Department of Natural Resources
Resource Assessment Service
MARYLAND GEOLOGICAL SURVEY
Emery T. Cleaves, Director

REPORT OF INVESTIGATIONS NO. 69

THE GEOHYDROLOGY AND WATER-SUPPLY POTENTIAL OF THE LOWER PATAPSCO AQUIFER AND PATUXENT AQUIFERS IN THE INDIAN HEAD-BRYANS ROAD AREA, CHARLES COUNTY, MARYLAND

by

David C. Andreasen

Prepared in cooperation with
the Maryland Department of the Environment
and the
Charles County Department of Planning
and Growth Management

1999

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KEY RESULTS

The Indian Head-Bryans Road area, in northwestern Charles County, relies primarily on ground water pumped from the lower Patapsco aquifer. Approximately 1.8 million gallons per day were withdrawn in 1997. Increasing population in the area may require an additional 5 million gallons per day by 2020. The upper Patuxent aquifer, lying beneath the lower Patapsco, is a potential source for the projected increase in water demand.

The lower Patapsco and upper Patuxent aquifers are the primary sources of ground water in the Indian Head-Bryans Road area. (pgs. 9 to 32)

- The aquifers consist of fine to coarse sand separated by layers of dense clay.

- Transmissivity–a measure of the ability of the aquifer to transmit water–ranges from 190 to 1,100 feet squared per day in the lower Patapsco aquifer and 152 to 2,600 feet squared per day in the upper Patuxent aquifer. The lower Patuxent aquifer is less transmissive (80 feet squared per day) at the one site tested.

- The productivity of the lower Patapsco aquifer is constrained by less available drawdown in "updip" areas along the Potomac River. At the 1997 pumping rate (1.8 million gallons per day) and pumping-well distribution, water levels in the lower Patapsco aquifer have reached the 80-percent management level along the Potomac River shoreline in the central part of the Indian Head Peninsula.

- The Arundel Clay provides an effective hydraulic seal between the two aquifers in most places.

- The lower Patapsco and upper Patuxent aquifers exhibit lateral hydraulic continuity with the Waldorf-La Plata area. Lateral hydraulic continuity of the upper Patuxent aquifer is apparently disrupted by a flow barrier, the location of which is estimated to be northwest of Bryans Road.

Ground-water-flow model simulations which simulate conditions from 1998 to 2020 indicate that a total of 4 million gallons per day is available for future use from the combined lower Patapsco and upper Patuxent aquifers in northwestern Charles County. (pgs. 62 to 68)

- The lower Patapsco aquifer is capable of producing an additional 0.6 million gallons per day beyond the 1997 rate of approximately 2 million gallons per day (2.6 million gallons per day total) provided that 0.5 million gallons per day of existing production along the Potomac River is shifted to areas southeast of the Bryans Road-Indian Head area.

- The upper Patuxent aquifer is capable of supplying 3.4 million gallons per day before drawdowns reach the 80-percent management level along the Potomac River shoreline.

Projected 2020 water use in the lower Patapsco and upper Patuxent aquifers will cause significant water-level declines. (pgs. 60 to 62 and 73 to 76)

- Water levels in the lower Patapsco aquifer may decline by as much as 60 feet in the vicinity of Bryans Road and 20 feet at Indian Head between 1997 and 2020 because of increased pumpage from the lower Patapsco aquifer outside the Indian Head-Bryans Road area. Water-level declines exceed the 80-percent management level along the Potomac River in the central part of the Indian Head peninsula. The 80-percent management level is also exceeded in a small area northwest of Bryans Road along the Potomac River.

- The lowest water levels in the upper Patuxent aquifer simulated as model-cell averages are 330 feet below sea level based on withdrawals from the upper Patuxent aquifer of 2.1 million gallons per day, and 540 feet below sea level based on withdrawals of 4.0 million gallons per day.

- The upper Patuxent aquifer begins to de-water within a narrow band located along the Potomac River shoreline near Chapman's Landing and in some pumping wells when pumped at a rate of 4.7 million gallons per day; model-cell water levels are as low as 650 feet below sea level.

Pumping from the upper Patuxent aquifer will cause minimal head decline in the lower Patapsco aquifer. (pg. 76)

- Drawdown in 2020 in the lower Patapsco aquifer caused by 3.4 million gallons per day withdrawn from the upper Patuxent aquifer is less than 18 feet.

Water from the upper and lower Patuxent aquifers is a sodium bicarbonate type of good quality. (pg. 37)

- Dissolved concentrations of all major inorganic constituents were within the recommended limits set by the U.S. Environmental Protection Agency. Dissolved solids, pH (field), and specific conductance (laboratory) range from 214 to 378 milligrams per liter, 7.7 to 7.9, and 322 to 627 microsiemens per centimeter, respectively.

INTRODUCTION

A water-supply study of the Indian Head-Bryans Road area of Charles County by the U.S. Army Corps of Engineers (1993) indicates that water demand will increase from about 3 million gallons per day (Mgal/d) in 1990 to between 5.5 Mgal/d and 7.2 Mgal/d in 2012. The Corps' study concludes "that ground water appears to be the most economical solution for the area's water supply needs." It recommends that future supplies be withdrawn from the Patuxent aquifer[1] to minimize the effects of declining water levels on current lower Patapsco users, particularly domestic well owners. The purpose of this study is to determine whether the lower Patapsco and upper Patuxent aquifers in the Indian Head-Bryans Road area have sufficient production capacity to implement the recommended water-supply plan.

OBJECTIVES

The objectives of this report are to: (1) Define the geohydrologic framework of the lower Patapsco aquifer and Patuxent aquifers in northwestern Charles County with an emphasis on the Indian Head-Bryans Road area, including a determination of the hydraulic connectivity between the aquifers, and establish their relation to the aquifers pumped by public-supply wells at Waldorf and La Plata; (2) Establish an observation-well network in the lower Patapsco aquifer and Patuxent aquifers to monitor water-level changes in the model area; (3) Assess the geohydrologic characteristics of the lower Patapsco aquifer and Patuxent aquifers and evaluate quantitatively: (a) the amount of water-level decline caused by ground-water withdrawals from the lower Patapsco aquifer outside of the Indian Head-Bryans Road area, (b) the potential for increasing ground-water production from the lower Patapsco and upper Patuxent aquifers through the selection of optimum well locations, and (c) the potential for redirecting existing pumpage from the lower Patapsco aquifer into the upper Patuxent aquifer; and, (4) Determine the water quality of the Patuxent aquifers.

[1]In this report the Patuxent aquifer is divided into two units–the upper Patuxent aquifer, which is a major aquifer, and the lower Patuxent aquifer, which is a minor aquifer.

LOCATION OF STUDY AREA

The study area is in the northwestern part of Charles County, Maryland, and includes the Indian Head-Bryans Road area and most of Election District 7 (fig. 1). The study area also includes parts of Election Districts 2, 6, and 10. The Indian Head-Bryans Road area is shown on plate 1. To properly evaluate the ground-water-flow system, a larger area was included in the ground-water-flow model (fig. 1). The model area covers approximately 1,300 square miles (mi^2) and includes all of Charles County, parts of Calvert, Prince George's, and St. Mary's Counties, and adjacent parts of the Virginia Coastal Plain. Major population centers within Charles County include Waldorf and La Plata. The model area is located entirely within the Coastal Plain Physiographic Province. The northwest side of the model area is located approximately along the trend of the Fall Line.

The study area is composed primarily of forests, wetlands, and open space with a mixture of light commercial, residential, and agricultural development. The U.S. Naval Surface Warfare Center, on the Indian Head peninsula, is a major military/industrial facility. The majority of the study area is located within the Mattawoman Creek drainage basin, which discharges to the Potomac River (pl. 1). The area is heavily dissected by numerous small streams. Land-surface altitudes range from sea level to as much as 214 feet (ft) above sea level.

PREVIOUS STUDIES

Investigations pertaining to the geology and geohydrology of the geologic formations and aquifers covered in the study area were made by Clark and others (1918), Overbeck (1948), Otton (1955), and Slaughter and Otton (1968). An early investigation of the ground-water supply for the U.S. Naval Surface Warfare Center, including estimates of aquifer properties determined by aquifer tests, well inventory, and interpretations of water-level fluctuations, was made by Fiedler and Jacob (1939). Inventories of selected well data in Charles County, including well construction, chemical analyses, and water levels, were made by Slaughter and Laughlin

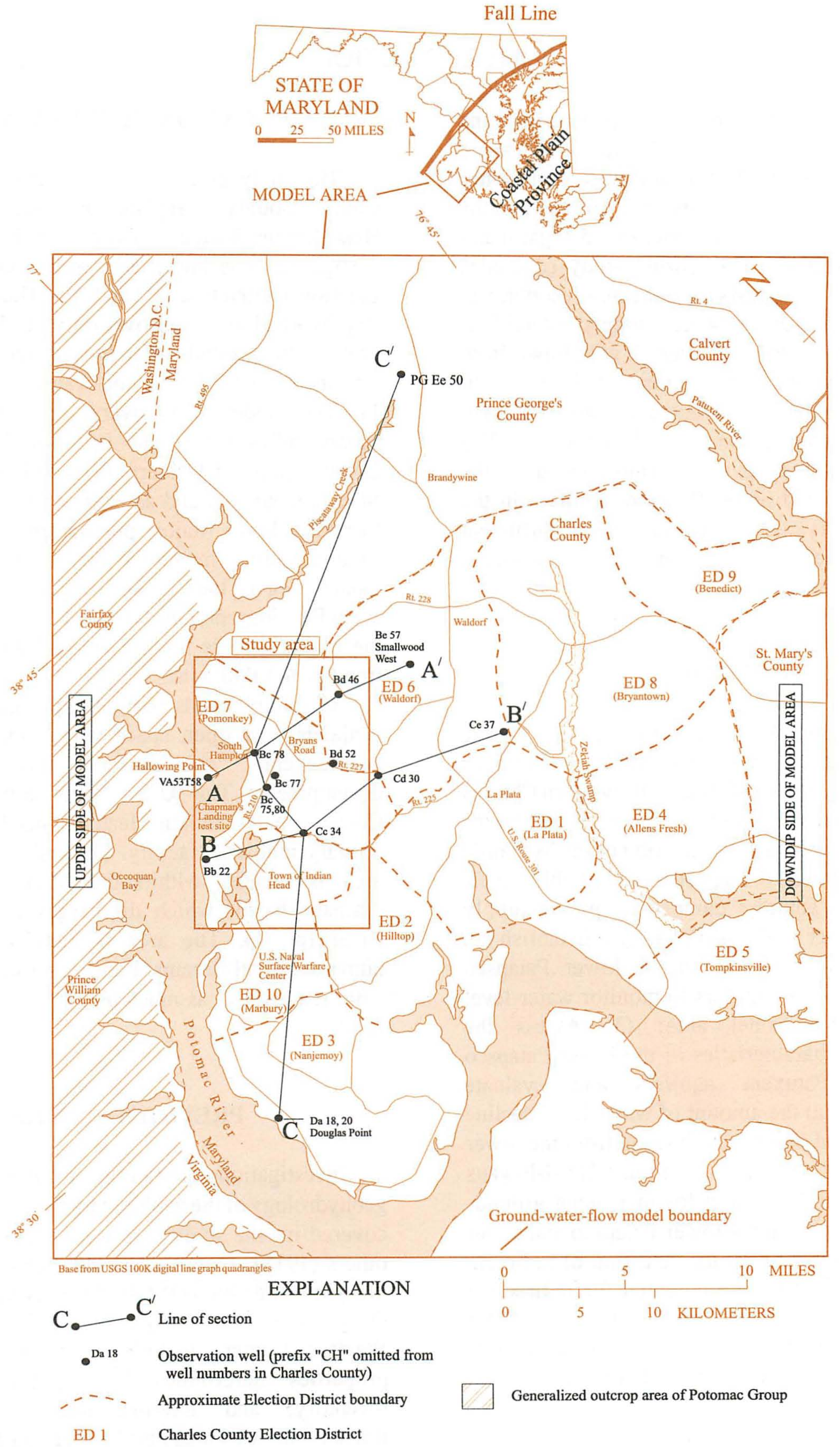


Figure 1. Study and model areas and location of geohydrologic cross-sections A-A′, B-B′, and C-C′.

(1966) and Weigle and Webb (1970). Ground-water levels measured between 1946-94 in an extensive network of observation wells in southern Maryland were compiled by Curtin and Dine (1995). The stratigraphy of the Cretaceous aquifers in the Waldorf /La Plata area was investigated by Wilson (1986) and Wilson and Fleck (1990). The water-supply potential of the aquifers developed in the Patapsco, Magothy, and Aquia Formations in the Waldorf-La Plata area was estimated using a three-dimensional ground-water-flow model by Fleck and Wilson (1990).

An investigation of the hydrogeology and pumpage history of the Potomac Group aquifer system in northwestern Charles County was made by Hiortdahl (1997). Part of that study focused on brackish-water intrusion as a function of ground-water withdrawal from the lower Patapsco aquifer at Indian Head. The first estimate of the water-supply potential of the Patuxent aquifer was made in the Bryans Road water-supply study conducted by the U.S. Army Corps of Engineers (1993). The initial findings of this study were presented in Maryland Geological Survey Open-File Report 98-02-9 (Andreasen and Mack, 1998).

METHODS OF INVESTIGATION

Methods of investigation used for this study included the review and compilation of existing Federal, state, and county ground-water data in the model area and vicinity, and a field inventory of high-capacity wells in the lower Patapsco and Patuxent aquifers. Data collected during the well inventory included location, altitude, water level, well construction, and, where possible, geophysical logs. Selected well records are given in Appendix A. Cross-sections and maps displaying the geohydrology of the lower Patapsco aquifer and Patuxent aquifers and their confining beds were prepared. Data sets of aquifer and confining-bed hydraulic parameters were developed for use in the U.S. Geological Survey's three-dimensional, finite-difference ground-water-flow model MODFLOW (McDonald and Harbaugh, 1988) code. The model, calibrated by matching simulated and historic water levels from 1952 through 1997, was used to predict water-level changes resulting from future ground-water use to 2020 in the lower Patapsco aquifer and Patuxent aquifers. Water samples were collected from selected wells screened in the upper and lower Patuxent aquifers and analyzed for major inorganic constituents. The analyses were made by the U.S. Geological Survey National Water-Quality Laboratory in Denver, Colorado.

An observation-well network, consisting in part of previously established observation wells, was developed in the model area to monitor water levels in the lower Patapsco aquifer and Patuxent aquifers. The observation- well network consisted of 32 wells screened in the lower Patapsco aquifer, 9 wells screened in the upper Patuxent aquifer, and 1 well screened in the lower Patuxent aquifer. Continuous water-level recorders were installed on 1 lower Patapsco well and 6 upper Patuxent wells.

Wells are identified in this report using the Maryland Geological Survey well-numbering system. In this numbering system, the first two letters are the county prefix (for example, CH for Charles County). The second part of the number consists of two letters that designate a 5-minute quadrangle within the county; the first letter (uppercase) denotes a 5-minute segment of latitude from north to south, and the second letter (lower case) denotes a 5-minute segment of longitude from west to east. The locations of 5-minute quadrangles in the study area are shown on plate 1. The wells are numbered sequentially in the order they were inventoried within each 5-minute quadrangle.

Altitudes of water-level measuring points on selected observation wells were determined by spirit level from National Geodetic Survey benchmarks.

TEST DRILLING

The major data collection component of this study was the drilling of three test holes that penetrated the basement-rock complex in the study area and the construction of observation wells screened in the upper and lower Patuxent aquifers. The purpose of the test drilling was to determine the total thickness of Coastal Plain sediments in the area of northwestern Charles County and to identify the depth, thickness, hydraulic properties, and lithology of the aquifers and confining beds beneath the lower Patapsco aquifer.

Test drilling started July 1996 at the Mattawoman Waste-Water Treatment Plant, located approximately 2 miles (mi) southeast of the Chapman's Landing test site (pl. 1). The drilling was carried out by contract with A.C. Schultes of Maryland, Inc. Basement rock was reached at a depth of 1,170 ft below land surface in well CH Cc 34 (fig. 2). The borehole was converted to an observation well screened in the upper Patuxent aquifer at depths of 874 to 884 ft and 945 to 955 ft below land surface. The second hole (CH Bc 80) was drilled at the Chapman's Landing site (fig. 1) adjacent to an existing production well (CH Bc 75—Chapman's Landing well 2) that was screened in the upper Patuxent aquifer. The hole reached the basement-rock complex at a depth of 1,142 ft below land surface and was converted to an observation well screened in the lower Patuxent aquifer at depths of 1,085 to 1,095 ft and 1,105 to 1,115 ft below land surface. The purpose of testing the lower Patuxent aquifer was primarily to investigate the possible presence of brackish or salty water. Split-spoon cores (1.75-inch [in.] diameter) were collected at selected intervals in both aquifer and confining-bed material below the lower Patapsco aquifer. The final test hole (CH Bd 52) was drilled adjacent to Route 227 near Mattawoman Creek, approximately 3 mi from the Chapman's Landing test site (pl. 1). The hole reached the basement-rock complex at a depth of 1,328 ft below land surface. The hole was converted to an observation well screened in the upper Patuxent aquifer at depths of 1,043 to 1,053 ft and 1,085 to 1,095 ft below land surface.

The test holes were 9 7/8-in. in diameter and drilled to top of basement. Drill cuttings, collected at 20-ft intervals, were briefly described in the field and stored in containers. The drill cuttings were later washed, examined, and described using a 60X-power binocular microscope (Appendix B.). Geophysical logs (16- and 64-in. normal resistivity, 6-ft lateral resistivity, single-point resistivity, gamma radiation, and caliper) (fig. 2) were completed prior to well construction. The holes were back-filled with Morie No. 1 gravel to a depth near the base of the deepest well-screen setting. Well-screen positions were determined based primarily on the results of the geophysical log tests. Two 10-ft sections of 4-in. stainless steel, wire-wound screen with 0.02-in. slot size, separated by a 4-in. pipe, were installed in each hole. A 10-ft section of 4-in. pipe was attached to the bottom of the deepest well screen. The holes were cased from land surface to the top well screen with 4-in. steel pipe. Gravel pack (Morie No. 1) was placed around the well screens to a depth midway in the confining bed immediately overlying the screened sands. Approximately 10 to 20 ft of bentonite was placed on top of the gravel pack using a tremie pipe. The remainder of the annular space was filled with cement grout. The correct settings of the well screens were verified using caliper logs. After test-well construction was complete, a 12-hour, constant-rate aquifer test was conducted on each well and continuous-reading water-level recorders were installed on the wells.

DEFINITION OF TERMS

Figure 3 illustrates schematically the following terms that are used to discuss the effects of pumpage on water levels:

1) *Total available drawdown* is the difference between the prepumping water level and the top of the confined (artesian) aquifer.

2) The *80-percent management level* is a water-level drawdown to 80-percent of the total available drawdown. In Maryland, ground-water allocations may be permitted that lower water levels to the 80-percent management level.

3) *Remaining available drawdown* is the difference between the 80-percent management level and the measured or simulated water level.

4) *Percentage of available drawdown remaining* is the ratio between remaining available drawdown and the available drawdown (based on the prepumping water level and the 80-percent management level).

The maximum yield of an aquifer in the predictive model is limited by the 80-percent management level.

The simulated water level used to calculate the remaining available drawdown is the model-cell water level, which represents an average water level for the cell. Aquifer water levels at specific sites within a model cell can be shallower or deeper than the cell average. The pumping water level in the well shown in figure 3 is deeper than both the aquifer water level and the simulated model-cell water level.

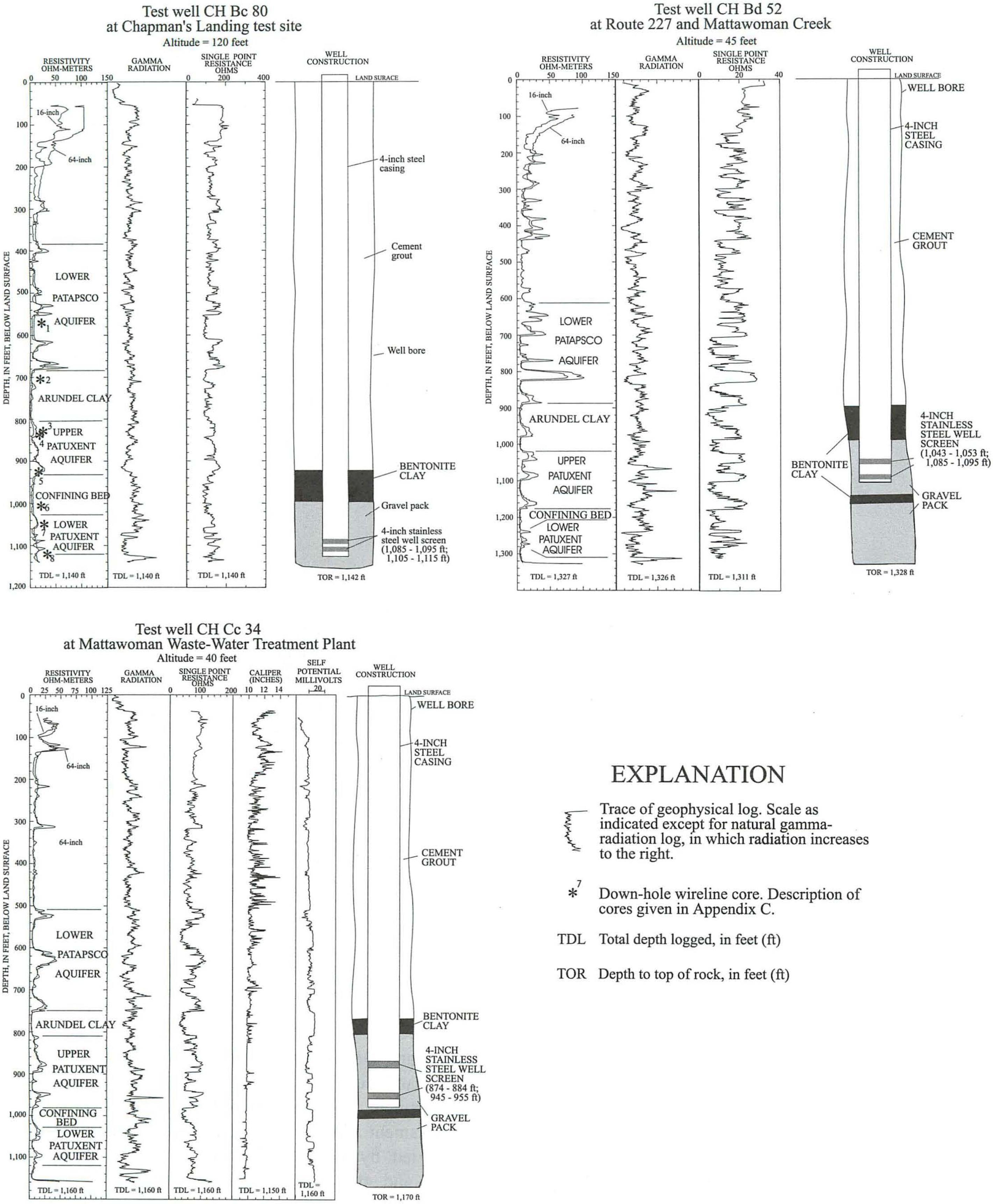
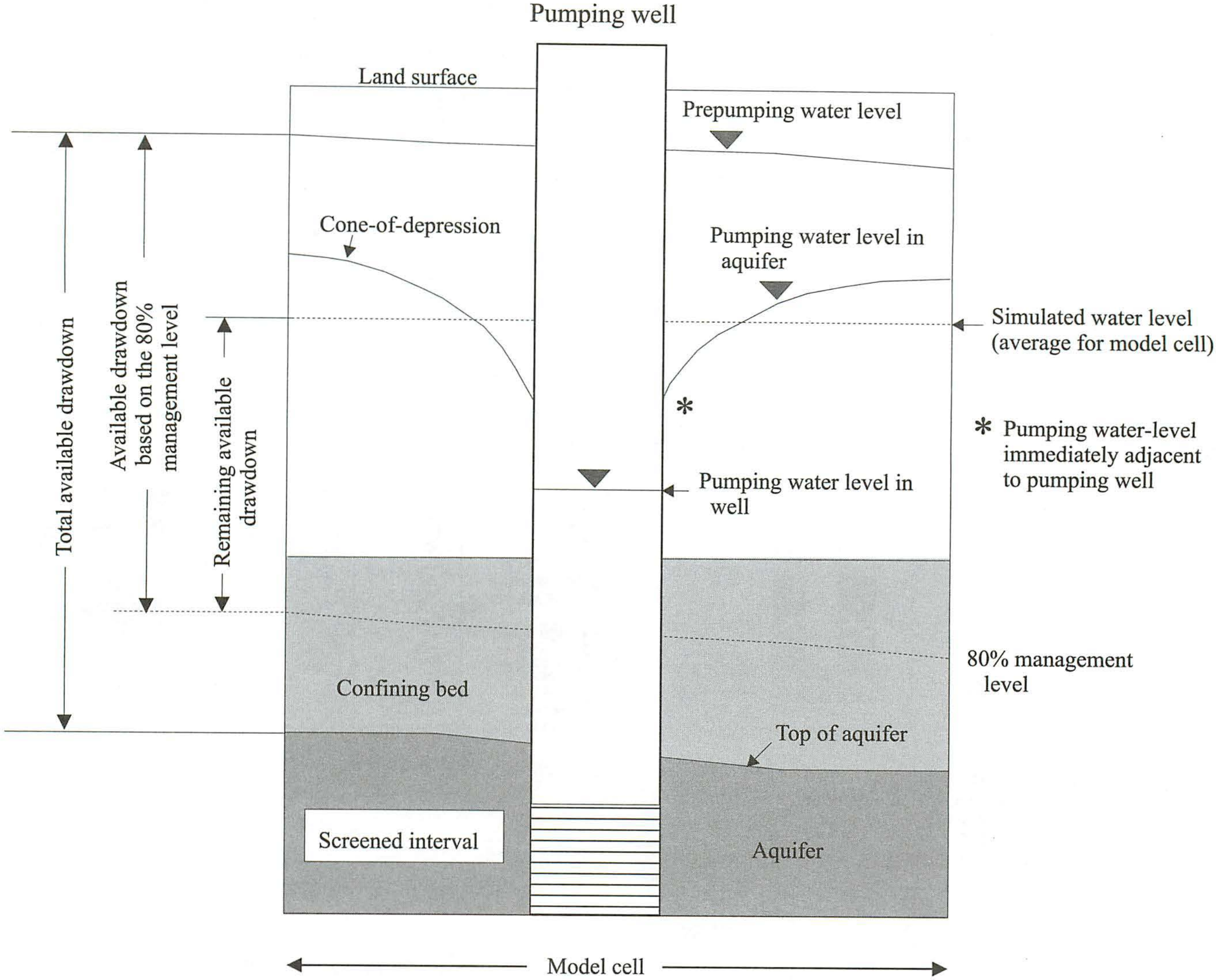


Figure 2. Geophysical logs, core depths, and well construction for test wells drilled during this study.



$$\text{Percentage available drawdown remaining} = \frac{\text{Remaining available drawdown based on simulated water level}}{\text{Available drawdown based on prepumping water level}}$$

Figure 3. Schematic showing remaining available drawdown and management water level.

The difference is caused by head loss due to well inefficiency, which is not simulated by the model; it varies from well to well.

ACKNOWLEDGMENTS

Funding support for this study was provided by the Board of Commissioners of Charles County, the Maryland Department of the Environment, and the Maryland Geological Survey, a unit of the Maryland Department of Natural Resources (Resource Assessment Service). Test-drilling sites were provided by Charles County, Legend Properties, Inc., and the Maryland Department of Natural Resources (Parks and Recreation Division). Legend Properties, Inc. allowed one of their production wells to be used for a 5-day aquifer test. Frederick

Mack and Harry Hansen contributed their expertise in southern Maryland geohydrology. Jonathan Edwards, Jr. examined drill cuttings from the test-well sites and described the basement rocks. Throughout the investigation, a review committee composed of representatives from the Charles County and Prince George's County governments, Town of Indian Head, and U.S. Naval Surface Warfare Center provided critical comments. Also included on the committee were two citizen representatives, Arthur Krueger and Lawrence Berger. David Drummond, Maryland Geological Survey, and William Fleck, U.S. Geological Survey (Water Resources Division) provided technical reviews of the report. The manuscript was edited and typed by Donajean Appel with additional editorial review by Claire Richardson.

GEOHYDROLOGY OF THE LOWER PATAPSCO AQUIFER AND PATUXENT AQUIFERS

FRAMEWORK

The study area is located within the Coastal Plain province of Maryland (fig. 1). The Coastal Plain province consists of layers of gravel, sand, silt, and clay that are gently sloped downward toward the southeast. The layers form geologic formations that range in age from Cretaceous to Holocene. The geologic units of principal concern in this study are the Patuxent Formation, Arundel Clay, and Patapsco Formation (tab. 1). Collectively, these formations, consisting of alternating beds of sand, silt, and clay, form the Potomac Group. The outcrop area of the Potomac Group occurs within an irregular band northwest of the study area in Virginia and Washington, D.C. (Cooke and Cloos, 1951; Mixon and others, 1989). Sand layers, which generally allow the transmission and extraction of water, form aquifers. In contrast, silt and clay layers, which impede flow of ground water and do not yield water to wells, form confining beds. The aquifers considered in this report consist of multiple sand layers within the Patapsco and Patuxent Formations; they include, from shallowest to deepest, the upper Patapsco aquifer, lower Patapsco aquifer, upper Patuxent aquifer, and lower Patuxent aquifer. The lower Patapsco aquifer is separated from the upper Patuxent aquifer by the Arundel Clay. The Patuxent aquifer was informally divided into the upper and lower aquifer units based on the presence of two discrete sand bodies within the Patuxent Formation. The outcrop areas of the aquifers occur within the outcrop area of the Potomac Group. Outcrop areas of the individual aquifers are not differentiated from the Potomac Group outcrop.

Four geohydrologic cross-sections extending through the study area were prepared (figs. 4-6, and pl. 2) along with a series of structure maps showing the altitude of the top of the basement rock and the altitude of the top and thickness of the lower Patapsco and upper Patuxent aquifers (figs. 7-11).

The top of basement rock is at approximately 680 ft below sea level west of Chapman's Landing at Hallowing Point, Virginia and increases in depth to about 1,730 ft below sea level at La Plata and about 2,550 ft below sea level at Lexington Park (figs. 4, 5, and 7; pl. 2). The dip of the basement rock is steepest near the western edge of the Coastal Plain sediments (about 50 ft per mile [ft/mi]) and decreases to about 30 ft/mi in the eastern part of Charles County. Seismic reflection data reported by Jacobeen (1972), Dames & Moore (1973), and Hansen (1978) suggest that faulting may offset the Coastal Plain—basement-rock contact by as much as 250 ft along a line extending from southern Prince George's County, through Waldorf, to about La Plata. An interpretation of this structure (called the Brandywine fault system) is shown in Wilson and Fleck (1990, fig. 3, pl. 3). The Brandywine fault system may also affect the overlying Coastal Plain sediments, resulting in offsets or dip reversals in the Patuxent and Patapsco aquifers near the proposed fault trend (Wilson and Fleck, 1990, fig. 4, pl. 3). The structure maps and cross-sections presented in this report are generalized in the area of the Brandywine fault system and do not display possible effects of faulting.

Fragments of basement rock recovered from CH Bd 52 and Cc 34 consist of fine-grained biotite-plagioclase-quartz gneiss (Appendix B). This rock resembles the Oella Formation, a crystalline rock that outcrops in the Piedmont of Baltimore and Howard

(Text continued on p. 19.)

Table 1. Geohydrologic units included in this study

[ft = feet]

Erathem	System	Series	Group	Formation	Lithology	Aquifers and confining beds	Approximate formation thickness (ft) in well CH Bc 80
Cenozoic	Tertiary	Pliocene		Upland deposits	Sand, gravel, silt, and clay; yellow and brown	Surficial aquifer	50
		Paleocene	Pamunkey	Aquia	Sand, silt, and clay; glauconitic; dark gray		90
Mesozoic	Cretaceous	Lower Cretaceous	Potomac	Patapsco	Sand, interbedded with multi-colored clay	upper Patapsco aquifer	170
					Clay and silt	Confining bed	70
					Alternating beds of fine to coarse sand, interbedded with thicker layers of dense clay	lower Patapsco aquifer	Total: 300 Sand (84) Clay and silt (216)
				Arundel	Clay, dense; red, purple, and brown with relatively thin beds of fine-grained sand	Arundel confining bed	120
				Patuxent	Sand, medium to coarse; clean; light gray; quartzose; with some small gravel	upper Patuxent aquifer	Total: 135 Sand and silt (80) Clay and silt (35)
					Clay and silt	Confining bed	93
					Sand with intergranular silt and clay	lower Patuxent aquifer	Total: 115 Sand (50) Clay and silt (65)
Pre-Cretaceous				Basement complex	Granite gneiss	None	Unknown

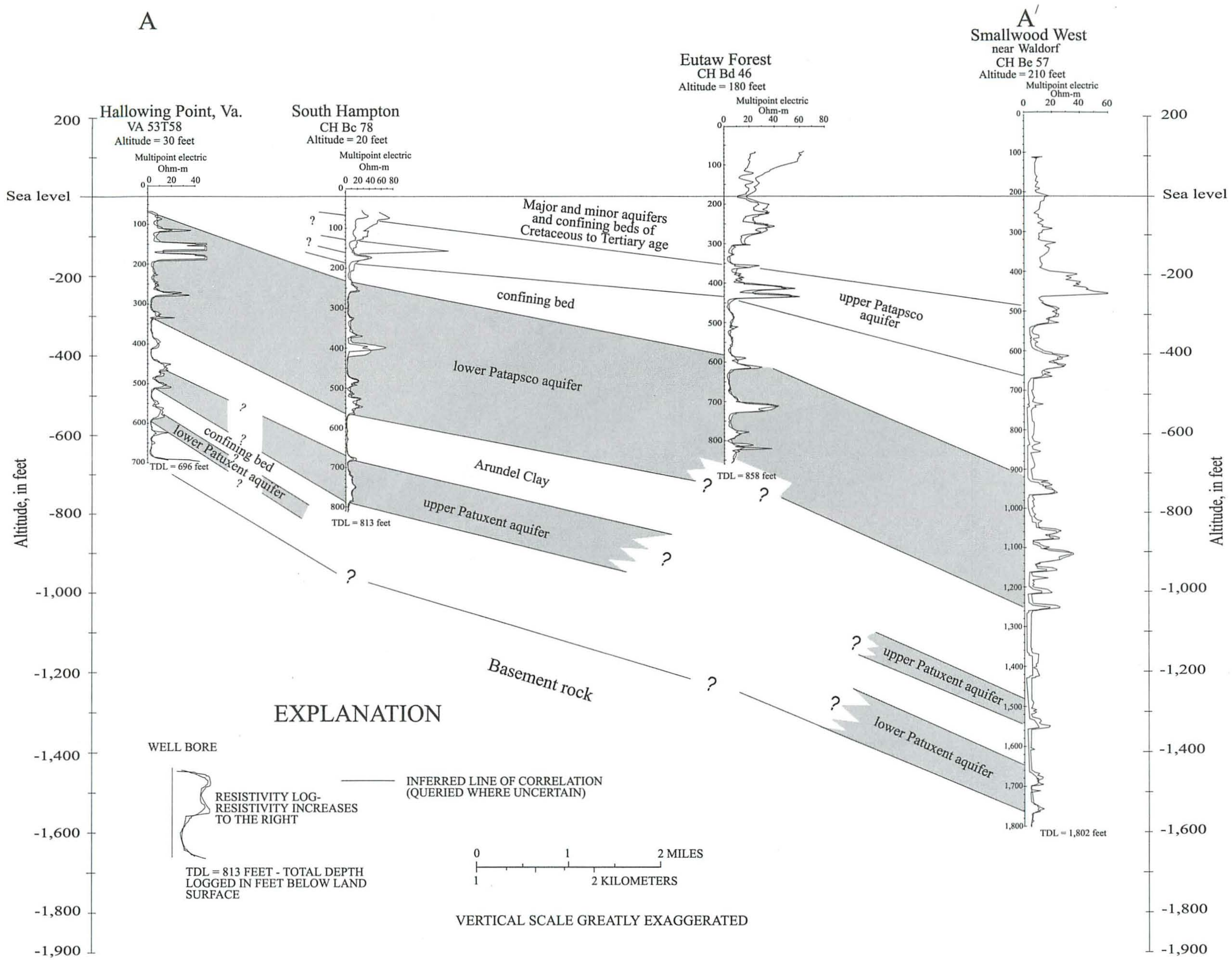


Figure 4. Geohydrologic cross-section A-A′ from Hallowing Point, Virginia, to Waldorf, Maryland.

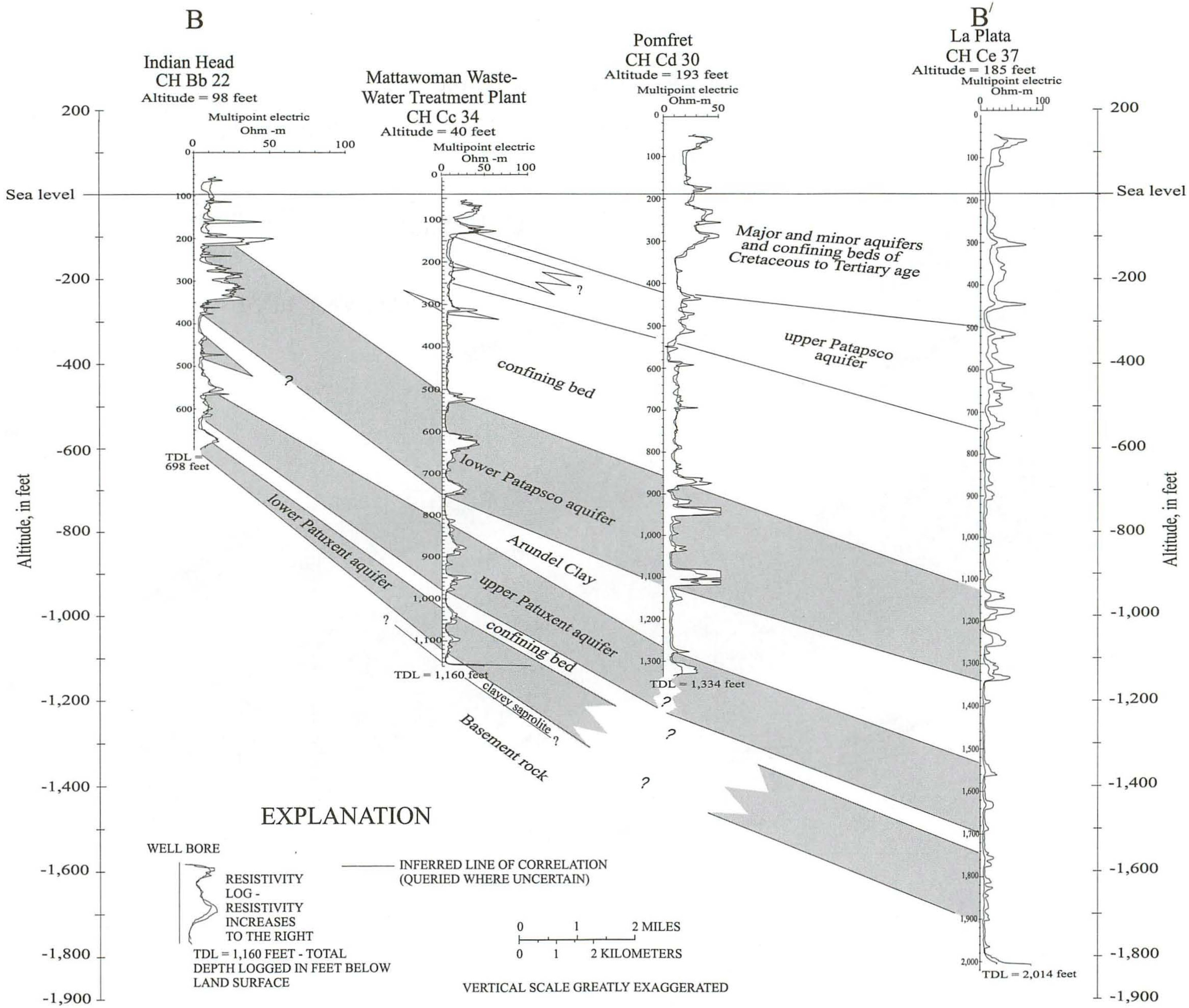


Figure 5. Geohydrologic cross-section B-B′ from Indian Head to La Plata, Maryland.

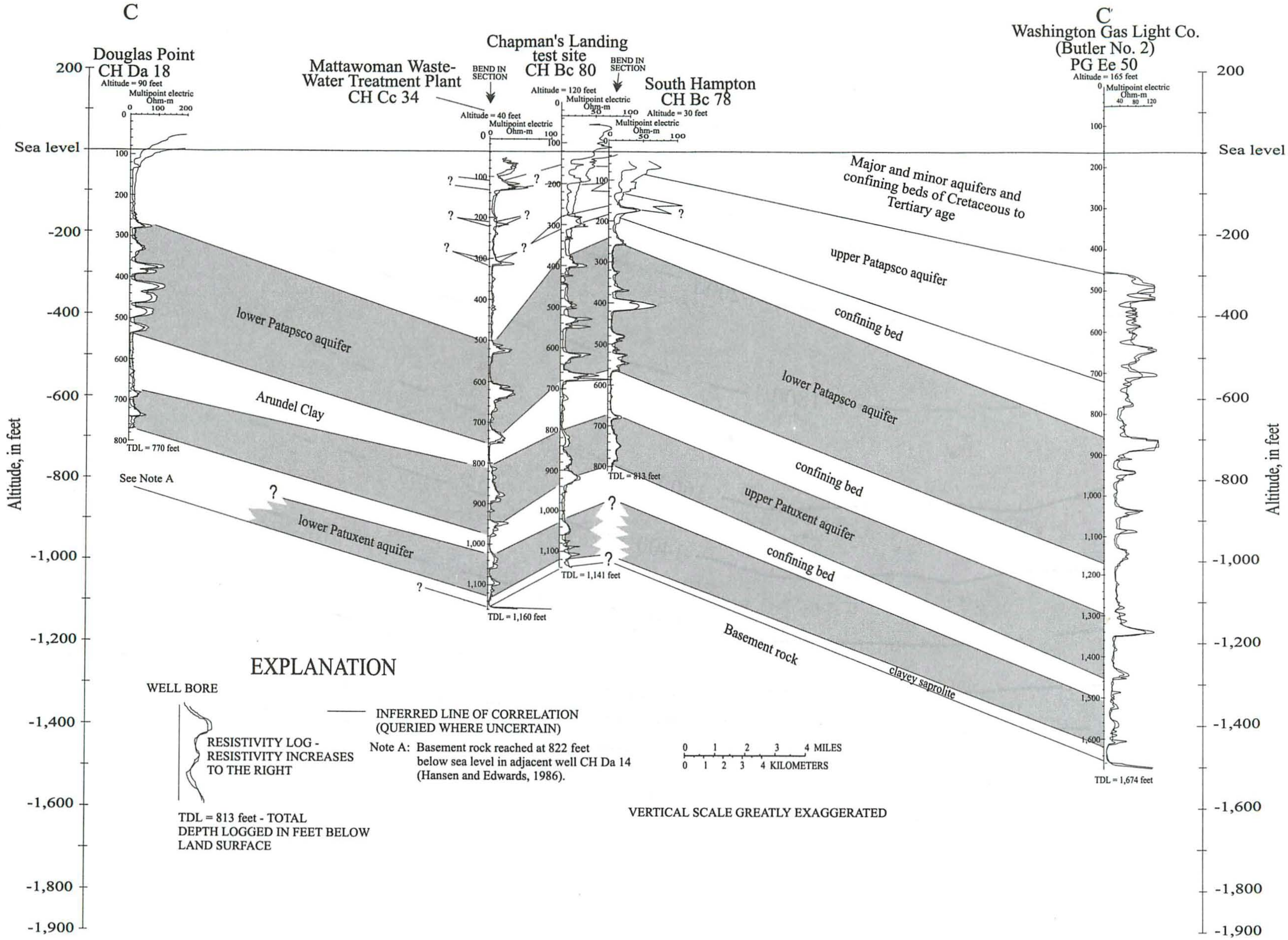
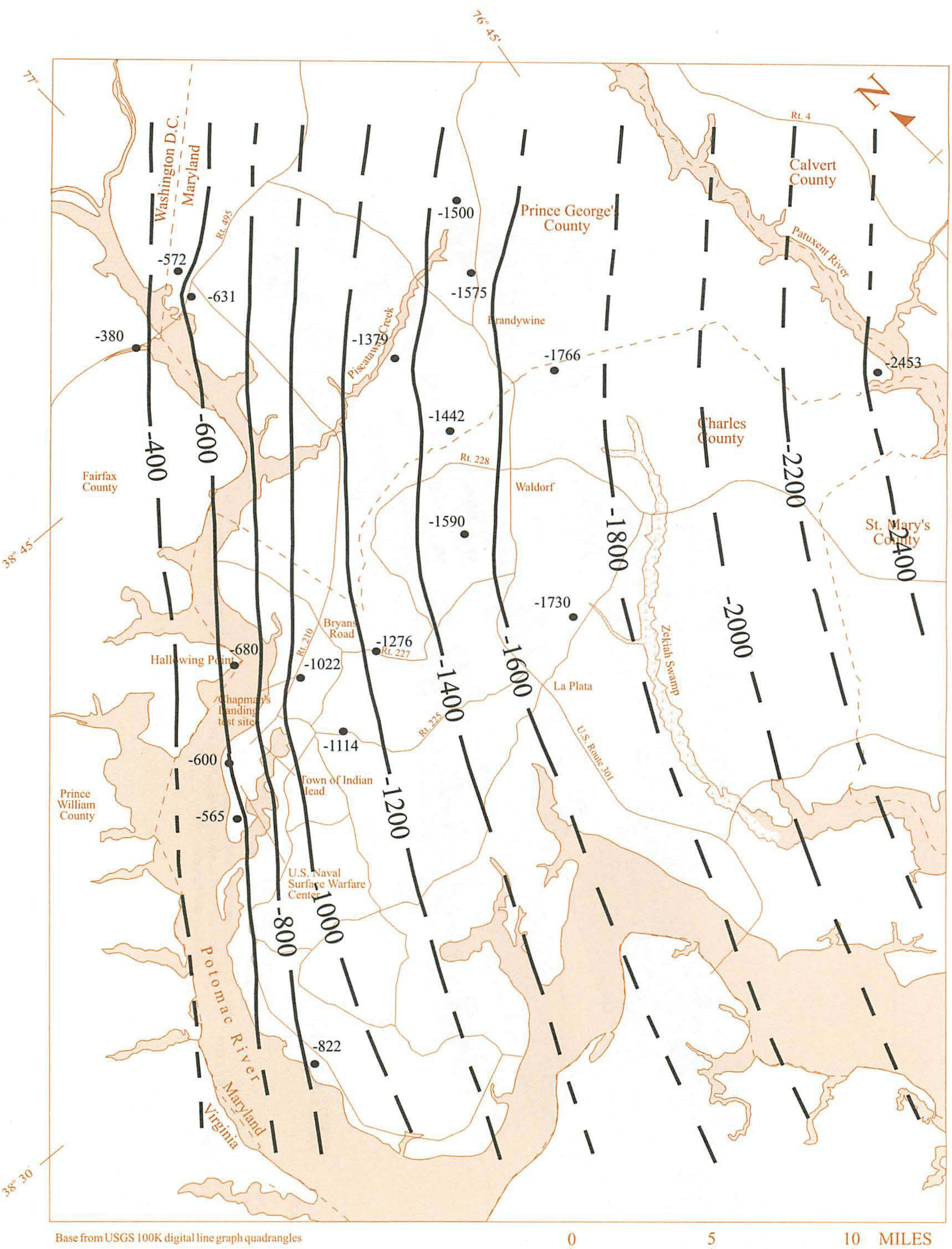


Figure 6. Geohydrologic cross-section C-C′ from Douglas Point to southern Prince George's County, Maryland.



