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

REPORT OF INVESTIGATIONS NO. 58

HYDROGEOLOGY, WATER-SUPPLY POTENTIAL, AND WATER QUALITY OF THE COASTAL PLAIN AQUIFERS OF HARFORD COUNTY, MARYLAND

by

David D. Drummond and Joel D. Blomquist

Prepared in cooperation with the
United States Department of Interior
Geological Survey
and
The Harford County Department of Public Works

1993

CONVERSION FACTORS, VERTICAL DATUM, AND WATER-QUALITY UNITS

Multiply inch-pound units	By	To obtain
	Length	
inch (in.)	25.4	millimeter (mm)
inch per year (in/yr)	0.02540	meter per year (m/yr)
foot (ft)	0.3048	meter (m)
foot per day (ft/d)	0.3048	meter per day (m/d)
foot squared per day (ft^2/d)	0.09290	meter squared per day (m^2/d)
	Area	
mile (mi)	1.609	kilometer (km)
square foot (ft^2)	0.09290	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
cubic foot (ft^3)	0.02832	cubic meter (m^3)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per day (ft^3/d)	0.02832	cubic meter per day (m^3/d)
gallon (gal)	3.785	liter (L)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
gallon per day (gal/d)	3.785	liter per day (L/d)
million gallons per day (Mgal/d)	3,785	cubic meters per day (m^3/d)

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

In this report, chemical concentration and water temperature are expressed in metric units. Chemical concentration is given in milligrams per liter (mg/L) or micrograms per liter (μg/L). Milligrams per liter is a unit expressing the concentration of chemical constituents in solution as weight of solute per unit volume of water. Tritium concentrations are expressed in picocuries per liter (pCi/L).

Values of the stable isotopes of hydrogen, oxygen, and carbon (δ^2H, $\delta^{18}O$ and $\delta^{13}C$) are expressed as per mil (parts per thousand) differences relative to arbitrary standards. The standards for ^2H and ^{18}O are standard mean ocean water (SMOW), and the standard for ^{13}C is the Pee Dee belemnite (PDB).

$$\text{per mil} = [(R - R_{std})/R_{std}] \times 1{,}000$$

where R and R_{std} are the isotope ratios of the sample and the standard, respectively.

Carbon-14 values are expressed as percent modern carbon-14. Precipitation that recharged the ground-water system after the beginning of nuclear-bomb testing in 1945 has values of carbon-14 greater than 100-percent modern. Radioactive fallout from nuclear testing raised the concentration of carbon-14 (and many other radioactive isotopes) above natural levels.

Water temperature is expressed in degrees Celsius (°C), which can be converted to degrees Fahrenheit (°F) by the following equation:

$$°F = 1.8\,(°C) + 32$$

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

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by

David D. Drummond and Joel D. Blomquist[1]

ABSTRACT

A study was conducted to investigate the hydrogeology of the Coastal Plain aquifers of Harford County, Maryland. The study refined the hydrogeologic framework, assessed the potential for the aquifer system to meet projected pumpage requirements, and documented chemical quality of ground water.

The Coastal Plain aquifer system of Harford County comprises a wedge-shaped body of sediments which dips and thickens to the southeast and is underlain by hard crystalline bedrock. The sediments comprise three lithostratigraphic units: the Talbot Formation of Pleistocene age, the upland gravels of Late Tertiary age, and the Potomac Group of Early Cretaceous age. The Talbot Formation consists of a shallow silty clay facies and a deeper gravelly sand facies interbedded with dark clay layers. The upland gravels form isolated patches of intercalated sand and gravel and thin lenses of silty clay, which cap some of the higher hills near the Fall Line. The Potomac Group consists of sand and gravel units intercalated with multicolored clay lenses. The lithology of the bedrock underlying the Coastal Plain sediments is poorly documented but probably consists of Piedmont schistose, gneissic, gabbroid, and amphibolide rocks observed in outcrops northwest of the Fall Line.

The Coastal Plain sequence was divided into four aquifers and three intervening confining units. The aquifer boundaries do not generally coincide with the stratigraphic unit boundaries. The aquifers were designated as aquifers 1, 2, 3, and 4, and the confining units were designated as 1, 2, and 3. This aquifer division is somewhat arbitrary and is poorly defined in places.

Base-flow measurements were made at several points along each of the seven major streams that drain the study area to estimate the amount of ground water that discharges into the surface-water system. Discharge ranged from 0 to 79.4 cubic feet per second, and ground-water specific discharge ranged from -4.7×10^{-3} to 11.7×10^{-3} feet per day, with a weighted average of 1.4×10^{-3} feet per day.

Almost all recharge to the regional ground-water system comes from precipitation, although small amounts could also be derived from losing reaches of streams and from brackish-water intrusion from the estuaries. The recharge water then flows through the aquifer system in directions and at rates that are controlled by aquifer properties, confining-unit properties, and head gradients.

A quasi-three-dimensional, finite-difference ground-water flow model was developed to simulate the response of water levels to projected pumpage in Coastal Plain aquifers. The effects of projected pumpage on water levels was evaluated by entering various pumpage scenarios into the model and simulating water levels until the year 2000 under average annual recharge conditions. Additional simulations were made with recharge reduced by 35 percent for 1 year (year 2001) and 3 years (year 2001 through 2003) to evaluate the effect on water levels of a drought similar to the drought in the mid-1960's.

A simulation in which pumping at the 1989 levels was continued until the year 2000 showed no significant additional drawdown from the 1989 potentiometric surfaces. A simulation in which 1989 pumpage was increased by 20 percent showed additional drawdowns of 4 feet in aquifer 2 at the Aberdeen well field and 4 feet in aquifer 3 at the Perryman well field. The greatest simulated drawdowns occurred in the "safe yield" simulation, in which pumping at the Perryman well field was increased until simulated pumping-water levels were reduced to 80 percent of available drawdown. Total "safe-yield" pumpage at the Perryman well field was 9.2 and 8.3 million gallons per day for average recharge and 1-year drought conditions, or 3.0 and 2.7 times the 1989 pumpage. Other alternative pumpage scenarios were simulated, such as the addition of a well field at Trimble Road, the addition of a well field at a powerplant near Perryman, the addition of a well field at a bleach-bottling plant near Perryman, average and maximum ground-water-appropriation permit amounts, and additional wells at the Perryman well field. The drought simulations indicate that water levels in aquifers 1, 2, and 3 generally would be about 5 feet deeper for a 1-year drought than for average recharge conditions, and about 14, 11, and 8 feet deeper, respectively, for a 3-year drought. Water levels in aquifer 4 were only slightly deeper in the drought simulations than under average recharge conditions.

[1]U.S. Geological Survey.

Particle-tracking analysis and examination of head gradients and fluxes were used to evaluate the potential for brackish-water intrusion and contaminant migration to pumping centers as a result of projected amounts of pumpage. The analysis indicated that the most probable projected pumping scenarios are not likely to result in brackish-water intrusion but could result in contaminant migration from Aberdeen Proving Ground.

Ground water in the Coastal Plain aquifers is mildly acidic and contains low total-dissolved-solids concentrations. The chemical facies of ground water are variable throughout the Coastal Plain. Water from deep confined aquifers is the chemically stable sodium bicarbonate type. Elevated concentrations of chloride and nitrate in ground water in much of the unconfined aquifer indicate that these contaminants are derived from anthropogenic sources. Other regional water-quality problems include the presence of iron and manganese in concentrations exceeding USEPA (U.S. Environmental Protection Agency) secondary maximum contaminant levels. Analyses of carbon-14 and tritium in ground water indicate that residence time in aquifer 2 is low (less than 50 years) and residence time in the deeper confined system is greater than 43 years.

Water-quality analyses from four Coastal Plain streams generally reflect the composition of ground water. Water from James Run and Winters Run have chemical facies similar to facies in ground water in the Piedmont. Water from Fosters Branch and Haha Branch is similar to the less mineralized water in the shallow Coastal Plain aquifers. Mass-balance calculations of upstream and downstream analyses in Cranberry Run were used to estimate the ionic concentration of ground-water discharge. The estimated discharge concentrations are averages of water concentrations from the unconfined aquifer, and indicate anthropogenic sources of chloride and nitrate in the Aberdeen and Perryman area of the Coastal Plain.

INTRODUCTION

The Coastal Plain area of Harford County is undergoing substantial commercial and residential growth. The population of Harford County increased from 76,722 in 1960 to 182,132 in 1990 (Jane Traynham, Maryland Office of Planning, written commun., 1991), and the demand for water has increased concomitantly. This increased demand for water led to concern by State and county officials that increased pumpage might lead to problems with the ground-water supply, including lowered ground-water levels, saltwater intrusion from the Chesapeake Bay and its tidal tributaries, contaminant migration from buried wastes, and reduced streamflow. To address these concerns, the Maryland Geological Survey, in cooperation with the U.S. Geological Survey, conducted an investigation of the ground-water resources of the Harford County Coastal Plain from 1986 through 1990.

PURPOSE AND SCOPE

This report presents the results of a 4-year study of the potential consequences of increased ground-water pumping in the Coastal Plain part of Harford County. It is intended to provide State and county officials with a better understanding of the hydrogeologic system, an estimate of potential problems caused by projected pumpage increases, and a summary of ground-water and stream-water quality.

The hydrogeologic framework was evaluated by inventorying about 100 existing wells, from which data were collected on lithology, water levels, aquifer characteristics, pumpage amounts, and water quality. Sixteen test wells were drilled at eight sites, and lithologic data, geophysical logs, and core samples were collected (tab. 1). Stream discharge was measured at 21 sites on 7 streams semiannually for 2 years, and water samples were collected at 7 of those sites for chemical analysis. Streamflow-gaging stations were installed at two of those sites to monitor discharge continuously. Ground-water flow was simulated using a quasi-three-dimensional finite-difference flow model. The model was calibrated using data from 1866 through 1989 and was used to simulate the effects of projected pumpage and possible droughts on ground-water levels.

LOCATION OF STUDY AREA

The study area is located in southeastern Harford County, Maryland (fig. 1), and includes the Coastal Plain part of the county, excluding Aberdeen Proving Ground and the area northeast of the town of Aberdeen. The study area is bounded on the northwest by the Fall Line (the boundary between the Coastal Plain and Piedmont provinces), on the northeast by the northeastern limit of the town of Aberdeen, on the southeast by the boundary of Aberdeen Proving Ground, and on the southwest by the Gunpowder River. The flow-model area extends northeast to Havre de Grace, and includes Aberdeen Proving Ground to incorporate the natural hydraulic boundaries of the Susquehanna River and Chesapeake Bay. The study area comprises 36 mi^2 and the flow-model area comprises 308 mi^2.

The study area, as defined here, is the area of main interest to county and State officials. It is the area of Harford County where most of the project resources were concentrated. Some surrounding areas were also included in the study, however. Many figures in this report show data for sites that are southeast and northeast of the study area.

WATER USE

Historical Pumpage

The first ground water used in the Harford County Coastal Plain was probably spring water used by the Susquehannock Indians and European settlers in the early 1600's. Numerous small springs and shallow wells were reported to supply ground water for domestic use throughout the Coastal Plain, but Darton (1896, p. 127-128) makes no mention of wells in Harford County. The earliest reported major ground-water withdrawal is for the town of Aberdeen, which used about 50,000 gal/d from a spring in the early part of this century (Clark, Mathews, and Berry, 1918, p. 415).

Most of the study area is served by public water supply, but, in some areas, homeowners and businesses rely on individual wells for their water supply. Domestic wells are estimated to provide about 112,000 gal/d or 2 percent of the total water needs of the Coastal Plain area (J. C. Wheeler, U.S. Geological Survey, written commun., 1989). Small commercial users (less than 10,000 gal/d) were appropriated 104,000 gal/d of ground water by the Maryland Water Resources Administration, or about 2 percent of total ground-water use in 1989. The U.S. Army was appropriated 312,000 gal/d of ground water and 6,000,000 gal/d of surface water from Deer Creek and Winters Run.

The major pumping centers in the study area are shown in figure 2. The largest pumping center is the county-operated well field at Perryman, which began pumping in 1971, and produced an average of 3.1 Mgal/d in 1989. In 1918, Clark and others (p. 415) reported that the town of Aberdeen used 0.05 Mgal/d supplied by a spring; an average of 1.3 Mgal/d was produced from two well fields in 1989. The Joppatowne well field began pumping around 1971, and produced an average of 0.25 Mgal/d in 1989. Smaller pumping centers in the study area include Price Brothers (96,000 gal/d) and Deinlein (13,000 gal/d). The well field at the Huber Corporation in Havre de Grace (fig. 1), which pumps water from Coastal Plain aquifers northeast of the study

Table 1.—Data on test wells in Harford County

[ft = feet; mg/L = milligrams per liter; G = geologist's log; E = electric log; GR = gamma-ray log; -- = data not collected]

Site	Well number	Latitude, longitude (° ' ")	State permit number	Altitude of land surface (ft)	Depth drilled (ft)	Screened interval (ft)	Core intervals (ft)	Logs	Chloride concentration (mg/L)	Date chloride concentration measured
Joppatowne (Mariner Point Park)	HA Ec 46	39 24 08 76 21 01	HA-81-4124	23.16	180	65- 75	40.0- 40.9 117.0-118.3	G, E, GR	6.6	08-23-88
	HA Ec 47	39 24 08 76 21 01	HA-81-4125	23.30	20	3- 13	5.0- 5.5	G	--	
Edgewood (Elementary School)	HA Dd 89	39 25 29 76 18 09	HA-81-4130	99.05	270	96-106 120-130	140.0-140.5 210.0-210.8	G, E, GR	3.5	04-20-88
	HA Dd 102[1/]	39 25 29 76 18 09			160		40.0- 41.2 122.0-122.1 124.0-124.1		--	
Willoughby Beach Boat Launch	HA De 181	39 26 06 76 14 58	HA-81-4134	12.22	317	264-269 275-280	60.0- 61.9 120.0-121.2 180.0-180.5 220.0-220.5	G, E, GR	7.4	04-13-88
	HA De 182	39 26 06 76 14 58	HA-81-4135	12.29	60	30- 40		G	16	03-31-88
	HA De 183	39 26 06 76 14 58	HA-81-4577	12.53	175	155-165			5.2	04-19-88
Cranberry Run Business Park	HA De 195	39 29 14 76 11 03	HA-81-4142	52.70	164	35- 45	64.0- 65.2 114.0-115.2 135.0-135.8	G, E, GR	26	04-12-88
Long Bar Harbor	HA Dd 91	39 27 21 76 15 03	HA-81-4136	19.73	154	58- 68	20.0- 21.0 64.0- 65.0 124.0-124.8	G, E, GR	3.7	04-15-88
	HA Dd 92	39 27 21 76 15 03	HA-81-4137	20.06	50	18- 28		G	55	01-17-89
Church Creek (at Ford's Lane)	HA De 197	39 28 19 76 13 09	HA-81-4140	19.08	140	75- 85	40.0- 41.5 70.0- 71.0 100.0-100.9	G, E, GR	1.8	04-06-88
	HA De 198	39 28 19 76 13 09	HA-81-4141	18.92	35	9- 19	15.0- 16.4 25.0- 26.9		14	08-25-88
	HA De 199	39 28 19 76 13 09	HA-81-4576	20.10	35	9- 19			--	
Trimble Road	HA Ed 47	39 24 55 76 19 21	HA-81-4128	90.50	277	190-200	47.0- 47.3 67.0- 67.3	G, E, GR	3.8	03-30-88
	HA Ed 48	39 24 55 76 19 21	HA-81-4578	91.20	140	118-128	121.0-122.8 167.0-167.1		9.3	04-27-88
	HA Ed 49	39 24 55 76 19 21	HA-81-4129	91.89	32	13- 23			21	03-29-88
Willoughby Woods	HA Dd 106	39 25 57 76 25 57	HA-81-4522	33.89	255	190-200	60.0- 60.9 160.0-160.9 240.0-241.6	G, E, GR	2.5	06-30-88

[1/] Well abandoned; originally designated HA Dd 88.

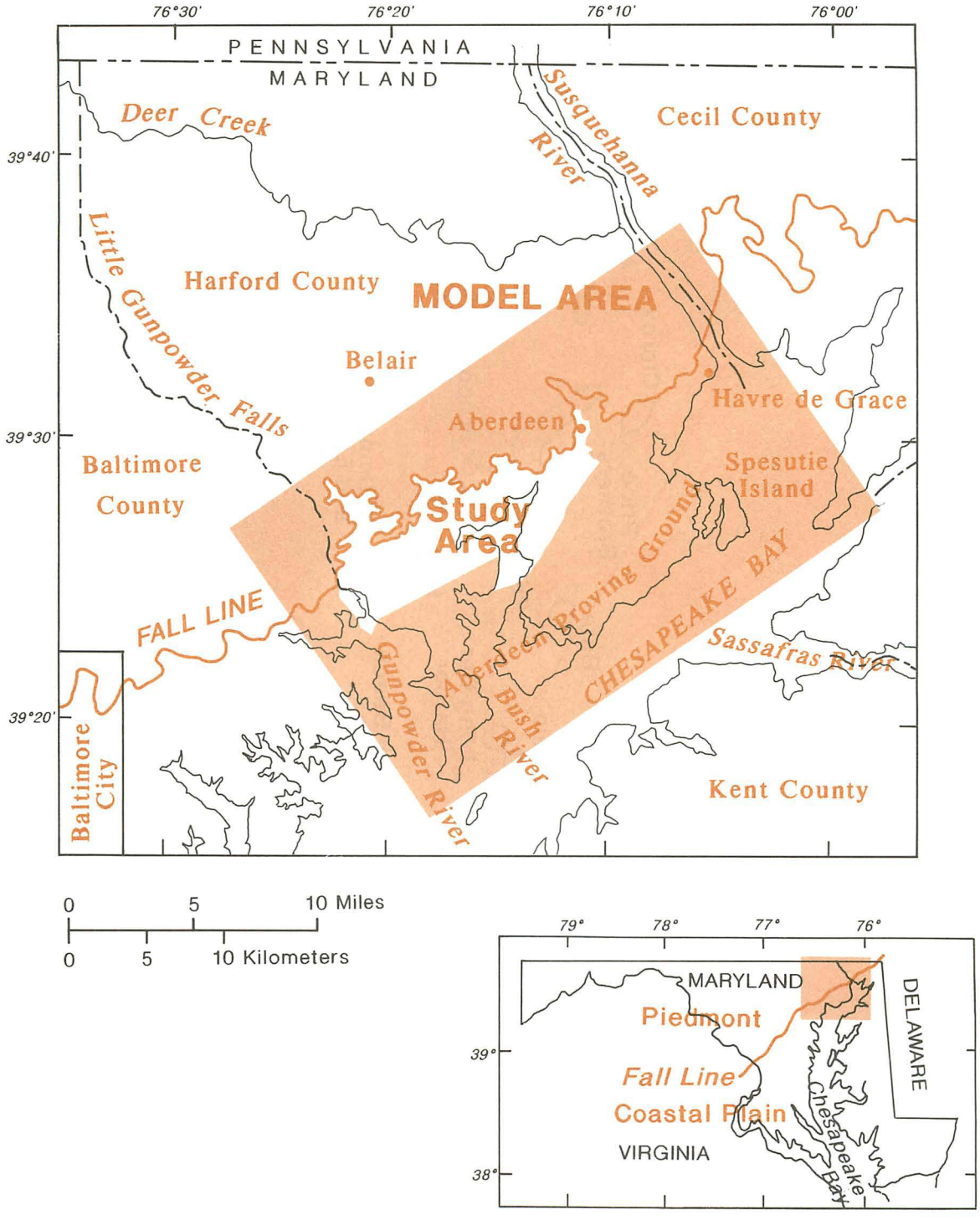
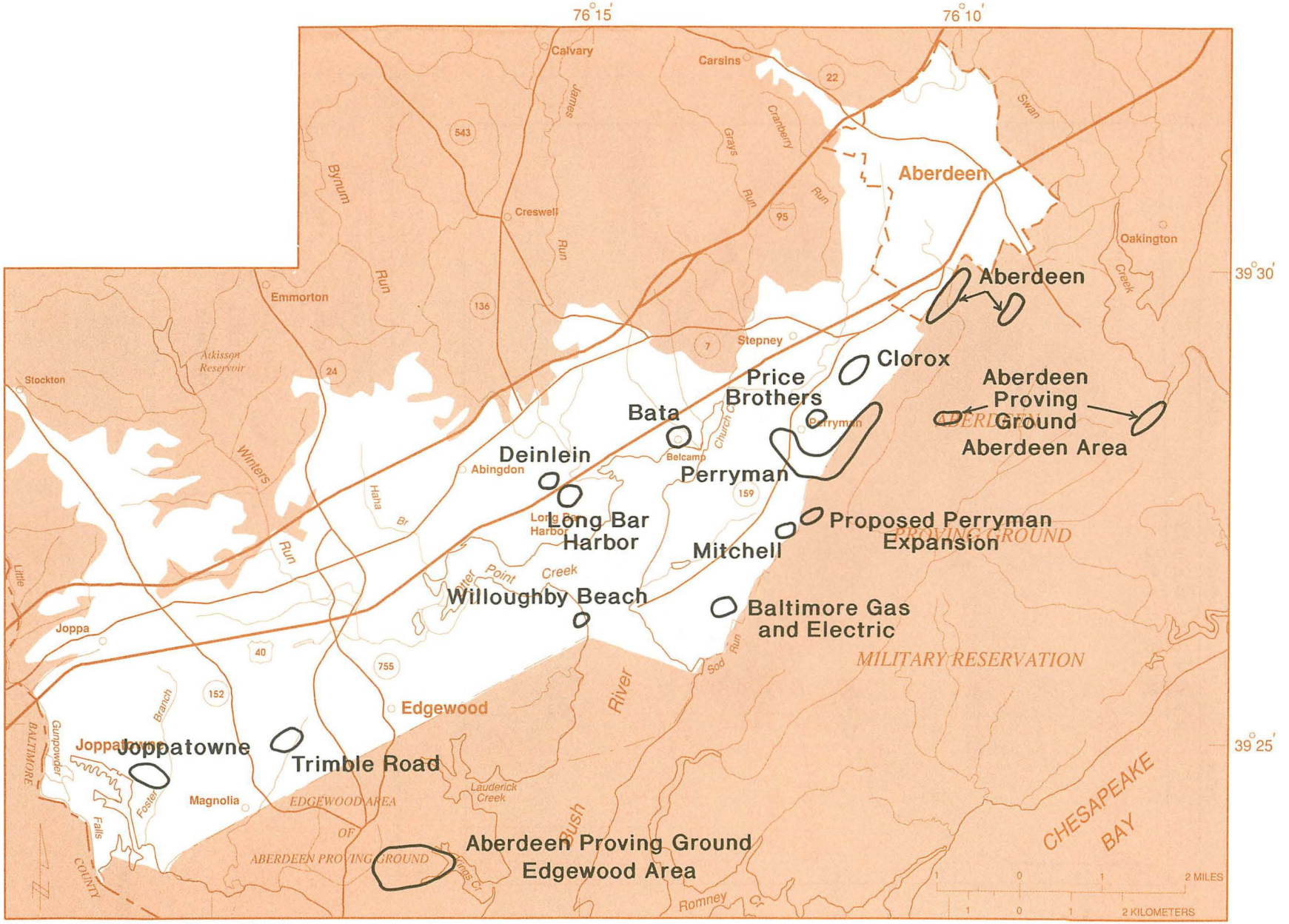


Figure 1.—Locations of study area and flow-model area.



Base map from U.S. Geological Survey, 1:100,000

Figure 2.—Locations of major pumping centers in the study area.

area produced 160,000 gal/d in 1989. Well fields at Aberdeen Proving Ground (Aberdeen and Edgewood areas), Bata Shoe Company, Mitchell Canning Company, Long Bar Harbor, and Willoughby Beach were major pumping centers in the past, but pumpage was greatly decreased or ceased altogether before 1989. Ground-water pumpage is tabulated in input data of the flow-modeling section of this report.

Projected Pumpage

Continued population growth and commercial development in Harford County will result in increased water demand. By 1994, much of the water supply for the county will probably be supplied by the Susquehanna aqueduct, which connects the Susquehanna River to Baltimore City. Nevertheless, ground-water withdrawals could also increase, perhaps to as much as 5,000,000 gal/d at the county-operated Perryman well field. In addition, new industries and businesses in eastern Harford County could draw their water supplies from wells.

Two major industrial users are expected to locate in the Coastal Plain in the near future—a bleach-bottling plant between Aberdeen and Perryman, and an oil-fired power plant 2 mi southwest of Perryman. The bleach-bottling plant is expected to pump about 200,000 gal/d maximum; the power plant is expected to pump about 110,000 gal/d in the early stage of construction, and about 963,000 gal/d when in full operation.

In 1988, the county initiated an exploratory drilling program to test the feasibility of a new well field at the Trimble Road site between Edgewood and Joppatowne. Three high-capacity wells were installed as well as numerous observation wells, and several pumping tests were run. The wells did not produce enough water to justify connecting them to the county water system, and the well field was abandoned. The possibility still exists, however, that the well field could be developed for future water supply.

The Joppatowne well field has been limited to 250,000 gal/d since 1976 because of the intrusion of brackish water from the Gunpowder River. Pumping is not expected to be increased in the future, although new wells located farther from the Gunpowder River might allow increased production without exacerbating the brackish-water problem. The well field at Long Bar Harbor has not been pumped since 1981, and no future use is planned.

METHODS OF INVESTIGATION

A literature search was conducted, in which reports from all known previous investigations that concerned the hydrogeology of the Harford County Coastal Plain and related topics were compiled. A well inventory was then performed in which selected wells in the study area were visited and data were collected on well location, elevation, and owner's name, and on water levels in the wells. Well-construction information was obtained from well permits and well-completion reports on file at the Maryland Geological Survey. A water-level network was established to obtain data on potentiometric head in each of the aquifers. A water-quality network was also established to obtain data on the chemistry of water in each of the aquifers.

Eight sites were selected for test-well drilling where data on water levels, water quality, or aquifer properties were lacking (tab. 1). Test wells were drilled using the hydraulic rotary method. Samples of drill cuttings were collected and used to prepare descriptive logs, and split-spoon cores were taken at selected intervals for lithologic, geochemical and palynological analysis. Geophysical logs were obtained from the deepest uncased borehole at each site, including: natural-gamma radiation log, single-point electrical-resistivity logs, and multipoint electrical-resistivity logs (tab. 1). At each site, wells were installed in each of the aquifers using 4-in.[1]-PVC casing and 4-in.-PVC slotted screen. A 6-in.- protective steel casing was then installed at the surface of each well with a locking steel cap. The wells were developed using compressed air, then pumped with a submersible pump for aquifer testing and chemical sampling.

Data compiled from the well inventory and test-well drilling program were used to construct cross sections, structure-contour maps, and potentiometric maps.

A digital ground-water flow model was developed to simulate the flow of water through the subsurface. The U.S. Geological Survey Modular Finite-Difference Ground-Water-Flow Model (McDonald and Harbaugh, 1988) was used in all simulations. The model simulated four layers, over a grid of 29 rows and 63 columns. The top layer was simulated as an unconfined aquifer to allow recharge, evapotranspiration, and interflow between the ground-water and surface-water systems. The model was calibrated primarily to 1989 conditions, then used to simulate projected and alternative pumping scenarios under average-recharge and drought conditions. It was also used to evaluate the effects of increased pumpage on ground-water levels, base flow to streams, brackish-water intrusion, and the potential for contaminant migration. A particle-tracking program (Pollock, 1989) was used to estimate contributing areas of well fields and to estimate the direction of contaminant migration.

Water samples were collected from wells and streams in the Coastal Plain and Piedmont to assess the water quality of the aquifer system. Ground-water samples were collected from 43 wells. Thirty-nine of these wells are located in the Coastal Plain and four are in the crystalline rocks of the Piedmont. Two of those wells were sampled three times during a 1-year period to gain an understanding of the ground-water chemical variability. The four Piedmont wells were sampled to develop an understanding of the geochemical conditions in formations contiguous with the Coastal Plain. Nine analyses from earlier studies were included to supplement the data that were collected.

Seven sites on four Coastal Plain streams were selected for streamwater-quality sampling. Three of the streams were sampled at two sites to document changes in water quality along

[1]In this report, well diameters refer to nominal inside diameters of well casings.

the stream reach. Stream sampling was conducted in conjunction with stream-seepage measurements during low-flow periods in August 1987, April and August 1988, and June 1989. Stream samples were collected and analyzed for the same major chemical constituents and physical properties as were the ground-water samples. The site on Cranberry Run at Perryman was also sampled for trace metals and isotopes.

Water samples were collected from these wells using standard ground-water sampling procedures as described in the National Handbook of Recommended Methods for Water-Data Acquisition (U.S. Geological Survey, 1977). Field measurements were made at the time of sampling for pH, alkalinity and bicarbonate, specific conductance, water temperature, and dissolved oxygen. Samples were collected and preserved in the field for analysis at the USGS Laboratory in Denver, Colo.

PREVIOUS INVESTIGATIONS

The Coastal Plain aquifers were first described by Darton (1896, p. 152), who provided sparse information on the hydrogeology of Harford County. Clark and others (1918) further described the aquifers of Harford County and tabulated data such as well depths, yields, and water levels. Bennett and Meyer (1952) extensively described the geology and hydrogeology of the Baltimore area, which included the Harford County Coastal Plain. Glaser (1969) described the petrology of the Potomac Group sediments in Maryland and Virginia. Owens (1969) described the geology of the Coastal Plain of Harford County. Nutter and Smigaj (1975) compiled ground-water information for Harford County, including well records, chemical data, and pumpage. Nutter (1977) reported on the ground-water resources of Harford County, and described water chemistry. Edwards and Hansen (1979) provided stratigraphic data from a deep hole drilled to bedrock in southeastern Harford County at Spesutie Island. Oliveros and Vroblesky (1989) described the hydrogeology of the Canal Creek area of Aberdeen Proving Ground, and Lorah and Vroblesky (1989) described the ground-water chemistry in the Canal Creek area. Trapp and Meisler (1992) summarized the U.S. Geological Survey Regional Aquifer-System Analysis study of the Northern Atlantic Coastal Plain aquifers.

WELL AND STREAM-STATION NUMBERING SYSTEM

Well locations are shown on the maps in the supplemental data section, at the end of this report. Well numbers are designated in the following manner. Each county in Maryland is divided into quadrangles of 5 minutes of latitude and 5 minutes of longitude (fig. 87). Each quadrangle is assigned a two-letter code; the first letter is determined by the latitude section, the second letter by the longitude section. The first group of letters in the well number indicates the county code (HA for Harford); the second group indicates the 5-minute quadrangle in which the well is located, and the third group is a sequential number generally assigned in the order in which the well was inventoried. Thus, HA De 181 is assigned to the 181st well inventoried in quadrangle De in Harford County.

Stream-station identification numbers are assigned according to downstream order. The complete eight-digit number for each station, for example 01581655, includes the two-digit part number "01" plus the six-digit downstream-order number "581655". The part number designates the major river basin; for example, part "01" is the North Atlantic slope basin.

ACKNOWLEDGMENTS

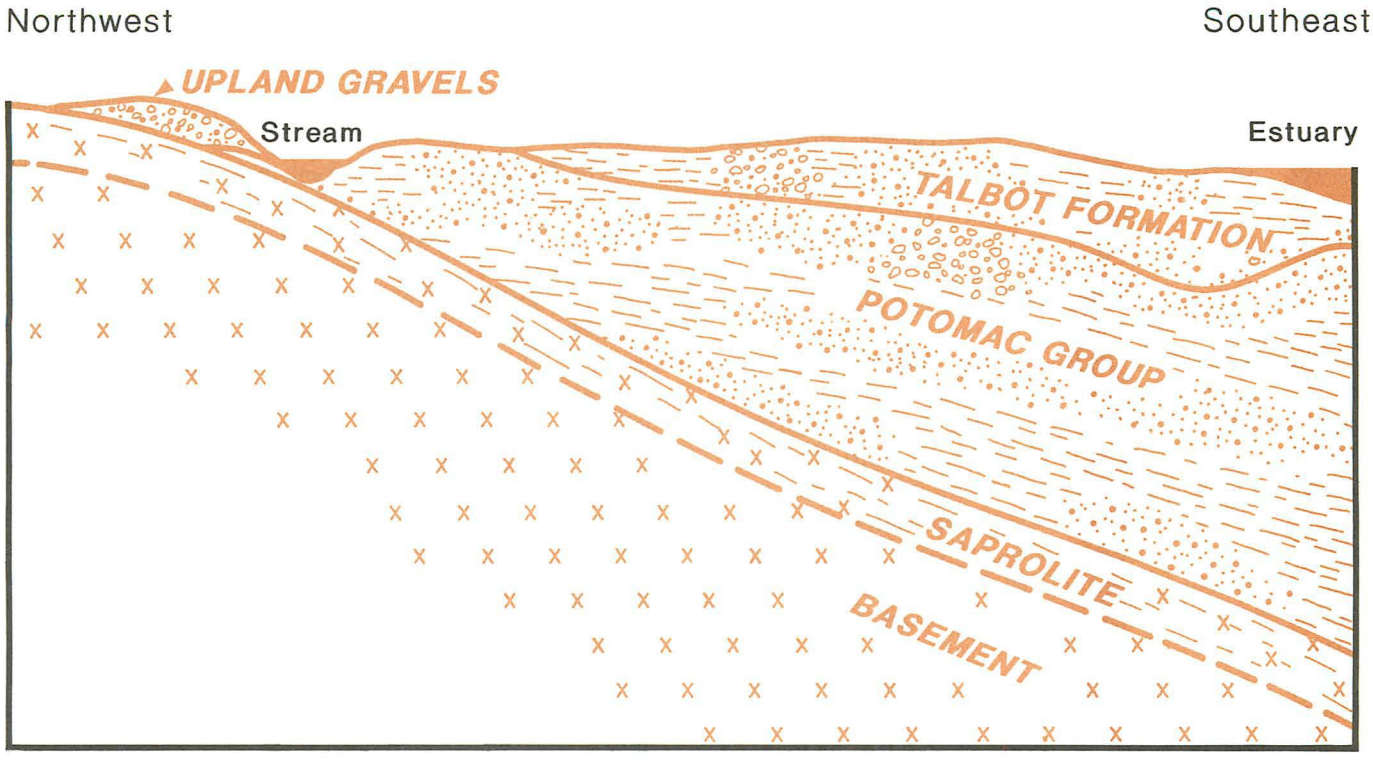
Financial support for this study was provided by the Maryland Geological Survey, the U.S. Geological Survey, and the Harford County Government.

The authors wish to express thanks to the Cranberry Run Business Center and the Perrywood Garden Associates for allowing test wells to be drilled on their properties, and to Aberdeen Proving Ground and the Baltimore Gas and Electric Company for supplying valuable data and for allowing water-level measurements in their wells. The authors would also like to thank the many homeowners and businesses who allowed water-level measurements and collection of water samples from their wells. Gilbert J. Brenner of the State University of New York at New Paltz performed palynological analyses of pollen, and Richard K. April of Colgate University performed X-ray, heavy-mineral, and exchangable-cation analyses of sediment samples.

HYDROGEOLOGY

Harford County spans two physiographic provinces—the Atlantic Coastal Plain and the Piedmont, which are separated by the Fall Line. The Coastal Plain is underlain by sediments such as clay, silt, sand, and gravel, which form productive aquifers in places. The Piedmont is underlain by hard crystalline rocks of the basement complex which are generally low-yielding aquifers (generally yielding less than 20 gal/min to wells). The scope of this report is limited to the Coastal Plain.

The Coastal Plain sediments of Harford County form a wedge-shaped body of sediments which were deposited on the southeastward-dipping surface of the Piedmont basement rocks (fig. 3). The wedge ranges in thickness from 0 ft at the Fall Line to about 700 ft at Spesutie Island (Edwards and Hansen, 1979). The sediments comprise three units: the Talbot Formation of Pleistocene age, the upland gravels of Late Tertiary age, and the Potomac Group of Early Cretaceous age. The Potomac Group



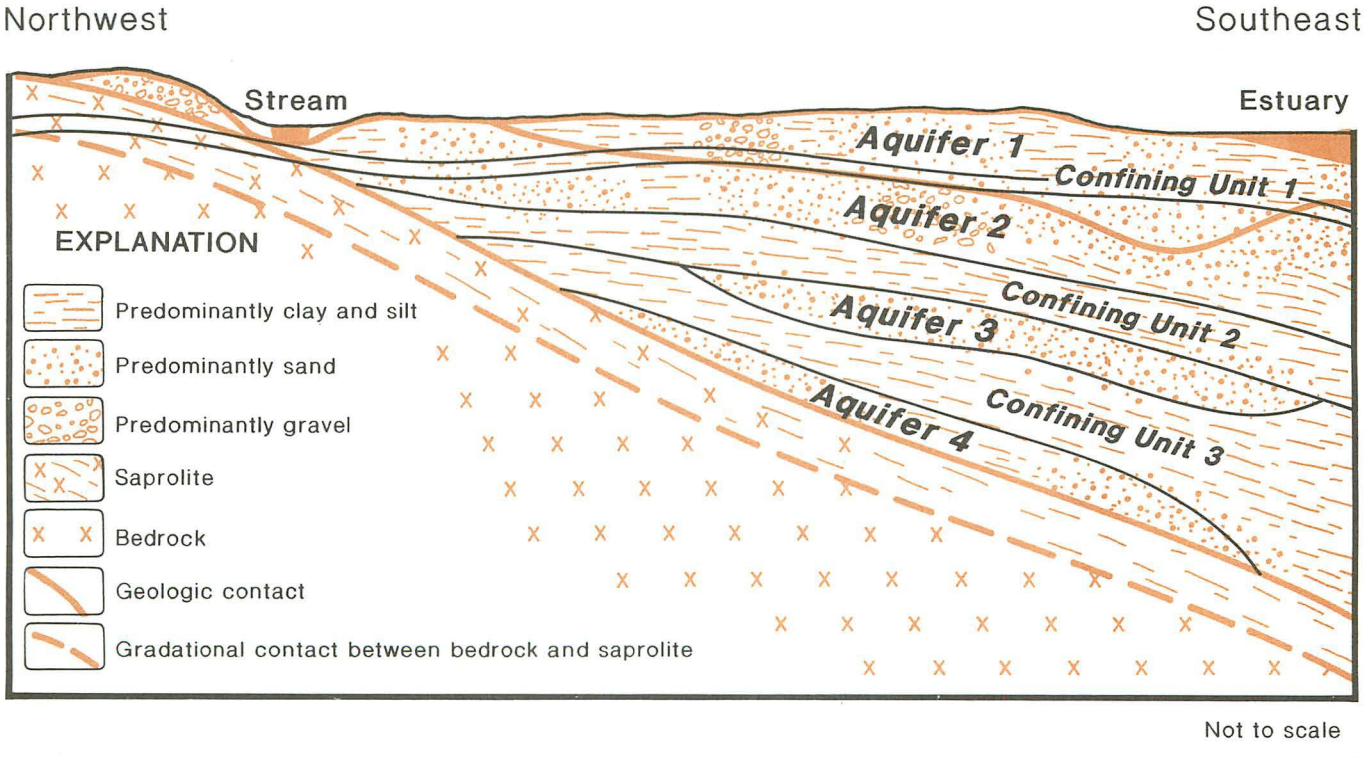


Figure 3.—Generalized cross section showing major stratigraphic units and hydrogeologic units in the Coastal Plain of Harford County.

has been further subdivided into the Patapsco, Arundel, and Patuxent Formations in the Baltimore area, but the subdivision is indefinite in Harford County. The crystalline rocks beneath the Coastal Plain sediments, referred to as "basement" or "bedrock," comprise several formations, predominantly of Paleozoic and Precambrian age (Southwick, 1969). The generalized stratigraphy of the Harford County Coastal Plain is shown in table 2.

STRATIGRAPHY

The stratigraphy of the Coastal Plain sediments in the outcrop area of Harford County was described by Brenner (1963), Owens (1969), and Glaser (1969). Edwards and Hansen (1979) described the stratigraphy at a deep test hole on Spesutie Island, about 6 mi southeast of the study area (fig. 1). Selected cores from the test holes drilled in this study were analyzed for pollen, heavy minerals, and clay assemblages to define the stratigraphic relationships in the shallow subsurface and to use the stratigraphy to improve the conceptual model of the hydrogeologic system.

The location of geologic and hydrogeologic sections is shown in figure 4. The stratigraphic data derived from the test wells is shown in geologic sections A-A′ and B-B′ in figures 5 and 6. The gamma logs of the wells are also shown in the geologic sections to indicate the sandy intervals (indicated by low gamma radiation) and clayey intervals (indicated by high gamma radiation). The geologic sections also show the core intervals and type of analyses performed on the cores. Stratigraphic determinations are shown where data are available from core analyses.

Talbot Formation

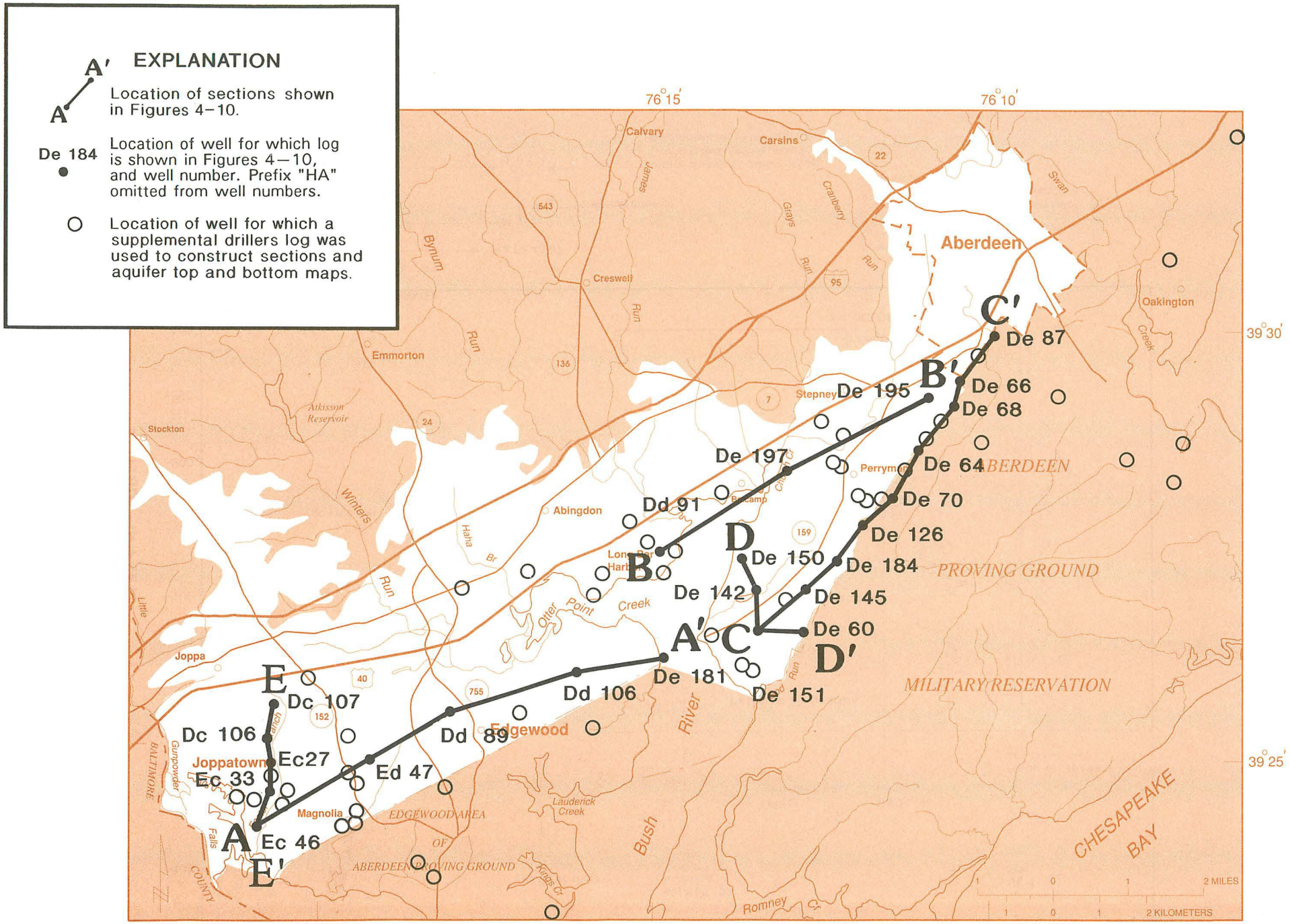
The shallowest stratigraphic unit in the study area is the Talbot Formation, a fluviatile unit of Pleistocene age. Owens (1969, p. 96–99) reported that the Talbot consists of a shallow silt and clay facies, up to 20 ft thick, and a deeper gravelly sand facies, as much as 35 ft thick, interbedded with dark clay layers as much as 10 ft thick. This description is generally accurate throughout the study area, although the clay layer in the gravelly sand facies at Long Bar Harbor is 24 ft thick. The lithology of the Talbot is extremely variable because of the changing thicknesses of the two facies (and absence in places) and the presence of the clay interbeds in the gravelly sand facies.

The Pleistocene age of the Talbot Formation was determined by regional relations rather than by age-dating floral assemblages, and no core samples from this study yielded datable pollen. These sediments are relatively young and compositionally immature—that is, they include relatively unstable components, such as amphiboles and pyroxenes in the heavy-mineral suites, and smectite in the clay assemblages (Owens, 1969, p. 98).

Core samples from the Long Bar Harbor (fig. 4) test-well site (HA Dd 91) contained heavy-mineral assemblages indicative of the Talbot Formation, including abundant hornblende and some pyroxenes at 20 ft (altitude 0 ft). The X-ray mineralogical

Table 2.—Generalized hydrogeology and stratigraphy of the Harford County Coastal Plain

System	Series	Hydro-geologic unit	Stratigraphic unit	Thickness (feet)	Lithology	Water-bearing properties
Quaternary	Pleistocene	Aquifer 1	Talbot Formation	0-60	Highly variable; clay, silt, sand, and gravel.	Functions as an unconfined or semiconfined aquifer where coarse-grained and a confining unit where fine-grained.
Tertiary(?)	Pliocene (?) and/or Upper Miocene(?)		Upland Gravels	0-40	Intercalated gravel and sand with thin lenses of silt-clay. Distributed as isolated patches.	Yields small amounts of water to domestic wells, but not an important aquifer because of limited extent.
Cretaceous	Lower Cretaceous	Aquifer 2	Potomac Group	0-630	Highly variable; interbedded light-colored sand, variegated silty clay, and very gravelly sand.	Functions as major confined and semiconfined aquifers where coarse-grained and confining units where fine-grained.
		Aquifer 3				
		Aquifer 4				
Paleozoic			Basement Complex		Various types of crystalline rock and saprolite.	Yields small amounts of water in the Piedmont and where the overlying Coastal Plain sediments are thin or impermeable.



Base map from U.S. Geological Survey, 1:100,000

Figure 4.—Locations of geologic and hydrogeologic sections.

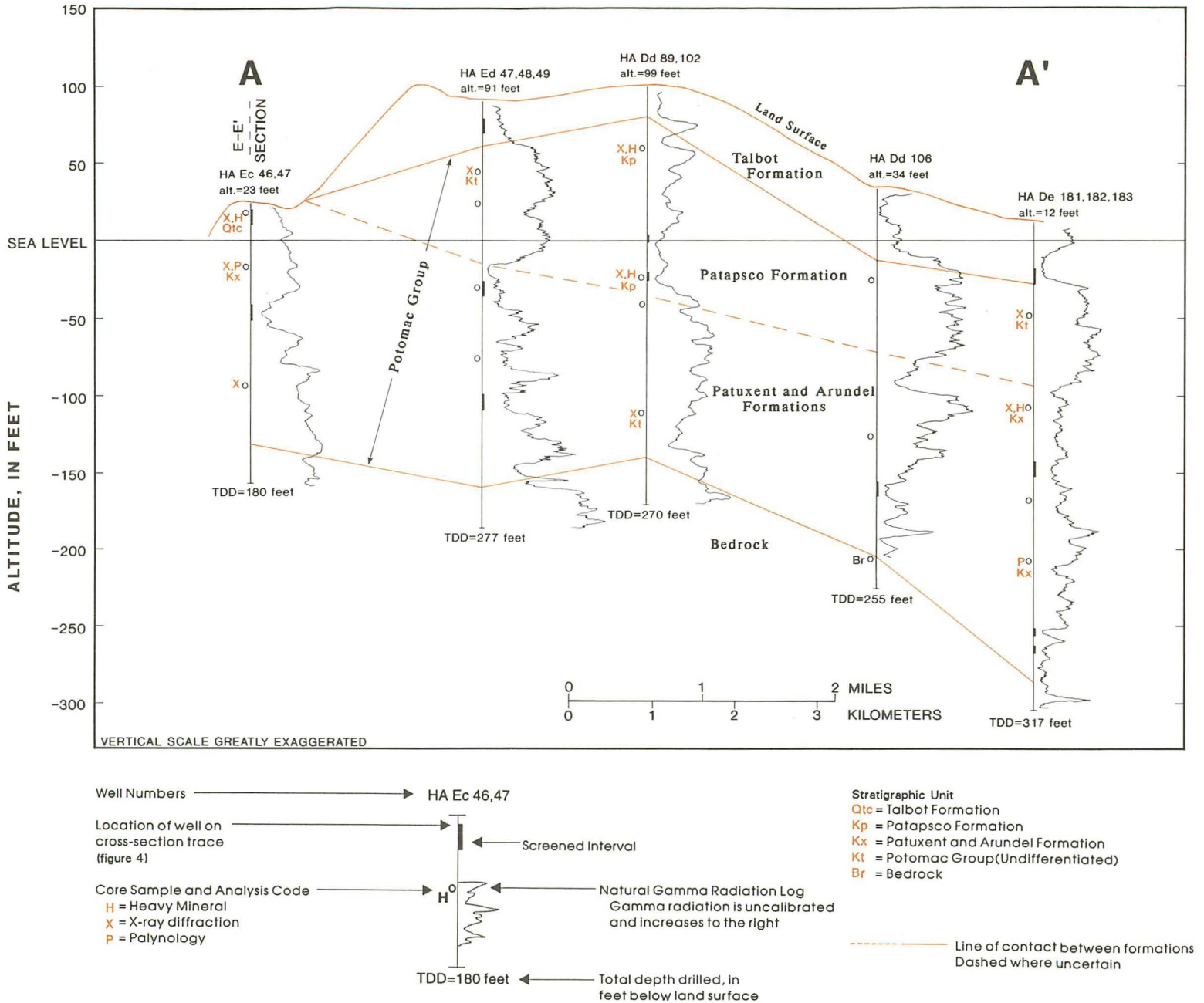


Figure 5.—Geologic section A-A′ showing major stratigraphic units and test-well data.

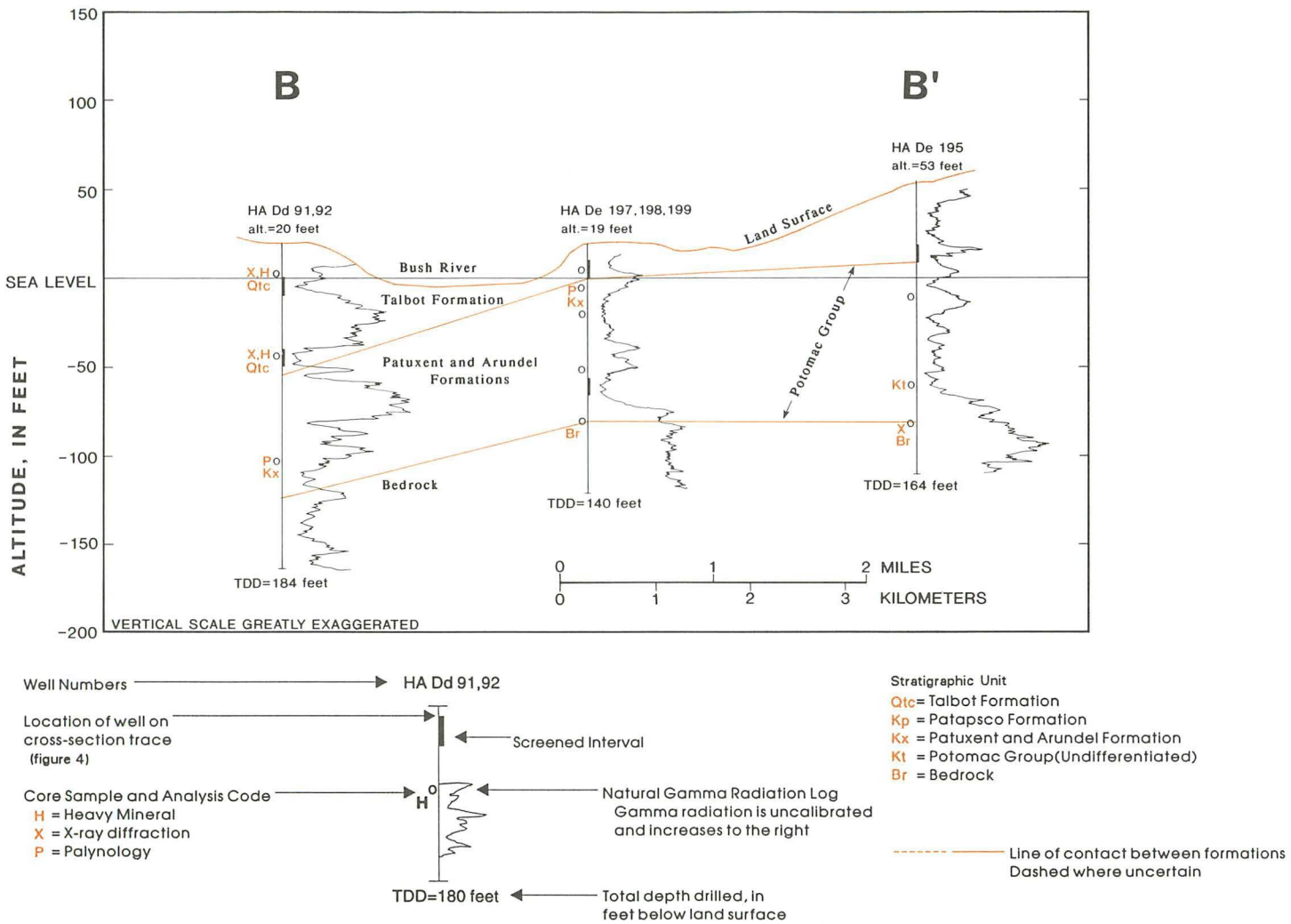


Figure 6.—Geologic section B-B′ showing major stratigraphic units and test-well data.

analysis of the sample at a 64-ft depth (altitude -44 ft) also indicated an immature sediment, with a significant amount of smectite. The sample at a 20-ft depth contained 5- to 20-percent feldspar indicating an immature composition. The core sample from a 5-ft depth (altitude 18 ft) at Joppatowne (HA Ec 47) also contained a high smectite content and lithic fragments, indicating that it is from the Talbot Formation.

