, freshwater aquifers in the Southeastern United States. Bulk resistivity was also tested as a geoelectrical analog for dissolved-solids concentrations in aquifer water. Bulk resistivity was defined as the average resistivity across a contributing interval measured by the long-normal (64-inch) or induction log. Grain-surface resistivity was empirically defined as the difference between aquifer bulk resistivity and aquifer water resistivity (computed from specific conductance). Sources of data were borehole geophysical logs and results of water-quality and aquifer-test analyses related to unconsolidated sands and clayey sands at more than a hundred sites in seven Southeastern States. Water-bearing units were composed of sediments ranging from the Late Cretaceous to middle Eocene.

All bivariate data were related using the logarithmic regression model $Y=AX^B$. Aquifer bulk resistivity and grain-surface resistivity were moderately correlated to horizontal hydraulic conductivity (70 and 72 percent correlation coefficients, respectively). Apparent formation factor, defined as the ratio of aquifer bulk resistivity to aquifer water resistivity, was shown to be poorly correlated with horizontal hydraulic conductivity (38 percent correlation coefficient). Aquifer bulk resistivity was shown to be highly correlated with dissolved-solids concentration and aquifer water resistivity (88 and 93 percent correlation coefficients, respectively).

Regression models using bulk resistivity and aquifer water resistivity as independent variables were applied at four locations in South Carolina and Louisiana to predict dissolved-solids concentrations in aquifer water. Absolute mean error of prediction was 20 and 6 percent, respectively. A regression model using bulk resistivity to predict horizontal hydraulic conductivity was applied at 27 sites in 6 Southeastern States, resulting in an absolute error ranging from 4 to 95 percent with a corresponding mean error of 43 percent.

INTRODUCTION

This report describes the development and application of several regression models that relate borehole geoelectrical properties to horizontal hydraulic conductivity and the dissolved-solids concentration in water of clastic, unconsolidated aquifers in the Southeastern United States. The regression models are applicable to regional as well as to local aquifer systems composed of unconsolidated sands and clayey sands. The area of investigation extends from the Coastal Plain of North Carolina, across the Atlantic and Gulf Coastal Plains of South Carolina, Georgia, Alabama, Mississippi, and Louisiana, and north into the Mississippi embayment to the vicinity of Memphis, Tenn. (fig. 1, table 1).

Borehole and well data were obtained from more than a hundred sites related to several Coastal Plain rock-stratigraphic units (tables 1, 2). To simplify the designation of aquifers for a regional investigation, a nomenclature based on chronostratigraphy was used. Aquifers were grouped into three generalized categories: Late Cretaceous, Paleocene and early Eocene, and middle Eocene (table 2). Where the Meridian Sand Formation of middle Eocene age is used for water supply, it generally is developed in combination with sands of the upper Wilcox Group. Accordingly, for this study, data related to the Meridian Sand were grouped with aquifers of Paleocene and early Eocene age.

The general lithology of Coastal Plain clastic aquifers does not vary substantially throughout the study area and is characterized by unconsolidated sand and clayey sand commonly thinly interbedded with clay. Quartz sand is ubiquitous to aquifers of the study area and ranges in size from coarse- to fine-grained. Clay is seldom entirely absent from water-bearing sands and commonly constitutes a substantial part of the aquifer matrix. Much of this clay is probably authigenic (Lee and Strickland, 1988; Chapelle and McMahon, 1991; McMahon and Chapelle, 1991) and occurs within the intergranular spaces of the aquifer matrix. The thickness of sand units in which wells are commonly screened is rarely less than 10 ft and seldom exceeds 200 ft (table 1). Regionally, the thickness of discrete water-bearing sand units decreases and the clay content increases downgradient from outcrops. The dissolved-solids concentration of aquifer waters also generally increases seaward or downgradient from outcrops (Clarke and others, 1983, 1985; Lee, 1988; Pettijohn, 1988).

Hydraulic and water-quality characteristics are highly variable throughout the study area. The dissolved-solids concentration in water samples collected from freshwater aquifers ranges from about 20 to 2,000 milligrams per liter (mg/L) (tables 3, 6). The observed horizontal hydraulic conductivity (K_h) of Coastal Plain aquifers ranges from about 4 to greater than 500 feet per day (ft/d) (tables 4, 7). Porosity of water-bearing sands regionally varies between 20 and 40 percent but variations within aquifers at a single well or locally between wells appear to be minor (Jones and Buford, 1951; Hosman and others, 1968; Zack, 1977; Cahill, 1982; Clarke and others, 1985; and Faye and McFadden, 1986). The observed temperature of aquifer water at the point of well discharge ranges from about 16 to 43°C (61 to 110°F) (table 3).

Borehole resistivity across intervals of water-bearing sands is highly variable locally (fig. 2) and areally (tables 3, 4). Average bulk resistivity (R_o) across contributing water-bearing intervals varies from less than 10 to about 600 ohm-meters (ohm-m) throughout the study area. Bulk resistivity represents the total electrical resistance contributed from all sources (grains, matrix material, and water) within the aquifer.

Most transmissivity data (table 4) were obtained from the files of the U.S. Geological Survey. Some transmissivity data were obtained from reports that summarize the results of aquifer-test analyses. These include, primarily, results described by Zack (1977), Aucott and Newcome (1986), Faye and McFadden (1986), and Slack and Darden (1991). Borehole geophysical logs, water-quality data, and well-construction data were, for the most part, obtained from the files of the U.S. Geological Survey (tables 1, 3).

THEORY AND CONCEPTS

In a clastic, porous media saturated with freshwater (dissolved-solids concentration less than 5,000 mg/L), both fluid flow and electrical current move in a tortuous path through the interstices of the media. Accordingly, electrical conductance of the clastic porous media may be substantially influenced by those properties of the media that enhance the ionic content and volume of interstitial water. Such properties can be characterized or measured by determining the specific conductance and dissolved-solids concentrations of the water, the degree of mineralization of the porous media (particularly the percentage of clay), the particle-size distribution of the clay, silt, and sand grain solids, and the media porosity. Other media properties that probably minimally affect electrical conductance are the sand grain shape and the nature of sand grain packing. Media hydraulic characteristics also vary according to changes in many of these same properties.

Consider that the bulk resistivity of a freshwater aquifer is, for the most part, a function of electrolyte resistivity (R_e) and matrix solids resistivity (R_m); therefore,

$$R_o = f(R_e, R_m). \quad (1)$$

Electrolyte resistivity is largely a function of the ionic strength of the aquifer water and ion exchange between the water and the surfaces of clays and other fine-grained aquifer solids. This latter process is termed surface conductance (Alger, 1966; Pfannkuch, 1969), the resistance equivalent for which is designated grain-surface resistivity (R_s) in this report; accordingly,

$$R_e = f(R_w, R_s), \quad (2)$$

where R_w is the resistivity of aquifer water. The magnitude of grain-surface resistivity decreases with increasing ionic exchange capacity between the aquifer water and the fine-grained aquifer solids exposed to this water (Alger, 1966). Thus, the greater the percentage of clays and sands of small grain size that comprise the aquifer and the greater the ionic content of the aquifer water, the smaller is the related grain-surface resistivity.

Grain-surface resistivity cannot be directly measured. In addition, the geophysical and electrochemical relations of grain-surface resistivity to other borehole geophysical and hydraulic properties are poorly understood and only empirical relations have been developed (Pfannkuch, 1969; Worthington, 1976, 1977; Urish, 1981; Huntley, 1986). A consistent, measurable relation that includes the bulk resistivity and water resistivity components of equations 1 and 2 has been observed, however, such that bulk resistivity always exceeds water resistivity for a saturated porous media (Keys and MacCary, 1971; Engineering Enterprises, Inc., written commun., August 23–24, 1983). Data reported for this study (tables 3, 4) and by Jones and Buford (1951), Turcan (1962), and Brown (1971) indicate that bulk resistivity in Southeastern Coastal Plain clastic, freshwater aquifers is consistently greater than aquifer water resistivity, and that water resistivity comprises a major percentage of bulk resistivity for any contributing interval.

Matrix solids resistivity is the result of electron conductance through the grain-to-grain contacts of contiguous sand grains of the aquifer. Quartz sand is virtually a nonconducting material and matrix solids resistivity is considered infinitely large.

Dimensional analyses by Muskat (1937) and De Wiest (1965) determined that horizontal hydraulic conductivity is directly proportional to the square of the diameter of aquifer pore openings. Therefore, increasing percentages of clay, silt, and fine-grained sand in a clastic aquifer tend to decrease both the average pore diameter and the average horizontal hydraulic conductivity. Such increases in clay and fine-grained sand in freshwater-saturated aquifers also tend to decrease grain-surface resistivity. Accordingly, grain-surface resistivity might be an appropriate geoelectrical analog for the horizontal hydraulic conductivity (K_h) of unconsolidated, clastic porous media; that is

$$K_h = f(R_s). \quad (3)$$

Alternatively, the variation of bulk resistivity across water-bearing sands and clayey sands (fig. 2) largely could be the result of changes in clay content, manifest as variations in grain-surface resistivity. Thus, bulk resistivity could also be a suitable geoelectrical analog for horizontal hydraulic conductivity.

To investigate the relations of aquifer bulk resistivity and grain-surface resistivity to horizontal hydraulic conductivity, grain-surface resistivity must first be defined in terms of geoelectrical properties that can be measured in the field. A parallel resistance model, similar to that used by Pfannkuch (1969), is used to relate aquifer bulk resistivity to electrolyte resistivity and matrix solids resistivity,

$$\frac{1}{R_o} = \frac{1}{R_e} + \frac{1}{R_m}. \quad (4)$$

Because matrix solids resistivity is considered to be infinite, equation 4 reduces to

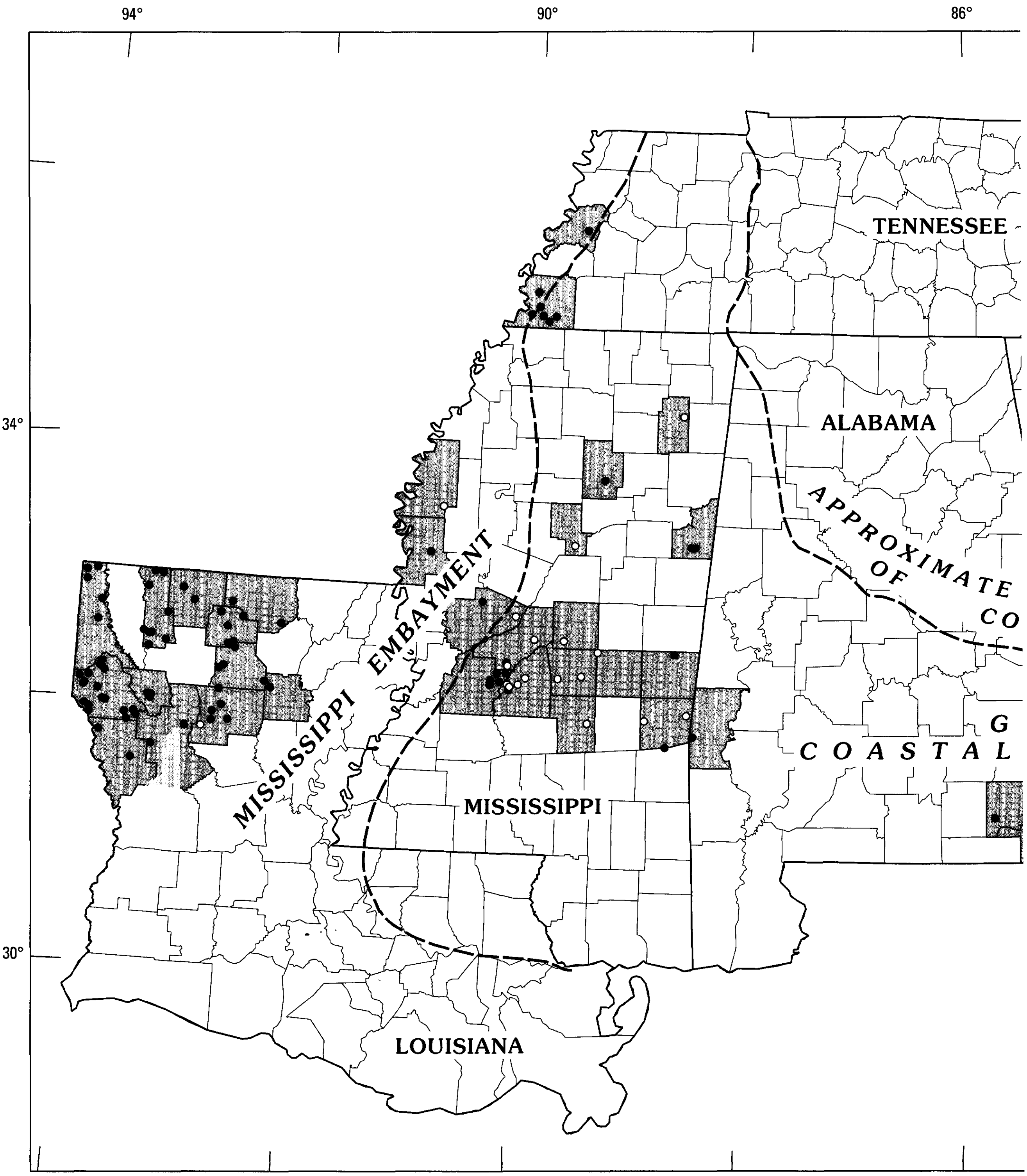
$$\frac{1}{R_o} = \frac{1}{R_e}, \text{ and} \quad (5)$$

$$R_o = R_e = f(R_w, R_s). \quad (6)$$

Because the exact, deterministic form of equation 2 is unknown, elementary hypothetical relations are used and substituted into equation 6 to evaluate grain-surface resistivity in terms of bulk resistivity and aquifer water resistivity. The hypothetical models applied in this study are a summation model ($R_e = R_w + R_s$) and a product model ($R_e = R_w \times R_s$).

Summation Model

The summation model explains grain-surface resistivity as the difference between bulk resistivity



Base modified from U.S. Geological Survey, National Atlas digital data, 1:2,000,000, 1970
Albers Equal-Area Conic projection
Standard parallels 29°30' and 45°30', central meridian -96°00'

Figure 1. Study area and county and site locations of wells.

