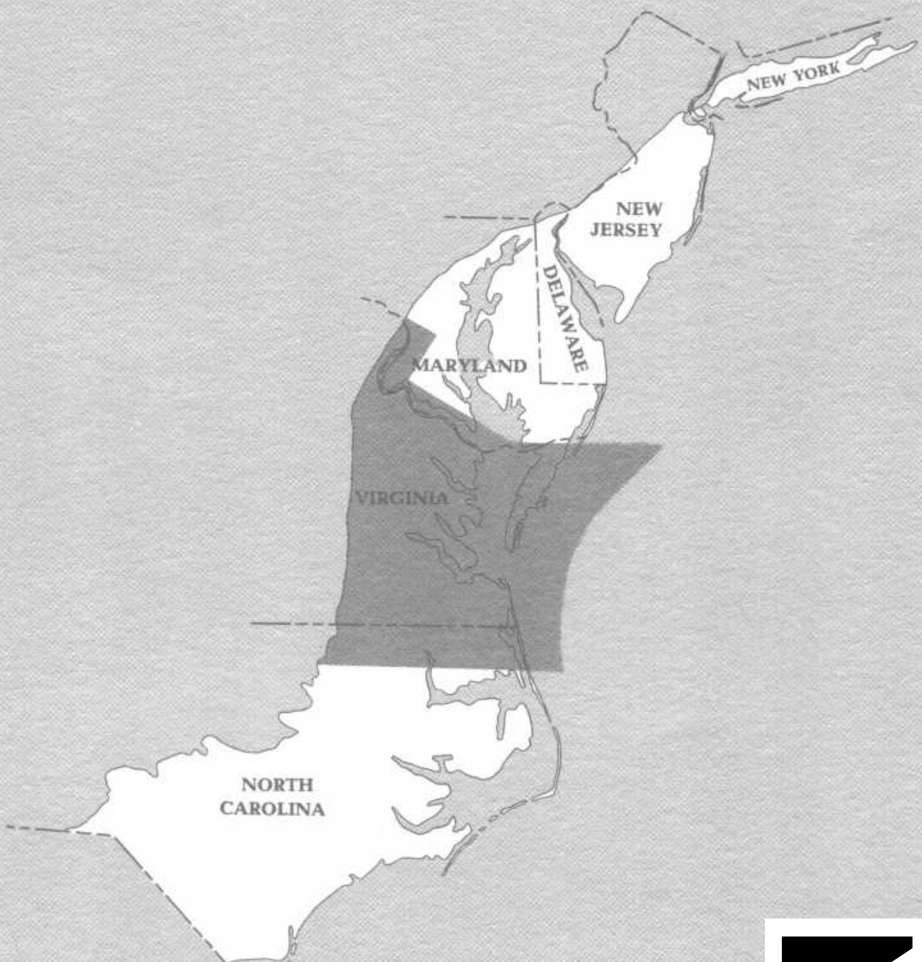
CONCEPTUALIZATION AND ANALYSIS OF GROUND-WATER FLOW SYSTEM IN THE COASTAL PLAIN OF VIRGINIA AND ADJACENT PARTS OF MARYLAND AND NORTH CAROLINA

REGIONAL AQUIFER-SYSTEM ANALYSIS



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Conceptualization and Analysis of Ground-Water Flow System in the Coastal Plain of Virginia and Adjacent Parts of Maryland and North Carolina

By JOHN F. HARSH *and* RANDELL J. LACZNIAK

REGIONAL AQUIFER-SYSTEM ANALYSIS—
NORTHERN ATLANTIC COASTAL PLAIN

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FOREWORD

THE REGIONAL AQUIFER-SYSTEM ANALYSIS PROGRAM

The Regional Aquifer-System Analysis (RASA) Program was started in 1978 following a congressional mandate to develop quantitative appraisals of the major ground-water systems of the United States. The RASA Program represents a systematic effort to study a number of the Nation's most important aquifer systems, which in aggregate underlie much of the country and which represent an important component of the Nation's total water supply. In general, the boundaries of these studies are identified by the hydrologic extent of each system and accordingly transcend the political subdivisions to which investigations have often arbitrarily been limited in the past. The broad objective for each study is to assemble geologic, hydrologic, and geochemical information, to analyze and develop an understanding of the system, and to develop predictive capabilities that will contribute to the effective management of the system. The use of computer simulation is an important element of the RASA studies, both to develop an understanding of the natural, undisturbed hydrologic system and the changes brought about in it by human activities, and to provide a means of predicting the regional effects of future pumping or other stresses.