EXPLANATION

-800 LINE OF EQUAL ALTITUDE OF THE TOP OF BASEMENT ROCK -- Dashed where uncertain. Interval 200 feet. Datum is sea level.

• -822 WELL-DATA POINT -- Number is altitude of the top of the basement rock in feet. Datum is sea level.

Figure 7. Approximate altitude of the top of the basement rock.

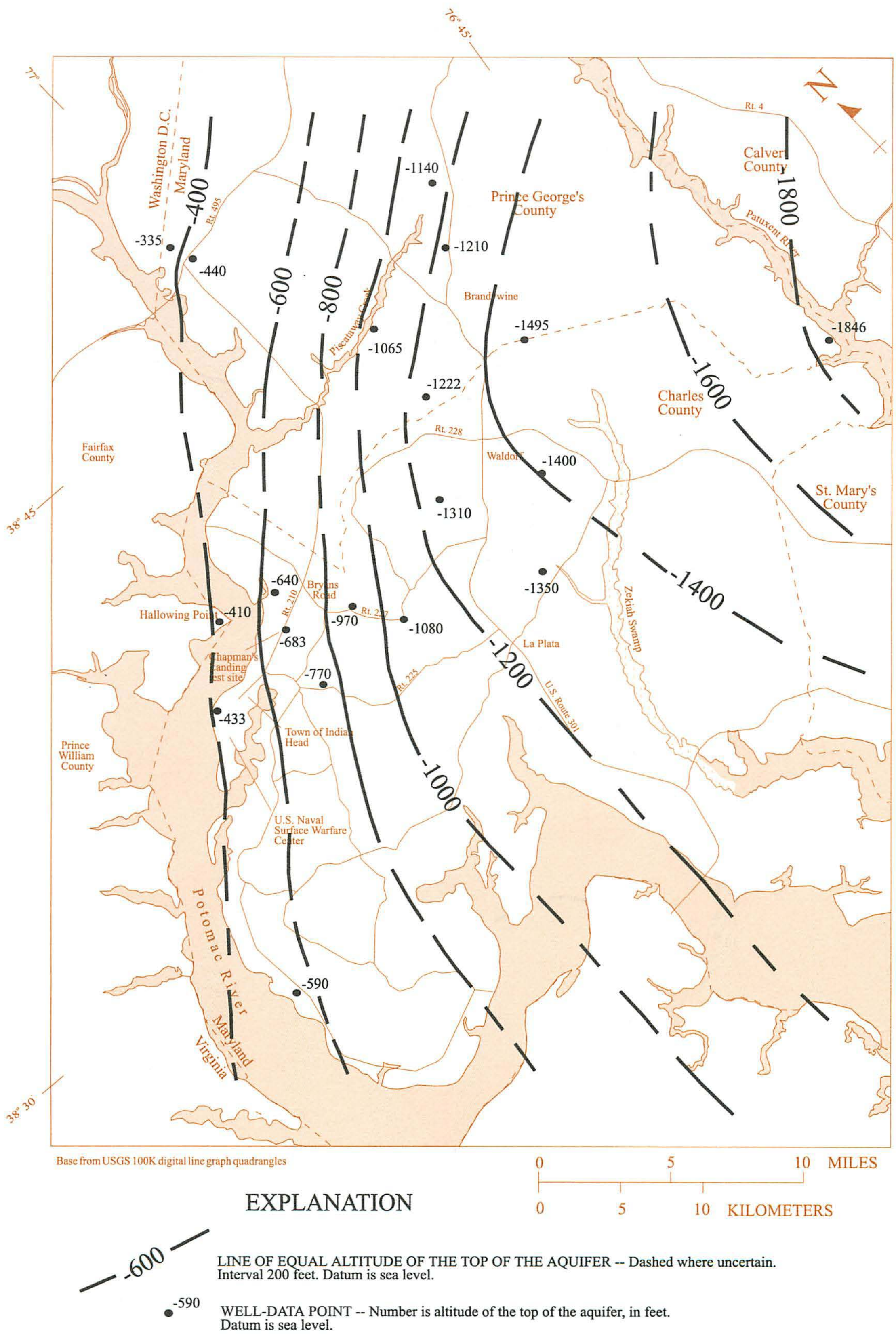
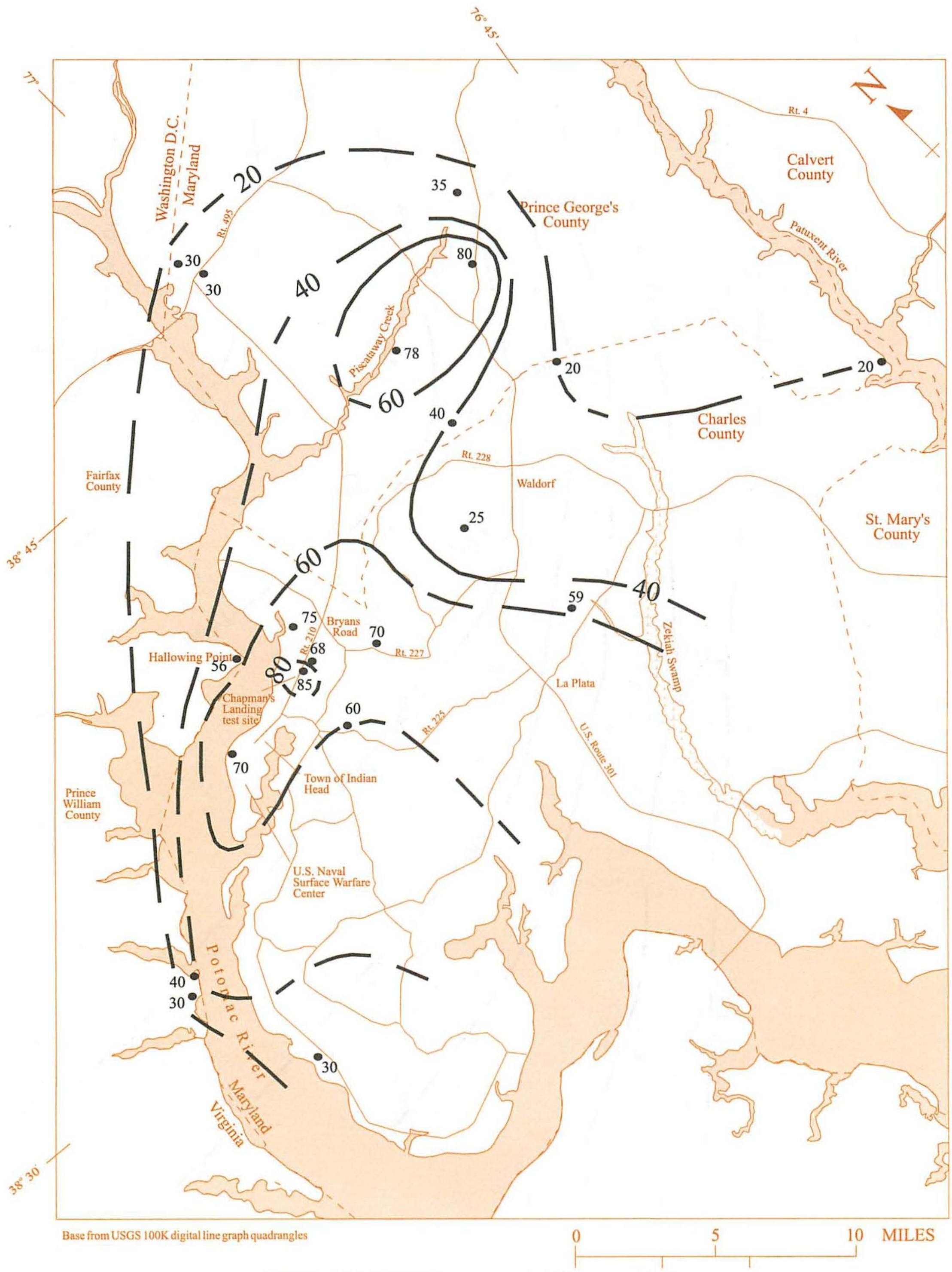


Figure 8. Approximate altitude of the top of the upper Patuxent aquifer.

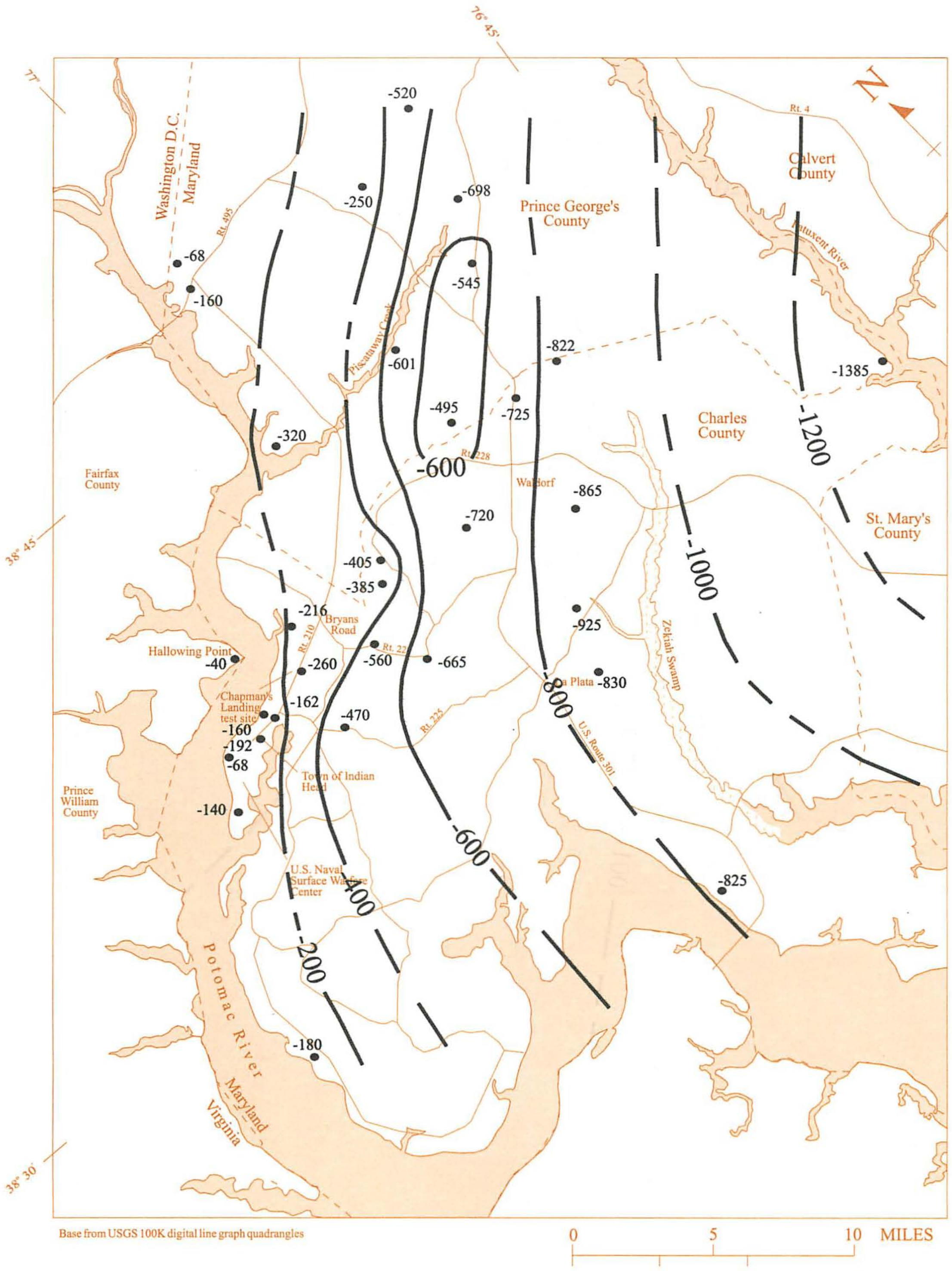


EXPLANATION

—40— LINE OF EQUAL AQUIFER THICKNESS. Interval 20 feet. Dashed where uncertain.

•20 CONTROL WELL. Number is total aquifer thickness, in feet.

Figure 9. Approximate thickness of the upper Patuxent aquifer.

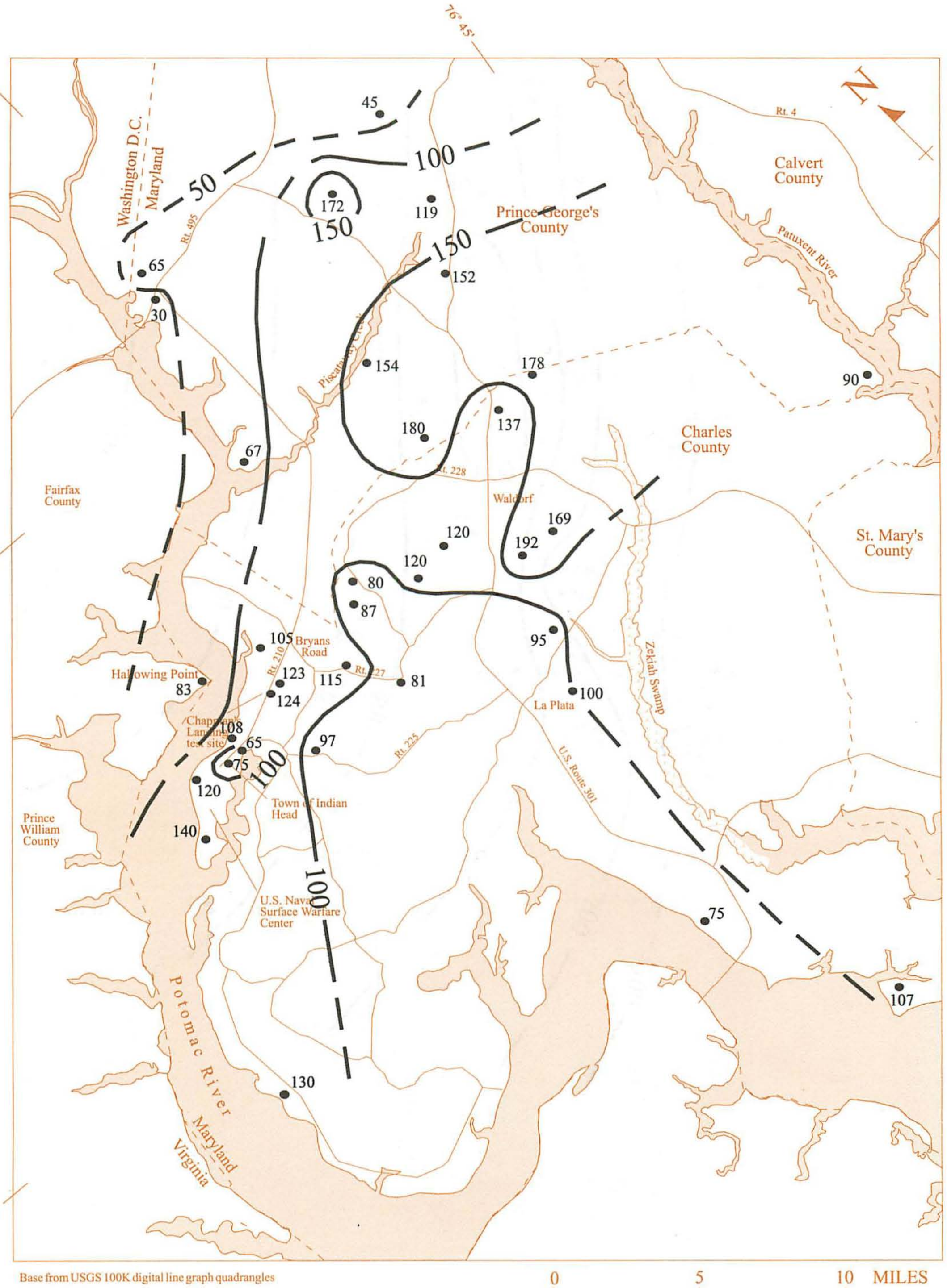


EXPLANATION

-200 LINE OF EQUAL ALTITUDE OF THE TOP OF THE AQUIFER -- Dashed where uncertain. Interval 200 feet. Datum is sea level.

-180 WELL-DATA POINT -- Number is altitude of the top of the aquifer, in feet. Datum is sea level.

Figure 10. Approximate altitude of the top of the lower Patapsco aquifer.



EXPLANATION

50 — LINE OF EQUAL AQUIFER THICKNESS. Interval is 50 feet. Dashed where uncertain.

130 CONTROL WELL. Number is total aquifer thickness, in feet

Figure 11. Approximate thickness of the lower Patapsco aquifer.

Counties (Jonathan Edwards, written commun., 1996). Rock chips collected in drill cuttings from CH Bc 75 (located near CH Bc 80) consist of coarse-grained, microcline-quartz granite or granite gneiss and fine-grained, garnetiferous, muscovite-biotite-plagioclase gneiss (Appendix B.).

The Patuxent Formation overlies the basement-rock complex. Contact between the basement rock and the Patuxent Formation is typically marked by 10 to 20 ft of light green, clayey saprolite (weathered rock). Sands within the Patuxent Formation are informally divided into the upper and lower aquifer units. Sand within the lower Patuxent aquifer is generally less abundant and finer-grained than sand in the upper Patuxent aquifer. Also, electric resistivity logs generally show lower values in the lower aquifer, indicating a higher clay content. Visual examination of the cores collected at 1,050 ft and 1,115 ft from well CH Bc 80 shows that the intergranular space is filled with a silt-clay matrix (Appendix C). Sieve analyses of the core samples show a relatively high percentage (19 percent) of silt-clay (Appendix C). The lower Patuxent aquifer is unlikely, therefore, to yield significant quantities of water. The top of the lower Patuxent aquifer is about 550 ft below sea level at Indian Head and increases to about 1,575 ft below sea level at La Plata (fig. 5). In the Indian Head-Bryans Road area, the lower Patuxent aquifer is about 20 to 50 ft thick. The lower Patuxent aquifer is overlain by approximately 20 to 90 ft of dense clay.

The upper Patuxent aquifer consists chiefly of fine to coarse sand separated by dense green and brown clay layers. A core sample collected at 825 ft in well CH Bc 80 indicates that the sand may, in places, contain appreciable amounts of silt and clay (Appendix C). The top of the aquifer varies in depth from about 400 ft below sea level at Indian Head to about 1,350 ft below sea level at Waldorf (figs. 4, 5, and 8). The thickness of the upper Patuxent aquifer is greatest at the Chapman's Landing test site (85 ft) and in an area near Piscataway Creek in southern Prince George's County (80 ft). Generally, however, it is less than 60 ft in the rest of the model area. The increased thickness at the Chapman's Landing test site may be attributed to local stacking of fluvial, channel-sand deposits. In places individual channel-fill deposits may coalesce vertically to form multistory sand bodies (Potter, 1967).

The upper and lower Patuxent aquifers are, at least locally, hydraulically connected through a leaky confining layer. Evidence of this is provided in the response of water levels in the lower Patuxent aquifer to pumpage in the upper Patuxent aquifer at the Chapman's Landing test site (well CH Bc 80).

The upper Patuxent aquifer is separated from the overlying lower Patapsco aquifer by the Arundel Clay. Within the study area, the Arundel Clay is a relatively low permeability clay interbedded with thin beds of fine-grained, gray sand. Drill cuttings from the test holes indicate a dense, red, purple, and brown clay (Appendix B). Cores from test well CH Bc 80 indicate a light gray, reddish-brown, tough clay, interbedded with thin layers of sand (Appendix C). The altitude of the top of the Arundel Clay varies from about 275 ft below sea level at Indian Head (fig. 5) to about 1,500 ft below sea level in the eastern part of Charles County (pl. 2). Total thickness ranges from about 55 ft in the test well at Mattawoman Waste-Water Treatment Plant to more than 300 ft in the southeastern part of Prince George's County. The Arundel Clay is approximately 120 ft thick at the Chapman's Landing test site. The Arundel Clay functions as an effective confining layer separating the upper Patuxent and lower Patapsco aquifers in most areas because it is a relatively thick, low-permeability clay. The hydraulic connection between the Patuxent and Patapsco aquifers is greatest at sites where the Arundel Clay is thinner than normal or unusually sandy.

The lower Patapsco aquifer is composed of alternating layers of fine to coarse, light gray and brown sand, and tough clay. The lower Patapsco aquifer referred to in this report correlates downdip with the La Plata aquifer system (Wilson and Fleck, 1990). The depth to the top of the aquifer ranges from 68 ft below sea level at Indian Head to more than 1,300 ft below sea level in the eastern part of Charles County (fig. 10). Aquifer thickness ranges from approximately 60 ft at Indian Head to more than 150 ft in north-central Charles County and south-central Prince George's County (fig. 11). Most of the wells in the project area previously described as being completed in the Patuxent aquifer (Otton, 1955; Slaughter and Otton, 1968; Hiortdahl, 1997) were reassigned to the lower Patapsco aquifer based on newly obtained test-well data.

The lower Patapsco aquifer is overlain by a relatively thick (up to 300 ft), low permeability clay layer within the Patapsco Formation. This clay layer, separating the lower Patapsco aquifer from the overlying upper Patapsco aquifer, restricts the flow of water between the aquifers. Channeling beneath the Potomac River (either recent channeling or paleochannels) may have reduced the thickness of the clay layer overlying the lower Patapsco aquifer (Hiortdahl, 1997). The extent to which the confining layer has been eroded adjacent to the Indian Head-Bryans Road area is unknown.

HYDRAULIC PROPERTIES

Transmissivity is the measure of an aquifer's ability to transmit water. Transmissivity of the upper Patuxent aquifer, determined by constant-rate aquifer tests in two test wells drilled during this study, was 656 and 152 feet squared per day (ft^2/d) for wells CH Bd 52 and CH Cc 34, respectively. The recovering water level was plotted against the ratio of time since pumping started divided by time since pumping stopped (fig. 12). Transmissivity was calculated using a formula developed by Theis (1935) and Cooper and Jacob (1946). The wells were pumped at rates of 60 gallons per minute (gpm) in well CH Bd 52 and 50 gpm in well CH Cc 34, both for 8 hours. The calculated transmissivity values are probably lower than the actual transmissivity due in part to the short length of well screen (20 ft), partial penetration of the well screens in the aquifer, and incomplete well development. Transmissivity of the lower Patuxent aquifer was 51 ft^2/d in test well CH Bc 80 (fig. 12). This well was pumped at a rate of 35 gpm for 8 hours.

Transmissivity determined in eight additional wells screened in the upper Patuxent aquifer and three wells screened in both the upper and lower Patuxent aquifers within the model area ranged from 104 to 2,600 ft^2/d (tab. 2). These wells were not screened in all sands of the aquifers, so estimates of total transmissivity were made to account for partial penetration. First, the horizontal hydraulic conductivity of the sand layers screened was estimated by dividing the calculated transmissivity by the length of the well screen. The total sand thickness determined by geophysical and lithologic logs was then multiplied by the horizontal hydraulic conductivity. The estimated transmissivity for the total aquifer thickness ranged from 230 to 4,400 ft^2/d for the wells screened in the upper Patuxent aquifer. Transmissivity is greatest in the area between Bryans Road and Indian Head, as determined by aquifer tests on wells CH Bc 75 and 77 (Chapman's Landing wells 2 and 1, respectively). Transmissivity decreases to the north, south, and east of this area. A possible explanation for the localized area of high transmissivity may be the presence of stacked channel-sand deposits. The transmissivity of the upper Patuxent aquifer in the Indian Head area has not been tested; however, geophysical logs show less sand compared to the Chapman's Landing test site, indicating a lower transmissivity. The distribution of transmissivity values determined by aquifer tests for the upper Patuxent aquifer is shown in figure 13. Regional trends in transmissivity distribution across the model area can not be established given the scarcity of data points.

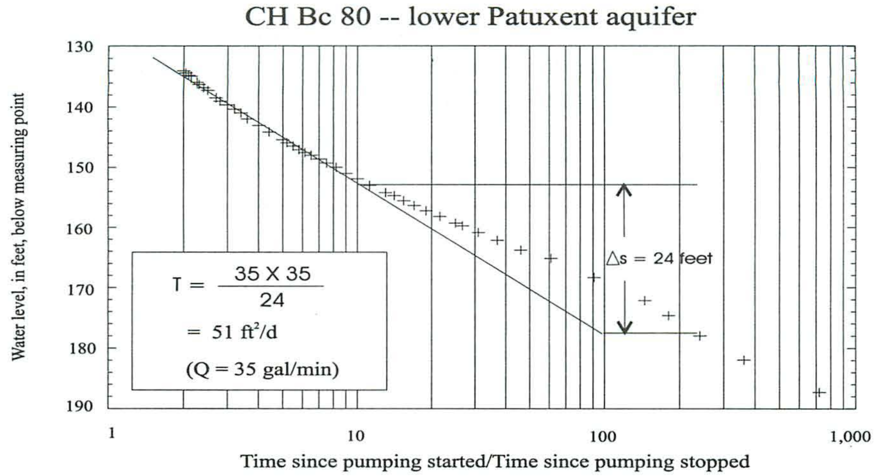
Storage coefficient is a measure of an aquifer's ability to release or take into storage water per unit change in hydraulic head. Storage coefficient of the upper and lower Patuxent aquifers were estimated from the barometric efficiency determined in the test wells using a formula described by Jacob (1940) (cited in Lohman, 1972, p. 9). The resulting storage coefficients for wells CH Bc 80, Bc 77, Bd 52, and Cc 34 were 3.4×10^{-5}, 1.1×10^{-4}, 9.2×10^{-5}, and 1.6×10^{-4}, respectively. The median value is 1.5×10^{-4}. Fleck and Vroblesky (1996) reported storage coefficients of the Patuxent aquifer from 1×10^{-5} to 1×10^{-3} with an average of 2.6×10^{-4}.

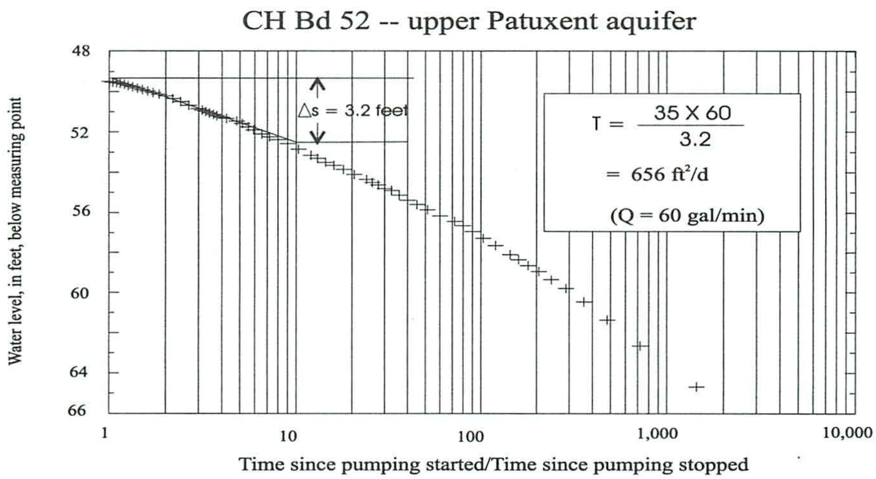
Transmissivity values of the lower Patapsco aquifer determined from aquifer tests range from approximately 190 to 3,500 ft^2/d within the model area (tab. 3). Transmissivity of the full aquifer estimated using the previously described method ranged from 250 to 5,600 ft^2/d. The distribution of transmissivity determined by aquifer tests of the lower Patapsco aquifer is shown in figure 14. In the vicinity of Waldorf and La Plata transmissivity ranges between 500 and 3,500 ft^2/d. In comparison, the transmissivity of the lower Patapsco aquifer is less than 1,200 ft^2/d in the Indian Head-Bryans Road area.

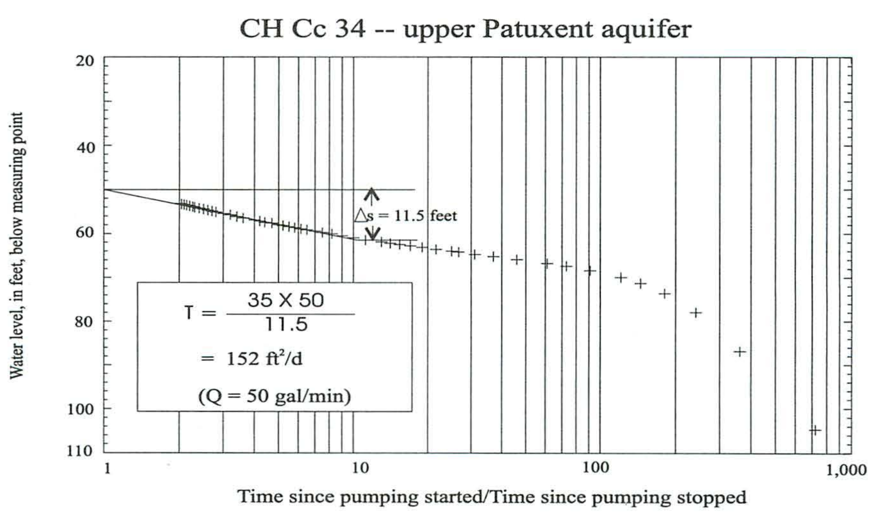
Storage coefficients of the lower Patapsco in southern Maryland are reported to range from 3×10^{-5} to 5×10^{-3} (Mack, 1962; Hansen, 1972; Fleck and Vroblesky, 1996). Slaughter and Otton (1968) reported storage coefficients ranging from 2×10^{-4} to 4×10^{-3} in the Indian Head area.

WATER LEVELS AND DIRECTION OF GROUND-WATER FLOW

The potentiometric surface of the lower Patapsco aquifer during the fall of 1997 is shown in figure 15. Also shown on the map are locations of wells or well fields pumping more than 10,000 gallons per day (gal/d) (annual average). The highest water level occurs in southern Prince George's County at 8 ft above sea level. The potentiometric surface decreases southward toward cones-of-depression centered around well fields in Waldorf and La Plata. The deepest water level, 169 ft below sea level, was measured at Waldorf. A shallower







$$T \text{ (transmissivity)} = \frac{35 \times Q}{\Delta s}\text{, in feet squared per day (ft}^2\text{/d)}$$

Q = pumping rate, in gallons per minute (gal/min)

Δs = drawdown, in feet (ft) per log cycle

Figure 12. Calculation of transmissivity using the Jacob straight-line method for the upper Patuxent aquifer in test wells drilled during this study.

Table 2. Transmissivity data for the upper Patuxent aquifer in Charles County and southern Prince George's County, Maryland and Prince William County, Virginia

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

Well number	Cumulative screen length, (ft)	Total aquifer thickness, (ft)	Horizontal hydraulic conductivity, (ft/d)	Transmissivity, (ft^2/d) Aquifer test analyses	Transmissivity, (ft^2/d) Estimated using total aquifer thickness
[1]Quantico well 2	42	42	--	520	[2]520
[1]Quantico well 4	26	26	--	440	[2]440
CH Bc 75	50	85	52	2,600	4,400
CH Bc 77	30	68	61	1,830	4,100
CH Bc 78	90	75	--	937	[2]937
[3]CH Bc 80	20	40	2	51	80
CH Bd 52	20	65	33	656	2,100
CH Cc 34	20	64	8	152	510
CH Ce 57	60	117	2	104	230
CH Da 18	20	20	--	637	[2]637
[1]PG Eb 2	30	30	--	900	[2]900
[4]PG Ec 41	20	30	70	1,400	2,100
PG Ec 46	20	approx. 30	25	500	750
PG Fd 59	30	approx. 80	4	113	320

[1]Well is screened in both the upper and lower sands of the Patuxent aquifer
[2]Entire aquifer was screened
[3]Well is screened in the lower Patuxent aquifer
[4]Test on well screen set in the upper Patuxent aquifer

cone-of-depression occurs in the vicinity of the Potomac Electric Power Company's (PEPCO) Morgantown Power Plant located in the southern part of Charles County. The highest concentrated pumpage in the Indian Head-Bryans Road area, (0.86 Mgal/d in 1997), is located on the Indian Head peninsula at the U.S. Naval Surface Warfare Center; however, less drawdown (higher water levels) occurs in this area than in other parts of the study area where the pumpage is lower. This is likely the result of a combination of higher transmissivity in this area and a possible interconnection with the Potomac River through channels eroded into the aquifer. A hydraulic interconnection between the aquifer and the Potomac River would result in a recharge boundary, thereby stabilizing water levels.

Current heads in the lower Patapsco aquifer have declined significantly from estimated pre-stressed levels. All pre-stressed heads in the lower Patapsco aquifer had to be equal to or greater than sea level. In an unstressed Coastal Plain aquifer, all heads must be equal to or greater than the altitude of the lowest discharge boundary (ocean or bay at sea-level altitude). Compared to prepumping conditions, heads in the lower Patapsco aquifer have declined by as much as 170 ft at Waldorf and 40 to 105 ft in the Indian Head-Bryans Road area.

Figure 13. Transmissivity distribution of the upper Patuxent aquifer in Charles County and southern Prince George's County.

Table 3. Transmissivity data for the lower Patapsco aquifer in Charles County and southern Prince George's County

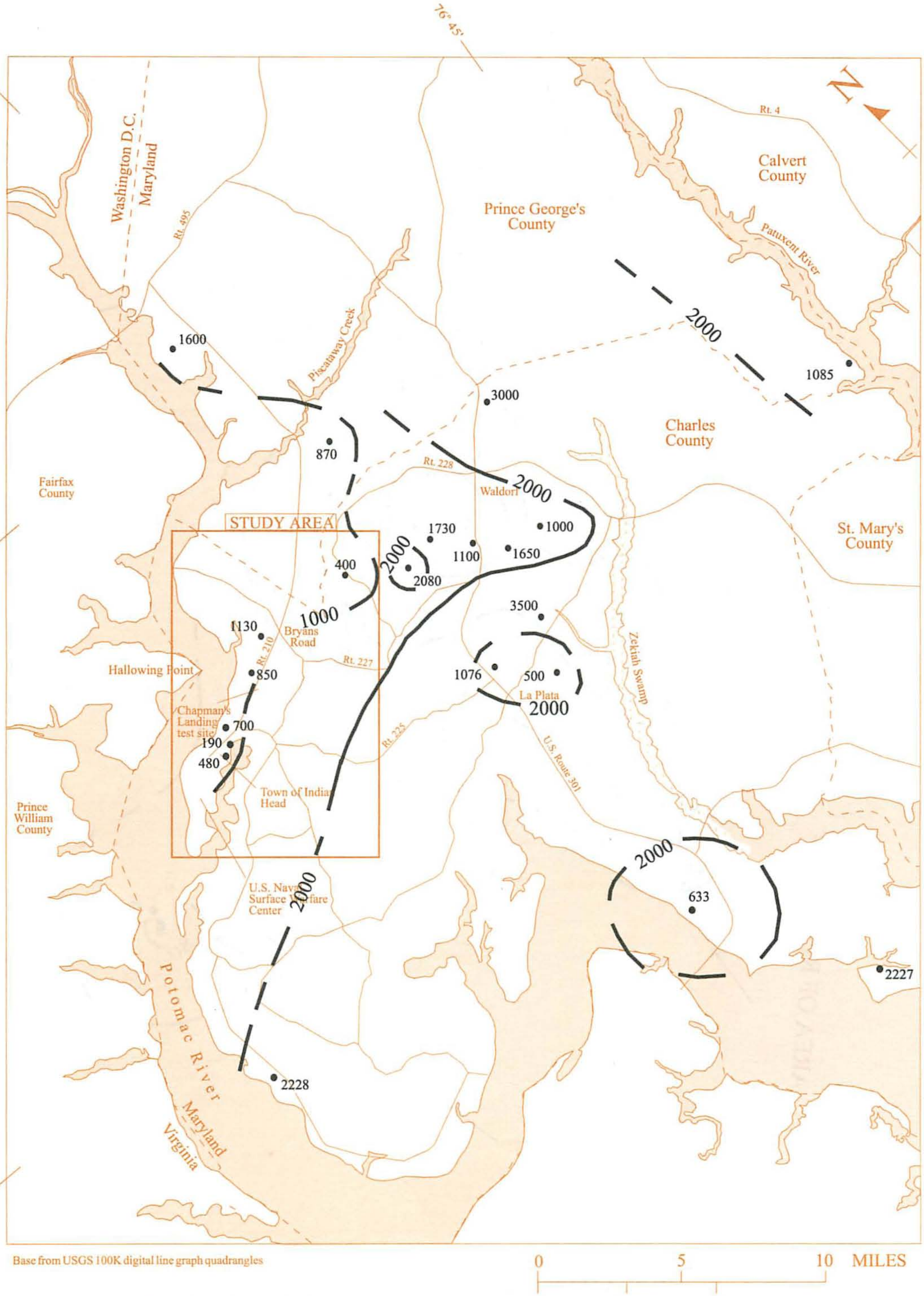
[ft = feet; ft/d = feet per day; ft²/d = feet squared per day]

Well number	Cumulative screen length, (ft)	Total aquifer thickness, (ft)	Horizontal hydraulic conductivity, (ft/d)	Transmissivity, (ft^2/d)	
				Aquifer test analyses	Estimated using total aquifer thickness
CH Bc 6	50	approx. 110	14	700	1,500
CH Bc 70	50	65	3.8	190	250
CH Bc 72	63	75	7.6	480	570
CH Bc 74	36	approx. 44	24	850	1,100
CH Bc 76	65			1,130	[1]1,130
CH Bd 46	45	80	9	400	700
CH Be 58	151			1,730	[1]1,730
CH Be 64	95	103	12	1,100	1,240
CH Be 66	104	120	20	2,080	2,400
CH Be 67	192			1,650	[1]1,650
CH Bf 147	169			1,000	[1]1,000
CH Bf 150	140			3,000	[1]3,000
CH Ce 43	95	95	37	3,500	3,500
CH Ce 51	90	100	6	500	600
CH Ce 56	125			1,076	[1]1,076
CH Da 19	50	80	44	2,228	3,500
CH Ee 91	55	75	12	633	900
CH Ff 60	84	107	26	2,227	2,800
PG Eb 20	60			1,600	[1]1,600
PG Fc 31	14	approx. 90	62	870	5,600
PG Hf 31	52	90	21	1,085	1,900

[1]Entire aquifer was screened

The general direction of horizontal ground-water flow in the lower Patapsco aquifer is indicated on figure 15. The primary direction of flow is from the north and west toward well fields at Indian Head, Bryans Road, Waldorf, La Plata, and Morgantown. Water entering from the recharge area (located within the aquifer outcrop area) in Virginia and Washington, D.C. flows downdip and is captured by the pumping wells. Part of the ground-water flow bypasses the pumping wells and continues in a downdip direction towards the southeast.

In contrast to water levels in the lower Patapsco aquifer, water levels in the upper Patuxent aquifer are much higher. Water levels in the upper Patuxent aquifer measured in observation wells during the fall of 1997

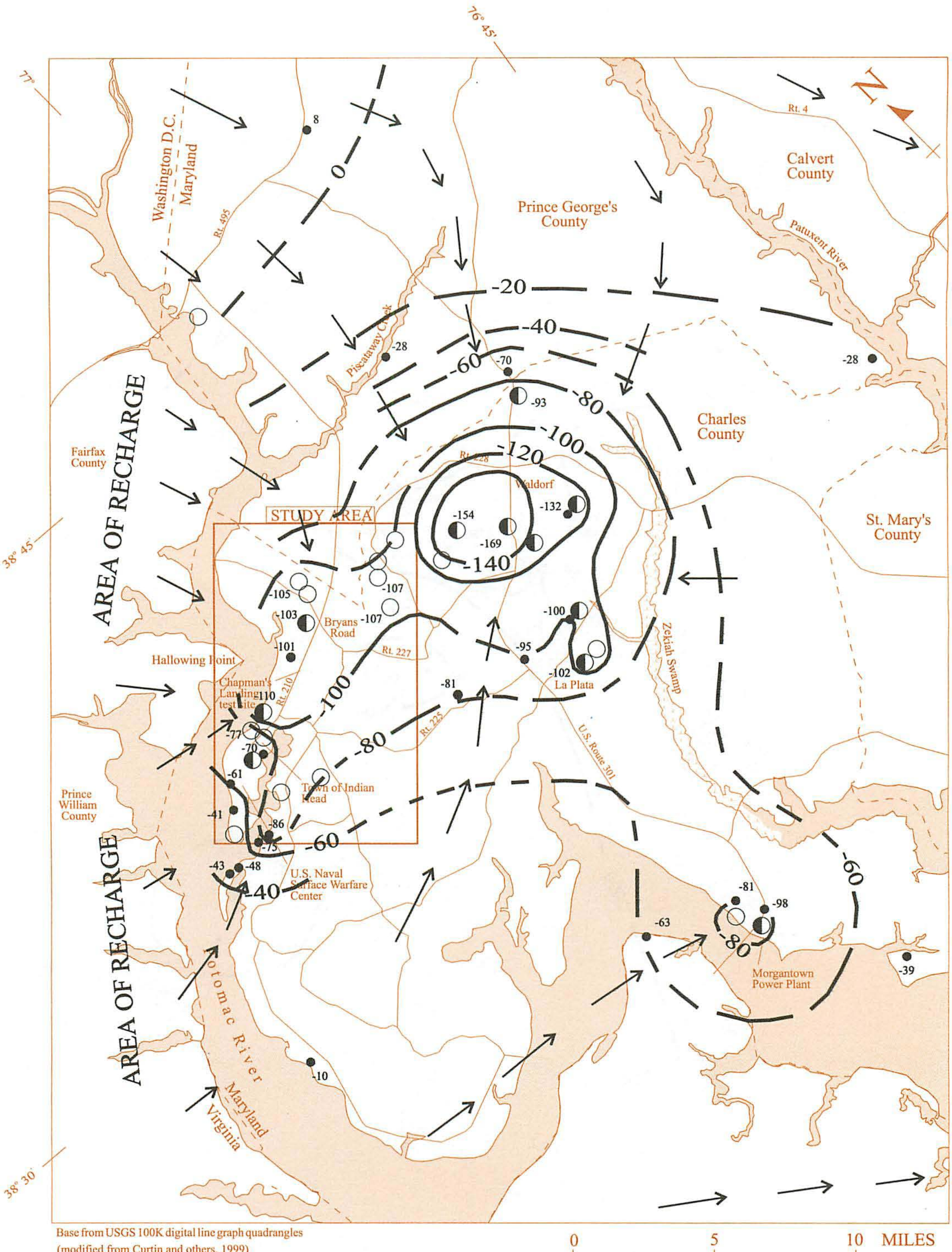


EXPLANATION

1000 — Approximate line of equal transmissivity, in feet squared per day. Contour interval is irregular. Dashed where uncertain.

• 2228 Transmissivity, in feet squared per day, from aquifer tests (table 3).

Figure 14. Transmissivity distribution of the lower Patapsco aquifer in Charles County and southern Prince George's County.



EXPLANATION

POTENTIOMETRIC SURFACE -- Shows approximate altitude of water level, in feet related to sea level. Contour interval is 20 feet. Dashed where uncertain.

WELL -- Number is water level in feet related to sea level. Symbol indicates average yield from well or well field, in gallons per day:

-10 Observation well

-105 10,000 to 100,000

-102 100,000 to 1,000,000

Direction of ground-water flow

Figure 15. Potentiometric surface of the lower Patapsco aquifer in Charles County and southern Prince George's County during the fall, 1997.

ranged from 8 ft below sea level to 8 ft above sea level (fig. 16). Water levels within the study area are affected by pumping from a production well screened in the upper Patuxent aquifer at South Hampton (CH Bc 78). Prior to the start of pumping at South Hampton in March 1997, water levels measured in the upper Patuxent aquifer were above sea level with the exception of CH Da 18 at Douglas Point and CH Cc 34 at the Mattawoman Waste-Water Treatment Plant. The deeper water levels at those sites may be attributed to leakage upwards to the lower Patapsco aquifer.

EFFECTS OF PUMPAGE ON WATER LEVELS

Regulatory guidelines established by the Maryland Department of the Environment prohibit drawdowns resulting from pumpage to exceed the 80-percent management water level (fig. 3). In the Indian Head-Bryans Road area, the amount of remaining available drawdown under prepumping conditions ranged from 90 to 300 ft for the lower Patapsco aquifer and 350 to 650 ft for the upper Patuxent aquifer. Pumping from the lower Patapsco aquifer has significantly reduced the amount of remaining available drawdown within the study area. The remaining drawdown available in the lower Patapsco aquifer in 1997 ranged from 0 to 200 ft (0 to 60 percent) in the Indian Head-Bryans Road area and 30 to 400 ft (30 to 70 percent) elsewhere in the study area (fig. 17). The 80-percent management level was reached in a small area along the Potomac River shoreline in the central part of the Indian Head peninsula. Less drawdown is available in updip (northwest) areas of the aquifer because the top of the aquifer is relatively shallow. In the vicinity of Waldorf and La Plata, the percentage of available drawdown remaining in the lower Patapsco aquifer ranges from 60 to 70 percent (460 to 700 ft).

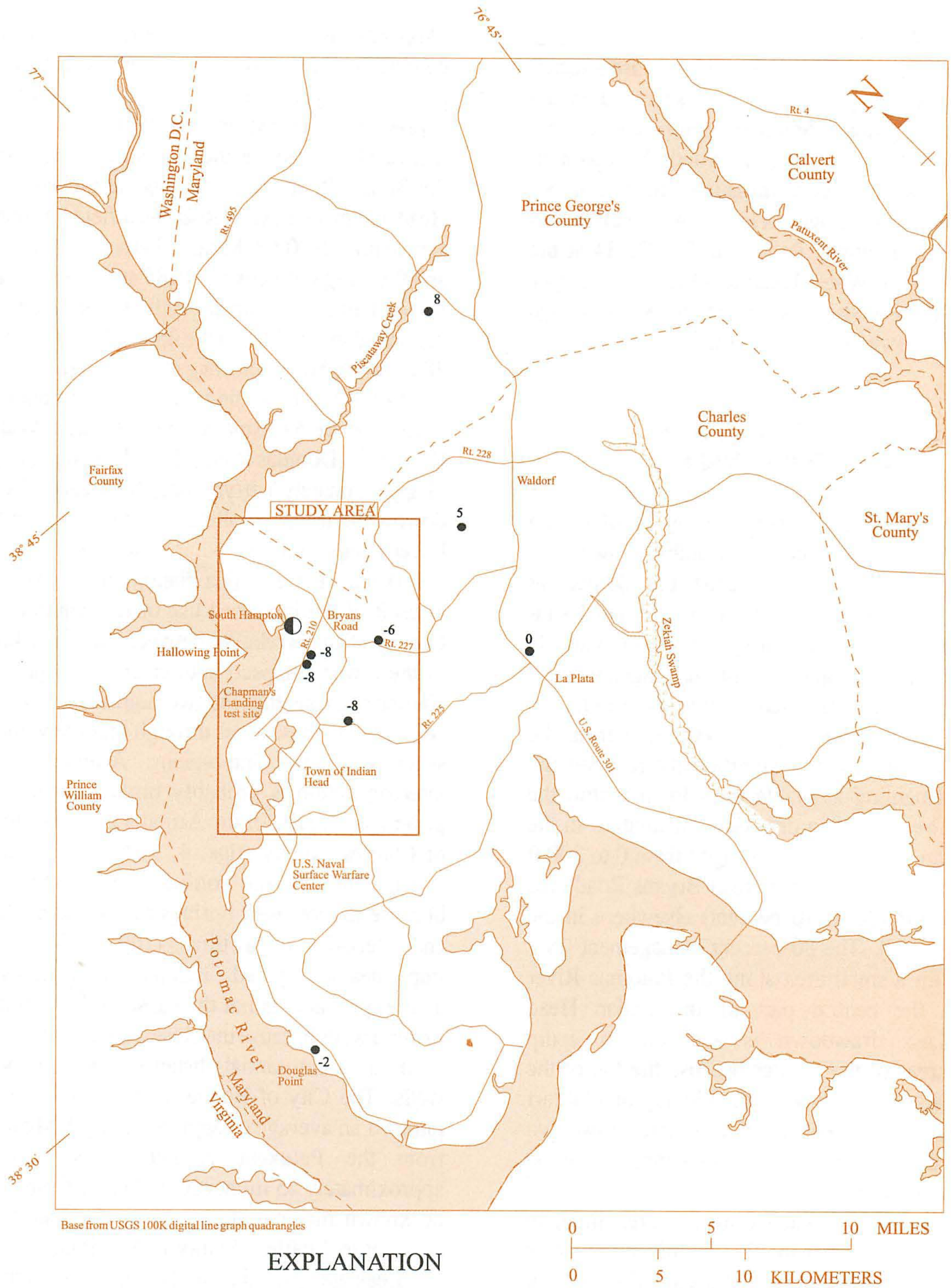
The percentage of available drawdown remaining in the upper Patuxent aquifer in 1997 is only slightly less than its original amount because of the small amount of water currently being pumped. Available drawdown remaining in 1997 ranged from 350 to 700 ft in the Indian Head-Bryans Road area (fig. 17).