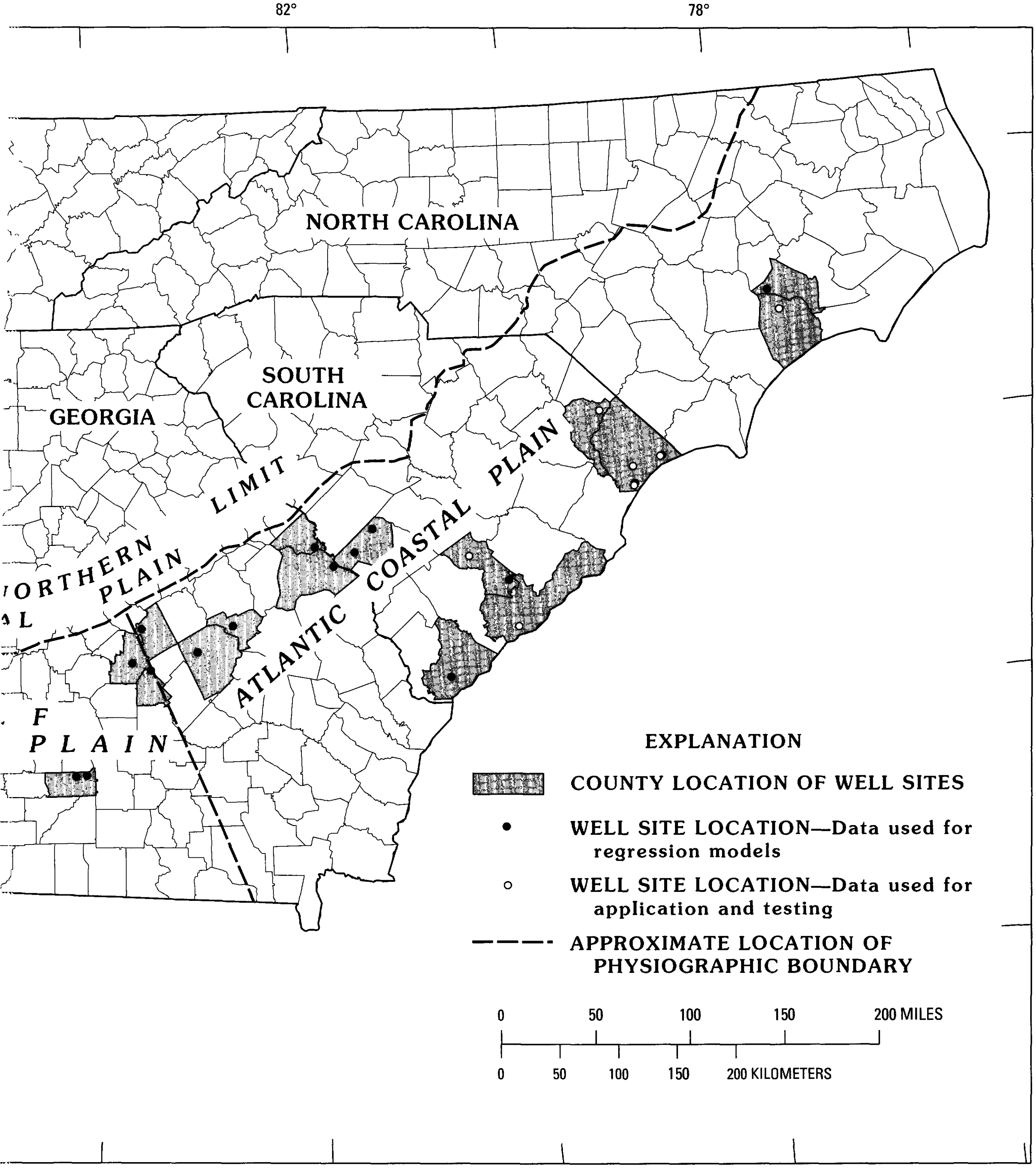

82°
78°
NORTH CAROLINA
SOUTH CAROLINA
GEORGIA
LIMIT
NORTHERN
PLAIN
ATLANTIC COASTAL PLAIN
PLAIN
EXPLANATION
COUNTY LOCATION OF WELL SITES
WELL SITE LOCATION—Data used for regression models
WELL SITE LOCATION—Data used for application and testing
APPROXIMATE LOCATION OF PHYSIOGRAPHIC BOUNDARY
0 50 100 150 200 MILES
0 50 100 150 200 KILOMETERS

Table 1. Summary of well location and construction data

[Deg, degrees; Min, minutes; Sec, seconds; gal/min, gallons per minute; —, no data]

County	State well number	Local well name	Latitude Deg	Latitude Min	Latitude Sec	Longitude Deg	Longitude Min	Longitude Sec	Reported water-bearing unit(s)	Total screen length (ft)	Estimated contributing interval (ft)	Openings diameter (in.)	Test discharge (gal/min)
Alabama													
Choctaw	CHO-1	Choctaw County #1	31	55	53	88	27	31	Nanafalia Formation	20	120	4	200
Dale	—	Fort Rucker #9 (TW3)	31	20	09	85	42	55	Tuscahoma Formation Nanafalia Formation Clayton Formation Providence Sand.	140	290	10	500
Georgia													
Burke	31Z002	Bechtel Corp. #1 (TW-1)	33	08	28	81	45	42	Middendorf Formation	125	318	10	1,200
Dougherty	12L021	Albany TW-10	31	35	34	84	10	30	Providence Sand	35	32	—	—
Dougherty	13L021	Miller Brewing Company PW2	31	35	47	84	04	44	Tallahatta Formation	200	254	12	1,400
Dougherty	13L022	Miller Brewing Company PW3	31	36	09	84	04	35	Tallahatta Formation	200	312	12	1,430
Houston	16T002	Pabst Brewing Co. #4	32	26	19	83	38	12	Selma Group	100	630	12	1,560
Johnston	24V001	Wrightsville Firetower (USGS TW-1)	32	42	09	82	43	02	Middendorf Formation	60	158	1/4	—
Laurens	21U004	Laurens TW-3 (I-16 Rest Stop)	32	30	30	83	02	43	Middendorf Formation	40	124	4	—
Pulaski	18T001	Arrowhead (USGS TW-1)	32	22	45	83	29	01	Selma Group	40	48	4	—
Richmond	30AA13	Kimberly-Clark Observation Well #1	33	16	27	81	55	58	Selma Group	50	247	4	500
Richmond	30AA15	Kimberly-Clark Observation Well #3	33	16	30	81	55	54	Selma Group	50	278	4	500
Twiggs	17V004	J.M. Huber HP5	32	41	50	83	33	21	Selma Group	60	156	12	1,180
Louisiana													
Caddo	CD-435	Blanchard Test Hole #1	32	36	08	93	51	24	Wilcox Group	19	16	1/4	10
Caddo	CD-447	Vivian #3	32	53	57	93	58	57	Wilcox Group	15	15	1/4	32
Caddo	CD-460	Rodessa Water Test #1	32	58	13	93	59	31	Carrizo Formation	15	36	1/4	37
Caddo	CD-492	Town Of Belcher Water System Well #2	32	44	52	93	49	54	Wilcox Group	10	30	1/4	50
Caddo	CD-498A	Ida Test Well #2	32	59	37	93	53	54	Sparta Sand	10	15	1/4	37
Caldwell	CA-98	Cotton Plant Test #2	32	10	34	92	16	18	Sparta Sand	20	20	2	25
Claiborne	CL-135A	Claiborne Parish Police Jury Well #1	32	52	59	93	06	16	Sparta Sand	12	93	3	43
Claiborne	CL-140A	Homer Test Well #2	32	47	53	92	59	57	Sparta Sand	20	46	4	50
Claiborne	CL-140B	Homer Test Well #2	32	47	53	92	59	57	Sparta Sand	20	44	4	60
Desoto	DS-372A	Stanley Water Test Well #1	31	56	22	93	53	35	Wilcox Group	10	10	1/4	38
Desoto	DS-372B	Stanley Water Test Well #1	31	56	22	93	53	35	Wilcox Group	10	10	1/2	25
Desoto	DS-372C	Stanley Water Test Well #1	31	56	22	93	53	35	Wilcox Group	13	56	1/4	60
Desoto	DS-376	S. Mansfield #1	31	59	41	93	45	18	Wilcox Group	10	10	4	54
Desoto	DS-377	Longstreet Water Test Well #1	32	05	53	93	57	02	Wilcox Group	10	10	3	30

Table 1. Summary of well location and construction data—Continued

County	State well number	Local well name	Latitude Deg	Latitude Min	Latitude Sec	Longitude Deg	Longitude Min	Longitude Sec	Reported water-bearing unit(s)	Total screen length (ft)	Estimated contributing interval (ft)	Openings diameter (in.)	Test discharge (gal/min)
						Louisiana—Continued							
Desoto	DS-381A	Keatchie Water Test Well #1	32	11	15	93	54	26	Wilcox Group	10	24	3	30
Desoto	DS-381B	Keatchie Water Test Well #1	32	11	15	93	54	26	Wilcox Group	10	30	3	30
Desoto	DS-386	Toledo Bend Park Site #2	31	54	05	93	53	40	Wilcox Group	10	44	4	65
Desoto	DS-391	Stanley Water System	31	57	28	93	55	39	Wilcox Group	10	10	3	14
Desoto	DS-396	Rambin-Wallace Community Test Well #1	31	54	56	93	27	46	Wilcox Group	10	24	2	30
Desoto	DS-397	Rambin-Wallace Test #2	31	53	57	93	27	03	Wilcox Group	10	54	4	18
Desoto	DS-403	Wallace Community Water System Test #2	31	54	56	93	34	18	Wilcox Group	10	10	4	40
Desoto	DS-404A	Wallace Community Water System Test #3	31	51	25	93	32	16	Wilcox Group	10	24	4	24
Desoto	DS-404B	Wallace Community Water System Test #3	31	51	25	93	32	16	Wilcox Group	10	44	3	23
Desoto	DS-406	Grand Cane Test #1	32	04	54	93	48	45	Wilcox Group	10	32	2	50
Desoto	DS-409	N. Desoto Water System Test #3	32	15	07	93	48	37	Wilcox Group	10	46	3	43
Desoto	DS-414B	N. Desoto Water System Well #3	32	13	37	93	46	18	Wilcox Group	10	10	2	50
Desoto	DS-417	Mansfield Test Well #2	31	59	55	93	46	29	Wilcox Group	10	22	3	40
Desoto	DS-423	N. Desoto Test Well #2	32	17	44	93	48	54	Wilcox Group	22	22	[1]4	34
Desoto	DS-458	Keatchie Water System	32	09	58	93	59	24	Wilcox Group	10	18	3	40
Desoto	DS-459	Keatchie Test Well #2	32	06	50	93	56	41	Wilcox Group	20	20	3	42
Jackson	JA-101B	Girl Scout Camp Test Well	32	12	49	92	19	04	Sparta Sand	20	78	2.75	43
Jackson	JA-136	Riser Road Community Water District Well	32	28	08	92	37	17	Sparta Sand	20	63	3	38
Jackson	JA-140	Bear Creek #2	32	17	51	92	44	42	Sparta Sand	10	78	2	28
Jackson	JA-150	Pumkin Center Test #1	32	19	04	92	42	03	Sparta Sand	10	11	2	28
Lincoln	LN-117	Ruston State School #1	32	42	02	92	32	26	Sparta Sand	15	32	2	33
Lincoln	LN-131B	S.D. Beard Property Water Well Test	32	36	58	92	41	18	Sparta Sand	10	66	3	30
Lincoln	LN-135A	Hico Water Test #2	32	43	25	92	45	02	Sparta Sand	10	52	3	25
Lincoln	LN-140	Wesley Chapel Water Well	32	29	00	92	40	40	Sparta Sand	10	62	3	25
Lincoln	LN-151	Ruston Test Well	32	29	47	92	38	25	Sparta Sand	20	132	4	33
Lincoln	LN-48	Ruston Water Well #1	32	31	30	92	39	51	Sparta Sand	60	104	10	800
Natchitoches	NA-362	Clarence Water Well	31	50	52	93	01	02	Wilcox Group	10	46	4	35
Natchitoches	NA-413	Robeline Test Well #2	31	41	41	93	19	21	Wilcox Group	10	32	2	75
Red River	RR-181	Edgefield Test Hole #1	32	02	46	93	19	35	Wilcox Group	10	10	[1]4	20
Red River	RR-182	Edgefield #2	32	03	05	93	20	14	Wilcox Group	10	30	2	33
Red River	RR-241	Choushatta Industrial Test Park #2	32	01	25	93	20	39	Wilcox Group	10	14	2	20
Red River	RR-247	Choushatta Test #1	32	02	07	93	21	09	Wilcox Group	10	22	3	43
Red River	RR-249	Edgefield Observation Well	32	03	06	93	20	07	Wilcox Group	10	42	4	50
Red River	RR-251	Halfway-Carroll Test #3	32	03	10	93	21	47	Wilcox Group	10	20	3	38
Sabine	SA-407A	Many Test Hole #3	31	34	41	93	28	55	Wilcox Group	20	32	[1]4	26
Sabine	SA-407B	Many Test Hole #3	31	34	41	93	28	55	Wilcox Group	20	20	[1]4	30
Sabine	SA-431	Toledo Bend Test Site #4	31	46	00	93	46	56	Wilcox Group	10	22	4	62
Union	UN-57	Bernice Test Well	32	48	33	92	39	11	Sparta Sand	10	36	3	56
Union	UN-71B	Rocky Branch Water Test #2	32	40	03	92	12	09	Sparta Sand	20	42	2	36

Table 1. Summary of well location and construction data—Continued

County	State well number	Local well name	Latitude Deg	Latitude Min	Latitude Sec	Longitude Deg	Longitude Min	Longitude Sec	Reported water-bearing unit(s)	Total screen length (ft)	Estimated contributing interval (ft)	Openings diameter (in.)	Test discharge (gal/min)
Louisiana—Continued													
Webster	WE-139	Louisiana Ordnance Plant	32	32	44	93	26	23	Wilcox Group	70	66	8	260
Webster	WE-265	Jenkins Water Test Well #1	32	31	36	93	23	35	Carrizo Formation	10	34	3	50
Webster	WE-268	Old Shongaloo Water Well Test #2	32	59	35	93	18	00	Sparta Sand	10	24	4	41
Webster	WE-270	Jenkins Water Test Well #2	32	31	37	93	22	31	Carrizo Formation	10	26	3	40
Webster	WE-281	Central Test Well #1	32	28	53	93	14	09	Carrizo Formation	10	28	4	38
Webster	WE-291	Palmetto Beach Community #1	32	25	53	93	23	35	Wilcox Group	10	22	4	35
Webster	WE-292B	North Shongaloo Community Water Well	33	00	33	93	21	52	Sparta Sand	10	64	3	43
Webster	WE-308	Thomasville Test Well #1	32	52	39	93	25	52	Sparta Sand	10	29	3	20
Webster	WE-321A	Germantown Water Test Well #1	32	42	05	93	13	46	Sparta Sand	10	62	3	43
Webster	WE-321B	Germantown Water Test Well #1	32	42	05	93	13	46	Sparta Sand	10	34	3	50
Winn	WI-113	Hurricane Creek #2	32	01	18	92	41	41	Sparta Sand	10	70	3	25
Winn	WI-114	Gum Springs Water Well Test	31	53	53	92	47	00	Sparta Sand	20	88	3	25
Winn	WI-120	Winnfield Test #3	31	55	06	92	37	43	Sparta Sand	10	40	2	35
Winn	WI-127	Calvin Test #1	31	58	02	92	46	41	Sparta Sand	10	44	4	33
Winn	WI-140	Gansville Test Well	32	08	34	92	44	10	Sparta Sand	20	54	2	30
Winn	WI-143	Calvin Test Well	31	57	56	92	46	35	Sparta Sand	10	48	3	30
Mississippi													
Calhoun	K101	Calhoun City Well #1	33	51	18	89	17	59	Gordo Formation	57	38	12	240
Clarke	R31	Hiwanee Water Assn. #1	31	51	03	88	41	02	Lower Wilcox Group	70	129	8	450
Hinds	G84	City Of Jackson "W-D"	32	18	45	90	16	58	Sparta Sand	60	166	8	610
Hinds	H146	City Of Jackson "N-B"	32	22	20	90	14	00	Sparta Sand	60	110	8	610
Hinds	H149	City Of Jackson	32	23	06	90	09	42	Sparta Sand	60	243	8	600
Hinds	H188	Jackson Zoo Well #1	32	19	09	90	13	22	Sparta Sand	32	70	6	170
Hinds	M99	City Of Jackson "W-B"	32	16	48	90	17	00	Sparta Sand	65	95	8	610
Lauderdale	C53	Naval Air Station #4	32	33	15	88	37	23	Lower Wilcox Group	61	104	8	700
Lauderdale	C54	Naval Air Station #1	32	33	14	88	36	59	Lower Wilcox Group	47	74	8	610
Lowndes	P20	Weyerhaeuser #2	33	21	46	88	28	02	Coker Formation	156	148	10	2,000
Lowndes	P21	Weyerhaeuser #3	33	21	46	88	27	10	Coker Formation	156	180	6	754
Madison	W74	Town Of Madison	32	27	02	90	08	23	Sparta Sand	50	102	8	560
Rankin	K119	Town Of Pearl	32	15	18	90	07	11	Sparta Sand	60	210	8	610
Washington	L70	Arcola Well #3	33	16	19	90	52	22	Sparta Sand	50	202	6	250
Yazoo	G81	Mississippi Chemical Corp. Test Well	32	54	21	90	22	43	Meridian Sand Wilcox Group	260	108	6	900
North Carolina													
Jones	T27U1	Weyerhauser Well #2	35	00	51	77	35	09	Peedee Formation	30	52	6	80