The final interpretive results of the RASA Program are presented in a series of U.S. Geological Survey Professional Papers that describe the geology, hydrology, and geochemistry of each regional aquifer system. Each study within the RASA Program is assigned a single Professional Paper number, and where the volume of interpretive material warrants, separate topical chapters that consider the principal elements of the investigation may be published. The series of RASA interpretive reports begins with Professional Paper 1400 and thereafter will continue in numerical sequence as the interpretive products of subsequent studies become available.

Dallas L. Peck
Director

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METRIC CONVERSION FACTORS

For readers who wish to convert measurements from the inch-pound system of units to the metric system of units, the conversion factors are listed below:

Multiply inch-pound unit	By	To obtain metric unit
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
foot per day (ft/d)	0.3048	meter per day (m/d)
foot squared per day (ft^2/d)	0.0929	meter squared per day (m^2/d)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
gallon per day (gal/d)	3.78540	liter per day (L/d)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
inch per year (in/yr)	25.4	millimeter per year (mm/yr)

ALTITUDE DATUM

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

CONCEPTUALIZATION AND ANALYSIS OF GROUND-WATER FLOW SYSTEM IN THE COASTAL PLAIN OF VIRGINIA AND ADJACENT PARTS OF MARYLAND AND NORTH CAROLINA

By JOHN F. HARSH and RANDELL J. LACZNIAK

ABSTRACT

This report presents the results of a study of the ground-water flow system in the Coastal Plain of Virginia and adjacent parts of Maryland and North Carolina. The ground-water flow system consists of a water-table aquifer and an underlying sequence of confined aquifers and intervening confining units composed of unconsolidated sand and clay. Water levels have declined steadily, and cones of depression have expanded and coalesced around major ground-water withdrawal centers. A digital flow model was developed to enhance knowledge of the behavior of the ground-water flow system in response to its development. Transmissivity and vertical leakance maps were developed for each aquifer and confining unit. The model was calibrated to simulate ground-water flow within the system under both prepumping and pumping conditions. Simulated prepumping potentiometric-surface maps indicate that regional movement of ground water was from the Fall Line toward coastal areas and that local movement of ground water was from interfluves toward major river valleys. Maps of simulated prepumping flow across confining units show that most recharge occurred in narrow bands approximately parallel to the Fall Line and under interfluves and that discharge was toward major river valleys and coastal water. Simulated prepumping rates of recharge into the confined aquifer system from the water-table aquifer varied up to 3.2 inches per year (in/yr), and rates of discharge out of the confined system varied up to 2.8 in/yr.

Ten pumping periods covering 90 years (yr) of withdrawal simulated the history of ground-water development. Simulated potentiometric-surface maps for 1980 show lowered water levels and the development of coalescing cones of depression around the cities of Franklin, Suffolk, and Williamsburg and the town of West Point, all in Virginia. The largest simulated decline in water level, about 210 feet (ft), was near Franklin. Water budgets indicate that over the period of simulation (1891–1980) (1) pumpage from the model area increased by about 105 million gallons per day (Mgal/d), (2) lateral boundary outflow increased by about 5 Mgal/d, (3) ground-water flow to streams and coastal water decreased by about 107.5 Mgal/d, (4) lateral boundary inflow increased by about 0.7 Mgal/d, and (5) water released from aquifer storage increased by about 1.6 Mgal/d. The difference between total inflow and total outflow is the numerical truncation error of the digital simulation. Analysis of water budgets for individual confined aquifers shows that the major source of water supplied to wells was vertical leakage induced through confining units by pumping. Simulated rates of recharge into the confined aquifer system at the end of the final pumping period (1980) varied up to 3.8 in/yr, and simulated rates of discharge out of the confined system varied up to 2.2 in/yr. Results of simulations show an increase of about 110 Mgal/d into the confined system from the unconfined system over the period of simulation. This increase in flow into the confined system affected local discharge of ground water to streams and regional discharge to coastal water. Withdrawal of ground water from the confined aquifers also induced brackish water from Chesapeake Bay into the confined system.

