HYDROGEOLOGIC FRAMEWORK OF THE VIRGINIA COASTAL PLAIN

By ANDREW A. MENG III *and* JOHN F. HARSH

REGIONAL AQUIFER-SYSTEM ANALYSIS

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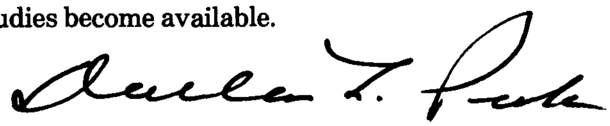
FOREWORD

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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(Plates are in pocket)

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CONVERSION FACTORS

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

Multiply	By	To obtain
ft (feet)	0.3048	m (meters)
mi (miles)	1.609	km (kilometers)
mi^2 (square miles)	2.590	km^2 (square kilometers)
ft/mi (feet/mile)	0.18943	m/km (meters per kilometers)

REGIONAL AQUIFER-SYSTEM ANALYSIS

HYDROGEOLOGIC FRAMEWORK OF THE VIRGINIA COASTAL PLAIN

By ANDREW A. MENG III and JOHN F. HARSH

ABSTRACT

This report defines the hydrogeologic framework of the Virginia Coastal Plain and is a product of a comprehensive regional study to define the geology, hydrology, and geochemistry of the northern Atlantic Coastal Plain aquifer system extending from North Carolina to Long Island, New York.

The Virginia Coastal Plain consists of an eastward-thickening wedge of generally unconsolidated, interbedded sands and clays, ranging in age from Early Cretaceous to Holocene. These sediments range in thickness from more than 6,000 feet beneath the northeastern part of the Eastern Shore Peninsula to nearly 0 feet along the Fall Line. Eight confined aquifers, eight confining units, and an uppermost water-table aquifer are delineated as the hydrogeologic framework of the Coastal Plain sediments in Virginia. The nine regional aquifers, from oldest to youngest, are lower, middle, and upper Potomac, Brightseat, Aquia, Chickahominy-Piney Point, St. Marys-Choptank, Yorktown-Eastover, and Columbia. The Brightseat is a newly identified and correlated aquifer of early Paleocene age. This study is one of other, similar studies of the Coastal Plain areas in North Carolina, Maryland-Delaware, New Jersey, and Long Island, New York. These combined studies provide a system of hydrogeologic units that can be identified and correlated throughout the northern Atlantic Coastal Plain.

Data for this study were collected and analyzed from October 1979 to May 1983. The nine aquifers and eight confining units are identified and delineated by use of geophysical logs, drillers' information, and stratigraphic and paleontologic data. By correlating geophysical logs with hydrologic, stratigraphic, and paleontologic data throughout the Coastal Plain, a comprehensive multilayered framework of aquifers and confining units, each with distinct lithologic properties, was developed.

Cross sections show the stratigraphic relationships of aquifers and confining units in the hydrogeologic framework of the Virginia Coastal Plain. Maps show confining-unit thicknesses and altitudes of aquifer tops, provide the basis for assigning aquifers to screened intervals of observation and production wells, and are used for the development of a comprehensive observation-well network in the Virginia Coastal Plain.

INTRODUCTION

In 1977, Congress appropriated funds for a series of ground-water-assessment studies titled the "Regional Aquifer-System Analysis" (RASA) program; this program was designed to identify and evaluate the water resources of major aquifer systems on a regional scale in the United States. In 1979, the U.S. Geological Survey began a comprehensive regional investigation, as part of the RASA program, to define the hydrogeology and geochemistry, and to simulate ground-water flow, in the northern Atlantic Coastal Plain that extends from North Carolina to Long Island, N.Y. (fig. 1). Subsequently, the northern Atlantic Coastal Plain RASA investigation was subdivided into five state-level RASA studies. The Virginia RASA, headquartered in the Virginia Office, Mid-Atlantic District, of the U.S. Geological Survey, was assigned the responsibility of defining a regional hydrogeologic framework and of simulating ground-water flow in the Coastal Plain province of Virginia (fig. 1). This report describes the hydrogeologic framework developed as part of the Virginia RASA study. Companion RASA studies were also conducted for the Coastal Plain areas of North Carolina, Maryland-Delaware, New Jersey, and Long Island, N.Y. (fig. 1). Collectively, these individual studies form a regional system of hydrogeologic units that can be identified and correlated between adjoining States throughout the northern Atlantic Coastal Plain.

PURPOSE AND SCOPE

This report is the result of part of the Virginia RASA study to (1) identify and define the regional hydrogeologic framework of the Coastal Plain sediments of Virginia, and (2) further understand the subsurface Coastal Plain geology and hydrology. The description of the hydrogeologic framework presented herein provides the basis for the RASA modeling study in Virginia.

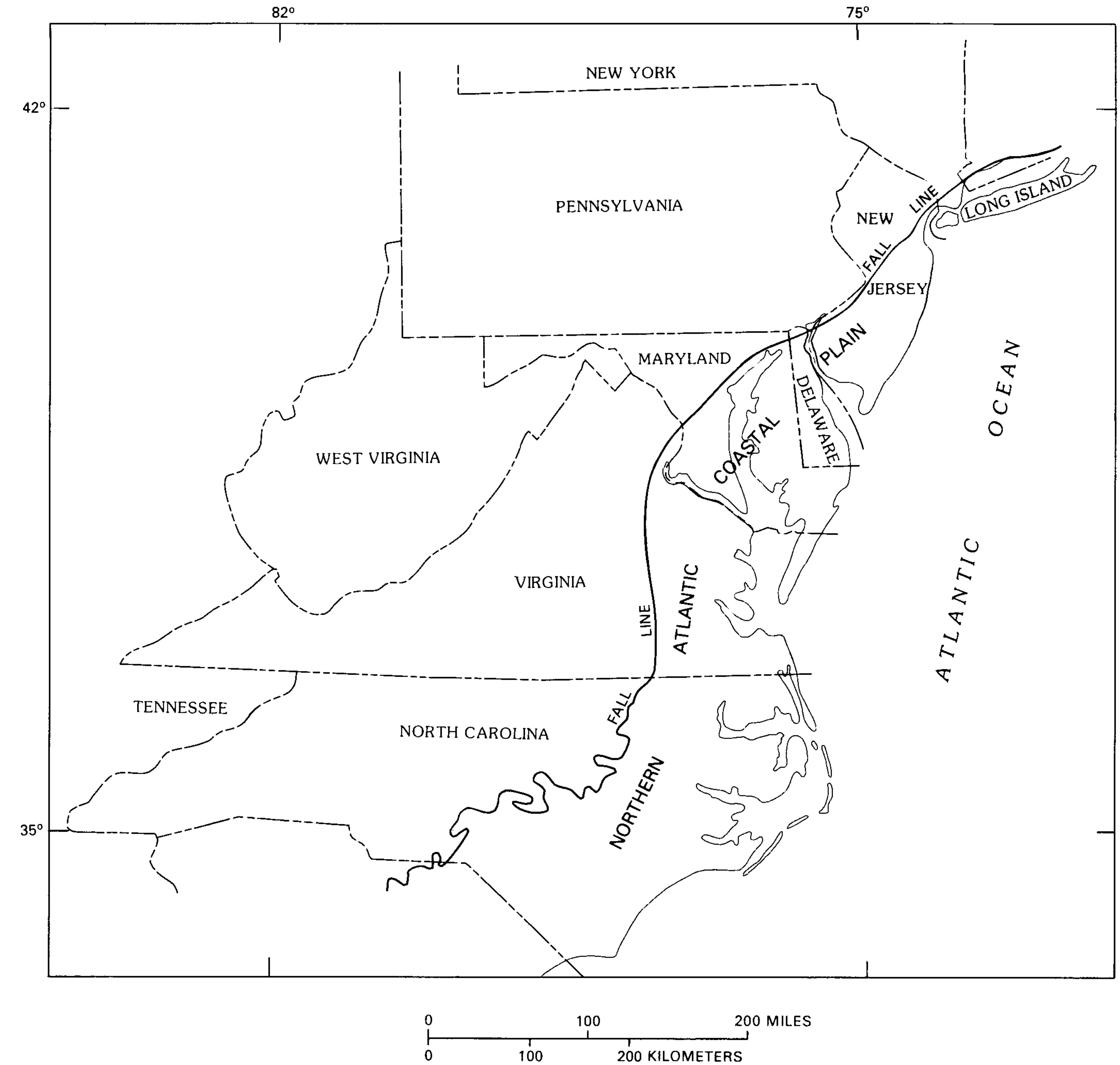

FIGURE 1.—Location of northern Atlantic Coastal Plain.

Specific objectives of this report are to: (1) identify and divide the sediments of the Virginia Coastal Plain into regional hydrogeologic units, (2) delineate and describe the boundaries, stratigraphic relationships, and characteristics of the hydrogeologic units, (3) provide data to construct a digital model to simulate ground-water flow in the Virginia Coastal Plain, and (4) provide data to generate the regional hydrogeologic framework and to construct a regional ground-water flow model of the entire northern Atlantic Coastal Plain from North Carolina to Long Island, N.Y.

The scope of this study is to define a system of hydrogeologic units for the Virginia Coastal Plain that correlates with a regional hydrogeologic framework. The regional hydrogeologic framework is composed of ten aquifers and nine confining units and is based on published literature describing the hydrogeology in the Coastal Plain areas of New Jersey and Maryland. The

Virginia Coastal Plain hydrogeologic units, as presented in this report, have been divided into nine regional aquifers with eight confining units, encompassing nine geochronologic epochs that range in age from Early Cretaceous to Holocene. This hydrogeologic framework correlates areally and hydrologically with units in adjoining States. The hydrogeologic units in the Virginia Coastal Plain are described in terms of age, lithology, stratigraphic position, configuration, areal extent, depositional environment, regional correlations, and their characteristic geophysical log signatures, beginning with the oldest stratigraphic unit and ending with the youngest. Also, the aquifer-unit descriptions briefly refer to the general use and availability of ground water, but a detailed discussion of water supply and water quality is beyond the scope of this report.

LOCATION AND EXTENT

The study area (fig. 2) comprises all of the Coastal Plain physiographic province of Virginia. It encompasses the eastern third of the State and consists of about 13,000 mi^2. The study area is approximately 125 mi wide across the northern section, and 165 mi long along the western section. It is bounded on the west by the Fall Line, a physiographic boundary that separates the Piedmont province from the Coastal Plain province. The Fall Line runs generally north-south near or through the cities of Alexandria, Fredericksburg, Richmond, Petersburg, and Emporia (fig. 2), and closely corresponds to the present route of Interstate 95. The study area is also bounded by Maryland on the north, North Carolina on the south, and by the Atlantic Ocean on the east. For the purpose of this report, the study area is informally divided into five principal geographic regions: the western, central, eastern, northern, and southern. For more precise geographical orientations, the five principal regions are further subdivided into more specific parts, such as the northwestern, north-central, northeastern, west-central, east-central, southwestern, south-central, and southeastern. The above areas and regions are referred to throughout the text so that explanations of the interrelationships and areal extent of the hydrogeologic units can be related to specific parts of the Virginia Coastal Plain.

PREVIOUS INVESTIGATIONS

Many reports describe specific aspects of the geology or ground-water resources in the Coastal Plain of Virginia, but none describe the hydrogeologic framework as a whole. Clark and Miller (1912) provide the first comprehensive view on the geology and physiography of the Coastal Plain in Virginia. Sanford (1913) presents the first integrated view of geology and ground-water resources throughout the Virginia Coastal Plain. Cederstrom (1945a, 1957) describes the hydrogeology of southeastern Virginia and the York-James Peninsula. Sinnott and Tibbitts (1954, 1957, 1968) define the availability of ground water and the uppermost stratigraphy in the Eastern Shore Peninsula of Virginia. The investigation by Brown and others (1972) correlates 17 chronostratigraphic rock units and depicts regional permeability-distribution maps based on the 17 delineated time-rock units for the northern Atlantic Coastal Plain sediments. The Virginia State Water Control Board (1970, 1973, 1974), Siudyla and others (1977, 1981), and Fennema and Newton (1982) present data on ground-water conditions in various county and peninsulawide areas in the Virginia Coastal Plain. A stratigraphic-data report published by the Virginia Division of Mineral Resources (1980) on a U.S. Geological Survey core hole at Oak Grove, Va., supplies invaluable information on subsurface geology in the northwestern part of the Virginia Coastal Plain. Numerous reports prepared by consultants describe the ground-water conditions and potential yields of important aquifers in various parts of the Virginia Coastal Plain, especially the southeastern area. In addition to the information cited above, other important data sources include works by: Cederstrom (1943, 1945b); Richards (1945, 1948, 1967); Spangler and Peterson (1950); Hack (1957); Brenner (1963); Nogan (1964); Drobnyk (1965); Glaser (1969); Hazel (1969); Johnson and Goodwin (1969); Cushing and others (1973); Onuschak (1972); Oaks and Coch (1973); Blackwelder and Ward (1976); Doyle (1977); Doyle and Robbins (1977); Hansen (1978); Blackwelder (1980); Gleason (1980); Ward and Blackwelder (1980); Ward (1980); Meisler (1981); Larson (1981); and Gibson (1982).

METHODS OF STUDY

Data used in this study were collected, analyzed, and interpreted during the period from October 1979 to May 1983. Literature pertinent to the lithology, stratigraphy, and ground-water resources of the study area and the adjoining States was reviewed and synthesized. Water-well and stratigraphic test-hole data consisting of borehole-geophysical logs, drillers' logs, well-completion reports, geologic logs, and paleontologic and core-sample analyses were compiled. This information, together with hydrogeologic interpretations provided by adjoining northern Atlantic Coastal Plain RASA studies, supplies the data used to define the regional hydrogeologic framework of the Virginia Coastal Plain.

Borehole-geophysical logs and drillers' information, supported by pertinent stratigraphic and hydrologic

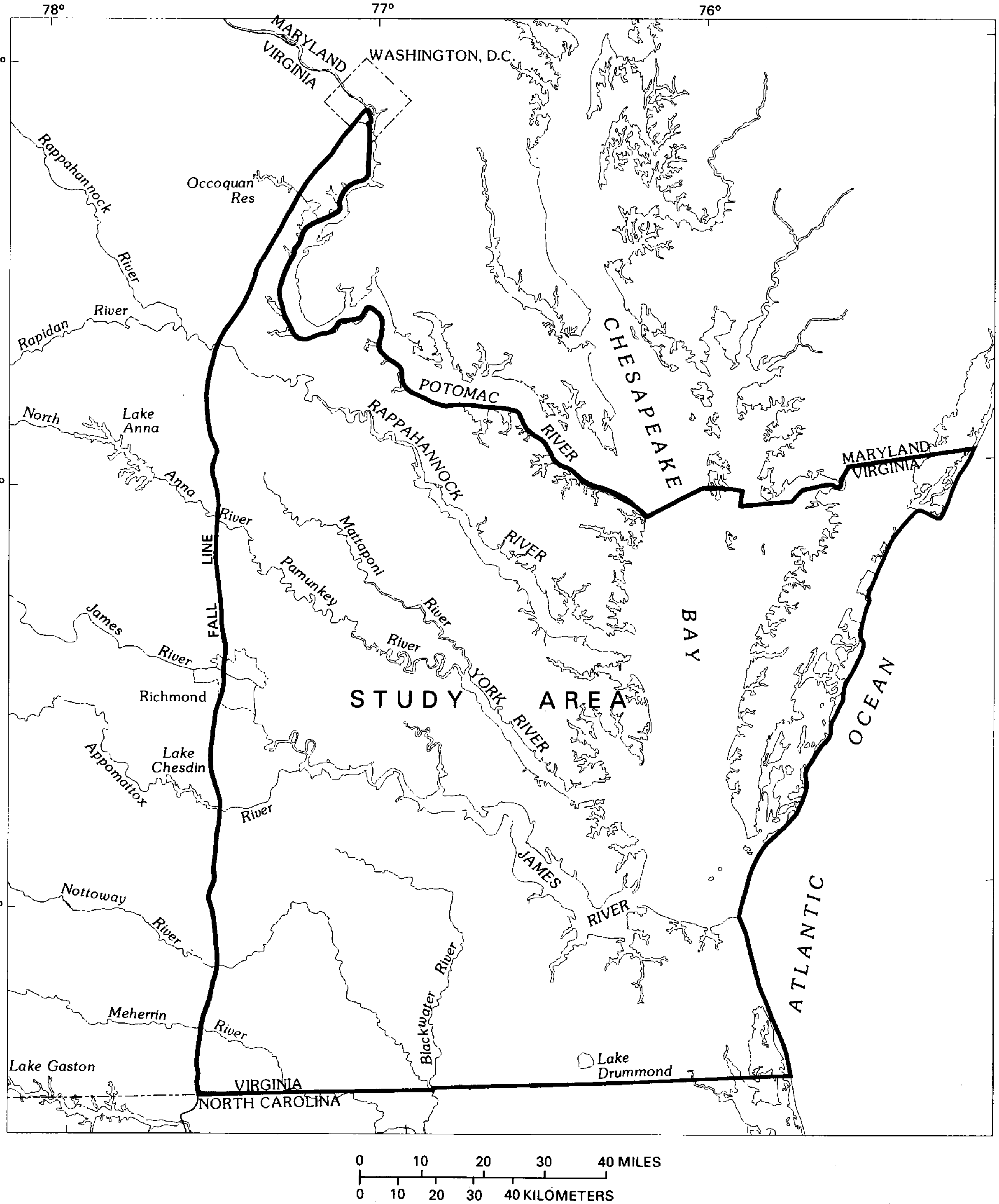

FIGURE 2.—Location of study area.

data, were used to provide the basis for the identification, correlation, and definition of the areally comprehensive hydrogeologic framework of the Virginia Coastal Plain. Borehole-geophysical logs are a qualitative, graphic representation of the subsurface environment penetrated by drilling. These logs portray a continuous, scaled record of the character of the subsurface sediments, and are used to identify formations and the relative salinity of formation waters. Details on the interpretation, correlation, and application of borehole geophysics to hydrogeologic investigations are given by Keys and MacCary (1971). The types of borehole-geophysical logs most commonly used in this study consist primarily of electric-resistivity and natural-gamma logs. Spontaneous potential (S.P.) and single-point and multipoint electric-resistivity logs identify lithologic contacts, determine gross sand-to-clay ratios in each hydrogeologic unit, and indicate the relative quality of water in the aquifer units. Natural-gamma logs define regional lithologic facies changes in units and dip directions of strata that contain particularly high gamma-emitting lithologies or marker beds. Drillers' information includes sample logs, commonly called drillers' logs or cuttings logs, and well-completion reports. Sample logs describe the physical properties of sediments penetrated during drilling operations. Well-completion reports provide information on depths to screened intervals and water levels in finished wells. Geologic logs provide a detailed, usually microscopic, description and identification of the lithology of cuttings collected from the drilled holes. Paleontologic analyses of cuttings and core samples provide biostratigraphic data on the ages of sediments. Core-sample analyses also provide information on specific lithologic and depositional characteristics of the subsurface sediments not otherwise obtainable from drill cuttings.

Lithologic trends in the type and distribution of sediments are derived by analysis of stratigraphic, borehole, and water-well information. These trends were identified on the basis of stratigraphic and lithologic relationships obtained from different drilled holes over large areas and areally extensive lithologic and geophysical marker units. Log signatures depicting sand lithologies are identified and labeled as aquifers on the geophysical logs; in contrast, log signatures depicting clay lithologies are identified and labeled as confining units (fig. 3). A regional correlation of aquifers and confining units in the Virginia Coastal Plain was developed by comparing geophysical logs and chronostratigraphic and lithostratigraphic units across adjoining State boundaries.

WELL-NUMBERING SYSTEM

The well-numbering system used by the U.S. Geological Survey in Virginia is based on the "Index to Topographic Maps of Virginia" (U.S. Geological Survey, 1978). Topographic map quadrangles covering 7½-min of latitude and longitude, published at a scale of 1:24,000, or 1 in = 2,000 ft, are identified by numbers and letters starting in the southwest corner of the State. The quadrangles are numbered 1 through 69 from west to east beginning at 83°45′ west longitude, and lettered A through Z (omitting letters I and O) from south to north, beginning at 36°30′ north latitude. The area covered by the Coastal Plain includes generally the quadrangles numbered from 50 to 69 containing the letters from A to V. Wells are identified and numbered serially within each 7½-min quadrangle. As an example, figure 4 shows the south-central section of the study area. Well 53A2 is in quadrangle 53A and is the second well in that quadrangle for which the location and other data were recorded by the U.S. Geological Survey. All wells selected as controls for this hydrogeologic framework are listed by increasing well number in the appendix of this report.

ACKNOWLEDGMENTS

Acknowledgment is given to the Bureau of Surveillance and Field Studies and the Tidewater Regional Office of the Virginia State Water Control Board, for furnishing well information, selected stratigraphic cores, and geophysical logs. The authors wish to thank R.L. Magette Co., Gammon Well Co., and Layne-Atlantic Co. for providing single-point electric-resistivity geophysical logs and well data, and to the many drillers in the Virginia Coastal Plain who have supplied valuable information concerning the nature of sediments and their water-bearing properties. Special thanks go to Sydnor Hydrodynamics, Inc. for providing comprehensive well data, multipoint electric-resistivity and natural-gamma geophysical logs, and for their conscientious and continuous efforts in obtaining subsurface hydrogeologic information.

The authors express appreciation to the Virginia Division of Mineral Resources for providing a preliminary revised surficial geologic map of the Virginia Coastal Plain sediments. The authors also wish to convey appreciation to L.W. Ward, L.E. Edwards, R.B. Mixon, J.P. Owens, L. McCarten, and T.G. Gibson, of the U.S. Geological Survey, for providing valuable and timely stratigraphic information and analysis.

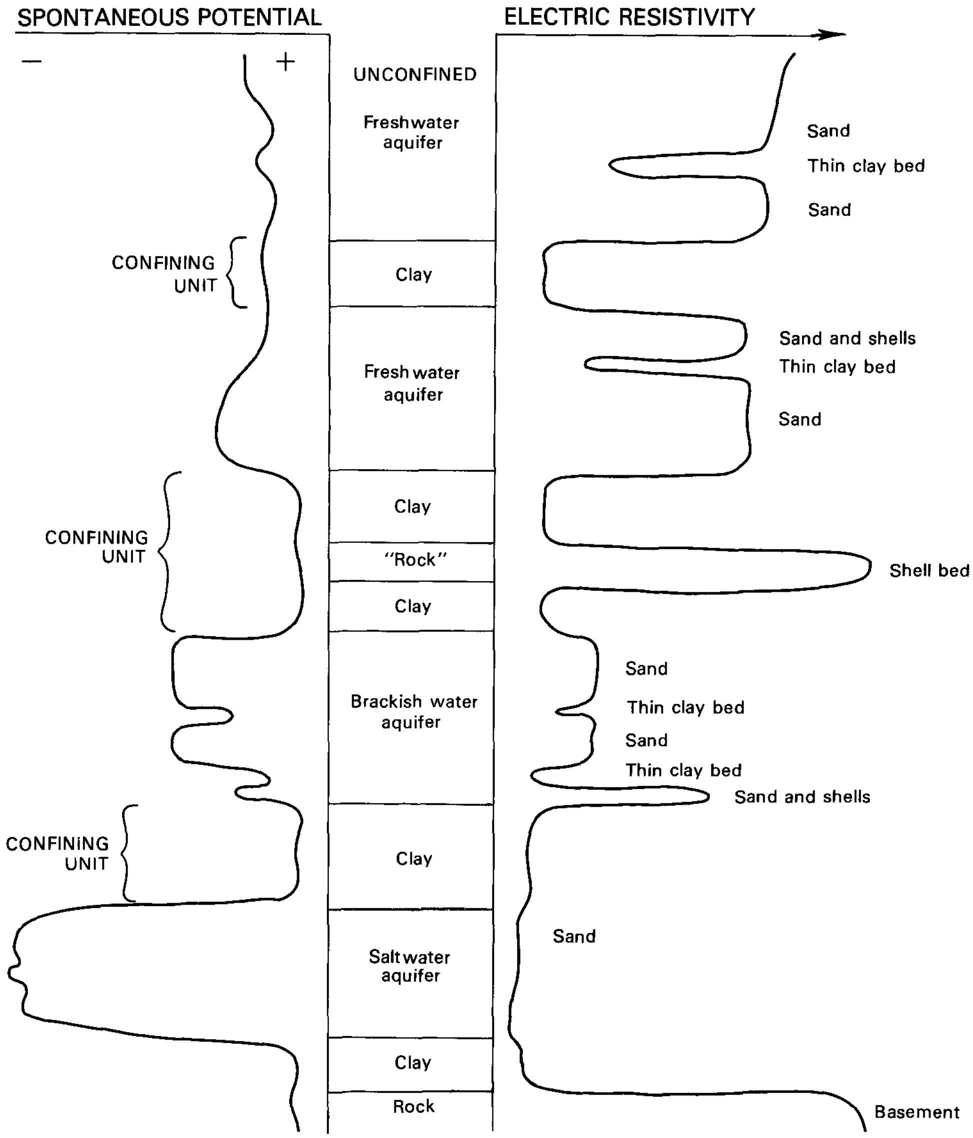

FIGURE 3.—Idealized geophysical log showing aquifers and confining units and characteristic electric and spontaneous potential traces.

GENERAL GEOLOGY

The study area is part of the Atlantic Coastal Plain province that extends from Cape Cod, Mass., southward to the Gulf of Mexico. The Coastal Plain province of Virginia consists of an eastward-thickening sedimentary wedge (fig. 5) composed principally of unconsolidated gravels, sands, silts, and clays, with variable amounts of shells. This sedimentary wedge generally is devoid of hard rocks, although calcareous cementations are present locally, forming thin lithified strata. The unconsolidated deposits rest on a rock surface, referred to as the "basement," that slopes gently eastward. The sediments attain a maximum thickness of over 6,000 ft in the northeastern part of the study area. Onuschak (1972) reports that the sediments are 6,186 ft thick beneath the Eastern Shore Peninsula at Temperanceville, Va. (fig. 5). Coastal Plain sediments thin westward to nearly zero thickness at the Fall Line and are highly dissected by streams throughout the western region. Small, isolated erosional remnants of Coastal Plain deposits are common, just west of the main sedimentary wedge, in the Fall Line area. The surface of the Virginia Coastal Plain consists of a series of broad gently sloping, highly dissected terraces bounded by seaward-facing, ocean-cut escarpments extending generally north-south across the province. Most of the study area is less than 100 ft in altitude and one-fifth is covered by water, principally the Chesapeake Bay. The land surface is highest along the

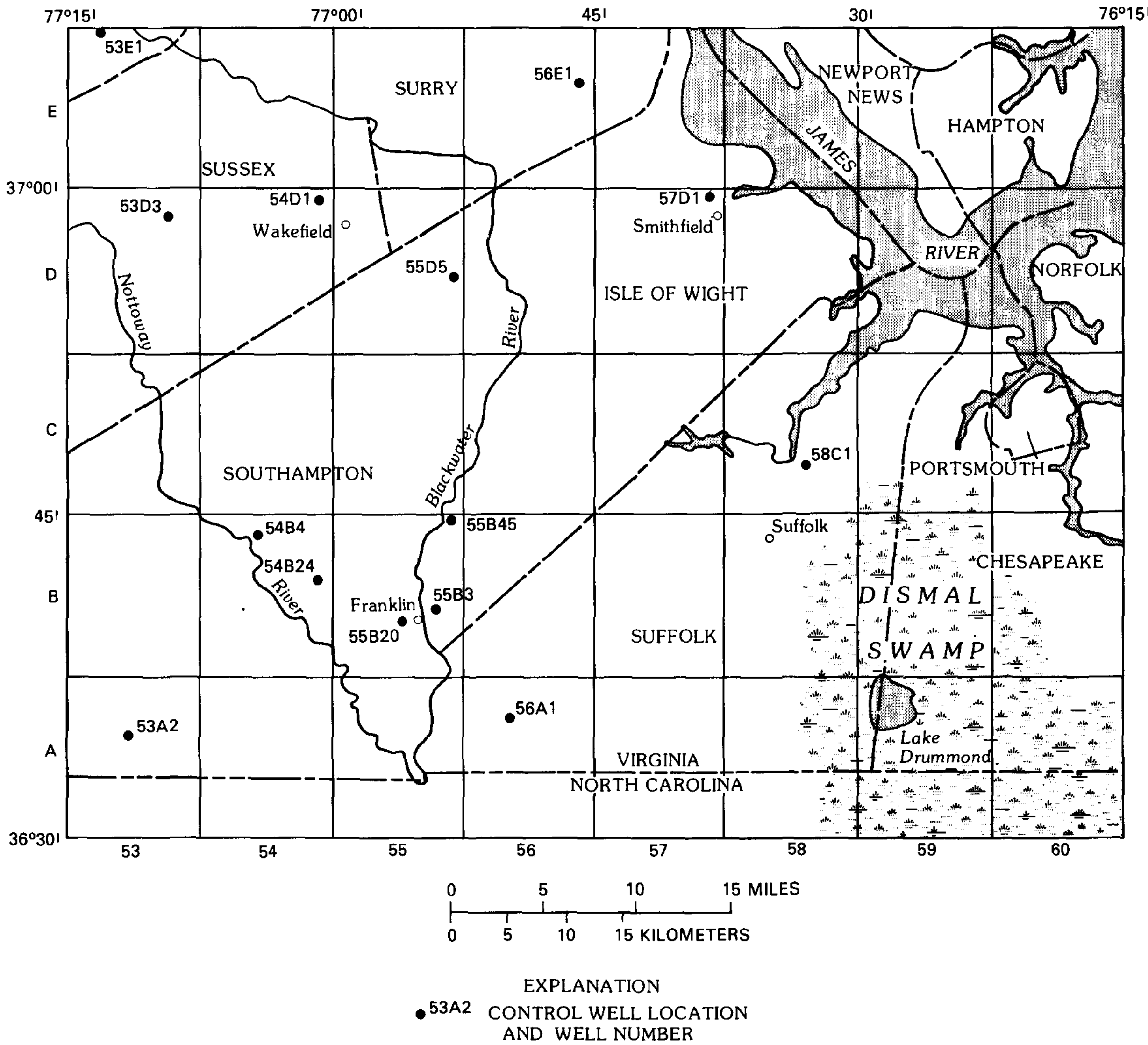

FIGURE 4.–Example of well-numbering system.

Fall Line, especially in the northwestern part of the study area. The sedimentary section, in general, consists of a thick sequence of nonmarine deposits overlain by a much thinner sequence of marine deposits. These deposits are, for the most part, undeformed throughout, except for slight warping and tilting, with associated local faulting. All depositional units strike approximately parallel, or subparallel, to the Fall Line. The average dip of each successively younger depositional unit decreases upward, with the oldest deposits dipping nearly the same as the basement-rock surface (about 40 ft/mi) and the youngest deposits dipping less than 3 ft/mi. Sediments range in age from Early Cretaceous to Holocene, and have a complex history of deposition and erosion.

DEPOSITIONAL HISTORY

Many different depositional environments existed during the formation of the Virginia Coastal Plain. Numerous marine transgressions and regressions, punctuated by varying periods of erosion, produced an assorted, but ordered, array of sediments in the study area. The shoreline has occupied positions far to the east of the present shoreline, as evidenced by offshore submerged Pleistocene barrier beach deposits, and positions at least as far west as the Fall Line, as shown by marine deposits at the Fall Line.

Ages of sediments exposed at the surface within the study area consist of Early Cretaceous, Paleocene, Eocene, Oligocene, Miocene, Pliocene, Pleistocene, and

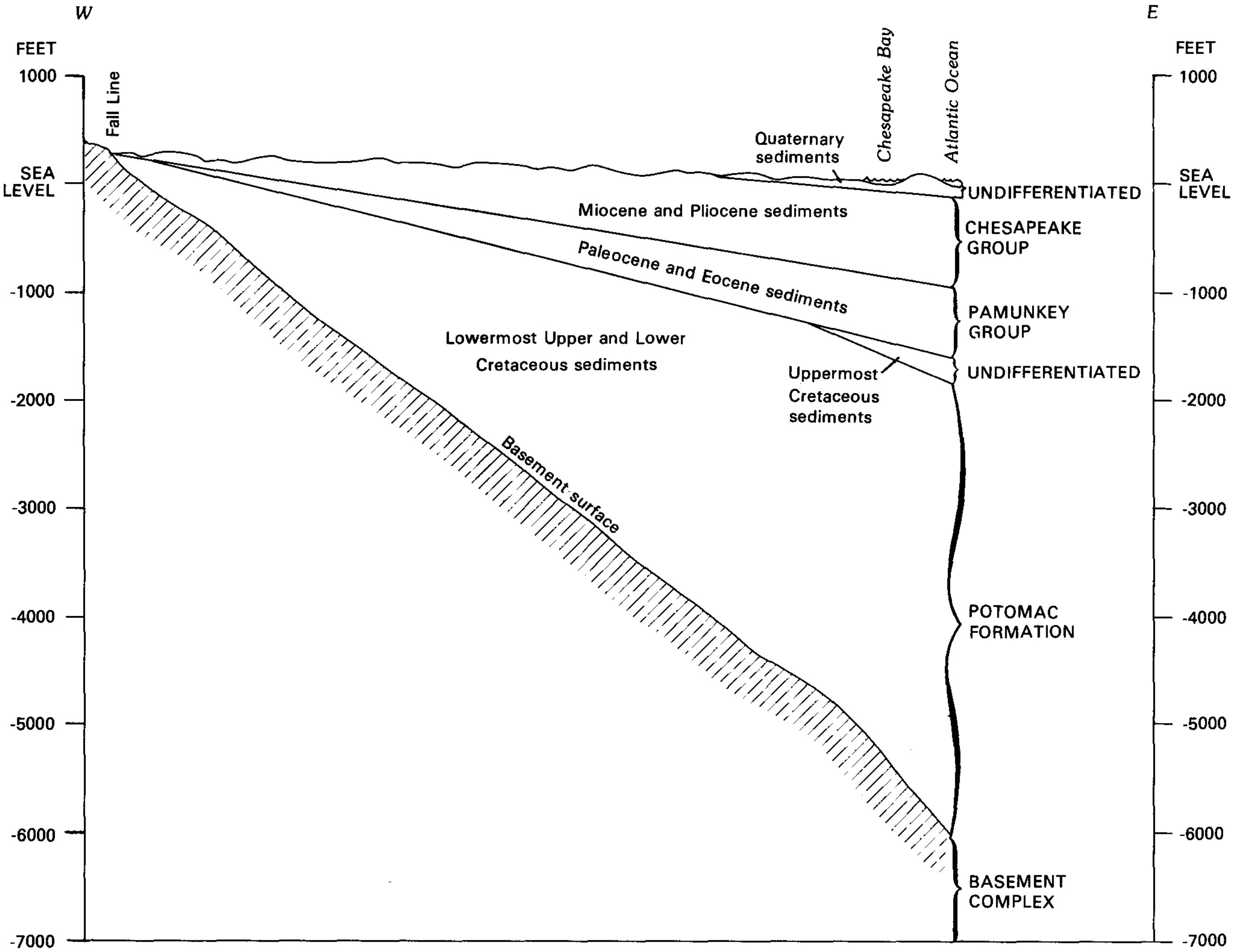

FIGURE 5.–Generalized geologic section showing eastward-thickening sedimentary wedge of Virginia Coastal Plain.

Holocene. Sediments of Late Cretaceous age are overlain by younger sediments and are not exposed at the surface in the study area. Sediments of Early Cretaceous and Paleocene age crop out extensively between the Fall Line and the Potomac River in the northwestern part of the study area. Sediments of Eocene, Oligocene, and Miocene age are exposed principally along the major stream valleys throughout the western and central regions of the study area. The uppermost sediments of Pliocene, Pleistocene, and Holocene age crop out extensively in broad areas throughout the eastern and southern regions, and, to a lesser extent, in the central and north-central parts of the study area. The Coastal Plain deposits of Virginia can be divided into five principal lithostratigraphic groups based primarily on their mode of deposition. These five groups, from oldest to youngest, are (1) Lower Cretaceous and lowermost part of the Upper Cretaceous Potomac Formation, (2) uppermost Cretaceous deposits, (3) lower Tertiary Pamunkey Group, (4) upper Tertiary Chesapeake Group, and (5) Quaternary sediments, undifferentiated.

Throughout the Early Cretaceous, the land area now comprising the study area was elevated in relation to sea level, and thick sequences of fluvial-deltaic continental and marginal marine sediments were deposited on a broad rock surface. These sediments, at first, were deposited by high-gradient streams, which formed large subaerial deltas that prograded into the Cretaceous seas. As the deltas developed, the depositional pattern gradually changed to a lower-gradient, subaqueous environment throughout the latter half of the Early Cretaceous. Early in the Late Cretaceous, the first major marine transgression occurred, which inundated the eastern half of the study area with shallow seas and broad estuaries. A marine regression soon followed that resulted in a long period of nondeposition which lasted throughout most of the remaining Late Cretaceous. Toward the end of the Late Cretaceous, marine seas once again transgressed into the study area, but only marginally along the northeastern and southeastern sections, where a very thin veneer of clays, sandy clays, and marls was deposited. Throughout the following Tertiary period, interbasinal marine seas covered the study area to varying degrees and deposited relatively thin, but areally extensive, sediments that consisted primarily of glauconite, diatoms, sands, silts, clays, and shells. These Tertiary marine deposits represent two major lithologically distinct groups: the glauconitic sands, silts, and clays of the Pamunkey Group; and the shelly clays, silts, and sandy clays of the Chesapeake Group. Sediments of Quaternary age overlie much of the Tertiary deposits. These sediments include fluvial and marine deposits that reflect Pleistocene sea-level fluctuations.