Table 1. Summary of well location and construction data—Continued

County	State well number	Local well name	Latitude Deg	Latitude Min	Latitude Sec	Longitude Deg	Longitude Min	Longitude Sec	Reported water-bearing unit(s)	Total screen length (ft)	Estimated contributing interval (ft)	Openings diameter (in.)	Test discharge (gal/min)
						South Carolina							
Barnwell	BW-79	Town Of Williston	33	23	48	81	24	07	Middendorf Formation	100	330	10	1,400
Barnwell	SRP 905–120p	Savannah River Plant	33	13	40	81	34	31	Middendorf Formation	50	70	6	750
Beaufort	BFT-454	Hilton Head Deep Well	32	14	46	80	44	40	Cape Fear Formation Middendorf Formation.	82	184	—	—
Dorchester	DOR-221	Oakbrook Well #3	32	57	32	80	09	46	Black Creek Formation	69	64	6	600
Horry	HO-336	North Myrtle Beach #2	33	50	16	78	40	24	Black Creek Formation	150	320	8	500
Horry	HO-416	Ocean Lakes #6	33	38	15	78	57	42	Black Creek Formation	120	384	8	400
						Tennessee							
Lauderdale	LD:H-6	City Of Ripley #2	35	44	44	89	31	42	Memphis Sand	—	90	12	590
Shelby	SH:J-104	Memphis Light, Gas, and Water	35	05	38	90	01	45	Memphis Sand	—	70	6	1,680
Shelby	SH:K-73	Memphis Light, Gas, and Water Test #6	35	05	15	89	55	36	Memphis Sand	—	130	—	1,700
Shelby	SH:L-69	Memphis Light, Gas, and Water	35	02	59	89	52	13	MemphisSand	—	110	—	820
Shelby	SH:L-8	Germantown Well #2	35	05	04	89	48	32	Memphis Sand	—	102	—	300
Shelby	SH:P-25	Buckeye #10	35	09	14	89	57	41	Wilcox Group	167	195	12	1,200
Shelby	SH:U-18	Dupont Well #5	35	16	00	89	58	43	Memphis Sand	80	102	10	1,570
						Application and Test Sites							
						Alabama							
Houston	—	—	31	12	30	85	25	00	Tuscahoma Formation Nanafalia Formation Clayton Formation.	—	[3]240	—	[2]620
						Louisiana							
Desoto	DS-411	—	31	52	37	93	53	38	Wilcox Group	20	56	4	25
Winn	WI-115B	—	31	51	15	92	52	39	Sparta Sand	10	12	2	12
						Mississippi							
Bolivar	T131	—	33	36	35	90	46	05	Sparta Sand	81	84	8	270
Clark	K8	—	32	05	26	88	29	58	Lower Wilcox Group	40	82	8	280
Clark	L51	—	32	02	39	88	52	54	Sparta Sand	40	126	6	280
Leake	O34	—	32	37	52	89	37	35	Lower Wilcox	60	72	6	340
Lee	F31	—	34	21	09	88	35	04	McShan Formation	60	114	6	160
Madison	O46	—	32	38	02	89	54	15	Meridian Sand Upper Wilcox Group.	71	96	6	410
Madison	W69	—	32	25	14	90	08	09	Sparta Sand	81	202	10	940
Montgomery	M12	—	33	21	09	89	33	23	Lower Wilcox Group	51	88	6	170
Newton	A34	—	32	33	41	89	19	11	Middle Wilcox Group	31	80	8	470
Rankin	G42	—	32	20	32	89	58	02	Sparta Sand	40	134	6	330

Table 1. Summary of well location and construction data—Continued

County	State well number	Local well name	Latitude Deg	Latitude Min	Latitude Sec	Longitude Deg	Longitude Min	Longitude Sec	Reported water-bearing unit(s)	Total screen length (ft)	Estimated contributing interval (ft)	Openings diameter (in.)	Test discharge (gal/min)
Mississippi—Continued													
Rankin	G51	—	32	20	34	89	58	20	Sparta Sand	70	105	8	300
Rankin	K120	—	32	16	40	90	07	08	Sparta Sand	50	65	8	600
Rankin	K175	—	32	17	36	90	08	41	Sparta Sand	80	146	8	750
Rankin	K186	—	32	17	10	90	02	38	Sparta Sand	100	114	8	770
Scott	J35	—	32	20	51	89	40	19	Sparta Sand	122	190	8	680
Scott	L45	—	32	21	57	89	27	19	Meridian Sand	110	144	8	1,000
Smith	L26	—	32	00	46	89	23	20	Sparta Sand	61	142	6	320
Yazoo	O30	—	32	48	26	90	03	52	Meridian Sand Upper Wilcox Group.	60	84	6	230
North Carolina													
Onslow	V25P4	—	34	51	31	77	29	16	Black Creek Formation	55	66	6	750
South Carolina													
Charleston	CH-186	—	32	36	00	80	06	22	Middendorf Formation	116	260	8	450
Dorchester	DOR-211	—	33	09	25	80	31	18	Ellenton Formation Black Creek Formation Cape Fear Formation.	60	84	—	—
Horry	HO-309	—	33	45	43	78	57	42	Black Creek Formation	15	70	4	32
Horry	HO-335	—	33	49	34	78	41	15	Black Creek Formation	195	420	8	500
Horry	HO-353	—	33	37	15	78	57	42	Black Creek Formation	70	110	6	300
Marion	MRN-67	—	34	11	56	79	14	04	Black Creek Formation	50	208	8	570
Marion	MRN-78	—	31	12	30	85	25	00	Black Creek Formation Middendorf Formation Cape Fear Formation.	90	90	—	—

[1] Reported casing diameter.
[2] Aquifer-test discharge at City of Dothan well #9.
[3] Estimate based on electric log data at nearby Selma Street well.

Table 2. Generalized correlation of geologic units and aquifer units

System	Series	Group		Geologic units West	Geologic units East	Aquifer unit
Tertiary	Eocene	Claiborne	Memphis Sand	Sparta Sand		middle Eocene
				Tallahatta Formation		
				Carrizo Formation	Meridian Sand member of the Tallahatta Formation	Paleocene and early Eocene
	Paleocene	Wilcox		Tuscahoma Formation		
				Nanafalia Formation		
		Midway		Clayton Formation	Ellenton[1] Formation	
Cretaceous	Upper Cretaceous	Selma		Providence Sand	Peedee[2] Formation	Late Cretaceous
				Ripley Formation		
				Cusseta Sand[2]	Black Creek[2] Formation	
				Blufftown Formation		
				Eutaw Formation	Middendorf[3] Formation	
				McShan Formation	Cape Fear[4] Formation	
		Tuscaloosa		Gordo Formation		
				Coker Formation		

[1] Not part of Midway Group.
[2] Not part of Selma Group.
[3] Part of Lumbee Group.
[4] Not part of Tuscaloosa Group.

and aquifer water resistivity. Because horizontal hydraulic conductivity is also explained as a function of grain-surface resistivity,

$$K_h=f\,(R_s)=f\,(R_o-R_w). \qquad (7)$$

Product Model

The relation of grain-surface resistivity to bulk resistivity and water resistivity explained by the product model is expressed by the following equation,

$$K_h=(f\,(R_s)=f\,(R_o/R_w). \qquad (8)$$

The right-hand side of equation 8 generally corresponds to the definition of apparent formation factor (F_a) described by Pfannkuch (1969) and Worthington (1977). Apparent formation factor is the ratio of bulk resistivity to water resistivity in freshwater-saturated porous media containing clays or other conductive solids and previously has been used to estimate horizontal hydraulic conductivity (Alger, 1966; Croft, 1971; Urish, 1981; Biella and others, 1983; Alger and Harrison, 1989). Intrinsic formation factor (F) is similarly defined but applies only to porous media saturated with highly conductive electrolytes, such as brines (Archie, 1942). Where porous media are saturated with brine, geoelectrical conductance is almost entirely through the electrolyte (pore spaces); grain-surface conductance is minimal. All subsequent references to formation factor are to apparent formation factor.

Application of equations 7 and 8 at well sites requires a data base that includes aquifer-test results or laboratory determinations of hydraulic characteristics, borehole lithologic and well construction logs, calibrated borehole resistivity logs, and chemical analyses of water samples from the completed wells.

Table 3. Summary of borehole geoelectrical properties and aquifer water-quality characteristics at well sites

[ohm-m, ohm-meter; µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; —, no data]

County	State well number	Local well name	Average bulk resistivity (R_o) (ohm-m)	Water discharge temperature (°C)	Specific conductance of well discharge (µS/cm)	Water resistivity at 25°C (R_w) (ohm-m)	Water resistivity at discharge temperature (R_{wx}) (ohm- m)	Dissolved-solids concentration of well discharge (mg/L)
			Alabama					
Choctaw	CHO-1	Choctaw County #1	31	33.0	900	11.1	9.5	[1]535
Dale	—	Fort Rucker #9 (TW-3)	120	23.5	320	31.3	32.3	—
			Georgia					
Burke	31Z002	Bechtel Corp. #1 (TW-1)	200	—	[2]180	55.6	55.6	—
Dougherty	12L021	Albany TW-10	30	24.0	560	17.9	18.3	[3]242
Dougherty	13L021	Miller Brewing Company PW2	100	20.0	321	31.2	34.9	192
Dougherty	13L022	Miller Brewing Company PW3	66	20.0	321	31.2	34.9	192
Houston	16T002	Pabst Brewing Co. #4	580	19.0	35	286	328	[4]31
Johnston	24V001	Wrightsville Firetower (USGS TW-1).	110	30.0	145	69	62.3	[4]112
Laurens	21U004	Laurens TW-3 (I-16 Rest Stop)	120	24.9	115	87	87.2	[4]75
Pulaski	18T001	Arrowhead (USGS TW-1)	280	24.5	79	127	128	[4]26
Richmond	30AA13	Kimberly-Clark Observation Well #1.	170	25.0	120	83.3	83.3	88
Richmond	30AA15	Kimberly-Clark Observation Well #3.	200	25.0	107	93.5	93.5	91
Twiggs	17V004	J.M. Huber HP5	430	—	46	217	217	[5]47
			Louisiana					
Caddo	CD-435	Blanchard Test Hole #1	21	20.6	916	10.9	12.0	517
Caddo	CD-447	Vivian #3.	32	—	697	14.3	14.3	419
Caddo	CD-460	Rodessa Water Test #1	33	—	916	10.9	10.9	204
Caddo	CD-492	Town Of Belcher Water System Well #2.	15	—	1,550	6.5	6.5	902
Caddo	CD-498A	Ida Test Well #2	45	—	273	36.6	36.6	151
Caldwell	CA-98	Cotton Plant Test #2	18	—	1,360	7.4	7.4	836
Claiborne	CL-135A	Claiborne Parish Police Jury Well #1.	160	—	139	71.9	71.9	170
Claiborne	CL-140A	Homer Test Well #2	140	—	190	52.6	52.6	137
Claiborne	CL-140B	Homer Test Well #2	150	—	200	50.0	50.0	169
Desoto	DS-372A	Stanley Water Test Well #1	100	—	189	52.9	52.9	162
Desoto	DS-372B	Stanley Water Test Well #1	23	21.6	1,160	8.6	9.3	738
Desoto	DS-372C	Stanley Water Test Well #1	29	21.6	1,310	7.6	8.2	805
Desoto	DS-376	S. Mansfield #1	33	21.7	607	16.5	17.8	379
Desoto	DS-377	Longstreet Water Test Well #1	27	21.9	772	13.0	13.9	463
Desoto	DS-381A	Keatchie Water Test Well #1	27	23.3	765	13.1	13.6	458
Desoto	DS-381B	Keatchie Water Test Well #1	30	22.8	885	11.3	11.9	526
Desoto	DS-386	Toledo Bend Site #2	27	21.1	1,510	6.6	7.2	889
Desoto	DS-391	Stanley Water System	29	21.7	1,800	5.6	6.0	1,070
Desoto	DS-396	Rambin-Wallace Community Test Well #1.	90	20.5	384	26.0	28.8	260
Desoto	DS-397	Rambin-Wallace Test #2	30	21.5	1,030	9.7	10.5	681
Desoto	DS-403	Wallace Community Water System Test #2.	40	21.1	403	24.8	27.1	267
Desoto	DS-404A	Wallace Community Water System Test #3.	27	21.5	772	13.0	14.1	481
Desoto	DS-404B	Wallace Community Water System Test #3.	27	22.5	768	13.0	13.7	469
Desoto	DS-406	Grand Cane Test #1	30	21.0	570	17.5	19.1	341
Desoto	DS-409	N. Desoto Water System Test #3	27	23.9	1,620	6.2	6.3	921
Desoto	DS-414B	N. Desoto Water System Well #3	20	—	1,660	6.0	6.0	940

Table 3. Summary of borehole geoelectrical properties and aquifer water-quality characteristics at well sites—Continued

