Department of Natural Resources
MARYLAND GEOLOGICAL SURVEY
Kenneth N. Weaver, Director

REPORT OF INVESTIGATIONS NO. 53

GEOLOGY AND HYDROLOGIC ASSESSMENT OF COASTAL PLAIN AQUIFERS IN THE WALDORF AREA, CHARLES COUNTY, MARYLAND

GEOLOGY, HYDROGEOLOGIC FRAMEWORK, AND WATER QUALITY

by

John M. Wilson
and
William B. Fleck

WATER-SUPPLY POTENTIAL OF THE AQUIFERS

by

William B. Fleck
and
John M. Wilson

Prepared in cooperation with the
United States Department of the Interior
Geological Survey
and
The Charles County Board of Commissioners

1990

CONVERSION FACTORS AND ABBREVIATIONS

For the convenience of readers who may prefer to use metric (International System) units rather than the inch-pound units used in this report, values may be converted using the following factors:

Multiply inch-pound unit	by	To obtain metric unit
	Length	
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow	
inch per year (in/yr)	25.4	millimeter per year (mm/yr)
gallon per minute (gal/min)	0.06308	liter per second (L/s)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
	Hydraulic properties	
foot per day (ft/d)	0.3048	meter per day (m/d)
foot squared per day (ft^2/d)	0.09290	meter squared per day (m^2/d)
gallon per minute per foot [(gal/min)/ft]	0.2070	liter per second per meter [(L/s)/m]
cubic foot per day per cubic foot [$(ft^3/d)/ft^3$]	1	cubic meter per day per cubic meter [$(m^3/d)/m^3$]

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

Water temperature, specific conductance, and chemical concentration are given in metric units. Water temperature in degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) by using the following equation:

$$°F = 1.8\ (°C) + 32$$

Specific conductance of water is expressed in microsiemens per centimeter at 25 °C (μS/cm). This unit is identical to micromhos per centimeter at 25 °C, formerly used by the U.S. Geological Survey.

Chemical concentration in water is expressed in milligrams per liter (mg/L) and micrograms per liter (μg/L).

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by John M. Wilson and William B. Fleck

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GEOLOGY AND HYDROLOGIC ASSESSMENT OF COASTAL PLAIN AQUIFERS IN THE WALDORF AREA, CHARLES COUNTY, MARYLAND

ABSTRACT

From the stratigraphically highest aquifer to the lowest, the hydrogeologic section at Waldorf, Maryland, consists of the surficial aquifer, the Aquia aquifer, the Waldorf aquifer system, the White Plains aquifer, the La Plata aquifer system, and the Patuxent aquifer system. The Waldorf aquifer system consists of three discrete mappable aquifers—the Monmouth, Magothy, and St. Charles—that together form an interconnected hydrologic unit. Measured transmissivities range from 2,000 to 8,500 feet squared per day (ft^2/d) in the Waldorf aquifer system, 20 to 2,000 ft^2/d in the White Plains aquifer, and 400 to 3,500 ft^2/d in the La Plata aquifer system. The Waldorf and La Plata aquifer systems are the primary sources of water to the Waldorf public-supply system.

Stratigraphic correlations show that a northeast-striking, up-to-the-east, reverse fault of the Brandywine fault system trends through the western part of the Waldorf area. The fault has up to 250 feet (ft) of throw at the pre-Cretaceous basement. Beds within the Patuxent and Arundel Formations (undivided) and the lower part of the Patapsco Formation may be offset across the fault. The upper part of the Patapsco, Magothy, and Severn Formations, and Tertiary formations deposited prior to the Calvert Formation show dip reversals and form a west-dipping flexure. The Potomac Group in the Waldorf area has thinned by as much as 150 ft and the Nanjemoy Formation has thinned by about 70 ft on the upthrown side of the fault.

The Aquia, Monmouth, and Magothy aquifers at Waldorf contain a moderately hard to hard, calcium sodium bicarbonate-type water. The St. Charles aquifer contains a softer, more sodic-type water than the overlying Magothy and Monmouth aquifers. Water from the White Plains aquifer is a soft, sodium calcium bicarbonate-type water. The La Plata and Patuxent aquifer systems contain a very soft, sodium bicarbonate-type water. Concentrations of total dissolved solids generally increase as the depth of the aquifer increases.

A digital ground-water-flow model of the significant aquifers in the area of Waldorf in Charles County, Maryland, was constructed. The flow model consisted of 38 rows, 29 columns, and 7 layers. The seven layers represented by the model included the following units: the surficial, Aquia, Monmouth, Magothy, St. Charles, and White Plains aquifers and the La Plata aquifer system. The model cells differed in size from 0.12 square miles (mi^2) in the immediate Waldorf area to 12 mi^2 at the model's edge.

The model was calibrated for transient pumping conditions from 1900 to 1985. Calibration was attained by comparing simulated heads to measured heads for about 130 observation wells. Pumpage input to the model ranged from a minimum of 0.02 million gallons per day (Mgal/d) for 1900 to a maximum of 15.6 Mgal/d for 1985. Maximum modeled transmissivities for the calibrated model ranged from 3,500 ft^2/d for the Aquia aquifer, to 12,000 ft^2/d for the Magothy aquifer.

The ground-water-flow model was used to simulate head changes through the year 2020 for seven different pumpage scenarios. The results of these scenarios indicated that additional pumpages of 4.2 and 1.9 Mgal/d would result in 95 and 225 ft of additional drawdown in the La Plata aquifer system and White Plains aquifer, respectively. Also, an additional pumpage of about 0.90 Mgal/d from the Waldorf aquifer system would produce additional drawdowns of about 15 ft in the Waldorf area.

Three of the scenarios were devised to estimate the amount of ground water that could be withdrawn, such that a limit of 80 percent of the total available drawdown would not be exceeded. When the Waldorf aquifer system, White Plains aquifer, and La Plata aquifer system were separately stressed until the 80-percent available drawdown was reached, withdrawal rates of 6.6, 6.1, and 15.2 Mgal/d, respectively, were obtained.

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INTRODUCTION

BACKGROUND

The town of Waldorf lies in north-central Charles County, Md., about 80 mi (miles) south of Baltimore, Md., and 25 mi southeast of Washington, D.C. (fig. 1). Over the past 40 years, Waldorf has grown from a small rural village along the old Pennsylvania Railroad into one of the largest population centers in southern Maryland (fig. 2). The population of the Waldorf area increased from a little more than 1,000 in 1960 to about 26,500 in 1980 (Maryland Department of Economic and Community Development, written commun., 1987). Through 1987, the urbanization of the Waldorf area paralleled two major highways—U.S. Route 301 and Maryland Route 5 (fig. 2). U.S. Route 301 connects Waldorf to the north with Baltimore, Md., and to the south with Norfolk, Va. Maryland Route 5 provides a direct route from Waldorf to Washington, D.C., and also provides access to Calvert and St. Marys Counties. Relatively inexpensive housing, major transportation routes, and proximity to Washington, D.C., a regional center of employment, continue to attract new residents to the Waldorf area (Pacey, 1983).

An increasing demand for water has accompanied the population growth of Waldorf. The water needs of Waldorf's population have been met by developing the area's ground-water resources because of the lack of significant surface-water resources. The primary aquifer system supplying water to the Waldorf area from 1948 to 1985 was the Waldorf aquifer system[1]. Prior to 1948, the surficial aquifer (water-table aquifer) provided adequate amounts of water to the residents of Waldorf. In 1948, individuals and businesses that required larger amounts of water than the surficial aquifer could reliably produce began to use the Waldorf aquifer system. From 1948 to 1958, the demands of these individual homeowners and businesses were met by wells that yielded less than 100 gal/min (gallons per minute). In 1958, a few wells that yielded from 100 to 250 gal/min were drilled to supply several businesses in Waldorf. By 1960, the need for a central public-supply system to provide for the area's growing population was evident, and in 1962, the first two production wells of the Waldorf public-supply system began operation. During the next 20 years, six more production wells, each capable of yielding greater than 500 gal/min, were added to the town's public-supply system. Of these six wells, five were screened solely in the Waldorf aquifer system and one was screened in both the Waldorf aquifer system and the White Plains aquifer[2].

Graphs in Mack and others (1983) show that water levels in the Waldorf aquifer system (Magothy aquifer of their report) declined by as much as 85 ft from 1962 to 1980. During this period, pumpage from the Waldorf aquifer system increased from about 0.15 Mgal/d in 1962 to about 2 Mgal/d in 1980 (Mack and others, 1983). By 1985, pumpage from the Waldorf aquifer system had increased to 2.7 Mgal/d, and, in response, water levels in the aquifer system declined an additional 10 ft. On the basis of their regional model of the Magothy aquifer, Mack and Mandle (1977) predicted that unacceptable water-level declines in the subcrop area of the Waldorf aquifer system (their Magothy aquifer) would occur if pumpage from the Waldorf aquifer system reached 4.5 Mgal/d.

A test well drilled in 1984 indicated that the lower sands of the Patapsco Formation (the La Plata aquifer system[3]) were productive in the Waldorf area (Wilson, 1986). By 1986, three high-capacity production wells screened in the La Plata aquifer system were added to the Waldorf public-supply system.

PURPOSE AND SCOPE

The purpose of this report is to describe the geology and ground-water hydrology of the Waldorf area and to quantify the ground-water production potential of the area's aquifers. The report is presented in three major sections. The purpose of the first section of the report is to describe the geology, hydrogeologic framework, and water quality of the Waldorf area.

[1]The Waldorf aquifer system as defined in this report is composed of three aquifers—the Monmouth, Magothy, and St. Charles. It is equivalent to the Waldorf aquifer system and the upper sands of the upper Patapsco aquifer system described by Wilson (1986). The Magothy aquifer of Mack and Mandle (1977) and Mack and others (1983) forms part of the Waldorf aquifer system.

[2]The White Plains aquifer underlies the Waldorf aquifer system. It is equivalent to the lower sands of the upper Patapsco aquifer system of Wilson (1986). The White Plains aquifer is a new name proposed in this report. The origin of the name is from the small town of White Plains which lies about 2 mi south of Waldorf.

[3]The La Plata aquifer system in this report is equivalent to the La Plata aquifer system of Hansen (1980) and the middle Patapsco aquifer and lower Patapsco aquifer system of Wilson (1986).

Figure 1.—Location of Waldorf, Charles County, Maryland.

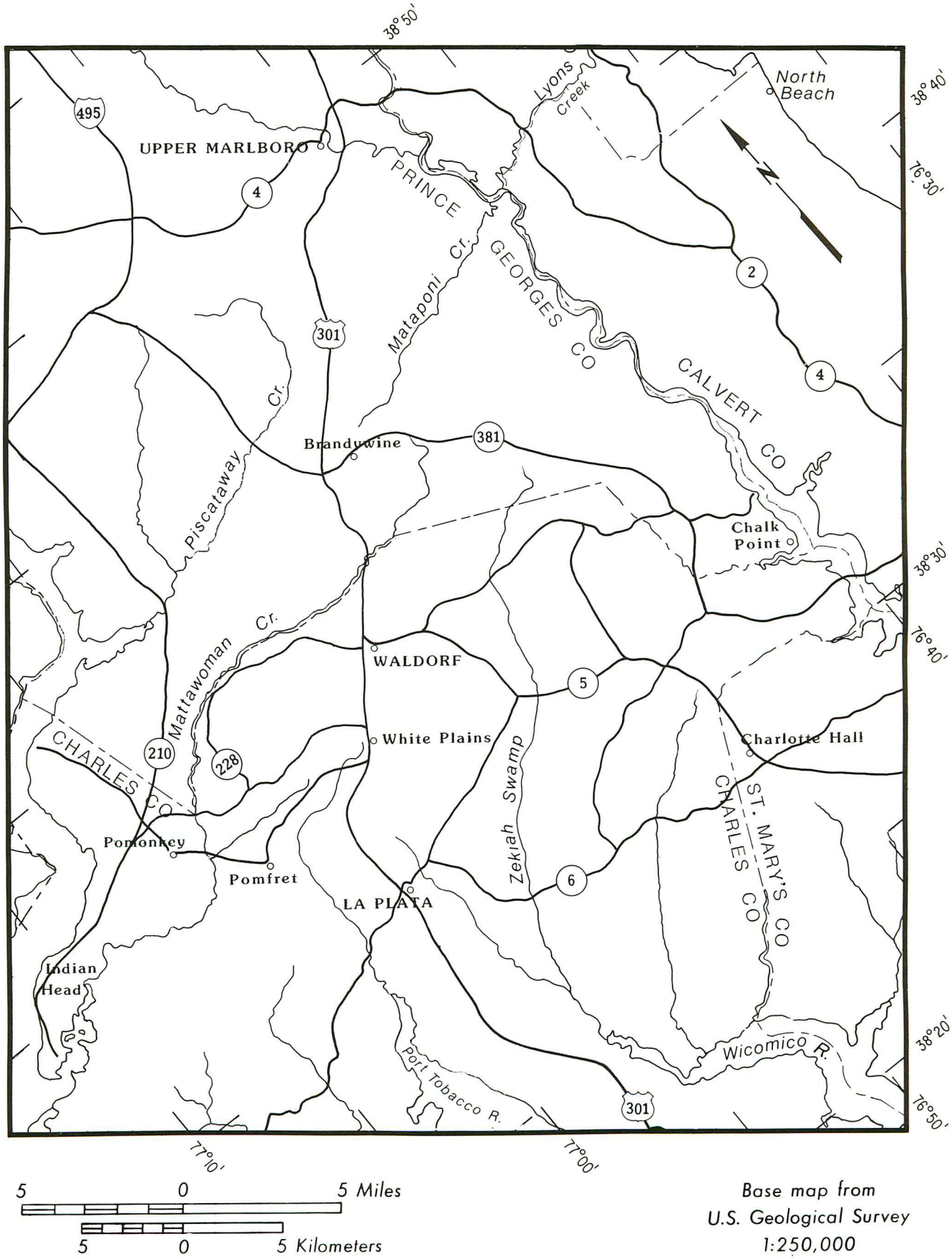


Figure 2.—Location of Waldorf and the study area.

Hydrogeologic sections, structure-contour maps of the tops of formations, contour maps of the tops of aquifers, and trilinear water-analysis diagrams are used to illustrate these topics. The ground-water-flow model described in the second section of the report is based upon the hydrogeologic framework described in the first section. Information relevant to the topics discussed in the first section of the report (basic geologic, hydrologic, and water-chemistry data, and the results of the micropaleontologic analyses of selected cores) are included in a series of appendixes that form the third and final section of the report.

PREVIOUS STUDIES

The work of many individuals in different disciplines of the earth sciences has contributed to our present understanding of the hydrogeology of Charles County. Darton (1896) described several wells and their aquifers in Charles County and nearby parts of Prince Georges County. Later, Fiedler and Jacob (1939) conducted a detailed investigation of the aquifers and well fields at the naval installation at Indian Head. Results of the first comprehensive investigation of the geology and hydrology of Charles County were described by Dryden and Overbeck (1948). Study of the hydrogeology of Charles County continued with a regional review of the hydrogeology of southern Maryland by Otton (1955). Slaughter and Laughlin (1966) compiled hydrogeologic data for Charles County, and Slaughter and Otton (1968) described the water resources of Charles County. In a regional study that included Charles County, Hansen (1968) used lithologic and electric logs to construct a cross-section correlation network of the Cretaceous sediments in southern Maryland that included several sections through Charles County. Additionally, Hansen (1968) related the subsurface geologic framework of sediments in the Potomac Group to their hydrologic potential.

Hydrogeologic studies specific to the Waldorf area include Mack and Mandle's (1977) ground-water-flow model of the Magothy aquifer in southern Maryland, and Mack and others' (1983) description of the water-level declines in the Magothy aquifer (Waldorf aquifer system). Wilson (1986) reevaluated the hydrogeologic framework and stratigraphy of the Waldorf area and proposed the name "Waldorf aquifer system" for the series of sands in the Waldorf area that were called the Magothy aquifer by previous workers. Wilson (1986) also evaluated the La Plata aquifer system in the Waldorf area based on information gathered from an exploratory test well and production well. Chapelle and others (1987) described the effects of bacterial metabolism on ground-water geochemical processes in the confined aquifers at Waldorf. Other studies of interest include Pacey's (1983) description of the water-supply resources, ground-water production systems and water usage in Charles County, and Miller and others' (1984) water-supply resources development and management plan for Charles County. Whitman, Requardt and Associates, consulting engineers, completed a report on the Waldorf area's water-supply system for the Charles County Department of Public Works in 1985.

Several geologic and paleontologic studies conducted in southern Maryland are germane to the hydrogeology of Charles County. Glaser (1969) related the sedimentation patterns of the Magothy and Potomac Formations of the Mid-Atlantic Coastal Plain to the structure of their Cretaceous depositional basin. Jacobeen (1972) presented evidence for the presence of faulting in the subsurface a few miles north of Waldorf in the Brandywine area of southern Prince Georges County. Dames & Moore, Inc. (1973), presented seismic evidence of basement faulting in Charles County. More recently, Hansen (1978) related pinch-outs in the Upper Cretaceous and Lower Paleocene formations in southern Maryland to depositional control effected by the basement structure of the south flank of the Salisbury Embayment. Brenner (1963) established the presence of two major palynozones within the Patapsco Formation and further work by Doyle (1969), Wolfe and Pakiser (1971), Wolfe (1976), and Doyle and Robbins (1977) expanded and refined the palynologic zonations of the Cretaceous sediments of Maryland.

LOCATION OF STUDY AREA

The focus of this study is the Waldorf area of north-central Charles County. The term "Waldorf area," as used in this report, corresponds to the region of Charles County that lies within about a 5-mi radius of the intersection of U.S. Route 301 and Maryland Route 5 (pl. 8). To effectively study the Waldorf area, a region of about 986-mi^2 in southern Maryland was delineated for detailed geologic and hydrologic study. This region is shown in figure 2. The development of the ground-water-flow model, however, required the correlation of aquifers on a regional basis. Consequently, most of southern Maryland from southern Anne Arundel County south to the Potomac River was included in the model area.

METHODS OF INVESTIGATION

The investigation of the geology and aquifers of the Waldorf area drew on a variety of data sources. Published reports and unpublished data on file at the Maryland Geological Survey and U.S. Geological Survey were reviewed to obtain information concerning the stratigraphy, aquifer characteristics, and water chemistry of the study area. Nine wells and one stratigraphic test hole drilled during the course of this study

provided new hydrogeologic data. Four of these wells were completed as observation wells as part of this project's drilling program—three were screened in the St. Charles aquifer[4] and one was screened in the White Plains aquifer. Continuous water-level recorders were installed on two of the four observation wells. The remaining five wells were drilled for the Charles County Department of Public Works—three were completed as La Plata aquifer system production wells, one was completed as an observation well in the Patuxent aquifer system, and one was completed as a production well in the Waldorf aquifer system. Pumping and recovery tests were made in the nine wells to calculate aquifer transmissivity values. Water samples were collected from seven production wells of the Waldorf public-supply system and five observation wells. The water samples were analyzed by the water-quality laboratory of the U.S. Geological Survey. The stratigraphic test hole was a 620-ft deep continuous core hole drilled to the upper part of the Patapsco Formation as a cooperative endeavor between the Geologic and Water Resources Divisions of the U.S. Geological Survey, and the Maryland Geological Survey. Microfossil analyses of core samples recovered from the stratigraphic test hole and cores taken in other boreholes were used to aid in establishing the stratigraphy of the study area.

Geophysical, lithologic, and micropaleontologic data were used to construct hydrogeologic sections, structure-contour maps of the tops of the formations, and contour maps of the tops of the aquifers. The hydrogeologic framework revealed by these sections and maps was used to develop the numerical ground-water-flow model described in the second section of this report.

[4]The St. Charles aquifer is the basal aquifer of the Waldorf aquifer system. It is equivalent to the upper sands of Wilson's (1986) upper Patapsco aquifer system. The St. Charles aquifer is a new name proposed in this report. The name "St. Charles" is derived from the residential community of St. Charles City, which is adjacent to the older town of Waldorf.

ACKNOWLEDGMENTS

Officials of the Charles County Department of Public Works who helped plan and expedite this study include Susan Weber, Chief of Sanitation, and Stefan Koczerzuk, Chief of Engineering. Thanks is given to the above individuals and all the employees of the Charles County Department of Public Works who through their help and cooperation made invaluable contributions to the success of this study.

The authors wish to express thanks to the contractors and drilling crews who drilled wells for this study and to those who drilled wells under contract to the Charles County Department of Public Works. Other individuals who provided help and assistance during the study include: Louis Vlangas, Whitman, Requardt and Associates; Stephen Curtin and Judith Wheeler, U.S. Geological Survey; and Frederick Mack, Maryland Geological Survey. Lucy McCartan, U.S. Geological Survey, and Harry Hansen, Maryland Geological Survey, provided helpful expertise regarding the stratigraphy and geology of the Waldorf area. Gilbert Brenner, State University of New York at New Paltz, analyzed the microfossil content of selected core samples. Thomas Gibson, Laurel Bybell, and George Andrews, U.S. Geological Survey, analyzed the microfossil content of cores from the Waldorf core hole. Francis Chapelle, U.S. Geological Survey, did much of the early ground-water sampling of the Waldorf public-supply system wells and also the drill-site work on this study's first observation well. Sheryl Protani, U.S. Geological Survey, provided constructive editorial advice. Donna Lowry, U.S. Geological Survey, typed the manuscript, and Donajean Appel, Maryland Geological Survey, typed the tables and well logs. Jean Hyatt, U.S. Geological Survey, drafted the illustrations in the second section and the base maps. Cynthia Lang-Bachur, Maryland Geological Survey, drafted the illustrations for the first section.

GEOLOGY

Waldorf and the north-central region of Charles County lie in the western part of the Coastal Plain province of Maryland (fig. 1). The sediments of the Maryland Coastal Plain form a wedge of generally unconsolidated sand, silt, and clay that thickens from a few feet at the Fall Line (the contact of the Piedmont and Coastal Plain provinces) to more than 7,500 ft at the Maryland coast. At Waldorf, the Coastal Plain sediments are unconsolidated Cretaceous, Tertiary, and recent clastics that were deposited in fluvio-deltaic or marine environments. These unconsolidated sediments overlie generally consolidated, pre-Cretaceous rocks that are referred to as the "basement" rocks in this report. The thickness of the Coastal Plain section ranges from about 1,600 ft to almost 2,000 ft in the Waldorf area (pl. 1).

Several boreholes drilled through the full thickness of the Coastal Plain sediments penetrated the pre-Cretaceous basement in the Waldorf area. Data from these wells, numerous shallower wells, and test holes drilled to basement near the town of Brandywine in southern Prince Georges County were used to define the stratigraphy of the Waldorf area. A stratigraphic column summarizing the geologic units present at Waldorf is shown in table 1. The stratigraphy of north-central Charles County is further illustrated by a series of geophysical-log cross sections (pls. 1-6) and structure-contour maps (figs. 3-5). A map of the location of the wells and test holes used to construct the cross sections and structure-contour maps is shown in figure 7. Basic hydrologic data for the wells and test holes used in this report are found in appendix A. Descriptive logs of significant wells and test holes, selected core samples, and the stratigraphic core holes (CH Bf 148 and 149) are found in appendixes B, C, and D, respectively.

GEOLOGIC SECTION AT WALDORF

Pre-Cretaceous Basement Rocks

Crystalline metamorphic rocks and consolidated, red sandstones and shales form the basement rocks that underlie the Coastal Plain section in the Waldorf area. The crystalline metamorphic rocks are the oldest (probably Paleozoic) and stratigraphically lowest rocks found at Waldorf. In well CH Be 57 (pls. 3 and 4), a schist similar to the pelitic schist of the Wissahickon Group is present at a depth of 1,791 ft below land surface (Hansen and Edwards, 1986). North of Waldorf, in the Brandywine region of Prince Georges County, some of the wells drilled to basement also encountered schist and gneiss beneath the Coastal Plain sediments (Jacobeen, 1972). The consolidated, red sandstones, conglomerates, and shales are assigned to the Triassic (?) to Jurassic (?) Newark Supergroup (Jacobeen, 1972; Hansen and Edwards, 1986). The consolidated red beds, where present in the section, unconformably overlie the crystalline metamorphic rocks. In well CH Ce 37 (pl. 6), located about 2 mi south of Waldorf, red sandstones and shales were found at 1,976 ft below land surface (Hansen and Edwards, 1986). Similar red sandstones and shales were found underlying the Coastal Plain sediments in wells drilled a few miles north of Waldorf in the Brandywine region of Prince Georges County (Jacobeen, 1972). The full thickness of the Triassic (?) and Jurassic (?) sediments at Waldorf is not known.

Potomac Group

In central Maryland, the Potomac Group is separated into three formations. From stratigraphically lowest to highest, the formations are the Patuxent, Arundel, and Patapsco Formations (Glaser, 1969). At Waldorf, the subdivision of the Potomac Group into three formations is possible in the subsurface if well control is adequate. In much of Maryland, however, it is not always possible to recognize formation contacts within the Potomac Group either in outcrop or the subsurface. North of Waldorf in the subsurface of Prince Georges County, the Arundel Formation is difficult to differentiate from the Patuxent Formation because facies changes within the formations have increased the sandiness of the section (Glaser, 1969; Hansen, 1969).

The Patuxent Formation is the basal formation of the Lower and Upper Cretaceous Potomac Group at Waldorf. The Patuxent Formation unconformably overlies the Triassic (?) and Jurassic (?) red beds and crystalline metamorphic rocks of the pre-Cretaceous basement. The Patuxent consists of grayish tan, fine to coarse, commonly clayey, quartzose sands that are interbedded with thick sequences of hard, mostly gray but also variegated red and brown clays. Sands occur in sequences that average about 20 ft thick and range from less than 10 ft to a maximum of about 30 ft. The Patuxent Formation ranges from 220 to 350 ft thick in the Waldorf and La Plata areas (pls. 1, 3, 4, and 6).

Sands in the Patuxent at Waldorf comprise about 30 to 40 percent of the total thickness of the formation. For example, a total of 105 ft of sand, equal to 40 percent of the formation thickness of the Patuxent, is present at well CH Bf 144 (pls. 1 and 6). Sands in the Patuxent Formation at wells CH Be 57 and CH Ce 37 (pl. 6), however, equal about 30 percent of the formation thickness. Sand thicknesses were determined from electric logs using the inflection point method of Lynch (1962). These data agree

Table 1.—Generalized subsurface stratigraphy of the Waldorf area, Charles County, Maryland

Erathem	System	Series	European stage	Group	Formation 1/	Lithology	Aquifers and hydrologic properties	Formation thickness (feet)
Cenozoic	Tertiary	Pliocene ?			Upland Deposits (Western Shore)	Orange-tan medium to coarse sand and gravel; silts and clays.	The surficial aquifer; can provide small amounts of water.	20-50
		Miocene	Upper					
			Middle to Lower	Chesapeake	Calvert Formation	Brownish-green clays and clayey silts.	Leaky confining unit.	90-100
		Eocene	Middle to Lower	Pamunkey	Nanjemoy Formation	Medium to dark greenish-black, silty clays and some fine clayey sands; glauconitic	Leaky confining unit.	90-125
		?	?		Marlboro Clay	Medium reddish-brown and light gray clays.	Confining unit.	15-30
		Paleocene	Upper		Aquia Formation	Greenish-black, glauconitic, silty clays and fine sands. Some glauconitic, fine to medium sands. Fossiliferous.	The Aquia aquifer and leaky confining units.	100-140
			Lower		Brightseat Formation	Greenish-gray, fine, clayey, silts and sands, glauconitic.	Leaky confining unit.	0?-15
Mesozoic	Cretaceous	Upper	Maestrich-tian		Severn Formation	Gray, medium to coarse, clean quartzose sands. Some dark and light gray silty clays. Glauconite bearing at some localities.	The Monmouth aquifer; part of the Waldorf aquifer system. Also forms a leaky confining unit.	0-70
			Lower Campanian to Santonian		Magothy Formation	Gray, fine to coarse, clean, quartzose sands with some small gravel. Some light gray clays.	The Magothy aquifer. Part of the Waldorf aquifer system.	0-95
		?	Cenomanian	Potomac	Patapsco Formation	Grayish tan to brownish gray fine to coarse, clean to clayey, and silty sands; and hard, variegated, red, gray and brown clays.	The St. Charles aquifer, part of the Waldorf aquifer system. The White Plains aquifer. The La Plata aquifer system. Also forms leaky and tight confining units.	800-900
		Lower	Albian		Arundel Formation	Variegated red, gray and brown, hard and tight clays. Some silty and fine sandy lenses.	Effective and widespread confining unit.	200-260
			Lower Albian to Barremian		Patuxent Formation	Gray and tan, fine to coarse sands; and hard variegated, red brown, and gray clays.	The Patuxent aquifer system	220-350
	Jurassic (?) Triassic (?)			Newark (Super group)		Consolidated red shales, sand-stones, and conglomerates.	None	0 -?
Paleo-zoic				Wissa-hickon (?)		Crystalline metamorphics, chlorite schists, and gneisses.	None	?

with the northward trend of increasing sand unit thickness within the Patuxent Formation of southern Maryland described by Hansen (1969).

The Arundel Formation conformably overlies the Patuxent Formation at Waldorf. The Arundel consists of thick sequences of very hard, variegated red, brown, and gray clays with some interbedded silty sands. The Arundel Formation is separated from the Patuxent and Patapsco Formations at Waldorf on the basis of lithology and stratigraphic correlations (pls. 1, 3, 4, and 6). The absence of sands is the lithologic criterion used to distinguish the Arundel Formation from the underlying Patuxent Formation and the overlying Patapsco Formation. The thickness of the Arundel Formation at Waldorf ranges from about 200 to 260 ft (pls. 1 and 3).

The sand-bearing Patapsco Formation unconformably overlies the Arundel Formation throughout the subsurface at Waldorf. Generally, a medium to coarse basal sand marks the unconformable contact of the Patapsco Formation with the Arundel. The Patapsco at Waldorf consists of fine to coarse, clayey to clean, quartzose sands and some gravels; the sands are interbedded at a scale of a few feet to tens of feet with hard, variegated red, brown, and gray clays. The thickness of the Patapsco in the Waldorf area ranges from 800 to 900 ft (pl. 3). Sand sequences within the Patapsco range from less than 10 to about 50 ft thick.

The cumulative thickness of sands as a percent of total formation thickness increases within the Patapsco Formation northward through Waldorf. South of Waldorf at well CH Ce 37 (pl. 6), the percentage of sand in the Patapsco is about 22 percent. In Waldorf, at wells CH Be 57 and CH Bf 146 (pls. 3, 4, and 6), sands within the Patapsco equal about 28 percent of the thickness of the formation. However, at well CH Bf 144 (pls. 1 and 6), only 1.5 mi northeast of well CH Bf 146 (pls. 3, 4, and 6), sand comprises almost 50 percent of the thickness of the formation. These sand percentages, determined by the method of Lynch (1962), are in agreement with the northward trend of increased sand content in the Patapsco Formation described by Hansen (1969).

Magothy Formation

The Upper Cretaceous Magothy Formation unconformably overlies the Lower and Upper Cretaceous Patapsco Formation at Waldorf. The Magothy at Waldorf consists of light gray, medium to coarse and gravelly quartzose sands, and subordinate, medium gray, clayey silts. The Magothy-Patapsco Formation contact is an erosional unconformity characterized by coarse and gravelly basal sands of the Magothy truncating either mottled red, brown, and gray clays or brownish gray, fine, clayey sands of the Patapsco Formation.

In the subsurface, the Magothy Formation is a widespread unit that extends throughout the northern half of the Salisbury Embayment from Long Island, N.Y., south to southern Maryland and the Delmarva Peninsula. The Magothy thins and reaches the southwestern limit of its extent about 4 mi southwest of Waldorf (pls. 3, 4, and 6). The thickness of the Magothy Formation in the Waldorf and La Plata area ranges from a few feet at the edge of its extent to about 95 ft in the northeastern part of Waldorf at well CH Bf 144. Regionally, the Magothy Formation thickens in a northeasterly direction from Waldorf.

The thinning of the Magothy Formation south and west of Waldorf may, in part, be caused by its increasing proximity to the edge of the formation's depositional basin. The hydrogeologic sections (pls. 3, 4, and 6), however, show that the Magothy is unconformably overlain and truncated by younger sediments both to the south and west of Waldorf. South of Waldorf, these younger sediments are tentatively assigned to the Upper Cretaceous Severn Formation[5] (pl. 6). West of Waldorf, the Severn and Brightseat Formations overlie and truncate the Magothy Formation (pls. 1 and 3). East of Waldorf in southern Maryland, Hansen (1978) attributes the southern limit of the Upper Cretaceous Magothy, Matawan, and Severn Formations to erosion and truncation by overlapping lower Tertiary sediments.

Severn Formation

The Upper Cretaceous Severn Formation unconformably overlies the Magothy Formation at Waldorf. The Severn ranges from several feet thick to more than 70 ft thick in the Waldorf area (pls. 1-6). The Severn is Maestrichtian in age and was deposited in a marine inner-shelf environment (Minard, 1979; apps. E and F). At Waldorf, the Severn consists of light gray to dark gray clays, and medium to granular, clean, quartz dominant sands. Some glauconite was logged in the upper clayey part of the formation in the northern part of Waldorf at well CH Bf 144. In well CH Bf 146 a white to light pinkish gray clay occurs at the base of the formation. From this basal clay, the formation coarsens upward through a dark gray, micaceous, very clayey silt and fine sand, to a 24-ft-thick, clean, medium to gravelly quartzose sand. From the top of this coarse sand, the Severn fines upward to a dark gray, micaceous, fine sandy clay.

A lenticular-shaped (pl. 6), quartz-dominant sand facies of the Severn Formation is present at Waldorf. This sand facies of the Severn reaches a maximum thickness of

[5]The name "Severn" was reintroduced into the stratigraphic nomenclature by Minard and others (1977) to replace the name "Monmouth" for the unit that unconformably overlies the Magothy Formation and is unconformably overlain by either the Brightseat or Aquia Formations on the western shore of Maryland (Minard, 1979). The use of the name "Severn" is restricted to the western shore of Maryland.

45 ft at well CH Bf 145 (pl. 6). The lenticular shape and the coarse quartz sands of this facies are suggestive of deposition as an offshore bar that was quite close to the paleoshoreline. Minard (1979) mapped a mature orthoquartzose sand facies of the Severn in outcrop west of Bowie, Md. He noted that the coarse-grained, mature orthoquartzose character of the sands and the absence of glauconite indicate nearshore deposition close to the sediment source area.

West and updip of well CH Bf 145, the Severn Formation and its sand facies thin until only a clayey facies of the Severn is present. This clay facies of the Severn extends as a 5-to 10-ft-thick unit for several miles west of Waldorf (pl. 2). South of Waldorf, a clayey facies of the Severn, probably less than 10 ft thick, extends to the La Plata area (Lucy McCartan, U.S. Geological Survey, oral commun., 1987) (pl. 6). In northeastern Charles County, little data regarding the Severn Formation exist and the thickness and extent of the sandy facies of the formation are unknown.

Waldorf is near the southwestern limit of the Severn's distribution in Maryland. As with the underlying Magothy Formation, the areal extent of the Severn to the south and west of Waldorf may be controlled, in part, by thinning of the Severn due to increasing proximity to the edge of its depositional basin. The presence of a nearshore sand facies in the Severn at Waldorf implies that Waldorf lies close to the edge of the Severn's depositional basin. Additionally, erosion prior to deposition of the overlapping sediments of the Brightseat Formation (pls. 1-6) has caused thinning of the Severn.

Tertiary Formations

The lower Paleocene Brightseat Formation unconformably overlies the Upper Cretaceous Severn Formation in the Waldorf area. The Brightseat at Waldorf is a medium greenish gray, micaceous, glauconite-bearing, clayey, fine sand and silt. The presence of the Brightseat at Waldorf is confirmed by micropaleontological analyses (apps. E and F). The Brightseat is a thin unit (about 15 ft thick) in the Waldorf area.

At Waldorf, the upper Paleocene Aquia Formation unconformably overlies the lower Paleocene Brightseat Formation. In the Waldorf area, the Aquia is primarily a dark olive green to olive gray, glauconitic, fossiliferous, clayey, fine sand and silt. Generally, one or two thin beds of 3- to 5-ft-thick, relatively clay-free, medium to dark green, glauconitic, fine- to medium-grained sand are present within the Aquia Formation at Waldorf. The Aquia at Waldorf ranges from about 100 to 140 ft thick (pls. 1-6).

Calcite-cemented strata 1 to 3 ft thick are common in the Aquia Formation (Ward, 1985). At Waldorf, a calcite-cemented bed about 4 ft thick was cored in well CH Bf 148 about 22 ft below the top of the formation. This bed and the fine- to medium-grained beds of sand found below it appear on the resistivity logs of the core hole as a high resistivity zone that is characterized on the logs by a spike-like deflection to the right. This resistivity spike in the upper part of the Aquia is traceable throughout the Waldorf area (pls. 1-6).

The upper Paleocene and lower Eocene (?) Marlboro Clay conformably overlies the Aquia at Waldorf. The Marlboro Clay at Waldorf is a dense, medium reddish-brown, silty clay. The Marlboro forms a readily identifiable and widespread marker bed throughout much of southern Maryland. In addition to the characteristic reddish color generally found at Waldorf, the Marlboro may also exhibit a light silvery gray color (Glaser, 1971). At Waldorf, the Marlboro ranges from 15 to 30 ft thick.

The lower Eocene Nanjemoy Formation overlies the Marlboro Clay. Paleontologic evidence gathered from the stratigraphic core holes, wells CH Bf 148 and 149 (app. F), indicates that the Nanjemoy may conformably overlie the Marlboro Clay at Waldorf. The Marlboro Clay below the contact is, however, heavily burrowed. This suggests that the contact of these two units is unconformable. Even if the contact of these two units is erosive, there was little time lost between deposition of the two units (McCartan and others, 1988). The Nanjemoy is predominantly a dark olive green to olive black, micaceous, glauconitic, clayey silt with some beds of dark green, fine to medium, glauconite-bearing sands in the upper part of the formation. The thickness of the Nanjemoy at Waldorf ranges from about 90 to 125 ft.

Unconformably overlying the Nanjemoy at Waldorf is the lower Miocene Calvert Formation. The Calvert is a light to medium, olive gray to olive green, micaceous, clayey silt. The thickness of the Calvert in the Waldorf area is about 90 to 100 ft. The formation is the basal unit of the Chesapeake Group and it represents deposition in a marine shelf environment (Gibson, 1982). None of the younger formations of the Chesapeake Group are present in the section at Waldorf.

In the Waldorf area, the Calvert is unconformably overlain by the Pliocene Upland Deposits (western shore) of Weaver and others (1968). The Upland Deposits consist of orange-tan, silty, fine to very coarse sands and gravels, and yellowish to orange, silty clays. The Upland Deposits range from 20 to 50 ft thick and crop out throughout the Waldorf area.

STRUCTURAL GEOLOGY OF NORTH-CENTRAL CHARLES COUNTY

A northeast-striking fault system (fig. 3) and related west-dipping flexure (figs. 4 and 5) lie just west of and parallel to Route 301 (pl. 8) in the Waldorf area of northern Charles County. The faults and related folds in the Waldorf area are a continuation of the Brandywine structure of southern Prince Georges and northern Charles Counties described by Jacobeen (1972). Jacobeen (1972)

interpreted the Brandywine structure in Prince Georges County as a series of en echelon, high-angle reverse faults that are upthrown to the east. The sense of movement of the fault shown in the hydrogeologic sections and structure contour maps is also that of an up-to-the-east, high-angle reverse fault. Jacobeen (1972) presented evidence that the Brandywine fault system was active during the Early Cretaceous and that there was additional movement during the late Eocene and possibly middle Miocene.

Mixon and Newell (1977) attribute the origin of the Brandywine fault system to reversal of movement in response to regional compressional stress along a preexisting zone of crustal weakness that was probably associated with an early Mesozoic basin border fault. Reverse faults generally imply compressional stress and Sbar and Sykes (1973) showed that regional east-west-trending compressional stress fields were present in eastern North America during the late Mesozoic and Cenozoic Eras. Hansen and Edwards (1986) point out that Waldorf and the surrounding area may lie above the northwestern border of a buried early Mesozoic rift basin because of the presence of Triassic (?) and Jurassic (?) sediments in the subsurface near La Plata and to the northeast in southern Prince Georges County, and because Triassic (?) and Jurassic (?) sediments are absent in wells, such as CH Be 57 (pls. 3 and 4), located a short distance to the west of Waldorf. Lucy McCartan (U.S. Geological Survey, oral commun., 1988) has mapped other faults in the Waldorf and La Plata area that are part of the Brandywine fault system.

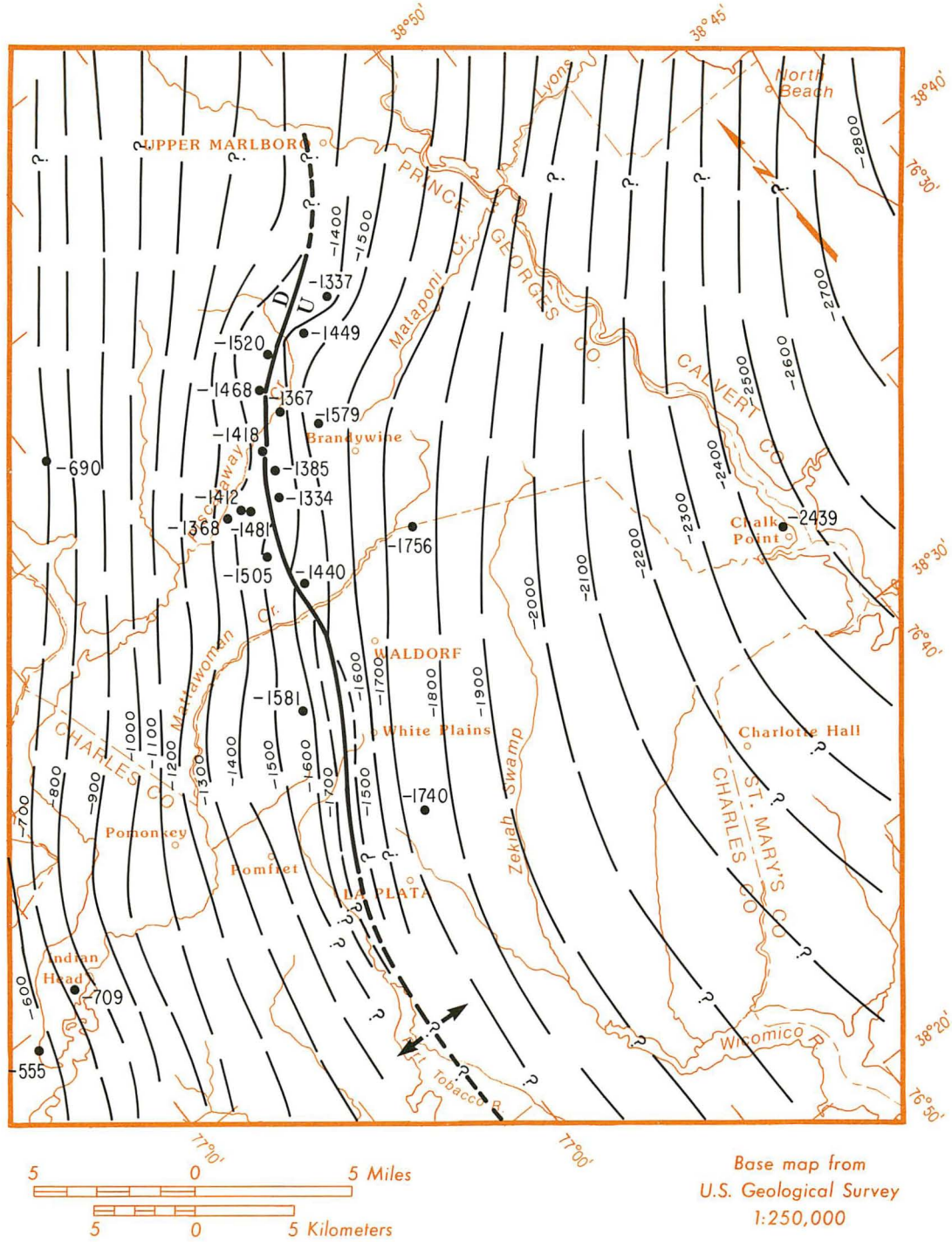
The effects of faulting on the formations of the Waldorf area is shown by the hydrogeologic sections (pls. 2-4), structure-contour maps (figs. 3-5), and the thickness map of the Potomac Group (fig. 6). The structure-contour map of the top of basement (fig. 3) shows the trace of a major fault of the Brandywine fault system, and the structure-contour maps of the top of the Patapsco and Aquia Formations (figs. 4 and 5) show the northeast-striking flexure caused by the faulting. The basement rocks and the Patuxent, Arundel, and probably the lower part of the Patapsco Formation are offset across the fault (pls. 3 and 4). Seismic sections in Jacobeen (1972) and Dames & Moore, Inc. (1973), show probable bed offsets extending up into the lower part of the Patapsco Formation. The throw of the Brandywine fault at basement in Waldorf is about 250 ft. Neither the available seismic data nor the hydrogeologic sections demonstrate bed offsets in the upper part of the Patapsco, the Upper Cretaceous units, or the pre-Calvert Tertiary formations. Consequently, the deformation of these units is interpreted as a flexure on the hydrogeologic sections and structure-contour maps.

Structure-contour maps of the tops of the Patapsco and Aquia Formations (figs. 4 and 5) show that the flexure occurs over a distance of about 1,000 ft. This concurs with data in Dames & Moore, Inc. (1973) that indicate the folding of the Marlboro Clay in the Brandywine region of southern Prince Georges County occurred over a distance of less than 1,000 ft. The top of the Aquia Formation dips west at about 350 ft/mi (feet per mile) and the top of the Patapsco Formation dips west from 400 to 500 ft/mi along the steepest parts of the flexure (figs. 4 and 5). Hydrogeologic sections B-B', C-C', and X-X' (pls. 2, 3, and 4) show that the dip of the Marlboro Clay is about 350 ft/mi west and that the dip of the Magothy Formation is between 400 and 500 ft/mi west along the steepest part of the flexure. These dip reversals contrast with the regional dip of about 50 ft/mi east. The increased dip of the deeper formations indicates that the Brandywine fault system was sporadically active during the late Mesozoic and Cenozoic Eras.

Offset of beds in the upper part of the Patapsco Formation and younger units in the subsurface at Waldorf is not precluded by the available data. Outcrops of both the Nanjemoy Formation and Marlboro Clay in Charles County show bed offsets (J.D. Glaser, Maryland Geological Survey, oral commun., 1988). Also, Dryden (1932) describes possible faults in outcrops of the Pliocene Upland Deposits near the town of Upper Marlboro. Although the amount of throw on these surficial faults is small, apparently only several feet, the faulting indicates the occurrence of post-Cretaceous faulting of sufficient magnitude to cause surface expression and offset in Tertiary units that overlie 700 to 1,500 ft of Coastal Plain sediments. The faulting about 3 mi south of Upper Marlboro described by Dryden (1932) probably is associated with the Brandywine fault system (fig. 3).

The total thickness of Coastal Plain sediments thins by about 250 ft across the fault trace. Some of the thinning of the Coastal Plain section has apparently occurred within the Potomac Group. The thickness map of the Potomac Group (fig. 6) suggests the Potomac Group is probably about 150 ft thinner on the upthrown side of the fault compared to the downthrown side in the Waldorf area. In addition, hydrogeologic section X-X' (pl. 4) shows that the Potomac Group is about 100 ft thinner in well PG Fc 5, which is located on the upthrown side of the fault, than in well CH Be 57, which is located on the downthrown side of the fault about 4 mi to the southwest along strike. Quantitative analysis of formation thickness within the Potomac Group is not possible with the presently available data because the correlation lines within the Potomac Group are not sufficiently defined. Well control is adequate, however, to quantify changes in the formation thickness of the Nanjemoy Formation. Hydrogeologic sections C-C' and X-X' show that the Nanjemoy thins by about 70 ft across the fault (pls. 3 and 4) and also suggest some thinning of the Aquia Formation. Nondeposition or higher rates of erosion on the eastern, upthrown side of the fault relative to the western, downthrown side may have caused the thinning in the Nanjemoy and Aquia Forma-

(Text continued on p. 18.)



5 0 5 Miles

5 0 5 Kilometers

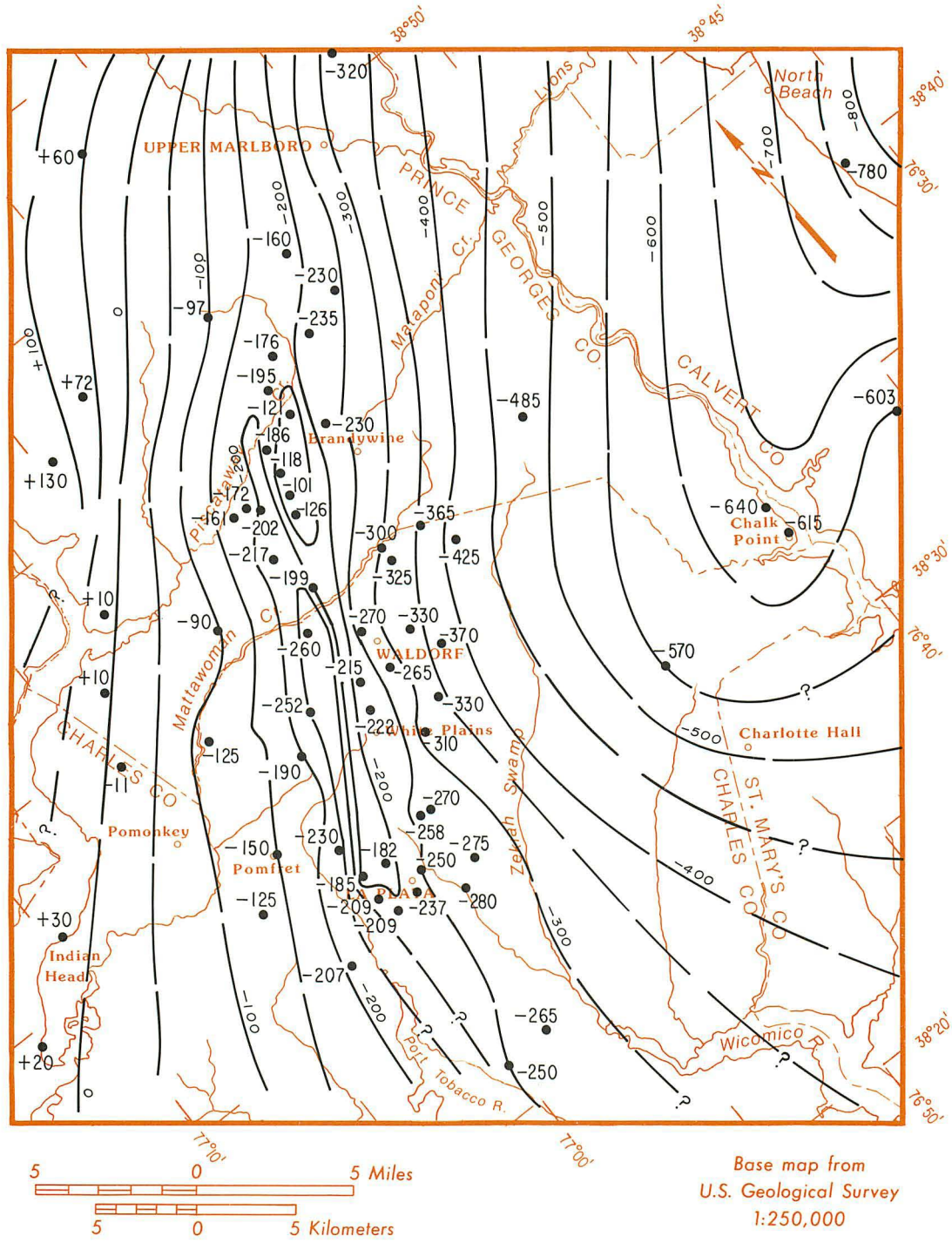
Base map from U.S. Geological Survey 1:250,000

EXPLANATION

-1449 ●	Data point and altitude in feet below (-) sea level.
? -700	Line of equal altitude. Dashed where well control sparse. Queried where uncertain.
?	Trace of reverse fault. Dashed where well control sparse. Queried where uncertain.
?	Flexure.
U	Upthrown block.
D	Downthrown block.

Contour interval is 100 feet.

Figure 3.—Altitude of the top of the pre-Cretaceous basement rocks.



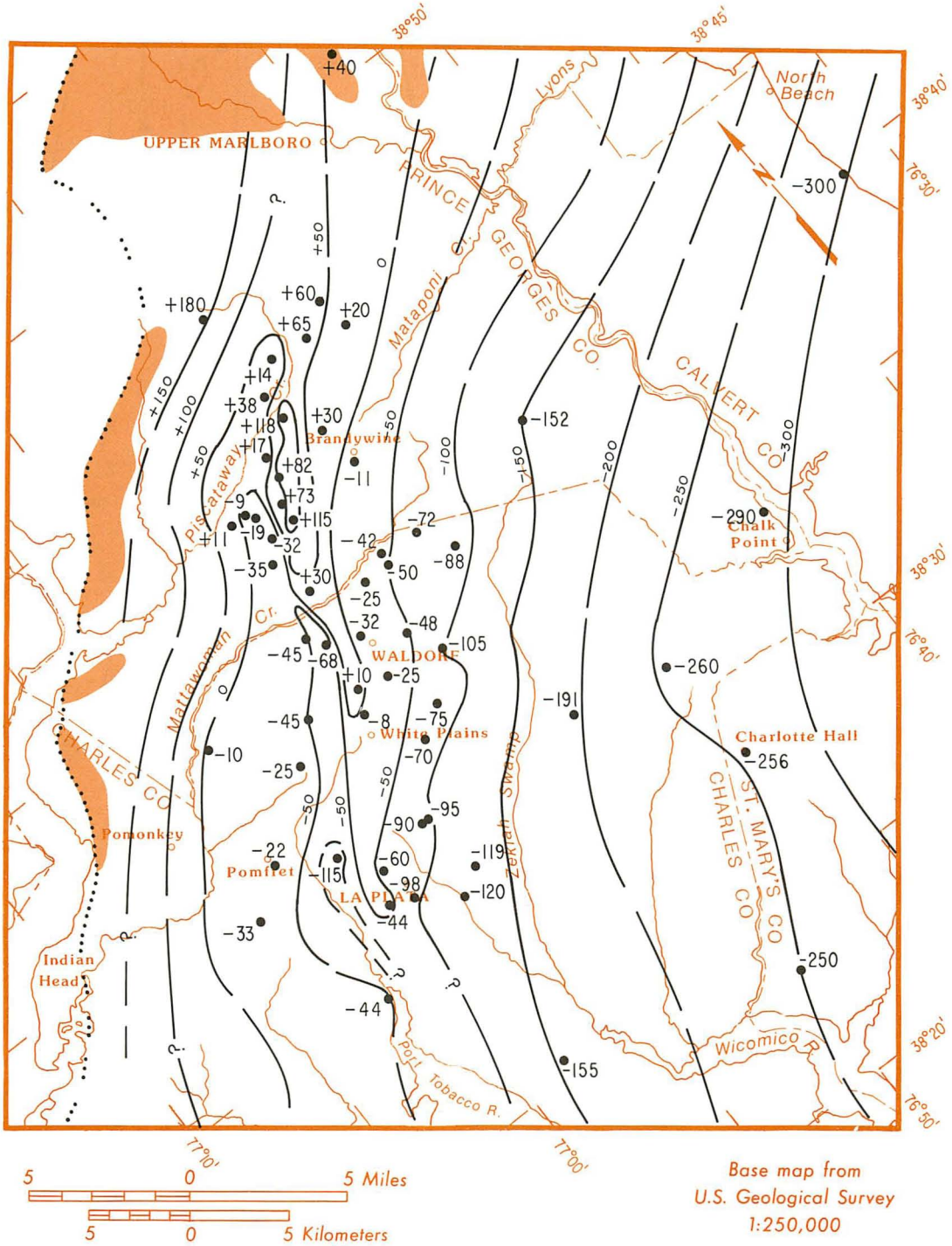
EXPLANATION

-185 Data point and altitude, in feet above (+) and below (—) sea level.

-100 Line of equal altitude. Dashed where well control sparse. Queried where uncertain.

Contour interval 50 feet. Datum is sea level.

Figure 4.—Altitude of the top of the Patapsco Formation.



5 0 5 Miles

5 0 5 Kilometers

Base map from U.S. Geological Survey 1:250,000

EXPLANATION

-115 Data point and altitude in feet above (+) and below (-) sea level.

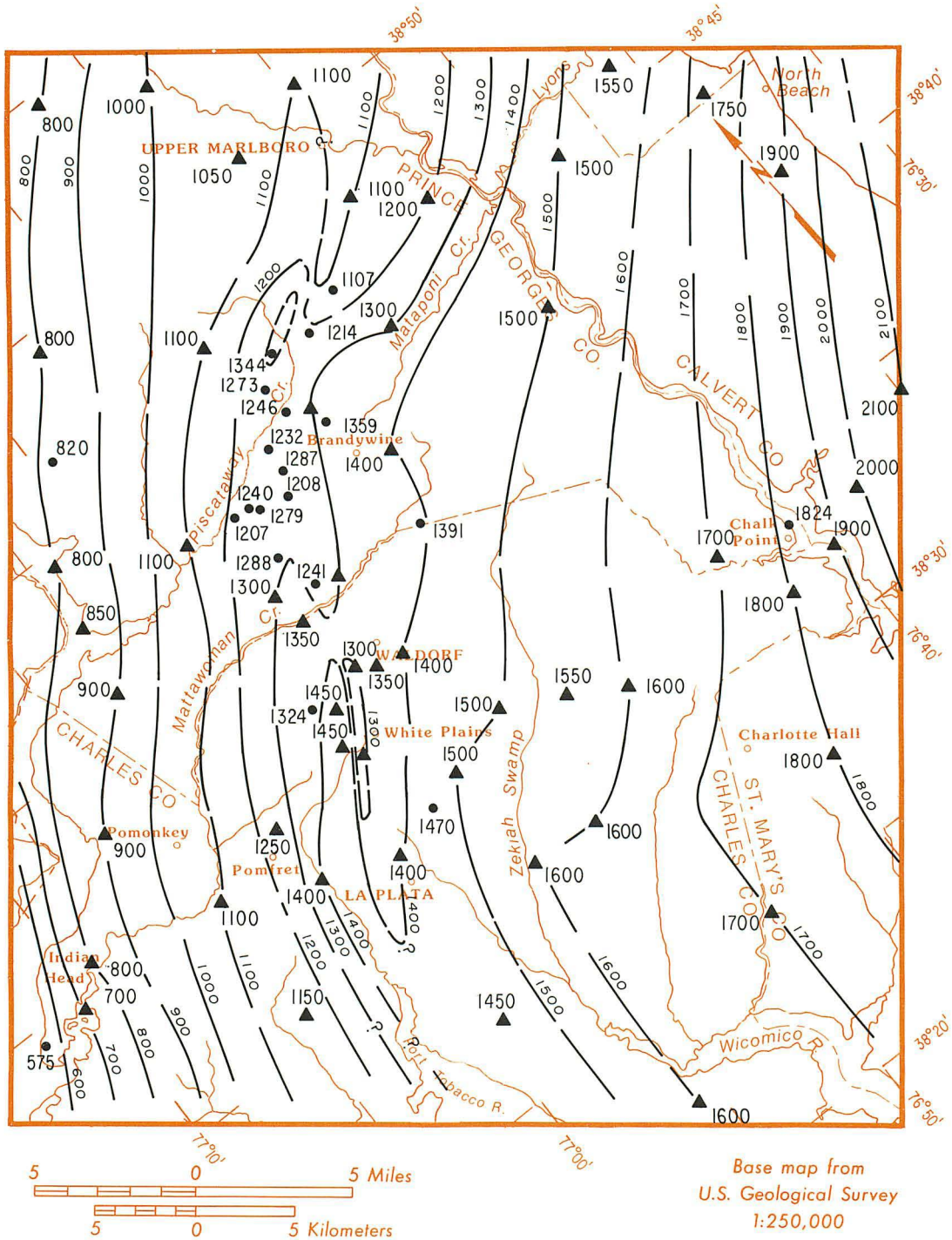
-50 Line of equal altitude. Dashed where well control sparse. Queried where uncertain.

Approximate limit of formation.

Approximate outcrop area of formation.

Contour interval 50 feet.

Figure 5.—Altitude of the top of the Aquia Formation.



EXPLANATION

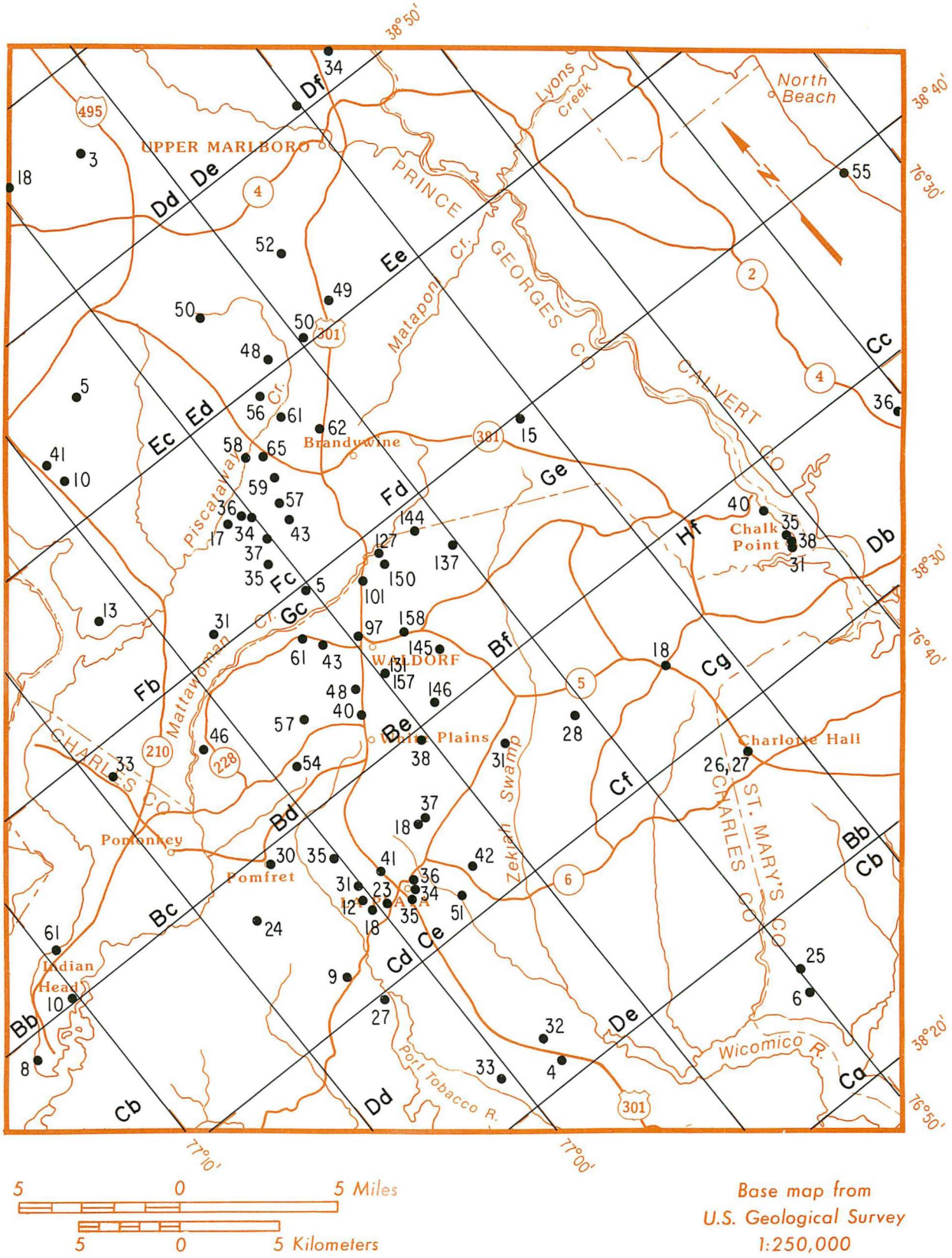
1324 ● Data point and thickness determined from geophysical logs.

850 ▲ Data point and thickness calculated by superposition of the structure--contour maps of the top of pre-Cretaceous basement (Fig. 3) and top of the Patapsco Formation (Fig. 4).

?—600— Line of equal thickness penetrated. Dashed where well control sparse. Queried where uncertain.

Contour interval is 100 feet.

Figure 6.—Thickness of the Potomac Group.



5 0 5 Miles

5 0 5 Kilometers

Base map from U.S. Geological Survey 1:250,000

EXPLANATION

146 ● Site of well or test hole and well number.

Be County well location quadrangle.

Figure 7.—Location of wells and test holes used for hydrogeologic control.

tions. Fault-related thickness changes in the Magothy, Severn, Brightseat, Aquia, and Marlboro Clay cannot be proven with the available data. Evidence suggestive of fault-related thinning of the Magothy aquifer, however, is discussed in the section "Hydrogeologic Framework."

The thinning of formations on the eastern side of the fault suggests when faulting occurred. Thinning of the Potomac Group suggests that the fault was active during the Early Cretaceous. Recurrent activity in the Eocene is indicated by the 70 ft of missing section in the Nanjemoy Formation (pl. 4). Possible thinning of the Aquia Formation suggests some faulting may have occurred during Paleocene. The Miocene Calvert Formation shows a slight flexure (about 8 ft) across the fault trace in southern Prince Georges County (Jacobeen, 1972). The flexure in the Calvert Formation may have resulted from recurrent faulting during the Miocene or Pliocene; however, the slight flexure in the Calvert Formation could easily represent draping of sediments over a pre-existing structure.

HYDROGEOLOGIC FRAMEWORK

HYDROLOGIC UNIT NOMENCLATURE

The various nomenclature schemes that have been devised and applied to the hydrologic units in northern Charles County are compared in table 2. The table shows the confusion that could arise regarding the various names used to identify aquifers within the Patapsco and Patuxent Formations in Charles County. Confusion over what constitutes the "Magothy aquifer" in northern Charles County has occurred. Several of the reports listed in table 2 contain different definitions of what comprises the Magothy aquifer.

Several reasons account for the confusion that has surrounded the hydrostratigraphy of northern Charles County. First, earlier researchers were working with less data than are presently available for this hydrostratigraphically complex region. Also, several of these reports focused on regions other than northern Charles County and the aquifer nomenclature of these reports was extended to northern Charles County. In addition, hydrogeologists in Maryland generally followed the common practice of naming aquifers after geologic formations. The use of geologic formation names as the basis of aquifer names has caused confusion regarding the hydrostratigraphy of northern Charles County because formation contacts do not always correspond to hydrologic boundaries.

Confusion over aquifer names may, at first, appear unimportant. However, the accurate definition and identification of a region's aquifers is essential when the amount of pumpage from an aquifer is regulated, when potential aquifers are misidentified and consequently bypassed, and when confusion arises because of contradictions in the scientific literature. Each of these situations has occurred in the Waldorf area.

The need to formally revise some of the aquifer names currently used in the Waldorf/La Plata area is evident. Based upon the results of this investigation and following the aquifer nomenclature guidelines in Laney and Davidson (1986), the aquifer nomenclature for north-central and northwestern Charles County has been revised to reflect an aquifer's hydrologic boundaries and not an aquifer's occurrence in a particular geologic formation.

The aquifers that are present in the Patapsco Formation at Waldorf are mappable aquifers in north-central Charles County because of good subsurface control. However, there are not enough data to extend these aquifers as mappable units throughout the entire study area east and northeast of Waldorf and south of La Plata. Subsurface control is adequate to demonstrate hydraulic continuity for the shallower Aquia and Magothy aquifers throughout the study area. Consequently, the names "Aquia" and "Magothy" are properly used to identify these aquifers.

This report uses the term "aquifer system" as a hydrologic unit descriptor. The relationship of an aquifer to an aquifer system is, in part, one of scale and is dependent upon the size of the study area. More importantly, an aquifer system is comprised of either named aquifers or unnamed permeable beds that are separated by confining units.These confining units may locally impede the flow of ground water, but they do not greatly affect the regional ground-water flow of the system (Poland and others, 1972). The key difference between an aquifer system comprised of named aquifers, "the Waldorf aquifer system," and one comprised of unnamed permeable beds, "the La Plata aquifer system," is that the aquifers that comprise the Waldorf aquifer system are mappable hydrologic units at the scale of this study and the sands that comprise the La Plata aquifer system are not.