Results of sensitivity analyses indicate that simulated water levels are more sensitive to decreases in aquifer transmissivity and confining unit vertical hydraulic conductivity than to increases in these properties. Lowering the storage coefficient of an aquifer had minimal effect on simulated water levels, whereas increasing the storage coefficient had a much more significant effect. The effect of confining unit storage is shown to be insignificant if it is assumed that the water released from confining unit storage is attributable to the compressibility of water only.

Manuscript approved for publication July 18, 1986.

INTRODUCTION

Ground water is an important source of industrial, municipal, domestic, and agricultural water supplies in the northern Atlantic Coastal Plain. The continued withdrawal of ground water has caused a steady decline of water levels and the expansion and coalescence of cones of depression centered at major pumping centers. This decline concerns ground-water users and those responsible for the study and management of the resource. More hydrologic information is needed to better understand ground-water flow in the aquifers of the northern Atlantic Coastal Plain.

In 1978, the U.S. Geological Survey began a comprehensive program of regional investigations, known as the

Regional Aquifer-System Analysis (RASA), to describe the hydrogeology of major aquifers in the United States. The study of the northern Atlantic Coastal Plain aquifer system began in 1979. The northern Atlantic Coastal Plain was divided into five subregional projects extending from Long Island, N.Y., through North Carolina (Meisler, 1980). One of the five subregional projects defines the hydrogeologic framework and analyzes ground-water flow in the multiaquifer system of the Virginia Coastal Plain. Two reports have resulted from the subregional project: a report by Meng and Harsh (1988) that describes the hydrogeologic framework, and this report, which provides the results of an analysis of ground-water flow in the multiaquifer system of the Coastal Plain of Virginia and adjacent parts of Maryland and North Carolina.

PURPOSE AND SCOPE

The purposes of this report are to describe the ground-water flow system in the Coastal Plain of Virginia and to provide an analysis of the response of the ground-water flow system to past and present ground-water withdrawals through the use of a digital flow model. Specifically, the report describes (1) the conceptualization of the ground-water flow system, (2) the development of the subregional digital flow model, (3) the simulation of the ground-water flow system, and (4) the sensitivity of the digital flow model to changes in selected hydraulic characteristics of the ground-water flow system.

Available hydrologic data provided most of the necessary information for the interpretation and conceptualization of the multiaquifer system. The physical boundaries of individual aquifers and confining units are presented in hydrogeologic maps by Meng and Harsh (1988). Hydraulic characteristics of aquifers and confining units were initially estimated from (1) analysis of geophysical and lithologic logs of water wells and geologic test holes, (2) laboratory tests of core samples, (3) data on specific capacity of wells, and (4) available selected aquifer tests. The ground-water flow system was simulated through the use of a digital flow model. Hydraulic characteristics of the ground-water flow system were adjusted to calibrate the model to measured water levels throughout the history of ground-water development (1891–1980). Sensitivity of model-generated water levels to selected variations in hydraulic characteristics was tested. The information presented is intended to assist those involved in the management of the ground-water resource in the Coastal Plain aquifers of Virginia.