Long-term water-level data indicate that lower Patapsco water levels have stabilized or recovered slightly at the U.S. Naval Surface Warfare Center (Curtin and Dine, 1995). This is related to a pumpage decrease of approximately 0.5 Mgal/d at the U.S. Naval Surface Warfare Center between 1985 and 1997 (Appendix F). Water levels northeast of Indian Head continue to decline at a rate of approximately 2 to 3 feet per year (ft/yr) as a result of the expanding cone-of-depression centered in the Waldorf area and from increased pumping at the Town of Indian Head and in the Bryans Road area. Pumpage at the Town of Indian Head and in the Bryans Road well field has increased by approximately 0.08 Mgal/d between 1985 and 1997, and 0.04 Mgal/d between 1985 and 1996, respectively. Lower Patapsco pumpage in the Bryans Road well field decreased in 1997 when the upper Patuxent well (CH Bc 78 at South Hampton) began pumping.

Water levels in the upper Patuxent aquifer in two wells, CH Be 57 (Smallwood West near Waldorf) and CH Da 18 (Douglas Point), have been declining at a rate of approximately 1 ft/yr since about 1986 (fig. 18). The downward trend parallels that of water levels in the lower Patapsco in two other wells, CH Da 20 (Douglas Point) and CH Ce 37 (La Plata), which have declined as a result of the increased use of that aquifer in Charles County. The correlation between the water-level trends in the lower Patapsco aquifer and the upper Patuxent aquifer suggests that the two aquifers are hydraulically connected in these areas through relatively thin or sandy sections in the intervening Arundel Clay. This interconnection is probably limited areally, given the general continuity of the Arundel Clay throughout most of Charles County (figs. 4, 5, 6; pl. 2). Appreciable leakage through the confining bed itself is unlikely because in most well borings the Arundel Clay has the characteristics of a thick (100 to 300 ft), dense, impermeable clay bed. Pumpage in the upper Patuxent aquifer probably is not the cause of the declining heads in these wells because the closest significant withdrawals occur at a substantial distance from the observation wells. The City of Bowie in Prince George's County pumped an average of approximately 1 Mgal/d in 1995 from the Patuxent aquifer. This well field is approximately 25 mi north of Charles County. There is no known major pumpage from the Patuxent aquifer adjacent to Charles County in Virginia.

Leakage upward from the upper Patuxent aquifer to the lower Patapsco aquifer may also be occurring in the vicinity of the test well at the Mattawoman Waste-Water Treatment Plant. Water levels measured in that well are deeper relative to the upper Patuxent aquifer water levels measured in other wells within the study area. Also, the Arundel Clay is thinner (55 ft) at that site.

A 5-day aquifer test of the upper Patuxent aquifer was conducted to (1) determine the lateral hydraulic connection between sands within the upper Patuxent



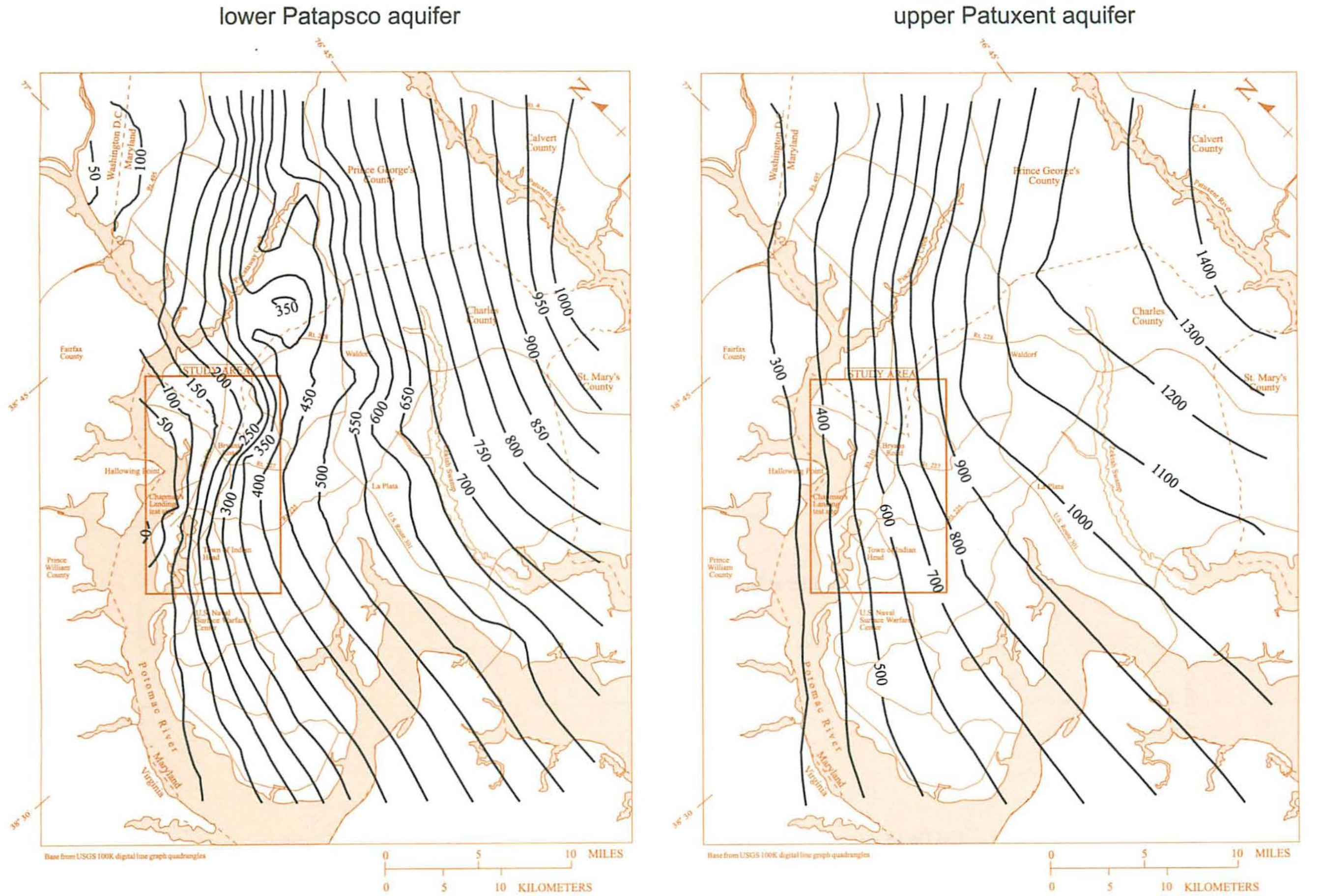
EXPLANATION

WELL-- Number is water level in feet related to sea level. Symbol indicates average yield from well, in gallons per day:

-2 ● Observation well.

◐ 100,000 to 1,000,000

Figure 16. Potentiometric surface of the upper Patuxent aquifer in Charles County and southern Prince George's County during the fall, 1997.



EXPLANATION

0 Remaining available drawdown, in feet. Contour interval is 50 or 100 feet.

Figure 17. Remaining available drawdown in the lower Patapsco and upper Patuxent aquifers in 1997.

aquifer, (2) determine if pumping from the upper Patuxent aquifer would have short term effects on water levels in the lower Patapsco aquifer, and (3) determine the presence of flow boundaries within the upper Patuxent aquifer. During the test, well CH Bc 75 (Chapman's Landing well 2), screened in the upper Patuxent aquifer, was pumped continuously at a rate of 500 gpm for 5 days (November 19-24, 1996). During and after the test, water levels were observed in wells screened in the upper Patuxent aquifer (wells CH Bc 77, 78, Bd 52, Cc 34, and Da 18) (fig. 19). Water levels were observed in lower Patapsco wells at Montrose Farms (CH Bc 81), Laurel Drive (CH Bc 79, located approximately 0.5 mi northwest of CH Bc 75), Potomac Heights (CH Bc 24), and in a public-supply well at Hallowing Point, Virginia (Hallowing Point well 1A). Although the deepest screen in the Hallowing Point well may be set within the Patuxent aquifer, it was isolated

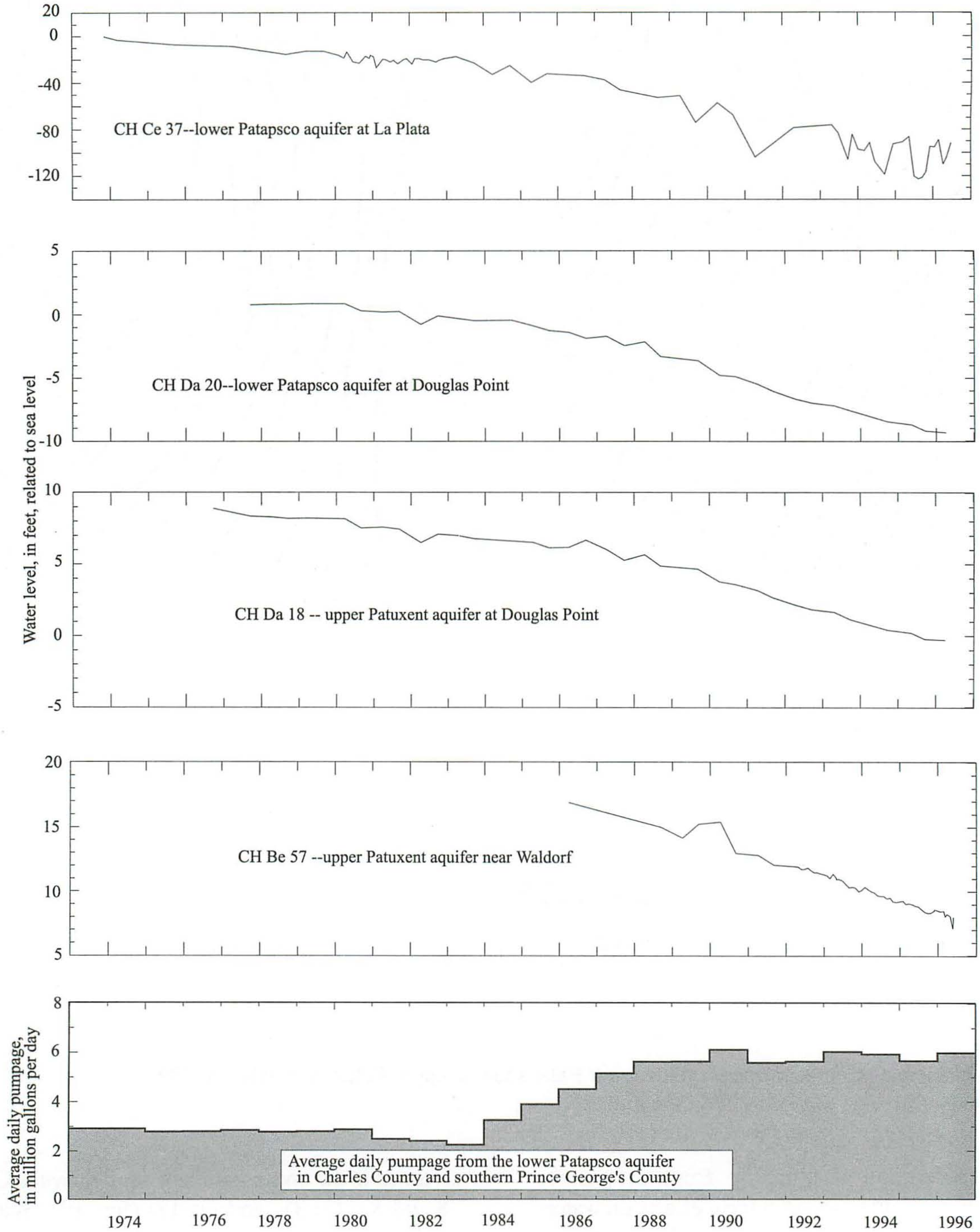


Figure 18. Water levels in the upper Patuxent and lower Patapsco aquifers related to pumpage in the lower Patapsco aquifer in Charles County and southern Prince George's County.

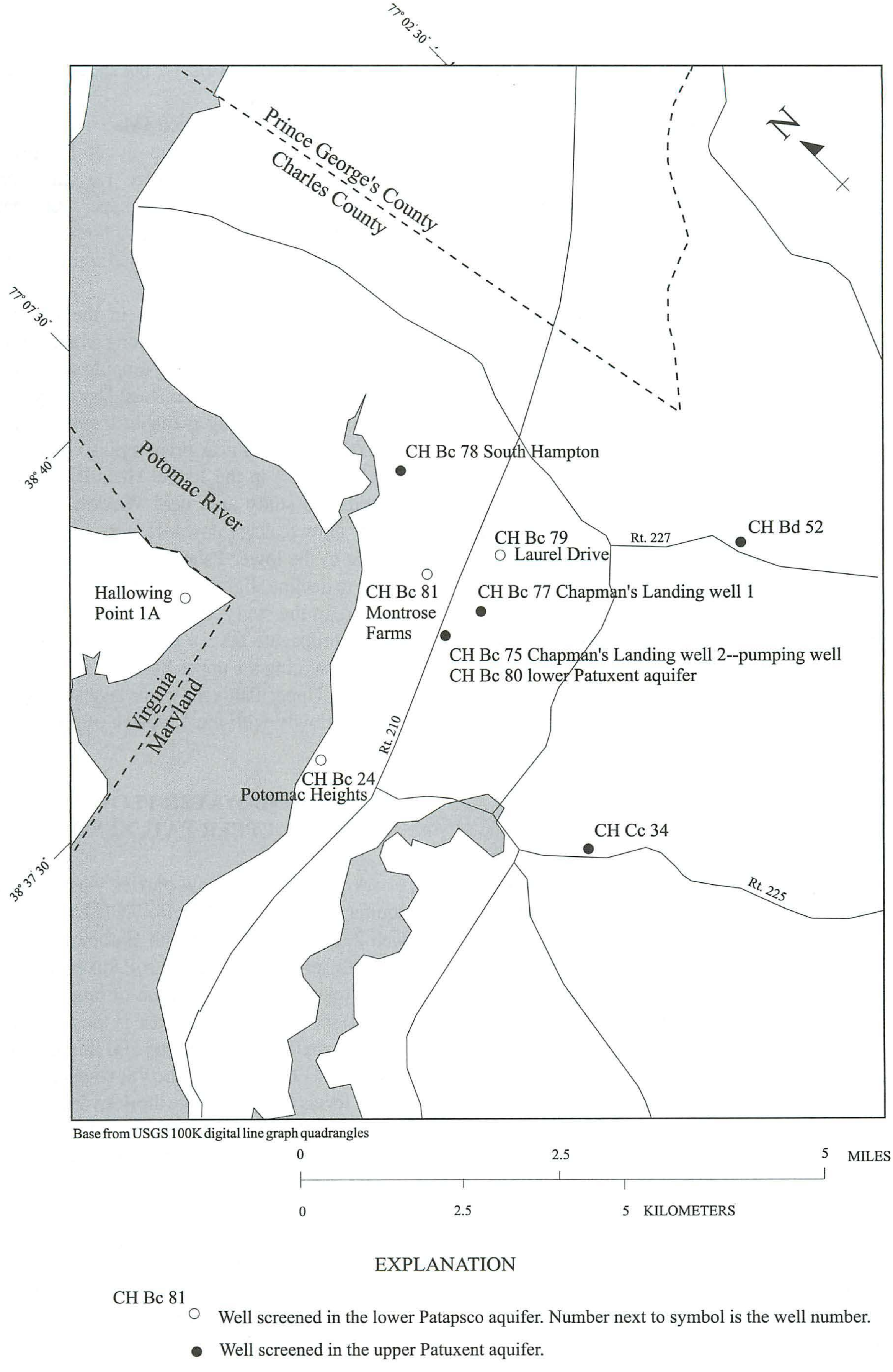


Figure 19. Location of wells monitored during a 5-day aquifer test of well CH Bc 75 (Chapman's Landing well 2).

from the upper screens by a packer. Of the few other wells inventoried in adjacent areas of Virginia, all had well screen positions above the Patuxent aquifer.

The results of the testing showed hydraulic continuity between sands in the upper Patuxent aquifer in the study area (fig. 20). All of the wells screened in the upper Patuxent aquifer showed some decline in head as a result of the pumping. The water level in the pumping well (CH Bc 75) at the end of the 5-day period was approximately 80 ft below sea level. Drawdown ranged from approximately 80 ft at the pumping well to less than 1 ft at test wells CH Bd 52 and CH Cc 34, located about 2.5 mi to the southeast and south, respectively. Water levels generally recovered slowly after the pumping stopped; however, in test wells CH Bd 52 and CH Cc 34, there was no appreciable recovery 6 weeks after the test ended. The water level in test well CH Bc 80, screened in the lower Patuxent aquifer and located 56 ft from the pumping well, declined approximately 1 ft, indicating that the upper and lower Patuxent aquifers are hydraulically connected. The effect of pumping on water levels in the Patuxent aquifer across the Potomac River in Virginia could not be determined.

Water levels observed in the lower Patapsco aquifer were not affected by the pumping. This indicates that the Arundel Clay is, at least in the short term, an effective confining bed.

The first continuous withdrawal of water for public supply in the study area from the upper Patuxent aquifer occurred at South Hampton (CH Bc 78) in March 1997. The effect of this pumping on water levels within the study area is shown in figure 21. During the period March 1997 though February 1998, the well at South Hampton pumped an average of 0.094 Mgal/d. As a result, water levels in wells screened in the upper Patuxent aquifer within the study area declined 4.5 to 8 ft. Prepumping water levels were generally about at sea level, and pumping levels were as deep as 8.5 ft below sea level. Water-levels declined less in wells screened in the upper Patuxent aquifer outside the study area. The water level in well CH Be 57 (Smallwood West), located approximately 7.5 mi. from South Hampton, declined 1.5 ft. Water-level declines at more distant observation wells CH Ce 57 and CH Da 18 (9.5 and 15 mi from South Hampton, respectively) were less than 1 ft. During September and October, when pumpage at South Hampton was held constant at 0.15 Mgal/d, water levels began to flatten out or reach equilibrium with respect to pumpage. During November, when the well at South Hampton was turned off, water levels recovered in well CH Bc 77, but showed little recovery in the other wells.

During the same period (March 1997 to February 1998), water levels in the lower Patapsco aquifer observed at Montrose Farms 1.3 mi. from South Hampton did not respond to upper Patuxent aquifer pumpage. The water levels did, however, respond to pumpage from the lower Patapsco aquifer at the Bryans Road well field (fig. 21).

To summarize, pumpage in the lower Patapsco aquifer has reduced the remaining available drawdown from 90 to 300 ft under prepumping conditions to 0 to 200 ft in 1997 in the Indian Head-Bryans Road area. In contrast, the remaining available drawdown in the upper Patuxent aquifer is near prepumping conditions, 350 to 700 ft in 1997 in the Indian Head-Bryans Road area. Outside the study area near Waldorf and at Douglas Point, slow leakage upwards from the upper Patuxent aquifer to the lower Patapsco aquifer has caused water levels to decline slightly over time in the upper Patuxent aquifer. In the study area, short-term pumpage effects do not propagate across the confining layer (Arundel Clay) separating the upper Patuxent and lower Patuxent aquifers. Upper Patuxent water levels in the study area recover slowly with the cessation of pumping.

GROUND-WATER-FLOW BARRIER IN THE UPPER PATUXENT AQUIFER

A ground-water-flow barrier was detected during aquifer tests of wells CH Bc 75 (Chapman's Landing well 2) and CH Bc 78 (South Hampton well 2), which are both screened in the upper Patuxent aquifer. Water levels related to the logarithm of time (since pumping started) show a distinct increase in the rate of drawdown after approximately 1,000 and 200 minutes of pumping in wells CH Bc 75 and Ch Bc 78, respectively (fig. 22). Water levels that plot above the drawdown curve in well CH Bc 75 shortly after 1,000 minutes were caused by two brief intervals during which the pump stopped. The increased rate of drawdown occurs when the expanding cone-of-depression developed around the pumping wells reach an impervious boundary (Heath, 1987).

The barrier effect could be caused by a pinchout (updip thinning) of the aquifer, or a vertical offset in the aquifer caused by faulting. Sands of the Patuxent Formation were deposited in a shifting, fluvial-deltaic environment which typically produces laterally discontinuous (lensoidal) deposits. This type of deposit contains pinchouts that disrupt the lateral hydraulic

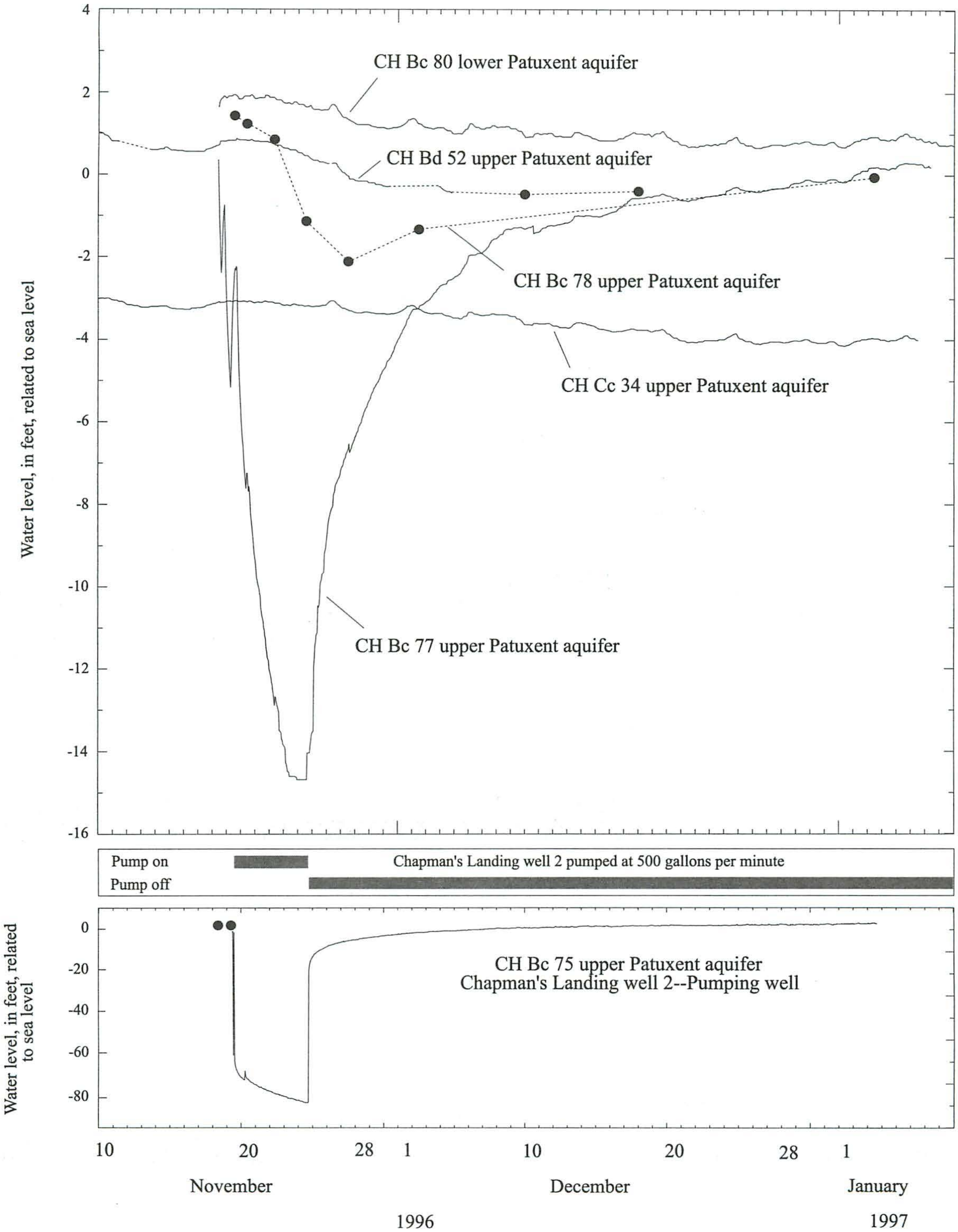


Figure 20. Water-level fluctuations in the upper and lower Patuxent aquifers during a 5-day aquifer test conducted November 19-24, 1996 on the upper Patuxent aquifer in well CH Bc 75 (Chapman's Landing well 2).

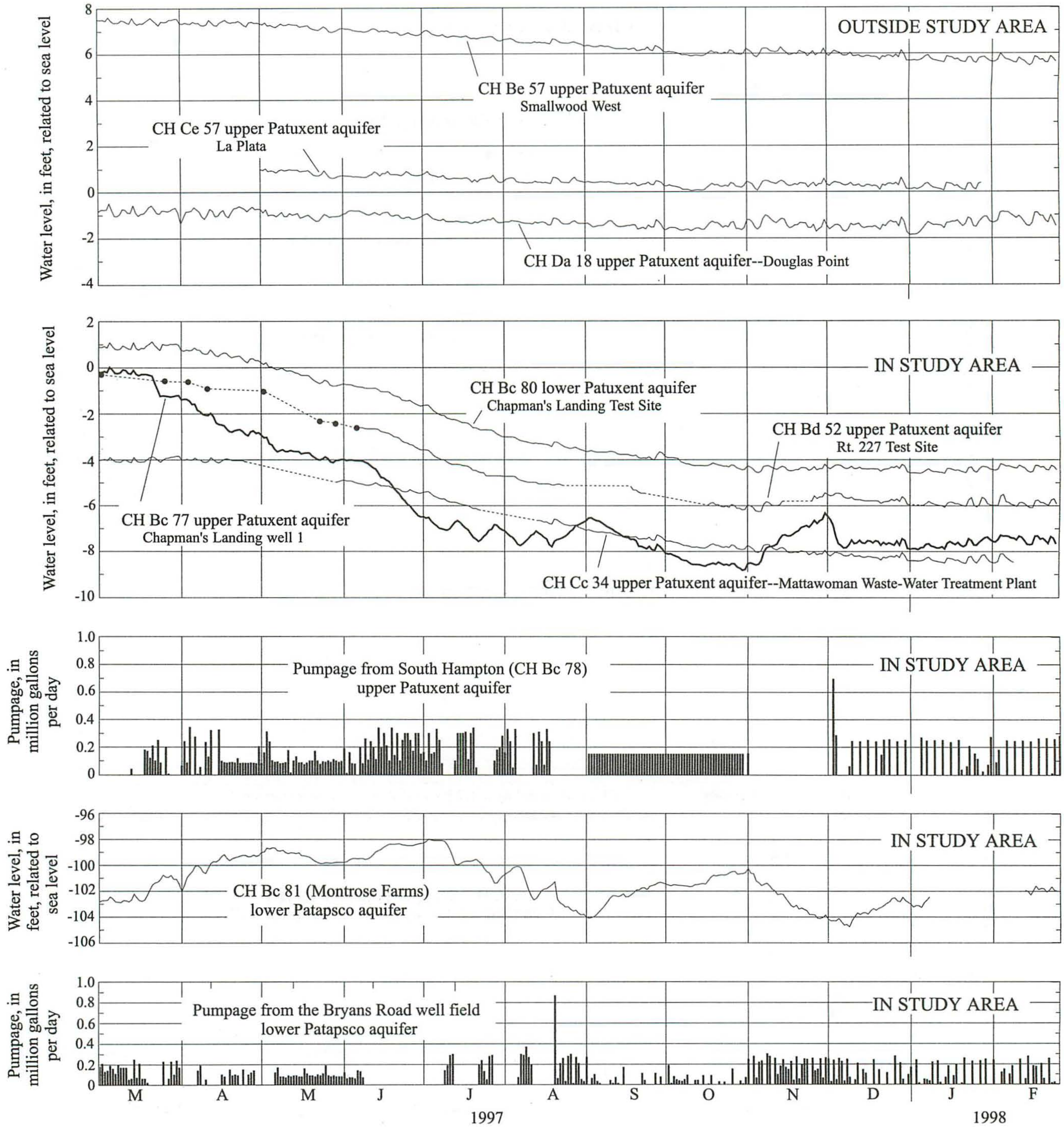
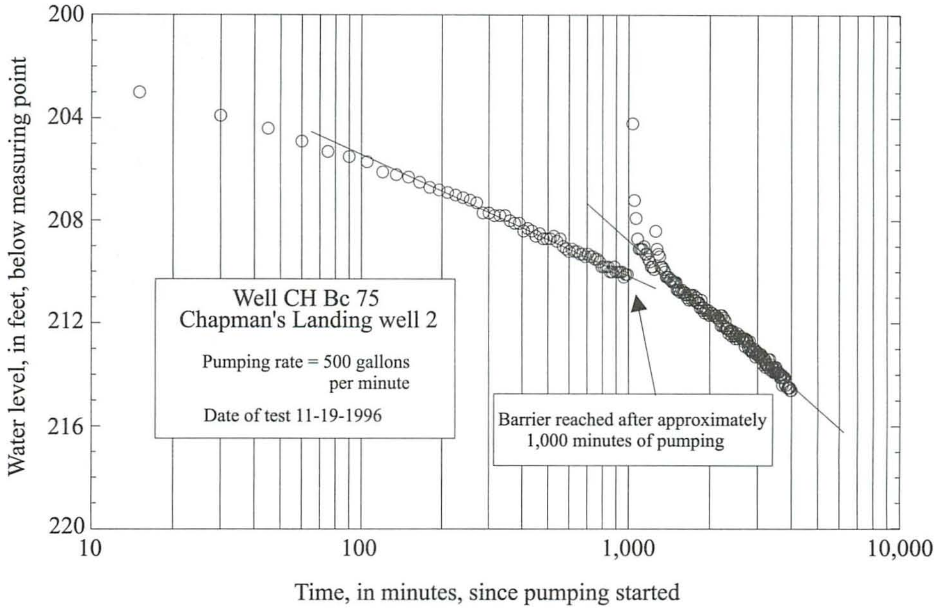


Figure 21. Water-level fluctuations in the upper and lower Patuxent and lower Patapsco aquifers related to upper Patuxent pumpage at South Hampton and lower Patapsco pumpage at Bryans Road.



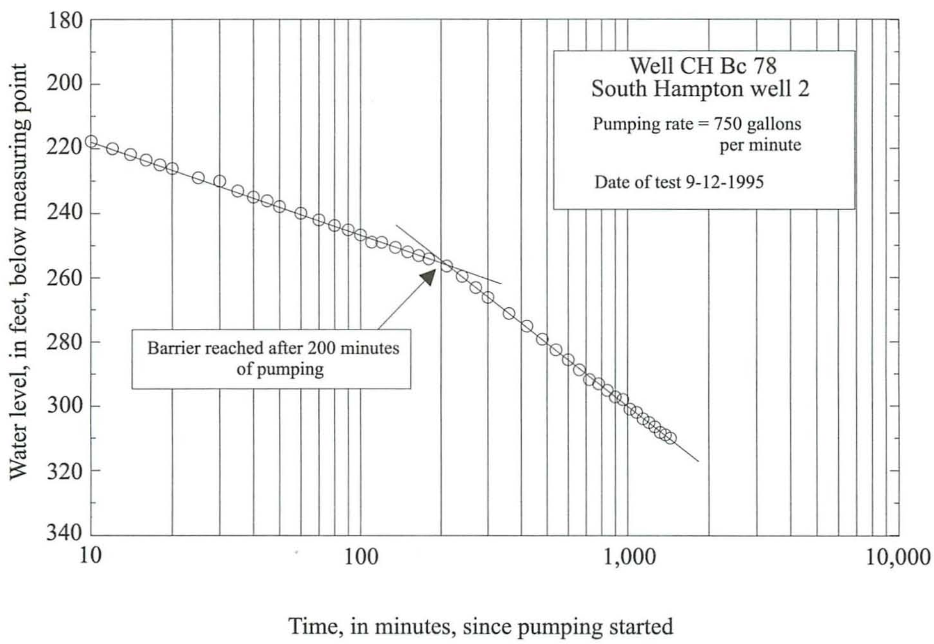


Figure 22. Semi-log plots of drawdown in wells CH Bc 75 and CH Bc 78 showing ground-water-flow barrier.

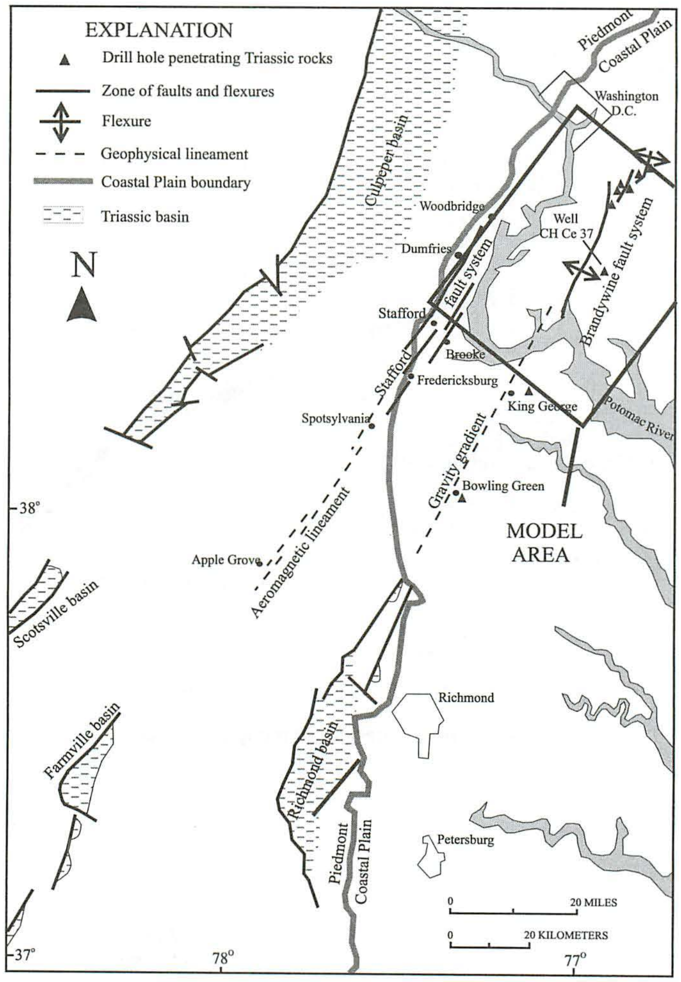


Figure 23. Alignment of the Stafford and Brandywine fault systems proposed by Mixon and Newell (1977).

continuity of the aquifer. Faults can also disrupt lateral hydraulic continuity by vertically displacing sand layers. The occurrence of faults in the underlying basement rock has been documented by previous investigators. Using seismic data, Jacobeen (1972) described a series of *en echelon*[2], high-angle reverse faults (Brandywine fault system) in southern Prince George's County. Wilson and Fleck (1990) presented evidence of the continuation of that fault system southward toward Waldorf, and described the geohydrologic implications of the faulting in Charles County. A series of *en echelon*, northeast-striking, northwest-dipping, high-angle reverse faults (Stafford fault system) was mapped southwest of the study area in Virginia by Mixon and Newell (1977) and Mixon and others (1988) (fig. 23). The Stafford fault system parallels the northeast-trending reach of the Potomac River and may extend into the project area. The displacement across the faults in Virginia attains a maximum of 200 ft and decreases upward through the Potomac Group sediments (Mixon and Newell, 1977).

The location of the barrier indicated by the aquifer-test data could not be determined without additional observation wells. Also, subsurface lithologic control is insufficient to identify and map the barrier. The estimated location of the barrier is probably updip from South Hampton and the Chapman's Landing test site based on the following observations: (1) As previously discussed, the upper Patuxent aquifer is hydraulically

[2]Faults having overlapping or staggered alignments.

continuous within the study area and eastward to the Waldorf, La Plata, and Douglas Point areas. The hydraulic connection with sands of the upper Patuxent aquifer updip in Virginia, however, has not been determined; (2) this location coincides with the trend of the Stafford fault system; and (3) the Coastal Plain sediments updip from the well sites in Charles County thin considerably toward the Fall Line in Virginia. Flow barriers in the upper Patuxent aquifer could reduce its productivity, at least locally, by restricting the amount of lateral ground-water flow.

WATER QUALITY OF THE UPPER AND LOWER PATUXENT AQUIFERS

Chemical analyses were conducted on water from wells screened in the lower Patuxent aquifer (CH Bc 80), and upper Patuxent aquifer (CH Bc 75, CH Bd 52, and CH Cc 34). Results indicate that the water from both aquifers is a sodium bicarbonate type of good quality. Table 4 lists the constituents analyzed. All reporting levels for dissolved constituents are within the recommended limits set by the U.S. Environmental Protection Agency (1986). Dissolved solids, pH (field), and specific conductance (laboratory) range from 214 to 378 milligrams per liter (mg/L), 7.7 to 7.9, and 322 to 627 microsiemens per centimeter (μS/cm), respectively. Fluoride concentrations range between 0.8 to 1.3 mg/L, which provide natural fluoridation (Kula and Hansen, 1989). Dissolved iron concentrations range from 17 to 100 micrograms per liter (μg/L). The lowest value for iron (17 μg/L) is from CH Bc 75 and the highest value (100 μg/L) is from CH Cc 34. Dissolved chloride, ranging from 16 to 43 mg/L, exceeds the typical background concentrations found in overlying, confined aquifers. For example, Chapelle and Drummond (1983) and Wilson and Fleck (1990) reported that the concentration of naturally occurring chloride in the Aquia, Magothy, and Patapsco aquifers is less than 4 mg/L in southern Maryland.

GROUND-WATER USE

Stress on the Magothy and upper Patapsco aquifers caused by the water demands of a growing population in the northern and central parts of Charles County has resulted in increased use of the deeper lower Patapsco aquifer, particularly in the vicinity of Waldorf. Ground-water use for large users (average pumpage greater than 10,000 gal/d) from the lower Patapsco aquifer in the model area increased from less than 0.5 Mgal/d prior to 1920 to 2.9 Mgal/d in 1975 (Appendixes E and F). In 1997, the amount withdrawn from the lower Patapsco in the model area equaled 5.5 Mgal/d (Appendix D, Part I). The majority of this pumpage (2.6 Mgal/d) occurred in the Waldorf area (fig. 24).

Ground-water use for large users (average pumpage greater than 10,000 gal/d) from the lower Patapsco aquifer in the Indian Head-Bryans Road area increased from less than 0.5 Mgal/d prior to 1920 to 1.8 Mgal/d in 1975 (Appendixes E and F). In 1997, the amount withdrawn from the lower Patapsco in the Indian Head-Bryans Road area equaled 1.6 Mgal/d (Appendix D). The decline in pumpage between 1975 and 1997 is attributed mainly to a decrease in pumpage at the U.S. Naval Surface Warfare Center.

Individual, residential wells screened in the lower Patapsco aquifer within the study area pumped an estimated 0.16 Mgal/d; the majority of the residential wells in the study area occur outside of the Indian Head-Bryans Road area which is serviced almost exclusively by public-supply wells. This figure is based on approximately 550 wells pumping an average of 300 gal/d. The well count was made by comparing well depths for wells completed between 1970 and 1992 to the altitude of the lower Patapsco aquifer (Maryland Department of the Environment, per. commun., 1998). The majority of residential pumpage from the lower Patapsco aquifer is in the area north of the Indian Head-Bryans Road area. South of the Indian Head-Bryans Road area, most residential wells are screened in the upper Patapsco aquifer.

The largest ground-water users in 1997 in the Indian Head-Bryans Road area were the U.S. Naval Surface Warfare Center and the Town of Indian Head, which pumped approximately 0.9 and 0.3 Mgal/d, respectively, from the lower Patapsco aquifer. Included in this amount are production wells CH Bc 67 (Town of Indian Head well 3) and CH Cb 35 (U.S. Naval Surface Warfare Center well 16A) that withdrew 0.12 Mgal/d from a sandy zone considered to be part of the Arundel Clay.

The only ground-water appropriation permits issued for the upper Patuxent aquifer in the study area are for a well at South Hampton operated by the Charles County Department of Facilities (Maryland Department of the Environment Ground-Water

Table 4. Chemical analyses of water from the upper and lower Patuxent aquifers sampled in test wells CH Bc 80, Bd 52, and Cc 34, and production well CH Bc 75

[mg/L = milligrams per liter; µg/L = micrograms per liter; µS/cm = microsiemens per centimeter at 25°C; deg. C = degrees Centigrade]

Well number	Aquifer	Alkalinity, laboratory (mg/L as $CaCO_3$)	Bromide, dissolved (mg/L)	Calcium, dissolved (mg/L)	Chloride, dissolved (mg/L)	Fluoride, dissolved (mg/L)	Iron, dissolved (µg/L)	Iron, total (µg/L)
CH Bc 75	upper Patuxent	129	--	0.47	16	0.90	17	30
CH Bc 80	lower Patuxent	252	0.16	.48	43	.90	48	580
CH Bd 52	upper Patuxent	192	.10	.83	20	.80	80	250
CH Cc 34	upper Patuxent	151	.090	.29	21	1.3	100	--

Well number	Magnesium, dissolved (mg/L)	Manganese, dissolved (µg/L)	Manganese, total (µg/L)	Nitrogen, NO_2 + NO^3 total (mg/L)	pH, field	pH, laboratory	Potassium, dissolved (mg/L)	Phosphorus, total (mg/L)
CH Bc 75	0.08	2	10	--	7.9	8.2	1.8	2
CH Bc 80	.23	8	20	--	7.8	8.2	3.3	--
CH Bd 52	.15	9	10	--	7.7	8.0	2.4	--
CH Cc 34	.11	13	--	0.090	7.8	8.0	2.5	1.30

Well number	Silica, dissolved (mg/L)	Specific conductance, field (µS/cm)	Specific conductance, laboratory, (µS/cm)	Sodium, dissolved (mg/L)	Dissolved solids residue at 180 deg. C, dissolved (mg/L)	Sulfate, dissolved (mg/L)	Tempera-ture, (deg. C)
CH Bc 75	22	306	322	68	214	7.7	19.5
CH Bc 80	16	593	627	150	378	7.8	21.3
CH Bd 52	34	425	443	98	278	8.4	20.3
CH Cc 34	38	373	381	85	244	9.0	21.4

Appropriation Permit CH95G023) and for private wells at Chapman's Landing (Permit CH93G029). The yearly average amounts appropriated are 0.16 Mgal/d and 0.39 Mgal/d for South Hampton and Chapman's Landing, respectively (Appendix D, Part II). In March 1997, South Hampton well 2 (CH Bc 78) was put into production. Average daily discharge based on monthly totals ranged from 0.045 to 0.19 Mgal/d for the period March 1997 through February 1998 (Charles County Department of Utilities, written commun., 1998). This pumpage is the first confirmed use of the upper Patuxent aquifer within the study area. Aside from water withdrawn during aquifer tests, the wells at Chapman's Landing (CH Bc 75 and CH Bc 77) have not been pumped.

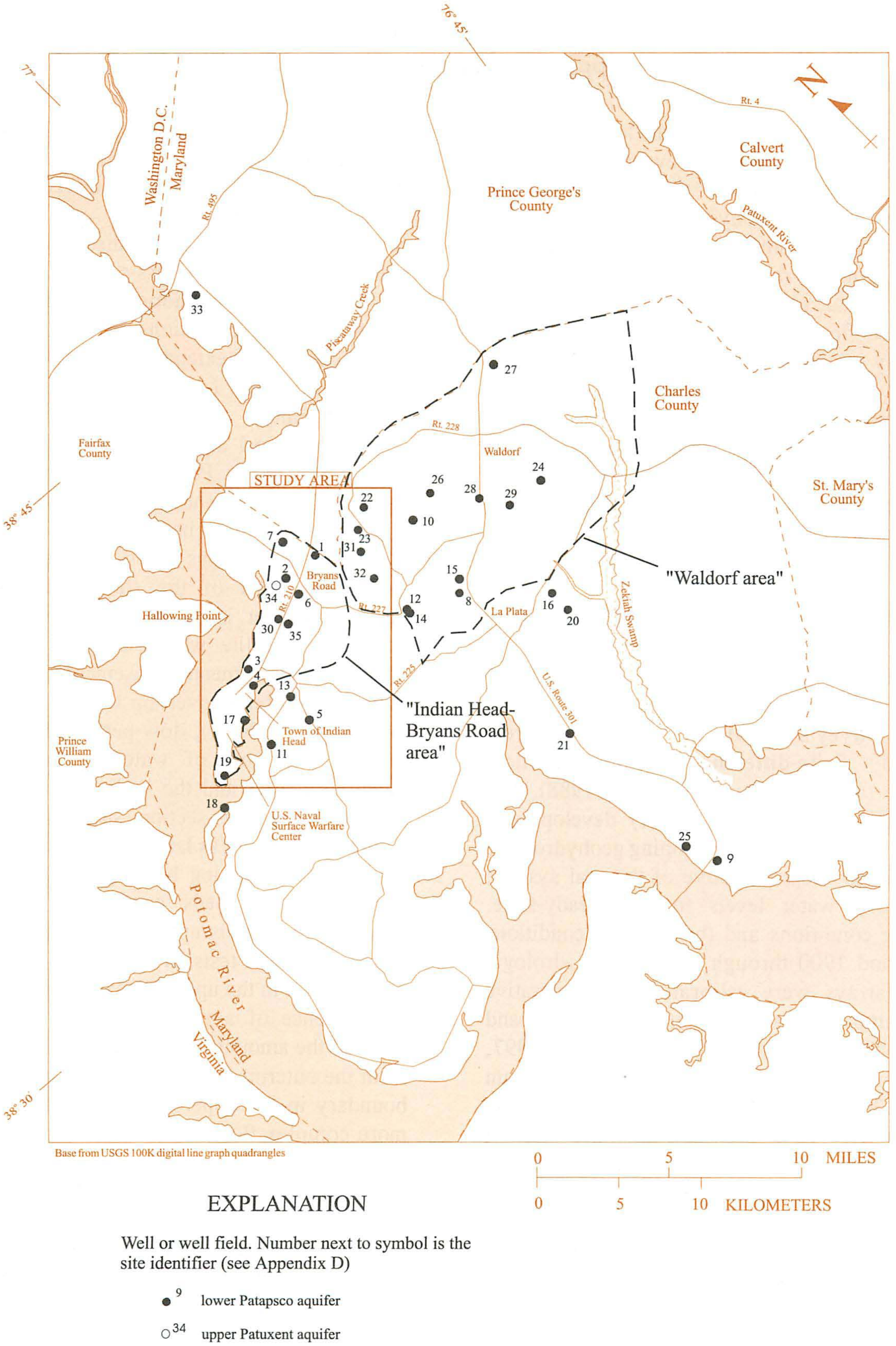


Figure 24. Locations of appropriated water use in 1997 greater than 10,000 gallons per day in the lower Patapsco and upper Patuxent aquifers.

WATER-SUPPLY POTENTIAL OF THE LOWER PATAPSCO AND UPPER PATUXENT AQUIFERS

The water-supply potential of the lower Patapsco and upper Patuxent aquifers was evaluated through a two-step process. First, the geohydrologic information (i.e., geohydrologic framework, hydraulic properties, and water levels) presented in the first part of this report was used to construct a three-dimensional, ground-water-flow model. Then, the calibrated flow model was used to estimate the water-supply potential of the two aquifers. The water-supply potential of the lower Patuxent aquifer was not evaluated since it functions only as a minor aquifer and, therefore, is not an important source for future supply. The effect on water levels from direct pumpage and from leakage across confining layers was also evaluated.

SIMULATION OF GROUND-WATER FLOW

Ground-water flow in the lower Patapsco aquifer and Patuxent aquifers was simulated using the U.S. Geological Survey's MODFLOW program, a three-dimensional, finite-difference ground-water-flow model code (McDonald and Harbaugh, 1988). The modeling process consisted of: (1) developing a conceptual flow model, (2) developing geohydrologic parameter arrays representative of the real system, (3) simulating water levels for (a) steady-state, prepumping conditions and (b) transient conditions for the period 1900 through 1997; geohydrologic parameter arrays were calibrated in an iterative process using estimated prepumping heads and measured water-level data from 1952 through 1997, and (4) simulating water levels for the period from 1998 to 2020 for selected pumping scenarios. The model area (fig. 1) in Maryland includes most of Charles County, northern Calvert and St. Mary's Counties, and southern Prince George's County. The model area also extends into the southern part of the District of Columbia and into Fairfax, King George, Prince William, and Stafford Counties in Virginia.