The structure of the ground-water flow model is based on the aquifers identified at Waldorf. Consequently, hydraulic continuity of the aquifers mapped in northern Charles County with stratigraphically equivalent aquifers that exist outside northern Charles County was assumed for modeling purposes. To minimize confusion regarding their discussion, aquifers outside the Waldorf area that were modeled as having hydraulic continuity with the

Table 2.—Correlation chart of aquifer names used in this report with those used in previous reports for northern Charles and southern Prince Georges Counties, Maryland

Dryden and Overbeck, 1948	Otton, 1955	Mack, 1966	Slaughter and Otton, 1968	Hansen, 1968	Mack and Mandle, 1977 Mack and others, 1983	Miller and others, 1984	Wilson, 1986		This report	
Aquia aquifer	Aquia aquifer	Aquia aquifer	Aquia aquifer	Aquia aquifer	Aquia aquifer	Aquia aquifer	Aquia aquifer		Aquia aquifer	
Cretaceous aquifers	Magothy aquifer	Magothy aquifer	Monmouth aquifer (considered minor) Magothy aquifer	Magothy aquifer	Magothy aquifer (includes "Raritan sands")	Magothy aquifer	Waldorf aquifer system	Monmouth aquifer Magothy aquifer Sands of the Patapsco Formation in "sand on sand" contact with the Magothy aquifer	Waldorf aquifer system	Monmouth aquifer Magothy aquifer St. Charles aquifer
	Patapsco and Raritan aquifers	Patapsco aquifers	Raritan and Patapsco aquifers	Raritan and Patapsco aquifers	Patapsco aquifers	Upper/Middle Patapsco aquifer zone	Upper Patapsco aquifer system		White Plains aquifer	
	Patuxent aquifers 1/		Patuxent aquifers 1/				Middle Patapsco aquifer system		La Plata aquifer system 1/	
						Lower Patapsco aquifer zone	Lower Patapsco aquifer system			
		Patuxent aquifers (Athena sand)		Patuxent aquifers	Patuxent aquifers	Patuxent aquifers	Patuxent aquifer system		Patuxent aquifer system	

1/ Aquifers assigned to the La Plata aquifer system of this report were included in the Patuxent aquifers of Otton (1955) and Slaughter and Otton (1968).

aquifers at Waldorf are referred to as "equivalents" to their respective aquifers in the Waldorf area. For example, the White Plains aquifer is a mappable aquifer in northern Charles and southern Prince Georges Counties. Outside of this region, where the White Plains aquifer is not a mappable aquifer, the aquifers correlative to the White Plains aquifer at Waldorf are referred to as the "White Plains equivalents." Unlike the aquifer names established for the Waldorf area, the aquifer equivalents are not proposed as new aquifer names and their use is restricted to this report.

HYDROGEOLOGY

Surficial Aquifer and Underlying Confining Unit

The surficial aquifer in the Waldorf area generally is unconfined and forms the stratigraphically highest aquifer in the study area. In north-central Charles County, the surficial aquifer is composed of sands and gravels of the Upland Deposits (western shore) of Weaver and others (1968). The saturated thickness of the surficial aquifer ranges from about 10 to 40 ft. In other parts of the study area, sands and gravels of the Lowland Deposits (western shore) (Weaver and others, 1968) comprise the surficial aquifer. Throughout the study area, the outcrop belts of sediments stratigraphically lower than the Upland Deposits are also considered part of the surficial aquifer.

The confining unit that underlies the surficial aquifer ranges from about 150 to 300 ft thick at Waldorf (pls. 1-6). In northern Charles County, the confining unit consists of the sediments of the Calvert and Nanjemoy Formations, the Marlboro Clay, and the upper part of the Aquia Formation. The average vertical hydraulic conductivity of this confining unit at Waldorf is estimated at about 10^{-5} ft/d (feet per day). This value is based, in part, on measured vertical hydraulic conductivities that ranged from 10^{-7} to 10^{-5} ft/d in cores taken from the Marlboro Clay and the Chesapeake Group (Mack and Mandle, 1977). There is stratification of the vertical hydraulic conductivity of this confining unit because of the different lithologies that compose it. The clayey silts and fine, clayey sands of the Nanjemoy and upper part of the Aquia are the sandiest sections of the confining unit. These sediments have an estimated vertical hydraulic conductivity on the order of 10^{-4} ft/d. The sediments of the Calvert Formation and Marlboro Clay are the less permeable sections of the confining unit. These units have an estimated vertical hydraulic conductivity of about 10^{-7} to 10^{-6} ft/d. The stratigraphic relation of the confining unit that underlies the surficial aquifer to the formations that comprise it is illustrated schematically in figure 8 and in detail on plates 1-6.

Aquia Aquifer and Underlying Confining Unit

The Aquia aquifer in the Waldorf area of Charles County is a confined aquifer about 90 ft thick. Despite its thickness, the Aquia is a poor aquifer in the Waldorf area and is bypassed by well drillers for deeper, more productive sands. The estimated average transmissivity of the Aquia at Waldorf is about 40 ft^2/d (feet squared per day) and the hydraulic conductivity of the aquifer is about 0.5 ft/d. The low transmissivity of the Aquia is caused by the clayey silts and fine sands that comprise much of the Aquia in the Waldorf area. Resistivity logs in the Waldorf area indicate, however, that the Aquia aquifer is consistently more sandy than the overlying confining unit formed by the Marlboro Clay, Nanjemoy, and Calvert Formations (pls. 1-6). In the Aquia aquifer at Waldorf, beds of medium to coarse sands 3 to 5 ft thick are present. Generally, only two or three beds of the coarser sand, separated by clayey, fine sands, are present within a vertical slice through the Aquia aquifer in the Waldorf area. The contacts of the Aquia aquifer with its upper and lower confining units are picked so that all the beds of coarser sands are included in the aquifer.

The transmissivity map of the Aquia aquifer (pl. 7A) illustrates the regional variation and trends in the aquifer's transmissivity. The transmissivity map of the Aquia aquifer, as with all the transmissivity maps on plate 7, represents the aquifer transmissivity used in the calibrated ground-water-flow model. During the model calibration, these transmissivities were generally adjusted less than an order of magnitude from the initial transmissivities determined from pumping-test data, aquifer thickness maps, and areal estimates of hydraulic conductivity. South, southwest, and east of Waldorf, the transmissivity of the Aquia increases and it becomes an important aquifer for both domestic and public-supply use. Although the Aquia is not used in the Waldorf area, it is an important source of water to the Waldorf public-supply system because it provides water, by way of downward leakage, to the sands of the underlying Waldorf aquifer system.

The stratigraphic relation of the Aquia Formation to the underlying formations in the Waldorf area controls the characteristics of the confining unit that separates the Aquia aquifer from the underlying aquifers. The Aquia Formation overlaps lower Paleocene and Cretaceous formations in southern Maryland (Hansen, 1978). In the Waldorf area, the unconformable overlap of the Aquia Formation, the thinning and truncation of the underlying Magothy and Severn Formations, and facies changes in the upper part of the Patapsco Formation cause the confining unit that underlies the Aquia aquifer to vary in thickness and texture (pls. 1-6; fig. 8). Also, the overlapping sediments of the Aquia Formation result in the Aquia aquifer overlying several stratigraphically lower aquifers to the west and south of Waldorf (pls. 1-6; fig. 8).

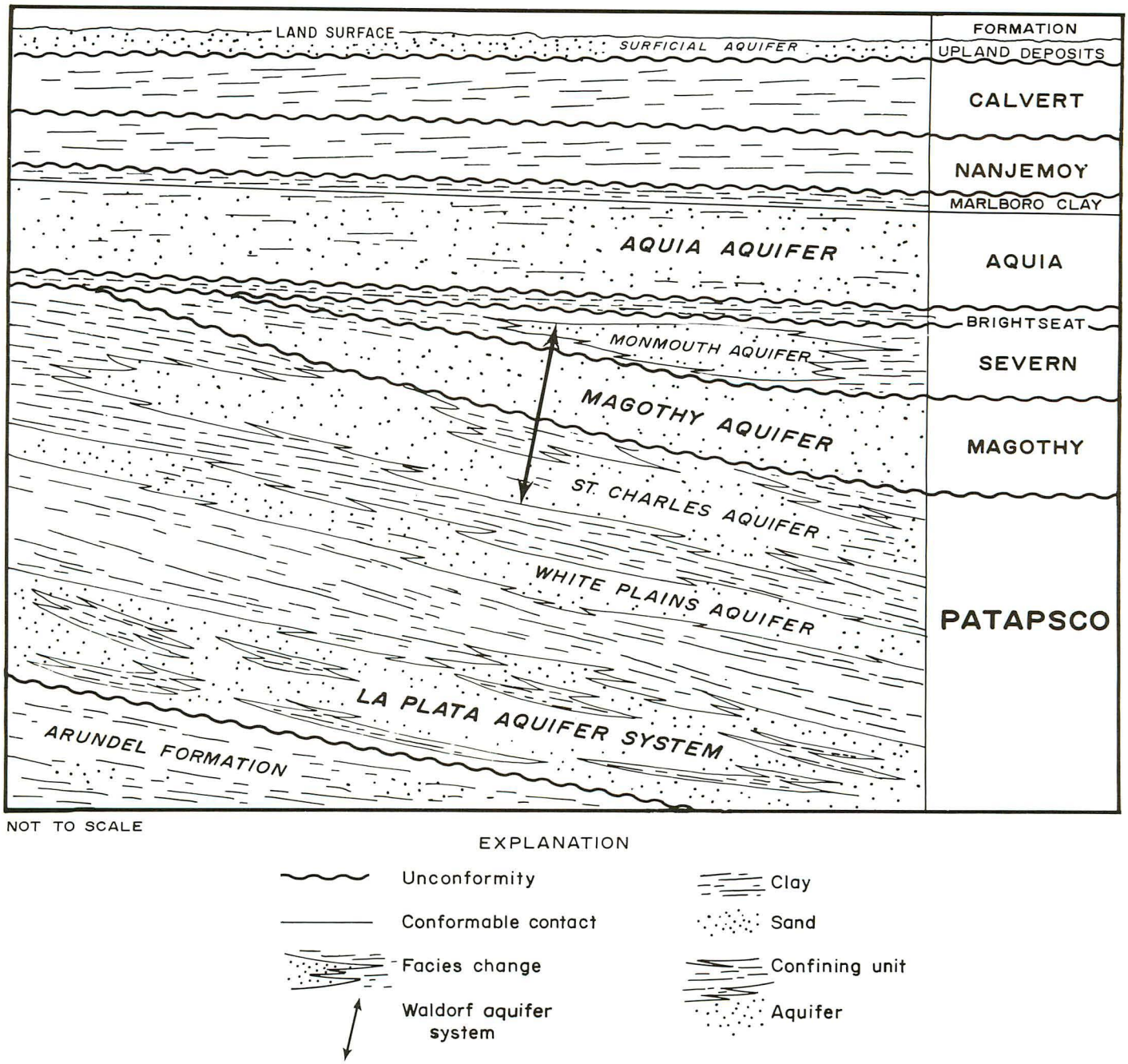


Figure 8.—Examples of the stratigraphic relations among the formations, aquifers, and confining units that overlie the Arundel Formation in north-central Charles County.

The key factor in the effectiveness of the confining unit that underlies the Aquia aquifer at Waldorf is whether tight clays in the upper Patapsco Formation are part of the confining unit. Where the clays of the Patapsco Formation are present, the estimated vertical hydraulic conductivity of the confining unit is about 10^{-7} to 10^{-6} ft/d. In the regions where tight clays of the Patapsco Formation are absent, the confining unit is comprised of more leaky and silty clays in the basal part of the Aquia, Brightseat, Severn, or upper Magothy Formations (pls. 1-6). A vertical hydraulic conductivity of about 10^{-4} to 10^{-3} ft/d is estimated for the regions of the confining unit where tight clays of the Patapsco Formation are absent.

In the northeastern part of Charles County, the eastern part of Prince Georges County, and in Calvert and Anne Arundel Counties, the Aquia Formation is more sandy than at Waldorf and practically the entire Aquia Formation constitutes the Aquia aquifer. In these regions,

the Monmouth aquifer is not always present and clayey silts of the Severn and Matawan[6] Formations form the confining unit that separates the Aquia aquifer from the Magothy aquifer. The estimated vertical hydraulic conductivity of the confining unit in these areas is 10^{-4} ft/d based on the cores taken by Mack and Mandle (1977).

Waldorf Aquifer System

The Waldorf aquifer system is an interconnected hydrologic unit that is formed from the Monmouth, Magothy, and St. Charles aquifers. Thin and leaky confining units and sand-on-sand contacts form hydraulic connections between the aquifers that result in these three aquifers functioning as one hydrologic unit (fig. 8; pls. 1-6). The three aquifers that comprise the Waldorf aquifer system have different areal extent (fig. 9). Consequently, the top of the Waldorf aquifer system is a surface formed of the tops of the Monmouth, Magothy, and St. Charles aquifers. Figure 9 shows the mappable limit of the Waldorf aquifer system and the areal extent of the aquifers that comprise it.

The contour maps of the tops of aquifers (figs. 10, 11, 13-15) show the effects of the faulting in the Waldorf area, but they are not a good representation of the structural geology. Unlike the maps of the tops of the formations, the contours of the tops of the aquifers do not form a time-synchronous surface. The top of an aquifer is generally a more irregular surface than the surface formed by a formation contact. This is especially true of the Waldorf and La Plata aquifer systems (figs. 9, 15), both of which exhibit complex sand stratigraphy.

Monmouth aquifer and underlying confining unit

The upper aquifer of the Waldorf aquifer system is the Monmouth aquifer. The areal extent of the Monmouth aquifer, where it forms part of the Waldorf aquifer system, is limited to north-central Charls County and adjacent parts of southern Prince Georges County (fig. 10). The Monmouth aquifer at Waldorf is equivalent to the sand facies of the Severn Formation described earlier. The Monmouth aquifer ranges in thickness from a few feet at the edge of its distribution to about 45 ft in well CH Bf 145 (pl. 6). Transmissivities of the Monmouth aquifer range from less than 100 ft^2/d at the edge of its extent to more than 4,000 ft^2/d in the eastern part of Waldorf (pl. 7B). The stratigraphic relations and thickness changes of the Monmouth aquifer in the Waldorf area are shown on plates 1 through 6. The distribution of the Monmouth aquifer east of well CH Bf 145 (pl. 2) is not well documented because of the limited amount of drill-hole data that exists in eastern Charles County. A sandy facies of the Severn Formation is present in southeastern Prince Georges County (well PG Hf 40, fig. 7). This sand facies may be a continuation of the Monmouth aquifer at Waldorf, but at present, there are not enough drill-hole data to correlate these aquifers.

Regionally, drill-hole data indicate that the Monmouth aquifer is absent throughout most of eastern Prince Georges, Calvert, and southern Anne Arundel Counties. Northeast of the model area, near Annapolis, another sand facies of the Severn Formation exists. This sand facies is not a continuation of the Monmouth aquifer in the Waldorf area.

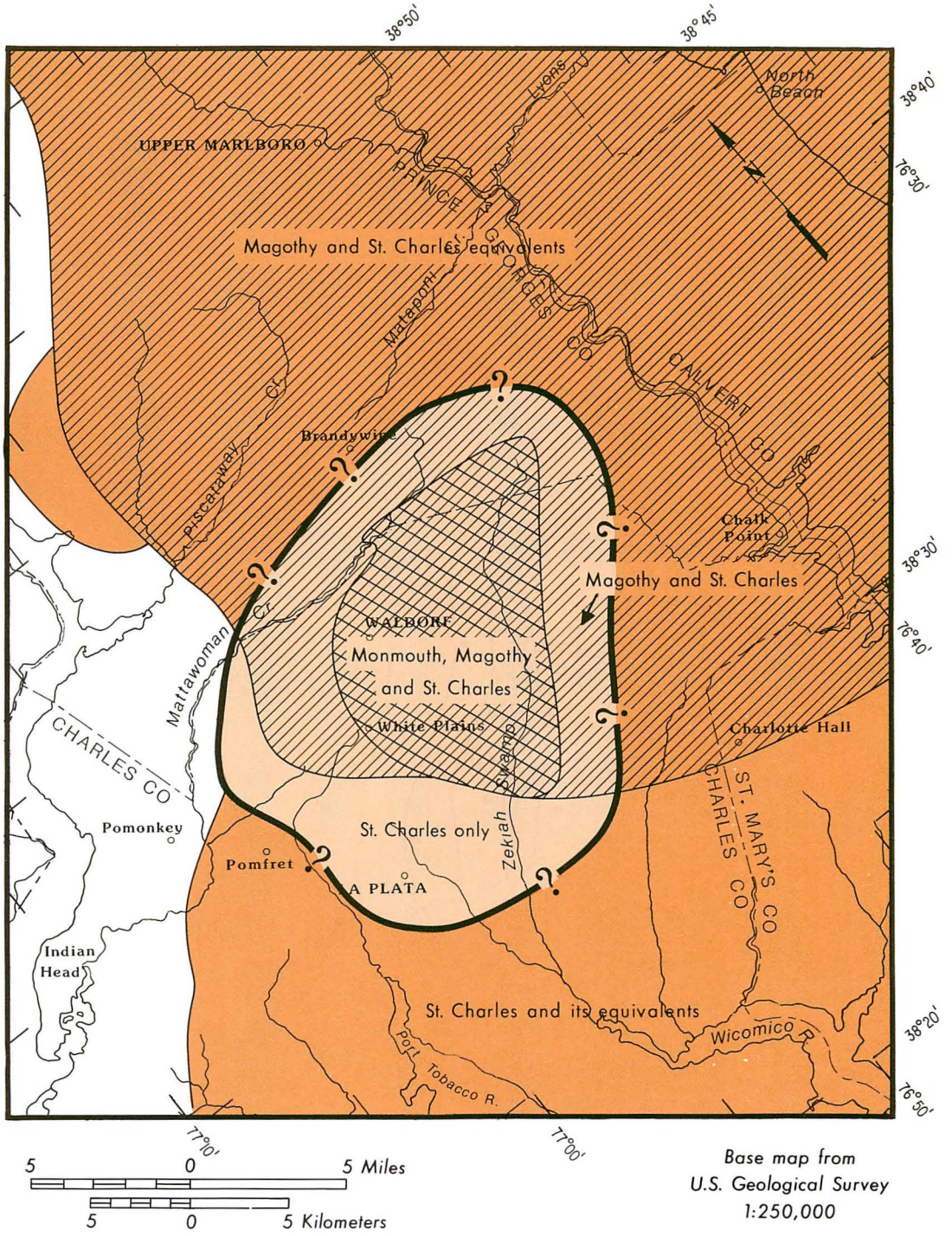
The confining unit that underlies the Monmouth aquifer in the Waldorf area separates the Monmouth from the Magothy aquifer. The confining unit consists of clayey sands and silts of the basal Severn and upper Magothy Formations. The unit ranges in thickness from about 10 ft in well CH Be 48 to a maximum of about 20 ft in well CH Bf 145 (pls. 3 and 6). The confining unit has an estimated vertical hydraulic conductivity of about 10^{-2} to 1 ft/d. The relatively high conductivity of the confining unit results in a good hydraulic connection between the Monmouth and Magothy aquifers in northern Charles County.

Magothy aquifer and underlying confining unit

The Magothy aquifer is an important regional aquifer in the Coastal Plain of Maryland. The southwestern limit of the Magothy aquifer (fig. 11, 12; pls. 3, 6) is within about 4 mi of Waldorf. At Waldorf, the Magothy aquifer forms the middle unit of the Waldorf aquifer system. The Magothy aquifer consists of fine to coarse, quartz sands and gravels. The base of the Magothy aquifer consists of a coarse sand and gravel zone that corresponds to the base of the Magothy Formation and marks the unconformable contact of the Magothy Formation with the underlying Patapsco Formation. The top of the Magothy aquifer is picked at the base of the clayey silts and sands that commonly form the upper part of the Magothy Formation. In the Waldorf area, the thickness of the Magothy aquifer ranges from a few feet at the edge of the aquifer's areal extent to about 90 ft (fig. 12).

The transmissivity of the Magothy aquifer in the Waldorf area ranges from less than 100 ft^2/d near the edge of the aquifer's extent to more than 2,500 ft^2/d near the center of Waldorf (pl. 7C). In eastern Charles County, the transmissivity of the Magothy ranges between 1,000 and 4,000 ft^2/d, but near the southern and southeastern limits of the Magothy's extent the transmissivity of the aquifer rapidly decreases to zero. Northeast of Waldorf, the Magothy aquifer thickens and the transmissivity of the aquifer increases progressively from about 2,500 ft^2/d at Waldorf to between about 6,000 and 15,000 ft^2/d in north-

[6]The Matawan Formation in Maryland is an Upper Cretaceous (Campanian), glauconite-bearing clayey silt. The Matawan underlies the Severn and overlies the Magothy Formation. The Matawan Formation has not been found at Waldorf.



EXPLANATION

—?— Mappable limit of the Waldorf aquifer system

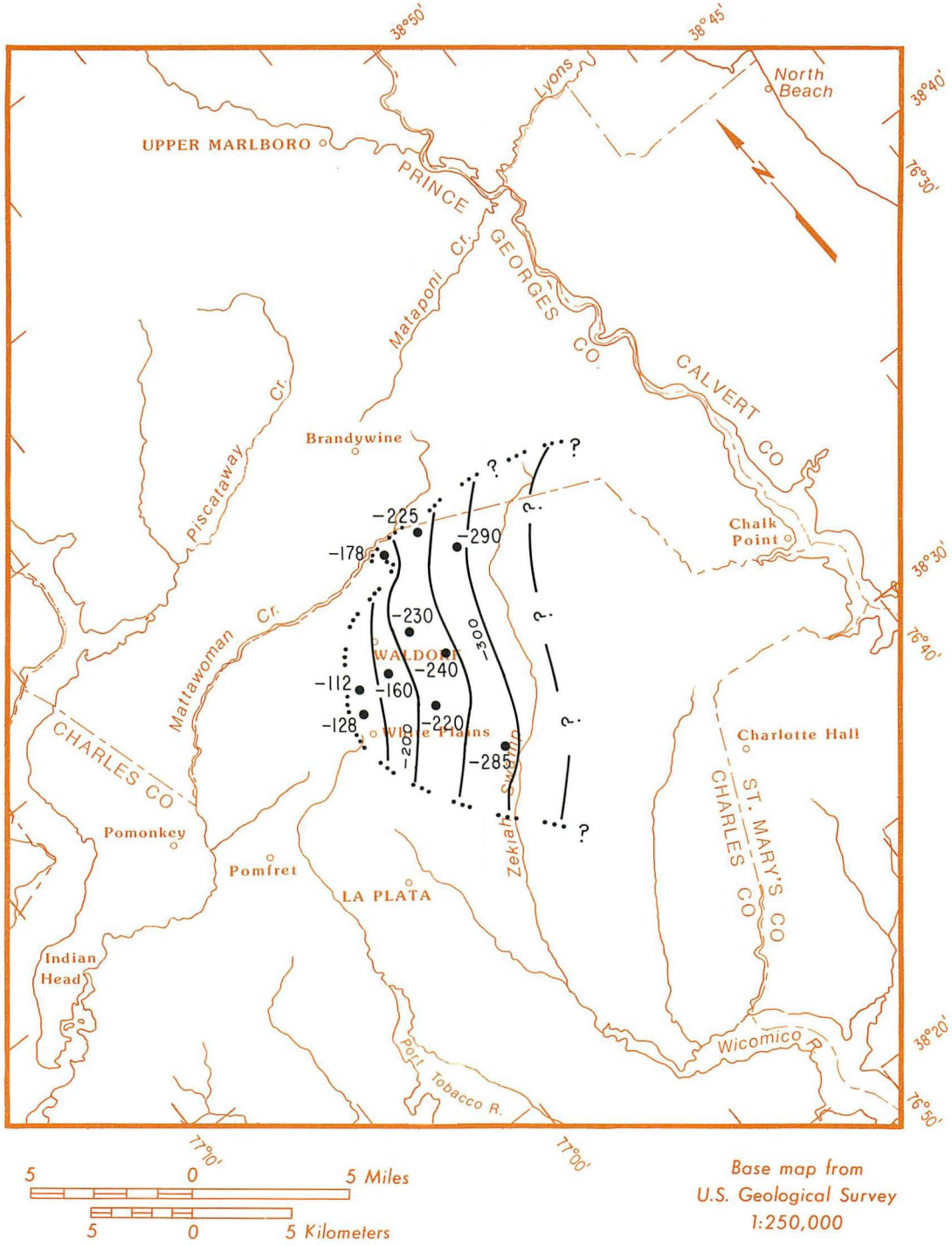
Monmouth aquifer in the study area

Magothy aquifer

St. Charles aquifer and its equivalents

St. Charles aquifer only.

Figure 9.—Mappable extent of the Waldorf aquifer system and the areal relations of the aquifers that comprise the Waldorf aquifer system.



EXPLANATION

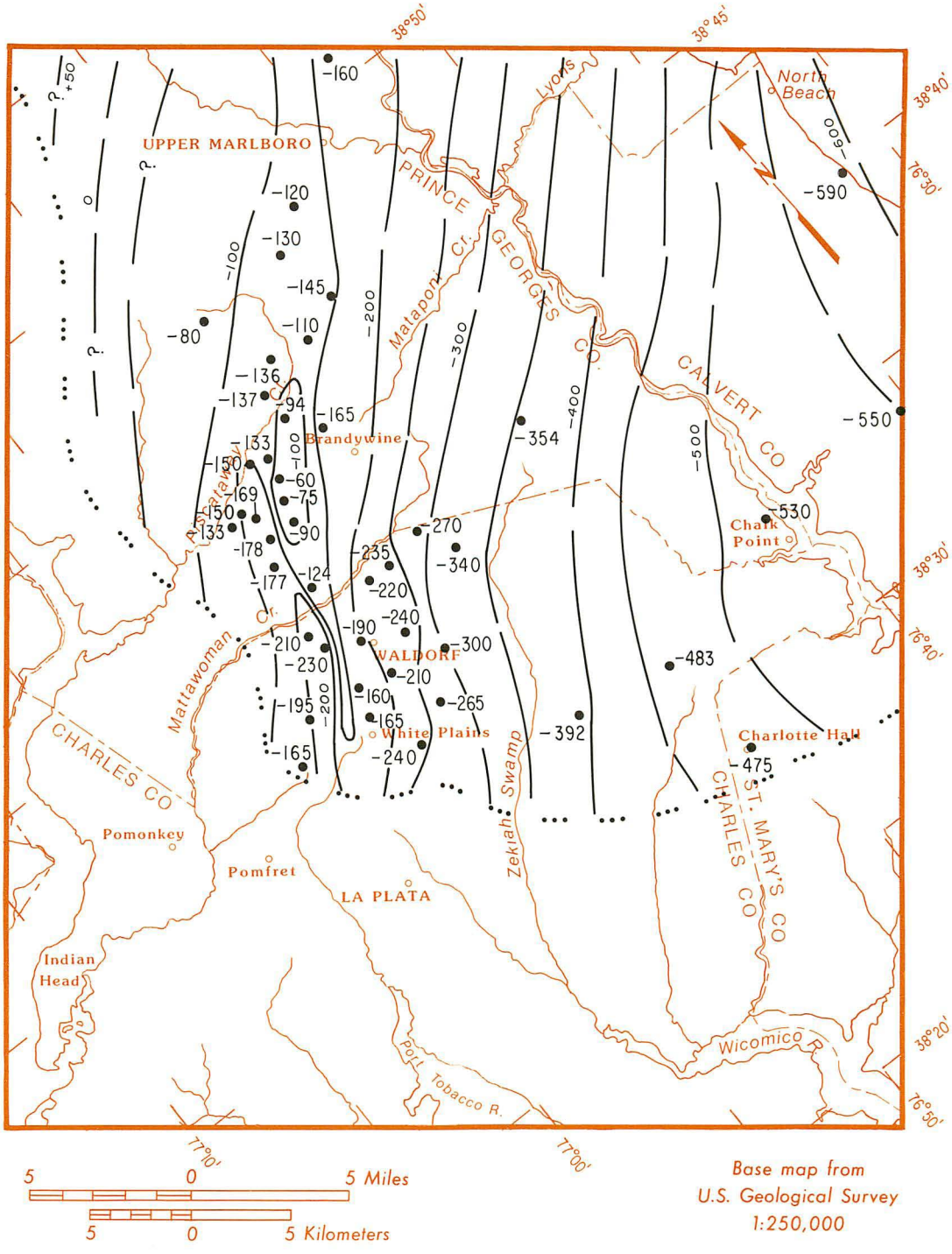
-285 ● Data point and altitude in feet below (—) sea level.

?—300 Line of equal altitude. Dashed where well control sparse. Queried where uncertain.

··· ··· ··· ···? Boundary of Monmouth aquifer. Eastern boundary of aquifer unknown.

Contour interval is 50 feet. Datum is sea level.

Figure 10.—Altitude of the top of the Monmouth aquifer.



5 0 5 Miles

5 0 5 Kilometers

Base map from U.S. Geological Survey 1:250,000

EXPLANATION

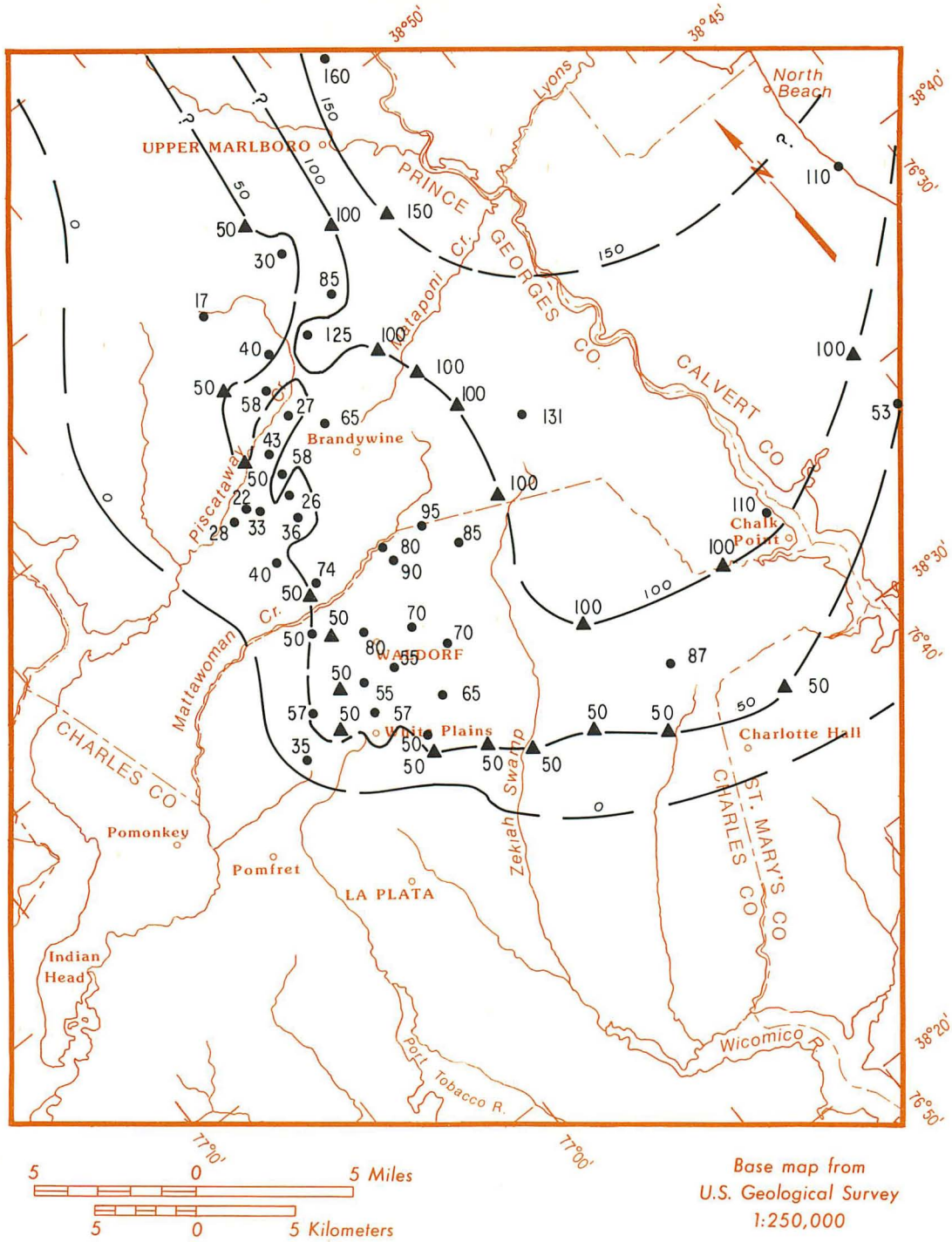
-165 ● Data point and altitude in feet above (+) and below (—) sea level.

?—300 Line of equal altitude. Dashed where well control sparse. Queried where uncertain.

... ... Western and southern boundary of the Magothy aquifer.

Contour interval 50 feet. Datum is sea level.

Figure 11.—Altitude of the top of the Magothy aquifer.



EXPLANATION

85 ● Data point and thickness determined from geophysical logs.

100 ▲ Data point and thickness calculated by superposition of the contour map of the top of the Magothy aquifer (Fig. 11) and structure-contour map of the Patapsco Formation (Fig. 4)

? 100 Line of equal thickness penetrated. Dashed where well control sparse. Queried where uncertain.

Contour interval 50 feet.

Figure 12.—Thickness of the Magothy aquifer.

eastern Prince Georges and southern Anne Arundel Counties (pl. 7C).

The thickness of the Magothy aquifer may have been controlled by topographic highs, possibly the result of pre-Magothy faulting, that influenced the course of the Magothy fluvio-deltaic system. In addition, the thickness and extent of the Magothy Formation and aquifer is reduced by erosional truncation of the Magothy by the overlying Severn Formation or, where the Severn is absent, the overlying Brightseat and Aquia Formations (fig. 12).

In the Waldorf area, the confining unit that underlies the Magothy aquifer separates the Magothy from the St. Charles aquifer, the basal aquifer of the Waldorf aquifer system (pls. 1-6; fig. 8). East and northeast of Waldorf, beyond the mappable extent of the St. Charles aquifer, the confining unit beneath the Magothy aquifer separates the Magothy from aquifers in the upper part of the Patapsco Formation that are hydraulically correlated with the St. Charles aquifer.

The lithology and vertical hydraulic conductivity of the confining unit that underlies the Magothy aquifer in north-central Charles County differ because of the irregular sand distribution in the underlying St. Charles aquifer and the truncation of the upper part of the Patapsco Formation by Magothy sediments. For example, at well CH Bf 144 (pls. 1 and 6), the St. Charles aquifer consists of several stacked sands and the confining unit that separates the Magothy aquifer from the St. Charles aquifer consists of about 15 ft of relatively permeable, clayey silt. In contrast, at well CH Bf 146, the St. Charles aquifer consists of only one sand, a sand correlated with the basal sand of the St. Charles at well CH Bf 144. The confining unit that overlies the St. Charles aquifer at well CH Bf 146 consists of about 90 ft of tight clays. The estimated vertical hydraulic conductivity values of this confining unit range from about 10^{-7} to 10^{-6} ft/d for localities such as well CH Bf 146, to about 10^{-1} ft/d for localities such as well CH Bf 144. Even though parts of the confining unit underlying the Magothy aquifer consist of thick, relatively impermeable clays in the Waldorf area, breaches in the confining unit (pls. 1-6; fig. 8) are widespread enough to cause the St. Charles aquifer and the overlying Magothy aquifer to function as an interconnected hydrologic system.

Regionally, the confining unit that separates the Magothy from the underlying aquifers of the Patapsco Formation, the St. Charles equivalents of this report, is relatively permeable. For example, in southern Prince Georges County, well PG Fd 62 (Hansen, 1968, pls. 11 and 14) has a confining unit only 20 ft thick. Well PG Ee 49 (Hansen, 1968, pls. 10 and 14), located about 5 mi northeast of well PG Fd 62, has a thicker (about 70 ft) confining unit, but only 20 ft of the confining unit at this site is a relatively tight clay and the remainder is a leakier, clayey silt. As in the Waldorf region, the occurrences of sand-on-sand contacts and leaky, clayey-silt confining beds underlying the Magothy aquifer are common enough to cause the Magothy aquifer and the uppermost aquifers of the Patapsco Formation to form an interconnected hydraulic system throughout much of Prince Georges, Calvert, and southern Anne Arundel Counties.

St. Charles aquifer and underlying confining unit

The St. Charles aquifer is the basal aquifer of the Waldorf aquifer system and the uppermost aquifer within the Patapsco Formation at Waldorf. The texture, thickness, and distribution of the sands that comprise the St. Charles aquifer are irregular (pls. 1-6). The aquifer is comprised of both clayey silt and fine sand, and clay-free, fine to coarse sand. In the Waldorf area, the St. Charles aquifer ranges in thickness from about 10 to 40 ft. In at least one well (CH Bf 150), however, the St. Charles aquifer is absent because at this site only a clay facies occurs in the upper part of the Patapsco Formation. Transmissivities measured in the St. Charles aquifer range from about 450 to 4,500 ft^2/d (table 3). The transmissivity distribution of the St. Charles aquifer is shown on plate 7D.

The mappable extent of the St. Charles aquifer is shown on the contour map of the top of the St. Charles aquifer (fig. 13). The limit of the St. Charles aquifer is drawn about 1 mi west of the limit of the Magothy aquifer based on hydrogeologic sections B-B′ and C-C′ (pls. 2 and 3). In the La Plata area, the mappable extent of the St. Charles aquifer extends just south of La Plata. The top of the St. Charles aquifer reflects the underlying basement faulting, but the contours do not represent a time-synchronous surface. The structure contours beyond the marked limits of the St. Charles aquifer are at the top of the first water-bearing sand in the Patapsco Formation that is assumed to have lateral hydraulic continuity with the St. Charles aquifer. The limits of the St. Charles aquifer to the south and east of Waldorf are probably more a function of the amount of data available rather than the aquifer's lateral extent.

In western Charles County, the St. Charles aquifer and its equivalent aquifers are absent. In the southwest-central region of Charles County, near Pomfret, the limited amount of well data available indicate that few water-bearing sands are present within the Patapsco Formation. Transmissivities of the sands in this region are estimated at less than 500 ft^2/d.

At La Plata, the transmissivity of the St. Charles aquifer is less than 1,000 ft^2/d. Several of the older and now unused town production wells are screened in the St. Charles and underlying White Plains aquifers. South and southeast of La Plata, the sands correlative with the St. Charles aquifer have transmissivities that range from less than 100 to about 500 ft^2/d.

Table 3.—Transmissivity values calculated from pumping and recovery tests in Charles County, Maryland

[ft^2/d = feet squared per day]

Well number	Aquifer or aquifer system	Transmissivity [1/] (ft^2/d)
CH Bd 46	La Plata	400
CH Be 42	Waldorf	2,700
CH Be 48	Waldorf and White Plains	2,000
CH Be 57	Patuxent	30
CH Be 58	La Plata	1,730
CH Be 60	White Plains	20
CH Be 61 (next to CH-Be 42)	Waldorf	3,300
CH Bf 127	Waldorf	2,900
CH Bf 144	Waldorf	2,600
CH Bf 145	Waldorf	8,500
CH Bf 147	La Plata	
	(10 to 100 log cycle)	1,900
	(100 to 1,000 log cycle)	1,000
CH Bf 150	La Plata	3,000
CH Bf 151	St. Charles	4,500
CH Bf 157	St. Charles	450
CH Bf 158	St. Charles	1,400
CH Ce 38	St. Charles and White Plains	1,400
CH Ce 43	La Plata	3,500
CH Ce 51	La Plata	500

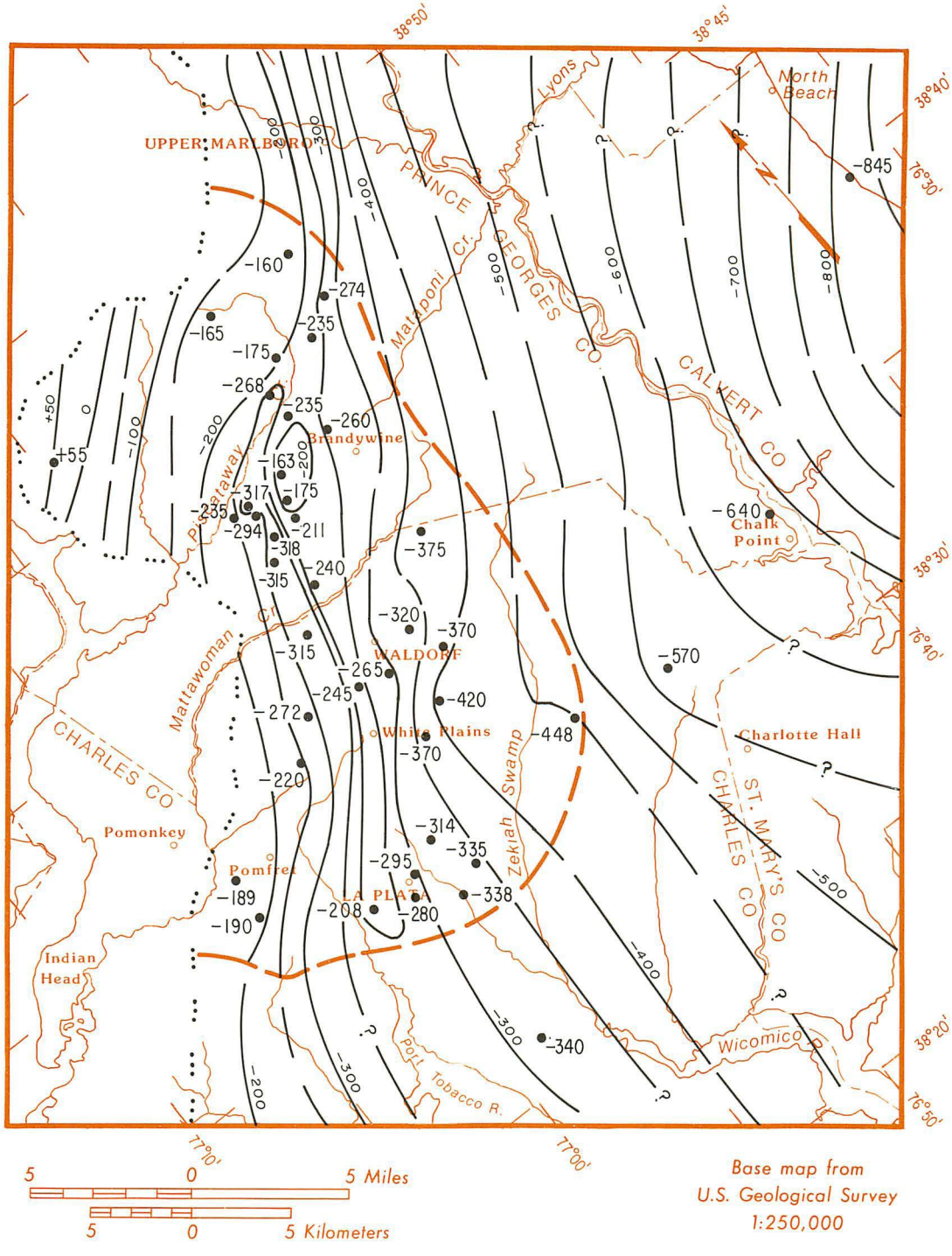
[1/] Transmissivities calculated by using the residual drawdown plotted against t/t′ described in Briggs and Fiedler (1966); additional data regarding these pumping tests and wells are found in appendix A.

The confining unit that underlies the St. Charles aquifer and its correlative sands is comprised of the relatively tight clays of the Patapsco Formation. Hydraulic conductivities of these clays are estimated at about 10^{-7} to 10^{-6} ft/d. The thickness of this confining unit ranges from about 20 ft in well CH Be 48 (pl. 3) to about 60 ft in well CH Bf 144 (pls. 1 and 6). No drill holes in the Waldorf area show breaches in the confining unit that underlies the St. Charles aquifer. Northeast of Waldorf, in central and southern Prince Georges County, the increased percentage of sand in the Patapsco Formation has reduced the thickness and effectiveness of this confining unit.

White Plains Aquifer and Underlying Confining Unit

The White Plains aquifer and its equivalents occur throughout almost the entire study area (fig. 14). Like the St. Charles aquifer, the distribution, thickness, and texture of the sands in the White Plains aquifer are irregular. Sediment textures within the White Plains range from clayey silt and fine sand to clay-free, fine to coarse sand. The thickness of the sand in the aquifer ranges from about 15 ft in well CH Be 57 to about 45 ft in well CH Be 61.

The transmissivity of the White Plains aquifer (pl. 7F) differs because of the variable texture and distribution



EXPLANATION

-265 ● Data point and altitude in feet above (+) and below (—) sea level

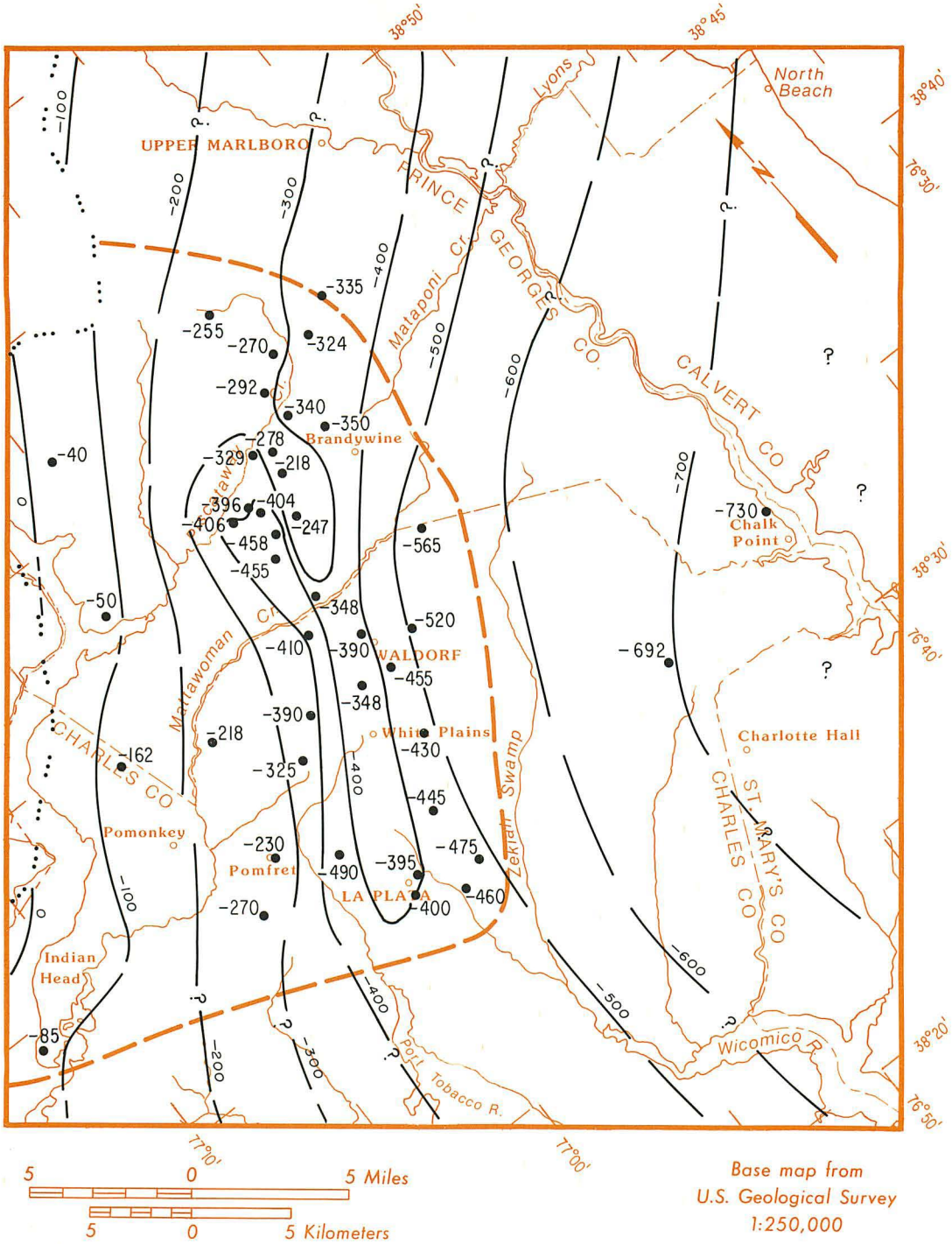
-100 Line of equal altitude. Dashed where well control sparse. Queried where uncertain.

Mappable limit of the St. Charles aquifer.

Western boundary of the St. Charles aquifer and its equivalents.

Contour interval is 50 feet. Datum is sea level.

Figure 13.—Altitude of the top of the St. Charles aquifer and equivalent aquifers.



EXPLANATION

-520 ● Data point and altitude in feet below (–) sea level.

?—100 Line of equal altitude. Dashed where well control is sparse. Queried where uncertain.

Mappable limit of the White Plains aquifer.

... ... Western boundary of the White Plains aquifer and its equivalents.

Contour interval is 100 feet. Datum is sea level.

Figure 14.—Altitude of the top of the White Plains aquifer and equivalent aquifers.

of the aquifer's sands. The transmissivity of the White Plains aquifer in the Waldorf area ranges from about 20 ft^2/d in well CH Be 60 (fig. 7) to an estimated 2,000 ft^2/d in well CH Be 61 (pl. 2). The variability in the thickness and texture of the White Plains aquifer over short distances in the Waldorf/La Plata area reflects the different sedimentary facies of the fluvio-deltaic depositional environment of the Patapsco Formation. The thickness of the aquifer, shown in the hydrogeologic sections (pls. 1-6),implies that the transmissivity of the White Plains is generally lower than that of the overlying St. Charles aquifer in much of the Waldorf area.

The White Plains aquifer is productive in the Waldorf area and in the region west of Waldorf to at least as far west as well CH Bd 46 (pl. 3; fig. 7). West of well CH Bd 46, borehole data are limited and at present, the White Plains aquifer is not mappable west of well CH Bd 46.

Across the Charles County border, in the Brandywine region of southern Prince Georges County, sands occur throughout the section at the expected stratigraphic level of the White Plains aquifer and are considered part of the White Plains aquifer (fig. 14). Section X-X′ (pl. 4) shows the continuation of the White Plains aquifer into southernmost Prince Georges County at well PG Gc 5. In the Brandywine region, the White Plains aquifer is generally thicker (20 to 45 ft), sandier, and therefore probably more transmissive than farther south in Charles County.

Underlying the White Plains aquifer in Charles County is a thick and tight confining unit that separates the White Plains from the La Plata aquifer system. Hydraulic conductivity values for this confining unit are estimated at 10^{-7} to 10^{-6} ft/d. The confining unit underlying the White Plains aquifer ranges from 100 to 250 ft thick (pl. 6). Consequently, the White Plains aquifer and its equivalent aquifers are hydraulically isolated from the underlying La Plata aquifer system throughout most of Charles County.

La Plata Aquifer System and Underlying Confining Unit

The La Plata aquifer system[7] consists of sequences of sands that are, to varying degrees, hydraulically connected. In the Waldorf area, the top of the La Plata aquifer system is picked at the top of the first sands that are present in the expected stratigraphic interval of the aquifer (pls. 1, 3-6). The lower boundary of the La Plata aquifer system is the contact of the basal sand of the Patapsco Formation with the underlying clays of the Arundel Formation. The contours of the top of the La Plata aquifer system are shown in figure 15. Three stratigraphic horizons were mapped as the top surface of the La Plata aquifer system because facies changes in the Patapsco Formation have resulted in the addition of sands to the Patapsco section. A major addition of sands to the La Plata aquifer system occurs at Waldorf (fig. 15, pls. 4 and 6). Consequently, transmissivities of the La Plata aquifer system are higher in the northeastern part of Waldorf than in the southern part (pl. 7G).

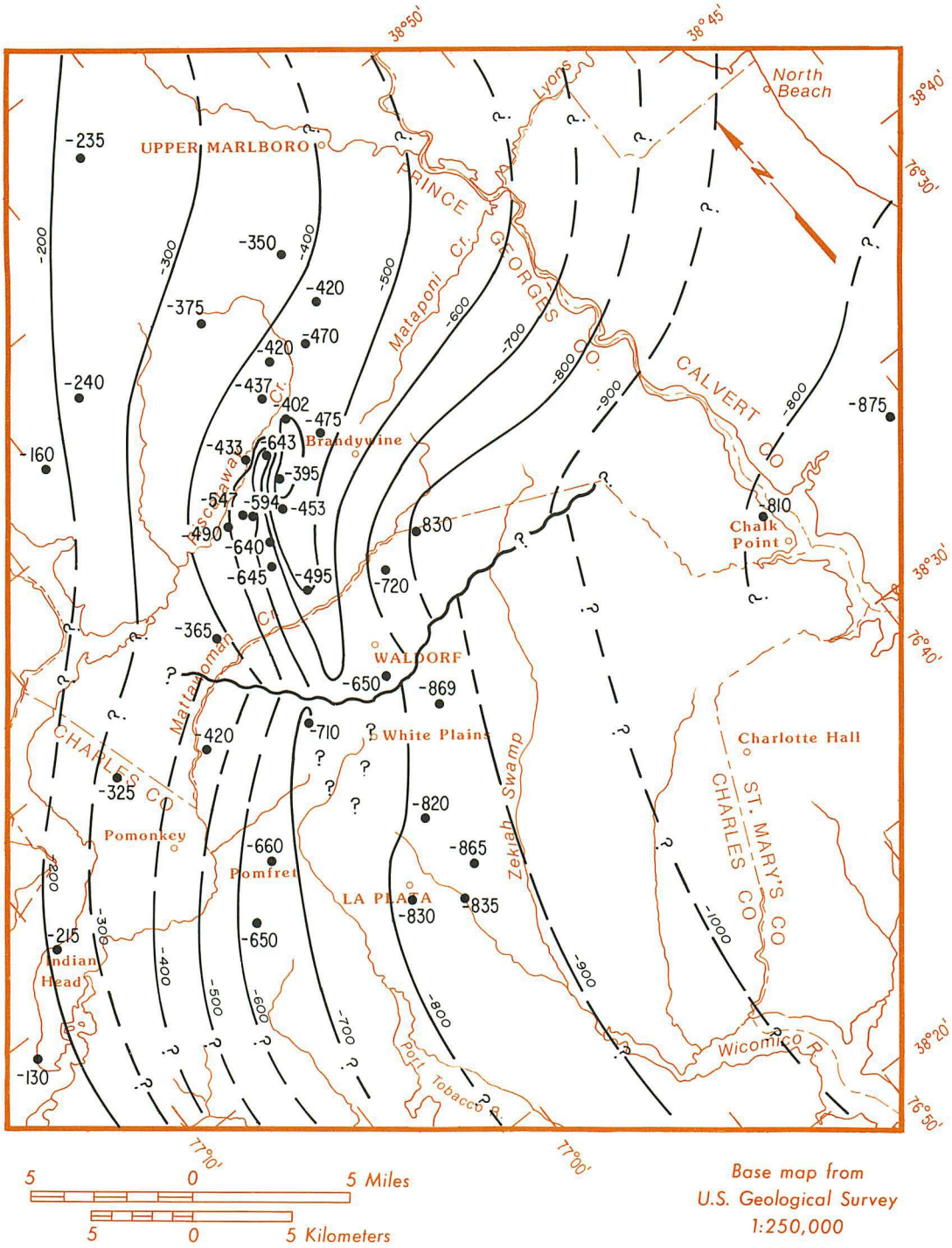
The cumulative sand thickness of the La Plata aquifer system ranges from about 90 to 300 ft in the Waldorf/La Plata area. The measured transmissivities of the La Plata aquifer system range from 400 to 3,500 ft^2/d (table 3). Transmissivities of the La Plata aquifer system and its equivalents continue to increase northeast of Waldorf (pl. 7G). The increase in transmissivity is a function of the general trend of increasing sand content within the Patapsco Formation described by Hansen (1969).

The confining unit that underlies the La Plata aquifer system and its equivalent aquifers throughout southern Maryland is a thick section of tight clays and clayey silts that form the Arundel Formation. In the Waldorf area, the thickness of the Arundel Formation ranges from about 200 to 260 ft (pls. 1, 3). Northeast of Waldorf, in the Brandywine area of Prince Georges County and in Charles County at well CH Be 57 (pls. 3 and 4), the Arundel Formation is about 80 to 100 ft thick. In general, the Arundel is an effective confining unit between the La Plata aquifer system and the underlying Patuxent aquifer system throughout Charles County. The estimated vertical hydraulic conductivity of the Arundel Formation is 10^{-7} ft/d.

Patuxent Aquifer System

The Patuxent aquifer system consists of several sands that are probably hydraulically connected in north-central Charles County. Several of the hydrogeologic sections show wells which have penetrated the Patuxent aquifer system (pls. 1, 3, 4, and 6). The cumulative sand thickness of the Patuxent aquifer system in the Waldorf area is about 100 ft. In the Waldorf area, the transmissivity of the sands which comprise the Patuxent aquifer system is relatively low. The transmissivity of a sand within the Patuxent aquifer system was measured at 30 ft^2/d in test well CH Be 57 (table 3). Partial penetration of the aquifer and difficulty in development of the test well, however, resulted in a measured transmissivity that is lower than the actual transmissivity of the entire aquifer system. West of well CH Be 57, in well CH Cd 30 near Pomfret, the transmissivity of an upper sand within the Patuxent aquifer system is about 250 ft^2/d. This transmissivity was calculated from the results of an 8-hour pumping test done by the well driller. The percentage of coarser sands within the Patuxent aquifer system may in-

[7]The name "La Plata aquifer system" was first used to identify the aquifers of the lower part of the Patapsco Formation in central Charles and southern Prince Georges Counties by Hansen (1980).



EXPLANATION

-594 ● Data point and altitude in feet below (—) sea level.

-700 Line of equal altitude. Dashed where well control sparse. Queried where uncertain.

Termination of contour line at approximate limit of contoured surface.

Contour interval is 100 feet. Datum is sea level.

Figure 15.—Altitude of the top of the La Plata aquifer system.

crease updip (west) of Waldorf because the Patuxent Formation is closer to its sediment source area. Consequently, the transmissivity of the Patuxent aquifer system may increase west of Waldorf. At well CH Bd 46 near Eutaw Forest, the estimated depth of the Patuxent Formation is about 1,100 ft below sea level.

Underlying the basal sands of the Patuxent aquifer system in the Waldorf area are either basal clays of the Patuxent Formation or the pre-Cretaceous basement rocks. None of the consolidated rocks that underlie the Patuxent aquifer system have potential for ground-water production in the Waldorf area.

WATER QUALITY

Back's (1966) hydrochemical facies classifications (table 4; fig. 16) were used to classify the ground water in the aquifers of the Waldorf area. Water in the confined aquifers at Waldorf progressively changes from a moderately hard, calcium sodium bicarbonate-type water in the upper aquifers, to a very soft, sodium bicarbonate-type water in the deeper aquifers (fig. 17; table 5). These changes in water chemistry generally agree with Back's (1966) observations of increasing sodium concentrations with increased depth in the Coastal Plain aquifers of Maryland. Similarities and differences in the percent composition of major ions in ground water from the different aquifers at Waldorf provide evidence that supports the hydrogeologic framework described previously.

The surficial aquifer at Waldorf has different types of water (fig. 17). Back (1966) attributes the variable types of water within the water-table aquifers of Maryland to control of the water chemistry by local aquifer conditions. The underlying Aquia aquifer, sampled just north of Waldorf, contains a moderately hard [110 mg/L (milligrams per liter)], calcium sodium bicarbonate-type water (fig. 17). Back (1966) proposed that recharge leaking

Table 4.—Classification of water by hydrochemical facies (from Back, 1966, p. A13)

[Ca = calcium; Mg = magnesium; Na = sodium; K = potassium; HCO_3 = bicarbonate; CO_3 = carbonate; Cl= chloride; SO_4= sulfate; -- means not applicable]

	Percentage of constituents as equivalents per million			
	Ca + Mg	Na + K	HCO_3 + CO_3	Cl + SO_4
Cation facies:				
Calcium-magnesium	90-100	0< 10	--	--
Calcium-sodium	50- 90	10< 50	--	--
Sodium-calcium	10- 50	50< 90	--	--
Sodium-potassium	0- 10	90-100	--	--
Anion facies:				
Bicarbonate	--	--	90-100	0< 10
Bicarbonate-chloride-sulfate	--	--	50- 90	10< 50
Chloride-sulfate-bicarbonate	--	--	10- 50	50< 90
Chloride-sulfate	--	--	0- 10	90-100

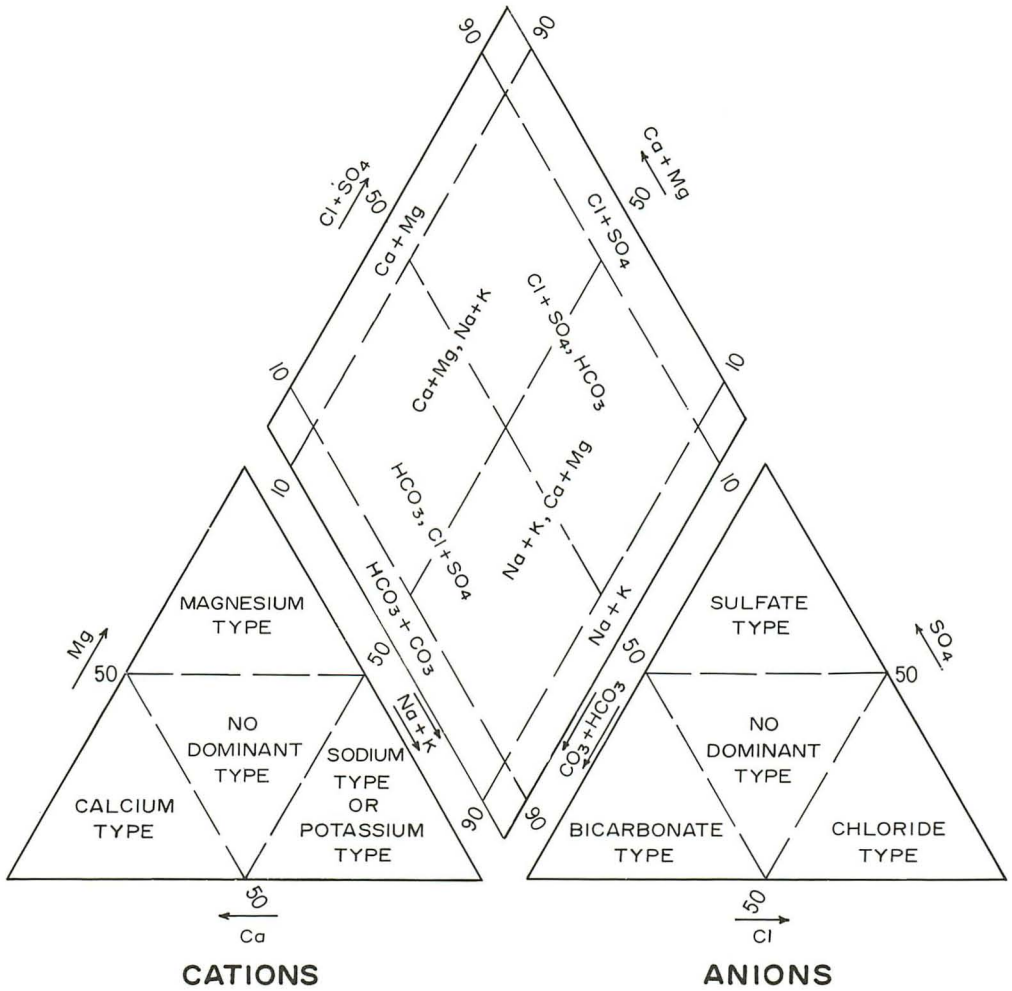


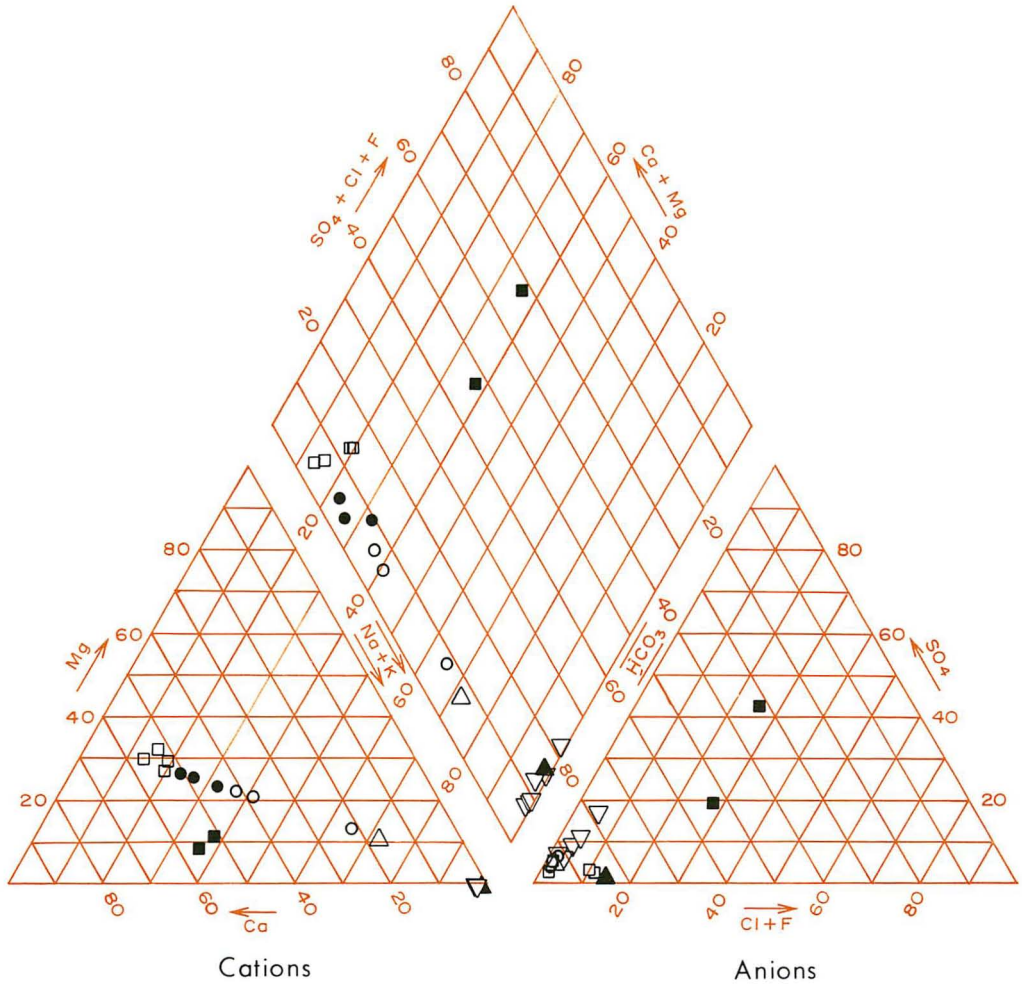
Figure 16.—Hydrochemical facies as percentage of total equivalents per million.

downward from the surficial aquifer dissolves shell material in the confining units and results in high calcium and magnesium concentrations in the upper confined aquifers of the Coastal Plain of Maryland. In the Aquia aquifer at Waldorf, this process and the dissolution of shells within the Aquia aquifer has resulted in a calcium sodium bicarbonate-type water.

Table 5—Classification of water by hardness values (Modified from Durfor and Becker, 1964, p. 27)

Hardness range (mg/L as calcium carbonate)	Descriptive term
0-10	Very soft
11-60	Soft
61-120	Moderately hard
121-180	Hard
More than 180	Very hard

The Monmouth and Magothy aquifers contain a hard (140 to 170 mg/L), calcium sodium bicarbonate-type water that is very similar to the Aquia aquifer water sampled in well PG Fc 22 (app. G). In contrast, water from the St. Charles aquifer, the basal aquifer of the Waldorf aquifer system, is softer (50 to 100 mg/L) and ranges from a calcium sodium bicarbonate-type water to a sodium calcium bicarbonate-type water. Sodium and potassium account for 38 to almost 70 percent of the cation fraction for the St. Charles aquifer as compared to an average of 15 percent for the Magothy and Monmouth aquifers at Waldorf (fig. 17). Following Back's (1966) model, the higher percentage of sodium in the St. Charles aquifer compared to the Monmouth and Magothy aquifers are most likely due to cation exchange of calcium and magnesium for sodium on clays in the confining unit that separates the aquifers. This would imply that there is some downward leakage from the Magothy aquifer to the St. Charles in parts of the Waldorf area. Differences in the major ionic composition between samples from the St. Charles aquifer are attributed to the degree of hydraulic



EXPLANATION

Symbol	Aquifer or aquifer system screened
■	Surficial aquifer
□	Aquia, Monmouth or Magothy aquifer screened separately
●	Monmouth or Magothy aquifer screened with the St. Charles aquifer
○	St. Charles aquifer
△	White Plains aquifer
▽	La Plata aquifer system
▲	Patuxent aquifer system

Figure 17.—Hydrochemical facies of aquifers in the Waldorf area.

connection between the St. Charles aquifer and the overlying Magothy and Monmouth aquifers at each sample site. Sites where the water chemistry is similar may lie close to breaches in the confining unit.