STRUCTURAL SETTING

Crustal deformation along the Atlantic continental margin has produced the regionally downwarped Atlantic Coastal Plain province and the adjoining regionally uplifted Piedmont province. Weathered rock debris eroded from the uplifted areas was transported and deposited into the downwarped areas as Coastal Plain sediments. The Coastal Plain's thin western edge, defined by the Fall Line, marks the limit of the unconsolidated sediments overlapping onto the crystalline rocks of the Piedmont highlands. The Coastal Plain sediments thicken and extend eastward to the submerged margin of the Continental Shelf approximately 65 mi offshore of Virginia. Within the regionally downwarped area, local differential subsidence produced a series of structural highs and lows, commonly referred to as arches and embayments (basins). Thick accumulations of sediments were deposited within the embayments, with thinner accumulations over the arches. The arches, in effect, separated each of the basins, and together with other environmental factors, produced basins with characteristic depositional sequences. Deposition in the Virginia Coastal Plain was affected by three major structural deformation features. These structural features are, from north to south, the Salisbury embayment, the Norfolk arch, and the Albemarle embayment (fig. 6).

The Coastal Plain of northern and central Virginia forms the southern flank of the Salisbury embayment (Richards, 1948)—an eastward-plunging, open-ended sedimentary basin with an axis that trends across southern Maryland. Structure contours of the top of the basement rocks (fig. 6) bend noticeably toward the northwest as they approach the axis of the Salisbury embayment.

This structural low has had a pronounced influence on the deposition of sediments throughout the northern and central sections of the study area. Lower Cretaceous fluvial-deltaic deposits thicken considerably toward the axis of the embayment; Glaser (1968) reports that more than 70 percent of the sedimentary section in southern Maryland and northern Virginia is composed of Lower Cretaceous sediments. Lower to middle Tertiary marine deposits also thicken toward the axis of the embayment in this area, but the uppermost Tertiary marine and overlying Quaternary fluvial and marine deposits seem not to be affected by the embayment structure.

In contrast to the structural low that flanks the northern and central sections, a structural high is located midway in the southern section of the study area. This structural high was originally termed the "Fort Monroe High," by Richards and Straley (1953), and now is more commonly referred to as the "Norfolk arch" (Gibson, 1967). The axis of this structural high dips gently eastward beneath the Coastal Plain sediments (fig. 6). This arch has had a strong control on the deposition of some sediments in the southern part of the study area. Stratigraphic evidence indicates that the Norfolk arch was most active throughout Late Cretaceous and Paleogene time (J.P. Owens, U.S. Geological Survey, oral commun., 1983). Generally, the sediments thin drastically as they approach the arch from both the north and south, and some sediments are missing from the area because of nondeposition or erosion. Like the Salisbury embayment, this arch has not noticeably affected the deposition of upper Tertiary marine and Quaternary fluvial and marine deposits.

The Norfolk arch separates two distinct sedimentary basins that are characterized by their Paleogene deposits—the glauconite-rich Salisbury embayment to the north from the limestone-rich Albemarle embayment to the south. The arch is probably the controlling structural feature responsible for the general lack of limestone-type deposits in the Coastal Plain areas to the north. Being relatively higher than the surrounding basinal areas, this arch modified the depositional environment to the south and restricted the northward migration of southern limestone-depositing seas across the arch. Generally, the sediments north of the arch dip to the northeast and sediments south of the arch dip to the southeast into basinal lows.

South of the Norfolk arch, deposition in the Virginia Coastal Plain was influenced by yet another basement low in central North Carolina, named the "Albemarle Embayment" by Straley and Richards (1950). This embayment, also referred to as the "Hatteras Low" by Johnson and Straley (1953), is a broad, open-ended sedimentary basin that dips gently eastward. The south flank of the Norfolk arch is the northern limit of the limestone-rich Albemarle embayment. Sediments in the

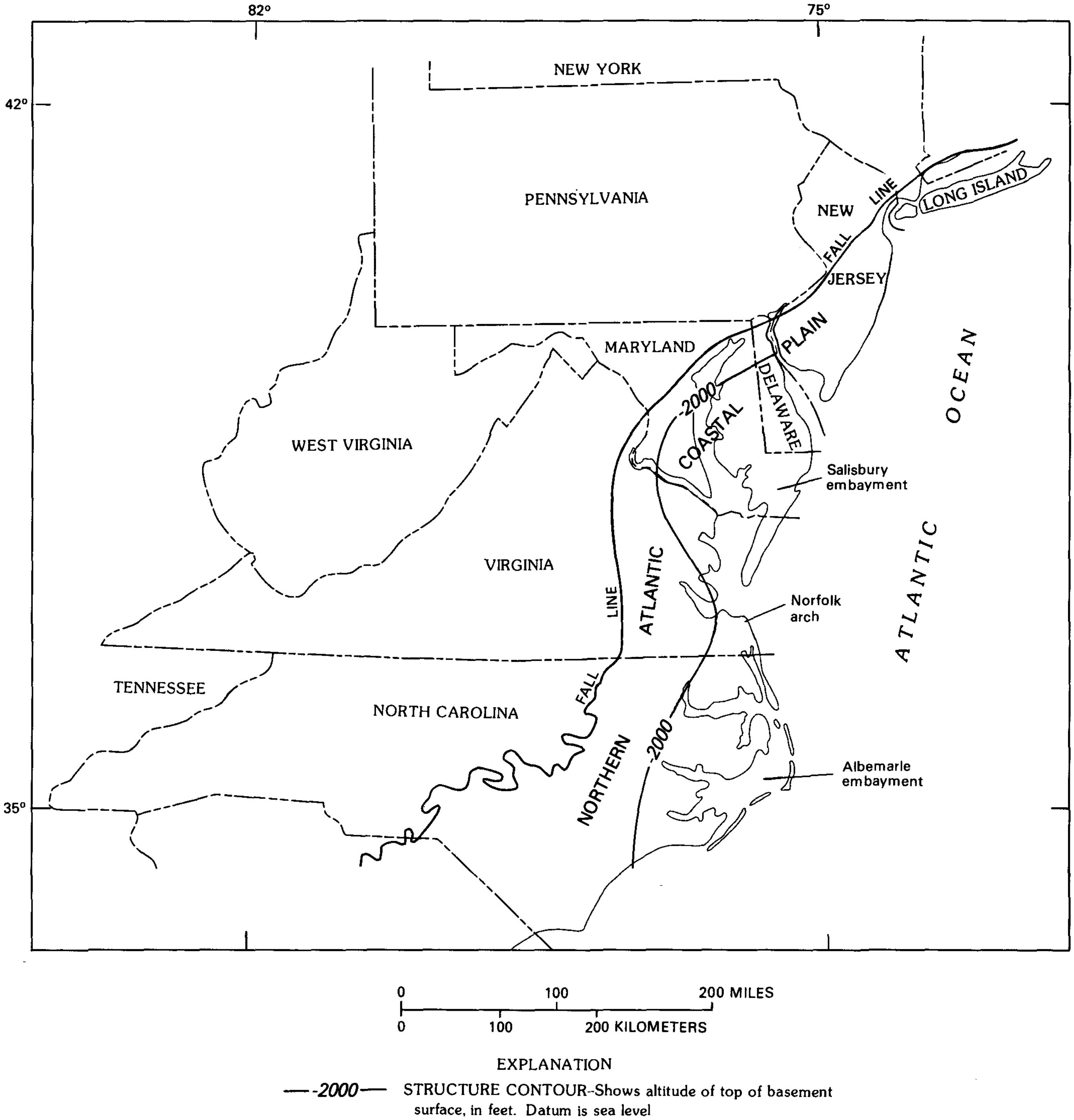

FIGURE 6.—Major structural basement-deformation features of the Virginia Coastal Plain and adjoining areas.

lowermost part of the study area (south of the structural basement high) are generally much finer grained than sediments to the north. In this area, limestone stringers and limy-matrix deposits of Paleogene age are common. These limy deposits become more numerous and thicker in the northern North Carolina Coastal Plain (M.D. Winner, Jr., U.S. Geological Survey, oral commun., 1982), and eventually thicken into the extensive limestone beds of Eocene, Oligocene, and Miocene age in the central North Carolina Coastal Plain.

HYDROGEOLOGIC FRAMEWORK

The regional hydrogeologic framework described in this report identifies and delineates eight major confined aquifers, eight major confining units, and an uppermost water-table aquifer. Recognition of the nine aquifers and eight confining units is based on lithologic and hydrologic characteristics of geologic formations, and is supported by analysis of water-level data. Hydrogeologic units are defined on the basis of their water-bearing properties and not necessarily on stratigraphic boundaries. A formation may contain more than one hydrogeologic unit, or may be an aquifer in one area and a confining unit in another. Therefore, the hydrogeologic units commonly consist of combinations or divisions of geologic formations.

The hydrogeologic names of aquifers and confining units used in this report are based on the name of the predominant geologic formation, or formations, that comprise each unit. Geologic names are used so that a clear and concise relationship is developed between stratigraphic formations and their hydrologic properties. With this geologically orientated nomenclature, the hydrogeologic unit name will immediately indicate a qualitative description and relative position to those familiar with Virginia Coastal Plain stratigraphy. For those not familiar with the Virginia Coastal Plain, each hydrogeologic unit is described in the following sections of this report and delineated on maps and hydrogeologic sections following the text of this report. Regional correlations of hydrogeologic units in the Virginia Coastal Plain with those in adjoining States are included in the description of each aquifer and confining unit based on written and oral communications with D.A. Vroblesky (U.S. Geological Survey, 1984) in Maryland and M.E. Winner (U.S. Geological Survey, 1984) in North Carolina. The correlative aquifer- and confining-unit names in adjoining States are terms applied by the RASA studies in the respective States and usually reflect the name of the predominant geologic formation, or formations, that compose each aquifer unit. However, the correlative confining-unit names in North Carolina were not given hydrogeologic names, as was done for the Virginia Coastal Plain. Rather, these correlative confining units in North Carolina are simply denoted as "the confining unit overlying . . ." a particular aquifer.

For the purposes of continuity and clarity, only one set of geologic names is used throughout the study area, even though the study area includes parts of two distinct sedimentary-basin systems—the Salisbury and Albemarle embayments. The geologic formations that developed within the Salisbury basin are the predominant depositional units throughout most of the study area; therefore, these formation names are used. The much smaller, lowermost part of the study area, in which sediment depositional history was controlled primarily by the Albemarle basin system, is similar in deposition and stratigraphy to the study area to the north, and, therefore, these units are denoted accordingly.

The regional hydrogeologic units identified in this study and the corresponding hydrogeologic units of adjoining RASA studies are illustrated on plate 1. Also illustrated are diagnostic and correlative ages, stages, pollen zones, corresponding group names and formation names, lithologies, origins, and areal distribution of each framework unit, together with a combined, idealized, single-point electric-resistivity and lithologic log representative of the total hydrogeologic section. This plate provides a quick reference for the characteristics and correlations associated with the regional hydrogeologic units identified throughout the Virginia Coastal Plain. Table 1 provides an overview of significant Virginia Coastal Plain stratigraphic nomenclature, from a review of present and past literature, relative to the hydrogeologic units identified in this study and the corresponding modeling units used in the ground-water flow model developed under the Virginia RASA study (Harsh and Laczniak, 1983, p. 592).

Stratigraphic test-well and water-well data from more than 600 sites throughout the study area were compiled, analyzed, and interpreted. Of these, 185 control wells were selected as being representative of the hydrogeologic framework of the Virginia Coastal Plain. Control-well identifiers and their locations are shown in figure 7 together with the lines of hydrogeologic sections (pls. 2–4) that were developed to illustrate the stratigraphic relationships of the hydrogeologic units. These control wells were selected on the basis of location and quality of the geophysical, hydrologic, and stratigraphic data.

Stratigraphic- and geophysical-log data necessary for the identification and correlation of each hydrogeologic unit are not available for some parts of the study area. Generally, the areas from the western shore of the Chesapeake Bay to the Fall Line, and south of the James River, contain the most complete data required for hydrogeologic correlations. In areas where data are not available, or where borehole information does not extend deeply enough, hydrogeologic units are correlated by projecting dips of the units from known data points, commonly from the updip sections, into those areas that lack sufficient data (Hansen, 1969b). Two major areas that commonly lack data are the Chesapeake Bay and the Eastern Shore Peninsula.

Hydrogeologic correlations of the lower hydrogeologic units beneath the Chesapeake Bay are, for the most part, approximate due to the general lack of borehole

TABLE 1.—*Significant stratigraphic nomenclature in relation to hydrogeologic framework*

PERIOD	EPOCH	AGE	GROUP	STRATIGRAPHIC FORMATION	VIRGINIA RASA HYDROGEOLOGIC UNIT
QUATERNARY	HOLOCENE	POST-GLACIAL		Holocene deposits	Columbia aquifer
	PLEISTOCENE	WISCONSIN TO NEBRASKAN		Pleistocene undifferentiated deposits	
TERTIARY	PLIOCENE	PIACENZIAN		Bacons Castle Formation (Oaks and Coch, 1973)	Yorktown confining unit
		ZANCLEAN	Chesapeake Group	Yorktown Formation	Yorktown-Eastover aquifer
	MIOCENE	MESSINIAN / TORTONIAN		Eastover Formation	
					St. Marys confining unit
		SERRAVALLIAN		St. Marys Formation	
				Choptank Formation	St. Marys-Choptank aquifer
		LANGHIAN / BURDIGALIAN		Calvert Formation	Calvert confining unit
		AQUITANIAN		Old Church Formation	Chickahominy-Piney Point aquifer
	OLIGOCENE	CHICKASAWHAYAN[1]		Not present in study area	
		VICKSBURGIAN[1]			
	EOCENE	JACKSONIAN[1]	Pamunkey Group	Chickahominy Formation	Chickahominy-Piney Point aquifer
		CLAIBORNIAN[1]		Piney Point Formation	
		SABINIAN[1]		Nanjemoy Formation	Nanjemoy-Marlboro clay confining unit
	PALEOCENE			Marlboro clay	
		MIDWAYAN[1]		Aquia Formation	Aquia aquifer
				Brightseat Formation	Brightseat confining unit
					Brightseat aquifer
CRETACEOUS	LATE CRETACEOUS	MAASTRICHTIAN		Undifferentiated sediments	Upper Potomac confining unit
		CAMPANIAN			
		SANTONIAN			
		CONIACIAN			
		TURONIAN			
		CENOMANIAN		Potomac Formation	Upper Potomac aquifer
	EARLY CRETACEOUS	ALBIAN			Middle Potomac confining unit
					Middle Potomac aquifer
		APTIAN			Lower Potomac confining unit
		BARREMIAN			
		HAUTERIVIAN			Lower Potomac aquifer
		VALANGINIAN			
		BERRIASIAN			

[1]Commonly used ages in Atlantic Coastal Plain province

units and modeling units of the Virginia Coastal Plain RASA study

VIRGINIA RASA MODEL UNIT	RADER 1983	TEIFKE 1973	CEDERSTROM 1957	CLARK AND MILLER 1912	BROWN, MILLER, AND SWAIN 1972
AQ10	Alluvial deposits Tabb Formation Norfolk Formation Windsor Formation	Columbia Group	Columbia Group	Columbia Group: Talbot Formation ?——? Wicomico Formation ?——? Sunderland Formation	Rocks of post Miocene age
CU9	Chesapeake Group: Bacons Castle Formation			Lafayette Formation	
AQ9	Yorktown Formation and Eastover Formation (undifferentiated)				
CU8		Yorktown Formation	Chesapeake Group: Yorktown Formation ?——?	Chesapeake Group: Yorktown Formation ?——?	Rocks of late Miocene age
AQ8	St. Marys Formation, Choptank Formation, and Calvert Formation (undifferentiated)		St. Marys Formation ?——?	St. Marys Formation ?——?	Rocks of middle Miocene age
CU7		Calvert Formation	Calvert Formation	Calvert Formation	
AQ7					
AQ7	Pamunkey Group: Nanjemoy Formation	Calvert Formation (continued)	Chickahominy Formation Nanjemoy Formation	Pamunkey Group: Nanjemoy Formation	Rocks of Jackson age Rocks of Claiborne age
CU6	Marlboro clay	Nanjemoy Formation	?——? Aquia Formation	?——? Aquia aquifer	Rocks of Sabine age
AQ6	Aquia Formation				
CU3	Brightseat Formation				Rocks of Midway age
AQ3					
CU3	Unit A Unit B Unit C Unit D	Mattaponi Formation	Mattaponi Formation		Rocks of unit A Rocks of unit B Rocks of unit C Rocks of unit D
AQ3	Unit E	"Transitional beds"	?——?		Rocks of unit E
CU2	Unit F			Potomac Group: Patapsco Formation	Rocks of unit F
AQ2	Unit G	Patuxent Formation	Potomac Group	?——?	Rocks of unit G
CU1	Unit H			Patuxent Formation	Rocks of unit H
AQ1					

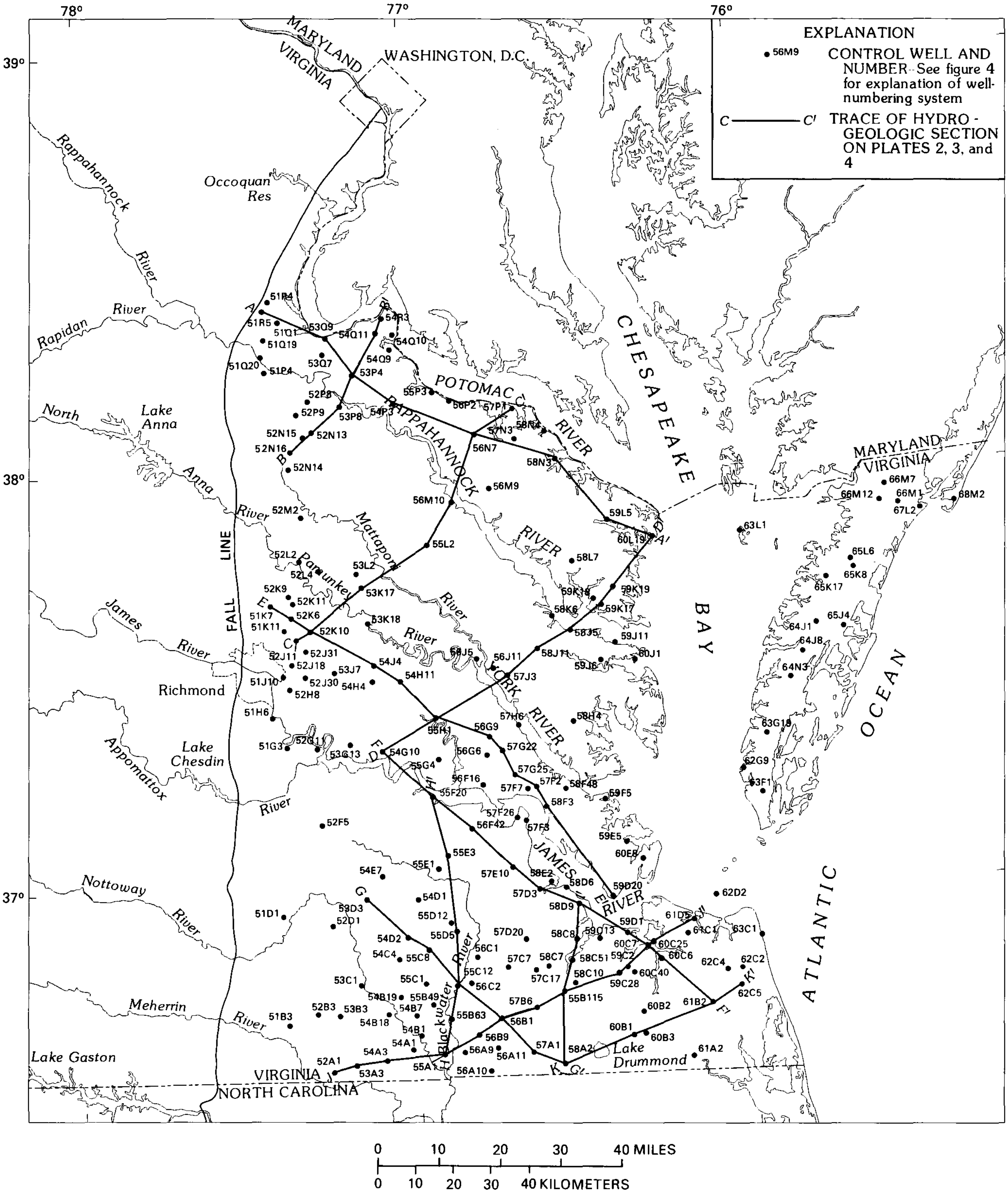

FIGURE 7.—Location of control wells, well numbers, and lines of hydrogeologic sections.

information. There are no wells that extend to the basement in this area. Water wells located on Tangier Island (63L1, fig. 7) and the water-test well (62D2, fig. 7) located at milemarker 3.7 on the Chesapeake Bay Bridge-Tunnel provide only partial borehole information to depths of 1,000 ft and 1,500 ft, respectively. The uppermost hydrogeologic units beneath the Chesapeake Bay and its tributaries were studied in detail because of interest in the erosional effects induced by sea-level lowering during Pleistocene glaciations. This erosion created deeply incised stream channels in the Coastal Plain sediments (Hack, 1957; Harrison and others, 1965), which caused a disruption in aquifer and confining-unit continuity and a change in the distribution of hydraulic heads within the affected aquifers.

The hydrogeology of the sediments beneath the Eastern Shore Peninsula has been previously investigated to a depth of approximately 450 ft (Sinnott and Tibbitts, 1954, 1957, 1968; Fennema and Newton, 1982). This area has only three wells—the J&J Taylor oil-test well, the Coast Guard Cobb Island well, and the New York, Philadelphia, and Norfolk Railroad Co. well—which were drilled to 1,000 ft or greater. Only the J&J Taylor well (66M1, fig. 7) has either geophysical and geologic information available for analysis. The general lack of deeper hydrogeologic data throughout the Eastern Shore Peninsula area makes correlations of most hydrogeologic units only tentative south of well 66M1.

The information obtained from the interpretation and correlation of geophysical logs, as illustrated in the hydrogeologic sections, was then used to construct sets of hydrogeologic unit maps (figs. 8–24) delineating thicknesses of confining units and altitudes of aquifer tops. For the most part, the hydrogeologic sections and maps can be used to determine the relative positions of, and depths to, the major aquifers and confining units. However, these hydrogeologic sections and maps are to be used only as a guide, and, because of the variable nature of subsurface sediments, should not be a substitute for test-hole drilling, especially in areas where data are sparse. Outcrop areas of the geologic formation, or formations, that form hydrogeologic units are illustrated on the Geologic Map of Virginia (Milici and others, 1963). It is important to note that, in many cases, the hydrogeologic units constitute only the sandy or clayey facies of specific geologic formations and, therefore, represent an undefined part of the geologic outcrop areas.

Identification of each hydrogeologic unit is based on biostratigraphic and lithostratigraphic analysis obtained from literature describing outcrops, core samples, and (or) cuttings. A test hole (well 58H4, fig. 7) was drilled, in cooperation with the Virginia State Water Control Board's Bureau of Surveillance and Field Studies, to obtain stratigraphic and hydrologic data by analyses of core samples, cuttings, water-level measurements, water samples, and geophysical logs. Correlation and delineation of the identified hydrogeologic units are based on compiled data in combination with the interpretation of geophysical logs, drillers' logs, and water-level data.

BASEMENT COMPLEX

The basement, which is overlain unconformably by the unconsolidated deposits of the Virginia Coastal Plain, generally consists of a gently eastward-dipping erosional surface of warped, crystalline rocks (fig. 8). This basement rock emerges along the Fall Line and extends westward forming the Piedmont province. The exposed Piedmont complex consists mainly of massive igneous and highly deformed metamorphic rocks that range in age from Precambrian to Lower Paleozoic (Milici and others, 1963), but also includes unmetamorphosed, consolidated sediments and igneous intrusives of probable Triassic age within isolated grabens and half grabens (fig. 8). It seems reasonable to assume that basement rocks underlying the Coastal Plain in Virginia are similar to the adjacent exposed rocks of the Piedmont terrain. It should be noted that evidence is conflicting (Brown and others, 1972; Doyle and Robbins, 1977) concerning the presence of consolidated Jurassic sediments within the study area. If, in fact, these consolidated sediments are present, they would be considered as part of the basement complex.

The slope of the basement-rock surface ranges from 50 to 100 ft/mi near the Fall Line; the slope then decreases to about 40 ft/mi to the Atlantic Coast (fig. 8). Data from wells that penetrate basement rock in the Coastal Plain (fig. 8) indicate an irregular, undulating surface composed of the aforementioned variable lithologies. Many authors document these irregularities in the basement surface beneath the Coastal Plain and suggest various origins. Cederstrom (1945b) interprets many of the local steep-sided basement features common throughout the Coastal Plain to be stream-cut channels and erosional scarps. Other studies, however, (Minard and others, 1974; Mixon and Newell, 1977) suggest that major breaks in slope of the basement surface can be attributed more to faulting and warping than to erosion. In wells that penetrate the basement, drillers' logs indicate that a saprolitic mantle overlies the basement surface in many places, which suggests that not all of the underlying basement surface was eroded. The basement surface forms the basal limit of the study area and is overlain principally by sediments of the lower Potomac aquifer. The basement surface is overlain by younger-age deposits only near the Fall Line.

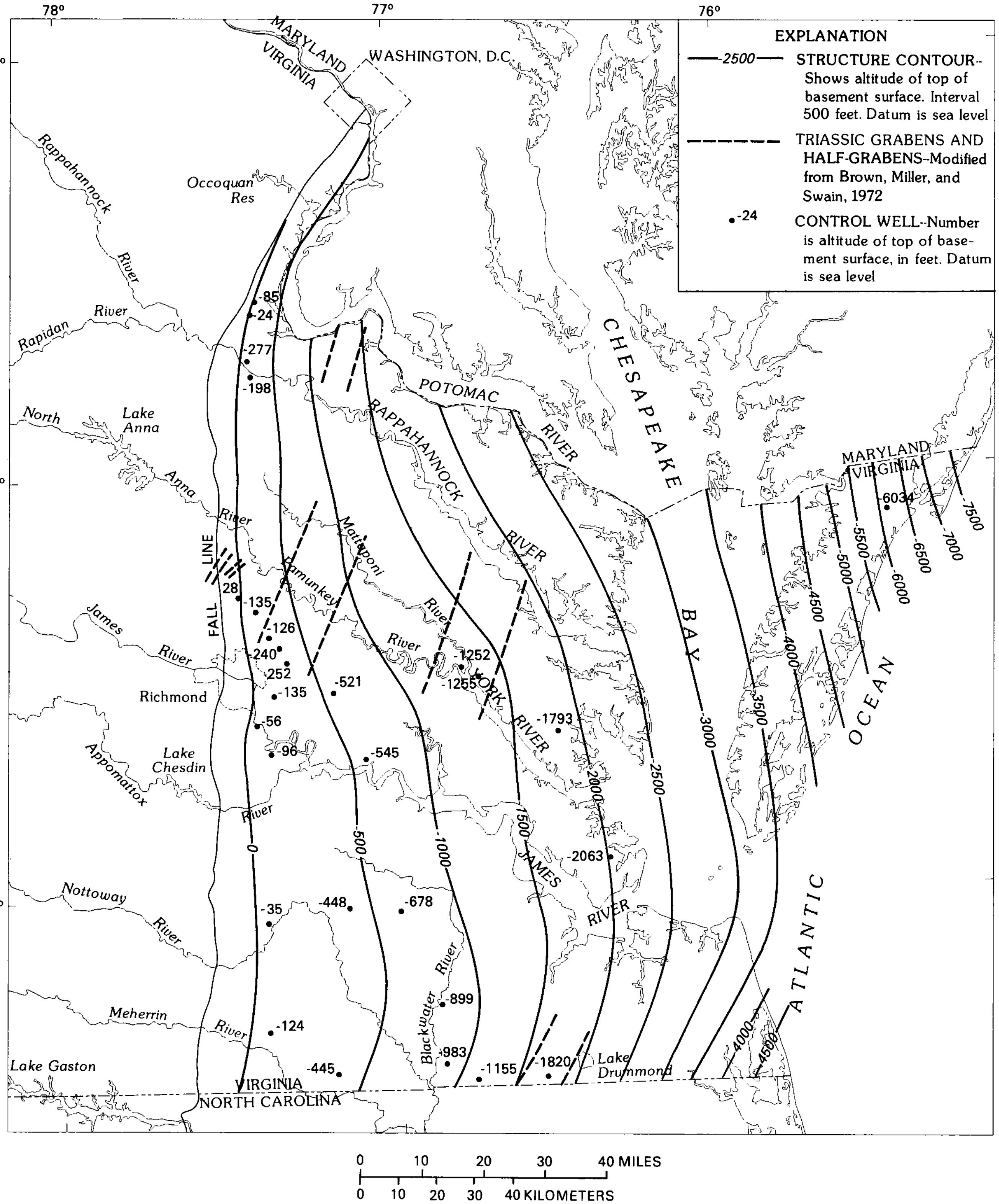

FIGURE 8.—Altitude of top of basement surface.

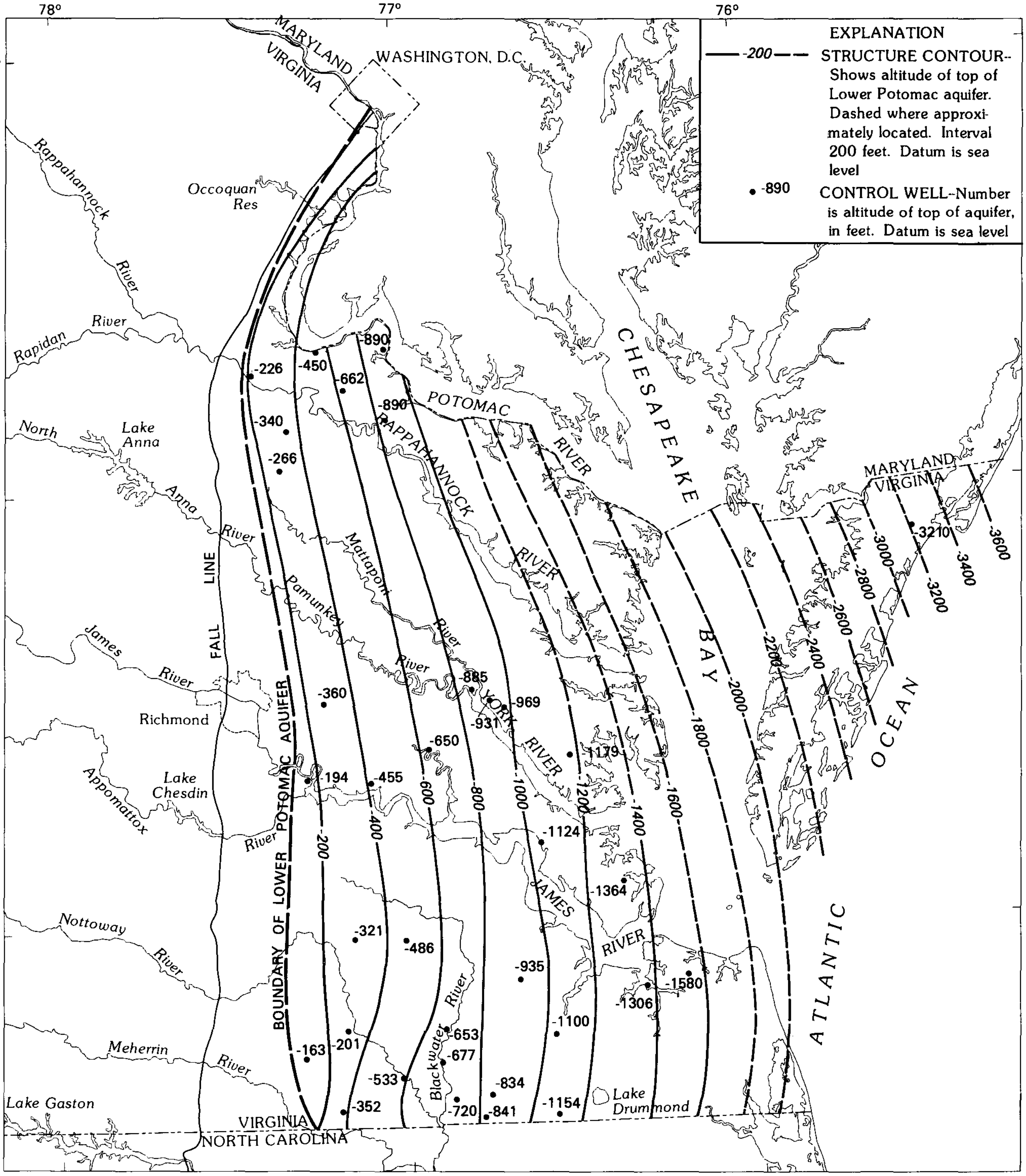

Figure 9.—Altitude of top of lower Potomac aquifer.

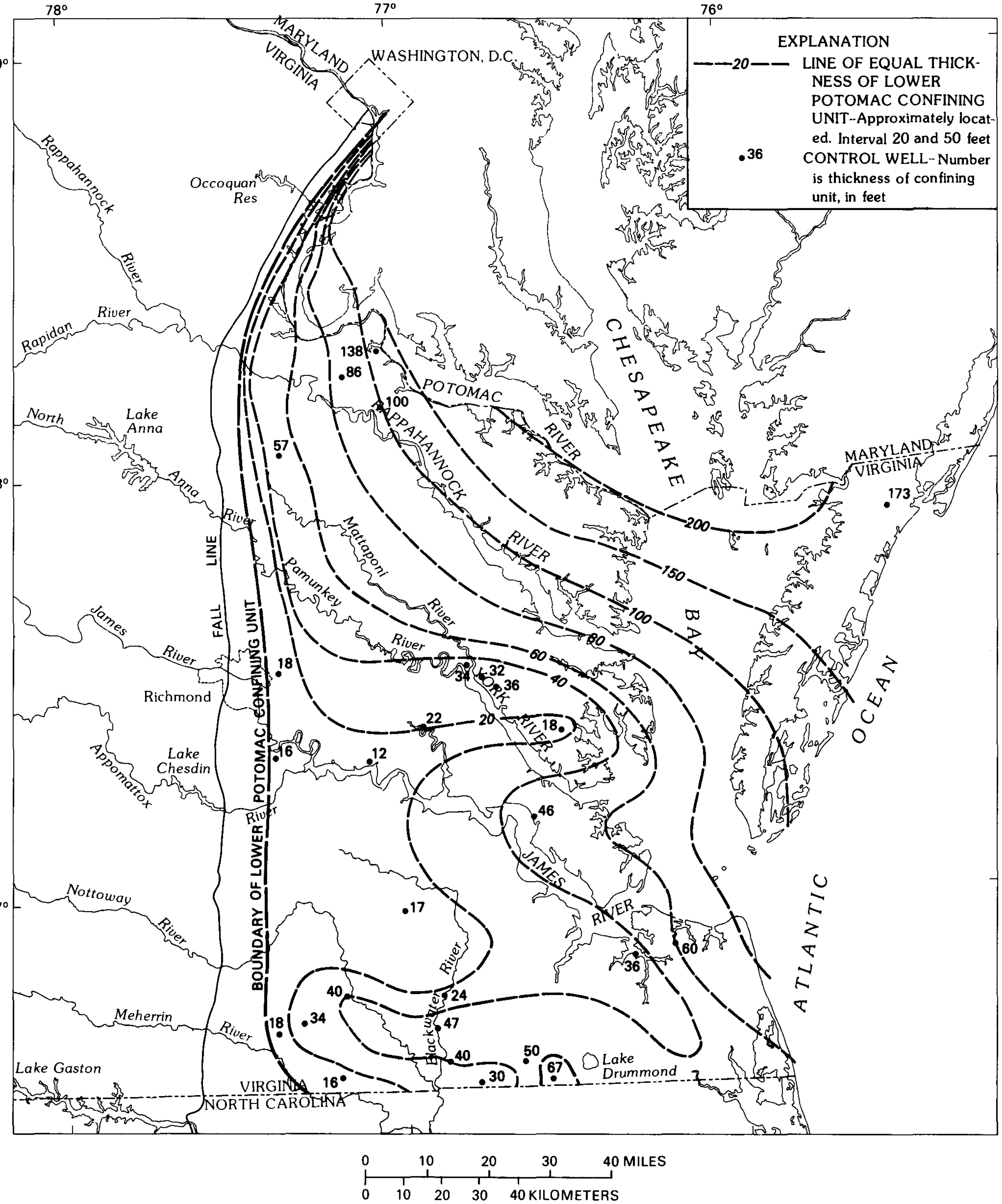

FIGURE 10.—Thickness of lower Potomac confining unit.