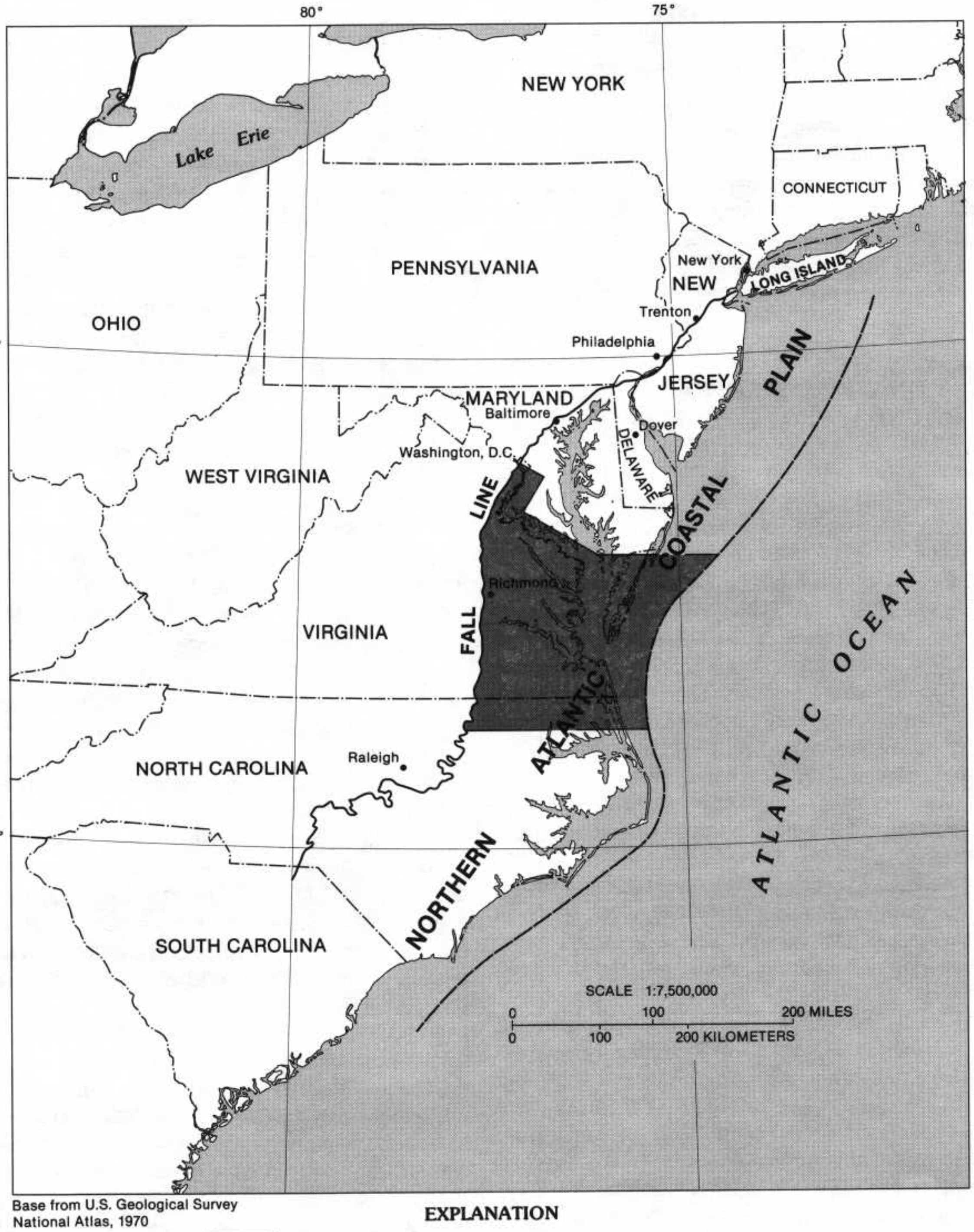
Data used to develop the subregional digital flow model were also used to develop a regional digital flow model of the northern Atlantic Coastal Plain aquifer system (Meisler, 1980). The regional model analyzed the entire ground-water flow system of the northern Atlantic Coastal Plain and provided lateral boundary flows to the individual subregional models.