Upland Gravels

The upland gravels, an alluvial unit of Late Tertiary age, are stratigraphically older than the Talbot Formation. The upland gravels form isolated patches that cap some hills near the Fall Line. In places, they overlie Potomac Group sediments; in other places they overlie Piedmont rocks and are isolated from the rest of the Coastal Plain sediments. The maximum thickness of this unit is 40 ft. The lithology of this unit is variable, and consists of intercalated sand and gravel, and thin, discontinuous lenses of silt and clay. No datable floral assemblages have been reported from the upland gravels in Harford County. The age determination is based on their similarity to Late Tertiary gravel beds in Brandywine, Md., where a Late Miocene floral assemblage has been documented (McCartin and others, 1990, p. 311). Owens (1969, p. 95) tentatively assigned the upland gravels to the Pliocene. No test wells drilled for this study penetrated the upland gravels.

Potomac Group

The deepest sedimentary stratigraphic unit underlying the study area is the Potomac Group, a fluviatile deposit of Early Cretaceous age. The Potomac Group ranges in thickness in the study area from 0 ft to about 300 ft at Sod Run (fig. 4), and is about 627 ft thick at the Spesutie Island test hole. In the Baltimore area to the southeast, the Potomac Group is divided into three formational units—the Patapsco, Arundel, and Patuxent Formations. The Patapsco and Patuxent are lithologically similar, and consist predominantly of sandy units intercalated with multicolored clay lenses. They are separated by the distinctive red-and-gray massive clay of the Arundel Formation. Brenner (1963) observed that the microfloral assemblages of the Patuxent and Arundel Formations were indistinguishable and assigned these formations to palynological Zone I, which correlates with the Barremian(?) and Aptian stages of the Early Cretaceous. The presence of angiosperm (flowering plants) pollen in the Patapsco Formation distinguishes it from the underlying formations. Brenner (1963) assigned the Patapsco Formation to palynological Zone II and correlated it with the Albian stage of the Early Cretaceous.

The heavy-mineral suites of the Patuxent and Patapsco Formations are also distinct. The Patuxent Formation contains a staurolite-kyanite assemblage, whereas the Patapsco contains a zircon-tourmaline-rutile assemblage (Bennett and Meyer, 1952; Owens, 1969). Anderson (1948) observed that epidote is common in heavy-mineral assemblages of the Patapsco Formation on the Eastern Shore of Maryland.

Northeast of Baltimore, the Arundel Clay is difficult to identify and division of the Potomac Group into formational units on the basis of lithology becomes difficult (Owens, 1969). Without the distinctive marker bed of the Arundel Clay, separation of the Patuxent and Patapsco Formations requires either palynological dating or heavy-mineral analysis.

Seven core samples and one outcrop sample were analyzed for palynology. Four samples were barren and four yielded Zone I palynomorphs that are characteristic of the Patuxent and Arundel Formations. No samples contained Zone II palynomorphs characteristic of the Patapsco Formation. In fact, the only irrefutable Zone II assemblage reported in the literature for Harford County is from the 188- to 190-ft core of the Spesutie Island test hole (Edwards and Hansen, 1979). The scarcity of data necessary to identify the Patapsco Formation makes it difficult to subdivide the Potomac Group in Harford County.

The heavy-mineral analyses provide some additional age-related information. The core from a 120-ft depth (altitude -108 ft) in well HA De 181 (fig. 5) contains high percentages of staurolite and kyanite, indicative of the Patuxent Formation. The scarcity of amphiboles, pyroxene, feldspar, and smectite indicate that the sediments are compositionally mature and originate from the Cretaceous period. The core samples from HA Dd 102 at depths of 40 ft (altitude -59 ft) and 120 ft (altitude -21 ft) (fig. 5) are probably from the Patapsco Formation on the basis of small proportions of staurolite. The large proportion of epidote at 124-ft depth (altitude -25 ft) (67.2 percent) and the large proportions of zircon, tourmaline, and rutile at 40-ft depth (altitude -59 ft) (19.1, 27.9, and 1.5 percent) also indicate that these samples are from the Patapsco Formation. The large proportions of apatite from these two samples are unusual because apatite has not been reported in the outcrop or shallow subsurface sediments in Baltimore or Harford Counties. Two sediment samples with large proportions of apatite (15 and 24 percent) were reported (Anderson, 1948) from depths of 6,930 and 7,040 ft in Worcester County, on the Eastern Shore of Maryland. Both samples were from the Patuxent Formation.

The core samples from wells HA De 181 at a 61-ft depth (altitude -49 ft) and HA Ed 47 at 47 ft (altitude -35 ft) contain low percentages of smectite, indicating mature clay assemblages, and thus, Potomac Group origin. The formations from which these samples originated cannot be determined. The sample from HA Ec 47 at a 117-ft depth (altitude -94 ft) also contains a small percentage of smectite, and because the sample was collected deeper than the Patuxent sample at a 40-ft depth, it must also be from the Patuxent Formation.

Basement Complex

The geology of the Piedmont rocks of Harford County was mapped and studied in detail by Southwick (1969), and the geology of the crystalline basement rocks was described from the deep test hole at Spesutie Island by Edwards and Hansen (1979). No systematic study has been undertaken to describe the basement rock complex beneath the Coastal Plain sediments in Harford County.

The crystalline rocks that abut the Fall Line adjacent to the study area include the Wissahickon Formation, the James Run Gneiss, the Port Deposit Gneiss, the Setters Formation (quartzite and schist), and the Baltimore Gneiss to the southwest, and the metagabbro and amphibolite rocks to the northeast (Southwick, 1969). These rocks probably extend southeastward beneath the Coastal Plain sediments, but spatial control is insufficient to map them.

AQUIFER DESCRIPTIONS

The lithology of the Coastal Plain sediments in Harford County is extremely variable, giving rise to hydrogeologic units (aquifers and confining units) of limited extent. Additionally, the boundaries of hydrogeologic units in places do not coincide with the boundaries of stratigraphic units. For example, a sand bed in the Talbot Formation could directly overlie a sand bed in the Potomac Group, forming a single hydrogeologic unit. For these reasons, the traditional aquifer designations, based on stratigraphic relations, are not particularly useful in the study area. In this report, the Coastal Plain sequence was divided into four aquifers and three confining units, from shallowest to deepest, designated aquifers 1, 2, 3, and 4, and separated by confining units 1, 2, and 3. This designation is arbitrary and, in places, poorly defined, but necessary primarily for flow-modeling purposes.

The distribution of aquifers and confining units is shown in hydrogeologic sections A-A′, B-B′, C-C′, D-D′, and E-E′ in figures 7 through 11. The section locations are shown in figure 4. The sections were prepared by using 74 drillers' logs, only some of which are displayed.

The aquifers and confining units are described in order of descending occurrence. The sediments are variable and some generalization was necessary to divide them into aquifers and confining units. In general, the aquifers include some impermeable sediments and the confining units include some permeable sediments. Hydraulic properties determined from aquifer and laboratory tests are site-specific and might not be applicable over large areas. The hydraulic-conductivity maps for each of the aquifers were constructed by compiling 74 drillers' and geologists' logs and estimating the hydraulic conductivities for each aquifer and confining unit the borehole penetrated on the basis of lithology.

Continuous water-level recorders were installed on 10 observation wells. The hydrographs generated from the water-level data can be compared to other time-series data, such as tidal fluctuations, barometric fluctuations, river stage, and precipitation events to determine the causes of water-level changes in the wells. Graphs of these data are shown in figure 13 at the same scale as the hydrographs from the wells (figures 17, 21, 25, and 29), and the locations of the data points and hydrographs are shown in figure 12. The graphs include tide level from a temporary tide gage installed at Willoughby Beach, barometric pressure and daily precipitation from a weather station at Phillips Field on Aberdeen Proving Ground, and stream stage from a temporary streamflow gage on Cranberry Run at Perryman.

Aquifer 1

Aquifer 1 is an unconfined aquifer and is the shallowest hydrogeologic unit in the study area. It includes much of the Talbot Formation, all of the upland gravels where they are contiguous with the Coastal Plain outcrop, and the shallow part of the Potomac Group where it crops out. Because of the extreme lithologic variability of the shallow sediments throughout the study area, no attempt was made to exclude the fine-grained, low-permeability sediments from aquifer 1. It is a surficial aquifer that blankets the area and receives recharge from precipitation, provides base flow to streams, discharges water as evapotranspiration, and discharges water to the Chesapeake Bay and its tidal tributaries.

Extent

Aquifer 1, by definition, extends throughout the entire study area. The upper boundary is the land surface or upper limit of the water table (fig. 14), and its altitude ranges from sea level at the shoreline to about 360 ft above sea level at the innermost edge of the Coastal Plain. The lower boundary of the aquifer is defined as a surface 1 ft above the upper surface of aquifer 2 (fig. 15), and its altitude ranges from about 75 ft below sea level in the southeastern part of the study area to more than 125 ft above sea level near Carsins. There is no natural well-defined bottom surface of this aquifer because of its variability. The thickness of aquifer 1 ranges from about 5 to 225 ft.

Most of the Talbot Formation is included in this aquifer, with the exception of some sandy units in the lower part of the formation. At Long Bar Harbor a deep sand in the Talbot Formation (well HA Dd 91) is hydraulically confined and separated from the shallower sand in aquifer 1, and the deeper sand was included in aquifer 2 (figs. 6 and 8). Similarly, the sands in the Perryman area between sea level and approximately 25 ft above sea level are probably of Talbot origin and comprise a productive semiconfined aquifer included in aquifer 2 (fig. 9). The patches of upland gravels that are contiguous with the main part of the Coastal Plain are shallow and unconfined, and were included in aquifer 1. Where Potomac Group sediments crop out in the southeastern part of the study area and northwest of Aberdeen, the shallow part of these sediments was included in aquifer 1.

Hydraulic Properties

Few data are available on the hydraulic properties of aquifer 1 in the study area. Oliveros and Vroblesky (1989) reported horizontal hydraulic conductivity values derived from slug tests ranging from 11 to 44 ft/d (ft per day) and averaging 23 ft/d for the surficial aquifer in the Canal Creek area, about 1 mi south-

(Text continued on p. 25.)

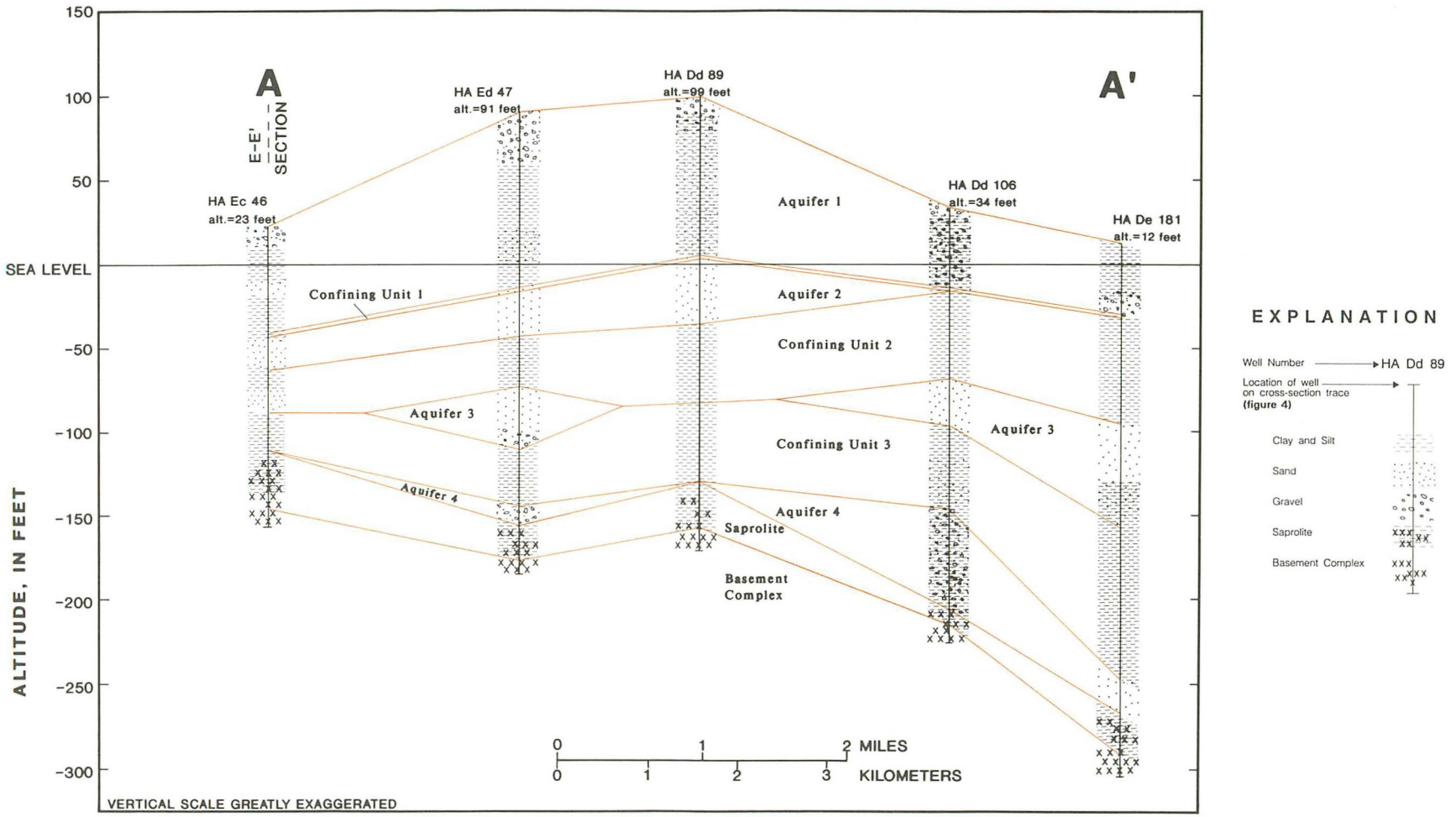


Figure 7.—Hydrogeologic section A-A′ showing major hydrogeologic units in the Coastal Plain of Harford County.

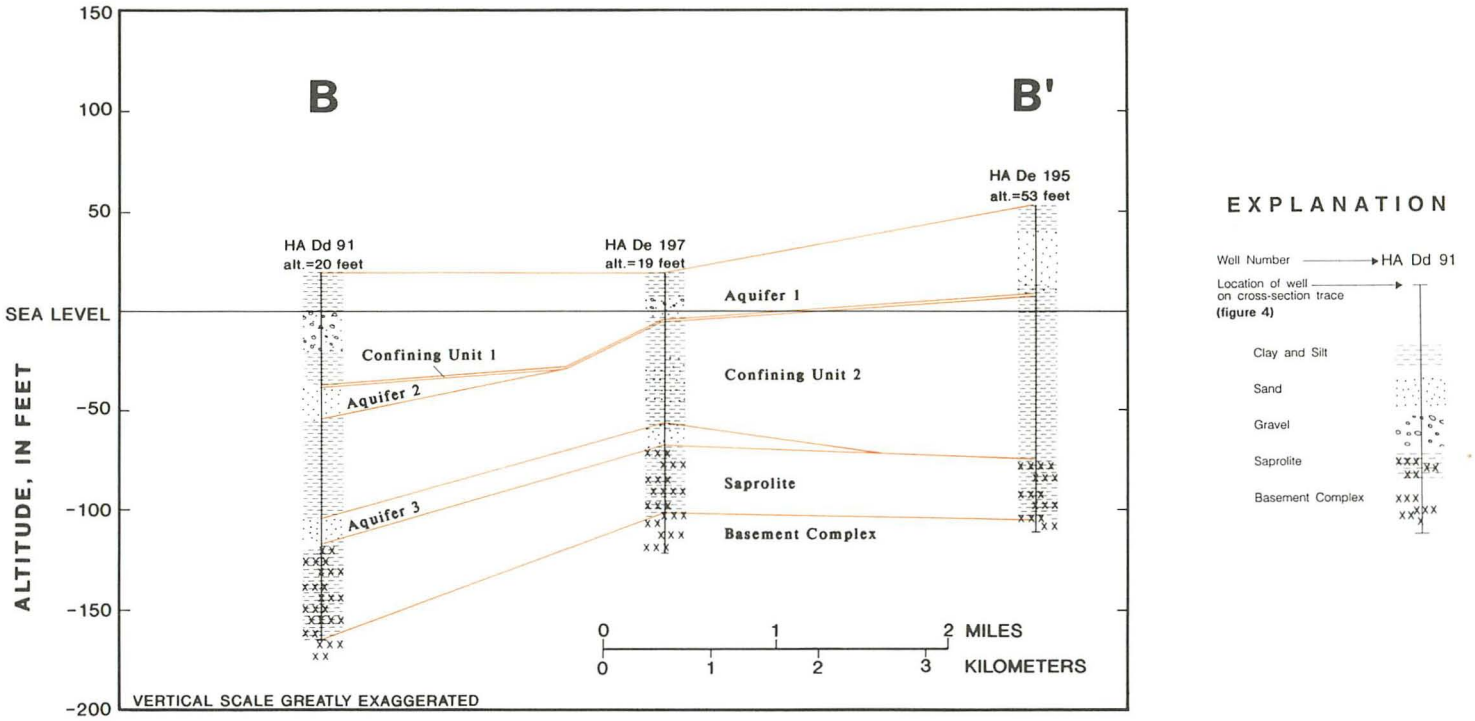


Figure 8.—Hydrogeologic section B-B′ showing major hydrogeologic units in the Coastal Plain of Harford County.

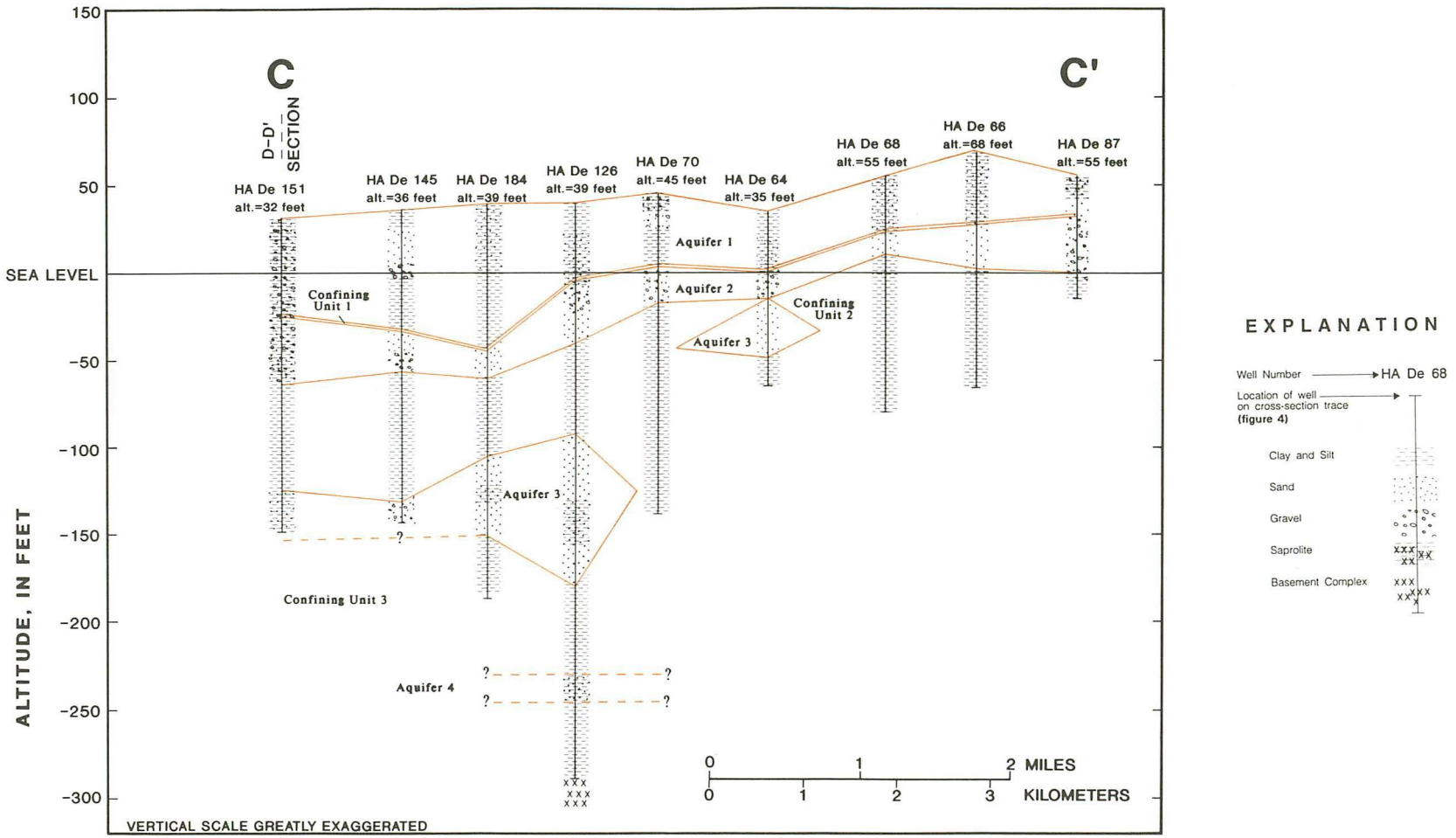


Figure 9.—Hydrogeologic section C-C′ showing major hydrogeologic units in the Coastal Plain of Harford County.

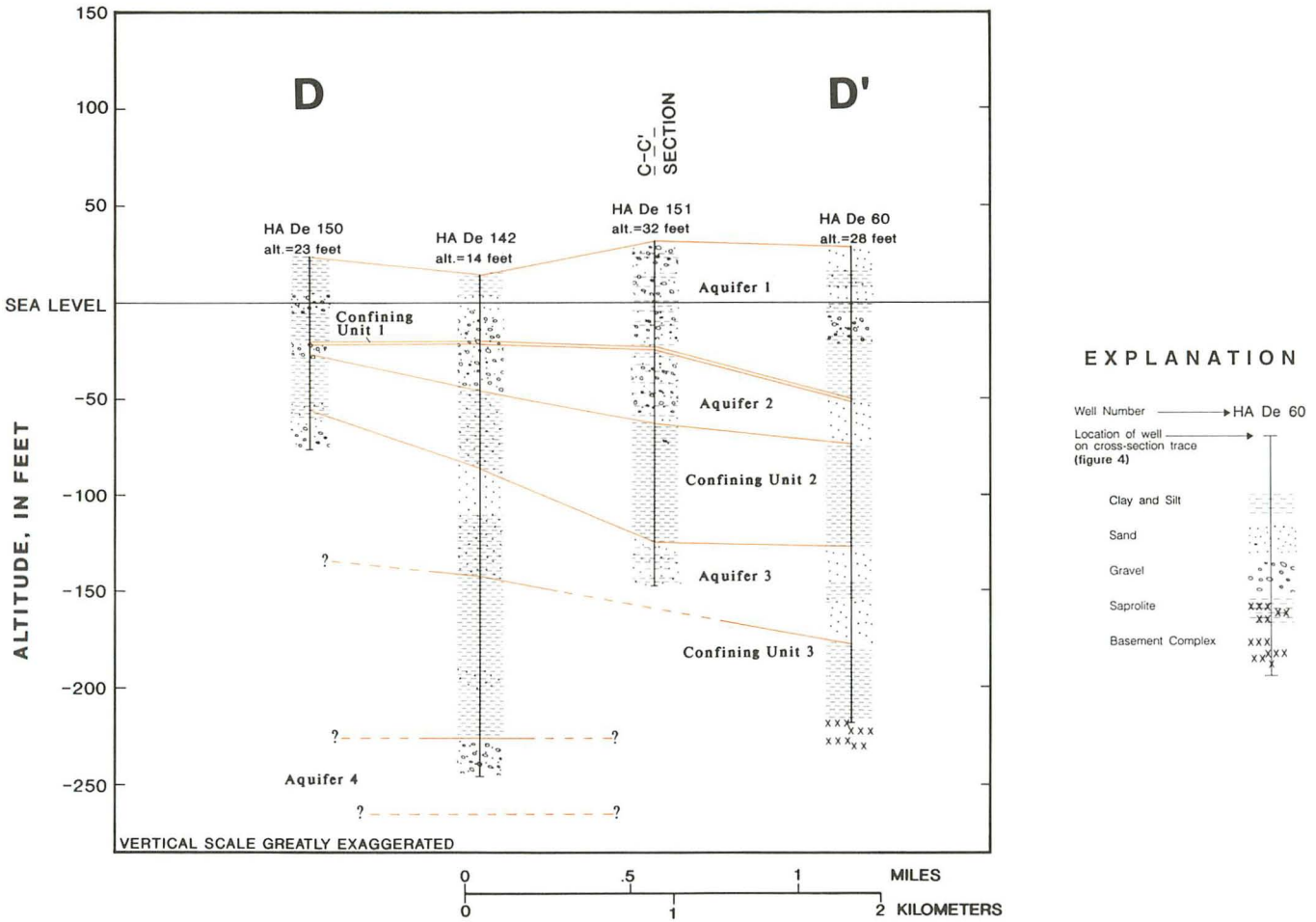


Figure 10.—Hydrogeologic section D-D′ showing major hydrogeologic units in the Coastal Plain of Harford County.

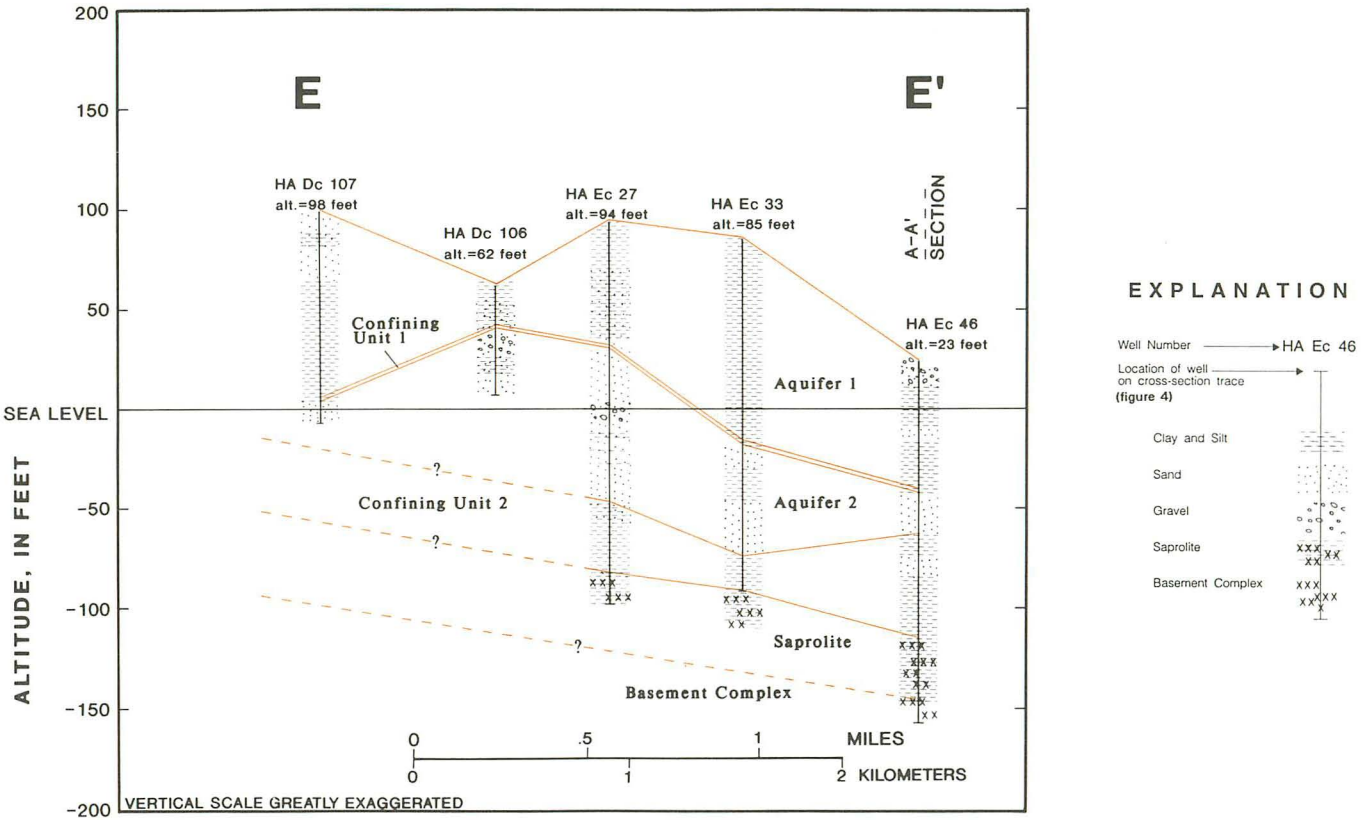
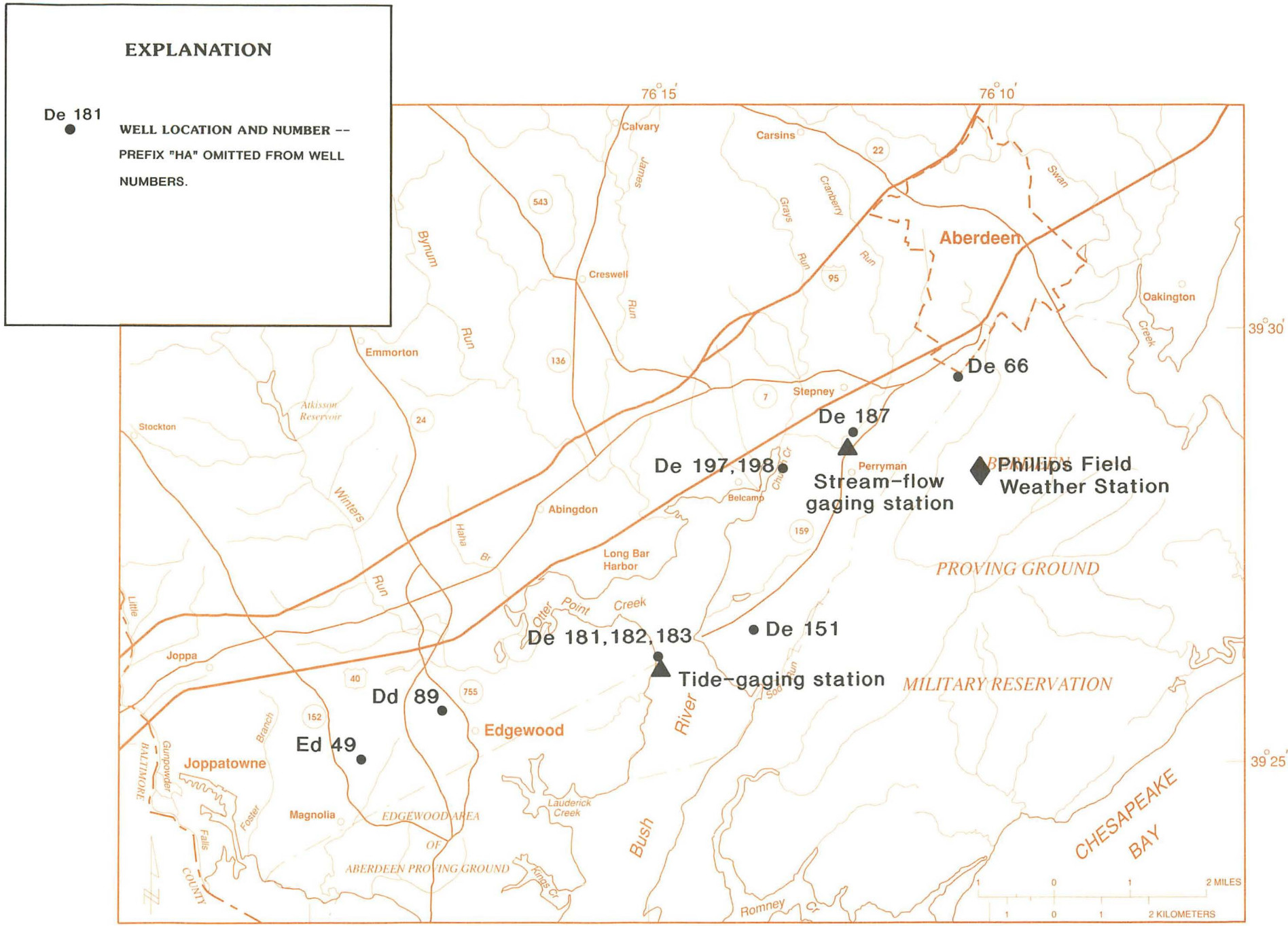


Figure 11.—Hydrogeologic section E-E′ showing major hydrogeologic units in the Coastal Plain of Harford County.



Base map from U.S. Geological Survey, 1:100,000

Figure 12.—Locations of wells with hydrographs, Phillips Field weather station, streamflow-gaging station at Perryman, and tidal-gaging station at Willoughby Beach.

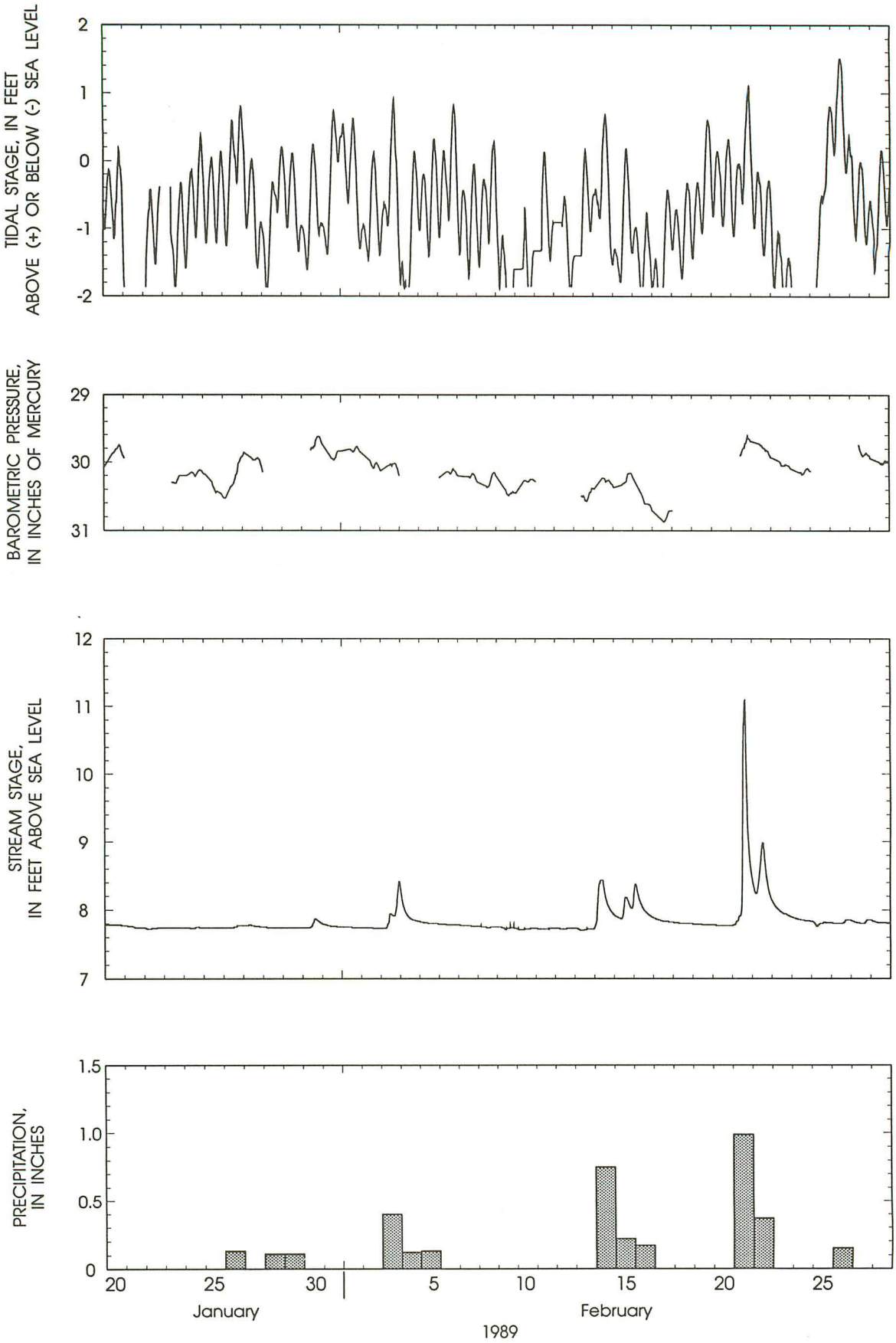
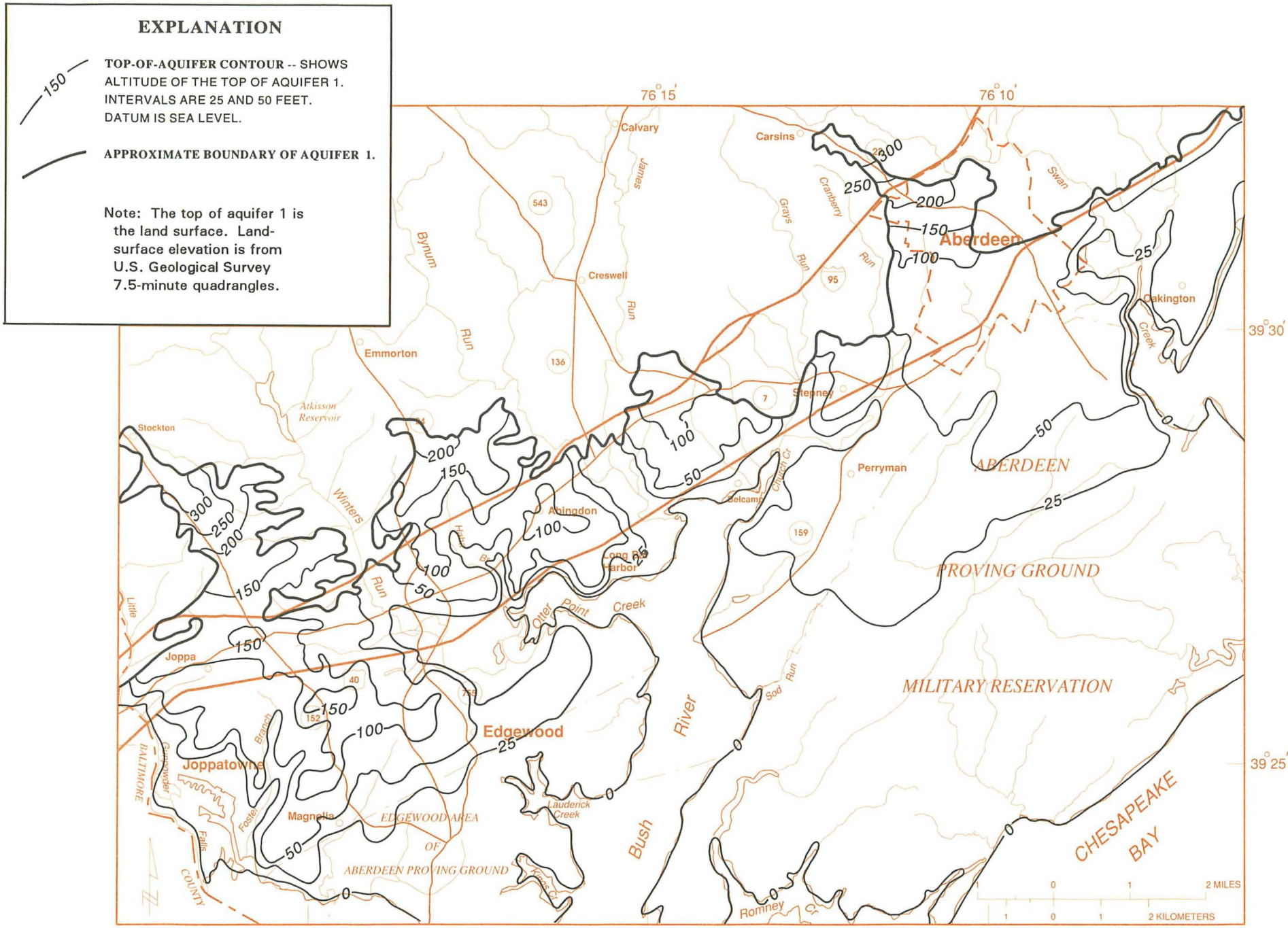
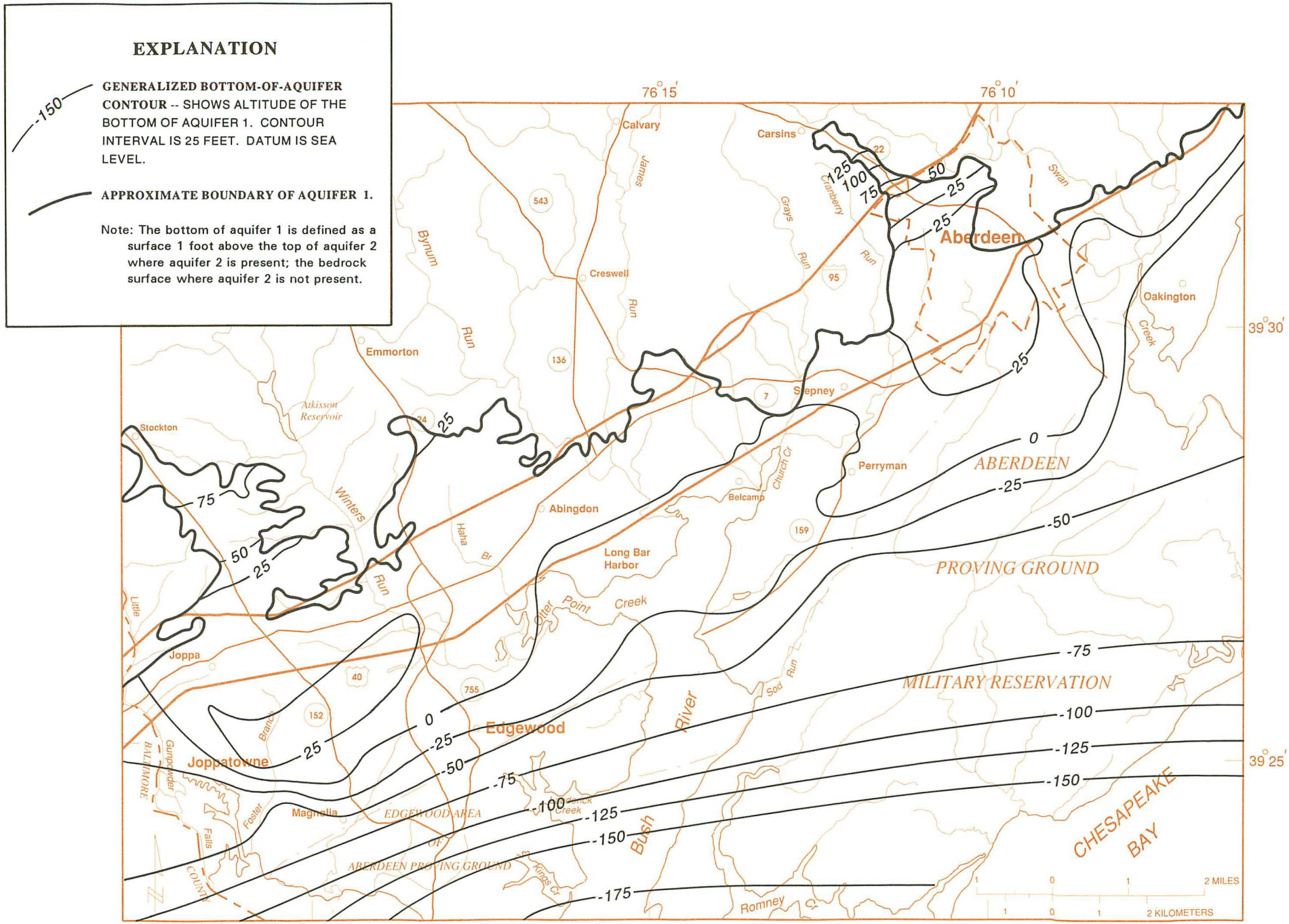


Figure 13.—Precipitation and barometric pressure at Phillips Field, stream stage at Cranberry Run at Perryman, and tidal stage at the Bush River at Willoughby Beach, January 20 to February 28, 1989.



Base map from U.S. Geological Survey, 1:100,000

Figure 14.—Altitude of top of aquifer 1.



Base map from U.S. Geological Survey, 1:100,000

Figure 15.—Altitude of bottom of aquifer 1.

east of Magnolia (tab. 3). The surficial aquifer is included in aquifer 1. Horizontal hydraulic conductivities derived from model calibration range from 2.0 to 630 ft/d. The lower range of these values is low for aquifer material and reflects the effects of some low-permeability sediments in the aquifer. Specific-yield data are not available for this aquifer, but probably range from 0.01 to 0.30 (Freeze and Cherry, 1979, p. 61).

Water Levels

Water levels in aquifer 1 represent the altitude of the water table. Perched water tables, which are higher than the regional water table could also be present locally. Figure 16 shows the altitude of the water table based on water-level measurements made in May 1989. The contour locations were determined primarily by the elevations of perennial streams and were supplemented by measured ground-water levels.

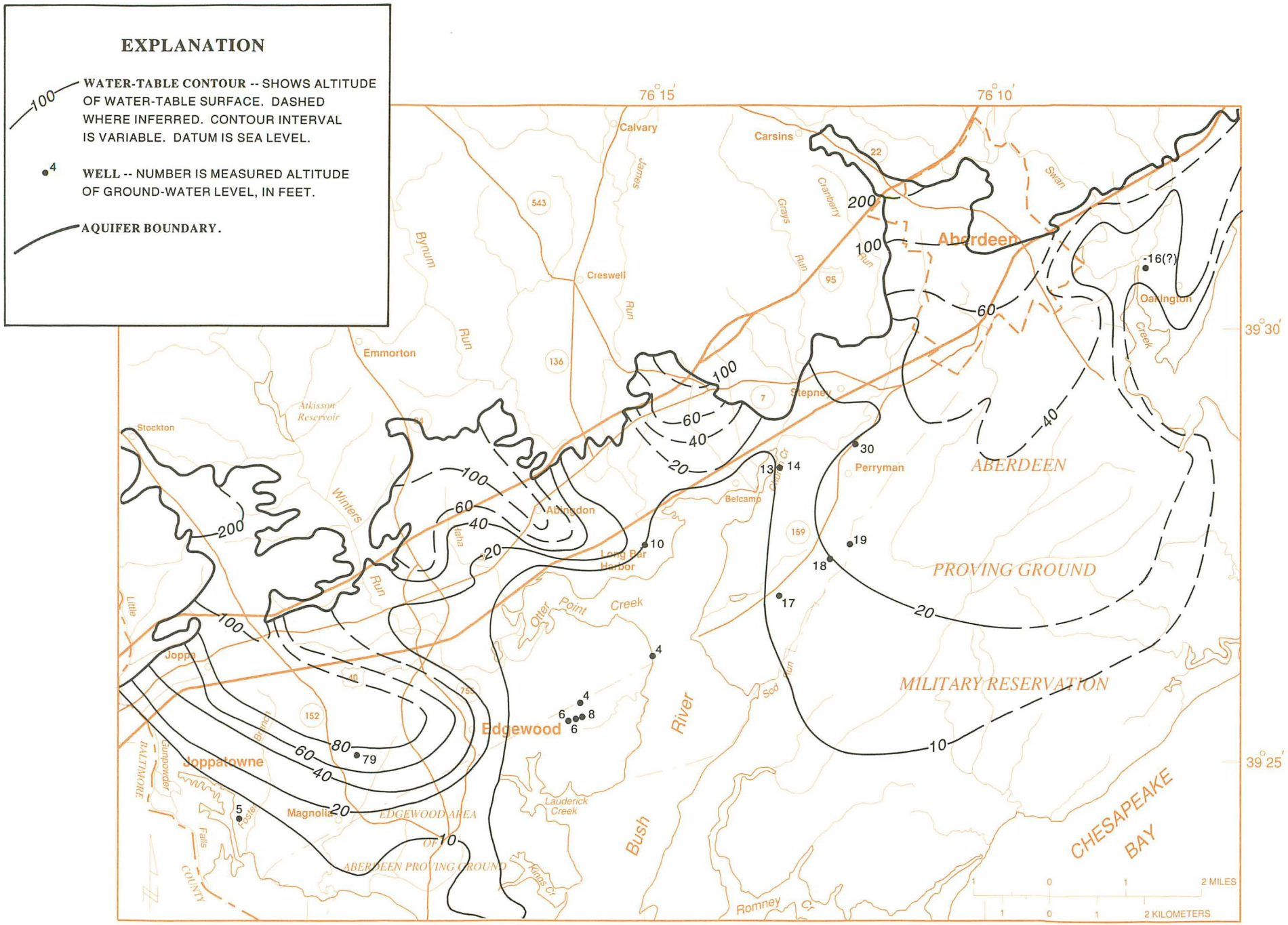
The water-table altitude ranges from over 200 ft above sea level in the topographically higher parts of the Coastal Plain at Stockton and Carsins to near sea level at the tidal estuaries. Water-table altitudes are high to the southeast on the Edgewood and Aberdeen peninsulas, and water-table altitudes are low to the northwest where the major stream valleys intersect the water table. The head distribution in aquifer 1 indicates that the aquifer is recharged primarily in the upland areas near the Fall Line. Water flows toward the low-elevation areas and discharges near the tidal estuaries. Water also leaks downward into underlying aquifers in the areas where water-table altitudes are high. Numerous shallow flow systems in which water in aquifer 1 follows short flow paths to nearby streams also are present.

Table 3.—Hydraulic properties of aquifers

[ft^2/d = feet squared per day; ft/d = feet per day; -- = data not available]

Location	Well number	Aquifer	Transmissivity (ft^2/d)	Hydraulic conductivity (ft/d)	Storativity	Source
Cranberry Run	HA De 196	1	210	6.6	--	2
Canal Creek	1	1	400	23	--	2
Long Bar Harbor	HA Dd 91	2	300	30	--	2
Perryman	HA De 76	2	35,000	750	0.0004	4
Perryman	HA De 77	2	30,000	870	.0006	4
Perryman	HA De 128	2	17,000	480	--	4
Joppatowne	HA Ec 18	2	6,600	220	--	5
Joppatowne	HA Ec 19	2	4,000	72	--	6
Aberdeen Proving Ground-Edgewood Area	HA Ed 14	2	340	14	.03	5
Trimble Road	HA Ed 48	2	270	8.9	--	2
Trimble Road	1	2	2,200	72	--	4
Canal Creek	1	2	2,500	50	--	3
Perryman	HA De 58	3	5,200	100	.0002-.002	4
Perryman	HA De 59	3	6,500	130	.0002-.002	4
Perryman	HA De 64	3	3,000	770	--	4
Perryman	HA De 67	3	1,500	430	.00004	4
Perryman	HA De 124	3	3,700	50	--	4
Perryman	HA De 129	3	3,400	85	.00007-.001	4
Church Creek	HA De 197	3	62	6.2	--	2

[1] Average value from several aquifer tests.
[2] This study.
[3] Oliveros and Vroblesky (1989).
[4] Whitman, Requardt and Associates (1976).
[5] Maryland Geological Survey files.
[6] Hansen (1972).



Base map from U.S. Geological Survey, 1:100,000

Figure 16.—Altitude of water table in aquifer 1, May 1989.

Hydrographs of four wells screened in aquifer 1 for the period January 20 through February 28, 1989, display distinctive patterns that are indicative of the aquifer conditions at each location (fig. 17). The hydrograph for well HA Ed 49 is fairly flat with a muted delayed response to recharge events. A small rise is barely discernable on February 22, 1989, during a major storm (fig. 13). Water levels tend to increase gradually after major periods of precipitation and decline gradually during periods of little or no precipitation. The absence of a water-level response to barometric fluctuations indicates that the aquifer is unconfined. These conditions are confirmed by the hydrology at that site: The well is near the side of a hill distant from major streams or estuaries, and it is screened in a shallow sand that is not overlain by confining material.

The hydrograph for well HA De 198 shows a similar pattern in that the water levels rise after major periods of precipitation, but the rises are more rapid, indicating faster recharge. A slight semidiurnal tidal fluctuation (fig. 13) is superimposed on the curve because of the proximity of the well to the tidal Church Creek. The bottom of the aquifer is at sea level and the aquifer does not extend beneath the estuary, which explains the low amplitude of the tidal fluctuation.

Well HA De 187 is located next to Cranberry Run at the stream gage in Perryman. The hydrograph for this well shows a pattern similar to the stream-stage hydrograph (fig. 13), with rapid water-level rises in response to precipitation, followed by slightly slower declines. The similar pattern indicates interconnection between the stream and aquifer 1. The storm responses on the well hydrograph are superimposed on a water-level trend similar to that of HA Ed 49, in which the water levels increase slowly in response to precipitation and decrease slowly during rainless periods.