Conceptual Model

The first step in developing a digital representation of the ground-water-flow system is the construction of a conceptual model. The purpose of the conceptual model is to define, in general terms, the geohydrologic framework, direction of ground-water flow under pumping and non-pumping conditions, recharge and discharge areas, and boundary conditions. Cross-sectional schematics of the conceptual flow models for prepumping and current pumping conditions are shown in figure 25. The cross-sections extend midway through the model area from the Fall Line in Virginia southeast to St. Mary's County.

The principal aquifers of concern in this study include the lower Patapsco aquifer and Patuxent aquifers. The Patuxent aquifer was sub-divided into upper and lower units based on borehole geophysical evidence that shows two distinct sand zones throughout most of the study area. The lower Patuxent aquifer is underlain by low-permeability clay and saprolite which directly overlies either crystalline or sedimentary basement rocks. The lower Patapsco aquifer is overlain by a clay layer. This thick (up to 300 ft), low-permeability clay layer restricts the flow of water between the lower Patapsco aquifer and the shallower upper Patapsco aquifer. In the cross-sections shown in figure 25, the aquifers are shown as laterally continuous across the model area. Thinning beds, pinchouts, or vertical displacement of beds caused by faulting may, however, locally disrupt the lateral continuity of the aquifers. Aquifer tests on wells CH Bc 75 and CH Bc 78, screened in the upper Patuxent aquifer, indicated the presence of a flow barrier or boundary that reduced the amount of recharge flowing to the wells from the outcrop (recharge) area. The presence of a boundary in the upper Patuxent aquifer suggests a more complex flow system than is presented in the conceptual model.

Under prepumping conditions, water enters the outcrop areas (recharge areas) of the lower Patapsco and upper and lower Patuxent aquifers as precipitation and flows downdip in a southeasterly direction. The recharge areas for these aquifers within the model area are located mostly in the Coastal Plain part of northern Virginia and southern Washington, D.C.. The general patterns of ground-water-flow were based on topographic relief and prepumping head distributions simulated by two

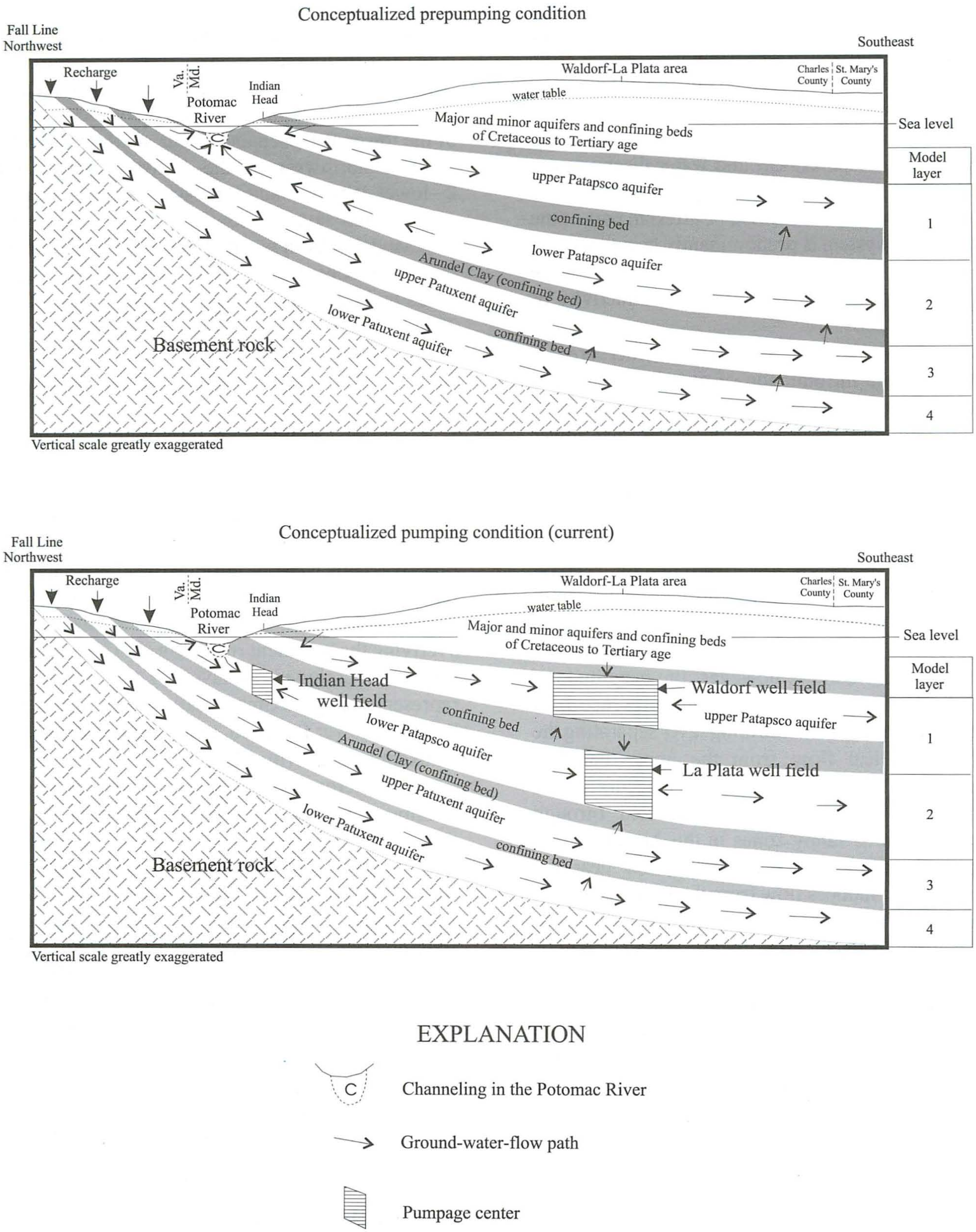


Figure 25. Conceptual ground-water-flow model.

regional ground-water-flow models (Harsh and Laczniak, 1990; Fleck and Vroblesky, 1996).Within the recharge areas some water is captured by tidal and non-tidal Potomac River tributaries. Water from recharge (outcrop) areas located outside of the model area enters along the northeastern and southwestern sides of the model in both the Patuxent aquifers and lower Patapsco aquifer. Ground water discharges to the Potomac River in the updip areas or flows downdip. Flow in the confined or artesian part of the ground-water system is predominantly horizontal due to relatively low vertical head gradients between aquifers and low vertical hydraulic conductivity of the confining beds.

Ground-water flow within the model area is altered with the introduction of pumping wells. To illustrate the effect of pumping on the current flow system, pumping centers in the upper and lower Patapsco aquifers at Indian Head, Waldorf and La Plata were projected onto the cross-section shown in figure 25. In the vicinity of the pumping centers, horizontal ground-water-flow rates are increased and flow paths are altered towards pumping centers. Increased vertical head gradients associated with pumping in the vicinity of Waldorf and La Plata causes some vertical flow between the upper and lower Patapsco aquifers; however, the magnitude of vertical flow is low because of the presence of a thick, low-permeability confining layer separating the aquifers. Vertical flow from the upper Patuxent aquifer to the lower Patapsco aquifer occurs where the aquifers are hydraulically connected through unusually thin or sandy zones in the Arundel Clay. Pumping in the lower Patapsco aquifer near the Potomac River induces flow from the Potomac River. Recharging river water enters the lower Patapsco aquifer through its subcrop under Occoquan Bay or through channeling in the overlying confining bed. The presence of elevated chloride concentrations in well water sampled in the Indian Head area near the brackish Potomac River indicates that the lower Patapsco aquifer is recharged in part by the Potomac River (Hiortdahl, 1997).

Grid Design and Model Layers

The model area was discretized into a grid containing 6,696 cells (93 rows and 72 columns) (fig. 26). Cell dimensions are irregular, with the smallest cells (measuring 1,000 x 1,000 ft) placed in the study area. The northwestern edge of the model coincides approximately with the Fall Line. The model area measures approximately 41 x 32 mi. The model consisted of four layers, representing, from top to bottom: layer 1—upper Patapsco aquifer southeast of the Potomac River, and the outcrop or recharge areas of the lower Patapsco and upper and lower Patuxent aquifers northwest of the Potomac River; layer 2—lower Patapsco aquifer; layer 3—upper Patuxent aquifer; and layer 4—lower Patuxent aquifer (fig. 27). Model cells in layers 2 to 4 were active; that is, the model solved for head in these layers, whereas heads in model layer 1 were specified. Model layers 2 to 4 were treated as confined aquifers with transmissivity constant through time.

Boundary Conditions

The types of boundaries used in the model include no-flow boundaries, constant-head boundaries, and general-head boundaries. No-flow (inactive) cells were assigned at the base of layer 4 to represent the contact between the lower Patuxent aquifer and the low permeability clay and saprolite overlying the basement rocks (fig. 27). No-flow cells were also assigned in layers 1, 2, 3, and 4 to represent the approximate updip extent of the upper Patapsco, lower Patapsco, upper Patuxent, and lower Patuxent aquifers (fig. 26).

The outcrop or recharge areas, where water-table conditions prevail in the upper and lower Patuxent and lower Patapsco aquifers, function as a boundary. This recharge boundary was represented in model layers 2 to 4 by placing constant-head cells set to an approximate water-table altitude in model layer 1 and assigning high vertical leakance to the confining bed overlying each aquifer in its outcrop area. The use of constant-head cells to represent the water table is justified because the water table does not fluctuate significantly. The constant-head boundary in layer 1 and the direct hydraulic connection between layer 1 and layers 2 to 4 provides an infinite source of water. The water-table altitude was estimated from the altitude of land surface and was not varied during transient simulations. Outcrop areas are only generally located because of the difficulty in differentiating between aquifer units at the surface. Constant-head cells (sea-level altitude) were assigned to layer 1 in areas where the lower Patapsco aquifer and Patuxent aquifers subcrop beneath the Potomac

Figure 26. Grid and boundary conditions used in the finite-difference ground-water-flow model.

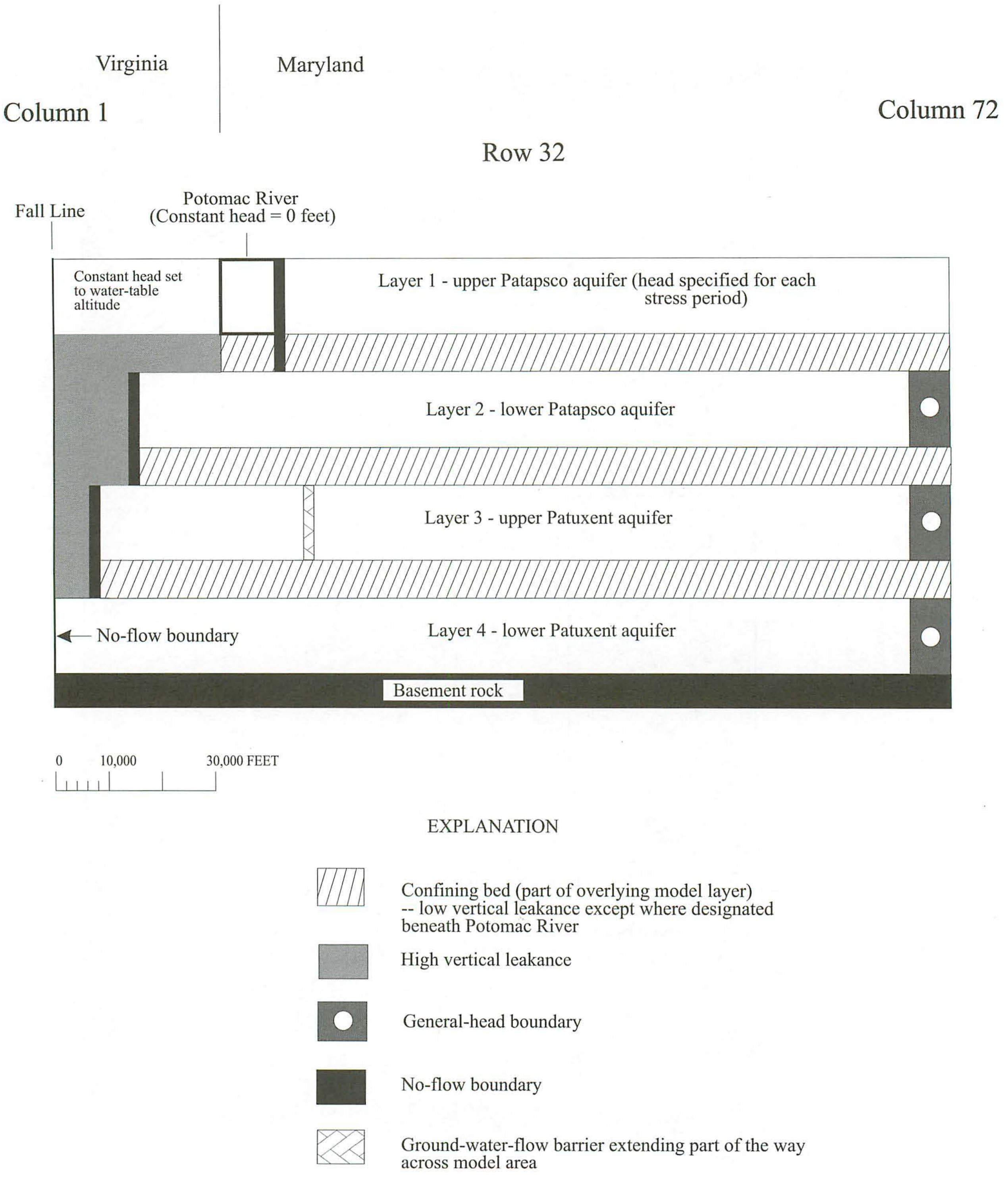


Figure 27. Generalized cross-section along model row 32.

River and its tributaries. Further discussion of the recharge boundary is given in the subsequent section entitled "Recharge".

Specified-head cells (cells held at a constant-head value for each stress period) in the transient model simulations were assigned in layer 1 to represent water-level fluctuations in the upper Patapsco aquifer. In the steady-state simulation, constant-head cells represent estimated, prepumping water levels in the upper Patapsco aquifer.

The northeastern, southeastern, and southwestern sides of the model lack natural flow boundaries. To simulate flow in those areas, general-head boundaries were used in model layers 2, 3, and 4. A general-head boundary allows the flux across the boundary to vary as a function of the head gradient. Flow into or out of a cell containing the boundary is proportional to: (1) the difference between the simulated head in the cell and the head assigned to an external specified-head source, and (2) the hydraulic conductance between the cell and the source (McDonald and Harbaugh, 1988). Heads assigned to the general-head boundary were adjusted during the transient simulation (1900-97) to represent temporal changes in head outside the model area.

A ground-water flow-barrier in the upper Patuxent aquifer (layer 3), surmised from aquifer tests of wells CH Bc 75 and CH Bc 78, is simulated in the model. The effect of the barrier on the ground-water system is a reduction in flow from the recharge area. This barrier is represented by a line of low horizontal hydraulic conductivity (1×10^{-9} ft/d) in model layer 3. It is simulated in the model as approximately 10 mi long and is positioned roughly parallel to the Fall Line. The barrier is located about 1.2 mi from well CH Bc 75 (Chapman's Landing well 2). The location, extent, and horizontal hydraulic conductivity of the barrier were determined during transient model calibration. In the model, the barrier is restricted to layer 3 and in this regard is more representative of a lithologic change within the aquifer than bed offset caused by faulting. At present, comparable geohydrologic evidence for a barrier is lacking for model layers 2 (lower Patapsco) and 4 (lower Patuxent), although future investigations could reveal its presence.

Recharge

Little information is available on recharge rates to the lower Patapsco aquifer and Patuxent aquifers in the model area. The recharge areas of these aquifers are mainly located in a combined urbanized and wooded area between the Potomac River and the Fall Line in Virginia. Many variables control the amount of recharge entering the aquifers. Some of these variables include, (1) the amount of infiltration to the water table from precipitation versus runoff—highly urbanized areas tend to increase runoff and decrease infiltration, (2) vertical permeability of the unsaturated sediments, (3) the amount of water discharged to streams, and (4) ground-water withdrawals—in particular, consumptive use. A study by McFarland (1997) estimated recharge rates for Potomac Group aquifers outcropping in an area south of Richmond, Virginia. This area has both geohydrologic and land-use characteristics similar to those in the Coastal Plain area in northern Virginia. McFarland (1997) estimated that total recharge to the unconfined aquifer in the Fall Zone equaled 10 inches per year (in./yr) under steady-state conditions. Of that amount, 0.5 in./yr recharged the deep, confined aquifers in downgradient areas. Recharge estimates were based on results from a ground-water-flow model.

Recharge to model layers 2, 3, and 4 from precipitation enters the model through approximated outcrop areas of the lower Patapsco aquifer and Patuxent aquifers. These areas were assigned in the model as uniformly wide bands lying parallel to the northwestern side of the model (Fall Line) and located approximately within the area mapped as Potomac Group outcrop in Virginia (Cooke and Cloos, 1951; Mixon and others, 1989) (fig. 1). Initially, recharge was specified as a constant flux (approximately 0.5 in./yr); however, this resulted in excessive drawdown in the predictive scenario that simulated maximum yield in the upper Patuxent aquifer. Because additional recharge could not be induced by a decline in head along the boundary, drawdown accelerated as the outwardly migrating cone-of-depression reached the recharge area. To correct this problem, the recharge boundary was converted to a head-dependent flux boundary. As described earlier, heads assigned to model layer 1 in the recharge areas of the upper and lower Patuxent and lower Patapsco aquifers approximated the water-table altitude. The amount of recharge entering model layers 2, 3, and 4 was controlled by the vertical head gradient and the vertical leakance between those layers and layer 1. Vertical leakance was adjusted during calibration of the steady-state, prepumping simulation such that recharge rates equaled 0.01, 0.01, and 0.05 in./yr for the lower Patapsco, upper Patuxent, and lower Patuxent aquifers, respectively. Recharge is greater in model layer 4 because less flow is captured by the Potomac River. Recharge rates under 1997 pumping conditions simulated in the model equaled 0.67, 0.05, and 0.05 in./yr for the lower Patapsco, upper Patuxent, and lower Patuxent aquifers, respectively. Under pumping conditions, the lower Patapsco aquifer (model layer 2) is also recharged from the Potomac River through its subcrop where it crosses the river and through paleochannels that have breached the overlying confining bed.

Hydraulic Parameters

Transmissivity and Storage Coefficient

Transmissivity arrays were developed for input into the ground-water-flow model. Values for the lower Patapsco and upper Patuxent aquifers were initially assigned to each model cell based on distributed values of transmissivity calculated by aquifer test (figs. 13 and 14). In the case of the lower Patuxent aquifer, where only one aquifer-test data point exists (CH Bc 80), the transmissivity array was developed by multiplying the horizontal hydraulic conductivity determined from that aquifer test by the aquifer thicknesses. Transmissivity values assigned to areas lacking aquifer-test data are highly generalized. The data arrays for each layer were adjusted during model calibration.

The calibrated transmissivity array in layer 2 (lower Patapsco aquifer) ranges from approximately 0 to 3,000 ft^2/d (figure 28). Transmissivity was greatest in the southeastern area of the Indian Head peninsula and in southern Prince George's County. As the aquifer thins toward the outcrop area (northwest) the transmissivity decreases. Transmissivity assigned to layer 3 (upper Patuxent aquifer) ranges from approximately 0 to 2,000 ft^2/d (fig. 29). Values are greatest in the area of the Chapman's Landing test site and decrease in all directions from that location. Transmissivity decreases sharply across the simulated flow boundary. The range of values for calibrated transmissivities in layers 2 and 3 fall within the range of aquifer transmissivities determined from aquifer tests (tabs. 2 and 3). The modeled transmissivity in layer 4 (lower Patuxent aquifer) ranges from 0 to 500 ft^2/d.

Storage coefficient assigned in the model was determined during calibration. In model layer 2, storage coefficient was 2×10^{-4} throughout most of the layer, except in the vicinity of La Plata where the value was 5×10^{-4}. In model layers 3 and 4, storage coefficient was 2×10^{-4} and 7×10^{-5}, respectively, throughout most of the layer. In the vicinity of the Chapman's Landing test site, storage coefficient was 6×10^{-4} and 9×10^{-5} for model layers 3 and 4, respectively.

Vertical Leakance

Leakance values used in the model for the confining beds overlying the following aquifers were: the lower Patapsco aquifer, 10^{-8} cubic feet per day per cubic foot (1/d), the upper Patuxent aquifer, 9×10^{-7} to 1×10^{-10} 1/d, and the lower Patuxent aquifer, 10^{-6} 1/d. These values are consistent with those used by Mack and Achmad (1986) in a flow-modeling study of Potomac Group aquifers in Anne Arundel County, approximately 20 mi north of the model area.

Leakage between model layers 2 and 3 (lower Patapsco and upper Patuxent aquifers) varies across the model area. Leakance was increased in the vicinity of Waldorf, in the southern part of the model area near the Potomac River, and in southern Prince George's County. These areas were chosen based on declining water levels in the upper Patuxent aquifer which correlate with increasing pumpage in the lower Patapsco aquifer. Leakage was also increased in the vicinity of the test well at the Mattawoman Waste-Water Treatment Plant to account for the lower water level measured in that well relative to water levels measured in other wells screened in the upper Patuxent aquifer within the study area.

Leakage was simulated between the upper and lower Patuxent aquifers based on results of a 5-day

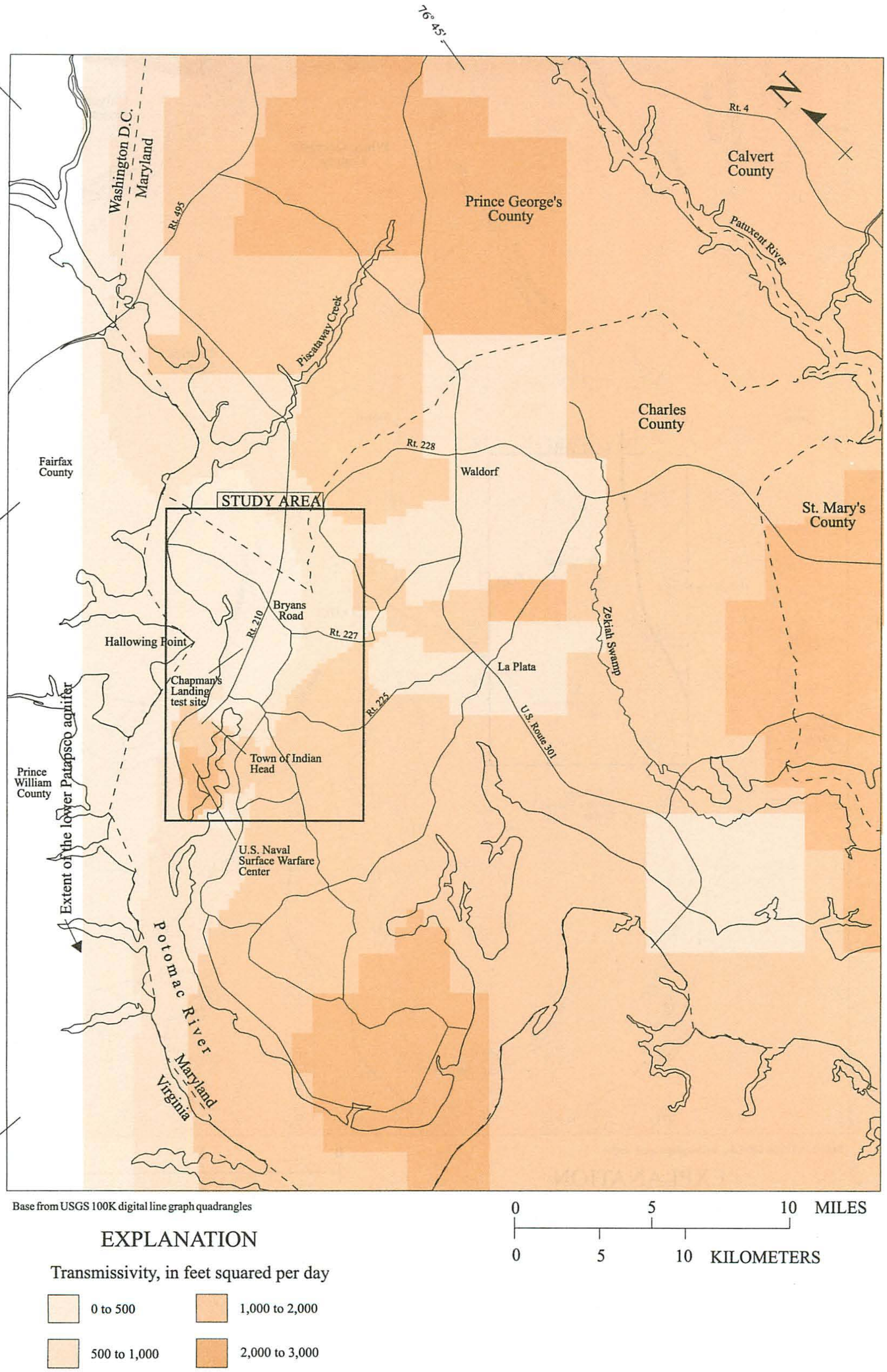


Figure 28. Transmissivity zones assigned to model layer 2.

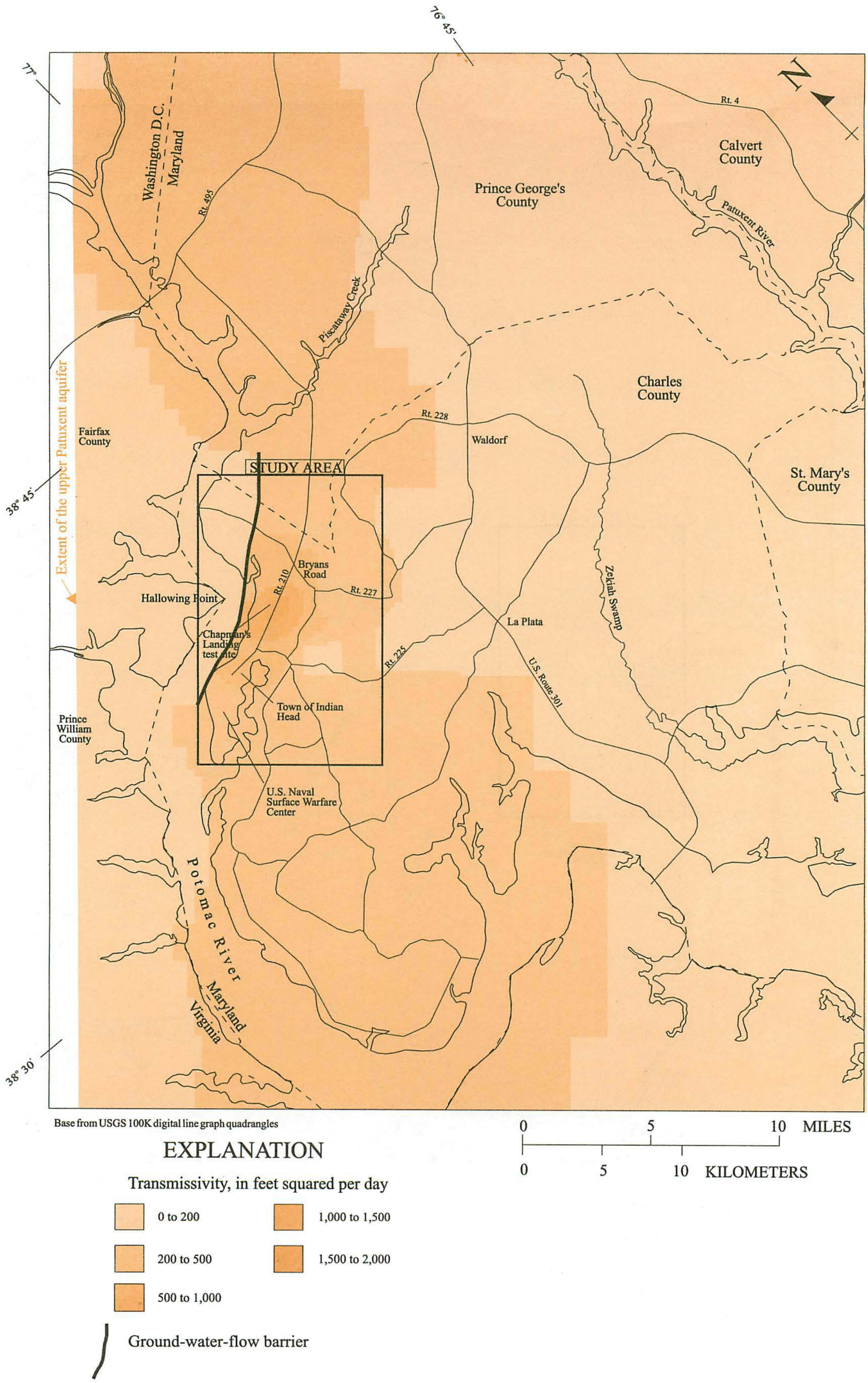


Figure 29. Transmissivity zones assigned to model layer 3.

aquifer test. The test showed a 1-foot decline in water levels in the lower Patuxent aquifer associated with pumping from the upper Patuxent aquifer. Leakance in the confining layer overlying the lower Patuxent aquifer was determined during calibration of the transient ground-water-flow model.

Pumpage

Individual ground-water withdrawals exceeding 10,000 gallons per day (gal/d) from the lower Patapsco aquifer along with estimates of domestic, self-supplied use was input to the model. Total simulated pumpage in model layer 2 (lower Patapsco aquifer) in 1997 in the model area was 5.7 Mgal/d. Total simulated pumpage in model layer 2 in the Indian Head-Bryans Road area was 1.8 Mgal/d in 1997. Simulated pumpage from domestic wells (included in the total) in layer 2 was estimated at 0.16 Mgal/d in the Indian Head-Bryans Road area, based on approximately 550 wells screened in the lower Patapsco aquifer. An average pumping rate of 300 gal/d was assumed and the number of domestic wells was estimated from screen depths of wells completed between 1970 and 1992 (Maryland Department of the Environment, per. commun., 1998).

The only known ground-water pumpage from the upper Patuxent aquifer in 1997 is located at South Hampton. The yearly average withdrawal rate at South Hampton of 0.094 Mgal/d from well CH Bc 78 was input to layer 3 of the model.

Steady-State Flow Simulation

Prior to simulating transient ground-water-flow, a steady-state, prepumping condition was simulated. This is a condition under which inflow is balanced by outflow such that heads and the volume of water in storage are constant. Head output from the steady-state, prepumping simulation is used for the initial-head condition in the transient simulation. Head conditions for the period prior to the start of pumping in the lower Patapsco aquifer (pre-1900) were imposed for the steady-state simulation. Water-level data for this period are lacking; therefore, the model was calibrated to a conceptualized pattern of ground-water flow and head distribution developed by two regional ground-water-flow models of the Potomac Group aquifers (Harsh and Laczniak, 1990; Fleck and Vroblesky, 1996). Transmissivity, horizontal hydraulic conductance and head along the general-head boundaries, vertical leakance, and recharge controlled by vertical leakance in the outcrop areas were adjusted during calibration.

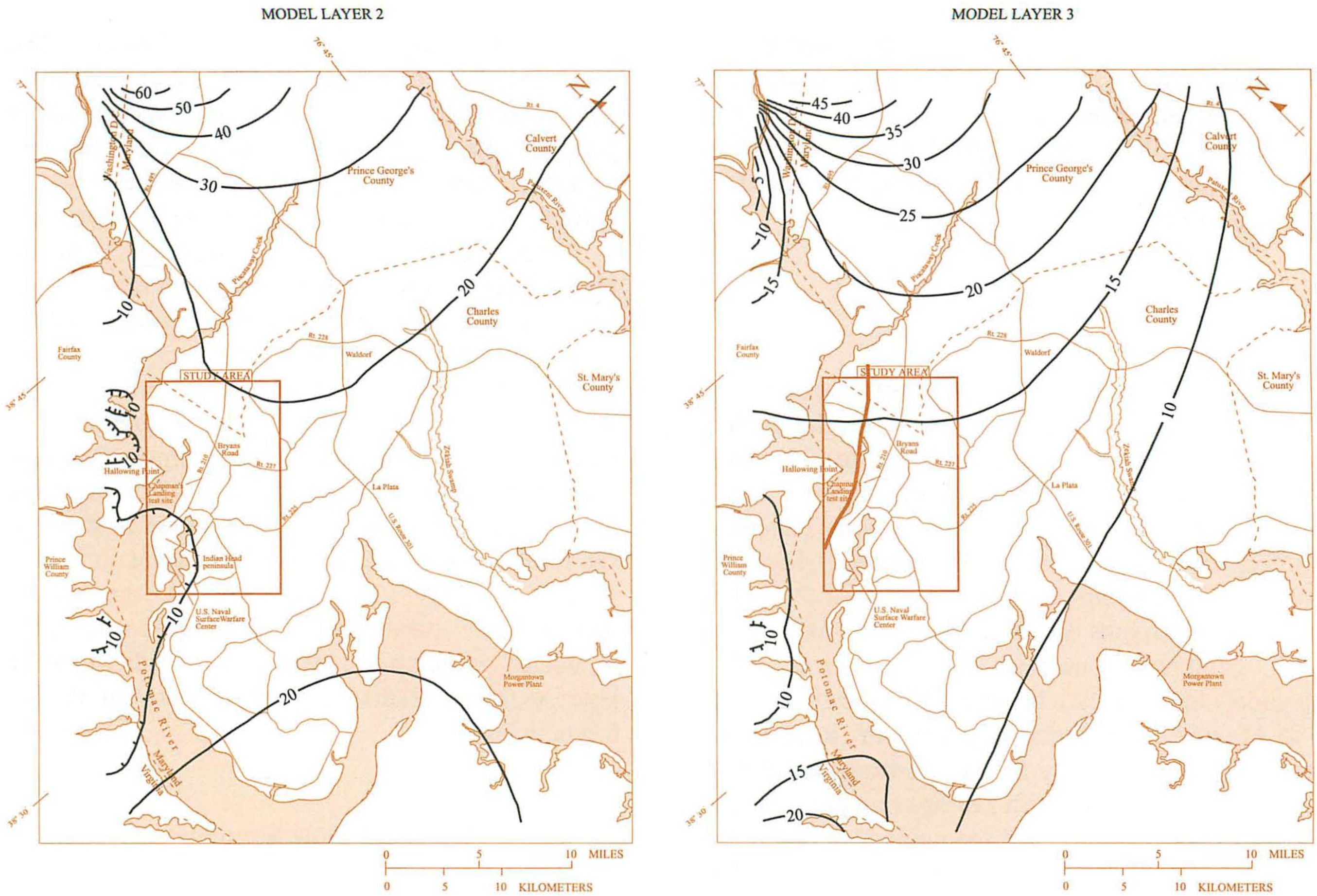
Simulated prepumping, steady-state heads in model layer 2 (lower Patapsco aquifer) ranged from approximately 60 ft above sea level in the northern part of the model area near Washington, D.C. to sea level at the Potomac River near the Indian Head peninsula (fig. 30). The simulated prepumping, steady-state heads in model layer 3 (upper Patuxent aquifer) ranged from approximately 45 ft above sea level near Washington, D.C. to less than 10 ft above sea level along Potomac River tributaries in Prince William County, Virginia and in the south-southeastern part of the model area (fig. 30). Simulated prepumping, steady-state heads in model layer 4 (lower Patuxent aquifer) were similar to heads in layer 3.

Transient-Flow Simulation

Initial Conditions and Time Discretization

Heads from the calibrated prepumping, steady-state flow simulation were used for the starting heads for the transient-flow simulation (1900-97). The hydraulic parameter arrays and boundary conditions used in the calibrated prepumping, steady-state flow simulation were used initially in the transient simulation, then adjusted during model calibration. Recharge to model layers 2, 3, and 4, which is controlled by both vertical leakance and head gradients beneath the outcrop areas, equaled 0.01, 0.01, and 0.05 in./yr, respectively, at the start of the transient simulation.

Time was discretized into 129 stress periods. The length of the stress periods varied from 10 years to 1 day as shown in table 5. The stress periods were composed of either one or two time steps. The model solves a set of ground-water-flow equations and produces head output at the end of each time step. Stress-period duration was shortened after 1975 because yearly pumpage data was reported after that time. Also, more frequent water-level data are available to calibrate the model after 1975. One-day stress periods were simulated between August and October 1997 so that daily pumpage data in the upper



EXPLANATION

—20— Potentiometric contour of simulated heads. Contour interval is 5 or 10 feet. Datum is sea level.

Ground-water-flow barrier

Bases from USGS 100K digital line graph quadrangles

Figure 30. Model-simulated potentiometric surface of layers 2 and 3 for steady-state, prepumping conditions.

Patuxent aquifer at South Hampton and continuous water-level records from the observation-well network could be used in model calibration.

Model Calibration

The transient flow-model was calibrated by systematically varying transmissivities, storage coefficients, vertical leakances, and general-head boundary heads and horizontal hydraulic conductances until simulated heads matched observed heads. Also adjusted during model calibration were the position, length, and horizontal hydraulic conductance of the ground-water-flow barrier in layer 3. Calibration was considered complete when the lowest value for the root-mean-square error (Miller and Kahn, 1962) for the match between simulated

Table 5. Time discretization used in transient groundwater-flow model

Stress periods	Duration of stress period (days)	Time steps	Period simulated
1 to 6	3,650	1	1900-59
7	5,475	1	1960-74
8 to 29	365	2	1975-96
30	59	1	Jan. and Feb., 1997
31 to 35	30 or 31	1	Mar. through July, 1997
36 to 127	1	1	Aug. through Oct., 1997
128	30	1	Nov., 1997
129	31	1	Dec., 1997

and observed heads was obtained at the end of the simulated period (December, 1997). Twenty-six wells (19 lower Patapsco, 6 upper Patuxent, and 1 lower Patuxent) were used in calibrating the model (fig. 31). The root-mean-square error obtained for the calibrated model at the end of the transient simulation was 12.2 ft. The root-mean-square error for the lower Patapsco and upper Patuxent aquifer data was 14.2 and 1.3, respectively. The slope of the trend line of simulated versus observed water levels for the 26 well-control points computed by linear regression was 1.14 (fig. 32). This, in comparison to the slope of 1.0 for an exact match, indicates an acceptable calibration with respect to the objectives of the study (fig. 32). The simulated head distribution under steady-state, prepumping conditions was checked periodically after changes were made to parameters in the transient model.

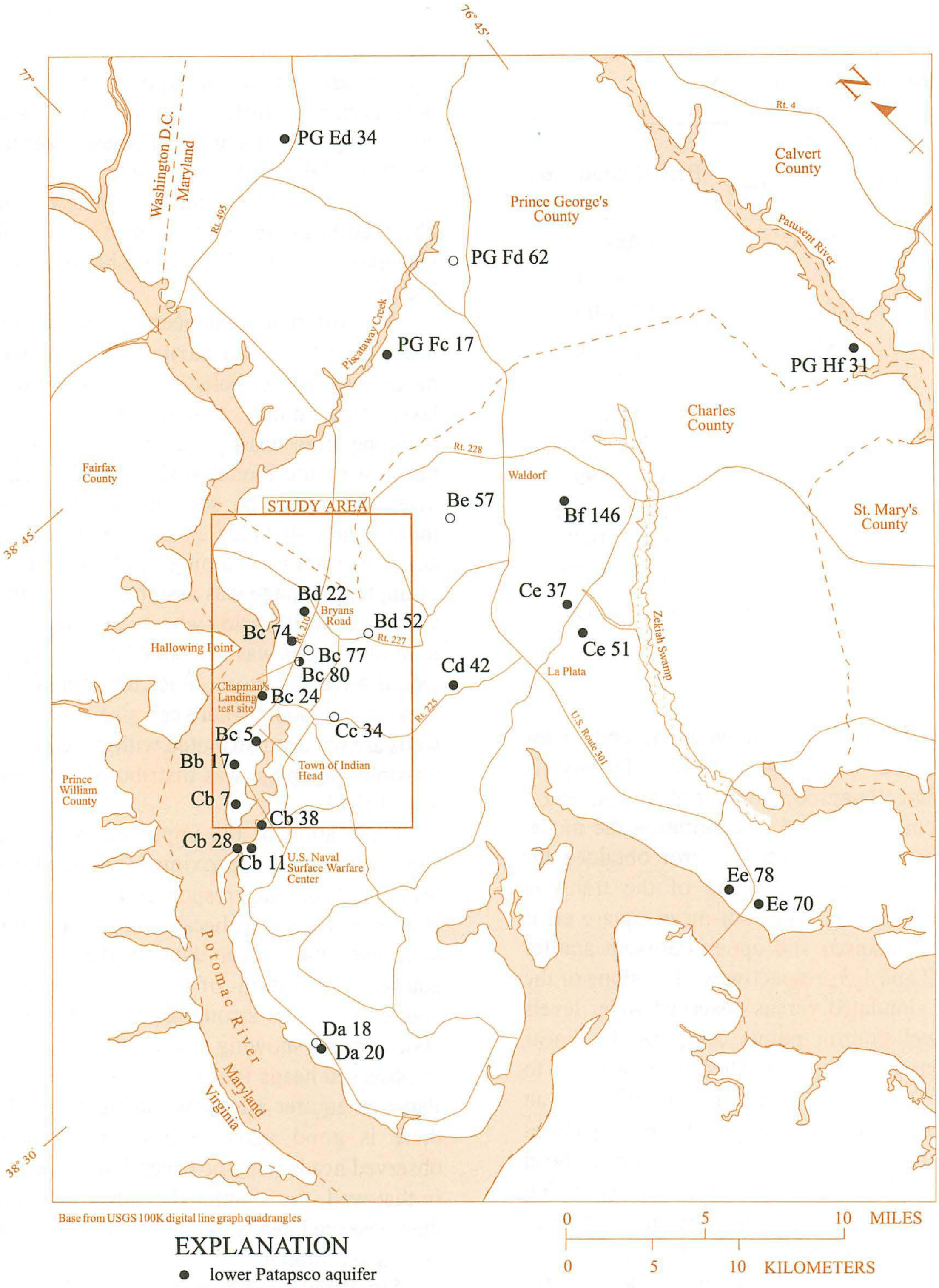
Selected hydrographs of simulated and yearly medians of observed heads in the lower Patapsco aquifer are shown in figures 33 and 34. Water levels measured between 1952 and 1997 were available for calibration. The relation between simulated and observed heads over time offers a qualitative measure of the model's accuracy. Simulated and observed water levels for each well are in general agreement.

Simulated head contours and measured heads in observation wells for 1997 for the lower Patapsco aquifer are shown in figure 35. The simulated potentiometric surface shows cones-of-depression coinciding with the areas of deepest observed water levels at Waldorf, La Plata, and at the Morgantown Power Plant. The simulated heads matched the observed heads in most cases to within 10 to 20 ft. Generally, simulated heads are higher than observed heads.

The differences between simulated and observed heads may be in part attributed to the averaging of heads over model cells and stress periods. Water-level fluctuations caused by local, short-term pumping from nearby wells could not be simulated because of the model scale of both area and time discretizations. The distribution of pumpage for individual well fields as assigned in the model was also important in obtaining a precise head match. For example, pumpage was assigned to a central location within a well field where pumpage data from individual wells was unavailable. This representation would have the most effect on simulated heads in areas of the model where cell size is small and where wells are widely distributed within well fields. Where possible, pumpage was distributed between wells in a well field.

Calibration of the upper Patuxent aquifer was supplemented by approximately 9 months of water-level data showing responses to pumping at South Hampton. However, because of the lack of long-term historical water-level data in the upper Patuxent aquifer, calibration of model parameters in that aquifer is not as strong as in the lower Patapsco. Hydrographs showing simulated and yearly medians of observed heads in six wells screened in the upper Patuxent aquifer are shown in figure 36. Generally, there is good agreement between simulated and observed heads with the exception of well CH Be 57. In that well, the simulated heads are 4 to 6 ft lower than observed heads; however, the trends of the two curves are similar.

Simulated head contours for 1997 for the upper Patuxent aquifer and observed water levels are shown in figure 37. The simulated potentiometric surface shows a cone-of-depression centered around the production well at South Hampton. In 1997, pumpage from this well averaged 94,000 gal/d. The simulated heads match closely with the few available water levels measured in observation wells.



EXPLANATION

- ● lower Patapsco aquifer
- ○ upper Patuxent aquifer
- ◑ lower Patuxent aquifer

Number next to symbol is the well number (Charles County prefix "CH" is omitted)

Figure 31. Location of wells used in model calibration.

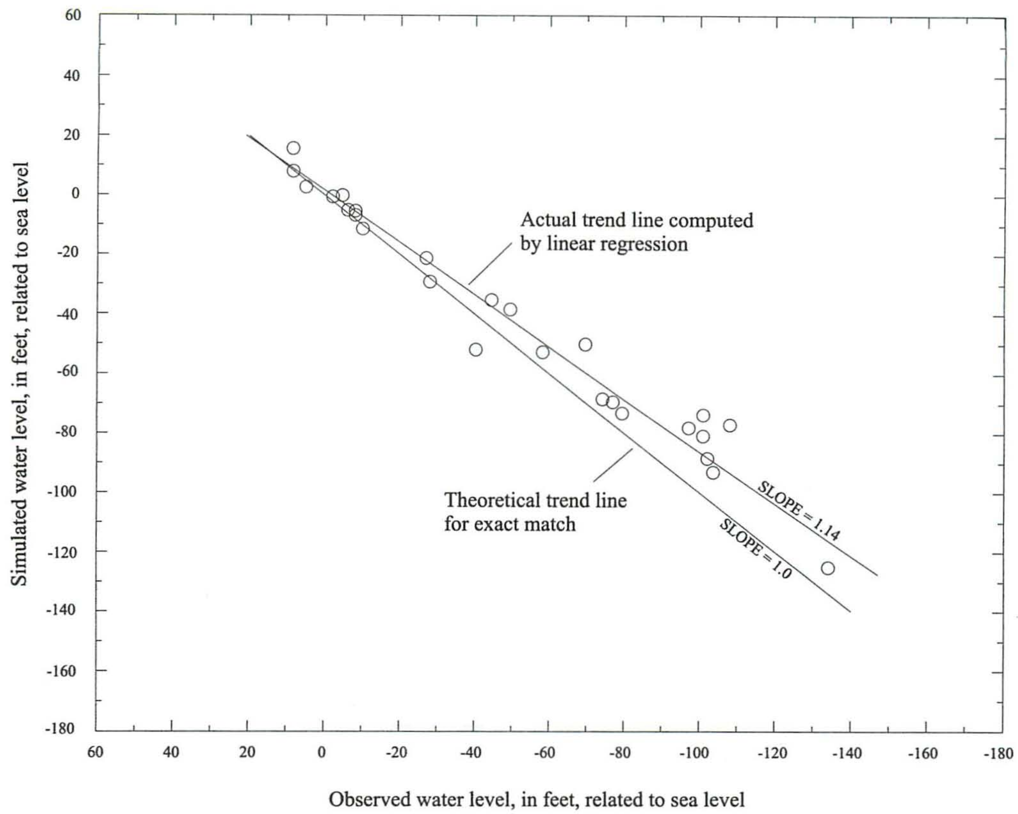


Figure 32. Relation between observed and simulated water levels in the lower Patapsco aquifer for December 1997.