Ground water from the underlying White Plains aquifer is a very soft (hardness of 10 mg/L), sodium calcium bicarbonate-type water (fig. 17). Like the overlying St. Charles aquifer, the sodium levels in the White Plains aquifer are attributed to cation exchange of calcium for sodium on clays in the overlying confining unit and within the aquifer. Also, shell-bearing units are thin or absent in the updip recharge area of the White Plains aquifer in western Charles and Prince Georges Counties. Back (1966) observed the absence of a calcium and magnesium dominant water in the upgradient recharge areas of aquifers in the Potomac Group and attributed the low levels of calcium and magnesium to the absence of overlying shelly aquifers and confining units. Geochemical differences between the water of the White Plains and St. Charles aquifers support the division of these sands within the upper part of the Patapsco Formation into two aquifers.

The La Plata aquifer system contains a very soft (hardness of 1 to 3 mg/L), sodium bicarbonate-type water (fig. 17). The updip recharge area of the La Plata aquifer system is in western Charles and Prince Georges Counties. Shell-bearing confining units are thin in this region and are absent along the flow path of the aquifer. Consequently, as Back (1966) proposed, the absence of a source of calcium ions and cation-exchange reactions within the aquifer and adjacent confining unit result in a sodium dominant type water. The marked differences between the water of the La Plata aquifer system and the overlying White Plains aquifer indicate that the aquifers are hydraulically separated.

Water from the Patuxent aquifer system at Waldorf is a very soft (hardness of 1 mg/L), sodium bicarbonate-type (fig. 17). Chloride accounts for about 15 percent and sulfate accounts for less than 3 percent of the anion fraction of the water in the Patuxent. Cation-exchange reactions and the absence of shell-bearing confining units result in sodium dominance in water of the Patuxent aquifer system.

The dissolved-solids concentrations of the aquifers in the Waldorf area increase with the depth of the aquifers when the analytical results are grouped as shown in table 6. The Waldorf aquifer system and the White Plains aquifer generally have lower concentrations of dissolved solids (152 to 190 mg/L) than the underlying La Plata aquifer system (183 to 296 mg/L). The Patuxent aquifer system, the deepest aquifer in the region, has the highest dissolved-solids concentration (484 mg/L). Although no wells in the Aquia aquifer exist in Waldorf, one well (PG Fc 22) in the Aquia, located several miles northwest of Waldorf, has the lowest dissolved-solids concentration (142 mg/L).

In the aquifers that occur within the Cretaceous sediments of southern Maryland, the concentration of dissolved solids generally increases as the distance along the aquifer's flow path increases (Back, 1966, p. A37). The concentration of dissolved solids increases with depth at Waldorf because water in the deeper aquifer systems has traveled significantly farther along its flow path than water in the shallower aquifers. The lack of significant differences in dissolved-solids concentration between the aquifers that comprise the Waldorf aquifer system and the White Plains aquifer are probably the result of generally similar flow-path lengths.

The pH of the confined aquifers at Waldorf ranges from a low of 7.4 to a high of 8.5. The water temperature in samples from the Waldorf aquifer system averaged 17 °C (degrees Celsius) and the water temperature of the sample from the White Plains aquifer was 18 °C. Water temperature in samples from the La Plata and Patuxent aquifer systems in the Waldorf area average 21.6 and 23 °C, respectively.

Sodium concentrations in the Waldorf aquifer system and the White Plains aquifer are near or slightly above the 20 mg/L U.S. Environmental Protection Agency (EPA) guidance level for people on a sodium restricted diet (Federal Register, Nov. 13, 1985). Sodium concentrations (56-180 mg/L) in the La Plata and Patuxent aquifer systems exceed the EPA suggested guidance level. As of 1987, the EPA has not proposed a recommended concentration level for sodium in drinking water. The EPA has established a fluoride-concentration limit in drinking water of 4.0 mg/L for health reasons and 2.0 mg/L for aesthetic reasons (Code of Federal Regulations, 1987). The highest fluoride levels determined were slightly greater than 1.0 mg/L in samples from the La Plata aquifer system (app. G).

Water from the confined aquifers at Waldorf is potable. The Charles County Department of Public Works is currently treating water from the La Plata aquifer system to increase the water's hardness (S. Weber, Charles County Department of Public Works, oral commun., 1987). This is done as a public service so that users do not experience changes in the hardness of their tap water when ground-water production is rotated between the Waldorf and La Plata aquifer systems. Chlorination is the only other treatment that ground water for the Waldorf public-supply system receives.

Table 6.—Concentration of dissolved solids in the confined aquifers of north-central Charles and southern Prince Georges Counties, Maryland

[mg/L = milligrams per liter; -- means not applicable]

Aquifer	Mean (mg/L)	Standard deviation (mg/L)	Range (mg/L)	Number of samples
Aquia aquifer	142	--	--	1
Waldorf aquifer system and the White Plains aquifer	174	15	152-190	12
La Plata aquifer system	227	44	183-296	6
Patuxent aquifer system	484	--	--	1

SUMMARY AND CONCLUSIONS

The nomenclature of the aquifers in the Waldorf area was revised to reflect the hydraulic relations among the aquifers and correlation of hydrogeologic units. The names "St. Charles aquifer" and "White Plains aquifer" are proposed for the mappable aquifers in the upper part of the Patapsco Formation. The Waldorf aquifer system consists of the St. Charles, Magothy, and Monmouth aquifers. The La Plata aquifer system includes the hydraulically interconnected sands that lie in the lower part of the Patapsco Formation in north-central Charles and southern Prince Georges Counties.

Correlation of hydrostratigraphic units in north-central Charles County showed that three aquifers—the Monmouth, Magothy, and St. Charles—function as one hydrologic unit. These three aquifers, collectively designated the "Waldorf aquifer system," are a major source of ground water to the Waldorf area. The Monmouth aquifer is an areally restricted hydrologic unit in the Waldorf area that corresponds to a sandy facies of the Severn Formation. A thin, leaky confining unit separates the Monmouth aquifer from the underlying Magothy aquifer. The Magothy aquifer is comprised only of sands that lie within the Magothy Formation. The southwestern limit of the Monmouth and Magothy aquifers lies within 5 mi of Waldorf. The St. Charles aquifer underlies the Magothy in north-central Charles County. The St. Charles aquifer is comprised of sands that lie in the uppermost part of the Patapsco Formation. Sand-on-sand contacts, and thin and leaky zones in the confining unit that separates the St. Charles aquifer from the Magothy aquifer result in a good hydraulic connection between the aquifers. In parts of the Waldorf area, however, this confining unit consists of up to 90 ft of tight clays. Measured transmissivities in the wells screened in two or more aquifers of the Waldorf aquifer system range from 2,000 to 8,500 ft^2/d.

The White Plains aquifer underlies the St. Charles aquifer and forms a discrete mappable aquifer in the Waldorf area. The confining unit that separates the White Plains aquifer from the overlying St. Charles aquifer system is not widely breached like the confining units between the aquifers of the Waldorf aquifer system. Transmissivities of the White Plains aquifer range from 20 ft^2/d to an estimated 2,000 ft^2/d because of the variable thickness and texture of the aquifer's sands.

Underlying the White Plains aquifer are the sands of the La Plata aquifer system. The La Plata aquifer system

is composed of hydraulically interconnected sands in the lower part of the Patapsco Formation. A thick and effective clay confining unit separates the La Plata aquifer system from the overlying White Plains aquifer. Measured transmissivities of the La Plata aquifer system range from about 400 to 3,500 ft^2/d. The La Plata aquifer system was first used to supply water to the Waldorf area in 1986 and is now a major source of ground water to the Waldorf public-supply system.

The Patuxent aquifer system is the lowermost water-bearing unit in north-central Charles County. The tight clays of the Arundel Formation form the confining unit between the Patuxent and La Plata aquifer systems. The Patuxent aquifer system is comprised of discrete sands within the Patuxent Formation that probably are hydraulically interconnected in a manner similar to the sands of the La Plata aquifer system. Transmissivities of the Patuxent aquifer appear relatively low; the limited test data available suggest transmissivities ranging from less than 100 ft^2/d to a maximum of 1,000 ft^2/d. Although the Patuxent aquifer system currently is not used to supply ground water to Waldorf, it may be a viable source of water in the western part of north-central Charles County.

Structure-contour maps and hydrogeologic sections show the continuation of the Brandywine structural trend through the Waldorf area. The relative movement of a major fault in the Waldorf area is up-to-the-east, and Jacobeen's (1972) interpretation that reverse faulting is the dominant fault type in the Brandywine structural trend is accepted. The hydrogeologic sections suggest that the pre-Cretaceous basement rocks, the Patuxent, Arundel, and the lower part of the Patapsco Formations are offset across the fault. The throw of the fault is about 250 ft at basement. The Upper Cretaceous and Tertiary formations that lie below the Calvert Formation are probably not offset across the fault. Instead, these units form a west-dipping flexure. The Brandywine fault system was sporadically active during the early to middle Cretaceous, Eocene, and possibly the Paleocene. The Nanjemoy Formation thins by about 70 ft, and the Potomac Group may thin by as much as 150 ft across the trace of the fault. Present data indicate that little or no recurrent movement of the fault system occurred in the Waldorf area during or after the middle Miocene because no major flexure or thinning is seen in the Calvert Formation.

The water of the aquifers at Waldorf progresses from a moderately hard to hard, calcium sodium bicarbonate-type water in the upper confined aquifers (the Aquia, Monmouth, and Magothy aquifers), to a soft, sodium calcium bicarbonate-type water in the White Plains aquifer, and finally to a very soft, sodium bicarbonate-type water in the La Plata and Patuxent aquifer systems. The changes in water type are, in part, controlled by the hydrostratigraphic relations of the aquifers at Waldorf. Concentrations of dissolved solids generally increase as the depth of the aquifer system increases. The concentration of dissolved solids equaled 142 mg/L in a sample from the Aquia aquifer near Waldorf, averaged 174 mg/L in the Waldorf aquifer system and the White Plains aquifer, averaged 227 mg/L in the La Plata aquifer system, and equaled 484 mg/L in a sample from the Patuxent aquifer system.

WATER-SUPPLY POTENTIAL OF THE AQUIFERS

by

William B. Fleck and John M. Wilson

INTRODUCTION

BACKGROUND

The most critical factor affecting water demand in the Waldorf area is the amount of water used by the area's residential population (Pacey, 1983). From 1960 to 1980, there was a 24-fold increase in the area's population which was accompanied by a 14-fold increase in water use. In 1980, residential water use accounted for 77 percent of the 2.06 Mgal/d pumped by the Waldorf public-supply system (Pacey, 1983). By 1985, the residential population of the Waldorf area was greater than 27,000, and ground-water use averaged 2.7 Mgal/d. Pacey (1983) forecast that the Waldorf area's residential population would range from a low of 74,000 to a high of 97,000 in the year 2000. Using these forecasts, Pacey (1983) estimated that the Waldorf area's water use in the year 2000 could range from a low of 4.66 Mgal/d to a high of 6.09 Mgal/d. Whitman, Requardt and Associates (1985) forecast a water demand for the Waldorf area of 4.9 Mgal/d in the year 2000. Pacey (1983) extended her forecasts through the year 2020, and for that year, estimated that water use in the Waldorf area would range from 6.07 to 7.49 Mgal/d. During the decade 1989-98, the region of northern Charles County that lies west of Waldorf, within about 5 mi of U.S. Route 301, is expected to experience the greatest residential population increase. Waldorf has rapidly grown from a small town into an urban population center. The continued growth of the Waldorf area is, in part, dependent on an adequate supply of potable water.

PURPOSE AND SCOPE

The purpose of this section of the report is to quantify the ground-water production potential of the area's aquifers. This objective was achieved by the use of a ground-water-flow model of the aquifers in the Waldorf area; the model was developed based on the hydrogeologic framework described earlier in this report. Included in this section are descriptions of the construction of the ground-water-flow model and the effects of hypothetical future water-supply demands on the aquifers at Waldorf. The construction and calibration of the model and the results of seven simulated scenarios are described. The calibrated model was used to simulate the aquifers' response to the most probable pumpage scenarios through the year 2020. In addition, the resource limit of each aquifer was determined. A series of potentiometric-head and percentage-of-available-drawdown maps for each scenario are used to illustrate the results of the model simulations.

LOCATION OF THE MODELED AREA

The region of primary interest is an area of about 986 mi^2 surrounding the town of Waldorf (fig. 2). This area encompasses north-central Charles County and small parts of Prince Georges, Calvert, and St. Marys Counties. An area larger than the primary study area was included in the ground-water-flow model to ensure that the model boundaries were not affected by simulated pumpage in the Waldorf area. The total area simulated in the model is about 1,650 mi^2 (pl. 7A-G). The effects of ground-water withdrawals outside the modeled area were quantified in order that the model's boundary cells could be simulated accurately.

METHODS OF INVESTIGATION

Prepumping hydraulic head data for each aquifer were obtained by reviewing published literature and data files. The prepumping potentiometric surface of the aquifers was computer generated. The steady-state model was considered calibrated when the computer-generated calibration heads were within 10 percent of the observed heads. The model was calibrated by adjusting aquifer properties until simulated heads matched observed heads. Hydrographs from continuous water-level recorders and hydrographs generated from periodic measurements were used to complete the transient calibration of the model. Scenarios of future ground-water needs for the seven simulations were determined by reviewing the recent forecasts of ground-water demands for the Waldorf area and by discussion with officials and planners of the Charles County Department of Public Works. The calibrated model was used to estimate the head changes that would occur in the aquifers in response to possible future pumpage scenarios. The model also was used to estimate the water-production potential of these aquifers within the Waldorf area. The optimal yield is defined, herein, as the pumpage resulting in 80 percent of the total available drawdown. The total available drawdown is the difference between the 1900 head and the top of the aquifer.

SIMULATION OF GROUND-WATER FLOW

APPROACH

A digital model developed by McDonald and Harbaugh (1984) was used to simulate ground-water flow and to estimate the water-supply potential of the aquifers. The program uses finite-difference numerical methods to solve the partial differentials of the general ground-water-flow equation. This is accomplished by subdividing the model area into rectangular cells where the properties of the medium are assumed to be uniform. The properties which are continuous are replaced by the finite-difference approximations at the center point of each cell. A set of N algebraic equations with N unknowns, where N is the number of cells, is solved simultaneously. For this study, about 7,700 equations were solved simultaneously using the strongly implicit procedure.

PREVIOUS MODELS

Mack and Mandle (1977) used their ground-water-flow model of the Magothy aquifer in southern Maryland to simulate water-level changes in the "Magothy aquifer" of northern Charles County. They indicated that the optimal yield from the "Magothy aquifer" in northern Charles County is 4.5 Mgal/d. This was based on the assumption of 41.6 Mgal/d total withdrawal from the "Magothy aquifer" in southern Maryland and simulated drawdowns exceeding total available drawdown along the western margin of the aquifer. Mack and others (1983) documented water-level declines in the "Magothy aquifer" in the Waldorf area and attributed these water-level declines to increased pumpage from the aquifer. The Maryland Water Resources Administration (WRA) developed a water-supply resources development and management plan for Charles County (Miller and others, 1984). As part of their analysis of declining water levels in the "Magothy aquifer" in the Waldorf area, the WRA refined the two-dimensional finite-difference ground-water-flow model of Mack and Mandle (1977). On the basis of model simulations, the WRA limited withdrawals from the "Magothy aquifer" in the Waldorf area to an annualized rate of 3.5 Mgal/d.

MODEL CONCEPTUALIZATION AND DESIGN

The movement of ground water in two dimensions through heterogeneous porous material, typical of the Coastal Plain sediments of Maryland, can be described by the general equation of ground-water flow. The equation calculates heads at any given time. The calculation is dependent on aquifer transmissivities, aquifer storage, withdrawals, leakage through the confining units, and boundary conditions. A conceptualized model of the ground-water-flow system, figure 18, is the basis for designing the structure of the digital model used to solve the equation of ground-water flow. Figure 19 shows the structure of the model along a typical section and indicates the idealized patterns of ground-water flow in two dimensions. Generally, flow is from the water-table aquifer as leakage through the confining system into underlying aquifers. Flow continues downward as leakage into successively deeper aquifers. Flow within the aquifers is generally eastward. There are, of course, some local variations to the foregoing description. One such variation is the localized upward flow through the confining units underlying the Potomac River, as shown in figure 19.

Simulation of ground-water flow in the Waldorf area requires specification of (1) the geometry of the system, (2) the discretization of time and space, (3) boundary conditions, (4) hydraulic properties of the system, and (5) rates of ground-water withdrawals. The geometry of the system describes the hydrogeologic framework including the location, the extent and thickness of the aquifers, confining units, and outcrop areas of the aquifers. Space discretization is the rectangular gridding, horizontally and vertically, of the modeled area. Time is discretized into intervals referred to as "stress periods" during which ground-water withdrawals remain constant. Types of boundary conditions, as discussed later, are areas across which there is no flow and areas where the head in the aquifer remains constant. Hydraulic properties simulated are the transmissivity and storage coefficient of the aquifers and the vertical hydraulic conductivity of the confining units.

The model was used to estimate head changes for selected pumpage scenarios through the year 2020 in northern Charles County as a means of estimating optimal yields. The first step was to calibrate a three-dimensional model that would simulate flow in seven layers under prepumping steady-state conditions. The steady-state model was used to establish initial head conditions for a transient model.

Assumptions

A digital ground-water-flow model is a mathematical approximation of a physical system. This involves assumptions about the nature of ground-water flow, hydraulic properties of the hydrogeologic units, and boundary conditions. The important assumptions for this model are:

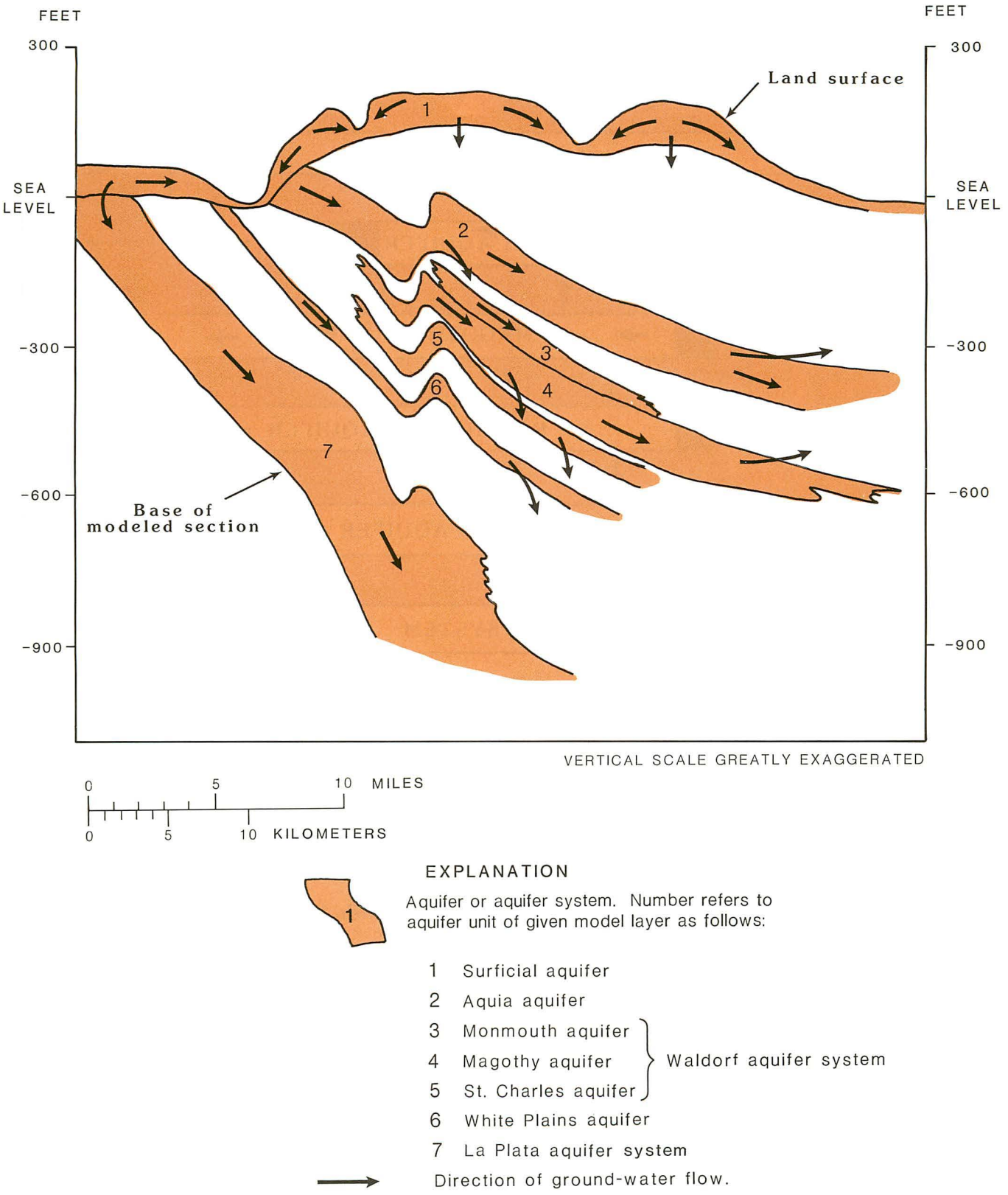


Figure 18.—Generalized hydrogeologic section along model row 18 showing general ground-water-flow patterns.

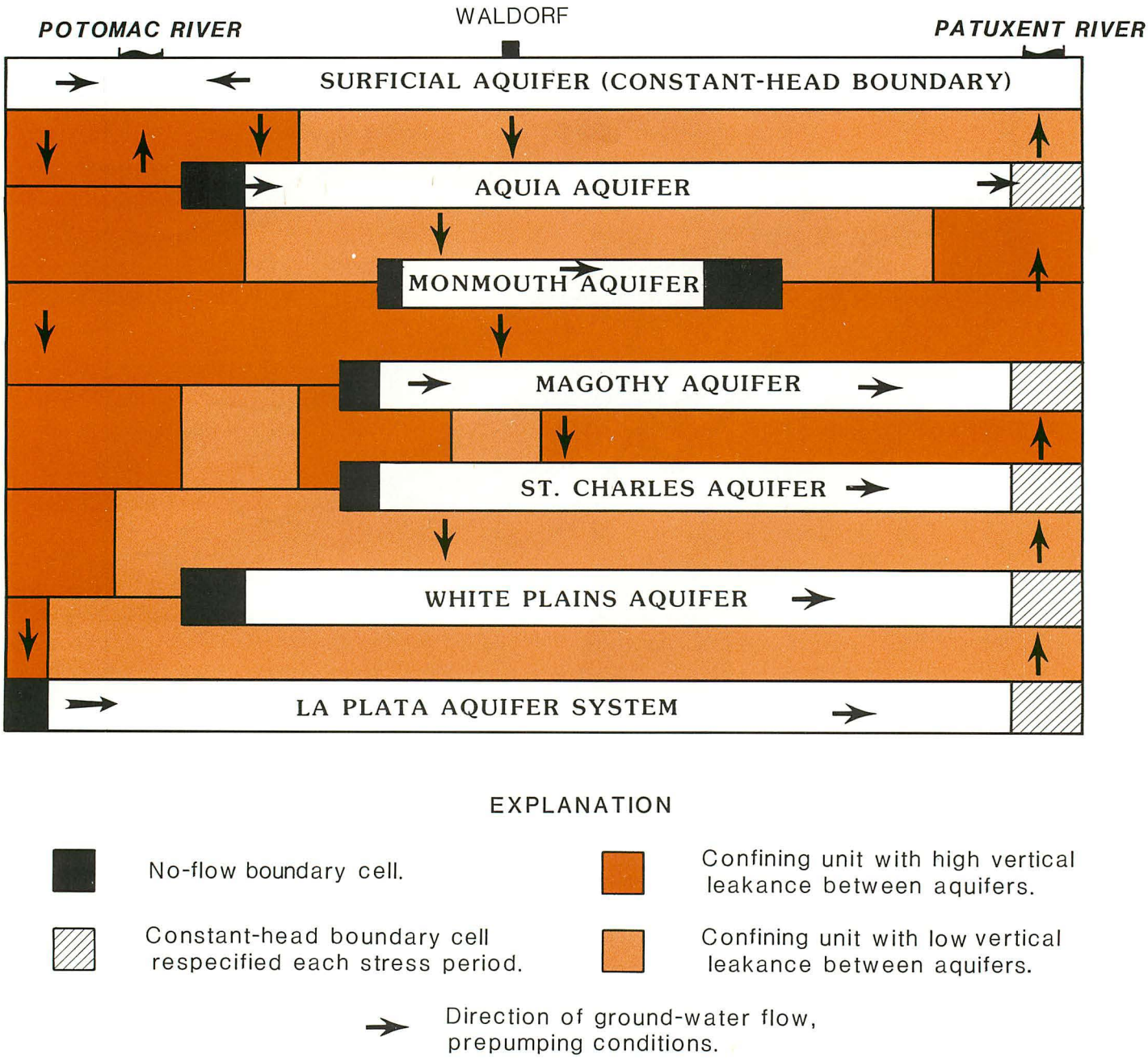


Figure 19.—Structure of the flow model along model row 18.

1. The head in each cell represents an average head for the cell. This is a good approximation for the Waldorf area where cells are generally less than 0.25 mi^2 in area. Around the perimeter of the model, however, where cells increase in size up to 12 mi^2, this is a gross approximation.

2. Heads in the uppermost layer represent water-table conditions and are held constant throughout all simulations. These constant heads act as sources of recharge to or as sinks of discharge from the aquifer system. The heads in the surficial aquifer vary seasonally, but only within a limited range of about 10 ft.

3. Hydraulic conductivity of the aquifers is isotropic and all flow within the aquifers is horizontal. There is no detailed information on this property; however, areal anisotropy is probably small.

4. Flow through the confining units is vertical and represents leakage between aquifers.

5. The Arundel Formation underlying and along the western side of the La Plata aquifer system is considered to act as a no-flow boundary because of its very low transmissivity.

6. In several layers, the aquifers pinch out laterally as sand grades into silt and clay. These pinch-out areas can be assumed to be no-flow boundaries.

Grid

The grid of the flow model (fig. 20) was aligned to best match orthogonally with the principal direction of ground-water flow in southern Maryland, which is toward the southeast. The modeled area is divided into a rectangular grid of 38 rows, 29 columns, and 7 layers. Figure 19 is a conceptual representation of the model along row 18. Each layer has 1,102 cells (fig. 20). The cells are rectangular and differ in size, with the smallest cells centered around Waldorf. The cells gradually increase in size toward the limits of the modeled area. The total modeled area is 1,653.6 mi^2. The maximum and minimum dimensions along the side of any cell are 6.0 and 0.3 mi, respectively. The maximum area of any cell is 12 mi^2. The grid is superimposed upon a seven-layer system. Each of the layers represents one aquifer (table 7).

Boundaries

An initial step in the design of the digital model was to select appropriate boundaries. Two types of model-boundary conditions—constant-head and no-flow—were used in the model. Constant-head boundaries assume that the head at the boundary remains constant with time and has the effect of providing an infinite source or sink for water. No-flow boundaries, as used in this model, assume that the transmissivity of the aquifer at the boundary is zero and thus no water can flow across the boundary. These boundaries are consistent with the hydrogeologic framework. However, because most of the aquifers modeled in this study do not have natural hydrologic boundaries within the area of primary interest, the area modeled was considerably larger than the primary study area. As a result, the effects of the boundary conditions on model results in the immediate Waldorf area are diminished. Boundary conditions for each of the seven layers are described as follows.

The surficial (water-table) aquifer encompasses the entire modeled area and heads representing the water table were held constant throughout the entire time period simulated. As previously indicated, the water table fluctuates on a seasonal basis, but has remained relatively constant since the earliest recorded water levels. The water table in the surficial aquifer was estimated from the altitude of perennial streams that intersect the water table (fig. 21). The constant-head conditions of the water-table aquifer act as the source of recharge through the confining units to underlying aquifers where the underlying aquifers subcrop.

The Aquia aquifer subcrops below the surficial aquifer along its western margin. At the truncation of the Aquia along its western margin, the boundary cells were specified as no-flow. The confining unit above the subcrop was modeled with high leakance values to simulate direct hydraulic connection with the surficial aquifer. Thus, the constant heads in the surficial aquifer control the heads in the Aquia aquifer subcrop area. To the north, east, and south along the model perimeter, the cells were set as constant heads (pl. 7A) that were respecified for each stress period. Potentiometric maps from Otton (1955), Slaughter and Otton (1968), Chapelle and Drummond (1983), and Mack and others (1983) were used to specify heads for the constant-head boundary conditions.

The Monmouth aquifer within the modeled area is restricted to north-central Charles County and southeastern Prince Georges County. Thus, the aquifer was surrounded by no-flow boundaries (pl. 7B).

The Magothy aquifer is truncated both to the west and south of Waldorf (pl. 7C). Therefore, a no-flow boundary was designated along these two sides. The northern and eastern extent of the aquifer in the modeled area was a constant-head boundary that was specified for each stress period. The northern boundary closely corresponds to a ground-water divide located between the major pumping centers to the northeast and the Waldorf area to the south. The constant heads were determined from extensive field data and previously published potentiometric maps (Mack and others, 1983).

The western margin of the St. Charles aquifer (pl. 7D) was modeled as a no-flow boundary. As with the La Plata aquifer system and White Plains aquifer, the heads of the St. Charles aquifer along the northern, eastern, and southern edges of the model were specified and held constant for each stress period; these heads were determined from limited field data.

The western limit of the White Plains aquifer (pl. 7F) was modeled as a no-flow boundary. The confining unit overlying the subcrop area was modeled with high leakance values to represent a sand-on-sand contact, thus enabling the constant heads in the surficial aquifer to control the heads in the White Plains aquifer. Along the northern, eastern, and southern edges, the boundary is a constant head that is specified for each stress period, but may change from stress period to stress period. As with the La Plata aquifer system, these heads were determined from limited field data.

The La Plata aquifer system (pl. 7G) is truncated along the western edge of the modeled area and was

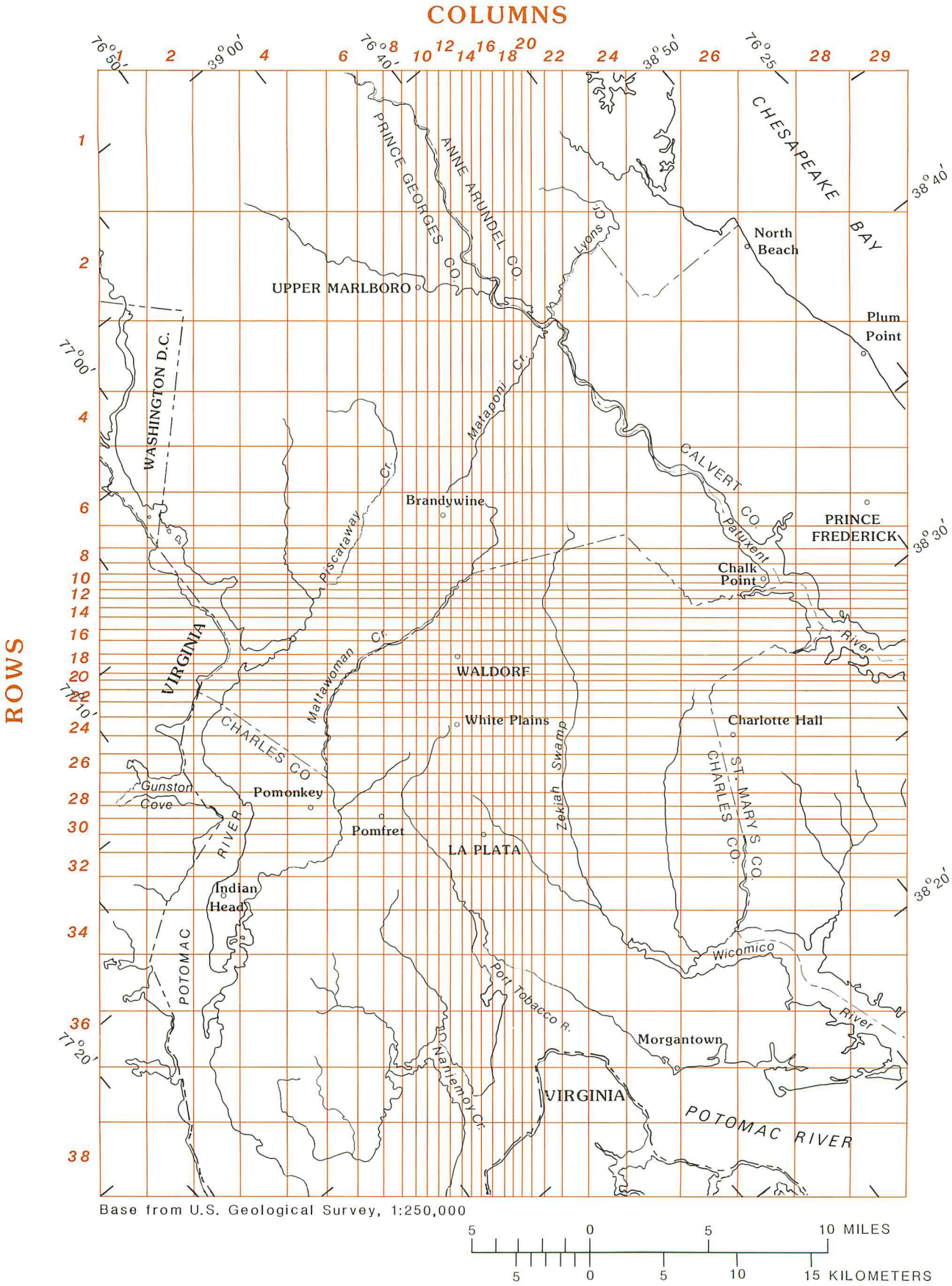


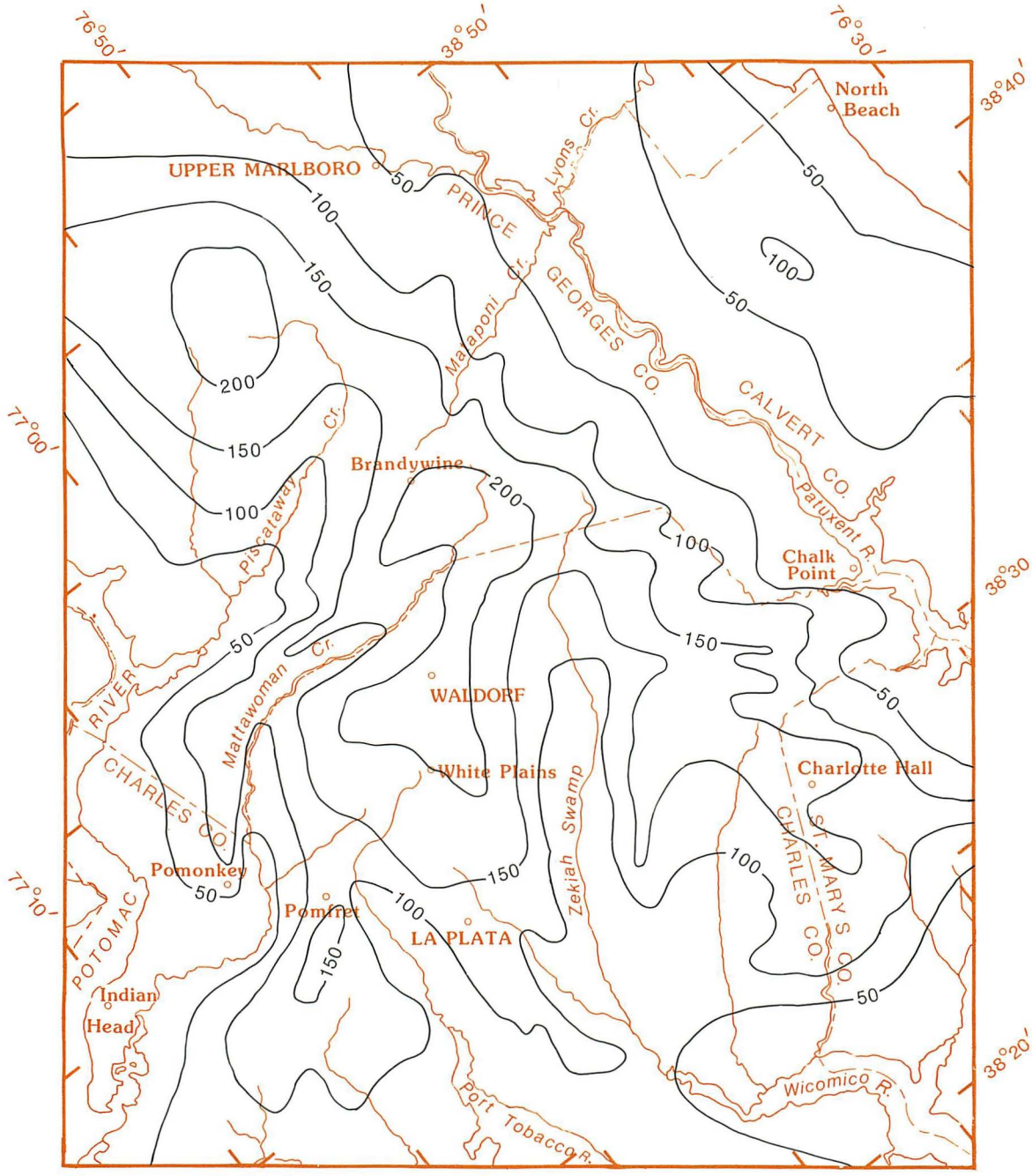
Figure 20.—Location and design of grid used in the ground-water flow model.

Table 7.—Correlation chart of the hydrogeologic units found in the southern Maryland Atlantic Coastal Plain, the hydrogeologic units in the Waldorf area of Charles County, and their corresponding layers in the ground-water-flow model described in this report

Aquifers and aquifer systems of the southern Maryland Coastal Plain	Aquifers and aquifer systems of the Waldorf area of Charles County	Corresponding layer in the digital flow model of this report
Surficial aquifer	Surficial aquifer	Layer 1
Piney Point-Nanjemoy aquifer	Not present	Not modeled
Aquia aquifer	Aquia aquifer	Layer 2
Mattaponi aquifer	Not present	Not modeled
Monmouth aquifer	Monmouth aquifer[2/]	Layer 3
Magothy aquifer	Magothy aquifer [2/]	Layer 4
Patapsco aquifers[1/]	St. Charles aquifer[2/]	Layer 5
	White Plains aquifer	Layer 6
	La Plata aquifer system	Layer 7
Patuxent aquifer	Patuxent aquifer system	Not modeled

1/ Aquifers comprised of sands found in the Patapsco Formation. Various workers have grouped and subdivided the aquifers that occur in the Patapsco Formation on an informal and areally limited basis. See table 2.

2/ Waldorf aquifer system is comprised of the Monmouth, Magothy, and St. Charles aquifers.



Base from U.S. Geological Survey, 1:250,000

5 0 5 MILES

5 0 5 KILOMETERS

EXPLANATION

—150— Contour showing the altitude of the water-table surface. Contour interval is 50 feet. Datum is sea level.

Figure 21.—Altitude of the water table in the surficial aquifer.

modeled as a no-flow boundary. Heads in the subcrop are controlled by the overlying constant-head boundary condition of the surficial aquifer by assigning to the intervening confining unit high leakances to represent a sand-on-sand contact. Along the northern, eastern, and southern perimeter of the model, the heads were held constant for the duration of each stress period, but were adjusted from one stress period to the next. These constant heads around the perimeter were specified based upon limited field data, especially along the eastern side.

Initial Conditions

Initial conditions include digitized input to the model of hydraulic heads that represent prepumping conditions. Prepumping head maps were constructed for each of the seven modeled aquifers using data obtained from Overbeck, 1951; Meyer, 1952; Ferguson, 1953; Otton, 1955; Mack, 1962; and Slaughter and Otton, 1968. The Monmouth and Magothy aquifers in the modeled area are highly interconnected; therefore, it was assumed that the initial head distribution of these two aquifers was the same.

Aquifer Transmissivity

Initial transmissivities were generated from aquifer thickness and horizontal hydraulic conductivity arrays. Thickness maps for each aquifer were constructed from geophysical logs. Hydraulic conductivities were plotted and average values were used over small regions. Transmissivities calculated from field tests during this study are shown in table 3. These values were input to arrays and, in turn, transmissivities were generated.

Confining Unit Leakance

Initial leakance values were input to the model for each of the six confining units. Thicknesses of the confining units were determined from geophysical logs. Regional estimates of vertical hydraulic conductivities for each confining unit were made based upon drillers' logs, geophysical logs, and some permeability tests of core samples.

Sensitivity Analysis

Prior to calibration, sensitivity analyses were performed on six inputs: transmissivity, confining-unit leakance, storage coefficients, pumpage, constant heads that remained constant throughout the simulation (heads in the surficial aquifer), and constant-head boundaries that remained constant for each stress period. The uncalibrated model was run for a period of 1 year with arbitrary pumpage applied at 17 locations in the Magothy aquifer. This preliminary analysis provided an indication of the inputs to which the model was sensitive. The largest simulated head changes (averaging greater than 20 ft) occurred when either leakance or pumpage was increased 10-fold. To a lesser extent, sizeable head changes (averaging between 10 and 20 ft) occurred when either transmissivity or leakance was decreased by a factor of 10. Other changes in the inputs resulted in average head changes of less than 10 ft.

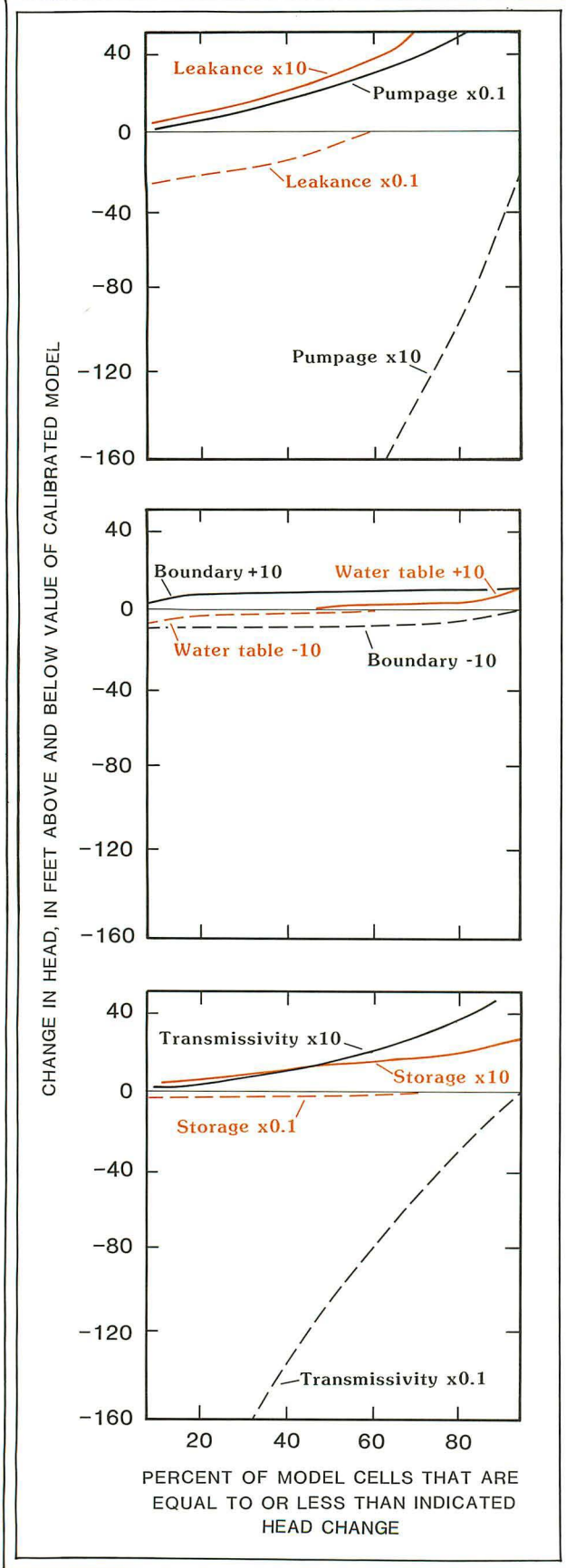
A second sensitivity analysis was performed on the calibrated model. The results of this analysis, shown in figure 22, also indicated that the model is sensitive to changes in transmissivity, leakance and pumpage. Decreasing transmissivity while holding all other variables constant has the same effect on the simulated head distribution as increasing pumpage while holding all other variables constant. Therefore, because the large magnitude of pumpage is known, the model is sensitive to decreasing the transmissivities.

MODEL CALIBRATION

Before a model is used to determine water-supply potential, it is necessary to calibrate the model. Calibration under transient pumping conditions can be accomplished by reproducing historical water-level changes. The calibration procedure used here involved adjusting inputs to the model until model-computed heads approximated observed water levels. Calibration was a two-step procedure. The first step was a steady-state simulation to roughly approximate prepumping heads. The second step was a transient simulation in which model results approximated head changes due to pumping.

For the steady-state calibration, the earliest known heads reported in the literature were assumed to be a close approximation to prepumping conditions. The constant heads of the water-table aquifer were well known and therefore were not adjusted during calibration. Because leakance and transmissivity were less known than other inputs, and because the model is sensitive to these properties, the leakance and transmissivity values were adjusted until the simulated heads roughly approximated the earliest known heads. The final head distribution for each aquifer was then used as the initial head distribution for the transient calibration.

During calibration simulations, some of the inputs were adjusted and model heads were compared to hydrographs for about 130 observation wells. As previously stated, sensitivity analysis indicated that the model was sensitive to transmissivity and pumpage. The constant heads in the surficial aquifer and along the model perimeter were well known and therefore were not adjusted during calibration. Leakances of the confining units, transmissivities of the aquifers, and pumpage were less well known and more important in controlling the final head distribution; each was adjusted in order to attain a calibration. Sensitivity analysis indicated that storage coefficients had little effect on model results



EXPLANATION

Leakance	Leakance values for all confining units multiplied by indicated value.
Pumpage	Pumpage rates for all aquifers multiplied by indicated value.
Boundary	Head values for all constant-head cells located around perimeter of model varied by feet.
Water table	Head values for constant-head cells located in layer 1 varied by feet.
Transmissivity	Transmissivity values for all aquifers multiplied by indicated amount.
Storage	Storage coefficients for all aquifers multiplied by indicated amount.

Figure 22.—Magnitude of simulated head changes with changes of model inputs.

(fig. 22) and, therefore, storage coefficients were not adjusted during calibration.

The transient model simulations were divided into 22 stress periods; table 8 indicates the time period simulated for each stress period. Pumpage was respecified for each stress period as shown in table 8. Total simulated pumpage in the model for the period 1900-85 increased from 0.02 to 15.6 Mgal/d.

The final transmissivity distributions for the calibrated model are shown on plate 7 for each aquifer. Adjustments of individual transmissivity values during the calibration process were generally small and only exceeded 0.5 orders of magnitude change along the trace of the Brandywine fault system (fig. 3). Reducing the transmissivity distribution along the fault trace by 50 to 90 percent of the initially input transmissivities improved the match of model heads with measured observation-well heads. The original transmissivity distribution of the model did not account for a possible reduction in the transmissivity that could have occurred as a result of the faulting.

Faulting could reduce the transmissivity of the aquifers by bed offsets or by thinning of the aquifers. Seismic sections in Jacobeen (1972) and Dames & Moore, Inc. (1973), show probable bed offsets extending into the lower part of the Patapsco Formation. Bed offsets in the lower part of the Patapsco Formation would reduce the transmissivity along the fault zone in the La Plata aquifer system if the aquifer sands were faulted against clay beds. It is possible that bed offsets also occurred in the higher aquifers, but the available well control is inadequate to demonstrate this. The map showing the thickness of the Magothy aquifer (fig. 12) suggests the possibility of some thinning in the aquifer along the fault trace. As noted previously, this may be the result of sedimentation patterns within the Magothy and not a direct result of

Table 8.—Stress periods and pumpage for transient simulations

Stress period	Time simulated	Pumpage, by aquifer layers, in tens of thousand gallons per day						
		2	3	4	5	6	7	Total
1	1900-1919	0.5	0.0	0.8	0.0	0.0	1.0	2.3
2	1920-1929	2.7	0	1.1	0	<.1	1.0	4.9
3	1930-1939	2.8	0	18.8	0	4.5	1.0	27.1
4	1940-1949	35.6	.8	49.6	1.9	25.2	59.6	172.7
5	1950-1959	52.1	1.3	54.5	8.4	54.1	155.4	325.8
6	1960-1969	94.2	5.1	133.7	22.5	175.6	409.9	841.0
7	1970	119.1	7.5	192.8	32.8	191.5	498.0	1,041.7
8	1971	130.8	7.5	227.1	33.1	193.0	543.5	1,135.0
9	1972	132.0	8.0	218.1	33.6	188.8	497.8	1,078.3
10	1973	137.4	8.8	204.3	36.2	183.4	469.0	1,039.1
11	1974	140.0	10.9	218.3	39.5	179.3	471.6	1,059.6
12	1975	148.9	11.7	261.0	41.0	186.6	438.8	1,088.0
13	1976	152.7	9.9	291.1	50.3	183.1	427.3	1,114.4
14	1977	163.4	6.5	261.7	48.0	182.4	424.2	1,086.2
15	1978	168.6	13.4	298.1	60.5	198.5	416.4	1,155.5
16	1979	176.0	20.9	299.2	49.5	181.4	478.4	1,205.4
17	1980	191.1	26.8	356.4	57.9	188.5	412.7	1,233.4
18	1981	185.1	39.7	623.6	72.1	153.3	347.5	1,421.3
19	1982	190.8	39.1	554.7	75.3	190.7	277.2	1,327.8
20	1983	201.2	46.3	611.1	79.3	132.4	161.4	1,231.7
21	1984	218.7	43.8	602.2	92.5	156.6	320.0	1,433.8
22	1985	242.4	39.8	651.6	92.5	149.2	383.9	1,559.4

faulting. Regardless of the cause of a thinner Magothy aquifer along the trace of the fault, lowering of the modeled transmissivity of the Magothy aquifer in that region is justified.

The range of transmissivity for each aquifer or aquifer system based on the calibrated model was: Aquia, 3.5 to 3,500 ft^2/d; Monmouth, 0.51 to 5,625 ft^2/d; Magothy, 40 to 12,000 ft^2/d; St. Charles, 5 to 5,000 ft^2/d; White Plains, 10 to 5,200 ft^2/d; and La Plata, 20 to 8,750 ft^2/d. To attain calibration, leakance values for the confining units were adjusted. Generally, the original input values were adjusted no more than one order of magnitude. The range of leakances of the calibrated model for the confining units overlying the following aquifers or aquifer system were: Aquia, 10^{-8} to 10^{-4} $(ft^3/d)/ft^3$ (cubic feet per day per cubic foot); Monmouth, 10^{-8} to 10^{-4} $(ft^3/d)/ft^3$; Magothy, 10^{-7} to 10^{-2} $(ft^3/d)/ft^3$; St. Charles, 10^{-7} to 10^{-2} $(ft^3/d)/ft^3$; White Plains, 10^{-8} to 10^{-7} $(ft^3/d)/ft^3$; and La Plata, 10^{-8} to 10^{-6} $(ft^3/d)/ft^3$.

Table 9 indicates pumpage input for stress period 22 (1985) and figures 23-28 show the distribution of the pumpage, cell by cell. Historical pumpage data for major users were obtained from J. C. Wheeler and F. D. Wilde (U.S. Geological Survey, written commun., 1988), Maryland Water Resources Administration files, and J.C. Wheeler (U.S. Geological Survey, written commun., 1986). Pumpage within Virginia was obtained from R.J. Laczniak (U.S. Geological Survey, written commun., 1985). Initially, attempts were made to calibrate the model using only major pumpage. However, sensitivity analysis, as previously discussed, indicated that the model is sensitive to pumpage input. Therefore, estimates based on water usage and demographic data (Mack, 1962; Pacey, 1983; Thompson and others, 1977; Washington Suburban Sanitary Commission, 1986; and Maryland Department of State Planning, 1981) were made for domestic pumpage for each stress period and entered into the model. The importance of these estimates for each aquifer differed considerably. Domestic pumpage estimated for the Aquia aquifer was a significant factor in the final calibration. For the other aquifers, the effect of domestic pumpage was less significant.

Transmissivity, leakance, and domestic pumpage values were adjusted until the output heads reasonably matched the observed heads in hydrographs of about 130 observation wells. The results for 17 of these hydrographs are shown in figures 29-34. These 17 hydrographs are from wells which are located near the area of concern (fig. 35) and are representative of the full set of hydrographs.

As indicated in table 9, about 66 percent of the pumpage from the Aquia aquifer is domestic and is widely spaced throughout the model area (fig. 23). Thus, the decline in heads shown by observation wells for the Aquia aquifer (fig. 29) is regional. This regional head decline due to extensive domestic pumpage is approximated by the simulated heads also shown in figure 29.

There was only one observation well available for the Monmouth aquifer. The observed heads for this well (fig.

(Text continued on p. 60.)

Table 9.—Pumpage input to calibrated model for stress period 22, 1985

Aquifer or aquifer system	Pumpage, in million gallons per day			
	Major water use	Domestic	Domestic as a percentage of total water use	Total
Aquia	0.83	1.59	66	2.42
Monmouth	.35	.05	12	.40
Magothy	6.20	.31	5	6.51
St. Charles	.78	.15	16	.93
White Plains	1.25	.24	16	1.49
La Plata	3.84	0	0	3.84
Total	13.25	2.34	15	15.59

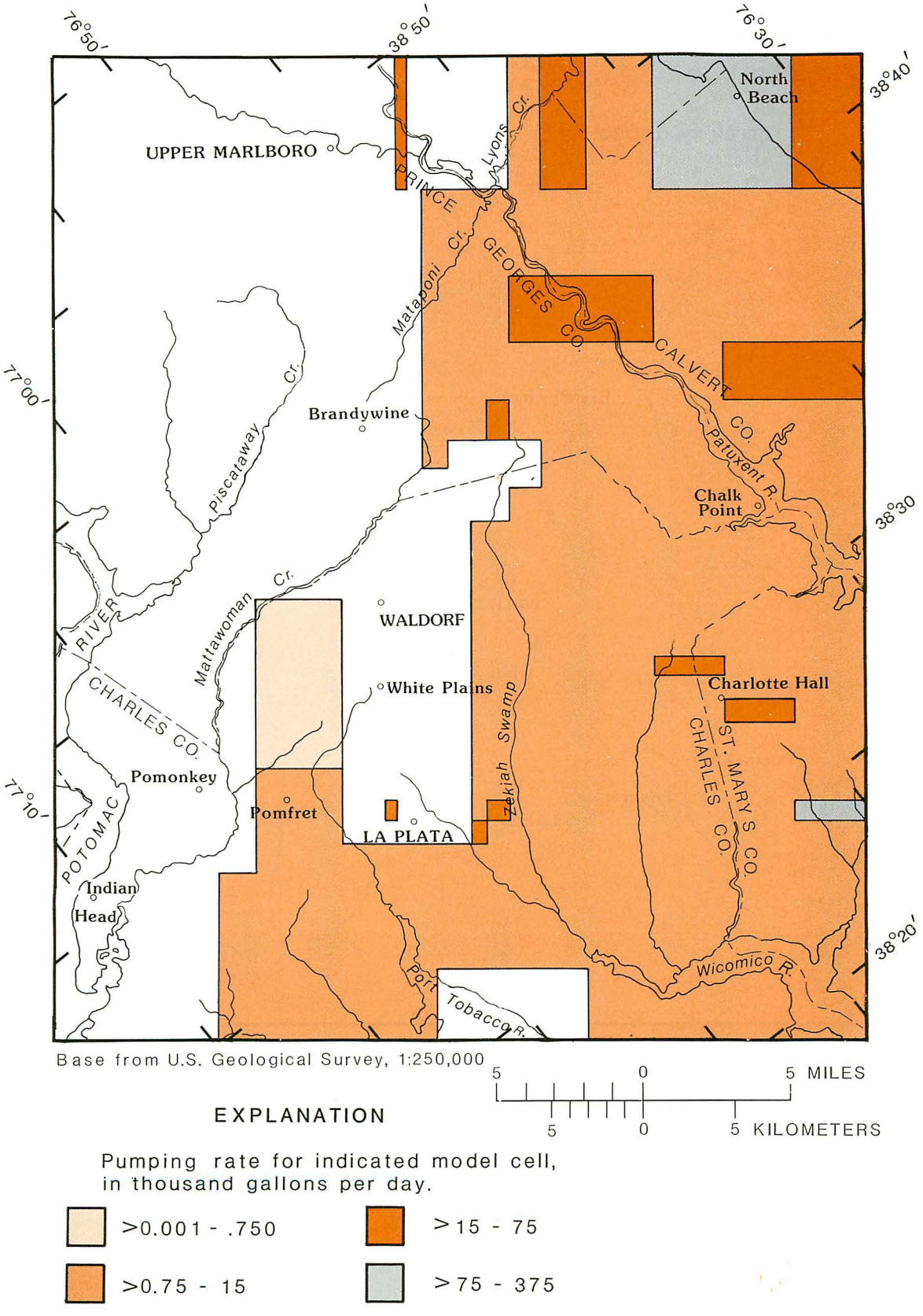
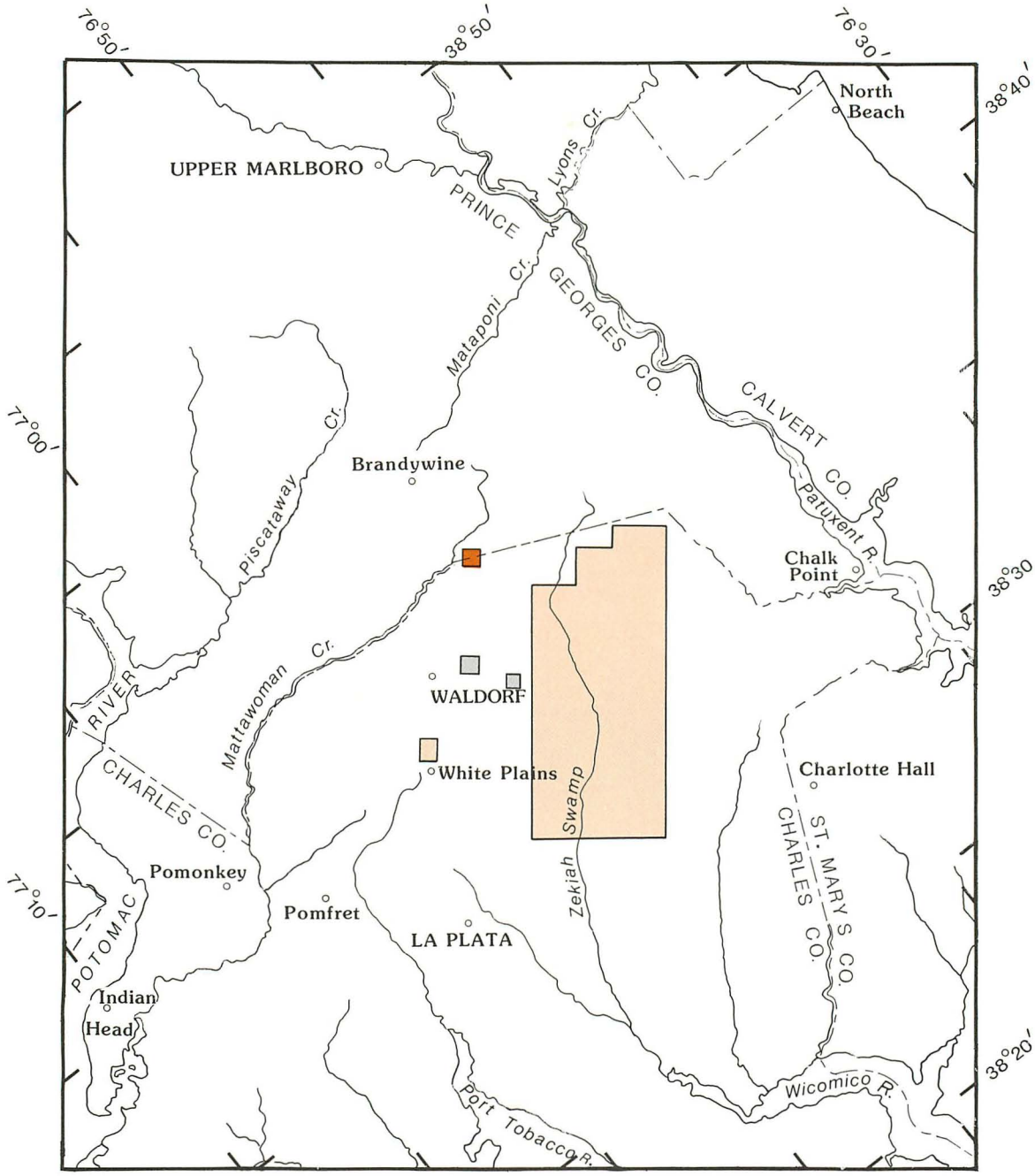


Figure 23.—Pumpage distribution in the Aquia aquifer for stress period 22 (1985).



Base from U.S. Geological Survey, 1:250,000

5 0 5 MILES

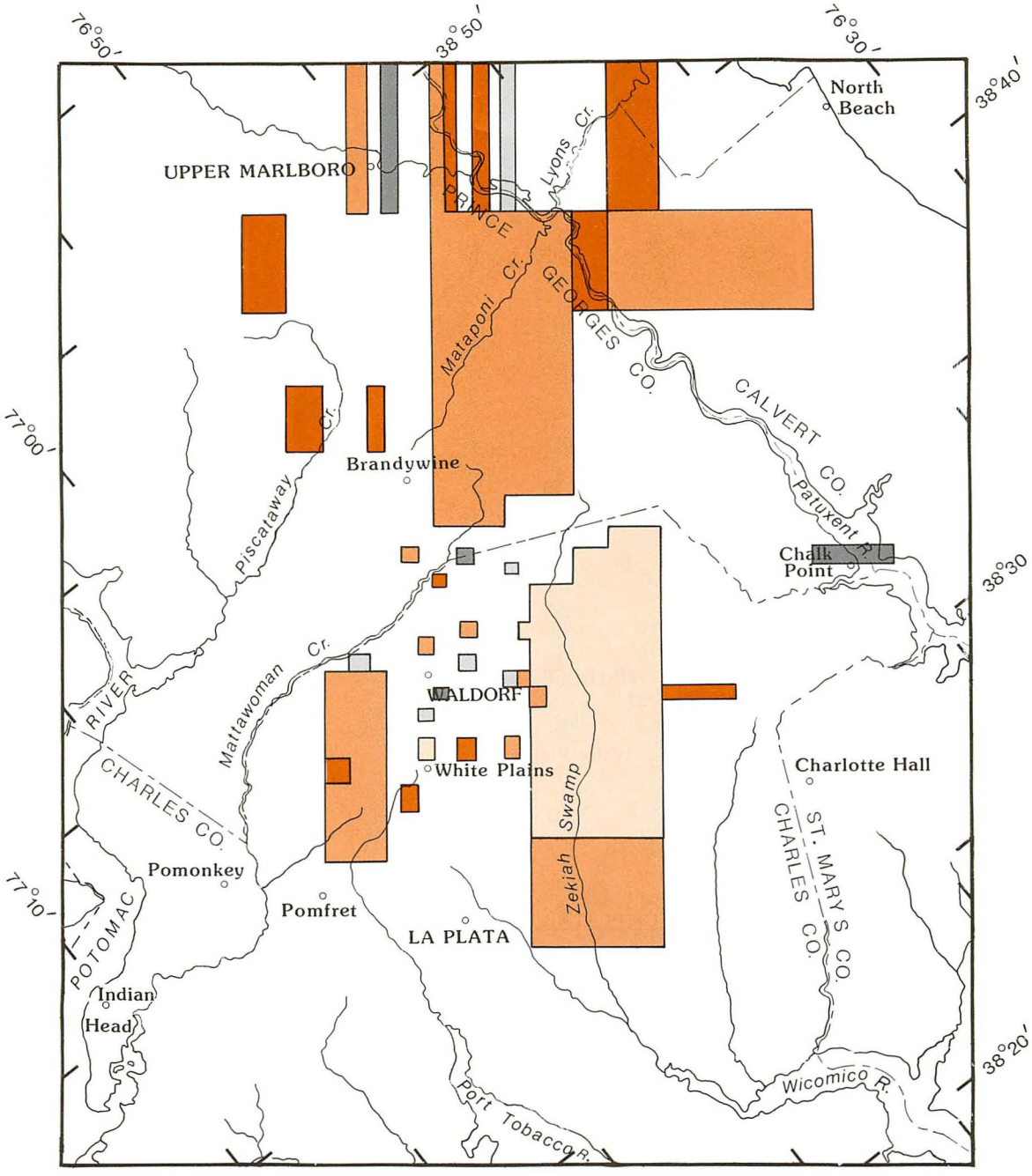
5 0 5 KILOMETERS

EXPLANATION

Pumping rate for indicated model cell, in thousand gallons per day.

- >0.001 - .750
- >15 - 75
- >75 - 375

Figure 24.—Pumpage distribution in the Monmouth aquifer for stress period 22 (1985).



Base from U.S. Geological Survey, 1:250,000

5 0 5 MILES

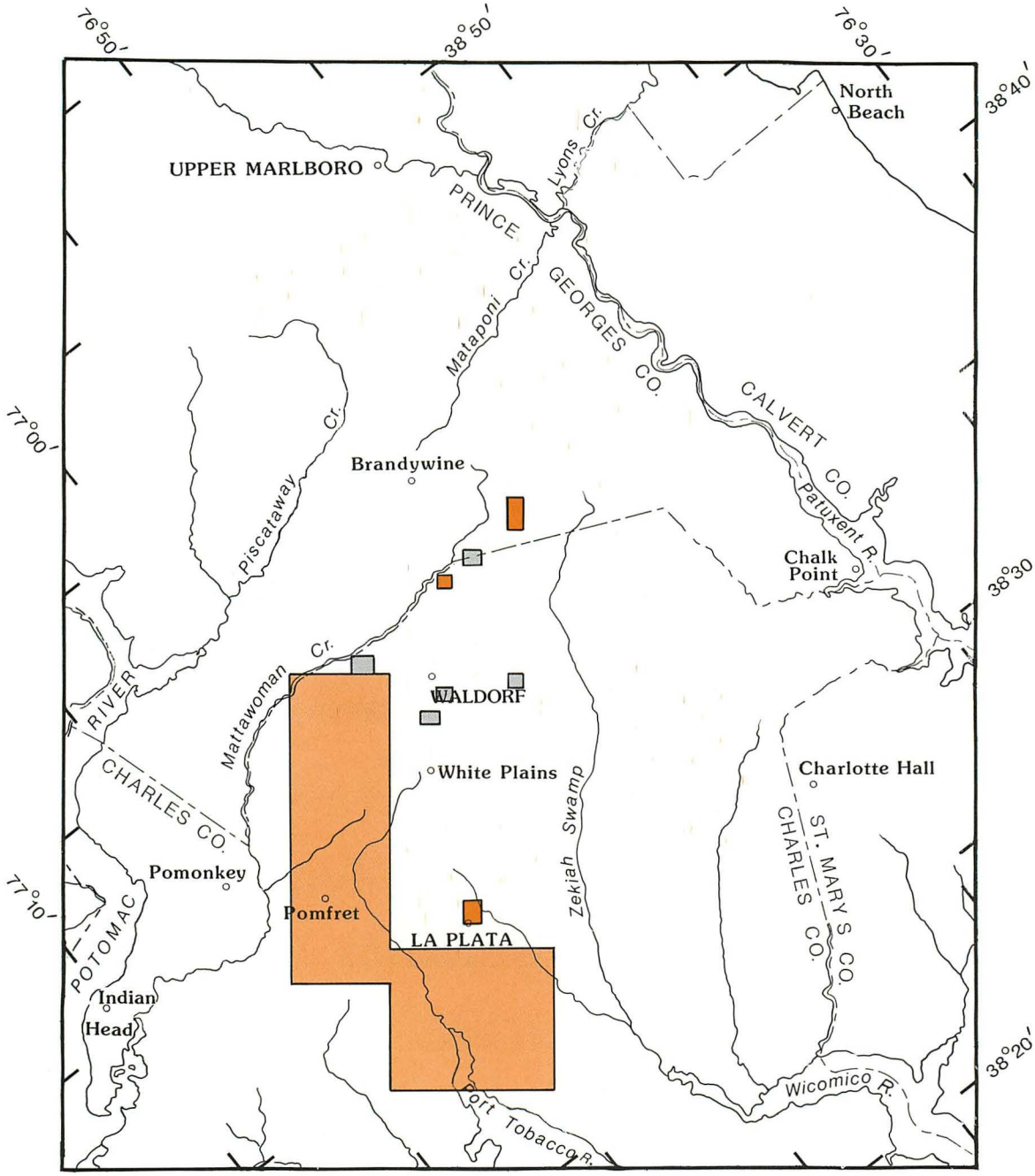
5 0 5 KILOMETERS

EXPLANATION

Pumping rate for indicated model cell, in thousand gallons per day.