County	State well number	Local well name	Average bulk resistivity (R_o) (ohm-m)	Water discharge temperature (°C)	Specific conductance of well discharge (µS/cm)	Water resistivity at 25°C (R_w) (ohm-m)	Water resistivity at discharge temperature (R_{wx}) (ohm- m)	Dissolved-solids concentration of well discharge (mg/L)
			Louisiana—Continued					
Desoto	DS-417	Mansfield Test Well #2	27	—	953	10.5	10.5	568
Desoto	DS-423	N. Desoto Test Well #2	40	22.2	539	18.6	19.8	331
Desoto	DS-458	Keatchie Water System	25	22.0	562	17.8	19.0	330
Desoto	DS-459	Keatchie Test Well #2	24	22.0	779	12.8	13.7	457
Jackson	JA-101B	Girl Scout Camp Test Well	37	22.5	1,090	9.2	9.7	681
Jackson	JA-136	Riser Road Community Water District Well.	45	25.6	536	18.7	18.5	331
Jackson	JA-140	Bear Creek #2	120	21.9	243	41.2	44.1	191
Jackson	JA-150	Pumkin Center Test #1	30	24.4	402	24.9	25.2	258
Lincoln	LN-117	Ruston State School #1	27	22.8	870	11.5	12.1	486
Lincoln	LN-131B	S.D. Beard Property Water Well Test.	95	22.8	277	36.1	37.9	192
Lincoln	LN-135A	Hico Water Test #2	60	22.2	316	31.6	33.6	231
Lincoln	LN-140	Wesley Chapel Water Well	45	23.6	409	24.4	25.2	283
Lincoln	LN-151	Ruston Test Well	60	26.0	408	24.5	24.0	274
Lincoln	LN-48	Ruston Water Well #1	150	25.0	252	39.7	39.7	187
Natchitoches	NA-362	Clarence Water Well	53	20.6	636	15.7	17.3	403
Natchitoches	NA-413	Robeline Test Well #2	25	23.1	1,240	8.1	8.4	789
Red River	RR-181	Edgefield Test Hole #1	46	25.8	345	29.0	28.5	217
Red River	RR-182	Edgefield #2	88	—	308	32.5	32.5	206
Red River	RR-241	Choushatta Industrial Park Test #2.	26	21.1	783	12.8	14.0	464
Red River	RR-247	Choushatta Test #1	32	19.4	706	14.2	16.1	396
Red River	RR-249	Edgefield Observation Well	55	18.3	265	37.7	44.0	188
Red River	RR-251	Halfway-Carroll Test #3	22	20.0	773	12.9	14.4	450
Sabine	SA-407A	Many Test Hole #3	23	21.9	1,280	7.8	8.4	800
Sabine	SA-407B	Many Test Hole #3	55	20.8	591	16.9	18.6	357
Sabine	SA-431	Toledo Bend Test Site #4	25	22.2	817	12.2	13.0	480
Union	UN-57	Bernice Test Well	150	24.7	410	24.4	24.6	290
Union	UN-71B	Rocky Branch Water Test #2	27	25.0	1,140	8.8	8.8	650
Webster	WE-139	Louisiana Ordnance Plant	32	21.7	676	14.8	15.9	412
Webster	WE-265	Jenkins Water Test Well #1	26	21.1	1,790	5.6	6.1	974
Webster	WE-268	Old Shongaloo Water Well Test #2.	40	22.2	472	21.2	22.6	290
Webster	WE-270	Jenkins Water Test Well #2	34	21.7	1,060	9.4	10.1	603
Webster	WE-281	Central Test Well #1	38	23.9	689	14.5	14.9	434
Webster	WE-291	Palmetto Beach Community #1	38	19.4	421	23.8	27.0	265
Webster	WE-292B	North Shongaloo Community Water Well.	54	20.6	611	16.4	18.1	365
Webster	WE-308	Thomasville Test Well #1	80	21.1	322	31.1	33.9	200
Webster	WE-321A	Germantown Water Test Well #1	160	22.8	168	59.5	62.4	150
Webster	WE-321B	Germantown Water Test Well #1	160	—	201	49.8	49.8	179
Winn	WI-113	Hurricane Creek #2	34	20.6	1,250	8.0	8.8	699
Winn	WI-114	Gum Springs Water Well Test	30	24.4	897	11.1	11.2	501
Winn	WI-120	Winnfield Test #3	30	—	840	11.9	11.9	494
Winn	WI-127	Calvin Test #1	32	21.7	979	10.2	11.0	566
Winn	WI-140	Gansville Test Well	37	22.2	851	11.8	12.6	528
Winn	WI-143	Calvin Test Well	27	22.2	1,080	9.3	9.9	603
			Mississippi					
Calhoun	K101	Calhoun City Well #3	41	33.3	1,135	8.8	7.5	—
Clarke	R31	Hiwanee Water Assn. #1	35	38.5	800	12.5	9.7	605

Table 3. Summary of borehole geoelectrical properties and aquifer water-quality characteristics at well sites—Continued

County	State well number	Local well name	Average bulk resistivity (R_o) (ohm-m)	Water discharge temperature (°C)	Specific conductance of well discharge (μS/cm)	Water resistivity at 25°C (R_w) (ohm-m)	Water resistivity at discharge temperature (R_{wx}) (ohm- m)	Dissolved-solids concentration of well discharge (mg/L)
			Mississippi—Continued					
Hinds	G84	City Of Jackson "W-D"	55	29.0	420	23.8	21.9	362
Hinds	H146	City Of Jackson "N-B"	78	28.0	390	25.6	24.1	267
Hinds	H149	City Of Jackson	66	28.0	340	29.4	27.6	—
Hinds	H188	Jackson Zoo Well #1	26	26.0	449	22.3	21.8	275
Hinds	M99	City Of Jackson "W-B"	60	30.6	420	23.8	21.3	337
Lauderdale	C53	Naval Air Station #4	400	—	61	164	164	66
Lauderdale	C54	Naval Air Station #1	400	—	68	147	147	54
Lowndes	P20	Weyerhaeuser #2	150	—	93	107	107	16
Lowndes	P21	Weyerhaeuser #3	150	—	117	85.5	85.5	22
Madison	W74	Town Of Madison	40	33.0	387	25.8	22.0	231
Rankin	K119	Town Of Pearl	40	31.0	370	27.0	23.9	217
Washington	L70	Arcola Well #3	40	27.0	610	16.4	15.7	479
Yazoo	G81	Mississippi Chemical Corp. Test Well.	70	35.0	670	14.9	12.3	408
			North Carolina					
Jones	T27U1	Weyerhauser Well #2	150	—	280	35.7	35.7	184
			South Carolina					
Barnwell	BW-79	Town Of Williston	270	20.0	56	179	200	36
Barnwell	SRP905–120P	Savannah River Plant	610	—	46	217	217	38
Beaufort	BFT-454	Hilton Head Deep Well	6.2	43.5	1,900	5.3	3.8	1,310
Dorchester	DOR-221	Oakbrook Well #3	11	31.1	980	10.2	9.0	—
Horry	HO-336	North Myrtle Beach #2	7.8	26.5	1,850	5.4	5.2	1,150
Horry	HO-416	Ocean Lakes #6	17	24.0	1,080	9.3	9.5	670
			Tennessee					
Lauderdale	LD:H-6	City Of Ripley #2	200	18.3	187	53.5	62.5	104
Shelby	SH:J-104	Memphis Light, Gas, and Water.	300	17.2	143	69.9	83.9	80
Shelby	SH:K-73	Memphis Light, Gas, and Water Test #6.	380	16.1	148	67.6	83.5	89
Shelby	SH:L-69	Memphis Light, Gas, and Water.	400	16.7	88	114	138	54
Shelby	SH:L-8	Germantown Well #2	550	17.2	63	159	190	47
Shelby	SH:P-25	Buckeye #10	190	21.7	174	57.5	61.9	125
Shelby	SH:U-18	Dupont Well #5	160	19.4	180	55.6	63.2	180

[1] Davis and others (1983).
[2] Water-quality data from makeup well #2 (K.R. Davis, Georgia Geologic Survey, written commun., 1989).
[3] Lee (1984).
[4] Water-quality data from Clarke and others, 1985.
[5] Water-quality data from well HP-6 (K.R. Davis, Georgia Geologic Survey, written commun., October 4, 1989).

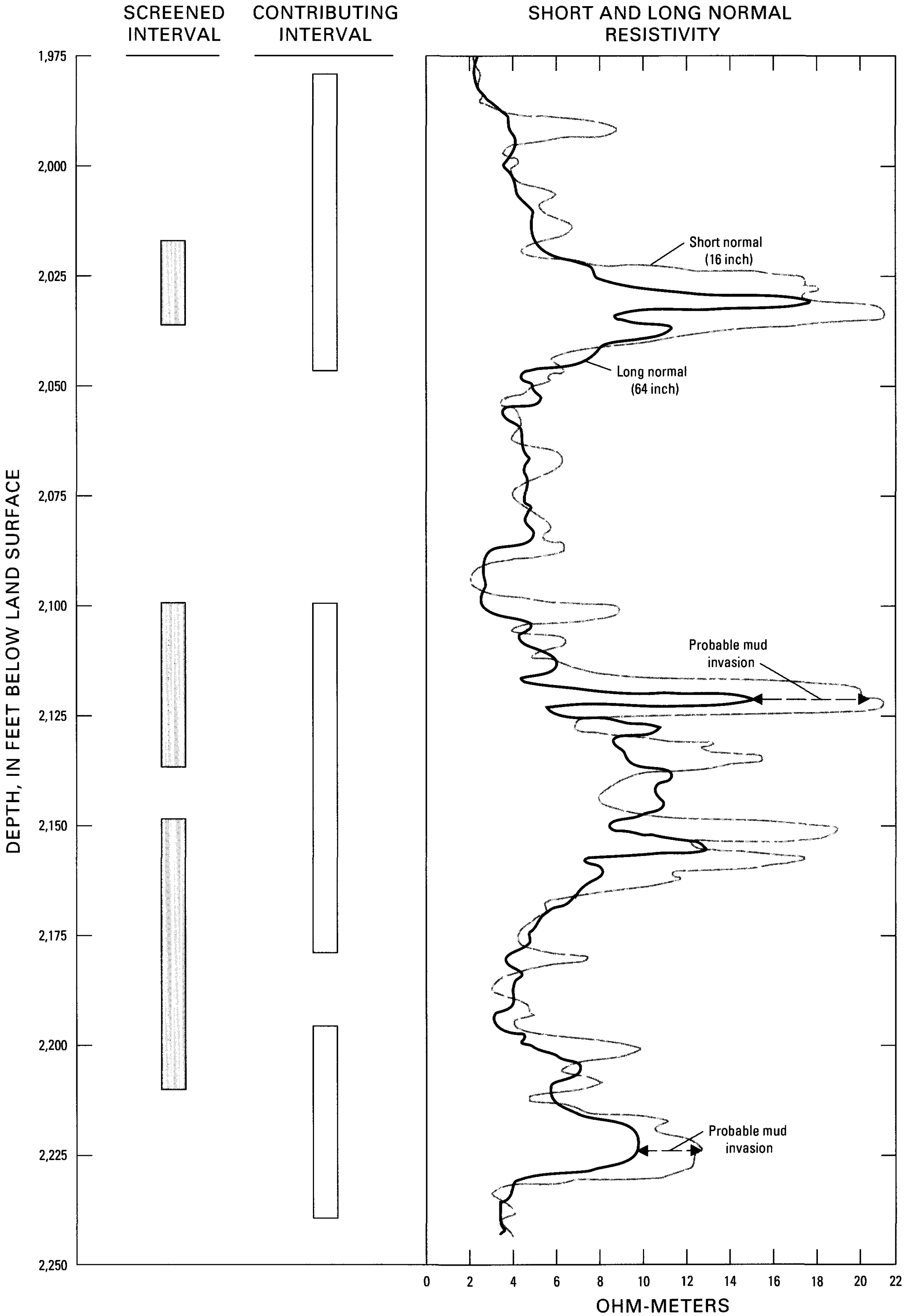


Figure 2. Resistivity borehole log at site CH-186 showing short- and long-normal curves and the screened and estimated contributing intervals.

Table 4. Summary of borehole geoelectrical properties and aquifer hydraulic characteristics at well sites
[ft²/d, feet squared per day; ft/d, feet per day; ohm-m, ohm meters; —, no data]

County	State well number	Local well name	Transmissivity (T) (ft²/d)	Average horizontal hydraulic conductivity (K_h)(ft/d)	Average bulk resistivity (R_o) (ohm-m)	Surface resistivity (R_s) R_s=[R_o−R_w] (ohm-m)	Surface resistivity (R_s) R_s=[R_o−R_{wx}] (ohm-m)
		Alabama					
Choctaw	CHO-1	Choctaw County #1	[1]4,000	33	31	20	22
Dale	—	Fort Rucker #9 (TW3)	[2]7,800	27	120	89	88
		Georgia					
Burke	31Z002	Bechtel Corp. #1 (TW-1)	[3]21,100	66	200	140	140
Dougherty	13L021	Miller Brewing Company PW2	[3]5,320	21	100	70	66
Dougherty	13L022	Miller Brewing Company PW3	[3]3,790	12	66	35	31
Houston	16T002	Pabst Brewing Co. #4	[3]32,300	51	580	290	250
Richmond	30AA13	Kimberly-Clark Observation Well #1	[3]4,950	20	170	90	90
Richmond	30AA15	Kimberly-Clark Observation Well #3	[3]6,550	24	200	110	110
Twiggs	17V004	J.M. Huber HP5	[3]8,710	56	430	210	210
		Louisiana					
Caddo	CD-435	Blanchard Test Hole #1	100	6.3	21	10	9
Caddo	CD-447	Vivian #3	240	16	32	18	18
Caddo	CD-460	Rodessa Water Test #1	270	7.5	33	22	22
Caddo	CD-492	Town Of Belcher Water System Well #2	160	5.3	15	8.5	8.5
Caddo	CD-498A	Ida Test Well #2	580	39	45	8.4	8.4
Caldwell	CA-98	Cotton Plant Test #2	620	31	18	11	11
Claiborne	CL-135A	Claiborne Parish Police Jury Well #1	11,400	120	160	92	92
Claiborne	CL-140A	Homer Test Well #2	5,480	120	140	87	87
Claiborne	CL-140B	Homer Test Well #2	6,020	140	150	100	100
Desoto	DS-372A	Stanley Water Test #1	310	31	100	47	47
Desoto	DS-372B	Stanley Water Test Well #1	80	8	23	14	14
Desoto	DS-372C	Stanley Water Test Well #1	640	11	29	21	21
Desoto	DS-376	S. Mansfield #1	330	33	33	17	15
Desoto	DS-377	Longstreet Water Test Well #1	90	9.0	27	14	13
Desoto	DS-381A	Keatchie Water Test Well #1	130	5.4	27	14	13
Desoto	DS-381B	Keatchie Water Test Well #1	670	22	30	19	18
Desoto	DS-386	Toledo Bend Park Site #2	1,870	43	27	20	20
Desoto	DS-391	Stanley Water System	200	20	29	23	23
Desoto	DS-396	Rambin-Wallace Community Test Well #1	820	34	90	64	61
Desoto	DS-397	Rambin-Wallace Test #2	1,040	19	30	20	20
Desoto	DS-403	Wallace Community Water System Test #2	190	19	40	15	13
Desoto	DS-404A	Wallace Community Water System Test #3	1,200	50	27	14	13
Desoto	DS-404B	Wallace Community Water System Test #3	900	21	27	14	13
Desoto	DS-406	Grand Cane Test #1	620	19	30	13	11
Desoto	DS-409	N. Desoto Water System Test #3	750	16	27	21	21
Desoto	DS-414B	N. Desoto Water System Well #3	110	11	20	14	14
Desoto	DS-417	Mansfield Test Well #2	620	28	27	17	17
Desoto	DS-423	N. Desoto Test Well #2	440	20	40	21	20
Desoto	DS-458	Keatchie Water System	230	13	25	7.2	6.0
Desoto	DS-459	Keatchie Test Well #2	180	9.0	24	11	10
Jackson	JA-101B	Girl Scout Camp Test Well	4,550	58	37	28	27
Jackson	JA-136	Riser Road Community Water District Well	3,880	62	45	26	27
Jackson	JA-140	Bear Creek #2	9,890	130	120	81	78
Jackson	JA-150	Pumkin Center Test #1	500	46	30	5.1	4.8
Lincoln	LN-117	Ruston State School #1	940	29	27	16	15
Lincoln	LN-131B	S.D. Beard Property Water Well Test	4,800	73	95	59	57
Lincoln	LN-135A	Hico Water Test #2	1,340	26	60	28	26
Lincoln	LN-140	Wesley Chapel Water Well	2,670	43	45	21	20