Mass Balance

The mass balance was calculated at the end of the transient simulation (stress period 129 or December, 1997). Total inflow to the confined part of the lower Patapsco and upper and lower Patuxent aquifers in model layers 2, 3, and 4, respectively, equaled 8.38 x 10^5 cubic feet per day (ft^3/d). This inflow was divided as follows: general-head boundaries along the northeastern, southeastern, and southwestern sides of the model, 5.1 x 10^5 ft^3/d (or 61 percent); outcrop area and Potomac River, 2.85 x 10^5 ft^3/d (or 34 percent); storage, 3.48 x 10^4 ft^3/d (or 4.1 percent); and leakage from layer 1 (upper Patapsco aquifer), 8.1 x 10^3 ft^3/d (or 0.97 percent). Total outflow was balanced against total inflow. Total outflow from the confined part of the lower Patapsco and upper and lower Patuxent aquifers was divided as follows: wells (layers 2 and 3), 7.7 x 10^5 ft^3/d (or 91.8 percent); general-head boundaries along the northeastern, southeastern, and southwestern sides of the model, 5.5 x 10^4 ft^3/d (or 6.6 percent); outcrop area, 1.21 x 10^4 ft^3/d (or 1.4 percent); and, storage, 1.94 x 10^3 ft^3/d (or 0.2 percent).

Recharge entering model layer 2 from the Potomac River accounted for 12.3 percent of the total inflow to that layer. The majority of this recharge entered from the subcrop area of the lower Patapsco aquifer under Occoquan Bay and from an adjacent area of the Potomac River. The Patuxent aquifers were not recharged by the Potomac River.

Sensitivity Analysis

An analysis was conducted to determine the sensitivity of model performance to changes in the input parameters. It is particularly important to estimate accurately those parameters that can result in relatively large errors in simulated head, if incorrectly assigned. The following model parameters were evaluated by globally increasing and decreasing

(Text continued on p. 59.)

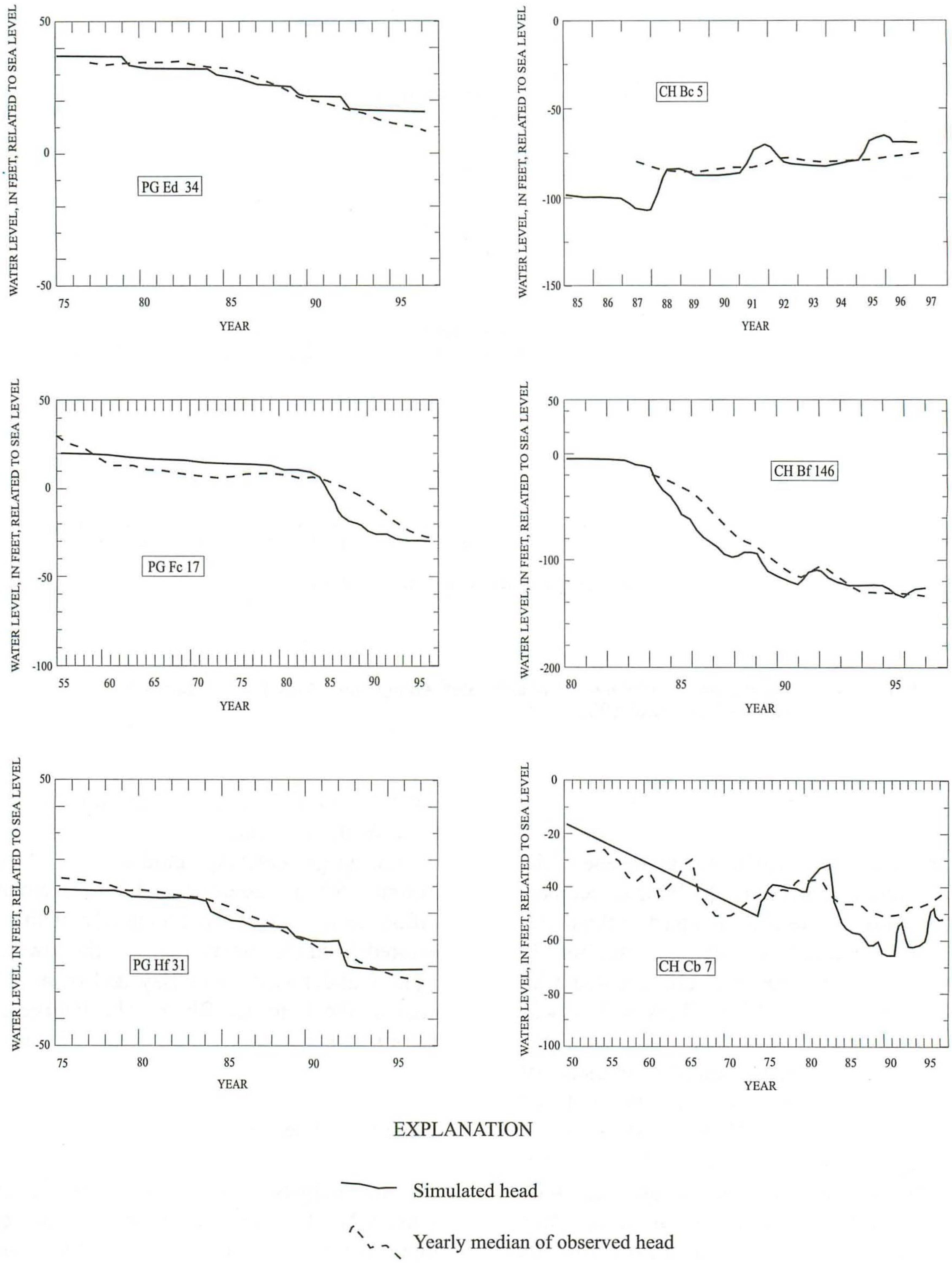


Figure 33. Measured and simulated heads in the lower Patapsco aquifer in Charles County and Prince George's County, 1950 to 1997.

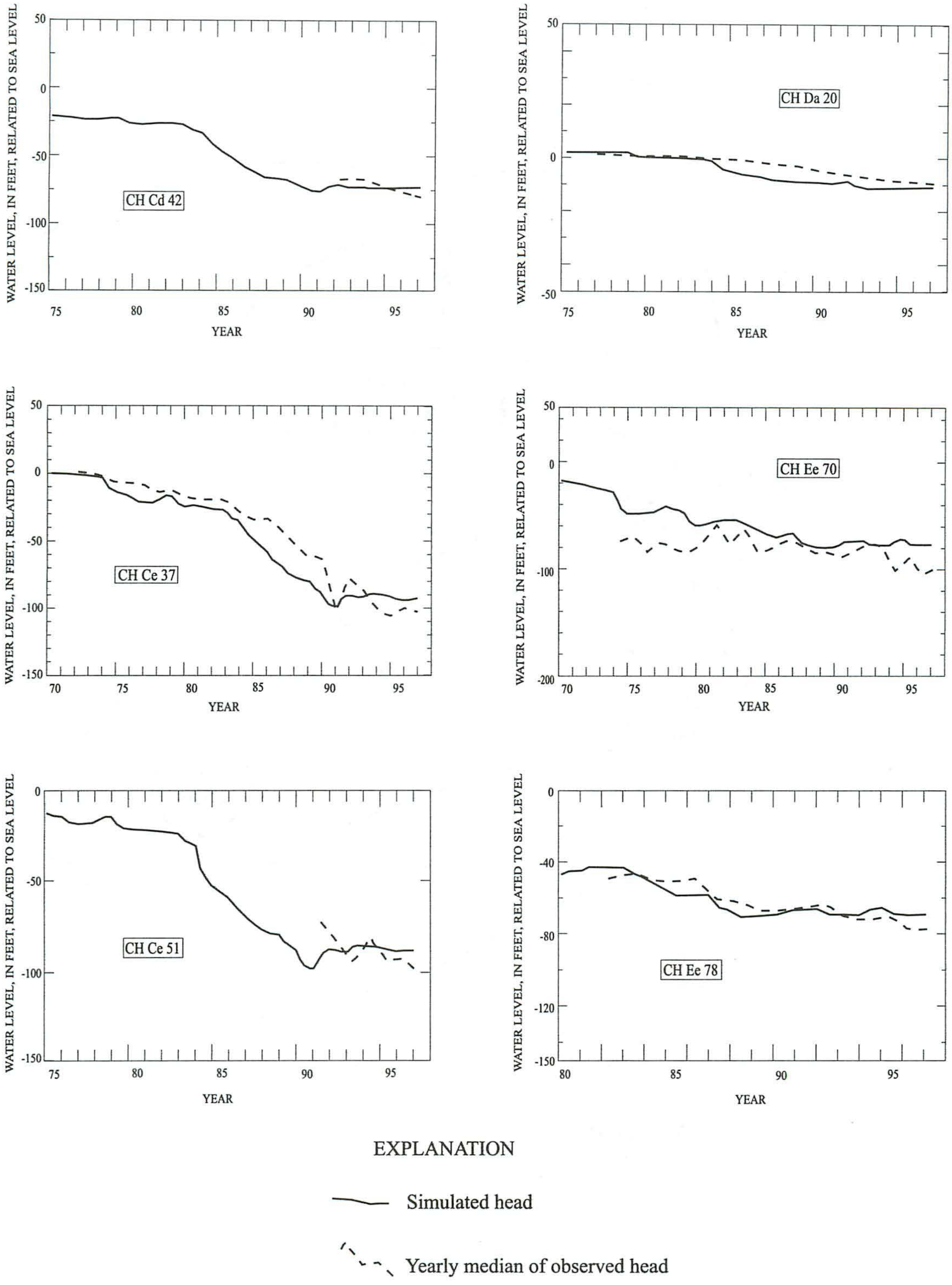


Figure 34. Measured and simulated heads in the lower Patapsco aquifer in Charles County, 1970 to 1997.

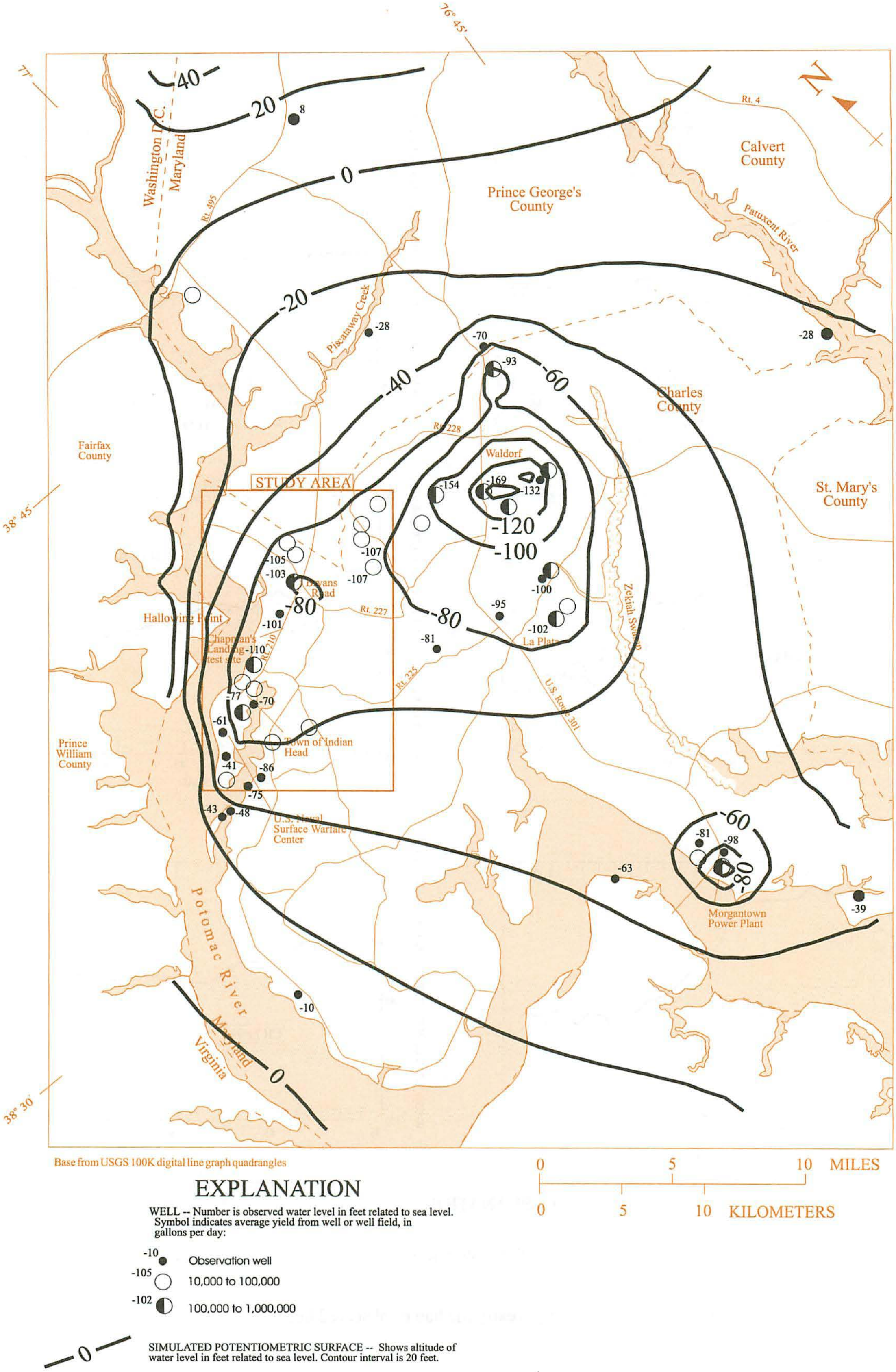


Figure 35. Simulated potentiometric surface and measured water levels in model layer 2 for 1997.

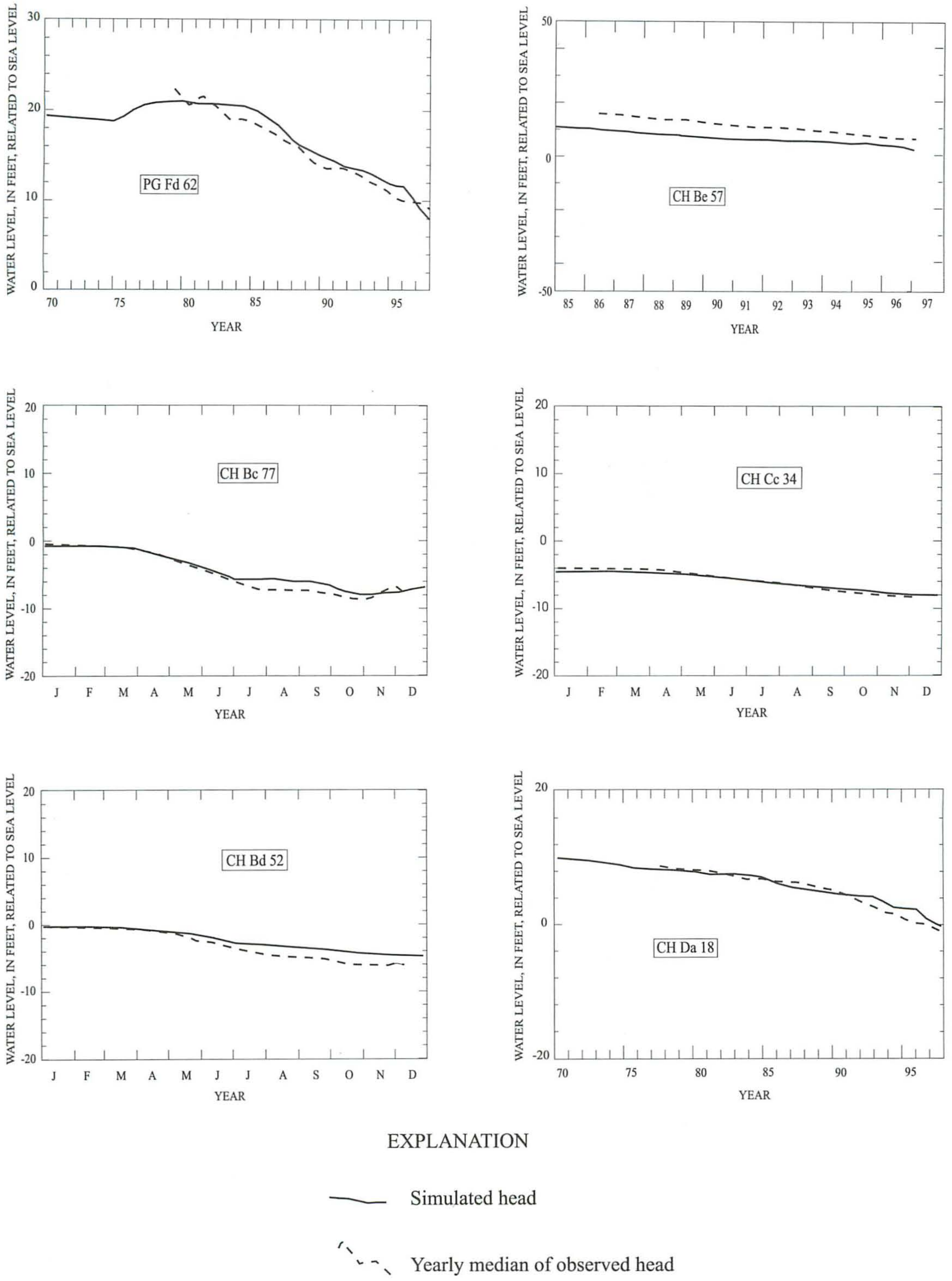
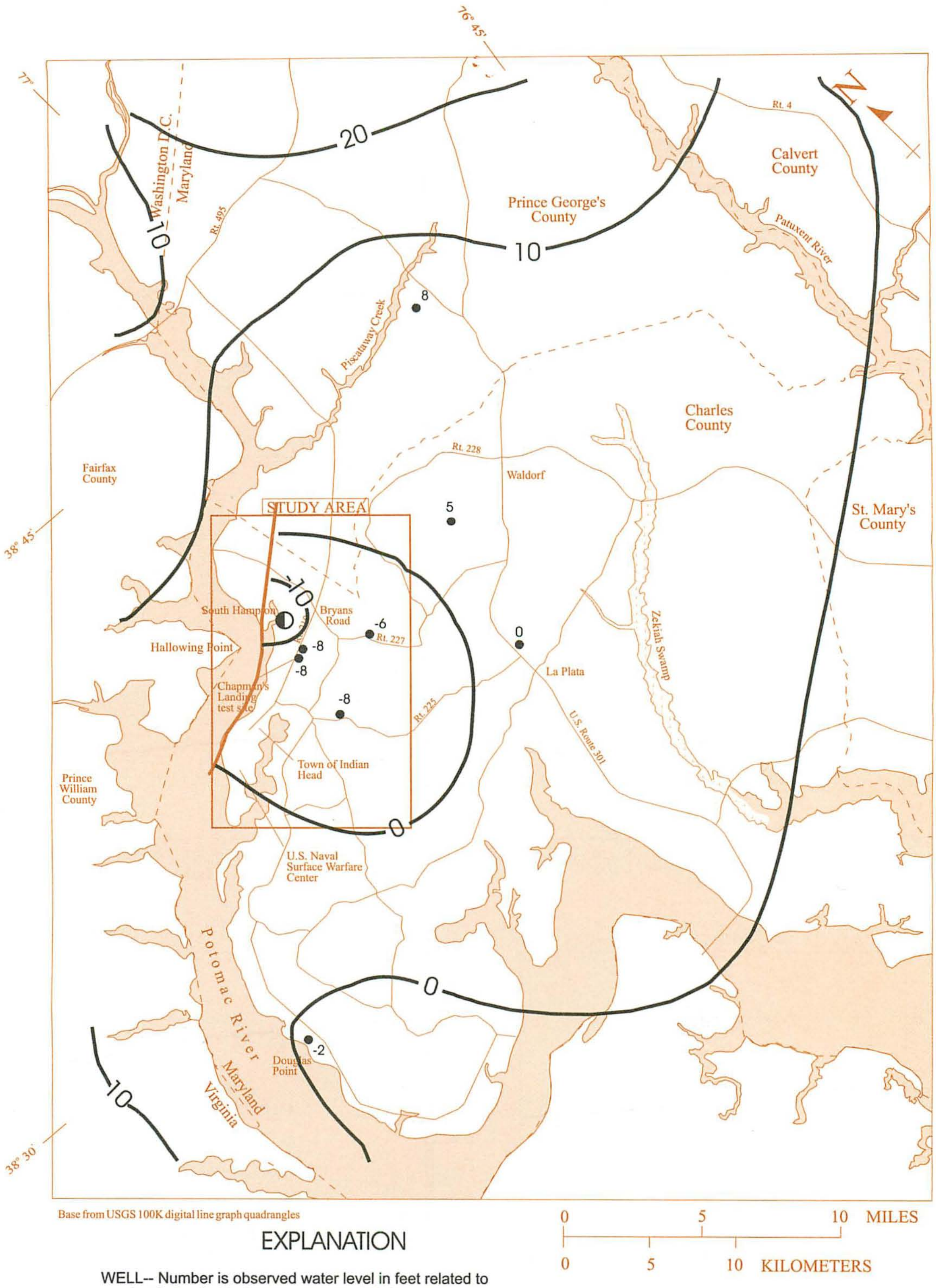


Figure 36. Measured and simulated heads in the upper Patuxent aquifer, 1970 to 1997.



EXPLANATION

WELL-- Number is observed water level in feet related to sea level. Symbol indicates average yield from well, in gallons per day:

-2 Observation well.

94,000

0 SIMULATED POTENTIOMETRIC SURFACE -- Shows altitude of water level in feet related to sea level. Contour interval 10 feet.

GROUND-WATER-FLOW BARRIER

Figure 37. Simulated potentiometric surface and measured water levels in model layer 3 for 1997.

each independently by multiples of the calibrated value: (1) leakance between layers 1, 2, and 3, (2) transmissivity in layers 2, 3, and 4, (3) storage coefficient in layers 2, 3, and 4, and (4) horizontal hydraulic conductance at the general-head boundaries in layers 2, 3, and 4. The root-mean-square error of the differences between simulated and measured heads in 19 lower Patapsco wells, 6 upper Patuxent wells, and 1 lower Patuxent well was calculated for each change in model parameter. The values are plotted on figure 38. Model values were varied within a reasonable range for each parameter. Some parameters vary over a much larger range than others.

Results indicate that the model is least sensitive to changes in horizontal hydraulic conductivity at the general-head boundaries and moderately sensitive to changes in storage coefficient. The model is most sensitive to changes in transmissivity and leakance. Increasing and decreasing transmissivity by a factor of 2 and 0.5 from the calibration point causes the root-mean-square error to increase to 38 and 42 ft, respectively. Increasing leakance by two orders of magnitude causes the root-mean-square error to increase to 34 ft.

On figure 38, root-mean-square errors slightly lower than the calibration point were obtained for leakance and horizontal hydraulic conductance suggesting a better fit between simulated and measured heads. This is somewhat misleading. Although smaller values of these parameters resulted in a slightly closer match between simulated and

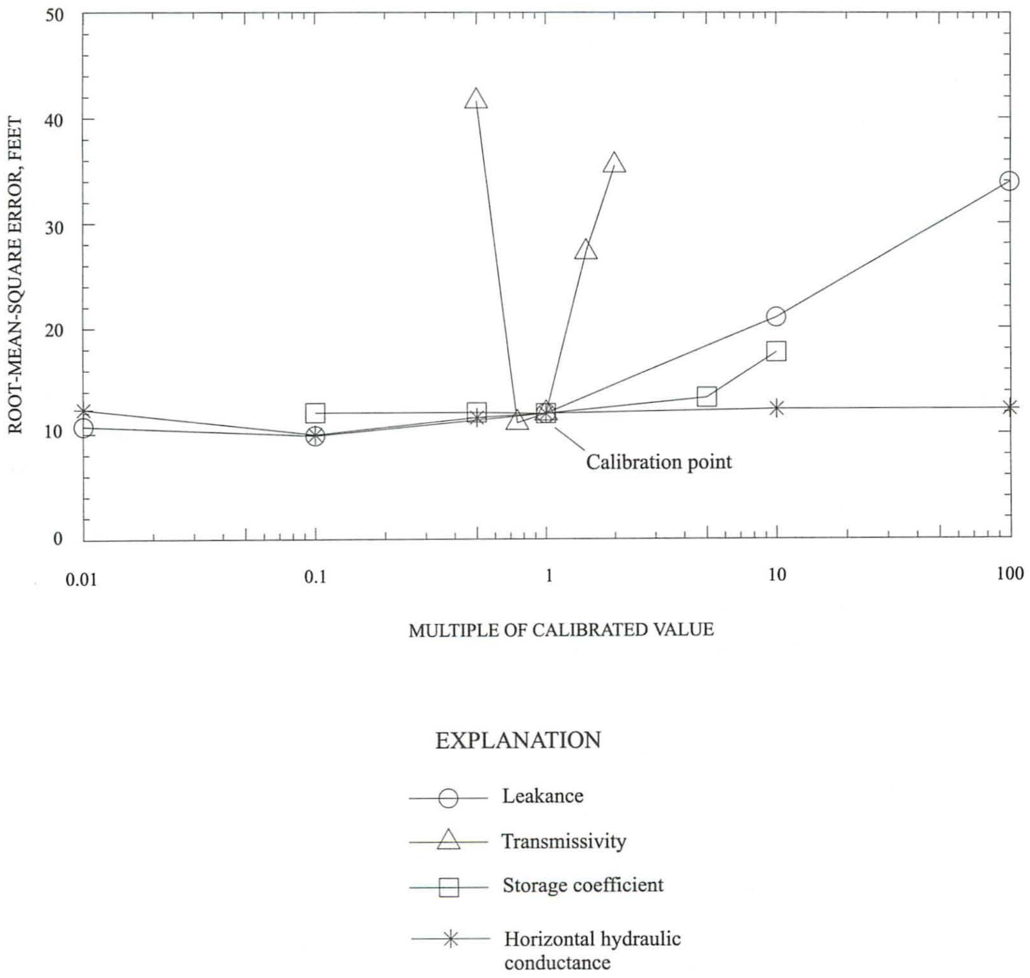


Figure 38. Effects of simulated head match by varying model parameters.

measured heads in the lower Patapsco aquifer, they caused worse agreement between simulated and measured heads in the upper and lower Patuxent aquifers.

PREDICTIVE MODEL SIMULATIONS

A series of predictive simulations was made using the calibrated ground-water-flow model. The model simulated heads in the lower Patapsco and upper Patuxent aquifers based on estimates of future water use through 2020. Existing, planned, and hypothetical well fields were used in the simulations. Additional future pumpage was assigned to areas where growth is expected to occur. Proximity to existing water-supply infrastructure and reduction of well interference through adequate well spacing were both considered when placing hypothetical wells in the model. Table 6 summarizes the five types of predictive model simulations performed for this study. In some instances multiple scenarios for a given predictive model simulation were made using different pumping alternatives.

Model Simulation I
Effect of Pumpage From the Lower Patapsco Aquifer Outside of the Indian Head-Bryans Road Area on Water Levels in the Lower Patapsco Aquifer Within the Study Area

Water levels in the lower Patapsco aquifer in the study area are affected by pumpage outside the Indian Head-Bryans Road area, particularly from the vicinity of Waldorf and La Plata. Increased pumping outside of the Indian Head-Bryans Road area will result in additional drawdown. Two model simulations were made for the purpose of quantifying this drawdown in the study area through 2020. The first simulation (Pumping Alternative IA) estimated the amount of drawdown that would occur in the study area if pumpage outside the Indian Head-Bryans Road area was at a level supportive of 2020 growth estimates. The second simulation (Pumping Alternative IB) is similar to Pumping Alternative IA except that all of the additional pumpage through 2020 in the Waldorf area was assumed to be supplied by a source other than the lower Patapsco aquifer. Additional sources of water in the Waldorf area include the upper Patapsco aquifer and water from outside Charles County purchased from the Washington Suburban Sanitary Commission. The Waldorf area is defined here as Election District 6 and the west-central part of Election District 8 (fig. 24).

Pumping Alternative IA

During this simulation, pumpage in the Indian Head-Bryans Road area was held constant at 1997 levels, while pumpage outside the Indian Head-Bryans Road area in Election Districts 1, 6, 8, and 10 (fig. 1) was increased incrementally (three 5-year intervals and one 7-year interval) to estimated 2020 levels. Total 2020 pumpage from the lower Patapsco aquifer in the model area in this simulation was 9.5 Mgal/d (1.8 Mgal/d in the Indian Head-Bryans Road area plus 7.7 Mgal/d outside the Indian Head-Bryans Road area). The Waldorf area pumped a total of 5.8 Mgal/d, which is 3.2 Mgal/d more than the 1997 rate. Pumpage estimates were based on 2020 population projections by election district (tab. 7) (Charles County Department of Planning and Growth Management, 1997) and assume that all future use is supplied by the lower Patapsco aquifer. The estimated pumpage increase in Election District 6 (Waldorf) of 3.2 Mgal/d was divided between Election District 6 (1.2 Mgal/d) and Election District 8 (2.0 Mgal/d). Shifting part of the water supply for Election District 6 eastward into Election District 8 reduces the amount of drawdown in the study area. Future use in Election Districts 2, 3, 4, 5, and 9 was assumed to be supplied by aquifers shallower than the lower Patapsco, in part because water demand in those areas will probably not require drilling to the deeper aquifer.

The results show that distant pumpage would cause heads to decline 50 to 60 ft in the vicinity of Bryans Road, approximately 20 ft at Indian Head, and as much as 150 ft between Waldorf and La Plata (fig. 39). Less than 1 percent of the drawdown in the study area is attributed to stabilization of heads as a result of 1997 pumpage. The percentage of available drawdown remaining based on this model simulation ranges between 0 and 35 percent in most of the Indian Head-Bryans Road area and as much as 60 percent on the eastern side of the study area (fig. 40). The available drawdown was exceeded in two areas along the Potomac River shoreline, in the central part of the Indian Head peninsula and northwest of Bryans

Table 6. Summary of results of model simulations I, II, III, IV, and V

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

INDIAN HEAD-BRYANS ROAD AREA		OUTSIDE OF INDIAN HEAD-BRYANS ROAD AREA		RESULTS OF MODEL SIMULATION (ALL MODEL SIMULATIONS WERE RUN THROUGH 2020)
Pumpage in lower Patapsco aquifer (Mgal/d)	**Pumpage in upper Patuxent aquifer (Mgal/d)**	**Pumpage in lower Patapsco aquifer (Mgal/d)**	**Pumpage in upper Patuxent aquifer (Mgal/d)**	
MODEL SIMULATION I: EFFECT OF PUMPAGE FROM THE LOWER PATAPSCO AQUIFER OUTSIDE OF THE INDIAN HEAD-BRYANS ROAD AREA ON WATER LEVELS IN THE LOWER PATAPSCO AQUIFER WITHIN THE STUDY AREA				
PUMPING ALTERNATIVE IA				
2	0	7.7 (5.8 in Waldorf area)	0	Water levels decline 50 to 60 ft in the vicinity of Bryans Road and approximately 20 ft at the Town of Indian Head between 1997 and 2020. The 80-percent management water level is reached along the Potomac River northwest of Bryans Road.
PUMPING ALTERNATIVE IB				
2	0	4.5 (pumpage in Waldorf area held at 1997 rate: 2.6 Mgal/d)	0	Water levels decline 20 to 30 ft in the vicinity of Bryans Road and less than 20 ft south of the Town of Indian Head.
MODEL SIMULATION II: MAXIMUM YIELD FROM THE LOWER PATAPSCO AQUIFER WITHIN THE STUDY AREA				
2.6[1]	0	7.7	0	The 80-percent management level is reached along the Potomac River northwest of Bryans Road.
MODEL SIMULATION III: MAXIMUM YIELD FROM THE UPPER PATUXENT AQUIFER WITHIN THE INDIAN HEAD-BRYANS ROAD AREA				
2.1	3.4	7.7	0	Less than 30 percent of available drawdown remains in the Indian Head-Bryans Road area. The 80-percent management water level is reached at the Potomac River shoreline. Pumping water levels are as low as 650 ft below sea level.
MODEL SIMULATION IV: SIMULATION OF POTENTIAL-DEVELOPMENT SCENARIOS				
PUMPING ALTERNATIVE IVA				
2.1	2.1	7.7	0	Percentage of available drawdown remaining in the upper Patuxent aquifer ranges from 30 to 50 percent within the Indian Head-Bryans Road area. Model cell water levels are as low as 330 ft below sea level.
PUMPING ALTERNATIVE IVB				
2.1	4.0	7.7	0	Available drawdown in the upper Patuxent aquifer is exceeded northwest of Rt. 210 between Indian Head and Bryans Road. Model cell water levels are as low as 540 ft below sea level.
PUMPING ALTERNATIVE IVC				
2.1	4.7	7.7	0	Available drawdown in the upper Patuxent aquifer is exceeded in most of the study area. Model cell water levels are as low as 650 ft below sea level and are below the top of the aquifer within a narrow band adjacent to the flow boundary near Chapman's Landing.
MODEL SIMULATION V: EFFECT OF PUMPAGE FROM THE UPPER PATUXENT AQUIFER ON WATER LEVELS IN THE LOWER PATAPSCO AQUIFER				
2	3.4	3.9	0	Drawdown between 1997 and 2020 in lower Patapsco aquifer is less than 18 ft in the Indian Head-Bryans Road area and less than 10 ft elsewhere in the model area.

[1] Area expanded to include entire study area

Road. Less drawdown is available in the updip section of the aquifer because the top of the aquifer is relatively shallow. Further development of the lower Patapsco aquifer, therefore, should be located downdip (southeast) of the Indian Head-Bryans Road area and include a reduction in pumpage in the updip areas. Remaining available drawdown ranges from 0 to 100 ft in the Indian Head-Bryans Road area (fig. 41). The potentiometric surface is 50 to 150 ft below sea level in the Indian Head-Bryans Road area and about 250 ft below sea level at Waldorf (fig. 42).

Table 7. Simulated water use in the lower Patapsco aquifer in 1997 and 2020 outside of the Indian Head-Bryans Road area based on population estimates for Election Districts 1, 5, 6, 8, and 10 (Pumping Alternative IA).

[Mgal/d = million gallons per day]

Election District[1]		Pumpage (Mgal/d)	
No.	Location	1997[2]	2020[3]
1	La Plata	0.59	1.1
5	Tompkinsville	0.7	0.7
6	Waldorf	2.6	3.8
8	Bryantown	0.0	2.0
10	Marbury	0.024	0.1
Total		3.914	7.7

[1] Locations of election districts are shown on figure 1.
[2] Based on appropriated water use over 10,000 gal/d reported to the State.
[3] Sum of pumpage reported in 1997 and pumpage estimated for the increase in population by 2020 (Charles County Department of Planning and Growth Management, 1997). Pumpage figures assume a per capita water- use rate of 80 gal/d.

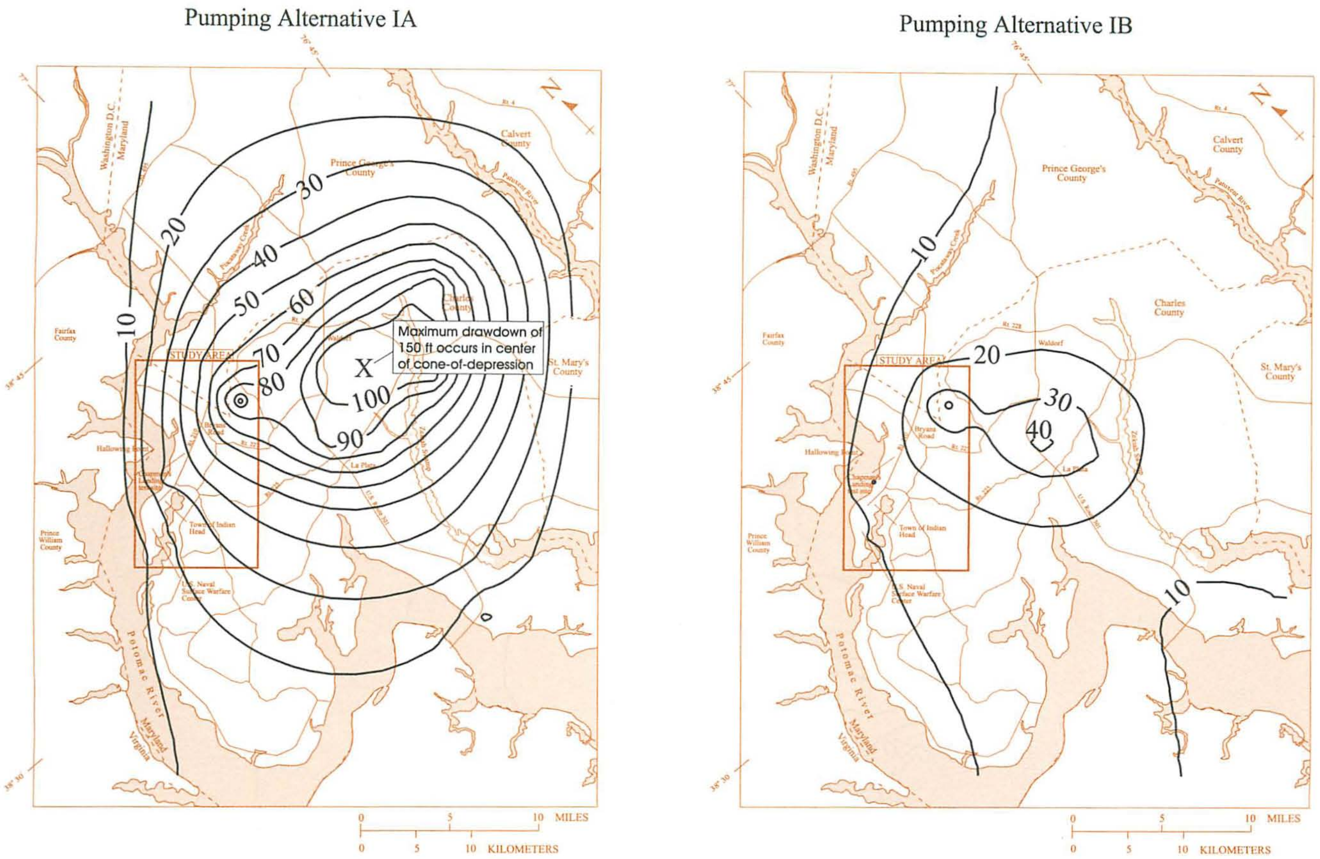
Pumping Alternative IB

During this simulation, pumpage was held constant at 1997 levels in the Indian Head-Bryans Road area, while pumpage outside of this area—with the exception of the Waldorf area—was increased to estimated 2020 levels. Pumpage in the lower Patapsco aquifer in the Waldorf area remained at 1997 levels (2.6 Mgal/d). The resulting drawdown was 20 to 30 ft in the vicinity of Bryans Road and was less than 10 ft south of the Town of Indian Head (fig. 39). In contrast to Pumping Alternative IA, available drawdown remaining in the vicinity of Bryans Road ranges from 50 to 60 percent (130 to 160 ft). The potentiometric surface was 50 to 125 ft below sea level in the Indian Head-Bryans Road area and about 150 ft below sea level at Waldorf (fig. 42).

Model Simulation II
Maximum Yield from the Lower Patapsco Aquifer Within the Study Area

Measured drawdown in the lower Patapsco aquifer had reached the 80-percent management level along the Potomac River in the central part of the Indian Head peninsula by 1997 (fig. 17). While additional available drawdown remains in the southeastern part of the study area, further development of the aquifer would worsen the condition along the Potomac River. Increasing pumping within the study area while maintaining the 1997 pumpage distribution near the Potomac River would result in an expansion of the area where drawdown exceeds the 80-percent management level. Further development of the aquifer is possible, however, if pumpage near the Potomac River is transferred to the southeastern part of the study area. The purpose of this model simulation is to estimate the maximum yield of the lower Patapsco aquifer within the study area by repositioning part of the current pumpage.

Model Simulation II indicates that the lower Patapsco aquifer could produce a maximum of approximately 2.6 Mgal/d within the study area provided that 0.5 Mgal/d of current production near the Potomac River is shifted to the southeastern border of the study area (fig. 43) . In this simulation, pumpage in the lower Patapsco aquifer was reduced at Potomac Heights, Town of Indian Head, Bryans Road, and Strawberry Hill by 0.177, 0.15, 0.097, and 0.075 Mgal/d, respectively, and transferred to hypothetical well fields in the lower Patapsco aquifer along the southeastern border of the study area (fig. 43). Pumpage at the new sites was increased incrementally from a total of 0.5 Mgal/d in 1998 to 1.1 Mgal/d in 2020. The overall increase in pumpage



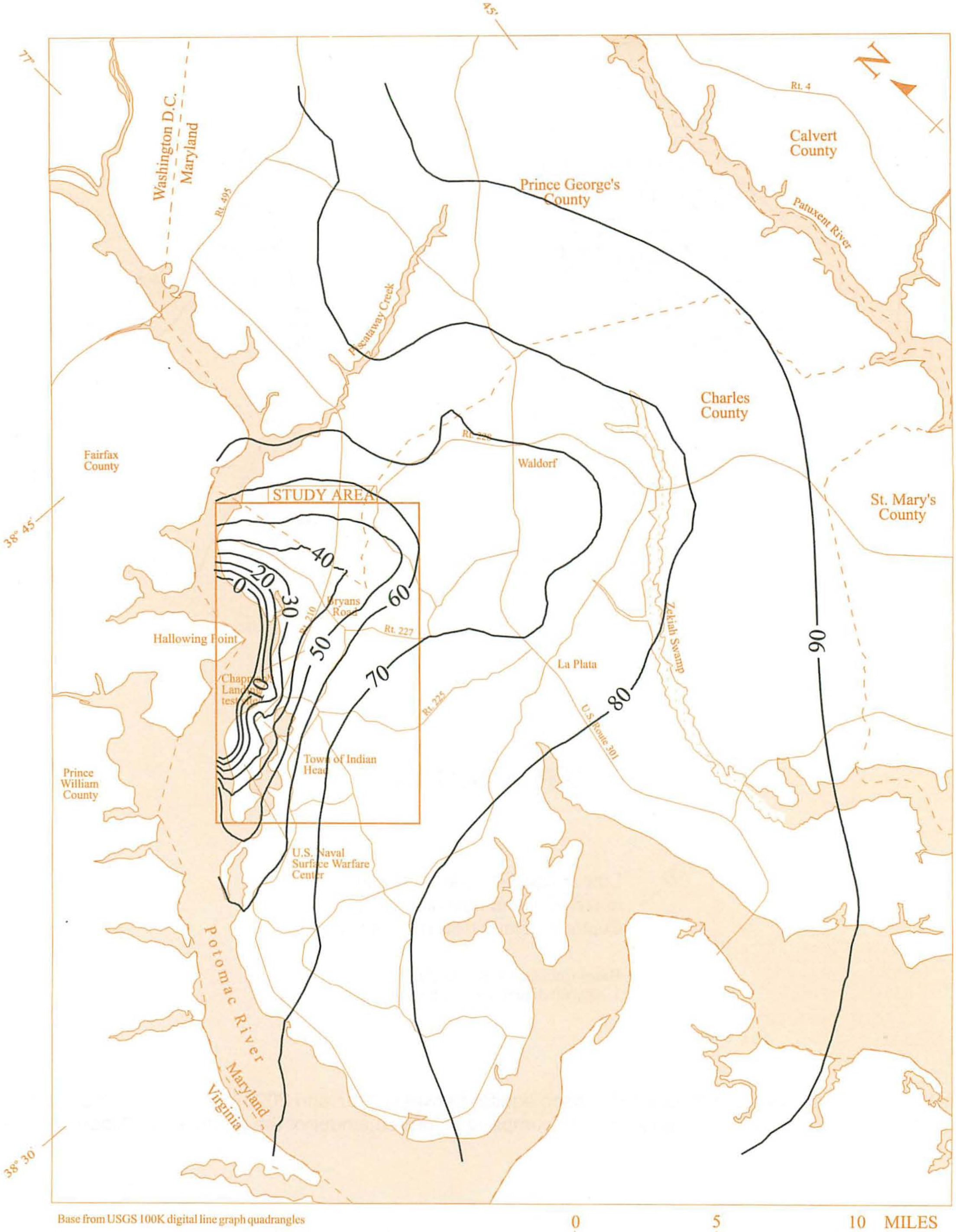
EXPLANATION

Line of equal simulated drawdown, in feet. Contour interval is 10 feet. Contours greater than 100 ft not shown.

Bases from U.S. Geological Survey 1:100,000 digital line graph quadrangles

Figure 39. Simulated drawdown in the lower Patapsco aquifer between 1997 and 2020 based on 1997 pumpage in the Indian Head-Bryans Road area and 2020 pumpage in the remainder of the model area (Model Simulations IA and IB).

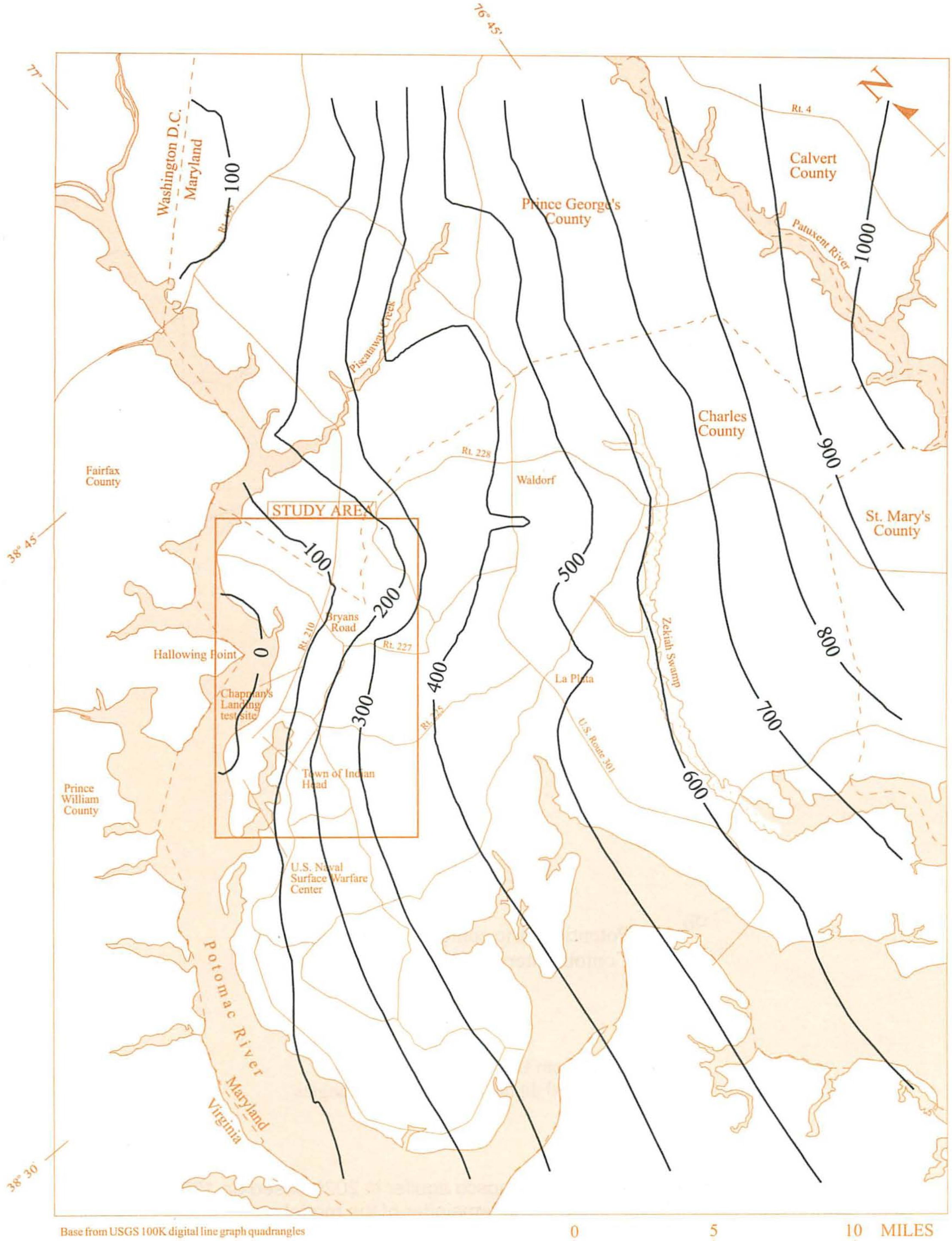
is 0.6 Mgal/d above current withdrawals (approximately 2 Mgal/d). Pumpage in the lower Patapsco aquifer was increased from 3.9 Mgal/d in 1998 to 7.7 Mgal/d in 2020 outside the study area to account for growth in the vicinity of Waldorf and La Plata. Results of the simulation indicate that remaining available drawdown is similar to that predicted for Simulation IA (fig. 41). In that simulation, pumpage in the study area was held at 1997 levels while pumpage outside the study area was increased to 7.7 Mgal/d.