- >0.001 - .75
- >15 - 75
- >0.75 - 15
- >75 - 375
- >375 - 750

Figure 25.—Pumpage distribution in the Magothy aquifer for stress period 22 (1985).



Base from U.S. Geological Survey, 1:250,000

5 0 5 MILES

5 0 5 KILOMETERS

EXPLANATION

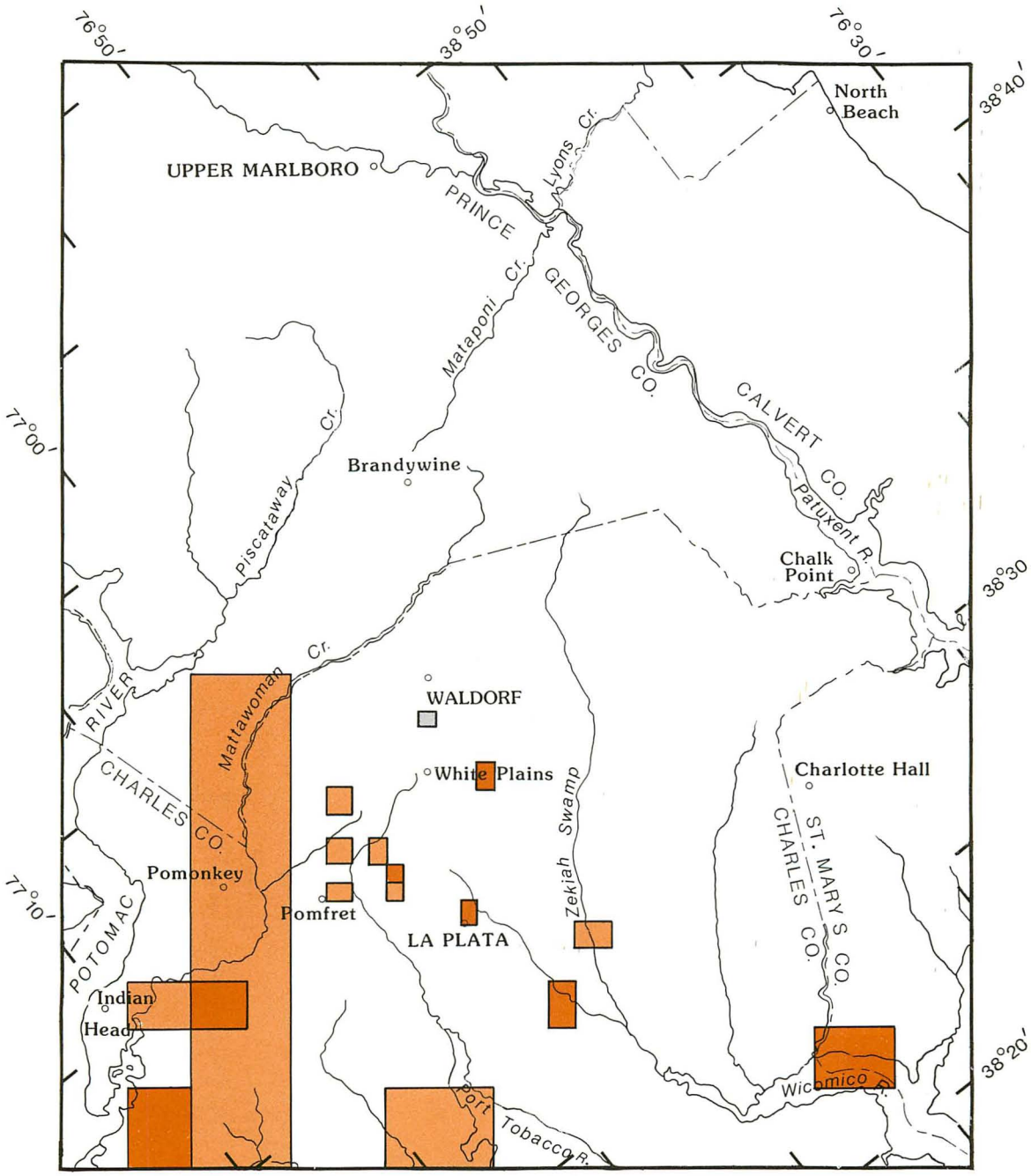
Pumping rate for indicated model cell, in thousand gallons per day.

> 0.75 - 15

> 15 - 75

> 75 - 375

Figure 26.—Pumpage distribution in the St. Charles aquifer for stress period 22 (1985).



Base from U.S. Geological Survey, 1:250,000

5 0 5 MILES

5 0 5 KILOMETERS

EXPLANATION

Pumping rate for indicated model cell, in thousand gallons per day.

> 0.75 - 15

> 15 - 75

> 75 - 375

Figure 27.—Pumpage distribution in the White Plains aquifer for stress period 22 (1985).

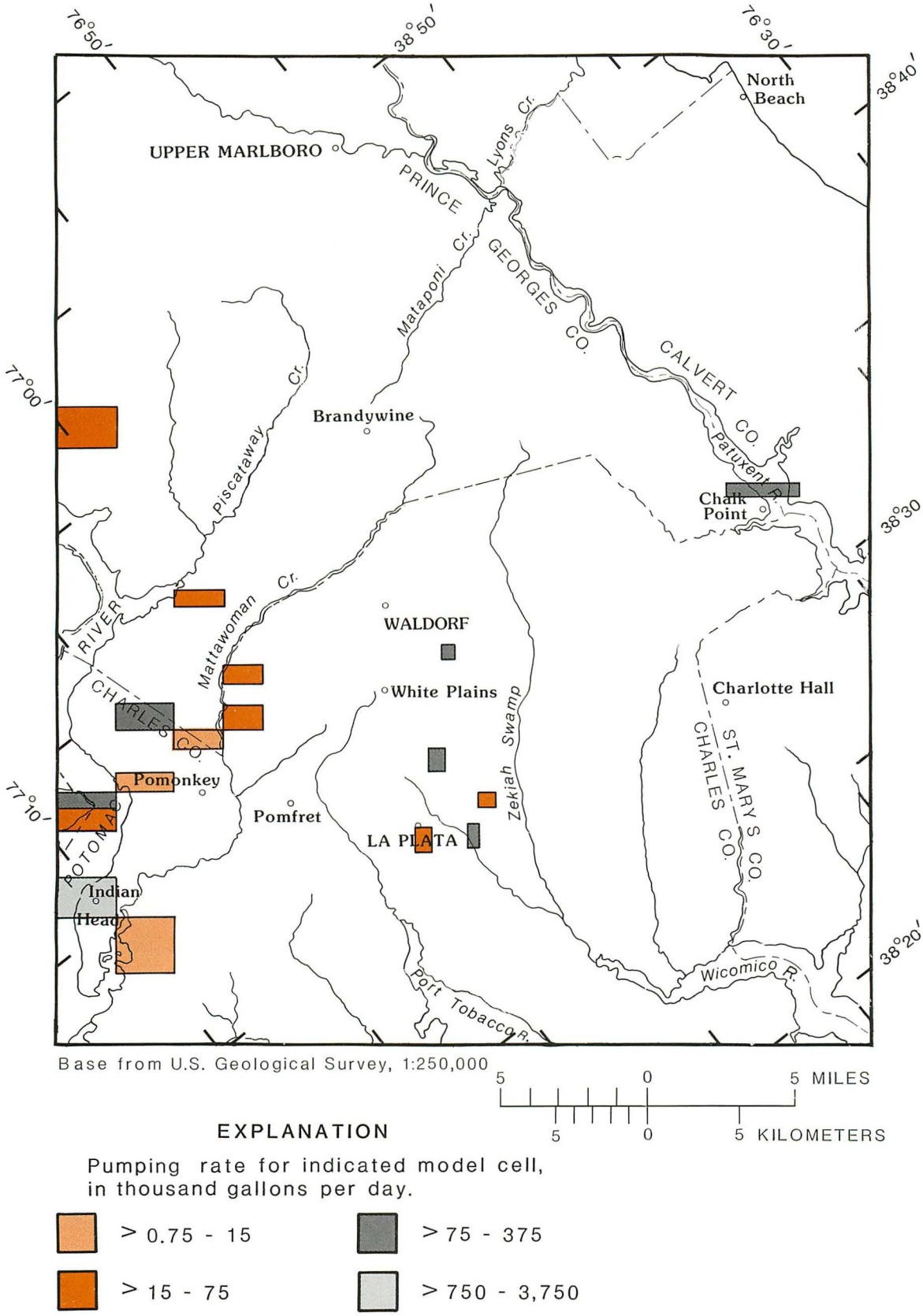


Figure 28.—Pumpage distribution in the La Plata aquifer system for stress period 22 (1985).

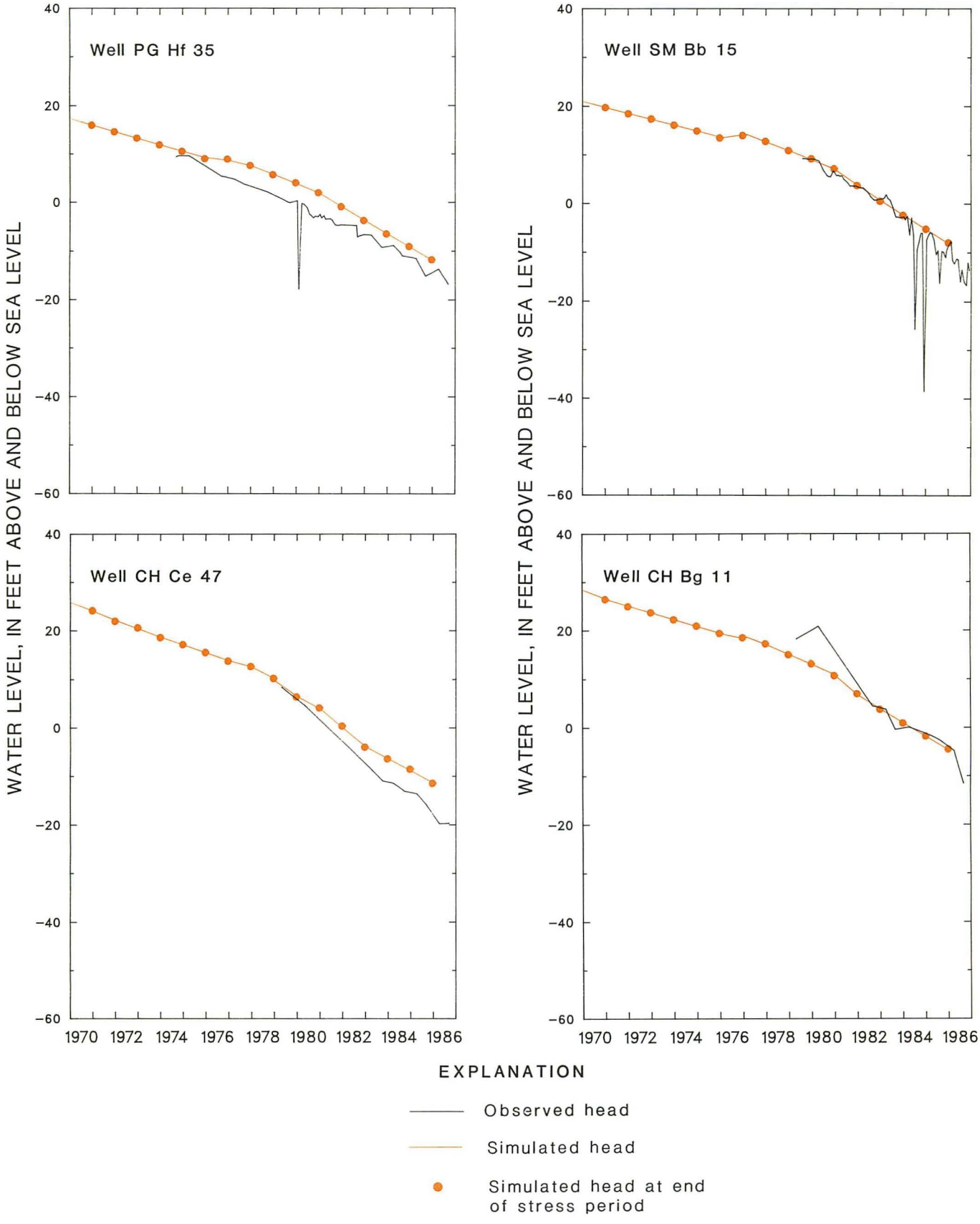


Figure 29.—Observed and simulated head changes in the Aquia aquifer.

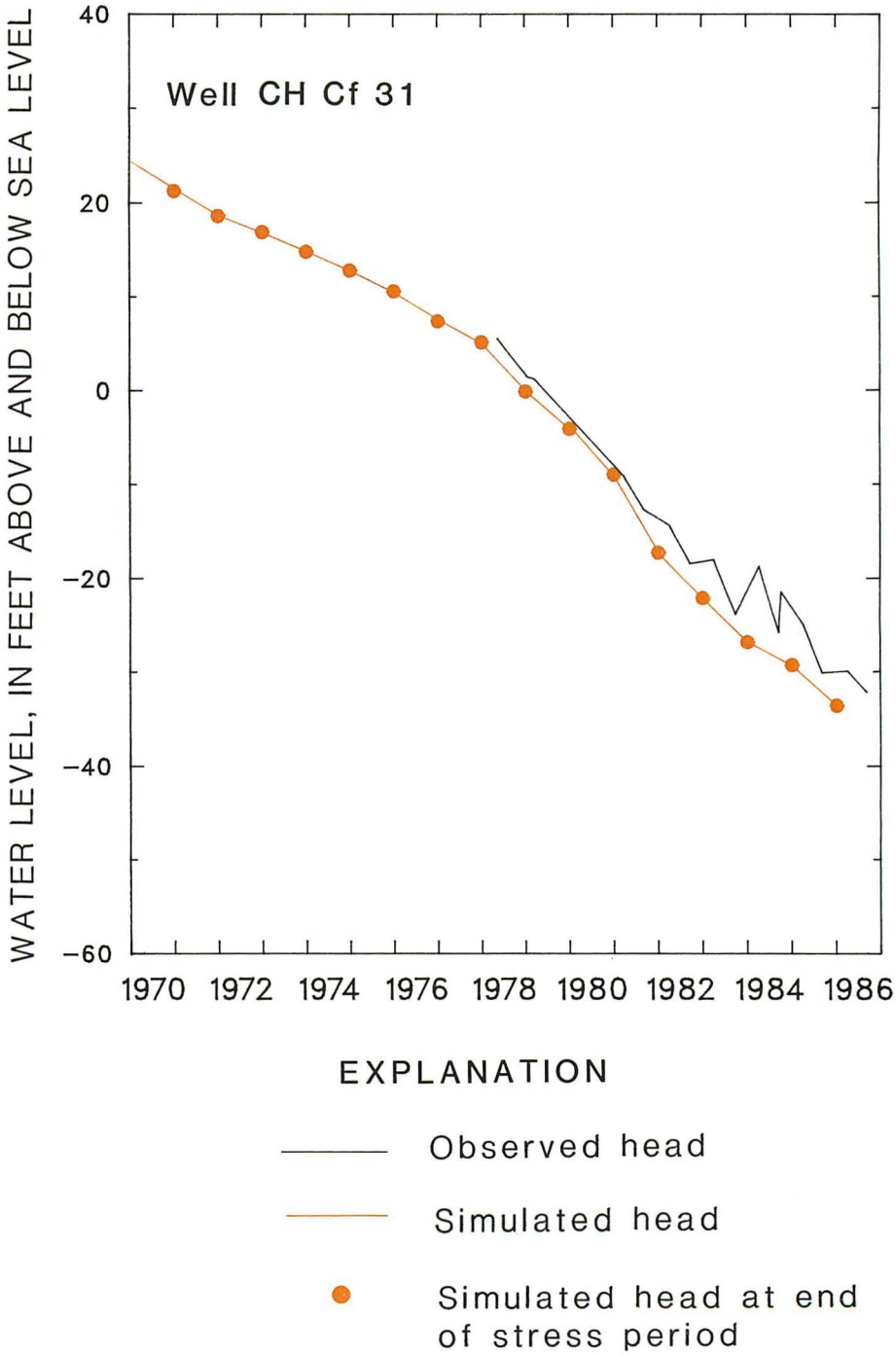


Figure 30.—Observed and simulated head changes in the Monmouth aquifer.

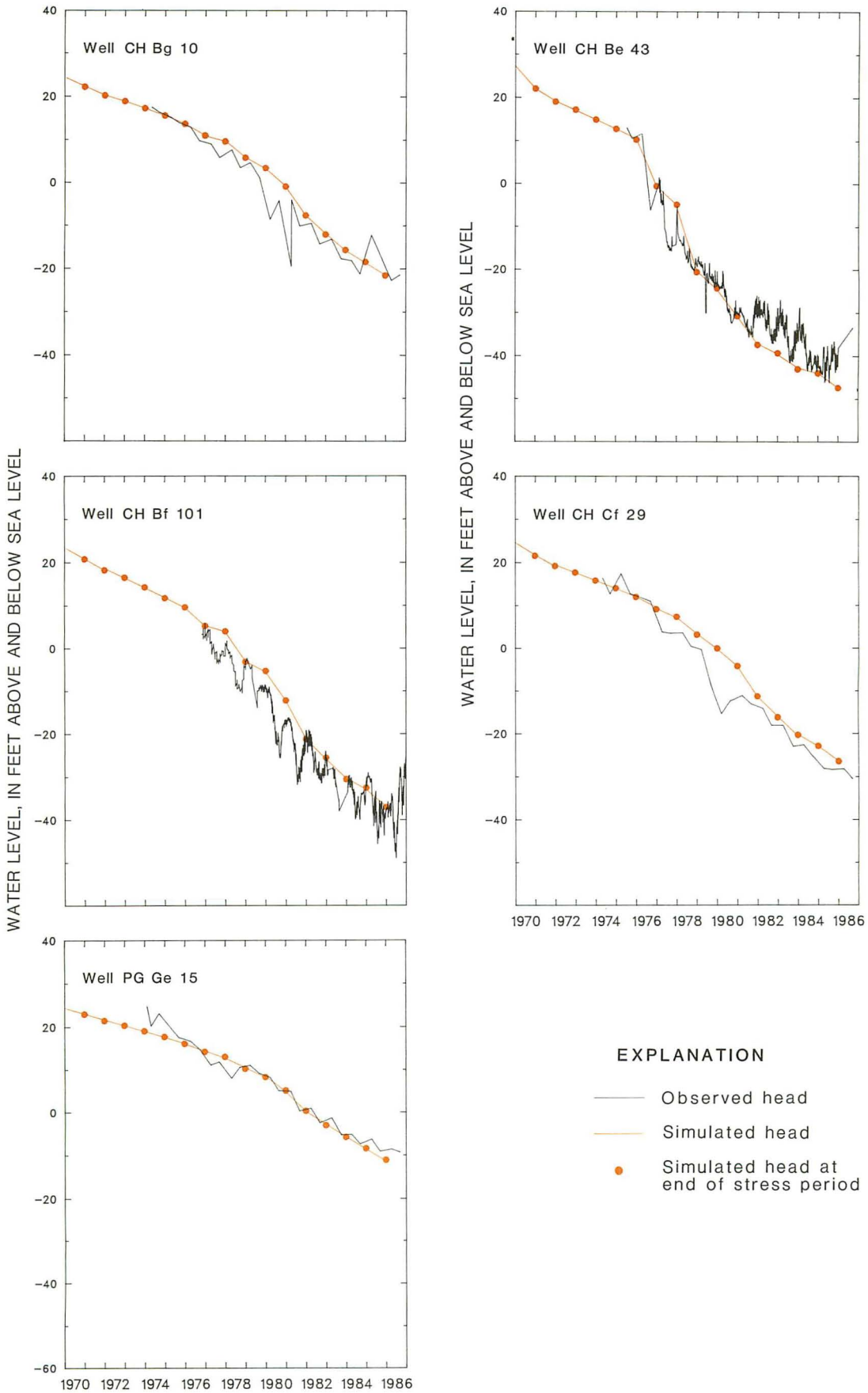


Figure 31.—Observed and simulated head changes in the Magothy aquifer.

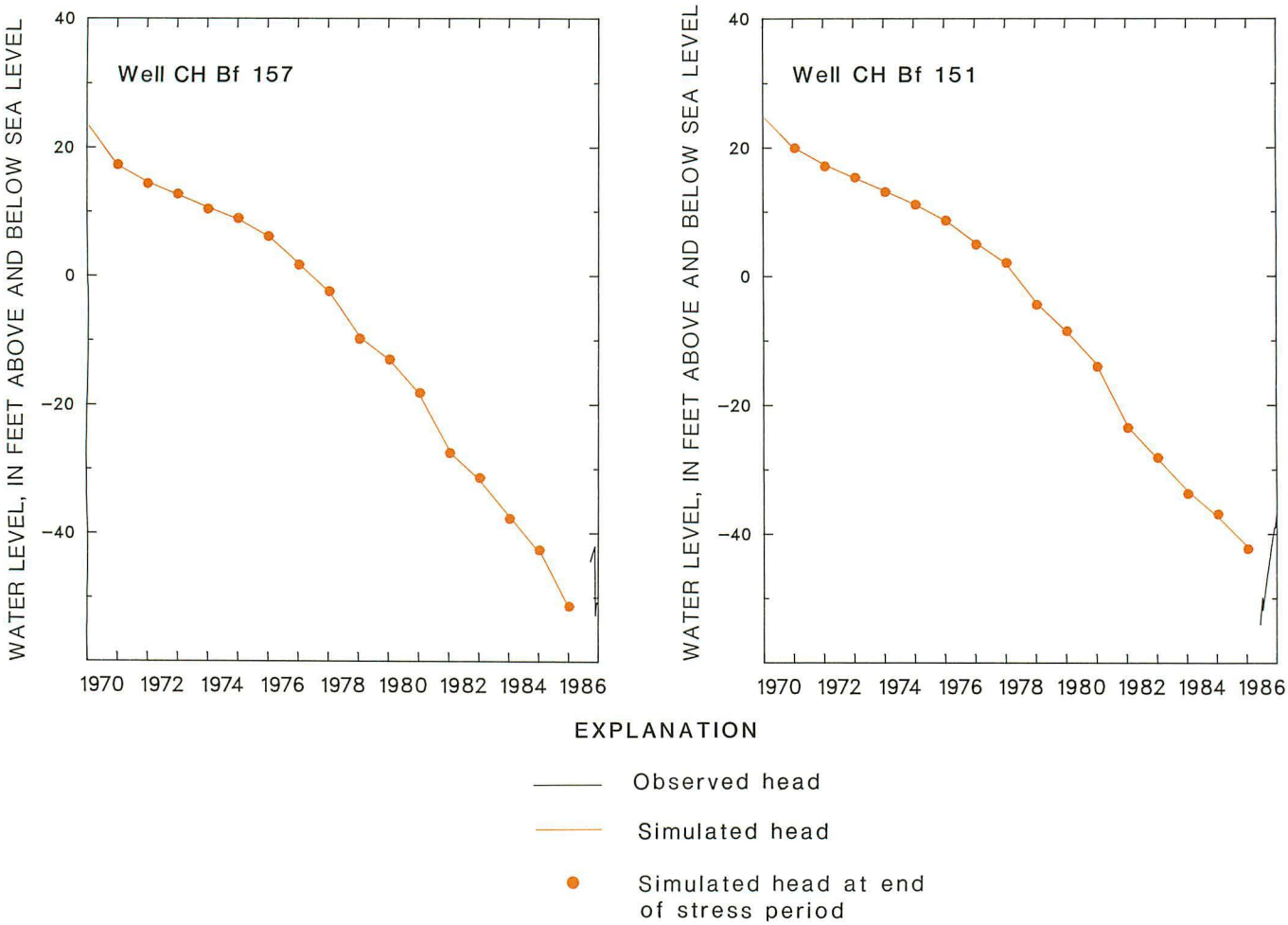


Figure 32.—Observed and simulated head changes in the St. Charles aquifer.

30) are closely approximated by the simulated heads. Total pumpage from the Monmouth aquifer for 1985 was only 0.40 Mgal/d. However, because the Monmouth aquifer is hydraulically connected with the Magothy aquifer, the high withdrawal rates in the Magothy aquifer have produced head declines in the Monmouth aquifer.

The close approximation between simulated heads and observed heads of the hydrographs shown in figure 31 indicates that the model is well calibrated for the Magothy aquifer. In the vicinity of Waldorf, pumpage from the Magothy aquifer was about 2.1 Mgal/d for 1985. This large withdrawal rate has resulted in large head declines in the Magothy aquifer as indicated by the hydrographs.

The two hydrographs of observed and simulated heads shown in figure 32 indicate that the St. Charles aquifer is calibrated. Both wells CH Bf 157 and CH Bf 151 were drilled during the study and heads were measured in 1986. The heads in both these observation wells were about 40 to 50 ft below sea level. Pumpage within a 2-mi radius of well CH Bf 151 for 1985 was 0.09 and 0.32 Mgal/d in the St. Charles and Magothy aquifers, respectively, and for well CH Bf 157, pumpage was 0.23 and 1.0 Mgal/d in the St. Charles and Magothy aquifers, respectively.

The two observation wells shown in figure 33 are both screened in the White Plains aquifer. The closest pumpage for stress period 22 to observation well CH Be 60 is about 2 mi to the east, about 0.08 Mgal/d, and 2 mi to the southwest, about 0.007 Mgal/d. Observation well CH Ce 38 is located in a cell for which there is about 0.04-Mgal/d pumpage in the model. Both these wells show the effects of this pumpage as do the model results.

Figure 34 shows hydrographs of observation wells screened in the La Plata aquifer system. Well CH Bc 17 is located near pumpage of about 1.6 Mgal/d for stress period 22. Except for the early stress periods and the 1981-83 stress periods, the simulated heads match the observed heads. The reported pumpage before 1970 and for the period 1981-83 is probably incorrect, resulting in a poor match between simulated and observed heads for well CH Bc 17 as when in figure 34. Because this pumpage is far from the Waldorf area and because the pumpage for 1985 is considered correct, no attempt was made to determine the actual pumpage for 1981-83 or the pumpage

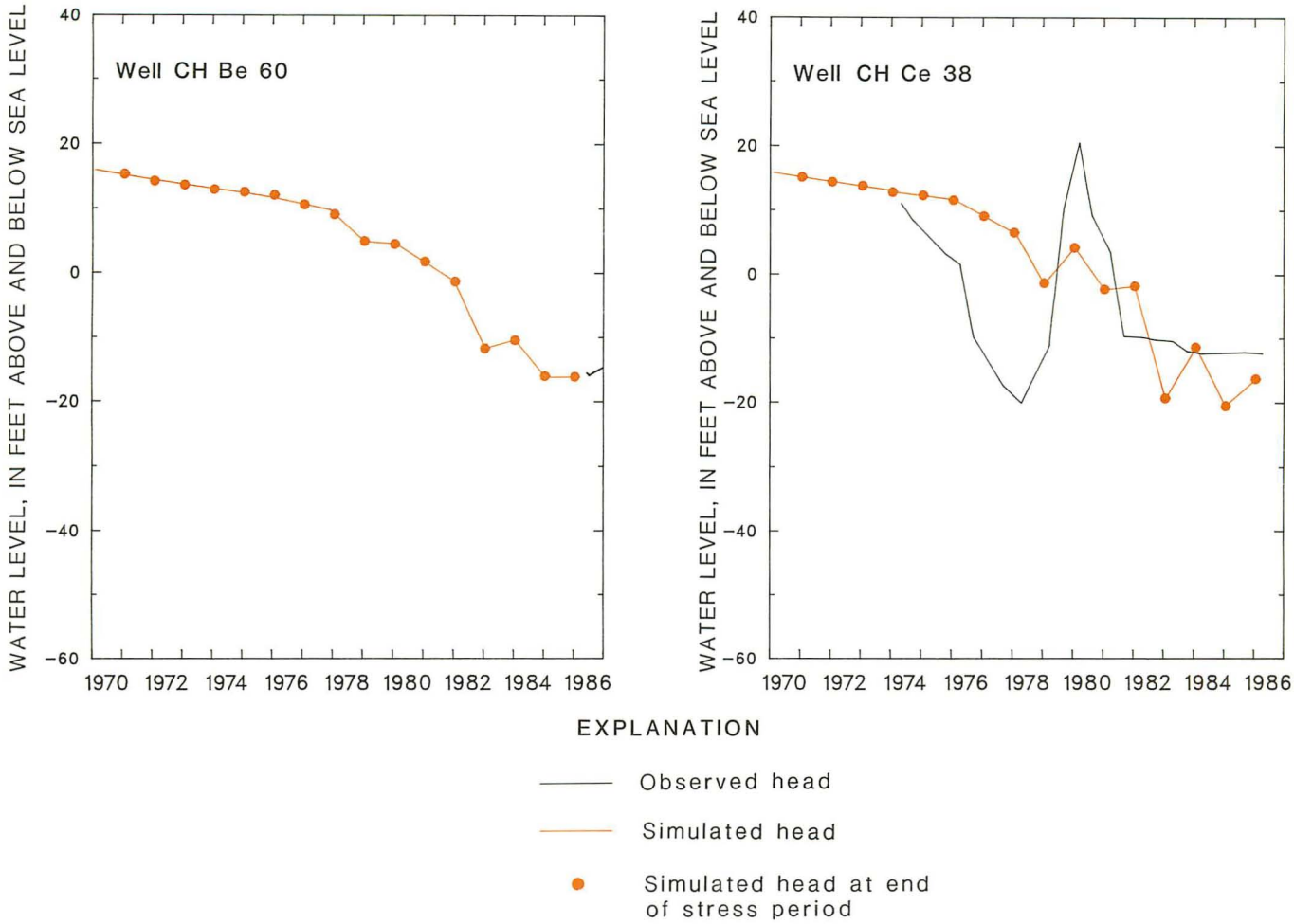


Figure 33.—Observed and simulated head changes in the White Plains aquifer.

before 1970. About 0.25 Mgal/d is withdrawn near well PG Hf 32 for stress period 22. Heads have been measured in this observation well since 1973 and are closely approximated by simulated heads. Well PG Fc 17 is in Prince Georges County, north of the study area. This part of Prince Georges County is serviced by the Washington Suburban Sanitary Commission and the nearest pumpage in this aquifer is about 5 mi away. The trend of the simulated heads for 1972-86 departs from that of the observed heads. This observation well, however, is located outside the study area, and because the simulated and observed heads are about the same, no further adjustments were made to model input.

Water-budget calculations for selected transient simulations indicate that the principal sources of water to the confined aquifers are from the constant-head cells. The constant-head cells in the surficial aquifer (layer 1) are held constant throughout the entire simulated period, 1900-85, and represent natural recharge and discharge areas. For 1985 (stress period 22), recharge to the confined system from the surficial aquifer was about 39.7 Mgal/d (fig. 36, table 10), which is equivalent to 0.5 in/yr (inches per year). About 17.6 Mgal/d of this water would have discharged from the surficial aquifer to streams, but instead, flowed through the upper confining unit because of pumping.

Another set of constant-head cells is located around the periphery of the model and is allowed to vary between stress periods. These constant heads represent the horizontal flow into and out of the model. For 1985 (stress period 22), flow into the model through these boundary cells was about 40.8 Mgal/d. Pumpage increased from 1919 to 1985 by about 700-fold. A concomitant increase of 1.6- and 1.8-fold occurred in lateral inflow and recharge to the confined aquifers, respectively. There was only a negligible amount of water derived from storage.

In 1985, simulated outflow from the confined aquifers occurred as lateral flow through the model boundary (56.3 Mgal/d), as natural upward discharge (10.4 Mgal/d), and as pumpage (15.6 Mgal/d). Pumpage increased from about 0.02 Mgal/d in stress period 1 to about 15.6 Mgal/d in stress period 22 (1985). The Magothy and Aquia aquifers and La Plata aquifer system in 1985 (stress period 22) accounted for about 80 percent of this pumpage. Lateral flow out of the model area increased from

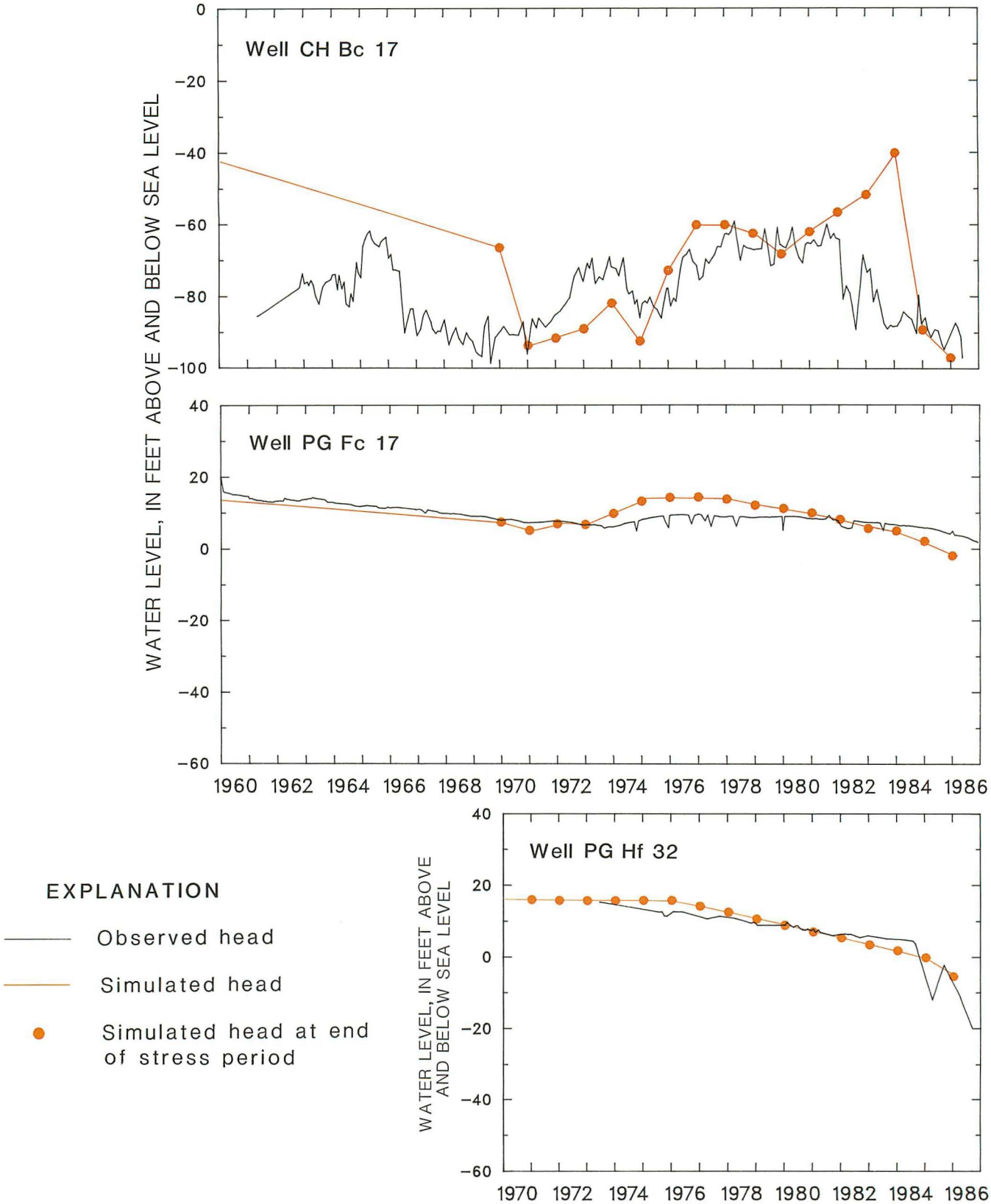
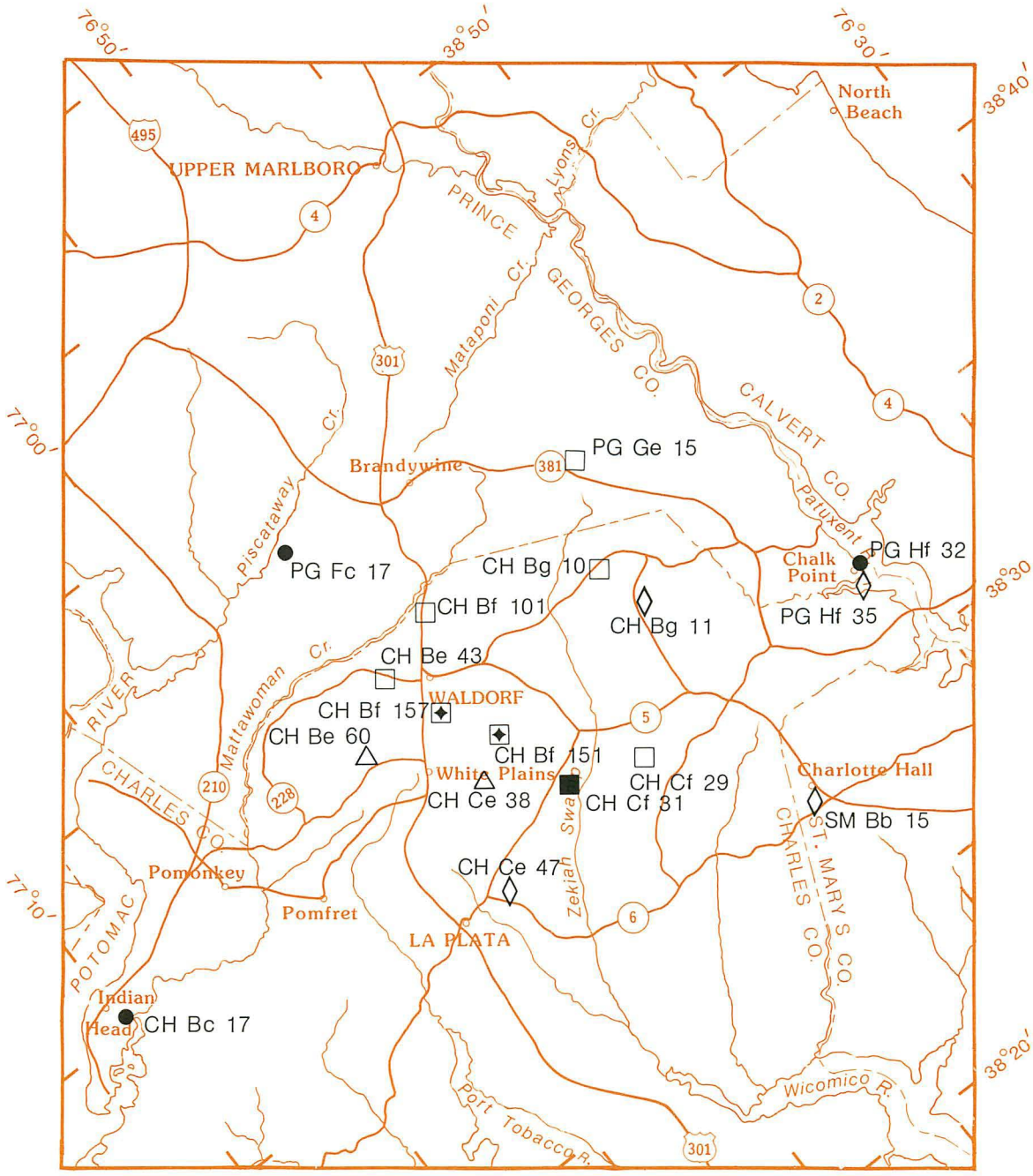


Figure 34.—Observed and simulated head changes in the La Plata aquifer system.



EXPLANATION

Symbol indicates aquifer or aquifer system and location of observation wells (see figures 29-34).

◊ Aquia aquifer

△ White Plains aquifer

● La Plata aquifer system

CH Bc 17 Well number of observation wells

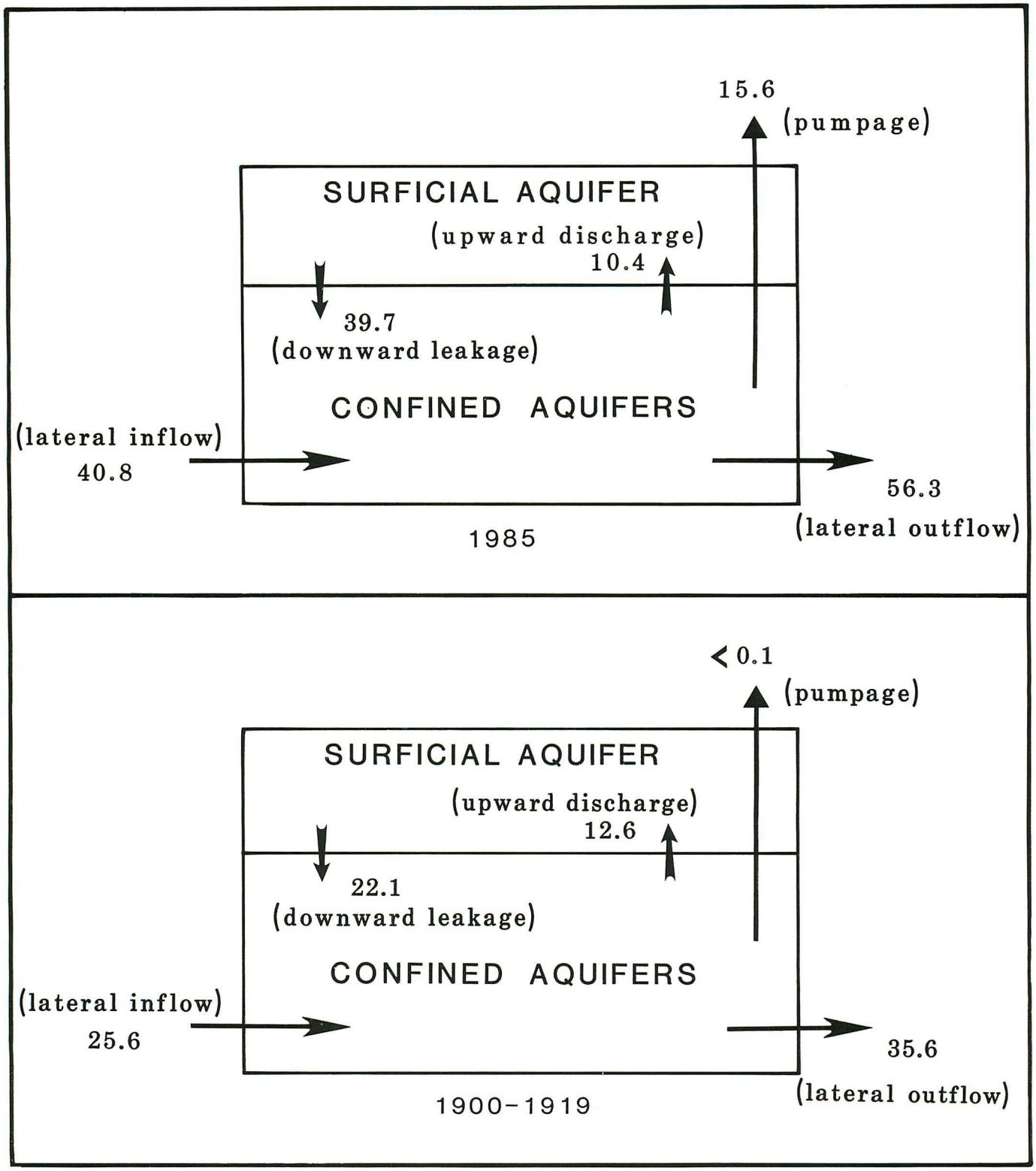
Waldorf aquifer system

■ Monmouth aquifer

□ Magothy aquifer

⊡ St. Charles aquifer

Figure 35.—Location of observation wells shown in hydrographs.



Values are in million gallons per day
(Change in storage not indicated)

Figure 36.—Simulated water budgets for 1900–19 and 1985.

Table 10.—Water-budget analysis for the transient simulation, 1900–85

[Units are in hundreds of thousand gallons per day, unless otherwise indicated; < = less than]

Budget item	Stress period 1 (1900-19)		Stress period 8 (1971)		Stress period 15 (1978)		Stress period 22 (1985)		Cumulative amounts (1900-85) (units in billion gallons)	
	In	Out	In	Out	In	Out	In	Out	In	Out
Change in storage	<1	<1	2	<1	3	<1	3	<1	6	2
Downward leakage from or upward discharge to surficial aquifer[1]	221	126	260	119	287	118	397	104	751	380
Lateral flow[2]	256	356	260	299	262	330	408	563	811	1,093
Wells	0	<1	0	114	0	116	0	156	0	120
Total	477	482	522	532	552	564	808	823	1,568	1,595
Percent error	1.25		2.06		2.09		1.80		1.69	

[1] Constant heads in surficial aquifer. These heads remained constant for entire simulation period.
[2] Constant heads that are respecified for each stress period.

1919 to 1985 by about 20.7 Mgal/d or 1.6-fold. This was a result of declining heads due to extensive pumping in some of the aquifers outside the limits of the model. For example, heads in the Aquia aquifer to the east of the modeled area declined about 40 ft from 1900 to 1985 (Chapelle and Drummond, 1983). The increase from 1919 to 1985 in lateral outflow was 5.5 Mgal/d greater than the increase of lateral inflow indicating that the pumpage outside the model area had a greater effect on the boundary flow than pumpage within the model area. Within the modeled area, there was a moderate decrease of about 17 percent of natural ground-water discharge (upward leakage to the surficial aquifer) from 1900 to 1985.

SIMULATION OF PUMPAGE SCENARIOS

Seven different scenarios were tested using the digital model to simulate the effects of pumping during the period 1985 to 2020. Four of the scenarios assessed the effects of given pumpage distributions on the ground-water system. The other three scenarios varied the pumpage to estimate the amount of ground water available without surpassing 80 percent of the available drawdown in the Waldorf area. Available drawdown is defined, herein, as the difference between the prepumping heads and the altitude of the top of the given aquifer. This was calculated for each cell. For each scenario, the percentage of this available drawdown for each cell was determined.

Scenario 1 added one production well to the model each year for 10 years starting in 1988. Scenario 2 added one production well every other year for 10 years starting in 1988. Scenario 3 added wells withdrawing from the La Plata aquifer system at sites where wells screened in the Waldorf aquifer system already exist. Scenario 4 simulated production wells screened in the Waldorf aquifer system at three sites where production wells screened in the La Plata aquifer system already exist. Scenarios 5 to 7 simulated pumpage such that drawdowns would not exceed 80 percent of the available drawdown in the Waldorf aquifer system, the White Plains aquifer, and the La Plata aquifer system, respectively.

The period 1986-2020 was simulated for all the pumpage scenarios, and model output is presented for the year 2020. Each simulation was divided into 22 stress periods as were the transient model simulations (table 8). The 22 stress periods are as follows: the years 1986-97 were divided into twelve 1-year stress periods, the years 1998-2015 were divided into nine 2-year stress periods, and the years 2016-20 were a single 5-year stress period.

It was assumed that during the simulated period 1986-2020, there would probably be some regional decline in heads. For the pumpage scenarios, a regional head decline of 10 ft was simulated. This regional decline was modeled by reducing the heads in the constant-head cells around the perimeter of the model by 0.45 ft from one stress period to the next. As previously indicated, the sensitivity analysis suggested that the model results were not overly sensitive to changes in these constant-head cells. A further test on the effects of these constant-head cells indicated that reducing these heads by 10 ft around the perimeter resulted in a head reduction in the study area of about 4 to 6 ft.

The effects on the head distribution for the La Plata aquifer system, White Plains aquifer, and Waldorf aquifer system are discussed separately. Because the St. Charles, Magothy, and Monmouth aquifers of the Waldorf aquifer system act as a single hydrologic unit within the study area, they are not discussed separately.

In 1986, Charles County added two new production wells screened in the La Plata aquifer system. In the model, these wells were located in cells row 12, column 14, and row 23, column 9 (fig. 20). These two wells were added to scenarios 1-4 and throughout each simulation were pumped at 0.50 Mgal/d.

In order to have a point of comparison, the model was used to simulate the period 1986-2020 with no additional pumpage except for the pumpage from the two production wells screened in the La Plata aquifer system described above. The results of this simulation are shown in figures 37-42. Figures 37-39 show the head distribution for the Waldorf aquifer system, White Plains aquifer, and La Plata aquifer system. Figures 40-42 show the percentage of available drawdown used by these aquifers. For the White Plains aquifer and La Plata aquifer system, only about 10 percent of the available drawdown is used in the Waldorf area. However, for the Waldorf aquifer system, up to 60 percent of the available drawdown is used.

Model results as shown in figures 37-61 are based upon average heads for each cell and are not the heads at individual pumping wells. Within the Waldorf area the cells are less than 0.25 mi^2 in size, and therefore the computed heads are more representative of all heads in the cell than in the larger cells outside the Waldorf area. However, even the heads in smaller cells may differ considerably from heads at pumping wells.

Scenario 1

Table 11 indicates well number and pumping rates of the 13 wells simulated in scenarios 1-4. In scenario 1, starting with well 1, one well was added each year from 1988 to 1997. The total additional pumpage for the period 1988-2020 was about 4.2 Mgal/d and 1.9 Mgal/d for the La Plata aquifer system and White Plains aquifer, respectively. Figures 43-47 show the results of this scenario at the end of the last stress period (2020).

The locations of six simulated wells screened in the La Plata aquifer system (wells 1-4, 7, and 8) are shown in figures 43-45. Because Charles County officials expect the greatest population growth to be in an area west of Waldorf (S. C. Weber, Charles County Department of Public Works, oral commun., 1986), most of the 10 wells in scenario 1 were located in this area. Also, the wells were located in areas of higher transmissivities.

Comparing figures 39 and 45, as much as 95 ft of additional drawdown was simulated for scenario 1. The lowest average heads for any cell, about 170 ft below sea level, are located in the cell with well 2. This is due to lower transmissivities west of Waldorf (pl. 7G). The simulated drawdown as a percentage of available drawdown in the vicinity of Waldorf (fig. 47) is only about 20 percent and increases to 30 percent in the vicinity of well 2.

The head distribution at the end of the simulation (2020) for the White Plains aquifer (fig. 44) shows that in the vicinity of wells 5, 6, and 10, final heads were about 250 ft below sea level. Comparing these heads with figure 38 indicates that the simulated pumpage of about 1.9 Mgal/d has resulted in drawdowns of an additional 225 ft in this area. The transmissivity distribution (pl. 7F) indicates that model transmissivities of the White Plains aquifer are about 30 to 50 percent of those of the La Plata aquifer system. Also, wells 5, 6, and 10 are located near the zone of low transmissivity associated with the fault trace previously discussed. Thus, simulated drawdowns in the White Plains aquifer were much greater for less pumpage (1.9 Mgal/d versus 4.2 Mgal/d) than in the La Plata aquifer system.

Figure 46 indicates that in the vicinity of Waldorf, the percentage of available drawdown used ranged from about 20 percent east of Waldorf to greater than 90 percent about 5 mi west of Waldorf. Thus, the pumpage of 1.9 Mgal/d in the White Plains aquifer has resulted in drawdown in excess of the 80-percent available drawdown criterion.

A comparison of figures 37 and 43 indicates that the effect of a total pumpage of about 6.1 Mgal/d in the La Plata aquifer system and White Plains aquifer has only lowered the heads in the Waldorf aquifer system by 10 ft in the immediate vicinity of Waldorf, and generally less than 5 ft within the area around Waldorf.

For scenarios 1-4, the Theis (1935) non-equilibrium equation, as modified by Cooper and Jacob (1946), was used to approximate the difference between the average head for the cell and the head for each simulated well. This analysis assumes that (1) the well is located at the center of the cell, (2) transmissivity within the cell does not vary, (3) the well is 100-percent efficient, and (4) the well penetrates the full thickness of the aquifer. This difference, as calculated, is a linear function of the pumping rate and the inverse of the transmissivity.

Table 11 indicates the difference between the head in a pumping well and the simulated head for the cell in which the well is located. For example, at the cell containing well 1, the simulated head in the La Plata aquifer system (fig. 45) is about 140 ft below sea level. Subtracting 60 ft (table 11) from the simulated head indicates that a well located at the center of the cell pumping at 0.65 Mgal/d would have an approximate pumping level of 200 ft below sea level. Similarly, for wells 2, 3, 4, 7, and 8 also simulated in the La Plata aquifer system, the approximate

(Text continued on p. 78.)

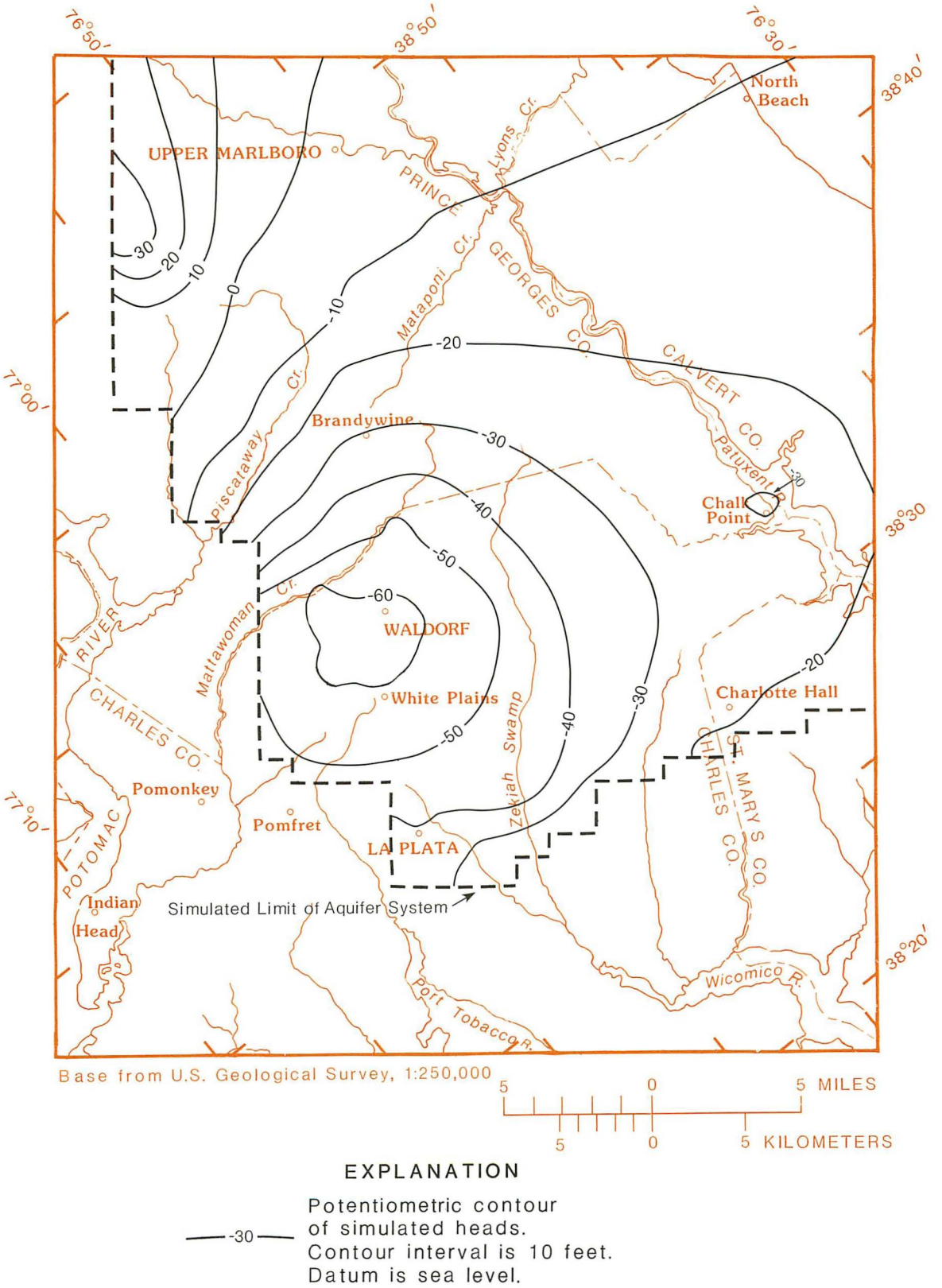
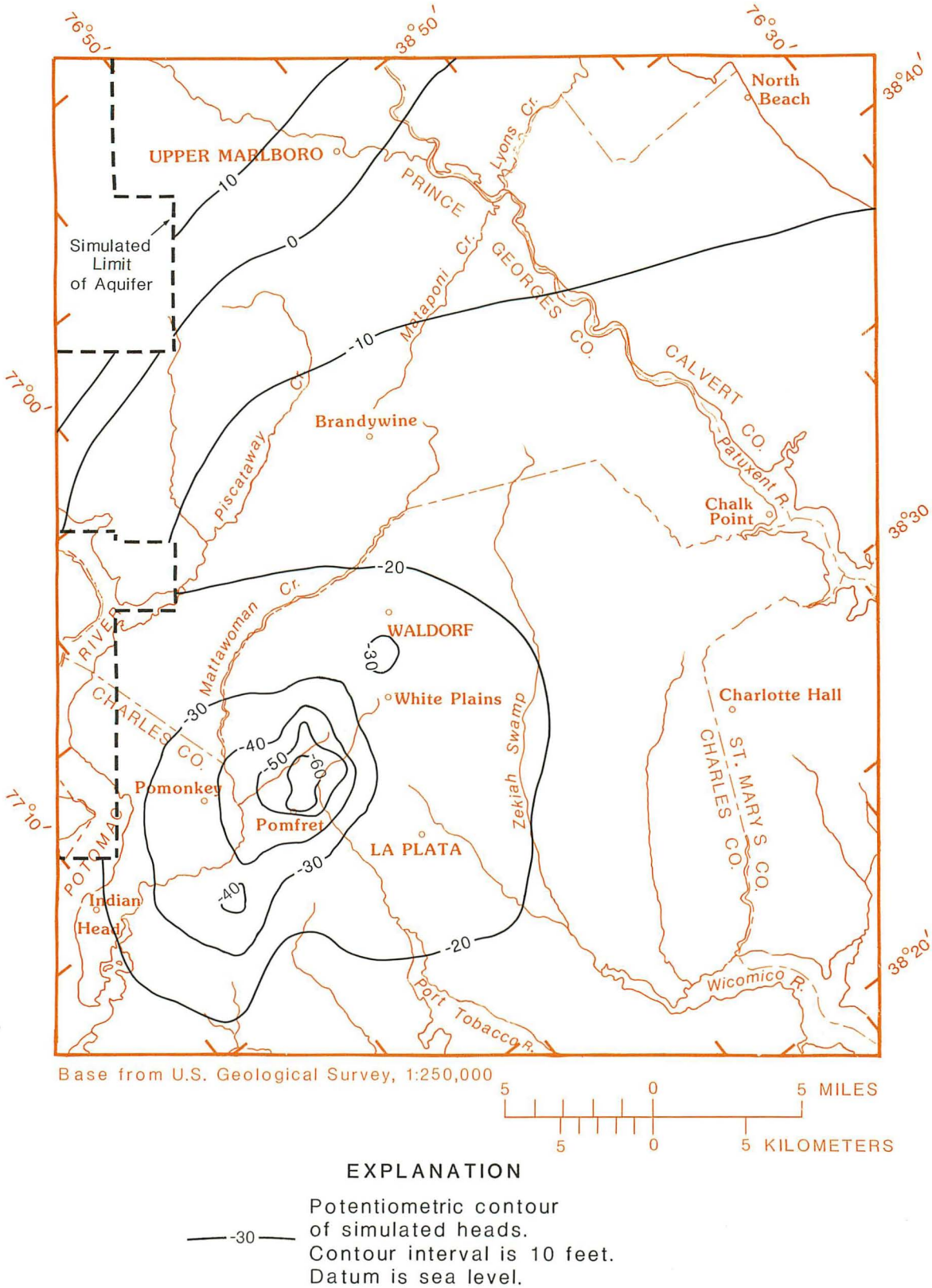


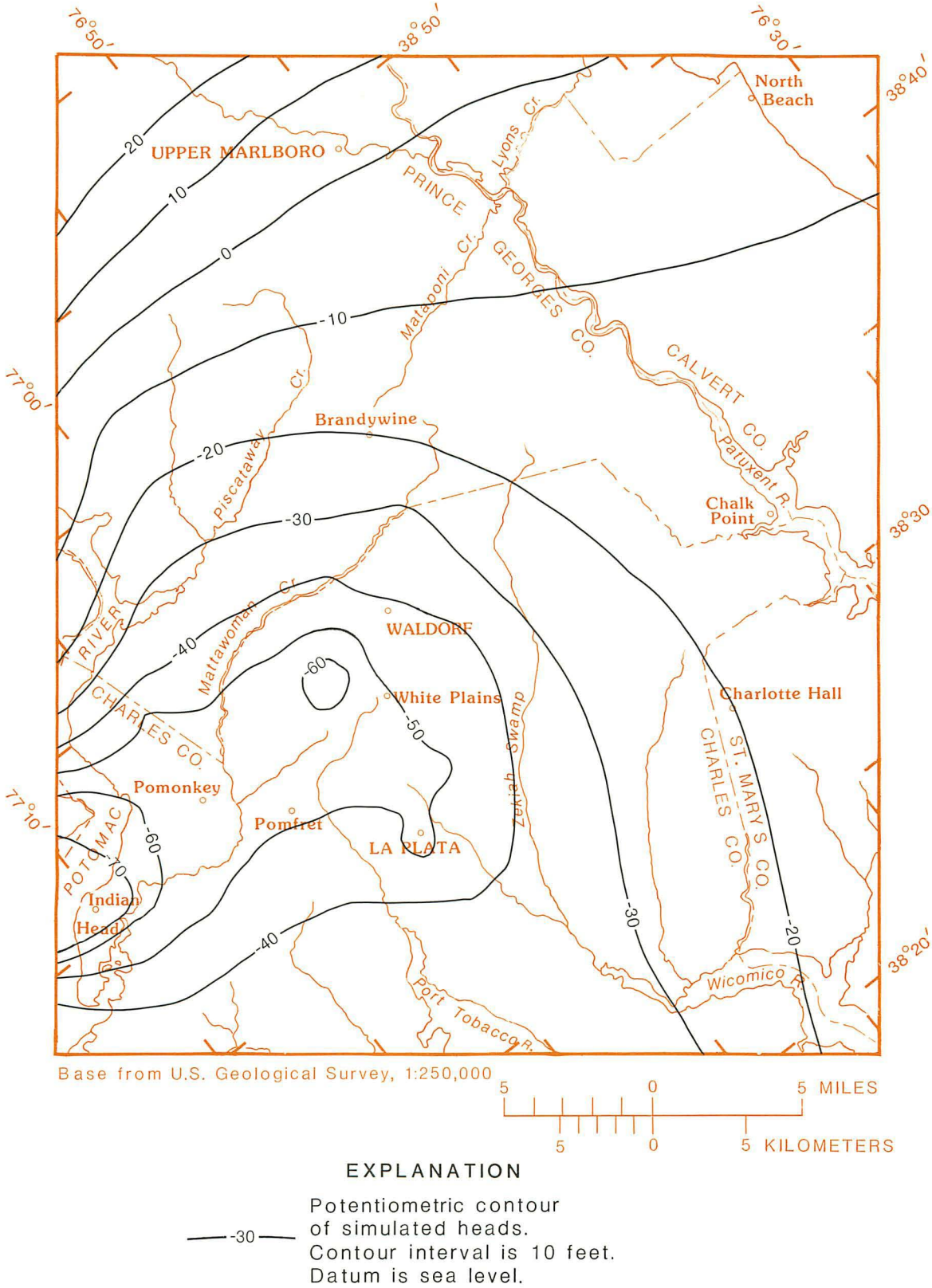
Figure 37.—Simulated heads in the Waldorf aquifer system, for 2020, assuming no additional pumpage in the model area.



EXPLANATION

—30— Potentiometric contour of simulated heads. Contour interval is 10 feet. Datum is sea level.

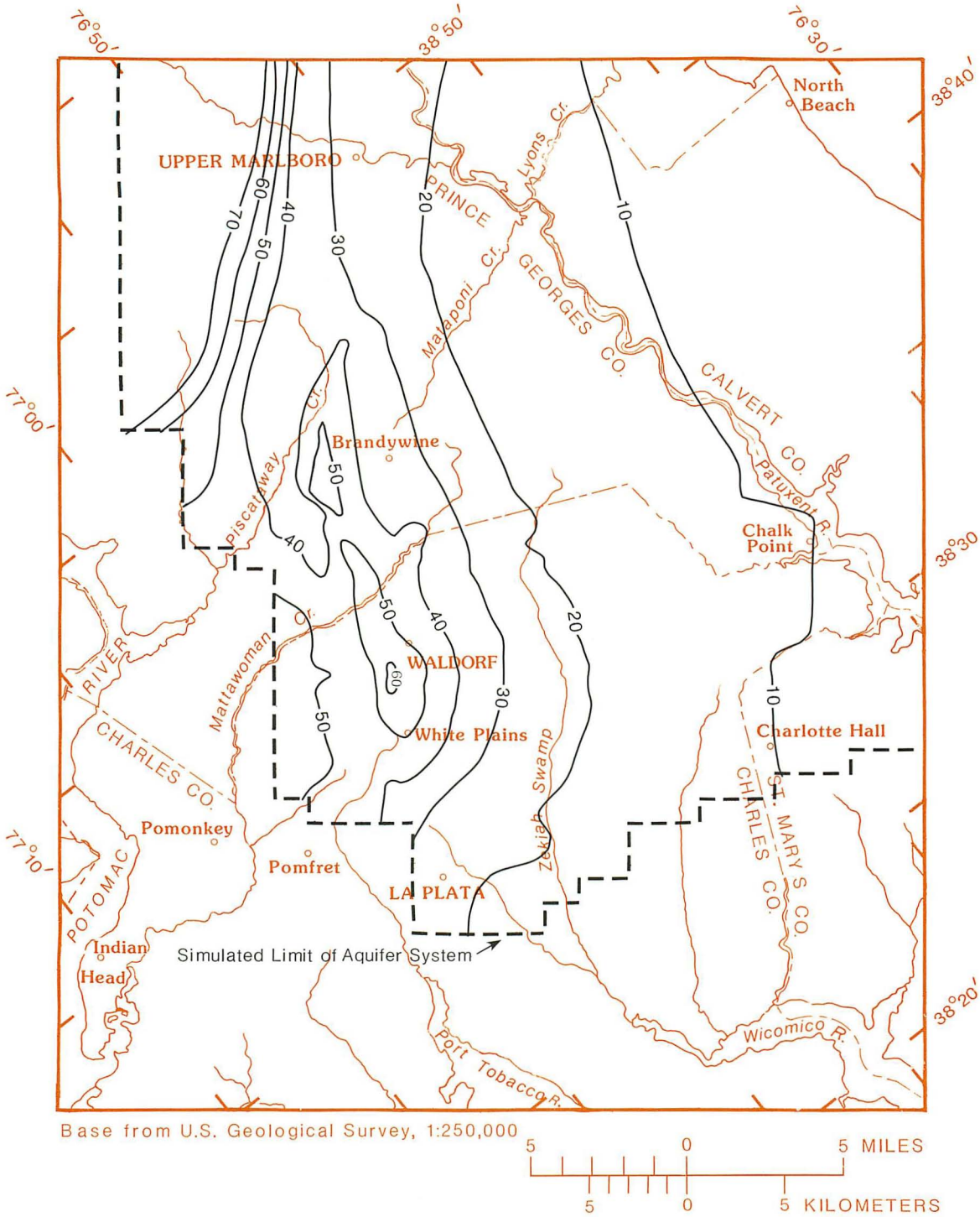
Figure 38.—Simulated heads in the White Plains aquifer, for 2020, assuming no additional pumpage in the model area.



EXPLANATION

—30— Potentiometric contour of simulated heads. Contour interval is 10 feet. Datum is sea level.