Table 4. Summary of borehole geoelectrical properties and aquifer hydraulic characteristics at well sites—Continued

County	State well number	Local well name	Transmissivity (T) (ft²/d)	Average horizontal hydraulic conductivity (K_h)(ft/d)	Average bulk resistivity (R_o) (ohm-m)	Surface resistivity (R_s) R_s=[R_o−R_w] (ohm-m)	R_s=[R_o−R_{wx}] (ohm-m)
		Louisiana—continued					
Lincoln	LN-151	Ruston Test Well	5,880	45	60	36	36
Lincoln	LN-48	Ruston Water Well #1	13,400	130	150	110	110
Natchitoches	NA-362	Clarence Water Well	1,600	35	53	37	36
Natchitoches	NA-413	Robeline Test Well #2	590	18	25	17	17
Red River	RR-181	Edgefield Test Hole #1	190	19	46	17	18
Red River	RR-182	Edgefield #2	1,230	41	88	56	56
Red River	RR-241	Choushatta Industrial Park Test #2	100	7.1	26	13	12
Red River	RR-247	Choushatta Test #1	440	20	32	18	16
Red River	RR-249	Edgefield Observation Well	1,420	34	55	17	11
Red River	RR-251	Halfway-Carroll Test #3	320	16	22	9.1	7.6
Sabine	SA-407A	Many Test Hole #3	310	9.7	23	15	15
Sabine	SA-407B	Many Test Hole #3	930	47	55	38	36
Sabine	SA-431	Toledo Bend Test Site #4	230	11	25	13	12
Union	UN-57	Bernice Test Well	5,130	140	150	120	120
Union	UN-71B	Rocky Branch Water Test #2	2,270	54	27	18	18
Webster	WE-139	Louisiana Ordnance Plant	1,260	19	32	17	16
Webster	WE-265	Jenkins Water Test Well #1	800	24	26	20	20
Webster	WE-268	Old Shongaloo Water Well Test #2	880	37	40	19	17
Webster	WE-270	Jenkins Water Test Well #2	630	24	34	25	24
Webster	WE-281	Central Test Well #1	1,120	40	38	24	23
Webster	WE-291	Palmetto Beach Community #1	320	15	38	14	11
Webster	WE-292B	North Shongaloo Community Water Well	5,080	79	54	38	36
Webster	WE-308	Thomasville Test Well #1	1,020	35	80	49	46
Webster	WE-321A	Germantown Water Test Well #1	7,620	120	160	100	100
Webster	WE-321B	Germantown Water Test Well #1	3,080	91	160	110	110
Winn	WI-113	Hurricane Creek #2	3,610	52	34	26	25
Winn	WI-114	Gum Springs Water Well Test	4,410	50	30	19	19
Winn	WI-120	Winnfield Test #3	2,140	54	30	18	18
Winn	WI-127	Calvin Test #1	2,540	58	32	22	21
Winn	WI-140	Gansville Test Well	1,740	32	37	25	24
Winn	WI-143	Calvin Test Well	2,670	56	27	18	17
		Mississippi					
Calhoun	K101	Calhoun City Well #3	[4]2,800	74	41	32	34
Clarke	R31	Hiwanee Water Assn. #1	[4]11,500	89	35	23	25
Hinds	G84	City Of Jackson "W-D"	[4]6,000	36	55	31	33
Hinds	H146	City Of Jackson "N-B"	[4]3,300	30	78	52	54
Hinds	H149	City Of Jackson	[4]13,000	54	66	37	38
Hinds	H188	Jackson Zoo Well #1	[4]1,800	26	26	3.7	4.2
Hinds	M99	City Of Jackson W-B	[4]4,700	50	60	36	39
Lauderdale	C53	Naval Air Station #4	[4]20,300	200	400	240	240
Lauderdale	C54	Naval Air Station #1	[4]21,700	290	400	250	250
Lowndes	P20	Weyerhaeuser #2	[4]8,700	59	150	43	43
Lowndes	P21	Weyerhaeuser #3	[4]5,900	33	150	65	65
Madison	W74	Town Of Madison	[4]4,100	40	40	14	18
Rankin	K119	Town Of Pearl	[4]9,800	47	40	13	16
Washington	L70	Arcola Well #3	[4]28,700	140	40	24	24
Yazoo	G81	Mississippi Chemical Corp. Test Well	[4]18,200	170	70	55	58
		North Carolina					
Jones	T27U1	Weyerhauser Well #2	2,200	42	150	110	110

Table 4. Summary of borehole geoelectrical properties and aquifer hydraulic characteristics at well sites—Continued

County	State well number	Local well name	Transmissivity (T) (ft²/d)	Average horizontal hydraulic conductivity (K_h)(ft/d)	Average bulk resistivity (R_o) (ohm-m)	Surface resistivity (R_s) R_s=[R_o−R_w] (ohm-m)	R_s=[R_o−R_{wx}] (ohm-m)
			South Carolina				
Barnwell	BW-79	Town Of Williston	[5]13,000	39	270	86	65
Dorchester	DOR-221	Oakbrook Well #3	590	9.2	11	0.8	2.0
Horry	HO-336	North Myrtle Beach #2	[5]2,000	6.3	7.8	2.4	2.6
Horry	HO-416	Ocean Lakes #6	[5]2,700	7.0	17	7.7	7.5
			Tennessee				
Lauderdale	LD:H-6	City Of Ripley #2	22,300	250	200	150	140
Shelby	SH:J-104	Memphis Light, Gas, and Water	19,800	280	300	230	220
Shelby	SH:K-73	Memphis Light, Gas, and Water Test #6	21,100	160	380	310	290
Shelby	SH:L-69	Memphis Light, Gas, and Water	26,700	240	400	290	260
Shelby	SH:L-8	Germantown Well #2	21,200	210	550	390	360
Shelby	SH:P-25	Buckeye #10	14,100	72	190	130	130
Shelby	SH:U-18	Dupont Well #5	56,800	560	160	100	97

[1] Davis and others (1983).
[2] Scott and others (1984).
[3] Faye and McFadden (1986).
[4] Slack and Darden (1991).
[5] Aucott and Newcome (1986).

RELATIONS OF BOREHOLE RESISTIVITY TO AQUIFER HYDRAULIC CHARACTERISTICS AND WATER QUALITY

Relations of geoelectrical properties to hydraulic and water-quality characteristics were developed using the general logarithmic regression model

$$Y=AX^B, \qquad (9)$$

where Y and X are dependent and independent variables, respectively, and A and B are regression coefficients. This model has previously been used by investigators to evaluate the relations of aquifer characteristics to geoelectrical properties (Alger, 1966; Mazac and others, 1985; Huntley, 1986; and Yao An Guo, 1986).

Measurements of bulk resistivity and horizontal hydraulic conductivity require an evaluation of the aquifer interval contributing water to a well (table 1). Contributing intervals were determined by comparing reported screened intervals to the thickness of juxtaposed sands and clayey sands identified on lithologic and corresponding borehole geophysical logs. Contributing intervals were commonly bounded above and below by clays of considerable thickness (fig. 2). In general, the estimated contributing interval for large-capacity wells (discharge greater than 500 gallons per minute (gal/min)) was somewhat to substantially larger than the screened interval. Where screened intervals were small compared to the total thickness of a water-bearing unit and well discharges were also comparatively small (ranging from 20 to 50 gal/min), contributing intervals and screened intervals frequently were considered coincident or nearly coincident.

Infrequently, large disparities occurred between the total screen length at a well and the total estimated contributing interval. At these sites, short-interval screens commonly were placed opposite relatively thick water-bearing sands. Because the contribution of each sand interval to total well discharge was unknown, the total sand thickness of partially screened intervals was considered the contributing interval. Estimates of total contributing interval at wells used in this study ranged from 10 to 630 ft and were considered to be accurate within ±25 percent of reported values (table 1).

Aquifer bulk resistivity for this study was considered to approximately equal resistivity measured by the long-normal (64-inch) resistivity log or by the deep induction log. Long-normal logs were unavailable at sites 31Z002, in Burke County, Ga., SH:P-25 in Shelby County, Tenn., and SRP

Table 5. Summary of results of regression analyses

[*DSC*, dissolved-solids concentration; *Fa*, apparent formation factor; K_h, horizontal hydraulic conductivity; R_o, bulk resistivity; R_{wx}, water resistivity; LC, Late Cretaceous; PLE, Paleocene-early Eocene; ME, middle Eocene]
(General equation $Y=AX^B$)

Dependent variable *Y*	Independent variable *X*	Coefficient *A*	Exponent *B*	Correlation coefficient (percent)	Standard error of estimate (log cycle)	Number of data pairs
K_h	(R_o-R_{wx})	3.8	0.66	72	0.68	105
K_h	*Fa*	14	1.0	38	.91	106
K_h	R_{wx}	5.7	.59	56	.82	106
K_h	R_o	1.8	.74	70	.70	105
R_{wx}	R_o	.56	.92	93	.35	111
DSC	R_o	8,500	−.85	−88	.44	106
DSC	R_{wx}	5,110	−.92	−96	.27	106
K_h (LC)	(R_o-R_{wx})	5.5	.43	80	.52	14
K_h (PLE)	(R_o-R_{wx})	1.5	.88	78	.56	47
K_h (ME)	(R_o-R_{wx})	8.9	.54	71	.56	44
K_h (LC)	R_o	3.2	.48	77	.55	14
K_h (PLE)	R_o	.57	1.0	78	.56	47
K_h (ME)	R_o	3.8	.67	71	.56	44

905–120p in Barnwell County, S.C., and resistivity measured by the short-normal (16-inch) log was used to estimate bulk resistivity. Average bulk resistivity for a contributing interval was determined by computing the area between the log trace and the line of zero resistivity and dividing by the respective vertical interval. Resistivity log scales varied throughout the study area. In general, vertical scale resolution was larger than 100 ft per inch and horizontal scale resolution was larger than 200 ohm-m per inch.

The formation temperature was considered equal to water temperature at the point of well discharge and was available at most well sites. Water-temperature measurements were considered accurate within ±0.5°C (table 3).

Specific conductance determined by laboratory or field measurements is commonly reported in micromhos or microsiemens per centimeter at a standard temperature of 25°C (77°F); therefore, it is related to aquifer water resistivity at 77°F in ohm-m, by the following expression (Miller and others, 1988),

$$R_{w77}=10{,}000/\mathit{specific\ conductance}. \quad (10)$$

Where water discharge temperatures were known (table 3), aquifer water resistivity (R_w) was converted from resistivity at the standard temperature of 77°F to the resistivity at the known temperature (R_{wx}). This conversion was accomplished using the equation described by Jorgensen (1989),

$$R_{wx}=\frac{R_{w77}\times 84}{T_x+7}, \quad (11)$$

where

R_{wx} is aquifer water resistivity at the observed water temperature at the point of well discharge, in ohm-m;

R_{w77} is aquifer water resistivity at the standard temperature, in ohm-m; and

T_x is water temperature at the point of well discharge, in degrees Fahrenheit.

Where well discharge temperatures were unknown, aquifer water resistivities were unadjusted and based on the standard temperature of 77°F. Aquifer water resistivity measurements at standard temperature are considered accurate within ±10 percent of reported values (table 3).

Computed values of horizontal hydraulic conductivity used in regression analyses (figs. 3–6, table 5) represent average aquifer transmissivity per unit length of contributing interval (table 1). Transmissivity values used to compute horizontal hydraulic conductivity were derived, for the most part, from analyses of single-well, aquifer-test data using modified nonequilibrium methods (Ferris and others, 1962). A few results of multiple-well, nonequilibrium analyses (Theis, 1935; Hantush and Jacob, 1955) were also used.

Uncertainty related to determinations of contributing interval, bulk resistivity, water resistivity, and horizontal hydraulic conductivity can be attributed to random and systematic errors of measurement, and to spatial variations of geoelectrical prop-

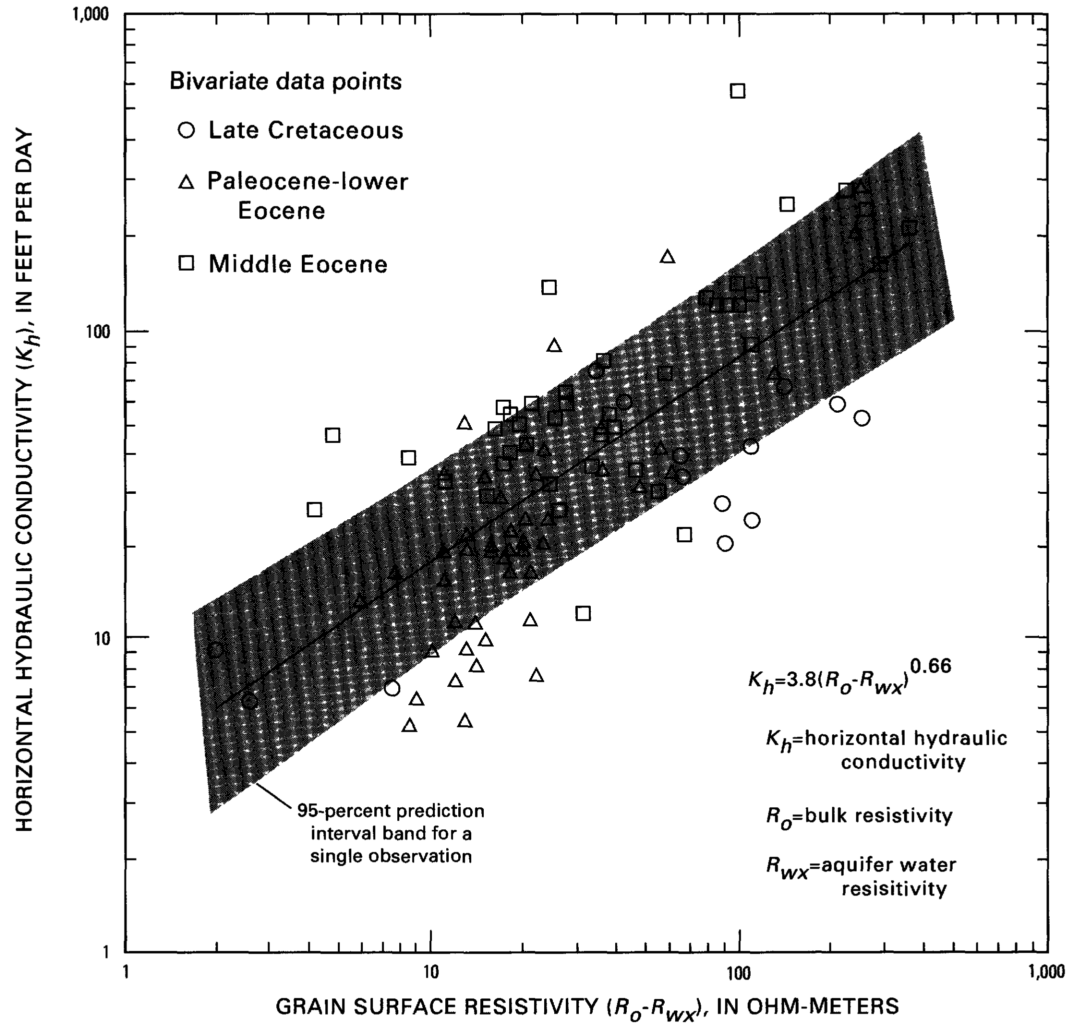


Figure 3. Relation of horizontal hydraulic conductivity to grain-surface resistivity as defined by the summation model.

erties and hydraulic characteristics. Measurement errors relate largely to inaccuracies caused by field and laboratory instruments or observations and could only be indirectly evaluated for this study. For example, site data were eliminated from further analyses where aquifer water resistivity exceeded average bulk resistivity. Such anomalies were reported infrequently and were attributed to instrument error.