GENERAL SETTING AND LOCATION OF STUDY AREA

The study area is located within the Atlantic Coastal Plain physiographic province and includes the entire Coastal Plain of Virginia and adjacent parts of the Coastal Plain of Maryland and North Carolina (fig. 1). The area covers about 17,000 square miles (mi^2) and is characterized by a gently seaward sloping land surface and a dissected lowland with a series of broad, seaward-facing, ocean-cut terraces trending north-south. The study area is underlain predominantly by unconsolidated clastic sediments of Early Cretaceous to Holocene age.

PREVIOUS INVESTIGATIONS

Important sources of data on the geology and hydrogeology of the Virginia Coastal Plain include reports by Richards (1945, 1948), Spangler and Peterson (1950), Bick and Coch (1969), Brown and others (1972), Johnson (1972), Teifke (1973), the Virginia Division of Mineral Resources (1980), and Meng and Harsh (1988). Darton (1896), Sanford (1913), Cederstrom (1945, 1957), Leggette and others (1966), Geraghty and Miller (1967, 1978a, 1978b, 1979a, 1979b), Sinnott (1968), the Virginia State Water Control Board (1973, 1974), Cushing and others (1973), Lichtler and Wait (1974), Brown and Cosner (1974), Siudyla and others (1977), Newton and Siudyla (1979), Harsh (1980), Siudyla and others (1981), and Fennema and Newton (1982) describe the geology and water resources in specific areas of the Coastal Plain of Virginia. Converse and others (1981) provide a comprehensive water-supply study for the City of Virginia Beach, Va. Brown and Silvey (1977) evaluate the feasibility of injecting freshwater into Cretaceous-age sand containing saline water at Norfolk, Va. Meisler (1981) documents the occurrence and distribution of salty ground water in the northern Atlantic Coastal Plain aquifer system. Larson (1981) describes the occurrence of salty ground water in the Coastal Plain aquifers of Virginia. Cosner (1975), Bal (1977, 1978), and Faust and others (1981) studied, by means of digital flow models, the movement of ground water in specific areas of the Virginia Coastal Plain. Layne-Western Company (1983) developed a steady-state electric analog model to simulate flow in the Cretaceous-age aquifers of Virginia and North Carolina.



EXPLANATION

STUDY AREA

ESTIMATED SEAWARD LIMIT OF FRESHWATER SYSTEM—Shows location of water that contains chloride concentrations of 10,000 milligrams per liter or less

FIGURE 1.—Location of study area within the northern Atlantic Coastal Plain.

ACKNOWLEDGMENTS

Acknowledgment is given to the Virginia State Water Control Board (VSWCB), the Virginia State Health Department, and the many water users in Virginia for furnishing information on ground-water withdrawals and water-supply wells. The authors wish to thank the VSWCB for providing core samples and completing an observation well in Gloucester County, Va. Thanks also is extended to the many drillers and consultants active in the area for providing access to well information.

CONCEPTUALIZATION OF GROUND-WATER FLOW SYSTEM

The ground-water flow system in the Coastal Plain of Virginia is a multiaquifer system consisting of an eastward-thickening wedge of unconsolidated sand and clay that unconformably rests on an uneven, eastward-sloping surface of crystalline rocks, referred to as the "basement." The Fall Line is the westernmost extent of these unconsolidated sediments and delineates their contact with the igneous and metamorphic rocks of the Piedmont physiographic province. The sediments attain a maximum thickness in northeastern Virginia; Onuschak (1972) reports that sediments are about 6,200 feet (ft) thick beneath the northern part of Virginia's Eastern Shore Peninsula. The wedge generally consists of a thick sequence of nonmarine deposits overlain by a thinner sequence of marine deposits. The sediments are mostly undeformed except for slight warping and tilting with associated minor faulting; they range in age from Early Cretaceous to Holocene and have a complex history of deposition and erosion (Meng and Harsh, 1988, p. C11).