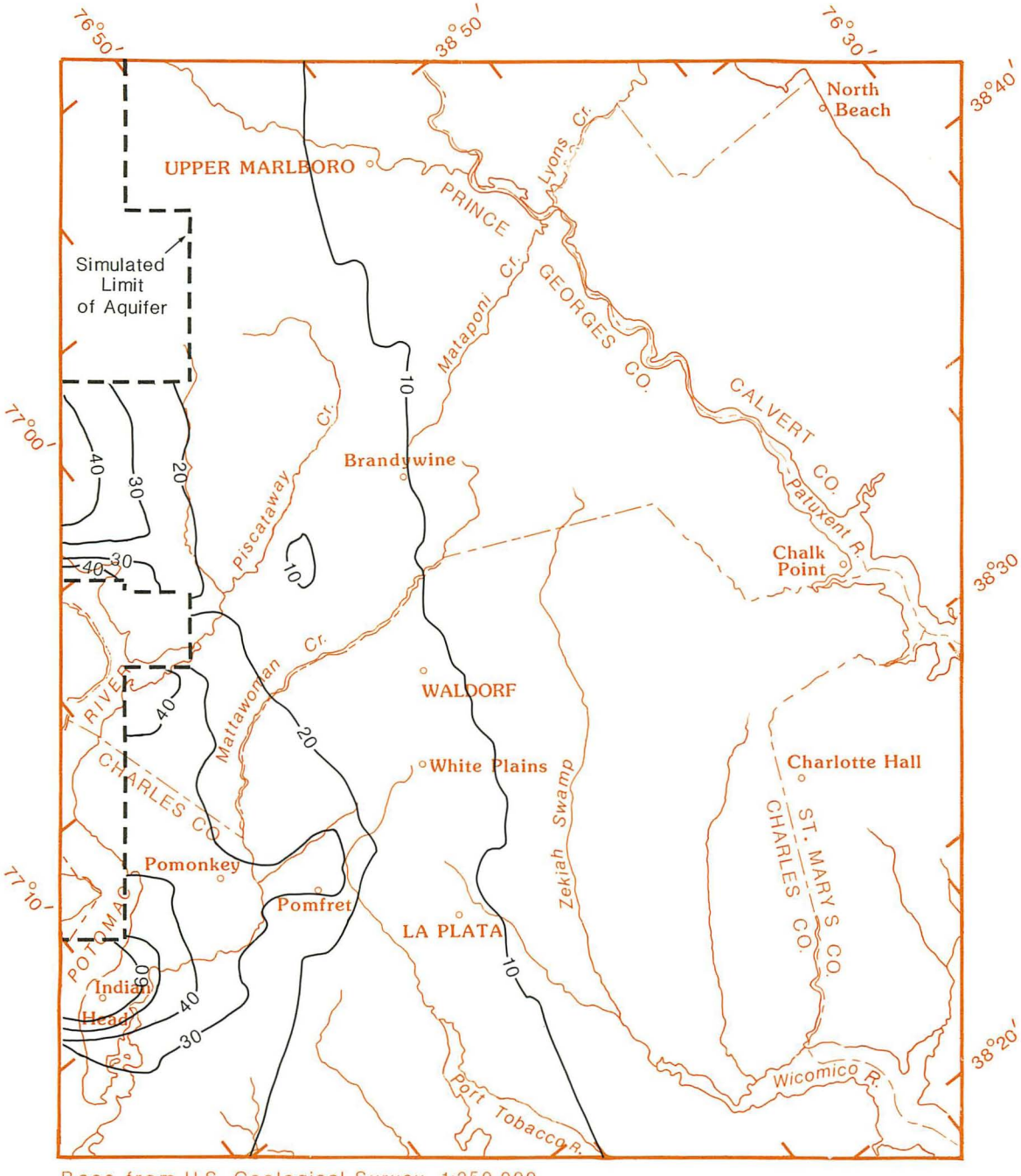
Figure 39.—Simulated heads in the La Plata aquifer system, for 2020, assuming no additional pumpage in the model area.



EXPLANATION

—30— Line of equal simulated drawdown, as a percent of total available drawdown. Interval is 10 percent.

Figure 40.—Percentage of available drawdown in the Waldorf aquifer system, for 2020, assuming no additional pumpage in the model area.



Base from U.S. Geological Survey, 1:250,000

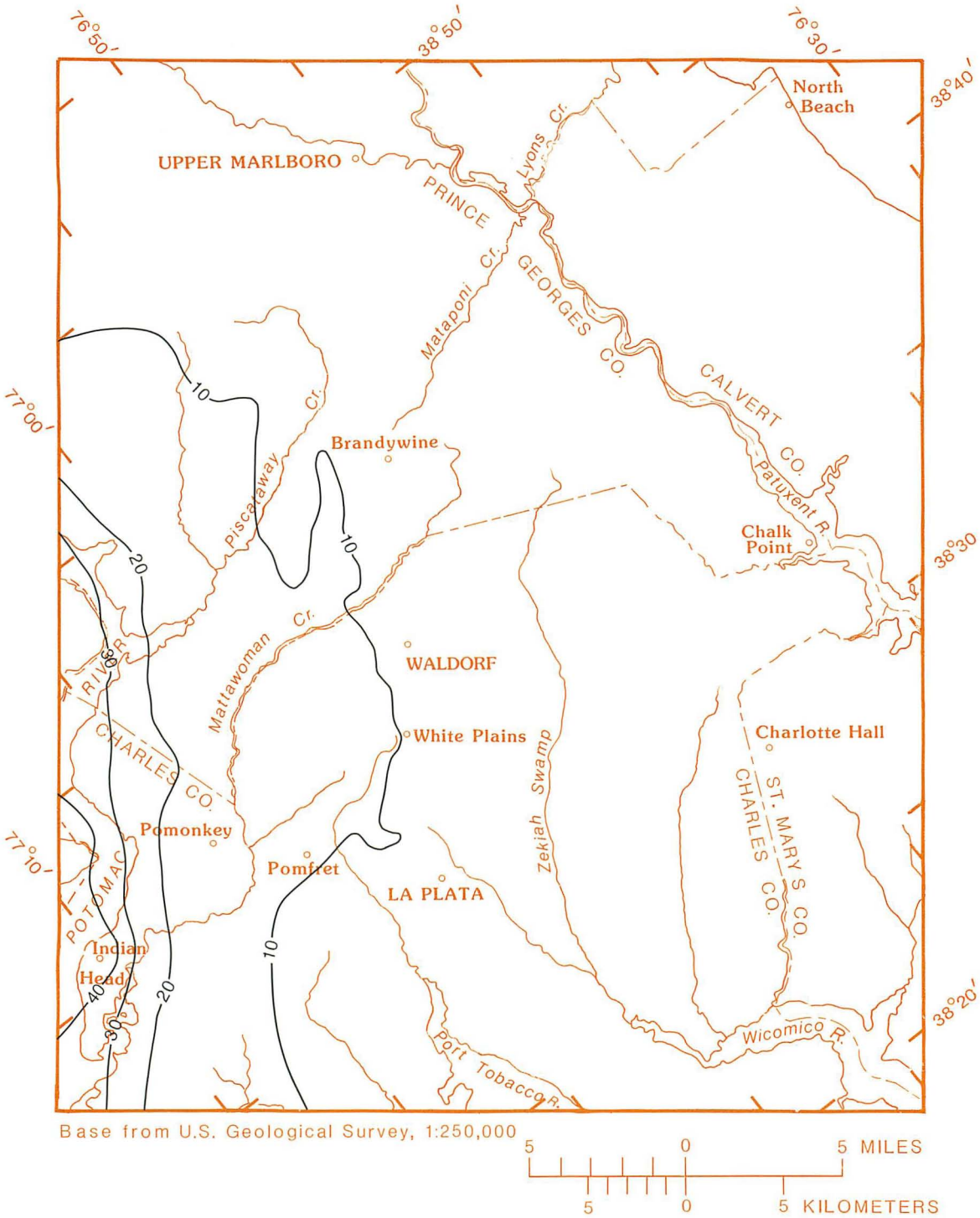
5 0 5 MILES

5 0 5 KILOMETERS

EXPLANATION

—30— Line of equal simulated drawdown, as a percent of total available drawdown. Interval is 10 percent.

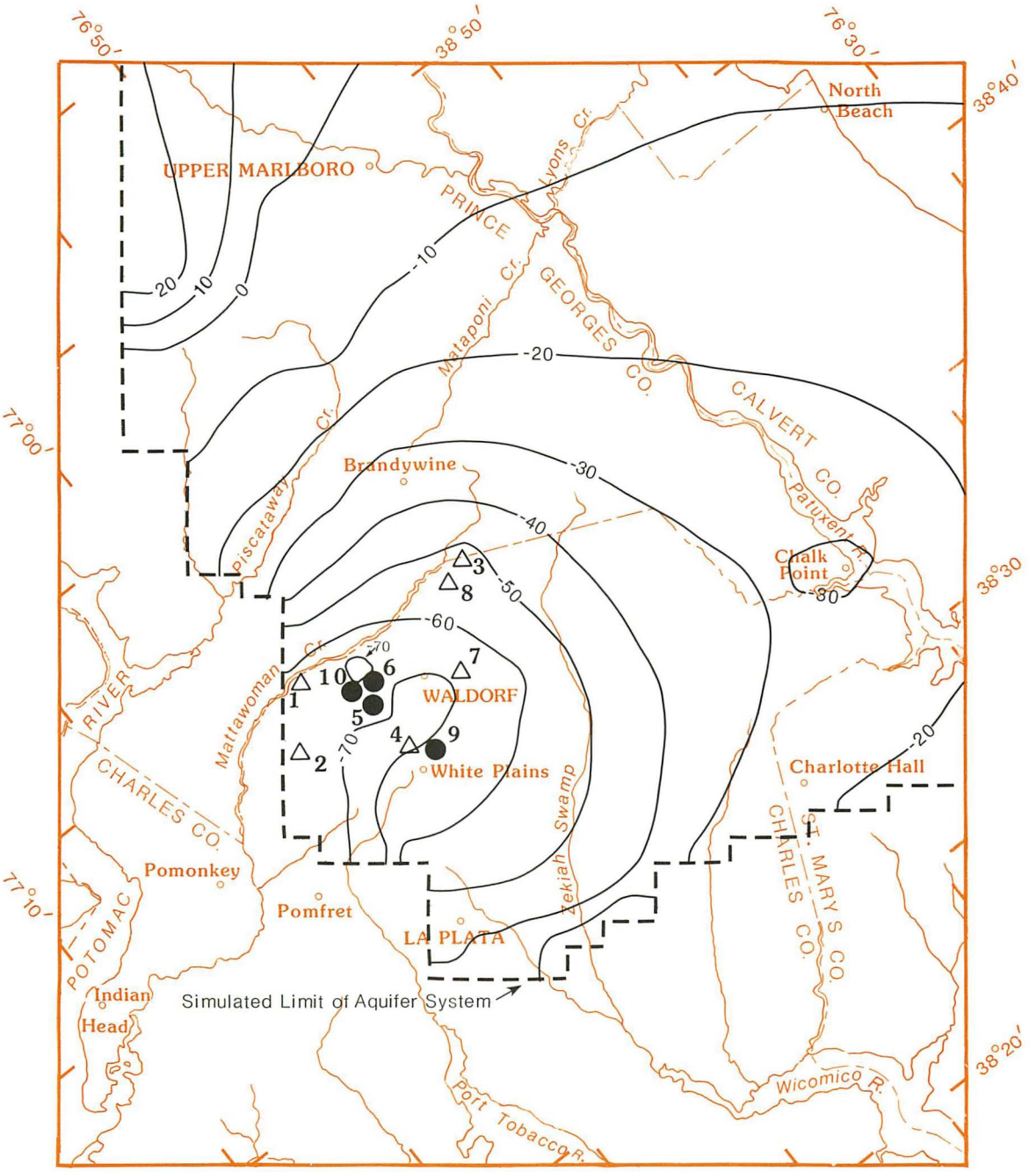
Figure 41.—Percentage of available drawdown in the White Plains aquifer, for 2020, assuming no additional pumpage in the model area.



EXPLANATION

—30— Line of equal simulated drawdown, as a percent of total available drawdown. Interval is 10 percent.

Figure 42.—Percentage of available drawdown in the La Plata aquifer system, for 2020, assuming no additional pumpage in the model area.



Base from U.S. Geological Survey, 1:250,000

5 0 5 MILES

5 0 5 KILOMETERS

EXPLANATION

—— -30 —— Potentiometric contour of simulated heads. Contour interval is 10 feet. Datum is sea level.

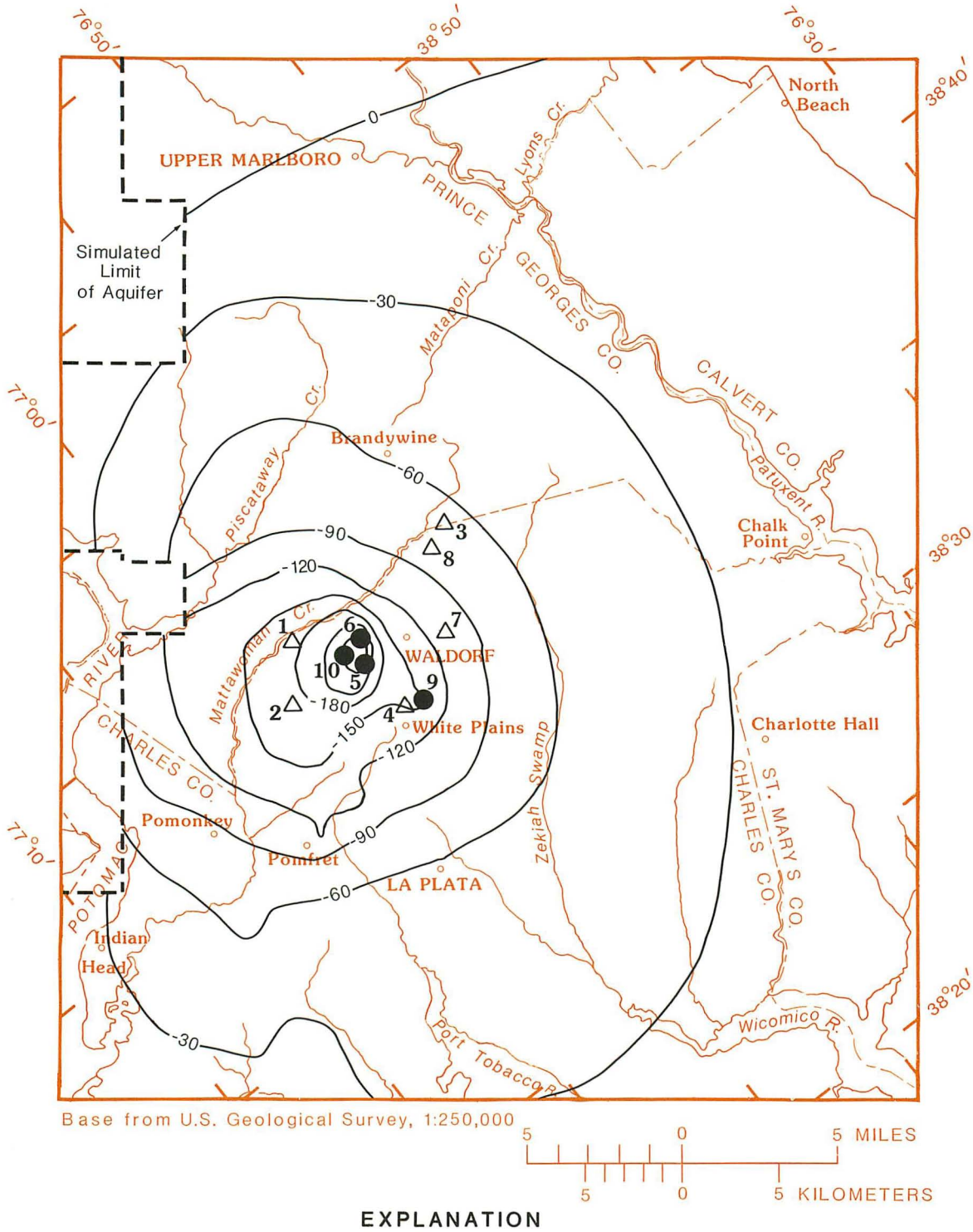
LOCATION OF HYPOTHETICAL WELLS IN THE:

● White Plains aquifer

△ La Plata aquifer system

5 Well number listed in table 11

Figure 43.—Simulated heads in the Waldorf aquifer system, for 2020, for scenario 1.



EXPLANATION

—-30— Potentiometric contour of simulated heads. Contour interval is 30 feet. Datum is sea level.

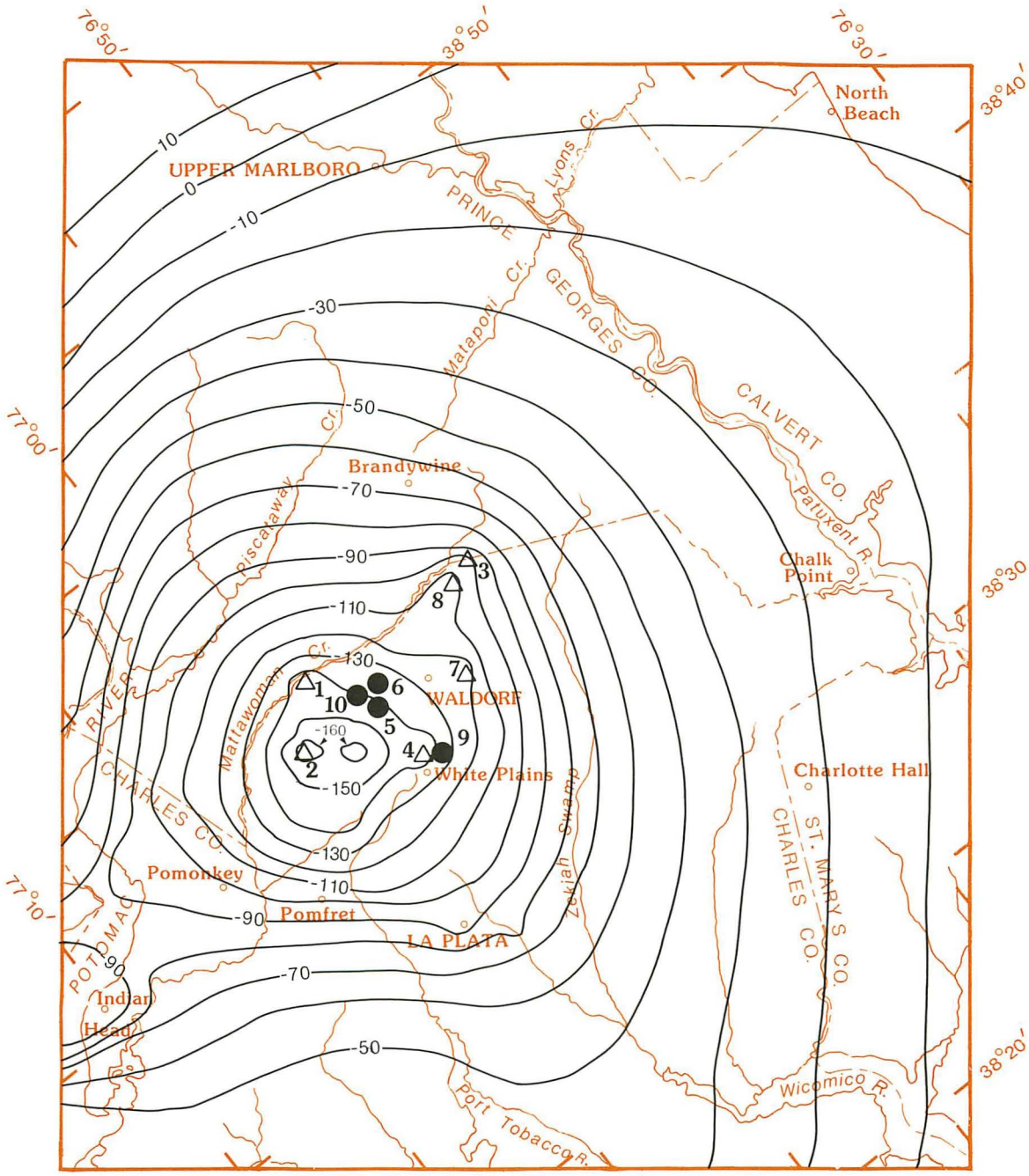
LOCATION OF HYPOTHETICAL WELLS IN THE:

● White Plains aquifer

△ La Plata aquifer system

5 Well number listed in table 11

Figure 44.—Simulated heads in the White Plains aquifer, for 2020, for scenario 1.



EXPLANATION

—30— Potentiometric contour of simulated heads. Contour interval is 10 feet. Datum is sea level.

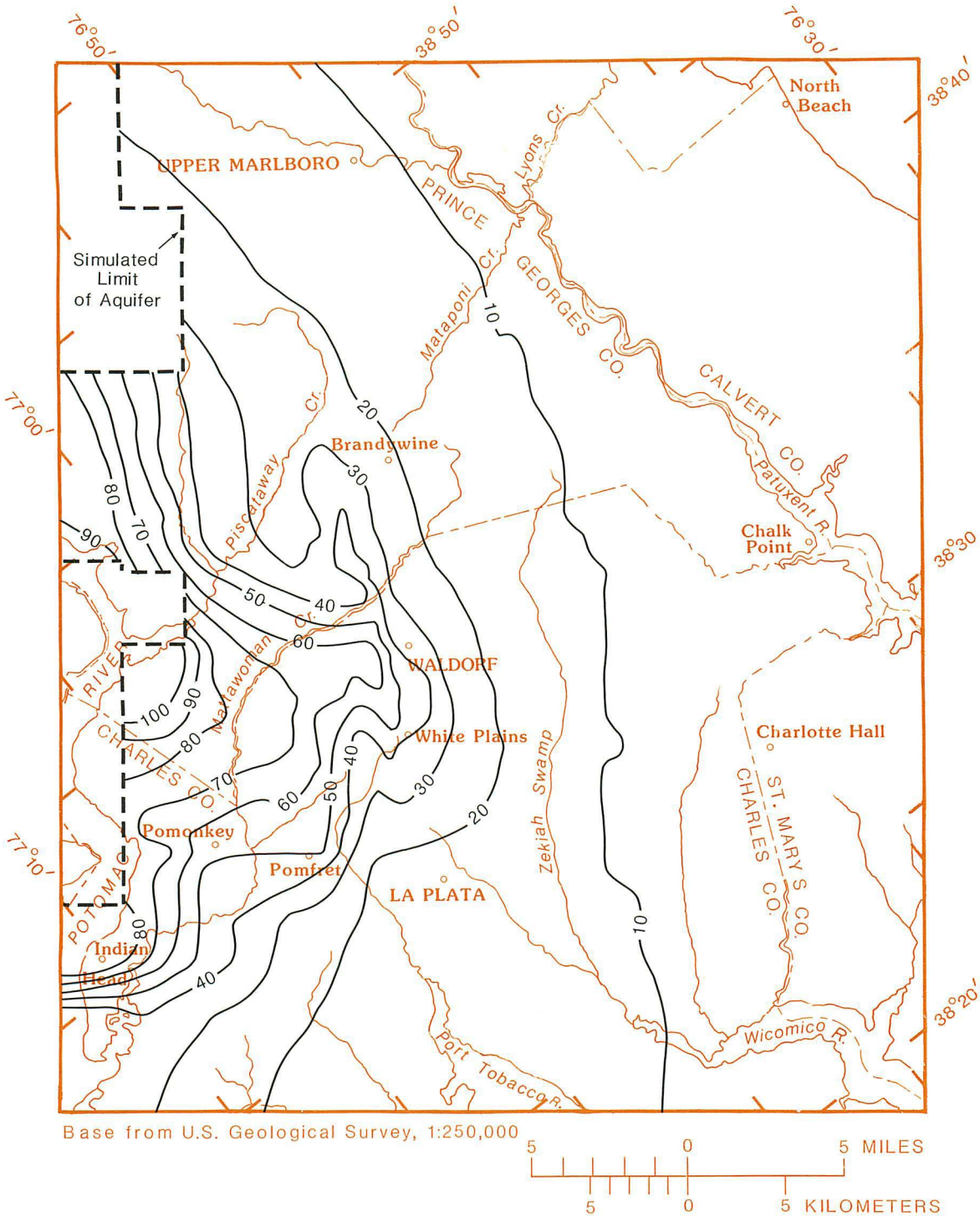
LOCATION OF HYPOTHETICAL WELLS IN THE:

● White Plains aquifer

△ La Plata aquifer system

5 Well number listed in table 11

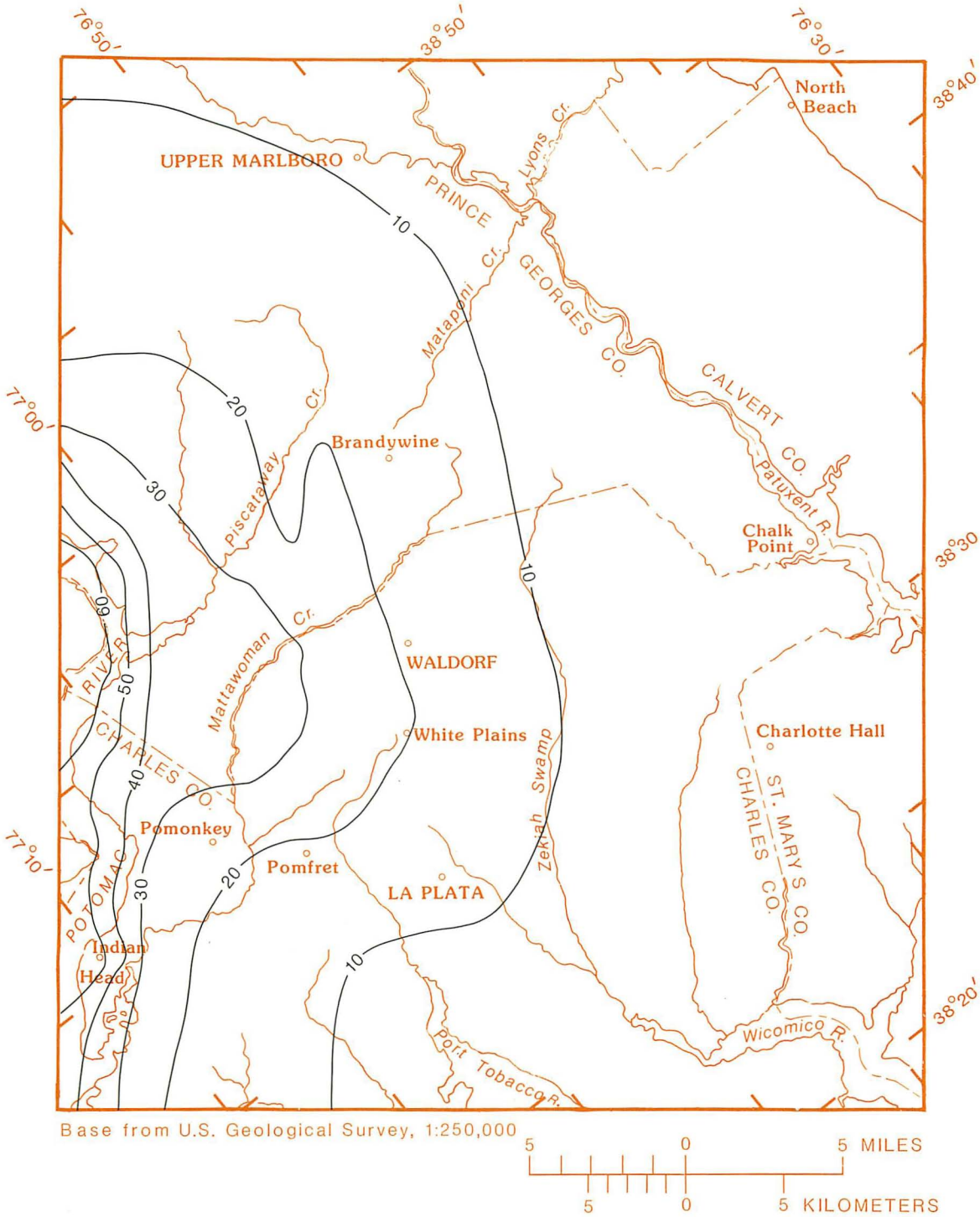
Figure 45.—Simulated heads in the La Plata aquifer system, for 2020, for scenario 1.



EXPLANATION

—30— Line of equal simulated drawdown, as a percent of total available drawdown. Interval is 10 percent.

Figure 46.—Percentage of available drawdown in the White Plains aquifer, for 2020, for scenario 1.



EXPLANATION

—30— Line of equal simulated drawdown, as a percent of total available drawdown. Interval is 10 percent.

Figure 47.—Percentage of available drawdown in the La Plata aquifer system, for 2020, for scenario 1.

Table 11.—Wells simulated for scenarios 1-4

[Mgal/d = million gallons per day; ft = feet]

Well number as shown in figures 43-45	Aquifer or aquifer system	Wells used in scenario: 1	2	3	4	Pumping rate (Mgal/d)	Head difference between cell and well 1/ (ft)
1	La Plata	x	x			0.65	60
2	La Plata	x	x			.58	70
3	La Plata	x	x	x		.86	40
4	La Plata	x	x	x		.72	60
5	White Plains	x	x			.36	110
6	White Plains	x				.58	120
7	La Plata	x		x		.58	60
8	La Plata	x				.86	40
9	White Plains	x				.65	80
10	White Plains	x				.29	90
11	Waldorf				x	.29	10
12	Waldorf				x	.29	10
13	Waldorf				x	.29	10

1/ Head difference between the simulated head for the cell and the calculated head in the hypothetical pumping well, rounded to the nearest 10 feet.

heads in the wells for the indicated pumping rates (table 11) are 230, 130, 200, 180, and 150 ft below sea level, respectively. For the four wells (5, 6, 9, and 10) simulated in the White Plains aquifer, the approximate heads in the wells for the indicated pumping rate are 360, 370, 230, and 340 ft below sea level, respectively.

Scenario 2

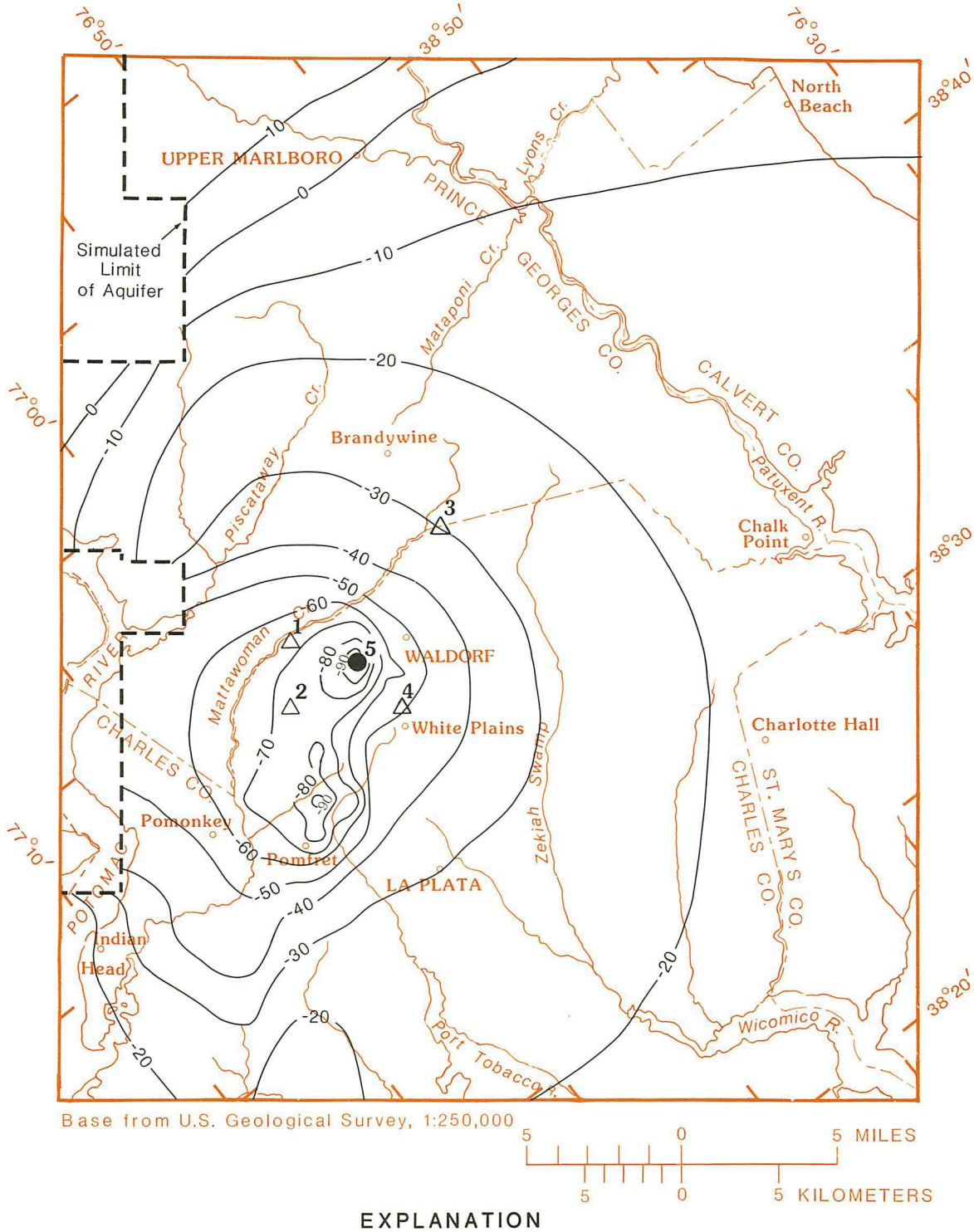
Scenario 2 was similar to scenario 1; however, only the first 5 of the original 10 hypothetical wells were simulated. An additional well was simulated every other year starting in 1988. As indicated in table 11, the wells simulated were wells 1-5. The simulated pumpage was about 2.8 Mgal/d and 0.36 Mgal/d in the La Plata aquifer system and White Plains aquifer, respectively. Figures 48 and 49 show the 2020 simulated head distributions for the White Plains aquifer and La Plata aquifer system.

The heads in the La Plata aquifer system (fig. 49) were lowered to as much as 140 ft below sea level. This is a head decline from the base simulation (fig. 39) of about 60 ft. As in scenario 1, the lowest heads are in the vicinity of well 2. Figure 48 indicates that the heads in the White Plains aquifer in the vicinity of well 5 are about 110 ft below sea level, which is a lowering of the heads from 1988 to 2020 of about 85 ft. Thus, as in scenario 1, the model results indicate that the potential for ground-water development of the La Plata aquifer system is considerably greater than for the White Plains aquifer.

Table 11 indicates the approximate difference between the head in a pumping well and the simulated head for the cell. For the simulated wells in the La Plata aquifer system, the heads in the wells are approximately 180, 210, 110, and 180 ft below sea level for wells 1, 2, 3, and 4, respectively. For simulated well 5 in the White Plains aquifer, the approximate head in the well is 230 ft below sea level.

Scenario 3

For scenario 3, pumpage was simulated from three wells (3, 4, and 7) in the La Plata aquifer system at locations that have existing wells pumping from the Waldorf aquifer system. The additional simulated pumpage in the La Plata aquifer system was 0.86, 0.72, and 0.58 Mgal/d from wells 3, 4, and 7, respectively, totaling 2.16 Mgal/d (table 11). No additional pumpage from the Waldorf aquifer system was simulated. However, at wells 3 and 7,



EXPLANATION

—30— Potentiometric contour of simulated heads. Contour interval is 10 feet. Datum is sea level.

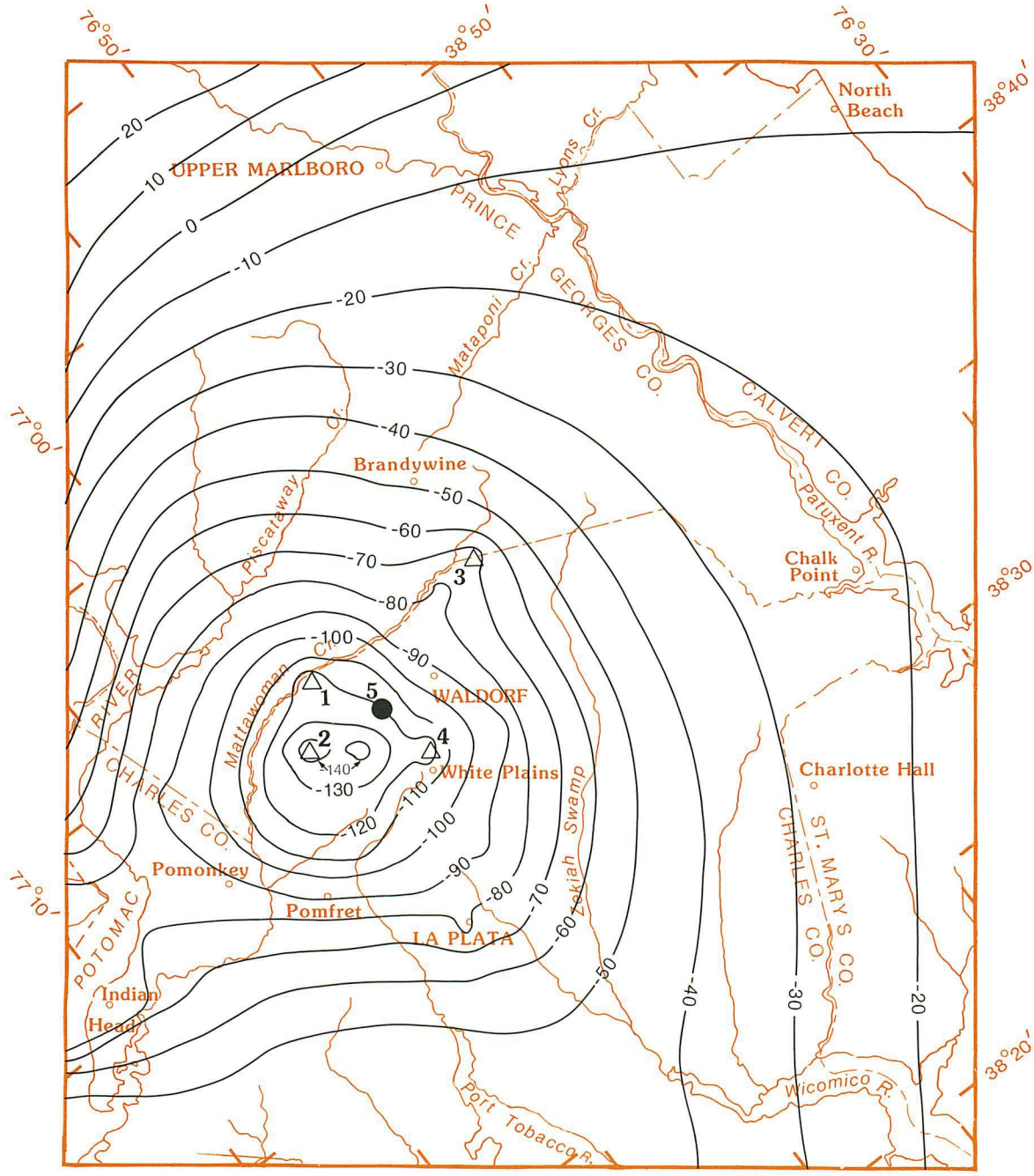
LOCATION OF HYPOTHETICAL WELLS IN THE:

● White Plains aquifer

△ La Plata aquifer system

5 Well number listed in table 11

Figure 48.—Simulated heads in the White Plains aquifer, for 2020, for scenario 2.



EXPLANATION

—— -30 —— Potentiometric contour of simulated heads. Contour interval is 10 feet. Datum is sea level.

LOCATION OF HYPOTHETICAL WELLS IN THE:

● White Plains aquifer

△ La Plata aquifer system

5 Well number listed in table 11

Figure 49.—Simulated heads in the La Plata aquifer system, for 2020, for scenario 2.

the existing 1985 pumpage from the Waldorf aquifer system was 0.62 and 0.31 Mgal/d, respectively; there was no pumping from the Waldorf aquifer system at well 4.

In the area of well 3, heads in both the Waldorf and La Plata aquifer systems were about 50 ft below sea level (figs. 50-51). This represents about an additional 20 ft of drawdown in the La Plata aquifer system and about 4 ft in the Waldorf aquifer system. In the area of well 4, drawdown in the La Plata aquifer system was an additional 40 ft, resulting in heads of about 90 ft below sea level (figs. 39 and 51). In the Waldorf aquifer system near well 4, the heads were lowered about 1 ft. In the vicinity of well 7, heads in the La Plata aquifer system at the end of the simulation were about 70 ft below sea level, which is an additional head decline of about 32 ft. The head change in the Waldorf aquifer system near well 7 was less than 1 ft.

The results of this scenario indicate that at these three pumping stations an additional 2.16 Mgal/d could be pumped from the La Plata aquifer system without excessive drawdowns in the La Plata aquifer system. In addition, the effects on the heads near production wells screened in the Waldorf aquifer system are negligible.

Heads for the simulated wells can be approximated by subtracting the head difference (table 11) from the simulated head shown in figure 51. The 2020 heads in wells 3, 4, and 7 are 90, 150, and 130 ft below sea level, respectively.

Scenario 4

This scenario simulates the addition of wells pumping from the Waldorf aquifer system to three sites where existing wells produce from the La Plata aquifer system. The La Plata aquifer system at Waldorf contains water that is very soft, and the Waldorf aquifer system generally contains moderately hard to hard water (app. G). The reason for adding wells screened in the Waldorf aquifer system to existing sites where wells pump from the La Plata aquifer system is to allow the hard and soft waters from the respective aquifer systems to be mixed before the water enters the town distribution system. Mixing of the hard and soft ground waters would reduce the likelihood of residents experiencing changes in the hardness of their tap water as production is rotated among well fields.

The locations of these hypothetical wells numbered 11, 12, and 13 (table 11) are shown in figure 52. Each well was pumped at 0.29 Mgal/d. Heads in the Waldorf aquifer system at the end of this simulation dropped to an altitude of 85 ft below sea level. Comparing figure 52 with figure 37 indicates that this is an additional 15-ft decline. Figure 53 shows that the available drawdown used is still less than 80 percent. Approximate heads in the wells (table 11) are about 10 ft lower than the simulated heads for the cells (fig. 52). Thus, model results indicate that wells yielding about 0.3 Mgal/d screened in the Waldorf aquifer system at these three sites would be feasible without adversely lowering the heads in the Waldorf aquifer system.

Scenario 5

Scenario 5 was the first of three scenarios to estimate the amount of ground water available in the Waldorf aquifer system, White Plains aquifer, and La Plata aquifer system. The criterion used to estimate the maximum amount available for each aquifer was the 80-percent available drawdown limit. As previously defined, 80 percent of the available drawdown is attained when drawdown in the aquifer is 80 percent of the difference between the prepumping heads and the top of the aquifer. In this study, that refers to the average drawdown for any of the model cells within the study area and not actual drawdowns in pumping wells.

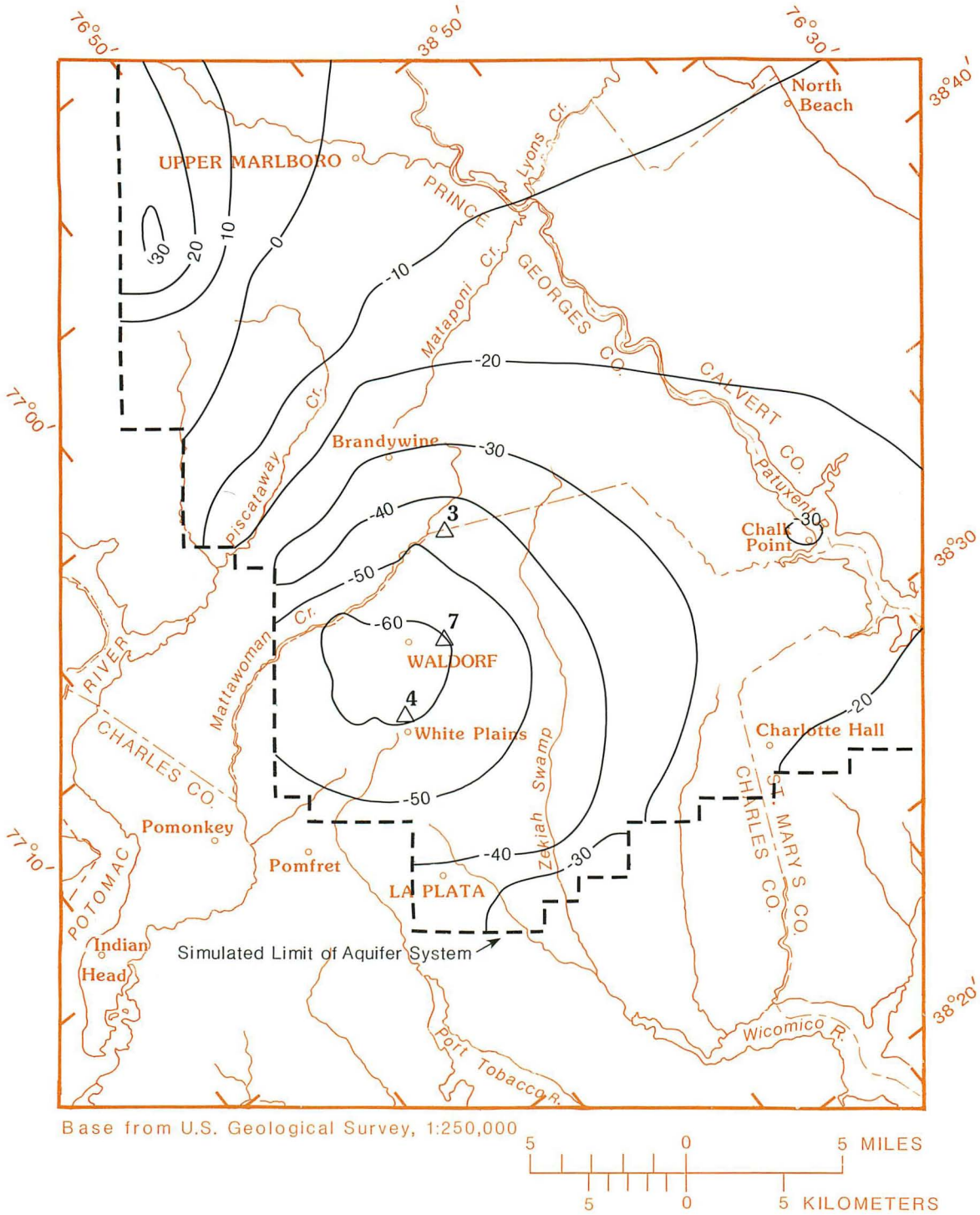
For scenarios 5-7, additional pumpage was entered into the model in an area within Charles County defined by a 5-mi radius around Waldorf. Generally, this additional pumpage was located to take advantage of higher transmissivities in the eastern portion of this area. Also, for each scenario, the pumpage of the other two scenarios was not entered into the model. Thus, simulating the total of the additional pumpage for all three scenarios simultaneously would result in greater drawdowns, probably exceeding the 80-percent available drawdown limit in all three aquifers.

For scenario 5, a number of model simulations were made to estimate the maximum amount of pumpage available without exceeding 80 percent of available drawdown within the study area. In 1985, the total pumpage from the Waldorf aquifer system equaled 3.1 Mgal/d (2.9 Mgal/d for public supply and 0.2 Mgal/d for other uses) (J.C. Wheeler, U.S. Geological Survey, written commun., 1986). This pumpage resulted in cell drawdowns that were about 55 percent of the total amount available. In scenario 5, an additional 2.5 Mgal/d of pumpage from the Waldorf aquifer system resulted in drawdown that reached the 80-percent limit (fig. 54) in a small area west of Waldorf. Thus, a total of about 5.6 Mgal/d within the Waldorf area would be, under this scenario, the maximum available from the Waldorf aquifer system.

The head distribution for the Waldorf aquifer system is shown in figure 55. Heads in cells near Waldorf are at an altitude of about 105 ft below sea level. However, if the pumpage is redistributed so that it is all located east of Waldorf, the maximum pumpage is as much as 6.6 Mgal/d (fig. 56). Figures 54 and 56 indicate two different cases for scenario 5, both of which result in meeting the 80-percent criterion.

In the first case, all the Charles County production wells screened in the Waldorf aquifer system that were in

(Text continued on p. 89.)



EXPLANATION

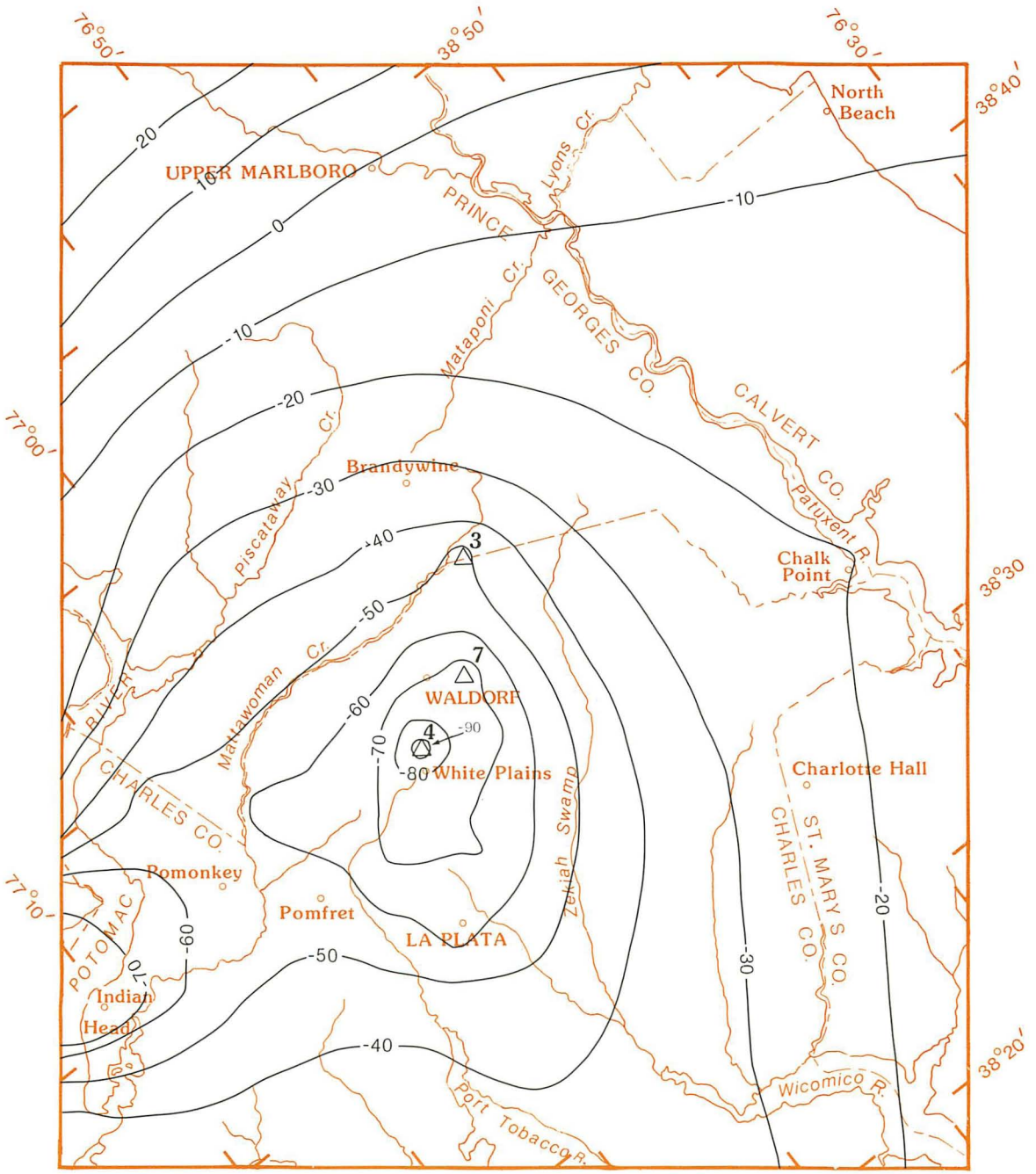
—30— Potentiometric contour of simulated heads. Contour interval is 10 feet. Datum is sea level.

LOCATION OF HYPOTHETICAL WELLS IN THE:

△ La Plata aquifer system

4 Well number listed in table 11

Figure 50.—Simulated heads in the Waldorf aquifer system, for 2020, for scenario 3.



EXPLANATION

—30— Potentiometric contour of simulated heads. Contour interval is 10 feet. Datum is sea level.

LOCATION OF HYPOTHETICAL WELLS IN THE:

△ La Plata aquifer system

4 Well number listed in table 11

Figure 51.—Simulated heads in the La Plata aquifer system, for 2020, for scenario 3.

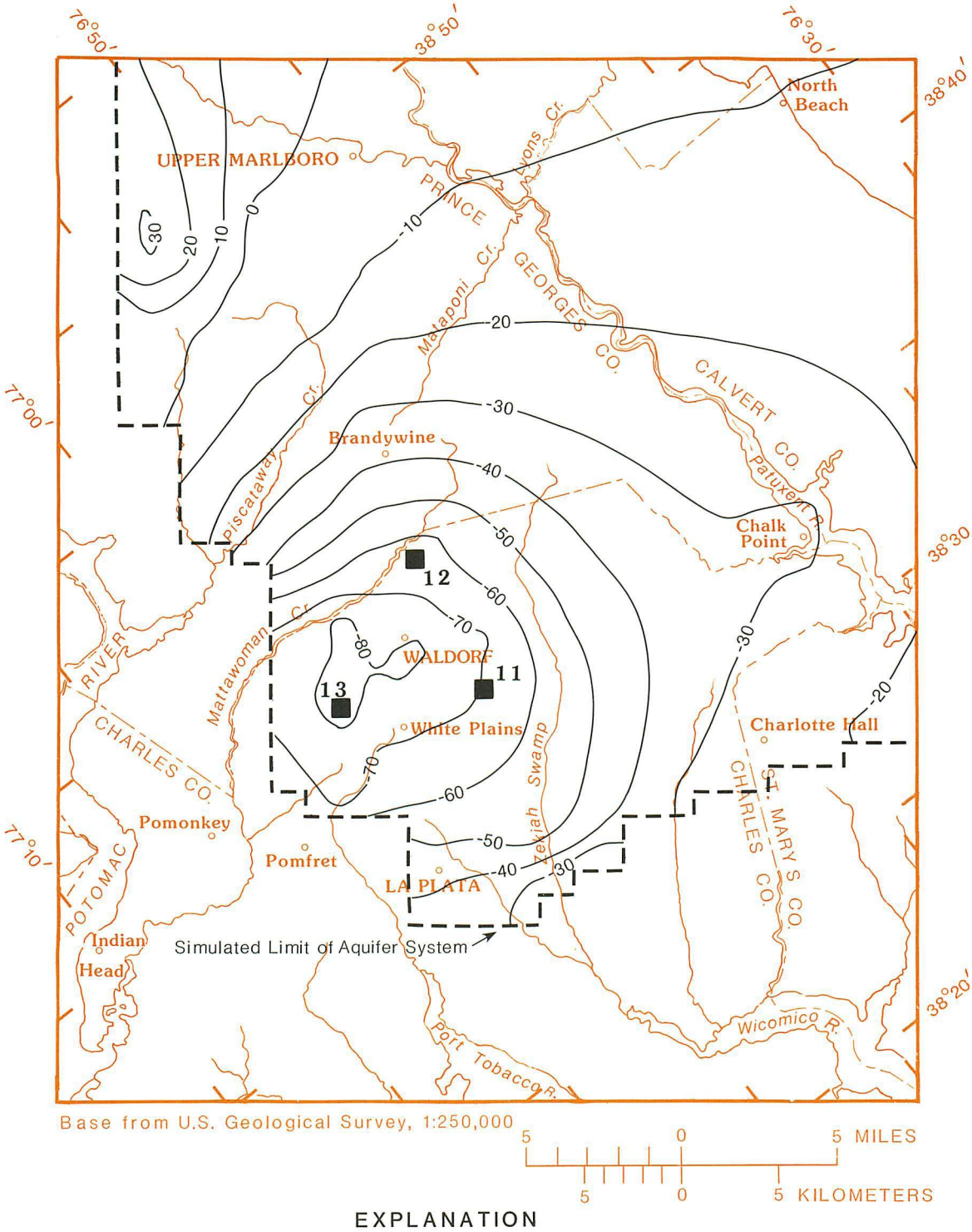
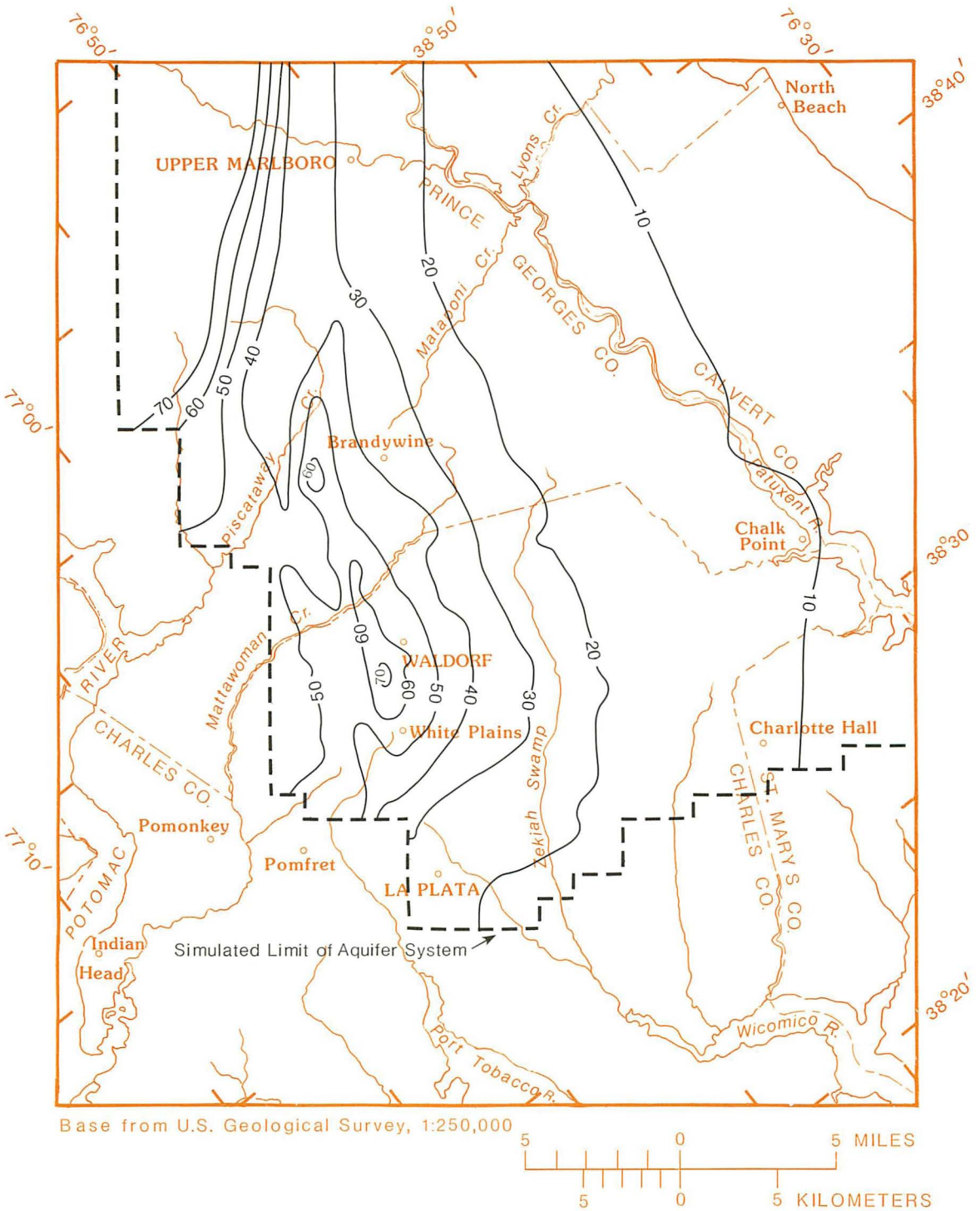


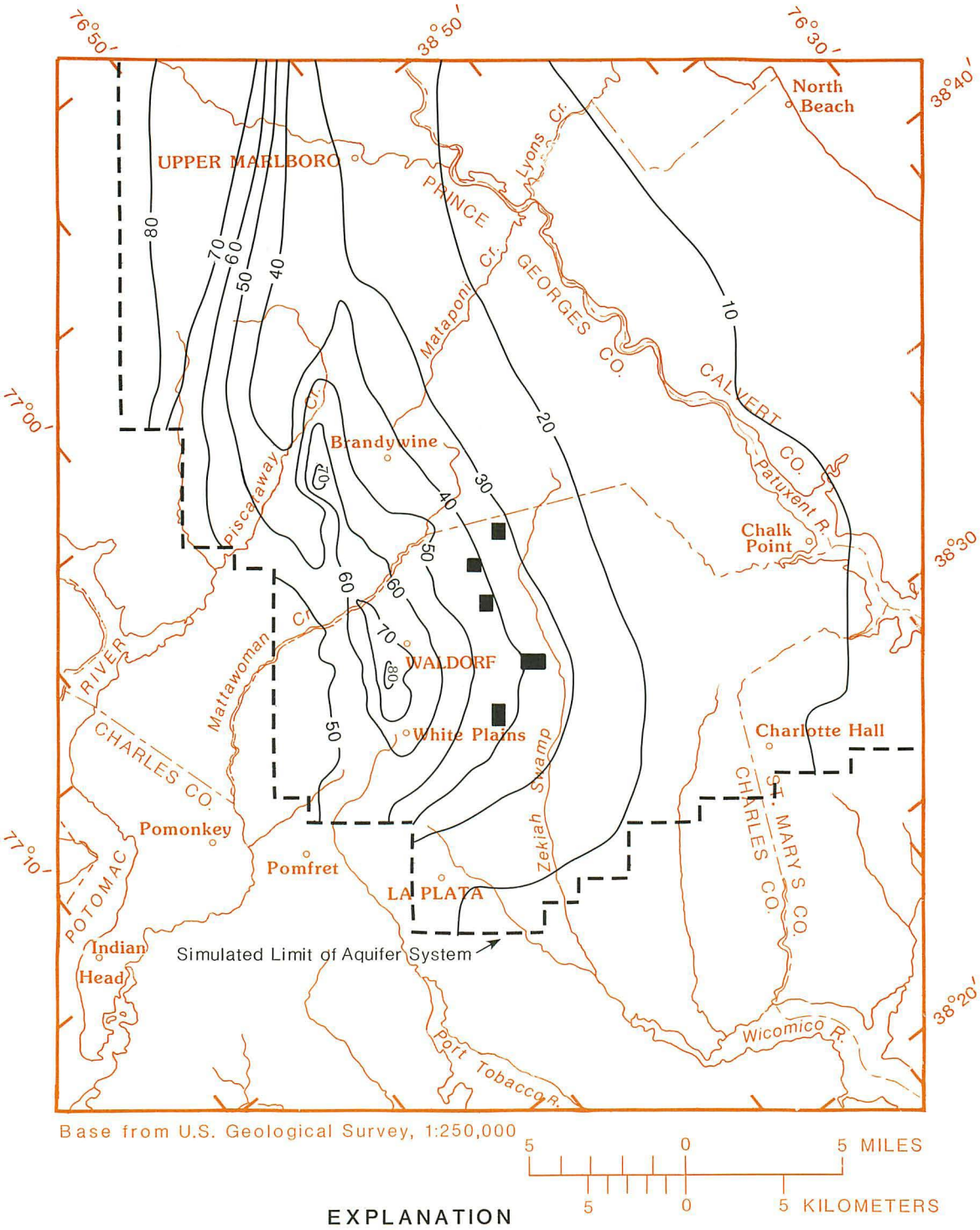
Figure 52.—Simulated heads in the Waldorf aquifer system, for 2020, for scenario 4.



EXPLANATION

—30— Line of equal simulated drawdown, as a percent of total available drawdown. Interval is 10 percent.

Figure 53.—Percentage of available drawdown in the Waldorf aquifer system, for 2020, for scenario 4.



Base from U.S. Geological Survey, 1:250,000

5 0 5 MILES

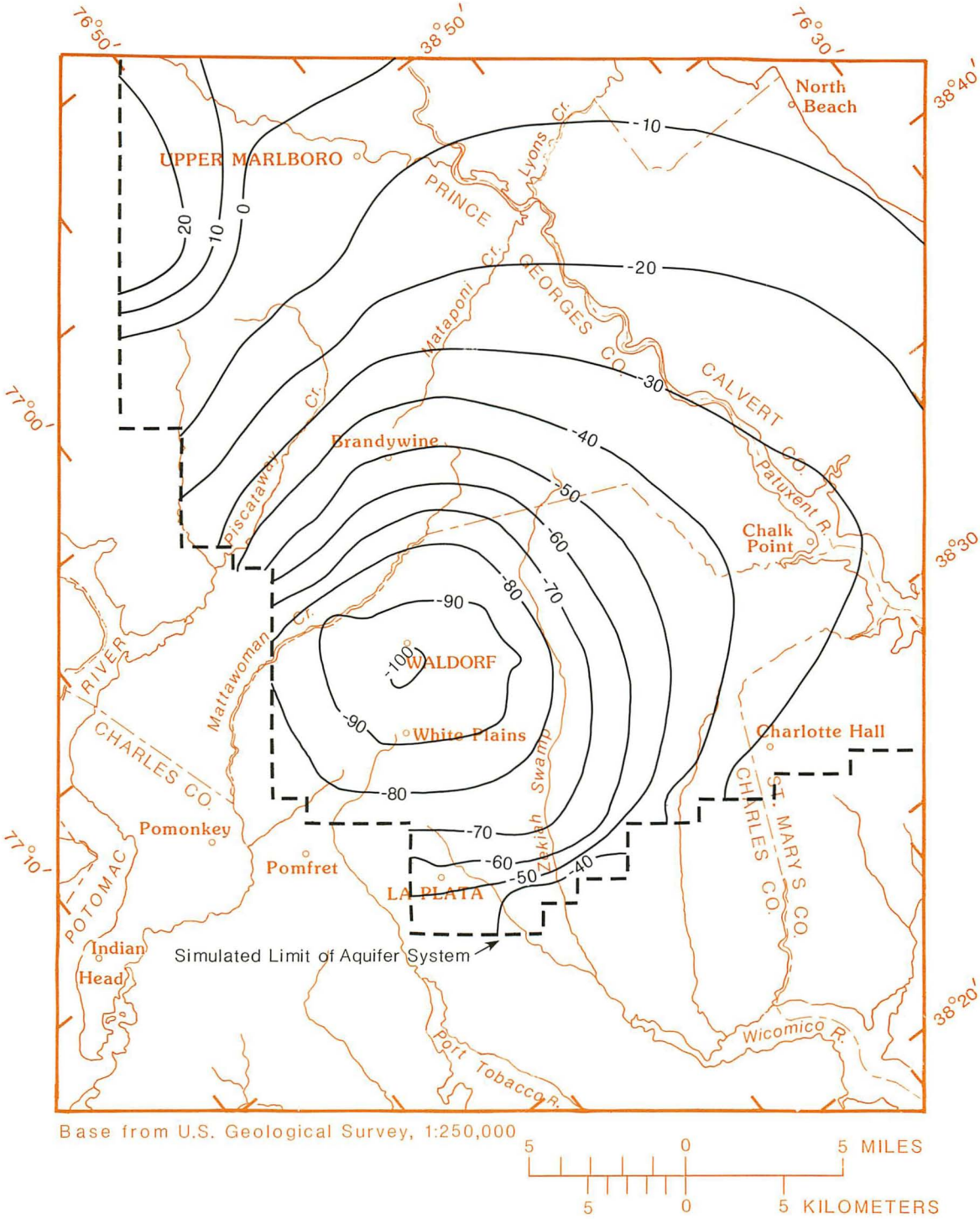
5 0 5 KILOMETERS

EXPLANATION

—30— Line of equal simulated drawdown, as a percent of total available drawdown. Interval is 10 percent.

Location of model cell with additional simulated pumpage.