Uncertainties related to transmissivity evaluations are probably the result of errors introduced by the spatial variation of aquifer hydraulic characteristics. Standard methods of analysis for transmissivity are generally based on assumptions that aquifer properties are spatially constant. Such assumptions are seldom, if ever, completely satisfied by water-bearing units. Regardless, standard methodologies of aquifer-test analysis have consistently been applied in the study area with apparently successful results (Hosman and others, 1968; Zack, 1977; Davis and others, 1983; Faye and McFadden, 1986; Slack and Darden, 1991) and transmissivity values reported here are considered equally valid (table 4). To account for uncertainty, computed transmissivity values are considered accurate within ±25 percent of reported values (table 4).

Differences in aquifer volume represented by borehole resistivity measurements and aquifer-test results may be substantial at large-capacity wells. Lateral variation in the hydraulic characteristics and geoelectrical properties of local water-bearing units is, however, probably small within the radius of influence of a pumping well. Thus, geoelectrical properties and hydraulic characteristics determined

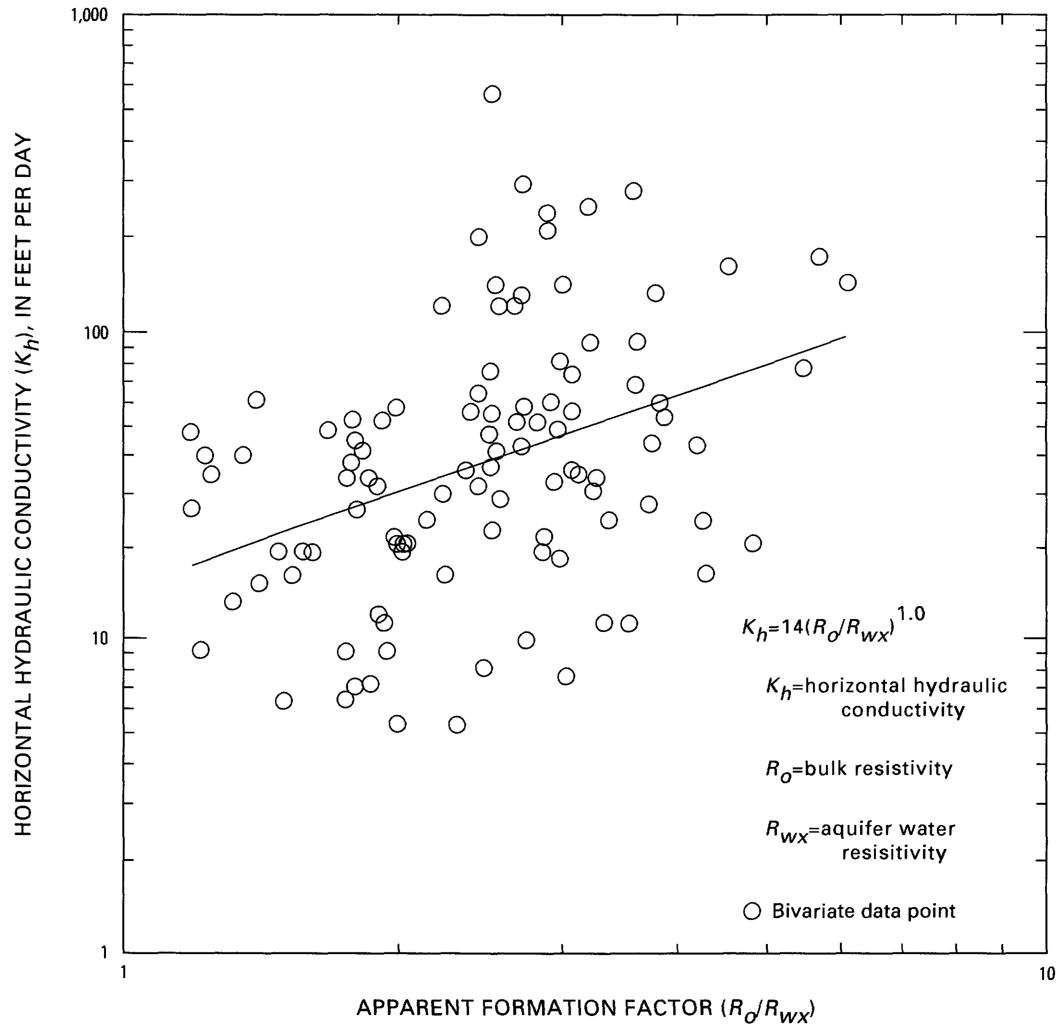


Figure 4. Relation of horizontal hydraulic conductivity to apparent formation factor as defined by the product model.

from substantially different aquifer volumes are considered representative of the entire aquifer volume contributing water to the well. To ensure that average hydraulic conductivity values were based on a representative aquifer volume, data from aquifer tests of short duration (less than 2 hours) were not used. Aquifer-test duration related to transmissivity data cited in this report exceeded 4 hours at most sites (table 4; Aucott and Newcome, 1986; Faye and McFadden, 1986; Slack and Darden, 1991).

Mud invasion of permeable zones during drilling also can substantially affect borehole resistivity and aquifer-test results. Where substantial invasion of drilling mud has occurred, resistivity measurements will reflect the geoelectrical properties of the drilling mud, rather than of the aquifer. In addition, analyses of aquifer-test data collected by pumping from mud-invaded sands generally result in computed transmissivities that are lower than corresponding values for contiguous noninvaded sands. Mud-invaded zones were identified by comparing the divergence between short- and long-normal resistivity measurements (fig. 2). Where invasion occurred across a substantial part of the contributing interval and well development appeared limited or ineffective, site data were rejected for further analyses.

Regression analyses using equation 9 were completed for various combinations of geoelectrical, hydraulic, and water-quality data listed in tables 3 and 4. Results of these analyses are summarized below (eqs. 12–17), in table 5, and in figures 3–9. Discharge temperature data were unavailable at 22 sites (table 3). Accordingly, water resistivity at

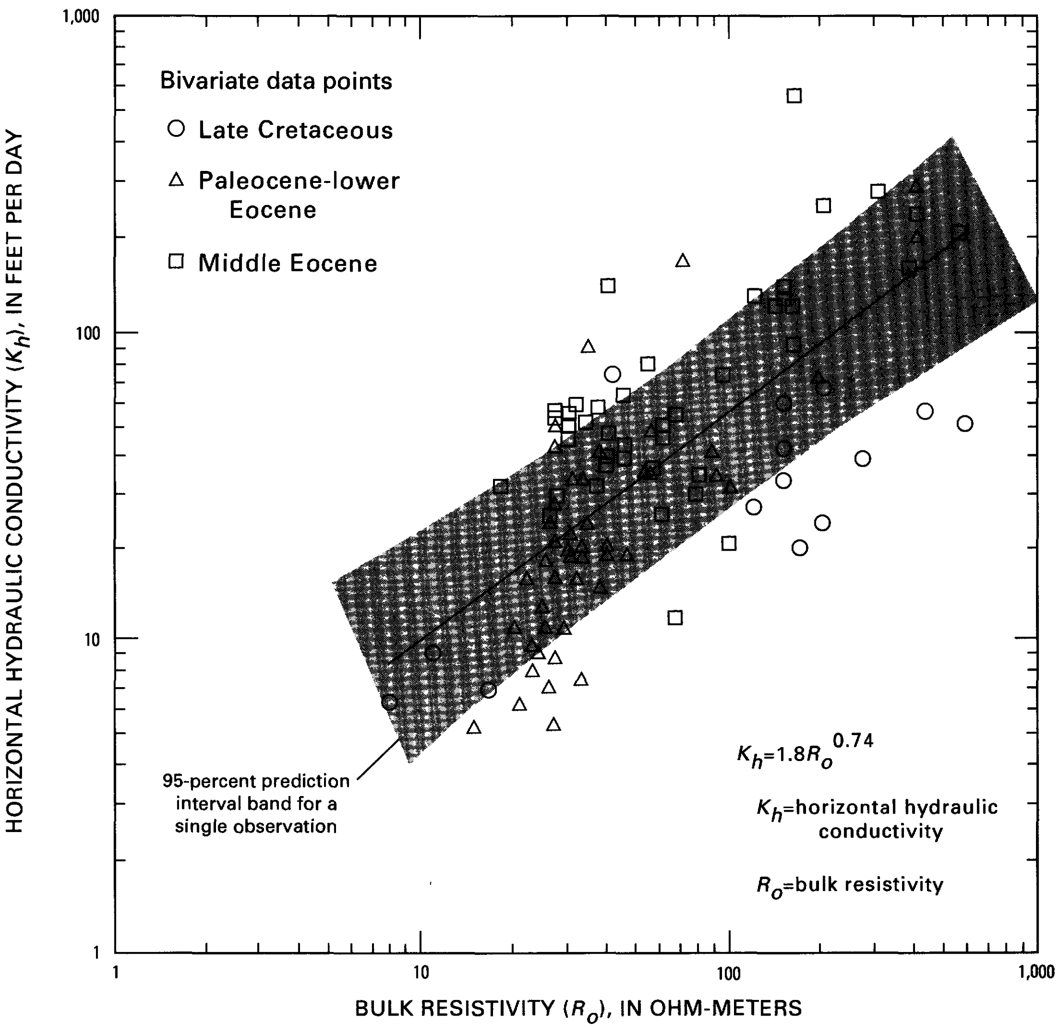


Figure 5. Relation of horizontal hydraulic conductivity to aquifer bulk resistivity.

these sites used in regression analyses (eqs. 13, 16) were standard (R_{w77}) rather than adjusted (R_{wx}). Correlation coefficients for all analyses range from about 70 to 96 percent, except for the product model relation of horizontal hydraulic conductivity to apparent formation factor, which is 38 percent (table 5). These results, when compared to the results of regression analyses based on the summation model (eq. 12) and aquifer bulk resistivity (eq. 17), indicate that the apparent formation factor (eq. 8) is not a useful geoelectrical analog for the horizontal hydraulic conductivity of clastic aquifers considered in this study. Accordingly, references in this report to relations of horizontal hydraulic conductivity to grain-surface resistivity refer only to the relation explained by the summation model (eq. 7).

Following are the regression equations that relate horizontal hydraulic conductivity (K_h), dissolved-solids concentrations (DSC) in aquifer water, and aquifer water resistivity (R_{wx}) to the borehole geoelectrical properties of bulk resistivity (R_o) and grain-surface resistivity (defined by the summation model ($R_o - R_{wx}$)):

$$K_h = 3.8(R_o - R_{wx})^{0.66}, \quad (12)$$

$$DSC = 5110R_{wx}^{-0.92}, \quad (13)$$

$$DSC = 8500R_o^{-0.85}, \quad (14)$$

$$R_{wx} = 0.56R_o^{0.92}, \quad (15)$$

$$K_h = 5.7R_{wx}^{0.59}, \text{ and} \quad (16)$$

$$K_h = 1.8R_o^{0.74}. \quad (17)$$

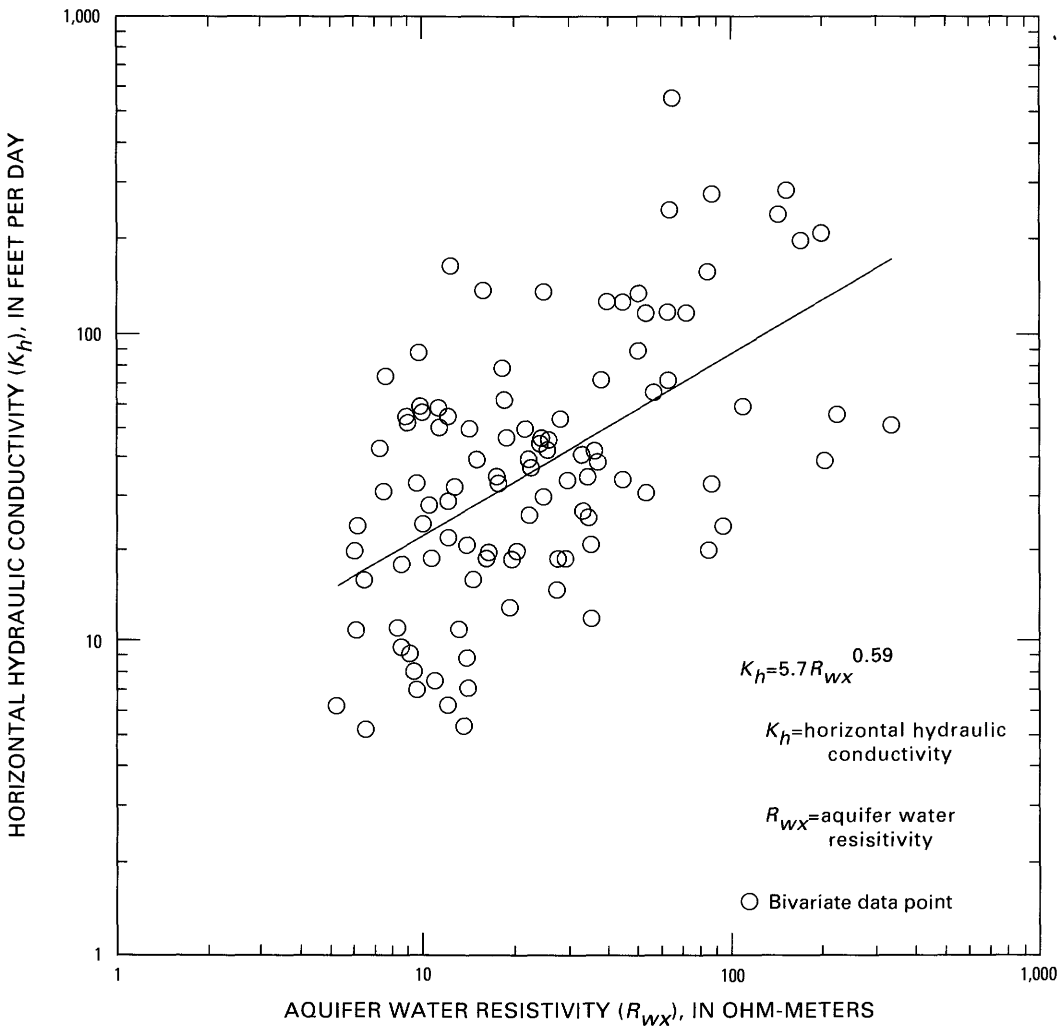


Figure 6. Relation of horizontal hydraulic conductivity to aquifer water resistivity.