The hydrograph for well HA De 182 shows semidiurnal tidal fluctuations nearly identical in period to the tidal fluctuations in the Bush River at Willoughby Beach (fig. 13). The amplitude range of the fluctuations in the well is about 40 percent of that in the Bush River. The tidal fluctuation indicates that the aquifer extends beneath the Bush River and could be hydraulically connected to it. The altitude of the bottom of the aquifer is deep enough here to support this contention, whereas the aquifer is not deep enough to extend below Church Creek near well HA De 198.

Confining Unit 1

Confining unit 1 extends throughout most of the study area and to the Chesapeake Bay southeast of the study area. It is present where aquifers 2, 3, or 4 are present. In areas where the deeper aquifers are not present, the confining unit is undefined. The upper boundary of confining unit 1 is defined by the lower boundary of aquifer 1, and the lower boundary of confining unit 1 is defined by the upper boundary of aquifer 2. This configuration is designed to assign confining unit 1 an arbitrary thickness of 1 ft for modeling purposes.

The lithology of confining unit 1 is primarily sandy silt and clay, but might include small areas of sand and gravel. No published data are available on the hydraulic properties of this unit. For modeling purposes, vertical hydraulic conductivities initially were estimated from lithologic logs and then adjusted during model calibration. The resulting vertical hydraulic conductivity values range from 5×10^{-4} to 5×10^{-1} ft/d.

Aquifer 2

Aquifer 2, which is subjacent to confining unit 1, is mostly confined but could be semiconfined in places. It includes sediments of the Potomac Group and Talbot Formation.

Extent

Aquifer 2 extends to the northwest either to the Fall Line or to the updip truncation, and to the southeast beyond the boundary of the study area (fig. 18). The aquifer boundaries were determined by interpreting about 75 lithologic logs. Aquifer 2 is bounded on the top by confining unit 1 and on the bottom by confining unit 2. The top of the aquifer ranges from about 25 ft above sea level near Aberdeen to about 75 ft below sea level in the southwest corner of the study area, and deeper to the southeast of the study area (fig. 18). The bottom of aquifer 2 ranges from about 10 ft above sea level near Aberdeen to about 160 ft below sea level near Sod Run, and deeper to the southwest of the study area (fig. 19). The thickness of aquifer 2 ranges from 0 ft to about 175 ft.

Hydraulic Properties

Horizontal hydraulic conductivities estimated from aquifer tests for aquifer 2 range from 8.9 to 870 ft/d. Hydraulic conductivity is lower where the aquifer contains abundant silt and clay and is highest near Perryman and Joppatowne where the aquifer contains predominantly sand and gravel. Transmissivity values estimated from aquifer tests range from 270 to 35,000 ft^2/d, and storage coefficients range from 0.0004 to 0.03 (tab. 3).

Water Levels

Water levels in aquifer 2 represent the potentiometric surface of the confined aquifer. Water levels measured in May 1989 are shown in figure 20 with the contours of altitude of the potentiometric surface. Water levels range from about 42 ft above sea level near Aberdeen to 5 ft above sea level near the tidal estuaries. The potentiometric surface shows the same general pattern displayed by the water table in aquifer 1—that is, relatively high altitudes in the high-elevation parts of the Edgewood and Aberdeen peninsulas and low altitudes near sea level at the shoreline of the Chesapeake Bay and along the Bush and Gunpowder Rivers. Differences in water levels indicate that ground water generally flows downward from aquifer 1 to aquifer 2 in

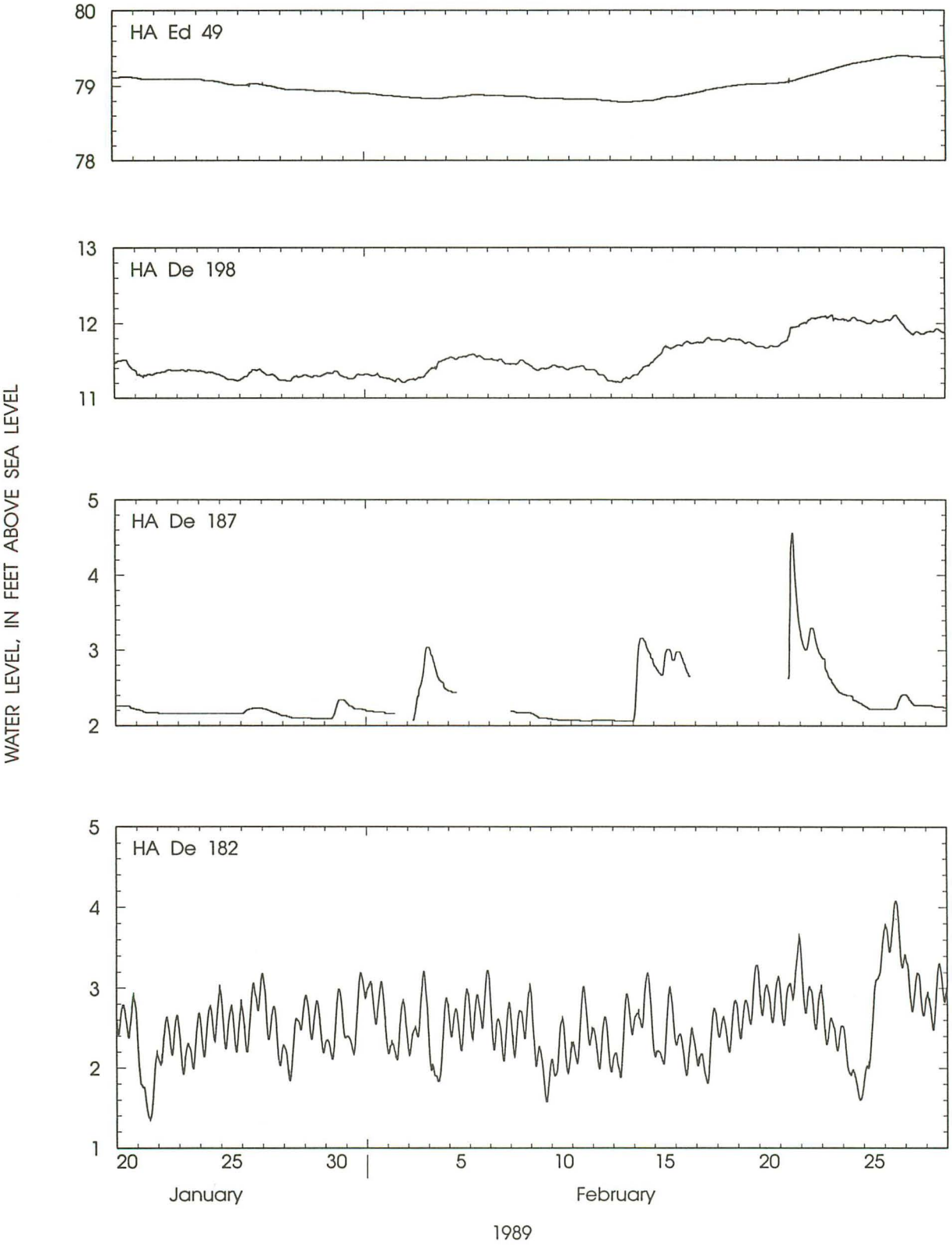
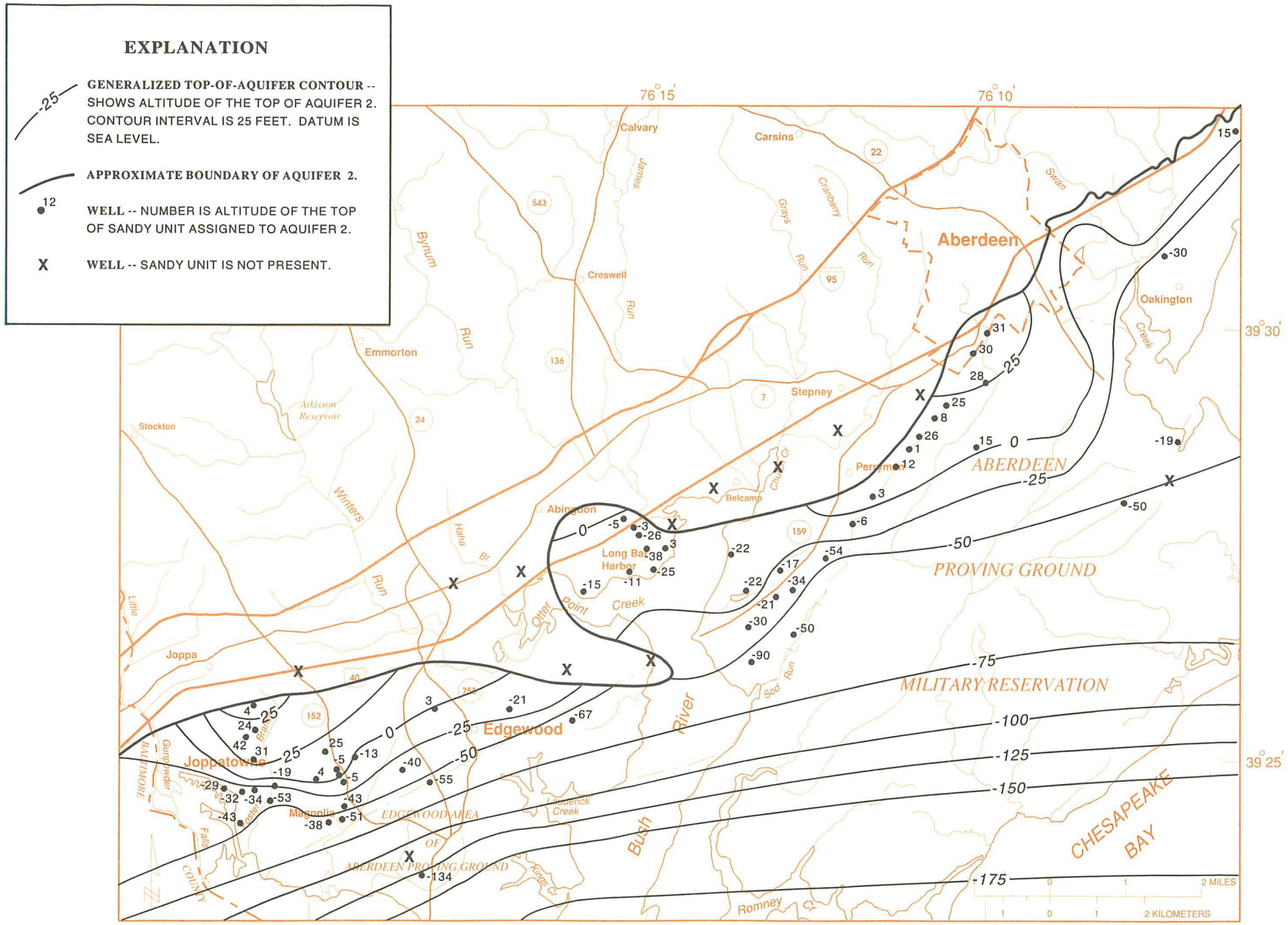


Figure 17.—Water levels in wells screened in aquifer 1, January 20 to February 28, 1989.



Base map from U.S. Geological Survey, 1:100,000

Figure 18.—Altitude of top of aquifer 2.

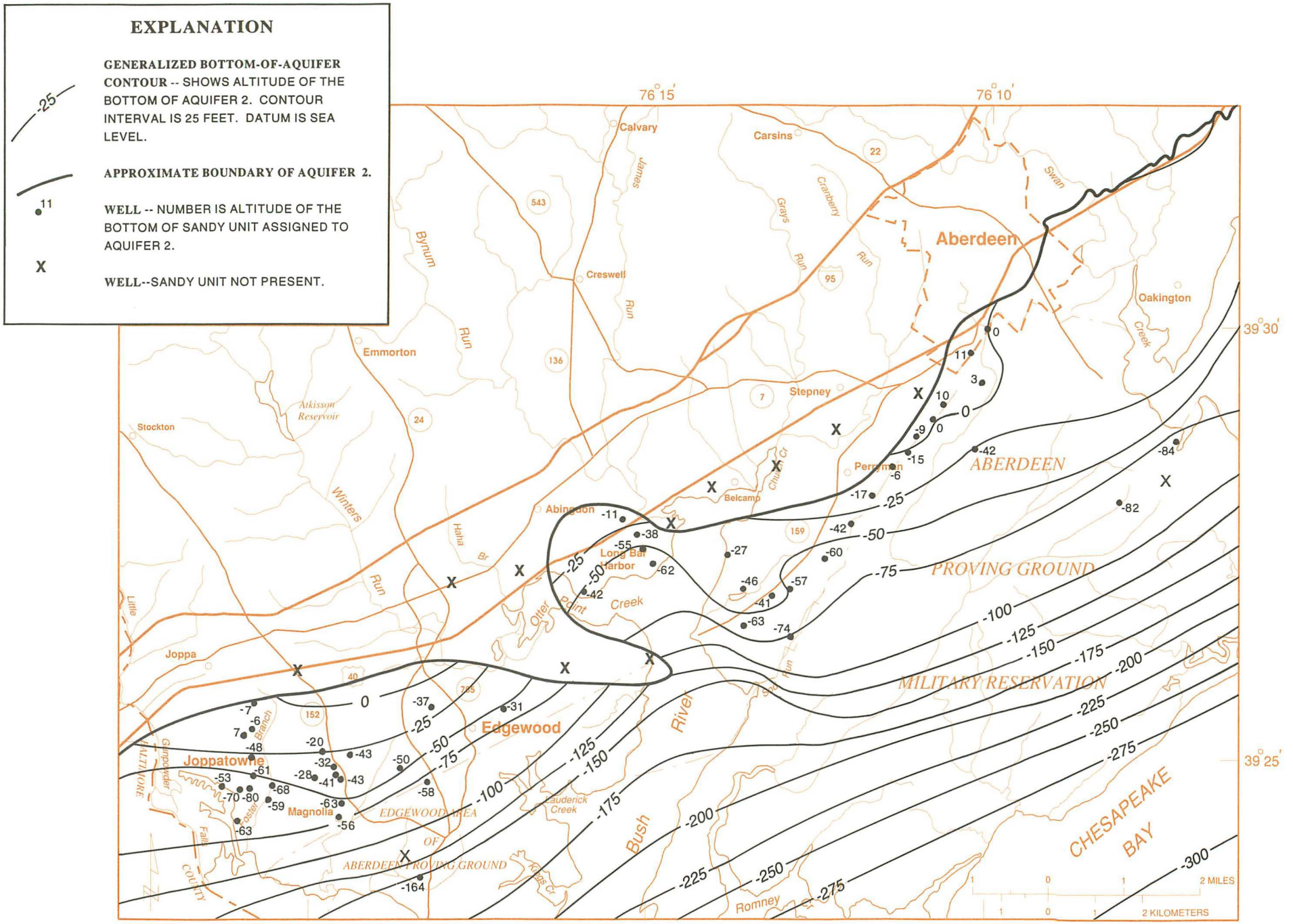


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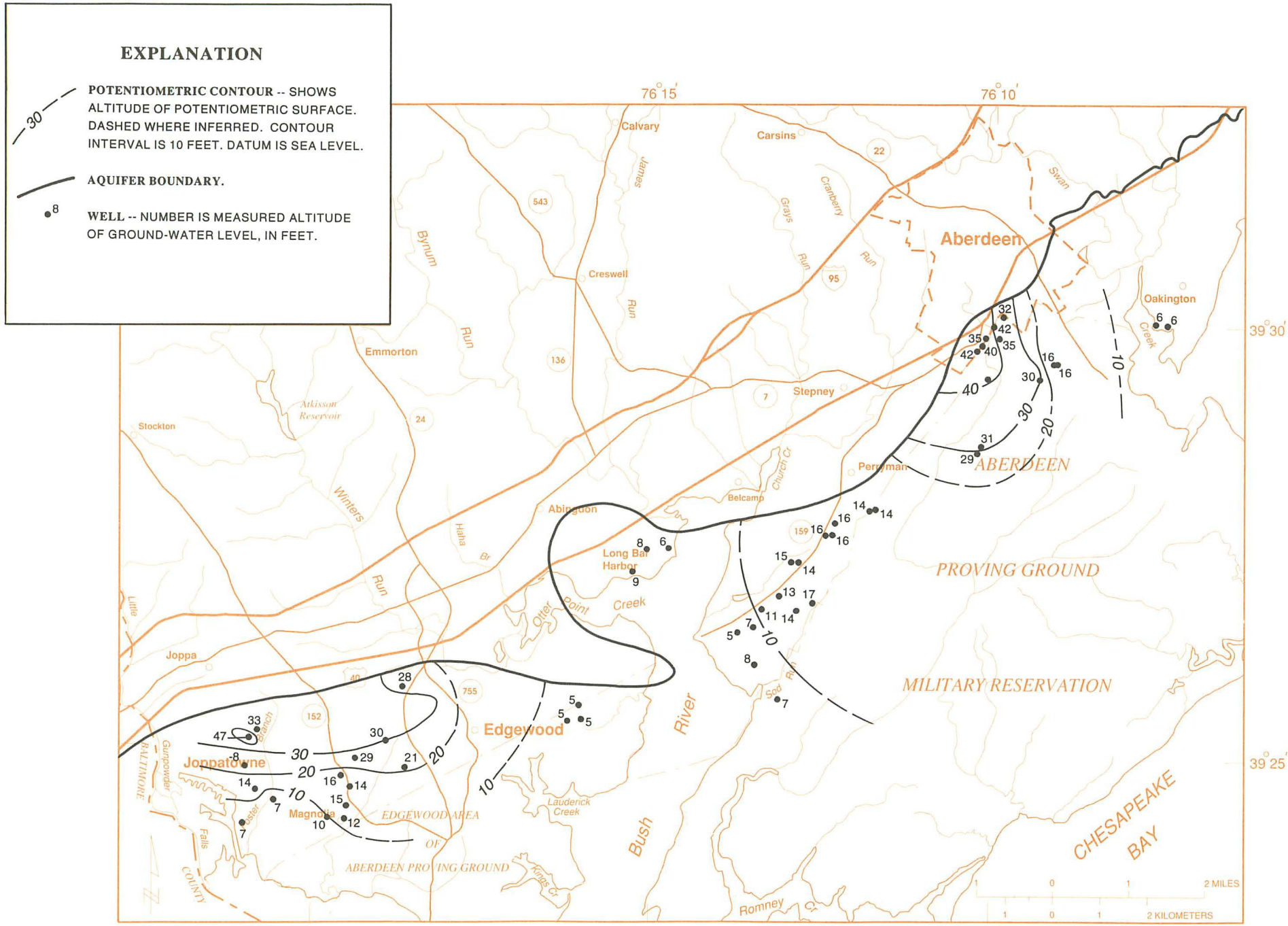
Figure 19.—Altitude of bottom of aquifer 2.



Base map from U.S. Geological Survey, 1:100,000

Figure 20.—Altitude of potentiometric surface in aquifer 2, May 1989.

the upland areas. Ground water in aquifer 2 flows toward the estuaries, and discharges upward into aquifer 1 near the estuaries.

Hydrographs for two wells screened in aquifer 2 are shown in figure 21. The hydrograph for well HA De 66 displays a gradual increase that indicates steady recharge from aquifer 1. The small water-level rise on February 22, 1989, was caused by heavy rain (fig. 13). The absence of a water-level response to barometric fluctuations and the abrupt recharge indicated by the water-level rise on February 22, 1989, indicate that aquifer 2 is semiconfined in this area. The hydrograph for well HA Dd 89 shows a fluctuation nearly identical to concurrent barometric-pressure fluctuations (fig. 13), which indicates that aquifer 2 is confined in this area.

Confining Unit 2

Confining unit 2 is present where either aquifer 3 or aquifer 4 is present. The top of confining unit 2 is defined by the bottom of aquifer 2, and the bottom is defined by the top of aquifer 3 or aquifer 4. Confining unit 2 consists predominantly of silt and clay, but could also include some isolated pockets of sand and gravel. Laboratory permeability tests on sediments from the Baltimore Gas and Electric Company plant site on the Bush River southwest of Perryman yielded vertical hydraulic conductivities of 4×10^{-5} to 2×10^{-3} ft/d (Geraghty & Miller, 1985, p. 20). Fine sand and silt had the highest vertical hydraulic conductivity, and silty clay and sandy clay had lower values of vertical hydraulic conductivity.

Aquifer 3

Aquifer 3, which is subjacent to confining unit 2, is a confined aquifer. It is composed entirely of Potomac Group sediments, predominantly sand with some gravel. The central part of the aquifer near the Bush River contains clayey and silty sand. The coarsest and thickest sands are present between Perryman and the Bush River (figs. 4 and 9).

Extent

Aquifer 3 extends from the eastern part of the study area to near Magnolia in the western part, where it is abruptly truncated (fig. 22). It extends to the northwest as far as the Fall Line near Stepney, and to its updip truncation elsewhere. The southeastern extent of the aquifer is unknown. It is bounded on the top by confining unit 2 and on the bottom by confining unit 3. The altitude of the top of aquifer 3 (fig. 22) ranges from about 30 ft above sea level near Abingdon and Stepney to about 200 ft below sea level on Aberdeen Proving Ground. The altitude of the bottom of the aquifer ranges from about 10 ft above sea level near Stepney to about 225 ft below sea level at Aberdeen Proving Ground (fig. 23). The thickness of aquifer 3 ranges from 0 ft to about 75 ft.

Hydraulic properties

Horizontal hydraulic conductivities estimated from aquifer tests for aquifer 3 range from 6.2 to 770 ft/d (tab. 3). Hydraulic conductivity is lowest near the Bush River and highest near Perryman. Transmissivity values estimated from aquifer tests range from 20 to 6,500 ft^2/d, and storage coefficients range from 0.00004 to 0.002 (tab. 3).

Water levels

Water levels in aquifer 3 represent the potentiometric surface of the confined aquifer. The altitude of the potentiometric

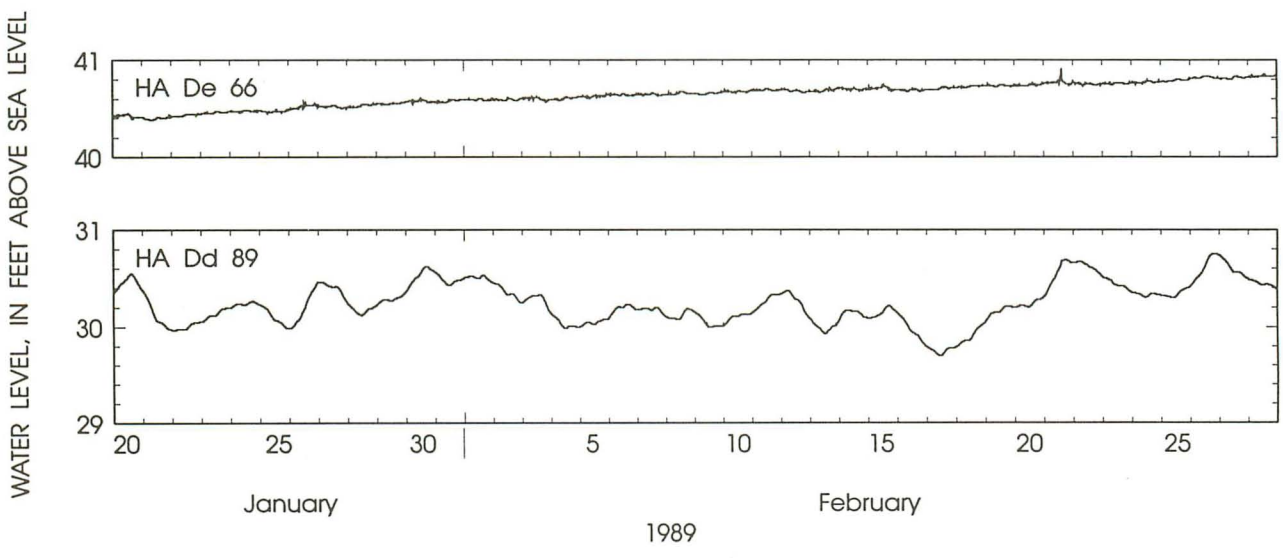
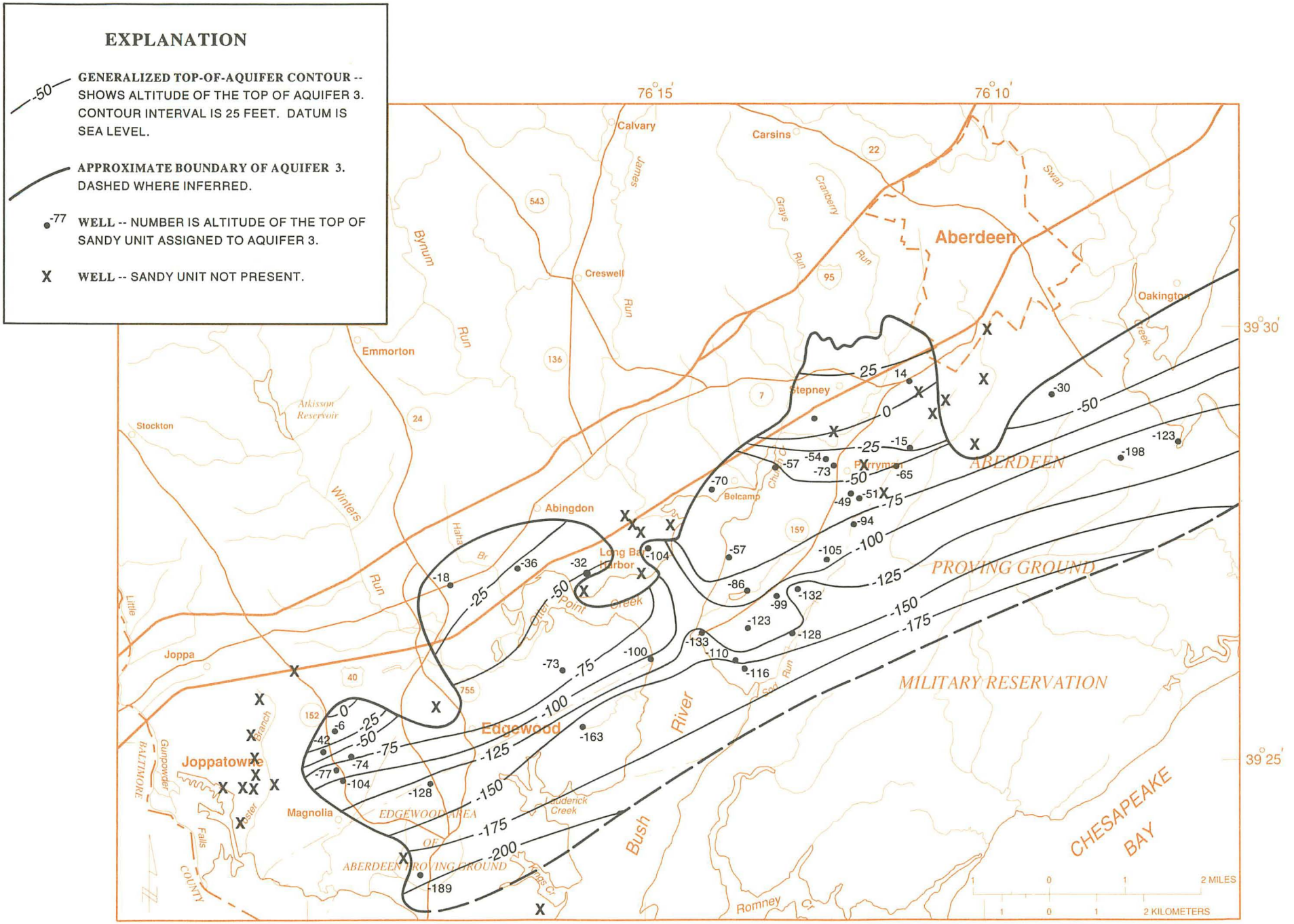
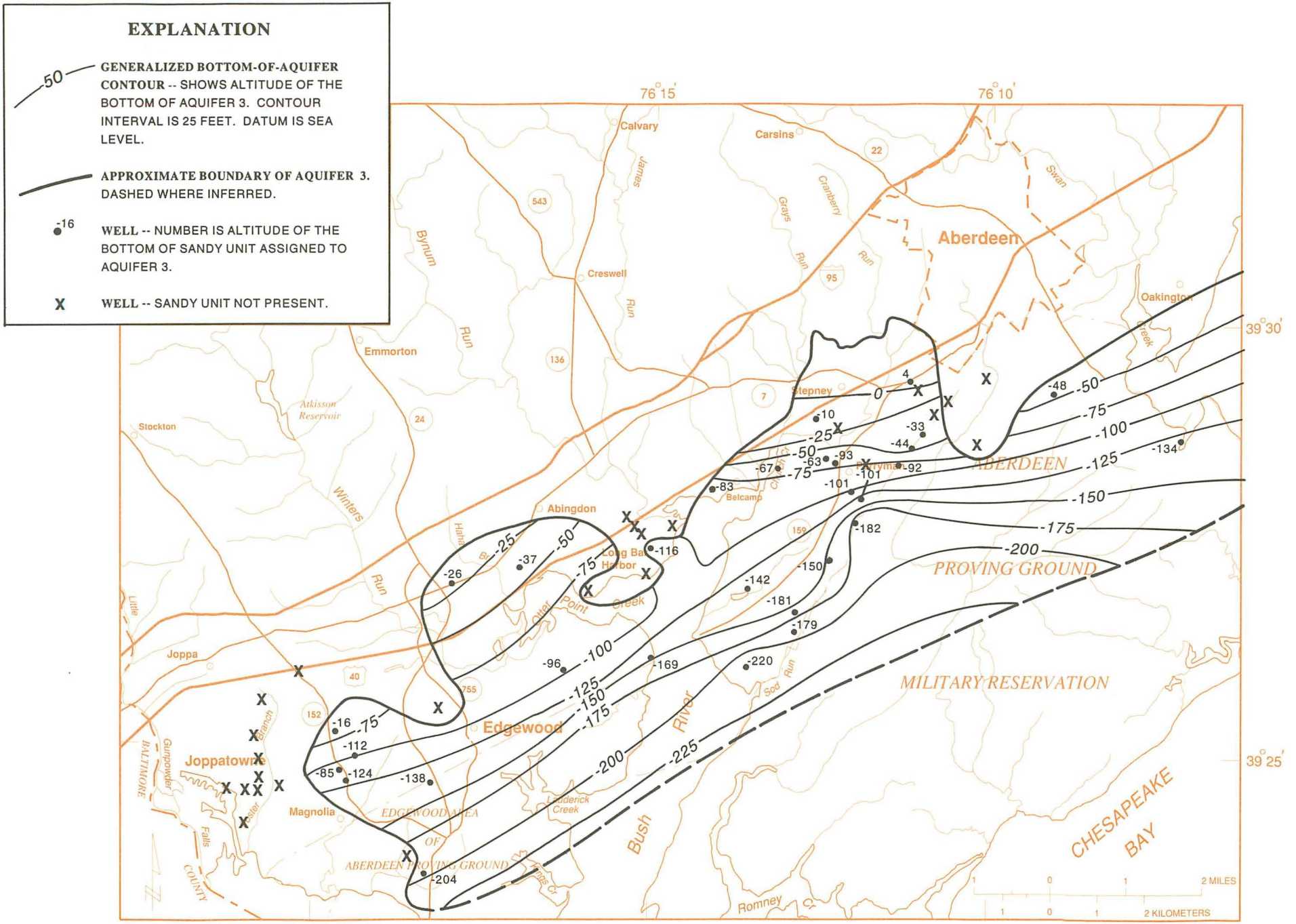


Figure 21.—Water levels in wells screened in aquifer 2, January 20 to February 28, 1989.



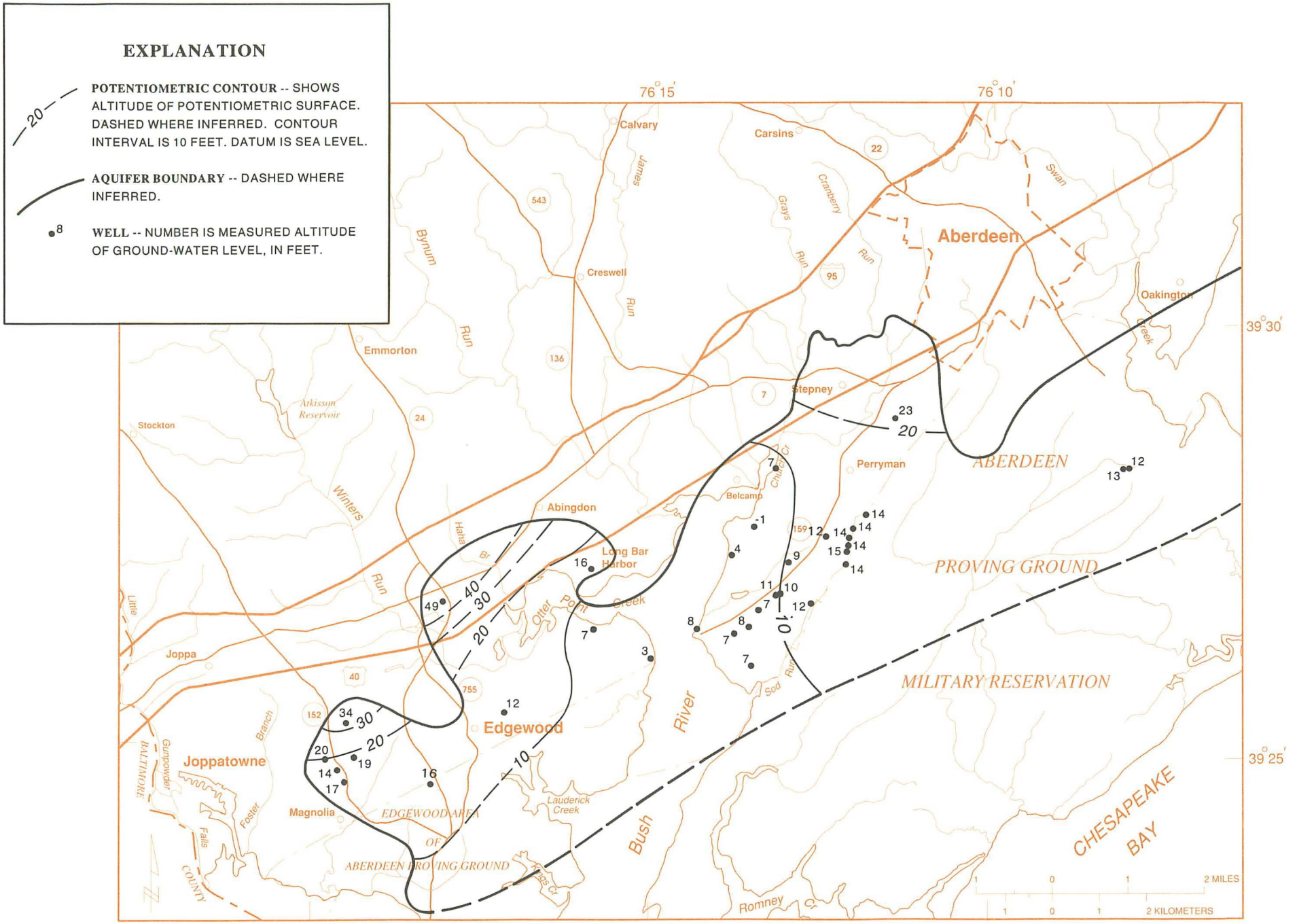
Base map from U.S. Geological Survey, 1:100,000

Figure 22.—Altitude of top of aquifer 3.



Base map from U.S. Geological Survey, 1:100,000

Figure 23.—Altitude of bottom of aquifer 3.



Base map from U.S. Geological Survey, 1:100,000

Figure 24.—Altitude of potentiometric surface in aquifer 3, May 1989.

surface during May 1989 ranged from more than 30 ft above sea level in topographically higher areas near Stepney, Abingdon, and Magnolia, to about sea level at the Bush River (fig. 24). Water leaks downward into aquifer 3 from overlying aquifers in the elevation areas. Ground water in aquifer 3 flows toward the estuaries and discharges upward to aquifer 2 near the estuaries.

Hydrographs for three wells screened in aquifer 3 are shown in figure 25. The hydrograph for well HA De 151 shows that water levels correlate with barometric pressure (fig. 13). The barometric-pressure induced fluctuation and the absence of transient recharge indicate that the aquifer is confined at this location. The hydrographs for wells HA De 197 and HA De 183 show strong tidal fluctuations, owing to their proximity to tidal estuaries (fig. 12). Minimum heads in well HA De 197 are about 6.7 ft above sea level, perhaps because Church Creek is emptied at very low tides. The hydrograph for well HA De 183 displays a barometric fluctuation superimposed on the tidal fluctuation, which indicates that aquifer 3 is confined in this area.

Confining Unit 3

Confining unit 3 is present in the same area as aquifer 4. The top of confining unit 3 is defined by the bottom of aquifer 3 and the bottom of confining unit 3 is defined by the top of aquifer 4. Confining unit 3 is predominantly silty and sandy clay with sparse sandy intervals. No data are available on the vertical hydraulic conductivity of this unit, but values derived from model calibration range from 6.3×10^{-8} to 6.3×10^{-7} ft/d.

Aquifer 4

Aquifer 4 is the deepest unconsolidated aquifer in the study area and is composed entirely of Potomac Group sediments. In general, it directly overlies crystalline bedrock and is confined throughout its extent. It is generally not used for large water supplies because of its depth and low transmissivity. Aquifer 4 con-

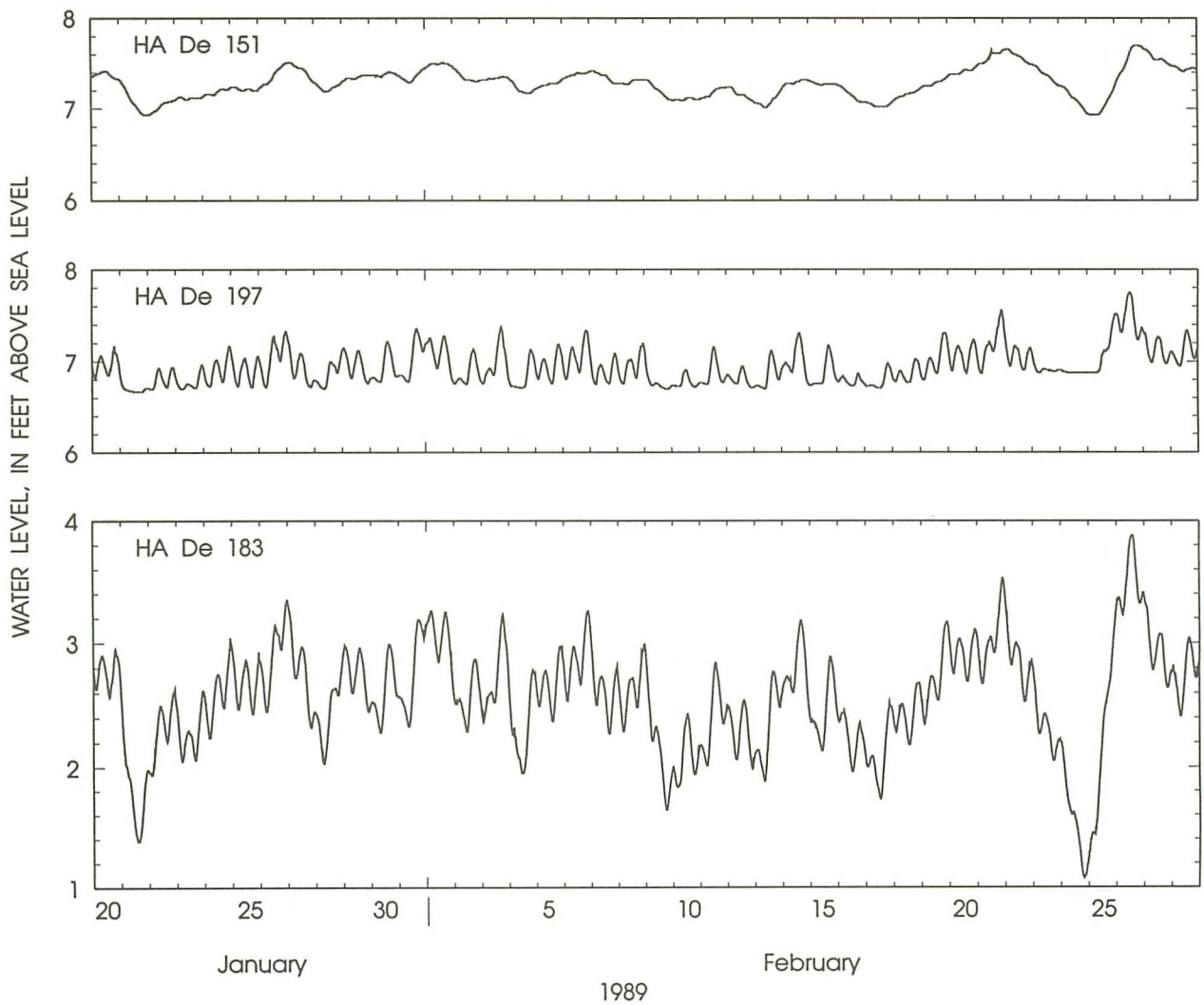


Figure 25.—Water levels in wells screened in aquifer 3, January 20 to February 28, 1989.

sists predominantly of silty sand, with coarse-grained, well-sorted sand in places.

Extent

Aquifer 4 forms an elongate lens of sand that trends from northeast to southwest, approximately parallel to regional strike (fig. 26). It pinches out updip and downdip, but the boundaries along strike are uncertain. It is bounded on the top by confining unit 3 and on the bottom by bedrock, except at well HA De 126 (fig. 9) where a clay interval is present between the aquifer and bedrock. The altitude of the top of the aquifer ranges from about 70 ft below sea level between Belcamp and Abingdon, to about 400 ft below sea level at Aberdeen Proving Ground (fig. 26). The bottom of the aquifer ranges from about 70 ft below sea level between Belcamp and Abingdon, to about 500 ft below sea level at Aberdeen Proving Ground (fig. 27). The thickness of aquifer 4 ranges from 0 to about 80 ft.

Hydraulic properties

A horizontal hydraulic conductivity value of 0.2 ft/d was estimated for the entire aquifer, except for the Long Bar Harbor area, where a value of 20 ft/d was estimated from model calibration. No storage coefficient data are available for aquifer 4, but a value of 0.0002, typical of confined aquifers (Freeze and Cherry, 1979), is probably a good estimate.

Water levels

Water levels in aquifer 4 represent the potentiometric surface of the confined aquifer. The altitude of the potentiometric surface measured during May 1989 is shown in figure 28 with measured water levels. Water levels were measured in three wells, and one of those measurements is suspect. Heads in the aquifer probably range from 5 and 10 ft above sea level; the lower values are present near the Bush River. Water leaks downward from overlying aquifers into aquifer 4 in the northeastern and southwestern parts of the aquifer. Ground water in aquifer 4 flows toward the central part of the aquifer and discharges upward near the Bush River.

A hydrograph for well HA De 181, which is screened in aquifer 4 at Willoughby Beach, is shown in figure 29. The hydrograph is similar to the hydrograph for well HA De 183, which is screened in aquifer 3 at the same site. The hydrograph shows a dominant semidiurnal tidal fluctuation superimposed on a barometric fluctuation, indicating that aquifer 4 is confined in this area and extends beneath the Bush River.

GROUND-WATER DISCHARGE TO STREAMS

Streams are generally discharge areas for the shallow ground-water system. The direction and rate of flow between the ground-water system and streams depends on the difference between the head in the water-table aquifer and the stream stage, and the hydraulic conductivity of the streambed material. During storms, some water enters streams from direct overland runoff and from interflow that never reaches the water table. Dry-weather streamflow is maintained by ground-water discharge. The relation between the ground-water and surface-water systems is an important consideration in this hydrogeologic study.

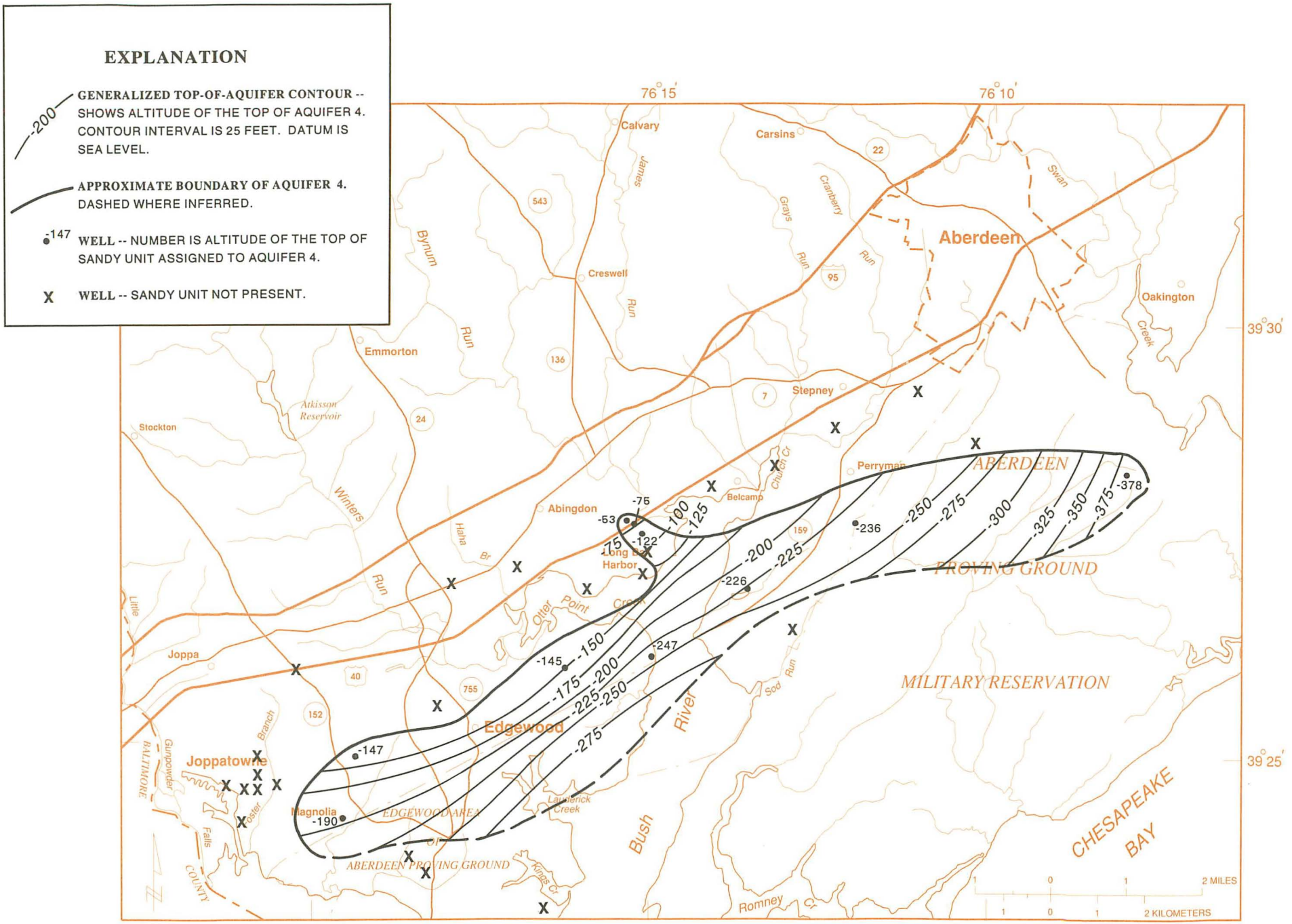
The major streams in the study area are Foster Branch, Reardon Inlet, Winters Run, Haha Branch, Bynum Run, James Run, Grays Run, and Cranberry Run (fig. 30). Foster Branch, Reardon Inlet, and Haha Branch are entirely within the Coastal Plain, whereas the other streams drain both Piedmont and Coastal Plain terrains. Grays Run is almost entirely within the Piedmont, with only the lower several hundred feet traversing Coastal Plain terrain before emptying into Church Creek.

Discharge of the major streams was measured in August 1987, April and August 1988, and June 1989. The measurements were made after at least 4 days of no rainfall so that only base flow would be measured. Measurements were made on each stream at the Fall Line that extends into the Piedmont and as far downstream on the nontidal reach as possible to estimate discharge contributed by the Coastal Plain aquifers. Additional measurements were made at intermediate points along stream reaches in the Coastal Plain to estimate contributions of subbasins. Grays Run was excluded from the measurements because it was impossible to obtain accurate measurements in its short Coastal Plain reach. In addition, two continuous streamflow-gaging stations were constructed on Cranberry Run at Route 40 and Perryman to obtain flow records from 1987 through 1989 and evaluate the response of streamflow to rainfall.

The greatest base flow measured was 79.4 ft^3/s on Winters Run on June 5, 1989 (tab. 4). Several streams were dry during the late summers of 1987 and 1988. When the upstream measurements are subtracted from the downstream measurement for a subbasin, then divided by the subbasin area, the resulting value represents the ground-water specific discharge (discharge per unit area) for the subbasin, and can be compared with other specific discharges such as recharge and evapotranspiration. Table 5 shows the ground-water specific discharges to streams. Negative values indicate water leaving the stream, presumably entering the ground-water system. The specific discharges of ground water range from -4.7×10^{-3} to 11.7×10^{-3} ft/d. In general, specific discharges are greater during the spring than in fall. Ground-water discharge into lower Winters Run could be affected by a nearby sand and gravel quarrying operation. Streamflow in Winters Run is affected by releases from Atkisson Reservoir.

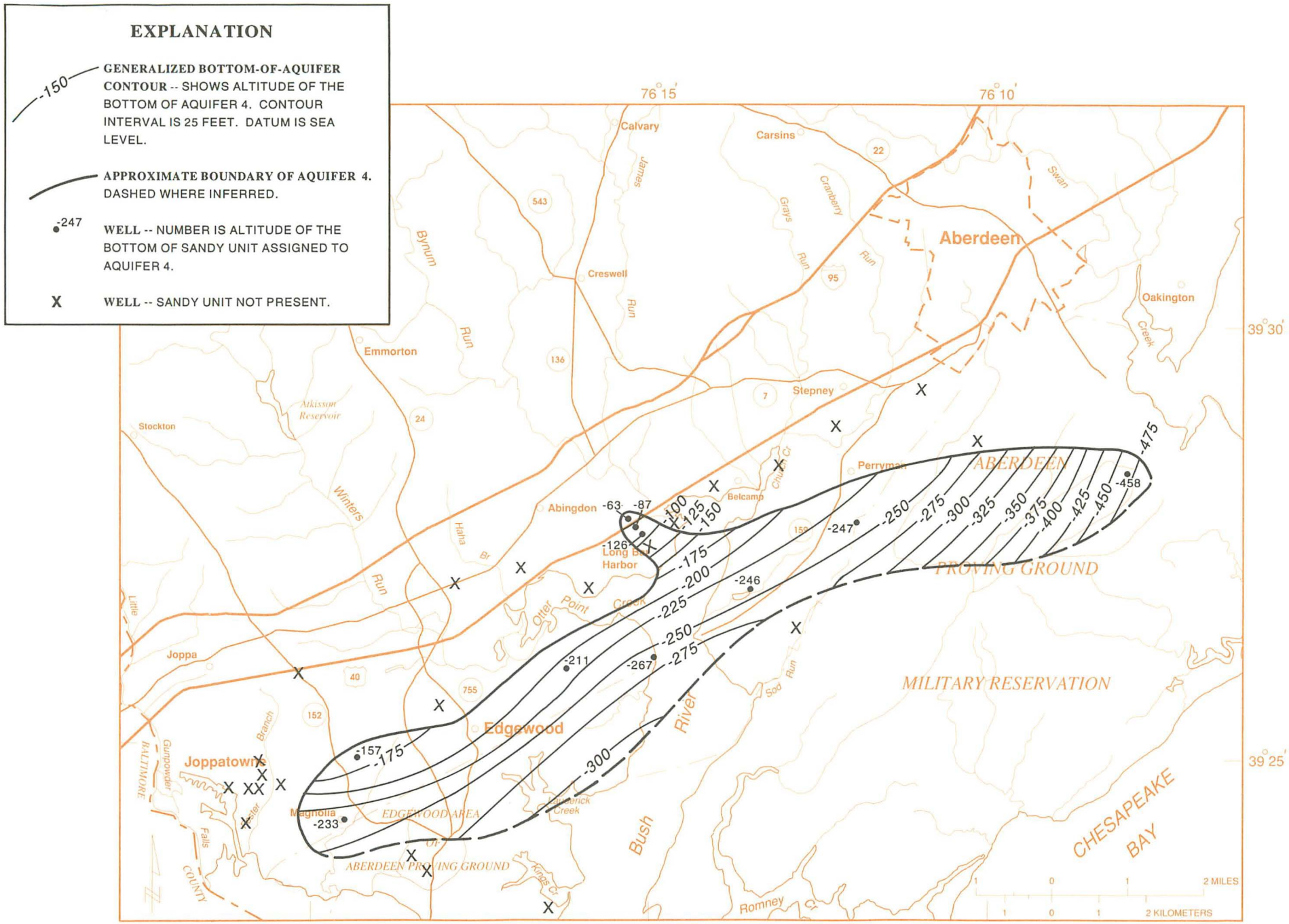
Subbasin weighted averages of ground-water specific discharge were calculated for each of the four measurements and for each of the subbasin types: Piedmont, Coastal Plain, and mixed. Averages were weighted by subbasin area. An average value of 1.42×10^{-3} ft/d was calculated, representing the average ground-water specific discharge into the streams during

(Text continued on p. 43.)