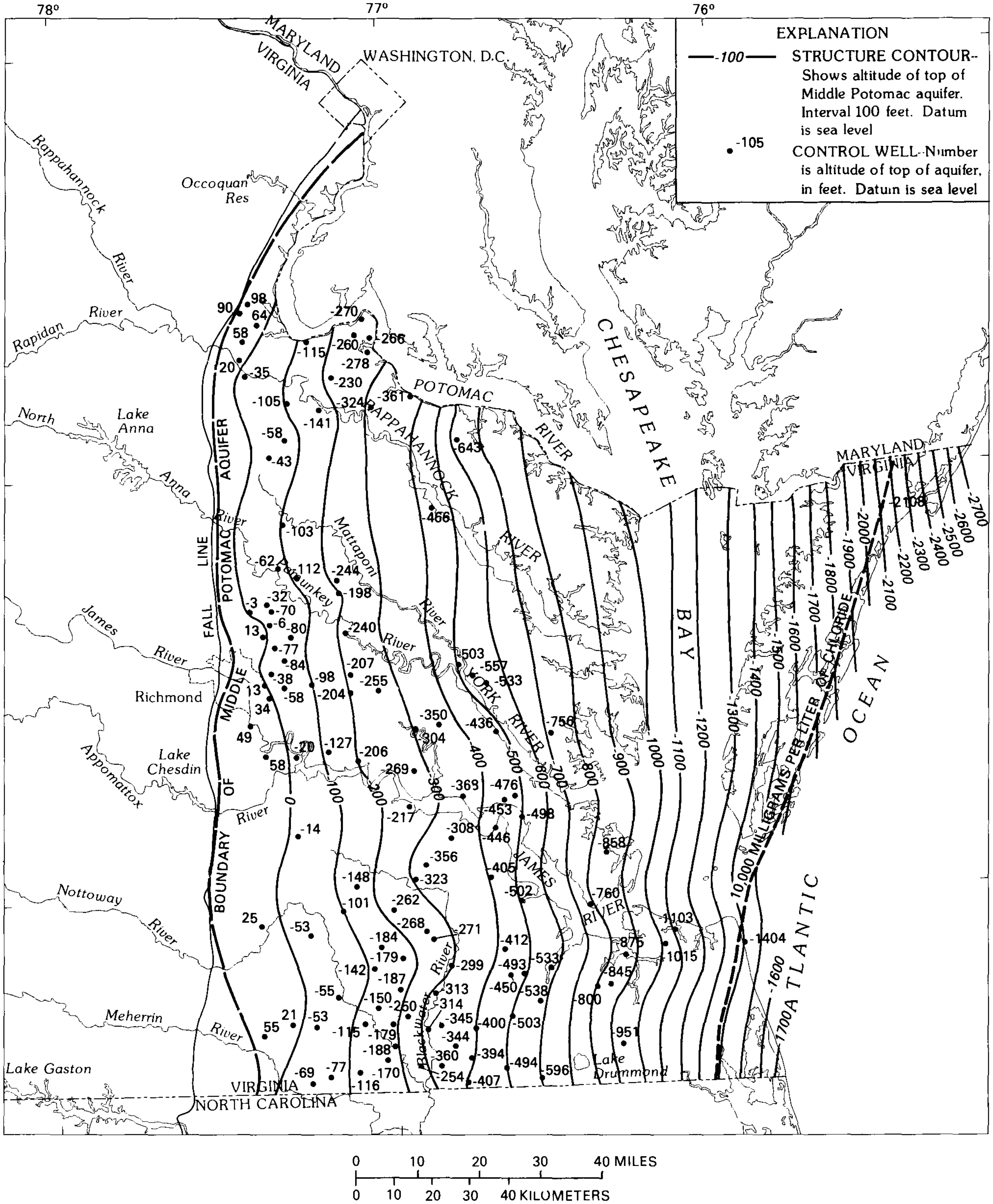

FIGURE 11.—Altitude of top of middle Potomac aquifer.

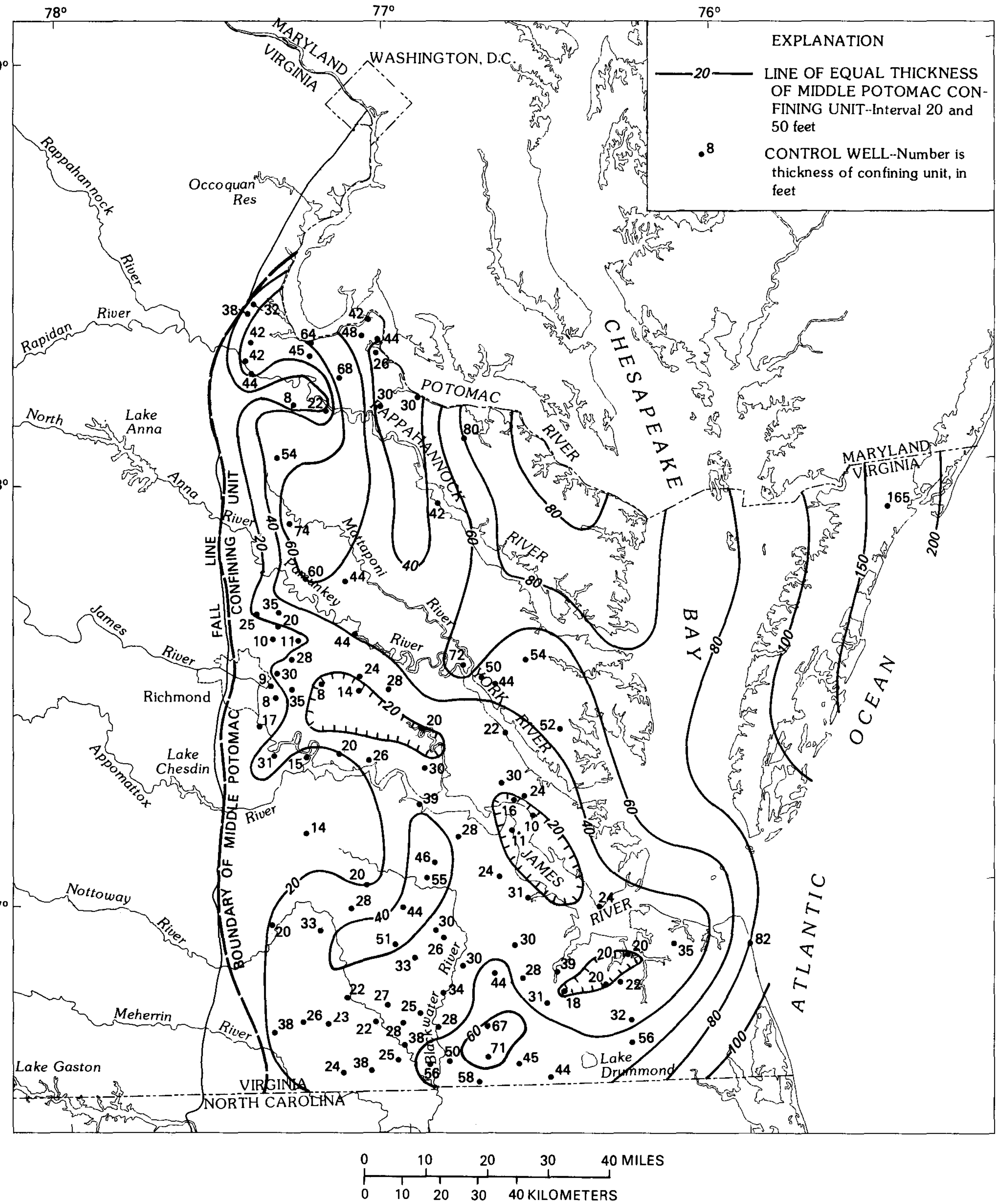

FIGURE 12.—Thickness of middle Potomac confining unit.

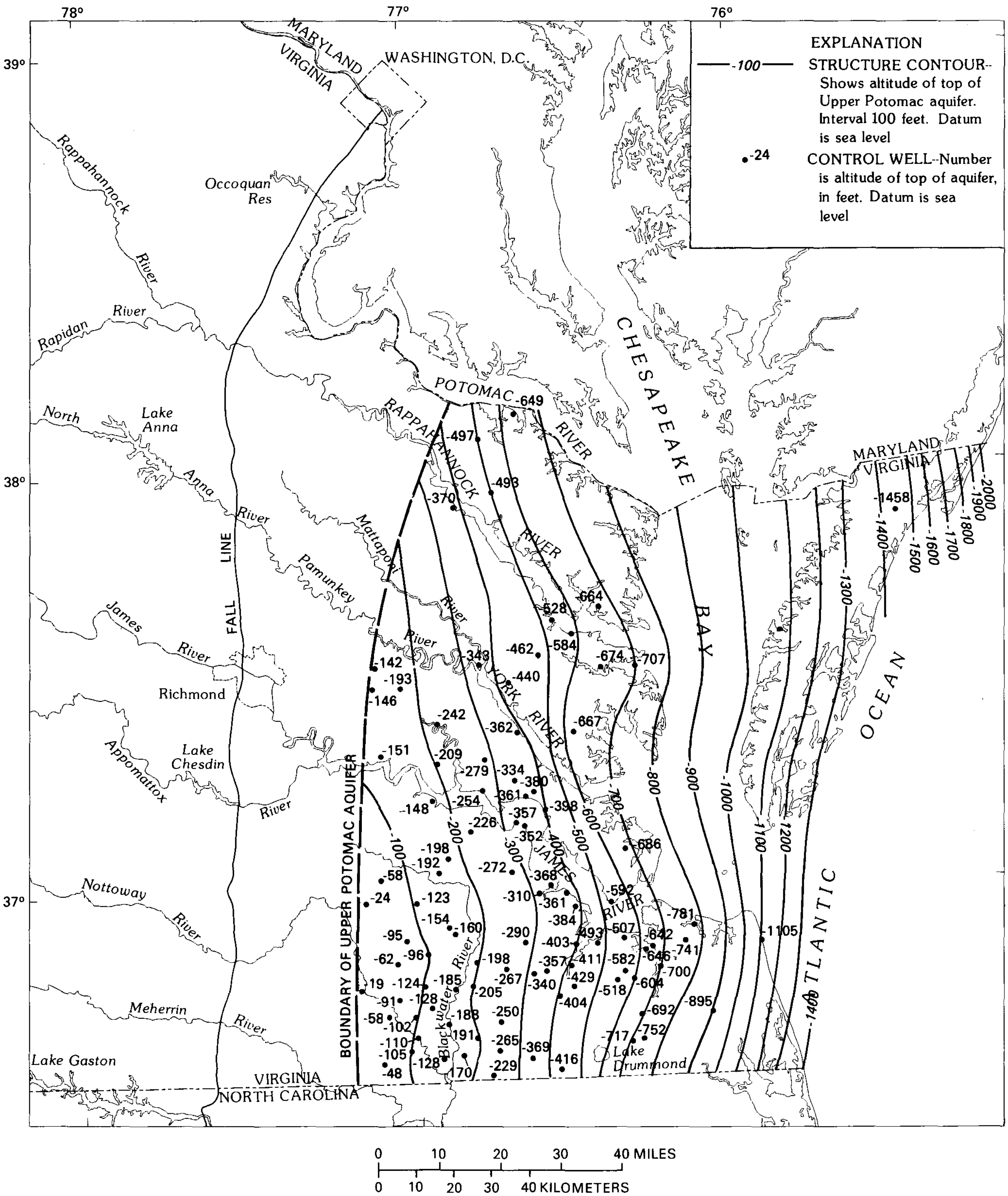

FIGURE 13.—Altitude of top of upper Potomac aquifer.

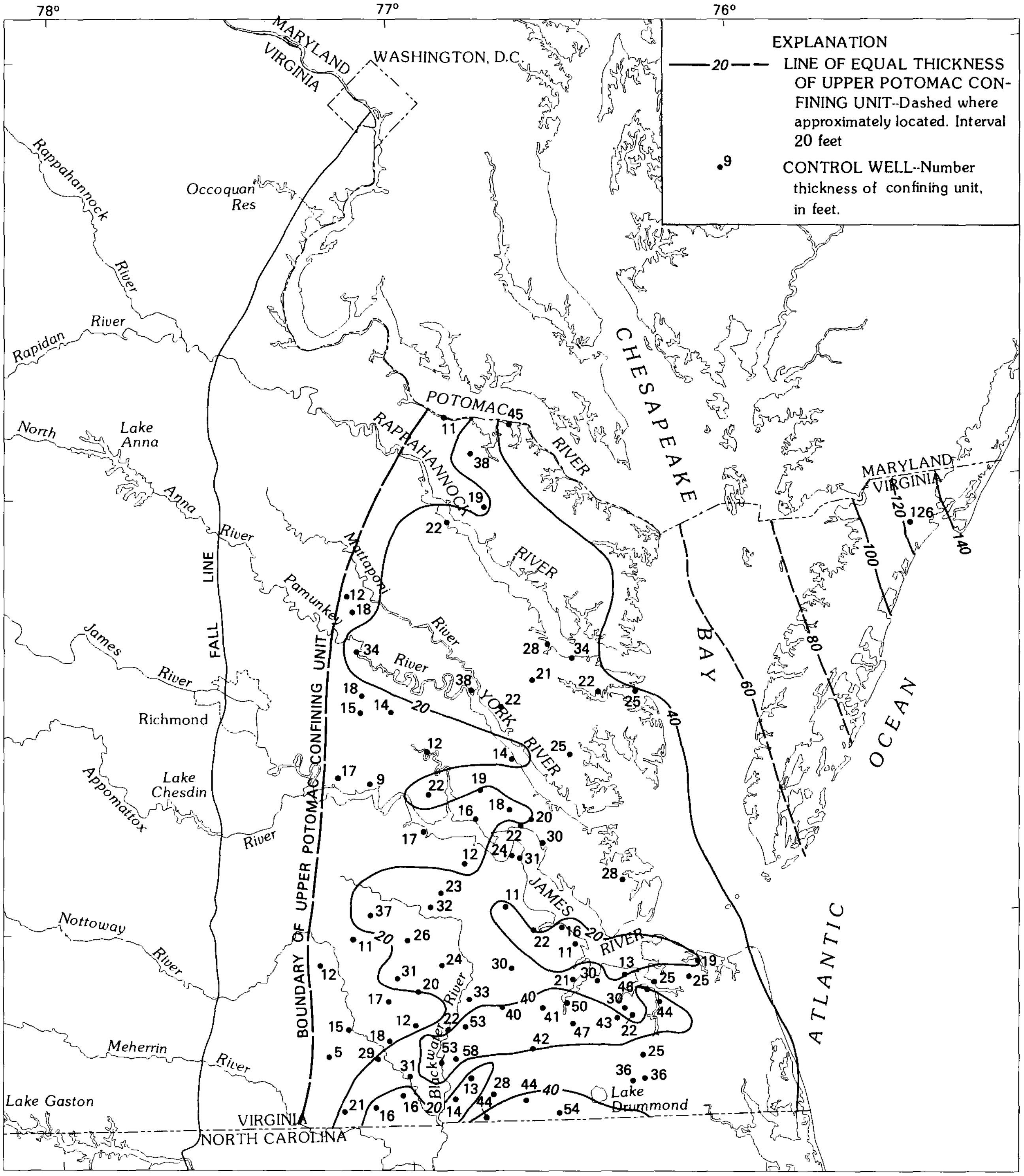

FIGURE 14.—Thickness of upper Potomac confining unit.

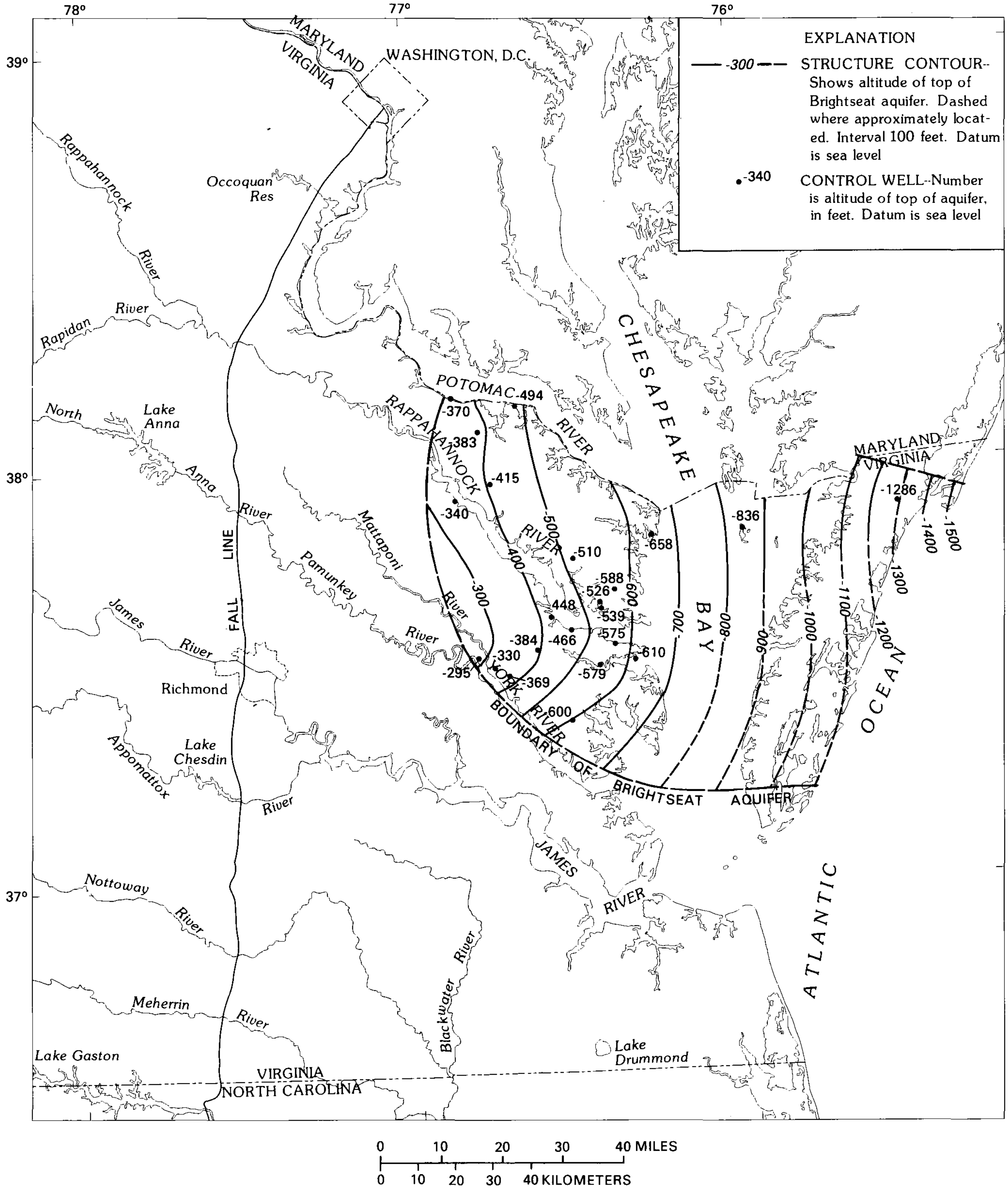

FIGURE 15.—Altitude of top of Brightseat aquifer.

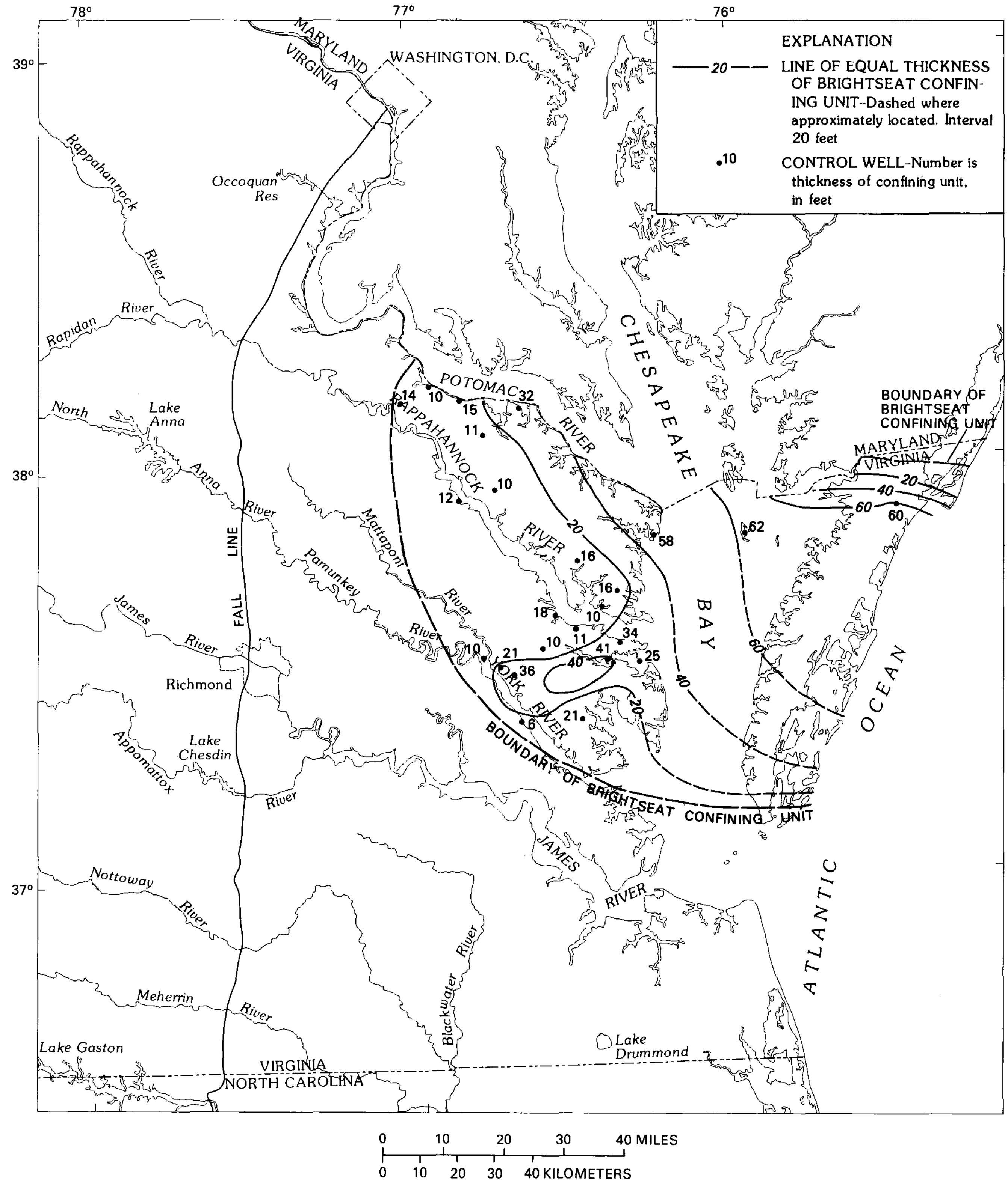

FIGURE 16.—Thickness of Brightseat confining unit.

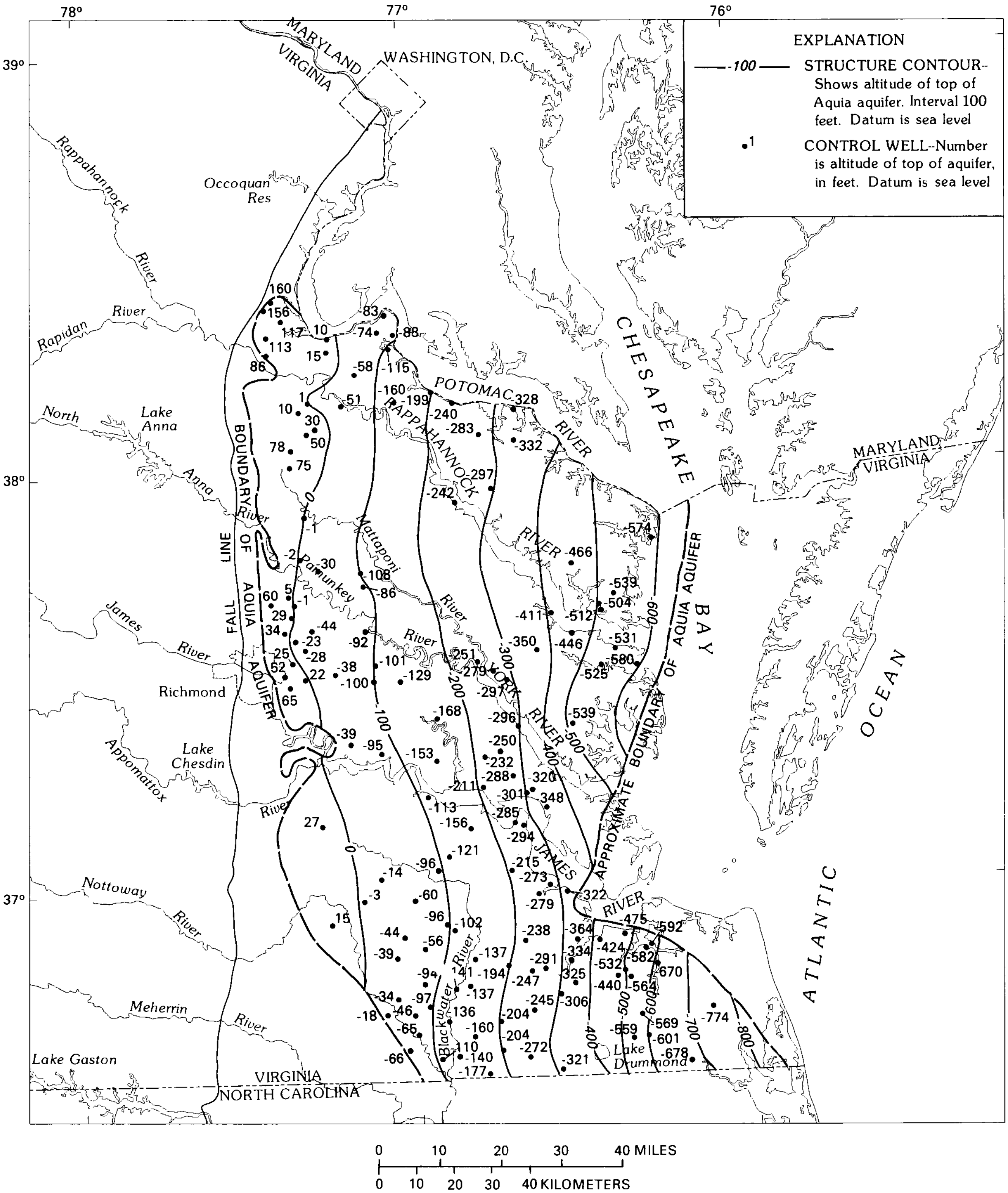

Figure 17.—Altitude of top of Aquia aquifer.

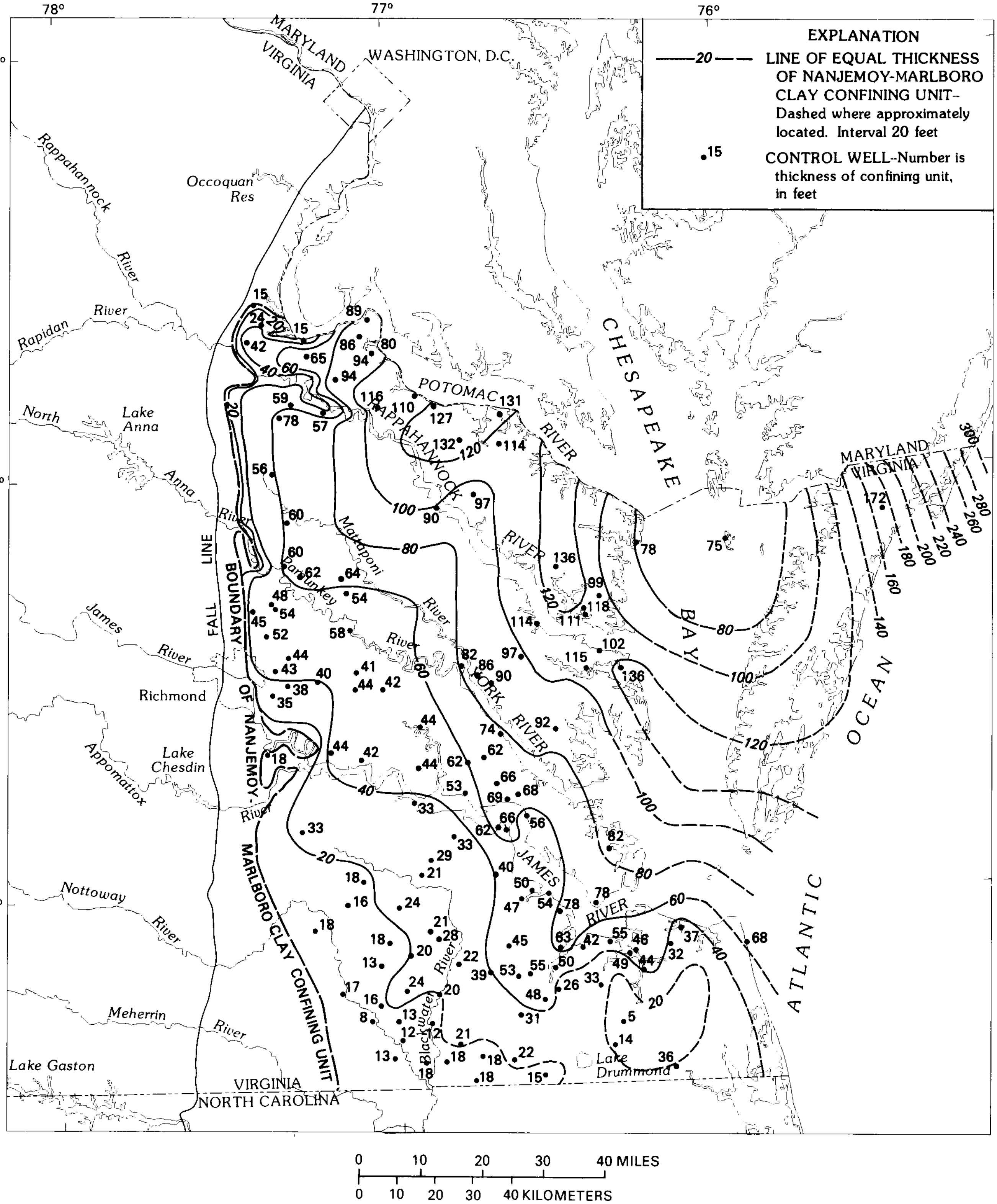

FIGURE 18.—Thickness of Nanjemoy-Marlboro Clay confining unit.

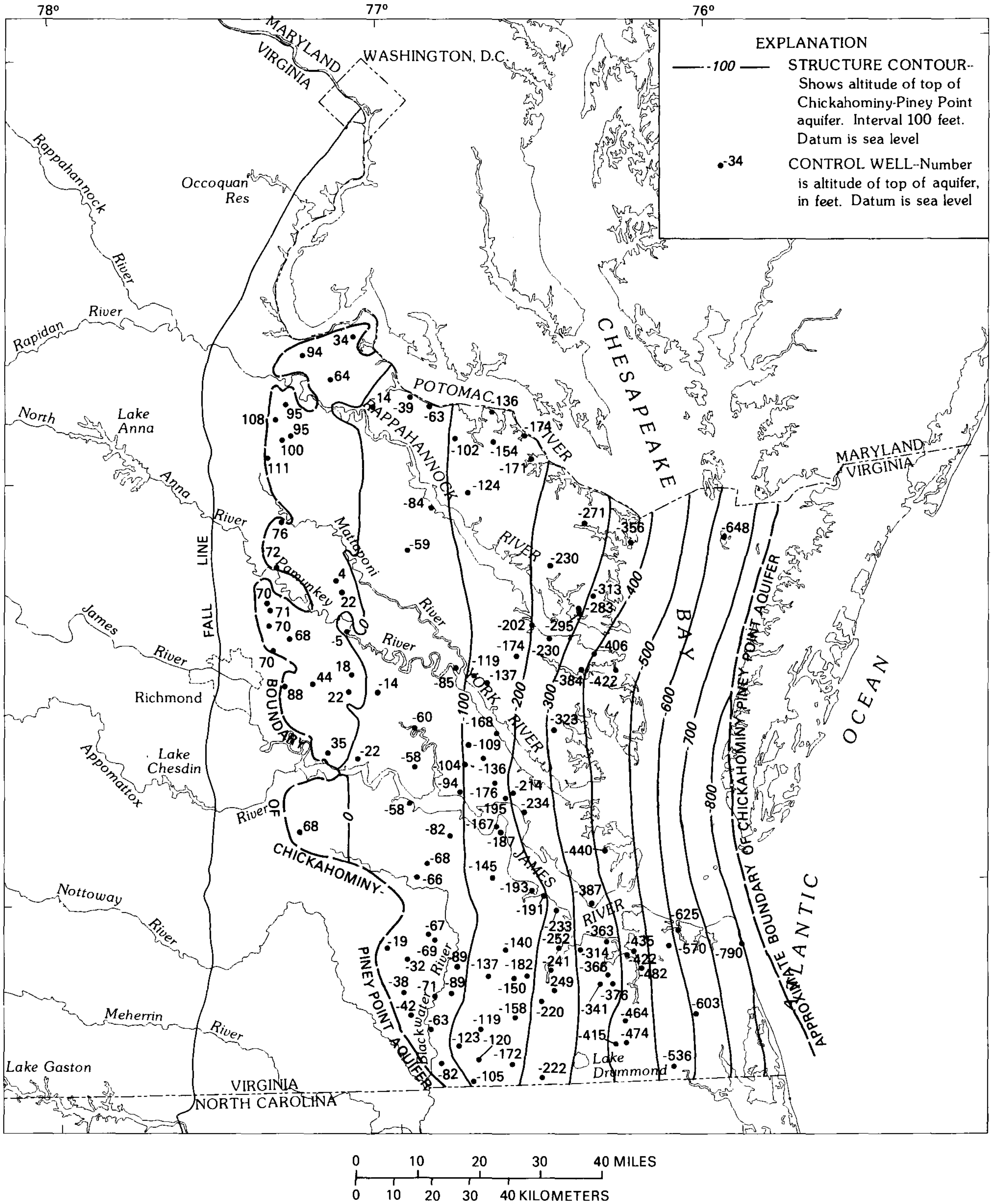

FIGURE 19.—Altitude of top of Chickahominy-Piney Point aquifer.

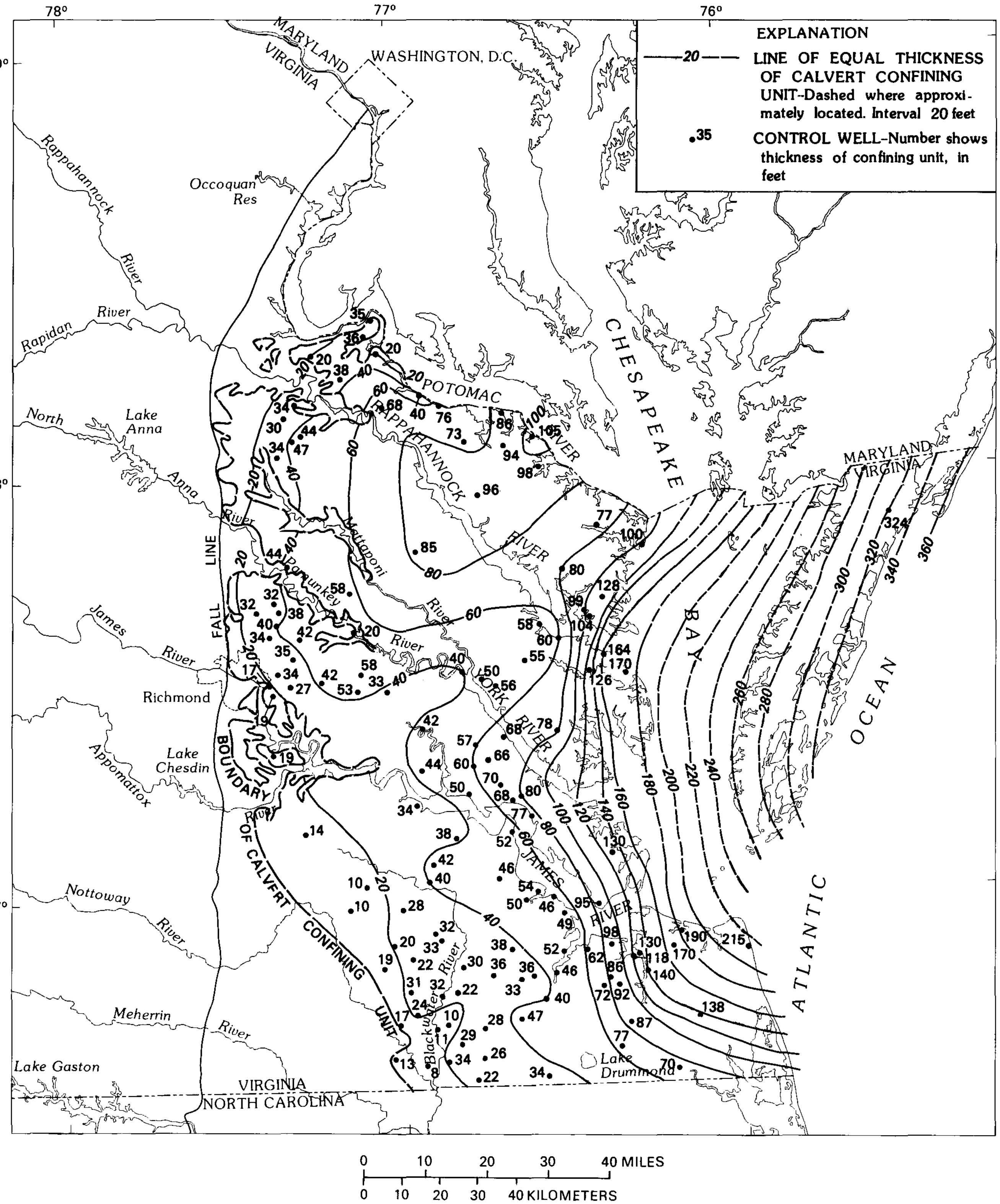

FIGURE 20.—Thickness of Calvert confining unit.