EXPLANATION

60 — Contour of simulated available drawdown remaining, in percent. Contour interval is 10 percent.

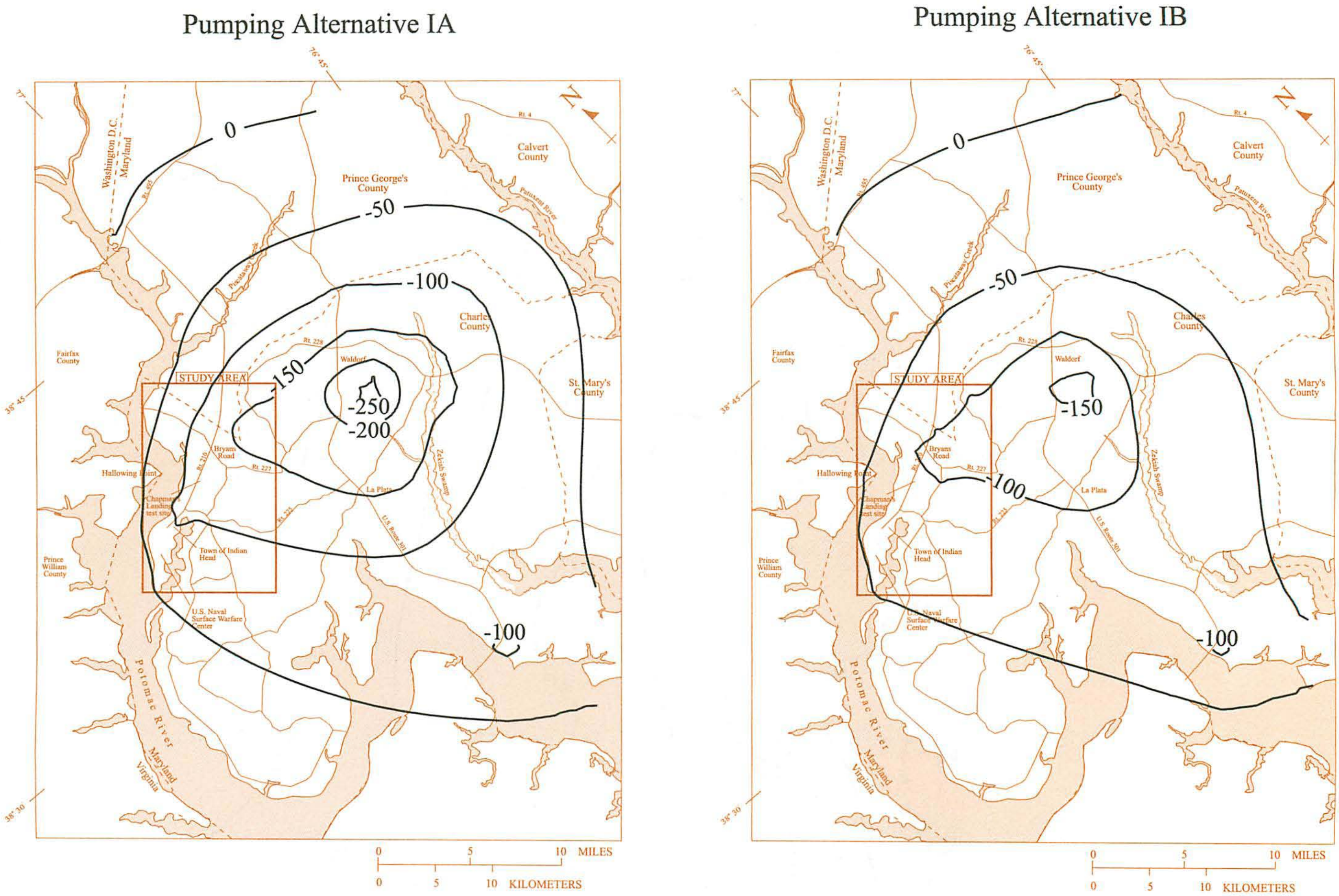
Figure 40. Percentage of available drawdown remaining in 2020 in the lower Patapsco aquifer based on 1997 pumpage in the Indian Head-Bryans Road area and 2020 pumpage in the remainder of the model area (Model Simulation IA).



EXPLANATION

0 Remaining available drawdown, in feet.
Contour interval is 100 feet.

Figure 41. Simulated remaining available drawdown in the lower Patapsco aquifer in 2020 (Model Simulation IA).



EXPLANATION

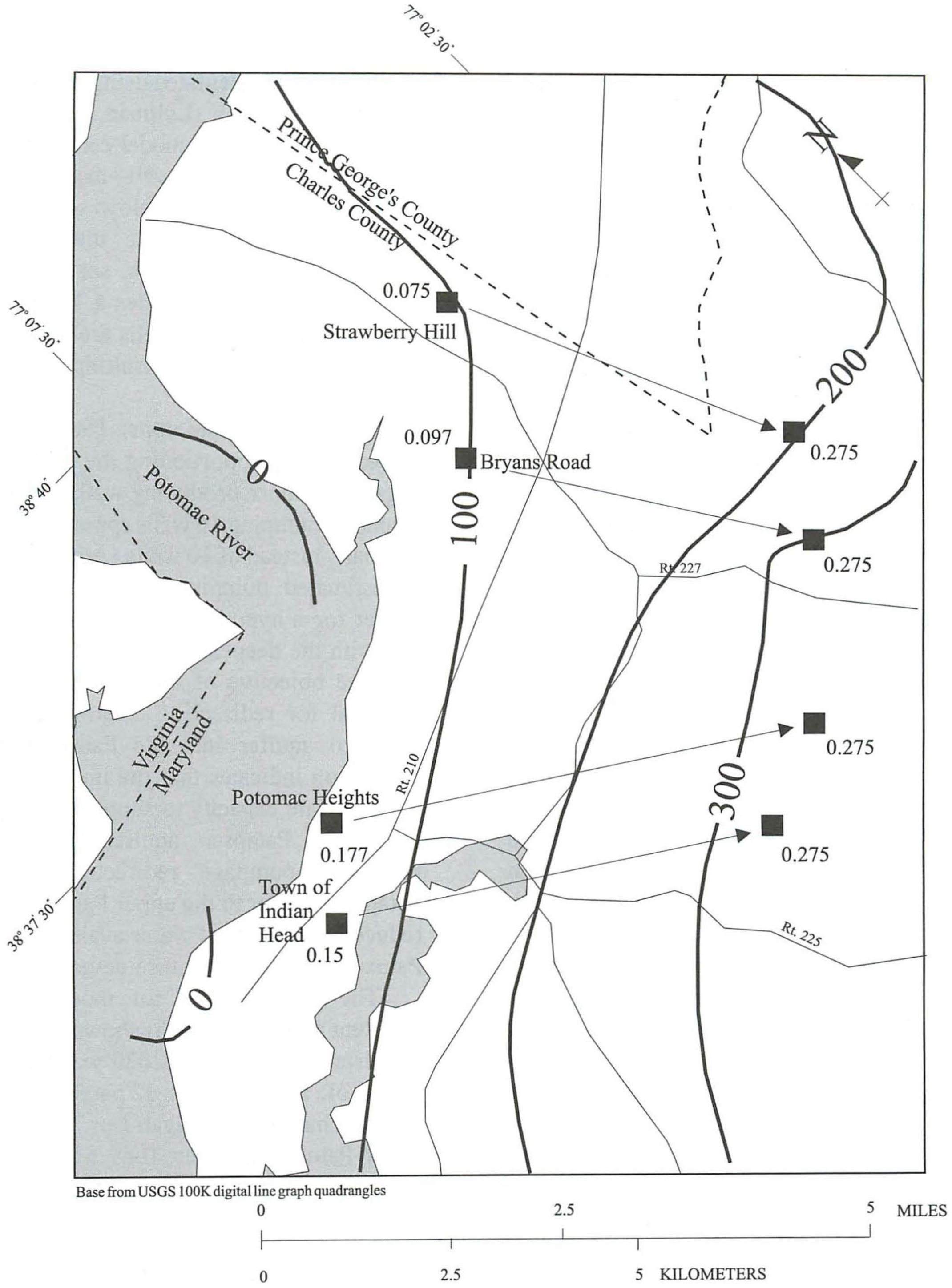
-50 Potentiometric contour of simulated heads. Contour interval 50 feet. Datum is sea level.

Bases from U.S. Geological Survey
1:100,000 digital line graph quadrangles

Figure 42. Simulated potentiometric surfaces of the lower Patapsco aquifer in 2020 based on 1997 pumpage in the Indian Head-Bryans Road area and 2020 pumpage in the remainder of the model area (Model Simulations IA and IB).

Model Simulation III
Maximum Yield from the Upper Patuxent Aquifer Within the Indian Head-Bryans Road Area

Simulation III estimates a maximum yield of the upper Patuxent aquifer within the Indian Head-Bryans Road area under the following three constraints. First, the yield of the aquifer was maximized while keeping water levels above the 80-percent management level through 2020. Secondly, the simulation assumed pumpage in the lower Patapsco aquifer to continue at 1997 rates within the Indian Head-Bryans Road area (Appendix D, Part I).



EXPLANATION

■ 0.15 Pumping model cell. Number next to symbol is pumpage in million gallons per day.

0 Remaining available drawdown, in feet. Contour interval is 100 feet.

Transfer of pumpage from existing to hypothetical simulated site.

Figure 43. Simulated remaining available drawdown in the lower Patapsco aquifer in 2020 (Model Simulation II).

Thirdly, pumpage in the lower Patapsco aquifer outside the Indian Head-Bryans Road area was increased from 3.9 Mgal/d in 1998 to 7.7 Mgal/d in 2020, as in Simulation IA.

The upper Patuxent aquifer was pumped at six proposed well sites, one hypothetical well site, and three existing well sites (Chapman's Landing wells 1 and 2; South Hampton) (fig. 44). Well-pumping rates used in the simulation are given in Appendix G. These sites were chosen as possible locations for upper Patuxent wells that would eventually be connected to a central water supply servicing the Bryans Road area (Greenhorne and O'Mara, 1995). Pumpage was increased incrementally (three 5-year intervals and one 7-year interval) in both aquifers. Generally, the well sites located in the more transmissive parts of the upper Patuxent aquifer were pumped at higher rates. One of the seven proposed well sites (Bryans Village) was relocated 1.1 mi south of its original position north of the Rt. 210-227 intersection to avoid well interference with the South Hampton well. A hypothetical well was also included 1 mi southeast from Chapman's Landing well 2. This well pumped 0.72 Mgal/d. The yield from the upper Patuxent aquifer under this pumping scheme is 3.4 Mgal/d. The total yield from both the lower Patapsco and upper Patuxent aquifers within the Indian Head-Bryans Road area is approximately 5.4 Mgal/d.

Results indicate that the percentage of available drawdown remaining in the upper Patuxent aquifer in 2020 is generally less than 30 percent in the Indian Head-Bryans Road area (fig. 45). Drawdowns reach the 80-percent management level along the Potomac River shoreline near Chapman's Landing. Remaining available drawdown, expressed in feet, ranges from 0 to 150 ft in the Indian Head-Bryans Road area (fig. 46). The simulated potentiometric surface in 2020 is mostly below sea level (fig. 47). In the Indian Head-Bryans Road area, heads range from 200 ft below sea level to more than 500 ft below sea level. The rate of water-level decline begins to stabilize at about 0.5 to 1 ft/yr after approximately 12 years of pumping.

The model calculates an average head for each model cell (fig. 3) and does not calculate the maximum drawdown immediately around a pumping well. It is important to estimate the additional drawdown next to pumping wells because those points represent the deepest anticipated water levels. This information is important as it relates to the 80-percent management level of the aquifer and pumping costs involved with deep water levels. The additional drawdown was calculated using a modified version of the Thiem equation (Lohman, 1972, p. 11). As an example, the deepest model-cell water level (in the hypothetical pumping well—model cell 39,42,3 in Appendix G) is 535 ft below sea level. The water level immediately outside the pumping well is estimated at 650 ft below sea level. The Thiem equation, however, assumes a 100-percent efficient well; in practice, most wells are no more than 70- to 75-percent efficient, resulting in even deeper pumping levels.

Drawdown in the upper Patuxent aquifer could be reduced by apportioning the same pumpage (3.4 Mgal/d) to more producing wells at lower rates. For example, pumping 16 wells spaced approximately 0.5 mi apart, instead of 10 wells (Appendix G), results in an estimated pumping water level that is 90 feet higher for a hypothetical well located in the model-cell with the deepest water level.

One objective of this report is to evaluate the potential for redirecting existing use of the lower Patapsco aquifer into the Patuxent aquifer. This simulation indicates that the upper Patuxent aquifer has adequate capacity to supply existing usage from the lower Patapsco aquifer in the study area. However, pumpage redirected from the lower Patapsco aquifer to the upper Patuxent aquifer would reduce the amount of water available from the upper Patuxent aquifer for future development.

The water budget for model layer 3 (upper Patuxent aquifer) (fig. 48) shows that the 3.4 Mgal/d withdrawn by wells in 2020 was balanced by a net inflow of: 1.1 Mgal/d or 32 percent from the outcrop area (recharge); 1.2 Mgal/d or 35 percent from the lower Patuxent aquifer; 0.69 Mgal/d or 20 percent from the northwestern, southeastern, and southwestern sides of the model; 0.28 Mgal/d or 8.2 percent from the lower Patapsco aquifer; and 0.088 Mgal/d or 2.6 percent from storage. Discrepancies in totals are caused by rounding. The volumetric rate of recharge entering the aquifer from the outcrop area (1.1 Mgal/d) is equivalent to 0.58 in./yr. This represents an increase of 0.53 in./yr from 0.05 in./yr entering the aquifer under 1997 pumping conditions. The increase in recharge is a result of the steepened head gradient between the outcrop and the study area caused by pumping, which diverts water within the outcrop area to the deeper, confined part of the aquifer.

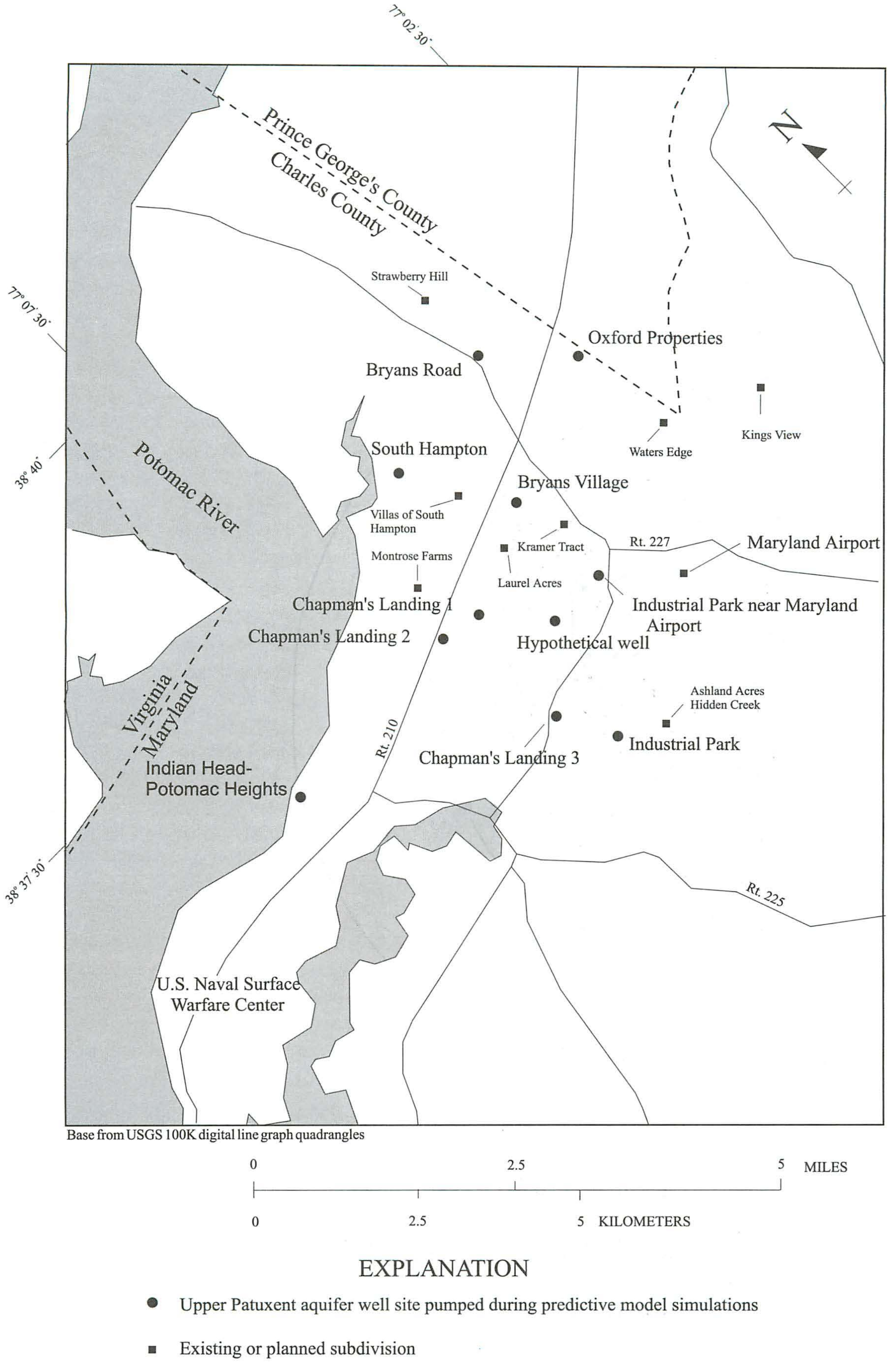
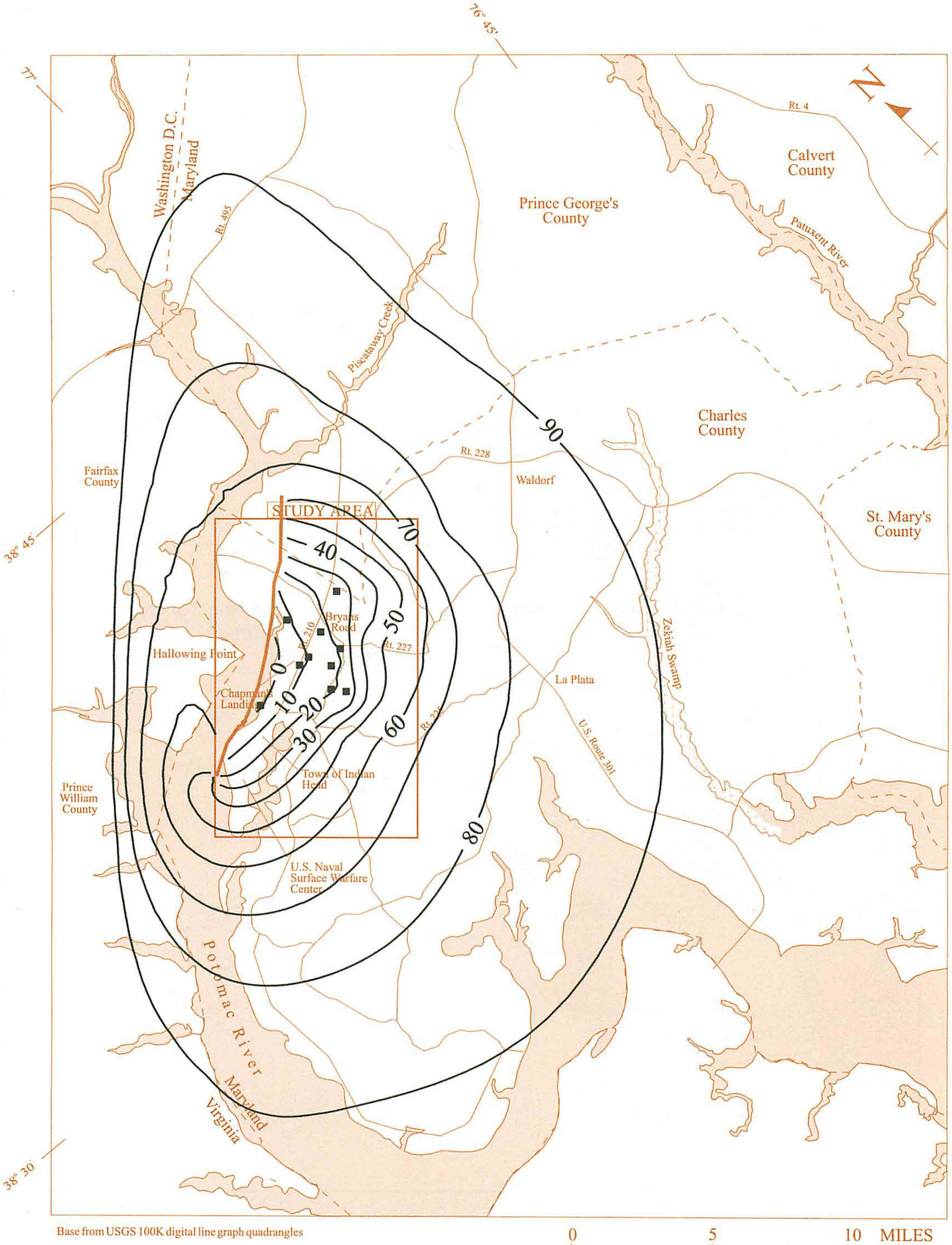


Figure 44. Well sites in the upper Patuxent aquifer used in predictive model simulations.



EXPLANATION

100 — Contour of simulated available drawdown remaining, in percent. Contour interval is 10 percent.

■ Pumping cell

Ground-water-flow barrier

Figure 45. Percentage of available drawdown remaining in 2020 in the upper Patuxent aquifer based on a pumping rate of 3.4 million gallons per day (Model Simulation III).

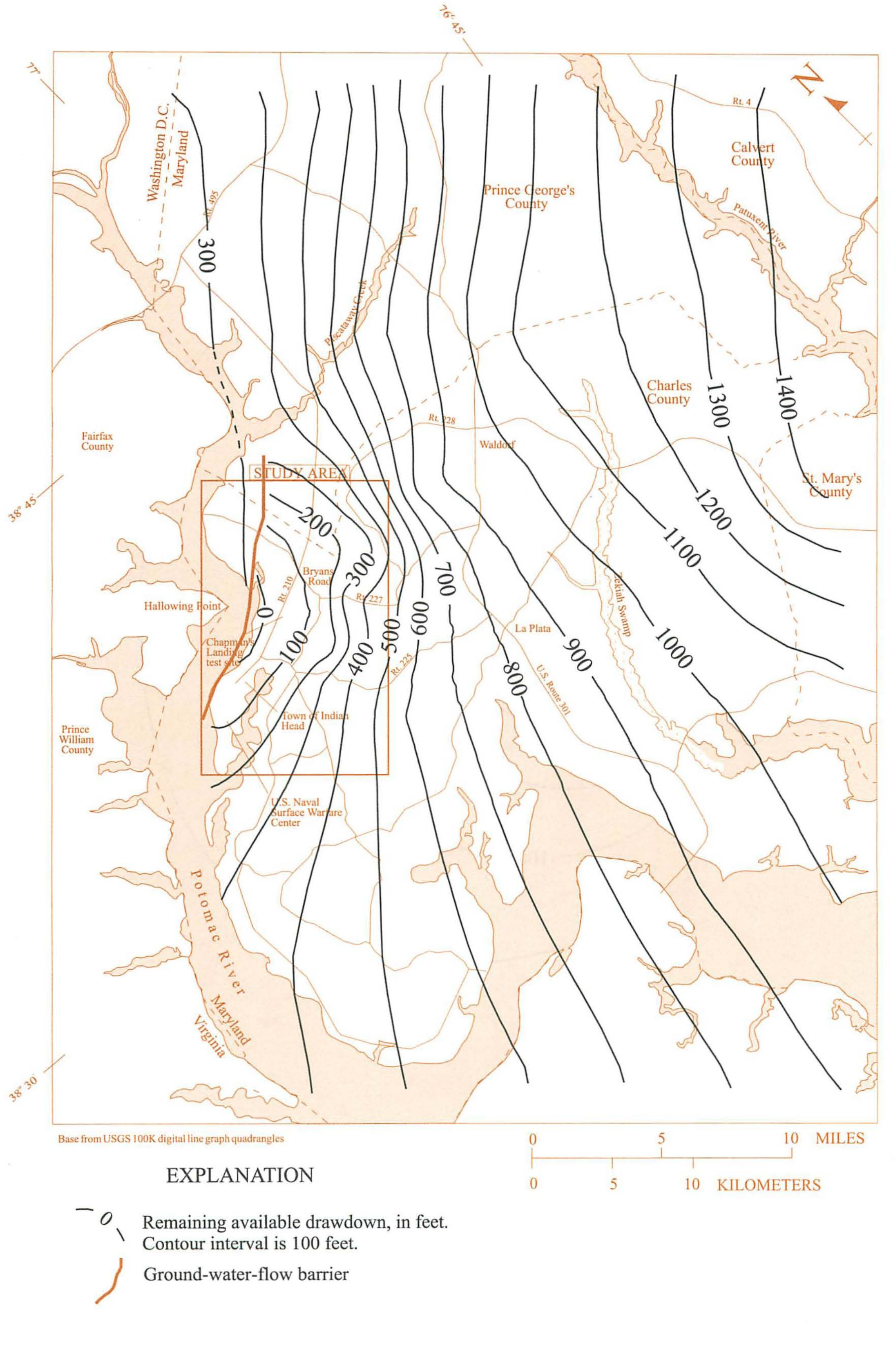
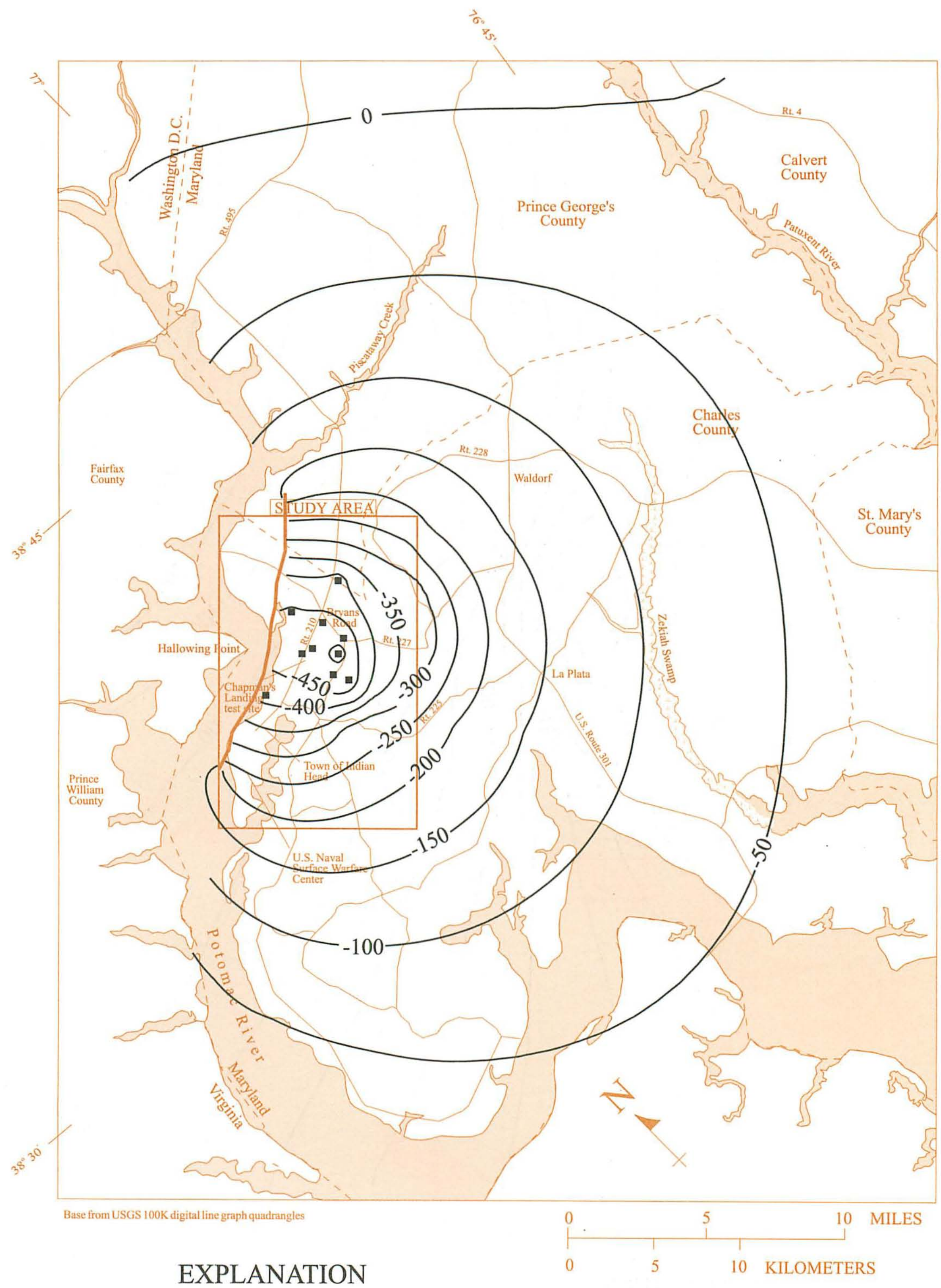


Figure 46. Simulated remaining available drawdown in the upper Patuxent aquifer in 2020 (Model Simulation III).



EXPLANATION

—-100— Potentiometric contour of simulated heads. Contour interval is 50 feet. Datum is sea level.

Ground-water-flow barrier

Figure 47. Simulated potentiometric surface of the upper Patuxent aquifer in 2020 (Model Simulation III).

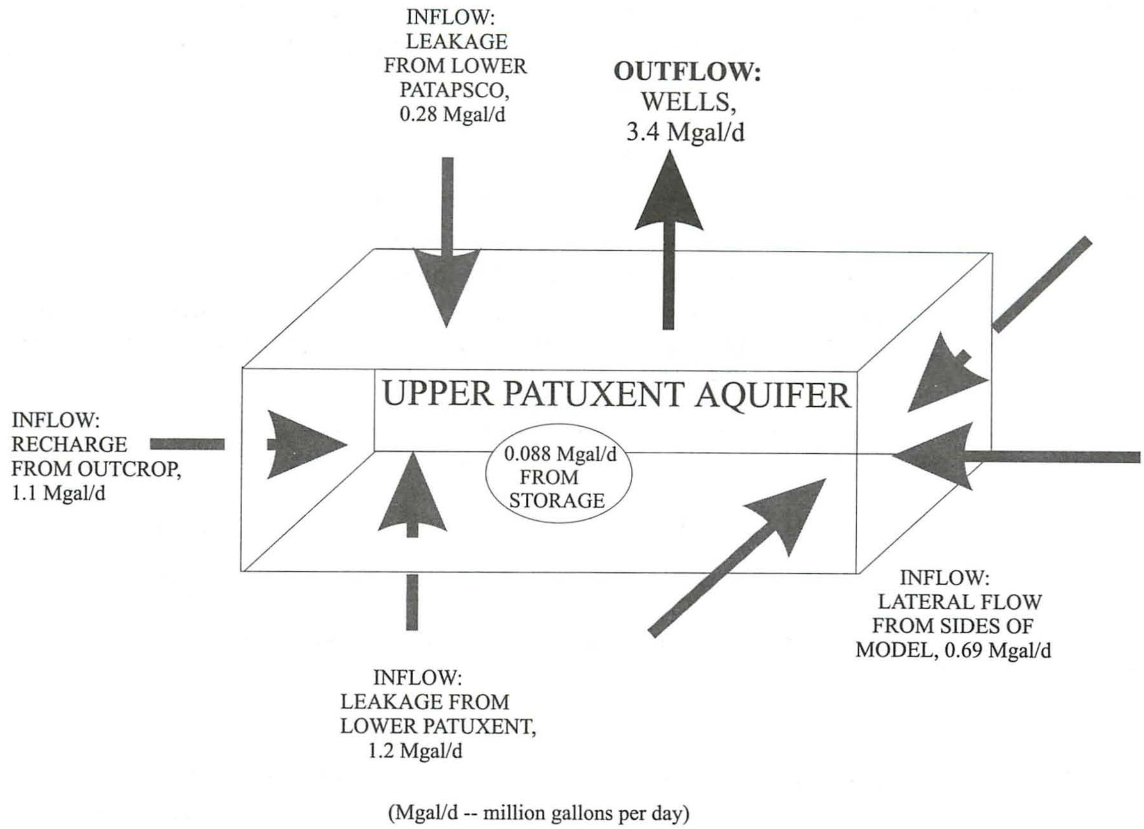


Figure 48. Water budget for model layer 3 (upper Patuxent aquifer) in 2020 based on a pumping rate of 3.4 million gallons per day (Model Simulation III).

Model Simulation IV
Simulation of Potential-Development Scenarios

Three pumping alternatives of Model Simulation IV were made to predict the impact on water levels for a range of pumping rates in the lower Patapsco and upper Patuxent aquifers in the Indian Head-Bryans Road area. The pumping rates used in the simulations were based on a series of potential-development scenarios in the Indian Head-Bryans Road area suggested by Cooksey and others (1993). In that report, water demand was based on existing use, approved or planned subdivisions, and estimates of the number of lots on vacant land with the potential for development. Estimates for commercial and industrial use were also made. Combined pumpage from the lower Patapsco and upper Patuxent aquifers within the Indian Head-Bryans Road area ranges from 4.1 to 6.7 Mgal/d (tab. 8). In all simulations, pumpage in the upper Patuxent aquifer was divided between some or all of the 10 well sites (fig. 44) discussed under predictive Simulation III, with the addition of planned wells located at the U.S. Naval Surface Warfare Center and at Bryans Road. Pumpage assigned to individual wells is given in Appendix H. The lower Patapsco aquifer outside the study area was pumped at the estimated 2020 amount used in predictive Model Simulation IA (7.7 Mgal/d).

Pumping Alternative IVA

The pumpage used in this simulation is the estimated amount required to supply current users (2 Mgal/d in the lower Patapsco aquifer) in addition to planned subdivisions (1.85 Mgal/d) and growth at the U.S. Naval Surface Warfare Center (0.26 Mgal/d). The list of planned subdivisions is contained in the report by Cooksey and others (1993; Attachment A) (Appendix I). In this pumping alternative, 2.1 Mgal/d was pumped from seven wells in the upper Patuxent aquifer (Appendix H) while the lower

Table 8. Pumpage values in 2020 for the lower Patapsco and upper Patuxent aquifers in the Indian Head-Bryans Road area for Model Pumping Alternatives IVA, IVB, and IVC

[Mgal/d = million gallons per day]

Pumping Alternative	Total lower Patapsco pumpage (Mgal/d)	Total upper Patuxent pumpage (Mgal/d)	Total pumpage from the lower Patapsco and upper Patuxent aquifers (Mgal/d)	Approximate additional population served in 2020[1/]
IVA	2	2.1	4.1	23,000
IVB	2	4.0	6.0	38,000
IVC	2	4.7	6.7	47,000

[1/] Based on water-use estimates for planned developments and potential residential growth made by Cooksey and others (1993) divided by 80 gal/d (average per capita water use).

Patapsco aquifer was pumped at 2 Mgal/d within the study area. At these pumping rates, the model-calculated head in the upper Patuxent aquifer was as low as 330 ft below sea level. The deepest water level immediately outside a pumping well is estimated to be 400 ft below sea level. The percentage of available drawdown remaining ranged from 30 to 50 percent in the Indian Head-Bryans Road area and up to 70 percent in other parts of the study area (fig. 49).

Pumping Alternative IVB

Pumpage used in this simulation represents the amount required to supply the users specified in Pumping Alternative IVA (4.1 Mgal/d) plus an additional 1.9 Mgal/d for potential residential and commercial development. This amount is equivalent to water-use scenario I of Cooksey and others (1993) and represents their low estimate of potential development in addition to what is currently planned. In Pumping Alternative IVB, 4.0 Mgal/d was pumped from the upper Patuxent aquifer while the lower Patapsco aquifer was pumped at 2 Mgal/d. At these pumping rates, drawdown exceeds the 80-percent management level northeast of Route 210 between Indian Head and Bryans Road (fig. 49). Model-calculated head in the upper Patuxent aquifer is as low as 540 ft below sea level. Projected growth in this simulation could be supported if 0.6 Mgal/d is shifted from the upper Patuxent aquifer to the lower Patapsco aquifer. Because of the limited amount of available drawdown in the lower Patapsco aquifer along the Potomac River, the additional pumpage would have to be located in the southeastern part of the study area, and it would have to be accompanied by a reduction in pumpage along the Potomac River as discussed in Model Simulation II.

Pumping Alternative IVC

The pumpage used in this simulation is equivalent to water-use scenario III of Cooksey and others (1993) and represents their high estimate of potential development in addition to what is currently planned. In Pumping Alternative IVC, 4.7 Mgal/d was pumped from the upper Patuxent aquifer and 2 Mgal/d was pumped from the lower Patapsco aquifer. At these pumping rates, available drawdown is exceeded in much of the study area (fig. 49). Model-calculated head in the upper Patuxent aquifer is as low as 650 ft below sea level. Model-calculated head is below the top of the aquifer within a narrow band located along the central part of the flow boundary near Chapman's Landing. Calculated water levels immediately outside 3 of 12 pumping wells are below

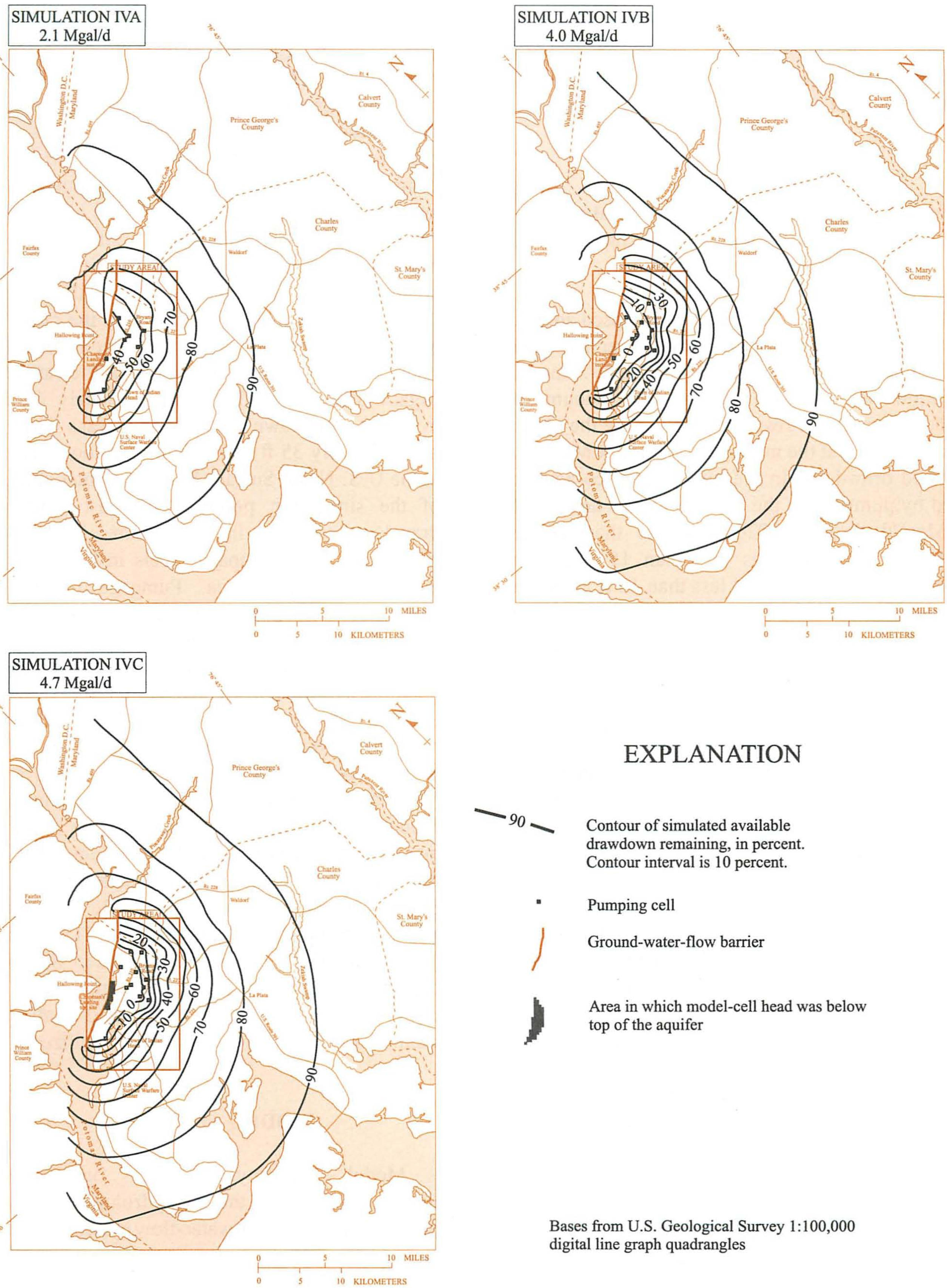


Figure 49. Percentage of available drawdown remaining for the upper Patuxent aquifer in 2020 based on pumping rates of 2.1, 4.0, and 4.7 million gallons per day (Model Simulations IVA, IVB, and IVC).

the top of the aquifer. The deepest water level calculated immediately outside a pumping well is 840 ft below sea level.

Model Simulation V
Effect of Pumpage from the Upper Patuxent Aquifer on Water Levels in the Lower Patapsco Aquifer

How water levels in the Lower Patapsco aquifer are affected by pumpage from the upper Patuxent aquifer is an important regulatory concern. A model simulation was made to estimate the amount of drawdown that could result from pumping the upper Patuxent aquifer at the maximum yield (3.4 Mgal/d). Simulated drawdown in the lower Patapsco aquifer caused by pumpage in the upper Patuxent aquifer of 3.4 Mgal/d through 2020 was less than 18 ft. Simulated drawdown was less than 15 ft in the vicinity of Bryans Road and less than 10 ft at Indian Head and elsewhere in the model area (fig. 50). The pumpage distribution in the upper Patuxent aquifer was the same as in Model Simulation III. The lower Patapsco aquifer was pumped at 1997 levels. The magnitude of this drawdown does not significantly reduce the amount of available drawdown remaining in the lower Patapsco aquifer. Flow from the lower Patapsco aquifer to the upper Patuxent aquifer in the Indian Head-Bryans Road area is small (4 percent) compared to the amount withdrawn by lower Patapsco wells in Simulation V.

In Model Simulation IA it was determined that water levels in the lower Patapsco aquifer would decline by as much as 60 ft in the vicinity of Bryans Road and approximately 20 ft at Indian Head as a result of future development of the aquifer in other parts of the county. Therefore, drawdown in the lower Patapsco aquifer caused by pumpage from the upper Patuxent aquifer will be less than half as much as the drawdown caused by pumpage of the lower Patapsco aquifer outside the study area.

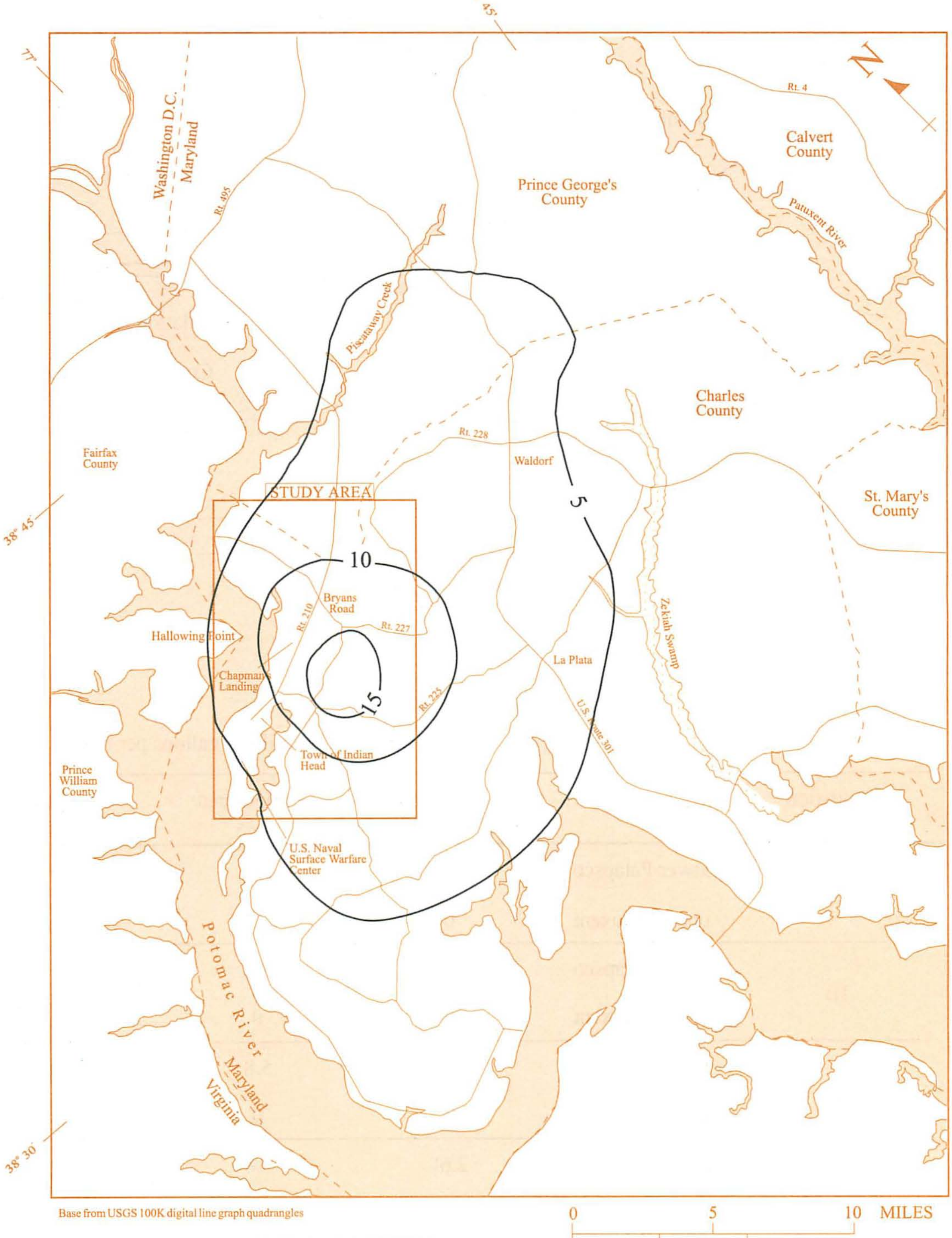
Transient Model-Simulated Head Changes in the Lower Patapsco and Upper Patuxent Aquifers

Simulated and observed head changes are shown for the lower Patapsco aquifer at Bryans Road (well CH Bd 22) and the U.S. Naval Surface Warfare Center (well CH Bc 5) (figs. 51 and 52, respectively). The 80-percent management level and top-of-aquifer are also shown. The hydrographs show the relative effect on simulated head changes caused by pumpage in Model Simulations IA, IB, II, and combined pumping conditions used in Simulations II and III for the period 1998-2020. The head changes represent model-cell values at each site. The greatest head decline occurs under the combined pumping conditions used in Simulations II and III—when the lower Patapsco aquifer is pumped at the rate of 2.6 Mgal/d in the study area (Simulation II) and the upper Patuxent aquifer is pumped at the rate of 3.4 Mgal/d (Simulation III). Approximately 60 ft of available drawdown remains at Bryans Road and approximately 35 ft of available drawdown remains at the U.S. Naval Surface Warfare Center at the end of the simulation period. The least amount of drawdown occurs in Simulation IB, which maintained 1997 pumpage levels in both the study area and Waldorf area. Pumpage through the simulation period was increased in three 5-year intervals and one 7-year interval. Heads essentially stabilize within 1 to 3 years after each increase in pumping as shown in figures 51 and 52.

Head decline in the upper Patuxent aquifer resulting from pumping simulated in Model Simulations III and IVA to IVC at CH Bc 77 (Chapman's Landing well 1) is shown in figure 53. Model Simulation III simulates the estimated maximum yield of the upper Patuxent aquifer. Under this simulation, head declines to within 60 ft of the 80-percent management level at CH Bc 77. When the aquifer is pumped at 4.0 and 4.7 Mgal/d (Simulations IVB and IVC, respectively), the 80-percent management level is exceeded in the model cell containing well CH Bc 77. At the end of all model simulations, heads have essentially stabilized.