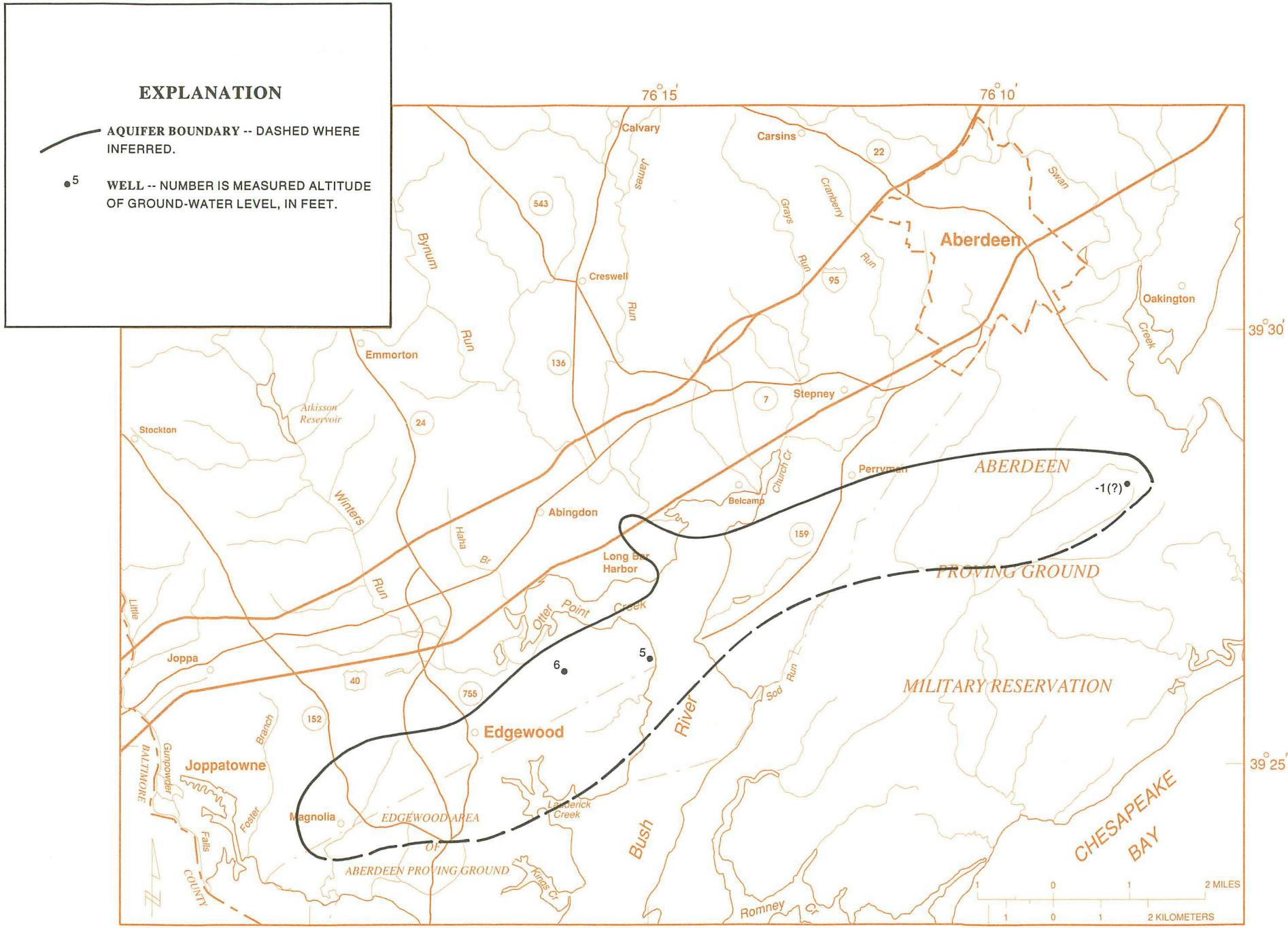
Base map from U.S. Geological Survey, 1:100,000

Figure 26.—Altitude of top of aquifer 4.



Base map from U.S. Geological Survey, 1:100,000

Figure 27.—Altitude of bottom of aquifer 4.



Base map from U.S. Geological Survey, 1:100,000

Figure 28.—Altitude of potentiometric surface in aquifer 4, May 1989.

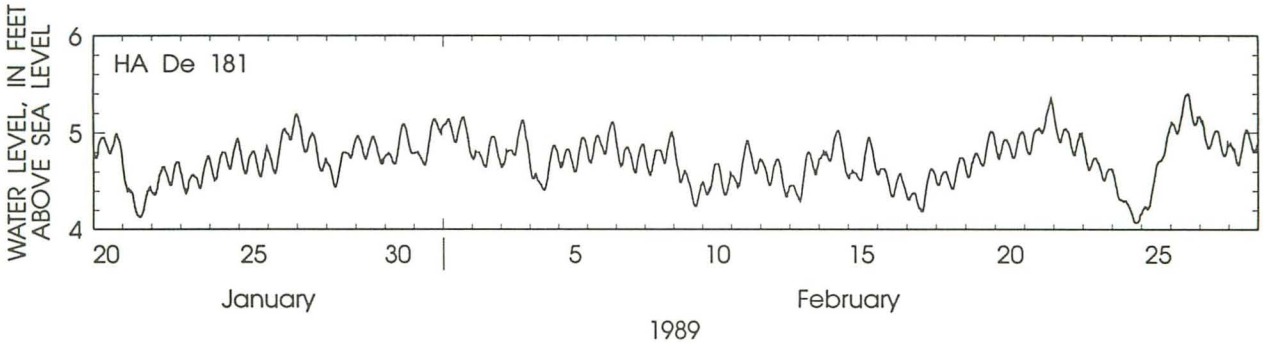


Figure 29.—Water levels in a well screened in aquifer 4, January 20 to February 28, 1989.

Table 4.—Stream-discharge measurements, 1987–89

Stream	Station number [1]	Discharge (cubic feet per second) 8/26/87	4/25/88	8/17/88	6/5/89	Average
Bynum Run	1600	2.61	19.30	4.90	22.70	12.38
	1601	2.53	20.90	4.34	24.70	13.12
James Run	1650	.64	8.25	1.00	8.68	4.64
	1651	.51	8.29	1.01	8.52	4.58
Cranberry Run	1654	.00	.89	.02	.52	.36
	1655	.01	.12	.00	.09	.06
	1656	.05	.18	.05	.09	.09
	1657	.19	1.91	.23	1.40	.93
	1658	.56	2.85	.83	2.40	1.66
Haha Branch	1670	.08	.35	.11	.24	.19
	1671	.18	.70	.20	.54	.41
Winters Run	1750	8.49	53.40	13.70	79.40	38.75
	1755	14.00	53.50	13.40	76.20	39.27
Foster Branch	5070	.06	.22	.07	.26	.15
	5071	.03	.25	.04	.25	.14
	5072	.00	.26	.03	.70	.25
	5073	.00	.06	.00	.05	.03
	5074	.00	.07	.00	.04	.03
Reardon Inlet	5120	.02	.28	.02	.07	.10
	5121	.00	.06	.05	.14	.06
	5122	.00	.06	.07	.28	.10

[1] Prefix 0158 omitted from stream-station numbers.

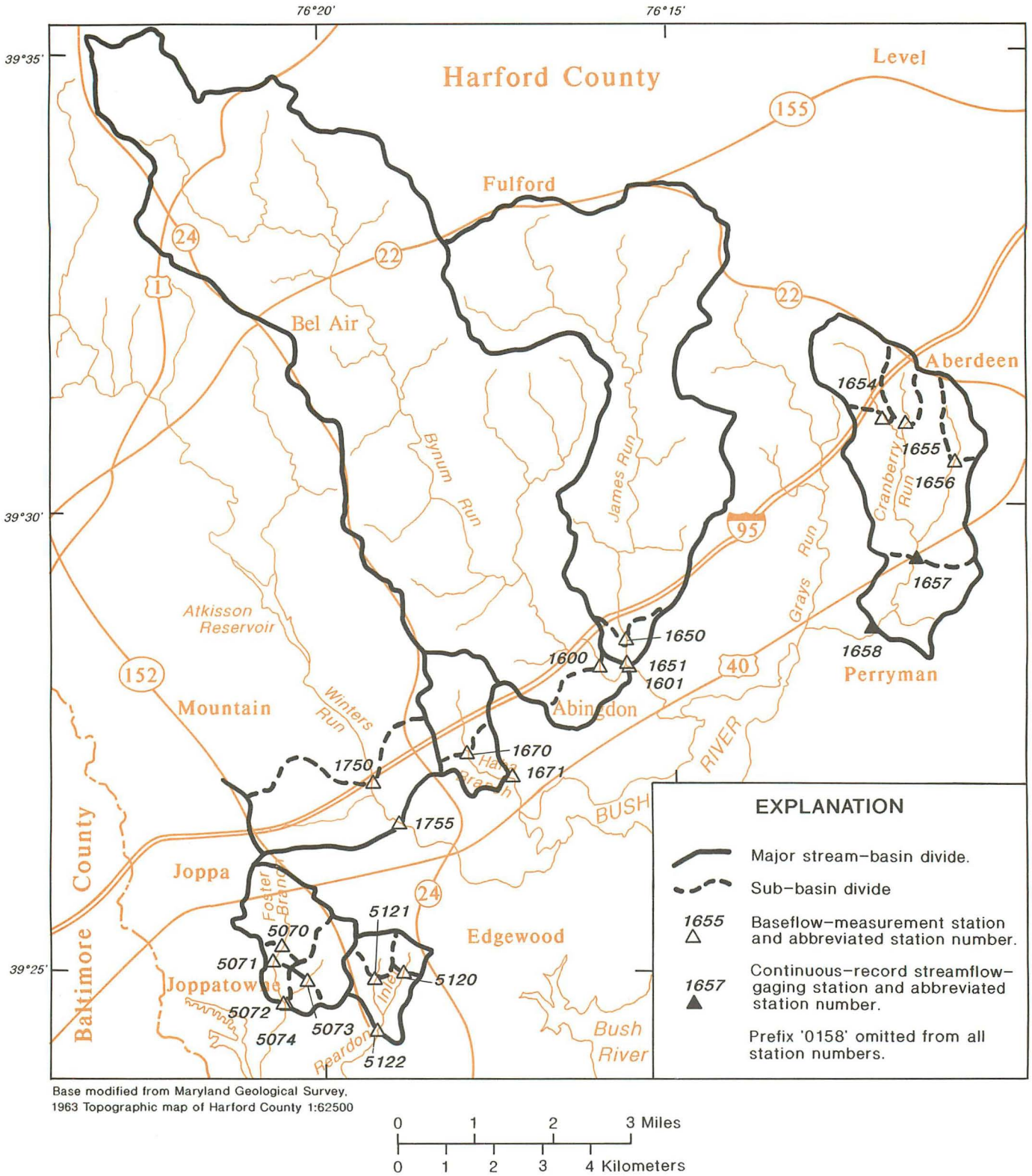


Figure 30.—Streams, drainage basins, streamflow-gaging stations, and base-flow measurement stations.

Table 5.—Ground-water specific discharges to streams

Stream	Station number [1]	Drainage area (square miles)	Specific discharge (feet per day x 10^{-3}) 8/26/87	4/25/88	8/17/88	6/5/89	Average
Bynum Run	1600	22.62	0.36	2.64	0.67	3.11	1.69
	1601	.53	-.47	9.37	-3.28	11.71	4.33
James Run	1650	11.00	.18	3.32	.28	2.44	1.31
	1651	.25	-1.63	.50	.13	-2.01	-.75
Cranberry Run	1654	.88	.00	3.13	.07	1.82	1.25
	1655	.36	.13	1.02	.00	.81	.49
	1656	.38	.43	1.50	.41	.77	.78
	1657	2.52	.15	.88	.20	.85	.52
	1658	1.10	1.03	2.64	1.68	2.81	2.04
Haha Branch	1670	.95	.26	1.14	.36	.79	.63
	1671	.40	.77	2.70	.69	2.32	1.62
Winters Run	1755	2.13	8.02	.15	-.44	-4.66	.77
Foster Branch	5070	.90	.20	.76	.24	.88	.52
	5071	.08	-1.19	1.11	-1.15	-.19	-.35
	5072	.14	-.59	.24	-.22	.99	.10
	5073	.51	.00	.38	.00	.33	.18
	5074	.15	.00	.20	.00	-.37	-.04
Reardon Inlet	5120	.16	.41	5.50	.39	1.29	1.90
	5121	.21	.00	.90	.75	2.21	.94
	5122	.52	-.13	-1.67	.00	.47	-.33
Weighted average [2]			.268	2.35	.46	2.61	1.42

[1] Prefix 0158 omitted from stream station numbers.
[2] Ground-water specific discharges in basin 1755 were excluded from the weighted average calculations because of effects of reservoir and quarrying operations.

a 2-year period in Coastal Plain and Piedmont terrains. The weighted average specific discharge in Piedmont terrain was somewhat higher (1.56×10^{-3} ft/d) than that for Coastal Plain terrain (1.08×10^{-3} ft/d). These values represent base-flow components of the ground-water-flow budget.

REGIONAL GROUND-WATER FLOW SYSTEM

The regional ground-water flow system in the Harford County Coastal Plain can be characterized by recharge, flow through the aquifers and confining units, and discharge (fig. 31). Recharge is mainly from precipitation, although small amounts could also derive from losing reaches of streams and from brackish-water intrusion from the estuaries. The ground water then flows through the aquifer system as controlled by aquifer and confining-unit properties and head gradients, and eventually discharges as base flow to streams, evapotranspiration, flow to estuaries, and pumpage. In transient situations, some water in the system could also accumulate or be released from ground-water storage. In general, the ground-water system is recharged in the upland areas near the Fall Line in aquifer 1. The water then flows downward into the underlying aquifers and toward the lowland areas near tidal estuaries. Ground water then flows upward to aquifer 1 and is discharged into the estuaries.

Water is conserved in the flow system, so all water must be accounted for in the hydrologic budget. Precipitation either re-

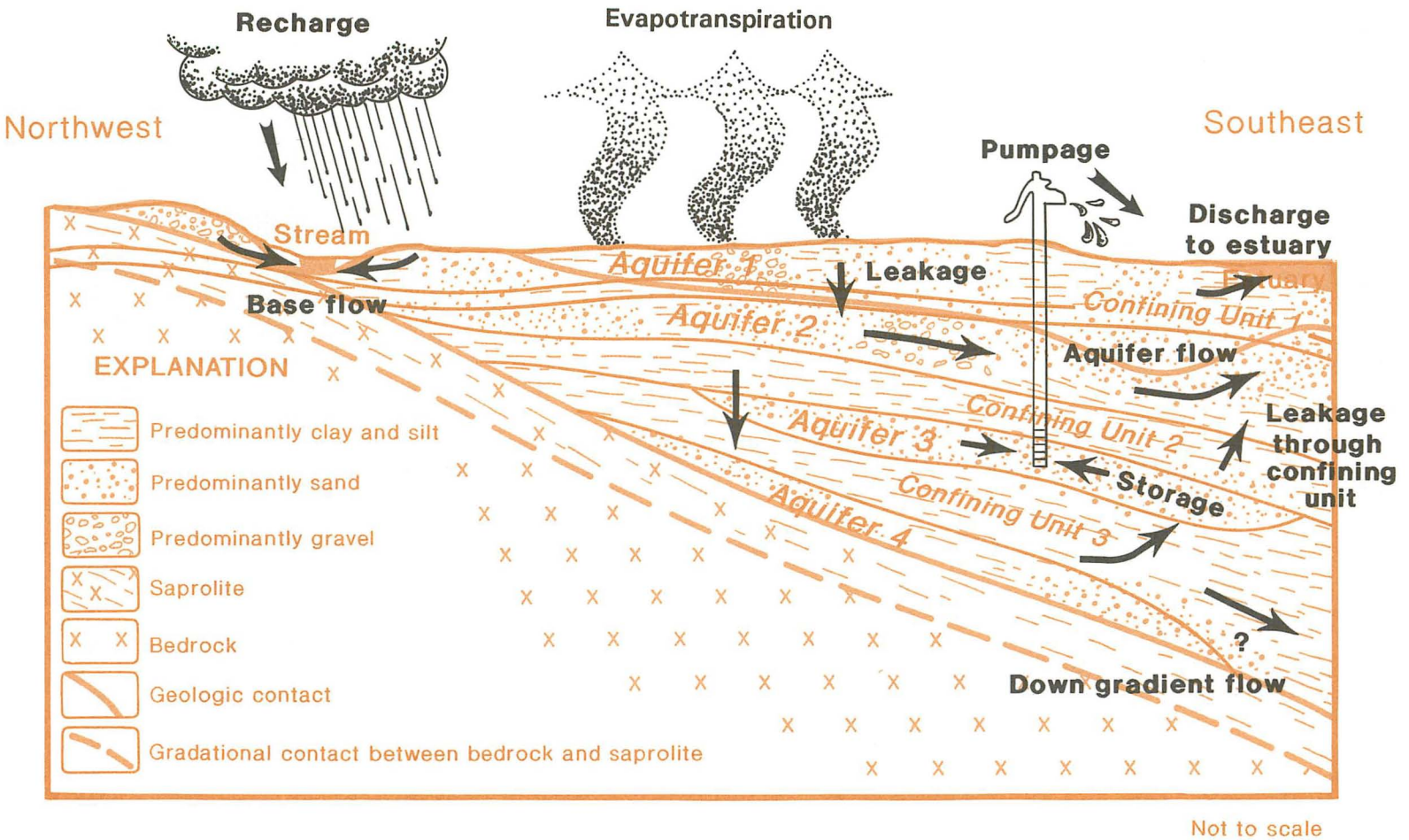


Figure 31.—Regional ground-water flow system in the Coastal Plain of Harford County.

charges the ground-water flow system, runs off to streams and other drainage systems, or returns to the atmosphere as soil evapotranspiration (ET). This relation can be expressed as

$$P = R + RO + ET_{soil}, \quad (1)$$

where

P = precipitation,
R = recharge,
RO = runoff, and
ET_{soil} = soil evapotranspiration.

Water lost through direct runoff and soil evapotranspiration never reaches the ground-water system and is not considered in the ground-water budget.

Water that reaches the ground-water system as recharge must eventually either go into ground-water storage or be discharged as base flow to streams, ground-water evapotranspiration, flow to estuaries, or pumpage. This relationship may be expressed as

$$R = ET_{gw} + BF + ED + PU + \Delta S, \quad (2)$$

where

ET_{gw} = ground-water evapotranspiration,
BF = base flow,
ED = estuarine discharge,
PU = pumpage, and
ΔS = change in storage.

Ground-water recharge was estimated by summing the rises in ground-water levels in the water-table aquifer that are caused by precipitation for a period of time, then multiplying by a specific yield of 0.1. The hydrograph for well HA De 198 was suitable for this purpose because it does not display fluctuations caused by tidal or barometric fluctuations (fig. 17). Estimates for several time periods during the winter, when evapotranspiration was at a minimum, yielded recharge values of 18 to 23 in/yr.

Evapotranspiration (ET) is the removal of water from the subsurface by transpiration of plants, and evaporation. It varies as a function of ground-water level, vegetation type, and atmospheric conditions and can vary greatly over space and time. Potential ET is the maximum water loss for an area that would occur if an unlimited supply of water were available to meet the ET demand (Freeze and Cherry, 1979). Actual ET is the portion of the potential ET that actually is removed from the subsurface under field conditions. Water that is removed from the unsaturated zone is referred to as "soil ET" and water removed from the saturated zone is referred to as "ground-water ET". A regional yearly average of actual ground-water ET was estimated to be 10.6 in/yr by calculating ET (combined soil ET and ground-water ET) by the method of Thornthwaite and Mather (1957), then multiplying that value by a ratio of actual ground-water ET to actual (combined soil and ground-water) ET. The ratio used for this calculation, 0.386, was derived from Rasmussen and Andreasen (1959) for the period April 1950 through March 1952 for the Beaverdam Creek basin in Wicomico County, Md. The ET values used in this calculation are shown in the following table:

	Estimated evapotranspiration, in inches per year		
	This study		Rasmussen and Andreason (1959)
	Potential	Actual	Actual
Soil ET	—	16.9	15.4
Ground-water ET	—	10.6	9.7
Combined ET	[1]28.9	[1]27.5	25.1

[1]Calculated by the method of Thornthwaite and Mather (1957).

Base flow, or ground-water discharge to streams, is discussed in the section "Ground-Water Discharge to Streams." Average base flow is about 1.42×10^{-3} ft/d, or 6.2 in/yr.

The amount of water discharging to the estuaries is difficult to measure directly. One method of estimation is to solve for ED in equation 2; another is flow modeling. Solving for ED in equation 2, assuming an R of 20 in/yr, an ET_{gw} of 10.6 in/yr, and a BF of 6.2 in/yr, and no pumpage or change in storage, yields an estuarine-discharge value of 3.2 in/yr. Achmad (1991) derived a value of 7.7 in/yr in his prepumping flow-model simulation in a similar study of the Glen Burnie area of Maryland.

Pumpage from aquifers in the Harford County Coastal Plain is described in the section "Introduction." Water is pumped from discrete points in the ground-water system rather than from a broad area as for recharge and ET, and, as such, a specific discharge for pumpage cannot be calculated in the same manner. If an arbitrary area is chosen that encompasses the major pumped wells, a specific discharge can be calculated for comparative purposes. Using the study area of 36 mi^2 (1.0×10^9 ft^2) and 1989 total pumpage of 656,000 ft^3/d (4,907,000 gal/d), this method yields a pumpage specific discharge of 2.9 in/yr. If a larger area were chosen for the calculation, the resultant value would be proportionally smaller.

Water will enter or leave storage only in transient situations; that is, when a hydraulic stress causes a change in water level. The stress could be a change in pumpage, recharge, or ET. The amount of water entering or leaving storage depends on the change in water level and the specific storage of the aquifer. A hypothetical change in water level of 1 ft/yr would cause a change in storage of 1.2 in/yr for aquifer 1 (specific yield = 0.1) and 0.0024 in/yr for aquifers 2, 3, and 4 (specific storage = 0.0002). Under steady-state conditions, the change in storage is zero.

WATER-SUPPLY POTENTIAL

The Coastal Plain aquifers of Harford County have the potential to supply a large amount of good-quality water to help meet the needs of the growing population. It is important, however, to ensure that an increase in pumping rates will not cause serious water quality or quantity problems in the major well fields and in surrounding wells. To evaluate the potential for the ground-water system to meet projected pumping demands, a ground-water flow model was developed to simulate the response of ground-water levels and flow to various pumping scenarios. The flow-model results were then evaluated in terms of potentially detrimental effects of pumping, such as greatly lowered water levels, brackish-water intrusion, and the migration of contaminants toward water supplies. A particle-tracking program that defines ground-water flow paths was used to help evaluate the potential for brackish-water intrusion and contaminant migration.

SIMULATION OF GROUND-WATER FLOW

The physical characteristics of the ground-water flow system were incorporated into a digital flow model, which was calibrated to simulate historical and present conditions and then used to simulate projected and alternative pumping conditions. The USGS's modular three-dimensional finite-difference ground-water flow model (MODFLOW; McDonald and Harbaugh, 1988) was used for these simulations. In the model, the aquifer system, which is continuous in space and time, is divided into discrete cells with average values for hydraulic properties assigned to each cell. Boundary conditions are specified at the edges of the model, and initial head conditions are specified at the beginning of the simulation. The model then calculates head values for each cell at specified time intervals.

Conceptualization

Important hydrogeologic features and processes are represented by the flow model. MODFLOW is a quasi-three-dimensional model, in which the aquifers are represented as active layers and the confining units as hydraulic conductance terms between the layers. The Harford County Coastal Plain aquifer system was divided into four aquifers and three confining units, as described in the "Hydrogeology" section of this report. The sediments were not deposited in well-defined and areally extensive layers of sand and as such, do not form well-defined aquifers and confining units. Thus, some generalization of the hydrogeologic framework was necessary, but the important features of the system were retained. Figure 32 shows schematically how the aquifer system is represented in the flow model. Figure 32 can be compared to figure 31 to show the correspondence between model layers and aquifers and confining units. Each aquifer was simulated as a distinct layer in the model. Each confining unit was represented by vertical leakage between adjacent aquifer layers. The numerical designations of aquifers and confining units correspond to the aquifer-layer numbers in the model (fig. 32).

Model layer 1 is the uppermost layer and simulates a water-table aquifer. It is designated as strictly unconfined and allows recharge (RECHARGE package of MODFLOW), evapotranspiration (ET package), flow to streams (RIVER package), and flow to tidal estuaries (as specified-head cells).

Model layers 2, 3, and 4 are progressively deeper layers that represent aquifers 2, 3, and 4. These layers were modeled as strictly confined. Aquifers 2, 3, and 4 do not receive recharge directly from the surface. Water enters these aquifers only as leakage through the confining units. Where aquifers 2 and 3 actually crop out a direct hydraulic connection with aquifer 1 was assumed, and high leakance values were entered for the overlying confining units.

The flow-model area is considerably larger than the study area so that the estuaries could be used as specified head boundaries, pumpage on Aberdeen Proving Ground (APG) could be simulated, and the no-flow boundary in layer 1 in the Piedmont could be placed far enough from the study area so that it would not affect model results in the area of main concern.

Because few data were available to delineate aquifers at APG, and the Piedmont aquifers do not correspond to the Coastal Plain aquifers, these areas to the southeast and northwest of the study area were treated differently in the model design. Piedmont rocks northwest of the study area are assumed to form a single unconfined aquifer whose bottom is 100 ft below land surface. The Piedmont aquifers were included in aquifer 1, and were assumed to be hydraulically connected with the Coastal Plain part of aquifer 1. The model assumes that below 100 ft rock fractures are nonexistent or closed too tightly to transmit water.

Numerous partially interconnected sand units were assumed to exist southeast of the study area, and were included in layer 2 as a single confined aquifer. Thus, layer 2 was extended to the southeast throughout the model area, but layers 3 and 4 were truncated to the southeast where data are sparse.

Model Description

Time Discretization

The model simulated conditions for the period 1866–1989 for purposes of model calibration, and for the period 1990–2001 for the projected pumping simulations (fig. 33). The model divides the time continuum into a series of "stress periods." Pumping (and other stresses) remain constant during each stress period. Each stress period may be further divided into "time steps." The model calculates heads and fluxes at the end of each time step. The first stress period in the calibration simulation is a

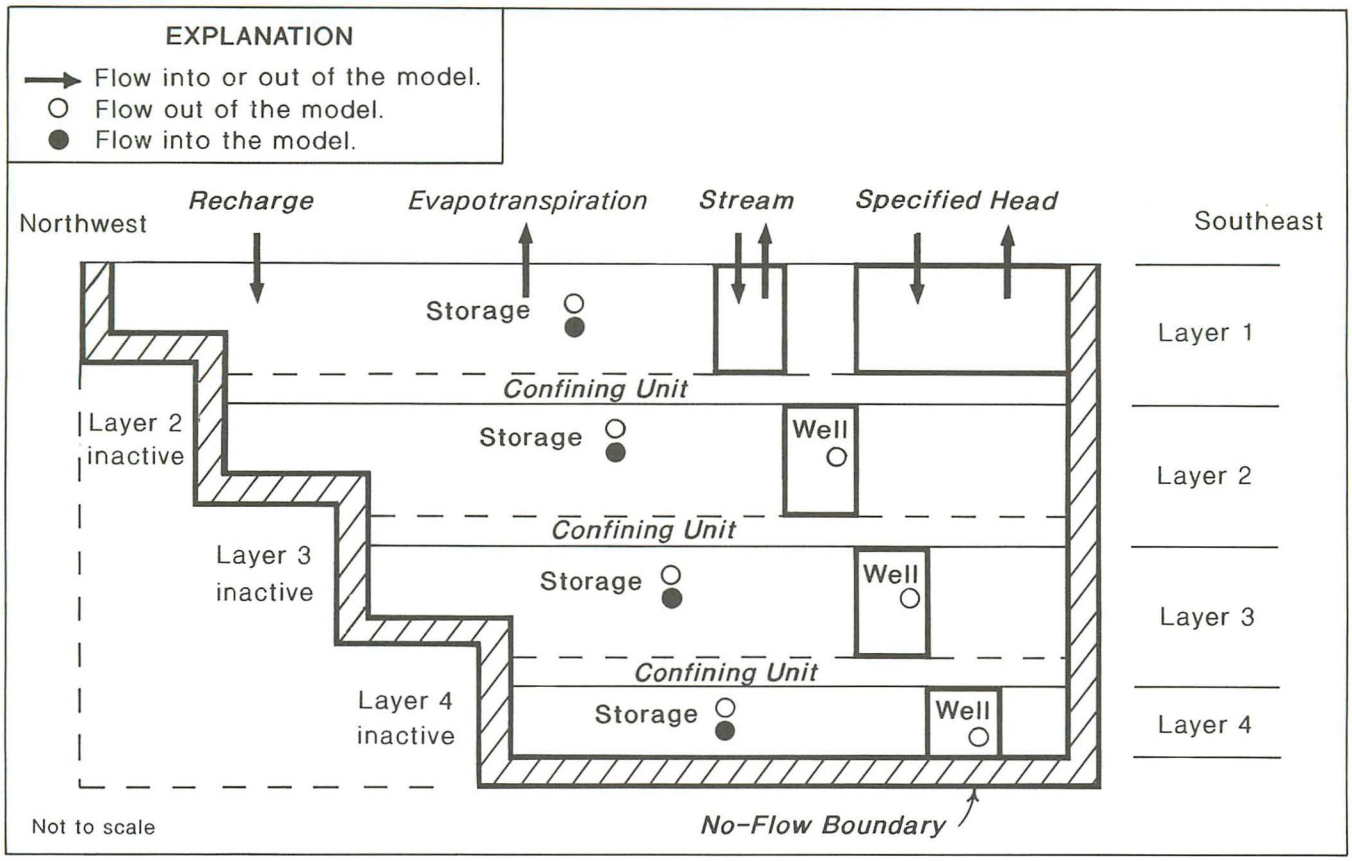


Figure 32.—Conceptualization of the ground-water flow model.

100-year prepumping period from 1866 through 1965. This period simulated only the natural hydrologic conditions—recharge, evapotranspiration, stream base flow, and estuarine discharge—but no pumpage. Although there was some pumping before 1965, it was less than 10 percent of the total pumpage in 1989, and was considered insignificant. The second stress period is 10 years long—1966–75, when the pumping from well fields at Perryman, Joppatowne, and Long Bar Harbor began, and pumping from Aberdeen increased from about 100 Mgal/yr to about 350 Mgal/yr. The third stress period is 13 years in length, from 1976 through 1988, when the major well fields in the area were developed to their present rates. The fourth stress period is 1 year in length and included only 1989. Pumping data for 1989 is considered complete and accurate, and this is the stress period primarily used to calibrate the flow model.

The projected pumping simulations, the fifth and sixth stress periods, all included 11 years of average recharge conditions (1990–2000), followed by 1 year of drought conditions in 2001. The choice of 2001 for drought conditions was arbitrary. One simulation was made with 3 years of drought conditions to evaluate the effects of a long-term drought.

Grid Design

The flow-model area is 22 mi by 14 mi, with a total area of 308 mi^2. The area was divided into 29 rows and 63 columns (fig. 34); the cells range from 0.25 to 1.0 mi on a side. The smaller cells were used in areas where greater accuracy was desired, such as Perryman and Edgewood. The grid was oriented in such a way as to roughly align the model edges with the Chesapeake Bay, the Susquehanna River, and the Gunpowder River to accommodate those natural hydrologic boundaries.

Boundary Conditions

Boundary conditions were specified along the model edges to represent conditions in the real aquifer system. A no-flow boundary was placed at the bottom of the model (beneath layer 4) where the bedrock permeability is significantly less than that of the aquifers (fig. 32). Specified-head boundaries (fig. 35) were placed in aquifer 1 to simulate the Chesapeake Bay and the Susquehanna, Gunpowder, and Bush Rivers. Specified heads at sea level were simulated for the tidal parts of those rivers, and progressively higher heads, to a maximum of 150 ft, were simulated for the upland reach of the Gunpowder River. A recharge/discharge boundary was placed at the top of layer 1 to simulate recharge from precipitation, discharge through evapotranspiration, and flow to the streams. No-flow boundaries were placed at the physical boundaries of each aquifer where the real boundaries are within the model area and at the edge of the model where the aquifers extend beyond the model area; no-flow boundaries were arbitrarily placed in aquifers 3 and 4 where the

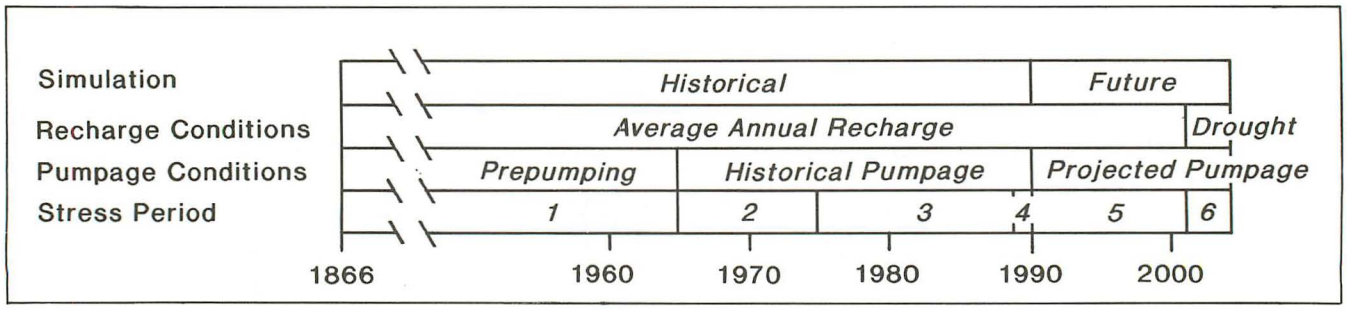


Figure 33.—Time discretization of the ground-water flow model.

southeastern extent of those aquifers is unknown (figs. 35, 36, 37, and 38).

The effect of the lateral no-flow boundaries on model results was evaluated in the sensitivity analysis. It was found that the boundaries had minimal effect on water levels in the study area in most of the simulations. The no-flow boundary in aquifer 3 could, however, significantly affect water levels for greatly increased pumping rates of simulations 7 and 12b. Simulated water levels near the no-flow boundary in aquifer 3 might not be accurate. The potentiometric-surface maps of aquifers 2 and 3 (figs. 20 and 24) indicate that most of the water in those aquifers discharges upward into the Chesapeake Bay and the Susquehanna and Gunpowder Rivers, which are just inside the model edges, and flow is not expected to cross the model edges where the no-flow boundaries were placed. The specified-head boundary in layer 1 that represents the Chesapeake Bay and the Susquehanna and Gunpowder Rivers intercepts any flow from aquifer 1. The northwestern no-flow boundary in layer 1 was placed in the Piedmont, and does not affect flow in the Coastal Plain aquifers.

Input Data

Hydrologic data entered into the model were obtained from the literature or estimated by various means, then adjusted within reasonable limits during model calibration. The values given here are the final calibrated values.

The horizontal hydraulic conductivity of aquifer 1 ranges from 2.0 to 630 ft/d (fig. 35). The altitude of the bottom of aquifer 1 ranges from 175 ft below sea level to 125 ft above sea level (fig. 15). An initial attempt was made to input the altitude of the irregular bottom surface of all sandy units in the unconfined aquifer; however, the poorly defined surface was so irregular that numerous cells went dry, causing serious convergence problems. Because more data were available to define the top of aquifer 2, the bottom of aquifer 1 was arbitrarily defined as being 1 ft above the top of aquifer 2. This assignment prevented most of the cells from drying up during the simulation, and defined the thickness of confining unit 1 as 1 ft.

The transmissivity arrays for confined aquifers 2, 3, and 4 were generated by calculating thickness arrays, then multiplying the thickness by the hydraulic conductivity at each cell.

The transmissivity of aquifer 2 is shown in figure 36. Values range from less than 1,000 ft^2/d, where the aquifer is silty, to greater than 40,000 ft^2/d at the Perryman well field. The transmissivity of aquifer 3 is shown in figure 37. Values range from less than 5,000 ft^2/d to about 20,000 ft^2/d near Sod Run where the sands are thickest and coarsest. The transmissivity of aquifer 4 is shown in figure 38. Values are generally low, and range from less than 5 ft^2/d to about 150 ft^2/d.

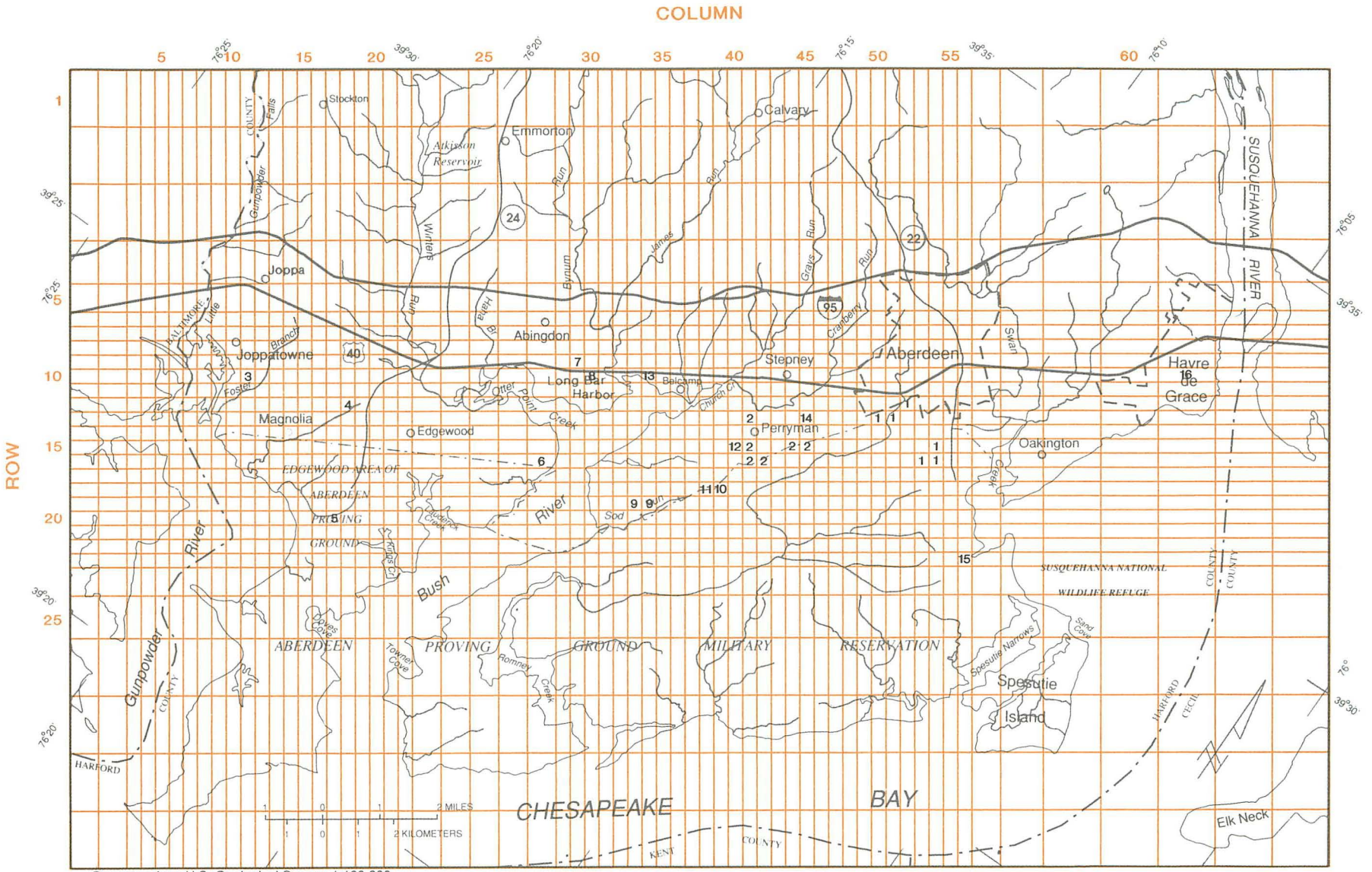
Leakance arrays for confining units 2 and 3 were calculated in a manner similar to the method used to calculate transmissivities. Leakances were calculated by dividing the vertical hydraulic conductivity by the thickness of the confining unit at each cell. The thickness was calculated at each cell by subtracting the altitudes of the top of the underlying aquifer from the bottom of the overlying aquifer.

Leakance values for confining unit 1 are shown in figure 39. Values range from about $10^{-5}/d$ (per day) near Magnolia to $10^{-1}/d$ near the northwestern limit of aquifer 2. Large leakance values were entered for confining unit 1 where aquifers 1 and 2 are in direct hydraulic connection. Leakance values for confining unit 2 are shown in figure 40. Values range from about $10^{-5}/d$ to about $10^{-2}/d$, with the higher values to the northeast and beneath the Bush River, and the lower values west of the Bush River. Leakance values for confining unit 3 are shown in figure 41. Values range from about $10^{-9}/d$ to $10^{-8}/d$. These values are very low because of the thickness and low permeability of the silty clay.

Recharge was applied to the upper surface of the model in aquifer 1. A value of 18 in/yr, or 0.0041 ft/d, was entered for the entire active area of aquifer 1 for the average recharge simulations. Recharge was reduced to 0.0027 ft/d (65 percent of the average recharge value) for the drought simulation at the end of the projected pumpage simulations (fig. 33). This reduction corresponds to a 35-percent reduction of long-term average precipitation during the 1965 drought.

Input for the RIVER package of MODFLOW includes the stage, or altitude of the stream-water surface, the elevation of the streambed bottom, and the conductance of the streambed material. The stream stage for each cell was estimated from a topographic map as the average value for all perennial stream

(Text continued on p. 57.)

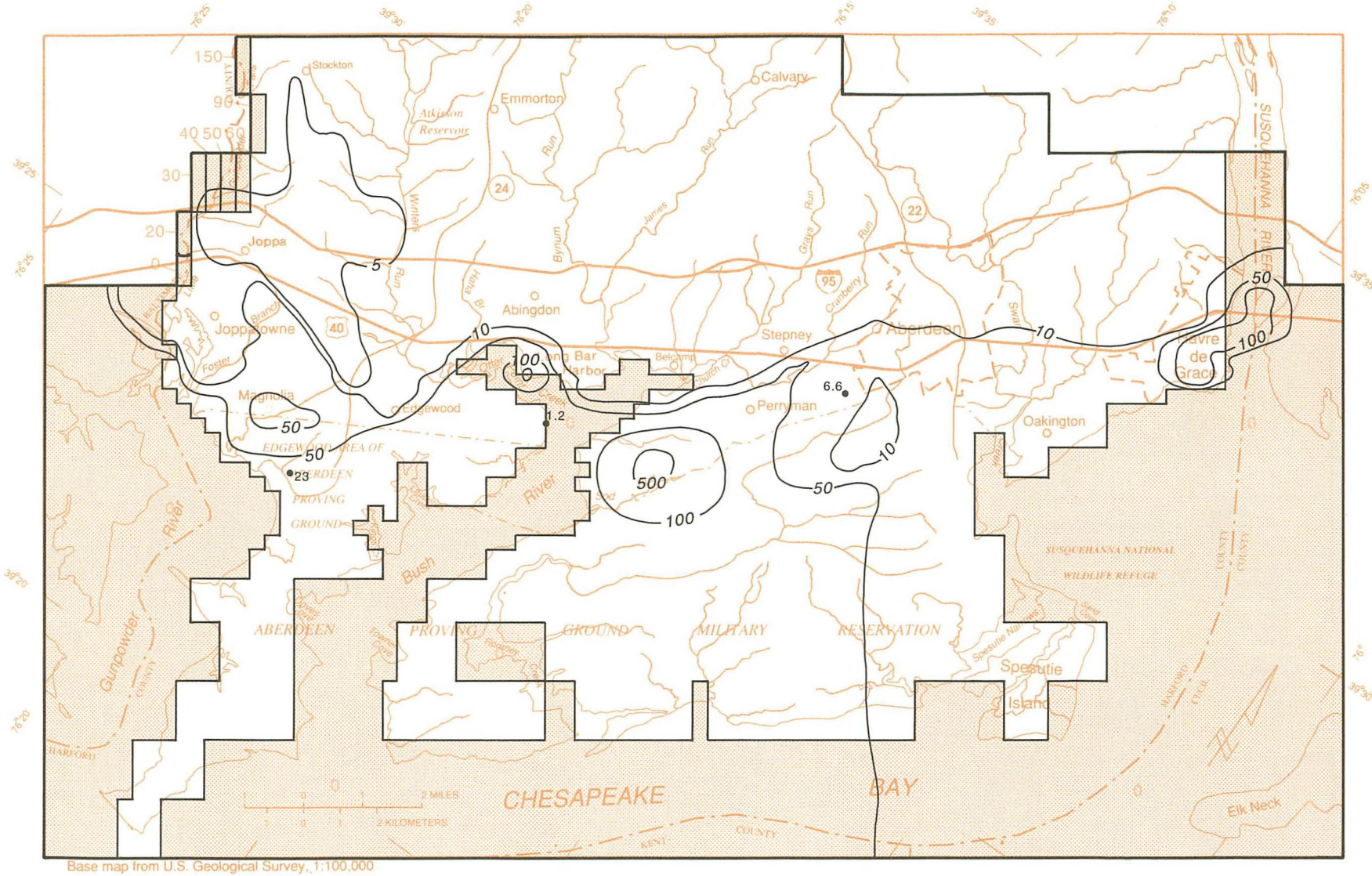


Base map from U.S. Geological Survey, 1:100,000

EXPLANATION

1 - ABERDEEN
2 - PERRYMAN
3 - JOPPATOWNE
4 - TRIMBLE ROAD
5 - U.S.ARMY - EDGEWOOD
6 - WILLOUGHBY BEACH
7 - DEINLEIN
8 - LONG BAR HARBOR
9 - BALTIMORE GAS AND ELECTRIC
10 - HYPOTHETICAL PERRYMAN WELLS
11 - MITCHELL
12 - PRICE BROTHERS
13 - BATA
14 - CLOROX
15 - U.S.ARMY - ABERDEEN
16 - HUBER

Figure 34.—Finite-difference grid and pumping centers simulated in the ground-water flow model.



Base map from U.S. Geological Survey, 1:100,000

EXPLANATION

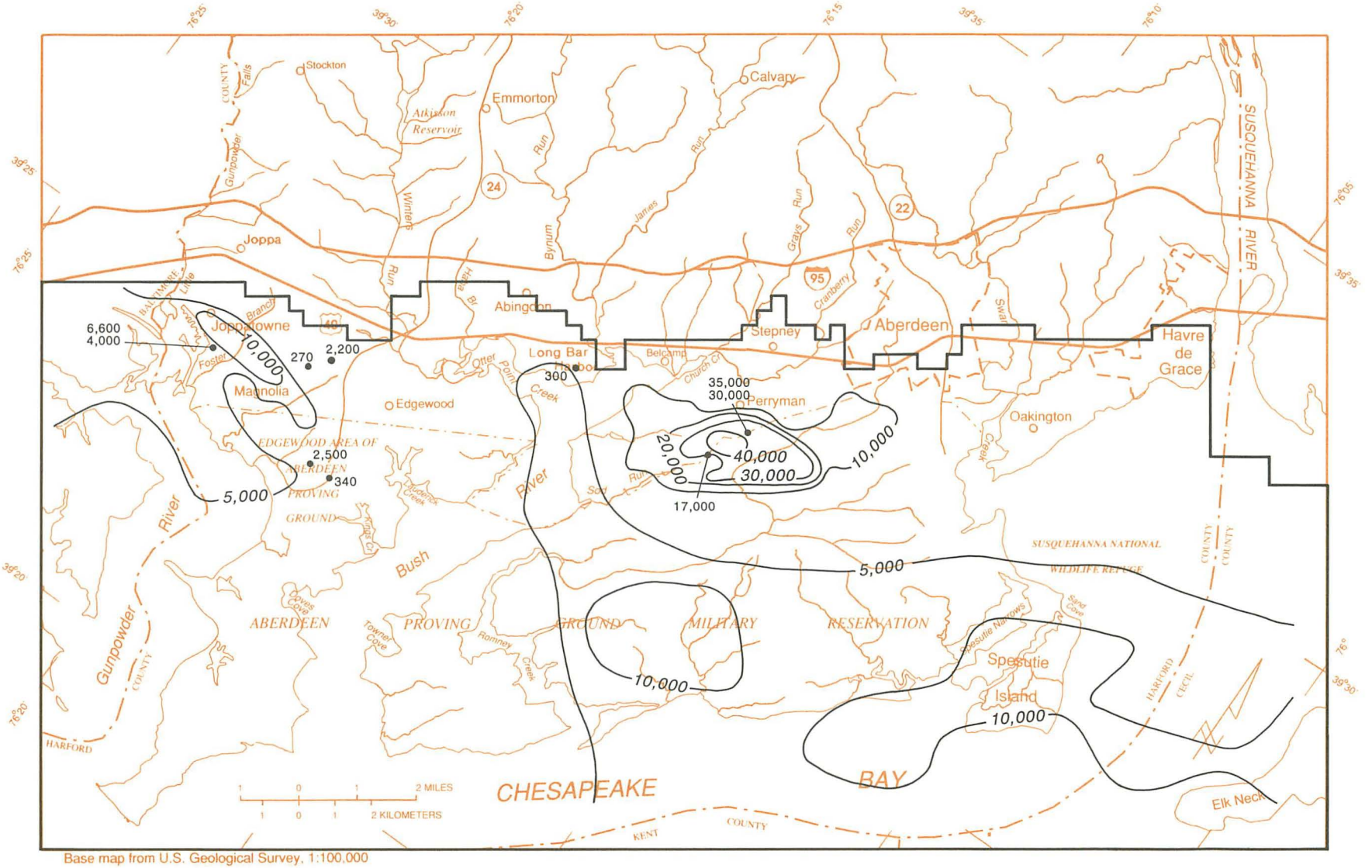
SPECIFIED-HEAD BOUNDARY. NUMBER IS SPECIFIED HEAD IN FEET. DATUM IS SEA LEVEL.

SIMULATED NO-FLOW BOUNDARY.

—10— **LINE OF EQUAL HYDRAULIC CONDUCTIVITY, IN FEET PER DAY.** CONTOUR INTERVAL IS VARIABLE.

●23 **WELL** -- NUMBER IS HYDRAULIC CONDUCTIVITY ESTIMATED FROM AQUIFER TESTS, IN FEET PER DAY.

Figure 35.—Boundaries and hydraulic conductivities specified for aquifer 1.



Base map from U.S. Geological Survey, 1:100,000

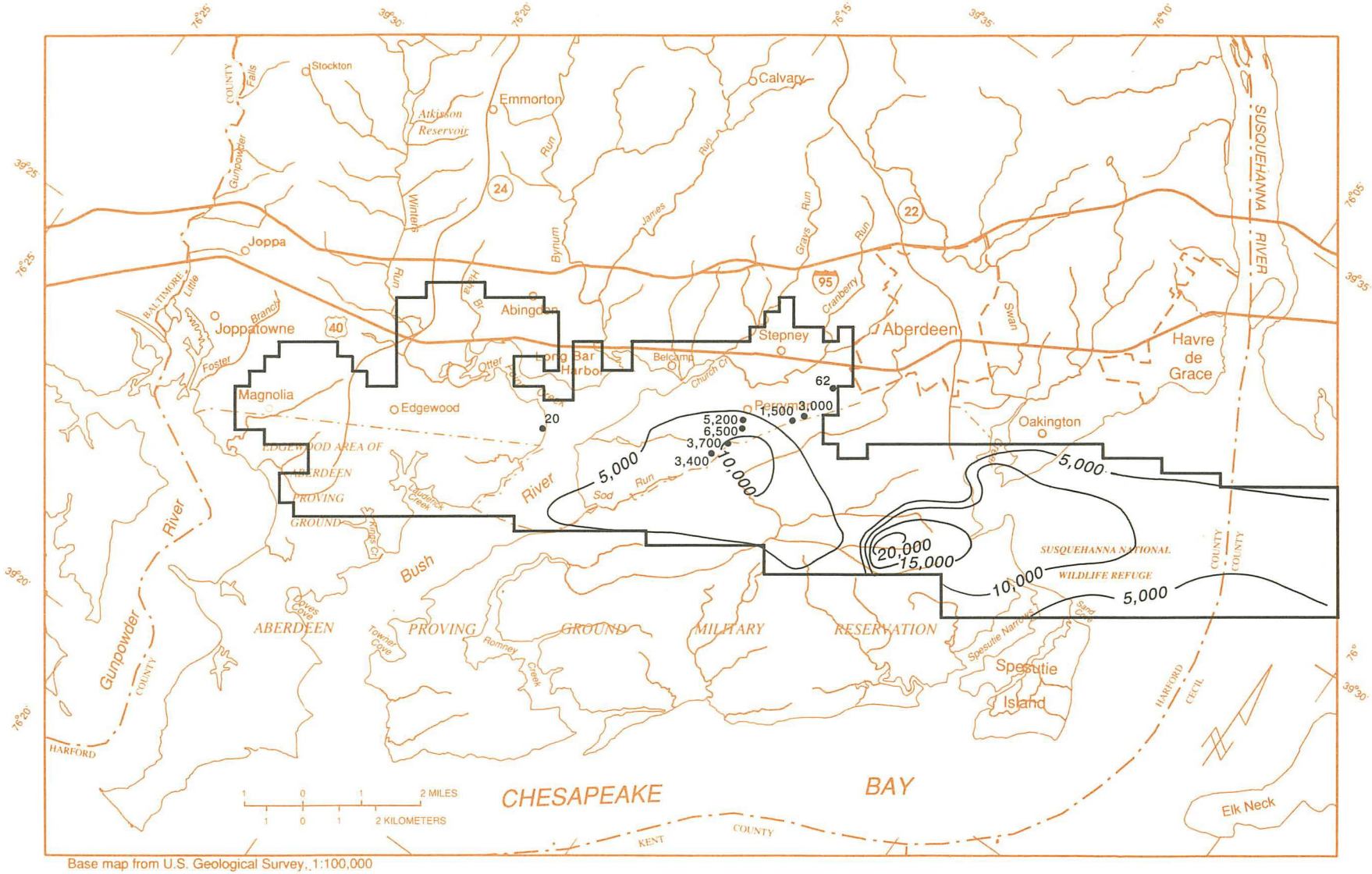
EXPLANATION

NO-FLOW BOUNDARY.