The sediments are subdivided into a sequence of discrete lithologic layers that form a regionally correlative geohydrologic framework of aquifers and confining units (fig. 2) (Meng and Harsh, 1988). The framework includes an unconfined, or water-table, aquifer underlain by a series of confined aquifers separated by intervening confining units. The subsurface correlations of aquifers and confining units are based primarily on analyses of geophysical and lithologic logs of wells. Table 1 (all tables at end of report) shows the relation between stratigraphic formations and hydrogeologic units defined for the Coastal Plain of Virginia. Table 2 summarizes the correlation of the hydrogeologic units of the Virginia Coastal Plain by Meng and Harsh (1988) with those of the adjoining States of Maryland (D.A. Vroblesky, U.S. Geological Survey, written commun., 1984) and North Carolina (M.D. Winner, U.S. Geological Survey, written commun., 1984).

Not all aquifers are continuous over the entire study area. The Black Creek and Peedee aquifers of North Carolina and the Matawan and Severn aquifers of southern Maryland (aquifers 4 and 5, table 2) are missing for the most part in the Coastal Plain of Virginia. The Brightseat aquifer, not present in North Carolina, is combined with the upper Potomac aquifer in the digital flow model (aquifer 3, table 2) because of the absence of a continuous intervening confining unit and similarities in hydraulic properties. The areal extent of aquifers and confining units is shown on maps of aquifer transmissivity and confining unit leakance presented in later sections of this report and in a report by Meng and Harsh (1988).

HYDRAULIC PROPERTIES

Transmissivity and storage coefficient are the hydraulic properties used to describe the ability of an aquifer to transmit and store water. Most hydraulic properties of aquifers in the Coastal Plain of Virginia have been determined from aquifer tests. Drawdown and recovery data generally are collected from an observation well positioned near a high-capacity production well that penetrates more than one aquifer. Other estimates of aquifer properties are determined from specific capacity (yield per unit of drawdown) and single-well tests of production wells that penetrate more than one aquifer. Because most wells penetrate more than one aquifer, direct application of these tests to determine hydraulic properties of an individual aquifer is difficult. Table 3 lists the type of data and method of analysis used to compute transmissivity. Locations of aquifer test sites are shown in figure 3. Applying results from aquifer tests over large areas is difficult because values represent only the test area and because of the assumptions inherent in the methods—that an aquifer is homogeneous and that test wells penetrate the entire aquifer.

Data on the hydraulic properties of individual confining units are sparse. Some vertical hydraulic conductivities have been estimated from laboratory tests of core samples (table 4). The locations of core holes are shown in figure 3. Laboratory values should be used with caution, because undisturbed core samples are difficult to obtain and typically represent only a small interval of a highly complex hydrogeologic unit.

DESCRIPTION OF HYDROGEOLOGIC UNITS

Each aquifer and overlying confining unit is assigned an identification number for model simulation, from 10 through 1 in descending order from land surface (table 2). The following sections summarize the lithology and