MODEL ACCURACY

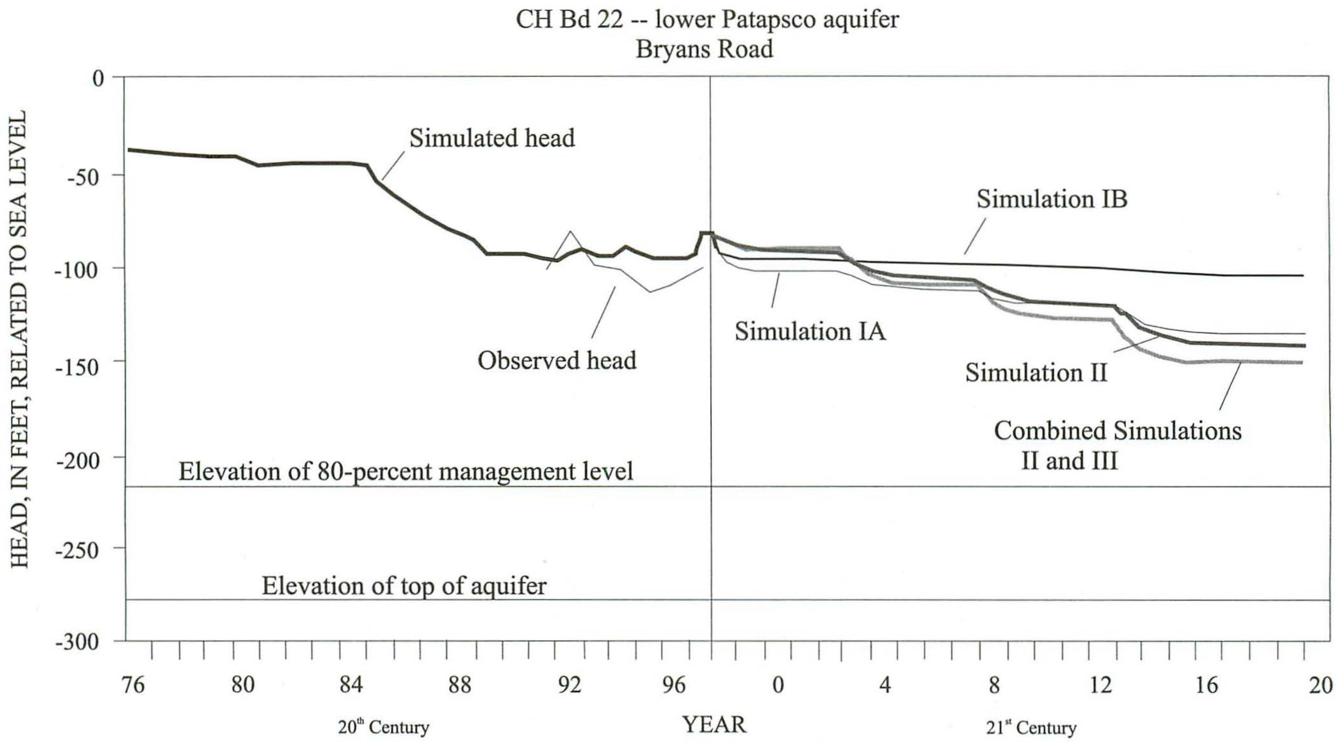
Model accuracy depends on a valid conceptualization of the geohydrologic framework controlling the ground-water-flow system and on the assignment of representative values to input parameters such as aquifer transmissivity, confining bed leakance, and pumpage. The accuracy of ground-water-flow models simulating historic conditions can be determined by comparing observed water levels to simulated water levels (fig. 31). The accuracy of the



EXPLANATION

— 10 — Line of equal simulated drawdown, in feet.

Figure 50. Simulated drawdown between 1997 and 2020 in the lower Patapsco aquifer caused by the withdrawal of 3.4 million gallons per day from the upper Patuxent aquifer.

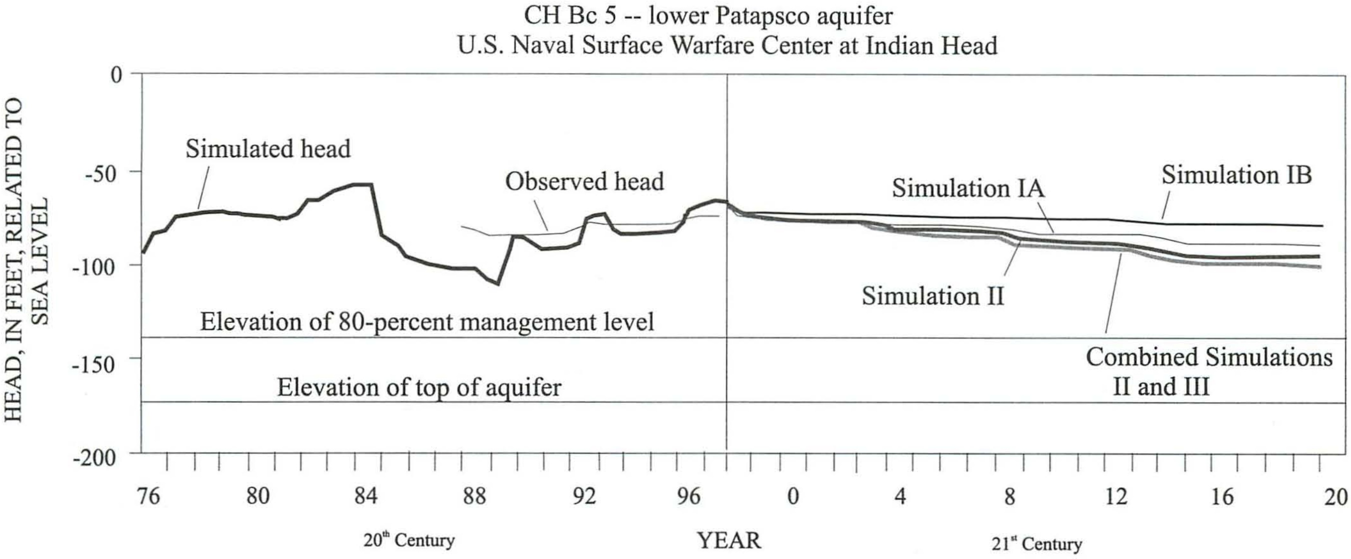


Pumpage, in million gallons per day

Simulation	Aquifer	Indian Head-Bryans Road area	Waldorf area	Other areas
IA	lower Patapsco	2	5.8	1.9
	upper Patuxent	0	0	0
IB	lower Patapsco	2	2.6	1.9
	upper Patuxent	0	0	0
II	lower Patapsco	2.6[1]	5.8	1.9
	upper Patuxent	0	0	0
Combined pumping conditions used in Simulations II and III	lower Patapsco	2.6[1]	5.8	1.9
	upper Patuxent	3.4	0	0

[1] Area expanded to include entire study area

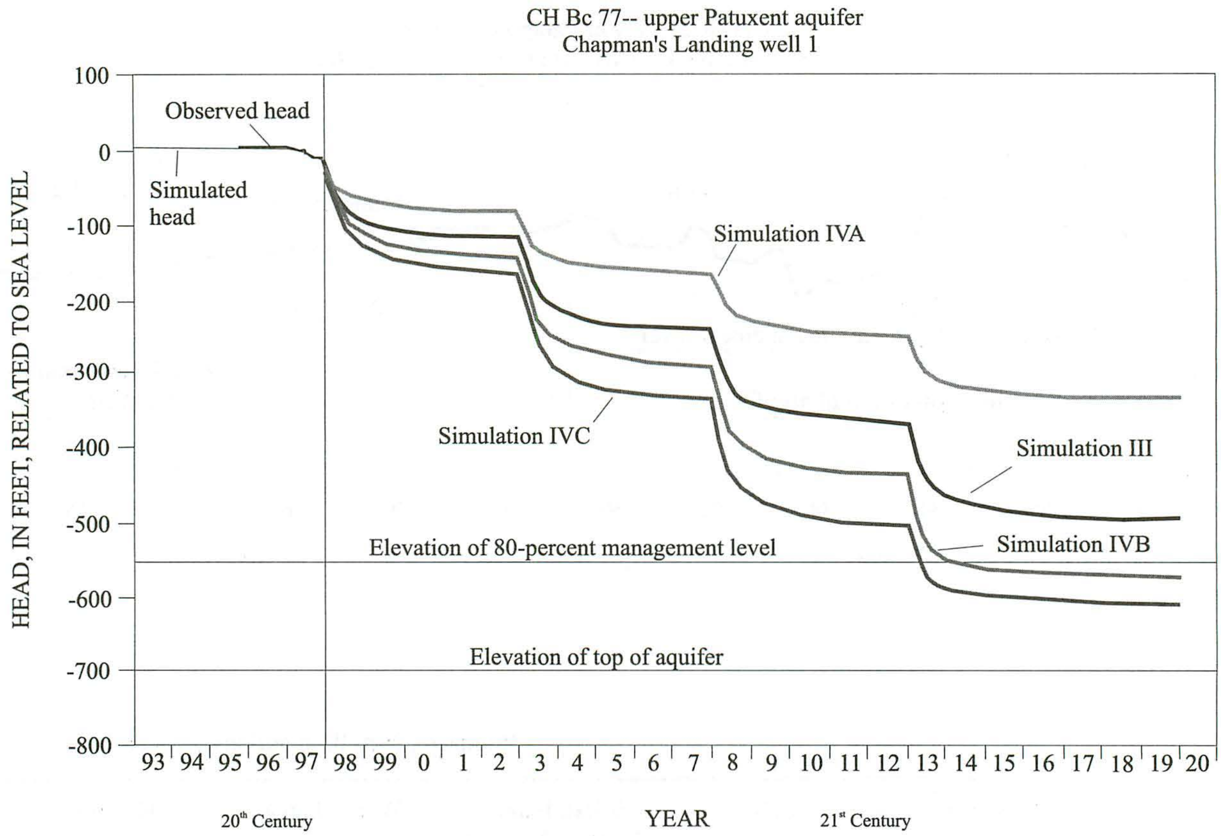
Figure 51. Model-simulated head changes in the lower Patapsco aquifer in well CH Bd 22 at Bryans Road, 1976 to 2020.



Simulation	Aquifer	Indian Head-Bryans Road area	Waldorf area	Other areas
		Pumpage, in million gallons per day		
IA	lower Patapsco	2	5.8	1.9
	upper Patuxent	0	0	0
IB	lower Patapsco	2	2.6	1.9
	upper Patuxent	0	0	0
II	lower Patapsco	2.6[1]	5.8	1.9
	upper Patuxent	0	0	0
Combined pumping conditions used in Simulations II and III	lower Patapsco	2.6[1]	5.8	1.9
	upper Patuxent	3.4	0	0

[1] Area expanded to include entire study area

Figure 52. Model-simulated head changes in the lower Patapsco aquifer in well CH Bc 5 at the U.S. Naval Surface Warfare Center (Indian Head), 1976 to 2020.



	Pumpage, in million gallons per day	
	upper Patuxent aquifer	lower Patapsco aquifer
Simulation III --	3.4	2 (Indian Head-Bryans Road area) 5.8 (Waldorf area) 1.9 (other areas)
Simulation IVA --	2.1	As above
Simulation IVB --	4.0	As above
Simulation IVC --	4.7	As above

Figure 53. Model-simulated head changes in the upper Patuxent aquifer in well CH Bc 77 (Chapman's Landing well 1), 1993 to 2020.

same model to predict future conditions, however, can only be verified by comparing observed conditions to simulated conditions at the end of the simulation period. Model performance can be evaluated and improved at intermediate steps as more data on water-level trends and pumpage become available. This is particularly important in the case of the upper Patuxent aquifer because no long-term pumpage has occurred in the model area to establish a cause-and-effect relation between pumping and water-level decline.

The observation-well network, established during this study, provides a basis to evaluate the accuracy of the future water-level conditions predicted by the model.

CONCLUSIONS

The findings discussed in this report address the following project objectives:

(1) Define the geohydrologic framework of the lower Patapsco aquifer and Patuxent aquifers in northwestern Charles County with an emphasis on the Indian Head-Bryans Road area: Based on geophysical logs, drill cuttings, and core samples from existing wells and from test wells drilled during the study, the lower Patapsco and upper Patuxent aquifers are separated by a confining bed (Arundel Clay) that ranges in thickness from 55 to 120 ft and chiefly consists of dense, red, purple, and brown clay. The upper Patuxent aquifer consists of layers of fine to coarse sand separated by layers of dense green clay. The transmissivity of the lower Patapsco and upper Patuxent aquifers ranges from 190 to 3,500 ft^2/d and 104 to 2,600 ft^2/d, respectively. These data indicate that the productivity of the upper Patuxent aquifer is low to moderate. In comparison, the lower Patapsco aquifer is a more transmissive aquifer, although constrained in the study area by less available drawdown. The lower Patuxent aquifer is less transmissive at the one site tested (80 ft^2d);

(2) Establish an observation-well network in the lower Patapsco aquifer and Patuxent aquifers: A network of 42 observation wells was established with 32 in the lower Patapsco aquifer, 9 in the upper Patuxent aquifer, and 1 in the lower Patuxent aquifer. The network should be monitored periodically in the future to determine the effect of pumping on water levels and to evaluate ground-water-flow model predictions;

(3) Assess the geohydrologic characteristics of the lower Patapsco aquifer and Patuxent aquifers and evaluate quantitatively: (a) the amount of drawdown in the lower Patapsco aquifer as a result of lower Patapsco pumpage outside the Indian Head-Bryans Road area: Water levels may decline by as much as 50 to 60 ft in the vicinity of Bryans Road between 1997 and 2020 and approximately 20 ft at the Town of Indian Head; *(b) the supply potential of the lower Patapsco and upper Patuxent aquifers within the Indian Head-Bryans Road area*: The lower Patapsco aquifer has reached its maximum supply capacity in the updip areas near the Potomac River. Further development of this aquifer, however, could be located downdip (southeast) of the Indian Head-Bryans Road area and include a reduction in pumpage in the updip areas. A total of 2.6 Mgal/d could be withdrawn from the lower Patapsco aquifer, if 0.5 Mgal/d is shifted to the southeast of the Indian Head-Bryans Road area. The upper Patuxent aquifer is capable of supplying approximately 3.4 Mgal/d before the drawdowns reach 80-percent management level. At this withdrawal rate, water levels as deep as 650 ft below sea level may occur in production wells; *(c) the potential for redirecting existing use of the lower Patapsco aquifer into the upper Patuxent aquifer*: The upper Patuxent aquifer has sufficient capacity to meet current demand in the Indian Head-Bryans Road area (approximately 2 Mgal/d) now being supplied by the lower Patapsco aquifer in the study area; however, this would reduce the amount of water available from the upper Patuxent aquifer for future development; and

(4) Determine the water quality of the Patuxent aquifers: Ground water from the upper and lower Patuxent aquifers is a sodium bicarbonate type with comparatively low concentrations of dissolved solids (214 to 378 mg/L). All reported levels for dissolved constituents are within the recommended limits set by the U.S. Environmental Protection Agency.

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APPENDIXES

Appendix A. Selected well records

[ft = feet; in. = inches; m-d-y = month, day, year; gal/min = gallons per minute; (gal/min)/ft = gallons per minute per foot; Charles County DPF = Charles County Department of Facilities; PEPCO = Potomac Electric Power Company; WSSC = Washington Suburban Sanitary Commission; USGS = U.S. Geological Survey; -- = not reported; Lppsc = lower Patapsco aquifer; Uppsc = upper Patapsco aquifer; Uptxn = upper Patuxent aquifer; Lptxn = lower Patuxent aquifer.]

Well number	State permit number	Owner or location	Driller	Completion year	Altitude of land surface (ft)	Total depth drilled (ft)	Diameter (in.)		Screen position (ft below land surface)	Aquifer	Water level (ft below land surface)		Date measured (m-d-y)	Yield (gal/min) (date)	Hours pumped	Specific capacity (gal/min/ft)
							Casing	Screen			Static (date)	Pumping				
CH Bb 6	--	US Navy, Group 1, Well 6	--	1915	38.3	398	8	8	251-261 301-311 376-397	Lppsc	--	212	12- -60	100	--	--
CH Bb 7	--	US Navy, Group 1, Well 7	--	1915	38.9	419	8	8	255-265 308-317 377-399	Lppsc	117 (7- -60)	240	12- -60	95 (3- -61)	--	--
CH Bb 9	--	US Navy, Group 1, Well 9	--	1915	32.1	399	8	8	185-195 235-245 285-294 355-376	Lppsc	150 (10- -60)	246	8- -60	110 (12- -60)	--	--
CH Bb 12	CH-01-3284	Town of Indian Head	Shannahan Artesian Well Co.	1953	95	515	10	10	238-245 248-260 288-298	Lppsc	149	204	12-10-53	220	8	4.0
CH Bb 17	--	US Navy, Well B	Sydnor Pump & Well Co.	1957	52	330	16, 10	10	240-294	Lppsc	105 (2- -57)	--	10- -60	450	--	--
CH Bb 19	CH-72-0122	US Navy, Well 2	Layne-Atlantic Co.	1972	90	405	20, 12	12	270-380	Lppsc	150	248	9-14-72	500	24	5
CH Bb 20	CH-71-0057	US Navy	Layne-Atlantic Co.	1971	50	408	6	6	199-224	Lppsc	83	182	2-10-71	250	24	2.5
CH Bb 22	CH-88-0847	US Navy	U.S. Geological Survey	1989	98	700	2	2	200-205	Lppsc	130	--	- -90	--	--	--
CH Bc 3	--	US Navy, Group 2, Well 12	--	1918	19	390	8	--	--	Lppsc	--	251	12- -60	115	--	--
CH Bc 5	--	US Navy, Group 2, Well 14	--	1918	39	430	8	--	--	Lppsc	--	234	12- -60	130	--	--
CH Bc 6	--	Potomac Heights	Layne-Atlantic Co.	1941	55	417	18, 8	8	362-412	Lppsc	174.5	238.5	5-5-45	385 (5- -41)	--	--
CH Bc 17	CH-01-1905	US Navy, Well 21	Washington Pump & Well Co.	1952	73	450	8	7.5	345-361	Lppsc	158.5	--	5-11-61	--	--	--

Appendix A. Selected well records--Continued

Well number	State permit number	Owner or location	Driller	Completion year	Altitude of land surface (ft)	Total depth drilled (ft)	Diameter (in.)		Screen position (ft below land surface)	Aquifer	Water level (ft below land surface)		Date measured (m-d-y)	Yield (gal/min) (date)	Hours pumped	Specific capacity (gal/min/ft)
							Casing	Screen			Static (date)	Pumping				
CH Bc 23	CH-03-0288	Town of Indian Head, Well 2	Shannahan Artesian Well Co.	1958	65	352	16, 10, 8	8	229-250 262-270 280-292 305-311	Lppsc	141	206	4-15-58	240	24	3.7
CH Bc 24	CH-02-0874	Potomac Heights, Well 2	Layne-Atlantic Co.	1955	72	446	10	10	384-399 415-435	Lppsc	122	135	10-10-55	250	4	19.2
CH Bc 29	CH-01-3628	Warder, James A.	Shannahan Artesian Well Co.	1953	172	442	4, 2	2	210-215 383-388 423-428	Lppsc	97	160	11-3-53	4.5	6	.07
CH Bc 46	CH-01-9008	Jenkins, John W., Jenkins Lane	Shannahan Artesian Well Co.	1955	182	639	4, 2	2	Unknown	Lppsc	170	245	6-5-55	30	4	.4
CH Bc 61	CH-05-6515	Potomac Heights, Test well	Layne-Atlantic Co.	1964	70	875	4, 2	2	439-444	Lppsc	122	--	4-10-64	6	48	--
CH Bc 62	CH-66-0049	Potomac Heights	Layne-Atlantic Co.	1966	50	470	6	6	376-406	Lppsc	170	270	3-24-66	160	20	1.6
CH Bc 64	CH-66-0049	Potomac Heights	Layne-Atlantic Co.	1966	48	540	6	6	414-424 444-464 494-514	Lppsc	125	250	8-30-66	200	8	1.6
CH Bc 65	CH-66-0043	Jenkins Lane Water Co.	Shannahan Artesian Well Co.	1966	176	622	6, 4	4	589-619	Lppsc	192	220	3-30-66	24	8	0.9
CH Bc 67	CH-72-0053	Town of Indian Head, Well 3	Shannahan Artesian Well Co.	1971	30	522	10, 5	5	488-498 511-522	Lppsc	102	181	12-12-71	300	24	3.8
CH Bc 68	CH-67-0051	Potomac Heights, Well 3	Layne-Atlantic Co.	1967	75	540	20, 8	8	414-424 444-464 494-514	Lppsc	148	288	2-24-67	517	24	3.7
CH Bc 70	CH-73-2329	Town of Indian Head, Well 4	CZ Enterprises	1979	35	483	8	8	372-392 412-442	Lppsc	80	306	8-1-79	96	24	.4
CH Bc 71	CH-73-2415	Town of Indian Head	CZ Enterprises	1979	28	410	2	2	400-410	Lppsc	82	250	8-1-79	17	5	.1

Appendix A. Selected well records--Continued

Well number	State permit number	Owner or location	Driller	Completion year	Altitude of land surface (ft)	Total depth drilled (ft)	Diameter (in.)		Screen position (ft below land surface)	Aquifer	Water level (ft below land surface)		Date measured (m-d-y)	Yield (gal/min) (date)	Hours pumped	Specific capacity (gal/min/ft)
							Casing	Screen			Static (date)	Pumping				
CH Bc 72	CH-81-0992	Town of Indian Head, Well 5	Sydnor Hydrodynamics, Inc.	1984	34	498	20, 12, 6	6	224-254 284-304 334-347	Lppsc	95.8 99	155.8 156	9-24-84 10-18-84	160 160	-- 24	-- 2.8
CH Bc 74	CH-81-2919	Montrose Farms	Shannahan Artesian Well Co.	1988	150	748	4, 2	3	550-566 574-589 637-642	Lppsc	231	256	9-20-88	53	24	2.1
CH Bc 75	CH-92-0500	Chapman's Landing, Well 2	Sydnor Hydrodynamics, Inc.	1993	125	1164	8	8	820-825 860-880 898-923	Uptxn	121	205	6-25-93	500	72	5.9
CH Bc 76	CH-88-1638	Charles Co. DPF, Bryans Road, Well 3	Sydnor Hydrodynamics, Inc.	1991	171	817	22, 16, 8	8	540-605	Lppsc	262	351	6-6-91	400	24	4.5
CH Bc 77	CH-88-1028	Chapman's Landing, Well 1	Branham Well Drillers	1990	98	990	16, 8, 6	6	925-955	Uptxn	94	174	8-10-90	270	24	3.4
CH Bc 78	CH-94-0394	Charles Co. DPF, South Hampton Well 2	Sydnor Hydrodynamics, Inc.	1995	34	815	10, 6	6	675-685 710-790	Uptxn	16	310	9-15-95	750	24	2.6
CH Bc 79	CH-04-9202	Laurel Water Co.	Shannahan Artesian Well Co.	1962	170	729	4, 2	3	714-729	Lppsc	186	215	12-7-62	8	5	.3
CH Bc 80	CH-94-0897	Maryland Geological Survey, Chapman's Landing	A.C. Schultes of Maryland	1996	123	1142	4	4	1085-1095 1105-1115	Lptxn	129	275	8-30-96	37	12	.2
CH Bc 81	CH-88-0482	Montrose Farms	Shannahan Artesian Well Co.	1990	150	656	6, 4	4	556-588 642-646	Lppsc	238	260	3-19-90	75	24	3.4
CH Bc 82	CH-94-1401	Potomac Heights, Observation well	Sydnor Hydrodynamics, Inc.	1997	75	520	8, 4	4	406-436 460-490	Lppsc	195	205	7-2-97	37	16	3.4

Appendix A. Selected well records--Continued

Well number	State permit number	Owner or location	Driller	Completion year	Altitude of land surface (ft)	Total depth drilled (ft)	Diameter (in.)		Screen position (ft below land surface)	Aquifer	Water level (ft below land surface)		Date measured (m-d-y)	Yield (gal/min) (date)	Hours pumped	Specific capacity (gal/min/ft)
							Casing	Screen			Static (date)	Pumping				
CH Bc 83	CH-94-1402	Potomac Heights, Production well	Sydnor Hydrodynamics, Inc.	1997	75	550	18, 10	10	400-445 455-490 507-532	Lppsc	193	256	11-19-97	400	24	6.3
CH Bd 16	CH-01-6856	Indian Head Manor, Well 1	Shannahan Artesian Well Co.	1954	180	506	4, 2	2	412-422 455-460	Lppsc	160	205	11-15-54	25	4	.6
CH Bd 17	CH-01-6857	Indian Head Manor, Well 2	Shannahan Artesian Well Co.	1954	170	460	4, 2	2	411-416 455-460	Lppsc	160	220	11-15-54	27	4	.4
CH Bd 18	CH-02-2911	Indian Head Manor, Well 3	Shannahan Artesian Well Co.	1956	178	673	6, 4	4	662-673	Lppsc	168	276	5-24-56	63	4	.6
CH Bd 22	CH-02-1161	Charles Co. DPF, Bryans Road, Wooster Drive	Shannahan Artesian Well Co.	1956	175	651	6, 4	4	628-644	Lppsc	179	255	4-14-56	60	4	0.8
CH Bd 29	CH-04-2481	Charles Co. DPF, Bryans Road, Well 2	Shannahan Artesian Well Co.	1961	170	626	6, 4	4	570-620	Uppsc	180	220	6-6-61	126	4	3.2
CH Bd 32	CH-67-0085	J C Parks School	East Coast Well Drilling, Inc.	1967	175	660	6	6	648-660	Lppsc	190	410	10-23-67	30	3	.1
CH Bd 33	CH-66-0079	Charles Co. DPF, Strawberry Hill Well 1	Layne-Atlantic Co.	1966	180	654	18, 10	10	536-556 561-586	Lppsc	194	250	8-30-66	400	8	7.1
CH Bd 35	CH-72-0050	Charles Co. DPF, Strawberry Hill Well 2	Layne-Atlantic Co.	1973	170	666	20, 10	10	595-645	Lppsc	205	259	4-9-73	300	8	5.6
CH Bd 38	CH-73-2270	Charles Co. DPF, Eutaw Forest	Sydnor Hydrodynamics, Inc.	1980	200	721	6, 4	4	696-721	Lppsc	205	--	1-12-80	--	--	--
CH Bd 40	CH-73-2417	Charles Co. DPF, Eutaw Forest	Shannahan Artesian Well Co.	1979	185	904	4, 2	3	736-741 825-846	Lppsc	212	249	8-21-79	26	12	.7

Appendix A. Selected well records--Continued

Well number	State permit number	Owner or location	Driller	Com-ple-tion year	Altitude of land surface (ft)	Total depth drilled (ft)	Diameter (in.)		Screen position (ft below land surface)	Aquifer	Water level (ft below land surface)		Date measured (m-d-y)	Yield (gal/min) (date)	Hours pumped	Specific capacity (gal/min/ft)
							Casing	Screen			Static (date)	Pumping				
CH Bd 44	CH-73-2500	Charles Co. DPF, Eutaw Forest	Sydnor Hydrodynamics, Inc.	1980	180	840	12, 6, 4	4	799-822	Lppsc	208	402	2-28-80	91	24	.5
CH Bd 46	CH-81-1714	Charles Co. DPF, Eutaw Forest	Sydnor Hydrodynamics, Inc.	1986	180	859	12, 6, 4	4	700-730 805-820	Lppsc	233	288	6-26-86	90	--	1.6
CH Bd 47	CH-88-0124	Charles Co. DPF, Laurel Branch	Sydnor Hydrodynamics, Inc.	1989	160	900	8, 6	6	734-779 843-858	Lppsc	305	377	1-5-89	140	8.5	1.9
CH Bd 48	CH-88-0765	Charles Co. DPF, Laurel Branch	Sydnor Hydrodynamics, Inc.	1990	130	843	8, 6	6	648-688 747-762 805-815	Lppsc	243	290	5-30-90	200	24	4.2
CH Bd 49	CH-93-0385	Charles Co. DPF, Dutton's Addition	Sydnor Hydrodynamics, Inc.	1994	183	1054	16, 8, 6	6	820-860 995-1040	Lppsc	280	370	10-21-94	223	32	2.5
CH Bd 50	CH-88-2044	Charles Co. DPF, Bryans Road, Well 4	Sydnor Hydrodynamics, Inc.	1991	180	724	16, 8, 6	6	591-606 618-638	Lppsc	263	414	12-31-91	280	24	1.8
CH Bd 51	CH-94-0037	Charles Co. DPF, Settle Woods	Sydnor Hydrodynamics, Inc.	1995	185	1057	8, 6	6	897-912 934-944 972-987 1010-1035	Lppsc	281	346	3-25-95	275	24	4.2
CH Bd 52	CH-94-0899	Maryland Geological Survey, Route 227	A.C. Schultes of Maryland	1996	47.50	1328	4	4	1043-1053 1085-1095	Uptxn	48	99	10-1-96	60	12	1.2
CH Be 57	CH-81-1194	Charles Co. DPF, Smallwood West	Layne-Atlantic Co.	1985	210	1806	6, 4	4	1666-1696	Uptxn	200	286	6-12-85	36	--	.4
CH Be 58	--	Charles Co. DPF, Smallwood West	Layne-Atlantic Co.	1985	210	1170	16, 8	8	925-964 1048-1160	Lppsc	237	350	8-29-85	550	24	4.9
CH Be 64	CH-88-0341	Charles Co. DPF, Billingsley Rd.	Sydnor Hydrodynamics, Inc.	1989	210	1201	24, 18, 8	8	895-900 915-925 948-958 1077-1102 1118-1163	Lppsc	298	473	5-15-89	550	36	3.1

Well number	State permit number	Owner or location	Driller	Com-ple-tion year	Altitude of land surface (ft)	Total depth drilled (ft)	Diameter (in.)		Screen position (ft below land surface)	Aquifer	Water level (ft below land surface)		Date measured (m-d-y)	Yield (gal/min) (date)	Hours pumped	Specific capacity (gal/min/ft)
							Casing	Screen			Static (date)	Pumping				
CH Be 66	CH-94-1043	Charles Co. DPF, Brookwood	A.C. Schultes of Maryland	1996	215	1233	8, 6	6	951-965 995-1003 1022-1078 1101-1109 1135-1153	Lppsc	337	385	12-12-96	325	24	6.8
CH Be 67	CH-94-0464	Charles Co. DPF, Cleveland Park	A.C. Schultes of Maryland	1996	190	1422	16, 8	8	970-975 985-990 1014-1022 1033-1043 1072-1084 1102-1120 1148-1158 1166-1202 1218-1238 1260-1276 1286-1298 1346-1358 1372-1400	Lppsc	318	436	2-1-96	600	24	5
CH Bf 146	CH-81-0593	Charles Co. DPF, St. Paul	Sydnor Hydrodynamics, Inc.	1983	193	1654	6	6	1059-1069 1073-1083 1161-1166 1170-1180 1184-1189 1195-1205 1244-1249 1252-1262 1298-1328 1342-1417	Lppsc	200	249	12-23-83	165	8	3.4
CH Bf 147	CH-81-0738	Charles Co. DPF, St. Paul	Sydnor Hydrodynamics, Inc.	1984	195	1440	20, 12	12	1059-1069 1073-1083 1161-1166 1170-1180 1184-1189 1195-1205 1244-1249 1252-1262 1298-1328 1342-1417	Lppsc	207	317	2-29-84	510	24	4.6

Appendix A. Selected well records--Continued

Well number	State permit number	Owner or location	Driller	Com-ple-tion year	Altitude of land surface (ft)	Total depth drilled (ft)	Diameter (in.) Casing	Diameter (in.) Screen	Screen position (ft below land surface)	Aquifer	Water level (ft below land surface) Static (date)	Water level (ft below land surface) Pumping	Date measured (m-d-y)	Yield (gal/min) (date)	Hours pumped	Specific capacity (gal/min/ft)
CH Bf 150	CH-81-1195	Charles Co. DPF, White Oak Drive	Sydnor Hydrodynamics, Inc.	1985	215	1347	24, 16, 8	8	797-800 890-898 938-970 1154-1176 1204-1240 1276-1285 1306-1336	Lppsc	228	313	7-24-85	554	72	6.5
CH Cb 7	CH-01-1908	US Navy, Well 19	Washington Pump and Well Co.	1952	36	400	8	7.5	144-167	Lppsc	67 86	140 159	3-3-52 --	200 200	24 24	2.7 2.7
CH Cb 11	--	US Navy, Well 43SN	Washington Pump and Well Co.	1945	5	454	--	--	--	Lppsc	30	157	1945	80 (1953)	--	--
CH Cb 18	CH-01-5753	US Navy, Well 17	Shannahan Artesian Well Co.	1954	30	452	16, 10	8	261-295	Lppsc	77 125	210 221	4-20-54 10- -60	350 332	12 --	2.6 3.5
CH Cb 19	CH-01-3185	US Navy, Well 18	Shannahan Artesian Well Co.	1954	32	605	16, 10, 8	8	208-220 274-302	Lppsc	95 100	187 175	5-15-54 10- -60	363 300	24 --	3.9 4
CH Cb 28	CH-04-1102	US Navy, Well 2012SN	Layne-Atlantic Co.	1961	5	331	24, 10	10	190-200 230-240 280-290	Lppsc	65	200	1-17-61	275	40	2.0
CH Cb 29	--	US Navy, Well 24A or A	Sydnor Pump & Well Co.	1957	12.4	350	16, 10	10	228-239 269-286	Lppsc	100	--	1957	383	--	--
CH Cb 35	CH-81-0572	US Navy, Well 16A	East Coast Well and Pump	1984	25	503	6, 4	4	433-461 467-486	Uptxn	84	255	12-6-84	226	24	1.3
CH Cb 38	--	U.S. Navy, Rum Point	Calvert Well Drilling	1978	4	235	4	2	220-235	Lppsc	18	100	5-30-78	20	5	.2
CH Cb 39	CH-73-2804	Sweden Point Marina, General Smallwood State Park	Shannahan Artesian Well Co.	1980	10	426	6, 4	4	301-311 373-383	Lppsc	79	166	12-17-80	32	24	0.4

Appendix A. Selected well records--Continued

Well number	State permit number	Owner or location	Driller	Com-ple-tion year	Altitude of land surface (ft)	Total depth drilled (ft)	Diameter (in.)		Screen position (ft below land surface)	Aquifer	Water level (ft below land surface)		Date measured (m-d-y)	Yield (gal/min) (date)	Hours pumped	Specific capacity (gal/min/ft)
							Casing	Screen			Static (date)	Pumping				
CH Cb 43	CH-92-0116	U.S. Navy, Well 15R	A.C. Schultes of Delaware	1992	24	310	26, 10	10	190-202 228-240 252-282	Lppsc	76	177	7-31-92	217	24	2.1
CH Cc 19	CH-03-9279	Red Hill Estates	R. Leatherbury	1960	140	216	2, 1.25	1.25	205-216	Lppsc	55	75	6-17-60	4	4	.2
CH Cc 20	CH-04-1715	Red Hill Estates	Suburban Pump & Well Co.	1961	130	348	6	4	343-348	Lppsc	134	158	7-7-61	22	12	.9
CH Cc 25	CH-68-0044	Du-Mar Estates Water Co., Inc.	Shannahan Artesian Well Co.	1968	75	406	6, 4	4	391-406	Lppsc	120	143	4-30-68	20	8	.9
CH Cc 28	CH-05-6912	Red Hill Estates	Willard Ward	1964	130	353	4	4	343-353	Lppsc	96	104	7-24-64	25	8	3.1
CH Cc 30	CH-69-0058	Lackey High School	Layne-Atlantic Co.	1969	95	494	8	8	273-278 314-329	Lppsc	129	220	3-17-69	76	8	.8
CH Cc 31	CH-73-1416	Dravo Corporation	Sydnor Hydrodynamics, Inc.	1977	35	563	6, 4	4	438-453 480-505 544-554	Lppsc	75	185	4-26-77	125	24	1.1
CH Cc 32	CH-73-0898	Red Hill Estates	Shannahan Artesian Well Co.	1976	135	375	4, 2	3	343-353	Lppsc	142	182	3-17-76	10	8	.2
CH Cc 34	CH-94-0898	Maryland Geological Survey, Mattawoman Waste-Water Treatment Plant	A.C. Schultes of Maryland	1996	41.82	1170	4	4	874-884 945-955	Uptxn	48.58 51	190.17 192	7-19-96 7-25-96	50 50	12 12	0.4 .3
CH Cd 24	CH-03-3114	US Navy	Sydnor Pump & Well Co.	1955	175	1003	6, 4.5	5.5	885-900 960-970	Lppsc	178	345	3-3-55	65	48	.4
CH Cd 30	CH-68-0042	Utilco, Inc., Pomfret Estates	Sydnor Pump & Well Co.	1968	193	1346	12, 6, 4	4	936-946 1085-1100 1108-1118 1310-1330	Lppsc	175	282	6-28-68	68	12	.6

Appendix A. Selected well records--Continued

Well number	State permit number	Owner or location	Driller	Completion year	Altitude of land surface (ft)	Total depth drilled (ft)	Diameter (in.)		Screen position (ft below land surface)	Aquifer	Water level (ft below land surface)		Date measured (m-d-y)	Yield (gal/min) (date)	Hours pumped	Specific capacity (gal/min/ft)
							Casing	Screen			Static (date)	Pumping				
CH Cd 33	CH-69-0105	Charles Co. Vocational Tech Center	Shannahan Artesian Well Co.	1969	190	917	4, 2	2	390-395 415-420 449-454 472-482 501-511	Lppsc	149	303	9-9-69	5	36	.03
CH Cd 42	CH-92-0025	Preswicke Hills Subdivision	Calvert Well Drilling Co.	1992	185	1020	4.5, 2	2	930-945	Lppsc	250	400	3-19-92	20	6	.1
CH Ce 8	CH-00-1398	Town of La Plata	Sydnor Pump and Well Co.	1947	149.4 m	1094	10, 8, 6	8	1040-1075	Lppsc	135	420	11-19-47	100	24	.4
CH Ce 35	CH-65-0013	Town of La Plata, Well 6	Sydnor Pump and Well Co.	1964	165	1252	10, 6	6	1058-1114	Lppsc	165	430	1-29-65	240	--	.9
CH Ce 37	CH-73-0219	U.S. Geological Survey	Sydnor Hydrodynamics, Inc.	1973	185	2014	16, 6, 4	4	1174-1184 1250-1260 1330-1340	Lppsc	187	217	11-12-73	120	24	4.0
CH Ce 42	CH-73-0575	Charles Co. DPF, Ellenwood Estates	Patuxent Pump & Well	1974	165	1090	6, 4	5	1030-1055 1070-1080	Lppsc	152	239	11-21-74	90	8	1.0
CH Ce 43	CH-73-0764	Town of La Plata, Well 8	A.C. Schultes, Inc.	1975	185	1345	12, 6	6	1113-1116 1131-1146 1165-1188 1233-1250 1305-1342	Lppsc	190	266	7-11-75	513	24	6.8
CH Ce 51	CH-81-0828	Town of La Plata, Well 9	Layne-Atlantic Co.	1984	150	1509	12	12	1250-1340	Lppsc	185	375	11-2-84	450	--	2.4
CH Ce 55	CH-94-1110	Town of La Plata, Well 10, Heritage Green	Sydnor Hydrodynamics, Inc.	1997	190	1304	18, 8	8	870-880 893-908 945-950 956-961 980-1000 1030-1035 1057-1062 1090-1130 1172-1192 1204-1219 1238-1263	Lppsc	28.8	344	6-27-97	576	48	10.2

Appendix A. Selected well records--Continued

Well number	State permit number	Owner or location	Driller	Com-ple-tion year	Altitude of land surface (ft)	Total depth drilled (ft)	Diameter (in.)		Screen position (ft below land surface)	Aquifer	Water level (ft below land surface)		Date measured (m-d-y)	Yield (gal/min) (date)	Hours pumped	Specific capacity (gal/min/ft)
							Casing	Screen			Static (date)	Pumping				
CH Ce 56	CH-94-1111	Town of La Plata, Observation well, Heritage Green	Sydnor Hydrodynamics, Inc.	1997	196	1307	14, 6, 4	4	896-906 945-950 957-962 993-1008 1024-1029 1037-1042 1094-1134 1166-1186 1204-1214 1248-1258	Lppsc	287	--	3-24-97	100	4	--
CH Ce 57	CH-94-1112	Town of La Plata, Observation well, Heritage Green	Sydnor Hydrodynamics, Inc.	1997	193.47	1871	6, 4	4	1406-1421 1500-1515 1668-1698	Uptxn	200	371	2-20-97	40	48	.2
CH Ce 58	CH-88-0856	Charles Co. DPF, Carmel Estates	Delmarva Drilling Co.	1989	184	1316	6	6	1225-1278	Lppsc	243	373	11-28-89	60	24	0.5
CH Ce 59	CH-92-0969	Turkey Hill Water Co.	Sydnor Hydrodynamics, Inc.	1994	198	988	6	6	585-595 640-650 672-677 805-840	Lppsc	266	438	6-15-94	40	48	.2
CH Da 18	CH-73-0586	PEPCO, Douglas Point Observation well	A.C. Schultes Co.	1975	90	772	8	8	684-694 730-740	Uptxn	81	--	--	--	--	--
CH Da 19	CH-73-0585	PEPCO, Douglas Point	A.C. Schultes Co.	1974	90	535	6	6	414-424 441-456 482-492 520-535	Lppsc	90	163	11-4-74	240	72	3.3
CH Da 20	CH-73-0590	PEPCO, Douglas Point Observation well	A.C. Schultes Co.	1974	90	522	6	6	420-425 444-449 481-486 517-522	Lppsc	68	--	--	--	--	--
CH De 39	CH-73-1803	Offutt Farm Assoc., Chapel Point	Shannahan Artesian Well Co.	1978	175	766	4, 2	3	703-713 739-744	Lppsc	172	208	7-21-78	10	3	.3

Appendix A. Selected well records--Continued

Well number	State permit number	Owner or location	Driller	Completion year	Altitude of land surface (ft)	Total depth drilled (ft)	Diameter (in.)		Screen position (ft below land surface)	Aquifer	Water level (ft below land surface)		Date measured (m-d-y)	Yield (gal/min) (date)	Hours pumped	Specific capacity (gal/min/ft)
							Casing	Screen			Static (date)	Pumping				
CH De 40	CH-73-1804	Offutt Farm Assoc., Chapel Point	Shannahan Artesian Well Co.	1978	170	762	6, 4	4	450-468 503-511 542-547 602-611 712-720	Lppsc	164	415	8-22-78	10	2	.04
CH De 41	CH-73-2073	Offutt Farm Assoc., Chapel Point	Shannahan Artesian Well Co.	1978	175	901	6, 4	4	673-681 695-720 738-745 790-797 826-832	Lppsc	162	218	9-3-78	41	12	0.7
CH Ee 68	CH-67-0080	PEPCO, Morgantown	Shannahan Artesian Well Co.	1967	22	1152	4, 2	2	1079-1099	Lppsc	10	28	6-20-67	30	24	1.7
CH Ee 69	CH-69-0089	PEPCO, Morgantown	Shannahan Artesian Well Co.	1970	22	1152	10, 8	6	1073-1104	Lppsc	22	184	1-16-70	372	24	2.3
CH Ee 70	CH-67-0081	PEPCO, Morgantown Plant	Shannahan Artesian Well Co.	1967	22.83	1132	2	2	1090-1100 1105-1115	Lppsc	10	21	7-15-67	25	24	2.3
CH Ee 71	CH-69-0090	PEPCO, Morgantown Plant	Shannahan Artesian Well Co.	1970	22	1113	10, 8	8	1072-1108	Lppsc	29	162	5-20-70	358	24	2.7
CH Ee 72	CH-69-0087	PEPCO, Morgantown	Shannahan Artesian Well Co.	1970	22	1117	10, 8	8	1081-1117	Lppsc	44	280	6-17-70	254	24	1.1
CH Ee 78	CH-73-1965	Charles Co. DPF, Clifton-on-the-Potomac	Leazer Pump & Well Co.	1979	70	1220	7	7	1148-1168 1189-1199	Lppsc	126	240	10-31-79	117	24	1.0
CH Ee 91	CH-81-0761	Charles Co. DPF, St. Anne's well at Clifton-on-the-Potomac	Layne-Atlantic Co.	1984	68	1214	12, 6	6	1000-1010 1033-1066 1084-1096	Lppsc	103	295	1-25-84	317	24	1.7
CH Ff 60	CH-81-0762	Swan Point	Layne-Atlantic Co.	1984	12	1100	10, 6	6	808-830 920-982	Lppsc	24	80	3-30-84	506	24	9.0

Appendix A. Selected well records--Continued

Well number	State permit number	Owner or location	Driller	Com-ple-tion year	Altitude of land surface (ft)	Total depth drilled (ft)	Diameter (in.)		Screen position (ft below land surface)	Aquifer	Water level (ft below land surface)		Date measured (m-d-y)	Yield (gal/min) (date)	Hours pumped	Specific capacity (gal/min/ft)
							Casing	Screen			Static (date)	Pumping				
CH Ff 62	CH-81-1970	Swan Point	Sydnor Hydrodynamics, Inc.	1986	12	1010	18, 10, 6	6	698-723 798-808 819-824 838-848 856-866 873-878 914-944 954-959 965-980	Lppsc	27	93	11-20-86	525	24	8.0
PG Eb 1	--	WSSC, Forest Heights, Well 1	Layne-Atlantic Co.	1945	20	603	18, 10, 8	8	357-377 568-588	Uptxn & Lptxn	100	340	12-18-45	439	48	1.8
PG Eb 2	PG-00-0339	WSSC, Forest Heights Well 2	Layne-Atlantic Co.	1946	22	630	20, 10, 8	10, 8	277-282 347-352 521-526 550-560 600-605	Uptxn & Lptxn	102	224	9-10-46	540	24	4.4
PG Eb 20	PG-02-5527	WSSC, Fort Foote Village	Layne-Atlantic Co.	1956	151	828	6	6	192-212 352-372 557-577	Lppsc	135 153 110	190 -- 320?	10-3-56 10-11-56 10-24-56	50 300 230	2 2 2	.9 -- 1.1
PG Eb 22	PG-01-0418	Potomac Vista Corp.	Columbia Pump & Well Co.	1952	100	275	6	6	275-285	Lppsc	110	200	7-25-52	34	8	.4
PG Eb 23	PG-02-0466	Potomac Vista Corp.	Layne-Atlantic Co.	1955	115	331	6	6	295-300 315-320	Lppsc	124	200	9-8-55	150	5	2.0
PG Ec 41	PG-03-8527	WSSC, Southlawn	Layne-Atlantic Co.	1960	179	875	6	6	241-261 630-650	Lppsc, Ptxn, & Uptxn	150 147	225 200	6-24-60 6-24-60	320 275	6 6	4.3 5.2
PG Ec 46	PG-03-9072	WSSC, (Kerby Hill Pumping Station)	Layne-Atlantic Co.	1960	71	804	6	6	577-597	Uptxn	46	210	9-22-60	285	8	1.7
PG Ed 34	PG-01-0424	Morningside Village Water Co.	Washington Pump and Well Co.	1952	270	793	8	--	773-793	Lppsc	236	315	11-5-52	135	12	1.7
PG Fb 13	--	Ft. Washington	Sydnor Pump & Well Co.	1942	176	654	14, 10, 8	8	575-618	Lppsc	155	287	11-28-42	342	49	2.6

Appendix A. Selected well records--Continued

Well number	State permit number	Owner or location	Driller	Com-ple-tion year	Altitude of land surface (ft)	Total depth drilled (ft)	Diameter (in.)		Screen position (ft below land surface)	Aquifer	Water level (ft below land surface)		Date measured (m-d-y)	Yield (gal/min) (date)	Hours pumped	Specific capacity (gal/min/ft)
							Casing	Screen			Static (date)	Pumping				
PG Fc 17	PG-12	Washington Gas Light Co., Thorne No. 2	Eakle & Holder Drilling Co.	1955	59	1728	6	--	712-716	Lppsc	28.62	--	10-27-55	--	--	--
PG Fc 31	PG-48904	Henry G. Ferguson Elem. School	Columbia Pump & Well Co. and Douglas & Dickinson, Inc.	1962	104	710	8	8, 2	677-681 689-699	Lppsc	97	120	10-12-62	120	12	5.2
PG Fd 59	PG-00-0004	Washington Gas Light Co. Moore No. 2	Eakle & Holder Drilling Co.	1955	172	1517	--	--	--	Uptxn?	--	--	12- -55	60	--	--
PG Fd 62	PG-10	Washington Gas Light Co., Robinson No. 2	Eakle & Holder Drilling Co.	1956	230	1812	--	--	1545-1580	Uptxn?	184	--	8-15-56	--	--	--
PG Hf 31	PG-73-0065	PEPCO, Chalk Point	Shannahan Artesian Well Co.	1973	10.02	2453	6, 4	4	1007-1034 1516-1541	Lppsc	6 above land surface	25	7-7-73	93	24	3.0
PG Hf 32	PG-73-0065	PEPCO, Chalk Point	Shannahan Artesian Well Co.	1973	10	1545	3, 2.5, 2	3	1025-1030 1525-1530	Lppsc	4 above land surface	45	5-30-73	15	4	.3
SM Df 84	SM-81-0119	Maryland Geological Survey Test well	A.C. Schultes & Sons, Inc.	1983	108.4	2679	6, 4	4	829-854 860-865 895-910	Uppsc[1]	115.7	161.4	1-4-83	193	24	4.2

[1]Screened interval called Mattaponi(?) aquifer in Hansen and Wilson (1984)

Appendix B. Descriptive log of washed drill cuttings from test holes drilled during this study.