Regression statistics for equations 12 and 17 (table 5) indicate that grain-surface resistivity as defined by the summation model (eq. 7) and bulk resistivity (R_o) are equally significant geoelectrical analogs for horizontal hydraulic conductivity (K_h).

Quasi-validation of the use of grain-surface resistivity as a geoelectrical analog for horizontal hydraulic conductivity is indicated by the regression analysis relating horizontal hydraulic conductivity (K_h) to aquifer water resistivity (R_{wx}, table 5, fig. 6). Consider that the grain-surface resistivity of a freshwater-saturated, unconsolidated, clastic porous media decreases as the percentage (and surface area) of fine-grained sediments increases. Such increases might be indicated by corresponding increases in the ionic strength of the aquifer water and in the ion exchange between the water and fine-grained sediments, particularly clays (Alger, 1966). Accordingly, a positive trend should be evident between horizontal hydraulic conductivity and the resistivity of aquifer water. Although regression statistics are not strongly conclusive (table 5), increasing values of aquifer water resistivity are shown to generally relate to increasing values of horizontal hydraulic conductivity.

Evaluation of figures 3 and 5 indicates that a general grouping of hydraulic conductivity data occurs based on the age of aquifer sediments; the lowest values generally relate to aquifers composed of sediments of Cretaceous age and the highest values generally correspond to aquifers composed of sediments of middle Eocene age. Thus, horizontal hydraulic conductivity and estimated values of grain-surface resistivity paired according to site and age were related using the logarithmic regression model (eq. 9). Data were grouped into three major

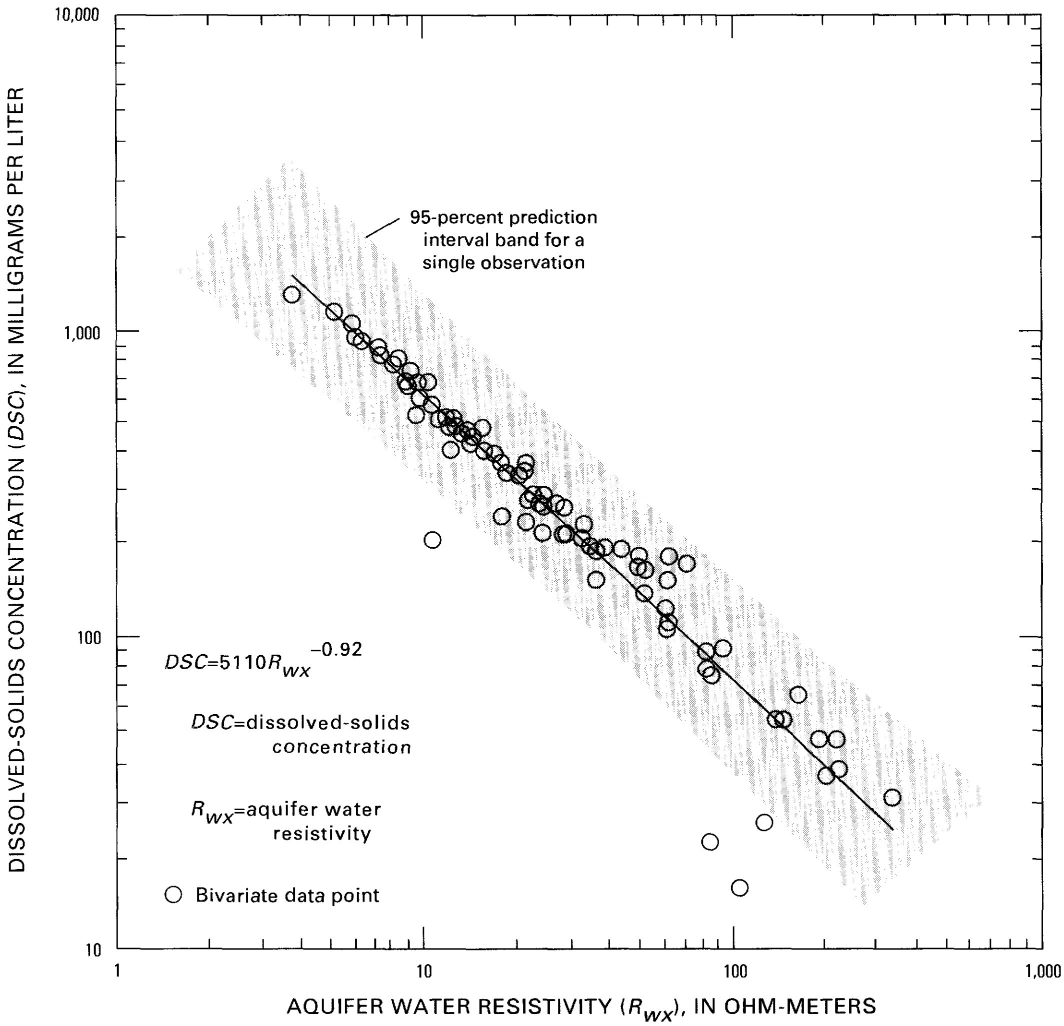


Figure 7. Relation of dissolved-solids concentration in aquifer water to aquifer water resistivity.

chronostratigraphic groups corresponding to aquifers composed of sediments of Late Cretaceous, Paleocene and early Eocene, and middle Eocene age. Regression equations describing these relations using surface resistivity (R_o-R_{wx}) as the independent variable are

Late Cretaceous

$$K_h=5.5(R_o-R_{wx})^{0.43}, \quad (18)$$

Paleocene and early Eocene

$$K_h=1.5(R_o-R_{wx})^{0.88}, \text{ and} \quad (19)$$

middle Eocene

$$K_h=8.9(R_o-R_{wx})^{0.54}. \quad (20)$$

Corresponding equations using bulk resistivity (R_o) as the independent variable are

Late Cretaceous

$$K_h=3.2R_o^{0.48}, \quad (21)$$

Paleocene and early Eocene

$$K_h=0.57R_o^{1.0}, \text{ and} \quad (22)$$

middle Eocene

$$K_h=3.8R_o^{0.67}. \quad (23)$$

Regression statistics for these equations indicate a moderate degree of correlation between the independent and dependent variables. Correlation coefficients range from 71 to 80 percent and standard errors of estimate range from 0.52 to 0.56 log cycles (table 5). Data pairs related to 14 sites were used to develop equations 18 and 21. These data were obtained from South Carolina, Georgia, and Mississippi. The number of site data pairs used to develop equations 19 and 22, and 20 and 23 are, respectively, 47 and 44 (table 5). Data related to equations 20 and 23 are the most widespread in the study area, ranging from Georgia to western Tennessee.

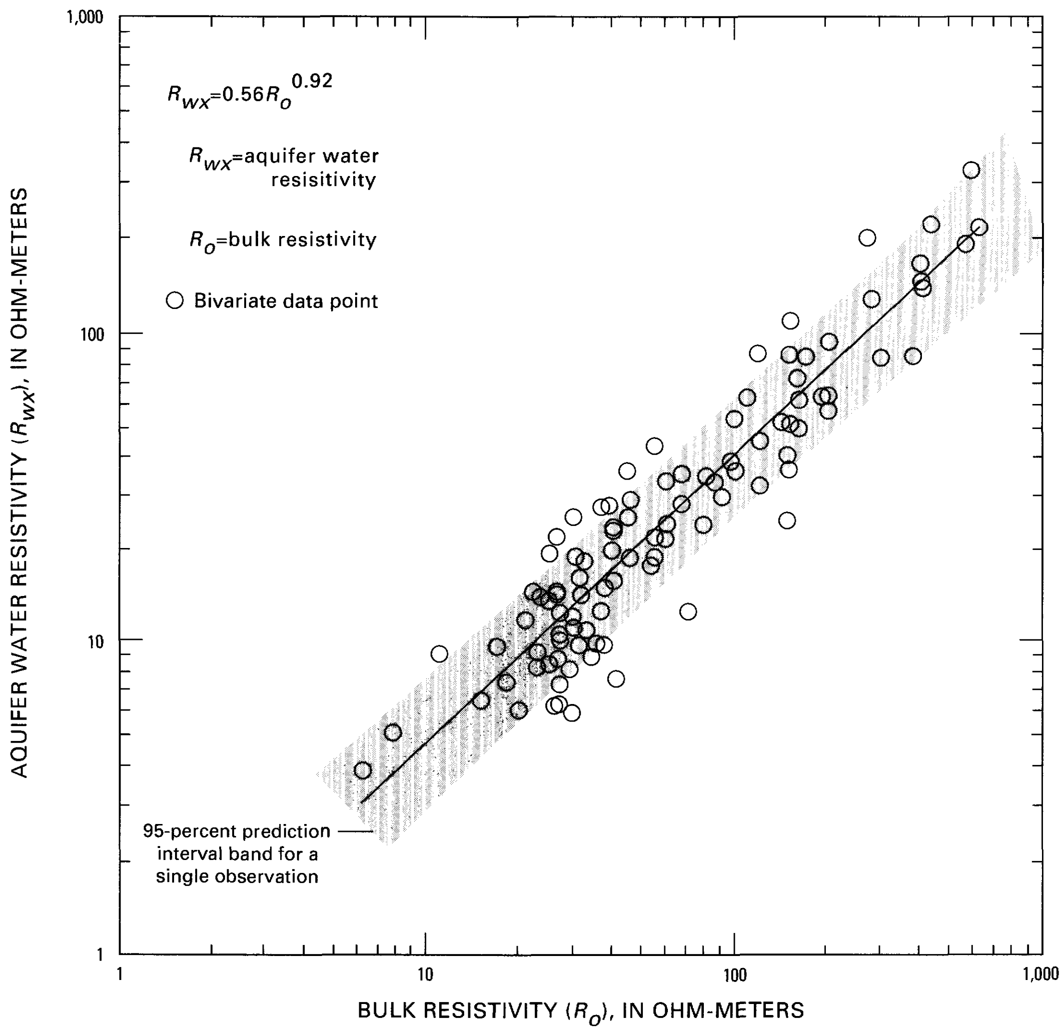


Figure 8. Relation of aquifer water resistivity to aquifer bulk resistivity.

APPLICATIONS AND TESTING OF REGRESSION MODELS

Equations 12–15 and 17–23 can be used to provide estimates of the vertical distribution of aquifer horizontal hydraulic conductivity (K_h), aquifer water resistivity (R_{wx}), and dissolved-solids concentration (*DSC*) of aquifer water at borehole sites in the study area. Applications should be limited to aquifers in the Southeastern United States consisting of unconsolidated sands and clayey sands ranging in age from Late Cretaceous to middle Eocene. Equations relating horizontal hydraulic conductivity to geoelectrical properties may not be valid for sand thicknesses less than 10 ft or for sands containing saline water. Specifically, the regression equations should not be applied to water-bearing sands where hydraulic and water-quality characteristics are substantially different from those used to develop the regression relations. In the absence of water-quality data, equations 15, 12, and 14 can be applied sequentially to provide estimates of aquifer water resistivity, horizontal hydraulic conductivity, and dissolved-solids concentration. All applications, with the exception of equation 13, require the use of reasonable surrogates of aquifer bulk resistivity, such as long-normal (64-inch) resistivity.

Regression equations 13–15 and 18–23 (tables 6–9) were applied to bivariate data from selected well sites in the Southeastern United States. Equations 13–15 were applied at several borehole sites, largely in South Carolina, where measurements of the specific conductance and dissolved-solids concentrations of aquifer water are reported at several depths (Lee, 1984).

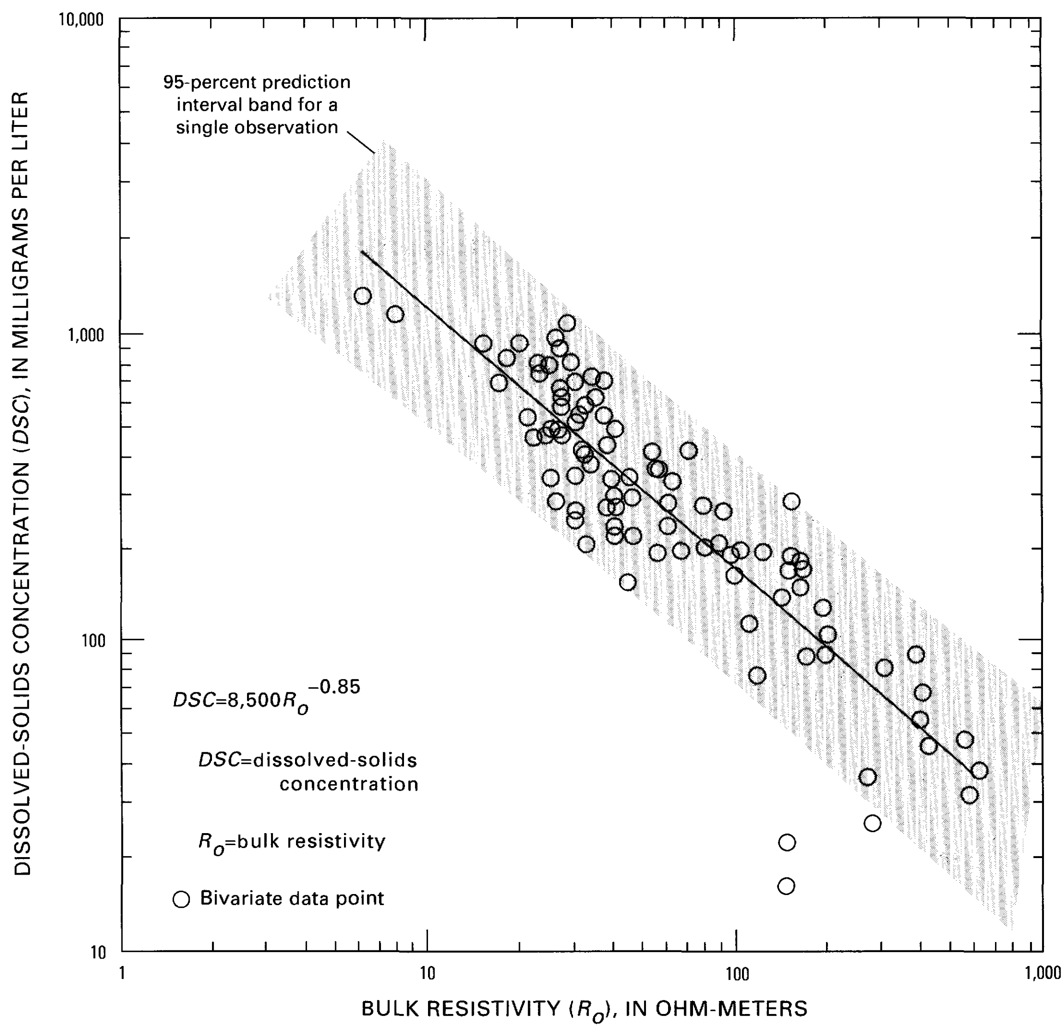


Figure 9. Relation of dissolved-solids concentration in aquifer water to aquifer bulk resistivity.