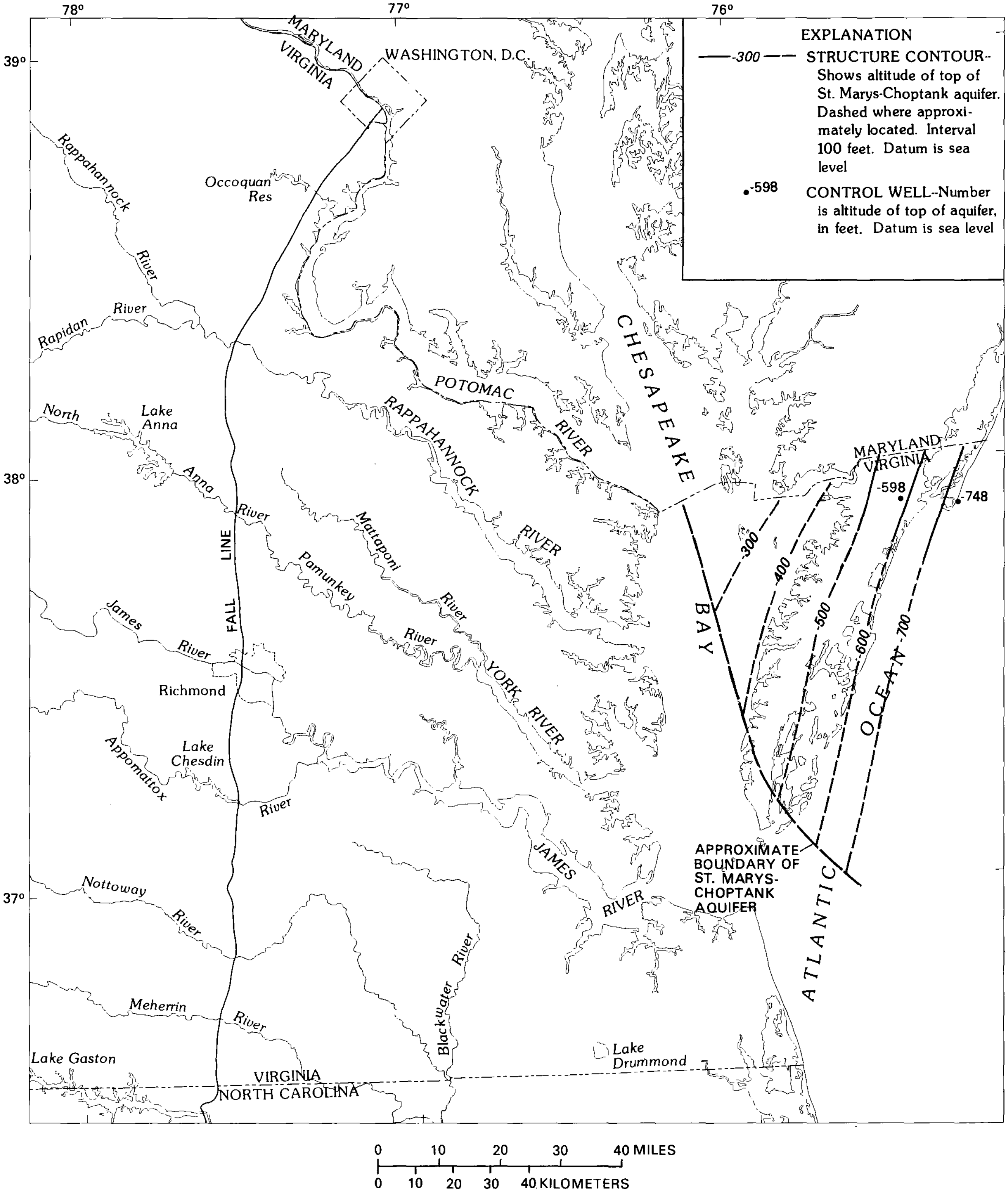

FIGURE 21.—Altitude of top of St. Marys-Choptank aquifer.

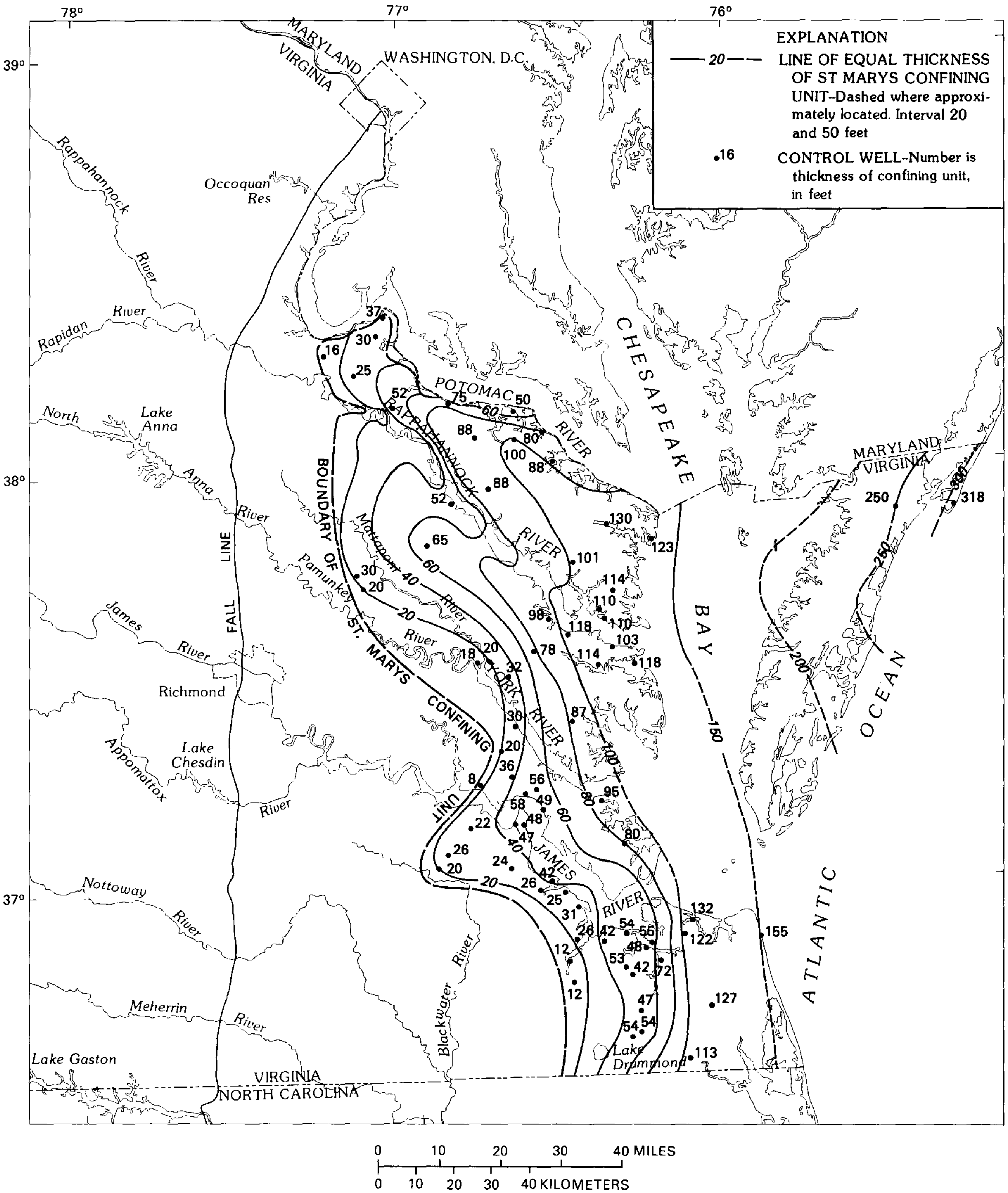

FIGURE 22.—Thickness of St. Marys confining unit.

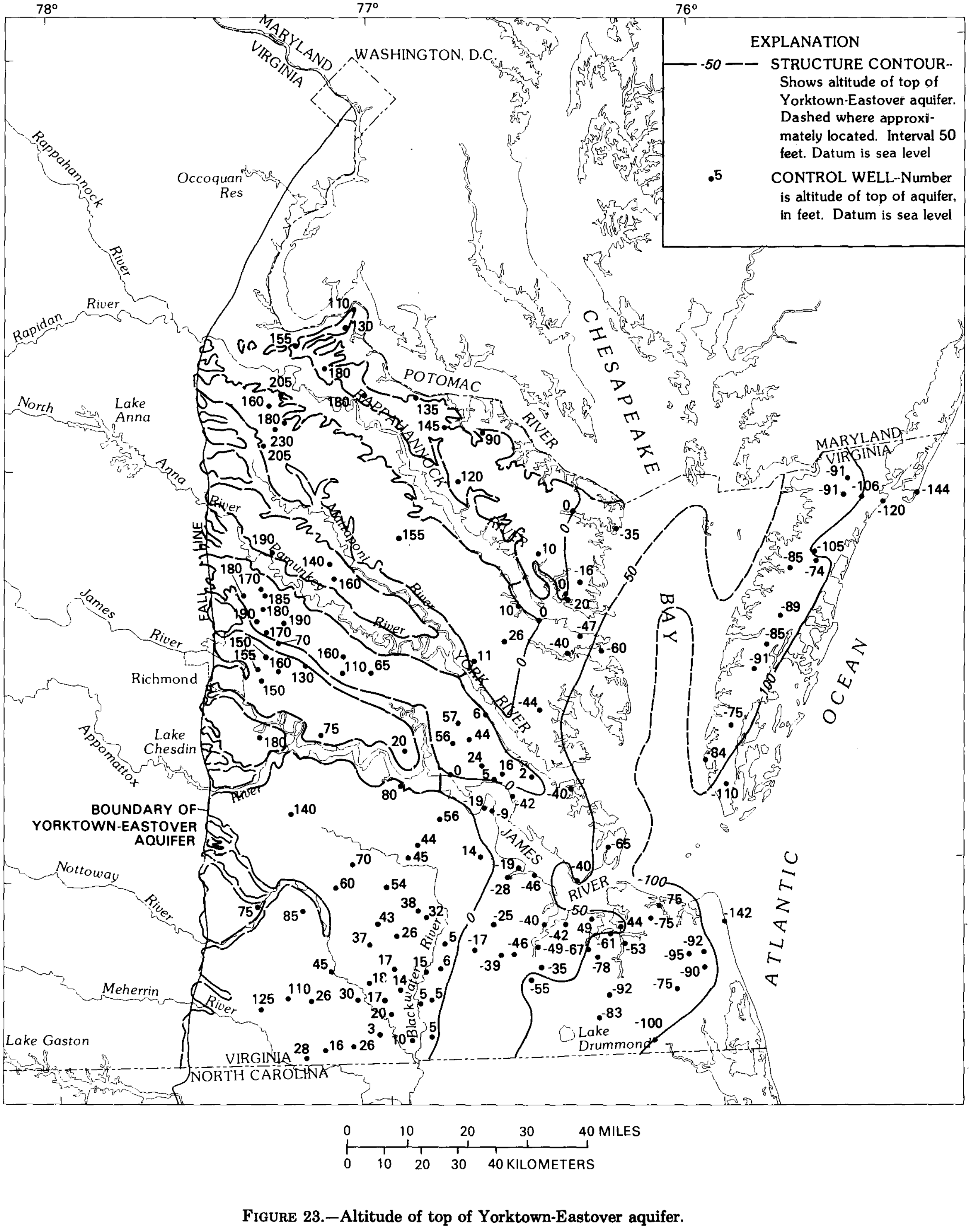

FIGURE 23.—Altitude of top of Yorktown-Eastover aquifer.

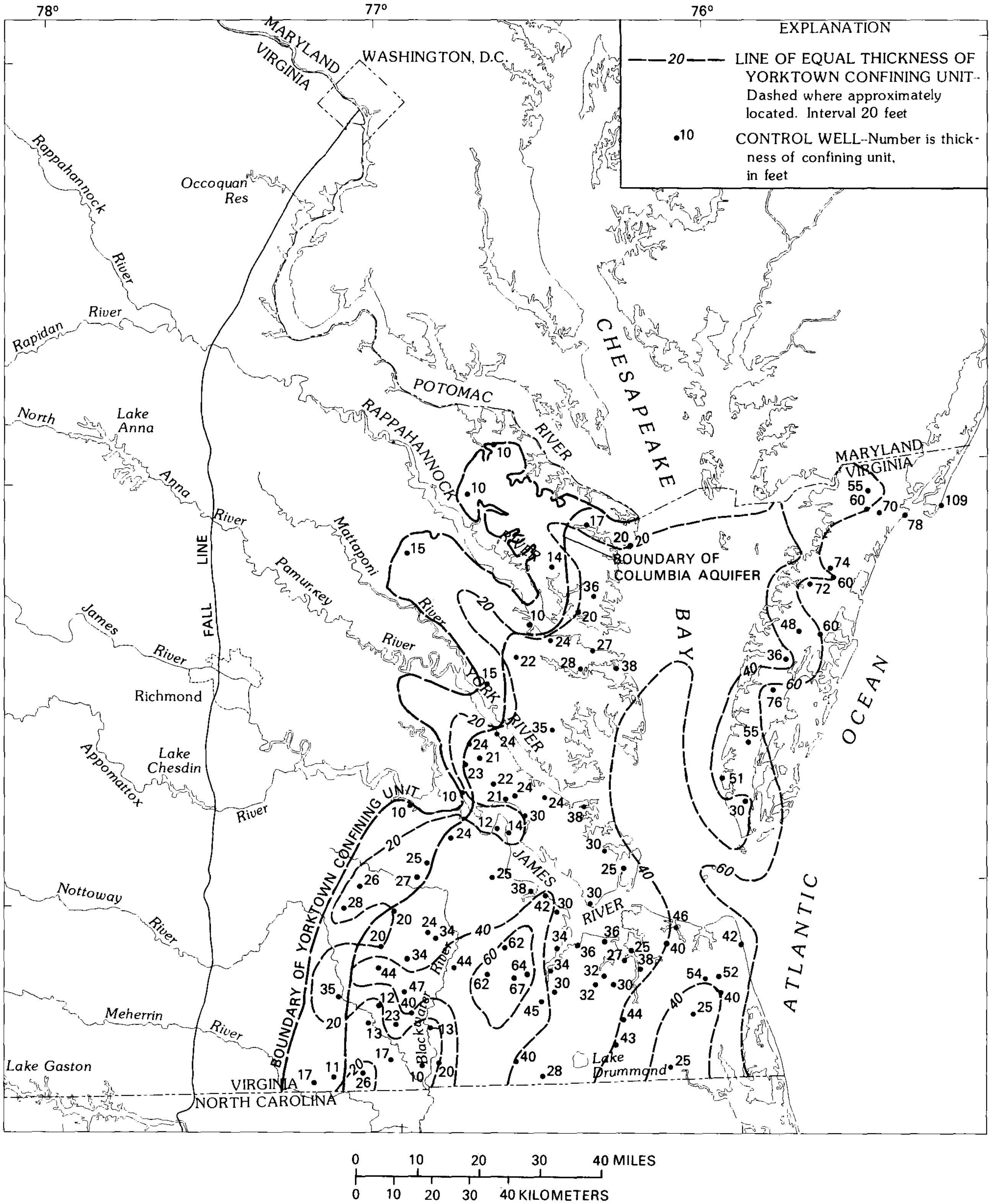

FIGURE 24.—Thickness of Yorktown confining unit.

LOWER AND LOWERMOST UPPER CRETACEOUS POTOMAC FORMATION

Fluvial-deltaic continental and marginal-marine deposits of Early to early Late Cretaceous age constitute the basal lithostratigraphic section known as the Potomac Formation (R.B. Mixon and A.J. Froelich, U.S. Geological Survey, oral commun., 1982). This stratigraphic section comprises the six lowermost hydrogeologic units and consists of three aquifers and three confining units in the hydrogeologic framework of the Virginia Coastal Plain. These hydrogeologic units are the lower, middle, and upper Potomac aquifers and the corresponding lower, middle, and upper Potomac confining units. The Potomac Formation, as used in this report, is commonly referred to in previous literature as the Potomac Group. The Potomac sediments consist of a massive, eastward-thickening wedge of interlensing gravels, sands, silts, and clays. Throughout the study area, the Potomac Formation rests nonconformably upon the basement rock surface and is separated by major regional unconformities from the overlying latest Cretaceous and various Tertiary-age deposits.

The Potomac sediments crop out just east of the Fall Line in the major river valleys of the study area and in an extensive arcuate band extending from the northwestern part of the study area northeastward through Maryland. Clark and Bibbins (1897) divided the Potomac sediments into four formations based on characteristic lithofacies recognized in outcrops between Washington, D.C., and Baltimore. The four formations consist of, from oldest to youngest: the Patuxent Formation, Arundel Clay, Patapsco Formation, and rocks of the former "Maryland Raritan" now assigned to the Patapsco. Corresponding associated lithologies of these four formations consist of massively bedded, light-colored coarse arkosic clayey sands and sandy clays that commonly contain gravels; massively bedded clays and finely laminated carbonaceous clays, typically light to dark in color; interbedded medium, lenticular sands and well-bedded, highly colored clays; and interbedded fine, blanket sands and thinly to thickly bedded, dark-colored clays. Similar lithologic units have been recognized (Cederstrom, 1945a; Spangler and Peterson, 1950; Richards, 1967) in the Potomac section throughout the study area, although they are not generally mapped as such because of their seemingly similar and discontinuous nature. Lack of definitive age relationships for the various Potomac sediments in the subsurface has, in the past, also hindered areal correlation of major lithic units owing to the sparsity of readily apparent guide fossils associated with these continental-deltaic deposits.

In Virginia, the Potomac sediments have not been as extensively studied as those in Maryland. In early studies of the Virginia Coastal Plain, Darton and Keith (1901), Clark and Miller (1912), and Sanford (1913) divided the Potomac sediments into the Patuxent and Patapsco Formations based primarily on lithologic and stratigraphic similarities with the type formations in Maryland. Later studies, however, generally have not recognized these formal divisions. These later studies can be divided into two basic groups: those that refer to the Potomac sediments as "Potomac Group undifferentiated" (primarily Cederstrom's works); and those that recognize the "Patuxent" with overlying "transitional beds" (Onuschak, 1972; Teifke, 1973; Daniels and Onuschak, 1974). The "Patuxent," as recognized and delineated by these later studies, is not correlative with the type Patuxent Formation of Maryland because it generally includes all Potomac sediments of Early Cretaceous age in the study area. This "Patuxent" should more properly be referred to as "Potomac Group undifferentiated," in comparison with other lithologic and stratigraphic studies (Brenner, 1963; Glaser, 1969; Robbins and others, 1975; Doyle and Hickey, 1976).

The characteristically variable lithologies and sparse macrofossils have made past stratigraphic correlation of these sediments as formations difficult, especially in the subsurface. The study of palynology (pollens and spores) has recently produced a systematic zonation scheme that qualitatively identifies and correlates the age relationships of sediments. This zonation is based on the analysis and identification of index microfossil flora that resulted from the evolution of land plants and are recognized worldwide as age indicators. Palynologic studies of the Potomac sediments provide, for the first time, a comprehensive stratigraphic zonation that can be used to identify equivalent-age deposits of continental and marginal-marine origins that normally contain few other diagnostic fossils.

Brenner's (1963) analysis of Lower Cretaceous pollens in the Potomac section of Maryland and Virginia resulted in the development of the first comprehensive palynostratigraphic zonation that definitively correlates the ages of sediments in outcrop with the ages of sediments in the subsurface. Other detailed palynological studies by Groot and others (1961), Doyle (1969), Wolfe and Pakiser (1971), Sirkin (1974), and Doyle and Hickey (1976) have led to important modifications and a more complete zonation of the total Potomac section. Robbins and others (1975) recently refined Brenner's zonation based on palynologic analysis of samples from four deep oil-test wells located within the Salisbury embayment. The palynostratigraphic zonation scheme developed by the above studies is now accepted and used to define the standard stages of the

Cretaceous Potomac Formation. Combined palynostratigraphic analyses (Brenner, 1963; Robbins and others, 1975; Doyle and Hickey, 1976; Doyle and Robbins, 1977; Reinhardt and others, 1980; L.A. Sirkin, Adelphi University, written commun., 1983) have identified five major pollen zones in the Cretaceous Potomac Formation of Virginia. These major pollen zones and their corresponding ages are: pre-Zone I, Berriasian to Barremian; Zone I, Barremian to early Albian; Zone II, middle to late Albian; Zone III, early Cenomanian; and Zone IV, middle to late Cenomanian (pl. 1). Other investigators (Glaser, 1969; Hansen, 1969a; Brown and others, 1972) have proposed that correlatable lithological and depositional patterns are related to most of the major pollen zones and their corresponding "formations." In this study, the hydrogeologic units identified within the Potomac section of Virginia are based on palynostratigraphic zonation, mode of deposition, lithologic characteristics, and hydrologic data. These units are then correlated and delineated throughout the study area by interpreting geophysical logs, drillers' logs, and water-level data. In general, all Cretaceous units strike approximately north-south and dip and thicken eastward. The delineated aquifer units are wedge-shaped in cross section and consist of a series of interbedded sands and clays. The delineated confining units are highly variable in thickness and consist of a series of areally interlayered silty and clayey deposits.

LOWER POTOMAC AQUIFER

The lower Potomac aquifer, by definition, consists of sandy palynostratigraphic pre-Zone I and Zone I sediments of the Potomac Formation. These sediments are early to middle Early Cretaceous (Berriasian through early Albian) in age and correlate with the Patuxent aquifer in Maryland, and the Lower Cretaceous aquifer in North Carolina (pl. 1). The lower Potomac aquifer is the lowermost confined aquifer in the hydrogeologic framework. It rests entirely on the basement surface and is overlain throughout its extent by the lower Potomac confining unit, except where it crops out along the Fall Line in the northwestern part of the study area. This aquifer attains a maximum thickness of 3,010 ft at well 66M1, in the northeastern part of the study area and thins to a featheredge along its western limit near the Fall Line. It dips eastward at about 30 ft/mi throughout the area. The lower Potomac aquifer consists predominantly of thick, interbedded sequences of angular to subangular coarse sands, clayey sands, and clays. This aquifer unit is equivalent to the Patuxent Formation of Maryland for which numerous lithologic descriptions concerning its characteristics have been written.

From outcrops in Virginia, Berry (in Clark and Miller, 1912, p. 63) describes the Patuxent Formation as medium to coarse, light-colored quartz sands containing lenses and beds of interstratified yellow, gray, and brown clays. Berry also reports that, in general, the sands are highly arkosic, crossbedded and clayey, commonly with micaceous and lignitic material, and that the Patuxent also contains varying amounts and sizes of gravels, either in beds, or sometimes interspersed through strata of finer materials. Palynostratigraphic and lithostratigraphic analysis of the Lower Cretaceous deposits from the Oak Grove core (well 54P3, fig. 7), by Reinhardt and others (1980), reveals that sediments of Cretaceous Zone I contain a massive lower interval of thickly bedded coarse sands and associated clay-clast conglomerates. This lower interval of Zone I sediments is herein identified in the hydrogeologic framework of the Virginia Coastal Plain as the lower Potomac aquifer. Typically, the sands of this series are composed of medium to very coarse subangular quartz, with abundant weathered potassium feldspar and some plagioclase. Reinhardt and others (1980) also note that the well-bedded clays of this lower interval are typically mixed-layer illite/smectite, whereas the interstitial and laminated clays are predominantly kaolinitic.

Few wells drilled in the study area penetrate the lower Potomac aquifer (fig. 9). Generally, only deep stratigraphic test wells and high-capacity production wells provide data required to correlate this aquifer. The lower Potomac aquifer is capable of producing large quantities of water, but generally lies too deep for all but large industrial applications. The overlying middle and upper Potomac aquifers supply much of the water used for smaller industrial, municipal, and domestic purposes. In addition, the lower Potomac aquifer contains increasingly higher chloride concentrations in the downdip direction, which further restricts its usage as a potable source of water.

Typical electric-resistivity log patterns of the lower Potomac aquifer sediments are best illustrated in geophysical logs of wells 54P3, plate 2, B-B′; 55H1, plate 3, D-D′ and E-E′; 58F3, plate 3, E-E′; 54G10, plate 3, D-D′ and F-F′; 58A2, plate 3, G-G′; and 53A3, plate 4, J-J′. Generally, these resistivity patterns are characteristically blocky in profile, indicating massively bedded sequences with relatively sharp lithologic contacts among sands, clayey sands, and clays. Very few patterns of gradational, fining-upwards sequences are observed on resistivity logs of the lower Potomac aquifer. However, where these patterns occur, they are usually restricted to the uppermost part of the sand beds. Resistivity logs also characteristically show low resistance values for the sandy sediments. The low resistance values are probably caused by the high percentage of interstitial clays commonly found in the aquifer sands, or by the higher chloride concentrations generally associated with the eastern half of this aquifer unit. Corresponding natural-gamma log patterns commonly reflect a high interstitial clay content also characteristic of the aquifer sands. Drillers commonly refer to the lower Potomac aquifer sediments as "coarse gray sands" that may contain "gravels," and "light to drab-colored clays." Most of the larger gravels encountered in the drilling process are too heavy to be brought to the surface by the drilling fluid and are pushed away from the borehole by the drill bit. Drillers also commonly describe the sands as "hard" or "tough" and the clays as "tight" or "hard." Either of these conditions results in noticeably increased drilling resistance and drilling time. Commonly, the drilled clays reach the surface as small, angular pieces.

The lithologic heterogeneity and discontinuous nature of the sediments in this unit makes correlation of individual sand and clay bodies extremely difficult, even over relatively short distances. The contour map delineating the top of this aquifer unit (fig. 9) is based on the tops of the uppermost sands in the unit. Because of the sparse data base available and the large distances between control wells, this map should only be used as a guide to indicate the approximate altitude at any specific site. Also, the uppermost part of this aquifer, as it is presently delineated, may include sediments of younger age. As more definitive data becomes available, especially from pollen analysis and water-level information, structure contours that depict the top of the lower Potomac aquifer can be refined accordingly.

Numerous studies (Glaser, 1969; Hansen, 1969a; Reinhardt and others, 1980; Hansen, 1982) of the lower Potomac sediments (pre-Zone I to middle Zone I) postulate that the paleoenvironment consisted of a subaerial high-gradient fluvial flood plain dominated by braided streams. Their interpretations are based on the predominance of coarse materials, the general lack of sorting, and overall bedding characteristics. Reinhardt and others (1980) observed glauconite and illitic clays in the lower Potomac sediments of the Oak Grove core (well 54P3). From this, they suggested that deposition occurred in a broad alluvial plain that was occasionally inundated by marine seas. The presence of glauconite was also observed by Anderson and others (1948) among alluvial sediments in cores from the lower Patuxent Formation at two deep oil-test wells, the Hammond and the J.D. Bethards, located in eastern Maryland, and a similar hypothesis was suggested. When viewed as a whole, sediments of the lower Potomac aquifer appear to represent the development of a continental delta (Reinhardt and others, 1980).

LOWER POTOMAC CONFINING UNIT

The lower Potomac confining unit is defined by the major clayey strata directly above the lower Potomac aquifer. These clay beds are predominantly restricted to upper palynostratigraphic Zone I, but may also include younger sediments (basal pollen Zone II). For the most part, this confining unit is middle Early Cretaceous (late Aptian to early Albian) in age. The lower Potomac confining unit correlates with the Potomac confining unit of Maryland and with the confining unit overlying the Lower Cretaceous aquifer of North Carolina (pl. 1). This confining unit crops out in the northwestern part of the study area between the Fall Line and the Potomac River just east of the outcropping lower Potomac aquifer, and in the major stream valleys just east of the Fall Line. It overlies and transgresses the lower Potomac aquifer throughout the study area, except where the aquifer crops out and is overlain by the middle Potomac aquifer. It attains a maximum known thickness of 173 ft (well 66M1) in the northeastern part of the study area and thins to a featheredge along its western limit near the Fall Line. The lower Potomac confining unit is usually the thickest bedded clay or, interbedded clay and sandy clay sequence, of pollen Zone I sediments. Most of this sequence of clayey sediments correlates with the Arundel Clay of Maryland, although the Arundel Clay is not generally recognized as a continuous unit in the subsurface. From outcrops in Maryland, Clark and Bibbins (1897, p. 485) originally identified and defined the Arundel Clay as a series of large and small lenses of drab-colored, tough clays, that are commonly highly carbonaceous and ferruginous. Analysis of the Cretaceous section in the Oak Grove core (well 54P3, fig. 7) by Reinhardt and others (1980) and Estabrook and Reinhardt (1980) provides the most definitive lithologic data for the lower Potomac confining unit. These studies identify and describe an upper interval of pollen Zone I sediments as a massive clay-dominated interval composed of thick sequences of finely laminated, carbonaceous clays interbedded with thin sandy clay beds. This upper interval of pollen Zone I sediments is herein identified as the lower Potomac confining unit in the hydrogeologic framework described in this report. Typically, the thickly bedded clays and sandy clays of this interval are mixed-layer illite/smectite that also contain a high percentage of expandable clays, while the laminated carbonaceous clays are predominantly kaolinitic (Reinhardt and others, 1980; Estabrook and Reinhardt, 1980).

As with the underlying lower Potomac aquifer, few wells drilled in the study area penetrate the lower Potomac confining unit. Generally, only data from deep stratigraphic test wells and high-capacity production wells can be used to correlate this unit.

Clay beds comprising the lower Potomac confining unit are not a continuous, areally extensive layer. Instead, these clays are a series of interlensing clayey deposits. Water-level measurements from observation wells indicate that these deposits act locally as confining units and when viewed regionally, represent a single confining unit, as shown by the thickness map of the lower Potomac confining unit (fig. 10). In some areas, such as in the western and central regions, the confining unit is relatively thin, ranging from 15 to 30 ft in thickness; in other areas, such as in the northern region, it attains a thickness of more than 200 ft.

Typical electric-resistivity log patterns of the lower Potomac confining unit sediments are best illustrated in geophysical logs of wells 51R5, plate 2, A-A′; 53P4, plate 2, A-A′ and B-B′; 54P3, plate 2, A-A′; 52N16, plate 2, B-B′; 57J3, plate 3, D-D′; 58F3, plate 3, E-E′; 54G10, plate 3, D-D′ and F-F′; 53D3, plate 3, G-G′; 55C12, plate 3, G-G′ and plate 4, H-H′; and 58A2, plate 3, G-G′ and plate 4, I-I′. Generally, these resistivity patterns are blocky in profile, indicating relatively sharp lithologic contacts between the thickly bedded confining clays with the overlying and underlying aquifer sands. Corresponding natural-gamma log patterns reflect the massively bedded nature of these clays; few interbedded sands are present. Drillers often refer to the lower Potomac confining unit clays as "hard" or "tough" and as "gray, red, or brown clay." Like the underlying interbedded clays of the lower Potomac aquifer, drillers commonly observe an increase in drilling time and resistance when penetrating these sediments, and the resulting cuttings are commonly small, angular pieces. Also, the underlying interbedded clays of the lower Potomac aquifer usually contain significantly more interbedded sands and sandy clays than are present at this horizon.

Studies (Brenner, 1963; Glaser, 1969; Hansen, 1969a, 1982; Reinhardt and others, 1980) of correlative strata to the lower Potomac confining unit suggest a change in the paleoenvironment from that of the lower Potomac aquifer. These studies indicate that the depositional environment and drainage patterns changed from a high-gradient to a lower-gradient fluvial flood plain, based on the predominance of finer grained clayey materials and their associated bedding characteristics. These studies also suggest that the resulting paleoenvironment consisted of quiet, shallow, discontinuous backswamp basins with little sediment input.

MIDDLE POTOMAC AQUIFER

The middle Potomac aquifer, by definition, consists of sandy palynostratigraphic Zone II sediments of the Potomac Formation. These sediments are late Early Cretaceous (middle to late Albian) in age and correlate with the lower part of the Patapsco aquifer in Maryland and the lower Cape Fear aquifer of North Carolina (pl. 1). The middle Potomac aquifer is the second lowest and thickest confined aquifer in the hydrogeologic framework. This aquifer crops out just east of the lower Potomac confining unit in the northwestern region of the study area and in a small area along the James and Appomattox Rivers near the Fall Line. It overlies the lower Potomac confining unit and is overlain by the middle Potomac confining unit. The middle Potomac aquifer attains a maximum known thickness of 929 ft (well 66M1) in the northeastern part of the study area and thins to a featheredge along its western limit near the Fall Line. It dips eastward at approximately 15 ft/mi in the western half of the study area and at 25 ft/mi in the eastern half. The middle Potomac aquifer consists of interlensing medium sands, silts, and clays of differing thickness. This aquifer is equivalent to the Patapsco Formation in Maryland as defined by Brenner (1963).

From outcrops in Maryland, Glaser (1968, p. 8) describes the Patapsco Formation as a thick sequence of interbedded variegated silty clay and fine to medium, gray to yellow sand. Glaser (1968) also reports that the clay lenses are typically thick, internally massive, and brightly mottled in red, yellow, gray, and purple, whereas the sands, occasionally with gravels, are similar to those in the Patuxent Formation, although they tend to be finer grained, more uniform, and more argillaceous. Berry (in Clark and Miller, 1912, p. 67) describes "Patapsco" sediments in Virginia much the same as Glaser describes them in Maryland, although Berry notes that the outcropping Virginia deposits are generally much more evenly colored than those in Maryland. Analysis of the Oak Grove core (well 54P3, fig. 7) by Reinhardt and others (1980, p. 41) reveals that sediments of Cretaceous pollen Zone II contain a lower sand-dominated interval characterized by distinct fining-upwards sand sequences interbedded with laminated or massive clays. This lower interval of pollen Zone II strata is herein identified in the hydrogeologic framework of the Virginia Coastal Plain as the middle Potomac aquifer. Typically, the sands of these fining-upwards sequences are composed of coarse to fine, angular to subangular quartz, and some plagioclase. These sands are also commonly micaceous and contain abundant heavy minerals. Reinhardt and others (1980) also note that the laminated and massive clays of this sequence are composed of mixed kaolinite and highly expandable illite/smectite.

More wells drilled in the study area penetrate this aquifer (fig. 11) than the underlying lower Potomac aquifer. Generally, most industrial and municipal wells throughout the western half of the study area use this aquifer, sometimes in combination with the underlying or overlying Potomac aquifers. This aquifer is capable of producing large quantities of high-quality water in the western half of the study area, but, like the underlying lower Potomac aquifer, it contains increasingly higher chloride concentrations in the downdip direction, which restricts its use as a source of potable water. In addition, the middle Potomac aquifer generally lies too deep for all but large industrial users in the eastern half of the study area.

Typical electric-resistivity log patterns of the middle Potomac aquifer sediments are best illustrated in geophysical logs of wells 53Q9, 53P4, and 54P3, plate 2, A-A'; 52N16, 53P8, 53P4, 54Q11, and 54R3, plate 2, B-B'; 52J11, plate 2, C-C'; 52K6, 54J4, 55H1, and 58F3, plate 3, E-E'; 54G10, 57E10, and 60C7, plate 3, F-F'; 53D3, plate 3, G-G'; and 53A3, 58B115, and 59C28, plate 4, J-J'. Generally, these resistivity log patterns are both triangular and saw-toothed in profile. The triangular profiles indicate the fining-upwards sequences characteristically associated with the aquifer sands. The saw-toothed profiles indicate the extensively interbedded sequences of sands, silts, and clays also characteristic of these sediments. These electric-resistivity patterns are both massive and narrow in profile and the sands usually contain sharp, lower lithologic contacts. Resistivity logs of the middle Potomac aquifer also characteristically show high-resistance values for the sandy sediments which help distinguish this aquifer from the underlying lower Potomac aquifer. The high-resistance values are indicative of the relatively clean sands common to this aquifer and the relatively low concentrations of dissolved solids characteristic of the water from this unit. Corresponding natural-gamma logs show pronounced saw-toothed clay and sand patterns with sharp lower and gradational upper lithologic contacts. The clay patterns of natural-gamma logs of the middle Potomac aquifer are more distinct than the sand patterns, indicating the well-bedded and massive nature of the clays. Drillers usually describe the middle Potomac aquifer sediments as "medium or coarse gray sands" with "red, brown, or multicolored clays." Drillers also commonly refer to the sands as "water sands" or "artesian sands." Generally, these sediments drill easily and the clays reach the surface as small, cohesive clay balls. The individual sand and clay beds of the middle Potomac aquifer, like the underlying lower Potomac aquifer, are also difficult to correlate between geophysical logs. The contour map delineating the top of this aquifer (fig. 11) is based on the tops of the uppermost sand beds. This map should only be used as a guide to indicate the approximate altitude to the top of this aquifer between control wells because of the interlensing nature of these sediments, the large distances between control points in some areas, and the general lack of data in the eastern half of the study area.

Studies (Glaser, 1969; Hansen, 1969a; Reinhardt and others, 1980) of Potomac strata herein defined as the middle Potomac aquifer and the correlative Patapsco strata in Maryland suggest that the paleoenvironment consisted of a low-gradient, subaerial, fluvial flood plain dominated by meandering streams. These deposits, which represent multiple fluvial processes, are dominated by channel sands, point bars, levees, flood plains, and backswamps. Reinhardt and others (1980, p. 41) note that no glauconite was observed in the cored sediments of the middle Potomac aquifer strata in the Oak Grove core and suggest that these deposits represent a more landward sedimentary assemblage than do the sediments of the underlying lower Potomac aquifer strata (p. 48). They also note (p. 47) that these deposits are distinctly continental in origin and, together with the underlying lower Potomac aquifer sediments, appear to represent the development of a continental delta.

MIDDLE POTOMAC CONFINING UNIT

The middle Potomac confining unit is defined by the major clayey strata directly above the middle Potomac aquifer. These clay beds are predominantly restricted to upper palynostratigraphic Zone II, but may also consist of younger sediments (basal Zone III), especially in the eastern half of the study area. The middle Potomac confining unit correlates with the western half of the Patapsco confining unit of Maryland and with the confining unit that overlies the lower Cape Fear aquifer of North Carolina (pl. 1). This confining unit crops out in the northwestern part of the study area between the middle Potomac aquifer and the Potomac River, and in the stream valleys of the Rappahannock, Pamunkey, James, and Appomattox Rivers just east of the outcropping middle Potomac aquifer. It overlies the middle Potomac aquifer and is overlain by the upper Potomac aquifer, except in the western part of the study area where it is transgressed by the Aquia aquifer. This confining unit attains a maximum known thickness of 203 ft at well 66M1 (fig. 7) in the northeastern part of the Eastern Shore Peninsula and thins to nearly zero thickness along its western limit near the Fall Line (fig. 12). Its thickness is highly variable, but the middle Potomac confining unit is commonly the thickest bedded clay or interbedded clay and sandy clay sequence of pollen Zone II sediments.

Definitive lithologic data are obtained from analysis of the Cretaceous section in the Oak Grove core (well 54P3, fig. 7) by Reinhardt and others (1980) and

Estabrook and Reinhardt (1980). Reinhardt and others (1980) identify and describe an upper interval of pollen Zone II sediments as a clay-dominated sequence characterized by highly sheared and locally mottled montmorillonitic red clay. This upper interval of pollen Zone II sediments in the Oak Grove core (well 54P3) is herein identified as the middle Potomac confining unit in the hydrogeologic framework of the Coastal Plain of Virginia. Typically, the clays of this confining unit are massive to thick-bedded, but are also finely laminated in places. These clays are similar in composition to the clays of the lower Potomac confining unit in that they consist primarily of mixed kaolinite and highly expandable illite/smectite (Reinhardt and others, 1980, p. 41). The laminated clays are silty, sandy, micaceous, and highly carbonaceous, whereas the massive clays are mottled, highly oxidized, and highly fractured. The middle Potomac confining unit is commonly characterized by a thick sequence of brightly colored, variegated, plastic clays. These variegated clays are used to identify this confining unit on drillers' logs.