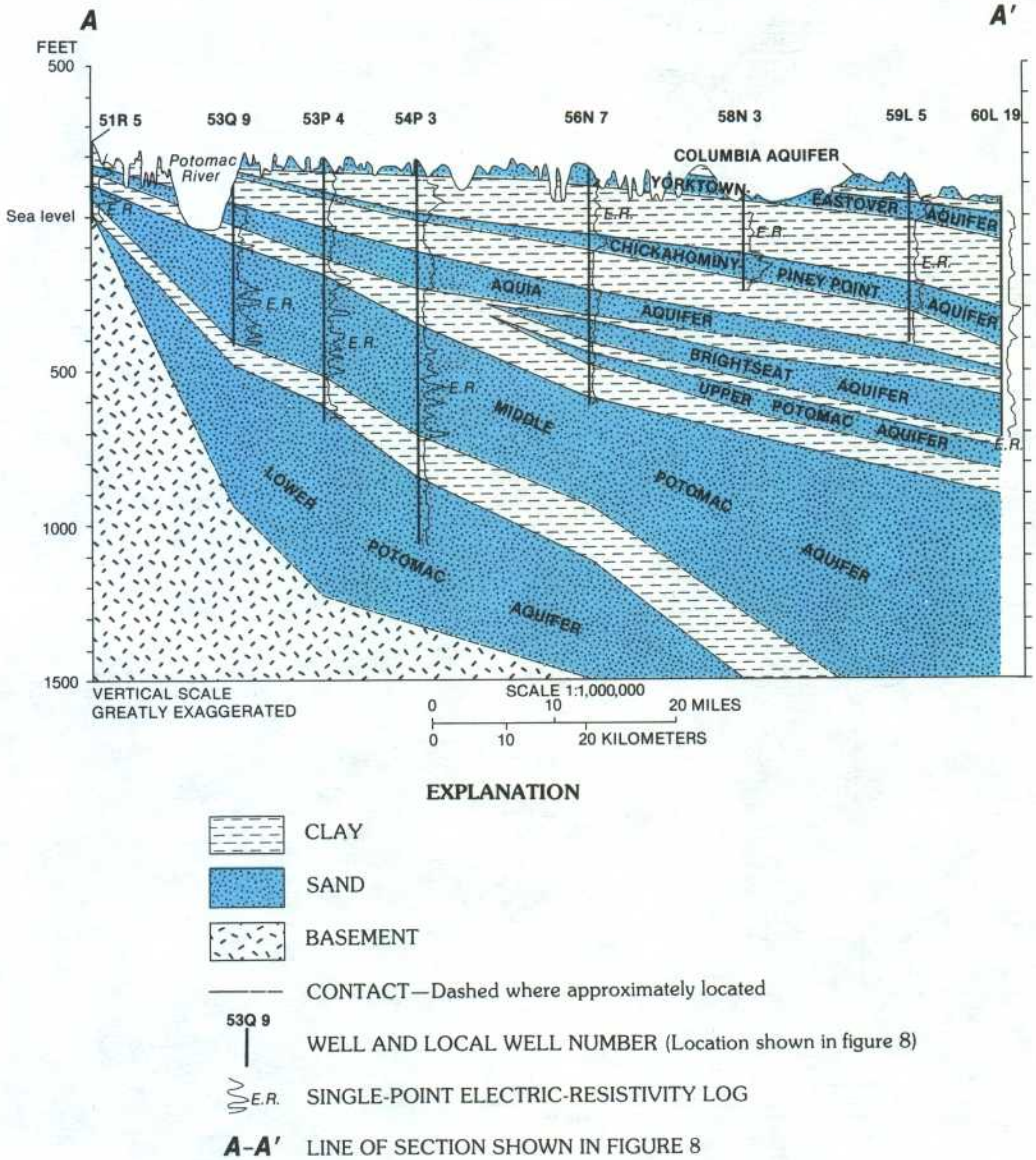


FIGURE 2.—Generalized hydrogeologic section of eastward-thickening wedge of alternating sand and clay.

hydraulic properties of aquifers and confining units of the study area. The reader is referred to Meng and Harsh (1988) for a more detailed description of the age, lithologic characteristics, stratigraphic position, depositional history, and areal extent of each hydrogeologic unit, except where otherwise referenced.

COLUMBIA AQUIFER

The Columbia aquifer, designated aquifer 10, is made up primarily of Holocene- and Pleistocene-age sediments that were deposited as channel fill and fluvial-marine terraces. The aquifer is composed of interbedded gravel, sand, silt, and clay and is unconfined throughout the study area. The aquifer is a major source of recharge to the underlying confined flow system and supplies water to rural and domestic users.

The saturated thickness of the Columbia aquifer ranges from about 15 ft near its western extent to about 80 ft in the southeastern part of the study area. Spatial variation in the hydraulic properties of the aquifer are not adequately defined by available data. Results from an aquifer test conducted at Northwest River Park in Chesapeake, Va., indicate a transmissivity of 250 feet squared per day (ft^2/d) (Siudyla and others, 1981). A specific yield of 0.15 was estimated by Cushing and others (1973) from analysis of aquifer-test data collected on the Eastern Shore Peninsula of Virginia.