CH Bc 80 CHAPMAN'S LANDING TEST SITE

Altitude of land surface = 123 feet

Depth, feet below land surface	Description
MINOR AQUIFERS AND CONFINING BEDS OF TERTIARY AGE (Undifferentiated)	
0-10	Sand, fine, brown, iron-stained quartz
10-60	Gravel, quartzose, subangular with fine-grained brown sand
60-70	Missed sample
70-100	Clay, silty, dark greenish-gray, with some weathered shell fragments
100-110	Clay, as above with increased weathered shell content
110-140	Clay, silty, light greenish-gray, glauconitic with some white silt
140-150	Clay, olive brown, slightly glauconitic; driller logged multi-colored clay from 143 feet -153 feet
UPPER PATAPSCO AQUIFER AND CONFINING BEDS	
150-160	Clay, white
160-190	Sand, very fine, clayey, reddish-brown
190-200	Sand, fine, tan, with some medium-grained, purple quartz
200-210	Sand, very fine, quartzose, light tan; driller logged very hard, red clay from 202 feet to 213 feet
205	Bit sample: Clay, dense, reddish-brown with thin, light gray laminations
210-220	Clay, silty, beige with some occasional medium-grained sand
220-240	Clay, silty, light reddish-brown
240-250	Missed sample
250-290	Clay, dense, red, white, yellow and gray
290-300	Clay, silty, yellowish-brown with some red and white clay
300-310	Sand, very fine to fine, silty, light brown
310-320	Sand, medium, light gray, clear and purple quartz grains
320-330	Clay, silty, light brown and gray
330-340	Sand, fine, clayey, light tan
340-360	Missed sample
360-370	Clay, silty, light tan
LOWER PATAPSCO AQUIFER	
370-380	Clay, white
380-390	Sand, fine, light gray
390-400	Clay, silty, light gray and tan
400-410	Sand, fine, light tan
410-420	Sand, fine to silty, light tan
420-430	Clay, gray with some silty sand
430-500	Clay, light green with some silty sand
500-510	Sand, fine to medium, gray
510-520	Clay, gray with some silty sand
520-530	Clay, light green and red
530-540	Sand, fine to very coarse, subangular, light tan
540-550	Missed sample
550-560	Sand, medium to coarse, light gray, purple and pink quartz
560	Bit sample: Clay, dense, gray and reddish-brown
560-590	Clay, gray
590-600	Clay, dense, red and white
600-610	Clay, dense, red, green and brown
610-620	Clay, red and green with fine, silty sand
620-640	Sand, medium, light gray, clear and purple quartz
640-650	Clay, olive gray, with some fine sand
650-660	Missed sample
660-670	Sand, fine, light gray with occasional coarse grains
670-690	Sand, fine to coarse, poorly sorted, light gray

CH Bc 80 CHAPMAN'S LANDING TEST SITE--CONTINUED

Depth, feet below land surface	Description
ARUNDEL CLAY	
690-825	Clay, red, light green and gray; difficult drilling from 790 feet to 810 feet
UPPER PATUXENT AQUIFER	
825-830	Sand, fine, reddish brown, silty
830-840	Sand, medium, light gray, clear and purple quartz
840-860	Sand, fine, light gray
860-870	Sand, medium, light gray
880-890	Sand, medium, light tan
890-920	Missed sample
CONFINING BED	
Note: Drill cuttings returns from 920 to 1,000 feet were sandy; however, geophysical logs indicate clay Driller's description from 920-1,000:	
920-930	Sand with layers of clay
930-938	Hard clay
938-948	Soft green clay with sand
948-988	Medium to coarse sand with green clay
988-1,000	Medium and hard green clay
1,000-1,040	Clay, gray and reddish-brown
LOWER PATUXENT AQUIFER	
1,040-1,050	Sand, fine, light gray with some gray and reddish-brown clay
1,050-1,060	Clay, brown with some silty sand
1,060-1,070	Sand, very fine, light gray, with red, reddish-brown and gray clay
1,070-1,080	Clay, gray, with some silty sand
1,080-1,090	Sand, very fine, light green with green clayey matrix
1,090-1,100	Sand, fine to medium, light gray with occasional coarse grains; driller logged rock from 1,095 feet to 1,096 feet
1,100-1,110	Sand, medium to coarse, light tan, composed predominantly of clear quartz
1,110-1,115	Sand with thin clay layers (driller's description)
1,115-1,137	Clay and layers of sand (driller's description)
1,137-1,138	Hard layer (driller's description)
1,138-1,140	Clay, "gummy" (driller's description)
BASEMENT ROCK	
1,140-1,142	Bed rock (driller's description)

Thin Section Analysis of Basement Cuttings from Well CH Bc 75 Located 56 feet from CH Bc 80

(Jonathan Edwards, written commun.)

Altitude = 123 feet above sea level

Depth Interval: 1,142 to 1,165 feet

Coarse-grained chips in the basement sample:

Microcline-quartz granite to granite gneiss

Biotite	Trace
Muscovite	1-2%
Microcline	10-20%
Quartz	78-88%

Grades in composition up to a sheared sillimanite- and microcline-bearing quartzite

Sillimanite	Trace
Microcline	1-2%
Quartz	98%

Fine-grained chips in the basement sample:

Fine-grained, garnetiferous, muscovite-biotite-plagioclase-quartz gneiss

Garnet	2%	(Corroded porphyroblasts up to 1 mm in size)
Muscovite	1-2%	(Occurs in amounts ranging from as little as a trace up to 10% in some chips)
Biotite	2-5%	
Microcline	Trace up to 5-10%	
Plagioclase	30-35%	
Quartz	50%	

CH Bd 52 RTE. 227 TEST SITE

Altitude of land surface = 48 feet

Depth, feet below land surface	Description
MINOR AQUIFERS AND CONFINING BEDS OF TERTIARY AGE (Undifferentiated)	
0-20	Clay, orange and gray interbedded with quartz sand and gravel
20-30	Silt, greenish-gray with small weathered shell fragments; drilled logged pink clay
30-40	Silt, greenish-gray, slightly micaceous with large shell fragments constituting more than 50 percent of sample
AQUIA AQUIFER	
40-50	Silty sand, orange and light green
60-70	Silt, dark green, slightly micaceous with some small weathered shell fragments
70-80	As above
80-90	Silt, light green with abundant small weathered shell fragments
90-100	As above
100-110	Clay, silty, orange and light green
110-120	As above
120-130	Silt, sandy, dark green, glauconitic, with small weathered shell fragments
BRIGHTSEAT(?) CONFINING BED	
130-140	Clay, silty, dark green, slightly micaceous with occasional small weathered shell fragments
140-150	Clay, slightly silty, dark green, slightly micaceous
UPPER PATAPSCO AQUIFER AND CONFINING BEDS	
150-160	Silt, sandy, orange and light green
160-170	Clay, silty, green with occasional, small iron concretions
170-180	Sand, silty, tan with occasional glauconite or goethite grains
180-190	Silt, sandy, orange and light green
190-200	Sand, fine, reddish-brown, composed of quartz and limonite
200-210	Sand, fine, reddish-brown, quartzose with occasional pink and purple quartz grains
210-220	Sand, fine to medium, tan with occasional small pods of limonite
220-230	Sand, silty, drab tan with occasional coarse clean pink and purple quartz grains; driller logged hard brown and gray clay
230-240	Missed sample; driller logged white and gray clay with layers of sand
240-250	Sand, silty; drab tan with some lignite and small pods of yellow silt
250-260	Clay, silty, light brown, with small pods of white and yellow clay
260-270	Silt, clayey, drab tan, with small pods of gray and yellowish-orange silt or clay and lignite
270-280	Sand, fine to silty, quartzose with some pink and purple fine sand grains and black silt
280-290	Silt, orange to tan with occasional pods of limonite
290-300	Silt, yellowish-tan, with small pods of white clay
300-310	Sand, very fine, light tan
310-320	Sand, very fine, light tan, with silt-size limonite
320-330	Sand, medium, light tan, clear, pink and purple quartz grains
330-340	Sand, medium, light tan, abundant purple quartz grains
340-350	Sand, fine to medium, light tan
350-360	Clay, silty, light brown with small pods of white and yellow silty clay

Appendix B. Descriptive log of washed drill cuttings from test holes drilled during this study--Continued

CH Bd 52 RTE. 227 TEST SITE--CONTINUED

Depth, feet below land surface	Description
360-370	As above, with the addition of some red clay
370-390	As above; driller logged hard layers
390-400	Clay, silty, tan with significant amounts of white, yellow and red clay
400-410	Sand, medium to coarse, light gray
410-420	Sand, medium to very coarse, light gray
420-430	Missing sample
430-440	Sand, medium to very coarse, clear, pink and purple, subangular quartz grains
440-450	As above, with predominantly clear and purple quartz grains
450-460	Sand, fine to coarse, light gray with silty matrix
460-470	Clay, silty, brown
470-480	Sand, fine to medium, light tan
480-490	Clay, silty, light brown with small pods of reddish-orange, white and yellow clay and occasional medium to coarse quartz grains
490-500	As above
500-510	Sand, fine to very coarse, light brown, silty clay matrix with small pods of reddish-orange clay
510-520	As above; driller logged hard multi-colored clay
520-530	Sand as in interval 500-510
530-540	As above
540-550	Clay, silty, light tan with small pods of light green silty clay
550-560	Clay, silty, light brown with small pods of reddish-orange and dark green silty clay
560-570	Clay, light brown and white
570-580	As above
580-590	Clay, white and red
590-600	As above
600-610	Clay, silty, white, red, brown and gray
610-620	Clay, white, red, and yellow; driller logged hard clay
620-630	Clay, light green; driller logged hard layers
LOWER PATAPSCO AQUIFER	
630-640	Silt, light brown
640-650	Silt, light brown with small pods of dark gray and white clay
650-660	As above
660-670	Sand, silty, light brown
670-680	Sand, fine to medium, clear and purple quartz grains
680-690	Missing sample
690-700	Clay, brown, light green and red
700-710	Clay, brown and light green
710-720	Sand, silty, light brown with light green and reddish-brown clay
720-730	Clay, silty, light brown
730-740	Sand, fine, light brown
740-750	Clay, light brown and light green; driller logged hard brown clay
750-770	As above
770-780	Clay, light green and reddish-brown; driller logged hard sandy clay
780-790	Sand, fine, light gray
790-800	Clay, silty, reddish-brown
800-810	Sand, fine to medium, light gray, white and purple quartz grains with occasional coarse sand; driller logged hard brown and gray clay
810-820	Missing sample
820-830	Sand, medium to coarse, light gray, white and purple quartz grains
830-840	Sand, as above, without coarse grains

CH Bd 52 RTE. 227 TEST SITE--CONTINUED

Depth, feet below land surface	Description
840-850	Sand, very fine to medium, light gray, white and purple quartz grains
850-860	Sand, fine, light tan
860-870	Sand, silty to fine, light tan with occasional medium sand
870-880	Sand, silty to coarse, poorly sorted, reddish-brown with some small pods of reddish-brown clay
880-890	Sand, silty to coarse, light gray
890-900	Sand, fine, light gray
ARUNDEL CLAY	
900-910	Sand, fine, light gray with small pods of gray clay
910-920	Clay, silty, light green and brown; driller logged hard multi-colored clay
920-930	Clay, light brown; driller logged hard clay
930-940	Clay, light green, light brown, white and reddish-brown; driller logged hard brown clay
940-950	Clay, light brown, white, reddish-brown with occasional very coarse quartz grains; driller logged hard brown clay
950-960	Clay, green, white and reddish-brown
960-970	Clay, as in interval 940-950
970-980	Clay, silty, reddish-brown
980-990	Sand, medium, light gray, well sorted
990-1,000	Sand, fine, light gray
1,000-1,010	Sand, silty to very coarse, dark gray, poorly sorted; driller logged hard red clay
1,010-1,020	Sand, silty, reddish-brown; driller logged hard red clay with layers of sand
UPPER PATUXENT AQUIFER	
1,020-1,040	Clay, silty, reddish-brown, light green and white
1,040-1,050	Sand, silty and clayey, light brown, light green clay
1,050-1,060	Silt, reddish-brown, with small pods of light green clay
1,060-1,070	Sand, fine to medium, light gray and purple quartz grains
1,070-1,080	Clay, silty, light brown and green
1,080-1,090	Missing sample
1,090-1,100	Sand, silty to very fine, light brown with some light green clay
1,100-1,120	Missing sample
1,120-1,130	Clay, silty, reddish-brown with minor amounts of fine sand; driller logged very hard brown clay
1,130-1,140	Missing sample
1,140-1,150	Clay, silty, reddish-brown and light green
1,150-1,160	Missing sample
1,160-1,170	Silt, reddish-brown
1,170-1,180	Sand, fine to medium, light gray and purple quartz grains; driller logged layers of rock
1,180-1,190	Clay, silty, white, light gray and brown
CONFINING BED	
1,190-1,210	As above
1,210-1,220	Clay, silty, light brown with minor amounts of fine sand
1,220-1,240	Clay, light brown and red
LOWER PATUXENT AQUIFER	
1,240-1,250	Sand, fine, tan with small pods of red clay or limonite
1,250-1,260	Sand, silty and clayey, light brown and green; driller logged very gray and red clay

CH Bd 52 RTE. 227 TEST SITE--CONTINUED

Depth, feet below land surface	Description
1,260-1,280	Clay, silty, light green and brown
1,280-1,290	Clay, silty and sandy, light green and brown
1,290-1,300	Clay, silty, light brown and green with minor amounts of medium quartz sand; driller logged rock from 1,301 feet to 1,318 feet and hard rock from 1,318 feet to 1,323 feet
1311	Bit sample: Clay, dense, dark greenish-gray with silty light green clay
BASEMENT ROCK	
1,323-1,328	Fine-grained, biotite-plagioclase-quartz gneiss chips resembling the basement rock described in well CH Cc 34 (Jonathan Edwards, Jr., written commun., 1996)

CH Cc 34 MATTAWOMAN WASTE-WATER TREATMENT PLANT

Altitude of land surface = 42 feet

Depth, feet below land surface	Description
MINOR AQUIFERS AND CONFINING BEDS OF TERTIARY AGE (Undifferentiated)	
0-10	Clay, pale yellow and white
10-20	Gravel, pale yellow, angular to subangular
20-30	Clay, light green and pale yellow with some angular gravel
30-40	Clay, silty, dark greenish-gray, glauconitic
40-50	Sand, fine to very coarse, angular, dark greenish-gray clayey matrix, with minor amounts of weathered shell; difficult drilling
50-60	Shell hash, weathered dark greenish-gray, clayey matrix
AQUIA AQUIFER	
60-70	As above
70-90	Shell hash, weathered, dark green glauconitic silt matrix
90-100	Sand, silty to very fine, dark green, composed of equal amounts of dark green glauconite and clear quartz with some weathered shell fragments
BRIGHTSEAT FM(?) CONFINING BED	
100-110	Silt, dark green with some weathered shell
UPPER PATAPSCO AQUIFER AND CONFINING BEDS	
110-120	Missed sample
120-130	Sand, fine to medium, tan, clear, pink and purple quartz grains
130-140	Sand, medium, light gray, clear, white, pink and purple quartz grains
140-150	Sand, silty to very fine, re-circulated (?) glauconitic silt, and silt-size to fine-grained limonite
150-160	Clay, silty, light gray, with fine-grained particles of limonite
160-180	Clay, sandy, light gray
180-190	Sand, medium to coarse, light gray, clear, white and purple quartz grains
190-200	Clay, silty, drab gray
200-210	Clay, silty, drab gray and yellow
210-220	Sand, coarse, light gray and purple quartz
220-230	Clay, light gray and yellow, with fine-grained limonite
230-240	Missed sample
240-260	Clay, light gray
260-280	Clay, light to dark gray, yellow and red
280-320	Missed sample
320-330	Sand, fine, light gray
330-340	Missed sample
340-350	Clay, drab gray, red, and yellow
350-360	As above, with some medium sand
360-370	Clay, drab gray
370-380	Clay, as in interval 340-350
380-390	Clay, gray
390-400	Clay, gray, yellow, red
400-410	Clay, gray, white, and red, dense
410-450	Clay, gray and white
450-470	Clay, gray, red, yellow and white
LOWER PATAPSCO AQUIFER	
470-510	Clay, red, gray and white with some fine sand
510-520	Clay, white, with some medium to coarse sand
520-530	Clay, silty, white
530-540	Sand, fine to medium with white clay
540-550	Sand, fine to coarse, light brown
550-560	Sand, fine, light gray with some light gray clay
560-580	Clay, white and gray
580-590	Missed sample

Appendix B. Descriptive log of washed drill cuttings from test holes drilled during this study--Continued

CH Cc 34 MATTAWOMAN WASTE-WATER TREATMENT PLANT--CONTINUED

Depth, feet below land surface	Description
590-620	Clay, reddish-brown and light green
620-630	Sand, medium tan, well sorted
630-640	Sand, fine to medium, tan with some coarse grains
640-650	Sand, fine to coarse, light gray
650-660	Clay, light green and reddish-brown, with some medium to coarse sand
660-670	Sand, fine, tan
670-680	Missed sample
680-690	Sand, fine to medium, tan with some occasional coarse quartz grains
690-700	Missed sample
700-710	Clay, silty, reddish-brown and green
710-720	Sand, fine to medium, tan
720-730	Clay, light gray, red and white
730-740	Sand, fine to medium, gray
740-750	Sand, fine to medium, gray, with some small angular pebbles
750-760	Sand, medium to coarse, gray, with some clay
ARUNDEL CLAY	
760-810	Clay, brown and gray
810-820	Clay, brown and gray with some fine sand
UPPER PATUXENT AQUIFER	
820-830	Sand, fine with some brown, red, and gray clay
830-840	Clay, sandy, green and reddish-brown
840-860	Clay, sandy, light green
860-870	Clay, silty, light green and white
870-880	Sand, fine to medium, light gray
880-890	Clay, sandy, light green
890-900	Clay, dense, green
900-910	Clay, dense, white and light green, with some clayey white sand
910-920	Missed sample
920-930	Sand, fine to medium, tan, angular, with some reddish-brown clay
930-940	Clay, reddish-brown and green
940-950	Sand, fine, light gray, white and purple quartz grains
950-960	Sand, medium, white, iron-stained, and purple quartz grains
960-990	Sand, fine to medium, grain coloration as above
CONFINING BED	
990-1,000	Clay, reddish-brown and light green
1,000-1,020	Clay, as above with some fine-grained sand
1,020-1,030	Clay, light green and white
1,030-1,040	Clay, silty, light green and reddish-brown
LOWER PATUXENT AQUIFER	
1,040-1,050	Sand, coarse, well sorted, subangular, white, clear and purple quartz grains
1,050-1,060	Sand, fine to medium, white
1,060-1,080	Clay, silty, gray
1,080-1,090	Clay, silty, light gray and reddish brown
1,090-1,100	Sand, fine to coarse, light gray, subangular
1,100-1,110	Sand, fine to medium, clayey, light green
1,110-1,120	Sand, medium to coarse, clear quartz grains
BASEMENT ROCK	
1,120-1,130	Clay, light green; driller logged rock from 1,126 feet to 1,127 feet
1,130-1,170	Clay, white, micaceous, silty with angular quartz grains and green, crystalline material; drilled like rock between 1,150 feet and 1,154 feet; driller logged hard rock from 1,154 feet to 1,162 feet

CH Cc 34 MATTAWOMAN WASTE-WATER TREATMENT PLANT--CONTINUED

Depth, feet below land surface	Description
1,170	Fine-grained, biotite (20%)-plagioclase (30%)-quartz (50%) gneiss chips resembling the Oella Formation, a crystalline rock that outcrops in the Piedmont of Baltimore and Howard Counties (Jonathan Edwards, Jr., written commun., 1996)

Appendix C. Core descriptions and sieve analyses--Well CH Bc 80 (Chapman's Landing Test Site)

Core descriptions--Well CH Bc 80 (Chapman's Landing Test Site)
Altitude of land surface: 123 feet
Date collected: August 8, 1996
(ft = feet; in. = inches)

LOWER PATAPSCO AQUIFER

1.	Depth cored:	564 ft
	Length of core:	13 in.
	Description:	Clay; grayish green, mottled reddish brown; cohesive and tough

ARUNDEL CLAY

2.	Depth cored:	700 ft
	Length of core:	24 in.
	Description:	Clay; reddish brown with light gray mottling; includes thin sandy layers; cohesive and tough

UPPER PATUXENT AQUIFER

3.	Depth cored:	825 ft
	Length of core:	7 in.
	Description:	Sand, fine to coarse; gray; with thin, very clayey layers; more friable in lower portion
4.	Depth cored:	830 ft
	Length of core:	4 in.
	Description:	Sand, fine to coarse; light gray; slightly clayey; cohesive when wet
5.	Depth cored:	920 ft
	Length of core:	3 in.
	Description:	Sand, fine to coarse; light gray; friable

CONFINING BED BETWEEN THE UPPER AND LOWER PATUXENT AQUIFER

6(a).	Depth cored:	1,000 ft
	Length of core:	About 2 in.
	Description:	Clay, with scattered sand grains; light greenish gray, mottled reddish brown; cohesive and tough

Apprendix C. Core descriptions and sieve analyses--Well CH Bc 80 (Chapman's Landing Test Site)--Continued

CONFINING BED BETWEEN THE UPPER AND LOWER PATUXENT AQUIFER--CONTINUED

6(b). Depth cored: 1,000 ft (second attempt)
Length of core: 9 in. (4 in. may be contamination)
Description: Clay, with scattered sand grains; light greenish gray, mottled reddish; cohesive and tough

LOWER PATUXENT AQUIFER

7. Depth cored: 1,050 ft
Length of core: 16 in.
Description: Sand, fine to medium with silty and clayey matrix; light gray; cohesive

8. Depth cored: 1,115 ft
Length of core: 14 in.
Description: Sand with clayey matrix; light greenish gray; alternating cohesive and friable

Sieve Analyses--Well CH Bc 80 (Chapman's Landing Test Site)
(ft = feet; mm = millimeters)

		Pebbles and granules	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay
					WEIGHT PERCENTAGE				
Depth (ft)	Aquifer	>2mm	1-2 mm	0.5-1 mm	0.25-0.5 mm	0.125-0.25 mm	0.063-0.125 mm	0.0039-0.063 mm	<0.0039 mm
825	upper Patuxent*	0.00	0.63	9.44	18.67	8.57	10.31	26.99	25.39
1,050	lower Patuxent	0.00	0.00	1.88	54.30	18.41	6.06	9.75	9.60
1,115	lower Patuxent	8.10	17.97	32.24	13.98	5.17	3.05	9.75	9.75

* Representative of clayey portions of core

Appendix D (Part I). Appropriated ground-water use (1997) over 10,000 gallons per day in the lower Patapsco aquifer in the model area

[MGS = Maryland Geological Survey; USGS = U.S. Geological Survey; Mgal/d = million gallons per day; PEPCO = Potomac Electric Power Company]

Site number[1]	Well owner or name-Charles County	Ground-water appropriation permit number (GAP)	MGS/USGS well no.	Model cell (column, row, layer)	Average amount appropriated (Mgal/d)	Yearly average pumpage reported in 1997 (Mgal/d)
1	Indian Head Manor	CH54G003	CH Bd 16	38,28,2	0.014	0.024[2]
			CH Bd 17	38,28,2		
			CH Bd 18	38,28,2		
2	Charles County Bryans Road	CH55G003	CH Bc 76	32,34,2	.273	.097[2]
			CH Bd 22	35,33,2		
			CH Bd 29	33,32,2		
			CH Bd 50	35,34,2		
3	Potomac Heights	CH55G008	CH Bc 6	25,50,2	.225	.177[2] no pumpage reported from July to Dec.
			CH Bc 24	25,50,2		
			CH Bc 68	25,50,2		
4	Town of Indian Head	CH57G003	CH Bc 23	23,58,2	.338	.293[2]
			CH Bc 67[3]	24,54,2		
			CH Bc 70	26,54,2		
			CH Bc 72	25,55,2		
5	Red Hill Estates	CH60G004	CH Cc 19	29,61,2	.014	.009 no pumpage reported from July to Dec.
			CH Cc 20	29,61,2		
			CH Cc 28	29,61,2		
			CH Cc 32	29,61,2		
6	Jenkins Lane	CH65G008	CH Bc 46	33,35,2	.014	.008[2]
			CH Bc 65	33,35,2		
7	Charles County. Strawberry Hill	CH66G005	CH Bd 33	32,27,2	.120	.075[2]
			CH Bd 35	32,27,2		
8	Charles County, Carmel Estates	CH66G108	CH Ce 58	61,36,2	.023	.011
9	PEPCO, Morgantown	CH67G011	CH Ee 68	68,85,2	.820	.575
			CH Ee 69	68,85,2		
			CH Ee 71	68,85,2		
			CH Ee 72	68,85,2		
10	Charles County, Brookwood	CH67G109	CH Be 66	58,22,2	.045	.017
11	Du-Mar Estates (Marbury)	CH68G002	CH Cc 25	29,65,2	.013	.005
12	Utilco, Inc. (Pomfret Estates)	CH68G004	CH Cd 30	57,39,2	.013	.009
13	Lackey High School	CH68G009	CH Cc 30	34,56,2	.010	.010
14	Charles County Vo-Tech	CH69G005	CH Cd 33	57,40,2	.015	.0035
15	Turkey Hill Water Co.	CH70G001[4]	CH Ce 59	61,33,2	.016	.009
16	Town of La Plata	CH70G003	CH Ce 35	63,46,2	.640	.570
			CH Ce 43	63,34,2		
			CH Ce 51	64,42,2		
			CH Ce 55	62,38,2		

Appendix D (Part I). Appropriated ground-water use (1997) over 10,000 gallons per day in the lower Patapsco aquifer in the model area--Continued

[MGS = Maryland Geological Survey; USGS = U.S. Geological Survey; Mgal/d = million gallons per day; PEPCO = Potomac Electric Power Company]

Site number[1]	Well owner or name-Charles County	Ground-water appropriation permit number (GAP)	MGS/USGS well no.	Model cell (column, row, layer)	Average amount appropriated (Mgal/d)	Yearly average pumpage reported in 1997 (Mgal/d)
17	U.S. Naval Surface Warfare Center (main base)	CH71G005	CH Bb 6	24,62,2	1.24	0.861[2]
			CH Bb 7	24,62,2		
			CH Bb 9	24,62,2		
			CH Bb 19	21,61,2		
			CH Bb 20	20,66,2		
			CH Bc 3	25,60,2		
			CH Cb 18	23,70,2		
			CH Cb 19	23,65,2		
			CH Cb 43	22,74,2		
			CH Cb 29	24,64,2		
18	U.S. Naval Surface Warfare Center (Stump Neck)	CH71G105	CH Cb 11	23,77,2	0.025	0.020
			CH Cb 28	21,78,2		
19	U.S. Naval Surface Warfare Center (industrial supply)	CH71G205	CH Cb 35[3]	21,72,2	.020	.066[2]
20	Charles County, Ellenwood	CH75G002	CH Ce 42	65,39,2	.035	.018
21	Chapel Point Subdivision	CH76G011	CH De 39	64,64,2	.024	.020
			CH De 40	64,64,2		
			CH De 41	64,64,2		
22	Charles County, Laurel Branch	CH77G036	CH Bd 47	48,20,2	.15	.122
			CH Bd 48	48,20,2		
23	Charles County, Eutaw Forest	CH78G015	CH Bd 38	48,23,2	.080	.061
			CH Bd 44	48,23,2		
			CH Bd 46	48,23,2		
24	Charles County, St. Paul	CH83G012	CH Bf 147	63,16,2	.60	.505
25	Charles County, St. Anne	CH83G014	CH Ee 91	67,83,2	.075	.043
26	Charles County, Smallwood West	CH83G112	CH Be 58	60,18,2	.600	.596
27	Charles County, White Oak Drive	CH83G212	CH Bf 150	62,9,2	.600	.559
28	Charles County, Billingsley Road	CH83G312	CH Be 64	62,18,2	.800	.439
29	Charles County, Cleveland Park	CH83G412	CH Be 67	63,20,2	.800	.265
30	Montrose Heights	CH88G003	CH Bc 74	32,40,2	.041	0
31	Charles County, Settle Woods	CH89G032	CH Bd 51	47,27,2	.300	.033
32	Duttons Addition	CH94G003	CH Bd 49	50,31,2	.008	.019 (estimated)

Appendix D (Part I). Appropriated ground-water use (1997) over 10,000 gallons per day in the lower Patapsco aquifer in the model area--Continued

[MGS = Maryland Geological Survey; USGS = U.S. Geological Survey; Mgal/d = million gallons per day; PEPCO = Potomac Electric Power Company]

Site number[1]	Well owner or name-Prince George's County	Ground-water appropriation permit number (GAP)	MGS/USGS well no.	Model cell (column, row, layer)	Average amount appropriated (Mgal/d)	Yearly average pumpage reported in 1997 (Mgal/d)
33	Potomac Vista Corporation	PG52G004	PG Eb 22 PG Eb 23	16,7,2 16,7,2	0.015	0.018

[1]Sites are located on figure 23
[2]In the Indian Head-Bryans Road area
[3]Screened in the upper Patuxent aquifer or sands in the Arundel Clay
[4]One well out of four which pump under this permit is screened in the lower Patapsco aquifer

Appendix D (Part II). Appropriated ground-water use (1997) over 10,000 gallons per day in the upper Patuxent aquifer in the model area

[MGS = Maryland Geological Survey; USGS = U.S. Geological Survey; Mgal/d = million gallons per day]

Site number[1]	Well owner or name-Charles County	Ground-water appropriation permit number (GAP)	MGS/USGS well no.	Model cell (column, row, layer)	Average amount appropriated (Mgal/d)	Yearly average pumpage reported in 1997 (Mgal/d)
34	Charles County, South Hampton	CH95G023	CH Bc 78	30,34,3	0.16	0.094[2]
35	Legend Properties, Inc.	CH93G029	CH Bc 75 CH Bc 77	32,42,3 34,41,3	0.39	0[2]

[1]Sites are located on figure 24
[2]In the Indian Head-Bryans Road area

Appendix E. Appropriated ground-water use over 10,000 gallons per day in the lower Patapsco and upper Patuxent aquifers in Charles County and southern Prince George's County for 1900-74

[Mgal/d = million gallons per day; Lppsc = lower Patapsco aquifer; Uptxn = upper Patuxent aquifer; PEPCO = Potomac Electric Power Company]

Owner	Ground-water Appropriation number (GAP)	Aquifer	Average daily pumpage for period (Mgal/d)						
			1900-09	1910-19	1920-29	1930-39	1940-49	1950-59	1960-74
Indian Head Manor	CH54G003	Lppsc	0		0	0	0	0	0.01
Charles County, Bryans Road	CH55G003	Lppsc	0		0	0	0	0.077	0.11
Potomac Heights	CH55G008	Lppsc	0		0	0.094	0.10	0.12	0.13
Town of Indian Head	CH57G003	Lppsc/ Uptxn[1]	0		0	0	0	0.015	0.026
Jenkins Lane	CH65G008	Lppsc	0		0	0	0	0.007	0.01
Charles County, Strawberry Hill	CH66G005	Lppsc	0		0	0	0	0	0.039
PEPCO, Morgantown	CH67G011	Lppsc	0		0	0	0	0	0.57
Lackey High School	CH68G009	Lppsc	0		0	0	0	0	0.012
Town of La Plata	CH70G003	Lppsc	0		0	0	0.089	0.12	0.15
U.S. Naval Surface Warfare Center	CH71G005	Lppsc	0.42	0.42	0.79	0.62	0.75	1.2	1.8
Town of Indian Head	CH71G007	Lppsc	0		0	0	0	0.091	0.20
Morningside Village and Gwynn Subdivision	PG94G006	Lppsc	0		0	0	0.044	0.10	0
Cedar Ridge	PG51G003	Uptxn	0		0	0	0	0	0.016
Calvert Manor Corporation	PG55G011	Lppsc	0		0	0	0	0.003	0.012
Forest Heights	PG74G017	Uptxn	0		0	0	0.16	0.32	0.31
Fort Foote	PG74G018	Lppsc	0		0	0	0	0.40	0.41

[1] Includes a well screened in the upper Patuxent aquifer or sands in the Arundel Clay.

Appendix F. Appropriated ground-water use over 10,000 gallons per day in the lower Patapsco and upper Patuxent aquifers in Charles County and southern Prince George's County for 1975-97.

[gal/d = gallons per day; Lppsc = lower Patapsco aquifer; Uptxn = upper Patuxent aquifer; PEPCO = Potomac Electric Power Company]

Owner	Ground-water appropriation number (GAP)	Aquifer	Average daily pumpage for year, 1,000 gallons per day																						
			75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97
Indian Head Manor	CH54G003	Lppsc	10.7	11.0	11.0	11.0	11.0	5.6	10.4	11.8	11.8	11.3	10.4	13.2	14.2	15.3	14.4	14.5	20.1	20.5	23.3	22.8	25.6	33.0	24.0
Charles County, Bryans Road	CH55G003	Lppsc	110	110	110	114	112	122	114	115	115	62.2	130	132	132	148	189	152	156	139	152	162	177	170	97
Potomac Heights	CH55G008	Lppsc	129	139	139	141	131	139	131	138	165	150	192	218	178	196	211	186	168	166	174	227	212	177	177
Town of Indian Head	CH57G003	Lppsc/ Uptxn[1]	24.6	24.7	24.7	24.7	21.9	53.1	58.3	15.6	33.5	51.5	47.2	34.4	30.4	33.4	35.5	31.6	109	141	137	257	292	314	293
Red Hill Estates	CH60G004	Lppsc	0	0	0	0	0	15.0	15.0	0	0	0.5	46.7	12.2	17	28.5	11.6	11.9	12.0	12.5	14.1	12.6	14.0	11.0	9.0
Jenkins Lane	CH65G008	Lppsc	9.6	9.6	11.5	9.9	9.3	9.2	9.0	9.3	9.8	10.0	10.4	10.2	9.8	9.8	9.8	9.8	10.9	11.0	10.8	9.6	11.1	10.0	8.0
Charles County, Strawberry Hill	CH66G005	Lppsc	48.2	51.2	51.2	62.2	59.2	61.3	63.1	93.2	103.2	98.3	104.0	52.3	118.5	90.0	73.1	71.4	72.7	70.6	72.8	69.4	67.0	61.0	75.0
PEPCO, Morgantown	CH67G011	Lppsc	818	820	785	702	767	762	661	607	620	694	607	620	516	670	728	682	571	576	666	644	542	650	575
Du-Mar Estates (Marbury)	CH68G002	Lppsc	6.3	8.8	9.6	9.6	12.0	10.2	9.8	19.5	10.7	10.8	12.6	12.0	16	17.6	17.6	15.5	12.8	11.9	14.6	10.9	10.2	9.0	5.0
Pomfret Estates	CH68G004	Lppsc/ Uptxn	0	0	0	0	0	0	0	0	0	0	13.0	8.2	8.2	8.4	8.6	8.4	8.2	10.3	11.3	11.6	8.8	9.0	9.0
Lackey High School	CH68G009	Lppsc	10.9	9.3	9.0	7.4	7.7	7.0	6.5	6.5	7.1	6.0	7.2	8.3	54.6	78.7	7.9	8.3	8.8	4.0	7.0	9.0	9.6	10.0	10.0
Charles County Vo-Tech	CH69G005	Lppsc	3.8	4.6	6.0	4.9	4.6	6.2	7.0	6.9	7.0	8.8	10.2	16.8	20.6	18.2	24.4	26.5	5.6	4.9	13.3	8.3	5.7	2.1	3.0
Town of La Plata	CH70G003	Lppsc	231	250	365	331	206	331	273	323	348	480	612	542	597	652	708	763	942	750	713	565	643	600	570
U.S. Naval Surface Warfare Center (Main base)	CH71G005	Lppsc	1,300	1,060	1,070	1,100	1,180	1,070	873	740	683	1,310	1,400	1,390	1,330	1,400	1,280	1,320	1,170	1,100	1,110	1,090	1,050	962	860
Town of Indian Head	CH71G007	Lppsc	186	261	209	211	213	208	160	216	19.7	178	182	188	204	227	239	266	203	188	192	97.8	0	0	0
U.S. Naval Surface Warfare Center (Stump Neck)	CH71G105	Lppsc	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18.9	15.5	18.5	14.7	17.0	20.0

Appendix F. Appropriated ground-water use over 10,000 gallons per day in the lower Patapsco and upper Patuxent aquifers in Charles County and southern Prince George's County for 1975-97--Continued.

[gal/d = gallons per day; Lppsc = lower Patapsco aquifer; Uptxn = upper Patuxent aquifer; PEPCO = Potomac Electric Power Company]

Owner	Ground-water appropriation number (GAP)	Aquifer	Average daily pumpage for year, 1,000 gallons per day																						
			75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97
U.S. Naval Surface Warfare Center (industrial supply)	CH71G205	Uptxn[1]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	48.4	49.2	59.4	57.0	93.0	66.0
Chapel Point Subdivision	CH76G011		0	0	0	0	0	0	0	0	0	0	0	0	0	4.1	8.0	9.0	13.6	12.2	15.8	18.3	19.8	17.0	20.0
Charles County, Laurel Branch	CH77G036	Lppsc	0	0	0	0	0.2	8.9	3.5	6.3	18.8	32.4	47.9	65.5	81.3	77.0	67.6	66.6	73.4	71.4	92.5	101	110	107	122
Charles County, Eutaw Forest	CH78G015	Lppsc	0	0	0	0	0.06	3.3	11.5	15.3	27.6	32.2	53.3	69.0	70.0	76.6	67.3	70.0	70.0	61.9	65.6	64.3	63.4	57.0	61.0
Charles County, St. Paul	CH83G012	Lppsc	0	0	0	0	0	0	0	0	0	48.0	306	441	556	631	492	583	541	393	552	581	558	569	505
Charles County, St. Anne's	CH83G014	Lppsc	0	0	0	0	0	0	0	0	0	0	0	15.7	36.3	46.0	47.0	48.2	51.3	48.6	50.0	48.4	48.6	45.0	43.0
Charles County, Smallwood West	CH83G112	Lppsc	0	0	0	0	0	0	0	0	0	0	0	307	527	643	636	636	592	624	627	617	593	595	596
Charles County, White Oak Drive	CH83G212	Lppsc	0	0	0	0	0	0	0	0	0	0	0	266	621	531	610	509	516	494	508	576	503	462	559
Charles County, Billingsley Rd.	CH83G312	Lppsc	0	0	0	0	0	0	0	0	0	0	0	0	0	0	106	527	728	577	665	672	642	641	439
Charles County, South Hampton	CH95G023	Uptxn	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	94.0
Potomac Vista Corporation	PG52G004	Lppsc	0	0	0	11.2	10.7	14.8	11.6	12.3	5.4	10.8	15.0	18.0	17.1	18.3	16.2	14.3	15.9	17.5	24.7	17.4	18.0	18.0	18.0

[1] Includes a well screened in the upper Patuxent aquifer or sands in the Arundel Clay.

Appendix G. Simulated pumpage for 2020 in the upper Patuxent aquifer used in predictive Model Simulation III

[Mgal/d = million gallons per day]

Site[1]	Model cell (column, row, layer)	Pumpage (Mgal/d)
Chapman's Landing 1	34,41,3	0.25
Chapman's Landing 2	32,42,3	.72
Chapman's Landing 3	38,46,3	.25
South Hampton	30,34,3	.15
Oxford Properties	39,28,3	.37
Bryans Village	36,36,3	.15
Industrial Park near Maryland Airport	40,39,3	.25
Industrial Park	41,47,3	.37
Indian Head-Potomac Heights	25,50,3	.13
Hypothetical well	39,42,3	.72
Total		3.4

[1] Sites are located on figure 43

Appendix H. Simulated pumpage for 2020 in the upper Patuxent aquifer used in predictive Model Simulations IVA, IVB, and IVC

[Mgal/d = million gallons per day]

Pumping Alternative IVA

Site[1]	Model cell (column, row, layer)	Pumpage (Mgal/d)
Chapman's Landing 1	34,41,3	0.72
Chapman's Landing 2	32,42,3	.25
Chapman's Landing 3	38,46,3	.31
South Hampton	30,34,3	.15
Industrial Park near Maryland Airport	40,39,3	.28
Indian Head-Potomac Heights	25,50,3	.13
Naval Surface Warfare Center	24,62,3	.26
Total		2.1

Pumping Alternative IVB

Site[1]	Model cell (column, row, layer)	Pumpage (Mgal/d)
Chapman's Landing 1	34,41,3	0.72
Chapman's Landing 2	32,42,3	.25
Chapman's Landing 3	38,46,3	.49
South Hampton	30,34,3	.15
Oxford Properties	39,28,3	.21
Bryans Village	36,36,3	.49
Industrial Park near Maryland Airport	40,39,3	.47
Industrial Park	41,47,3	.47
Indian Head-Potomac Heights	25,50,3	.13
Hypothetical well 1	39,42,3	.36
Naval Surface Warfare Center	24,62,3	.26
Total		4.0

[1] Sites are located on figure 43

Appendix H. Simulated pumpage for 2020 in the upper Patuxent aquifer used in predictive Model Simulations IVA, IVB, and IVC--Continued

[Mgal/d = million gallons per day]

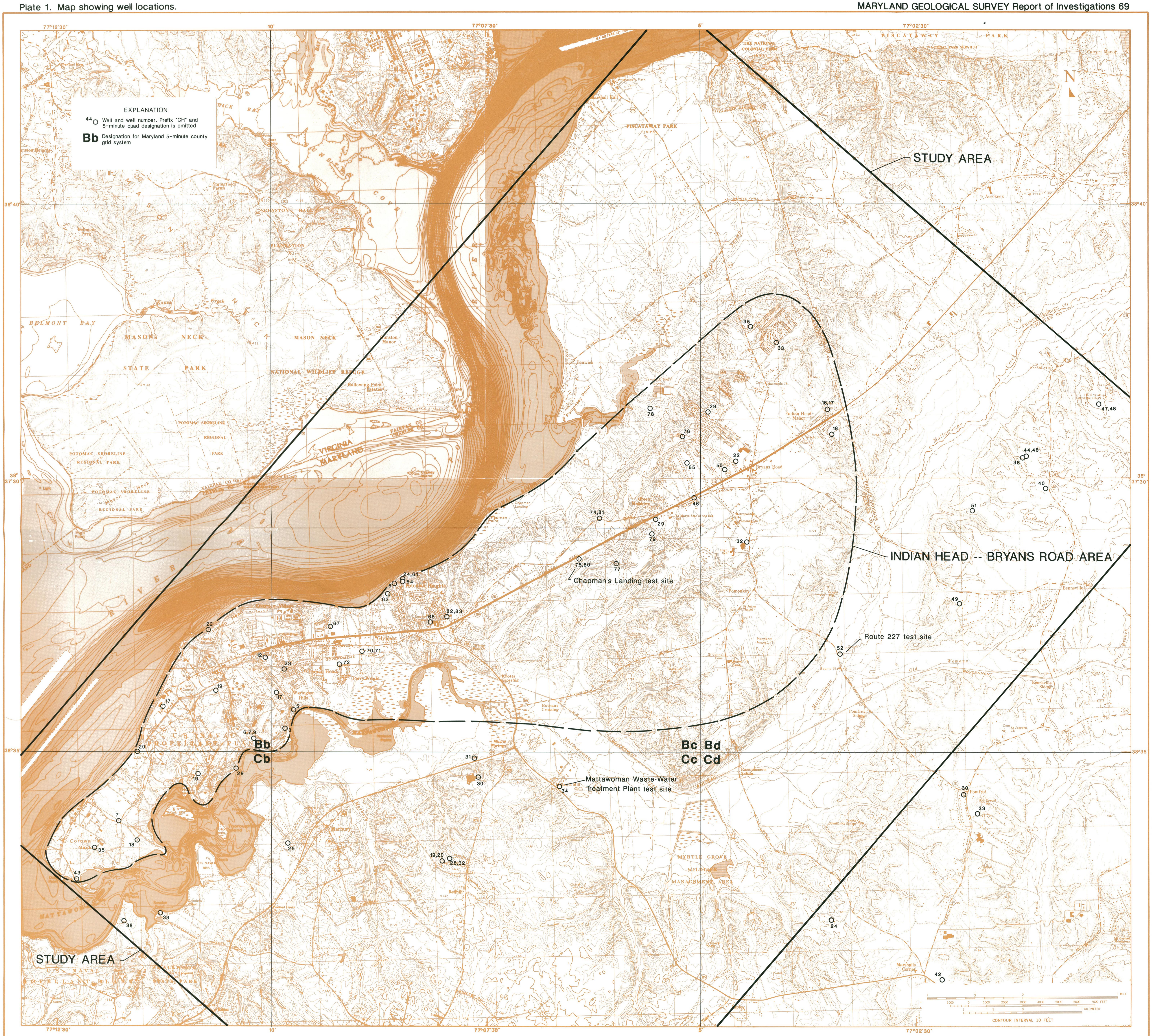
Pumping Alternative IVC		
Site[1]	Model cell (column, row, layer)	Pumpage (Mgal/d)
Chapman's Landing 1	34,41,3	0.72
Chapman's Landing 2	32,42,3	.25
Chapman's Landing 3	38,46,3	.47
South Hampton	30,34,3	.15
Oxford Properties	39,28,3	.29
Bryans Village	36,36,3	.51
Industrial Park near Maryland Airport	40,39,3	.47
Industrial Park	41,47,3	.72
Indian Head-Potomac Heights	25,50,3	.13
Bryans Road	34,28,2	.23
Hypothetical well 1	39,42,3	.51
Naval Surface Warfare Center	24,62,3	.26
Total		4.7

[1] Sites are located on figure 43

Appendix I. Planned subdivisions in the Indian Head-Bryans Road area (from Cooksey, Jenkins, and Associates, 1993; Attachment A)

Subdivision name[1]	Total number of housing units
South Hampton	325
Waters Edge[2]	269
Strawberry Hill	203
Kings View	407
Montrose Farm	161
Villas of South Hampton	407
Hidden Creek[2]	67
Ashland Acres[2]	11
Laurel Acres	282
Kramer Tract	116
Ellerbe Tract[2, 3]	50
Bryans Village	309
Chapman's Landing Phase I	576
Chapman's Landing	4,024

[1]Locations are given on figure 44.
[2]Application for subdivision has expired.
[3]Location unknown.



Base map from U.S. Geological Survey 1:24,000 quadrangles

Plate 2.--Geohydrologic cross-section D-D' from Chapman's Landing to Lexington Park, Maryland