Numerous water wells drilled in the western and central regions of the study area penetrate this confining unit. In areas where the upper Potomac aquifer overlies this unit, drillers commonly cease drilling upon reaching this thick variegated clay horizon. The clays identified as the middle Potomac confining unit are not a single, continuous, and areally extensive layer, but rather, are a series of interfingering deposits. Water-level data indicate that these clays act locally as confining units and, when viewed regionally, constitute a single confinement, as shown by the thickness map of the middle Potomac confining unit (fig. 12).

Typical electric-resistivity log patterns of the middle Potomac confining unit sediments are best illustrated in geophysical logs of wells 51R5, 54P3, 56N7, plate 2, A-A'; 52N16, 54R3, plate 2, B-B'; 52K6, 54J4, 54H11, 55H1, plate 3, E-E'; 53D3, 54D2, 55C8, plate 3, G-G'; and 52A1, 53A3, 54A3, 55A1, 56B9, plate 4, J-J'. Generally, these resistivity patterns are blocky in profile, indicating thickly bedded clays in relatively sharp lithologic contact with the aquifer sands above and in gradational lithologic contact with the aquifer sands below. The lithologies indicated by the resistivity patterns range from massive clays, as in wells 54P3, plate 2, A-A' and 56N7, plate 2, C-C', to thick clays interbedded with thin sands and sandy clays, as in well 55A1, plate 4, H-H'. Corresponding natural-gamma log patterns also typically indicate massively bedded clays with few interbedded sands or sandy clays. Drillers commonly refer to the middle Potomac confining unit clays as "slick or sticky" and as "multicolored or mixed colored clays." These multicolored clays, which are characteristically red, purple, gray, brown, olive, and yellow, are also referred to as mottled clays.

Studies on the paleoenvironment of the Potomac strata suggest that deposition of the middle Potomac confining unit occurred on broad, low-gradient, fluvial-deltaic plains containing extensive flood plains and swampy interfluves (Glaser, 1969, p. 73). Reinhardt and others (1980, p. 47) note that this clay-dominated upper pollen Zone II interval is a product of overbank deposition that was modified by weathering and diagenesis, and that these backswamp and flood basin deposits are distinctly continental in origin.

UPPER POTOMAC AQUIFER

The upper Potomac aquifer, by definition, consists of sandy palynostratigraphic Zone III and Zone IV sediments of the Potomac Formation. These sediments are early Late Cretaceous (Cenomanian) in age and correlate with the upper, easternmost sediments of the Patapsco aquifer in Maryland and the upper Cape Fear aquifer in North Carolina (pl. 1). This aquifer is restricted to the subsurface; it overlies most of the middle Potomac confining unit and is overlain by the upper Potomac confining unit. The upper Potomac aquifer dips eastward at approximately 15 ft/mi, attains a maximum known thickness of 425 ft at well 66M1 in the northeastern part of the study area, and pinches out along its western subsurface limit throughout the west-central part of the study area. The upper Potomac aquifer, like the other underlying Potomac aquifers, is a multizone unit consisting of stratified sands and clays.

The presence of lower Upper Cretaceous sediments at the top of the Potomac Formation in the study area has been alluded to by many investigators (Cederstrom, 1945a, 1957; Spangler and Peterson, 1950; Dorf, 1952; Richards, 1967), but the actual presence of these sediments in Virginia was not verified until the use of pollen analysis as a stratigraphic indicator. Palynostratigraphic analyses by Robbins and others (1975), Doyle and Robbins (1977), and L.A. Sirkin (Adelphi University, written commun., 1982, 1983) have indicated the presence of pollen Zones III and IV at the top of the Potomac Formation throughout the eastern half of the study area. These sediments are correlatable with the Raritan Formation of New Jersey and comprise the uppermost aquifer of the Potomac Formation in the study area.

The sands of the upper Potomac aquifer, as described from drillers' logs, are characteristically white, micaceous, very fine to medium quartz, and commonly contain carbonaceous material. Gravel is uncommon, and very coarse sand is rare. The interbedded clays of this aquifer, as described from drillers' logs, are characteristically dark, silty, highly micaceous, and typically contain carbonaceous material. Limited data are available that describe the lithologic characteristics of the upper Potomac aquifer in the study area; only one set of core samples from this unit has ever been analyzed. These core samples were obtained as part of the "Artificial Recharge" project conducted by the U.S. Geological Survey in cooperation with the city of Norfolk at the Moore's Bridge Water Treatment Facility, and are represented by well 61C1 in figure 7. Brown and Silvey (1977, p. 4) report that this unit consists of moderately sorted, angular to subangular, micaceous, fine to medium quartz sands that contain wood fragments and minor interstitial clays. Typical onsite core descriptions (D.L. Brown, U.S. Geological Survey, written commun., 1971) of the sandy intervals indicate that they are light yellow to greenish gray, clayey to clean, micaceous, slightly calcareous, poor to well sorted, subangular to subrounded, and very fine to medium grained. Similarly, the interbedded silty-clay intervals are described as yellow green to dark greenish gray, glauconitic, calcareous, micaceous, plastic, locally sandy, and containing shell fragments. More wells drilled in the study area penetrate the upper Potomac aquifer (fig. 13) than the underlying middle and lower Potomac aquifers. Generally, most light industrial and municipal ground-water users throughout the central part of the study area use this aquifer. This aquifer is capable of producing large quantities of generally good quality water suitable for most uses, but like the underlying Potomac aquifers, this aquifer contains water having chloride concentrations that increase downdip, thus precluding the use of the aquifer as a potable source of water in the eastern areas.

Typical electric-resistivity log patterns of the upper Potomac aquifer sediments are best illustrated in geophysical logs of wells 58J11, 58J5, plate 3, D-D'; 57G25, 57F2, plate 3, E-E'; 56F42, 57E10, 58D9, 60C7, plate 3, F-F'; 55D5, 55E3, plate 4, H-H'; 58B115, 58C51, plate 4, I-I'; and 54A3, 55A1, 59C28, 60C25, plate 4, J-J'. Generally, these resistivity patterns are very similar to the resistivity patterns of the underlying middle Potomac aquifer, but they are characteristically more massive and rounded in profile and are more easily correlated among logs. Also, the massively bedded sand sequences are commonly separated by thinner interbedded clays, as shown by the log of well 59C28 (pl. 4, J-J'). Corresponding natural-gamma logs commonly indicate the presence of interbedded sands and clays.

Drillers commonly refer to the upper Potomac aquifer sediments as "fine, white micaceous sands" and "dark micaceous clays," that frequently contain "wood fragments." They also note that these sediments are penetrated easily. On drillers' logs, the terms "variegated clay" and "red, brown and yellow clay" are noticeably absent from the descriptions of clays in this aquifer.

The contour map delineating the top of the upper Potomac aquifer (fig. 13) is based on the tops of the uppermost sand bodies identified at the control wells. Therefore, this map should only be used as a guide to indicate the approximate altitude of the top of this aquifer between control wells because of the interlensing nature of these sediments, the large distances between control points in some areas, and the general lack of data in the northern and eastern sections of the study area.

Sediments of the upper Potomac aquifer represent the effects of the first major marine transgression that inundated the study area. As the seas progressively encroached onto the delta complex, deposition occurred in everwidening estuaries and intertidal basins. Brown and Silvey (1977, p. 4) postulate that, based on grain size, deposition of the lower Upper Cretaceous sediments at well 61C1 (Moore's Bridge Water Treatment facility) took place in a littoral environment, possibly a tidal flat, with a semiprotected shoreline. Other studies of equivalent sediments in Maryland (Glaser, 1969; Hansen, 1969a) note the absence of typical marine transgressive strandline features, such as barrier beach and dune sediments, and suggest that deposition occurred in a marginal marine outer-delta environment with a vegetated, swampy shoreline.

UPPER POTOMAC CONFINING UNIT

The upper Potomac confining unit is defined by the major clayey strata directly above the upper Potomac aquifer. These clay beds are predominantly restricted to upper palynostratigraphic Zone IV, but also include clay beds of palynostratigraphic Zone III in the west-central parts of the study area and undifferentiated clays of latest Cretaceous age in the eastern regions of the study area. The upper Potomac confining unit correlates with the eastern part of the Patapsco confining unit in Maryland and the confining unit that overlies the upper Cape Fear aquifer in North Carolina (pl. 1). This confining unit is restricted to the subsurface; it overlies the upper Potomac aquifer and is overlain by the Brightseat aquifer in the north-central and northeastern regions of the study area, and by the Aquia aquifer throughout the remainder of its extent. It attains a maximum known thickness of 126 ft at well 66M1 in the northeastern part of the study area and pinches out along its western subsurface limit in the west-central part of the study area. The thickness of this confining unit is variable, but generally it thickens and dips to the northeast.

As in the case for the underlying upper Potomac aquifer, detailed lithologic data are available to the authors only from core samples obtained at well 61C1 located at the city of Norfolk during the Artificial Recharge project. The core information indicates (Brown and Silvey, 1977, p. 7) that the confining unit clays consist of highly expandable silty-clay to clayey-silt mixed-layer illite and montmorillonite, and minor amounts of kaolinite. On-site core descriptions (D.L. Brown, U.S. Geological Survey, written commun., 1971) describe this confining unit as a dark greenish-gray, micaceous, calcareous, slightly glauconitic and sandy, silty clay.

Numerous water wells drilled throughout the central and east-central regions of the study area penetrate and provide information on this confining unit. The clay beds identified as the upper Potomac confining unit are not a single, areally extensive layer, but rather, a series of interlayered clayey deposits. These individual clay layers are more extensive than the clayey deposits of the underlying middle and lower Potomac confining units and, therefore, are more easily correlated between wells. Water-level data indicate that individual clay units act locally as confining units and when viewed regionally, they constitute a single confinement as depicted by the thickness map of the upper Potomac confining unit (fig. 14).

Typical electric-resistivity log patterns of the upper Potomac confining unit sediments are best illustrated in geophysical logs of wells 58J11, 58J5, plate 3, D-D′; 57G22, 57G25, plate 3, E-E′; 57A1, plate 3, G-G′; and 60B1, plate 4, K-K′. Generally, these resistivity logs show broad U-shaped profiles that commonly contain numerous thin, interbedded sequences of sands and sandy clays. These sequences produce an erratic appearance in resistivity logs of the thick clay deposits of the upper Potomac confining unit. Drillers commonly refer to the upper Potomac confining unit sediments as "dark micaceous clays" or "dark sandy clays," that may contain shells or wood.

Like the underlying sediments of the upper Potomac aquifer, these confining units sediments also are the result of the first major marine transgression in the sedimentary section. The depositional environment was similar to that of the upper Potomac aquifer, but was a lower energy regime in a broad, low-lying outer delta.

UPPERMOST CRETACEOUS SEDIMENTS, UNDIFFERENTIATED

Marine deposits of latest Cretaceous age represent the next distinctive group of sediments in the sedimentary section. These deposits are sparsely represented in the eastern part of the study area. Uppermost Cretaceous sediments typically form relatively thin veneers of glauconitic clays, sandy clays, and chalky marls. The sediments attain a maximum known thickness of 70 ft at well 66M1 in the northeastern part of the study area and approximately 50 ft at well 61C1 in the southeastern part. These sediments are included as part of the upper Potomac confining-unit sequence and are not further differentiated in this report because of their restricted areal extent and their predominantly clayey composition.

After the regionwide Turonian erosional period, marine seas extensively covered the downwarped Coastal Plain areas of Maryland and North Carolina, depositing thick, extensive Upper Cretaceous marine sediments in the structural lows of the Salisbury and Albemarle embayments. Based on lithologic and paleontologic evidence, it appears that most of the Virginia Coastal Plain was elevated, in relation to sea level, throughout this time. Hansen (1978) proposes basement faulting along the southern limb of the Salisbury embayment as the mechanism responsible for the truncation or nondeposition of the uppermost Cretaceous deposits in the north-central and northwestern parts of the study area.

Cederstrom (1945a) suggests a Late Cretaceous age for deposits in the southeastern part of the study area, based on paleontological analysis of well cuttings. These sediments are reported to range from 10 to 100 ft thick and consist predominantly of clays and sandy clays. From correlation of geophysical logs and recent stratigraphic data, the authors determined that the thickness is 10 to 30 ft in southeastern Virginia. Brown and others (1972) also found the uppermost Cretaceous deposits in the southernmost part of the study area and, like Cederstrom, determined that the deposits are thin, predominantly clayey sediments, interbedded with a few thin sands. The Norfolk arch is undoubtedly the predominant controlling influence for the northern limit of these Upper Cretaceous deposits in southeastern Virginia.

PALEOCENE AND EOCENE PAMUNKEY GROUP

Marine deposits of Paleocene and Eocene age constitute the lower Tertiary (Paleogene) stratigraphic section known as the Pamunkey Group. From oldest to youngest, six formations consisting of the Brightseat, Aquia, Marlboro Clay, Nanjemoy, Piney Point, and Chickahominy comprise this group. From these six formations, five hydrogeologic units—three aquifers and two confining units—are identified. Throughout the study area, major regional unconformities separate the Pamunkey Group from the underlying Cretaceous deposits and the overlying upper Tertiary deposits. Within the Pamunkey Group lesser unconformities separate most of the formations. Generally, the

Pamunkey Group consists of glauconitic sands, silts, and clays, with varying amounts of shells. The notable exception is the Marlboro Clay, which consists solely of nonglauconitic, dense, plastic clay. Within the Aquia, Nanjemoy, and Piney Point Formations, cobble and boulder-sized calcareous concretions are common, as are thin layers of calcareous-cemented shell beds. By studying the sediment core collected at Oak Grove, Reinhardt and others (1980, p. 2) report that the depositional structures and sedimentary fabrics within the Pamunkey Group are representative of a depositional environment that was either extremely stable or a somewhat restricted marine shelf. Sedimentation occurred in a shallow, low-energy, inner to middle marine basin in the area north of the Norfolk arch (L. W. Ward, U.S. Geological Survey, personal commun., 1981). In the immediate area of the Norfolk arch, drillers' logs and geophysical logs indicate that the Pamunkey Group sediments thin considerably and become slightly coarser and less glauconitic, thus indicating a higher energy environment. South of the arch, the sediments again become noticeably finer, more glauconitic, and commonly contain a limy-mud matrix with numerous thin layers of limestone.

The reported presence of exposed greensand sediments in the study area dates back to the early 1800's. In 1891, the name Pamunkey was applied by Darton (1891) to the greensand sediments exposed along the Pamunkey River in Virginia, which he defined as a single formation of Eocene age. Shortly thereafter, Clark (1896, p. 3) identified two distinct stages—the Aquia Creek and Woodstock of the Eocene Pamunkey Formation. Subsequently, Clark and Martin (1901, p. 5) raised the Pamunkey Formation to group status and named the Aquia and Nanjemoy Formations within that group based on exposures along the Potomac River. The identifications of the remaining formations within the Pamunkey Group came much later and are discussed under the respective hydrogeologic sections.

The Pamunkey Group crops out extensively in the major stream valleys throughout the western parts of the study area. As a whole, this group of sediments thickens to the northeast, north of the Norfolk arch, and to the southeast, south of the arch. Generally, the sands of the Pamunkey Group yield abundant quantities of water that is suitable for most uses. Unlike the fluvial-deltaic deposits of the underlying Cretaceous sediments, the marine sediments of the Pamunkey Group generally consist of homogeneous and extensive blanket-type deposits that change little over large areas. Therefore, the depths to the tops of aquifers and the thicknesses of confining units tend to be fairly predictable, even between control wells separated by large distances.

BRIGHTSEAT AQUIFER

The Brightseat aquifer is herein defined as all interbedded sands of early Paleocene (Danian) age in the study area. The Brightseat aquifer correlates with the Brightseat aquifer of Maryland and pinches out southward against the north flank of the Norfolk arch (fig. 15). Therefore, no correlative hydrogeologic unit exists from the area of the Norfolk arch southward into North Carolina. This aquifer is the lowest Tertiary age aquifer in the study area. It overlies the upper Potomac confining unit and is overlain by the Brightseat confining unit throughout its extent. The Brightseat aquifer dips eastward at approximately 14 ft/mi and is lenticular in cross section. It attains a maximum thickness of more than 150 ft in the north-central part of the study area beneath the Chesapeake Bay and thins to nearly zero thickness along its western and southern limits.

As a result of the present study, the Brightseat aquifer became an identifiable and correlatable hydrogeologic unit in the Virginia Coastal Plain. Previous investigators placed these interbedded sediments within the Lower Cretaceous Potomac strata, with the exception of Darton and Keith (1901), who placed these beds in the Late Cretaceous. Recognition of this aquifer is based on geophysical-log correlations, in combination with analysis of drillers' logs and water-level data, throughout the north-central part of the study area and adjoining parts of southern Maryland. More recently, a definitive age for the unit was determined by foraminifers and pollen analysis of core samples obtained from a test well in Lexington Park, located in southern Maryland (H.J.Hansen, Maryland Geological Survey, written commun., 1983). Hansen and Wilson (1984, p. 11), from information obtained at the Lexington Park test well, tentatively identified correlative sediments in Maryland as the Mattaponi(?) Formation, and the sands as the Mattaponi(?) aquifer, based on Cederstrom's (1957) designation of Colonial Beach-type well. This report does not use the term "Mattaponi." Geophysical log interpretations, supported by paleontologic and lithologic data, have led the authors to doubt the existence of a Mattaponi Formation, as described by Cederstrom (1957) and later modified by Teifke (1973), within the study area. Definitive stratigraphic analysis obtained from the core hole at Oak Grove (Virginia Division of Mineral Resources, 1980), which is located near Cederstrom's designated Colonial Beach-type well, also raises serious doubt as to the existence of a Mattaponi Formation (Reinhardt and others, 1980, p. 4). In addition, Cederstrom (1957, p. 19) uses two drilled wells at Oak Grove to support his Mattaponi hypothesis, which, when compared to the Oak Grove core hole, show that correlative strata have been positively identified as the Aquia Formation and the Potomac Formation (Reinhardt and others, 1980).

This report follows Ward's (1984, p. 14) analysis and recommendation that the name Mattaponi be dropped from further usage because it was defined on age determinations derived from foraminifera, and that the designated strata of this formation had been previously assigned to other lithic units. The name Brightseat is derived from the Brightseat Formation, identified by Bennett and Collins (1952) from outcrops near the town of Brightseat, Md.; the Brightseat is described as a dark gray, micaceous, sandy clay, 4 to 8 ft thick, of early Paleocene age. The interbedded sand and clay facies of the Brightseat Formation, herein designated as the Brightseat aquifer, have never been recognized as a hydrogeologic unit previous to this study.

The Brightseat aquifer is restricted to the subsurface, and its eastern areal extent is not well defined owing to the lack of sufficient borehole and paleontologic information throughout the Eastern Shore Peninsula area. Thus far, correlation of this aquifer is limited to its area of extent, as shown in the aquifer top map (fig. 15), plus a small adjoining area in southern Maryland.

The Brightseat aquifer consists of interstratified blanket sands and silty clays. The sands, as described in drillers' logs, consist predominantly of fine, well-sorted, white quartz but also contain shells, lignite, mica, and minor amounts of glauconite. The clays, as described in drillers' logs, consist of dark, micaceous, silt and clay, commonly gray, dark green, and black, but also contain minor amounts of shells, sand, and lignite. From core samples of their Mattaponi(?) aquifer, Hansen and Wilson (1984, p. 11-13) describe the sands as typically gray, medium, moderately well sorted, clean and dominantly quartzose, and the clays as generally gray, but often mottled, with organic inclusions and thin laminae of light-colored, fine, micaceous sand and silt.

Numerous industrial and municipal ground-water users, especially the seafood-processing industries in the northern part of the study area, use this aquifer. This aquifer is capable of producing large quantities of high-quality water suitable for most uses. Hansen and Wilson (1984, p. 24) note that the water from this aquifer in Maryland is of excellent quality, relatively low in dissolved solids, and can be used with a minimum of treatment.

Typical electric-resistivity log patterns of the Brightseat aquifer sediments are best illustrated on geophysical logs of wells 56N7 and 60L19, plate 2, A-A'; 57P1, plate 2, C-C'; and 57J3, 58J11, and 59K17, plate 3, D-D'. Generally, the resistivity patterns are a series of U-shaped profiles. The U-shaped profiles indicate the characteristic interbedded clean sand and silty clay sequences associated with these aquifer sediments. In the updip section of this aquifer, the U-shaped patterns are commonly narrow, as in well 56N7, plate 2, A-A', and contain only one or two well-defined sand beds. In the downdip section, many more U-shaped patterns are evident; the silty clays and sands become thicker, as in well 60L19, plate 2, A-A', and typically are interstratified with thin clay beds. Corresponding natural-gamma logs exhibit well-defined clay and sand patterns with sharp lithologic contacts, which again indicate their well-bedded and alternating nature.

Drillers commonly refer to the Brightseat aquifer sediments as "fine white sands with some black sands" and "gray, dark, or black, micaceous clays," both sometimes containing shells and(or) lignite. Drillers also note that these sediments are readily penetrated in comparison to the underlying Potomac sediments. Individual sand and clay beds of the Brightseat aquifer are easily correlated among geophysical well logs because of their well-defined interbedded patterns. The contour map delineating the top of this aquifer (fig. 15) is based on the uppermost sand identified at each control well. Because of the interbedded characteristics of these sands, this map can be used to indicate, with a fair degree of accuracy, the approximate altitude of the top of this aquifer throughout its extent.

Based on its interbedded nature, lithologic characteristics, and its equivalent age and stratigraphic position with the type Brightseat Formation, this aquifer's environment of deposition seems to be dominated by intertidal marine processes and probably represents a nearshore or lagoonal environment. Hansen and Wilson (1984, p. 13) note that core analysis of their equivalent Mattaponi(?) aquifer reveals a sparse inner shelf fauna which indicates a water depth of less than 65 ft. Hansen (Maryland Geological Survey, oral commun., 1983) also suggests that these deposits probably represent a nearshore facies of the open-marine type Brightseat Formation.

BRIGHTSEAT CONFINING UNIT

The Brightseat confining unit is defined by the uppermost clay bed of the interbedded sand and clay sequence of early Paleocene (Danian) age deposits. This confining unit correlates with the Brightseat confining unit of Maryland. The Brightseat confining unit pinches out southward against the north flank of the Norfolk arch (fig. 16) and, therefore, has no correlative unit from the area of the Norfolk arch southward into North Carolina. It should be noted that geophysical and lithologic log correlations indicate the Brightseat confining unit is, for the most part, a continuation of the Brightseat Formation. The Brightseat Formation, as defined by Bennett and Collins (1952), is an early Paleocene, dark-gray, silty and sandy, micaceous clay that underlies the Aquia greensands. In the area of study, the Brightseat confining unit is areally restricted to that part of the Brightseat Formation that overlies the Brightseat aquifer. The Brightseat Formation crops out throughout the northwestern part of the study area, but its hydrogeologic significance changes. In the northwestern part of the study area, the Brightseat Formation comprises the upper part of the middle Potomac confining unit that separates the underlying middle Potomac aquifer from the overlying Aquia aquifer. In contrast, the Brightseat Formation in the north-central and northeastern parts of the study area wholly comprises the Brightseat confining unit that separates the underlying Brightseat aquifer from the overlying Aquia aquifer.

The Brightseat confining unit is restricted to the subsurface and its eastern areal extent is not well defined owing to the lack of sufficient borehole and paleontological information throughout the Eastern Shore Peninsula area. This confining unit attains a maximum known thickness of 62 ft at well 63L1 (fig. 7) in the northern part of the study area beneath the Chesapeake Bay and thins to nearly zero thickness along its western and southern limits (fig. 16). Its northwestern limit, where the Brightseat Formation continues northwestward as part of the middle Potomac confining unit, is an arbitrary break dependent on the limit of the underlying Brightseat aquifer.

The Brightseat confining unit consists of an areally extensive, silty clay bed which locally is interbedded with very thin sands or sandy clays. These clays are micaceous, commonly dark in color although light-gray, red and mottled clays are noted, and may contain shells and carbonaceous material. Hansen and Wilson (1984, p. 41) describe a core sample obtained from a correlative unit in the Lexington Park test well as a clayey silt, that contains very fine quartz sand, and is micaceous, slightly calcareous and lignitic, yellowish greenish gray, oxidized to dark orange in places.

Typical electric-resistivity log patterns of the Brightseat confining unit sediments are best illustrated on geophysical logs of wells 56N7 and 60L19, plate 2, A-A'; 56M10 and 57P1, plate 2, C-C'; and 58J11 and 59K17, plate 3, D-D'. Generally, these resistivity patterns are U-shaped in profile, indicating a well-bedded, silty clay in sharp lithologic contact with overlying and underlying aquifer sands. In some areas, the lower contact with the underlying Brightseat aquifer is gradational, as illustrated in geophysical well logs 57P1, plate 2, C-C', and 59K17, plate 3, D-D'. This confining unit may contain thin interbedded sands or clayey sands, as illustrated in geophysical well log 60L19, plate 2, A-A' and plate 3, D-D'. Corresponding natural-gamma log patterns commonly exhibit a pronounced clayey response to this confining-unit interval, again indicating a well-bedded clay or silty clay in sharp lithologic contact with overlying and underlying sands. Drillers commonly refer to Brightseat confining unit clays as "dark, micaceous clays," sometimes containing "sands, shells, and lignite." This confining unit is easily correlated among geophysical well logs because it has a large areal extent and, when evaluated in combination with drillers' logs, it immediately underlies the greensands (or blacksands) of the Aquia aquifer and overlies the predominantly white sands of the Brightseat aquifer.

AQUIA AQUIFER

The Aquia aquifer is defined by the predominantly sandy facies of the Aquia Formation. These sediments are late Paleocene (Thanetian) in age and correlate with the Aquia-Rancocas aquifer in Maryland and the Beaufort aquifer in North Carolina (pl. 1). The Aquia aquifer crops out extensively in most major stream valleys of the study area just east of outcrops of the middle Potomac confining unit and in a small area in the northwestern region just west of the Potomac River. It overlies three separate hydrogeologic units—the Brightseat confining unit in the north-central area; the upper Potomac confining unit in the central and southern regions; and the middle Potomac confining unit throughout the western region. In turn, the Aquia aquifer is overlain by the Nanjemoy-Marlboro Clay confining unit. The Aquia aquifer is a continuous, elongate-lenticular sand body that thins slightly to the west and thins greatly to the east, pinching out near the western shore of the Chesapeake Bay and along the southeastern part of the study area. In the northern and central regions the aquifer pinches out eastward. This pinch-out is based on subsurface studies by Hansen (1974) and Chapelle and Drummond (1983) in Maryland and was extrapolated into the study area by the authors. Evidence for the exact position of this pinch-out is lacking owing to the scarcity of borehole and stratigraphic data available in the eastern region of the study area. In the southern region, the eastern limit is based on lithologic and geophysical log data, but again its position is approximate because of the scarcity of data. The eastern pinch-out is due to a sand-to-clay facies change in the downdip section of this aquifer unit (Hansen, 1974, p. 15). The Aquia aquifer dips eastward at approximately 10 ft/mi and attains a maximum known thickness of 147 ft at well 54R3 (pl. 2, B-B') in the northwestern part of the study area. Generally, this aquifer is thickest in the northwestern and west-central regions of the study area, attaining an average thickness of 100 ft or more. In the north-central and central regions, its thickness commonly ranges from 40 to 70 ft, and in the southern regions its thickness is usually about 20 ft. It rapidly thins westward to nearly zero thickness and extends, mainly in the subsurface, to just east of the Fall Line along most of its length.

The Aquia aquifer consists of a predominantly massively bedded unit composed of very fine to medium glauconite and quartz sands, in variation and with minor amounts of shells and clay. From outcrops in its type area, Aquia Creek of Stafford County, Va., Clark (1896) first described the Aquia Formation as a marine unit consisting of greensands and greensand marls interbedded with local thin layers composed almost entirely of shells. From analysis of the Oak Grove core (well 54P3), Gibson and others (1980, p. 16) describe the Aquia Formation as very well-sorted, medium- to dark-green, massive, fine to medium glauconitic sand with sparse shelly intervals. Reinhardt and others (1980, p. 5), who also analyzed the Aquia section of the Oak Grove core, note that the Aquia contains illitic clay matrices (generally less than 10 percent by weight), carbonate cemented intervals, and a basal part containing coarse sands, pebbles, small bones, and fish teeth.

Numerous wells drilled in the study area penetrate this aquifer, and many light industrial, small municipal, and domestic users use the Aquia as a water-supply source. Chapelle and Drummond (1983, p. 75) report that ground water produced from the Aquia in Maryland is capable of supplying large quantities of water suitable for most uses. The Aquia in the northern two-thirds of the study area is very similar to the Aquia of Maryland, although somewhat thinner, and similar ground-water conditions exist. However, in the southern part of the study area, the Aquia is much finer grained, commonly contains a limy-mud matrix, and thin limestone beds, and is not commonly used as an aquifer.

Typical electric-resistivity log patterns of the Aquia aquifer sediments are illustrated on geophysical logs of wells 53P4, 54P3, 56N7, plate 2, A-A′; 52N16, 54Q11, 54R3, plate 2, B-B′; 53K17, 56M10, 57P1, plate 2, C-C′; 54H11, 55H1, 57G22, 57G25, plate 3, E-E′; and 54G10, 55F20, 56F42, plate 3, F-F′. Generally, these resistivity patterns are wave-shaped in profile, commonly a series of two or three waves which often contain sharp spiky peaks. The wave-shaped profiles indicate the massively bedded sequences of glauconitic sands characteristic of this aquifer, whereas the sharp spiky peaks indicate the shell beds and related, calcareously cemented shell layers also common in this aquifer. Noted in many resistivity logs, especially in the updip sections, is a pronounced thin U-shaped profile in the lowermost part of this aquifer. This U-shaped profile indicates the basal coarser part of this unit, as described previously from the Oak Grove core analysis. Resistivity logs generally indicate medium resistivity values for these sediments, except for the basal part, which generally has a high resistivity value. Also, resistivity logs exhibit sharp lower and upper lithologic contacts for the massive Aquia sand unit. Corresponding natural-gamma logs have a characteristically high erratic gamma response to these sediments, which appears to suggest an unusually high clay content, but in fact, is an indication of the high glauconite content. The hydrogeologic boundaries cannot be determined from natural-gamma logs because the lithologic contacts with the overlying and underlying clays are masked by the high gamma response to the glauconite. Drillers commonly refer to the Aquia aquifer sediments as "fine, blacksands or greensands" that often contain shells and(or) hard-streaks. Drillers note that these sediments are generally quite soft and at times refer to them as "running sands, or caving sands." The Aquia aquifer is easily correlated among geophysical logs because the resistivity pattern changes little from log to log and shows numerous correlatable shell-bed spikes. By using the combination of drillers' logs and geophysical logs, Aquia aquifer sands can be located between two distinctive clays—an upper pink, light-gray, or dark-brown clay and a lower dark-gray or black clay. The contour map delineating the top of this aquifer (pl. 17) can be used to indicate, very accurately, the altitude of the top of this aquifer throughout its extent. Thus, the top of this unit is fairly constant and can be predicted between control wells separated by large distances. Studies (Drobnyk, 1965; Hansen, 1974; Gibson and others, 1980) on the depositional environment of the Aquia Formation suggest that the Aquia was deposited in a shallow, inner shelf marine basin, below wave base, with slight fluctuation of water depths (100- to 330-ft range).

NANJEMOY-MARLBORO CLAY CONFINING UNIT

The Nanjemoy-Marlboro Clay confining unit is defined as the predominantly clayey deposits of the Nanjemoy and Marlboro Clay Formations. This confining unit is composed of two distinctly different formations—the lower Marlboro Clay and the upper Nanjemoy. These sediments are latest Paleocene to middle Eocene in age and correlate with the Nanjemoy-Marlboro confining unit in Maryland and the confining unit overlying the Beaufort aquifer in North Carolina (pl. 1). The Nanjemoy-Marlboro Clay confining unit crops out extensively in most of the major stream valleys of the study area just east of outcrops of the Aquia aquifer. It overlaps the Aquia aquifer and is overlain by the Chickahominy-Piney Point aquifer throughout most of the study area. This confining unit attains a maximum known thickness of 172 ft at well 66M1 in the northeastern part of the Eastern Shore Peninsula and thins to nearly zero thickness along its western limit near the Fall Line. Its thickness is somewhat variable (fig. 18), but generally this unit is wedge shaped and thickens towards the northeast. The lower formation (the Marlboro Clay) of this confining unit is areally restricted to the northern half of the study area and its eastern extent beneath the Chesapeake Bay and Eastern Shore Peninsula is not known owing to the lack of lithologic and stratigraphic data in these areas. The upper formation (the Nanjemoy) is areally extensive throughout the study area and comprises most of the thickness of this unit. In the southern area, the Marlboro Clay pinches out against the northern flank of the Norfolk arch and the Nanjemoy directly overlies the Aquia aquifer. The Marlboro Clay was first identified and described by Clark and Martin (1901) as a red clay and was considered, until just recently, to be the lowest member of the Nanjemoy Formation. Glaser, in 1971, raised the Marlboro Clay to formation status based on its mappability as a unit, and Gibson and others (1980, p. 29) report that it straddles the Paleocene-Eocene boundary. The name Nanjemoy also was first applied by Clark and Martin (1901) for highly argillaceous greensands and was divided into two members—a lower clayey Patapsco Member and an upper sandy Woodstock Member. In the northwestern part of the study area, the upper Woodstock Member of the Nanjemoy is considered to be part of the overlying Chickahominy-Piney Point aquifer because of its predominantly sandy facies. However, geophysical logs indicate that the Woodstock Member becomes increasingly clayey downdip and throughout the rest of the study area and it is, therefore, considered as part of the Nanjemoy-Marlboro Clay confining unit.

Lithologic analysis of the Tertiary section from the Oak Grove core hole (well 54P3) by Reinhardt, Newell, and others (1980) indicates that the Marlboro Clay consists of a compact, massively bedded, extensively burrowed, predominantly red to gray, mottled clay composed mostly of a kaolinite-illite mixture. They also note that this formation is essentially structureless, but contains irregular lenses of locally laminated and cross-laminated fine silt. Reinhardt, Newell, and others' (1980) analysis of the Nanjemoy reveals that it consists of a thick, massively bedded, dark-green to dark brown-green, variably clayey and shelly, micaceous greensand. The clay content ranges from 15 to 80 percent and is composed mostly of illite. They also note that this unit is extensively burrowed, which produces a mottled appearance to the sediments, and that the Nanjemoy becomes increasingly sandy in its upper part (i.e., Woodstock Member). The Marlboro Clay commonly ranges from 2 to 20 ft thick and the Nanjemoy commonly ranges from 20 to over 120 ft thick.

Typical electric-resistivity log patterns of the Nanjemoy-Marlboro Clay confining unit sediments are best illustrated on geophysical logs of wells 53P4, 54P3, 56N7, 59L5, 60L19, plate 2, A-A'; 52N13, 54Q11, 54R3, plate 2, B-B'; 52K10, 53K17, 56M10, 57P1, plate 2, C-C'; 55H1, 57J3, 58J11, 58J5, 59K17, 59K19, plate 3, D-D'; 52K6, 54J4, 54H11, 55H1, 57G22, 57G25, 58F3, plate 3, E-E'; 56F42, 57E10, 57D3, 58D9, 59D1, 60C6, plate 3, F-F'; and 58B115, 58C51, 58C8, plate 4, I-I'. Generally, the resistivity patterns are flat in profile, characteristic of massively bedded, predominantly clayey deposits. Commonly these flat profiles contain interbedded sandy clays or sands, which cause an erratic appearance to the generally flat resistivity patterns. The lower contact with the underlying Aquia aquifer is always sharp and pronounced, and the upper contact with the Chickahominy-Piney Point aquifer is also sharp and pronounced, but can be gradational, especially where the upper Woodstock Member of the Nanjemoy is predominantly sandy. In the southern part of the study area, this confining unit becomes considerably thinner as it approaches and transgresses the Norfolk arch area. Also, it becomes more interbedded with sands and sandy clays in the southeast, as illustrated in well logs 59C28 and 60C25, plate 4, J-J'. Corresponding natural-gamma log patterns indicate the presence of massively bedded glauconitic clayey sediments. Drillers commonly refer to the Nanjemoy-Marlboro Clay confining unit sediments as "pink, gray, or sometimes white clay" and "slick or sticky" for the Marlboro Clay, and as "dark green or brown-green, silty clays or sandy clays" commonly with "shells and black sands" for the Nanjemoy. These clayey confining-unit sediments are easily recognized on resistivity logs and drillers' logs by their characteristic thick clay pattern and stratigraphic position above the Aquia greensands. The Nanjemoy-Marlboro Clay confining unit is easily identified and correlated on resistivity logs because it is overlain and underlain by characteristic sands of the Chickahominy-Piney Point and Aquia aquifers, respectively.

Analyses from the Oak Grove core hole (Reinhardt and others, 1980; Gibson and others, 1980) indicate that the paleoenvironment, for the Marlboro Clay, consisted of a shallow and protected (ponded), low-energy, brackish water basin, such as an estuary or lagoon, and for the Nanjemoy, a stable or protected inner to middle marine shelf with water levels that ranged from about 50 to 230 ft.