—5,000— LINE OF EQUAL SIMULATED TRANSMISSIVITY. CONTOUR INTERVALS ARE 5,000 AND 10,000 FEET SQUARED PER DAY.

340 WELL -- NUMBER IS ESTIMATED TRANSMISSIVITY, IN FEET SQUARED PER DAY.

Figure 36.—Boundaries and transmissivities specified for aquifer 2.



Base map from U.S. Geological Survey, 1:100,000

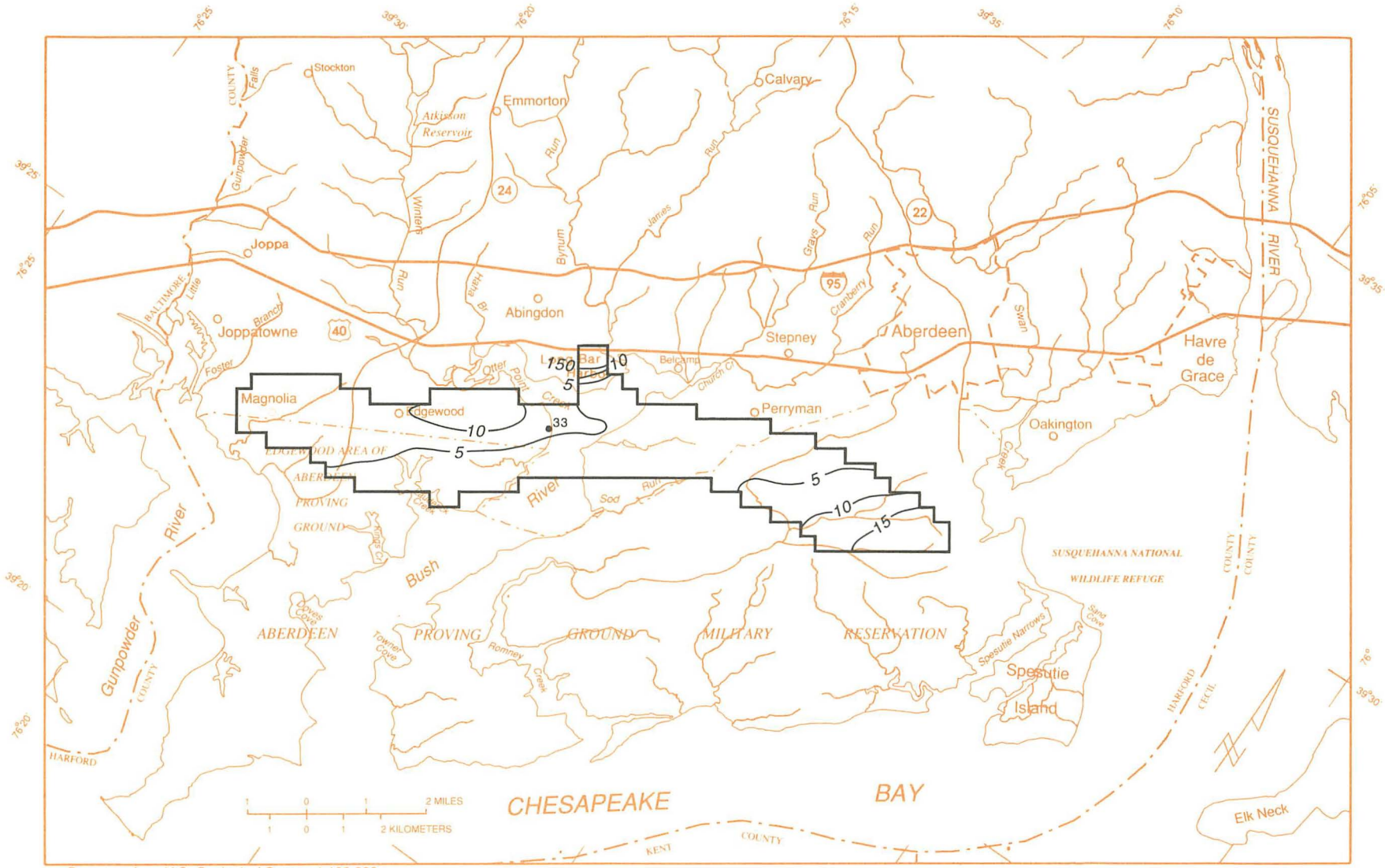
EXPLANATION

NO-FLOW BOUNDARY

—5,000— LINE OF EQUAL SIMULATED TRANSMISSIVITY. CONTOUR INTERVAL IS 5,000 FEET SQUARED PER DAY.

20 WELL--NUMBER IS ESTIMATED TRANSMISSIVITY, IN FEET SQUARED PER DAY.

Figure 37.—Boundaries and transmissivities specified for aquifer 3.



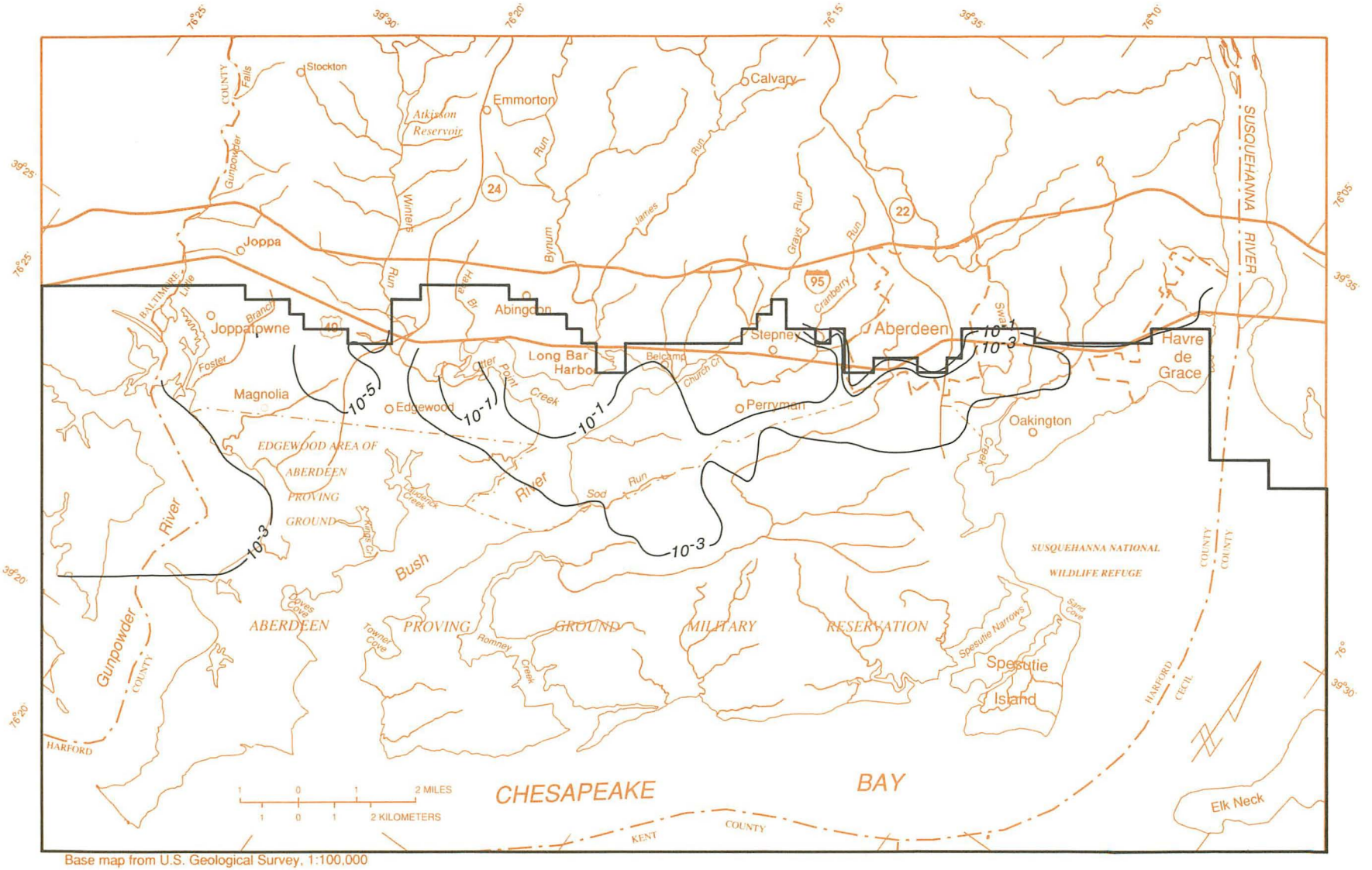
EXPLANATION

NO-FLOW BOUNDARY.

10 — LINE OF EQUAL SIMULATED TRANSMISSIVITY. CONTOUR INTERVALS ARE 5 AND 140 FEET SQUARED PER DAY.

33 WELL -- NUMBER IS ESTIMATED TRANSMISSIVITY, IN FEET SQUARED PER DAY.

Figure 38.—Boundaries and transmissivities specified for aquifer 4.



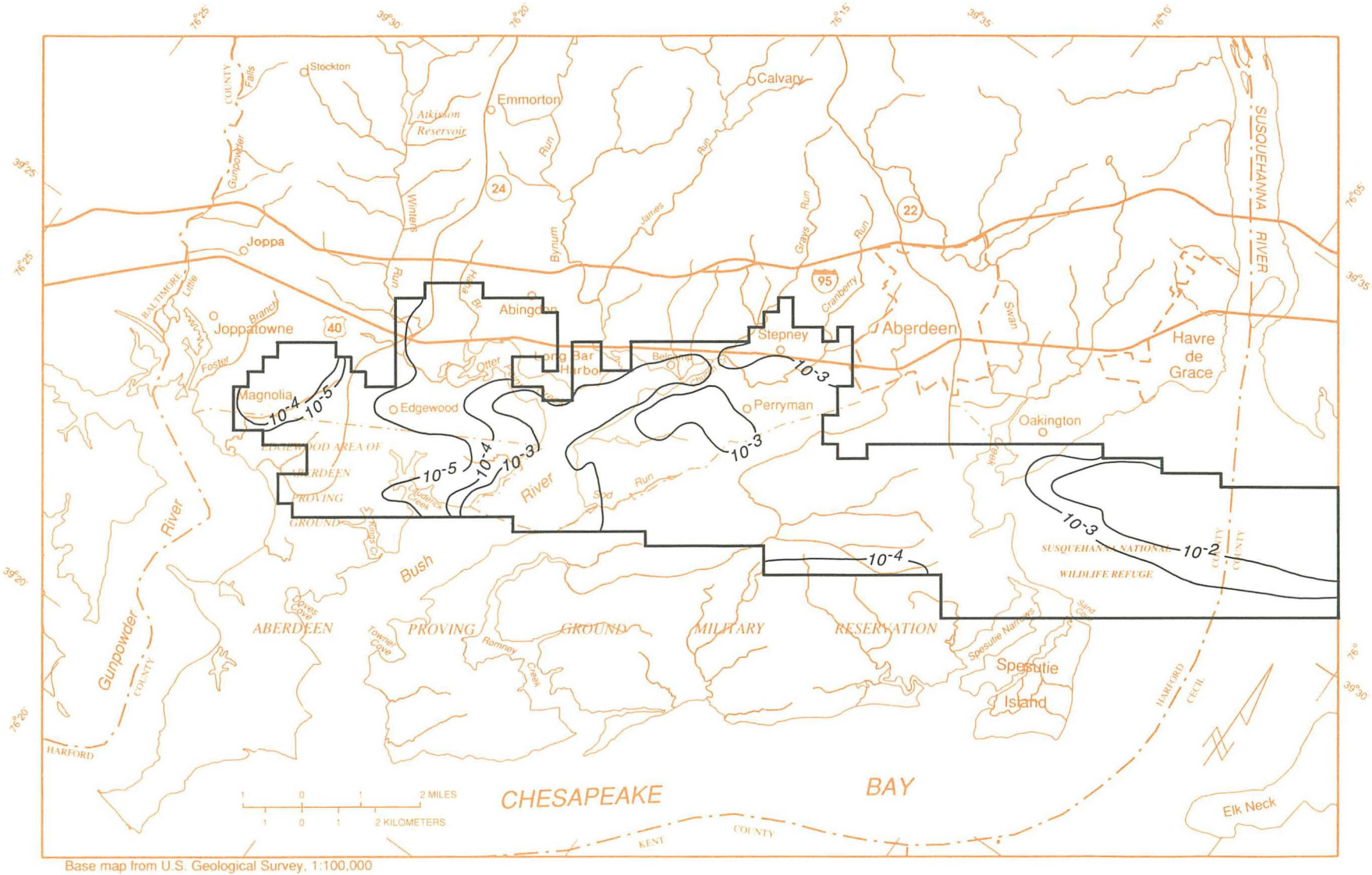
Base map from U.S. Geological Survey, 1:100,000

EXPLANATION

NO-FLOW BOUNDARY.

10^{-5} LINE OF EQUAL VERTICAL LEAKANCE, IN DAY $^{-1}$.
CONTOUR INTERVAL IS VARIABLE.

Figure 39.—Vertical leakance specified for confining unit 1.



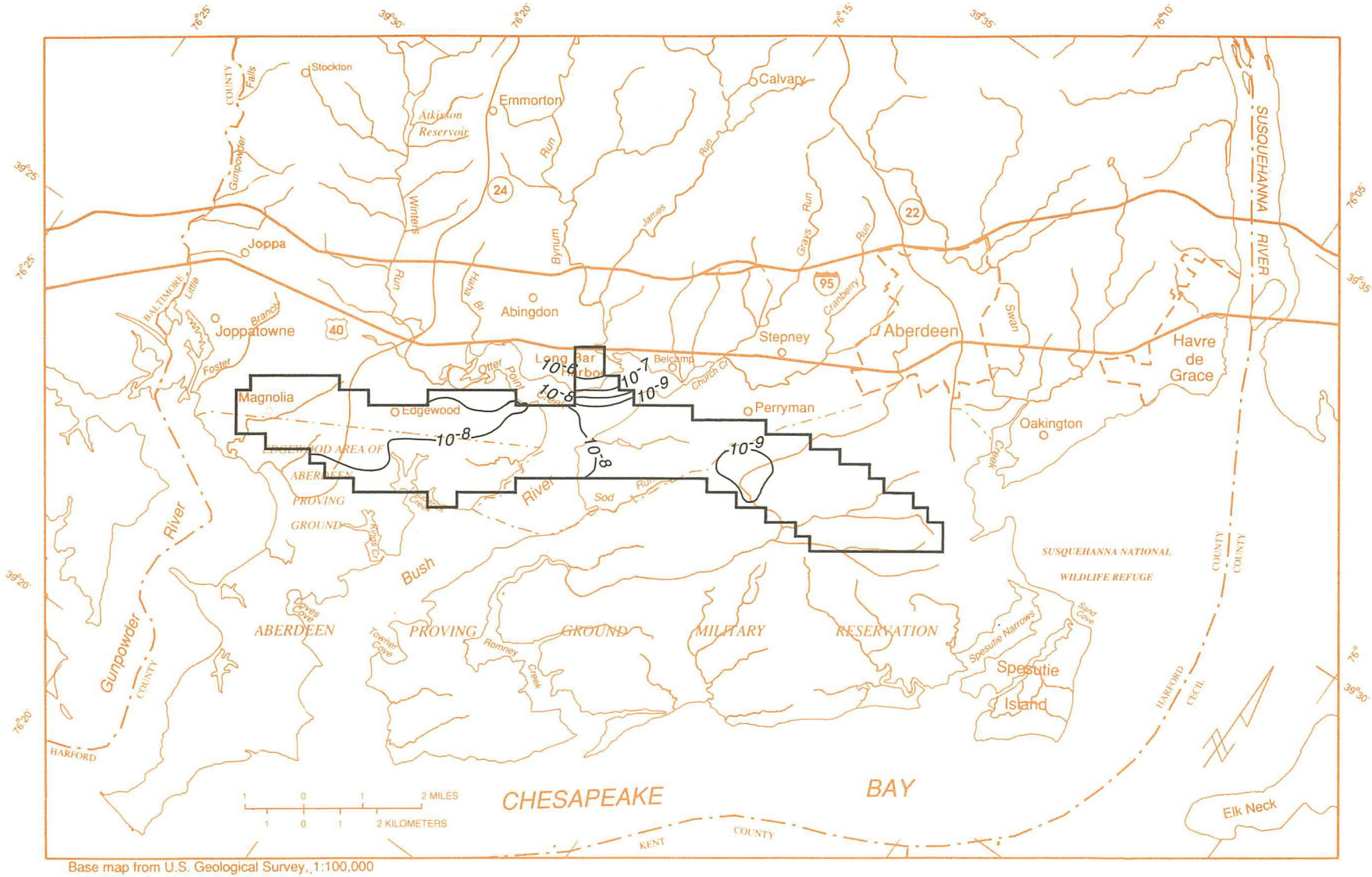
Base map from U.S. Geological Survey, 1:100,000

EXPLANATION

NO-FLOW BOUNDARY.

10^{-5} LINE OF EQUAL VERTICAL LEAKANCE, IN DAY $^{-1}$.
CONTOUR INTERVAL IS VARIABLE.

Figure 40.—Vertical leakance specified for confining unit 2.



Base map from U.S. Geological Survey., 1:100,000

EXPLANATION

NO-FLOW BOUNDARY.

10^{-8} LINE OF EQUAL VERTICAL LEAKANCE, IN DAY $^{-1}$. CONTOUR INTERVAL IS VARIABLE.

Figure 41.—Vertical leakance specified for confining unit 3.

reaches in that cell. Stream stages entered into the flow model range from sea level to 380 ft above sea level (tab. 24). The elevation of the streambed bottom was calculated by assuming a stream depth of 2 ft and subtracting that value from the stream stage. The conductance was calculated from the equation (McDonald and Harbaugh, 1988)

$$C = KLW/M, \quad (3)$$

where

C = conductance (ft^2/d),
K = hydraulic conductivity of the streambed material (ft/d),
L = sum of lengths of stream reaches (ft),
W = average width of stream reaches (ft), and
M = average thickness of streambed (ft).

The hydraulic conductivity was initially entered as 1.0 ft/d for all stream reaches and then adjusted globally to 0.44 ft/d during calibration. Stream lengths were totaled for each cell, stream widths were estimated from topographic maps, and streambed thickness was estimated at 3.0 ft for all reaches. Conductance values entered in the model range from 10 ft^2/d to 2.8×10^5 ft^2/d (tab. 24).

ET was withdrawn from each cell in aquifer 1 according to the depth below land surface of the simulated water table in that cell. A maximum ET rate of 18 in/yr was withdrawn from a cell if the depth to water table in that cell was less than 3 ft. No ET was withdrawn from a cell if the depth to water table in that cell was greater than 8 ft (referred to as the "extinction depth" by McDonald and Harbaugh, 1988). A linear relation was used to calculate ET in a cell if the depth to water table in that cell was between 3 and 8 ft. Model input for the altitude of maximum-ET surface (referred to as the "ET surface" by McDonald and Harbaugh, 1988) was generated by subtracting the depth of 3 ft from land-surface elevation, which is shown in figure 13 as the altitude of the top of aquifer 1.

Historical and projected pumpage was simulated by placing wells in the appropriate row, layer, and column (tab. 6) for each stress period. Historical pumpage was obtained from Wheeler and Wilde (1989) and estimated from well-owners' records. Projected pumpage was estimated from interviews with well owners, from consultants' recommendations for water-system expansion (Whitman, Requardt, and Associates, 1976) and from bracketed 1989 pumpage. Bracketed pumpage was arbitrarily determined by increasing and decreasing totals for 1989 pumpage by 20 percent.

Initial Conditions

Initial conditions were specified at the beginning of the prepumping run. The choice of initial conditions did not explicitly affect model results because the 100-year prepumping run was long enough to allow water levels to equilibrate to prepumping conditions. The prepumping water-table altitudes for aquifer 1 are shown in figure 42. Heads range from sea level at the shoreline to more than 300 ft above sea level in the northern part of the model area. The water-table surface is similar to the land surface, with highs beneath the uplands, and lows in the lowlands and stream valleys. The prepumping potentiometric surface for aquifer 2 is shown in figure 43. Heads range from about sea level beneath the tidal estuaries to about 50 ft above sea level at Aberdeen. The prepumping potentiometric surface for aquifer 3 is shown in figure 44. Heads range from about sea level beneath the Bush River and the Chesapeake Bay to about 40 ft above sea level near Aberdeen. The prepumping potentiometric surface for aquifer 4 is shown in figure 45. Heads range from about 12 ft above sea level near Magnolia to about 15 ft above sea level near Perryman.

Calibration

The flow model was calibrated by adjusting the model-input data within reasonable limits until the model output matched measured or estimated data. Data used to calibrate the model included water levels and hydrologic budget components, such as base flow to streams, evapotranspiration, and discharge to estuaries. Input data that are poorly known (such as transmissivity, streambed conductance, and recharge rates) were adjusted during calibration, but data known to be accurate (such as pumpage and streambed elevation) were not adjusted. The model was calibrated primarily to 1989 water levels because extensive historical data are lacking.

The first step in the calibration process was to simulate a reasonable water table in aquifer 1. Because hydraulic conditions in this aquifer are largely responsible for driving the flow through the deeper aquifers, their proper representation in the model is important. The water table is controlled by the shallow processes of recharge, evapotranspiration, base flow to (or from) streams, and flow to (or from) the specified head cell, and by the aquifer properties of hydraulic conductivity, specific yield, and altitude of the aquifer bottom.

Recharge was set at 0.0042 ft/d (tab. 7) and not adjusted during calibration. The maximum evapotranspiration was initially entered as 0.0027 ft/d as calculated by the method of Thornthwaite and Mather (1957), but was increased during calibration to 0.0042 ft/d. This value produced an actual groundwater evapotranspiration rate of 0.0015 ft/d.

Base flow to (or from) streams is controlled by the altitude of water in the stream (or stream stage), the conductance of the streambed, and the simulated head in the water-table aquifer. Stream stage was adjusted in a few cells to produce a reasonable water-table elevation, but for the most part it was not altered. The conductance of the stream cells was changed globally (throughout the modeled area) by changing the hydraulic conductivity in equation 3. Initially, a value of 1.0 ft/d was entered for hydraulic conductivity for all stream cells, then adjusted to match observed water-table altitudes in the stream valleys and to produce the proper amount of base flow for the entire modeled area.

Flow to specified-head cells represents discharge into (or from) tidal estuaries, the Chesapeake Bay, and the Gunpowder,

Table 6.—Pumpage data used in the Harford County flow model

[Sim = simulation; *, pumpage equal to 1989 pumpage]

Pumping center		Model location			Pumpage in cubic feet per day [1]							
					Calibration			Sim 1	Sim 2	Sim 3	Sim 4	Sim 5
Location	Owner/Operator	Layer	Row	Column	1966-1975	1976-1988	1989	1990-2001	1990-2001	1990-2001	1990-2001	1990-2001
Aberdeen	City of Aberdeen	2	13	50	23,048	24,254	28,676	*	34,411	22,941	*	*
		2	13	51	23,048	24,254	28,676	*	34,411	22,941	*	*
		2	12	52	23,048	24,254	28,676	*	34,411	22,941	*	*
		2	16	53	23,048	24,254	28,676	*	34,411	22,941	*	*
		2	16	54	23,048	24,254	28,676	*	34,411	22,941	*	*
		2	15	54	23,048	24,254	28,676	*	34,411	22,941	*	*
Aberdeen Proving Ground at Aberdeen	U.S. Army	2	23	56	2,814	0	0	*	*	*	*	*
		3	23	56	2,814	0	0	*	*	*	*	*
Aberdeen Proving Ground at Edgewood	U.S. Army	2	20	17	5,896	0	0	*	*	*	*	*
Belcamp	Bata Shoe Co.	3	10	34	5,494	134	134	*	161	107	*	*
Perryman	Mitchell Canning Co.	2	18	38	1,072	0	0	*	*	*	*	*
		3	18	38	1,072	0	0	*	*	*	*	*
Aberdeen	Price Brothers	3	15	40	8,978	13,936	12,864	*	*	*	*	*
Havre de Grace	J.M. Huber Inc.	2	10	61	20,234	22,378	21,172	*	*	*	*	*
Long Bar Harbor	Harford County Dept. of Public Works	4	10	30	0	4,360	0	*	*	*	*	*
Joppatowne	Joppatowne	2	10	11	39,664	53,332	32,964	*	39,557	26,371	*	*
Perryman	Harford County Dept. of Public Works	3	13	41	6,700	13,936	16,482	*	19,778	13,186	26,536	*
		3	13	41	10,720	20,904	24,656	*	29,587	19,725	39,696	*
		3	15	40	13,400	27,872	32,830	*	39,396	26,264	52,856	*
		3	15	41	13,400	27,872	32,830	*	39,396	26,264	52,856	*
		2	16	42	32,026	62,712	73,834	*	88,601	59,067	118,873	154,000
		2	16	41	56,146	108,004	127,300	*	152,760	101,840	204,953	192,000
		3	15	44	0	48,776	57,486	*	68,983	45,989	92,552	*
		3	15	45	0	41,808	49,312	*	59,174	39,450	79,392	*
Willoughby Beach	Willoughby Beach Water Co.	3	16	27	5,092	0	0	*	*	*	*	*
Abingdon	Kenneth Deinlein	2	9	29	0	15,946	1,742	*	2,090	1,394	*	*
Perryman Proposed Wells		3	18	39	0	0	0	*	*	*	*	*
		2	18	39	0	0	0	*	*	*	*	*
		2	18	39	0	0	0	*	*	*	*	*
		3	18	39	0	0	0	*	*	*	*	*
		3	18	39	0	0	0	*	*	*	*	*
Perryman	Clorox Corporation	3	13	45	0	0	0	*	*	*	*	*
Bush River Power Plant	Baltimore Gas and Electric Co.	2	19	33	0	0	0	*	*	*	*	*
		2	19	34	0	0	0	*	*	*	*	*
Trimble Road	Harford County Dept. of Public Works	2	12	18	0	0	0	*	*	*	*	*
	Totals				363,810	607,494	655,622	*	786,746	524,498	923,446	800,488

[1] Cubic feet per day x 7.48 = gallons per day.

Bush, and Susquehanna Rivers, and the nontidal reach of the Gunpowder River in the northwestern corner of the model area. No data are available to compare against the model-generated value of 4.4 in/yr (tab. 7) because the amount of discharge to estuaries is difficult to measure. The discharge is controlled by the altitude of the specified-head cells, hydraulic conductivity of the water-table aquifer, and heads in the water-table aquifer. Altitudes of the specified-head cells were not changed during calibration. The hydraulic conductivity of the water-table aquifer was adjusted to accurately simulate the observed water table. Simulated estuarine-discharge value of 4.4 in/yr is considerably lower than the value of 8.5 in/yr simulated for the Glen Burnie area by Achmad (1991), but is comparable considering that hydrologic conditions are somewhat different in the two areas. The specific yield of 0.1 for aquifer 1 was not changed during calibration, because the model was relatively insensitive to changes in specific yield.

The leakance of confining unit 1 was adjusted during calibration to allow the required amount of leakage between aquifers 1 and 2 and to produce the proper head distributions for aquifers 1 and 2.

The second step in model calibration was to adjust the transmissivity and leakance values for the deeper aquifers to match measured potentiometric surfaces and simulate the proper

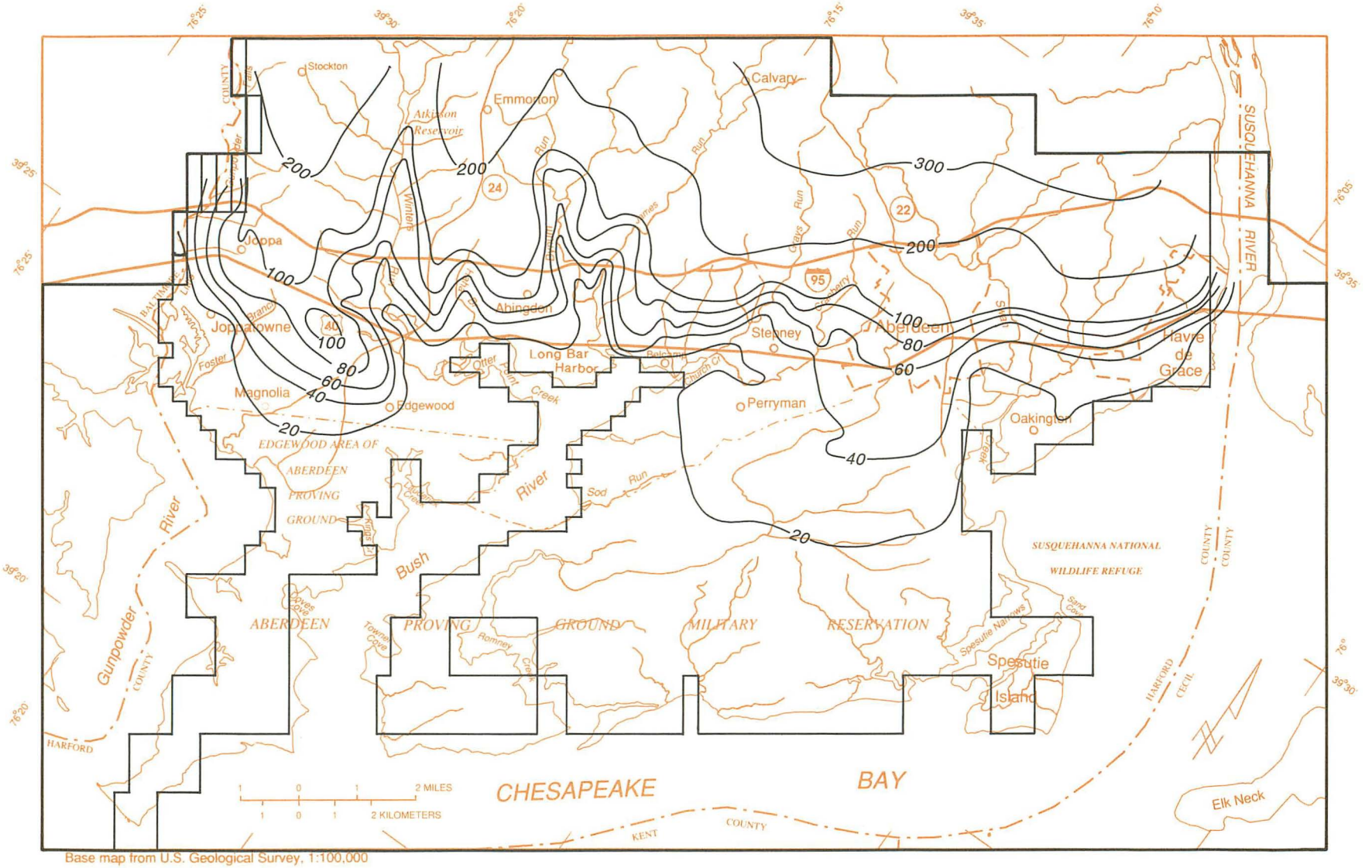
Sim 6 1990-2001	Sim 7a 1990-2001	Sim 7b 1990-2001	Sim 8 1990-2001	Sim 9 1990-2001	Sim 10a 1990-2001	Sim 10b 1990-2001	Sim 11 1990-2001	Sim 12a 1990-2001	Sim 12b 1990-2001	Sim 13 1990-2001
*	*	*	*	*	*	*	*	44,563	55,666	*
*	*	*	*	*	*	*	*	44,563	55,666	*
*	*	*	*	*	*	*	*	44,563	55,666	*
*	*	*	*	*	*	*	*	44,563	55,666	*
*	*	*	*	*	*	*	*	44,563	55,666	*
*	*	*	*	*	*	*	*	44,563	55,666	*
*	*	*	*	*	*	*	*	19,719	149,735	*
*	*	*	*	*	*	*	*	19,719	149,735	*
*	*	*	*	*	*	*	*	588	1,176	*
*	*	*	*	*	*	*	*	18,048	23,395	*
*	*	*	*	*	*	*	*	*	*	*
*	*	*	*	*	*	*	*	*	*	*
*	*	*	*	*	*	*	*	18,716	38,770	*
*	*	*	*	*	*	*	*	34,422	53,475	*
*	*	*	*	*	*	*	*	40,107	53,475	*
*	*	*	*	*	*	*	*	45,454	53,475	*
*	120,000	110,000	14,574	*	*	*	*	22,580	37,085	26,536
*	215,000	210,000	21,802	*	*	*	*	33,779	55,476	39,696
*	200,000	193,000	29,030	*	*	*	*	44,977	73,868	52,856
*	110,000	99,000	29,030	*	*	*	*	44,977	73,868	52,856
*	32,000	24,000	65,288	*	*	*	*	101,153	166,127	118,873
*	390,000	320,000	112,566	*	*	*	*	174,401	286,425	204,953
*	140,000	135,000	50,832	*	*	*	*	78,756	129,344	92,552
*	28,000	22,000	43,604	*	*	*	*	67,557	110,952	79,392
*	*	*	*	*	*	*	*	*	*	*
*	*	*	*	*	*	*	*	2,520	4,200	*
67,000	*	*	*	*	*	*	*	*	*	*
*	*	*	4,456	*	*	*	*	*	*	*
*	*	*	4,456	*	*	*	*	*	*	*
*	*	*	6,678	*	*	*	*	*	*	*
*	*	*	6,678	*	*	*	*	*	*	*
*	*	*	*	26,738	*	*	*	*	*	26,738
*	*	*	*	*	4,902	42,914	*	*	*	42,914
*	*	*	*	*	9,804	85,829	*	*	*	85,829
*	*	*	*	*	*	*	33,422	*	*	33,422
722,622	1,490,732	1,368,732	532,838	682,368	670,328	784,365	689,044	1,034,851	1,794,577	1,112,349

amount of flow between aquifers. The transmissivity values of aquifers 2, 3, and 4 were adjusted during calibration by changing the horizontal hydraulic conductivity values, and to a lesser extent, by changing aquifer thicknesses. In addition to changes made to individual cells in the hydraulic conductivity arrays, hydraulic conductivity of aquifers 2, 3, and 4 was reduced globally from the original estimates to produce transmissivities that were comparable to measured values.

The leakance arrays for aquifers 1, 2, and 3 were adjusted during calibration by changing the hydraulic conductivities used to calculate the leakances. Global and local changes in leakance were made to achieve a satisfactory match between simulated and observed conditions.

The model was considered calibrated when the simulated water-level surfaces of the aquifers were in close agreement with measured surfaces, and simulated hydrologic budget values, evapotranspiration, and seepage to streams and estuaries were in close agreement with their measured (or estimated) values. The calibration was considered acceptable when the simulated and measured water levels differed by less than 10 percent of the range of measured values in each aquifer, as judged by visual inspection of plotted and contoured data.

The prepumping and 1989 water-level surfaces were used to calibrate the model. Because prepumping hydrologic data are virtually nonexistent, simulated results were only checked for reasonableness. The water-level surface in aquifer 1 was also



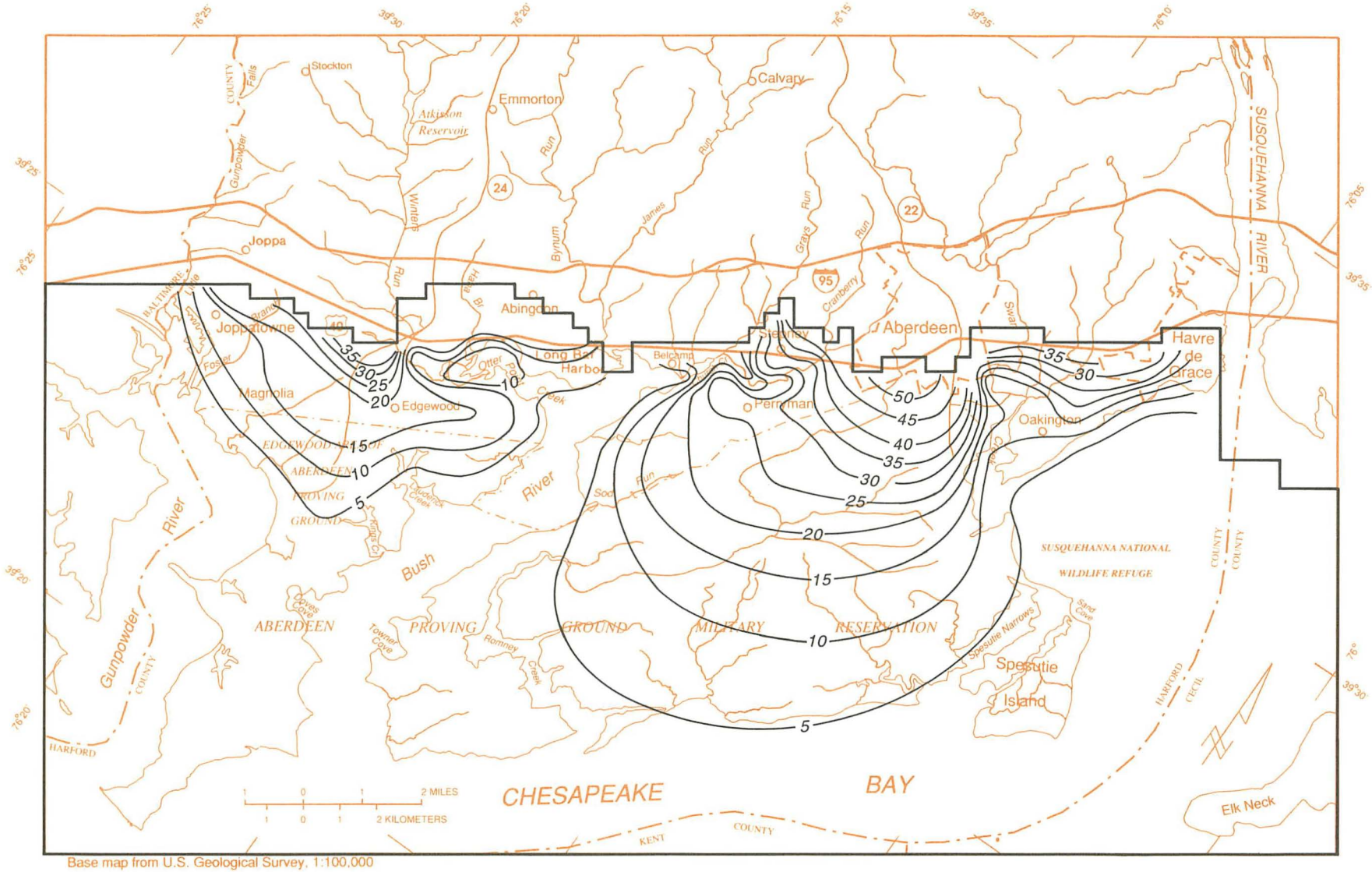
EXPLANATION

NO-FLOW BOUNDARY.

—10— LINE OF EQUAL SIMULATED ALTITUDE OF THE WATER TABLE. CONTOUR INTERVAL IS VARIABLE. DATUM IS SEA LEVEL.

SPECIFIED-HEAD BOUNDARY

Figure 42.—Simulated prepumping water-table altitude in aquifer 1.

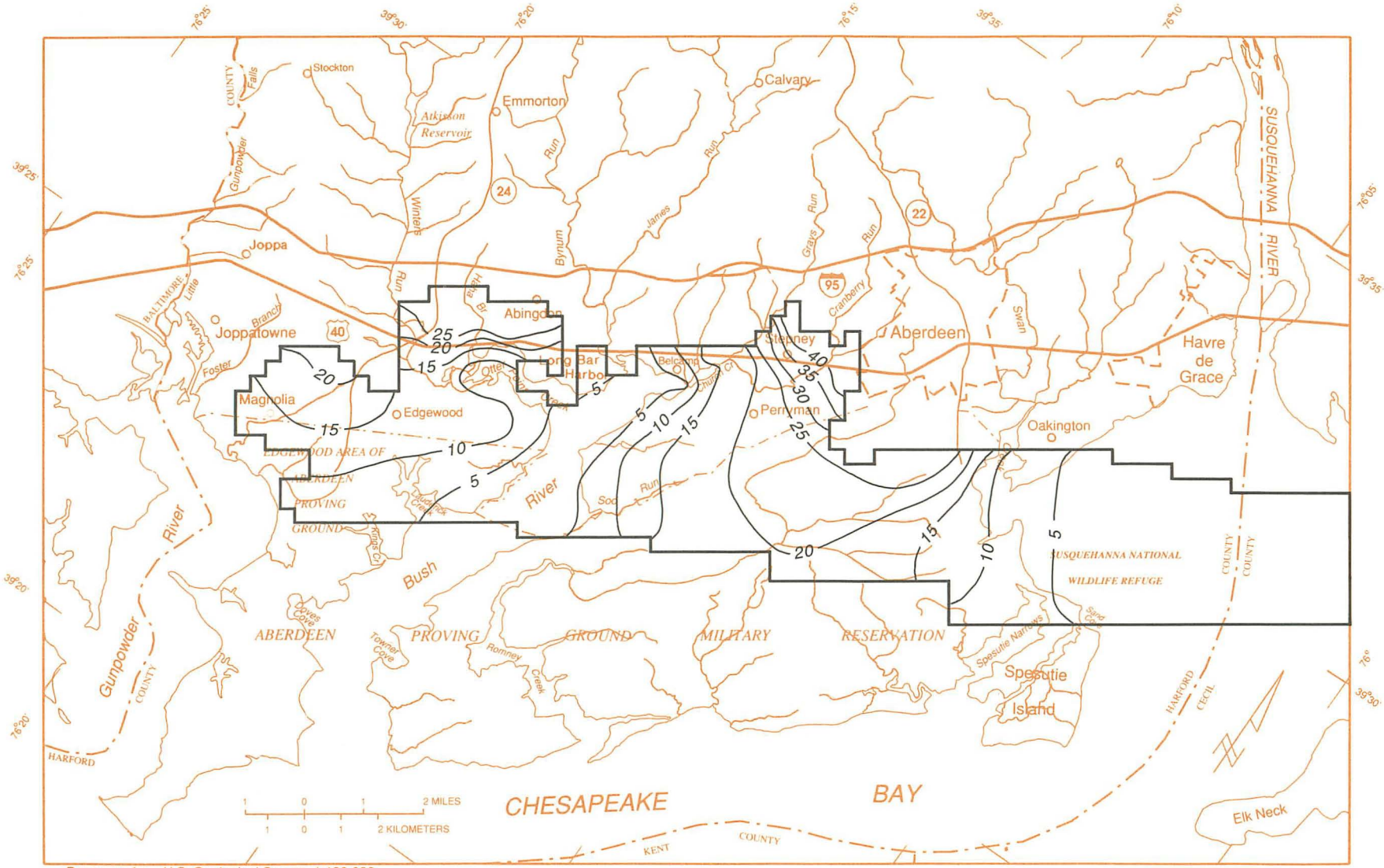


EXPLANATION

NO-FLOW BOUNDARY.

5 LINE OF EQUAL POTENTIOMETRIC HEAD. CONTOUR INTERVAL IS 5 FEET. DATUM IS SEA LEVEL.

Figure 43.—Simulated prepumping potentiometric surface in aquifer 2.



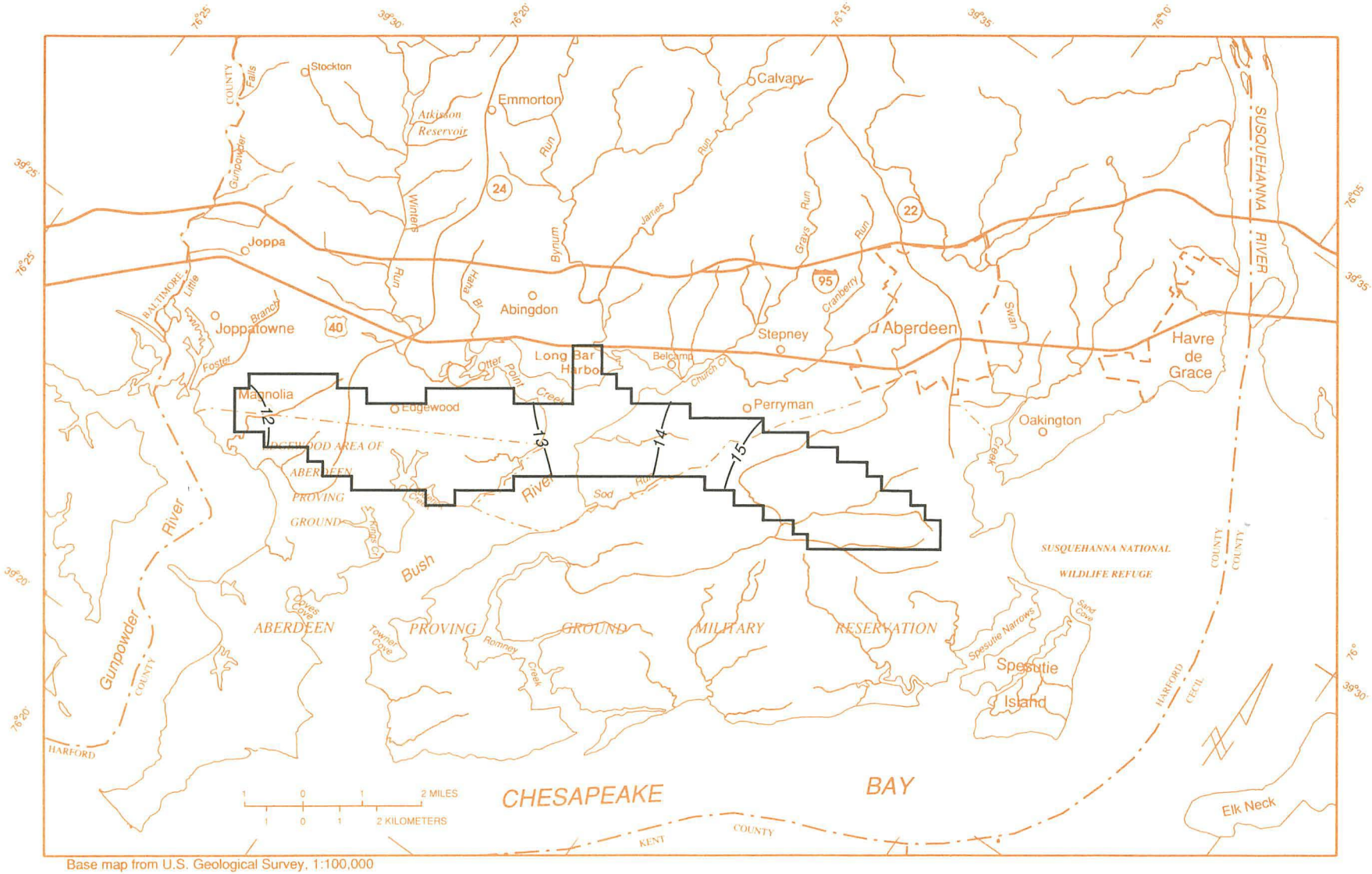
Base map from U.S. Geological Survey, 1:100,000

EXPLANATION

NO-FLOW BOUNDARY.

10 LINE OF EQUAL POTENTIOMETRIC HEAD. CONTOUR INTERVAL IS 5 FEET. DATUM IS SEA LEVEL.

Figure 44.—Simulated prepumping potentiometric surface in aquifer 3.



Base map from U.S. Geological Survey, 1:100,000

EXPLANATION

NO-FLOW BOUNDARY.

—15— LINE OF EQUAL SIMULATED POTENTIOMETRIC HEAD, IN FEET. DATUM IS SEA LEVEL. CONTOUR INTERVAL IS 1 FOOT.

Figure 45.—Simulated prepumping potentiometric surface in aquifer 4.

Table 7.—Flow components of the prepumping, 1989, 2000 (maximum safe yield), and 2001 (1-year drought) model simulations

[in/yr = inch per year; Mft³/d = million cubic feet per day]

Components	Flow rate							
	Prepumping		1989		2000		2001	
	in/yr	Mft^3/d	in/yr	Mft^3/d	in/yr	Mft^3/d	in/yr	Mft^3/d
Inflow:								
Recharge	18.4	19.0	18.4	19.0	18.4	19.0	10.9	11.2
Constant-head boundary	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.1
Stream leakage	0.2	0.1	0.2	0.1	0.2	0.1	0.3	0.3
Storage	0.0	0.0	0.0	0.0	0.0	0.0	3.2	3.3
Total[a]	18.6	19.1	18.6	19.1	18.6	19.1	14.6	14.9
Outflow:								
Constant-head boundary	4.4	4.5	4.3	4.4	4.0	4.1	3.1	3.2
Stream leakage	7.0	7.2	6.2	6.9	6.6	6.8	5.4	5.6
Pumpage	0.0	0.0	0.6	0.7	1.4	1.5	0.6	0.7
Evapotranspiration	7.2	7.4	6.9	7.1	6.6	6.8	5.5	5.6
Total[a]	18.6	19.1	18.6	19.1	18.6	19.2	14.6	15.1

[a]Discrepancies between inflow and outflow totals are due to rounding.

checked to compare water levels in streams (fig. 16).

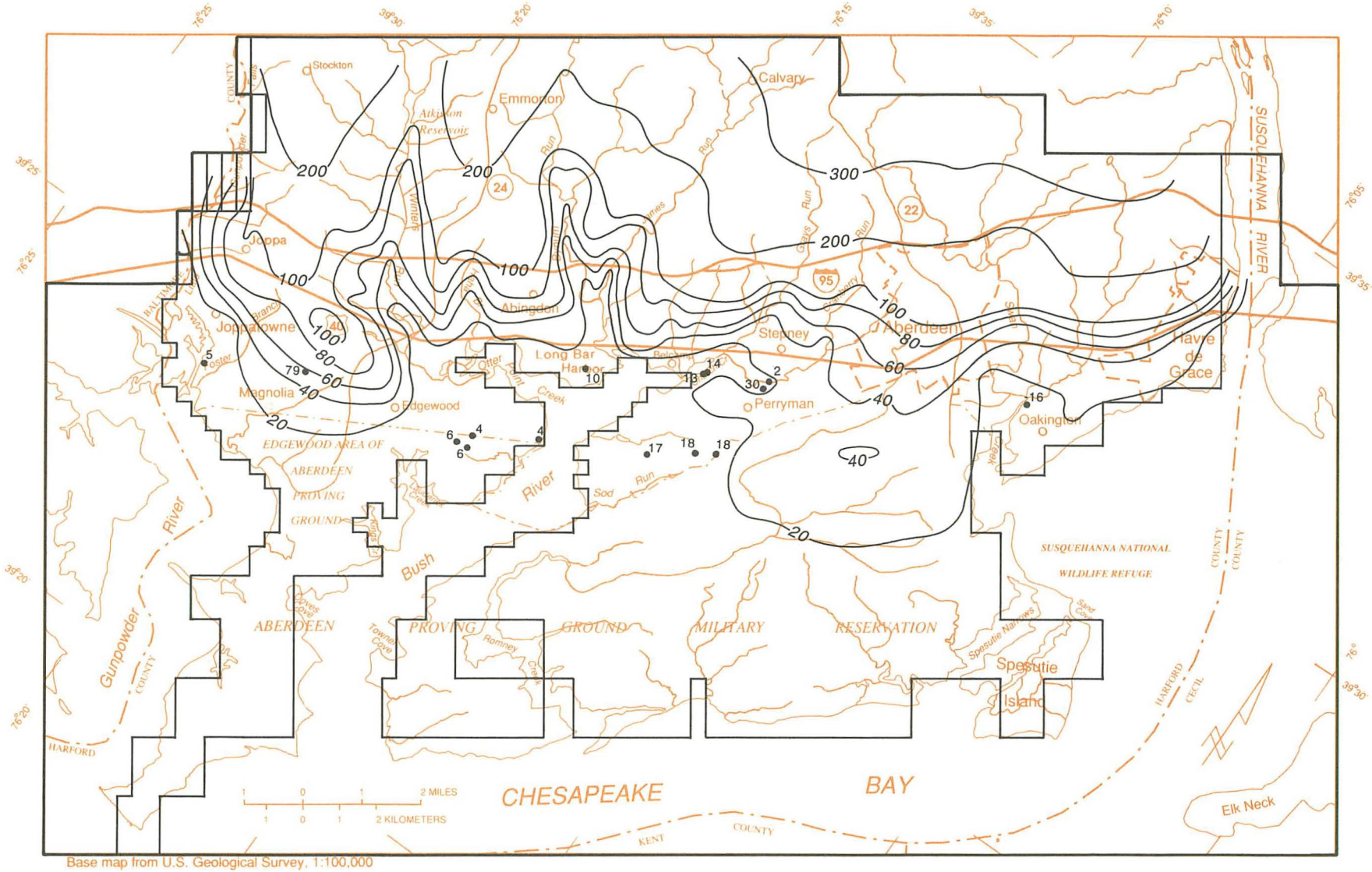
The prepumping water table in aquifer 1 ranges in altitude from sea level at the tidal estuaries to greater than 300 ft above sea level in the northern part of the model area (fig. 42). The prepumping potentiometric surface for aquifer 2 ranges in altitude from less than 5 ft above sea level beneath the tidal estuaries to about 50 ft above sea level at Aberdeen (fig. 43). A localized area of high water levels (altitudes as high as 35 ft) also is present in aquifer 2 near Edgewood. The prepumping potentiometric surface for aquifer 3 ranges in altitude from less than 5 ft above sea level beneath the tidal estuaries to about 40 ft above sea level near Aberdeen (fig. 44); a localized area of high water levels (altitudes as high as 25 ft) is also present in aquifer 3 near Edgewood. The prepumping potentiometric surface for aquifer 4 ranges in altitude from about 12 ft above sea level at Magnolia to about 15 ft above sea level near Perryman (fig. 45).

The simulated 1989 water-table altitudes in aquifer 1 have the same characteristics and range as the prepumping altitudes (fig. 46). In the Perryman area, water levels are a few ft lower than those in the prepumping simulation because of downward leakage into aquifer 2. Simulated water levels are generally close to measured water levels, considering the large range of measured values. The flow model cannot simulate the small-scale complexities of the water-table aquifer, however, and some inconsistencies can be expected. For example, the measured water level of 16 ft below sea level near Oakington (fig. 46) is difficult to reconcile with other water levels in the area as there is no documented pumpage in the area and no other physical processes are likely to appreciably draw down water levels. The altitude of the measuring point for that well may be inaccurate.