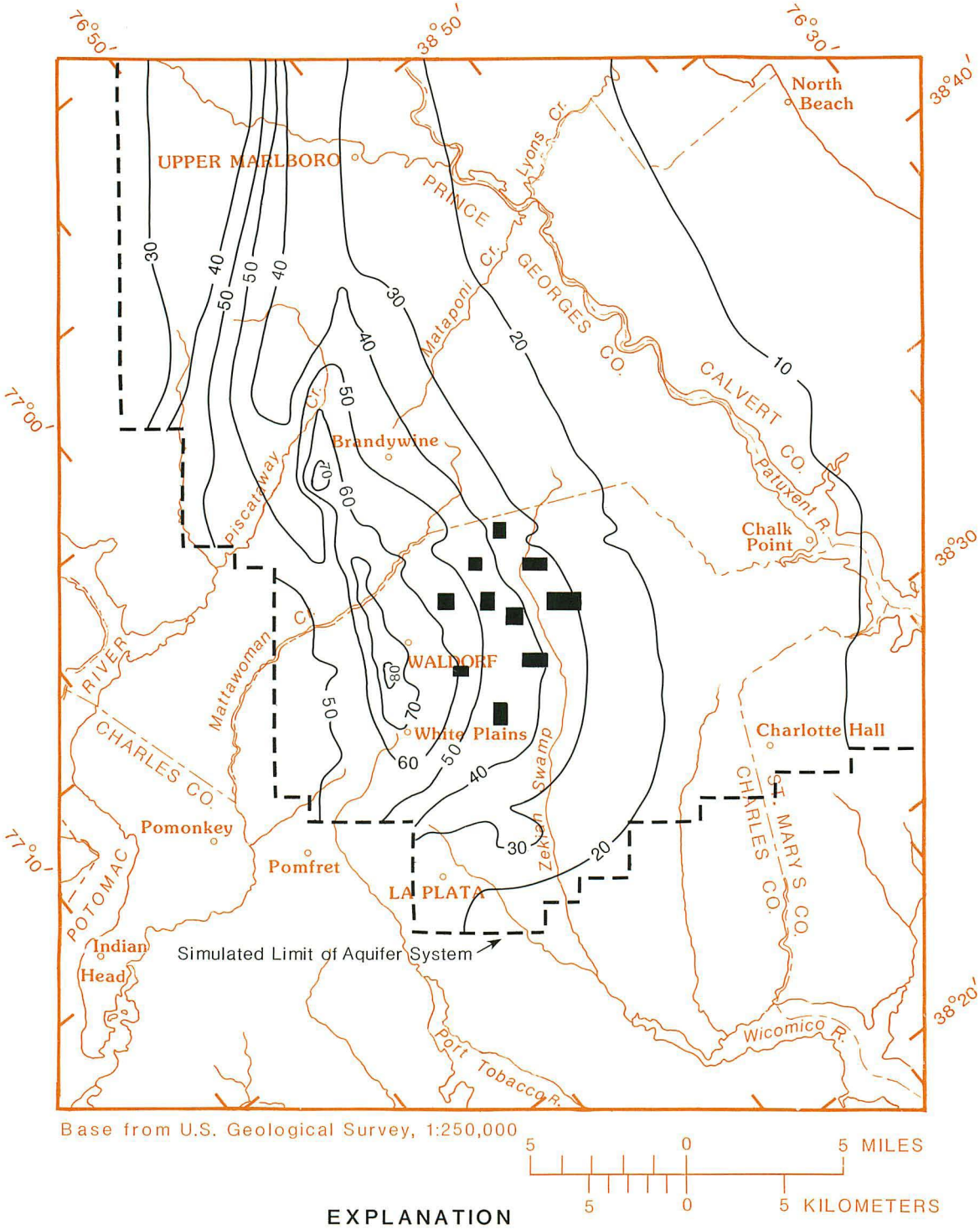
Figure 54.—Percentage of available drawdown in the Waldorf aquifer system, for 2020, for scenario 5 (case 1).



EXPLANATION

—30— Potentiometric contour of simulated heads. Contour interval is 10 feet. Datum is sea level.

Figure 55.—Simulated heads in the Waldorf aquifer system, for 2020, for scenario 5 (case 1).



EXPLANATION

—30— Line of equal simulated drawdown, as a percent of total available drawdown. Interval is 10 percent.

Location of model cell with additional simulated pumpage.

Figure 56.—Percentage of available drawdown in the Waldorf aquifer system, for 2020, for scenario 5 (case 2).

use in 1985 are simulated (table 12). Added to these seven production wells are five wells as shown in figure 54, each withdrawing 0.50 Mgal/d. The total withdrawals as simulated by the model are about 5.6 Mgal/d. In the second case, the simulated wells were located east of Waldorf to take advantage of higher transmissivities and greater available drawdowns. Thus, the Charles County production wells located west of Waldorf are not simulated (table 12), resulting in only four pumping wells. Ten new hypothetical wells are added to the simulation. These wells are all located east of Waldorf (fig. 56) and each is simulated to pump 0.47 Mgal/d. The total pumpage simulated for this case is about 6.6 Mgal/d.

Thus, by relocating the pumpage from three wells (1.3 Mgal/d) west of Waldorf to new locations east of Waldorf, the maximum available pumpage from the Waldorf aquifer, as simulated by the model, is increased by about 1 Mgal/d. This is a result of higher transmissivities and greater available drawdowns east of Waldorf.

The results of Mack and Mandle's (1977) model simulations suggest that the maximum available pumpage from the Magothy aquifer in northern Charles County is about 4.5 Mgal/d. This is less than the amount of pumpage simulated by the ground-water-flow model of this report. Mack and Mandle's (1977) model, however, simulated only the Magothy aquifer and not the entire Waldorf aquifer system. The maximum transmissivity of the Magothy aquifer in their model for the Waldorf area was between 2,000 and 3,000 ft^2/d. This is close to the maximum values used in the model of this report for the Magothy aquifer. However, the maximum transmissivity for the Waldorf aquifer system, as used in the model of this report, is about 11,000 ft^2/d.

Scenario 6

The ground-water-flow model also was used to estimate maximum withdrawals from the White Plains aquifer. To obtain this maximum, the model simulated 12 wells, each pumping at 0.50 Mgal/d. The total pumpage for the White Plains aquifer for scenario 6 was about 6.1 Mgal/d. This total pumpage included about 0.13 Mgal/d of pumpage for 1985 plus the 6.0 Mgal/d of the 12 wells added for scenario 6. These 12 wells were all located on the eastern side of the study area (fig. 57) in order to take advantage of the higher transmissivities and the slightly greater available drawdowns. Figure 57 indicates that the 80-percent limit was nearly reached in a small area in Prince Georges County just north of the Charles County line, 3 mi northeast of Waldorf. Figure 58 indicates that the lowest heads (located west of Waldorf) are about 320 ft below sea level. It would not be practical to set pumps at such depths, which means that the practical limit would be less than 6.1 Mgal/d. Also, the heads shown in figure 58 are average heads for a given cell. Actual drawdown at the well would be greater, reducing even further the practical limits of ground-water withdrawals from the White Plains aquifer.

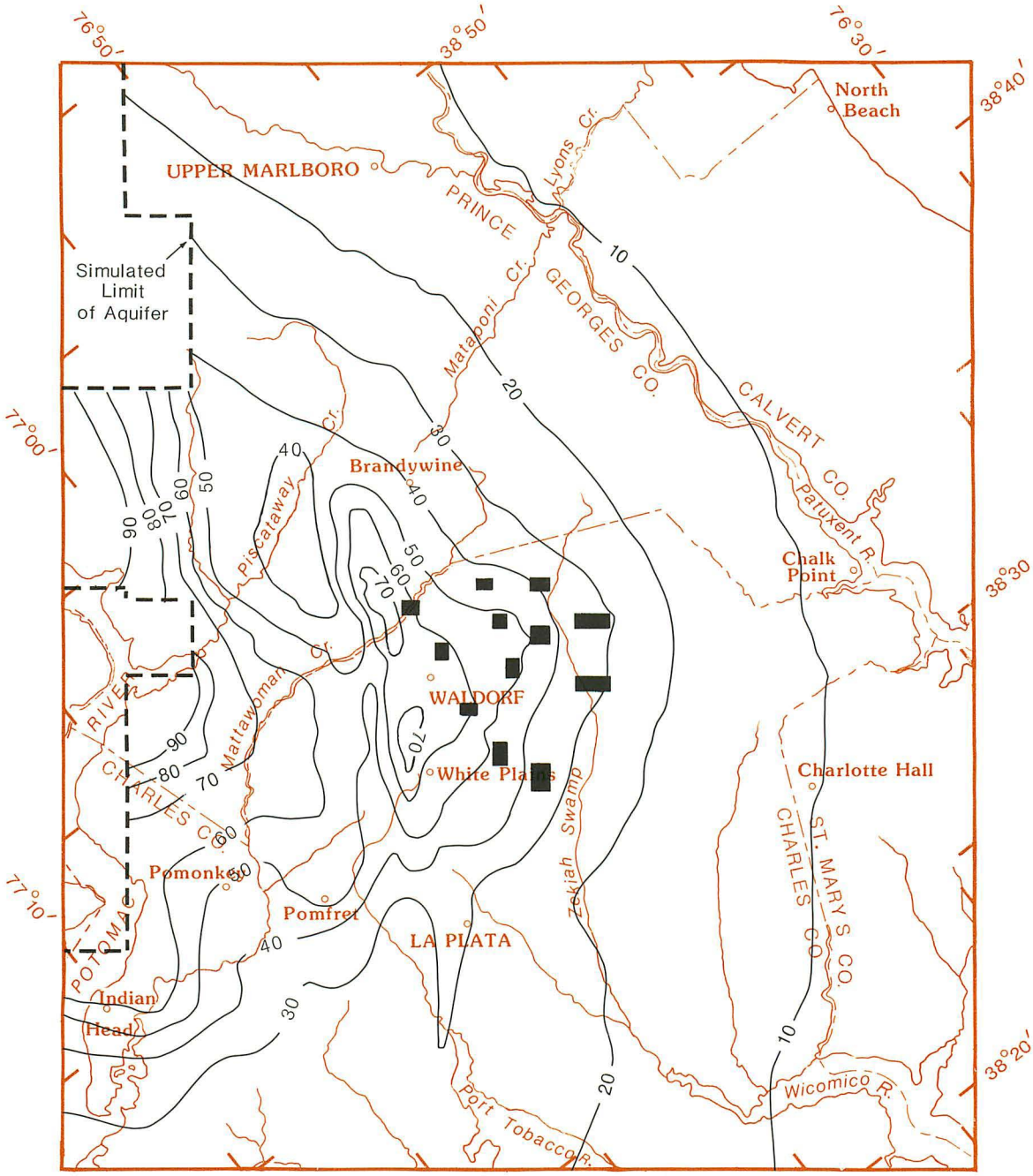
In order to obtain the theoretical limit of 6.1 Mgal/d, essentially all the simulated pumpage was located

(Text continued on p. 95.)

Table 12.—Location and magnitude of pumpage from Charles County production wells as simulated in scenario 5

[Mgal/d = million gallons per day]

Cells		Case		Pumping rate	Charles County well name	Well number
Row	Column	1	2	(Mgal/d)	(see appendix A)	
9	16	x	x	0.62	Pinefield	CH Bf 144
11	14	x	x	.13	Mattawoman- Beantown	CH Bf 132
17	9	x		.33	Westwood Dr.	CH Be 42
17	16	x	x	.31	John Hanson School	CH Bf 142
18	19	x	x	.60	Piney Church	CH Bf 145
19	14	x		.75	St. Charles	CH Bf 136
21	13	x		.19	Towne Plaza	CH Be 48

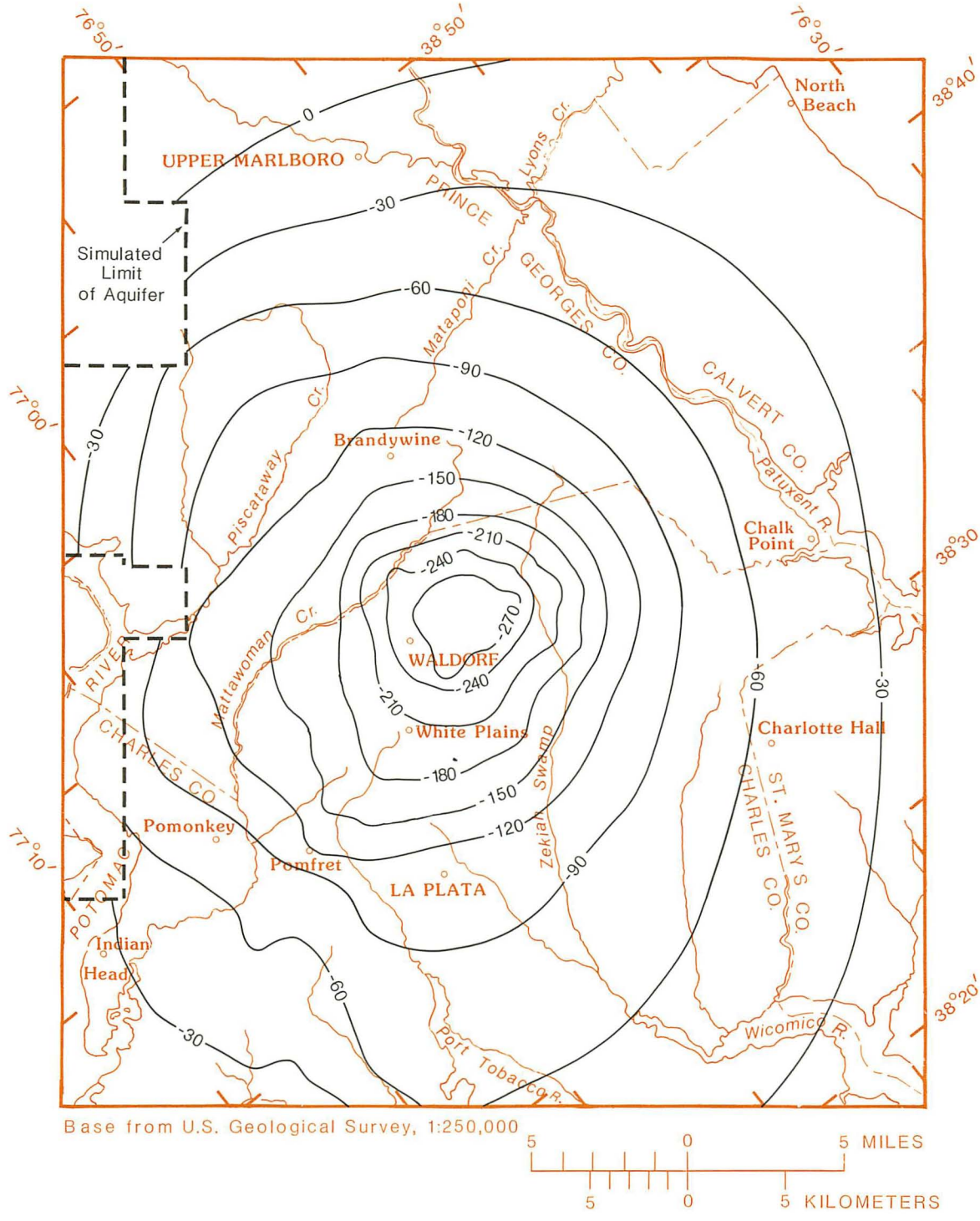


EXPLANATION

30 — Line of equal simulated drawdown, as a percent of total available drawdown. Interval is 10 percent.

Location of model cell with additional simulated pumpage.

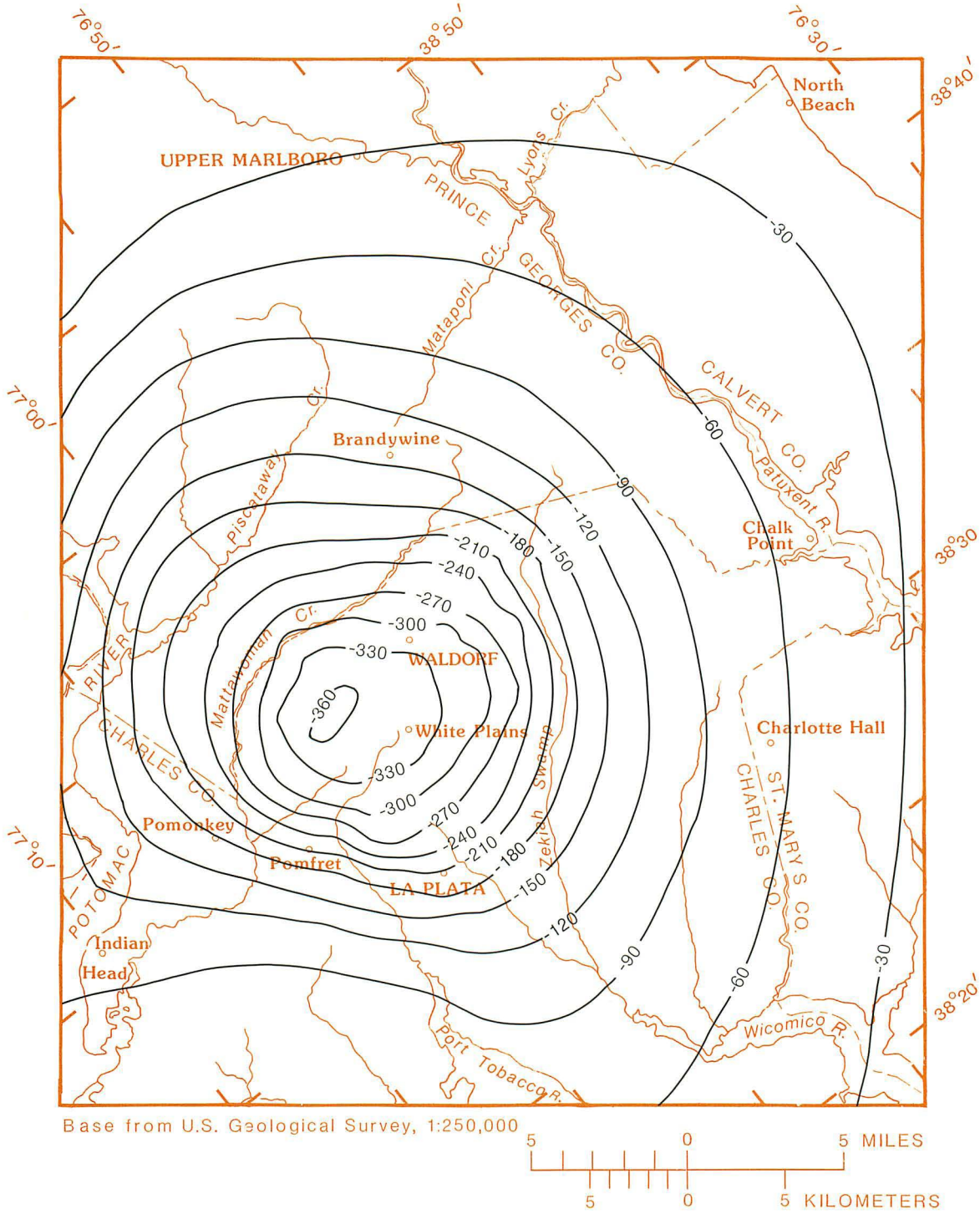
Figure 57.—Percentage of available drawdown in the White Plains aquifer, for 2020, for scenario 6.



EXPLANATION

—— -90 —— Potentiometric contour of simulated heads. Contour interval is 30 feet. Datum is sea level.

Figure 58.—Simulated heads in the White Plains aquifer, for 2020, for scenario 6.



Base from U.S. Geological Survey, 1:250,000

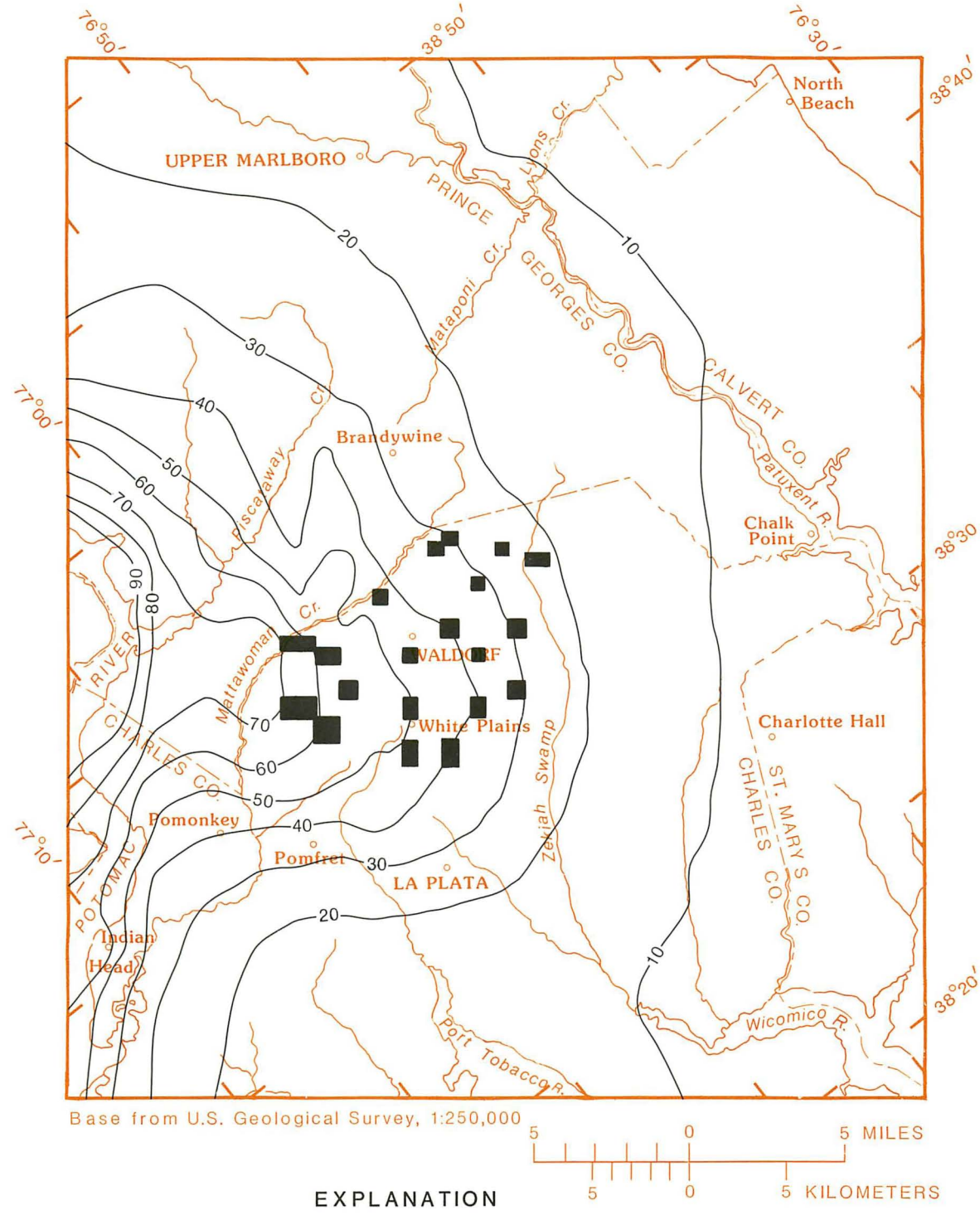
5 0 5 MILES

5 0 5 KILOMETERS

EXPLANATION

—— -90 —— Potentiometric contour of simulated heads. Contour interval is 30 feet. Datum is sea level.

Figure 59.—Simulated heads in the La Plata aquifer system, for 2020, for scenario 7 (15.2 Mgal/d).

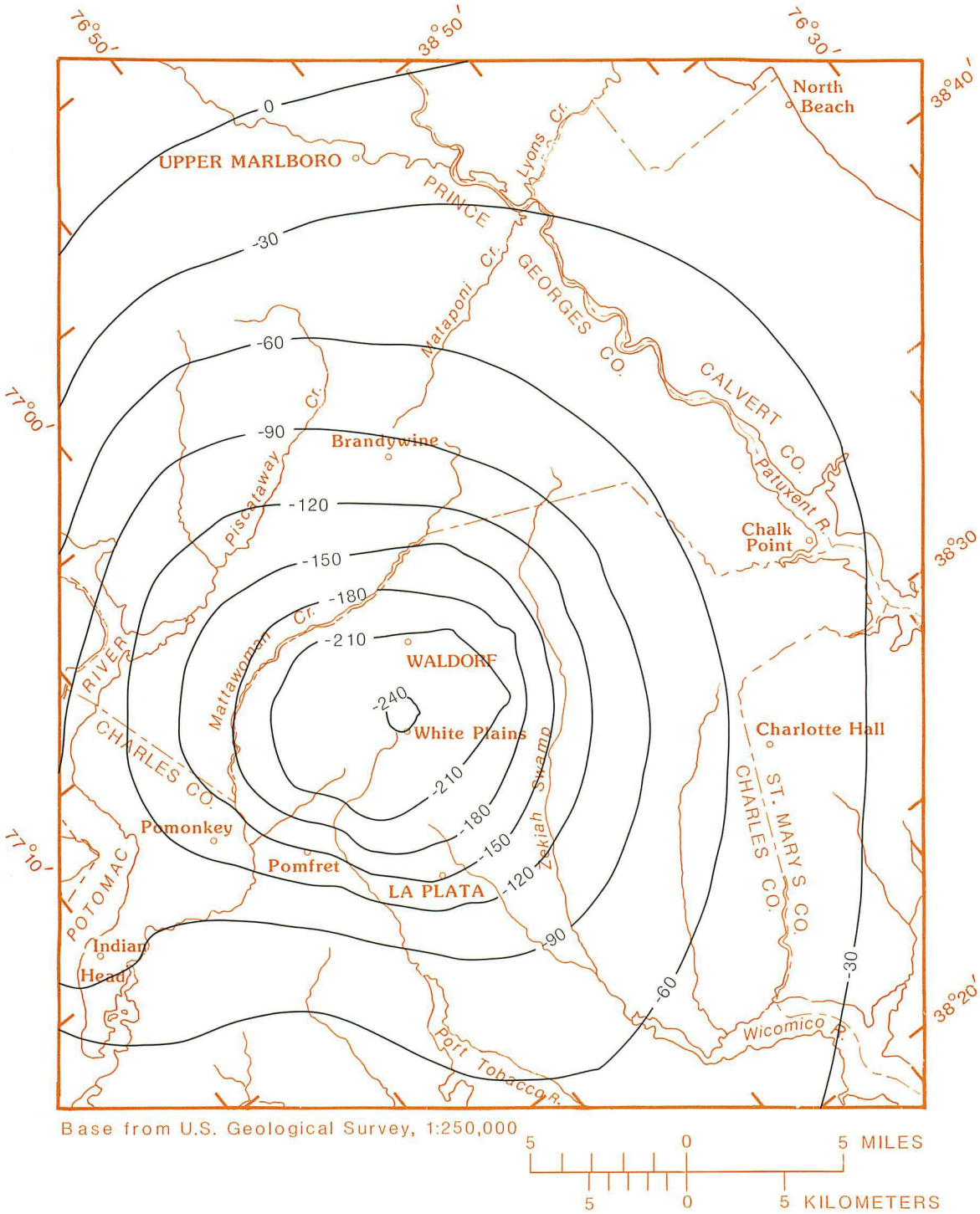


EXPLANATION

—30— Line of equal simulated drawdown, as a percent of total available drawdown. Interval is 10 percent.

Location of model cell with additional simulated pumpage.

Figure 60.—Percentage of available drawdown in the La Plata aquifer system, for 2020, for scenario 7 (15.2 Mgal/d).



EXPLANATION

—— -90 —— Potentiometric contour of simulated heads. Contour interval is 30 feet. Datum is sea level.

Figure 61.—Simulated heads in the La Plata aquifer system, for 2020, for scenario 7 (10.2 Mgal/d).

in the eastern part of the Waldorf area. In scenario 2, simulated pumpage of 1.9 Mgal/d from the White Plains aquifer resulted in drawdowns at the 80-percent limit. This simulated pumpage was located in the western part of the Waldorf area. Thus, by locating additional pumping wells in the more transmissive eastern part of the aquifer, about 3 times as much ground water could be pumped and still meet the 80-percent drawdown constraint.

Scenario 7

Pumpage in the Waldorf area for scenario 7 (figs. 59-61) from the La Plata aquifer system for 1985 was about 0.18 Mgal/d. The model was used to simulate an additional 0.75 Mgal/d at each of 20 locations as shown in figure 60. This total simulated pumpage of about 15.2 Mgal/d resulted in heads as low as 360 ft below sea level. Figure 60 indicates that in the western part of the Waldorf area, heads have been lowered to about 75 percent of the available drawdown. Thus, this scenario indicates that the theoretical maximum available from the La Plata aquifer system is about 15 Mgal/d. The heads shown in figure 59 are model-generated average heads for any given cell. Heads at a production well at these pumping rates would be much lower. Pumping the same 20 wells at about 67 percent of the rate used in this scenario would raise heads in the study area about 80 ft (fig. 61).

SUMMARY AND CONCLUSIONS

A ground-water-flow model was constructed to assess the water-supply potential of the aquifers underlying the Waldorf area of north-central Charles County. The total modeled area was about 1,650 mi^2 and was divided by a finite-difference grid consisting of 38 rows and 29 columns. Seven layers were simulated representing the surficial, Aquia, Monmouth, Magothy, St. Charles, and White Plains aquifers, and the La Plata aquifer system. Cells differed in size from 0.12 to 12 mi^2. Model boundaries included the surficial aquifer specified as a constant-head boundary, constant-head boundaries on three sides of the confined aquifers that were held constant for each stress period, and no-flow boundaries specified where aquifers pinch out or are truncated.

The sensitivity of the model results to six different inputs indicated that changing leakances, decreasing transmissivities, and increasing pumpage by an order of magnitude resulted in average head changes of greater than 10 ft. The model was less sensitive to changes in storage coefficients, increasing transmissivities, decreasing pumpage, and changes in the constant heads.

The ground-water-flow model was calibrated under transient conditions for the period 1900 to 1985. The model was divided into 22 stress periods. Each stress period from 1970 to 1985 consisted of 1 year. The model was considered calibrated when the simulated heads approximated observed heads for about 130 observation wells. Pumpage withdrawal rates increased from about 0.02 Mgal/d for 1900-19 to 15.6 Mgal/d for 1985. The maximum pumpage for any aquifer was about 6.5 Mgal/d from the Magothy aquifer. To calibrate the model, adjustments principally were made to transmissivity and leakance values. Maximum modeled transmissivities for the aquifers were 3,500 ft^2/d for the Aquia, 5,625 ft^2/d for the Monmouth, 12,000 ft^2/d for the Magothy, 5,000 ft^2/d for the St. Charles, 5,200 ft^2/d for the White Plains, and 8,750 ft^2/d for the La Plata aquifer system.

Water-budget analysis for the model indicated that for 1985, about 39.7 Mgal/d of water leaked downward into the confined aquifers from the surficial aquifer, and about 40.8 Mgal/d entered as lateral flow at the model boundary. Natural discharge from the confined aquifers to the surficial aquifer was 10.4 Mgal/d, pumpage was 15.6 Mgal/d, and lateral flow from the modeled area was 56.3 Mgal/d.

The ground-water-flow model was used to make simulations of seven pumpage scenarios. In the first scenario, 10 new wells were added, one each year from 1988 to 1997. Pumpage from these 10 wells was about 4.2 Mgal/d from the La Plata aquifer system and 1.9 Mgal/d from the White Plains aquifer. The result was a maximum lowering of heads during the simulated period of 95 and 225 ft in the La Plata aquifer system and White Plains aquifer, respectively. This drawdown amounted to maximums of about 20 and 90 percent of available drawdown in the Waldorf area. A second scenario added five wells during the years 1988 to 1997 at pumping rates of 2.8 and 0.36 Mgal/d for the La Plata aquifer system and White Plains aquifer, respectively, resulting in a maximum lowering of heads during the simulation period of 60 and 85 ft for the La Plata aquifer system and the White Plains aquifer, respectively.

A third scenario simulated three wells pumping from the La Plata aquifer system at a total rate of about 2.2 Mgal/d; each of the three pumping wells was located at the site of an existing production well screened in the Waldorf aquifer system. Heads in the La Plata aquifer system declined about 20 ft during the simulation. However,

heads in the Waldorf aquifer system declined 4 ft or less. A fourth scenario simulated three wells in the Waldorf aquifer system at sites where production wells exist in the La Plata aquifer system. The total pumping rate of the three wells was 0.87 Mgal/d, which resulted in an additional 15 ft of drawdown; however, this was still less than 80 percent of the available drawdown.

Estimates were made of the quantity of ground water available from the Waldorf aquifer system, White Plains aquifer, and La Plata aquifer system. The assumption was made that the maximum amount of available ground water is obtained when drawdowns in the aquifers are 80 percent of the available drawdown within the study area. When the aquifers and aquifer systems were pumped one at a time, the estimated maximum pumping rates were about 6.6, 6.1, and 15.2 Mgal/d for the Waldorf aquifer system, White Plains aquifer, and La Plata aquifer system, respectively. Pumping at these rates in all three aquifers and aquifer systems at the same time would cause the 80-percent available drawdown to be exceeded. Calculations of drawdowns in the hypothetical wells indicated that the practical pump-intake depth and not the 80-percent available drawdown may sometimes be the limiting factor in production.

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APPENDIXES

Appendix A.—Records of selected wells and test holes in Charles County, Maryland

This table lists records of wells and test holes located within Charles County that are mentioned in this report. Wells and test holes that lie within a radius of about 10 mi of Waldorf are located on plate 8. Wells that fall outside this 10-mi radius are located in figure 4. Basic geohydrologic data for wells and test holes outside of Charles County are found in the following sources: Lucas, 1976, for Anne Arundel County; Tompkins, 1983, for Prince Georges County; Drummond, 1984 for Calvert and St. Marys Counties. Additional well data regarding Charles County are found in Slaughter and Laughlin, 1966. Reevaluation of the stratigraphy and geohydrology of Charles County by Hansen, 1968, Wilson, 1986, and this report has resulted in revision of several of the aquifer designations used by Slaughter and Laughlin, 1966.

Well number	State permit number	Owner	Driller	Date completed	Elevation (ft above sea level)	Depth of hole (ft below land surface)	Screen intervals (ft below land surface)
CH Bb 10	--	U.S. NAVY	--	1920	26	1200	--
CH Bc 17	CH 11905	U.S. NAVY	WASH. PUMP & WELL	1952	73.4	450	345-361
CH Bc 61	CH 56515	POTOMAC HEIGHTS MUTUAL INC.	LAYNE-ATLANTIC	1964	70	875	439-444
CH Bd 33	CH 66-0079	POTOMAC UTILITIES	LAYNE-ATLANTIC	1966	180	654	536-556 561-586
CH Bd 46	CH 81-1714	CHAS. COUNTY D.P.W.	SYDNOR HYDRO.	1986	180	859	700-730, 805-820
CH Be 25	--	B.F. RICHARDSON	--	--	210	21	OPEN HOLE
CH Be 40	CH 42573	CHAS. COUNTY D.P.W.	SYDNOR HYDRO.	1961	209	453	350-370, 388-428
CH Be 41	CH 70-0068	CHAS. COUNTY D.P.W.	SYDNOR HYDRO.	1970	205	580	416-460, 516-556
CH Be 42	CH 73-0216	CHAS. COUNTY D.P.W.	LAYNE-ATLANTIC	1974	219	587	426-476, 527-567
CH Be 43	CH 71-0066	CHAS. COUNTY D.P.W.	PATUX. PUMP & WELL	1971	217.4	459	433-459
CH Be 48	CH 81-0135	CHAS. COUNTY D.P.W.	C.Z. ENTERPRISES	1982	207	900	375-430, 450-515, 552-596
CH Be 54	CH 81-0118	MCCLOY	EAST COAST	1982	200	478	--
CH Be 57	CH 81-1194	CHAS. COUNTY D.P.W.	LAYNE-ATLANTIC	1985	210	1802	1666-1696
CH Be 58	--	CHAS. COUNTY D.P.W.	LAYNE-ATLANTIC	1985	210	1170	925-964, 1048-1160
CH Be 59	CH 81-1468	U.S. GEOL. SURVEY	EAST COAST	1985	210	697	--
CH Be 60	CH 81-1468	U.S. GEOL. SURVEY	EAST COAST	1986	210	659	610-625
CH Be 61	CH 81-2310	CHAS. COUNTY D.P.W.	SYDNOR HYDRO.	1987	213	701	419-434, 446-466, 535-560
CH Bf 15	CH 791	L.L. PARLETT	WASH. PUMP. & WELL	1946	215	392	380-391
CH Bf 97	CH 29945	WALDORF DRIVE IN	SYDNOR HYDRO.	1958	220	602	370-378, 430-435, 457-465, 470-482
CH Bf 101	CH 11882	M. WASHINGTON MOTEL	SYDNOR HYDRO.	1953	219.5	477	423-438, 449-475
CH Bf 113	--	GEORGE M. MCSWEENEY	--	--	200	35	OPEN HOLE
CH Bf 127	CH 42572	CHAS. COUNTY D.P.W.	SYDNOR HYDRO.	1961	213	602	452-485, 490-517
CH Bf 128	CH 31306	SOUTHERN MD. NOVELTY	PATUX. PUMP & WELL	1958	218	430	420-430
CH Bf 131	CH 65-0052	CHAS. COUNTY D.P.W.	LAYNE-ATLANTIC	1965	225	930	--
CH Bf 132	CH 68-0017	BELLEWOOD SUBDIVISION	PATUX. PUMP & WELL	1967	200	600	580-600

Screen diameter (inches)	Water level: Static (ft below land surface)	Water level: Date measured	Yield (gal/min)	Draw-down (ft)	Specific capacity [(gal/min)/ft)]	Use of well	Aquifers screened or aquifer system	Remarks	Well number
--	--	--	--	--	--	T	--	BASEMENT WELL	CH Bb 10
7.5	158.6	05/61	--	--	--	A	LA PLATA	CALIBRATION WELL	CH Bc 17
2	122	04/64	6	--	--	T	PATUXENT	TEST HOLE	CH Bc 61
10	194	08/66	400	56	7.2	P	LA PLATA		CH Bd 33
4	233.5	06/86	90	54.5	1.7	P	LA PLATA	EUTAW FOREST	CH Bd 46
--	9.7	11/60	--	--	--	U	SURFICIAL		CH Be 25
8	149	06/20/61	434	64	6.8	P	MONMOUTH MAGOTHY	SOUTH WELL	CH Be 40
4	180	06/08/70	201	25	8.0	T	MAGOTHY ST. CHARLES	WESTWOOD DRIVE TEST WELL	CH Be 41
8	202	03/07/74	500	117	4.3	O	MAGOTHY ST. CHARLES	WESTWOOD DRIVE PRODUCTION WELL	CH Be 42
5	180	04/08/71	75	65	1.2	O	MAGOTHY	SUN VALLEY CALIBRATION WELL	CH-BE 43
12	239.4	07/22/82	503	64	7.9	P	MAGOTHY ST. CHARLES WHITE PLAINS	TOWNE PLAZA	CH Be 48
--	--	--	--	--	--	D	--		CH Be 54
4	199.4	06/12/85	36	86	0.4	T,O	PATUXENT	SMALLWOOD DRIVE	CH Be 57
8	236.6	08/29/85	550	113.7	4.8	P	LA PLATA	SMALLWOOD DRIVE	CH Be 58
--	--	--	--	--	--	A	--	SMALLWOOD DRIVE	CH Be 59
4	231.9	04/23/86	27	144	0.2	T,O	WHITE PLAINS	SMALLWOOD DRIVE CALIBRATION WELL	CH Be 60
8	254.0	08/12/87	690	85.5	8.1	P	MAGOTHY ST. CHARLES	WESTWOOD DRIVE PRODUCTION WELL	CH Be 61
6	160	09/46	50	27	1.9	U	MONMOUTH		CH Bf 15
8	170.5	04/23/58	220	84	2.6	U	AQUIA MONMOUTH MAGOTHY		CH Bf 97
6	172	03/53	94	78	1.2	O	MONMOUTH? MAGOTHY		CH Bf 101
--	29.3	11/15/60	--	--	--	A	SURFICIAL		CH Bf 113
8	168	05/25/61	453	35	12.9	P	MAGOTHY	MATTAWOMAN-BEANTOWN WELL	CH Bf 127
2.5	170	07/58	25	35	0.7	O	MAGOTHY		CH Bf 128
--	-	-	-	-	-	T	--	SITE OF CH Bf 133 AND CH Bf 136	CH BF 131
4.5	185	11/06/67	35	115	0.3	O,P	MAGOTHY	CALIBRATION WELL	CH Bf 132

ABBREVIATIONS

AQUIFERS: UPA = Upper Patapsco Formation aquifer unspecified.
USE OF WELL: A = abandoned; C = commercial; D = domestic; I = Institutional; O = observation; P = production; T = test; U = unused.

Appendix A.—Continued

Well number	State permit number	Owner	Driller	Date completed	Elevation (ft above sea level)	Depth of hole (ft below land surface)	Screen intervals (ft below land surface)
CH Bf 133	CH 70-0069	CHAS. COUNTY D.P.W.	SYDNOR HYDRO.	1970	224	523	436-506
CH Bf 134	CH 70-0067	CHAS. COUNTY D.P.W.	SYDNOR HYDRO.	1970	203	564	402-422, 485-546
CH Bf 135	CH 73-0182	MD FISHERIES ADM.	LAYNE-ATLANTIC	1973	208	667	572-588, 612-618
CH Bf 136	CH 70-0087	CHAS. COUNTY D.P.W.	SYDNOR HYDRO.	1970	224	506	436-506
CH Bf 137	CH 73-0794	MD FISHERIES ADM.	C.Z. ENTERPRISES	1975	203	662	--
CH Bf 141	CH 73-0794	MD. FISHERIES ADM.	C.Z. ENTERPRISES	1976	202	638	555-575, 600-630
CH Bf 142	CH 73-1750	CHAS. COUNTY D.P.W.	SYDNOR HYDRO.	1978	203	570	382-402, 464-524
CH Bf 143	CH 73-1828	U.S. NAVY	SHANNAHAN ARTESIAN	1978	208	479	469-479
CH Bf 144	CH 73-2423	CHAS. COUNTY D.P.W.	LAYNE-ATLANTIC	1979	210	1967	479.5-580.8, 599.8-620 659.5-700
CH Bf 145	CH 73-2889	CHAS. COUNTY D.P.W.	SYDNOR HYDRO	1981	195	750	442-487, 497-512, 522-592
CH Bf 146	CH 81-0593	CHAS. COUNTY D.P.W.	SYDNOR HYDRO.	1983	192	1650	1059-1069, 1073-1083 1161-1166, 1170-1180 1184-1189, 1195-1205 1244-1249, 1252-1262 1298-1328, 1342-1417
CH Bf 147	CH 81-0593	CHAS. COUNTY D.P.W.	SYDNOR HYDRO.	1984	195	1440	SCREENS ARE SET ONE FOOT HIGHER THAN IN CH Bf 146.
CH Bf 148	NONE	MD. GEOL. SURVEY	U.S. GEOL. SURVEY	1984	210	480	NONE
CH Bf 149	NONE	MD. GEOL. SURVEY	U.S. GEOL. SURVEY	1985	210	616	NONE
CH Bf 150	CH 81-1195	CHAS. COUNTY D.P.W.	SYDNOR HYDRO.	1985	215	1352	890-898, 938-970, 1154-1176, 1204-1240 1276-1285, 1306-1336
CH Bf 151	CH 81-1265	U.S. GEOL. SURVEY	EAST COAST	1985	195	680	645-660
CH Bf 157	CH 81-1846	U.S. GEOL. SURVEY	W.C. SERVICES	1986	225	640	608-623
CH Bf 158	CH 81-1847	U.S. GEOL. SURVEY	W.C. SERVICES	1986	203	802	630-645
CH Bg 10	CH 17619	BOARD OF EDUCATION	SHANNAHAN ARTESIAN	1955	197	620	591-599, 603-610
CH Bg 11	CH 73-1818	GALLANT GREEN STORE	FRANKS WELL DRILLING	1978	197	440	430-440
CH Cb 8	CH 11932	U.S. NAVY	SHANNAHAN ARTESIAN	1953	38	619	85-93, 123.5-133, 221-229, 232-234
CH Cd 9	CH 9771	BOARD OF EDUCATION	WASH. PUMP. & WELL	1952	149	423	416-423
CH Cd 12	CH 10168	JOHN H. MITCHELL	J.W. WILSON	1952	64	420	240-260, 400-420
CH Cd 18	CH 32029	G.E. HYATT JR.	PATUX. PUMP & WELL	1958	150	410	400-410
CH Cd 24	CH 33114	U.S. NAVY	SYDNOR HYDRO.	1955	175	1003	885-900, 960-970
CH Cd 30	CH 68-0042	UTILICO INC.	SYDNOR HYDRO.	1968	193	1346	936-946, 1085-1100 1108-1113, 1310-1330
CH Cd 31	CH 66-0072	KEECH-NEAVE DEV.	SYDNOR HYDRO.	1966	130	650	406-436, 472-482, 504-509, 523-528, 557-562

Screen diameter (inches)	Water level: Static (ft below land surface)	Water level: Date measured	Yield (gal/min)	Draw-down (ft)	Specific capacity [(gal/min)/ft)]	Use of well	Aquifers screened or aquifer system	Remarks	Well number
4	201.4	05/70	201	60	3.4	O	MAGOTHY ST. CHARLES	ST. CHARLES SITE	CH Bf 133
4	182	08/70	250	60	4.2	O	MAGOTHY	JOHN HANSON TEST	CH Bf 134
6	190	08/73	200	82	2.4	O	MAGOTHY	CEDARVILLE ST. PK.	CH Bf 135
10	200	07/70	560	45	12.4	P	MAGOTHY ST. CHARLES	ST. CHARLES SITE PRODUCTION WELL	CH Bf 136
--	--	--	--	--	--	A	--	ABANDONED; REPLACED BY CH BF 141	CH Bf 137
8	192	01/07/76	400	71	5.6	P	MONMOUTH? MAGOTHY	FISH HATCHERY	CH Bf 141
8	195	03/24/78	754	89	8.5	P	MONMOUTH MAGOTHY	JOHN HANSON SCH. PRODUCTION WELL	CH Bf 142
4	210	02/28/78	15	15	1.0	O	MAGOTHY	NIKE SITE	CH Bf 143
12	203.5	02/01/80	520	38	13.7	P	MAGOTHY ST. CHARLES	PINEFIELD PRODUCTION WELL	CH Bf 144
12	224.8	05/81	510	30	17.0	P	MONMOUTH MAGOTHY	PINEY CHURCH PRODUCTION WELL	CH Bf 145
6	200.5	12/21/83	164	46.7	3.5	T,O	LA PLATA	ST. PAULS TEST	CH Bf 146
12	207	02/26/84	510	110	4.6	P	LA PLATA	ST. PAULS PRODUCTION WELL	CH BF 147
--	--	--	--	--	--	--	--	CORE HOLE	CH Bf 148
--	--	--	--	--	--	--	--	CORE HOLE	CH Bf 149
8	225.6	07/15/85	554	85.5	6.5	P	LA PLATA	ST. PETERS PRODUCTION WELL	CH Bf 150
4	232.7	03/13/86	115	114	1.0	O	ST. CHARLES	ST. PAULS SITE CALIBRATION WELL	CH Bf 151
4	266.5	09/08/86	30	90.6	0.3	O	ST. CHARLES	ST. CHARLES SITE	CH Bf 157
4	222.9	09/17/86	50	124	0.4	O	ST. CHARLES	JOHN HANSON SITE	CH Bf 158
4	153	05/03/55	30	167	0.2	I	MAGOTHY	CALIBRATION WELL	CH Bg 10
2	180	01/27/78	7	15	0.5	C	AQUIA	CALIBRATION WELL	CH Bg 11
12, 12 10, 10	52	05/28/53	559	79	7.1	U	LA PLATA		CH Cb 8
5.5	130	05/28/52	40	204	0.2	I	UPA		CH Cd 9
1.5	22	06/03/52	10	21	0.5	D	UPA		CH Cd 12
2.5	105	09/12/58	10	39	0.3	D	UPA		CH Cd 18
5.5	178	03/03/55	65	167	0.4	P	LA PLATA		CH Cd 24
4	175	06/26/68	68	107	0.6	P	LA PLATA PATUXENT		CH Cd 30
6	80.2	06/20/66	105	85	1.2	P	ST. CHARLES WHITE PLAINS		CH Cd 31

Appendix A.—Continued

Well number	State permit number	Owner	Driller	Date completed	Elevation (ft above sea level)	Depth of hole (ft below land surface)	Screen intervals (ft below land surface)
CH Cd 35	CH 73-0601	RODNEY FEIST	PATUX. PUMP & WELL	1974	180	1206	--
CH Ce 3	--	TOWN OF LA PLATA	SYDNOR HYDRO.	1929	186	650?	--
CH Ce 4	--	TOWN OF LA PLATA	SYDNOR HYDRO.	1936	190	652	610-620
CH Ce 8	CH 1398	TOWN OF LA PLATA	SYDNOR HYDRO.	1947	149	1094	24 FEET SCREEN FROM 1040-1075
CH Ce 16	CH 6365	TOWN OF LA PLATA	SYDNOR HYDRO.	1950	188	608	583-598
CH Ce 18	CH 31514	ARMY CORPS OF ENG.	J. R. BELL	1958	197	1219	1178-1211
CH Ce 30	CH 34886	TOWN OF LA PLATA	SHANNAHAN ARTESIAN	1959	190	637	493-502, 519-525, 569-578, 618-625, 632-637
CH Ce 34	CH 45274	BLUE HAVEN REST.	SHANNAHAN ARTESIAN	1962	195	442	431-442
CH Ce 35	CH 65-0013	TOWN OF LA PLATA	SYDNOR HYDRO.	1965	165	1252	1058-1114
CH Ce 36	CH 68-0064	TOWN OF LA PLATA	CLARENCE BROOKEN	1968	150	630	460-480, 485-495, 580-630
CH Ce 37	CH 73-0219	U.S. GEOL. SUR.	SYDNOR HYDRO.	1974	185	2014	1147-1157 1250-1260 1330-1340
CH Ce 38	CH 73-0269	WHITE PLAINS REGIONAL PARK	SYDNOR HYDRO.	1973	190	702	580-600, 643-663, 674-694
CH Ce 40	CH 69-0099	TOWN OF LA PLATA	SHANNAHAN ARTESIAN	1969	190	711	348-358
CH Ce 41	CH 70-0062	TOWN OF LA PLATA	SHANNAHAN ARTESIAN	1970	190	364	348-358
CH Ce 42	CH 73-0575	ELLENWOOD ESTATES	PATUX. PUMP & WELL	1974	165	1090	1030-1055, 1080-1090
CH Ce 43	CH 73-0764	TOWN OF LA PLATA	A.C. SCHULTES	1973	185	1440	1134-1149, 1168-1191 1237-1255, 1306-1345
CH Ce 47	CH 73-0727	DAVID DEL ROSARIO	EAST COAST	1975	156	440	361-371, 373-378
CH Ce 51	--	CHAS. COUNTY D.P.W.	LAYNE-ATLANTIC	1984	150	1509	1250-1340
CH Ce 52	--	U.S. GEOL. SUR.	U.S. GEOL. SUR.	1984	130	297	NONE
CH Cf 28	CH 67-0066	BOARD OF EDUCATION	EAST COAST	1967	177	700	593-613
CH Cf 29	CH 70-0034	BOARD OF EDUCATION	SCHIMMINGER	1970	177	613?	593-613?
CH Cf 31	CH 73-1841	DENNIS ANDERSON	EAST COAST	1978	166	485	467-477
CH Cg 1	CH 850	SO. MD. ELECTRIC	COLUMB. PUMP & WELL	1946	179	548	538-548
CH Cg 13	CH 27976	DAVID HUME	COLUMB. PUMP & WELL	1957	175	410	395-410
CH Cg 18	CH 73-0560	U.S. GEOL. SUR.	DELMARVA DRILLING	1974	165	1030	699-709
CH Ch 14	CH 73-2790	CHAS. COUNTY D.P.W.	C.Z. ENTERPRISES	1981	10	474	368-448
CH Dd 27	CH 40849	PORT TOBACCO MARINA	A.L. WILSON	1960	3	147	127-147
CH Dd 33	CH 26769	LOYOLA RETREAT HOUSE	WASH. PUMP & WELL	1957	100	694	687-694
CH De 4	CH 1231	V. B. WELSH	HAGMAN	1947	110	420	408.5-420.5
CH De 32	CH 52502	A.T. & T.	LAYNE-ATLANTIC	1963	155	759	500-510

Screen diameter (inches)	Water level: Static (ft below land surface)	Water level: Date measured	Yield (gal/min)	Draw-down (ft)	Specific capacity [(gal/min)/ft)]	Use of well	Aquifers screened or aquifer system	Remarks	Well number
--	--	--	--	--	--	A	--	NO PRODUCTIVE SANDS	CH Cd 35
6	160	1929	60	71	0.8	A	WHITE PLAINS (?)	LA PLATA WELL #1	CH Ce 3
6	231.5	1963	--	--	--	A	WHITE PLAINS (?)	LA PLATA WELL #2	CH Ce 4
8	135.0	1947	100	285	0.4	A	LA PLATA	LA PLATA WELL #3	CH Ce 8
6	210	1950	60	--	--	A	WHITE PLAINS (?)	LA PLATA WELL # 4	CH Ce 16
6	190	1958	210	158	1.3	A	LA PLATA	SUPPLIED ARMY RADIO STATION	CH Ce 18
6	170	1959	--	244	--	P	ST. CHARLES WHITE PLAINS	LA PLATA WELL #5	CH Ce 30
2	180	03/62	7.5	12	0.6	O	MAGOTHY		CH Ce 34
6	165	1965	240	275	0.9	P	LA PLATA	LA PLATA WELL #6	CH Ce 35
2	226	09/68	10	48	0.2	T	ST. CHARLES WHITE PLAINS	TESTED AQUIA ALSO	CH Ce 36
4	189	11/73	120	30	4.0	T,O	LA PLATA	TEST FOR CH Ce 43	CH Ce 37
6	173	12/73	167	108	1.5	P	ST. CHARLES WHITE PLAINS	CALIBRATION WELL	CH Ce 38
2	151.5	1969	7.5	19.5	0.5	T	AQUIA	TEST FOR CH Ce 41	CH Ce 40
4	151	1970	45	99	0.3	P	AQUIA		CH Ce 41
5	152	1974	90	87	1.0	P	LA PLATA		CH Ce 42
6	190	1975	513	76	6.8	P	LA PLATA	LA PLATA WELL # 8	CH Ce 43
2	148	1975	--	--	--	D	AQUIA	CALIBRATION WELL	CH Ce 47
12	185	1984	450	190	2.4	P	LA PLATA	LA PLATA WELL #9	CH Ce 51
--	--	--	--	--	--	T	--	TEST HOLE	CH Ce 52
6	150	04/67	30	150	0.2	A	MAGOTHY	REPLACED BY CF 29	CH Cf 28
--	--	--	--	--	--	I	MAGOTHY	CALIBRATION WELL	CH Cf 29
3	159	03/78	50	11	4.5	D	MONMOUTH	CALIBRATION WELL	CH Cf 31
6	150	10/46	50	150	0.3	I	AQUIA		CH Cg 1
6	140	09/57	60	85	0.7	D	AQUIA		CH Cg 13
2	152	11/74	30	48	0.6	T	MAGOTHY		CH Cg 18
5	16	03/81	271	99	2.8	T	AQUIA		CH Ch 14
1.5	FLOWED	10/60	17	>10	--	C	AQUIA		CH Dd 27
4	104	06/57	10	196	0.1	O	WHITE PLAINS		CH Dd 33
4.5	100	05/47	20	80	0.3	U	ST. CHARLES		CH De 4
8	146	08/63	60	54	1.1	C	ST. CHARLES		CH De 32

Appendix B.—Lithologic logs of selected wells

The formation contacts shown on the lithologic logs were picked from the geophysical logs. This in some instances means that changes in the described lithology do not always coincide with the actual lithologic and formation contacts picked from the geophysical logs. This disparity is in part caused by the timelag between when an interval was drilled and when the cuttings from the drilled interval reached the top of the hole. Other difficulties regarding the collection of representative cuttings include mixing of the cuttings from different depths in the borehole as the cuttings are pumped up the hole and recirculation of the finer sediments within the borehole. Also, the very fine sediments and clays are difficult to sample routinely and these finer cuttings are often not well represented in the samples. The problems associated with the collection of drill cuttings increase with the depth of the hole.

CH Bf 127 (the North well)
Reconstructed lithologic log

Altitude = 213 feet

Lithology	Thickness (feet)	Depth (feet)
UPLAND DEPOSITS		
Silt, and fine sand, very clayey, yellow-tan.	5	5
Silt, as above; mixed with some medium to coarse, quartz sand.	5	10
Sand, fine to coarse, silty, feldspar-bearing, orange-tan.	10	20
Sand, coarse to very coarse, small pebbles, feldspar-bearing, orange-tan.	7	27
Sand, medium to very coarse, silty, clayey matrix, orange-tan.	5	32
Gravel, small quartz pebbles, and fine to coarse, iron-stained, orange-tan, silty sand.	13	45
CALVERT FORMATION		
Silt, clayey, micaceous, light greenish-gray; some orange, silty clay.	2	47
Sand, fine sand silty, clayey matrix, orange-tan; mixed with coarse, quartz sand.	15	62
Silt, and fine sand, clayey matrix, micaceous, light brown.	10	72
Silt, clayey, micaceous, light greenish-gray.	71	143
NANJEMOY FORMATION		
Sand, fine and silty, micaceous, slightly glauconitic, light greenish-gray.	10	153
Sand, fine to medium, silty, micaceous, glauconitic, medium greenish-gray.	10	163
Sand, fine, silty and some medium, glauconitic, micaceous, medium greenish-gray.	30	193
Sand, fine, silty, micaceous, glauconitic, light clay matrix, medium gray.	18	211
Clay, silty and fine sand, micaceous, some glauconite, shell fragments common, medium gray.	20	231
Clay, silty and fine sand, micaceous, pink.	10	241
MARLBORO CLAY		
Clay, silty, micaceous, tan, light pinkish-beige, and pink.	10	251
Clay, as above, some shell.	12	263
AQUIA FORMATION		
Sand, fine, silty, light clay matrix, micaceous, glauconitic (30 percent), shell fragments common, medium greenish-gray.	11	274
Shell, coarse; mixed with sand as above.	3.5	277.5
Silt, with some fine sand, heavy clay matrix, slightly glauconitic, shell fragments common, greenish-gray.	8.5	286
Sand, fine, silty, clayey matrix, glauconitic, micaceous, some shell fragments, grayish-green.	15	301
Sand, fine, silty, some medium, very glauconitic, some shell fragments, dark greenish-gray.	20	321
Sand, fine, silty, clayey matrix, some shell fragments, medium greenish-gray.	20	341
Sand, fine, some medium, glauconitic, micaceous, shell fragments common, greenish-gray.	10	351
Silt, and fine sand, glauconitic, shell fragments common, medium greenish-gray.	20	371
Silt, and very fine sand, clayey, glauconitic, micaceous, some shell fragments, medium gray.	10	381
BRIGHTSEAT FORMATION		
Sand, fine, some medium, silty, with light clay matrix, glauconitic, micaceous, medium gray.	10	391
SEVERN FORMATION		
Silt, and fine sand, clayey, micaceous, some glauconite, shell fragments common, medium gray.	10	401
Silt, heavy, clayey matrix, micaceous, greenish-gray.	10	411

Appendix B.—Continued

CH Bf 127 - Continued

Lithology	Thickness (feet)	Depth (feet)
SEVERN FORMATION (Continued)		
Silt, very clayey, micaceous, shell fragments common, greenish-gray.	10	421
Silt, and very fine sand, clayey, micaceous, shell fragments common, medium greenish-gray.	5	426
Silt, very clayey, micaceous, shell fragments, medium gray.	5	431
Clay, silty, micaceous, shell fragments common, dark gray.	10	441
MAGOTHY FORMATION		
Sand, fine and silty, clayey, micaceous, some shell fragments, lignite-bearing, dark gray.	10	451
Sand, fine to very coarse, quartzose, lignite-bearing, shell fragments, medium gray.	10	461
PATAPSCO FORMATION		
Sand, fine to coarse, some very coarse, quartzose, lignitic, medium gray.	10	471
Sand, medium to very coarse, range fine to very coarse, quartzose, lignite-bearing, light gray.	10	481
Sand, medium to coarse, range fine to very coarse, quartzose, lignitic, medium light gray.	10	491
Sand, fine to medium, range silt to coarse, quartzose, medium light gray.	10	501
Sand, fine to coarse, range silt to very coarse, quartzose, lignite-bearing, medium light gray.	16	517
Clay, tough, yellow (driller's description; no sample cuttings available).	10	527
Clay, gray (driller's description; no sample cuttings available).	20	547
Clay, tough, red and gray (driller's description; no sample cuttings available).	10	557
Clay, yellow and gray (driller's description; no sample cuttings available).	10	567
Clay, tough, chocolate brown (driller's description; no sample cuttings available).	10	577
Clay, silty, gray (driller's description; no sample cuttings available).	25	602

CH Bf 131 and CH Bf 157 (St. Charles site)
Reconstructed lithologic log

Altitude = 225 feet

Lithology	Thickness (feet)	Depth (feet)
UPLAND DEPOSITS		
Sand, silty, clayey, light gray, with orange-tan stain.	8	8
Sand, fine, orange-tan; and clay, white.	9	17
Gravel, coarse, and sand, medium to very coarse, orange-tan.	13	30
CALVERT FORMATION		
Silt, clayey, some fine sand, light gray.	50	80
Silt, very clayey, micaceous, light grayish-green; with some fine, silty sand.	40	120
NANJEMOY FORMATION		
Clay, silty, some fine sand, light gray.	20	140
Sand, very fine, silty, and clayey, micaceous, light gray.	23	163
Sand, fine to medium, silty, with little clay matrix, glauconitic, medium gray.	4	167
Sand, fine to medium, clayey, glauconitic, mica-bearing, greenish-black (salt-and-pepper appearance).	27	194
Silt, fine sand, very clayey matrix, some shell ghosts and shell fragments, micaceous, medium gray.	41	235
MARLBORO CLAY		
Clay, silty, light pinkish-gray.	25	260

Appendix B.—Continued

CH Bf 131 and CH Bf 157 - Continued

Lithology	Thickness (feet)	Depth (feet)
AQUIA FORMATION		
Silt, very clayey, micaceous, shell fragments common, medium gray.	9	269
Sand, fine to medium, clayey, glauconitic, shell fragments common, mica-bearing, medium gray.	11	280
Sand, fine, some medium and coarse, clayey and silty, glauconitic, mica-bearing, shell fragments common. Driller reports beds of very hard, cemented shells and sand.	20	300
Sand, fine to medium, clayey, very glauconitic, dark greenish-gray.	28	328
Sand, medium, clayey, glauconitic, greenish and tan. Some 1-ft-thick cemented beds.	21	349
Sand, fine to medium, silty and clayey, glauconitic, micaceous, medium greenish-gray.	33	382
BRIGHTSEAT FORMATION		
Sand, fine to medium, silty and clayey, glauconitic, micaceous, medium greenish-gray.	8	390
SEVERN FORMATION		
Silt, and fine sand, clayey, medium gray to black.	30	420
MAGOTHY FORMATION		
Sand, fine, silty and very clayey, very dark gray.	25	445
Sand, fine to coarse, light gray.	58	503
PATAPSCO FORMATION		
Clay, variegated, red, gray, and green, very hard.	22	525
Sand, packed hard.	31	556
Clay, red, white, and gray.	29	585
Hard pan (iron-cemented zone).	1	586
Clay, silty, gray.	8	594
Sand, fine to medium silty, light gray, some weathered glauconite and iron-cemented grains.	24	618
Sand, fine to coarse, mica-bearing, some weathered glauconite, light pinkish-gray.	4	622
Silt and fine sand, very clayey, micaceous, oxidized orange-tan, some shell fragments.	38	660
Clay, very hard, medium gray; interbedded with orange-tan silt and fine sand.	31	691
Sand, fine and silty, interbedded with gray, silty clay	29	720
Clay, silty gray and orange-tan	50	770
Clay, silty, variegated, gray, orange, and red; some 2- to 4-ft-thick beds of fine to coarse, iron-stained, orange-tan sand.	44	814
Sand, fine and silty, clayey matrix, micaceous, light gray; some shell fragments present.	10	824
Clay, silty, red, and gray; mixed with fine, silty, orange-tan sand in cuttings.	60	884
Clay, silty, variegated, rust-red, orange, yellow, and gray.	20	904
Sand, medium, mica-bearing, light gray. Sand becomes coarser towards bottom of interval.	26	930
Clay, slightly silty, stiff, variegated, rust-red, pink, and gray (bit sample).	5	935

Reconstructed lithologic log constructed from driller's log of wells CH Bf 131 and CH Bf 157. Geologist's sample descriptions of cuttings from CH Bf 131 and geophysical logs from wells CH Bf 131 and CH Bf 137.

Appendix B.—Continued

CH Bf 146 (the St. Paul site)
Reconstructed lithologic log
[Wells Ch Bf 147 and CH Bf 151 occur at the same site as CH Bf 146]

Altitude = 192 feet

Lithology	Thickness (feet)	Depth (feet)
Top Soil	1	1
UPLAND DEPOSITS		
Sand, medium to coarse, range silt to cobble, moderate to poorly sorted, feldspar-bearing, chert common, orange-tan; pebble and cobble zone from 6 to 8 feet	18	19
CALVERT FORMATION		
Clay, silty and fine sandy, mica-bearing, yellowish-orange (oxidized).	7	26
Clay, silty and fine sandy, mica-bearing, medium olive-gray.	14	40
Silt, and fine sand, very clayey, micaceous, medium olive-gray, shell fragments common.	20	60
Sand, fine, silty and clayey, micaceous, medium olive-gray.	15	75
Clay, silty and fine sandy, micaceous, medium olive-gray.	5	80
Sand, fine silty and very clayey, micaceous, medium olive-gray.	20	100
Clay, silty and fine sandy, micaceous, medium olive-gray.	25	125
NANJEMOY FORMATION		
Sand, fine, silty and clayey, glauconitic, micaceous, medium gray. Glauconite: fresh, polylobate, greenish-black grains (15% of sample). Quartz: angular to subangular, clear.	45	170
Sand, fine, range silt to medium, clayey, glauconitic, micaceous, medium gray, (slightly coarser, less clayey and more glauconitic (≈20%) than above).	30	200
Sand, fine, silty and clayey, glauconitic, micaceous, medium gray.	20	220
Clay, silty and fine sandy, glauconitic, micaceous, medium gray.	30	250
MARLBORO CLAY		
Clay, silty, micaceous, reddish-brown and gray, glauconite-bearing (possible contamination).	10	260
Clay, as above; mixed with greenish-black, medium-grained, glauconitic sand.	10	270
AQUIA FORMATION		
Clay, as above; mixed with greenish-black, fine-grained, glauconitic sand. (Clay possible contamination.)	10	280
Sand, fine to medium, heavy clay matrix, glauconitic (≈30 to 40% of sample), greenish-black.	20	300
Sand, fine to medium, heavy clay matrix, glauconitic, greenish-black; mixed with some maroon, silty clay (possibly contamination).	10	310
Sand, fine to medium, heavy clay matrix, glauconitic (≈40 to 50% of sample), grayish-green.	10	320
Sand, medium, range fine to coarse, light clay matrix, glauconitic, calcite-cemented grain aggregates, greenish-black. Driller reports shell layers. Glauconite: greenish-black, fresh, polylobate grains (≈50% of sample). Quartz: subangular, iron-stained and clear.	10	330
Sand, fine to medium, heavy clay matrix, glauconitic, greenish-black. Driller reports shell layers.	10	340
Sand, fine to medium, light clay matrix, glauconitic, greenish-black. Driller reports shell layers.	20	360
Sand, fine, some medium, heavy clay matrix, glauconitic, greenish-black.	28	388
BRIGHTSEAT FORMATION		
Sand, fine to medium, light clay matrix, glauconitic, greenish-black.	14	402
SEVERN FORMATION		
Sand, fine, very clayey, micaceous, glauconite-bearing, dark gray. Glauconite: less abundant than above (cuttings ≈20% glauconite).	18	420
Sand, medium to coarse, some small gravel, lignitic, feldspar-bearing, light gray. Sands become coarser toward bottom of interval.	24	444
Silt, and fine sand, heavy clay matrix, micaceous, traces of shell fragments, dark gray; with fine to medium, silty sand, light gray with carbonaceous bands; and white to slightly pink, tough clay interbedded with fine, silty sand.	31	475

Appendix B.—Continued

CH Bf 146 (the St. Paul site) - Continued
Reconstructed lithologic log
[Wells Ch Bf 147 and CH Bf 151 occur at the same site as CH Bf 146]

Lithology	Thickness (feet)	Depth (feet)
MAGOTHY FORMATION		
Sand, fine to coarse, small pebbles common, range silt to pebble size, feldspar-bearing, light gray.	47	522
PATAPSCO FORMATION[1]		
Clay, silty, medium gray, brown, and red. Tough clay, slow drilling.	18	540
Clay, slightly silty, tough red, and gray; mixed with rust-brown, fine, silty, micaceous sand.	10	550
Clay, some silt, red, brown, and gray. Very tough, very slow drilling.	20	570
Clay, slightly silty, red and brown; mixed with brown, fine to medium, silty sand.	30	600
Clay, silty, light gray; mixed with brown, fine to medium, silty sand.	26	626
Sand, medium, range fine to coarse, light clay matrix, lignite-bearing, light gray.	24	650
Sand, medium to coarse, range silt to very coarse, feldspathic, orange-tan and gray; abundant grayish-tan, small pebbles.	15	665
Sand, fine, silty, micaceous, light gray and light tan; interbedded with clay.	35	700
Silt, and fine sand, heavy clay matrix, micaceous, brown; interbedded with light gray, clayey silt and red and brown, silty, micaceous clay.	40	740
Silt, and fine sand, heavy clay matrix, micaceous, lignite-bearing, brown; interbedded with light gray, silty clay.	32	772
Clay, silty, light gray.	14	786
Sand, from geophysical logs; no samples.	10	796
Clay, variegated reddish-brown, maroon, brown, and gray; with some 2-ft thick beds of fine, clayey sand.	64	860
Sand, fine to medium, clayey matrix, silty, micaceous, light brown.	10	870
Clay, red and brown, tough.	36	906
Sand, fine, clayey, orange-tan; ilmenite? common.	6	912
Clay, tough, reddish-brown, with pods of light gray, clayey silt.	8	920
Clay, stiff, rust-red and gray (drill-collar sample).	10	930
Clay, silty, red and gray; mixed with brown, fine, clayey sand.	10	940
Clay, some silt, brown, red, and gray; mixed with brown, fine, clayey sand.	10	950
Sand, fine, silty, and clayey, micaceous, brown; with some gray, clayey silt; trace lignite.	20	970
Sand, medium to coarse, clayey, feldspar-bearing, brownish-gray; mixed with gray, silty clay.	10	980
Clay, red and gray; mixed with brown, fine, clayey sand.	10	990
Silt, and fine sand, very clayey, micaceous, brown; chips of gray, silty clay present.	10	1,000
Clay, red, gray, and brown; mixed with brown and gray, fine, silty and clayey sand.	10	1,010
Silt, and fine sand, very clayey, lignite-bearing, micaceous, brown; mixed with chips of gray, silty clay.	10	1,020
Sand, fine, brown, silty and clayey, weathered shell fragments; chips of red, brown, and gray clay.	10	1,030
Sand, fine, silty, very clayey, micaceous, brown; mixed with chips of gray, silty clay.	10	1,040
Clay, brown, and reddish-brown, some gray, silty clay.	20	1,060
Sand, fine, range silt to medium, clayey, brownish-gray.	10	1,070
Clay, reddish-brown, red, and dark gray, silt-free.	10	1,080
Clay, reddish-brown, red, and gray; mixed with gray and tan, fine, clayey sand.	20	1,100
Clay, reddish-brown, red, and dark gray; some tan, fine, clayey sand.	10	1,110
Sand, fine, silty, and clayey, brown; trace lignite.	10	1,120
Sand, fine, range silt to medium, clayey, brown, some weathered shell fragments.	10	1,130
Sand, fine to medium silty and clayey, brown, some weathered shell fragments. Chips of orange and gray clay present.	10	1,140
Clay, reddish-brown, red, and gray; some gray, silty clay present.	10	1,150
Clay, reddish-brown, red, and gray; mixed with fine, clayey, gray, and orange-tan sand.	10	1,160
Sand, fine to medium, silty and clayey, brown; mixed with gray and reddish-brown, silty clay.	10	1,170
Sand, fine to medium, some coarse, silty and clayey, lignite common, some weathered shell, grayish-brown; mixed with some gray, silty clay.	10	1,180

[1]See note at end of log.