CHICKAHOMINY-PINEY POINT AQUIFER

The Chickahominy-Piney Point aquifer is defined for the most part by the predominantly sandy deposits of the Chickahominy and Piney Point Formations. The Piney Point comprises most of the aquifer unit, with the Chickahominy and the Woodstock Member of the Nanjemoy Formations comprising the remainder. These sediments are middle to late Eocene in age and correlate with the Piney Point-Nanjemoy aquifer in Maryland and the Castle Hayne aquifer in North Carolina (pl. 1). The Chickahominy-Piney Point aquifer crops out in most of the major stream valleys of the study area from the James River northward, just east of outcrops of the Nanjemoy-Marlboro Clay confining unit. It overlies the Nanjemoy-Marlboro Clay confining unit and is overlain and transgressed by the Calvert confining unit. The Chickahominy-Piney Point aquifer is wedge shaped in cross section, thickens eastward, and thins to nearly zero thickness along its western limit in the western part of the study area. Similar to the Aquia aquifer, this aquifer undergoes a sand-to-clay facies change that causes it to pinch-out in the vicinity of the Eastern Shore Peninsula (fig. 19). East of this line, the aquifer becomes predominantly clayey. The eastern limit (pinch-out) of this aquifer is an approximate boundary based on subsurface studies done in Maryland and Delaware by Hansen (1972), Leahy (1982), Chapelle and Drummond (1983) and extrapolated by the authors into the study area. Evidence for the exact position of this pinch-out is lacking due to the scarcity of borehole and stratigraphic data available in the northeastern and east-central parts of the study area. In the southeastern area, lithologic and geophysical log data indicate that the Chickahominy-Piney Point aquifer is continuous throughout the area and that the facies change probably occurs offshore. The Chickahominy-Piney Point aquifer dips eastward at approximately 12 ft/mi. In the western half of the study area, the contours of the top of the aquifer are more widely spaced than in the eastern half due to postdepositional erosion and subsequent beveling of the Piney Point Formation during the Oligocene and early Miocene (Otton, 1955; Hansen, 1972, 1977). Also, the northwestern limit is not the actual margin of the Piney Point Formation, but rather reflects the limit of the upper, predominantly sandy facies, of the underlying Nanjemoy Formation (the Woodstock Member) which are hydrologically connected to the Chickahominy-Piney Point aquifer. This aquifer attains a maximum known thickness of 140 ft at well 60L19, plates 2, A-A′ and 3, D-D′, in the north-central region of the study area, and 165 ft at well 61B2, plates 3, F-F′ and 4, K-K′, in the southeastern region. It generally ranges from 50 to 100 ft thick throughout most of the study area.

The Chickahominy-Piney Point aquifer consists of thickly bedded olive-green to dark greenish-gray, fine to coarse, glauconitic quartz sands interbedded with thin glauconitic/illitic clays and calcareously cemented shell beds. The Piney Point Formation was first identified (Shifflett, 1948) from characteristic foraminifera in cuttings of drilled wells in the Coastal Plain of southern Maryland. This unit was later named and defined by Otton (1955), again based on sample cuttings in Maryland, as a fine to medium glauconitic sand interspersed with thin shell rock layers, and containing a diagnostic late Eocene age foraminiferal assemblage. The Piney Point has since been redefined by Brown and others (1972) to be middle Eocene in age. Cushman and Cederstrom (1945, p. 2) identify and define the Chickahominy Formation as a highly glauconitic clay interbedded with glauconitic sands and shell rock layers, and containing characteristic foraminiferal fauna of late Eocene age. The type well for the Chickahominy Formation is located in Yorktown, Va., but many other wells throughout the lower York-James Peninsula penetrate this formation. During this study, the authors noticed no appreciable difference or distinction between the Chickahominy and Piney Point Formations based on lithologic and geophysical log-correlations; therefore, they were combined into the same aquifer unit. It should be noted that the Chickahominy-Piney Point aquifer also contains sediments of late Oligocene and early Miocene age. These sediments are very thin and typically consist of fine-grained, white, quartzose sands with glauconite and shells interspersed throughout. The glauconite is primarily reworked material (L.W. Ward, U.S. Geological Survey, oral commun., 1983) and the shells commonly form thin indurated layers in the subsurface, much like the shell layers of the Piney Point Formation. Ward (1985) has identified these sediments in outcrops along major streams in the central part of the study area and proposes the name "Old Church Formation" for this unit, assigning it to the basal part of the Chesapeake Group. Analyses (L.E. Edwards, U.S. Geological Survey, written commun., 1982 and 1983) of core samples from Gloucester County (well 58H4) and the cities of Suffolk (well 58B115) and Chesapeake (near well 58A2) have also identified the presence of these deposits. Electric-resistivity logs, in conjunction with paleontological analysis, indicate that these sandy deposits directly overlie the Piney Point and Chickahominy Formations and, for this reason, are included in the Chickahominy-Piney Point aquifer and are not further differentiated in this report.

Numerous wells in the study area penetrate and provide information on this aquifer. Many light industrial, small municipal, and domestic users use the Chickahominy-Piney Point aquifer as a water-supply source. Chapelle and Drummond (1983, p. 75) report that ground water produced by the Piney Point in Maryland is capable of supplying large quantities of water suitable for most uses. The Chickahominy-Piney Point aquifer of Virginia is very similar in nature to the Piney Point-Nanjemoy aquifer of Maryland, and it is expected that generally similar ground-water conditions exist.

Typical electric-resistivity log patterns of the Chickahominy-Piney Point aquifer sediments are best illustrated on geophysical logs of wells 56N7, 58N3, 59L5, 60L19, plate 2, A-A'; 52K10, 53K17, 55L2, 56M10, 57P1, plate 2, C-C'; 55H1, 57J3, 58J11, 58J5, plate 3, D-D'; 54J4, 56G9, 57G22, 57G25, plate 3, E-E'; 56F42, 58D9, 59D1, 60C7, plate 3, F-F'; 57A1, plate 3, G-G'; 58B115, 58C51, plate 4, I-I'; and 59C28, 60C25, plate 4, J-J'. Generally, these resistivity patterns are both rectangular and spiky in profile, and commonly, two distinct sand units are recognized, especially in the eastern half of the aquifer's extent. The rectangular profiles indicate the thickly bedded, clean sands characteristic of this aquifer and the spiky profiles indicate the numerous calcareous-cemented shell beds also characteristically associated with this aquifer. The indurated shell beds within this aquifer are usually quite thin, a few inches to 1 or 2 ft, but may locally reach thicknesses of 8 ft or more. Resistivity logs generally exhibit very high resistance values for these sediments and the upper and lower contacts with the overlying Calvert and underlying Nanjemoy-Marlboro Clay confining units are commonly sharp and abrupt. Corresponding natural-gamma logs commonly exhibit a highly erratic pattern for these sediments, responding to the glauconite and quartz sands and interbedded clays. Generally, hydrogeologic boundaries cannot be determined from natural-gamma logs of these sediments because of the highly irregular responses and also because the glauconite produces a claylike response that masks the sand-clay contacts. Drillers commonly refer to the Chickahominy-Piney Point aquifer sediments as "black and white sands, or salt and pepper sands" containing "shell rock, limestone, and dark silty clay" interspersed throughout the sands. The Chickahominy-Piney Point aquifer is easily correlated among geophysical resistivity logs because of its characteristic pattern and because it generally lies between two thick clay beds, as illustrated on geophysical logs of wells 58J11, plate 3, D-D' and 56N7, plate 2, C-C'. The contour map delineating the top of this aquifer (fig. 19) can be used to indicate, fairly accurately, its approximate altitude throughout the study area. The top of this unit is fairly constant and uniform and can be predicted between points separated by large distances.

Studies (Hansen, 1972) indicate that the depositional environment of the Piney Point Formation consisted of a marine transgression and that the sediments were deposited on a shallow, inner to middle marine shelf dominated by longshore currents.

MIOCENE AND PLIOCENE CHESAPEAKE GROUP

Marine deposits of Miocene and Pliocene age constitute the upper Tertiary (Neogene) stratigraphic section known as the Chesapeake Group. This group consists of six formations (excluding the lowermost Old Church Formation, previously discussed), which are, from oldest to youngest, the Calvert, Choptank, St. Marys, Eastover, Yorktown, and Chowan River. The first five formations compose two aquifers and three confining units: the Calvert confining unit, St. Marys-Choptank aquifer, St. Marys confining unit, Yorktown-Eastover aquifer, and Yorktown confining unit, within the Chesapeake Group. Sediments of the Chowan River Formation are hydrologically part of the surficial unconfined aquifer system and are discussed in the section on the Columbia aquifer. The Pliocene Bacons Castle Formation as used by Oaks and Coch (1973) is included in the Yorktown-Eastover aquifer and the Yorktown confining unit because it is hydrologically part of both units.

Throughout the study area, major regional unconformities separate the Chesapeake Group from the underlying lower Tertiary Pamunkey Group and the overlying Quaternary sediments, undifferentiated. Within the Chesapeake Group lesser unconformities separate each of the formations. The Chesapeake Group generally consists of an eastward-thickening wedge of intermixed shelly sands, silts, and clays, which can be divided on the basis of sediment size into a very fine lower part, composed of the Calvert, Choptank, and St. Marys Formations; a very fine to medium intermediate part, composed of the Eastover Formation; and a fine to very coarse upper part, composed of the Yorktown Formation. The lower sequence typically consists of silty clays interbedded and intermixed with very fine sands, diatomite, and some shells. The intermediate part typically consists of shelly, silty to clayey, fine to medium sands; and the upper part typically consists of fine to medium shelly sands, with interbedded silty clays, shell layers, and very coarse basal lag deposits. For most of the Chesapeake Group, sedimentation occurred in a shallow, low-energy, inner-shelf marine basin that was below wave base, as indicated by the predominance of clays and silts. Throughout

Chesapeake time, effective sea level in the marine basin fluctuated, but generally declined during deposition of each successive formation; that is, sedimentation occurred in a progressively shoaling environment with deposition finally taking place in a shallow, embayed sublittoral marine environment, as indicated by barrier complexes and the diversity of near-shore sediments in the Yorktown Formation. Also, throughout Chesapeake time, the locus of deposition shifted continually southward with each succeeding formation, from the Salisbury embayment in southern Maryland past the Norfork arch in southern Virginia and into the Albemarle embayment of North Carolina (Ward, 1984, p. 68).

Recognition of the typical strata in the Chesapeake Group (clay, sand, and shell beds) in the Coastal Plain dates back to the late 1700's and throughout the 1800's. Exposures along the western shore of the Chesapeake Bay in Maryland were originally termed the "Chesapeake Formation" by Darton (1891, p. 433). In 1892, Dall and Harris changed Darton's term to "Chesapeake Group," and, in 1902 Shattuck named three formations—the Calvert, Choptank, and St. Marys—within the Chesapeake Group. Shortly following, Clark and Miller (1906) added a fourth formation—the Yorktown. In 1980, Ward and Blackwelder named the Eastover, and the Chowan River was named by Blackwelder (1981).

The Chesapeake Group crops out extensively throughout the study area. The lower formations are exposed mostly in the major stream valleys of the western area from the Appomattox and James Rivers northward, while the upper formations crop out in broad reaches throughout the western and central areas, and in major stream valleys of the southeastern area. Sediments of the Chesapeake Group thicken to the northeast, north of the Norfolk arch, and to the southeast, south of the arch. The predominantly sandy deposits of the upper Chesapeake Group yield large quantities of water that are generally suitable for most uses; whereas, the predominantly clayey deposits of the lower Chesapeake Group form thick confining units throughout the study area. These lower sediments consist of homogeneous and areally extensive blanket-type deposits that, for the most part, change little over large areas. However, the upper sediments tend to vary more in composition and thickness areally, owing to their nature of deposition and the effects of erosional processes.

CALVERT CONFINING UNIT

The Calvert confining unit is defined by the predominantly clayey deposits of the Calvert Formation. These sediments are early to middle Miocene in age and correlate with the lower Chesapeake confining unit in Maryland and the confining unit overlying the Castle Hayne aquifer in North Carolina (pl. 1). The Calvert confining unit crops out extensively in most of the major stream valleys in the western part of the study area, just east of the outcropping Chickahominy-Piney Point aquifer or the Nanjemoy-Marlboro Clay confining unit. It overlies the Chickahominy-Piney Point aquifer and is overlain primarily by the St. Marys confining unit. In the northeastern and east-central parts of the study area it is overlain by the St. Marys-Choptank aquifer and in the western part, by the Yorktown-Eastover aquifer. This confining unit is wedge shaped in cross section and thickens and dips eastward. It attains a maximum known thickness of 350 ft at well 66M1 (fig. 7) in the northeastern part of the study area and thins to nearly zero thickness along its western limit near the Fall Line.

The Calvert confining unit consists of interbedded shelly sandy clays, silty clays, and diatomite, and is typically dark grayish-green in color. A characteristic lag deposit consisting of coarse quartz sand and pebbles, phosphate pebbles and phosphatic sharks' teeth, shells, and bone fragments, generally marks the basal contact of the Calvert confining unit with the underlying Chickahominy-Piney Point aquifer. The Calvert Formation was named by Shattuck in 1902 from exposures along the western shore of the Chesapeake Bay at Calvert Cliffs, Md. From analysis of the Oak Grove core hole (well 54P3), Reinhardt and others (1980, p. 8) described the Calvert as a gray and very fine-textured sediment with fine, angular quartz sand in a silt to clay matrix in the upper part of the formation underlain by a thin diatomite and basal clay intermixed with coarse quartz sand.

Typical electric-resistivity log patterns of sediments in the Calvert confining unit are best illustrated on geophysical logs of wells 56N7, 58N3, 59L5, 60L19, plate 2, A-A'; 55L2, 57P1, plate 2, C-C'; 57J3, 58J11, 59K17, plate 3, D-D'; 56G9, 57G22, 57G25, 57F2, 58F3, plate 3, E-E'; and 57E10, 58D9, 59D1, 60C7, plate 3, F-F'. Generally, the resistivity patterns are "flat" in profile, characteristic of massively-bedded predominantly clayey deposits. Noticeable, however, within the typically flat profile are small, short "spikes" and "hills," which reflect the interbedded shell, sand, and diatomaceous layers. The resistivity pattern for well 54P3 (the Oak Grove core hole), plate 2, A-A', is typical of a profile of the Calvert confining unit because of abundant diatomite in this region. Diatomaceous sediments are high in silica, and thus produce higher resistivity profiles on geophysical logs that should normally show a flat clayey pattern. The lower contact with the underlying Chickahominy-Piney Point aquifer is very sharp and pronounced, and the upper contact with the St. Marys confining unit is usually marked by a series of spikes representing thin sandy layers on resistivity logs. In the western part of the study area, where the Calvert confining unit is overlain by the Yorktown-Eastover aquifer, the contact is usually marked by a steady increase in resistivity on geophysical logs. Likewise, in the eastern part of the study area, where the Calvert confining unit is overlain by the St. Marys-Choptank aquifer, the contact is also marked on geophysical logs by a steady increase in resistivity. Corresponding natural-gamma log patterns also indicate massively-bedded predominantly clayey deposits for this confining unit, and its base is marked by a very high gamma-response spike. This very high gamma spike is the most characteristic and diagnostic natural-gamma log pattern in the Virginia Coastal Plain. It is caused by the basal phosphate lag deposit mentioned previously and is used as one of the primary marker-bed features in geophysical log correlations. The only place in which this characteristic gamma-log pattern is missing is in the western part of the study area near the Fall Line where, presumably, the phosphate was never deposited.

Drillers commonly refer to the sediments in the Calvert confining unit as "blue, gray, or green clays or marls" sometimes containing sands or shells. The Calvert confining unit is easily correlated on geophysical resistivity logs because its characteristic flat pattern is directly above the high resistivity pattern of the Chickahominy-Piney Point aquifer. The contour map delineating the thickness of the confining unit (fig. 20) can be used to predict, fairly accurately, its approximate thickness between points that are separated by large distances.

Studies (Reinhardt and others, 1980, p. 2; Blackwelder and Ward, 1976, p. 11; and Gibson, 1982, p. 11) indicate that the depositional environment of the Calvert Formation was below wave-base in a siliceous, inner to middle-marine shelf that oscillated between semiprotected embayment to open-ocean circulation.

ST. MARYS-CHOPTANK AQUIFER

The St. Marys-Choptank aquifer is defined by the predominantly sandy facies of the St. Marys and Choptank Formations. These sediments are middle Miocene in age and correlate with the lower Chesapeake aquifer in Maryland and the Pungo River aquifer in North Carolina (pl. 1). The St. Marys-Choptank aquifer is restricted to the subsurface in the northeastern and east-central parts of the study area and its updip limit has not been defined owing to the lack of sufficient borehole and paleontologic information. It partially overlies the Calvert confining unit and is overlain by the St. Marys confining unit. The St. Marys-Choptank aquifer is wedge shaped in cross section, thickens northeastward, and pinches out updip beneath the Chesapeake Bay (fig. 21). It also pinches out southward against the Norfolk arch and, thus, no direct connection exists across the southeastern area with the Pungo River aquifer in North Carolina. This aquifer strikes generally north-south and is 160 ft thick at well 66M1. The St. Marys and Choptank Formations were names applied by Shattuck (1902) for exposures in Maryland's St. Marys County and along the Choptank River, respectively.

Only two wells—66M1 and 68M2 (fig. 7)—located in the northeastern part of the Eastern Shore Peninsula of Virginia penetrate deeply enough to provide information on the St. Marys-Choptank aquifer in Virginia. All other wells on the Eastern Shore Peninsula, for which there are reliable data, penetrate only to the overlying Yorktown-Eastover or Columbia aquifers. Therefore, identification and analysis of the St. Marys-Choptank aquifer is primarily from previous hydrogeologic studies (Rasmussen and Slaughter, 1955; Hansen, 1972; Cushing and others, 1973) conducted in the eastern part of Maryland. Based on these studies, sparse geophysical data, and thickness and structure-contour maps of overlying and underlying hydrogeologic units in the area, the St. Marys-Choptank aquifer has been extrapolated into the eastern part of the study area (fig. 21). In these previous studies, equivalent strata to the St. Marys-Choptank aquifer are described as fine to medium-grained, gray, quartzose sands, often containing shells and interlayered with clays and silts. The driller's log from well 68M2 describes the sediments as fine sands with soft clays and hard streaks. Sinnott and Tibbetts (1954, p. 16; 1968, p. 29 and 81) concluded, after studying the ground-water resources of the Eastern Shore Peninsula, that water from sands below 300 ft is likely to be of a quality unsuitable for most uses. More recent ground-water studies by Hansen (1972, p. 112-115) and Cushing and others (1973, pls. 6-8) utilizing water-quality analyses from wells in nearby Maryland support Sinnott and Tibbetts' premise about poor quality water below 300 ft. In Virginia, there are no known users of the St. Marys-Choptank aquifer. The depositional environment of the sandy facies in the St. Marys and Choptank Formations reflect the influence of delta outbuilding (southward) into the Salisbury embayment from New Jersey (Gibson, 1982, p. 1-18). Generally, the depositional environment consisted of a shallow, open-marine, inner-shelf setting that was modified by varying water depths and sporadic influxes of terrigenous clastic sediments from the north (Gibson, 1984, p. 5).

ST. MARYS CONFINING UNIT

The St. Marys confining unit is defined by the predominantly clayey facies of the St. Marys Formation, but also includes, in places, the lower clayey facies of the Eastover Formation. These sediments are middle to late Miocene in age and correlate with the St. Marys confining unit in Maryland and the confining unit overlying the Pungo River aquifer in North Carolina (pl. 1). The St. Marys confining unit is restricted to the subsurface except where it crops out in the Rappahannock River valley in the northwestern part of the study area. It overlies the St. Marys-Choptank aquifer in the eastern part of the study area and overlies the Calvert confining unit throughout the central part. It is overlain by the Yorktown-Eastover aquifer throughout its extent. This confining unit is wedge shaped in cross section and thickens and dips eastward. It attains a maximum known thickness of 318 ft at well 68M2 (fig. 7) in the northeastern part of the study area and thins to nearly zero thickness along its western limit (fig. 22). The lower part of this confining unit (the St. Marys Formation) is restricted to the central, north-central, and northeastern parts of the study area (Blackwelder and Ward, 1976, p. 19). Its southern limit was probably influenced by the effects of the Norfolk arch. The upper part of this confining unit (the clayey facies of the Eastover Formation) is extensive throughout the study area, probably contributing much of this confining unit's thickness in the central and western areas and certainly all of it in the southeastern area.

The St. Marys confining unit consists of interbedded silty and sandy clay with varying amounts of shells and is typically bluish-gray to gray in color. Gibson (1982, p. 14) described the St. Marys Formation as dominantly clay and sandy clay, generally finer grained and more clayey than the underlying formations of the Chesapeake Group, somewhat massive, and slightly fossiliferous. The lower clayey facies of the Eastover Formation, as described by Ward and Blackwelder (1980, p. 12), consists of poorly sorted, sandy clay that fines upward to clay, is greenish-gray in color, and sparsely fossiliferous.

Typical electric-resistivity log patterns of sediments in the St. Marys confining unit are best illustrated on geophysical logs of wells 56N7, 59L5, 60L19, plate 2, A-A'; 57J3, 58J11, 59K17, plate 3, D-D'; 57G25, 57F2, 58F3, 59D20, plate 3, E-E'; and 58D9, 59D1, 60C7, plate 3, F-F'. Generally, the resistivity patterns are "flat" in profile, characteristic of massively bedded, predominantly clayey deposits. Commonly these flat profiles contain interbedded sandy clays which cause a "hilly" or "spiky" appearance to the generally flat resistivity patterns. The contact with the underlying Calvert confining unit is usually marked by a small spike or hill on resistivity logs (see logs previously mentioned), indicating a basal shelly and (or) sandy clay layer. The upper contact with the Yorktown-Eastover aquifer is generally marked by a gradual but steady increase in resistivity on geophysical logs, indicating progressively more sandy sediments. Corresponding natural-gamma log patterns also indicate the presence of massively bedded clayey sediments. Drillers commonly refer to the sediments of the St. Marys confining unit as "blue or gray clays, or sandy clays."

Ward (1984, p. 68) described the depositional environment as a broad, shallow, open-marine to partially embayed, inner-shelf area.

YORKTOWN-EASTOVER AQUIFER

The Yorktown-Eastover aquifer is defined, for the most part, by the predominantly sandy deposits of the Yorktown Formation and the upper part of the Eastover Formation in the Chesapeake Group, but also includes the sandy facies of the Bacons Castle Formation as used by Oaks and Coch (1973). These sediments are late Miocene and Pliocene in age and correlate with the upper Chesapeake aquifer in Maryland and the Yorktown aquifer in North Carolina (pl. 1). The Yorktown-Eastover aquifer overlies the St. Marys confining unit in the eastern and central parts of the study area, and the Calvert confining unit in the western and south-central parts. It is overlain by the Yorktown confining unit in the central and eastern parts of the study area, and is generally unconfined throughout the western part. This aquifer extends throughout the study area except in the middle to upper reaches of major stream valleys and their larger tributaries where it has been removed by erosion (fig. 23). It crops out in a broad area covering most of the uplands in the western and north-central parts of the study area. It is also exposed along stream valleys throughout the central and southeastern parts. The aquifer is much thinner and more highly dissected in the northern, western, and central parts of the Virginia Coastal Plain than in the southern part, where it thickens considerably. The Yorktown-Eastover aquifer is wedge shaped in cross section, thickens and dips eastward, and thins to nearly zero thickness along its western and stream-eroded limits. It attains a maximum known thickness of 296 ft at well 68M2 (fig. 7) in the northeastern area, and 240 ft at well 63C1 (fig. 7) in the southeastern part. In the eastern half of the study area its thickness generally ranges between 100 to 200 ft.

The Yorktown-Eastover aquifer typically consists of interlayered, thick to massively-bedded shelly sands separated by thinner clay beds. In the western half of the study area the clays of this aquifer are very thin and areally discontinuous; however, in the downdip region the clays become more massive and extensive, subdividing the aquifer into three distinct subunits (Converse, Ward, Davis, and Dixon, 1981).

Geologically, the Yorktown-Eastover aquifer consists of three formations that each represent marine transgressions resulting in shallow, embayed areas, with each having similar characteristic depositional patterns. Generally, the formations fine upwards from a basal coarse sand and gravel lag deposit, through a fine to medium, shelly, sand facies, and are capped by a very fine silty clay facies. These various lithofacies represent a succession of depositional environments from estuarine to marine. Besides fining upwards, the units also fine towards the east, with the majority of sediments being coarser in the western area and finer near the coast. The Eastover Formation was recently identified and named by Ward and Blackwelder (1980) for exposures along the James River, Surry County, Va. This formation consists of a series of sediments that stretches from Maryland south into North Carolina. Its upper sandy facies, which comprises the lower part of the Yorktown-Eastover aquifer, is described as consisting of a fine to medium-grained, well-sorted, shelly sand with occasional clay layers, and grayish-blue in color. The Yorktown Formation, which constitutes the greater part of this aquifer, was originally named by Clark and Martin (1906) for exposures along the York River near Yorktown, Va. Johnson (1969) recognized eight lithofacies within the Yorktown ranging from sand through sandy shell and shell beds to silty clays. The surficial Bacons Castle Formation was named by Coch (1965) for deposits west of Surry Scarp, a north-northeast trending erosional feature (Bick and Coch, 1969), and consists of a lower sandy facies and an upper bedded-silt facies. The exposed lower sandy facies defines the eastern limit of the unconfined Yorktown-Eastover aquifer. Most wells in the study area penetrate and provide information on this aquifer. The Yorktown-Eastover aquifer is primarily used for light industrial and domestic supply; however, in the eastern part of the study area it supplies most of the water for all users. Also, in the eastern part of its area, the lower part of the aquifer contains water that tends to be high in chlorides, thus limiting its use.

Typical electric-resistivity log patterns of sediments in the Yorktown-Eastover aquifer are best illustrated on geophysical logs of wells 57G22, 57G25, 57F2, 59D20, plate 3, E-E′; 56F42, 57D3, 59D1, 60C7, plate 3, F-F′; and 54A3, 55A1, 56B9, 58B115, 60C25, plate 4, J-J′. Generally, these resistivity patterns are highly variable and erratic, indicating its interbedded nature of sands and clays. Commonly though, there are distinct sandy zones and clayey zones that are easily correlated from one log to another. Resistivity logs generally exhibit very high values for these sediments, and the upper and lower contacts with the overlying Yorktown confining unit and the underlying St. Marys or Calvert confining units are easily recognized. Corresponding natural-gamma logs of these sediments generally indicate a highly sandy unit with interbedded clays. Drillers commonly refer to the sediments in the Yorktown-Eastover aquifer as "sands, shells, and clays," frequently with hard shell layers and gray to yellow in color. Studies (Johnson, 1969, 1972; Blackwelder and Ward, 1976; Ward and Blackwelder, 1980) indicate that the depositional environment of the Eastover, Yorktown, and Bacons Castle Formations consisted of a large, very shallow, embayed shelf that was alternately exposed and submerged by temperate marine seas.

YORKTOWN CONFINING UNIT

The Yorktown confining unit is defined by the predominantly clayey deposits of the upper parts of the Yorktown Formation and the Bacons Castle Formation (Oaks and Coch, 1973). These sediments are Pliocene in age and correlate with the upper Chesapeake confining unit in Maryland and the confining unit overlying the Yorktown aquifer in North Carolina (pl. 1). The Yorktown confining unit crops out along the major stream valleys of the central area just east of the outcropping Yorktown-Eastover aquifer. It overlies the Yorktown-Eastover aquifer throughout the central and eastern part of the study area and is overlain by the Columbia aquifer wherever land-surface elevation is less than 100 ft. The Yorktown confining unit is not a single, areally extensive clay layer, but rather, is a series of coalescing clay layers at or near the top of the Yorktown or Bacons Castle Formations. These clay layers are the final stage of the fining-upwards depositional sequences which initially formed the underlying sandy sediments of the Yorktown-Eastover aquifer. This confining unit is wedge shaped in cross section, dips eastward, and attains a maximum known thickness of 109 ft at well 68M2 (fig. 7) in the northeastern part of the study area. Its thickness is variable (fig. 24), but generally increases eastward. The Yorktown confining unit consists of very fine sandy to silty clays that are highly variable in color, varying from multicolored to dark gray. This confining unit lies at or very near the surface throughout the central part of the study area where it is highly dissected or thinned by streams. In the northern and central parts, the confining unit is correlated primarily by drillers' logs and natural-gamma logs, because electric-resistivity logs commonly stop recording within 20 to 40 ft of the surface. In the eastern and southern parts, however, it is easily recognized in all types of logs. Typical electric-resistivity log patterns of sediments of the Yorktown confining unit are best illustrated on geophysical logs of wells 54D2, 56B1, 57A1, plate 3, G-G′; 55D5, plate 4, H-H′; 58B115, 58C51, plate 4, I-I′; 54A3, 56B9, 56B1, plate 4, J-J′; and 60B1, 61B2, 62C5, plate 4, K-K′. Commonly, the resistivity patterns exhibited are a broad U-shaped profile indicating the uppermost competent clay unit in the stratigraphic section. These clays were deposited on a shallow, marine shelf in broad lagoonal and bay areas.

QUATERNARY SEDIMENTS, UNDIFFERENTIATED

COLUMBIA AQUIFER

The Columbia aquifer is defined by the predominantly sandy surficial deposits above the Yorktown confining unit. These sediments are, for the most part, Pleistocene and Holocene in age, but also include sandy Pliocene sediments that lie above the clayey deposits of the Yorktown confining unit. The aquifer correlates with the surficial aquifers in Maryland and North Carolina. The Columbia aquifer is generally unconfined; however, clayey sediments within it may produce local confined or semi-confined conditions. This aquifer is highly variable in thickness, but generally thickens eastward and attains its maximum known thickness along the southeastern coast of the study area.

The sediments composing this aquifer mostly consist of a series of formations that are the result of Pleistocene marine transgressions. The Pleistocene sediments consist of formations locally known as the Windsor, Charles City, Chuckatuck, Shirley, and Tabb (G.H. Johnson, College of William and Mary, oral commun., 1984). In this report the Columbia aquifer also includes the upper Pliocene Chowan River Formation of the Chesapeake Group. Each formation is similar in lithology and mode of deposition and generally is characterized by a fining-upwards depositional sequence, much like the sediments of the Yorktown-Eastover aquifer. Each is composed of a very coarse gravelly lag deposit that grades up through sands to fine silts and clays. Generally, all land surfaces less than 100 ft above sea level are covered by sediments of the Columbia aquifer (fig. 24). The Columbia aquifer is used primarily for domestic water supply, especially throughout the eastern parts of the study area.

SUMMARY AND CONCLUSIONS

The sediments of the Virginia Coastal Plain form an eastward-thickening wedge of unconsolidated gravel, sand, silt, and clay, with differing amounts of shells. This wedge forms a multilayered aquifer system that lies on a warped surface of basement rocks. The major part of the aquifer system consists of a thick sequence of discontinuous nonmarine sands and interbedded clays, overlain by a thinner sequence of generally continuous marine sands and clays. The sediments range in age from Early Cretaceous to Holocene and have a complex depositional and erosional history.

The sediments of the Virginia Coastal Plain were divided into nine aquifers and eight confining units as part of the northern Atlantic Coastal Plain Regional Aquifer-System Analysis study. The nine aquifers identified and described in this report are the lower Potomac, middle Potomac, upper Potomac, Brightseat, Aquia, Chickahominy-Piney Point, St. Marys-Choptank, Yorktown-Eastover, and Columbia. The Brightseat is a newly named and defined aquifer in the Virginia Coastal Plain.

The nine aquifers and eight confining units were identified, correlated, and traced by use of borehole geophysical logs, drillers' information, lithologic, paleontologic, and water-level data. Patterns of characteristic geophysical log signatures and characteristic lithologies provide the basis for defining the hydrogeologic units throughout the Virginia Coastal Plain. Data required for the identification and correlation of regional hydrogeologic units are sparse or lacking in some areas of the Virginia Coastal Plain. The authors recognize that new geologic and hydrologic data from test holes and water wells will help refine this framework in those areas of recognized data deficiencies and that alternative local hydrogeologic interpretations are possible.

The hydrogeologic framework is illustrated by use of hydrogeologic sections and maps of confining-unit thickness and altitude of tops of aquifers. The Virginia Coastal Plain hydrogeologic framework is continuous with those simultaneously developed in the Coastal Plains of Maryland and North Carolina, and forms part of a regional hydrogeologic framework of the northern Atlantic Coastal Plain from North Carolina to Long Island, N.Y. It also forms part of the conceptual basis for the regional digital ground-water flow model of the northern Atlantic Coastal Plain and the ground-water flow model for the Virginia Coastal Plain.

It is intended that the results of this study be used to provide a basic conceptual framework for other hydrogeologic studies within the Virginia Coastal Plain area, such as county, basinwide, or site-specific investigations. Results of this study will also provide a basis for the development and siting of a comprehensive observation well network in the Coastal Plain of Virginia.

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APPENDIX

RECORD OF CONTROL WELLS AND HYDROGEOLOGIC DATA

Example

Control Well Number	Latitude (degrees-minutes-seconds)	Longitude	Owner	Altitude of Land Surface (feet)	Altitude of Bottom of Logged Hole (feet)	Types of Logs Used
51B 3	36 41 09 N	077 23 07 W	USGS	125	-124 BSMT	E,G,J

CU1 18	CU2 38	CU3 M	CUB M	CU6 M	CU7 M	CU8 M	CU9 M		
AQ1 M	AQ2 +55	AQ3 M	AQB M	AQ6 M	AQ7 M	AQ8 M	AQ9 +125	AQ10 M	

Explanation of abbreviations and symbols

BSMT Basement
D Driller's log
E Electric log
G Geologic log
J Gamma log

Confining-unit name

CU1	Lower Potomac	CU6	Nanjemoy-Marlboro Clay
CU2	Middle Potomac	CU7	Calvert
CU3	Upper Potomac	CU8	St. Marys
CUB	Brightseat	CU9	Yorktown

M Confining unit not present in well
38 Thickness in feet of confining unit
-- No data

Aquifer name

AQ1	Lower Potomac	AQ7	Chickahominy-Piney Point
AQ2	Middle Potomac	AQ8	St. Marys-Choptank
AQ3	Upper Potomac	AQ9	Yorktown-Eastover
AQB	Brightseat	AQ10	Columbia
AQ6	Aquia		

M Aquifer not present in well
+55 Altitude of top of aquifer in feet above (+) or below (-) sea level
-- No data

Control Well Number	Latitude (degrees-minutes-seconds)	Longitude (degrees-minutes-seconds)	Owner	Altitude of Land Surface (feet)	Altitude of Bottom of Logged Hole (feet)	Types of Logs Used
51B 3	36 41 09 N	077 23 07 W	USGS	125	-124 BSMT	E,G,J
	CU1 18 CU2 38 CU3 M CUB M CU6 M CU7 M CU8 M CU9 M					
	AQ1 M AQ2 +55 AQ3 M AQB M AQ6 M AQ7 M AQ8 M AQ9 +125 AQ10 M					
51D 1	36 56 36 N	077 23 57 W	TOWN OF STONY CREEK	75	-35 BSMT	D,E
	CU1 M CU2 20 CU3 M CUB M CU6 M CU7 M CU8 M CU9 M					
	AQ1 M AQ2 +25 AQ3 M AQB M AQ6 M AQ7 M AQ8 M AQ9 +75 AQ10 M					
51G 3	37 20 44 N	077 22 40 W	SAFEWAY STORES, INC.	180	-96 BSMT	D,E
	CU1 16 CU2 31 CU3 M CUB M CU6 18 CU7 19 CU8 M CU9 M					
	AQ1 M AQ2 +58 AQ3 M AQB M AQ6 M AQ7 M AQ8 M AQ9 +180 AQ10 M					
51H 6	37 25 16 N	077 25 31 W	RICHMOND NAT. BATTLEFIELD PARK	85	-56 BSMT	D,E,J
	CU1 -- CU2 17 CU3 M CUB M CU6 M CU7 M CU8 M CU9 M					
	AQ1 -- AQ2 +49 AQ3 M AQB M AQ6 M AQ7 M AQ8 M AQ9 M AQ10 +85					
51J 10	37 30 50 N	077 22 48 W	COMMONWEALTH SAND & GRAVEL CO.	155	-128	D,E
	CU1 >24 CU2 19 CU3 M CUB M CU6 53 CU7 17 CU8 M CU9 M					
	AQ1 -- AQ2 +13 AQ3 M AQB M AQ6 +52 AQ7 M AQ8 M AQ9 +155 AQ10 M					
51K 7	37 39 22 N	077 22 34 W	SYDNOR HYDRODYNAMICS, INC.	180	-135 BSMT	D,E
	CU1 M CU2 25 CU3 M CUB M CU6 45 CU7 32 CU8 M CU9 M					
	AQ1 M AQ2 -3 AQ3 M AQB M AQ6 +60 AQ7 M AQ8 M AQ9 +180 AQ10 M					
51K 11	37 37 38 N	077 22 55 W	MAYFIELD FARMS	190	-126 BSMT	D,E,G,J
	CU1 M CU2 10 CU3 M CUB M CU6 52 CU7 34 CU8 M CU9 M					
	AQ1 M AQ2 +13 AQ3 M AQB M AQ6 +34 AQ7 M AQ8 M AQ9 +190 AQ10 M					
51P 4	38 14 54 N	077 25 16 W	SYDNOR HYDRODYNAMICS, INC.	75	-198 BSMT	D,E
	CU1 >8 CU2 44 CU3 M CUB M CU6 12 CU7 M CU8 M CU9 M					
	AQ1 -- AQ2 -35 AQ3 M AQB M AQ6 +12 AQ7 M AQ8 M AQ9 M AQ10 +75					

Control Well Number	Latitude (degrees-minutes-seconds)	Longitude (degrees-minutes-seconds)	Owner	Altitude of Land Surface (feet)	Altitude of Bottom of Logged Hole (feet)	Types of Logs Used
51Q 1	38 22 20 N	077 22 32 W	RESEARCH HOMES, INC.	185	-145	D,E,J

CU1 --	CU2 28	CU3 M	CUB M	CU6 24	CU7 M	CU8 M	CU9 M		
AQ1 --	AQ2 +64	AQ3 M	AQB M	AQ6 +117	AQ7 M	AQ8 M	AQ9 M	AQ10 +185	

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface (feet)	Altitude of Bottom of Logged Hole (feet)	Types of Logs Used
51Q 19	38 19 49 N	077 25 08 W	STAFFORD SCHOOL BOARD	200	-40	D,E