The simulated 1989 potentiometric surface for aquifer 2 (fig. 47) has the same general features as the prepumping surface (fig. 43), but water levels are as much as 10 ft lower in the Perryman area and 2 ft lower in the Joppatowne area. This is caused by pumpage from aquifer 2 and leakage into aquifer 3, which also is pumped. The simulated potentiometric surface is generally within 5 ft of measured water levels. The relatively low measured water level of 8 ft below sea level near Joppatowne could result from a well screened in an isolated or low-permeability sand. Domestic pumpage from the sand could be enough to draw water levels down below sea level.

The simulated 1989 potentiometric surface for aquifer 3 (fig. 48) has the same general features as the prepumping surface, but water levels are as much as 15 ft lower in the Perryman area because of pumping from the aquifer. The simulated potentiometric surface is within 5 ft of measured water levels except in the area north of Magnolia, where a measured water level is about 10 ft higher than the simulated level.

The simulated 1989 potentiometric surface for aquifer 4 (fig. 49) has somewhat different features than the prepumping surface. Water levels declined as much as 8 ft throughout the aquifer because of upward leakage into aquifer 3. The two measured water levels near Edgewood are within 1 ft of simulated levels. The measured water level of 1 ft below sea level is about 13 ft deeper than simulated water levels in that area. The difference could result from undocumented pumpage from aquifer 4 at Aberdeen Proving Ground.



EXPLANATION

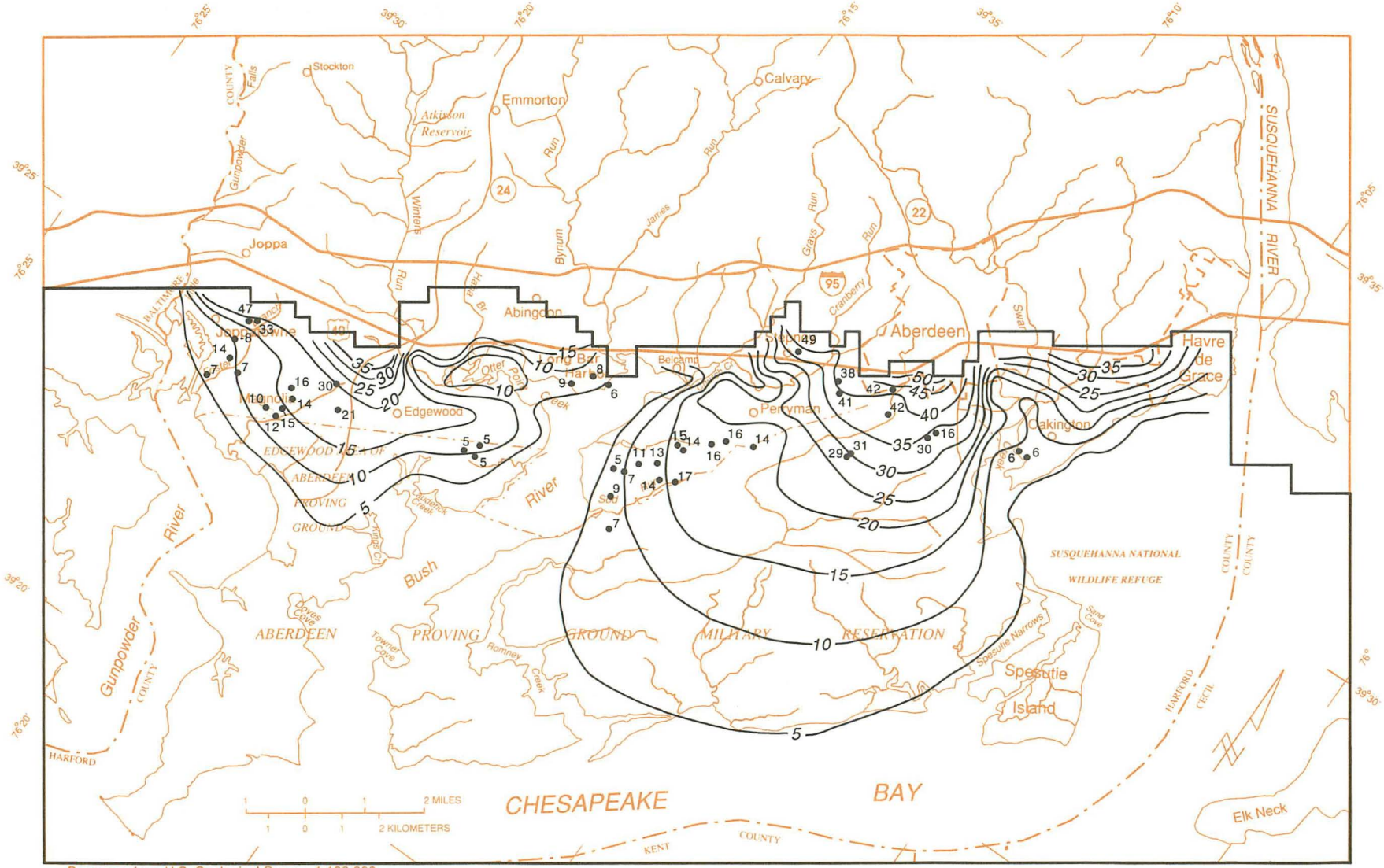
NO-FLOW BOUNDARY.

SPECIFIED-HEAD BOUNDARY.

—20— LINE OF EQUAL SIMULATED WATER-TABLE ALTITUDE. DASHED WHERE INFERRED. CONTOUR INTERVAL IS VARIABLE. DATUM IS SEA LEVEL.

•18 MEASURED ALTITUDE OF WATER LEVEL, IN FEET

Figure 46.—Simulated and measured water-table altitudes in aquifer 1, 1989.



Base map from U.S. Geological Survey, 1:100,000

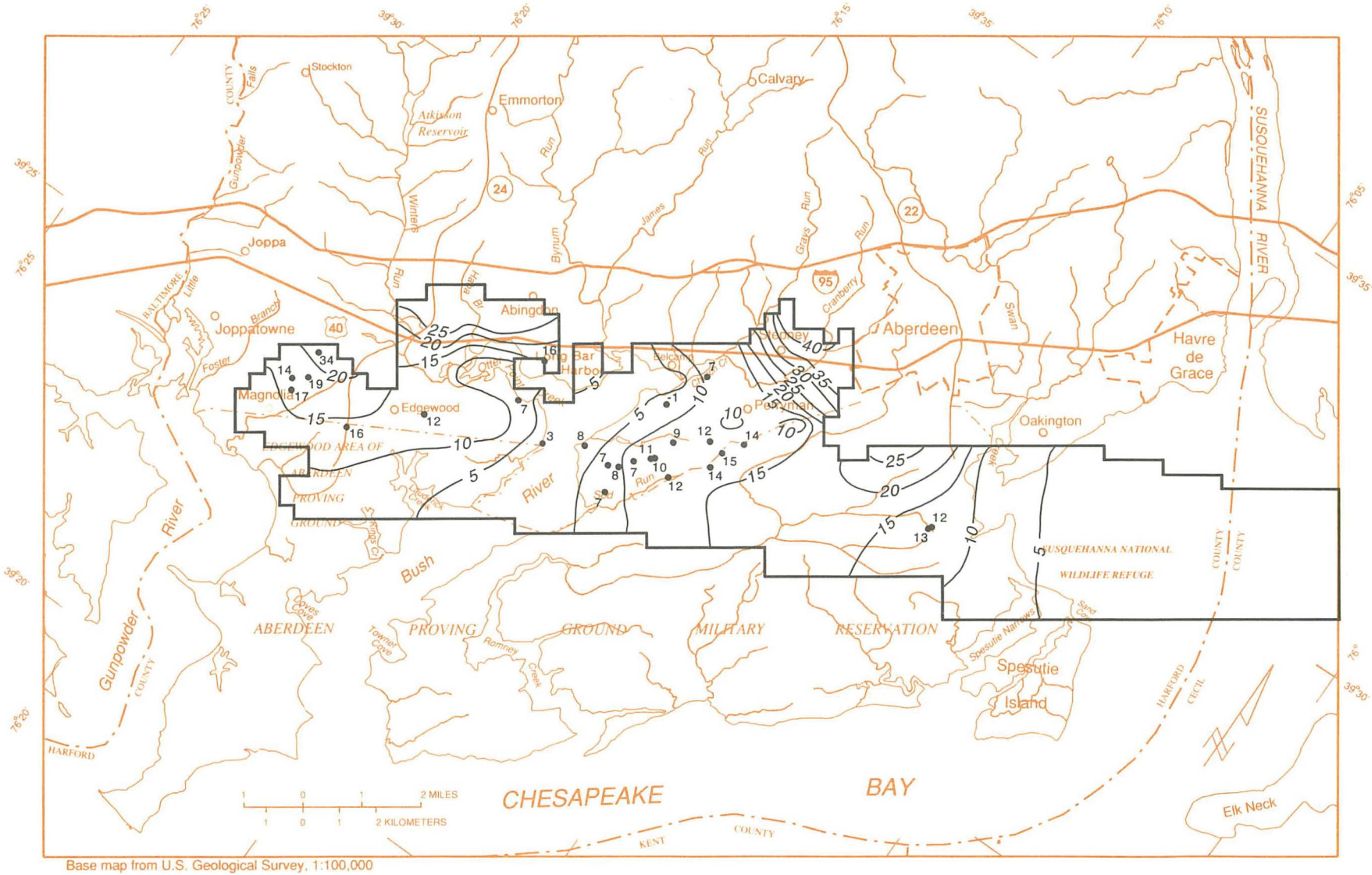
EXPLANATION

NO-FLOW BOUNDARY.

5 LINE OF EQUAL SIMULATED POTENTIOMETRIC HEAD. DASHED WHERE INFERRED. CONTOUR INTERVAL IS 5 FEET. DATUM IS SEA LEVEL.

5 MEASURED ALTITUDE OF GROUND-WATER LEVEL, IN FEET.

Figure 47.—Simulated potentiometric surface and measured ground-water levels in aquifer 2, 1989.



Base map from U.S. Geological Survey, 1:100,000

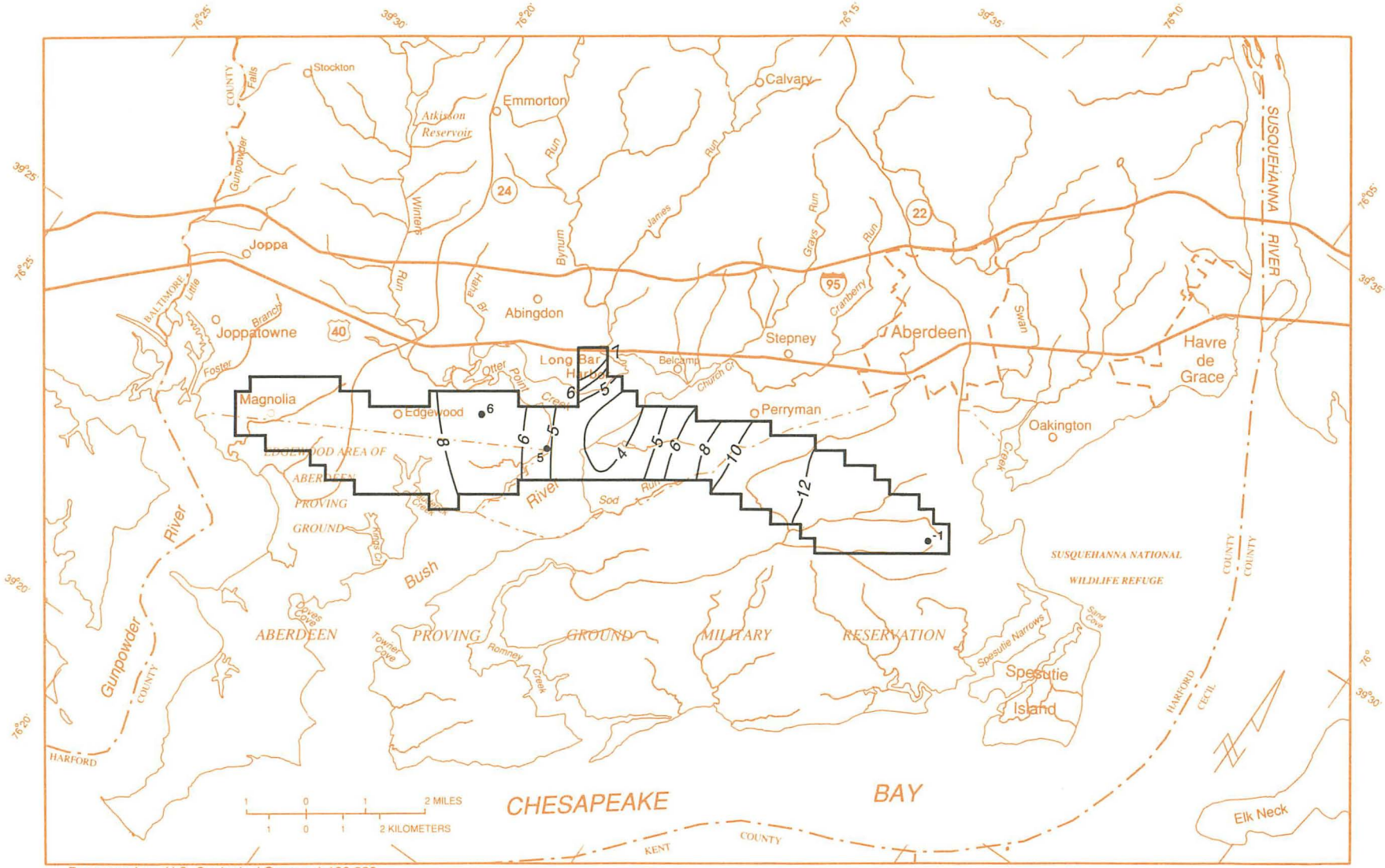
EXPLANATION

NO-FLOW BOUNDARY.

10 LINE OF EQUAL SIMULATED POTENTIOMETRIC HEAD. CONTOUR INTERVAL IS 5 FEET. DATUM IS SEA LEVEL.

12 MEASURED ALTITUDE OF GROUND-WATER LEVEL, IN FEET.

Figure 48.—Simulated potentiometric surface and measured ground-water levels in aquifer 3, 1989.



Base map from U.S. Geological Survey, 1:100,000

EXPLANATION

NO-FLOW BOUNDARY.

—10— LINE OF EQUAL POTENTIOMETRIC HEAD. CONTOUR INTERVAL IS VARIABLE. DATUM IS SEA LEVEL.

•6 MEASURED ALTITUDE OF GROUND-WATER LEVEL, IN FEET.

Figure 49.—Simulated potentiometric surface and measured ground-water levels in aquifer 4, 1989.

Sensitivity Analysis

A sensitivity analysis of the calibrated flow model was conducted to evaluate model response to variations in input values. This analysis indicates which input data are most likely to cause errors in model output as a result of inaccuracies in those data. The sensitivity analysis was performed by globally changing individual input data within reasonable limits while keeping all others at their calibrated values. The model was then run in the same manner as the calibration simulation and the results were compared to the calibration results. The greater the change in model results, the more sensitive the model is to the input value under investigation.

Model sensitivity was judged on the basis of head differences between the calibration simulation and the sensitivity simulations. The model was considered to have low sensitivity to input values which, when adjusted over a reasonable range of values, resulted in head differences of less than 1 ft; moderate sensitivity to input values that resulted in differences between 1 and 10 ft; and high sensitivity to input values that resulted in differences greater than 10 ft. The changes made in the input data were somewhat arbitrary and the resultant head changes are not strictly comparable. Thus, the results of the sensitivity analysis are generalized. Table 8 summarizes the results of the sensitivity analysis.

The model was highly sensitive to hydraulic conductivity of aquifer 1; transmissivity of aquifers 2, 3, and 4; vertical leakance of confining units 2, 3, and 4; and storage coefficient of aquifer 4. The model was moderately sensitive to evapotranspiration rate, recharge rate, and placement of the southern no-flow boundary in aquifer 3. The model had low sensitivity to storage coefficients of aquifers 1, 2, and 3. The sensitivity of the evapotranspiration surface and extinction depth are difficult to evaluate because small changes in their input values caused oscillation and non-convergence of the solution. The large changes in model results caused by relatively small changes in these input values indicate, however, that the model was highly sensitive to these input values.

Table 8.—Results of the flow-model sensitivity analysis

Change of input data	Maximum head difference[1] (in feet)
Increase storage coefficient of aquifer 1 from 0.10 to 0.15 (unitless)	0
Decrease storage coefficient of aquifer 1 from 0.10 to 0.08 (unitless)	0
Increase hydraulic conductivity of aquifer 1 x 2	41
Decrease hydraulic conductivity of aquifer 1 x .5	11
Increase vertical leakance of confining unit 1 x 10	45
Decrease vertical leakance of confining unit 1 x .1	30
Increase ET surface x 1.01	3
Decrease ET surface x .999	0
Increase ET extinction depth from 5 to 10 feet	3
Decrease ET extinction depth from 5 to 4 feet	1
Increase ET rate x 1.15	9
Decrease ET rate x .85	8
Increase recharge rate x 1.15	9
Decrease recharge rate x .85	10
Increase altitude of bottom of aquifer 1 x 1.1	22
Decrease altitude of bottom of aquifer 1 x .9	15
Increase river bed conductance x 10	55
Increase altitude of river stage 5 feet	8
Decrease altitude of river bottom 5 feet	4
Increase storage coefficient of aquifer 2 from 0.0002 to 0.002 (unitless)	0
Decrease storage coefficient of aquifer 2 from 0.0002 to 0.00002(unitless)	0
Increase transmissivity of aquifer 2 x 2	14
Decrease transmissivity of aquifer 2 x .5	17
Increase vertical leakance of confining unit 2 x 10	25
Decrease vertical leakance of confining unit 2 x .1	29
Increase storage coefficient of aquifer 3 from 0.0002 to 0.002 (unitless)	0
Decrease storage coefficient of aquifer 3 from 0.0002 to 0.00002(unitless)	0
Increase transmissivity of aquifer 3 x 2	11
Decrease transmissivity of aquifer 3 x .5	11
Increase vertical leakance of confining unit 3 x 10	3
Decrease vertical leakance of confining unit 3 x .1	2
Extend southern boundary of aquifer 3 to model edge	4
Increase storage coefficient of aquifer 4 from 0.0002 to 0.002 (unitless)	0
Decrease storage coefficient of aquifer 4 from 0.0002 to 0.00002 (unitless)	0
Increase transmissivity of aquifer 4 x 2	5
Decrease transmissivity of aquifer 4 x .5	124
Extend model boundaries 0.25 miles	8

[1]Difference between calibration simulation and sensitivity analysis simulation.

Projected Pumpage

The flow model was used to estimate the effects of projected pumpage on ground-water levels and flow for the 12-year period, 1990–2001. Simulations for 1990 to 2000 were run with conditions identical to those of the calibration period except for pumpage. Simulations for the year 2001 were run for reduced recharge conditions (65 percent of calibrated average recharge) to evaluate potential effects of severe drought conditions such as those of the mid-1960's. Simulated heads and hydrologic budget values were compared to those from the 1989 simulation to evaluate the effects of projected pumpage.

Many of the simulations resulted in head differences of only a few feet from the 1989 head values. The results are shown on head-difference diagrams in which head differences between the simulated 1989 head distribution and the projected head distribution are plotted. This was done by subtracting the simulated projected head at each cell from the simulated 1989 head at each cell and contouring the resultant head-difference distribution. Projected heads that are lower than 1989 heads plot as negative values and projected heads that are higher than 1989 heads plot as positive values. Projected pumpage simulations that produced head changes of less than 5 ft are generally not shown in the figures. All calculated heads are averages for the cells, and pumping levels in individual wells could be lower than indicated by the figures.

Simulation 1

Simulation 1 represents the continuation of 1989 pumpage through 2001. The same pumpage array was used for the average recharge simulation (1990–2000) and the 1-year drought simulation. Two additional years of drought conditions were evaluated for this simulation to determine if the ground-water-flow system was approaching equilibrium.

Water levels changed less than 2 ft in aquifers 1, 2, and 3 as compared to 1989 water levels for this simulation. Water levels increased in aquifer 4 by about 4 ft in the Long Bar Harbor area because of recovery from pumpage during 1976–88. The negligible water-level changes in the shallow aquifers indicate equilibrium had been reached by 1989. Streamflow did not change significantly from 1989 conditions.

Results of the 1-year-drought simulation (the year 2001) show similar ground-water flow patterns in aquifers 1, 2, and 3 (figs. 50, 51, and 52), but water levels are generally about 5 ft lower than the 1989 water levels. Water levels in aquifers 1 and 2 have been lowered below sea level in some of the low-lying areas in the southeastern part of the model area. Water levels in aquifer 4 are unaffected by the drought because of aquifer depth, and low leakance of the overlying confining unit and delayed response time to changes in recharge conditions. Streamflow decreased by about 22 percent compared to 1989 conditions.

Results of the 3-year drought simulation show continued water-level declines in aquifers 1, 2, and 3. Water levels in aquifer 4 have also declined slightly because of the drought conditions. The continued declines indicate that the ground-water-flow system would take at least 3 years to equilibrate to severe drought conditions similar to those of the mid-1960's.

Simulation 2

All input for simulation 2 is identical to input for simulation 1, except that pumpage was increased by 20 percent (tab. 6). Water levels are generally similar to simulated 1989 water levels, except in the Aberdeen and Perryman areas. Water levels in aquifers 1 and 2 declined about 4 ft at the Aberdeen well field and about 1 ft in the Perryman area. Water levels in aquifer 3 declined about 4 ft in the Perryman area. Water levels in aquifer 4 are unchanged from those in simulation 1. Streamflow decreased about 0.5 percent compared to 1989 conditions.

Simulation 3

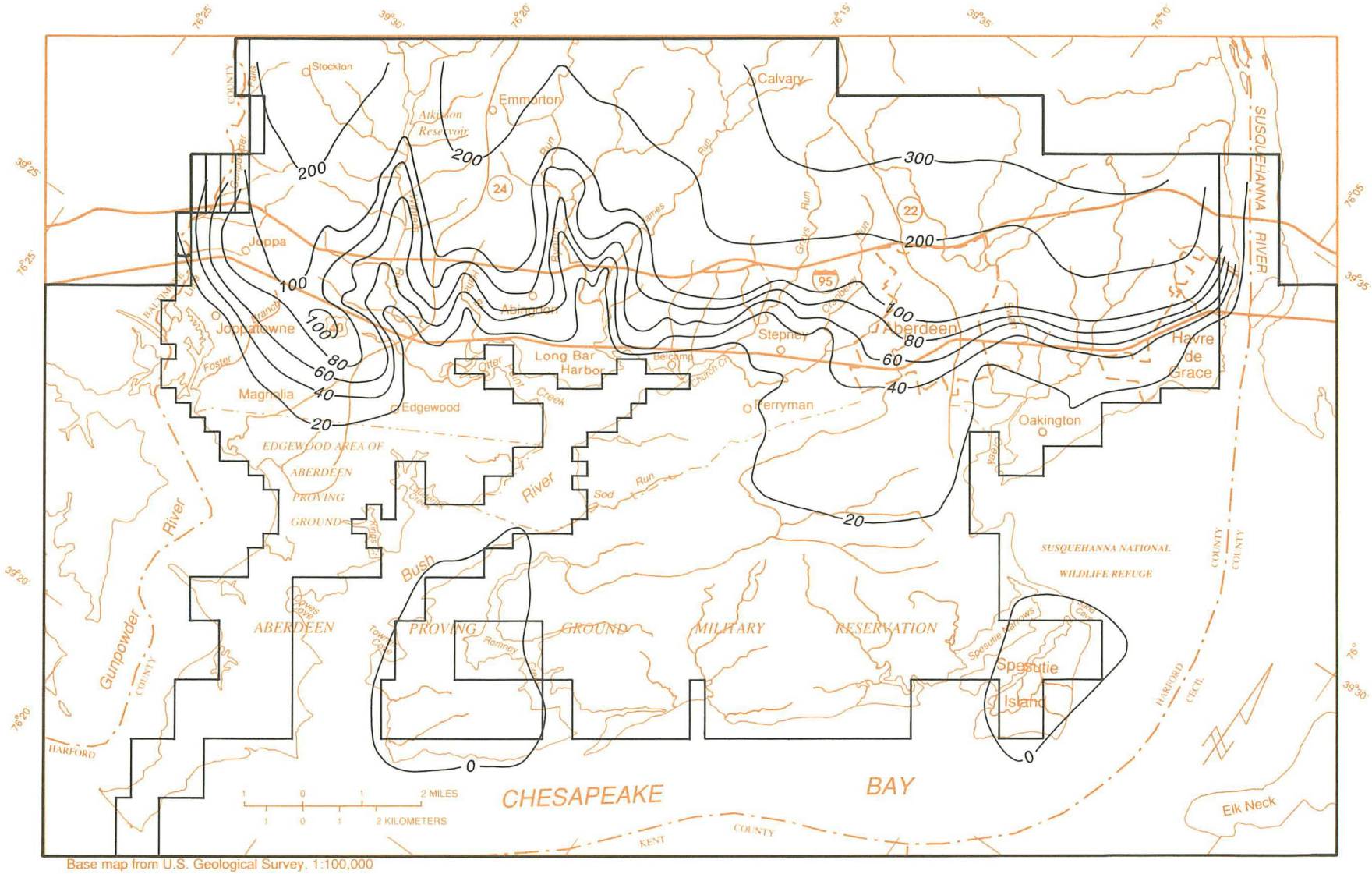
Simulation 3 is identical to simulation 1, except that pumpage was decreased by 20 percent (tab. 6). Water levels are at most 2 to 3 ft higher in aquifers 1 and 2 than simulated 1989 water levels; water levels are almost 4 ft higher in aquifer 3 than simulated 1989 water levels in the Perryman area. Water levels in aquifer 4 are unchanged from those in simulation 1. Streamflow increased about 0.5 percent compared to 1989 conditions.

Simulation 4

Simulation 4 is identical to simulation 1, except that total pumpage at the Perryman well field was increased from 410,000 to 661,000 ft^3/d by proportionally increasing pumpage at each well (tab. 6). This represents a 61-percent increase in pumpage at the Perryman well field compared to withdrawals in 1989. Water levels at the Perryman well field declined by as much as 5 ft in aquifers 1 and 2. Water levels in aquifer 3 declined as much as 13 ft from simulated 1989 water levels (fig. 53). Water levels in aquifer 4 are unchanged from those in simulation 1. Streamflow decreased about 1 percent compared to 1989 streamflow.

Simulation 5

Simulation 5 is identical to simulation 1, except that pumpage at Perryman well field wells 5 and 6 (both screened in aquifer 2) was increased to 192,000 and 154,000 ft^3/d, respectively (tab. 6). These increases were recommended by Whitman, Requardt and Associates (1976) in their report to Harford County on improving production from the Perryman well field. Water levels at the Perryman well field declined as much as 4 ft in aquifers 1 and 2. Water levels in aquifer 3 are within 2 ft of simulated 1989 water levels, and water levels in aquifer 4 are unchanged from those in simulation 1. Streamflow decreased about 0.5 percent as compared to 1989 streamflow.



Base map from U.S. Geological Survey, 1:100,000

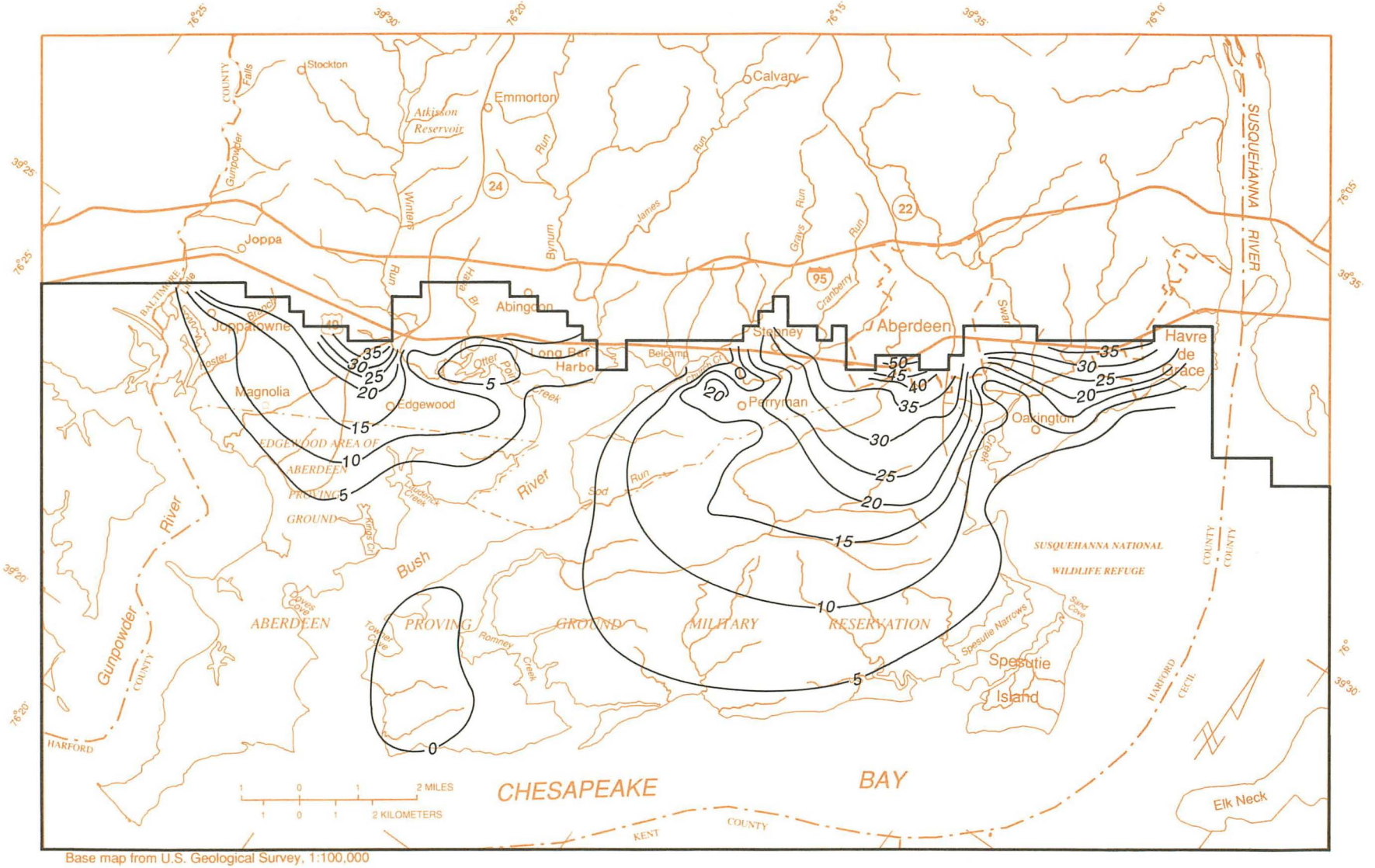
EXPLANATION

NO-FLOW BOUNDARY.

—20— LINE OF EQUAL SIMULATED WATER-TABLE ALTITUDE, IN FEET ABOVE SEA LEVEL. DASHED WHERE INFERRED. CONTOUR INTERVAL IS VARIABLE.

SPECIFIED-HEAD BOUNDARY.

Figure 50.—Simulated water-table altitude in aquifer 1 for year 2001, 1-year drought conditions.



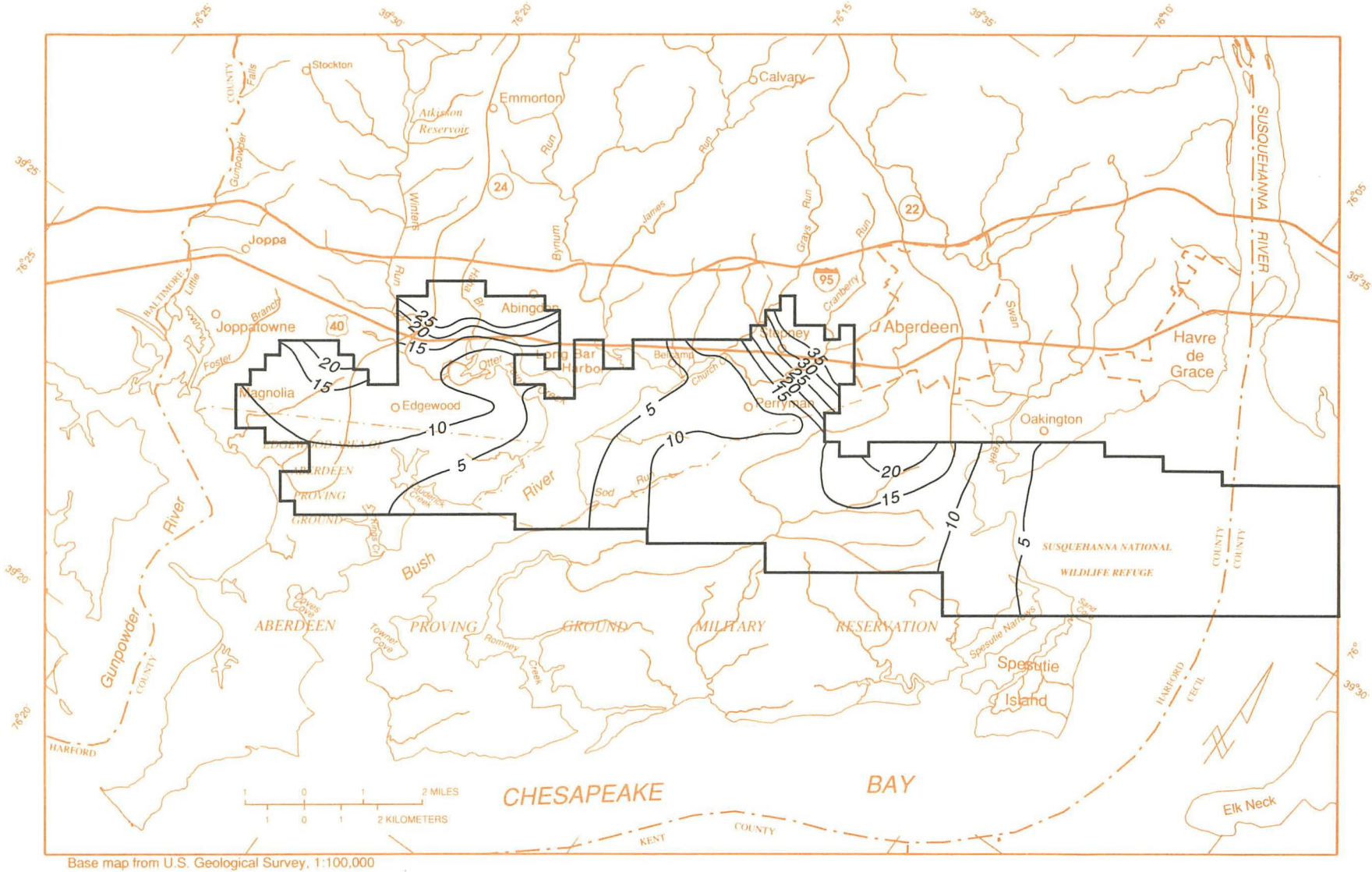
Base map from U.S. Geological Survey, 1:100,000

EXPLANATION

NO-FLOW BOUNDARY.

10 — LINE OF EQUAL SIMULATED POTENTIOMETRIC HEAD, IN FEET. CONTOUR INTERVAL is 5 FEET. DATUM IS SEA LEVEL.

Figure 51.—Simulated potentiometric surface in aquifer 2 for year 2001, 1-year drought conditions.

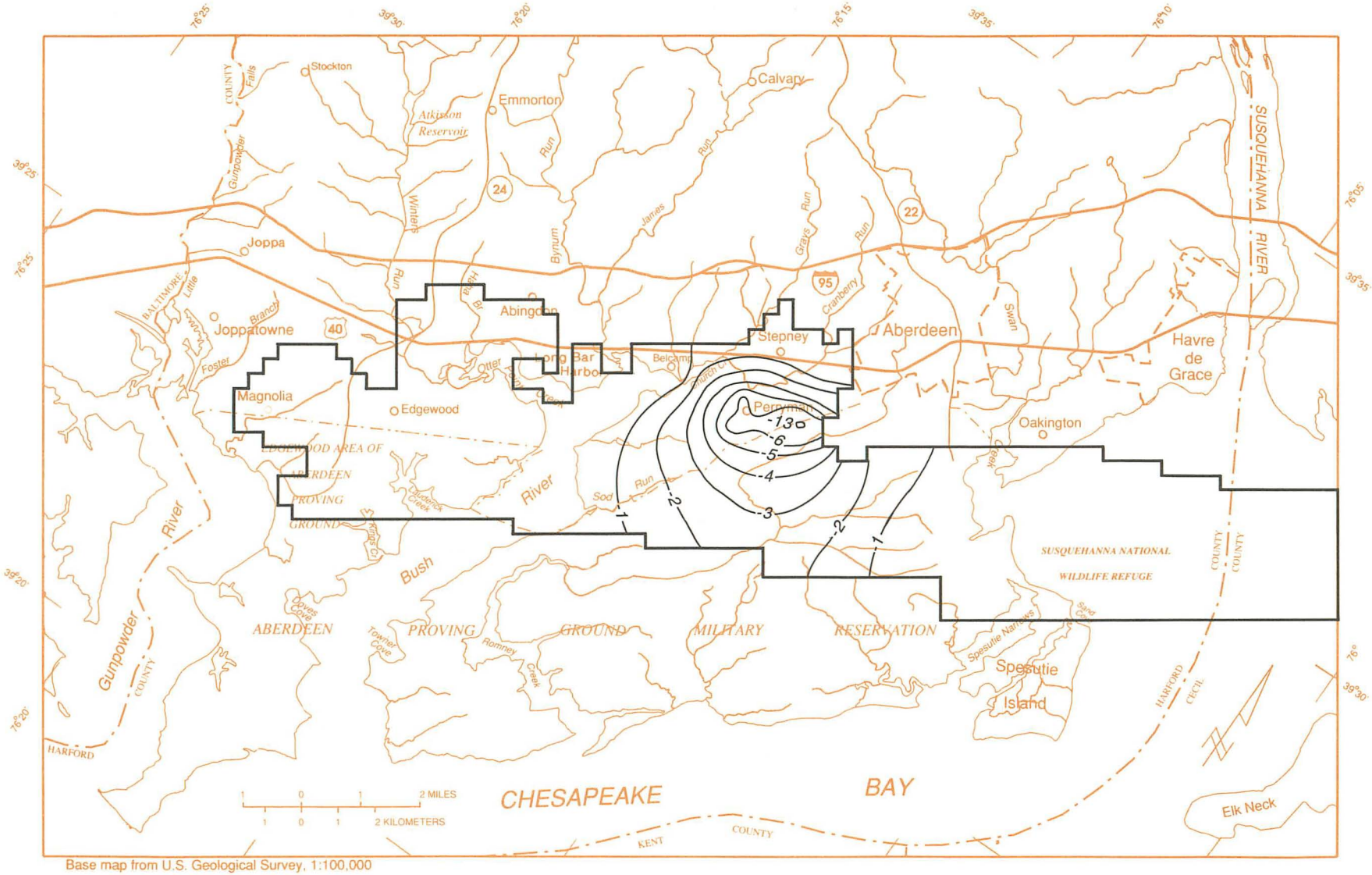


EXPLANATION

NO-FLOW BOUNDARY.

5 LINE OF EQUAL SIMULATED POTENTIOMETRIC HEAD, IN FEET. CONTOUR INTERVAL IS 5 FEET. DATUM IS SEA LEVEL.

Figure 52.—Simulated potentiometric surface in aquifer 3 for year 2001, 1-year drought conditions.



Base map from U.S. Geological Survey, 1:100,000

EXPLANATION

NO-FLOW BOUNDARY.

-1 LINE OF EQUAL SIMULATED HEAD DIFFERENCE, IN FEET. CONTOUR INTERVAL IS VARIABLE.

Figure 53.—Difference between simulated potentiometric surfaces in aquifer 3 for 1989–2000, simulation 4.

Simulation 6

Simulation 6 is identical to simulation 1 except for the addition of a production well that pumps 67,000 ft^3/d at cell (18, 39) in aquifer 3 (tab. 6). Installation of such a well was recommended by Whitman, Requardt and Associates (1976). Water levels in aquifer 3 around the new well are about 3 ft lower in this simulation than for simulated 1989 water levels. Water levels in aquifers 1, 2, and 3 are about the same as in simulation 1. Streamflow did not change significantly as compared to 1989 streamflow.

Simulation 7

Simulation 7 was used to estimate the maximum "safe yield" of the Perryman well field. The safe yield is defined as the pumpage that will cause drawdowns in pumping wells equivalent to 80 percent of the depth from the prepumping water level to the top of the aquifer in which the well is screened. The safe yield was estimated using an iterative procedure in which pumpage from each well was increased until water levels in all wells were within 1 ft of the 80-percent criterion.

The flow model calculates spatially averaged water levels in each cell rather than pumping levels in individual wells, so a procedure was developed to estimate pumping levels using average calculated cell water levels, individual well pumpage and aquifer characteristics. Trescott and others (1976, p. 10) used the following equation to relate the additional drawdown in a well to the well's pumping rate:

$$s = \frac{2.3Q}{2\pi T} \log_{10} \left[\frac{a}{4.18 r_w} \right] \qquad (4)$$

where

s = additional drawdown in the well;
Q = well pumping rate;
T = transmissivity of the aquifer;
r_w = radius of the well;
a = cell width.

Rearranging equation 4 and entering the cell width of 1,320 ft (all cells in the Perryman area are squares of the same size), the equation becomes

$$s = \frac{0.37Q}{T} (2.44 - \log_{10} r_w). \qquad (5)$$

Equation 5 was used to estimate drawdown in each production well after a model run. Pumping rates of each well were adjusted by trial and error until heads in all production wells were within 1 ft of the chosen criterion. Adjusted rates for each well are shown in table 6. Transmissivity values used to estimate drawdowns in wells were from aquifer tests of those wells rather than transmissivities entered in the flow model which are generalized and averaged over the entire cell. "Safe well yields" were estimated for average recharge conditions (simulation 7a) and drought conditions (simulation 7b).

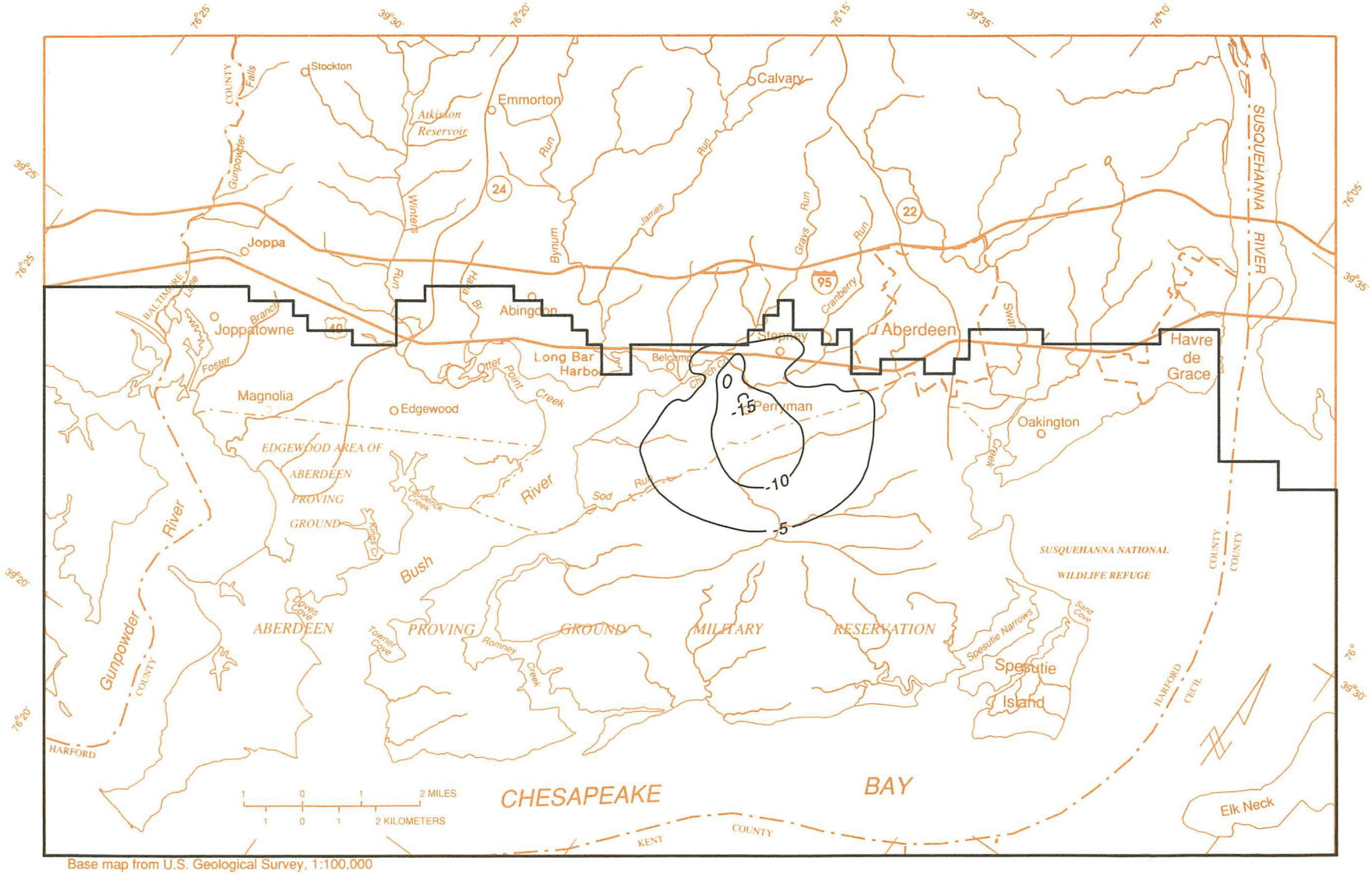
Under average recharge conditions, water levels in aquifer 1 are as much as 18 ft deeper than simulated 1989 water levels. Lowered water levels are caused by downward leakage into aquifer 2. Water levels in aquifer 2 are also about 18 ft lower than 1989 simulated water levels (fig. 54). This simulation was designed to draw pumping water levels down to the criterion depth, so model-calculated water levels are near that depth. Water levels in aquifer 3 are as much as 49 ft deeper in this simulation than those simulated for 1989. The deepest water levels are centered at the Perryman well field (fig. 55). Streamflow decreased about 3 percent as compared to 1989 streamflow. This decrease, of about 2.5 ft^3/s, would only affect the streams in the Perryman area, Cranberry Run, Grays Run, Romney Creek, and Sod Run. Discharge on Cranberry Run (the only stream in the area for which discharge measurements were made) ranged from 0 to 2.85 ft^3/s. Although not all of the reduced discharge would come from Cranberry Run, the similarity of values indicates that "safe yield" pumping rates would significantly affect streamflow in the Perryman area. The flow model was not calibrated to simulate streamflow along individual streams, so a detailed analysis cannot be made.

Simulation 7b was designed to estimate the safe yield of the Perryman well field during 1 year of drought conditions (recharge reduced to 65 percent of the average annual rate). Pumpage was reduced at each well in the Perryman well field until the 80-percent drawdown criterion was obtained under reduced recharge conditions. Because recharge is reduced, the safe yield is significantly lower than it would be under average recharge conditions. Water levels (cell averages) in aquifer 1 are as much as 23 ft lower than 1989 simulated water levels (fig. 56). The lowered water levels in aquifer 1 are caused primarily by downward leakage into aquifer 2. Water levels in aquifer 2 are as much as 39 ft lower than 1989 simulated water levels (fig. 57). Water levels in aquifer 3 are as much as 49 ft deeper than 1989 simulated water levels (fig. 58). Drawdowns in aquifers 1, 2, and 3 are centered at the Perryman well field. Water levels in aquifer 4 are the same as those in simulation 1. Streamflow decreased about 25 percent as compared to 1989 streamflow.

These simulations indicate that the maximum amount of water that can be withdrawn from the Perryman well field is 1,235,000 ft^3/d under average recharge conditions and 1,113,000 ft^3/d under drought conditions, or about 3.0 and 2.7 times the 1989 pumpage. These estimates are based only on the 80-percent drawdown criterion at the pumping wells, and do not consider other possible limiting effects, such as brackish-water intrusion, contaminant migration, or the dewatering of nearby wells. Any of these factors could become problems at the "safe yield" pumpage. Steady-state conditions were not reached during the drought simulation, indicating that the "safe yield" would be lower if drought conditions continued for more than 1 year.

Simulation 8

Simulation 8 represents the addition of four new wells to the Perryman well field at two sites—one well in aquifer 2 and one



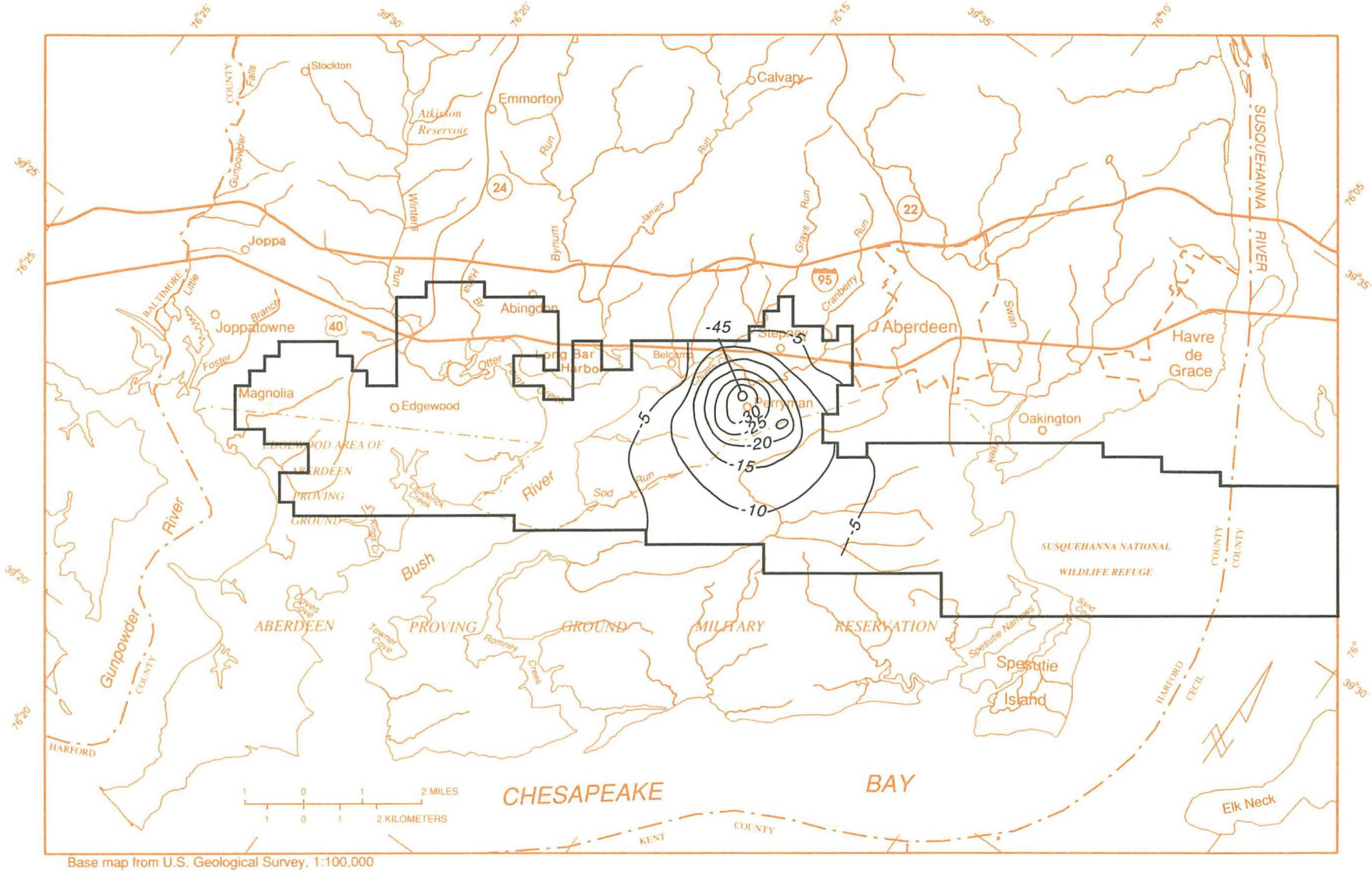
Base map from U.S. Geological Survey, 1:100,000

EXPLANATION

NO-FLOW BOUNDARY.

-10 LINE OF EQUAL SIMULATED HEAD DIFFERENCE, IN FEET. CONTOUR INTERVAL IS 5 FEET.

Figure 54.—Difference between simulated potentiometric surfaces in aquifer 2 for 1989–2000, simulation 7a.