Appendix B.—Continued

CH Bf 146 (the St. Paul site) - Continued
Reconstructed lithologic log
[Wells Ch Bf 147 and CH Bf 151 occur at the same site as CH Bf 146]

Lithology	Thickness (feet)	Depth (feet)
PATAPSCO FORMATION (Continued)		
Sand, fine to medium, range silt to coarse,, light clay matrix, quartzose, medium brown. (Driller reports gravel layer from 1,180 to 1,184 ft and tough, brown clay at 1,184 ft).	10	1,190
Silt, heavy clay matrix, brown; mixed with fine to coarse, quartzose sand.	10	1,200
Sand, medium to coarse, quartzose, brown; mixed with brown and red, micaceous clay.	10	1,210
Sand, fine, range silt to coarse, heavy clay matrix, brown; mixed with chips of tough, reddish-brown clay.	10	1,220
Sand, fine, silty, range silt to medium, moderate clay matrix, medium brown.	10	1,230
Clay, tough, reddish-brown and dark brown, some pods of beige, clayey silt.	10	1,240
Clay, slightly silty, micaceous, gray, greenish-gray and reddish-brown.	10	1,250
Sand, fine, silty, range silt to medium, light clay matrix, brown; mixed with chips of light gray, silty clay.	10	1,260
Silt, some fine sand, heavy clay matrix, micaceous, light gray and light brown.	10	1,270
Clay, and fine, silty sand, reddish-brown and medium gray.	10	1,280
Clay, silt-free, variegated reddish-brown, red, and gray.	10	1,290
Clay, reddish-brown and gray; mixed with brown, fine, silty, mica-bearing sand.	10	1,300
Clay, silt-free, reddish-brown and medium brown, mixed with light gray, silty clay.	20	1,320
Clay, reddish-brown and medium gray; mixed with light gray, clayey, micaceous silt.	10	1,330
Clay, reddish-brown and medium gray, mica-bearing; mixed with a little brown, fine to medium sand.	20	1,350
Clay, reddish-brown and gray; mixed with gray, quartzose, mica-bearing sand.	10	1,360
Clay, reddish-brown; mixed with greenish-gray, fine to medium, clayey sand.	10	1,370
Sand, fine to medium, range silt to coarse, light clayey matrix, light brown.	10	1,380
Clay, reddish-brown, maroon, and gray; mixed with fine to medium quartz sand.	10	1,390
Sand, fine to coarse, mostly medium, quartzose, heavy clay matrix, reddish-brown.	10	1,400
Clay, reddish-brown and medium gray; mixed with some tan-gray, fine sand.	10	1,410
Sand, fine to medium, silty, heavy clay matrix, medium brown.	10	1,420
ARUNDEL FORMATION[1] (Contact at 1,417 feet)		
Clay, silty, gray; mixed with some brown, fine to medium, clayey sand. Some coarse, brown sand present.	20	1,440
Clay, reddish-brown; mixed with fine to medium, quartzose sand.	20	1,460
Sand, medium, range fine to coarse, heavy clay matrix, reddish-brown.	10	1,470
Sand, fine to medium, and silty, ranges up to coarse, light clay matrix, orange-tan.	10	1,480
Sand, fine and silty, ranges up to coarse, moderate clay matrix, reddish-brown; mixed with clumps of pinkish-beige, clayey silt.	10	1,490
Sand, fine to medium, quartzose, heavy clay matrix, reddish-brown.	10	1,500
Clay, reddish-brown, brown, and orange; mixed with some bluish-gray, silty clay.	30	1,530
Clay, fine to medium sandy, reddish-brown.	10	1,540
Clay, reddish-brown and red.	20	1,560
Clay, reddish-brown and gray; mixed with fine, clayey sand.	10	1,570
Clay, medium gray; mixed with fine, clayey sand.	20	1,590
Clay, medium gray, reddish-brown and red; mixed with fine to medium, clayey sand.	57	1,647

[1]Because of sample return lag time and poor return of clayey sediments, Patapsco Formation descriptions at depths greater than 700 feet and Arundel Formation descriptions may not be entirely representative of actual lithology or the lithology inferred from the geophysical logs.

Appendix B.—Continued

CH Bf 158 (John Hanson site)
Reconstructed driller's log

Altitude = 203 feet

Lithology	Thickness (feet)	Depth (feet)
UPLAND DEPOSITS		
Sand, yellow, and coarse gravel	20	20
Gravel, coarse.	5	25
CALVERT FORMATION		
Clay, gray.	15	40
Clay, greenish, with very fine sand.	15	55
Clay, gray and green.	25	80
Clay, green.	20	100
NANJEMOY FORMATION		
Clay, silty, green.	15	115
Clay, green.	10	125
Clay, light gray, with fine, black sand.	35	160
Sand, very fine, black and gray clay.	30	190
Clay, gray, and silty sand.	20	210
Clay, gray.	20	230
MARLBORO CLAY		
Clay, pinkish.	10	240
Clay, pink and gray; with pieces of shell.	15	255
AQUIA FORMATION		
Clay, gray, and large shells.	25	280
Clay, gray, some shells.	10	290
Clay, gray.	10	300
Clay, gray, and fine, black sand.	30	330
Clay, gray, some shells.	15	345
Clay, gray, and hard shells.	20	365
BRIGHTSEAT FORMATION		
Clay, light gray, and fine sand.	15	380
SEVERN FORMATION		
Clay, light gray, and fine sand.	40	420
MAGOTHY FORMATION		
Clay, light gray, and fine sand.	14	434
Clay, slow drilling.	4	438
Clay, silty.	7	445
Clay	16	461
Sand, and gray clay.	6	467
Clay, gray, and sand streaks.	13	480
Sand, and clay streaks.	20	500
Sand, and gray clay streaks.	20	520
PATAPSCO FORMATION		
Sand, and gray clay streaks.	10	530
Clay, red and white, slow drilling.	40	570
Clay, red and gray; with hard pan, slow drilling.	10	580
Clay, light brown, easier drilling.	25	605
Sand, fine; some medium to coarse, gray.	35	640
Clay, red, some gray.	45	685
Sand.	4	689
Clay, red.	13	702
Clay, very slow drilling.	12	714
Sand.	11	725
Clay, red, and shells.	15	740
Clay, red; thin layer of shells.	20	760
Clay, black and red; hard sand streaks.	20	780
Clay, red, and very hard sand streaks.	20	800

Appendix C.—Descriptions of core samples

CH Bf 127 (North Well site; alt. = 213 ft.)

Cored Interval (feet below land surface)	Lithology
301 to 302	Sand, fine, silty, light clayey matrix, moderately well sorted, glauconitic, mica-bearing, dark greenish-gray. Formation: Aquia
311 to 312	Sand, fine, silty, some medium, light clayey matrix, moderately well sorted, glauconitic, mica-bearing, dark greenish-gray. Formation: Aquia
321 to 322	Sand, fine, silty, some medium, moderately well sorted, mica-bearing, trace glauconite, medium gray. Formation: Aquia
331 to 332	Sand, fine to medium, some coarse, moderately sorted, glauconitic, mica-bearing, grayish-green. Shell fragments common. Formation: Aquia
341 to 342	Sand, fine, silty, some medium, moderately well sorted, glauconitic, mica-bearing, dark greenish-gray. Trace of shell fragments and shell ghosts. Formation: Aquia
351 to 352	Sand, medium, range fine to coarse, moderately well sorted, glauconitic, micaceous, dark greenish-gray. Shell fragments common. Formation: Aquia
361 to 362	Sand, medium, range fine to coarse, moderately well sorted, glauconitic, micaceous, dark greenish-gray. Shell fragments present. Formation: Aquia
371 to 372	Sand, fine to medium, very silty, moderately well sorted, micaceous, glauconitic, dark gray. Shell fragments and shell ghosts common. Formation: Aquia
381 to 382	Sand, fine to medium, silty, ranges to coarse, moderately sorted, micaceous, glauconitic, dark gray. Shell fragments present. Formation: Brightseat
391 to 392	Sand, fine, silty, clayey matrix, moderately well sorted, micaceous, medium gray with tan cast. Shell fragments present. Formation: Brightseat or Severn
411 to 412	Sand, fine, silty, clayey matrix, moderately well sorted, micaceous, medium gray with tannish cast. Formation: Severn
471 to 472	Sand, medium to coarse, range fine to very coarse, slight clay matrix binding some sand grains, well-preserved lignitic wood fragments, light gray. Formation: Magothy
526 to 527	Clay, very silty, micaceous, pink and gray. Formation: Patapsco
546 to 547	Silt, very clayey, micaceous, gray and pink. Formation: Patapsco

Appendix C.—Continued

CH Bf 127 (North Well site) - Continued

Cored Interval (feet below land surface)	Lithology
556 to 557	Clay, some silt, light gray, pink, and brick red. Formation: Patapsco
566 to 567	Silt, fine, clayey, white. Formation: Patapsco
576 to 577	Silt, very clayey, brick red and orange. Formation: Patapsco
586 to 587	Silt and fine sand, very clayey, very light gray and pink. Formation: Patapsco

CH Bf 151 (St. Pauls site; alt. = 195 ft.)

Cored Interval (feet below land surface)	Lithology	Recovery (inches)
47 to 49	Silt, with fine quartz sand. Formation: Calvert	12
62 to 64	Sand, very fine, light olive-gray (5 Y 5/2). Formation: Calvert	24
82 to 84	Silt, with very fine quartz sand, grayish-yellow (5 Y 7/2). Formation: Calvert	24
122 to 124	Sand, very fine, silty matrix, grayish-yellow (5 Y 6/2). Formation: Calvert	20
132 to 134	Sand, medium, silty matrix, glauconitic, grayish-olive green (5 GY 3/2). Formation: Nanjemoy	20
182 to 184	Sand, coarse, slightly silty, glauconitic, with some shell, greenish-black (5 GY 2/2). Formation: Nanjemoy	24
242 to 244	Silt, with coarse sand, slightly silty, glauconitic, some shell, olive-gray (5 Y 3/2). Formation: Nanjemoy	22
270 to 272	Clay, some lignite, pinkish-gray (5 YR 7/2). Formation: Marlboro Clay	9
302 to 304	Sand, medium, glauconitic, loosely cemented with calcite, yellowish-gray (5 Y 5/2). Formation: Aquia	10
342 to 344	Sand, medium, some silt, very glauconitic, grayish-olive (10 Y 4/2). Formation: Aquia	10
396 to 398	Sand, coarse, glauconitic, grayish-olive (10 Y 4/2). Formation: Brightseat	11

Appendix C.—Continued

CH Bf 151 (St. Pauls site) - Continued

Cored Interval (feet below land surface)	Lithology	Recovery (inches)
405 to 406	Sand, very fine, silty, olive-gray (5 Y 4/2). Formation: Severn	12
406 to 407	Sand, very fine, silty matrix, olive-gray (5 Y 4/2). Formation: Severn	12
450 to 452	Silt, very fine sand, lignitic, olive-gray (5 Y 4/2). Formation: Magothy	24
454 to 456	Silt, with some coarse sand, olive-gray (5 Y 4/2). Formation: Magothy	13
458	Silt, fine, very clayey, with traces of worn glauconite (contamination?), pale yellowish-brown (10 YR 6/2); with clay, dark brownish-gray (5 YR 3/1) and dark yellowish-brown (10 YR 4/2). Formation: Magothy	5
470 to 472	Silt, fine sand, streaks of lignite, light olive-gray (5 Y 6/1). Formation: Magothy	7
485 to 487	Sand, fine, streaks and pieces of lignite abundant, grayish-black (N 2). Formation: Magothy	5
488	Clay, silty, laminae of pale yellowish-brown, fine quartz sand, lignite-bearing, brownish-gray (5 YR 4/1). Formation: Magothy	3
518	Sand, fine, silty, mica-bearing, dark yellowish-brown (10 YR 4/2), mixed with small, iron-stained dark yellowish-brown quartz pebbles; and brownish-gray clay. Core may not represent all <u>in situ</u> material. Formation: Magothy	Sample broken up
522	Clay, trace silt, brownish-gray (5 YR 4/1). Formation: Patapsco	12
525 to 527	Clay, pale brown (5 YR 5/2). Formation: Patapsco	13
545 to 547	Clay, very silty, mottled white, yellow, and red. Formation: Patapsco	11
562	Clay, trace silt, dark yellowish-brown (10 YR 4/2) with dark reddish-brown (10 R 3/4) streaks and blebs of pale yellowish-orange (10 YR 6/6) silt. Formation: Patapsco	7
588	Clay, trace silt, dark yellowish-brown (10 YR 4/2) with blebs of very dark red (5 R 2/6) and dark yellowish-orange (10 YR 6/6) clayey silt. Formation: Patapsco	20
608	Sand, fine, clayey matrix, well sorted, pale yellowish-brown (10 YR 6/2); with less clayey, fine, moderate yellowish-brown (10 YR 5/4) sand. Formation: Patapsco	8

Appendix C.—Continued

Ch Bf 151 (St. Pauls site) - Continued

Cored Interval (feet below land surface)	Lithology	Recovery (inches)
662	Clay, mottled grayish-red (5 R 4/2) and dark reddish-brown (10 R 3/4). Formation: Patapsco	15

CH Bf 158 Sidewall Core Descriptions (John Hanson site; alt. = 203 ft.)

Cored Interval (feet below land surface)	Lithology	Recovery (inches)
238	Clay, trace of silt, olive-gray (5 Y 4/1); grades into pale yellowish-brown (10 YR 6/2) and light brown (5 YR 5/6) clay; grades into dark yellowish-brown (10 YR 4/2) clay. Formation: Marlboro Clay	11
268	Sand, silty, very clayey, glauconitic, olive-gray (5 Y 4/1). Formation: Aquia	8
338	Sand, fine, slightly clayey matrix, well sorted, glauconitic, olive-black (5 Y 2/1). Formation: Aquia	6
378	Sand, very fine, silty, slightly clayey matrix, glauconitic, mica-bearing, olive-black (5 Y 2/1). Formation: Brightseat	6
398	In situ material: Clay, silty, micaceous, glauconite-bearing, (fresh, botryoidal, green), dark olive-gray (5 Y 3/1). Formation: Severn	Mostly mudcake
408	Silt, with some fine sand, very clayey, micaceous, glauconite-bearing (blocky and subrounded grains), olive-black (5 Y 2/1). Formation: Severn	19
428	Silt, very clayey, micaceous, glauconite-bearing?, olive-black (5 Y 2/1). Formation: Magothy	14
638	Sand, fine to medium, slightly clayey matrix, moderately sorted, moderate yellowish-brown (10 YR 5/2). Formation: Patapsco	3
758	Clay, hard, lignite-bearing, brownish-gray (5 YR 4/1) to brownish-black (5 YR 2/1) where heavily carbonized. Formation: Patapsco	12
778	Clay, hard, trace silt, lignitic, brownish-gray (5 YR 4/1) to medium dark gray (N 4). Formation: Patapsco	17

Appendix D.—Field description* of core holes CH Bf 148 and CH Bf 149

[ft = feet; mm = millimeters; cm = centimeters]

Altitude = 210 feet

Lithology	Thickness (feet)	Depth (feet)
Description of CH Bf 148 (0 to 480 ft)		
UPLAND DEPOSITS		
Sand and gravel, yellow-tan (10 YR 6/6) (drill cuttings only).	37	37
CALVERT FORMATION		
Silt, clayey, very weathered, dark yellow, orange (cuttings only).	3	40
Silt, clayey, grayish-olive, (10 Y 4/2); burrowed.	1.5	41.5
No recovery.	4.5	46
Silt, clayey, grayish-olive (10 Y 3/2 to 4/2); burrowed.	3.7	49.7
No recovery.	6.3	56
Clay, silty, grayish-olive, (10 Y 4/2); burrowed [filled with silt, olive-brown (5 Y 3/4)].	4	60
Clay, silty, grayish-olive (10 Y 4/2); chalky mollusk fragment zone from 59.5 to 63 ft; burrows rare; becomes more clayey from 63.5 to 64.5 ft.	4.5	64.5
No recovery.	1.5	66
Clay, very minor silt to 67.5 ft; then rapidly grades to silty, fine sand at 70 ft, grayish-olive (10 Y 3/2); burrows up to 1 cm diameter, subtle mm to cm laminae; some small, polished phosphate pebbles; some fish scales, abundant sponge spicules.	4	70
Sand, silty, fine, grayish-olive (10 Y 3/2); rare, small phosphate pebbles, some laminae and some burrows, fish scales and sponge spicules.	2.9	72.9
No recovery.	3.1	76
Silt, clayey, grayish-olive, (10 Y 3/2).	2	78
No recovery.	8	86
Silt, clayey, moderate to olive-gray (5 Y 4/6); burrows 86.7 to 87.2 ft.	4	90
Silt, clayey, some fine, sandy clay zones, moderate olive-brown (5 Y 4/4); diatoms at 91 ft, two phosphatized brachiopods, burrows at 96 ft.	10	100
Silt, clayey, with zones of fine, sandy silt, moderate to dark olive-brown (5 Y 4/4 to 3/4); burrows and diatoms at 102 to 104 ft.	4.5	104.5
No recovery.	1.5	106
Silt, fine sandy, with slightly clayey matrix, grayish-blue (5 Y 4/6); burrows common, up to 1.5 cm, filled with clayey silt, grayish, olive-gray (10 Y 4/2); abundant small phosphate pebbles, some granular quartz; brown, thin; phosphatized shell fragments.	10	116
Sand, very fine and silty, interbedded with fine, sandy silt, grayish-olive (10 Y 3/2); burrows and very fine sand stringers.	3.9	119.9
No recovery.	6.1	126
Silt, clayey, some fine, silty sand, olive-brown (5 Y 4/6), grades to clayey, fine sand at base of interval; burrowed, very small phosphate pebbles and granular quartz; hard zone at 132.8 ft.	6.8	132.8
NANJEMOY FORMATION		
Sand, clayey, glauconitic, grayish-olive green (5 GY 3/2).	0.2	133
No recovery.	4	137

Appendix D.—Continued

Lithology	Thickness (feet)	Depth (feet)
Sand, fine to medium, silty and clayey, with more clayey zones, grayish-olive green, (5 GY 3/2); burrows common, some chalky mollusks, medium induration.	2.6	139.6
No recovery.	1.4	141
Sand, fine to coarse, clayey, some silty clay zones, glauconitic, grayish-olive (10 Y 4/2); abundant burrows (filled with clay and glauconite); very weathered pelecypod fragments.	11	152
No recovery.	4	156
Sand, fine to medium, clayey, glauconitic, grayish-olive (10 Y 3/2); burrowed, weathered (chalky) pelecypod fragments.	2.9	158.9
No recovery.	7.1	166
Sand, fine to medium, silty, glauconitic, grayish-olive (10 Y 3/2).	2.6	168.6
No recovery.	2.4	171
Sand, fine, silty, some coarse quartz, glauconitic, grayish-olive (10 Y 3/2); some coarse phosphate grains, weathered pelecypods.	1.6	172.6
No recovery.	3.4	176
Sand, fine to medium, clayey in places, glauconitic, grayish-olive (10 Y 3/2); burrowed, chalky pelecypods (sparse), mica-bearing, coarse quartz common, some phosphate granules.	5	181
Sand, fine to medium, clay laminae (0.5 cm), glauconitic; sands are olive-gray (5 Y 2/2); clays are olive-green (5 Y 3/2); burrowed, some sulfide grains.	5	186
Clay, fine, silty and sandy, glauconite-bearing, olive-gray (5 Y 3/2).	5	191
Sand, fine to medium, clayey, abundant glauconite, olive-gray (5 Y 3/2); chalky mollusk shells (sparse).	6.5	197.5
Clay, fine, sandy, and silty, glauconite abundant, olive-gray (5 Y 3/2); burrowed, chalky mollusks.	8.5	206
Silt, clayey, some fine sand, glauconite-bearing (very fine), olive-gray (5 Y 2/2); chalky gastropods and pelecypods.	12.4	218.4
MARLBORO CLAY		
Clay, very minor silt and sand, grayish-olive (10 Y 4/2); burrowed, cross-bedded.	3.6	222
Clay, very minor silt, dark yellowish-brown (10 YR 4/2); very hard zone at 222 ft.	6	228
No recovery.	8	236
Clay, slightly silty, moderate brown; upper few feet of interval show banding.	4.5	240.5
Clay, slightly silty, banded at mm to cm scale, alternating brown (5 YR 4/4) and light olive-gray (5 Y 6/1); banding is more pronounced at bottom of interval.	5.3	245.8
No recovery.	0.2	246
Clay, silty, glauconitic, with discontinuous, (mm) thick lenses of more silty clay, greenish-gray (5 G 6/1); lower 6 inches of interval heavily laminated.	1.6	247.6
Clay, silty, glauconitic, clayey silt lenses, dark yellowish-brown (10 YR 4/2); bioturbated.	1.0	248.6

Appendix D.—Continued

Lithology	Thickness (feet)	Depth (feet)
AQUIA FORMATION		
Clay, silty, with silt lenses and discontinuous clay laminae, well-sorted, glauconite-bearing, olive-gray (5 Y 3/2).	1.4	250
Clay, silt and very fine sand, glauconite-bearing, olive-black (5 Y 2/1).	1.6	251.6
Sand, very fine, with silty clay, micaceous, glauconitic, olive-gray (5 Y 3/2).	4.4	256
Sand, silty and very fine, micaceous, glauconitic, olive-gray (5 Y 3/2); bioturbated; Turritella shells scattered throughout interval; more shelly below 258 ft.	10	266
Sand, silty, fine (interval coarser than above), dusky yellowish (10 GY 3/2) to light olive-gray (5 Y 3/2); glauconitic; scattered shells, including Turritella.	1	267
No recovery.	2	269
Sand, medium to coarse, silty matrix, glauconitic, olive-gray (5 Y 3/2); some highly fossiliferous zones, some heavily indurated zones; lower 1 foot of interval is dusky green (5 G 3/2).	3.8	272.8
No recovery.	3.2	276
Sand, medium to coarse, silty matrix, glauconitic, dusky green (5 G 3/2); scattered fossils.	0.9	276.9
No recovery.	1.1	278
Sandstone, medium, well sorted, calcite-cemented, olive-gray (5Y 3/2).	2	280
Sand, medium, silty, very glauconitic, olive-gray (5 Y 3/2).	1	281
Sand, medium, silty, glauconitic, interbedded with more glauconite-rich beds, olive-gray (5Y 3/2).	0.5	281.5
Sandstone, medium, calcite-cemented, glauconite-rich, olive-gray (5 Y 3/2).	1.5	283
Sand, medium, well sorted, quartzose, glauconitic, grayish-olive green (5 GY 3/2); scattered burrows, some small (1 cm) pockets of coarse glauconite; scattered fossils.	1	284
Not logged.	2	286
Sand, medium, well-sorted, quartzose, glauconitic, grayish-olive green (5 GY 3/2); well indurated (calcite-cemented); scattered fossils.	0.8	286.8
Sand, medium, well-sorted, grayish-olive green (5 GY 3/2), glauconitic.	0.8	287.6
No recovery.	12.4	300
Sand, fine, grayish-olive (10 Y 3/2), glauconitic, slightly to heavily calcareous, burrowed, oyster shells; most glauconites are black, some green.	9.5	309.5
No recovery.	4.5	314
Sand, fine, some coarse, laminae of fine, sandy clay, grayish-olive (10 Y 3/2); burrowed (filled with glauconite); small oyster shells.	3	317
Sand, fine, glauconitic, grayish-olive (10 Y 4/2); burrowed (filled with clayey sand), mollusk shell fragments (sparse); strong sulfide odor.	1.0	318
No recovery.	8	326
Sand, fine to medium, well-sorted, glauconitic, grayish-olive (10 Y 4/2), massive; oyster shells.	3.5	329.5
No recovery.	6.5	336
Sand, fine, slightly clayey, glauconitic, calcite-cemented, olive-gray (5 Y 4/2); oyster shells.	2	338
No recovery.	8	346

Appendix D.—Continued

Lithology	Thickness (feet)	Depth (feet)
Sand, medium to coarse, glauconitic, olive-gray (5 Y 2/2).	1	347
Sand, fine to very fine, well-sorted, glauconitic, olive-gray (5Y 3/2); subtle burrows.	3.5	350.5
Not logged.	1.2	351.7
Sand, silty, fine, glauconitic, olive-gray (5 Y 3/2).	0.5	352.2
No recovery.	3.8	356
Sand, fine and very fine, well-sorted, some clay matrix, glauconitic, olive-gray (5 Y 3/2), olive-gray (5 Y 4/1), and brownish-gray (5 YR 4/1); burrowed, some shell fragments and shell ghosts.	4.5	360.5
No recovery.	0.5	361
Sand, fine, silty, little clay matrix, glauconitic, olive-gray (5 Y 3/2), with olive-brown (5 YR 4/1 to 5 Y 4/1) mottling; probable burrows.	1	362
No recovery.	1.6	363.6
Sand, very fine to fine, silty and slightly clayey; with bands of clay (probably infilled burrows), glauconitic, brownish-gray (5 YR 3/1); abundant shell ghosts (gastropods and other mollusks).	2.6	366.2
Sand, fine to medium, clayey, glauconitic, mottled grayish-olive green (5 GY 2/2) to olive-gray and olive-black (5 Y 3/1); mottled zones probably represent burrows.	9.8	376
Sand, very fine to fine, clayey, glauconitic, dark grayish-olive green (5 GY 2/2) to greenish-black (5 GY 2/1); shell ghosts.	3	379
Silt, clayey, glauconitic, phosphate granules, blue quartz, olive-gray (5 Y 3/2) to dark olive-brown (5 Y 3/4).	0.3	379.3
No recovery.	5.7	385
BRIGHTSEAT FORMATION		
No recovery.	7.5	392.5
Sand, fine, silty, shell fragments, olive-gray (5 Y 4/1).	1.5	394
Clay and silty clay, light olive-gray (5 Y 5/1) to olive-gray (5 Y 4/1); fine shells, thin burrows infilled with clay.	0.6	394.6
No recovery.	4.1	398.7
Clay, and silty clay, some silt/clay laminae, micaceous, olive-gray (5 Y 3/2) and light olive-gray (5 Y 4/2); no shells.	0.8	399.5
No recovery.	.5	400
SEVERN FORMATION		
No recovery.	1.0	401
Silt, fine, and silty clay; olive-gray (5 Y 4/1) to olive-black (5 Y 4/2), micaceous, carbonaceous flecks, probable burrows.	2.5	403.5
No recovery.	3.5	407
Sand, fine, silty, olive-gray (5 Y2/2), very micaceous, mottled (probable burrows).	3.8	410.8
Clay, silty, olive-gray (5 Y 2/2), shell ghosts.	2.5	413.3
No recovery.	2.7	416
Silt, fine sandy and clayey, olive-gray (5 Y 3/2); shell fragments common.	4.3	420.3
No recovery.	5.7	426

Appendix D.—Continued

Lithology	Thickness (feet)	Depth (feet)
Silt, fine sandy and clayey, some clayey spots, very micaceous, olive-black (5 Y 1/1); burrowed, hard.	2.3	428.3
No recovery.	7.7	436
Sand, fine to medium, silty and clayey matrix, micaceous, olive-black (5 Y 4/1); shell fragments.	2.6	438.6
MAGOTHY FORMATION		
Silt, slightly clayey matrix, with 2- to 3-inch thick clay beds, medium brownish-gray (5 YR 5/1); carbonaceous streaks, some hydrogen sulfide odor.	1.7	440.3
No recovery.	2.2	442.5
Sand, fine and silty, interbedded at a mm to cm scale with clay, light brownish-gray (5 YR 5/1) to olive-gray (5 Y 4/1); burrowed, plant fragments, pyrite or marcasite (?) nodules, pyrite-cemented quartz grains.	2.5	445
No recovery.	1	446
Clay, some silt with thin beds (mm) of clayey silt, dusky yellowish-brown (10 YR 2/2) to pale yellowish-brown (10 YR 8/2); burrowed (infilled with medium to coarse sand); lower inches of interval are heavily bioturbated and contain carbonaceous streaks.	1.2	447.2
No recovery.	2.8	450
Clay, olive-black (5 Y 2/1).	1	451
Sand, fine, silty (sugary), and silty clay, olive-gray (5 Y 4/1) (cuttings description; no core recovery).	3	454
Silt, clayey, and very fine sand, moderate olive-brown (5 Y 4/4) (cuttings description; no core recovery).	3	457
No recovery.	6.5	463.5
Sand, coarse, some fine to medium, medium light to medium dark gray (N 6 to N 4).	1	464.5
Clay, silty, dark gray (N 3).	0.5	465
Sand, very coarse, some fine to medium; becomes clayey at base of interval, medium dark gray (N 4).	1.3	466.3
No recovery.	0.7	467
Sand, medium to coarse, well-sorted, pale yellowish-brown (10 YR 6/2).	1	468
Sand, medium to coarse, well-sorted, grades to coarse and very coarse at base of interval; very light gray to light gray (N 8 to N 7).	2	470
No recovery.	2.5	472.5
Sand, coarse, ranges from fine to very coarse, very light brownish-gray (5 YR 7/1); many carbonaceous bands.	3.5	476
No recovery.	4	480
Cave-in of CH Bf 148		
Description of CH BF 149 (460 to 616 ft)		
Hole drilled to 460 ft.	460	460
No recovery.	7.7	467.7
Sand, medium to coarse, range silt to coarse, some silt laminae, light to medium olive-gray (5 Y 5/1 to 5 Y 3/1).	2.3	470
No recovery.	1	471
Sand, fine to medium, well-sorted; thin laminae, medium light gray (N 6); fine plant fragments in laminae and lenses.	2.9	473.9

Appendix D.—Continued

Lithology	Thickness (feet)	Depth (feet)
No recovery.	2.1	476
Sand, medium to coarse, some fine, light olive-gray (5 Y 5/1); large chunk of lignitic wood.	0.5	476.5
Sand, fine, silty, some clay, olive-black (5 Y 2/1).	0.5	477
No recovery.	4	481
Sand, medium in upper foot of interval, grades to coarse in lower 2 feet of interval, medium light gray (N 6); abundant blue quartz; some pyritized quartz.	3	484
No recovery.	4	488
Clay, silty, fine sand stringers; clay is dusky yellowish-brown (10 YR 2/2); sand is olive-gray (5Y 4/2), sand laminated with organic material, some pyrite-cemented zones, strong hydrogen sulfide and organic odor.	0.8	488.8
No recovery.	6.7	495.5
Sand, fine to medium, olive-gray (5 Y 4/1).	0.5	496
No recovery.	1	497
Sand, fine to medium, cemented, and loose gravel, very light to medium light gray (N 8 to N 6), and olive-gray (5 Y 4/1); small pebbles, some blue and rose quartz; (sample recovered from 496 to 500 ft, placed at 497 to 497.8 ft).	0.8	497.8
No recovery.	12.2	510
Sand, fine to medium, light olive-gray (5 Y 6/2); some coarse pebbles, chert and quartz (description of cuttings; no core recovery).	7	517
PATAPSCO FORMATION		
No recovery.	6.5	523.5
Clay, hard, light olive to olive-gray (5 Y 6/1 to 5 Y 3/1) (pebbles found in clay matrix probably were jammed into clay by core barrel).	0.5	524
Clay, with stringers of fine sand (mm scale), light olive-gray (5 Y 6/1) to olive-gray (5 Y 3/1), grades to gray-brown (5 YR 3/2) at base of interval.	5.5	529.5
Clay, silty, dark yellowish-brown (10 YR 4/2); abundant plant fragments.	0.5	530
Clay, silty, fine sand stringers, brownish-gray (5 Y 4/1), stiff.	4	534
No recovery.	2.5	536.5
Clay, silty, olive-gray (5 Y 4/1); organic streaks and inclusions, wood fragments at base of interval.	2.5	539
No recovery.	1.6	540.6
Clay, silty and clayey and medium sand, light olive-gray (5 Y 5/6).	3.9	544.5
Clay, silty, light olive-gray (5 Y 5/6).	1.5	546
Clay, fine sandy with thin beds of clayey, fine sand, mottled light gray (N 7), medium reddish-brown (10 R 4/6), and very pale orange (10 YR 8/2).	4	550
Clay, very hard, mostly medium reddish-brown (10 R 4/6), some light gray and pale orange as above.	1.5	551.5
No recovery.	0.3	551.8
Clay, stiff, mottled moderate reddish-brown (10 R 4/6), to light olive-brown (5 Y 5/6), and purple (5 P 4/2).	10	561.8
No recovery.	4.2	566

Appendix D.—Continued

Lithology	Thickness (feet)	Depth (feet)
Clay, with some granular quartz, mottled as above.	5.5	571.5
Clay, stiff, moderate brown (5 Y 4/4).	0.5	572
No recovery.	4	576
Clay, very hard, mottled light to dark brownish-red (5 Y 4/6 to 10 R 3/4) and light olive-gray (5 YR 5/1), with black, carbonaceous blebs and stringers.	2.5	578.5
No recovery.	7.5	586
Clay, with pockets and stringers of fine sand, dark reddish-brown (10 R 3/4), dark yellowish-brown (10 YR 4/2), moderate red (5 R 4/6), and a few medium gray (N 5) mottles.	10	596
Sand, fine, clayey, mica-bearing, light brownish-gray (5 YR 6/1).	0.5	596.5
Clay, stiff, mottled as above.	3.0	599.5
No recovery.	0.5	600
Clay, stiff, mottled dark yellowish-brown (10 YR 4/2), grayish-red (10 R 4/2).	1.5	601.5
Clay, stiff, olive-gray (5 Y 4/1); pyritized wood fragments.	4.5	606
Clay, silty, stiff, some fine silty sand and clayey sand in lower 2 feet of interval, mottled olive-gray (5 Y 4/1) and dark yellowish-brown (10 YR 4/2).	4	610
Clay, silty, stiff, mottled light olive-brown (5 Y 5/6) to dark reddish-brown (10 R 3/4).	4.6	614.6
Sand, fine, clayey, with silty clay, light olive-gray (5 Y 6/1).	1.4	616
Bottom of CH Bf 149 at 616 feet.		

*This log is a description of the core made at the drill site. Personnel of the U.S. Geological Survey who contributed to this description include: Margery Bugin, Frank Chapelle, Virginia M. Gonzales, and Lucy McCartan.

Appendix E.—Palynological and marine microfossil analyses of selected core samples (by Gilbert J. Brenner, State University of New York at New Paltz)

Well CH Be 57

Depth: 447 to 450 feet

Stage Determination: Zone V-VII, Turonian-Santonian
Stratigraphic Correlation: Lower Magothy Formation
Paleoecology: Nonmarine

Diagnostic Palynomorphs	Range (ACP)*	Frequency**
Spores and Pollen:		
Abietineaepollenites ornatus G & P	Zone IV (Raritan Formation)	R
Araucariacites australis	Common from Late Albian-Maestrichtian	C
Complexipollis sp. B Christopher, 1979	Zone V (upper Raritan Formation)	R
Labropollis sp. B Christopher, 1979	Zone V-VII	R
Plicapollis sp. 1 Christopher, 1979	Zone V-VII	R
Pinuspollenites spp.	Wide ranging	A
Pseudoplicapollis cuneata Christopher, 1979	Lower Zone VII	R
Rugubivesiculites reductus	Middle Albian-Maestrichtian	O
Rugubivesiculites rugosus	Late Albian-Maestrichtian	C
Tricolpites sp. B. Wolfe & Pakiser, 1971	Lower Zone VII (Magothy Formation)	R

Discussion

Several of the rarer forms found in this nonmarine sample are restricted to the South Amboy Fire Clay Member of the upper Raritan Formation of New Jersey and/or the Morgan beds of the Magothy Formation of New Jersey. The Normapolles are not abundant in this sample. The sample appears to be similar in age to the sample from well CH Bf 158 at 488 ft.

Depth: 635 feet

Stage Determination: Zone IIB, Middle Albian
Stratigraphic Correlation: Patapsco Formation
Paleoecology: Nonmarine

Diagnostic Palynomorphs	Range (ACP)	Frequency
Spores and Pollen:		
Appendicisporites tricornatus		R
Cicatricosisporites spp.	Wide ranging	A
Classopollis torosus	More abundant in Early Cretaceous	A
Cyathidites australis	Wide ranging	C
Pinuspollenites spp.	Wide ranging	C
Rugubivesiculites reductus	Middle Albian-Maestrichtian	O
Taurocusporites reduncus	Zone I-II	C
Tricolpites micromunus	Zone II-III	O

Discussion

The abundance of Classopollis and Cicatricosisporites is typical of Zones I-II assemblages in the Maryland Cretaceous. The most advanced angiosperm pollen grain found was the T. micromunus, a common form from Zone II which is not found in Zone I. Typical tricolporate forms that first appear in Zone III were not found in this sample.

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* ACP = Atlantic Coastal Plain

** R = Rare (<1%); O = Occasional (1-5%); C = Common (6-10%); A = Abundant (>10%)

Well Ch Bf 144

Depth: 404 to 405 feet

Stage Determination: Paleocene
Stratigraphic Correlation: Brightseat to Aquia Formations
Paleoecology: Marine

Diagnostic Plant Microfossils	Range (ACP)	Frequency
Land derived palynomorphs:		
Alnus sp.	Brightseat and Aquia Formations	R
Castanea sp.	Brightseat-Nanjemoy Formations	C
Casuarinidites cf. Sparsus	Danian-early Eocene	R
Nudopollis terminalis	Danian-Ypressian	R
Nudopollis thiergartii	Danian-late Paleocene	C
Thomsonipollis magnificoides	Maestrichtian-Ypressian	R
Triatripollenites marylandicus	Brightseat Formation	O
Trudopollis pertrudens	Paleocene-Eocene	R
Marine derived dinoflagellates:		
Exochosphaeridium complex	Severn Formation	R
Wetzerliella sp.	Danian-lower Miocene	R

Discussion

The stratigraphic range of the above pollen dates this sample as Paleocene. The Brightseat to Aquia Formation transition is still poorly defined in the palynological literature. Pollen of Alnus (called Pseudo-alnoid in AA De 100) was previously found in the AA De 100 well at 95-96 ft (Aquia) and 135-136 ft (Brightseat) (Mack, 1974).

Typical palynomorph assemblages from the Brightseat described by Groot and Groot (1962) and observed by this writer from the type Brightseat Formation do not appear in this sample; however, the zonation of the Danian-middle Paleocene part of the Atlantic Coastal Plain has not been palynologically established.

Depth: 426 to 427 feet

Stage Determination: Maestrichtian
Stratigraphic Correlation: Severn (Monmouth) Formation
Paleoecology: Marine

Diagnostic Plant Microfossils	Range (ACP)	Frequency
Land derived palynomorphs:		
(1) Extratriporopollenites nonperfectus	Santonian-Maestrichtian	C
(2) Sparganiaceaepollenites sp. Wanders	Maestrichtian	R
Marine derived palynomorphs:		
Deflandrea sp.	--	R

Discussion

Palynological recovery from this sample was very sparse. The few forms found (no. 1 and 2) are common constituents of the Navesink, Red Bank, and Tinton Formations of New Jersey. Correlative beds in Maryland are assigned to the Severn (Monmouth) Formation of Maestrichtian age.

Depth: 524 to 525 feet

Stage Determination: Santonian-Lower Campanian
Stratigraphic Correlation: Magothy Formation
Paleoecology: Nonmarine

Diagnostic Plant Microfossils	Range (ACP)	Frequency
Spores and Pollen:		
Araucariacites australis		C
Inaperturopollenites hiatus		A
Pinuspollenites spp.		C
Pseudoplicapollis longiannulatos	Magothy Formation	O
Rugubivesiculites rugosus	Albian-Maestrichtian	O
Tricolpopollenites micromunus	Albian-?	C
Tricolpopollenites minutus	Albian-?	C
(8) Tricolporites spp. (fig. 4, Wolfe and Pakiser)	Magothy Formation	R

Discussion

Recovery was sparse. Pseudoplicapollis longiannulatos has been reported from the South Amboy Clay Member of the Raritan Formation to the Morgan beds of the Magothy Formation of New Jersey by Christopher (1979). Wolfe and Pakiser (1971) described form no. 8 as Tricolporites spp. (fig. 4) from the Cliffwood beds of the Magothy Formation of New Jersey.

No marine palynomorphs were found in this sample.

Well CH Bf 144 - Continued

Depth: 624 to 625 feet

Stage Determination: Upper Albian
Stratigraphic Correlation: Patapsco Formation (Zone IIB-III?)
Paleoecology: Nonmarine

Diagnostic Plant Microfossils	Range (ACP)	Frequency
Spores and Pollen:		
Appendicisporites potomacensis	Zone I & II	R
Classopollis torosus	Zone I - Maestrichtian	O
Clavatipollènites minutus	Zone I-III	O
Podocarpidites potomacensis	Zone I & II	O
Taurocusporites reduncus	Zone IIA, B, & C	C
(6) Taurocusporites spackmani	Zone IIB & C	O
(7) Tricolpollenites micromunus	Zone IIB -?	O
Trilobosporites marylandensis	Zone I & II	R

Discussion

Species nos. 6 and 7 place this sample above Zone I (Barremian-Aptian). The sample contains the tricolpate form Tricolpopollenites micromunus which begins in Zone II and extends into Zone III. It is, however, more common in Zone II than in Zone III. The absence of typical Zone IIC forms (latest Albian) such as Tricolporopollenites distinctus and Tricolporopollenites triangulus do not permit me to designate a Zone IIC horizon. However, the sample is not rich in palynomorphs and in such a situation negative evidence may be more a factor of sample than age. The superpositon of this sample above the core sample at 881 feet, which contains some Zone IIC - III types, suggests Zone IIC or III.

Depth: 881 to 882 feet

Stage Determination: Middle to upper Albian (some contamination)
Stratigraphic Correlation: Patapsco Formation (Zone II-IIC?)
Paleoecology: Nonmarine - Lowland wooded Coastal Plain swamp indicated by high vitrain and Taxodiaceous and Classopollis grains.

Diagnostic Plant Microfossils	Range (ACP)	Frequency
Spores and Pollen:		
Abietineaepollenites microreticulatus	Zone I & II	O
Apiculatasporis babsae	Zone II & III	R
Araucariacites australis	Common above Zone I	C
Cingulatisporites eukirchensoides	Zone I & II	R
Classopollis torosus	Zone I - Maestrichtian	C
Clavatipollenites minutus	Most common in Zone IIB-C	C
Ephedripites multicostatus	Zone I & II	C
Eucommiidites troedsonii	Zone I - Maestrichtian	C
Inaperturopollenites hiatus	Zone II-III (rare in Zone III)	A
Tricolpopollenites micromunus	Zone II-III (rare in Zone III)	O
Tricolpites sp. B, Doyle (1975)	Zone IIB-III	R
Tricolpites minutus	Zone II-III	O
Tricolporoides sp. A, Doyle (1975)	Zone IIC-III	R
Tricolporopollenites distinctus	Zone IIC-III	R

Discussion

The presence of Zone IIC-III forms like Tricolporoides sp. A and Tricolporopollenites distinctus suggest Zone IIC-III. There appears, however, some uphole contamination in this core -- as indicated by the presence of a few grains of Cenozoic specimens of Carya.

Well CH Bf 146

Depth: 420 to 422 feet

Barren

Depth: 460 to 461 feet

Stage Determination: Maestrichtian
Stratigraphic Correlation: Monmouth Group of New Jersey
Paleoecology: Shallow water, marine shelf environment

Diagnostic Palynomorphs	Other Locality (ACP)***	Range at other (ACP) Locality	Frequency
Marine Microplankton:			
Adnatosphaeridium reticulense	NJ	Paleocene	O
Aeroligera senonensis	NJ	Coniacian to Maestrichtian	O
Australiella cooksoni	NJ	Maestrichtian to Paleocene	C
Baltisphaeridium cf. bifidum	--	Cenomian to Coniacian	C
Cornifera Oceanica	MD	Maestrichtian to Paleocene	R
Dinogymnium euclaensis	GB	Maestrichtian	R
Dinogymnium westralium	MD	Maestrichtian	C
Exochosphaeridium complex	MD	Maestrichtian	R
Fibradinium sp. A., Williams and Brideaux	GB	Maestrichtian	R
Spiniferites sp., Waanders	NJ	Maestrichtian	O
Svalbardella australina	MD	Maestrichtian to Paleocene	R
Spores and Pollen:			
Betulaceoipollenites sp.		Senonian-Paleocene	R
Densoisporites sp.		Early Cretaceous-Maestrichtian	R
Holkopollenites chemardensis		Maestrichtian-Paleocene	R
Maceopollenites sp.		Maestrichtian	R
Rugubivesiculites rugosus		Zone III - Maestrichtian	O
Tricolporopollenites distinctus		Zone III to Paleocene?	O

Discussion

Several species of dinoflagellates in this sample are restricted to the Maestrichtian from various localities in the Atlantic Coastal Plain. The whole assemblage is very similar to that described by Waanders (1974) in the Monmouth Group from Monmouth County, New Jersey.

Spores and pollen are a minor part of what is primarily a marine assemblage. The range of these types only places the sample in the Late Cretaceous. Typical Magothy triporate types are absent.

Depth: 461.5 feet

Barren

***Location symbols of Atlantic Coastal Plain localities of the dinoflagellates are:
GB = Grand Bank, Williams and Brideaux (1975); MD = Round Bay, Maryland, Benson (1976)
NJ = New Jersey, Waanders (1974).

Well CH Bf 146 - Continued

Depth: 461 to 462 feet

Stratigraphic Correlation: Same as the 460 to 461 foot core

Diagnostic Palynomorphs	Range
Spores and Pollen:	
Araucariacites australis	Jurassic-Cretaceous
Betulaceoipollenites sp.	Senonian-Paleocene
Cicatricosisporites spp.	Late Jurassic-Paleocene
Classopollis sp.	Late Triassic-Paleocene
Rugubivesiculites rugosus	Zone III-Maestrichtian
Tricolporopollenites distinctus	Zone III-Holocene
Tricopites micromunus	Zone II-Holocene
Tricolporopollenites triangularus	Zone III-?

Discussion

This sample was rich in amorphous organic material. The same small triporates found in the core from 460 to 461 feet occur in this core. No dinoflagellates were found.

Depth: 1,330 to 1,332 feet

Barren

Depth: 1,370 to 1,372 feet

Barren

Well CH Bf 158

Depth: 378 feet

Stage Determination: Paleocene
Stratigraphic Correlation: Brightseat and lower Aquia Formations
Paleoecology: Marine

Diagnostic Palynomorphs	Range (ACP)	Frequency
Spores and Pollen:		
Alnus sp.	Paleocene-Eocene	R
Carya sp.	Paleocene-Holocene	
Casuarinidites sp. Frederiksen, 1979	Paleocene (Aquia Formation)	R
Classopollis torosus	Barremian-Paleocene	O
Momipites flexus	Paleocene	R
Momipites tenuipolus	Paleocene-Eocene	C
Tricolporopollenites cingulum	Paleocene-Eocene	R
Dinoflagellates:		
Fibradinium annetropensa	Maestrichtian-Paleocene	C

Discussion

The palynomorph content of this sample is very sparse. Typical Maestrichtian Normapolles like Extratriporopollenites thornei and E. chemardensis are not present. Bisaccates with rugulate caps, as in the genus Rugubivesiculites, which are so common in the Monmouth Group and equivalents of New Jersey and Maryland, have not been found in this sample.

The diagnostic palynomorphs listed above suggest an age more compatible with the lower Paleocene. The common forms of Nudopollis that are commonly found at levels higher in the Aquia and Nanjemoy Formations were not found in this sample. The pollen of Carya found in this sample has not been seen in older Cretaceous horizons.

Well CH BF 158

Depth: 408 feet

Stage Determination: Maestrichtian
Stratigraphic Correlation: Severn Formation (Monmouth Formation of New Jersey)
Paleoecology: Marine

Diagnostic Palynomorphs	Range (ACP)	Frequency
Spores and Pollen:		
Holkopollenites chemardensis	Maestrichtian	O
Pinuspollenites spp.	Wide ranging	C
Rugubivesiculties convolutus	Maestrichtian	C
Rugubivesiculites rugosus	Late Albian-Maestrichtian	O
Dinoflagellates:		
Areoligera senonensis	Maestrichtian	O
Exochosphaeridium sp. complex	Maestrichtian	C
Svalbardella australina	Maestrichtian-Danian	O

Depth: 458 feet

Stage Determination: Santonian
Stratigraphic Correlation: Magothy Formation
Paleoecology: Nonmarine

Diagnostic Palynomorphs	Range (ACP)	Frequency
Spores and Pollen:		
Type CP3C-2 Wolfe, 1976	Campanian (Englishtown Formation of New Jersey)	R
Complexipollis spp.	Turonian-Campanian	C
Complexipollis sp. D Christopher, 1979	Turonian-Santonian	R
Momipites sp. E Christopher, 1979	Santonian	R
Pinuspollenites spp.	Wide ranging	A
Podocarpidites spp.	Wide ranging	C
Pseudoplicapollis spp.	Turonian-Santonian	O
Stereisporites congruens Wand.	Maestrichtian	C
Tricolporopollenites triangulus	Late Albian-Santonian	R

Depth: 488 feet

Stage Determination: Zone V-VII, Turonian-Santonian
Stratigraphic Correlation: Lower Magothy Formation
Paleoecology: Nonmarine

Diagnostic Palynomorphs	Range (ACP)	Frequency
Spores and Pollen:		
Araucariacites australis	Common from Late Albian-Maestrichtian	O
Complexipollis exiqua Christopher, 1979	Turonian-Coniacian	C
Complexipollis sp. C Christopher, 1979	Turonian (Zone V)	C
Rugubivesiculites rugosus	Late Albian-Maestrichtian	C
Tricolporopollenites triangulus	Late Albian-Santonian	C

Discussion

The number of palynomorphs recovered from this sample is poor. My age determination is based on the reasoning that the sample must be younger than Zone III because of the presence of two species of Complexipollis and older than typical Magothy Formation of late Santonian age because it lacks the more highly developed Normapolles, i.e., Plicapollis and Trudopollis of the upper Magothy Formation.

Depth: 532 feet

Barren

Appendix F.—Palynological and marine microfossil analyses from core holes CH Bf 148 and CH Bf 149 (by George W. Andrews and Laurel M. Bybell, U.S. Geological Survey and Gilbert J. Brenner, State University of New York at New Paltz)

Diatom analyses by George W. Andrews, U.S. Geological Survey, Reston, Va.

Depth: 101 feet - U.S.G.S. diatom locality 7295

Marker Diatoms
Delphineis ovata
Rhaphoneis margaritata
Rhaphoneis scalaris
Sceptroneis caduceus

Discussion

These diatoms are indicative of East Coast Diatom Zone 2 of Andrews (1978), and they suggest correlation with beds ranging in age from the upper part of Lithologic Unit 3 of Shattuck (1904), as it is exposed along Chesapeake Bay, to the lower part of Lithologic Unit 8 also exposed in the same area, and all within the Calvert Formation. This part of the Calvert Formation is from late early Miocene to early middle Miocene age.

Depth: 131 feet - U.S.G.S. diatom locality 7296

Marker Diatoms
Actinoptychus heliopelta
Rhaphoneis fossile
Rhaphoneis margaritata
Sceptroneis caduceus

Discussion

These diatoms are indicative of East Coast Diatom Zone 1 of Andrews (1978). Actinoptychus heliopelta and Rhaphoneis fossile are especially definitive of this Zone.

These diatoms suggest correlation with the lower part of Lithologic Unit 3 as defined by Shattuck (1904) which is exposed near Dunkirk on the Patuxent River in Maryland but not along Chesapeake Bay. Shattuck did not understand that a substantial hiatus (about 3 million years) occurred between the deposition of what he termed "Zone 3" on the Patuxent River and what he termed "Zone 3" on Chesapeake Bay. This older part of the Calvert Formation is approximately middle early Miocene in age.

The occurrence of East Coast Diatom Zone 1 in this well is important in that it extends the known occurrence of this zone approximately 13 miles southwestward from previously known deposits of this age along the Patuxent River.

Calcareous nannofossil analyses by Laurel M. Bybell, U.S. Geological Survey, Reston, VA

Depth: 137.3 feet

Age: Early Eocene, probably Zone NP11 of Martini, 1971)
Formation: Nanjemoy
Abundance: 1 specimen per 1-5 fields of view
Preservation: Fair

Diagnostic Species
Toweius occultatus
Transversopontis pulcher
Tribrachiatus orthostylus

Depth: 156.3 feet

Age: Early Eocene, probably Zone NP11
Formation: Nanjemoy
Abundance: 1 specimen per 1-5 fields of view
Preservation: Fair

Diagnostic Species
Toweius occultatus
Transversopontis pulcher
Tribrachiatus orthostylus

Depth: 205.2 feet

Age: Early Eocene, Zone NP10

Formation: Nanjemoy
Abundance: 1-5 specimens per field of view
Preservation: Poor

Diagnostic Species
Ellipsolithus macellus
Neochiastozygus junctus
Transversopontis pulcher
Tribrachiatus bramlettei

Depth: 213 feet

Age: Early Eocene, Zone NP10
Formation: Nanjemoy
Abundance: 5-10 specimens per field of view
Preservation: Pretty good

Diagnostic Species
Discoaster mediosus
Discoaster multiradiatus
Tribrachiatus bramlettei

Appendix F.—Continued

Depth: 215 feet

Age: Early Eocene, Zone NP10
Formation: Nanjemoy
Abundance: 1-5 specimens per field of view
Preservation: Fair

Diagnostic Species
Discoaster mediosus
Discoaster multiradiatus
Ellipsolithus distichus
Transversopontis pulcher
Zygrhablithus bijugatus

Depth: 217.7 feet
Age: Early Eocene, Zone NP10
Formation: Nanjemoy
Abundance: 1-5 specimens per field of view
Preservation: Fair

Diagnostic Species
Discoaster mediosus
Discoaster multiradiatus
Ellipsolithus distichus
Fasciculithus tympaniformis
Neochiastozygus junctus
Toweius craticulus
Transverspopontis pulcher
Tribrachiatus bramlettei
Zygodiscus herlyni
Zygrhablithus bijugatus

Depth: 218.3 feet

Age: Early Eocene, Zone NP10.
Formation: Nanjemoy
Abundance: 5-10 specimens per field of view
Preservation: Fair

Diagnostic Species
Discoaster mediosus
Discoaster multiradiatus
Ellipsolithus distichus
Fasciculithus tympaniformis
Neochiastozygus junctus
Toweius craticulus
Toweius eminens
Transversopontis pulcher
Tribrachiatus bramlettei
Zygodiscus herlyni

Depth: 219 feet

Barren of calcareous nannofossils.

Depth: 220.3 feet

Age: Late Paleocene, Zone NP9
Formation: Marlboro Clay
Abundance: 1 specimen per 5-10 fields of view
Preservation: Fair

Diagnostic Species
Discoaster multiradiatus
Neochiastozygus junctus
Toweius craticulus

Depth: 249.3 feet

Barren of calcareous nannofossils.

Depth: 251 feet

Age: Late Paleocene, Zone NP9
Formation: Aquia
Abundance: 1-5 specimens per field of view
Preservation: Pretty good

Diagnostic Species
Discoaster multiradiatus
Zygodiscus herlyni

Depth: 307 feet

Age: Late Paleocene, Zone NP8
Formation: Aquia

Diagnostic Species
Heliolithus cantabriae
Heliolithus riedeli

Depth: 359.2 feet

Age: Late Paleocene, probably Zone NP5
Formation: Aquia
Abundance: 1-5 specimens per field of view
Preservation: Pretty good

Diagnostic Species
Chiasmolithus bidens
Ellipsolithus distichus
Fasciculithus billii?
Toweius craticulus

Depth: 378 feet

Age: Late Paleocene, probably Zone NP5
Formation: Aquia
Abundance: 5-10 specimens per field of view at 500 x magnification
Preservation: Pretty good

Diagnostic Species
Chiasmolithus bidens
Cruciplacolithus tenuis
Ellipsolithus distichus
Fasciculithus sp.
Neochiastozygus concinnus

Depth: 394 feet

Age: Early Paleocene, Danian, Zone NP3
Formation: Brightseat
Abundance: 5-10 specimens per field of view at 500 x magnification
Preservation: Good

Diagnostic Species
Chiasmolithus danicus
Cruciplacolithus tenuis
Ericsonia subpertusa
Neococcolithes protenus
Placozygus sigmoides

Depth: 401 feet

Barren of calcareous nannofossils.

Depth: 410 feet

Barren of calcareous nannofossils.

Palynological and Dinoflagellate analyses by Gilbert J. Brenner, State University of New York (at New Paltz)

Depth: 394.3 feet

Stage Determination: Danian
Stratigraphic Correlation: Brightseat
Paleoecology: ? Marine

Diagnostic Palynomorphs	Range (ACP)*	Frequency**
Spores and Pollen:		
(1) Araucariacites australis	Neocomian-?Maestrichtian	O
Castanea types common from:	Paleocene-Eocene	O
Casuarinidites sparsus	Danian-Ypresian	R
Holkopollenites chemardensis	Maestrichtian-Paleocene	R
Nyssa sp. (Fairchild & Elsik, fig. 49)	Paleocene	R
(6) Rugubivesiculites rugosus	Late Albian-Maestrichtian	A
Unidentified dinoflagellate fragment		

Discussion

This sample contains what I believe to be reworked Cretaceous palynomorphs (nos. 1 & 6) mixed with forms like Holkopollenites chemardensis and Casuarinidites sparsus which are more typical of the lower Paleocene. Characteristic palynomorphs of the Aquia Formation, such as Nudopollis thiergarti and Trudopollis pertrudens, are not present.

Depth: 403.4 feet

Stage Determination: Maestrichtian
Stratigraphic Correlation: Severn Formation (Monmouth)
Paleoecology: Offshore Marine

Diagnostic Palynomorphs	Range	Frequency
Spores and Pollen:		
Pinuspollenites spp.	--	A
Rugubivesiculites rugosus	Late Albian-Maestrichtian	C
Dinoflagellates:		
Areoligera senonensis	Maestrichtian	O

Discussion

The diversity of palynomorphs in this sample is extremely poor. Bisaccate pinaceous grains dominate the assemblage with few other kinds of land derived palynomorphs present.

Areoligera senonensis in association with almost exclusively bisaccates has been interpreted by Waanders (1974) as indicative of offshore conditions in the Monmouth Group of New Jersey. A. senonensis is typical of the Maestrichtian of the Atlantic Coastal Plain.

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* ACP = Atlantic Coastal Plain

** R = Rare (<1%); O = Occasional (1-5%); C = Common (6-10%); A = Abundant (>10%)

Depth: 426.5 feet

Stage Determination: Maestrichtian
Stratigraphic Correlation: Severn Formation (Monmouth)
Paleoecology: Offshore Marine

Diagnostic Palynomorphs	Range (ACP)	Frequency
Spores and Pollen:		
Pinuspollenites spp.	Late Albian-Maestrichtian	A
Rubivesiculites rugosus	Late Albian-Maestrichtian	C
Dinoflagellates:		
Areoligera senonensis	Maestrichtian	O
Deflandrea sp.	--	R

Discussion

This sample is similar to the core at 403.4 feet.

Depth: 437.9 feet

Stage Determination: Maestrichtian
Stratigraphic Correlation: Severn Formation (Monmouth)
Paleoecology: Marine

Diagnostic Palynomorphs	Range (ACP)	Frequency
Spores and Pollen:		
4. Type NP-2	Campanian-Maestrichtian	R
Plicapollis sp.	Campanian-Maestrichtian	R
Rugubivesiculites rugosus	Late Albian-Maestrichtian	C
Tricolporopollenites cingulum	Maestrichtian-Tertiary	O
Dinoflagellates:		
Genus B of Benson 1976	Maestrichtian Range Top	O
Chatangiella robusta	Maestrichtian Range Top	R
Deflandrea cooksonii	Maestrichtian	A
Microdinium setosum	Maestrichtian Range Top	R

Depth: 450.5 feet

Stage Determination: ? Lower Campanian
Stratigraphic Correlation: ? Upper Magothy Formation
Paleoecology: Nonmarine to Marine

Diagnostic palynomorphs	Range (ACP)	Frequency
Spores and Pollen:		
(1) Type CP3 B-1 (Wolfe, 1976)	Campanian	R
(2) Type CP3 B-3 (Wolfe, 1976)	Campanian	R
Pseudoplicapollis endocuspis	Coniacian-Paleocene	C
Rugubivesiculites reductus	Middle Albian-Maestrichtian	C
Rugubivesiculites rugosus	Late Albian-Maestrichtian	A
Tricolporpollenites triangulus	Late Albian- ?	C

Discussion

Palynomorphs in this sample are very sparse; however, types nos. 1 & 2 suggest a Campanian age. A few rare dinoflagellate fragments indicate some marine influence.

Appendix F.—Continued

Depth: 457.9 feet

Stage Determination: Santonian
Stratigraphic Correlation: Magothy Formation
Paleoecology: Nonmarine

Diagnostic Palynomorphs	Range (ACP)	Frequency
Spores and Pollen:		
Araucariacites australis	Cretaceous-Holocene	A
Cicatricosisporites hallei	Cretaceous-Paleogene	O
Pinuspollenites sp.	Cretaceous-Holocene	C
(4) Tricolporites sp. q of Wolfe & Pakiser, 1971	Santonian-Campanian	O
(5) Tricolporites sp. type a.a. fig. 4z, in Wolfe & Pakiser, 1971	Santonian	O
Tricolporites distinctus	Late Albian- ?	C
Tricolporpollenites triangulus	Late Albian- ?	C
Rugubivesiculites rugosus	Late Albian-Maestrichtian	A

Discussion

Palynomorph recovery in this sample was very poor. Species nos. 4 & 5 have only been reported from the Amboy Stoneware Clay Member of the Magothy Formation of New Jersey by Wolfe and Pakiser (1971). Typical Normapolles of the Magothy and Raritan Formations of New Jersey were not found.

Depth: 488.2 feet

Stage Determination: Santonian
Stratigraphic Correlation: Magothy Formation
Paleoecology: Nonmarine

Diagnostic palynomorphs	Range (ACP)	Frequency
Spores and Pollen:		
Araucariacites australis	Cretaceous-Holocene	A
Complexipollis sp. in Christopher, 1979	Turonian-Santonian	O
Clavatipollenites minutus	Barremian-Santonian	O
Clavatipollenites tenellis Doyle & Robbins, 1977	Barremian-Santonian	O
Labrapollis sp. B Christopher, 1979	Turonian-Santonian	R
Pseudoplicapollis sp. B Christopher, 1979	Turonian-Santonian	O
Rugubivesiculites rugosus	Late Albian-Maestrichtian	A
Tricolporpollenites triangulus	Late Albian- ?	C
Ticolpites micromunus	Albian- ?	O

Depth: 526.9 feet

Stage Determination: Cenomanian
Stratigraphic Correlation: Zone III, "Raritan" of Maryland, fire clay at the base of the Raritan Formation
Paleoecology: Nonmarine

Diagnostic Palynomorphs	Range (ACP)	Frequency
Spores and Pollen:		
Cicatricosisporites patapscoensis	Zone IIB-III	O
Psilatriletes circumundulatus	Zone I-III	R
Retimonocolpites peroreticulatus	Barremian-Cenomanian	O
Rugubivesiculites reductus	Middle Albian-Maestrichtian	C
(5) Rugubivesiculites rugosus	Late Albian-Maestrichtian	A
Taurocusporites reduncus	Zone II-III	O
Tricolpites micromunus	Zone II-VI	O
Tricolpites cf. vulgaris, Doyle & Robbins, 1977	Zone III, late Albian	O
(9) Tricolpopollenites sp. A in Doyle & Robbins, 1977	Zone III, late Albian	O

Discussion

This sample contains several forms that are characteristic of the Patapsco Formation of Maryland and lacks the triporate grade of angiosperm evolution that begins in Zone IV of the Raritan Formation of New Jersey and develops extensively in the Magothy Formation. Species nos. 5 & 9 first appear in Zone III (Doyle & Robbins, 1977). In New Jersey the horizon correlative with this sample is the fire clay at the base of the Raritan Formation.

Depth: 537.3 feet

Stage Determination: Upper Albian
Stratigraphic Correlation: Zone IIC Elk Neck horizon of the Patapsco Formation
Paleoecology: Nonmarine

Diagnostic Palynomorphs	Range (ACP)	Frequency
Spores and Pollen:		
Appendicisporites potomacensis	Zones I-IIC	R
Araucariacites australis	More common above Zone I	R
Clavatipollenites minutus	Zones I-III	O
Parvisaccites amplus	Zones I-IIC	R
Podocarpidites epistratus	Zone IIB	R
Podocarpidites radiatus	Zones I-III	O
Rugubivesiculites reductus	Zones IIB-Maestrichtian	O
Tricolpites micromunus	Zones IIB-III	R
Tricolpites minutus	Zones IIB-III	R
Tricolporopollenites triangulus	Zones IIC-VII	O

Discussion

Palynomorphs in this sample represent a typical Patapsco suite. Zone IIC is the upper part of the Potomac Group and contains a transition microflora to the Maryland "Raritan" (Zone IV) which has been identified in the Elk Neck area. The occasional occurrence of Tricolpopollenites triangulus distinguishes this zone from Zone II.