CU1 --	CU2 42	CU3 M	CUB M	CU6 42	CU7 M	CU8 M	CU9 M	
AQ1 --	AQ2 +58	AQ3 M	AQB M	AQ6 +113	AQ7 M	AQ8 M	AQ9 M	AQ10 +200

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface (feet)	Altitude of Bottom of Logged Hole (feet)	Types of Logs Used
51Q 20	38 17 13 N	077 25 59 W	SYDNOR HYDRODYNAMICS, INC.	150	-277 BSMT	D,E

CU1 40	CU2 42	CU3 M	CUB M	CU6 24	CU7 M	CU8 M	CU9 M	
AQ1 -226	AQ2 +20	AQ3 M	AQB M	AQ6 +86	AQ7 M	AQ8 M	AQ9 M	AQ10 +150

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface (feet)	Altitude of Bottom of Logged Hole (feet)	Types of Logs Used
51R 4	38 25 26 N	077 24 21 W	STAFFORD COUNTY SCHOOL BOARD	210	-85 BSMT	D,E

CU1 M	CU2 32	CU3 M	CUB M	CU6 15	CU7 M	CU8 M	CU9 M	
AQ1 M	AQ2 +98	AQ3 M	AQB M	AQ6 +160	AQ7 M	AQ8 M	AQ9 M	AQ10 +210

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface (feet)	Altitude of Bottom of Logged Hole (feet)	Types of Logs Used
51R 5	38 23 38 N	077 25 50 W	FREDERICKSBURG MOTOR COURT	240	-24 BSMT	D,E

CU1 56	CU2 38	CU3 M	CUB M	CU6 44	CU7 M	CU8 M	CU9 M	
AQ1 M	AQ2 +90	AQ3 M	AQB M	AQ6 +156	AQ7 M	AQ8 M	AQ9 M	AQ10 +240

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface (feet)	Altitude of Bottom of Logged Hole (feet)	Types of Logs Used
52A 1	36 34 10 N	077 15 08 W	L. W. GRIZZARD	45	-181	D,E

CU1 M	CU2 77	CU3 M	CUB M	CU6 M	CU7 M	CU8 M	CU9 17	
AQ1 M	AQ2 -69	AQ3 M	AQB M	AQ6 M	AQ7 M	AQ8 M	AQ9 +28	AQ10 M

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface (feet)	Altitude of Bottom of Logged Hole (feet)	Types of Logs Used
52B 3	36 42 45 N	077 18 20 W	TOWN OF DREWRYVILLE	110	-188	D,E

CU1 34	CU2 26	CU3 5	CUB M	CU6 M	CU7 M	CU8 M	CU9 M	
AQ1 -163	AQ2 +21	AQ3 M	AQB M	AQ6 M	AQ7 M	AQ8 M	AQ9 +110	AQ10 M

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface (feet)	Altitude of Bottom of Logged Hole (feet)	Types of Logs Used
52D 1	36 55 09 N	077 15 29 W	SUSSEX COUNTY SCHOOL BOARD	85	-105	D,E

CU1 --	CU2 33	CU3 12	CUB M	CU6 18	CU7 M	CU8 M	CU9 M	
AQ1 --	AQ2 -53	AQ3 M	AQB M	AQ6 +15	AQ7 M	AQ8 M	AQ9 +85	AQ10 M

Control Well Number	Latitude (degrees-minutes-seconds)	Longitude (degrees-minutes-seconds)	Owner	Altitude of Land Surface (feet)	Altitude of Bottom of Logged Hole (feet)	Types of Logs Used
52F 5	37 09 33 N	077 17 04 W	PRINCE GEORGE COUNTY	140	-185	D,E,G
	CU1 -- CU2 14 CU3 M CUB M CU6 33 CU7 14 CU8 M CU9 M					
	AQ1 -- AQ2 -14 AQ3 M AQB M AQ6 +27 AQ7 +68 AQ8 M AQ9 +140 AQ10 M					
52G 11	37 20 33 N	077 17 12 W	PHILIP MORRIS, INC.	20	-198	D,E
	CU1 24 CU2 15 CU3 M CUB M CU6 M CU7 M CU8 M CU9 M					
	AQ1 -194 AQ2 -20 AQ3 M AQB M AQ6 M AQ7 M AQ8 M AQ9 M AQ10 +20					
52H 8	37 28 59 N	077 22 03 W	HENRICO COUNTY SCHOOL BOARD	150	-135 BSMT	D,E,G
	CU1 18 CU2 8 CU3 M CUB M CU6 35 CU7 19 CU8 M CU9 M					
	AQ1 -- AQ2 +34 AQ3 M AQB M AQ6 +65 AQ7 M AQ8 M AQ9 +150 AQ10 M					
52J 11	37 37 11 N	077 19 30 W	SYDNOR HYDRODYNAMICS, INC.	170	-240 BSMT	D,E
	CU1 -- CU2 30 CU3 M CUB M CU6 73 CU7 50 CU8 M CU9 M					
	AQ1 -- AQ2 -77 AQ3 M AQB M AQ6 -23 AQ7 +70 AQ8 M AQ9 +170 AQ10 M					
52J 18	37 32 40 N	077 21 37 W	HECKLER VILLAGE	150	-180	D,E
	CU1 >8 CU2 30 CU3 M CUB M CU6 43 CU7 34 CU8 M CU9 M					
	AQ1 -- AQ2 -38 AQ3 M AQB M AQ6 +25 AQ7 M AQ8 M AQ9 +150 AQ10 M					
52J 30	37 30 34 N	077 19 20 W	BYRD INTERNATIONAL AIRPORT	160	-88	D,E
	CU1 -- CU2 35 CU3 M CUB M CU6 38 CU7 27 CU8 M CU9 M					
	AQ1 -- AQ2 -58 AQ3 M AQB M AQ6 22 AQ7 +88 AQ8 M AQ9 +160 AQ10 M					
52J 31	37 34 31 N	077 19 18 W	F. D. THARPS	70	-236	D,E
	CU1 -- CU2 28 CU3 M CUB M CU6 44 CU7 35 CU8 M CU9 M					
	AQ1 -- AQ2 -84 AQ3 M AQB M AQ6 -28 AQ7 M AQ8 M AQ9 +70 AQ10 M					
52K 6	37 39 15 N	077 21 46 W	SYDNOR HYDRODYNAMICS, INC.	180	-190	D,E
	CU1 -- CU2 20 CU3 M CUB M CU6 31 CU7 40 CU8 M CU9 M					
	AQ1 -- AQ2 -6 AQ3 M AQB M AQ6 +29 AQ7 +70 AQ8 M AQ9 +180 AQ10 M					

Control Well Number	Latitude (degrees-minutes-seconds)	Longitude (degrees-minutes-seconds)	Owner	Altitude of Land Surface (feet)	Altitude of Bottom of Logged Hole (feet)	Types of Logs Used
52K 9	37 42 28 N	077 22 01 W	E. S. ROBERTSON	170	-90	D,E
	CU1 -- CU2 10 CU3 M CUB M CU6 48 CU7 32 CU8 M CU9 M					
	AQ1 -- AQ2 -32 AQ3 M AQB M AQ6 +5 AQ7 +70 AQ8 M AQ9 +170 AQ10 M					
52K 10	37 37 31 N	077 17 49 W	CONTINENTAL TELEPHONE, INC.	190	-177	D,E,G
	CU1 -- CU2 11 CU3 M CUB M CU6 67 CU7 42 CU8 M CU9 M					
	AQ1 -- AQ2 -80 AQ3 M AQB M AQ6 -44 AQ7 +68 AQ8 M AQ9 +190 AQ10 M					
52K 11	37 41 10 N	077 21 15 W	COLONIAL FORREST SUBDIV.	185	-145	D,E
	CU1 -- CU2 35 CU3 M CUB M CU6 54 CU7 38 CU8 M CU9 M					
	AQ1 -- AQ2 -70 AQ3 M AQB M AQ6 -1 AQ7 +71 AQ8 M AQ9 +185 AQ10 M					
52L 2	37 47 51 N	077 19 55 W	KIWANIS CLUB OF RICHMOND	190	-130	D,E,G
	CU1 -- CU2 26 CU3 M CUB M CU6 60 CU7 44 CU8 M CU9 M					
	AQ1 -- AQ2 -62 AQ3 M AQB M AQ6 -2 AQ7 +72 AQ8 M AQ9 +190 AQ10 M					
52L 4	37 46 05 N	077 16 43 W	C. W. ENGEL	60	-210	D,E
	CU1 -- CU2 60 CU3 M CUB M CU6 62 CU7 M CU8 M CU9 M					
	AQ1 -- AQ2 -112 AQ3 M AQB M AQ6 -30 AQ7 M AQ8 M AQ9 M AQ10 +60					
52M 2	37 54 02 N	077 19 05 W	D. C. BURRUSS	105	-157	D,E
	CU1 -- CU2 74 CU3 M CUB M CU6 60 CU7 17 CU8 M CU9 M					
	AQ1 -- AQ2 -103 AQ3 M AQB M AQ6 -1 AQ7 +76 AQ8 M AQ9 M AQ10 +105					
52N 13	38 06 15 N	077 16 47 W	USGS	180	-31	E,G,J
	CU1 -- CU2 -- CU3 -- CUB -- CU6 48 CU7 44 CU8 M CU9 M					
	AQ1 -- AQ2 -- AQ3 -- AQB -- AQ6 +30 AQ7 +95 AQ8 M AQ9 +180 AQ10 M					
52N 14	38 01 06 N	077 21 22 W	USGS	145	-7	E,G,J
	CU1 -- CU2 >20 CU3 M CUB M CU6 56 CU7 M CU8 M CU9 M					
	AQ1 -- AQ2 -- AQ3 M AQB M AQ6 +75 AQ7 M AQ8 M AQ9 M AQ10 +145					

Control Well Number	Latitude (degrees-minutes-seconds)	Longitude (degrees-minutes-seconds)	Owner	Altitude of Land Surface (feet)	Altitude of Bottom of Logged Hole (feet)	Types of Logs Used
52N 15	38 05 48 N	077 18 21 W	U.S. ARMY, FORT A. P. HILL	230	-280	D,E
	CU1 --	CU2 28	CU3 M	CUB M	CU6 30	CU7 47 CU8 M CU9 M
	AQ1 --	AQ2 -58	AQ3 M	AQB M	AQ6 +50	AQ7 +100 AQ8 M AQ9 +230 AQ10 M
52N 16	38 03 23 N	077 20 47 W	TOWN OF BOWLING GREEN	205	-314	D,E
	CU1 57	CU2 54	CU3 M	CUB M	CU6 21	CU7 34 CU8 M CU9 M
	AQ1 -266	AQ2 -43	AQ3 M	AQB M	AQ6 +78	AQ7 +111 AQ8 M AQ9 +205 AQ10 M
52P 8	38 10 48 N	077 17 33 W	U.S. ARMY, FORT A. P. HILL	205	-217	D,E
	CU1 --	CU2 8	CU3 M	CUB M	CU6 59	CU7 34 CU8 M CU9 M
	AQ1 --	AQ2 -105	AQ3 M	AQB M	AQ6 +1	AQ7 +95 AQ8 M AQ9 +205 AQ10 M
52P 9	38 08 56 N	077 19 45 W	U.S. ARMY, FORT A. P. HILL	160	-340	D,E
	CU1 >20	CU2 60	CU3 M	CUB M	CU6 78	CU7 30 CU8 M CU9 M
	AQ1 --	AQ2 -140	AQ3 M	AQB M	AQ6 +10	AQ7 +108 AQ8 M AQ9 +160 AQ10 M
53A 3	36 35 04 N	077 11 53 W	TOWN OF BOYKINS	40	-445 BSMT	D,E,G
	CU1 16	CU2 24	CU3 21	CUB M	CU6 M	CU7 M CU8 M CU9 11
	AQ1 -352	AQ2 -77	AQ3 M	AQB M	AQ6 M	AQ7 M AQ8 M AQ9 +16 AQ10 +40
53B 3	36 42 18 N	077 14 14 W	W. TURNER	105	-85	E
	CU1 M	CU2 23	CU3 5	CUB M	CU6 M	CU7 M CU8 M CU9 63
	AQ1 M	AQ2 -53	AQ3 M	AQB M	AQ6 M	AQ7 M AQ8 M AQ9 +26 AQ10 +105
53C 1	36 46 22 N	077 10 28 W	UNION CAMP EXP. FARM	105	-273	E
	CU1 40	CU2 22	CU3 15	CUB M	CU6 17	CU7 M CU8 M CU9 35
	AQ1 -201	AQ2 -55	AQ3 -19	AQB M	AQ6 M	AQ7 M AQ8 M AQ9 +45 AQ10 +105
53D 3	36 58 43 N	077 09 02 W	VASWCB	95	-448 BSMT	D,E,J
	CU1 12	CU2 28	CU3 11	CUB M	CU6 16	CU7 10 CU8 M CU9 28
	AQ1 -321	AQ2 -101	AQ3 -24	AQB M	AQ6 -3	AQ7 M AQ8 M AQ9 +60 AQ10 +95

Control Well Number	Latitude (degrees-minutes-seconds)	Longitude (degrees-minutes-seconds)	Owner	Altitude of Land Surface (feet)	Altitude of Bottom of Logged Hole (feet)	Types of Logs Used
[illegible]G 13	37 21 05 N	077 11 36 W	CHARLES CITY COUNTY	75	-250	D,E

CU1	--	CU2	20	CU3	17	CUB	M	CU6	44	CU7	9	CU8	M	CU9	M				
AQ1	--	AQ2	-127	AQ3	M	AQB	M	AQ6	-39	AQ7	+35	AQ8	M	AQ9	+75	AQ10	M		

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface	Altitude of Bottom of Logged Hole	Types of Logs Used
53I 7	37 30 58 N	077 13 59 W	BRADLEY ACRES	130	-521 BSMT	D,E,G

CU1	8	CU2	8	CU3	M	CUB	M	CU6	40	CU7	42	CU8	M	CU9	M		
AQ1	-288	AQ2	-98	AQ3	M	AQB	M	AQ6	-38	AQ7	+44	AQ8	M	AQ9	+130	AQ10	M

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface	Altitude of Bottom of Logged Hole	Types of Logs Used
53K 17	37 43 42 N	077 08 39 W	C&N CORPORATION	160	-240	D,E

CU1	--	CU2	18	CU3	18	CUB	M	CU6	54	CU7	58	CU8	20	CU9	M		
AQ1	--	AQ2	-198	AQ3	M	AQB	M	AQ6	-86	AQ7	+22	AQ8	M	AQ9	+160	AQ10	M

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface	Altitude of Bottom of Logged Hole	Types of Logs Used
53K 18	37 38 15 N	077 07 50 W	D. FLEET	30	-338	D,E

CU1	--	CU2	44	CU3	34	CUB	M	CU6	58	CU7	20	CU8	M	CU9	M		
AQ1	--	AQ2	-240	AQ3	M	AQB	M	AQ6	-92	AQ7	-5	AQ8	M	AQ9	M	AQ10	+30

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface	Altitude of Bottom of Logged Hole	Types of Logs Used
53L 2	37 45 40 N	077 09 21 W	L. A. LIPSCOMB	140	-290	D,E

CU1	--	CU2	44	CU3	12	CUB	M	CU6	64	CU7	60	CU8	30	CU9	M		
AQ1	--	AQ2	-244	AQ3	M	AQB	M	AQ6	-108	AQ7	+4	AQ8	M	AQ9	+140	AQ10	M

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface	Altitude of Bottom of Logged Hole	Types of Logs Used
53P 4	38 14 18 N	077 09 16 W	MT. ROSE CANNING CO.	180	-720	D,E

CU1	86	CU2	68	CU3	M	CUB	M	CU6	94	CU7	38	CU8	25	CU9	M		
AQ1	-662	AQ2	-230	AQ3	M	AQB	M	AQ6	-58	AQ7	+64	AQ8	M	AQ9	+180	AQ10	M

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface	Altitude of Bottom of Logged Hole	Types of Logs Used
53P 8	38 09 48 N	077 12 04 W	A. J. GOULDMAN	35	-375	D,E

CU1	--	CU2	22	CU3	M	CUB	M	CU6	57	UB7	M	CU8	M	UB9	M		
AQ1	--	AQ2	-141	AQ3	M	AQB	M	AQ6	-51	AQ7	M	AQ8	M	AQ9	M	AQ10	+35

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface	Altitude of Bottom of Logged Hole	Types of Logs Used
53Q 7	38 17 33 N	077 14 43 W	USGS	155	-85	E,G,J

CU1	--	CU2	45	CU3	M	CUB	M	CU6	65	CU7	20	CU8	16	CU9	M		
AQ1	--	AQ2	-85	AQ3	M	AQB	M	AQ6	+15	AQ7	+94	AQ8	M	AQ9	+155	AQ10	M

Control Well Number	Latitude (degrees-minutes-seconds)	Longitude (degrees-minutes-seconds)	Owner	Altitude of Land Surface (feet)	Altitude of Bottom of Logged Hole (feet)	Types of Logs Used
53Q 9	38 19 45 N	077 14 11 W	SYDNOR HYDRODYNAMICS, INC.	45	-453	D,E

CU1 >2	CU2 64	CU3 M	CUB M	CU6 15	CU7 M	CU8 M	CU9 M		
AQ1 --	AQ2 -115	AQ3 M	AQB M	AQ6 +10	AQ7 M	AQ8 M	AQ9 M	AQ10 +45	

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface (feet)	Altitude of Bottom of Logged Hole (feet)	Types of Logs Used
54A 1	36 37 22 N	077 01 46 W	W. BRITT	35	-231	D,E

CU1 --	CU2 25	CU3 16	CUB M	CU6 18	CU7 13	CU8 M	CU9 17	
AQ1 --	AQ2 -170	AQ3 -105	AQB M	AQ6 -66	AQ7 M	AQ8 M	AQ9 +3	AQ10 +35

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface (feet)	Altitude of Bottom of Logged Hole (feet)	Types of Logs Used
54A 3	36 35 21 N	077 06 36 W	J. T. PARKER	100	-248	E

CU1 --	CU2 38	CU3 16	CUB M	CU6 M	CU7 M	CU8 M	CU9 26	
AQ1 --	AQ2 -116	AQ3 -48	AQB M	AQ6 M	AQ7 M	AQ8 M	AQ9 +26	AQ10 +100

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface (feet)	Altitude of Bottom of Logged Hole (feet)	Types of Logs Used
54B 1	36 39 15 N	077 00 11 W	HERCULES POWDER CO.	20	-595	D,E

CU1 20	CU2 38	CU3 15	CUB M	CU6 12	CU7 M	CU8 M	CU9 M	
AQ1 -533	AQ2 -188	AQ3 -110	AQB M	AQ6 -65	AQ7 M	AQ8 M	AQ9 +20	AQ10 M

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface (feet)	Altitude of Bottom of Logged Hole (feet)	Types of Logs Used
54B 7	36 42 04 N	077 00 49 W	A. SIPINZSKY	40	-309	D,E

CU1 --	CU2 28	CU3 35	CUB M	CU6 13	CU7 17	CU8 M	CU9 23	
AQ1 --	AQ2 -179	AQ3 -102	AQB M	AQ6 -46	AQ7 M	AQ8 M	AQ9 +17	AQ10 M

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface (feet)	Altitude of Bottom of Logged Hole (feet)	Types of Logs Used
54B 18	36 42 11 N	077 05 43 W	F. E. NOTTINGHAM	50	-213	E

CU1 --	CU2 22	CU3 29	CUB M	CU6 8	CU7 M	CU8 M	CU9 13	
AQ1 --	AQ2 -115	AQ3 -58	AQB M	AQ6 -18	AQ7 M	AQ8 M	AQ9 +30	AQ10 +50

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface (feet)	Altitude of Bottom of Logged Hole (feet)	Types of Logs Used
54B 19	36 44 47	077 03 52	HYDER	50	-296	E

CU1 --	CU2 27	CU3 18	CUB M	CU6 16	CU7 M	CU8 M	CU9 12	
AQ1 --	AQ2 -150	AQ3 -91	AQB M	AQ6 -34	AQ7 M	AQ8 M	AQ9 +18	AQ10 +50

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface (feet)	Altitude of Bottom of Logged Hole (feet)	Types of Logs Used
54C 4	36 50 09 N	077 03 54 W	A. WILLIAMS	115	-240	D,E

CU1 --	CU2 18	CU3 17	CUB M	CU6 10	CU7 19	CU8 M	CU9 44	
AU1 --	AU2 -142	AU3 -62	AUB M	AU6 -39	AU7 -22	AU8 M	AU9 +37	AQ10 +115

Control Well Number	Latitude (degrees-minutes-seconds)	Longitude (degrees-minutes-seconds)	Owner	Altitude of Land Surface (feet)	Altitude of Bottom of Logged Hole (feet)	Types of Logs Used
54D 1	36 58 45 N	077 00 21 W	T. W. SPAIN	110	-678 BSMT	E,J

CU1 17	CU2 44	CU3 26	CUB M	CU6 24	CU7 28	CU8 M	CU9 20		
AQ1 -486	AQ2 -262	AQ3 -123	AQB M	AQ6 -60	AQ7 M	AQ8 M	AQ9 +54	AQ10 +110	

54D 2	36 53 31 N	077 02 08 W	R. H. WHITE	115	-255	D,E

CU1 --	CU2 51	CU3 31	CUB M	CU6 18	CU7 20	CU8 M	CU9 20	
AQ1 --	AQ2 -184	AQ3 -95	AQB M	AQ6 -44	AQ7 -19	AQ8 M	AQ9 +43	AQ10 +115

54E 7	37 01 56 N	077 06 38 W	TOWN OF WAVERLY	110	-343	D,E

CU1 --	CU2 20	CU3 37	CUB M	CU6 18	CU7 10	CU8 M	CU9 26	
AQ1 --	AQ2 -148	AQ3 -58	AQB M	AQ6 -14	AQ7 M	AQ8 M	AQ9 +70	AQ10 +110

54G 10	37 19 56 N	077 05 52 W	VASWCB	35	-545 BSMT	E,G,J

CU1 12	CU2 26	CU3 9	CUB M	CU6 42	CU7 17	CU8 M	CU9 M	
AQ1 -455	AQ2 -206	AQ3 -151	AQB M	AQ6 -95	AQ7 -22	AQ8 M	AQ9 M	AQ10 +35

54H 4	37 29 51 N	077 07 19 W	WOODHAVEN SHORES, INC.	110	-390	D,E

CU1 --	CU2 14	CU3 15	CUB M	CU6 44	CU7 53	CU8 M	CU9 M	
AQ1 --	AQ2 -204	AQ3 -146	AQB M	AQ6 -100	AQ7 +22	AQ8 M	AQ9 +110	AQ10 M

54H 11	37 29 58 N	077 02 36 W	VIRGINIA DEPT. OF HIGHWAYS	65	-338	D,E,J

CU1 --	CU2 28	CU3 14	CUB M	CU6 42	CU7 33	CU8 M	CU9 M	
AQ1 --	AQ2 -255	AQ3 -193	AQB M	AQ6 -129	AQ7 -14	AQ8 M	AQ9 +65	AQ10 M

54J 4	37 32 07 N	077 06 52 W	KENWOOD FARMS, INC.	160	-343	D,E,J

CU1 --	CU2 24	CU3 18	CUB M	CU6 41	CU7 58	CU8 M	CU9 M	
AQ1 --	AQ2 -207	AQ3 -142	AQB M	AQ6 -101	AQ7 +18	AQ8 M	AQ9 +160	AQ10 M

54P 3	38 10 10 N	077 02 19 W	USGS	180	-1180	D,E,G,J

CU1 100	CU2 30	CU3 M	CUB 14	CU6 116	CU7 68	CU8 52	CU9 M	
AQ1 -890	AQ2 -324	AQ3 M	AQB M	AQ6 -160	AQ7 -14	AQ8 M	AQ9 +180	AQ10 M

Control Well Number	Latitude (degrees-minutes-seconds)	Longitude (degrees-minutes-seconds)	Owner	Altitude of Land Surface (feet)	Altitude of Bottom of Logged Hole (feet)	Types of Logs Used
54Q 9	38 17 55 N	077 02 55 W	U.S. NAVY	25	-719	D,E
54Q 10	38 20 00 N	077 02 15 W	U.S. NAVY	20	-990	D,E
54Q 11	38 20 21 N	077 05 18 W	TOWN OF OWENS	130	-760	D,E
54R 3	38 22 42 N	077 03 47 W	J. B. CRALLE	110	-567	D,E
55A 1	36 36 07 N	076 56 00 W	H. DARDEN	20	-340	E,G
55B 49	36 43 36 N	076 57 56 W	LANKFORD NURSERY	95	-289	D,E
55B 63	36 41 21 N	076 54 51 W	UNION CAMP	30	-680	D,E,J
55C 1	36 46 30 N	076 59 17 W	M. HOLT	90	-240	D,E

Well										
54Q 9	CU1 --	CU2 26	CU3 M	CU5 M	CU6 94	CU7 20	CU8 M	CU9 M		
	AQ1 --	AQ2 -278	AQ3 M	AQ5 M	AQ6 -115	AQ7 M	AQ8 M	AQ9 M	AQ10 +25
54Q 10	CU1 138	CU2 44	CU3 M	CU5 M	CU6 80	CU7 M	CU8 M	CU9 M	
	AQ1 -890	AQ2 -266	AQ3 M	AQ5 M	AQ6 -88	AQ7 M	AQ8 M	AQ9 M	AQ10 +20
54Q 11	CU1 >6	CU2 48	CU3 M	CU5 M	CU6 86	CU7 36	CU8 30	CU9 M	
	AQ1 --	AQ2 -260	AQ3 M	AQ5 M	AQ6 -74	AQ7 +34	AQ8 M	AQ9 +130	AQ10 M
54R 3	CU1 --	CU2 42	CU3 M	CU5 M	CU6 83	CU7 35	CU8 37	CU9 M	
	AQ1 --	AQ2 -272	AQ3 M	AQ5 M	AQ6 -83	AQ7 M	AQ8 M	AQ9 +110	AQ10 M
55A 1	CU1 --	CU2 56	CU3 4	CU5 M	CU6 18	CU7 8	CU8 M	CU9 10	
	AQ1 --	AQ2 -254	AQ3 -128	AQ5 M	AQ6 -110	AQ7 M	AQ8 M	AQ9 +10	AQ10 M
55B 49	CU1 --	CU2 25	CU3 17	CU5 M	CU6 17	CU7 24	CU8 M	CU9 40	
	AQ1 --	AQ2 -250	AQ3 -128	AQ5 M	AQ6 -97	AQ7 -42	AQ8 M	AQ9 +14	AQ10 +95
55B 63	CU1 47	CU2 28	CU3 22	CU5 M	CU6 12	CU7 11	CU8 M	CU9 13	
	AQ1 -677	AQ2 -314	AQ3 -188	AQ5 M	AQ6 -136	AQ7 -63	AQ8 M	AQ9 +5	AQ10 +30
55C 1	CU1 --	CU2 17	CU3 12	CU5 M	CU6 24	CU7 31	CU8 M	CU9 47	
	AQ1 --	AQ2 -187	AQ3 -124	AQ5 M	AQ6 -94	AQ7 -38	AQ8 M	AQ9 +17	AQ10 +90

Control Well Number	Latitude (degrees-minutes-seconds)	Longitude (degrees-minutes-seconds)	Owner	Altitude of Land Surface (feet)	Altitude of Bottom of Logged Hole (feet)	Types of Logs Used
55C 8	36 51 24 N	076 58 34 W	H. W. WADE	80	-250	D,E

CU1 --	CU2 33	CU3 20	CUB M	CU6 20	CU7 22	CU8 M	CU9 34		
AQ1 --	AQ2 -179	AQ3 -96	AQB M	AQ6 -56	AQ7 -32	AQ8 M	AQ9 +26	AQ10 +80	

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface (feet)	Altitude of Bottom of Logged Hole (feet)	Types of Logs Used
55C 12	36 46 05 N	076 53 18 W	CITY OF VIRGINIA BEACH	15	-899 BSMT	D,E,J

CU1 24	CU2 34	CU3 22	CUB M	CU6 20	CU7 20	CU8 M	CU9 M	
AQ1 -653	AQ2 -313	AQ3 -185	AQB M	AQ6 -141	AQ7 -71	AQ8 M	AQ9 -20	AQ10 +15

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface (feet)	Altitude of Bottom of Logged Hole (feet)	Types of Logs Used
55D 5	36 54 15 N	076 53 20 W	TOWN OF IVOR	90	-420	D,E,J

CU1 --	CU2 26	CU3 14	CUB M	CU6 28	CU7 33	CU8 M	CU9 34	
AQ1 --	AQ2 -271	AQ3 -160	AQB M	AQ6 -112	AQ7 -69	AQ8 M	AQ9 +32	AQ10 +90

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface (feet)	Altitude of Bottom of Logged Hole (feet)	Types of Logs Used
55D 12	36 55 00 N	076 54 31 W	VIRGINIA DEPT. OF AGRICULTURE	80	-370	D,E

CU1 --	CU2 30	CU3 24	CUB M	CU6 21	CU7 32	CU8 M	CU9 24	
AQ1 --	AQ2 -268	AQ3 -154	AQB M	AQ6 -96	AQ7 -67	AQ8 M	AQ9 +38	AQ10 +80

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface (feet)	Altitude of Bottom of Logged Hole (feet)	Types of Logs Used
55E 1	37 02 45 N	076 56 06 W	TOWN OF DENDRON	110	-400	D,E,G

CU1 --	CU2 55	CU3 32	CUB M	CU6 21	CU7 40	CU8 20	CU9 27	
AQ1 --	AQ2 -323	AQ3 -192	AQB M	AQ6 -96	AQ7 -66	AQ8 M	AQ9 +45	AQ10 +110

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface (feet)	Altitude of Bottom of Logged Hole (feet)	Types of Logs Used
55E 3	37 04 51 N	076 54 18 W	SURRY COUNTY	90	-390	D,E,G

CU1 --	CU2 46	CU3 23	CUB M	CU6 29	CU7 42	CU8 26	CU9 25	
AQ1 --	AQ2 -356	AQ3 -198	AQB M	AQ6 -121	AQ7 -68	AQ8 M	AQ9 +44	AQ10 +90

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface (feet)	Altitude of Bottom of Logged Hole (feet)	Types of Logs Used
55F 20	37 13 21 N	076 57 06 W	TOWN OF CLAREMONT	90	-313	D,E

CU1 --	CU2 39	CU3 17	CUB M	CU6 33	CU7 34	CU8 M	CU9 10	
AQ1 --	AQ2 -217	AQ3 -148	AQB M	AQ6 -113	AQ7 -58	AQ8 M	AQ9 +80	AQ10 M

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface (feet)	Altitude of Bottom of Logged Hole (feet)	Types of Logs Used
55G 4	37 18 45 N	076 56 13 W	CHARLES CITY COUNTY	35	-303	D,E

CU1 --	CU2 30	CU3 22	CUB M	CU6 44	CU7 44	CU8 M	CU9 M	
AQ1 --	AQ2 -269	AQ3 -209	AQB M	AQ6 -153	AQ7 -58	AQ8 M	AQ9 +20	AQ10 +35

Control Well Number	Latitude (degrees-minutes-seconds)	Longitude (degrees-minutes-seconds)	Owner	Altitude of Land Surface (feet)	Altitude of Bottom of Logged Hole (feet)	Types of Logs Used
55H 1	37 24 28 N	076 56 15 W	CITY OF NEWPORT NEWS	10	-768	D,E,J

CU1 22	CU2 20	CU3 12	CUB M	CU6 44	CU7 42	CU8 M	CU9 M		
AQ1 -650	AQ2 -304	AQ3 -242	AQB M	AQ6 -168	AQ7 -60	AQ8 M	AQ9 M	AQ10 +10	

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface	Altitude of Bottom of Logged Hole	Types of Logs Used
55L 2	37 49 32 N	076 56 42 W	SYDNOR HYDRODYNAMICS, INC.	170	-130	D,E

CU1 --	CU2 --	CU3 --	CUB --	CU6 >8	CU7 85	CU8 65	CU9 15	
AQ1 --	AQ2 --	AQ3 --	AQB --	AQ6 --	AQ7 -59	AQ8 M	AQ9 +155	AQ10 M

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface	Altitude of Bottom of Logged Hole	Types of Logs Used
55P 3	38 11 22 N	076 55 31 W	NATIONAL PARK SERVICE	20	-790	D,E,J

CU1 --	CU2 30	CU3 M	CUB 10	CU6 110	CU7 40	CU8 M	CU9 M	
AQ1 --	AQ2 -361	AQ3 M	AQB M	AQ6 -199	AQ7 -39	AQ8 M	AQ9 M	AQ10 +20

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface	Altitude of Bottom of Logged Hole	Types of Logs Used
56A 9	36 36 25 N	076 52 26 W	VASWCB	80	-983 BSMT	D,E,J

CU1 37	CU2 50	CU3 14	CUB M	CU6 18	CU7 34	CU8 M	CU9 20	
AQ1 -720	AQ2 -360	AQ3 -170	AQB M	AQ6 -140	AQ7 -82	AQ8 M	AQ9 +5	AQ10 +80

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface	Altitude of Bottom of Logged Hole	Types of Logs Used
56A 10	36 33 45 N	076 47 02 W	VASWCB	45	-1155 BSMT	E,G,J

CU1 30	CU2 58	CU3 44	CUB M	CU6 18	CU7 22	CU8 M	CU9 9	
AQ1 -841	AQ2 -407	AQ3 -229	AQB M	AQ6 -177	AQ7 -105	AQ8 M	AQ9 +23	AQ10 +45

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface	Altitude of Bottom of Logged Hole	Types of Logs Used
56A 11	36 36 53 N	076 45 54 W	VASWCB	80	-1098	E,G,J

CU1 50	CU2 71	CU3 28	CUB M	CU6 18	CU7 26	CU8 M	CU9 21	
AQ1 -834	AQ2 -394	AQ3 -265	AQB M	AQ6 -204	AQ7 -120	AQ8 M	AQ9 +9	AQ10 +80

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface	Altitude of Bottom of Logged Hole	Types of Logs Used
56B 1	36 41 13 N	076 45 47 W	PEARCE	80	420	D,E

CU1 --	CU2 67	CU3 20	CUB M	CU6 25	CU7 28	CU8 M	CU9 37	
AQ1 --	AQ2 -400	AQ3 -250	AQB M	AQ6 -204	AQ7 -119	AQ8 M	AQ9 -12	AQ10 +84

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface	Altitude of Bottom of Logged Hole	Types of Logs Used
56B 9	36 38 57 N	076 49 46 W	J. E. RAWLS	85	-440	D,E

CU1 --	CU2 37	CU3 13	CUB M	CU6 21	CU7 29	CU8 M	CU9 52	
AQ1 --	AQ2 -344	AQ3 -191	AQB M	AQ6 -160	AQ7 -123	AQ8 M	AQ9 -23	AQ10 +85

Control Well Number	Latitude (degrees-minutes-seconds)	Longitude (degrees-minutes-seconds)	Owner	Altitude of Land Surface (feet)	Altitude of Bottom of Logged Hole (feet)	Types of Logs Used
56C 1	36 50 06 N	076 50 03 W	ZUNI PRESBYTERIAN SCHOOL	75	-421	D,E

CU1 -- CU2 30 CU3 33 CUB M CU6 22 CU7 30 CU8 M CU9 44
AQ1 -- AQ2 -299 AQ3 -198 AQB M AQ6 -137 AQ7 -89 AQ8 M AQ9 +5 AQ10 +75

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface	Altitude of Bottom of Logged Hole	Types of Logs Used
56C 2	36 46 14 N	076 50 53 W	W. HOLLAND	45	-295	E

CU1 -- CU2 >7 CU3 53 CUB M CU6 28 CU7 22 CU8 M CU9 29
AQ1 -- AQ2 -- AQ3 -205 AQB M AQ6 -137 AQ7 -89 AQ8 M AQ9 +6 AQ10 +45

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface	Altitude of Bottom of Logged Hole	Types of Logs Used
56F 16	37 14 34 N	076 48 15 W	SYDNOR HYDRODYNAMICS, INC.	30	-465	D,E,G

CU1 -- CU2 60 CU3 16 CUB M CU6 53 CU7 50 CU8 8 CU9 10
AQ1 -- AQ2 -368 AQ3 -254 AQB M AQ6 -211 AQ7 -94 AQ8 M AQ9 0 AQ10 +30

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface	Altitude of Bottom of Logged Hole	Types of Logs Used
56F 42	37 08 32 N	076 50 27 W	SYDNOR HYDRODYNAMICS, INC.	110	-375	D,E,G

CU1 -- CU2 28 CU3 12 CUB M CU6 33 CU7 38 CU8 22 CU9 24
AQ1 -- AQ2 -308 AQ3 -226 AQB M AQ6 -156 AQ7 -82 AQ8 M AQ9 +56 AQ10 +110

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface	Altitude of Bottom of Logged Hole	Types of Logs Used
56G 6	37 19 05 N	076 47 12 W	JAMES CITY SERVICE AUTHORITY	120	-306	D,E,G,J

CU1 -- CU2 -- CU3 19 CUB M CU6 62 CU7 60 CU8 M CU9 23
AQ1 -- AQ2 -- AQ3 -279 AQB M AQ6 -232 AQ7 -104 AQ8 M AQ9 +56 AQ10 +120

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface	Altitude of Bottom of Logged Hole	Types of Logs Used
56G 9	37 21 49 N	076 46 12 W	JAMES CITY SCHOOL BOARD	105	-195	D,E

CU1 -- CU2 -- CU3 -- CUB -- CU6 >24 CU7 57 CU8 M CU9 24
AQ1 -- AQ2 -- AQ3 -- AQB -- AQ6 -- AQ7 -109 AQ8 M AQ9 +57 AQ10 +105

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface	Altitude of Bottom of Logged Hole	Types of Logs Used
56J 5	37 32 46 N	076 48 30 W	CHESAPEAKE CORPORATION	25	-1252 BSMT	D,E,J

CU1 34 CU2 72 CU3 38 CUB 10 CU6 82 CU7 40 CU8 18 CU9 M
AQ1 -885 AQ2 -503 AQ3 -343 AQB -295 AQ6 -251 AQ7 -85 AQ8 M AQ9 M AQ10 +25