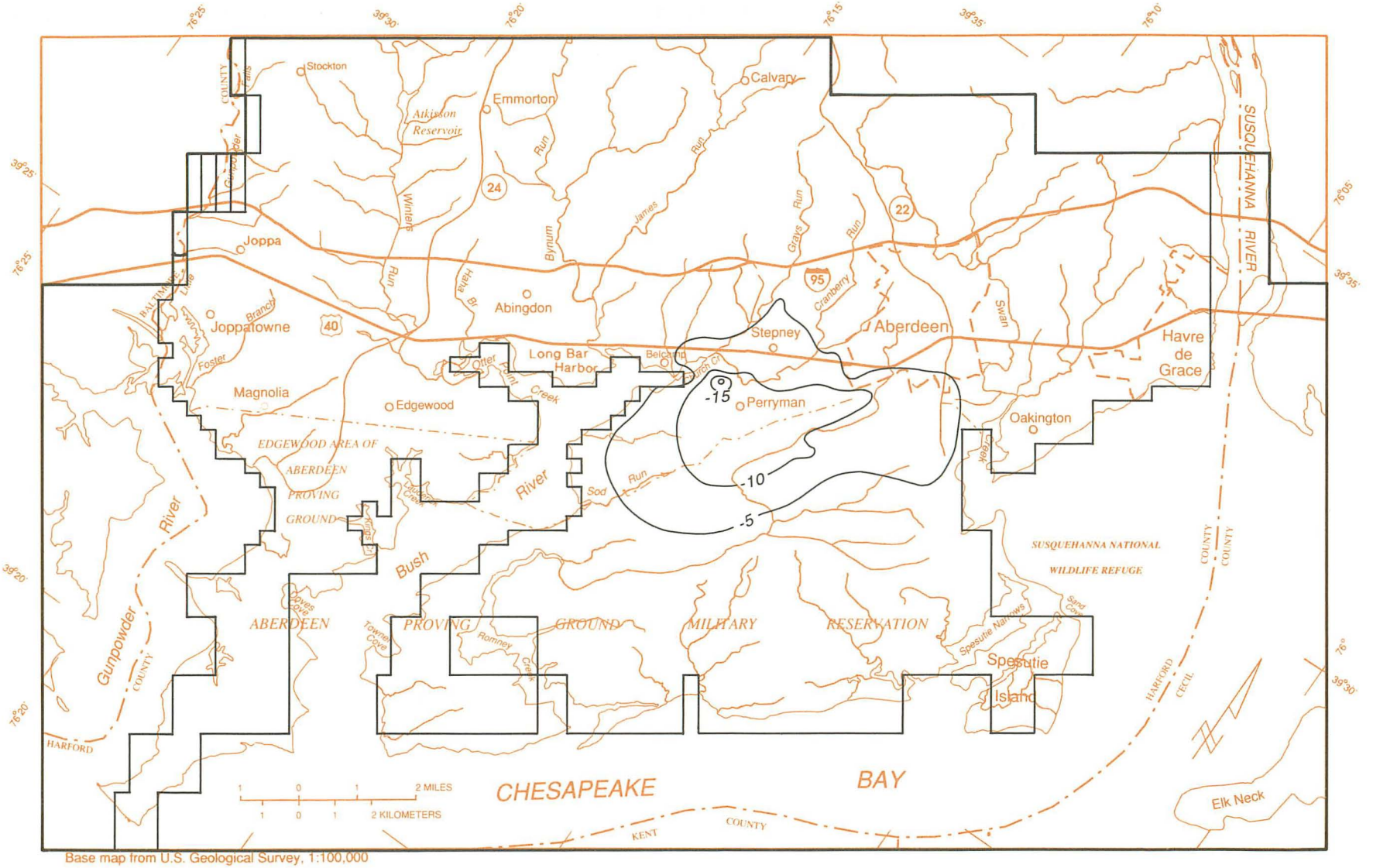
Base map from U.S. Geological Survey, 1:100,000

EXPLANATION

NO-FLOW BOUNDARY.

-10 LINE OF EQUAL SIMULATED HEAD DIFFERENCE, IN FEET. CONTOUR INTERVAL IS 5 FEET.

Figure 55.—Difference between simulated potentiometric surfaces in aquifer 3 for 1989–2000, simulation 7a.



Base map from U.S. Geological Survey, 1:100,000

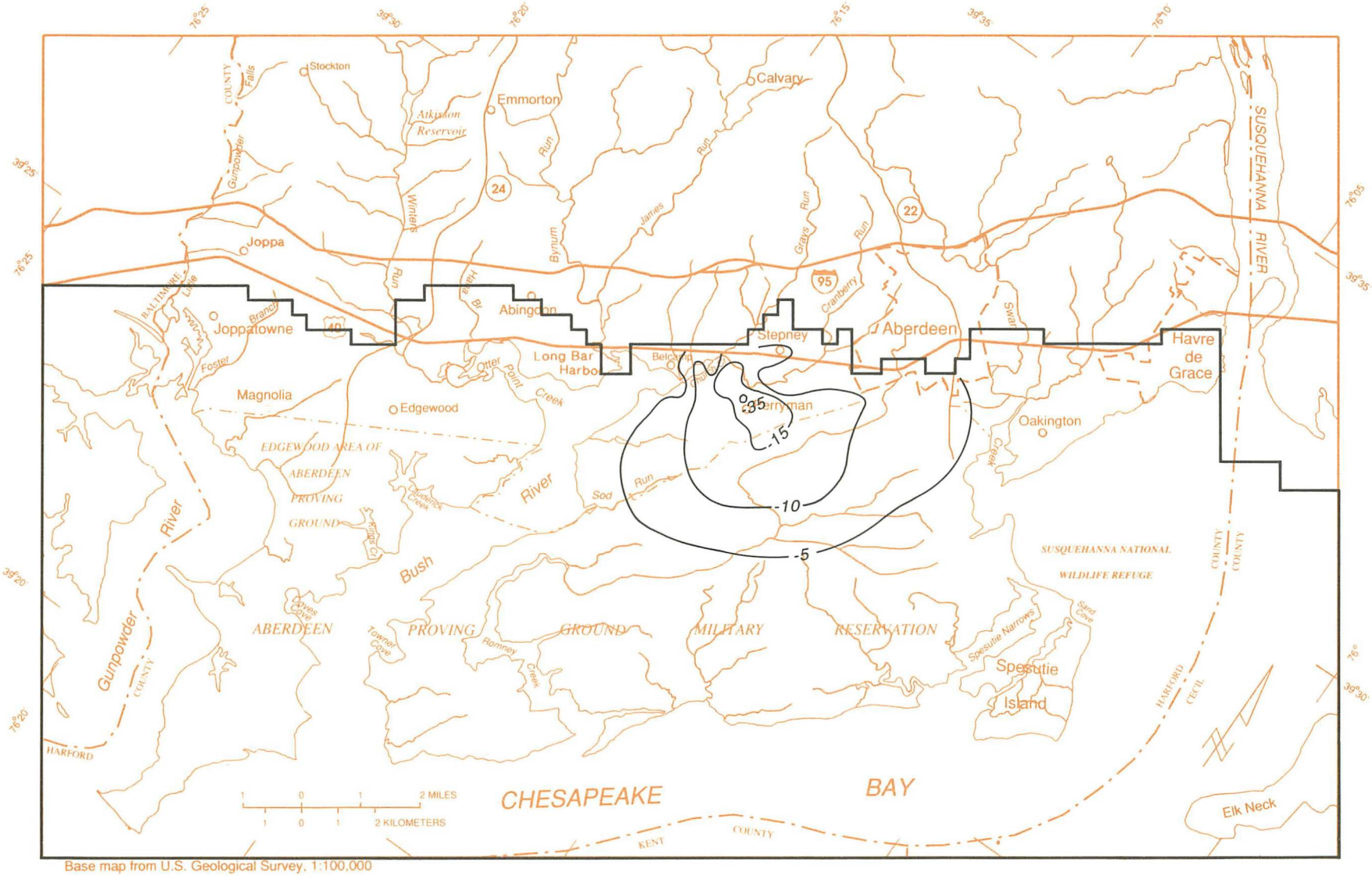
EXPLANATION

NO-FLOW BOUNDARY.

-5 LINE OF EQUAL SIMULATED HEAD DIFFERENCE, IN FEET. CONTOUR INTERVAL IS 5 FEET.

SPECIFIED-HEAD BOUNDARY.

Figure 56.—Difference between simulated potentiometric surfaces in aquifer 1 for 1989–2001, 1-year drought conditions, simulation 7b.



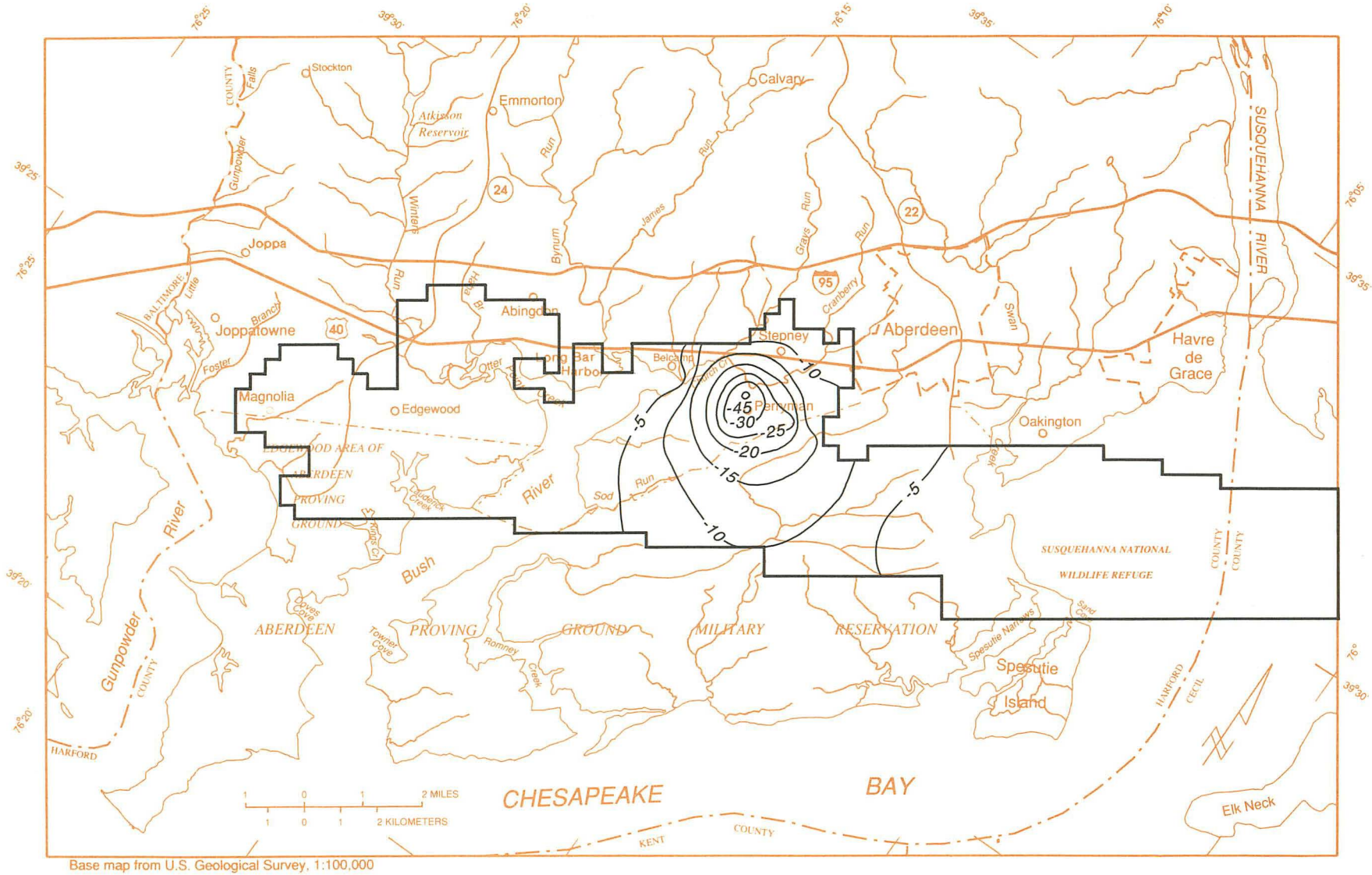
Base map from U.S. Geological Survey, 1:100,000

EXPLANATION

NO-FLOW BOUNDARY.

-10 LINE OF EQUAL SIMULATED HEAD DIFFERENCE, IN FEET. CONTOUR INTERVAL IS VARIABLE.

Figure 57.—Difference between simulated potentiometric surfaces in aquifer 2 for 1989–2001, 1-year drought conditions, simulation 7b.



Base map from U.S. Geological Survey, 1:100,000

EXPLANATION

NO-FLOW BOUNDARY.

-15 LINE OF EQUAL SIMULATED HEAD DIFFERENCE, IN FEET. CONTOUR INTERVAL IS VARIABLE.

Figure 58.—Difference between simulated potentiometric surfaces in aquifer 3 for 1989–2001, 1-year drought conditions, simulation 7b.

well in aquifer 3 at each location (fig. 34). The total pumpage from the four wells is 193,000 ft^3/d. Pumpage from the other wells in the well field was reduced by 193,000 ft^3/d, maintaining the total pumpage from the well field at the 1989 rate. This scenario follows one of the recommendations of Whitman, Requardt and Associates (1976) to distribute the pumpage and reduce drawdown during droughts. Water levels in all aquifers are within 2 ft of 1989 simulated water levels. Streamflow did not change significantly as compared to 1989 streamflow.

Simulation 9

Simulation 9 represents the addition of 27,000 ft^3/d of pumpage at the proposed bleach-bottling plant near Perryman (fig. 34). The pumpage is from aquifer 3. Water levels at the proposed plant are about 6 ft deeper in aquifer 3 than 1989 simulated water levels. Water levels in aquifers 1, 2, and 4 were unaffected by the additional pumpage. Streamflow did not change significantly as compared to 1989 streamflow.

Simulation 10

Simulation 10 represents the addition of three new production wells in aquifer 2 at the Baltimore Gas and Electric (BG&E) power plant near Perryman (fig. 34). Two withdrawal rates were simulated that correspond to the "simple cycle" (14,700 ft^3/d) and the "combined cycle" (129,000 ft^3/d) power-production configurations (Baltimore Gas & Electric, 1990).

Water levels in all aquifers are within 2 ft of 1989 simulated water levels for the simple cycle configuration. Water levels in aquifer 2 are about 7 ft lower than 1989 simulated water levels for the combined cycle configuration (fig. 59). Water levels in aquifers 1, 3, and 4 are within 2 ft of 1989 simulated water levels for the combined cycle configuration. Streamflow did not change significantly for either configuration as compared to 1989 streamflow.

Simulation 11

Simulation 11 represents the addition of 33,000 ft^3/d of pumpage from aquifer 2 at the Trimble Road well field (fig. 34). In 1987, three production wells were drilled at this site by Harford County to augment water production at the other county-operated well fields. The wells did not produce the expected quantity of water, however, and were not put into service. Although the county currently does not plan to develop the well field, pumpage from the site was simulated to evaluate the possible effects on ground-water contaminants in the Canal Creek area of Aberdeen Proving Ground. The results of the evaluation are described in the section "Particle-Tracking Simulations."

Water levels in aquifer 2 are as much as 15 ft deeper than 1989 simulated water levels (fig. 60). Water-level declines in aquifer 3 were similar to those in aquifer 2. Water levels in aquifers 1 and 4 were within 2 ft of 1989 simulated water levels. Streamflow did not change significantly as compared to 1989 streamflow.

Simulation 12

Simulation 12 represents the pumpage amounts listed on the ground-water appropriation permits issued by the Maryland Water Resources Administration. Two pumpage amounts were simulated—the average pumpage amount estimated on a yearly basis (simulation 12a), and the monthly maximum amount that the user is allowed to pump for 1 month out of the year (simulation 12b). The monthly maximum scenario is unrealistic because pumpage at the maximum amount is not permitted for a full year. The simulation demonstrates the effects of high withdrawal rates on ground-water levels.

In simulation 12a, water levels in aquifer 2 at the Aberdeen well field are about 13 ft deeper than simulated 1989 water levels (fig. 61). Water levels in aquifer 1 are similar to those in aquifer 2. Water levels in aquifer 3 at the Perryman well field are about 8 ft lower than 1989 simulated water levels. Simulated water levels in aquifer 4 are deeper than the bottom of the aquifer at Long Bar Harbor (fig. 62). This indicates that either aquifer 4 is incapable of producing the amount of water simulated in the model, or that the model is not accurately calibrated for this aquifer in the Long Bar Harbor area. Simulated transmissivities could be too low to allow sufficient flow in that area, and (or) ground water could be entering aquifer 4 from below. Streamflow decreased about 1 percent as compared to 1989 streamflow.

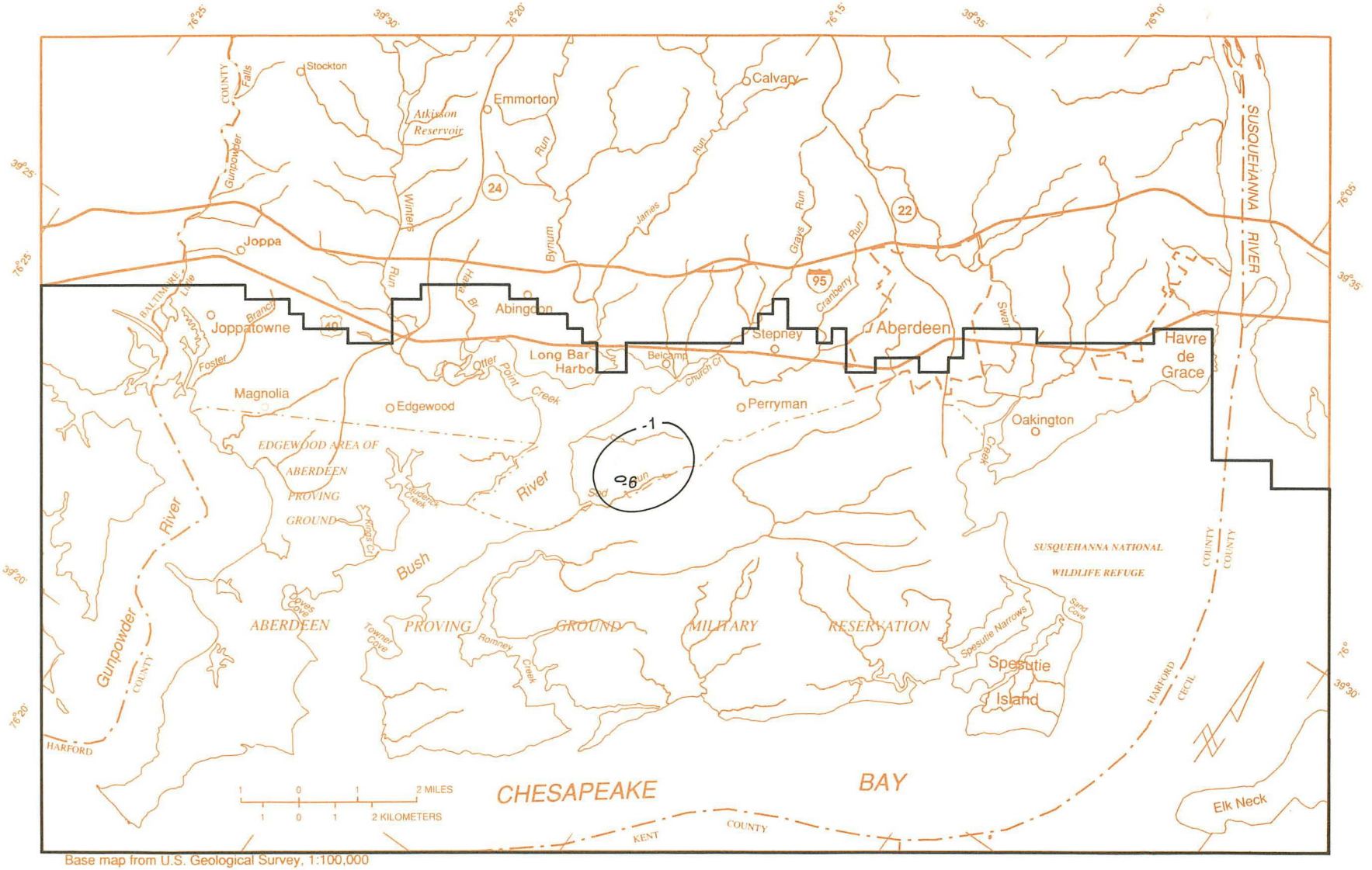
In simulation 12b, water levels in aquifer 1 are about 22 ft deeper at the Aberdeen well field and about 10 ft deeper around the Perryman well field than simulated 1989 water levels (fig. 63). In aquifer 2 water levels are about 27 ft deeper than simulated 1989 water levels, with the greatest decline at the Aberdeen well field (fig. 64). Water levels at Perryman are about 10 ft deeper and water levels at the Aberdeen Proving Ground well field are about 20 ft deeper in aquifer 3 than simulated 1989 water levels. Water levels are about 22 ft deeper than 1989 simulated water levels at the Perryman well field, and about 10 ft deeper at the Aberdeen Proving Ground well field (fig. 65). Simulated water levels in aquifer 4 are deeper than the bottom of the aquifer, indicating the same conditions prevail in this simulation as in simulation 12a. Streamflow decreased about 3 percent as compared to 1989 streamflow.

Simulation 13

Simulation 13 combines the pumpage represented in simulations 4, 9, 10b, and 11 (tab. 6). This represents the overall effect of pumping 670,000 ft^3/d from the Perryman well field, 27,000 ft^3/d at the bleach plant, 129,000 ft^3/d at the BG&E plant (combined-cycle configuration), and 33,000 ft^3/d at the Trimble Road well field (fig. 34).

Water levels in aquifer 1 are as much as 6 ft lower than 1989 simulated water levels, with the greatest declines at the Perryman well field. Water- level declines are less than 1 ft at the other pumping centers in aquifer 1. Water levels in aquifer 2 are about 6 ft deeper than 1989 simulated water levels at the Perryman and

(Text continued on p. 89.)



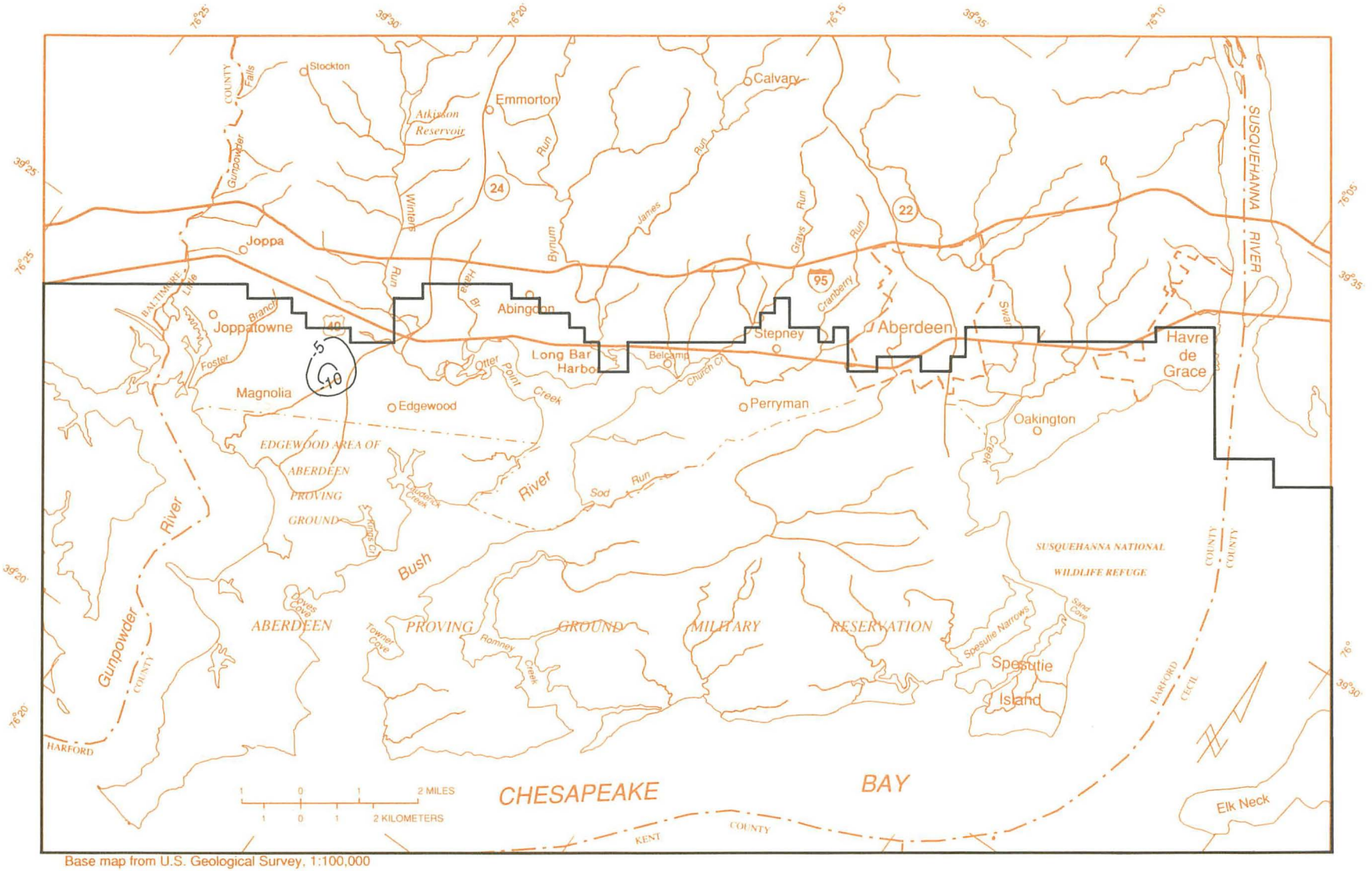
Base map from U.S. Geological Survey, 1:100,000

EXPLANATION

NO-FLOW BOUNDARY.

-1 LINE OF EQUAL SIMULATED HEAD DIFFERENCE, IN FEET. CONTOUR INTERVAL IS VARIABLE

Figure 59.—Difference between simulated potentiometric surfaces in aquifer 2 for 1989–2000, simulation 10.

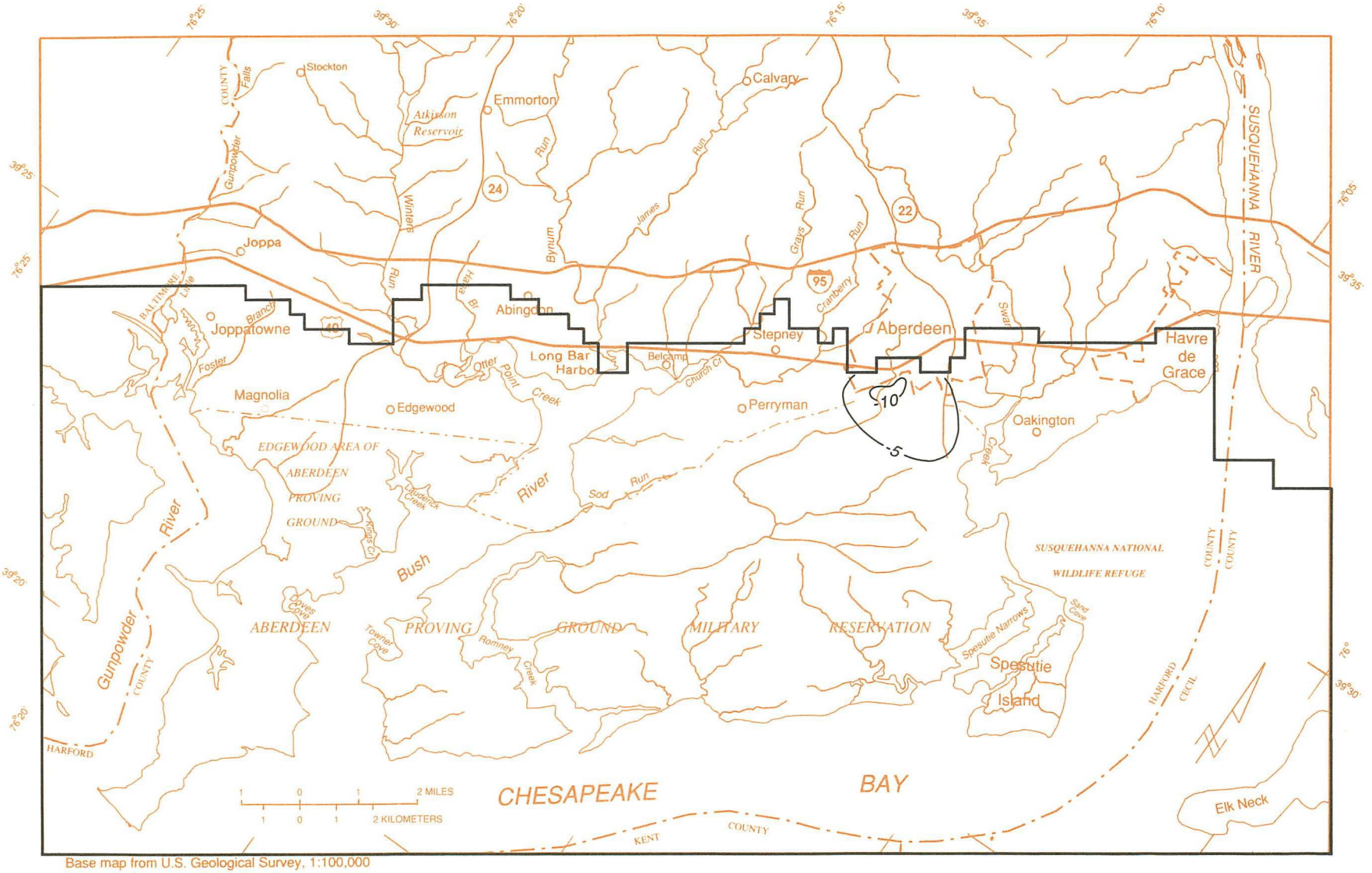


EXPLANATION

NO-FLOW BOUNDARY.

-5 LINE OF EQUAL SIMULATED HEAD DIFFERENCE, IN FEET. CONTOUR INTERVAL IS 5 FEET.

Figure 60.—Difference between simulated potentiometric surfaces in aquifer 2 for 1989–2000, simulation 11.



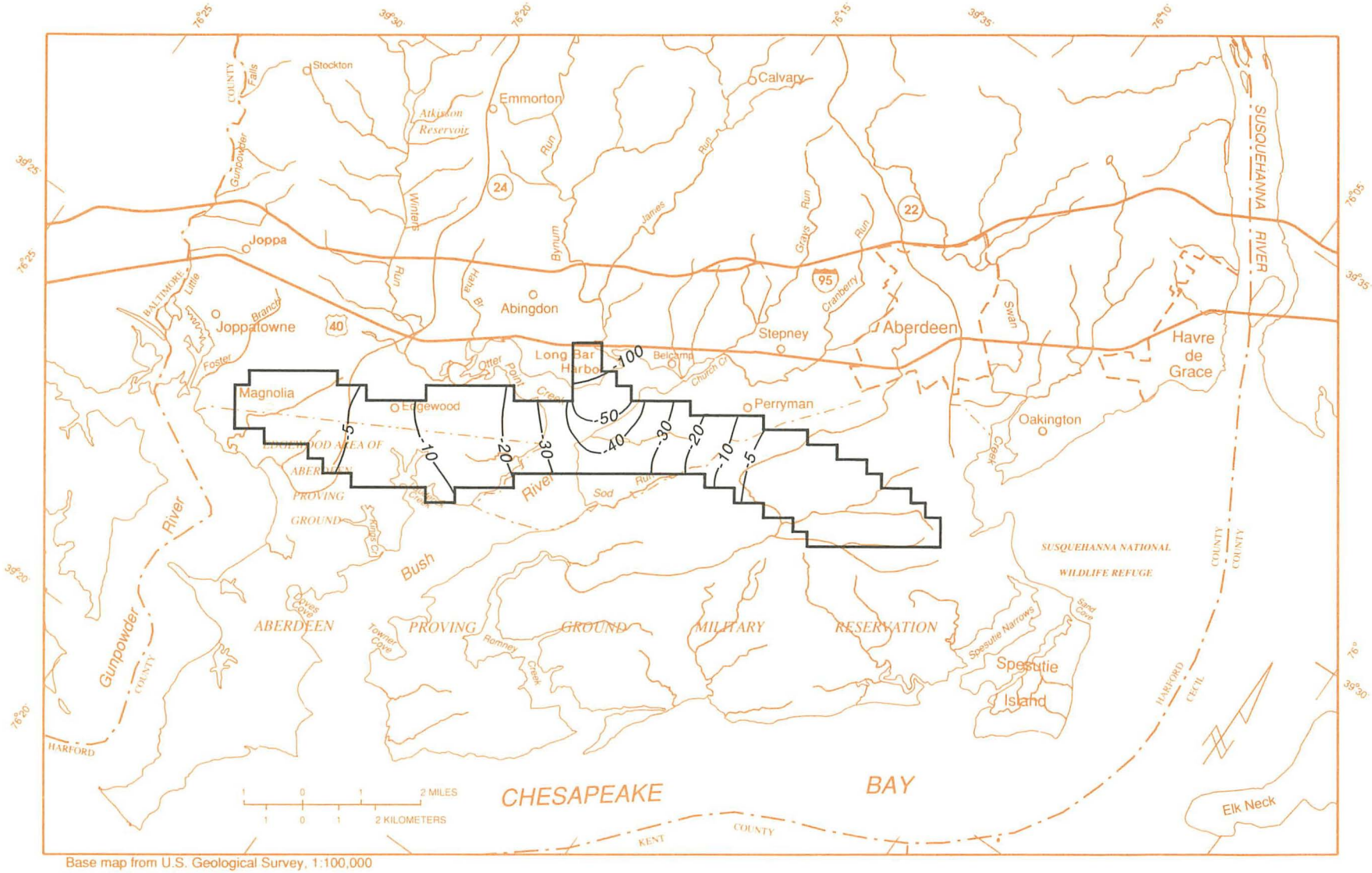
Base map from U.S. Geological Survey, 1:100,000

EXPLANATION

NO-FLOW BOUNDARY.

-5 LINE OF EQUAL SIMULATED HEAD DIFFERENCE, IN FEET. CONTOUR INTERVAL IS 5 FEET.

Figure 61.—Difference between simulated potentiometric surfaces in aquifer 2 for 1989–2000, simulation 12a.



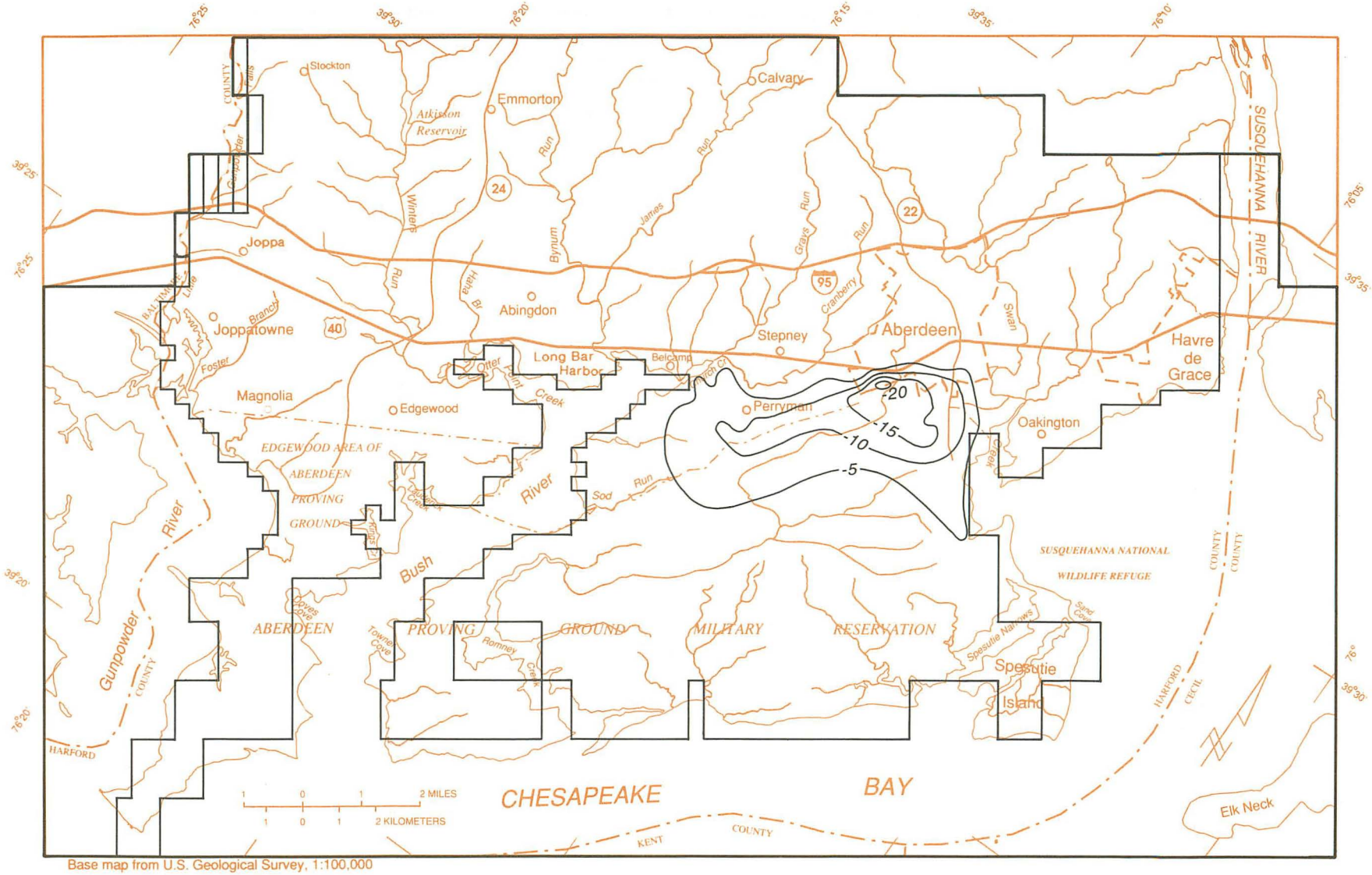
Base map from U.S. Geological Survey, 1:100,000

EXPLANATION

NO-FLOW BOUNDARY.

-10 LINE OF EQUAL SIMULATED HEAD DIFFERENCE, IN FEET. CONTOUR INTERVAL IS VARIABLE.

Figure 62.—Difference between simulated potentiometric surfaces in aquifer 4 for 1989–2000, simulation 12a.



Base map from U.S. Geological Survey, 1:100,000

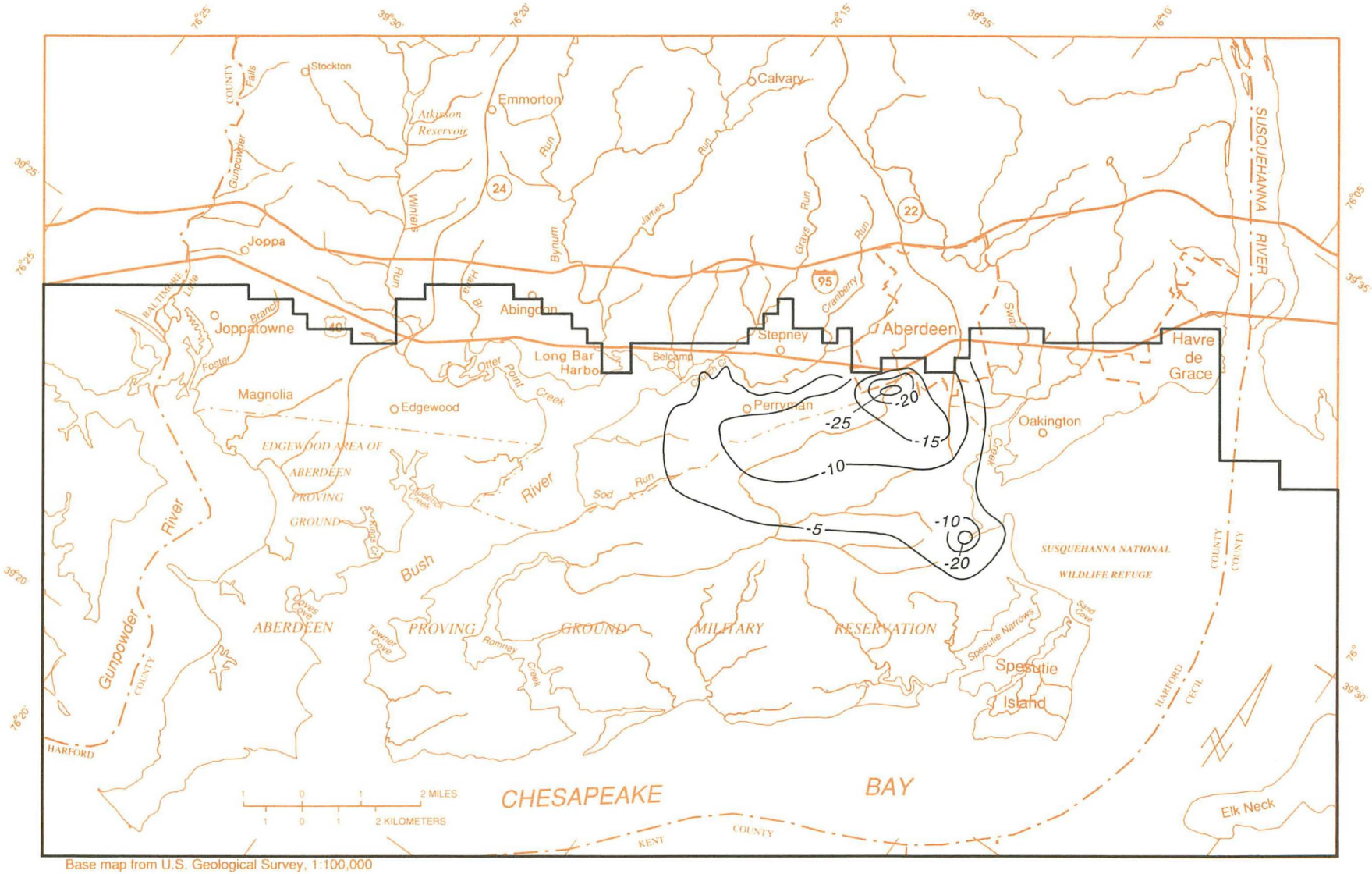
EXPLANATION

NO-FLOW BOUNDARY

-5 LINE OF EQUAL SIMULATED HEAD DIFFERENCE, IN FEET. CONTOUR INTERVAL IS 5 FEET.

SPECIFIED-HEAD BOUNDARY

Figure 63.—Difference between simulated potentiometric surfaces in aquifer 1 for 1989–2000, simulation 12b.



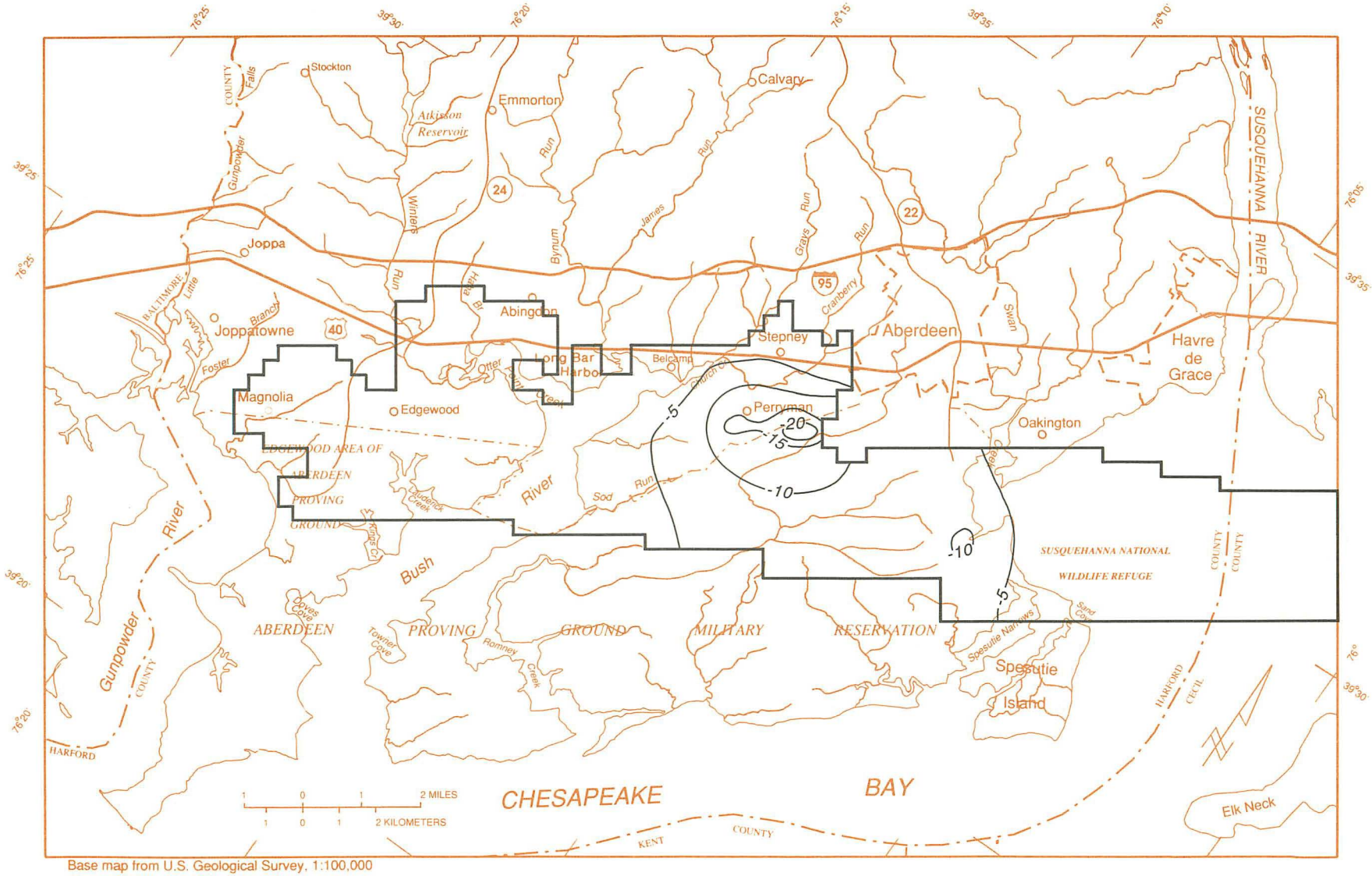
Base map from U.S. Geological Survey, 1:100,000

EXPLANATION

NO-FLOW BOUNDARY.

-10 LINE OF EQUAL SIMULATED HEAD DIFFERENCE, IN FEET. CONTOUR INTERVAL IS VARIABLE.

Figure 64.—Difference between simulated potentiometric surfaces in aquifer 2 for 1989–2000, simulation 12b.



Base map from U.S. Geological Survey, 1:100,000

EXPLANATION

NO-FLOW BOUNDARY.

-10 LINE OF EQUAL SIMULATED HEAD DIFFERENCE, IN FEET. CONTOUR INTERVAL IS 5 FEET.

Figure 65.—Difference between simulated potentiometric surfaces in aquifer 3 for 1989–2000, simulation 12b.

BG&E well fields, and about 16 ft deeper than 1989 water levels at the Trimble Road well field (fig. 66). Water levels in aquifer 3 are about 15 ft deeper than 1989 simulated water levels at the Perryman and Trimble Road well fields (fig. 67). Water levels in aquifer 4 are within 1 ft of 1989 levels in simulation 1. Streamflow decreased about 1 percent as compared to 1989 streamflow.

EFFECTS OF INCREASED DEVELOPMENT ON WATER QUALITY

Model simulations indicate that increased development of water supplies from the Coastal Plain aquifers could result in lowered water levels, which in turn could cause changes in ground-water flow paths and increases in flow rates. These new flow conditions could increase the potential for degradation of ground-water quality, primarily by migration of contaminants from land-surface sites such as landfills and dumping areas, and intrusion of brackish water from the Chesapeake Bay and its tidal tributaries. Contamination by infiltration of poor-quality water from losing stream reaches is also possible, although no serious contamination has been documented in streams in the study area. Most of the projected pumpage simulations indicated lowered water levels, but only simulations 7a, 7b, 9, 10, 11, 12, and 13 indicated head declines of more than 5 ft below 1989 levels. Head declines that are less than 5 ft are less than 2 percent of the range in water table altitudes, and probably will not significantly affect ground-water flow paths.

Brackish-Water Intrusion

Brackish-water intrusion has been documented at only one site in the Harford County Coastal Plain, at Joppatowne (Nutter, 1977, p. 31). The intrusion apparently resulted when dredging of the Joppatowne Marina removed low-permeability bottom sediments from a tidal part of Foster Branch. Chloride concentrations as high as 360 mg/L (milligrams per liter) were measured in well HA Ec 13 in November 1971 (Nutter, 1977, p. 31), and manganese concentrations as high as 650 μg/L (micrograms per liter) were measured in well HA Ec 14 in November 1972 (Nutter, 1977, p. 31). The intrusion problem was solved by drilling new well's farther inland and limiting withdrawals from the well field.

Although brackish-water intrusion in the study area is not a widespread phenomenon, it is a potential problem if water levels in the shallow coastal aquifers are lowered to within several feet of, or below sea level. Water levels in coastal aquifers remain above sea level in most of the projected pumpage scenarios, with the exception of simulations 7a, 7b, and 10. The potential for brackish-water intrusion under these simulated conditions is addressed in the section "Particle-Tracking Simulations."

Contaminant Migration

The presence of contaminated ground water has been documented at several sites in the Harford County Coastal Plain. Information regarding contaminant sites in Harford County is available from the Maryland Department of the Environment. The source of contamination in most cases is poorly constructed landfills or indiscriminate dumping of hazardous materials on the land surface. Other potential sources include the application of road salt, fertilizers, and pesticides. In all documented cases, the contaminants were introduced at the surface or shallow subsurface, and not into the deep subsurface.

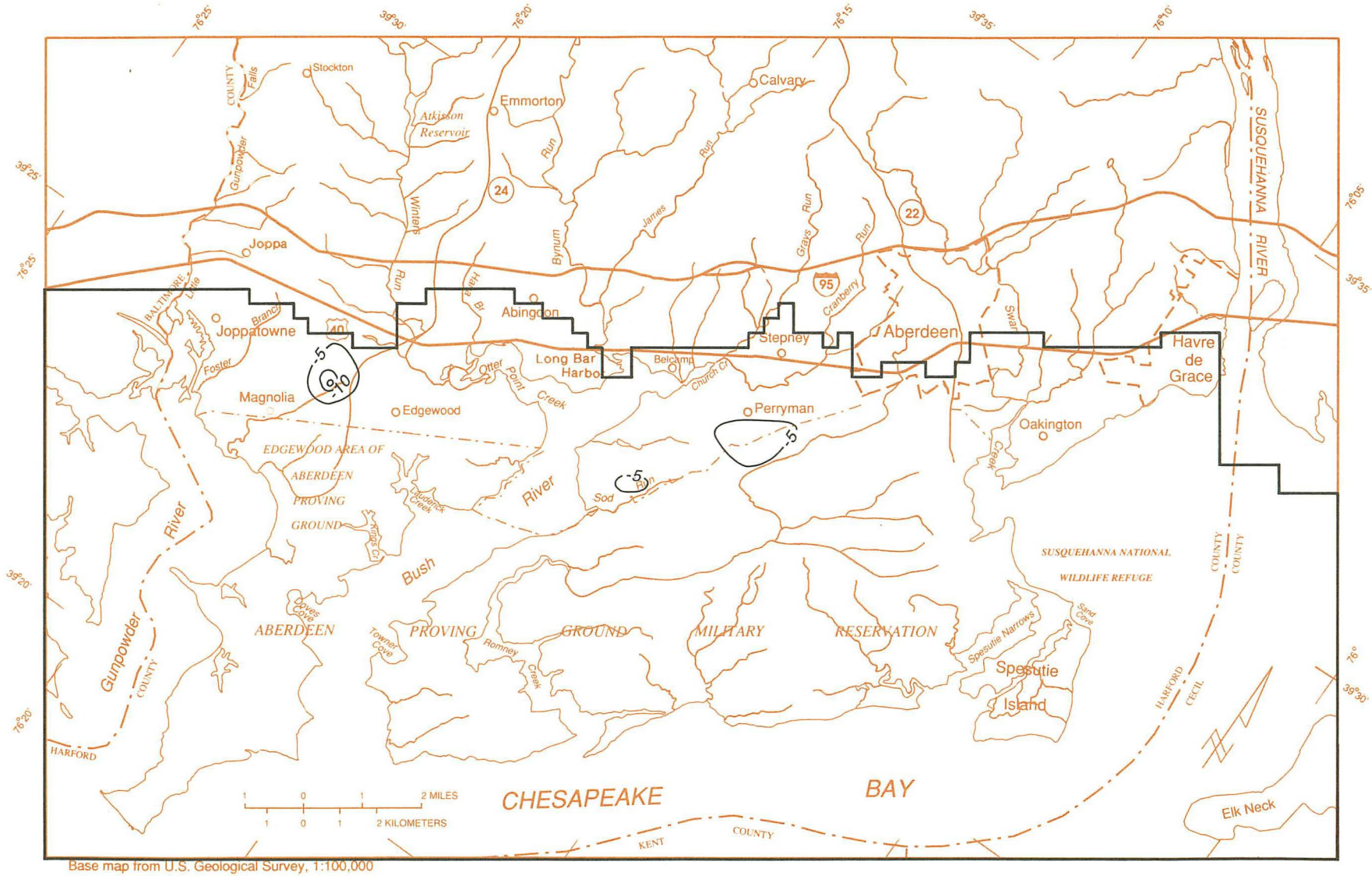
The migration of contaminants from landfills and dumping grounds is potentially the most serious threat to ground-water quality in Harford County. Increased pumpage from wells near contaminant sources could induce contaminant movement toward the wells by reversing head gradients, increasing flow rates, and increasing the contributing areas of the wells and well fields. The potential for contaminant migration is also addressed in the section "Particle-Tracking Simulations."

Road salt is apparently responsible for elevated chloride concentrations in several ground-water samples collected near major roads (tab. 12). Chloride concentrations attributed to road salt did not exceed the U.S. Environmental Protection Agency secondary maximum contaminant level (SMCL) of 250 mg/L. Water quality standards for Maryland are the same as those of the USEPA. Most road salt is probably washed into storm drains and does not reach the ground-water system. Where local conditions favor the accumulation of drainage in ditches, however, the saline water can percolate to the water table. Ground water contaminated by road salt can migrate short distances to shallow wells near major roads; however, this is not a significant problem because of the relatively minor amounts of salt applied and the infrequent application.