Depth: 577.9 feet

Stage Determination: Middle Albian
Stratigraphic Correlation: Zone IIB of the Patapsco Formation
Paleoecology: Nonmarine

Diagnostic palynomorphs	Range (ACP)	Frequency
Spores and Pollen:		
Appendicisporites potomacensis	Zones I-IIC	C
Appendicsporites tricornatatus	Zones I-II	R
Cicatricosisporites aralica	Zones I-II	O
Ephedripites patapscoensis	Zone IIB	R
Lycopodiacidites cristatus	Zones I-II	R
Parvisaccites radiatus	Zones I-II	R
Rugubivesiculites reductus	Zones IIB-Maestrichtian	C
Tricolpites micromunus	Zones II-III	O

Depth: 606.0 feet

Stage Determination: Middle Albian
Stratigraphic Correlation: Zone IIB of the Patapsco Formation
Paleoecology: Nonmarine

Diagnostic Palynomorphs	Range (ACP)	Frequency
Spores and Pollen:		
Appendicisporites potomacensis	Zones I-IIC	C
Cicatricosisporites brevilaesuratus	Zones I-II	C
Rugubivesiculites reductus	Zones IB-Maestrichtian	C
Tricolpites crassimurus	Zones II-III	C

Appendix G.—Chemical analyses of water from selected wells in Charles and southern Prince Georges Counties, Maryland

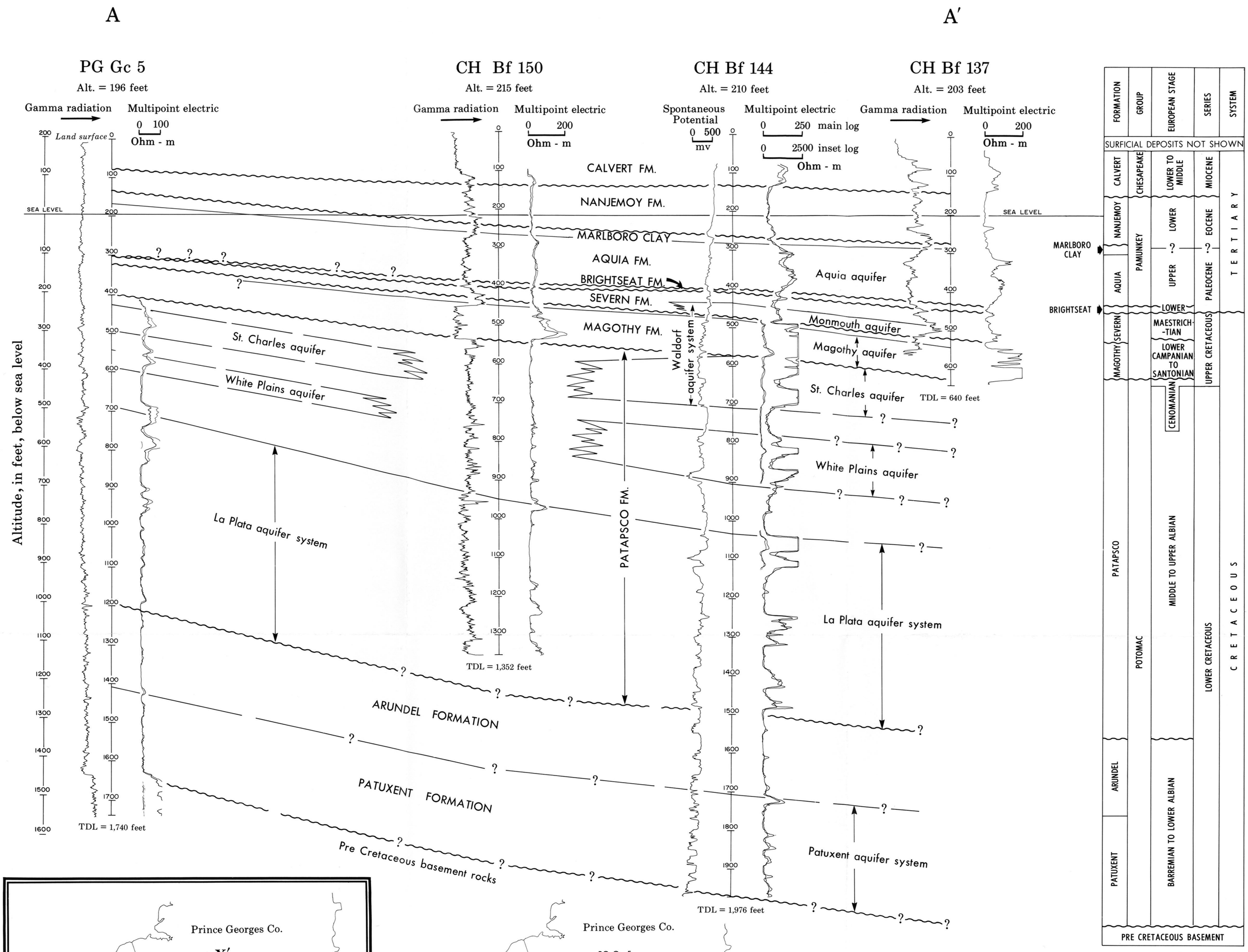
[mg/L = milligrams per liter; ug/L = micrograms per liter; uS/cm = microsiemens per centimeter]

Well Number		Aquifer or aquifer system	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Iron (dis-solved)	Iron (total) (ug/L)	Manganese (dissolved) (ug/L)*	Silica (mg/L)	Chloride (mg/L)	Fluoride (mg/L)
CH Bd	46	La Plata	0.6	0.3	95	3.7	219	450	24	33	2.9	1.4
CH Be	25	Surficial	53	5.4	54	9.8	--	490	10 (t)	8.8	48	0.2
CH Be	42	Waldorf	24	8.2	15	9.3	21	140	12	9.9	1.2	0.2
CH Be	48	Waldorf White Plains	35	12	16	11	260	440	32	10	1.2	0.2
CH Be	57	Patuxent	1.4	.52	180	2.8	680	2600	29	40	37.0	0.8
CH Be	58	La Plata	0.9	.30	70	2.6	31	60	18	38	1.9	1.0
CH Be	60	White Plains	2.5	1.0	64	6.1	85	610	29	10	1.6	0.5
CH Bf	15	Monmouth	44	15	6.3	9.9	--	800	--	16	1.2	0.1
CH Bf	113	Surficial	19	2.8	14	3.8	--	430	30 (t)	7.8	17	0.1
CH Bf	141	Waldorf	29	12	11	10	--	530	20 (t)	8.8	2.2	0.3
CH Bf	142	Magothy	36	13	8.8	11	540	550	30	11	1.0	0.2
CH Bf	144	Waldorf	29	9.7	10	9.0	300	450	21	9.7	0.9	0.3
CH Bf	145	Waldorf	37	13	7.0	11.0	390	580	30	12	1.3	0.2
CH Bf	146	La Plata	.48	.11	64	1.5	65	--	12	33	2.1	0.9
CH Bf	147	La Plata	.24	.19	66	1.6	140	--	17	83	2.6	0.9
CH Bf	150	La Plata	.21	.12	56	1.0	7	200	2	21	4.0	0.4
CH Bf	151	St. Charles	26	9.1	20.0	12.0	350	500	24	9.7	0.9	0.2
CH Bf	157	St. Charles	25	8.8	24.0	12.0	500	550	20	9.3	1.2	0.2
CH Bf	158	St. Charles	11	4.6	35.0.	8.0	530	560	10	9.9	0.7	0.4
CH Ce	37	La Plata	.20	.10	70.0	1.7	--	360	<10 (t)	37.0	2.1	1.2
CH Ce	51	La Plata	.26	.11	90	1.6	110	170	4	39.0	2.3	0.8
CH Cg	1	Aquia	29	13.0	5.3	14.0	--	2400	--	10.0	1.4	0.1
CH Cg	13	Aquia	32	9.2	8.5	12.0	--	170	<5 (t)	15.0	1.2	0.3
CH Cg	18	Magothy	19	7.8	27.0	11.0	--	740	20 (t)	8.6	0.1	0.4
CH Ch	14	Aquia	23	12	8.7	14	80	140	<1	14	0.9	0.2
PG Fc	22	Aquia	26	10	3.4	9.0	--	120	10 (t)	13	0.7	0.1
PG Ge	12	Aquia	34	14	3.6	11.0	--	290	<5 (t)	12	0.2	<0.1

*Exceptions: (l) denotes laboratory measured value;
(c) denotes calculated value;
(t) denotes total value.

Sulfate (mg/L)	Alkalinity (field) (mg/L as CaCO3)	Hardness (mg/L as CaCO3)	pH (field) (pH units)	Specific conductance (field) (uS/cm)*	Dissolved solids (mg/L)*	Water temper-ature (°C)	Date sampled (month/year)	Well Number
12	205	3	7.4	410	296	18.1	06/86	CH Bd 46
110	82	150	6.8	609	403	14.5	03/61	CH Be 25
12	129	94	8.0	290	156	--	10/84	CH Be 42
6.8	184	140	7.8	364	187	16.5	10/84	CH Be 48
10	310	6	7.8	730	459 (c)	23.0	06/85	CH Be 57
16	134	4	7.6	350	210	21.0	08/85	CH Be 58
7.7	140	10	7.4	310	181	17.0	04/86	CH Be 60
7.3	182	170	8.0	354	196	--	01/47	CH Bf 15
17.0	46	59	6.6	202	118	--	03/61	CH Bf 113
8.2	152	120	7.4	--	173 (c)	17.0	01/76	CH Bf 141
7.5	160	140	7.6	318 (l)	190	12.0	03/78	CH Bf 142
7.0	141	110	7.8	310	152	18.0	10/84	CH Bf 144
9.1	168	150	7.8	345	186	18.0	10/84	CH Bf 145
11	135 (l)	2	8.0	260	204	23.0	12/83	CH Bf 146
9.3	132 (l)	1	7.4	270	304	22.0	02/84	CH Bf 147
23	100	1	8.3	245	183	22.5	07/85	CH Bf 150
9.4	150	100	7.5	335	163	15.0	03/86	CH Bf 151
8.5	157 (l)	99	8.2	300	188	19.0	09/86	CH Bf 157
9.9	130	47	8.5	260	160	19.0	09/86	CH Bf 158
17	121	1	7.7	275	202 (c)	--	11/75	CH Ce 37
14	174	1	7.6	385	265	22.8	11/84	CH Ce 51
12	143	130	7.7	298	163	18.5	10/46	CH Cg 1
11	138	120	7.6	292	159	15.5	03/61	CH Cg 13
6.3	139	80	7.4	--	163 (c)	19.5	01/75	CH Cg 18
8.3	130 (l)	110	7.7	290	162	17.0	03/81	CH Ch 14
7.4	113	110	8.0	231	142	15.0	06/63	PG Fc 22
11.0	152	140	7.8	301	174	15.5	06/63	PG Ge 12

PLATE 1.—Hydrogeologic section A-A'



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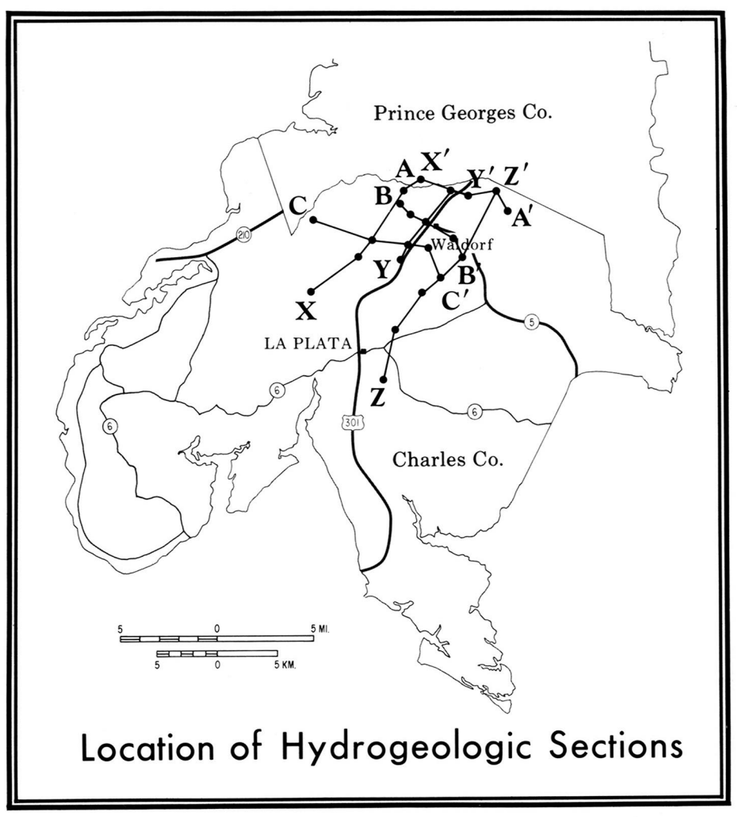
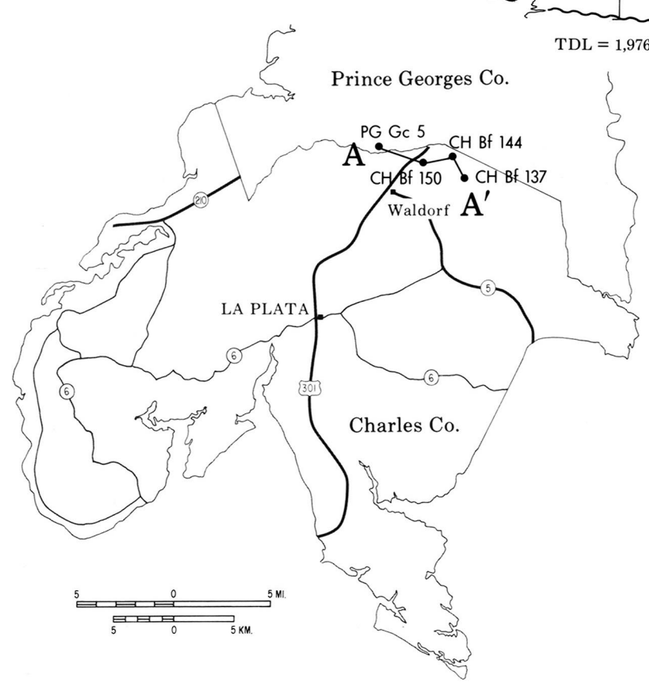
Maryland Geological Survey



Location of Hydrogeologic Sections



Location of Hydrogeologic Section

EXPLANATION

—?— Unconformity, queried where uncertain.

—?— Line of correlation

TDL Total depth logged

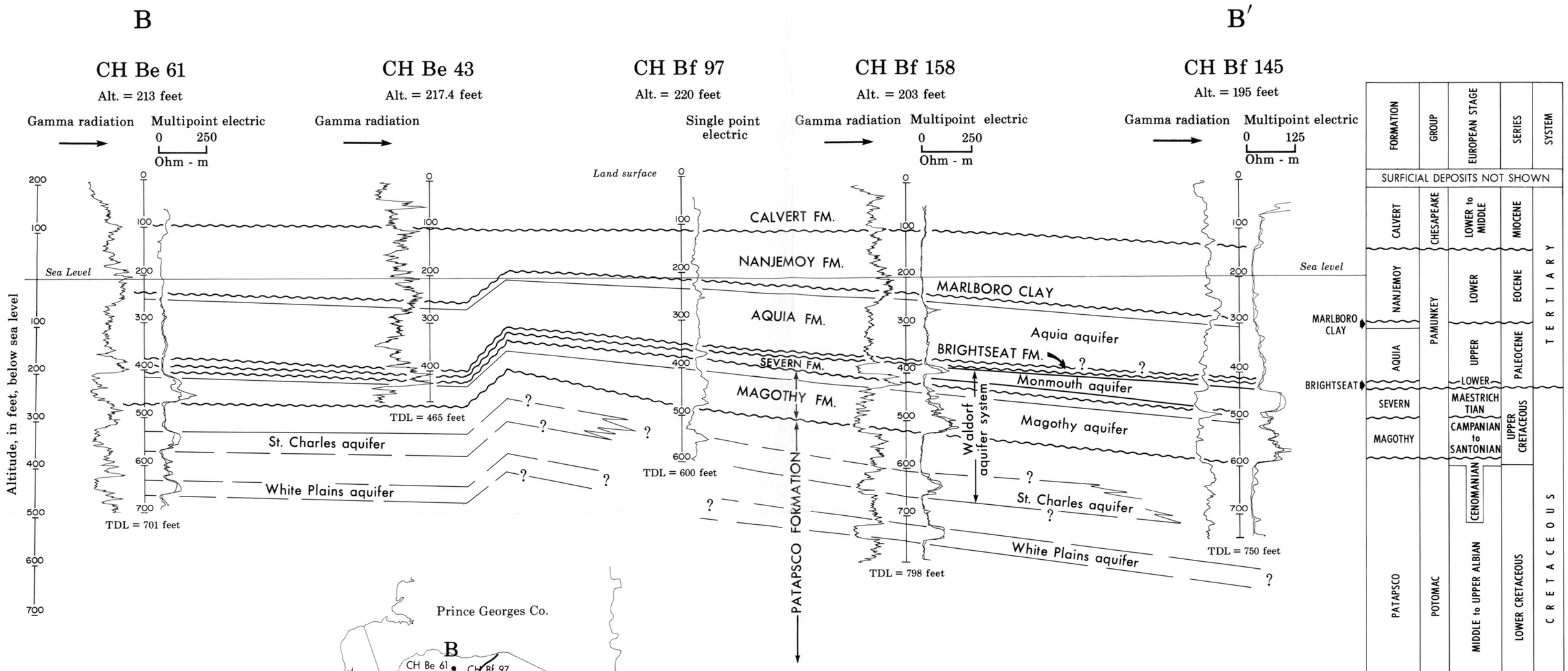
SCALE

0 1 2 *Miles*

0 .5 1 2 3 *Kilometers*

vertical exaggeration x 13

PLATE 2.—Hydrogeologic section B-B'



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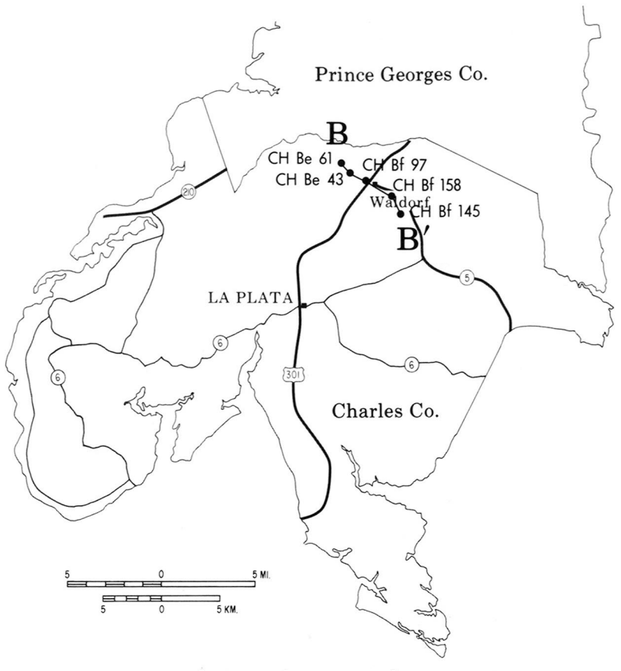


Location of Hydrogeologic Section

EXPLANATION

~?~ Unconformity, queried where uncertain.

—?— Line of correlation

TDL Total depth logged

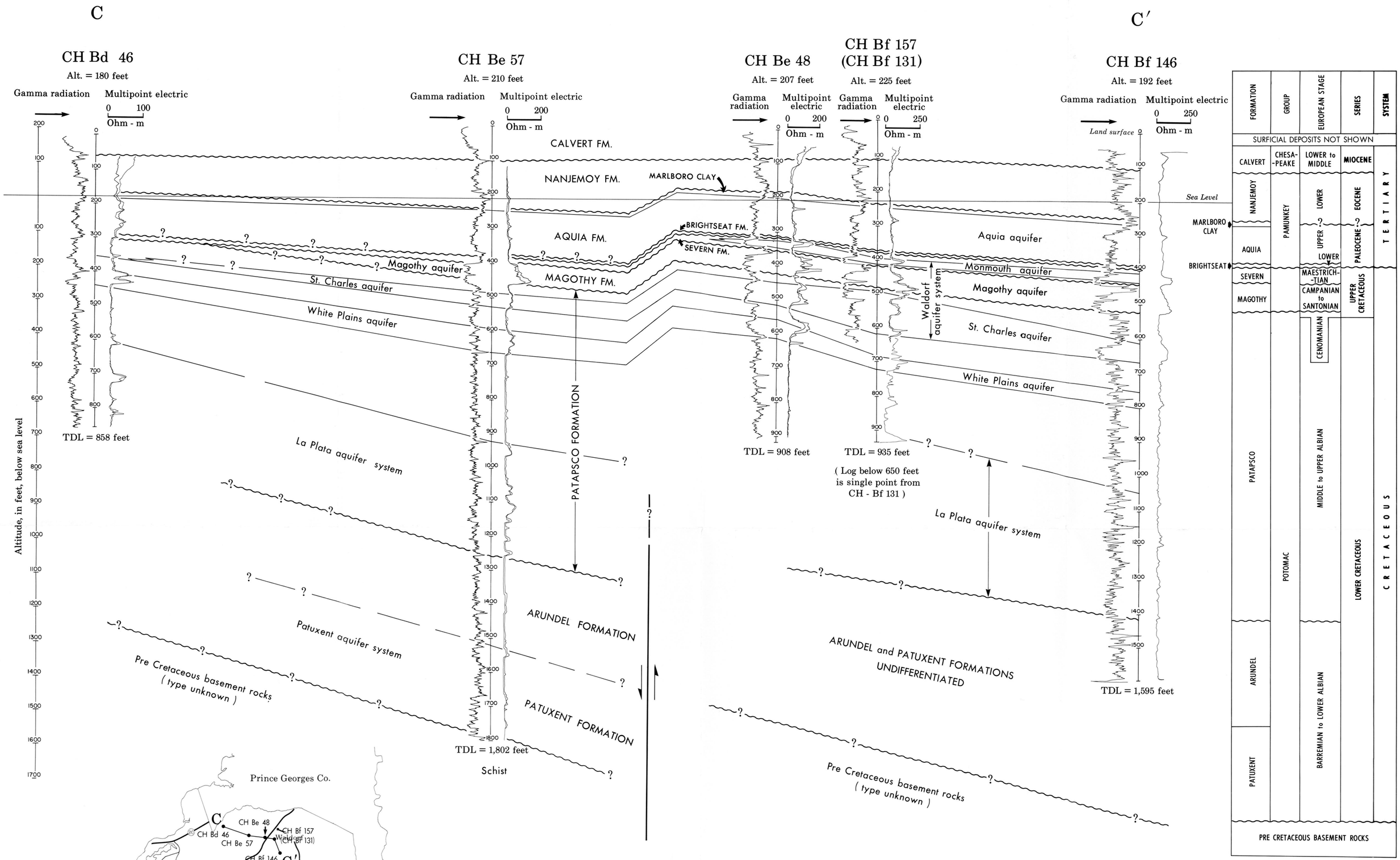
SCALE

0 1 2 *Miles*

0 .5 1 2 3 *Kilometers*

vertical exaggeration x 13

PLATE 3.—Hydrogeologic section C-C'



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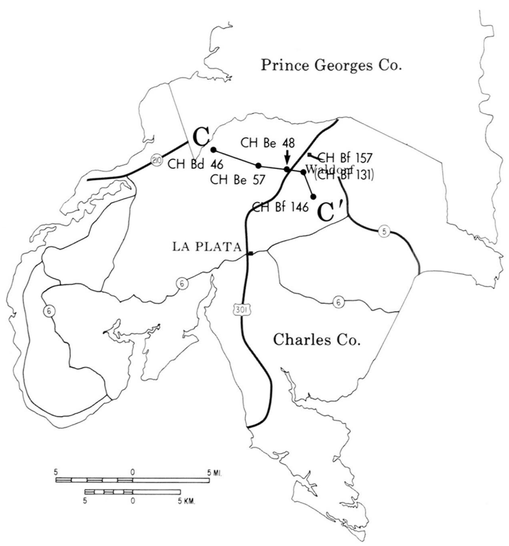


Location of Hydrogeologic Section

EXPLANATION

~?~ Unconformity, queried where uncertain.

—?— Line of correlation

TDL Total depth logged

Fault showing relative movement

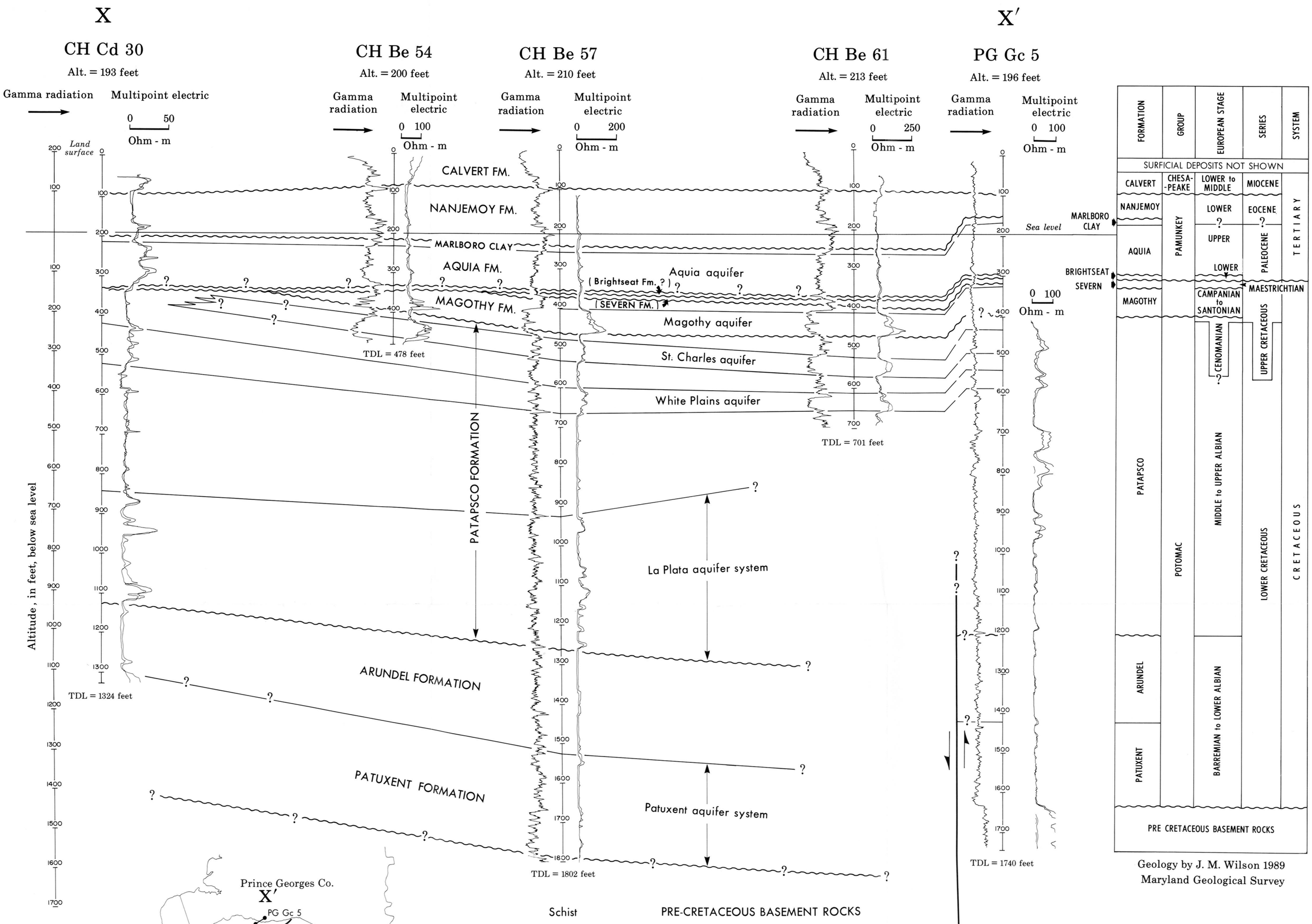
SCALE

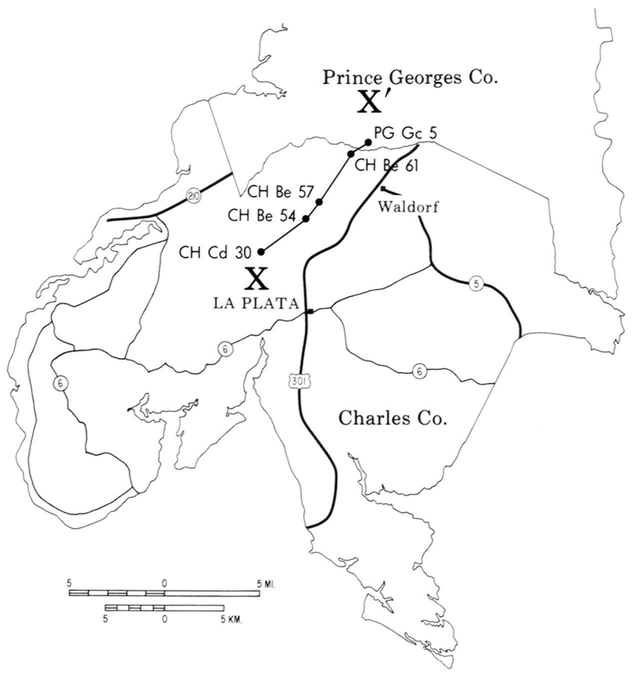
0 1 2 Miles

0 .5 1 2 3 Kilometers

vertical exaggeration x 13

PLATE 4.—Hydrogeologic section X-X'





Location of Hydrogeologic Section

SCALE

0 ½ 1 2 3 *Miles*

0 .5 1 2 3 4 *Kilometers*

vertical exaggeration x 20

EXPLANATION

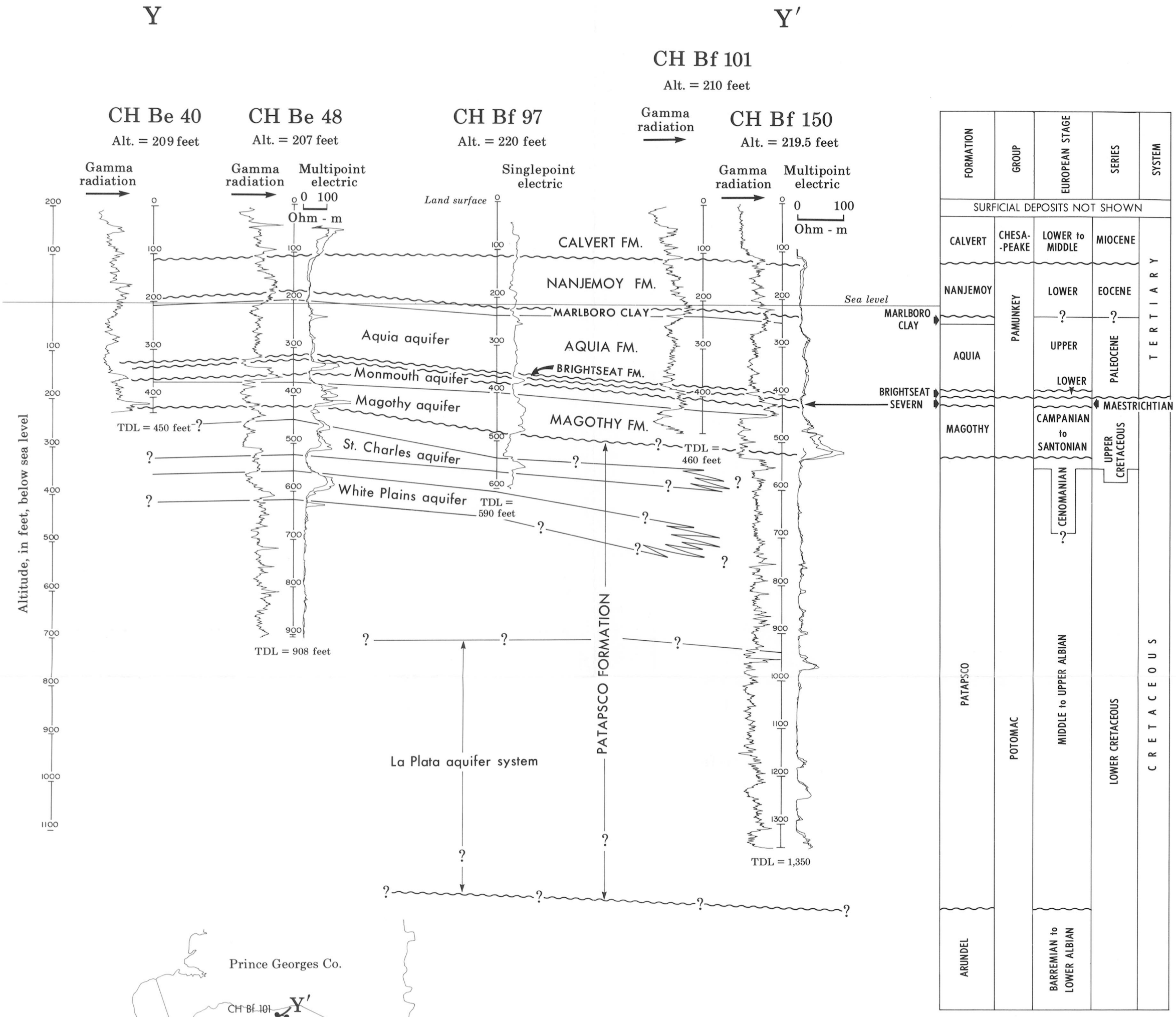
~?~ Unconformity, queried where uncertain.

—?— Line of correlation

TDL Total depth logged

Fault showing relative movement

PLATE 5.—Hydrogeologic section Y-Y'



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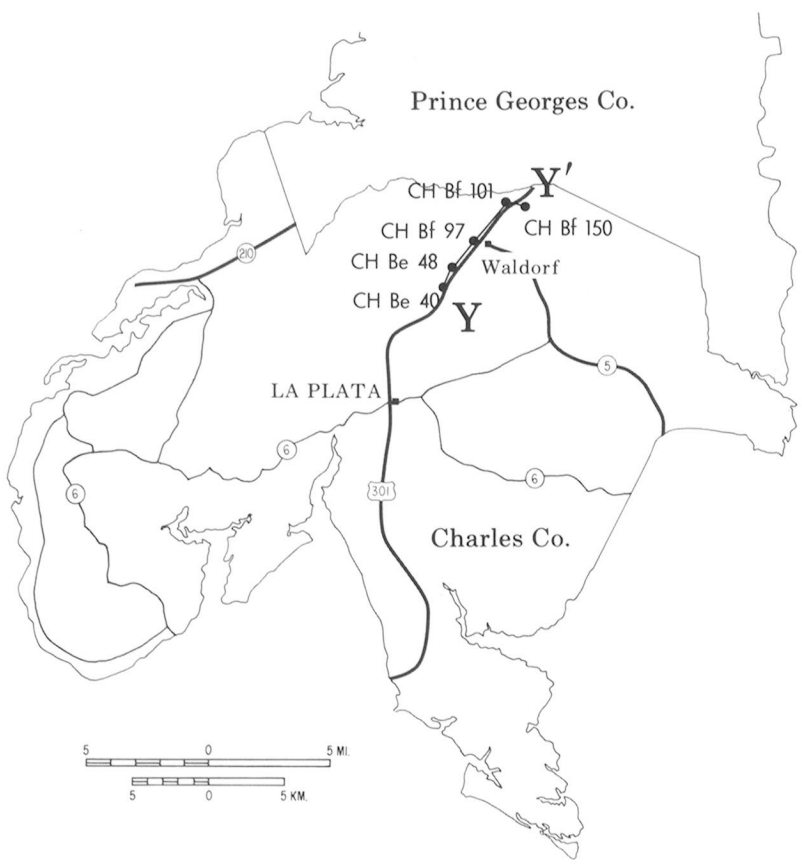


Location of Hydrogeologic Section

EXPLANATION

~?~ Unconformity, queried where uncertain.

—?— Line of correlation

TDL Total depth logged

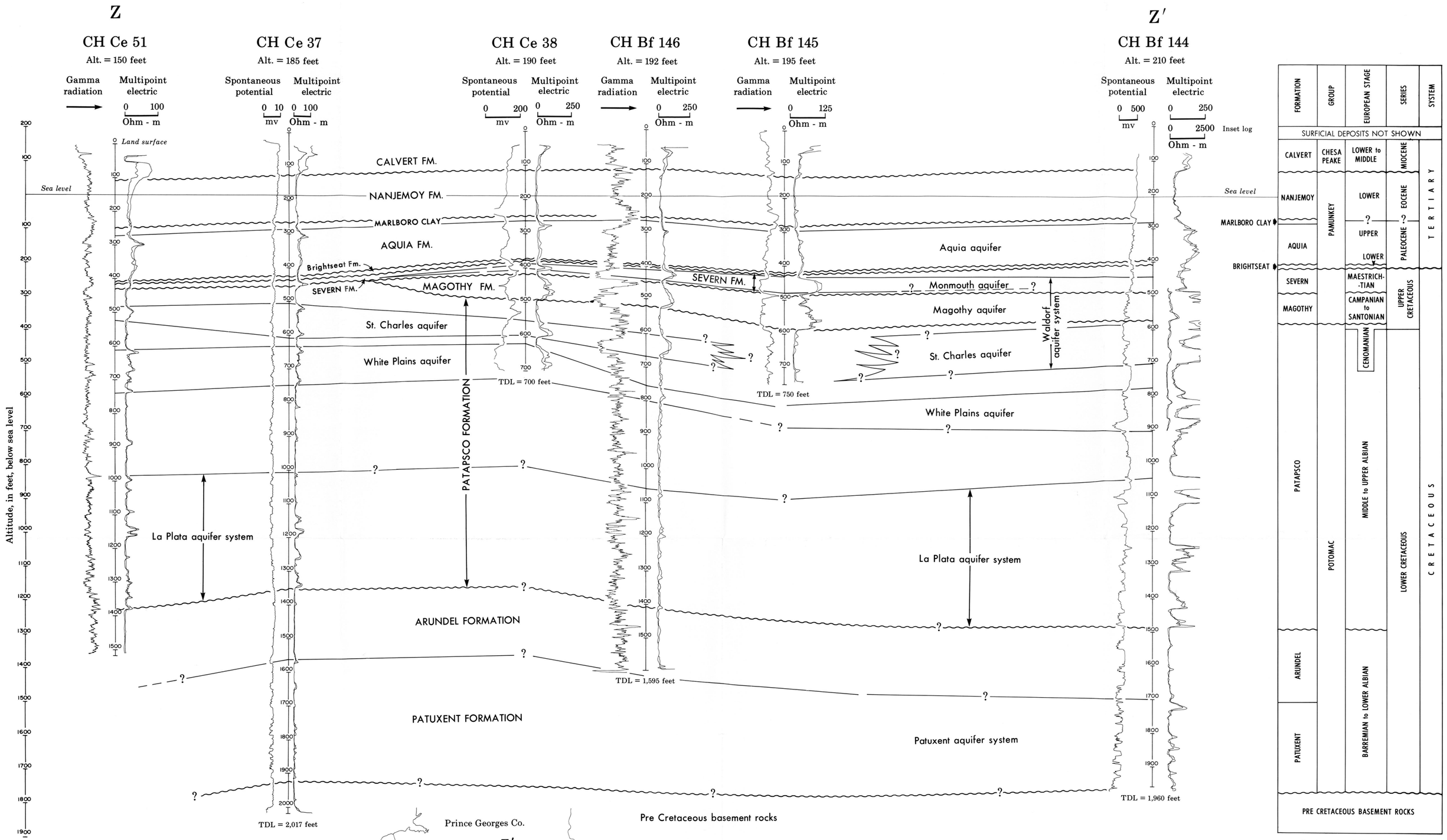
SCALE

0 ½ 1 2 3 *Miles*

0 .5 1 2 3 4 *Kilometers*

vertical exaggeration x 20

PLATE 6.—Hydrogeologic section Z-Z'



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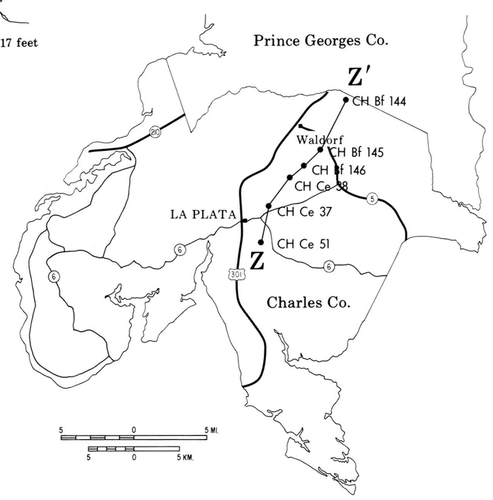


Location of Hydrogeologic Section

EXPLANATION

~?~ Unconformity, queried where uncertain.

—?— Line of correlation

TDL Total depth logged

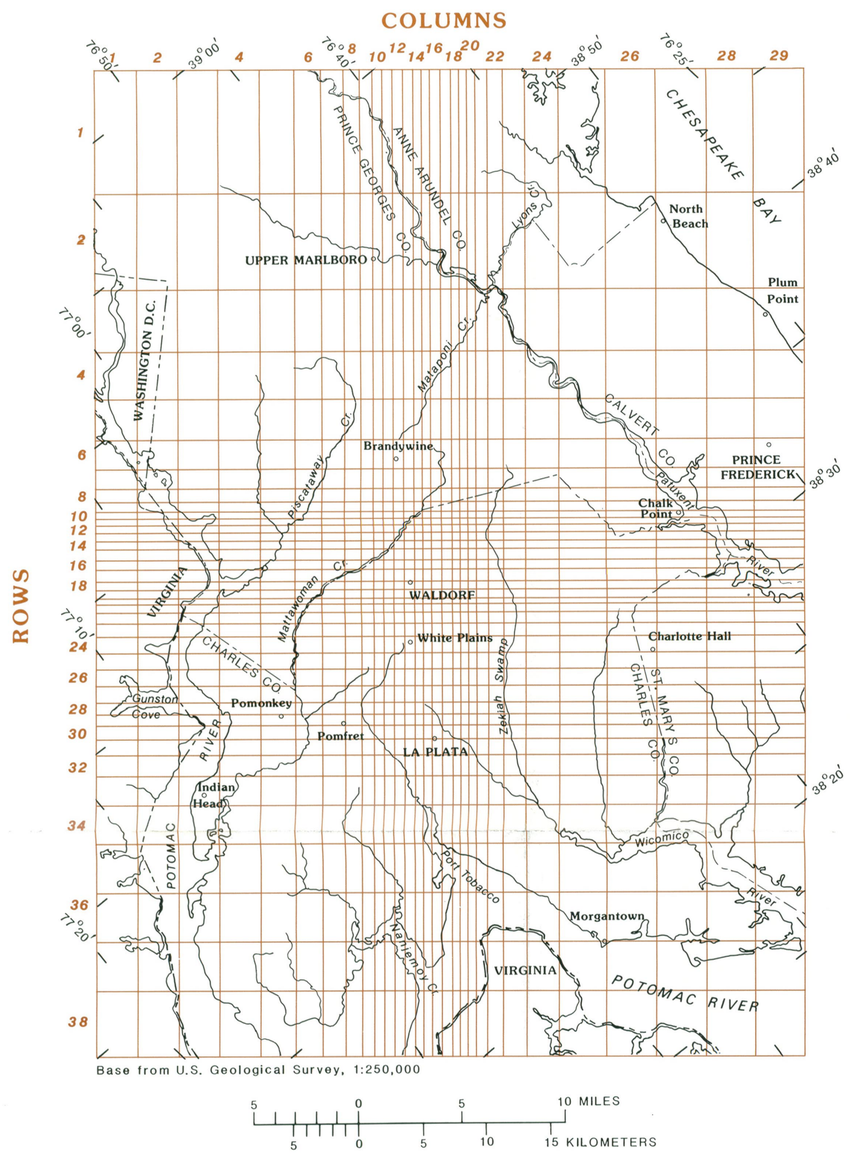
SCALE

0 ½ 1 2 3 *Miles*

0 .5 1 2 3 4 *Kilometers*

vertical exaggeration x 20

PLATE 7.—Transmissivity ranges and boundary conditions used in the model



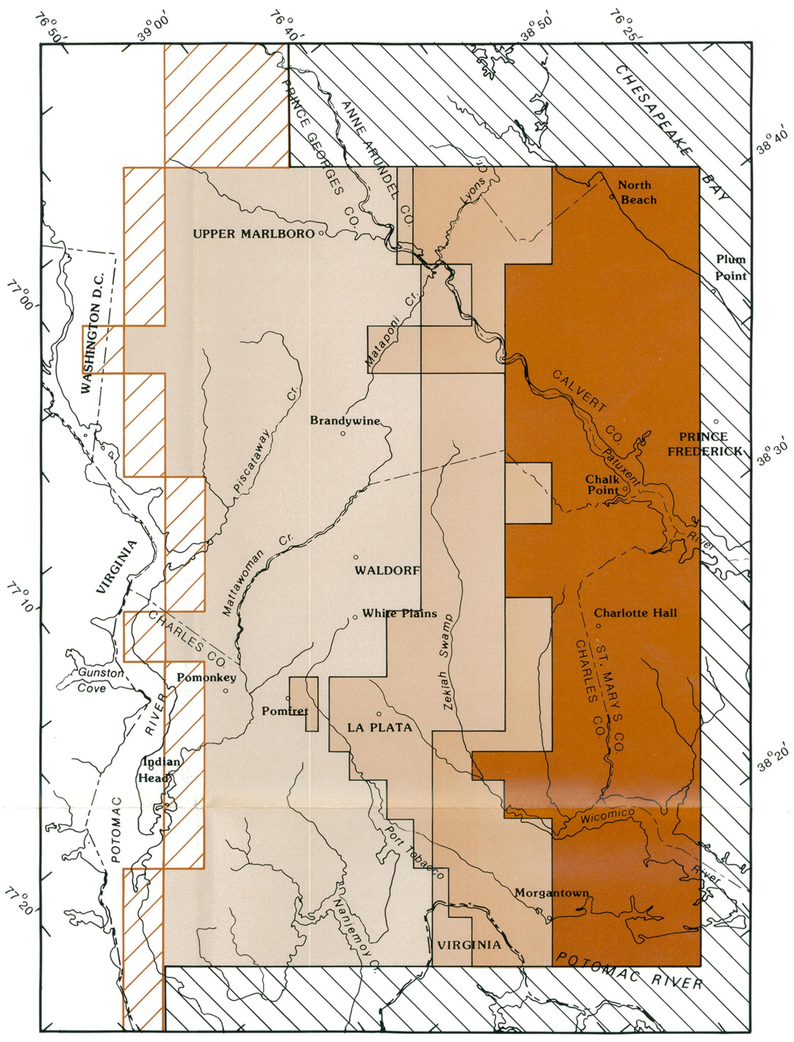
EXPLANATION

RANGE OF TRANSMISSIVITY
(feet squared per day)

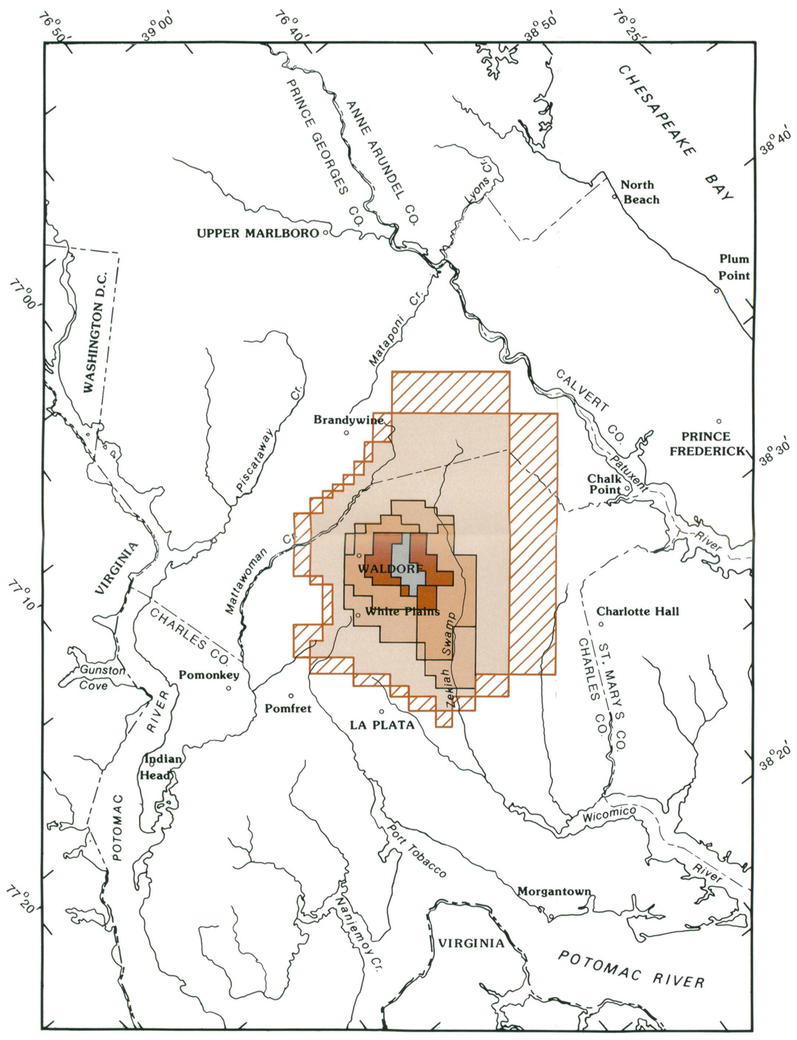
- >0 - 500
- >500 - 1,000
- >1,000 - 2,000
- >2,000 - 4,000
- >4,000 - 6,000
- >6,000 - 10,000
- >10,000 - 15,000

BOUNDARY CELLS

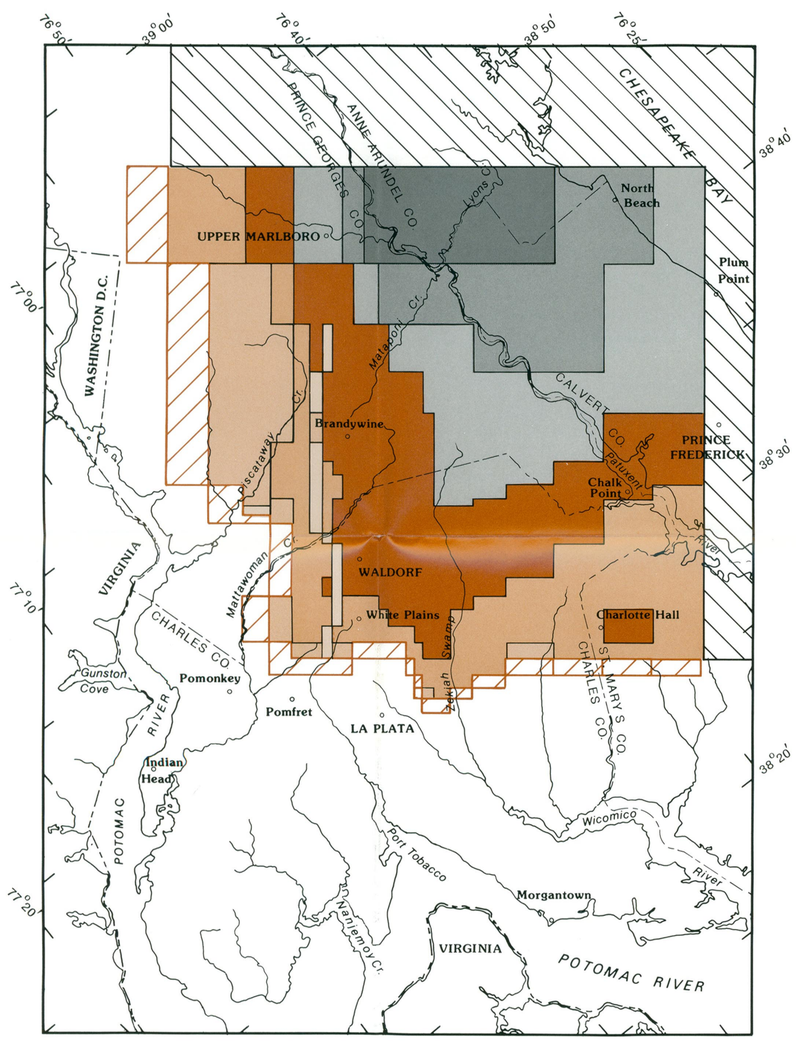
- No Flow
- Constant Head



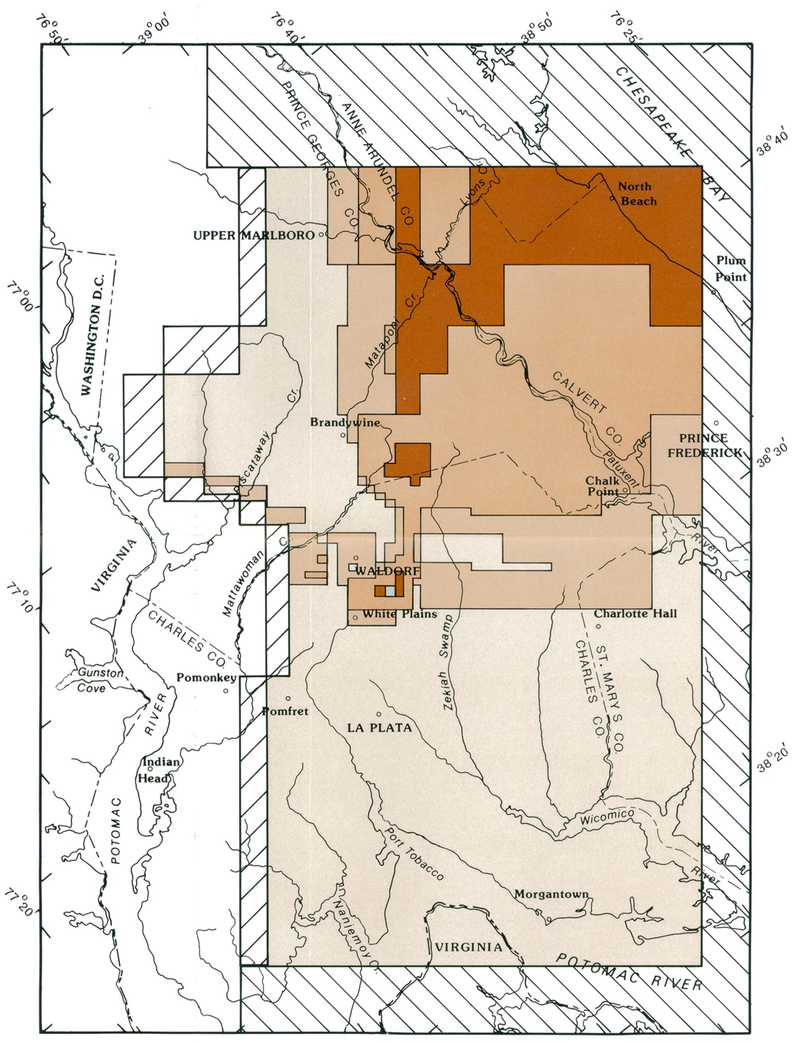
AQUIA AQUIFER (A)



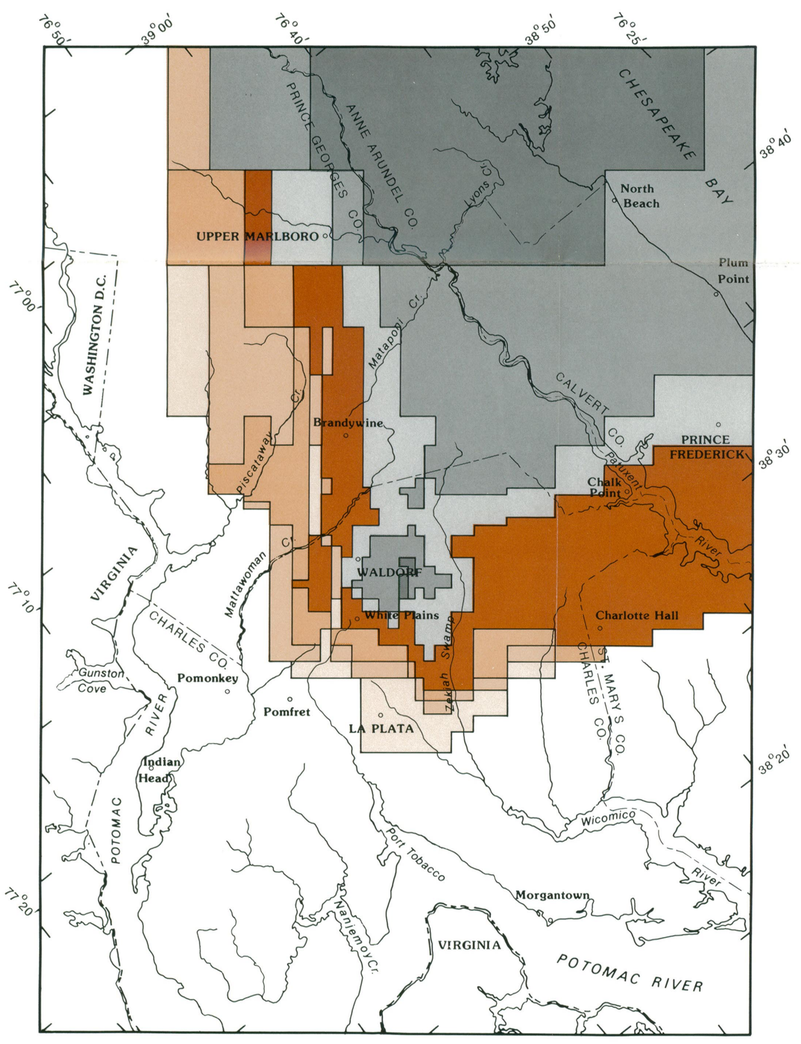
MONMOUTH AQUIFER (B)



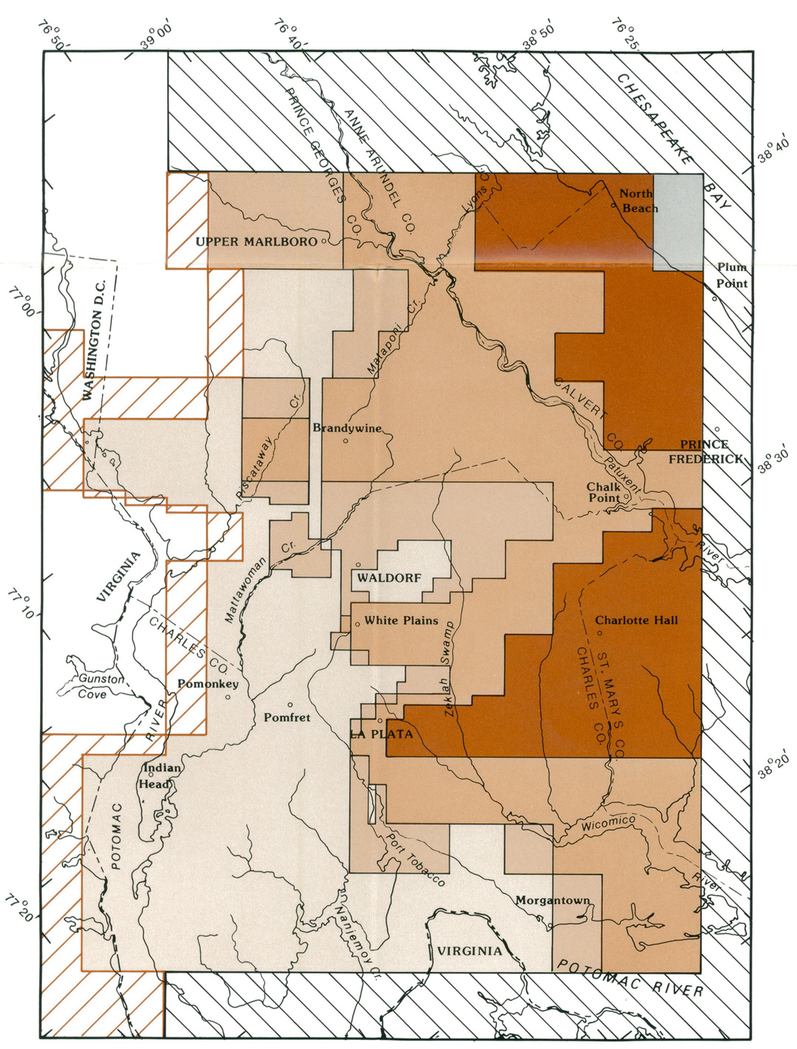
MAGOTHY AQUIFER (C)



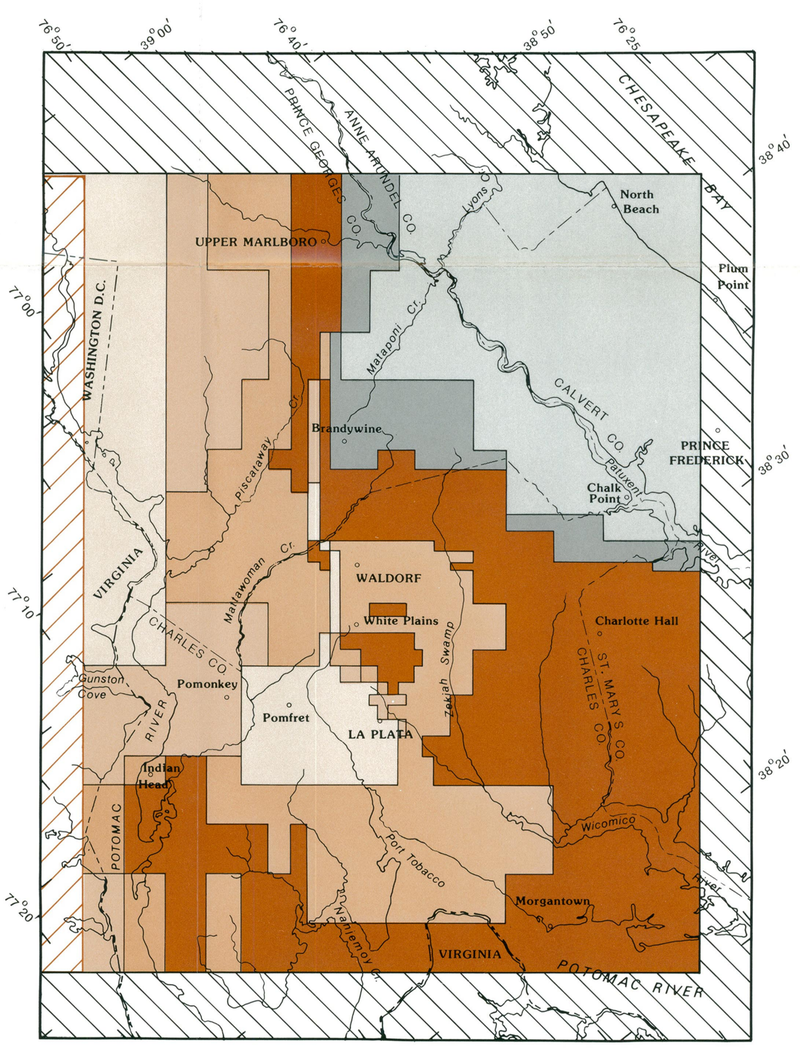
ST. CHARLES AQUIFER AND CORRELATIVE SANDS (D)



WALDORF AQUIFER SYSTEM AND CORRELATIVE SANDS (E)

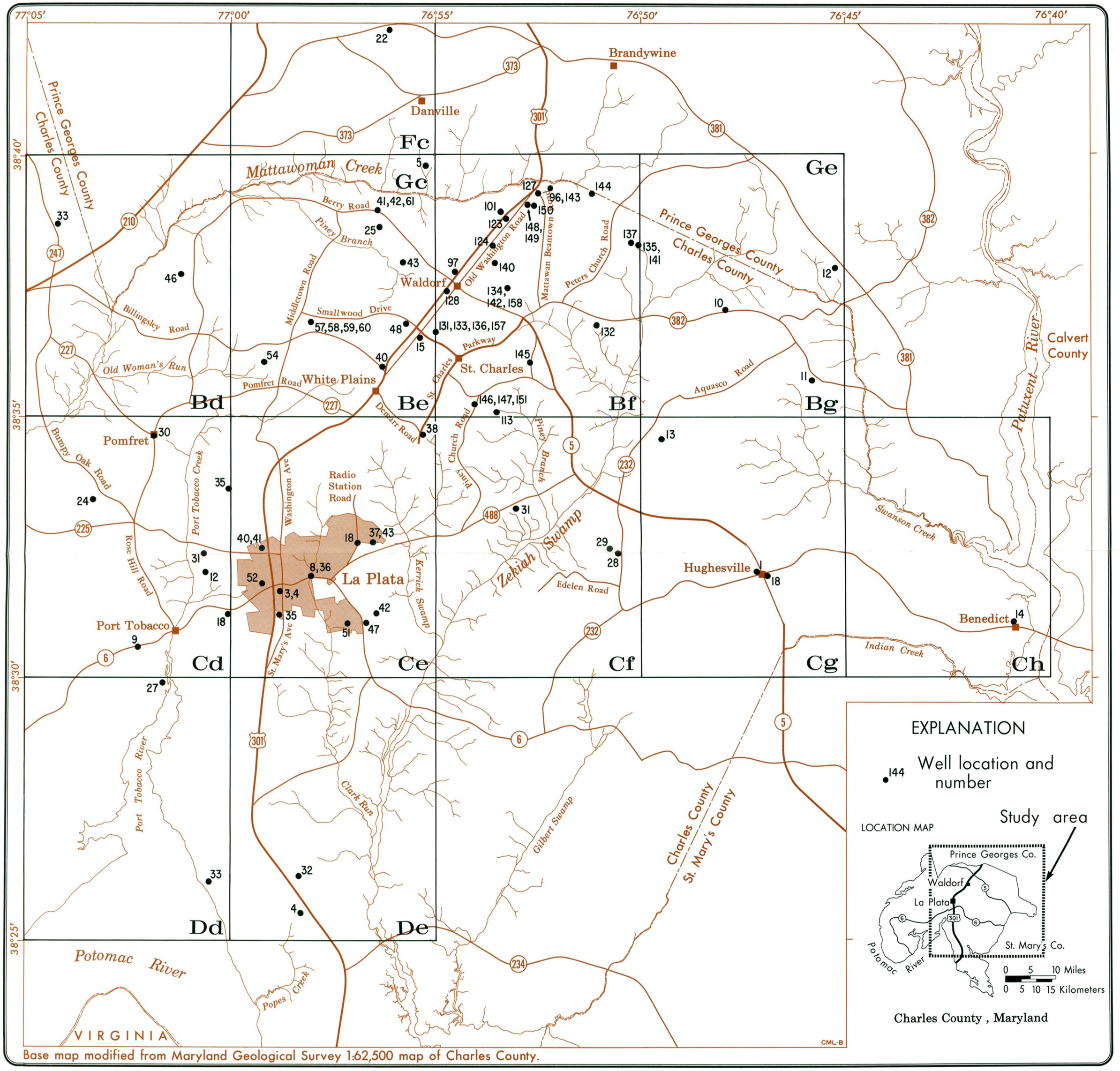


WHITE PLAINS AQUIFER AND CORRELATIVE SANDS (F)



LA PLATA AQUIFER AND CORRELATIVE SANDS (G)

PLATE 8.—Location of selected wells in Charles and southern Prince Georges Counties, Maryland



Base map modified from Maryland Geological Survey 1:62,500 map of Charles County.

MARYLAND GEOLOGICAL SURVEY
2300 St. Paul Street
Baltimore, Maryland 21218
(301) 554-5505

Selected Reports of Investigations

3. Water resources of the Salisbury area, Maryland, by D.H. Boggess and S.G. Heidel, 1968, 69 p. 3.00
5. Chemical quality reconnaissance of water of Maryland streams, by J.D. Thomas, 1966, 61 p. 2.00
7. Geophysical log cross-section network of the Cretaceous sediments of Southern Maryland, by H.J. Hansen, 1968, 56 p. 4.00
9. Chemical and physical character of municipal water supplies in Maryland, by J.D. Thomas and S.G. Heidel, 1969, 52 p. 1.00
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11. Petrology and origin of Potomac and Magothy (Cretaceous) sediments, Middle Atlantic Coastal Plain, by J.D. Glaser, 1969, 101 p. 3.50
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17. Water resources of Dorchester and Talbot Counties, Maryland: With special emphasis on the ground-water potential of the Cambridge and Easton areas, by F.K. Mack, W.E. Webb, and R.A. Gardner, 1971, 107 p. 5.25
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