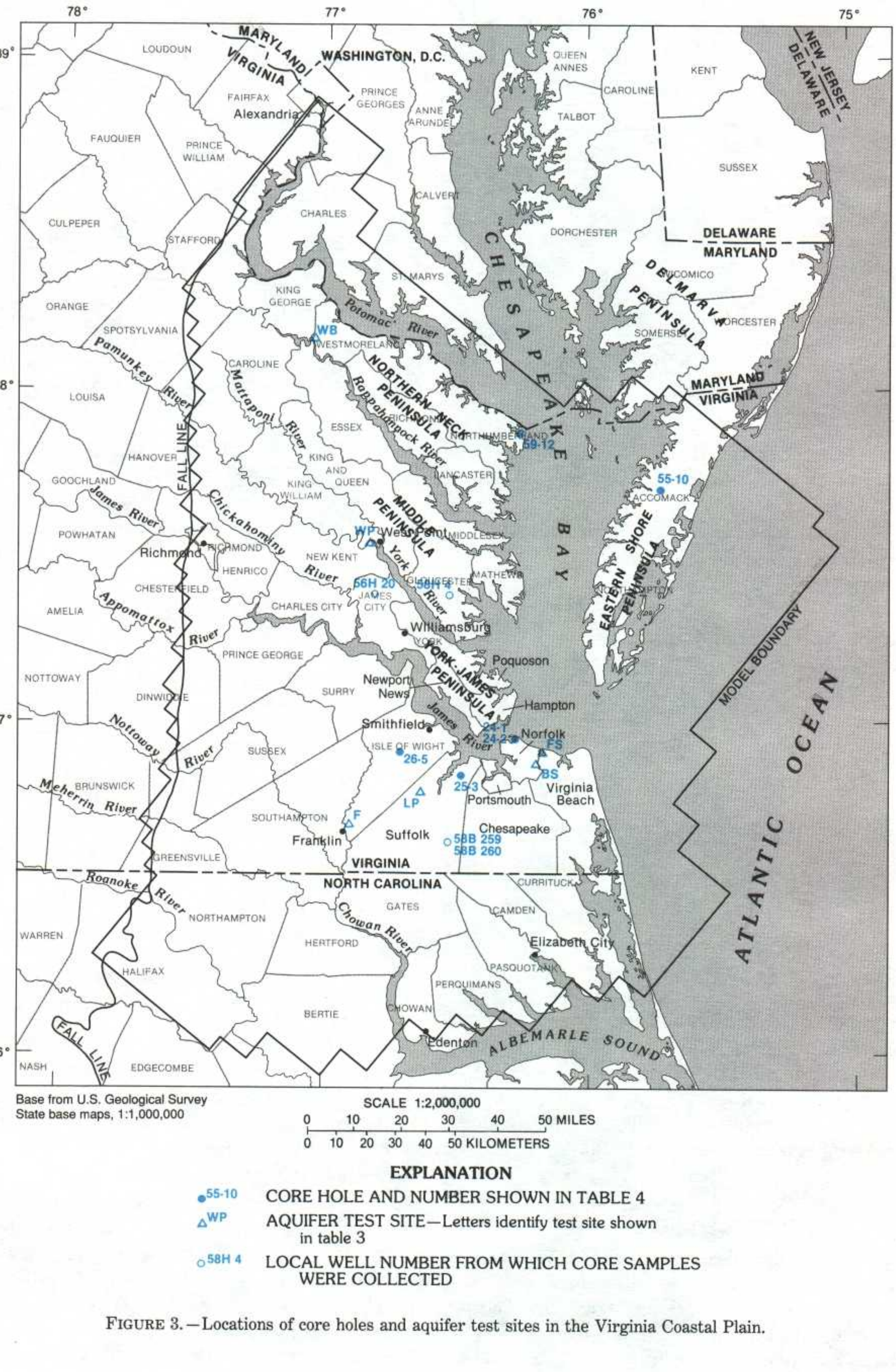


FIGURE 3.—Locations of core holes and aquifer test sites in the Virginia Coastal Plain.