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface	Altitude of Bottom of Logged Hole	Types of Logs Used
56J 11	37 31 26 N	076 45 41 W	CHESAPEAKE CORPORATION	15	-1255 BSMT	D,E,G

CU1 32 CU2 50 CU3 81 CUB 21 CU6 86 CU7 50 CU8 20 CU9 M
AQ1 -931 AQ2 -557 AQ3 -434 AQB -330 AQ6 -279 AQ7 -119 AQ8 M AQ9 M AQ10 +15

Control Well Number	Latitude (degrees-minutes-seconds)	Longitude (degrees-minutes-seconds)	Owner	Altitude of Land Surface (feet)	Altitude of Bottom of Logged Hole (feet)	Types of Logs Used
56M 9	37 57 33 N	076 45 18 W	TOWN OF WARSAW	130	-570	D,E

CU1 --	CU2 >18	CU3 19	CUB 10	CU6 97	CU7 96	CU8 88	CU9 10		
AQ1 --	AQ2 --	AQ3 -493	AQB -416	AQ6 -297	AQ7 -124	AQ8 M	AQ9 +120	AQ10 M	

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface (feet)	Altitude of Bottom of Logged Hole (feet)	Types of Logs Used
56M 10	37 55 41 N	076 51 43 W	TOWN OF TAPPAHANNOCK	20	-533	D,E

CU1 --	CU2 42	CU3 22	CUB 12	CU6 99	CU7 44	CU8 52	CU9 M	
AQ1 --	AQ2 -466	AQ3 -370	AQB -340	AQ6 -242	AQ7 -84	AQ8 M	AQ9 M	AQ10 +20

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface (feet)	Altitude of Bottom of Logged Hole (feet)	Types of Logs Used
56N 7	38 05 16 N	076 47 30 W	ARROWHEAD ASSOCIATES	145	-672	D,E

CU1 --	CU2 80	CU3 38	CUB 11	CU6 132	CU7 73	CU8 88	CU9 M	
AQ1 --	AQ2 -643	AQ3 -497	AQB -383	AQ6 -283	AQ7 -102	AQ8 M	AQ9 +145	AQ10 M

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface (feet)	Altitude of Bottom of Logged Hole (feet)	Types of Logs Used
56P 2	38 10 08 N	076 52 09 W	WESTMORELAND STATE PARK	135	-425	D,E

CU1 --	CU2 --	CU3 11	CUB 15	CU6 127	CU7 76	CU8 75	CU9 M	
AQ1 --	AQ2 --	AQ3 -391	AQB -370	AQ6 -240	AQ7 -63	AQ8 M	AQ9 +135	AQ10 M

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface (feet)	Altitude of Bottom of Logged Hole (feet)	Types of Logs Used
57A 1	36 36 08 N	076 40 07 W	VIRGINIA DEPT. OF HIGHWAYS	70	-550	E

CU1 --	CU2 45	CU3 44	CUB M	CU6 22	CU7 20	CU8 M	CU9 40	
AQ1 --	AQ2 -494	AQ3 -369	AQB M	AQ6 -272	AQ7 -172	AQ8 M	AQ9 -10	AQ10 +70

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface (feet)	Altitude of Bottom of Logged Hole (feet)	Types of Logs Used
57B 6	36 42 48 N	076 39 13 W	CITY OF SUFFOLK	55	-661	D,E,J

CU1 --	CU2 38	CU3 42	CUB M	CU6 31	CU7 47	CU8 M	CU9 22	
AQ1 --	AQ2 -503	AQ3 -360	AQB M	AQ6 -245	AQ7 -158	AQ8 M	AQ9 +3	AQ10 +55

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface (feet)	Altitude of Bottom of Logged Hole (feet)	Types of Logs Used
57C 7	36 48 47 N	076 44 38 W	M. H. ROBINSON	85	-375	D,E

CU1 --	CU2 --	CU3 40	CUB M	CU6 39	CU7 36	CU8 M	CU9 62	
AQ1 --	AQ2 --	AQ3 -267	AQB M	AQ6 -194	AQ7 -137	AQ8 M	AQ9 -17	AQ10 +85

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface (feet)	Altitude of Bottom of Logged Hole (feet)	Types of Logs Used
57C 17	36 48 10 N	076 39 21 W	CITY OF NORFOLK	40	-850	D,E,G

CU1 --	CU2 28	CU3 65	CUB M	CU6 42	CU7 33	CU8 M	CU9 55	
AQ1 --	AQ2 -450	AQ3 -340	AQB M	AQ6 -247	AQ7 -150	AQ8 M	AQ9 -39	AQ10 +40

Control Well Number	Latitude (degrees-minutes-seconds)	Longitude (degrees-minutes-seconds)	Owner	Altitude of Land Surface (feet)	Altitude of Bottom of Logged Hole (feet)	Types of Logs Used
57D 3	36 59 27 N	076 37 58 W	SMITHFIELD PACKING COMPANY	30	-570	E
	CU1 -- CU2 31 CU3 22 CUB M CU6 47 CU7 50 CU8 26 CU9 18					
	AQ1 -- AQ2 -502 AQ3 -310 AQB M AQ6 -279 AQ7 -200 AQ8 M AQ9 -28 AQ10 +30					
57D 20	36 52 32 N	076 40 56 W	CITY OF VIRGINIA BEACH	50	-910	D,E
	CU1 -- CU2 30 CU3 30 CUB M CU6 45 CU7 38 CU8 M CU9 43					
	AQ1 -- AQ2 -412 AQ3 -290 AQB M AQ6 -238 AQ7 -140 AQ8 M AQ9 -25 AQ10 +50					
57E 10	37 02 36 N	076 42 59 W	VASWCB	85	-615	D,E
	CU1 -- CU2 24 CU3 11 CUB M CU6 40 CU7 46 CU8 24 CU9 25					
	AQ1 -- AQ2 -405 AQ3 -272 AQB M AQ6 -215 AQ7 -145 AQ8 M AQ9 +14 AQ10 +85					
57F 2	37 14 21 N	076 38 28 W	WILLIAMSBURG COUNTRY CLUB	80	-513	D,E
	CU1 -- CU2 24 CU3 20 CUB M CU6 68 CU7 80 CU8 56 CU9 24					
	AQ1 -- AQ2 -476 AQ3 -380 AQB M AQ6 -320 AQ7 -214 AQ8 M AQ9 +16 AQ10 +80					
57F 3	37 09 16 N	076 40 19 W	VEPCO	25	-390	D,E
	CU1 -- CU2 -- CU3 31 CUB M CU6 66 CU7 52 CU8 48 CU9 14					
	AQ1 -- AQ2 -- AQ3 -352 AQB M AQ6 -294 AQ7 -187 AQ8 M AQ9 -9 AQ10 +25					
57F 7	37 13 43 N	076 40 08 W	BUSCH PROPERTIES, INC.	55	-455	D,E,G,J
	CU1 -- CU2 16 CU3 23 CUB M CU6 69 CU7 68 CU8 58 CU9 21					
	AQ1 -- AQ2 -453 AQ3 -361 AQB M AQ6 -301 AQ7 -195 AQ8 M AQ9 -5 AQ10 +55					
57F 26	37 09 51 N	076 41 57 W	VEPCO	35	-385	D,E
	CU1 -- CU2 -- CU3 24 CUB M CU6 62 CU7 60 CU8 47 CU9 12					
	AQ1 -- AQ2 -- AQ3 -357 AQB M AQ6 -285 AQ7 -167 AQ8 M AQ9 -19 AQ10 +35					
57G 22	37 19 34 N	076 44 14 W	SYDNOR HYDRODYNAMICS, INC.	100	-325	D,E,G
	CU1 -- CU2 -- CU3 >35 CUB M CU6 62 CU7 66 CU8 20 CU9 21					
	AQ1 -- AQ2 -- AQ3 -- AQB M AQ6 -250 AQ7 -136 AQ8 M AQ9 +44 AQ10 +100					

Control Well Number	Latitude (degrees-minutes-seconds)	Longitude (degrees-minutes-seconds)	Owner	Altitude of Land Surface (feet)	Altitude of Bottom of Logged Hole (feet)	Types of Logs Used			
57G 25	37 16 05 N	076 42 03 W	COLONIAL WILLIAMSBURG	70	-428	D,E			
	CU1 --	CU2 >28	CU3 18	CUB M	CU6 66	CU7 60	CU8 36	CU9 22	
	AQ1 --	AQ2 --	AQ3 -334	AQB M	AQ6 -288	AQ7 -176	AQ8 M	AQ9 +24	AQ10 +70
57H 6	37 23 10 N	076 41 14 W	TIDEWATER WATER COMPANY	50	-503	D,E			
	CU1 --	CU2 22	CU3 14	CUB 6	CU6 74	CU7 68	CU8 30	CU9 24	
	AQ1 --	AQ2 -436	AQ3 -362	AQB M	AQ6 -296	AQ7 -168	AQ8 M	AQ9 +6	AQ10 +50
57J 3	37 30 08 N	076 42 58 W	CHESAPEAKE CORPORATION	50	-1000	D,E			
	CU1 36	CU2 44	CU3 22	CUB 36	CU6 90	CU7 56	CU8 32	CU9 15	
	AQ1 -963	AQ2 -533	AQ3 -440	AQB -369	AQ6 -297	AQ7 -137	AQ8 M	AQ9 +11	AQ10 +50
57N 3	38 04 28 N	076 40 25 W	WESTMORELAND COUNTY	120	-373	D,E			
	CU1 --	CU2 --	CU3 --	CUB --	CU6 114	CU7 94	CU8 100	CU9 10	
	AQ1 --	AQ2 --	AQ3 --	AQB --	AQ6 -332	AQ7 -154	AQ8 M	AQ9 +90	AQ10 +120
57P 1	38 08 55 N	076 40 22 W	H.T.E. CORPORATION	10	-765	D,E			
	CU1 --	CU2 >57	CU3 45	CUB 32	CU6 131	CU7 86	CU8 50	CU9 M	
	AQ1 --	AQ2 --	AQ3 -649	AQB -494	AQ6 -328	AQ7 -136	AQ8 M	AQ9 M	AQ10 +10
58A 2	36 34 09 N	076 35 00 W	VASWCB	60	-1820 BSMT	D,E,G,J			
	CU1 67	CU2 44	CU3 54	CUB M	CU6 15	CU7 34	CU8 M	CU9 28	
	AQ1 -1154	AQ2 -596	AQ3 -416	AQB M	AQ6 -321	AQ7 -222	AQ8 M	AQ9 -26	AQ10 +60
58B115	36 44 52 N	076 35 14 W	CITY OF SUFFOLK	30	-980	D,E			
	CU1 --	CU2 31	CU3 83	CUB M	CU6 48	CU7 40	CU8 M	CU9 45	
	AQ1 --	AQ2 -538	AQ3 -404	AQB M	AQ6 -306	AQ7 -220	AQ8 M	AQ9 -55	AQ10 +30
58C 7	36 48 38 N	076 37 09 W	CITY OF NORFOLK	40	-899	D,E,G			
	CU1 --	CU2 12	CU3 41	CUB M	CU6 53	CU7 36	CU8 M	CU9 64	
	AQ1 --	AQ2 -493	AQ3 -357	AQB M	AQ6 -291	AQ7 -182	AQ8 M	AQ9 -46	AQ10 +40

Control Well Number	Latitude (degrees-minutes-seconds)	Longitude (degrees-minutes-seconds)	Owner	Altitude of Land Surface (feet)	Altitude of Bottom of Logged Hole (feet)	Types of Logs Used
58C 8	36 52 18 N	076 31 30 W	G. A. NIMMO	20	-558	E
58C 10	36 46 05 N	076 32 24 W	CITY OF SUFFOLK	25	-599	D,E,J
58C 51	36 49 04 N	076 33 05 W	CITY OF NORFOLK	5	-993	D,E
58D 6	36 59 39 N	076 33 30 W	RESCUE WATER COMPANY	20	-528	E
58D 9	36 57 27 N	076 31 39 W	VIRGINIA TIDEWATER PROPERTIES, INC.	15	-539	D,E
58E 2	37 00 31 N	076 36 12 W	V. H. MONETTE CO.	25	-475	E
58F 3	37 11 20 N	076 36 54 W	DOW BADISCHE, INC.	20	-1540	D,E,G,J
58F 48	37 13 49 N	076 32 57 W	YORK COUNTY PUBLIC WORKS	80	-100	D,E,J

58C 8

CU1	--	CU2	>14	CU3	21	CUB	M	CU6	63	CU7	52	CU8	26	CU9	34		
AQ1	--	AQ2	--	AQ3	-403	AQB	M	AQ6	-364	AQ7	-252	AQ8	M	AQ9	-40	AQ10	+20

58C 10

CU1	--	CU2	18	CU3	47	CUB	M	CU6	26	CU7	50	CU8	12	CU9	30		
AQ1	--	AQ2	-551	AQ3	-429	AQB	M	AQ6	-325	AQ7	-249	AQ8	M	AQ9	-35	AQ10	+25

58C 51

CU1	--	CU2	14	CU3	64	CUB	M	CU6	50	CU7	46	CU8	12	CU9	34		
AQ1	--	AQ2	-533	AQ3	-411	AQB	M	AQ6	-334	AQ7	-241	AQ8	M	AQ9	-49	AQ10	+5

58D 6

CU1	--	CU2	--	CU3	16	CUB	M	CU6	54	CU7	46	CU8	25	CU9	42		
AQ1	--	AQ2	--	AQ3	-361	AQB	M	AQ6	-322	AQ7	-191	AQ8	M	AQ9	-46	AQ10	+20

58D 9

CU1	--	CU2	--	CU3	9	CUB	M	CU6	78	CU7	49	CU8	31	CU9	--		
AQ1	--	AQ2	--	AQ3	-384	AQB	M	AQ6	M	AQ7	-233	AQ8	M	AQ9	--	AQ10	+15

58E 2

CU1	--	CU2	--	CU3	45	CUB	M	CU6	50	CU7	54	CU8	42	CU9	33		
AQ1	--	AQ2	--	AQ3	-358	AQB	M	AQ6	-273	AQ7	-193	AQ8	M	AQ9	-19	AQ10	+25

58F 3

CU1	46	CU2	10	CU3	30	CUB	M	CU6	56	CU7	77	CU8	49	CU9	30		
AQ1	-1124	AQ2	-498	AQ3	-398	AQB	M	AQ6	-348	AQ7	-234	AQ8	M	AQ9	-42	AQ10	+20

58F 48

CU1	--	CU2	--	CU3	--	CUB	--	CU6	--	CU7	--	CU8	>48	CU9	24		
AQ1	--	AQ2	--	AQ3	--	AQB	--	AQ6	--	AQ7	--	AQ8	--	AQ9	+2	AQ10	+80

Control Well Number	Latitude (degrees-minutes-seconds)	Longitude (degrees-minutes-seconds)	Owner	Altitude of Land Surface (feet)	Altitude of Bottom of Logged Hole (feet)	Types of Logs Used
58H 4	37 23 31 N	076 31 26 W	VASWCB	75	-1793 BSMT	D,E,G,J

CU1 18 CU2 52 CU3 25 CUB 21 CU6 92 CU7 78 CU8 87 CU9 35
AQ1 -1179 AQ2 -756 AQ3 -667 AQB -600 AQ6 -539 AQ7 -323 AQ8 M AQ9 -44 AQ10 +75

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface	Altitude of Bottom of Logged Hole	Types of Logs Used
58J 5	37 36 30 N	076 31 26 W	BARNHARDT FARMS	40	-702	D,E

CU1 -- CU2 -- CU3 34 CUB 11 CU6 86 CU7 60 CU8 118 CU9 24
AQ1 -- AQ2 -- AQ3 -584 AQB -466 AQ6 -446 AQ7 -230 AQ8 M AQ9 0 AQ10 +40

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface	Altitude of Bottom of Logged Hole	Types of Logs Used
58J 11	37 33 52 N	076 37 28 W	RAPPAHANOCK COMMUNITY COLLEGE	110	-590	D,E

CU1 -- CU2 54 CU3 21 CUB 10 CU6 97 CU7 55 CU8 78 CU9 22
AQ1 -- AQ2 -- AQ3 -462 AQB -384 AQ6 -350 AQ7 -174 AQ8 M AQ9 +26 AQ10 +11

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface	Altitude of Bottom of Logged Hole	Types of Logs Used
58K 6	37 38 18 N	076 34 42 W	TOWN OF URBANNA	20	-630	D,E

CU1 -- CU2 >16 CU3 28 CUB 18 CU6 114 CU7 58 CU8 98 CU9 10
AQ1 -- AQ2 -- AQ3 -528 AQB -448 AQ6 -411 AQ7 -202 AQ8 M AQ9 +10 AQ10 M

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface	Altitude of Bottom of Logged Hole	Types of Logs Used
58L 7	37 46 21 N	076 30 50 W	SYDNOR HYDRODYNAMICS, INC.	90	-607	D,E

CU1 -- CU2 -- CU3 -- CUB 16 CU6 136 CU7 80 CU8 101 CU9 14
AQ1 -- AQ2 -- AQ3 -- AQB -510 AQ6 -466 AQ7 -230 AQ8 M AQ9 +10 AQ10 +90

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface	Altitude of Bottom of Logged Hole	Types of Logs Used
58N 3	38 01 43 N	076 34 00 W	BELRUH OYSTER COMPANY	20	-300	D,E

CU1 -- CU2 -- CU3 -- CUB -- CU6 >44 CU7 98 CU8 88 CU9 M
AQ1 -- AQ2 -- AQ3 -- AQB -- AQ6 -- AQ7 -171 AQ8 M AQ9 M AQ10 +20

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface	Altitude of Bottom of Logged Hole	Types of Logs Used
58N 4	38 05 21 N	076 34 45 W	SANFORD CANNING COMPANY	15	-283	D,E

CU1 -- CU2 -- CU3 -- CUB -- CU6 >32 CU7 105 CU8 80 CU9 M
AQ1 -- AQ2 -- AQ3 -- AQB -- AQ6 -- AQ7 -174 AQ8 M AQ9 M AQ10 +15

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface	Altitude of Bottom of Logged Hole	Types of Logs Used
59C 2	36 48 08 N	076 23 15 W	VIRGINIA DIVISION OF FORESTRY	20	-633	E,G

CU1 -- CU2 -- CU3 30 CUB M CU6 86 CU7 86 CU8 53 CU9 32
AQ1 -- AQ2 -- AQ3 -582 AQB M AQ6 -532 AQ7 -366 AQ8 M AQ9 -30 AQ10 +20

Control Well Number	Latitude (degrees-minutes-seconds)	Longitude (degrees-minutes-seconds)	Owner	Altitude of Land Surface (feet)	Altitude of Bottom of Logged Hole (feet)	Types of Logs Used
59C 13	36 52 18 N	076 27 47 W	TIDEWATER WATER COMPANY	15	-640	D,E,J

CU1 --	CU2 >13	CU3 30	CUB M	CU6 42	CU7 62	CU8 42	CU9 36		
AQ1 --	AQ2 --	AQ3 -493	AQB M	AQ6 -424	AQ7 -314	AQ8 M	AQ9 -42	AQ10 +15	

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface	Altitude of Bottom of Logged Hole	Types of Logs Used
59C 28	36 47 02 N	076 24 55 W	CITY OF CHESAPEAKE	20	-980	D,E,J

CU1 --	CU2 20	CU3 43	CUB M	CU6 33	CU7 72	CU8 44	CU9 32		
AQ1 --	AQ2 -800	AQ3 -518	AQB M	AQ6 -440	AQ7 -341	AQ8 M	AQ9 -67	AQ10 +20	

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface	Altitude of Bottom of Logged Hole	Types of Logs Used
59D 1	36 52 55 N	076 23 11 W	TIDEWATER WATER COMPANY	15	-573	D,E

CU1 --	CU2 --	CU3 13	CUB M	CU6 55	CU7 98	CU8 54	CU9 36		
AQ1 --	AQ2 --	AQ3 -507	AQB M	AQ6 -475	AQ7 -363	AQ8 M	AQ9 -49	AQ10 +15	

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface	Altitude of Bottom of Logged Hole	Types of Logs Used
59D 20	36 58 40 N	076 25 50 W	CITY OF NEWPORT NEWS	20	-890	D,E

CU1 --	CU2 24	CU3 62	CUB M	CU6 78	CU7 95	CU8 72	CU9 30		
AQ1 --	AQ2 -780	AQ3 -592	AQB M	AQ6 M	AQ7 -387	AQ8 M	AQ9 -40	AQ10 +20	

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface	Altitude of Bottom of Logged Hole	Types of Logs Used
59E 5	37 05 38 N	076 22 43 W	NASA RESEARCH CENTER	10	-2063 BSMT	D,E,J

CU1 78	CU2 34	CU3 26	CUB M	CU6 84	CU7 130	CU8 80	CU9 30		
AQ1 -1364	AQ2 -858	AQ3 -696	AQB M	AQ6 M	AQ7 -440	AQ8 M	AQ9 -80	AQ10 +10	

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface	Altitude of Bottom of Logged Hole	Types of Logs Used
59F 5	37 12 21	076 26 26 W	YORK COUNTY PARK	10	-220	D,E

CU1 --	CU2 --	CU3 --	CUB --	CU6 --	CU7 --	CU8 95	CU9 38		
AQ1 --	AQ2 --	AQ3 --	AQB --	AQ6 --	AQ7 --	AQ8 --	AQ9 -40	AQ10 +10	

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface	Altitude of Bottom of Logged Hole	Types of Logs Used
59J 6	37 32 01 N	076 26 12 W	BAPTIST GEN. ASSN. OF VIRGINIA	55	-795	D,E

CU1 --	CU2 >15	CU3 22	CUB 41	CU6 115	CU7 126	CU8 114	CU9 28		
AQ1 --	AQ2 --	AQ3 -674	AQB -579	AQ6 -523	AQ7 -384	AQ8 M	AQ9 -40	AQ10 +55	

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface	Altitude of Bottom of Logged Hole	Types of Logs Used
59J 11	37 34 31 N	076 23 38 W	E. ANDERSON	25	-673	D,E

CU1 --	CU2 --	CU3 >18	CUB 34	CU6 102	CU7 164	CU8 103	CU9 27		
AQ1 --	AQ2 --	AQ3 --	AQB -575	AQ6 -531	AQ7 -406	AQ8 M	AQ9 -47	AQ10 +25	

Control Well Number	Latitude (degrees-minutes-seconds)	Longitude (degrees-minutes-seconds)	Owner	Altitude of Land Surface (feet)	Altitude of Bottom of Logged Hole (feet)	Types of Logs Used
59K 17	37 39 41 N	076 25 48 W	SYDNOR HYDRODYNAMICS, INC.	15	-655	D,E
59K 18	37 40 36 N	076 26 14 W	TIDES INN RESORT	25	-720	D,E
59K 19	37 42 12 N	076 23 09 W	TOWN OF KILMARNOCK	75	-707	D,E
59L 5	37 52 27 N	076 24 04 W	SYDNOR HYDRODYNAMICS, INC.	75	-475	D,E
60B 1	36 38 11 N	076 22 22 W	CANAL BANK MOTOR LODGE	15	-723	D,E
60B 2	36 41 49 N	076 20 19 W	J. LENSEY	15	-807	D,E
60B 3	36 38 36 N	076 20 17 W	VASWCB	15	-965	E,J
60C 6	36 48 53 N	076 17 09 W	LONE STAR CEMENT CORPORATION	10	-790	D,E,G

Control Well Number											
59K 17	CU1 --	CU2 --	CU3 >36	CUB 10	CU6 111	CU7 104	CU8 110	CU9 20			
	AQ1 --	AQ2 --	AQ3 --	AQB -539	AQ6 -512	AQ7 -295	AQ8 M	AQ9 -20	AQ10 +15		
59K 18	CU1 --	CU2 --	CU3 80	CUB 4	CU6 118	CU7 99	CU8 70	CU9 20			
	AQ1 --	AQ2 --	AQ3 -664	AQB -526	AQ6 -504	AQ7 -283	AQ8 M	AQ9 0	AQ10 +25		
59K 19	CU1 --	CU2 --	CU3 >12	CUB 16	CU6 99	CU7 128	CU8 114	CU9 36			
	AQ1 --	AQ2 --	AQ3 --	AQB -588	AQ6 -539	AQ7 -313	AQ8 M	AQ9 -16	AQ10 +75		
59L 5	CU1 --	CU2 --	CU3 --	CUB --	CU6 >104	CU7 77	CU8 130	CU9 17			
	AQ1 --	AQ2 --	AQ3 --	AQB --	AQ6 --	AQ7 -271	AQ8 M	AQ9 0	AQ10 +75		
60B 1	CU1 --	CU2 --	CU3 80	CUB M	CU6 14	CU7 77	CU8 54	CU9 43			
	AQ1 --	AQ2 --	AQ3 -717	AQB M	AQ6 -559	AQ7 -415	AQ8 M	AQ9 -83	AQ10 +15		
60B 2	CU1 --	CU2 --	CU3 80	CUB M	CU6 5	CU7 87	CU8 47	CU9 44			
	AQ1 --	AQ2 --	AQ3 -692	AQB M	AQ6 -569	AQ7 -464	AQ8 M	AQ9 -92	AQ10 +15		
60B 3	CU1 --	CU2 56	CU3 76	CUB M	CU6 26	CU7 126	CU8 54	CU9 --			
	AQ1 --	AQ2 -951	AQ3 -752	AQB M	AQ6 -601	AQ7 -471	AQ8 M	AQ9 --	AQ10 +15		
60C 6	CU1 --	CU2 --	CU3 14	CUB M	CU6 86	CU7 140	CU8 72	CU9 38			
	AQ1 --	AQ2 --	AQ3 -700	AQB M	AQ6 -670	AQ7 -482	AQ8 M	AQ9 -53	AQ10 +10		

Control Well Number	Latitude (degrees-minutes-seconds)	Longitude (degrees-minutes-seconds)	Owner	Altitude of Land Surface (feet)	Altitude of Bottom of Logged Hole (feet)	Types of Logs Used
60C 7	36 51 15 N	076 19 17 W	CITY OF PORTSMOUTH	10	-1444	D,E,G,J
60C 25	36 51 31 N	076 18 29 W	CAMPBELL SOUP COMPANY	10	-890	D,E,J
60C 40	36 47 02 N	076 21 56 W	CITY OF CHESAPEAKE	20	-940	D,E,G,J
60E 8	37 00 43 N	076 22 03 W	DIXIE HOSPITAL	15	-383	D,E
60J 1	37 31 58 N	076 19 50 W	SYDNOR HYDRODYNAMICS, INC.	10	-782	D,E
60L 19	37 49 47 N	076 16 34 W	HAYNIE PRODUCTS, INC.	10	-799	D,E
61A 2	36 34 48 N	076 12 12 W	CITY OF CHESAPEAKE	10	-690	D,E,G
61B 2	36 42 27 N	076 07 47 W	VASWCB	20	-1180	E,J

Control Well Number									
60C 7	CU1 36	CU2 20	CU3 46	CUB M	CU6 95	CU7 118	CU8 48	CU9 27	
	AQ1 -1306	AQ2 -875	AQ3 -646	AQB M	AQ6 -582	AQ7 -422	AQ8 M	AQ9 -61	AQ10 +10
60C 25	CU1 --	CU2 >30	CU3 25	CUB M	CU6 94	CU7 130	CU8 55	CU9 25	
	AQ1 --	AQ2 --	AQ3 -648	AQB M	AQ6 -592	AQ7 -435	AQ8 M	AQ9 -44	AQ10 +10
60C 40	CU1 --	CU2 22	CU3 22	CUB M	CU6 80	CU7 92	CU8 42	CU9 16	
	AQ1 --	AQ2 -845	AQ3 -604	AQB M	AQ6 -564	AQ7 -376	AQ8 M	AQ9 -78	AQ10 +20
60E 8	CU1 --	CU2 --	CU3 --	CUB --	CU6 --	CU7 --	CU8 >168	CU9 25	
	AQ1 --	AQ2 --	AQ3 --	AQB --	AQ6 --	AQ7 --	AQ8 --	AQ9 -65	AQ10 +15
60J 1	CU1 --	CU2 --	CU3 25	CUB 25	CU6 136	CU7 170	CU8 118	CU9 38	
	AQ1 --	AQ2 --	AQ3 -707	AQB -610	AQ6 -580	AQ7 -422	AQ8 M	AQ9 -60	AQ10 +10
60L 19	CU1 --	CU2 --	CU3 >26	CUB 58	CU6 78	CU7 100	CU8 123	CU9 20	
	AQ1 --	AQ2 --	AQ3 --	AQB -658	AQ6 -574	AQ7 -356	AQ8 M	AQ9 -35	AQ10 +10
61A 2	CU1 --	CU2 --	CU3 --	CUB --	CU6 36	CU7 70	CU8 113	CU9 25	
	AQ1 --	AQ2 --	AQ3 --	AQB --	AQ6 -678	AQ7 -536	AQ8 M	AQ9 -100	AQ10 +10
61B 2	CU1 --	CU2 --	CU3 65	CUB M	CU6 59	CU7 138	CU8 127	CU9 25	
	AQ1 --	AQ2 --	AQ3 -895	AQB M	AQ6 -774	AQ7 -603	AQ8 M	AQ9 -75	AQ10 +20

Control Well Number	Latitude (degrees-minutes-seconds)	Longitude (degrees-minutes-seconds)	Owner	Altitude of Land Surface (feet)	Altitude of Bottom of Logged Hole (feet)	Types of Logs Used
61C 1	36 52 21 N	076 12 15 W	USGS	15	-2457	E,G,J
61D 5	36 54 25 N	076 10 50 W	CITY OF VIRGINIA BEACH	25	-1593	E,G,J
62C 2	36 47 15 N	076 03 08 W	VASWCB	20	-378	E,G,J
62C 4	36 47 11 N	076 06 00 W	VASWCB	15	-385	E,G,J
62C 5	36 45 04 N	076 03 13 W	VASWCB	20	-380	D,E,G
62D 2	36 57 59 N	076 06 47 W	CHES. BAY BRIDGE TUNNEL AUTH.	3	-1502	D,J
62G 9	37 15 39 N	076 01 14 W	BAYSHORE CONCRETE COMPANY	10	-213	D,E
63C 1	36 52 00 N	075 58 51 W	BUSH DEVELOPMENT CORPORATION	20	-1567	D,E,J

Control Well Number	CU1	CU2	CU3	CUB	CU6	CU7	CU8	CU9	
61C 1	60	35	25	M	74	170	122	40	
61D 5	--	55	19	M	37	190	132	46	
62C 2	--	--	--	--	--	--	>120	52	
62C 4	--	--	--	--	--	--	>126	54	
62C 5	--	--	--	--	--	--	>92	40	
62D 2	--	--	--	--	--	--	--	--	
62G 9	--	--	--	--	--	--	--	51	
63C 1	--	82	105	M	68	215	155	42	

Control Well Number	AQ1	AQ2	AQ3	AQB	AQ6	AQ7	AQ8	AQ9	AQ10
61C 1	-1580	-1015	-741	M	M	-570	M	-75	+15
61D 5	--	-1103	-781	M	M	-625	M	-75	+25
62C 2	--	--	--	--	--	--	--	-92	+20
62C 4	--	--	--	--	--	--	--	-95	+13
62C 5	--	--	--	--	--	--	--	-90	+20
62D 2	--	--	--	---	--	--	--	--	--
62G 9	--	--	--	--	--	--	--	-84	+10
63C 1	--	-1404	-1105	M	M	-790	M	-142	+20

Control Well Number	Latitude (degrees-minutes-seconds)	Longitude	Owner	Altitude of Land Surface (feet)	Altitude of Bottom of Logged Hole (feet)	Types of Logs Used
63F 1	37 11 59 N	075 57 32 W	NORTHAMPTON SCHOOL BOARD	30	-461	D,E,G,J

CU1 --	CU2 --	CU3 --	CUB --	CU6 --	CU7 --	CU8 >93	CU9 30		
AQ1 --	AQ2 --	AQ3 --	AQB --	AQ6 --	AQ7 --	AQ8 --	AQ9 -110	AQ10 +30	

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface	Altitude of Bottom of Logged Hole	Types of Logs Used
63G 19	37 20 22 N	075 56 12 W	USGS	35	-200	E,G,J

CU1 --	CU2 --	CU3 --	CUB --	CU6 --	CU7 --	CU8 --	CU9 55	
AQ1 --	AQ2 --	AQ3 --	AQB --	AQ6 --	AQ7 --	AQ8 --	AQ9 -75	AQ10 +35

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface	Altitude of Bottom of Logged Hole	Types of Logs Used
63L 1	37 49 48 N	075 59 47 W	TANGIER CRAB COMPANY	2	-991	G,J

CU1 --	CU2 --	CU3 --	CUB 62	CU6 75	CU7 --	CU8 --	CU9 25	
AQ1 --	AQ2 --	AQ3 --	AQB -836	AQ6 M	AQ7 -618	AQ8 --	AQ9 -50	AQ10 +2

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface	Altitude of Bottom of Logged Hole	Types of Logs Used
64H 3	37 28 30 N	075 51 55 W	NORTHAMPTON HOSPITAL	35	-315	D,E

CU1 --	CU2 --	CU3 --	CUB --	CU6 --	CU7 --	CU8 >24	CU9 76	
AQ1 --	AQ2 --	AQ3 --	AQB --	AQ6 --	AQ7 --	AQ8 --	AQ9 -91	AQ10 +35

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface	Altitude of Bottom of Logged Hole	Types of Logs Used
64J 1	37 36 00 N	075 46 38 W	ACCOMACK SCHOOL BOARD	45	-405	D,E,J

CU1 --	CU2 --	CU3 --	CUB --	CU6 --	CU7 --	CU8 >138	CU9 48	
AQ1 --	AQ2 --	AQ3 --	AQB --	AQ6 --	AQ7 --	AQ8 --	AQ9 -89	AQ10 +45

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface	Altitude of Bottom of Logged Hole	Types of Logs Used
64J 8	37 32 01 N	075 49 16 W	EXMORE FOODS, INC.	35	-245	D,E

CU1 --	CU2 --	CU3 --	CUB --	CU6 --	CU7 --	CU8 --	CU9 36	
AQ1 --	AQ2 --	AQ3 --	AQB --	AQ6 --	AQ7 --	AQ8 --	AQ9 -85	AQ10 +35

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface	Altitude of Bottom of Logged Hole	Types of Logs Used
65J 4	37 35 28 N	075 42 08 W	GULF STREAM NURSERY	10	-290	D,E

CU1 --	CU2 --	CU3 --	CUB --	CU6 --	CU7 --	CU8 >7	CU9 60	
AQ1 --	AQ2 --	AQ3 --	AQB --	AQ6 --	AQ7 --	AQ8 --	AQ9 -100	AQ10 +10

Control Well Number	Latitude	Longitude	Owner	Altitude of Land Surface	Altitude of Bottom of Logged Hole	Types of Logs Used
65K 8	37 44 03 N	075 39 37 W	PERDUE FOODS, INC.	50	-290	D,E

CU1 --	CU2 --	CU3 --	CUB --	CU6 --	CU7 --	CU8 >37	CU9 60	
AQ1 --	AQ2 --	AQ3 --	AQB --	AQ6 --	AQ7 --	AQ8 --	AQ9 -74	AQ10 +50

Control Well Number	Latitude (degrees-minutes-seconds)	Longitude (degrees-minutes-seconds)	Owner	Altitude of Land Surface (feet)	Altitude of Bottom of Logged Hole (feet)	Types of Logs Used
65K 17	37 42 33 N	075 44 29 W	TOWN OF ONANCOCK	15	-265	D,E
	CU1 -- CU2 -- CU3 -- CUB -- CU6 -- CU7 -- CU8 -- CU9 72					
	AQ1 -- AQ2 -- AQ3 -- AQB -- AQ6 -- AQ7 -- AQ8 -- AQ9 -85 AQ10 +15					
65L 6	37 45 30 N	075 40 10 W	BYRD PACKING COMPANY	35	-251	D,E
	CU1 -- CU2 -- CU3 -- CUB -- CU6 -- CU7 -- CU8 -- CU9 74					
	AQ1 -- AQ2 -- AQ3 -- AQB -- AQ6 -- AQ7 -- AQ8 -- AQ9 -105 AQ10 +35					
66M 1	37 53 03 N	075 31 01 W	J&J TAYLOR ENTERPRISES	40	-6034 BSMT	E,G,J
	CU1 173 CU2 165 CU3 126 CUB 60 CU6 172 CU7 324 CU8 250 CU9 70					
	AQ1 -3210 AQ2 -2108 AQ3 -1458 AQB -1286 AQ6 M AQ7 M AQ8 -598 AQ9 -106 AQ10 +40					
66M 7	37 55 38 N	075 33 02 W	ATLANTIC HIGH SCHOOL	25	-425	D,E
	CU1 -- CU2 -- CU3 -- CUB -- CU6 -- CU7 -- CU8 >129 CU9 54					
	AQ1 -- AQ2 -- AQ3 -- AQB -- AQ6 -- AQ7 -- AQ8 -- AQ9 -91 AQ10 +25					
66M 12	37 53 21 N	075 33 44 W	HOLLY FARMS, INC.	40	-290	D,E
	CU1 -- CU2 -- CU3 -- CUB -- CU6 -- CU7 -- CU8 -- CU9 60					
	AQ1 -- AQ2 -- AQ3 -- AQB -- AQ6 -- AQ7 -- AQ8 -- AQ9 -91 AQ10 +40					
67L 2	37 52 20 N	075 26 54 W	NASA	10	-171	D,E
	CU1 -- CU2 -- CU3 -- CUB -- CU6 -- CU7 -- CU8 -- CU9 78					
	AQ1 -- AQ2 -- AQ3 -- AQB -- AQ6 -- AQ7 -- AQ8 -- AQ9 -120 AQ10 +10					
68M 2	37 53 24 N	075 20 25 W	NATIONAL PARK SERVICE	10	-790	D,E
	CU1 -- CU2 -- CU3 -- CUB -- CU6 -- CU7 -- CU8 318 CU9 109					
	AQ1 -- AQ2 -- AQ3 -- AQB -- AQ6 -- AQ7 -- AQ8 -748 AQ9 -144 AQ10 +10					