Equations 18, 19, 21, and 22 were applied at site CH-186, near Charleston, S.C. (table 1), where borehole geophysical logs, well construction information, aquifer hydraulics data, and water-quality data permit the computation of horizontal hydraulic conductivity using estimates of both grain-surface resistivity and bulk resistivity. Horizontal hydraulic conductivity values computed using regression models were compared to corresponding values determined from a single aquifer test using the completed well, and from laboratory permeameter analyses of core samples. Equations 21–23 were used to estimate horizontal hydraulic conductivity at 26 other sites where water resistivity data were unavailable.

The application of regression equations 12–15 and 17–23 indicates that aquifer water resistivity, dissolved-solids concentration, and horizontal hydraulic conductivity can be estimated with reasonable accuracy using appropriate geoelectrical analogs and regression-based models. Observed dissolved-solids concentrations at a total of four sites in South Carolina and Louisiana ranged from about 300 to 1,300 mg/L and were compared to estimates computed using bulk resistivity and aquifer water resistivity as independent variables (table 6). Estimates of dissolved-solids concentration based on aquifer water resistivity (eq. 13) were generally more accurate (particularly at high concentrations of dissolved solids) than estimates based on bulk resistivity (eq. 14), with mean absolute errors of 6.2 and 20 percent, respectively (table 8). Estimates of aquifer water resistivity based on bulk resistivity (eq. 15)

Table 6. Summary of regression model estimates of aquifer water-quality characteristics

[ohm-m, ohm meters; mg/L, milligrams per liter; °C, degrees Celsius; —, no data]

County	Well number	Reported sample depth (ft)	Water resistivity at 25°C (R_w) (ohm-m)	Temperature of discharge water (°C)	Water resistivity at discharge temperature (R_{wx}) (ohm-m)	Dissolved-solids concentration (*DSC*) (mg/L)	Average bulk resistivity (R_o) (ohm-m)	Computed water resistivity (R_{wx}, eq. 15) (ohm-m)	Computed dissolved-solids concentration (*DSC*, eq. 13) (mg/L)	Computed dissolved-solids concentration (*DSC*, eq. 14) (mg/L)	Reported water-bearing unit(s)
						South Carolina					
Charleston[1]	CH–186	2,030	3.2	30.0	2.9	2,060	10	4.7	1,920	1,200	Middendorf Formation
		2,120	5.9	31.0	5.2	1,070	7.2	3.4	1,120	1,600	Do.
		2,150	5.8	32.0	5.0	1,090	11	5.1	1,160	1,100	Do.
		2,250	4.1	32.0	3.6	1,510	8.8	4.1	1,570	1,300	Do.
Dorchester[2]	DOR–211	580–600	36.0	24.0	36.7	180	78	31	186	210	Ellenton Formation
		1,326–1,346	5.5	26.6	5.3	1,160	11	5.1	1,100	1,100	Black Creek Formation
		1,828–1,848	7.3	31.7	6.4	788	16	7.2	926	800	Cape Fear Formation
Marion[2]	MRN–78	345–355	18.2	20.4	20.2	313	73	29	322	220	Black Creek Formation
		517–537	11.8	21.4	12.8	496	36	15	489	400	Do.
		748–768	13.0	23.2	13.6	450	36	15	463	400	Middendorf Formation
		811–831	3.9	23.7	4.0	1,540	15	6.8	1,430	850	Do.
		1,010–1,030	3.5	23.0	3.7	1,700	10	4.7	1,530	1,200	Cape Fear Formation
						Louisiana					
Desoto[3]	DS–355	252–262	10.4	20.5	11.5	586	23	10	540	590	Wilcox Group

[1] Data obtained from the files of the U.S. Geological Survey.
[2] Lee (1984).
[3] Turcan (1962).

Table 7. *Summary of regression model estimates of horizontal hydraulic conductivity*

[ft/d, feet per day; ohm-m, ohm meters; —, no data]

County	Well number	Reported sample depth or estimated contributing interval (ft)	Water resistivity at 25°C (R_w) (ohm-m)	Temperature of discharge water(°C)	Water resistivity at discharge temperature (R_{wx}) (ohm-m)	Average bulk resistivity (R_o) (ohm-m)	Hydraulic conductivity (K_h) (ft/d)	Computed hydraulic conductivity (K_h) (eqs. 18, 19, or 20) (ft/d)	Computed hydraulic conductivity (K_h) (eqs. 21, 22, or 23) (ft/d)	Reported water-bearing unit(s)
						South Carolina				
Charleston	CH–186	[1]606	1.0	—	—	4.5	[2]3.6	4.5	2.6	Lower Eocene (unnamed)
		[1]640	.9	—	—	9.5	[2]5.6	10	5.4	Do.
		[1]2,030	3.2	30.0	2.9	11	[2]16	14	10	Middendorf Formation
		[1]2,120	5.9	31.0	5.2	7.2	[2]19	7.4	8.3	Do.
		[1]2,150	5.8	32.0	5.0	11	[2]17	12	10	Do.
Charleston	CH–186	1,980–2,240	[3]4.5	[3]31.0	4.2	[4]7.0	[5]13	8.6	8.1	Do.
						Alabama				
Houston	—	575–815	—	—	—	[10]42	[9]15	—	24	Tuscahoma Formation Nanafalia Formation Clayton Formation.
						Louisiana				
Desoto	DS–411	56–112	—	—	—	20	8.6	—	11	Wilcox Group
Winn	WI–115B	174–186	—	—	—	24	45	—	32	Sparta Sand
						Mississippi				
Bolivar	T131	1,388–1,472	—	—	—	13	[6]17	—	21	Sparta Sand
Clarke	K8	1,270–1,352	—	—	—	67	[6]31	—	38	Lower Wilcox Group
Clarke	L51	346–472	—	—	—	110	[6]160	—	89	Sparta Sand
Leake	Ø34	1,186–1,258	—	—	—	45	[6]40	—	26	Lower Wilcox Group
Lee	F31	346–460	—	—	—	8.0	[6]7.4	—	8.7	McShan Formation
Madison	Ø46	1,480–1,576	—	—	—	65	[6]19	—	37	Meridian Sand, Upper Wilcox Group.
Madison	W69	998–1,200	—	—	—	65	[6]35	—	62	Sparta Sand
Montgomery	M12	868–956	—	—	—	41	[6]4.5	—	23	Lower Wilcox Group
Newton	A34	480–560	—	—	—	48	[6]21	—	27	Middle Wilcox Group
Rankin	G42	1,228–1,362	—	—	—	75	[6]54	—	69	Sparta Sand
Rankin	G51	1,252–1,357	—	—	—	54	[6]80	—	55	Do.
Rankin	K120	800–865	—	—	—	60	[6]34	—	59	Do.
Rankin	K175	436–582	—	—	—	99	[6]47	—	83	Do.
Rankin	K186	1,200–1,314	—	—	—	55	[6]42	—	56	Do.
Scott	J35	710–900	—	—	—	37	[6]36	—	43	Do.
Scott	L45	1,246–1,390	—	—	—	46	[6]17	—	26	Meridian Sand
Smith	L26	876–1,018	—	—	—	64	[6]54	—	62	Sparta Sand
Yazoo	Ø30	1,424–1,508	—	—	—	49	[6]16	—	28	Meridian Sand

Table 7. Summary of regression model estimates of horizontal hydraulic conductivity—Continued

County	Well number	Reported sample depth or estimated contributing interval (ft)	Water resistivity at 25°C (R_w) (ohm-m)	Temperature of discharge water(°C)	Water resistivity at discharge temperature (R_{wx}) (ohm-m)	Aquifer bulk resistivity (R_o) (ohm-m)	Hydraulic conductivity (K_h) (ft/d)	Computed hydraulic conductivity (K_h) (eqs. 18, 19, or 20) (ft/d)	Computed hydraulic conductivity (K_h) (eqs. 21, 22, or 23) (ft/d)	Reported water-bearing unit(s)
						North Carolina				
Onslow	V25P4	552–618	—	—	—	55	35	—	22	Black Creek Formation
						South Carolina				
Horry	HO–309	350–420	—	—	—	24	[7]8.6	—	15	Black Creek Formation
Horry	HO–335	290–710	—	—	—	11	[8]7.4	—	10	Do.
Horry	HO–353	380–490	—	—	—	18	[8]7.3	—	13	Do.
Marion	MRN–67	216–424	—	—	—	48	[8]48	—	21	Do.

[1] Reported sample depth. Contributing interval estimated at ±5 ft from reported sample depth.

[2] Hydraulic conductivity based on results of permeameter tests. (W.A. Pryor, University of Cincinnati, written commun., December 4, 1974).

[3] Average of values reported at depths of 2,030 ft, 2,120 ft, 2,150 ft, and 2,250 ft. (table 6 and Parker Laboratory, Charleston, S.C., written commun., December 27, 1974).

[4] Average value computed across estimated contributing interval.

[5] Computed from results of aquifer test on finished well.

[6] Hydraulic conductivity based on transmissivity value from Slack and Darden (1991).

[7] Hydraulic conductivity based on transmissivity value from Zack (1977).

[8] Hydraulic conductivity based on transmissivity value from Aucott and Newcome (1986).

[9] Aquifer-test results from nearby wells Dothan #10 and #12.

[10] Estimate based on electric log data at nearby Selma Street well.

Table 8. Summary of error analyses of regression model estimates of aquifer water-quality characteristics

[*DSC*, dissolved-solids concentration; R_{wx}, water resistivity; R_o, bulk resistivity]

Dependent variable	Independent variable	Equation number	Number of estimates	Range of estimate error (percent)	Mean estimate error (percent)	Standard deviation of estimate error (percent)
DSC	R_{wx}	13	13	1.4–18	6.2	4
DSC	R_o	14	13	.7–50	20	17
R_{wx}	R_o	15	13	1.9–70	25	21

Table 9. Summary of error analyses of regression model estimates of horizontal hydraulic conductivity

[K_h, horizontal hydraulic conductivity; R_o, bulk resistivity; R_{wx}, water resistivity]

Dependent variable	Independent variable	Equation number	Number of estimates	Range of estimate error (percent)	Mean estimate error (percent)	Standard deviation of estimate error (percent)
K_h	R_o	21, 22, or 23	32	3.6–411	55	69
K_h	(R_o–R_{wx}) (CH–186 data)	18 or 19	6	13–79	40	25
K_h	R_o (CH–186 data)	21 or 22	6	3.6–56	34	18
K_h	R_o (without statistical outlier)	21, 22, or 23	31	3.6–95	43	23

resulted in absolute errors ranging from about 2 to 70 percent, and a mean error of 25 percent (table 8). Horizontal hydraulic conductivity was computed at site CH-186 using grain-surface resistivity and bulk resistivity as independent variables (eqs. 18, 19, and 21, 22). Estimates were compared to values of horizontal conductivity determined from permeameter analyses at five cored intervals and from aquifer-test results for the finished well. At three of the five intervals, errors of estimated horizontal hydraulic conductivity based on grain-surface resistivity were less than errors for corresponding values computed using bulk resistivity as the independent variable. These errors ranged from 13 to 79 percent and 4 to 56 percent, respectively (table 9). Results related to the finished well test were similar. Horizontal hydraulic conductivity was also computed at 26 other sites using only bulk resistivity as the independent variable (eqs. 21–23). Absolute error for all sites ranged from about 4 to 400 percent. Mean error was 55 percent (table 9). Absolute error at one site was larger than two standard deviations from the mean absolute error and is considered a statistical outlier (site M12, table 7). When the absolute error for this site was removed, the mean absolute error was 43 percent and the error range was 4 to 95 percent.

SUMMARY AND CONCLUSIONS

Aquifer bulk resistivity and grain-surface resistivity (inverse of surface conductance) were theoretically related to the horizontal hydraulic conductivity of freshwater aquifers composed of sands and clayey sands. Regression equations were subsequently used to test the theoretical concepts using borehole geophysical, water-quality, and hydraulic characteristics data obtained from more than a hundred well sites in the Southeastern Coastal Plain of the United States. Data were obtained from aquifers composed of sediments ranging in age from Late Cretaceous through middle Eocene. Bulk resistivity was estimated using long-normal (64-inch) and dual induction borehole resistivity logs. Grain-surface resistivity was empirically defined as the difference between bulk resistivity and aquifer water resistivity (computed from specific conductance). Horizontal hydraulic conductivity, as used in this report, is the average aquifer transmissivity per foot of contributing interval and ranged from about 4 to more than 500 ft/d. All paired data were related using the logarithmic regression model $Y=AX^B$. All paired data used in regression analyses were considered average values across a specified interval contributing water to a finished well. Estimated thicknesses of the contributing intervals ranged from 10 to about 600 ft.

Regression analyses indicate a moderate correlation between bulk and grain-surface resistivities and horizontal hydraulic conductivity. The correlation coefficients developed by using all hydraulic conductivity data (105 data pairs) were 70 and 72 percent, respectively. The correlation coefficients of similar analyses using data grouped by the age of water-bearing units (Late Cretaceous, 14 data pairs; Paleocene-early Eocene, 47 data pairs; and middle Eocene, 44 data pairs) ranged from 71 to 80 percent. These results indicate that aquifer bulk resistivity and grain-surface resistivity are useful geoelectrical analogs for the horizontal hydraulic conductivity of clastic, unconsolidated aquifers in the Southeastern United States.

Separate regressions of the resistivity and dissolved-solids concentrations of aquifer water using aquifer bulk resistivity as the independent variable indicated a high degree of correlation between these variables (correlation coefficients of 93 and 88 percent, respectively). An analysis of the relation of dissolved-solids concentration to aquifer water resistivity resulted in an exceptionally high degree of correlation (correlation coefficient of 96 percent). Dissolved-solids concentrations used in these analyses ranged from about 30 to 1,300 mg/L.

An analysis of the relation between horizontal hydraulic conductivity and apparent formation factor (ratio of aquifer bulk resistivity to aquifer water resistivity) resulted in a correlation coefficient of 38 percent. Although formation factor and apparent formation factor had previously been presented as useful geoelectrical analogs to horizontal hydraulic conductivity at a local scale, results of this study indicate that, at a regional scale, little or no significant correlation exists between apparent formation factor and horizontal hydraulic conductivity.

Regression equations presented in this report were applied and tested at a total of 27 sites in 6 Southeastern States. When used as independent variables, aquifer water resistivity and aquifer bulk resistivity were shown to reasonably predict the dissolved-solids concentration of aquifer water (mean absolute errors of about 6 and 20 percent, respectively). Similarly, bulk resistivity was used to estimate aquifer water resistivity (mean error of 25 percent). The absolute error of estimates of horizontal hydraulic conductivity computed using aquifer bulk resistivity as the independent variable ranged from about 4 to 400 percent. Mean absolute error was 55 percent. Elimination of one data point considered to be a statistical outlier improved the mean estimate error to 43 percent with an error range of 4 to 95 percent.

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