The agricultural application of fertilizers and pesticides is a potential source of ground-water contamination. Moderately high concentrations (14.0 mg/L) of nitrate were measured in several wells in the Perryman area; fertilizer application is probably the source of the nitrate. Increased pumpage at the Perryman well field might induce nitrate-laden shallow ground water to move toward the well field by increasing head gradients and flow rates, and by increasing the contributing area of the well field to encompass more agricultural area. This potential water-quality problem is addressed in the section "Particle-Tracking Simulations." Pesticide contamination of ground water has not been documented in the Harford County Coastal Plain, and was not addressed in the sampling program of this study.

Particle-Tracking Simulations

A particle-tracking analysis was used to evaluate the potential for subsurface movement of brackish water and contaminants to ground-water pumping centers. The USGS computer program MODPATH (Pollock, 1989) was used in both the forward-tracking and backward-tracking modes for these simulations. This program uses flow-model output to calculate flow within grid cells, then tracks a specified array of hypothetical particles along paths within and between the cells to determine flow directions and velocities. The movement of conservative dissolved solutes through the three-dimensional aquifer system can be simulated in this manner.



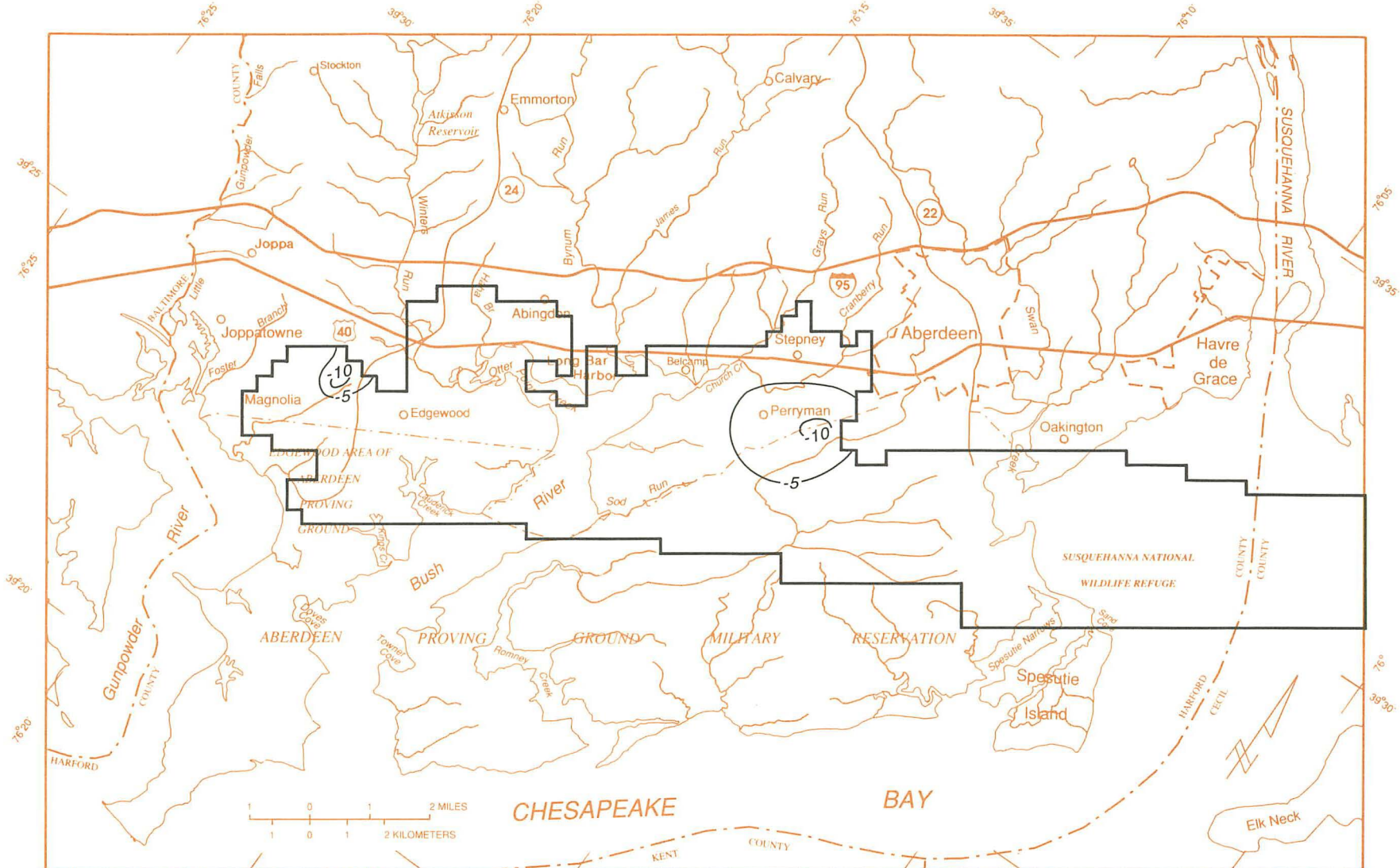
Base map from U.S. Geological Survey, 1:100,000

EXPLANATION

NO-FLOW BOUNDARY.

-5 LINE OF EQUAL SIMULATED HEAD DIFFERENCE, IN FEET. CONTOUR INTERVAL IS 5 FEET.

Figure 66.—Difference between simulated potentiometric surfaces in aquifer 2 for 1989–2000, simulation 13.



Base map from U.S. Geological Survey, 1:100,000

Figure 67.—Difference between simulated potentiometric surfaces in aquifer 3 for 1989–2000, simulation 13.

The particle-tracking method has several limitations that must be considered when interpreting the results. The method does not account for hydrodynamic dispersion, so the effects of mixing and spreading of solutes are not simulated. It does not account for chemical reactions, such as adsorption, degradation, transformation, and volatilization, which can retard the movement of solutes. The method uses a steady-state flow field as input, and cannot simulate a transient flow field. Given these limitations, and the approximate and non-unique nature of the flow-model results used for input, any application of the results of the particle-tracking simulations should be viewed only in general terms.

Input for MODPATH includes some data sets required by the flow model, and these were used directly or with minor modifications. In addition, MODPATH requires data arrays for the altitudes of the top and bottom of each aquifer, and porosity of each aquifer and confining unit. These altitudes are shown in figures 14, 15, 18, 19, 22, 23, 26, and 27. A porosity of 0.30 was used for all aquifers and 0.35 was used for all confining units. Total porosities determined from laboratory tests of 40 core samples from aquifers and confining units near Perryman ranged from 0.26 to 0.43 (Lentz and Kimball, 1984) and averaged 0.35. Effective porosities are probably slightly lower than total porosities, and the porosity of fine-grained sediments (confining units) is generally higher than that of coarse-grained sediments (aquifers). Sand and gravel deposits range in porosity from 25 to 50 percent, whereas silt and clay deposits range in porosity from 35 to 70 percent (Freeze and Cherry, 1979, p. 37).

Other input for MODPATH includes the initial arrangement of particles, the choice of forward- or backward-tracking, and the choice of capture or flow-through mode for particles entering weak sinks. These inputs are specific to each simulation and are described in the relevant sections. In forward-tracking simulations, initial particle locations are specified where water enters the flow system as recharge; the particles are then tracked in the forward direction as they flow through the system. In backward-tracking simulations, initial particle locations are specified where water leaves the flow system (such as from a supply well) and particles are tracked in the backward direction to the locations where the particles entered the flow system. Forward-tracking simulations are used to estimate the movement of solutes from landfills, and backward-tracking simulations are used to estimate contributing areas of production wells.

Model cells that contain wells or streams (sinks) present a special problem in the particle-tracking method. A strong sink exists where water flows into the cell through all six faces, and is not a problem because all particles that enter the cell will be

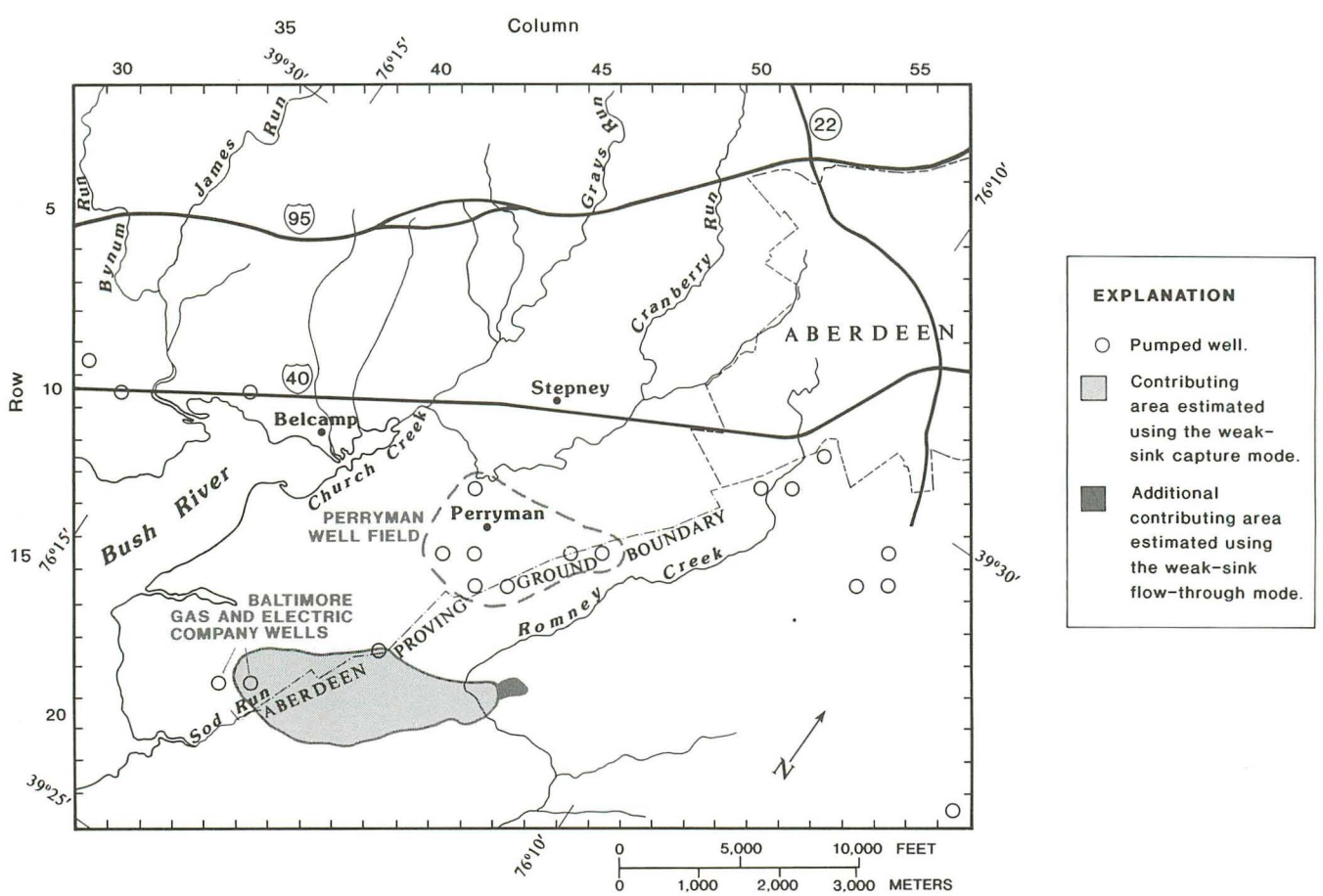


Figure 68.—Approximate extent of contributing area to hypothetical wells near Perryman.

discharged from that cell. A weak sink exists where water flows out of the cell through one or more of the faces. In this case, the program is unable to determine which particles should be discharged from the cell through wells or streams, and which particles should flow through the exit faces. The user must specify whether particles should all be captured and discharged from the cell or all pass through the exit faces. The two options, referred to as "capture mode" and "flow-through mode," can produce significantly different results that represent the extreme cases. Actual conditions in the ground-water flow system probably are between the two extremes.

The potential for movement of contaminated ground water to pumping centers was evaluated primarily by delineating the contributing areas of selected well fields. If the calculated contributing area of the pumping center encompasses a contamination site, contaminants could eventually migrate to the pumping center under the simulated conditions. An increase in pumpage would result in an increase in the size of the contributing area. Changes in pumpage distribution could also cause changes in the shape and extent of the contributing area. In some simulations, particles were also started at contamination sites to evaluate possible flow paths and discharge areas of contaminants. Particle-tracking analyses were performed only on those simulations in which pumpage was likely to induce contaminant migration.

The first particle-tracking simulation is based on model simulation 10b, in which three hypothetical production wells, discharging a total of 129,000 ft^3/d from aquifer 2, are added at the proposed power plant near Perryman. This simulation was used to estimate the contributing area of the wells. This simulation was run in forward-tracking mode by starting four evenly spaced particles in the top face of each cell in an area that encompassed the possible contributing area of the well field. The program identified the starting locations of the particles that eventually entered the pumped cells. The area defined by those starting locations is the estimated contributing area of the well field (fig. 68).

The estimated contributing area is about 2 mi long and 0.5 mi wide and extends from northeast to southwest. The area includes some streams, indicating that discharge from the well field is partially derived from ground water that otherwise would have discharged to streams as base flow. The contributing area (fig. 68) is slightly larger when the program is run in flow-through mode than in capture mode, because one stream cell is a weak sink. When the program is run in capture mode, water that enters that cell is discharged entirely into the stream and not allowed to pass through to the well field. Realistically, some water from that area will discharge to the stream and some will pass through to the well field.

The contributing area extends to the northeast because the regional flow direction is from northeast to southwest, toward the Bush River. The pumpage simulated at the power plant is insufficient to reverse the flow direction and draw large quantities of water from the southwest. This indicates that the wells at the power plant probably would not become contaminated with brackish water from the Bush River.

An additional particle-tracking simulation was made in which particles were started in the Bush River, representing brackish water. Landward movement of those particles would indicate that pumping at the power plant induces landward movement of brackish water. The simulation did not indicate any landward movement, and the particles all discharged into the river at their points of entry. This suggests that the simulated pumpage at the power plant is insufficient to reverse the head gradients between the estuary and the ground-water system and induce brackish-water intrusion.

A particle-tracking simulation was used to assess the potential for contaminants to migrate from the Canal Creek area of Aberdeen Proving Ground to the county-operated well field at Trimble Road (fig. 69). The analysis was based on simulation

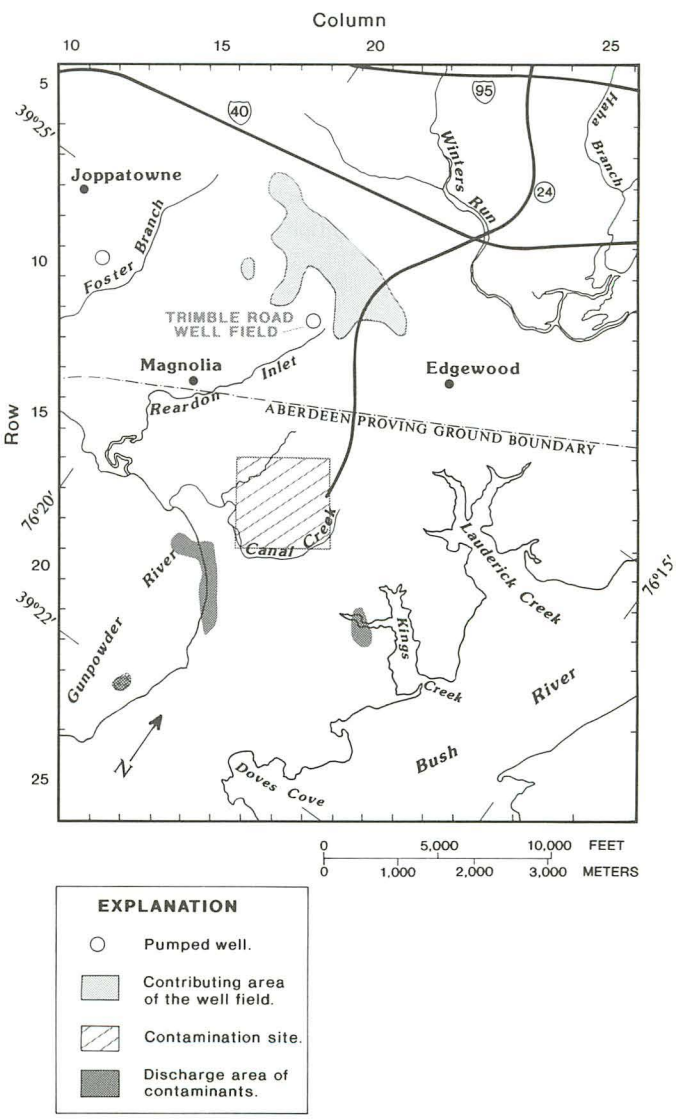


Figure 69.—Approximate extent of contributing area to the Trimble Road well field, and discharge area of the Canal Creek contamination site.

11, in which the Trimble Road well field was pumped at 33,000 ft^3/d. The simulation was in forward-tracking mode. Four particles that were evenly spaced in the top face of each cell in aquifer 1 were placed within an area that encompassed the possible contributing area of the well field. The particles that eventually discharged in the well field were identified, and the area that encompassed the starting locations of those particles was delineated to estimate the contributing area of the well field. The estimated area is irregularly shaped, about 2 mi long and 1 mi wide, and lies north of the well field. Regional head gradients are from north to south in this area, and the simulated pumpage in the well field is insufficient to reverse the gradients and draw water from the southern part of the area.

In the same simulation, particles were also placed in aquifer 1 in cells at the Canal Creek contamination site, between the East and West Branches of Canal Creek, where most chemical manufacturing and disposal activities took place (Lorah and Vroblesky, 1989). The particles were tracked in the forward direction to estimate the flow direction and discharge area of water emanating from the site. The particles discharge to the Gunpowder River and Kings Creek, but did not migrate toward the Trimble Road well field or the military boundary of APG. This simulation indicates that the addition of the Trimble Road well field, if pumping 33,000 ft^3/d, probably would not induce the migration of contaminants toward the well field.

The Perryman well field is the largest ground-water-pumping facility in Harford County, so it is important to understand the recharge sources of the well field. Several particle-tracking simulations were conducted to (1) estimate the contributing area of the Perryman well field under 1989 steady-state pumping conditions, (2) estimate the time required for recharge to reach the well field, and (3) estimate the contributing area of the well field under high-stress-pumping conditions.

The contributing area of the Perryman well field was estimated using MODPATH in forward-tracking mode. Particles were started in the top face of all cells in aquifer 1 that encompass the possible contributing area of the well field. The particles that eventually discharged through the wells were identified, and the area comprising the starting locations of those particles was the estimated contributing area of the well field. The contributing area that was estimated using the weak-sink capture mode is shown in figure 70. The contributing area was further divided into travel-time subareas. Each traveltime subarea is an area in which water that enters the ground-water system will be discharged through a well within a specific time range. For instance, water that recharges the system in the 5- to

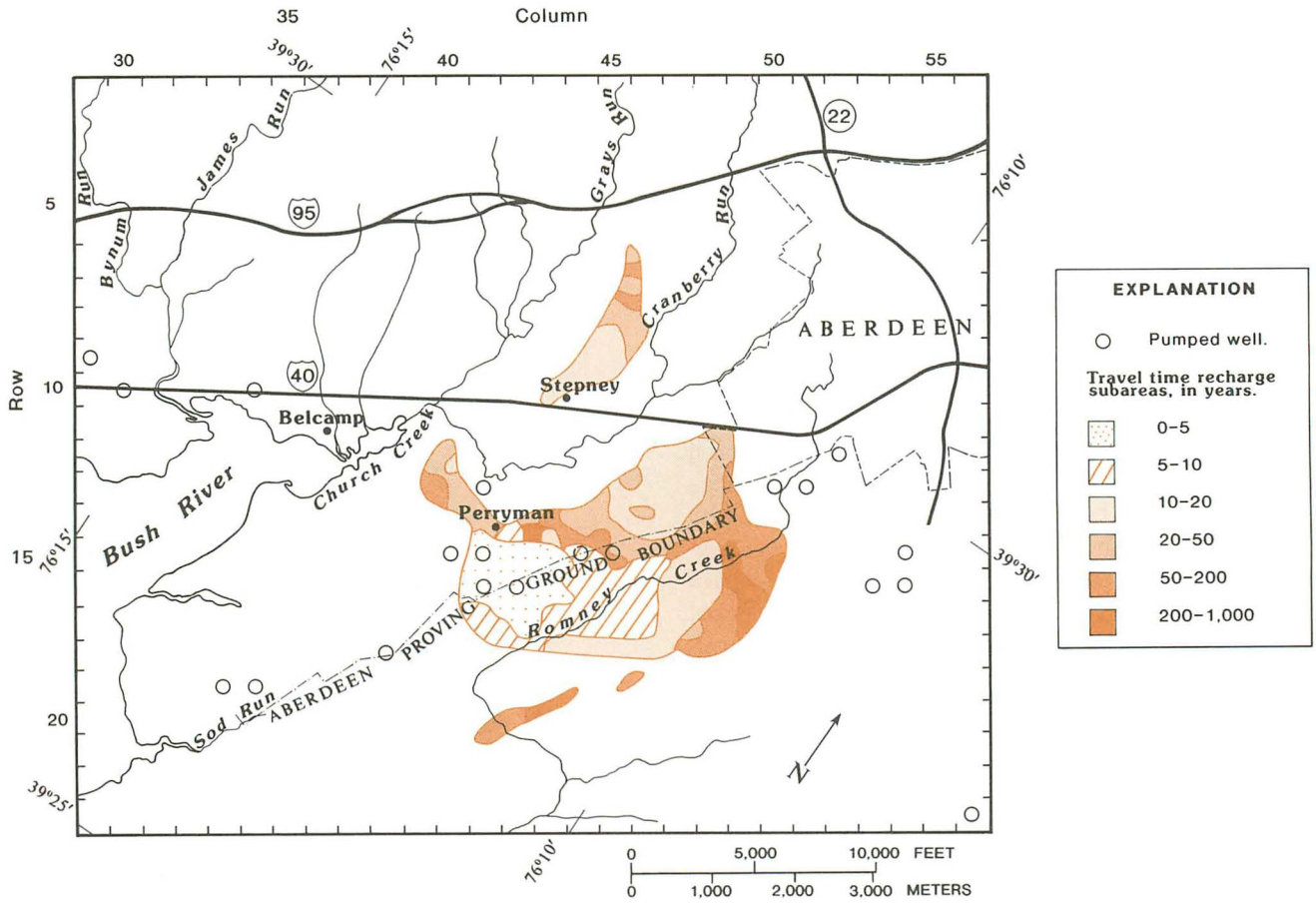


Figure 70.—Approximate extent of contributing area and traveltime subareas of the Perryman well field using the weak-sink capture mode.

10-year subarea will be discharged from a well in the Perryman well field in 5 to 10 years. The results that use the capture mode show a contributing area that extends to the northeast of the well field, about 2 mi long by 1½ mi wide. A second smaller contributing area is between Cranberry Run and Grays Run. Traveltimes range from less than 5 years to about 600 years. The smallest traveltimes occur in the immediate vicinity of the well field, and the greater traveltimes generally occur farther from the well field in the northeast. Large differences between adjacent traveltime subareas are found where water in one area flows a short distance to a nearby well, and water in the adjacent area must flow a longer distance to a different well. Two smaller outlying contributing areas are also present. The contributing area does not extend to the Bush River or Church Creek, but does encompass some areas of APG and some industrial and agricultural areas. This simulation indicates that under 1989 pumpage conditions, the Perryman well field probably will not induce brackish-water intrusion, but could induce contaminant migration from APG and other sources within the contributing area.

The same particle-tracking run was also made using the weak-sink flow-through mode, as the results of the traveltime analysis depend on the choice between the capture mode or flow-through mode. Water that enters a weak-sink cell in the capture mode will be discharged through that well immediately, resulting in the minimum possible traveltime. Water that enters a weak-sink cell in the flow-through mode will pass by that well and continue on its flow path until it reaches a strong sink, resulting in the maximum possible traveltime. The results using the flow-through mode are shown in figure 71. The total contributing area is the same as the area estimated using the capture mode, but the traveltime subareas are significantly different. Traveltimes are much greater, with about half of the contributing area in the 200- to 1,000-year subarea.

A third particle-tracking simulation for the Perryman well field was based on simulation 7a, which represents the maximum pumpage attainable without lowering water levels below the safe drawdown criterion. The contributing area delineated from this simulation (fig. 72) is about three times larger than the contributing area that was delineated using 1989 pumpage. The contributing area extends farther to the south and east into Aberdeen Proving Ground, and encompasses the Phillips Field landfill. Under these conditions, contaminants from the landfill could migrate toward the well field. The estimated contributing area in this simulation also extends beneath Church Creek, which indicates the potential for brackish-water intrusion under these pumping conditions.

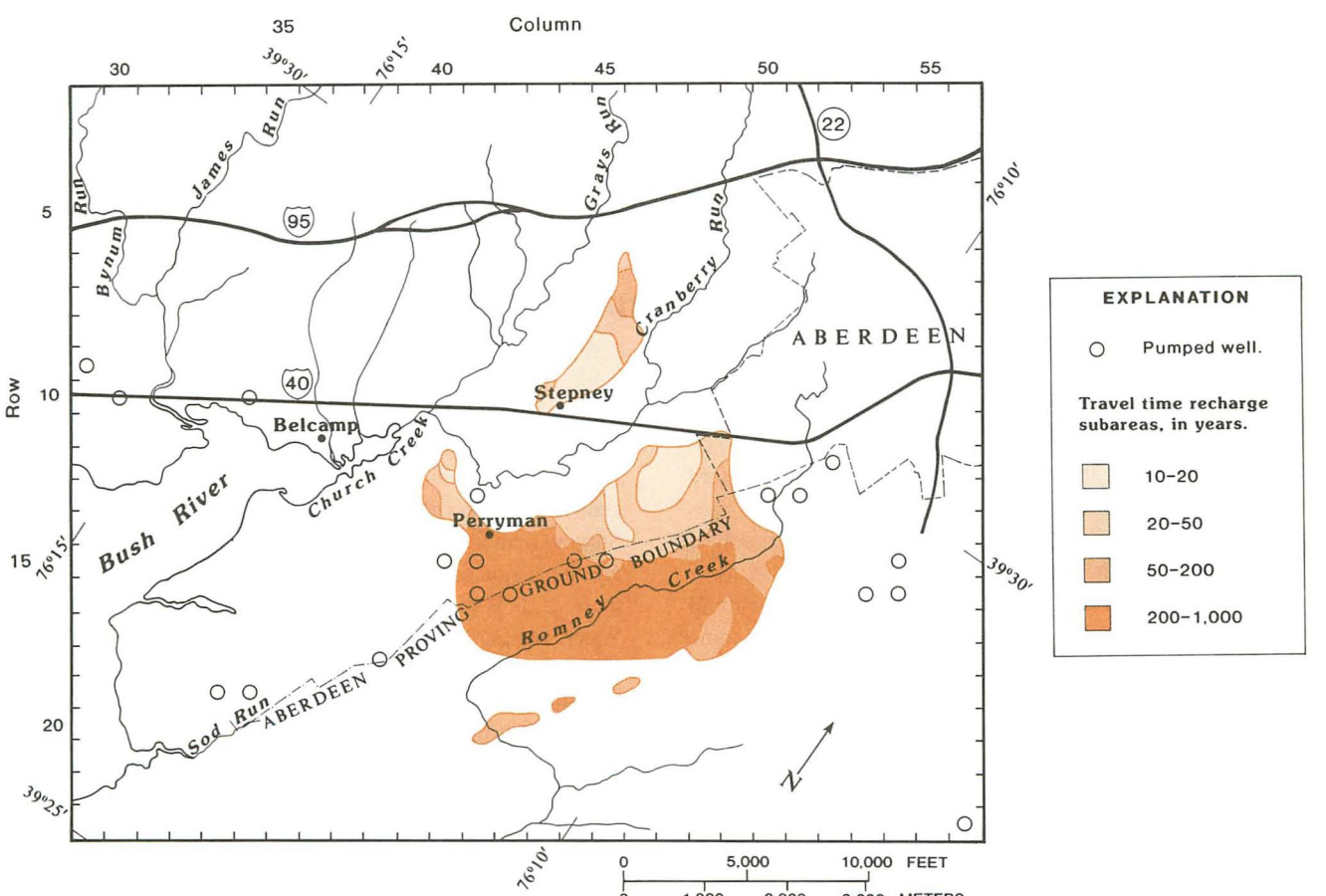


Figure 71.—Approximate extent of contributing area and traveltime subareas of the Perryman well field using the weak-sink flow-through mode.

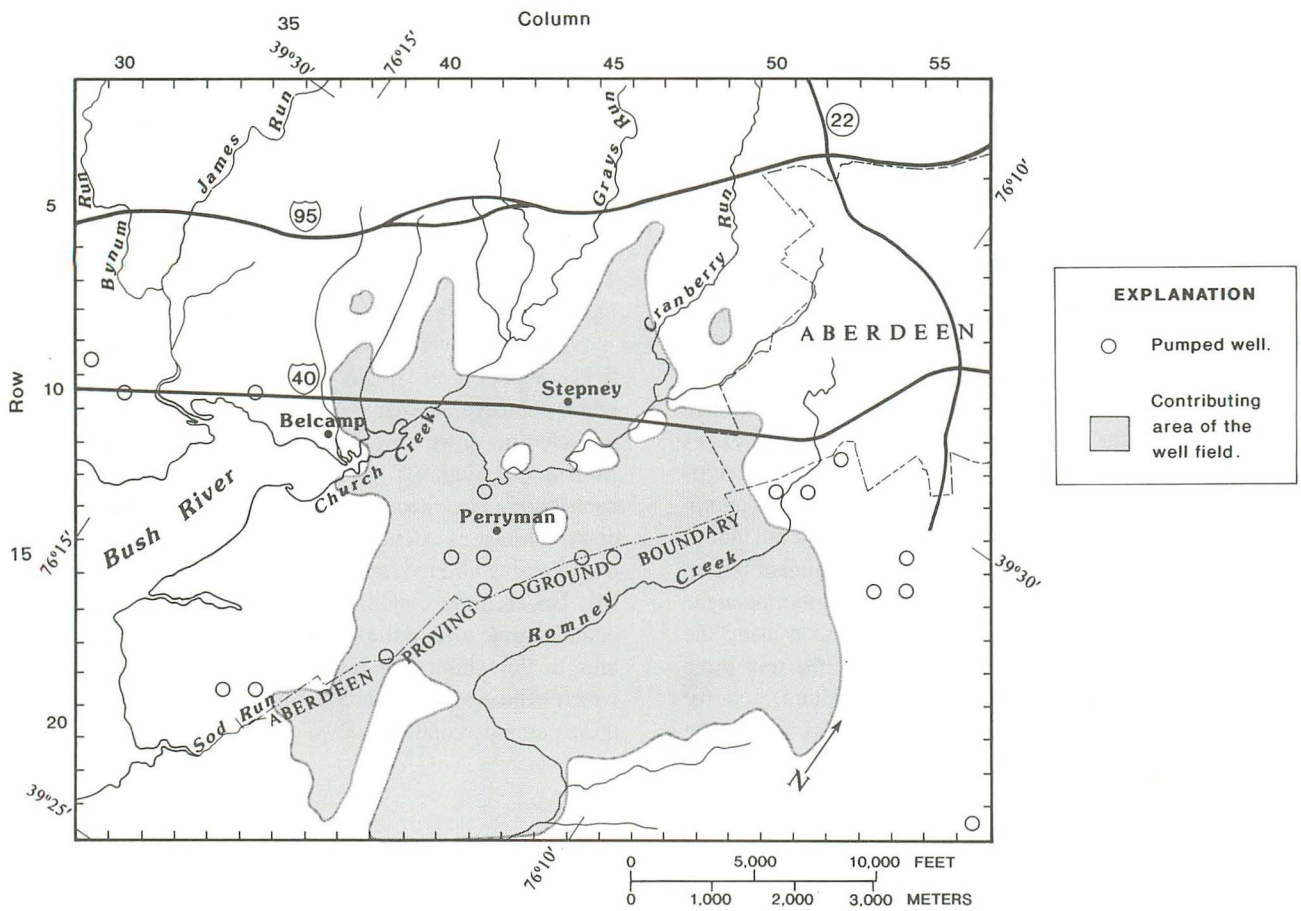


Figure 72.—Approximate extent of contributing area of the Perryman well field under maximum safe-yield conditions, simulation 7a.

WATER QUALITY

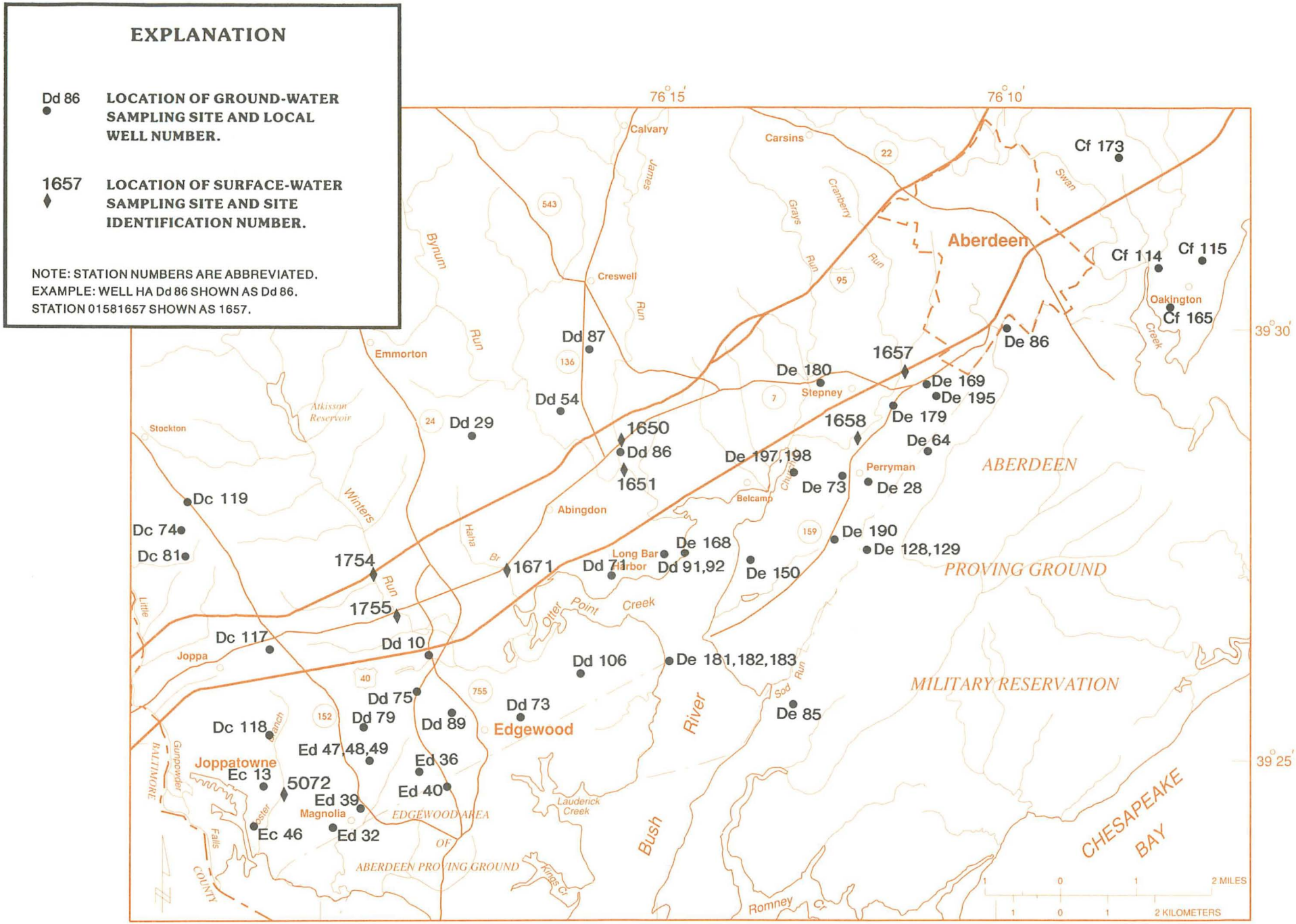
GROUND WATER

Ground water in the Coastal Plain aquifers of Harford County is generally suitable for domestic and industrial uses without treatment. The water is generally low in total dissolved solids (TDS) and hardness and has low pH. In some areas, however, the quality of ground water has been degraded by natural processes and anthropogenic contaminants. Water from some wells has elevated concentrations of chloride, nitrate, iron, and manganese.

A total of 43 wells and 7 stream sites were sampled for chemical analysis from 1987 to 1989 (fig. 73). Analyses for physical parameters, major chemical constituents, isotopes, and trace metals are presented in tables 12, 13, and 14.

The chemical composition of ground water initially depends upon the chemical composition of the recharge. Aquifer 1 is recharged primarily by precipitation, and the deeper confined aquifers are recharged by leakage from adjacent aquifers. In general, rainwater in Maryland is mildly acidic and has a low concentration of TDS. The pH of rain in the Catoctin Mountain of Frederick County, Maryland (about 60 mi west of the study area), ranges from 3.0 to 5.5, and has an average TDS concentration of less than 5 mg/L (Karen Rice, U.S. Geological Survey, written commun., 1992). Nitric acid and sulfuric acid are the major components of TDS in rainfall. The source of these acids is fuel combustion that began in the early 1900's. Water that recharged the ground-water system before the 1900's probably had a higher pH and a lower TDS concentration.

Changes in water quality in the Coastal Plain aquifers could be the result of any of the following processes: chemical reactions within the soil zone, dissolution and precipitation of minerals, ion exchange reactions, oxidation-reduction reactions, microbial respiration, or anthropogenic additions (fig. 74). The following discussion presents the range and distribution of the major inorganic constituents, and describes the possible sources of those constituents in the ground water of the Harford County Coastal Plain.



Base map from U.S. Geological Survey, 1:100,000

Figure 73.—Locations of water-quality sampling sites.

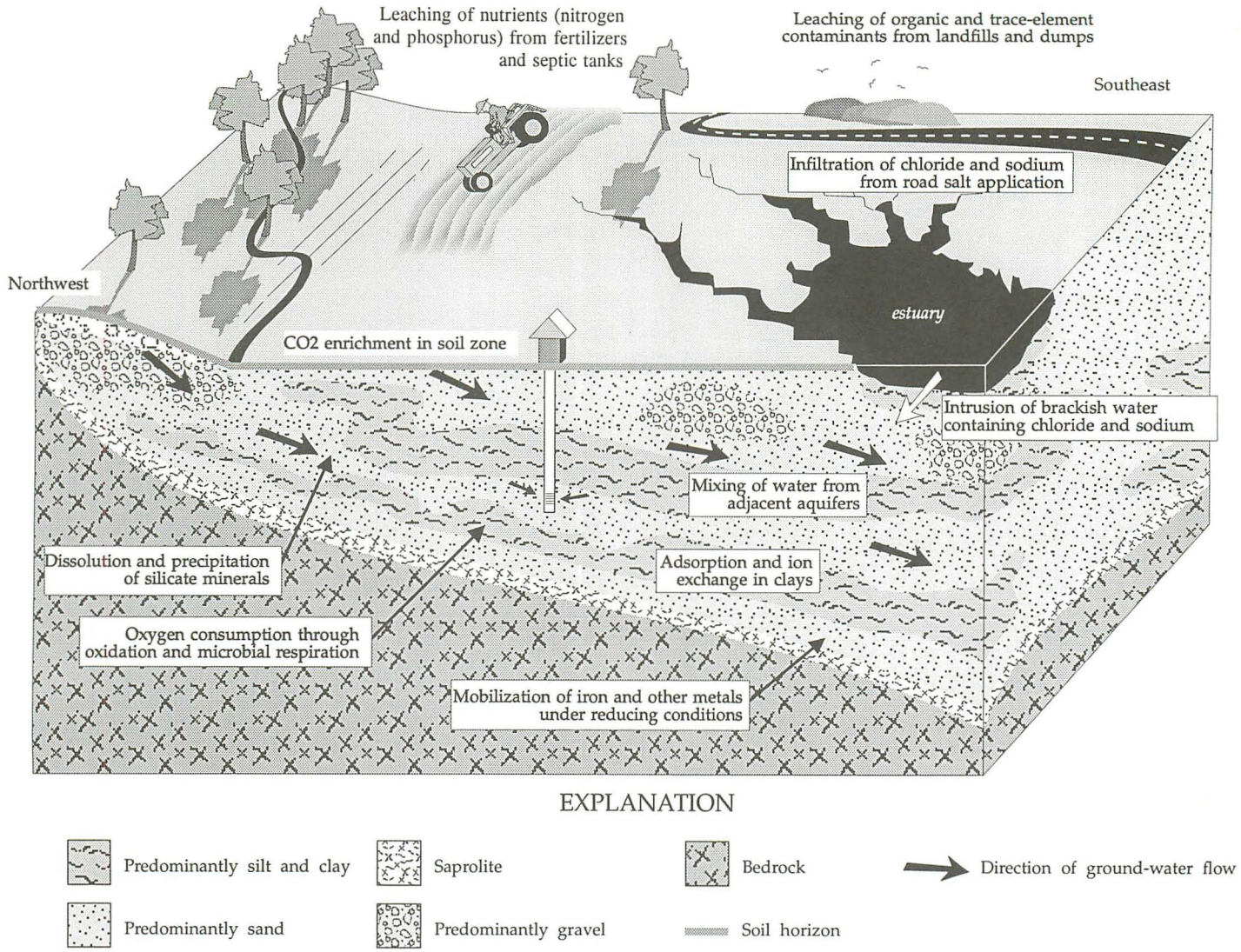


Figure 74.—Processes affecting water quality in Coastal Plain aquifers.

Chemical Properties

The statistical distribution of chemical properties including TDS, pH, hardness, and bicarbonate concentrations in water from Coastal Plain and Piedmont aquifers is shown by boxplots in figure 75. The shapes of the boxplots show the statistical nature of the concentration distributions. For example, the long symmetrical box for bicarbonate concentrations in aquifer 1 indicates a wide range of values evenly distributed about the median value, whereas the short asymmetrical box for bicarbonate concentrations in aquifer 3 indicates a narrow range of values with a skewed distribution.

Total dissolved solids is a measure of all dissolved minerals in a water sample. Concentrations of TDS in all ground-water samples from the Coastal Plain were low, ranging from 16 to 332 mg/L, with a median of 87 mg/L. No concentrations were greater than the 500 mg/L SMCL set by the USEPA for public-water supplies. SMCL's are set for constituents that have no known health risk, but can be displeasing in excessive concentrations for esthetic reasons such as taste and color. The low concentration of TDS indicates that these waters are only slightly more mineralized than rainwater, and this could be due to two factors: First, the aquifer sediments consist predominantly of quartz and kaolinite (tab. 23). Dissolution of quartz is a slow reaction and contributes only low concentrations of silica to solution. Kaolinite is a stable clay mineral in this geochemical environment, and does not contribute ions to solution. Second, the flow paths and residence times for these waters are relatively short, as the contributing area is within several miles of nearly all sampling points; therefore, the contact time between the ground water and aquifer sediments is relatively short.

Ground water in the different aquifers in the Coastal Plain and Piedmont contains different concentrations of TDS. A summary of TDS concentrations for water from the Coastal Plain

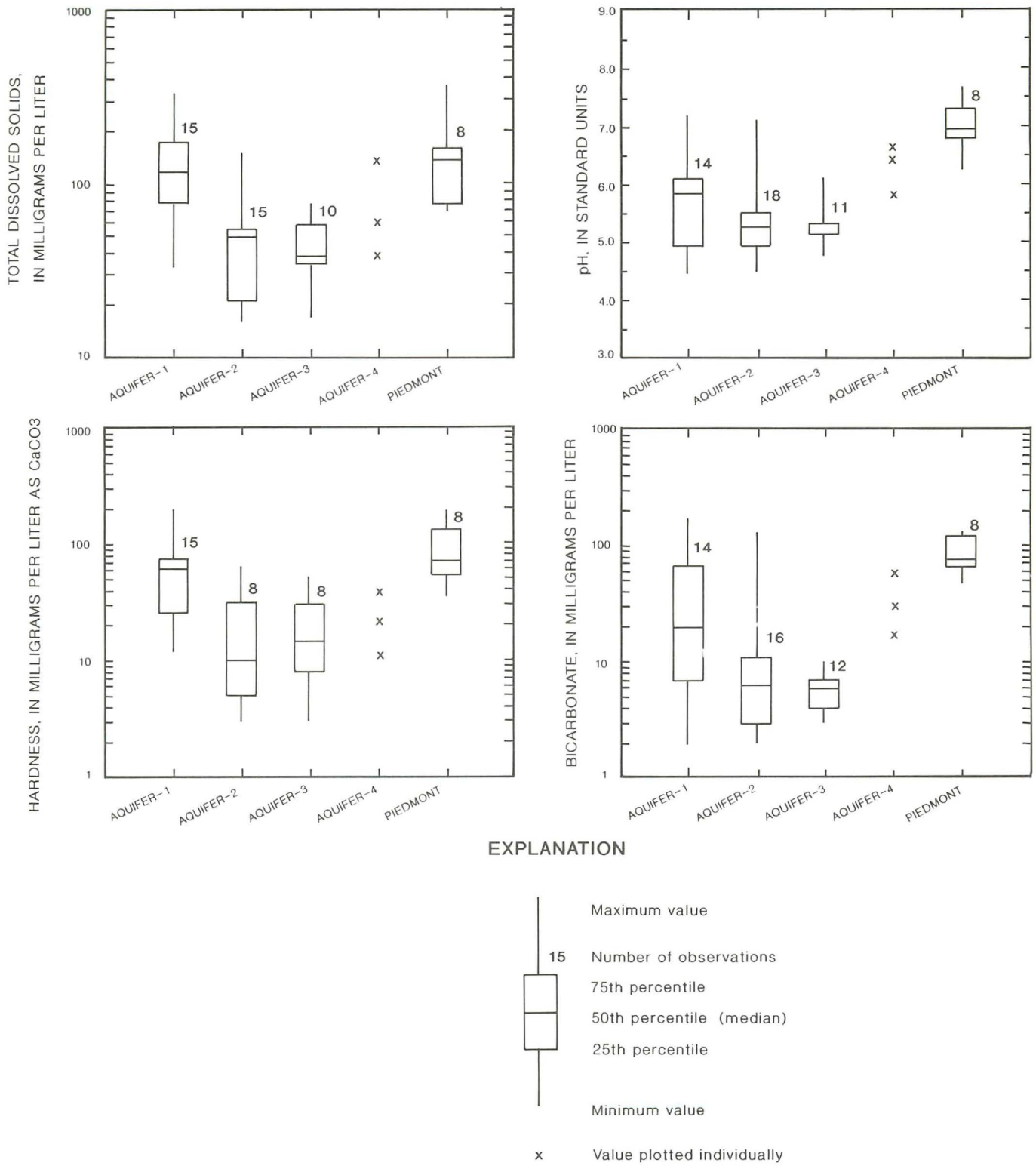


Figure 75.—Descriptive statistics on total dissolved solids, pH, hardness, and bicarbonate concentrations in ground water.

and Piedmont aquifers is presented in table 9 and boxplots are shown in figure 75. The median concentration (118 mg/L) in water from aquifer 1 is significantly higher than the median concentrations in water from the deeper aquifers, which range from 38 to 61 mg/L. Aquifer 1 is composed predominantly of sediments of the Talbot Formation which are chemically more unstable than sediments of the Potomac Group, and thus are more readily dissolved. Also, water in aquifer 1 is more likely to be affected by anthropogenic sources of solutes which could significantly contribute to dissolved solids. Water from the Piedmont aquifer has a median TDS concentration (135 mg/L) similar to water from aquifer 1.

The spatial distribution of dissolved solids in ground-water samples is shown in figure 76. In general, the highest TDS concentrations are in water from wells in Piedmont aquifers and in aquifer 1. The TDS concentrations in water from aquifers 2 and 3 are generally higher in the Perryman area than in the rest of the study area. The higher concentrations in the Perryman area could be the result of leakage through confining units 1 and 2, which are leakier in the Perryman area than in the rest of the study area.

The pH of a solution is the negative logarithm of the hydrogen activity. Lower pH values indicate higher acidity. Water from the Coastal Plain aquifers generally is acidic (fig. 75) with a median pH of 5.3, below the neutral pH of 7.0. High and low pH values are undesirable for drinking water, and the USEPA set SMCL's for pH of 8.5 and 6.5 units. None of the water samples had a pH higher than 8.5, but 87 percent of the samples had a pH lower than 6.5. Low pH can cause staining or corrosion of plumbing fixtures and elevated trace-metal concentrations from leaching of plumbing fixtures and aquifer material. Water from aquifer 1 had the widest range of values and a median pH of 5.9. Water from aquifers 2 and 3 had successively narrower ranges, with a median value of 5.3 for both. The pH of three samples from aquifer 4 ranged from 5.8 to 6.6. Water from the Piedmont had higher pH values, with a median value of 6.9.

Hardness is a property of water that causes formation of an insoluble residue when used with soap, and formation of a scale upon evaporation. Hardness is calculated by summing the concentration of calcium and magnesium in equivalent weight units of calcium carbonate. Hem (1985, p. 159) presents a standard scale for hardness in which waters with values less than 60 mg/L are considered soft; from 60 to 120 mg/L, moderately hard; from 120 to 180 mg/L, hard; and greater than 180 mg/L, very hard. The ranges for hardness in water from Coastal Plain and Piedmont aquifers are summarized in table 9 and shown as boxplots in figure 75. Generally, water from the confined Coastal Plain aquifers is soft, whereas water from the unconfined and Piedmont aquifers is soft to moderately hard. Ranges for hardness in water from aquifers 2, 3, and 4 were similar; the medians are skewed toward lower concentrations (fig. 76).

Bicarbonate is the dominant carbonate species in the mildly acidic ground water of Harford County. It is the principal component of alkalinity, which is the buffering capacity of water. Bicarbonate concentrations in water from Coastal Plain aquifers range from 2 mg/L at several wells to 170 mg/L at well HA Cf 114. Low concentrations of bicarbonate (low alkalinity) in the confined aquifer system indicate that these waters are poorly buffered, and large changes in acidity could result from the addition of acidic substances, such as acidic rain and disposal-site leachate. The main sources of dissolved bicarbonate in these waters are solution of carbon dioxide and dissolution of silicate minerals. Carbon dioxide is derived from the atmosphere, from plant respiration in the soil zone, and from the decay of organic matter.

Total organic-carbon (TOC) concentrations indicate the amount of organic substances in water, such as natural fulvic and humic acids, and anthropogenic organic solutes, such as petroleum-related products. TOC concentrations in water from Coastal Plain wells range from below the detection limit (0.1 mg/L) to 8.0 mg/L. The median values for TOC decrease with depth and range from 1.4 mg/L in aquifer 1 to 0.2 mg/L in aquifer 4. Oxidation of lignite in the aquifer matrix is probably the source of TOC at background concentrations (less than 5 mg/L). Brackish-water intrusion or anthropogenic inputs could be the source of elevated concentrations of TOC.

Dissolved-oxygen concentrations range from less than 0.1 mg/L in water from eight wells to 8.0 mg/L in well HA Dc 118 (tab. 12). A wide range of dissolved-oxygen concentrations was found in water from each aquifer with the exception of aquifer 4, where concentrations were all below 1.0 mg/L. Dissolved oxygen in ground water is supplied through recharge in the unsaturated zone (Hem, 1985). The amount of dissolved oxygen in ground water is a function of temperature, atmospheric inputs, microbial respiration, and oxidation-reduction reactions. Oxidation of reactive materials, such as pyrite and organic matter, could deplete oxygen in ground water along the flow path.

Inorganic Constituents

The following section discusses the presence of inorganic constituents in ground water of the Harford County Coastal Plain and adjacent Piedmont. The ranges and median concentrations of the major inorganic constituents are presented as boxplots in figure 77. The distributions of constituents that show areal trends (chloride and nitrate) are shown on separate maps.

Calcium concentrations were generally low in water from Coastal Plain wells, and ranged from less than 1 mg/L in water from several wells, to 37 mg/L in water from well HA Ed 49; the mean concentration was 5.0 mg/L. The mean concentration in water from Piedmont wells (19 mg/L) was higher than that from Coastal Plain wells because of the abundance of calcium-bearing minerals in Piedmont rock. Dissolved calcium could be derived from soil-zone reactions and from dissolution of silicate minerals, such as plagioclase feldspars and amphiboles (Hem, 1985). The addition of lime to soils to neutralize acidic fertilizers also could contribute significant amounts of calcium and magnesium to the shallow aquifers.

Magnesium concentrations were generally low in water from Coastal Plain wells, and ranged from less than 1 mg/L in

Table 9.—Summary descriptive statistics on pH measurements and concentrations of selected chemical constituents in ground water in Harford County

[mg/L = milligrams per liter; µg/L = micrograms per liter; n = number of samples; SMCL = USEPA secondary maximum contaminant level; MCL = USEPA maximum contaminant level; < = less than; > = greater than]

pH, in standard units [1]

Aquifer	Mean	Minimum	Maximum	Median	Total n	n < SMCL
1	5.87	4.47	8.20	5.85	14	10
2	5.38	4.51	7.10	5.27	18	17
3	5.32	4.76	6.12	5.32	11	11
4	6.28	5.79	6.60	6.45	3	2
Piedmont	6.94	6.26	7.69	6.94	8	2

1 SMCL range 6.5 - 7.5.

Total dissolved solids (sum of constituents), mg/L [2]

Aquifer	Mean	Minimum	Maximum	Median	Total n	n > SMCL
1	147.13	33	332	118	15	0
2	56.40	16	149	49	15	0
3	43.30	17	75	38	10	0
4	78.33	38	136	61	3	0
Piedmont	143.75	71	360	135	8	0

2 SMCL = 500 mg/L.

Hardness as $CaCO_3$, mg/L

Aquifer	Mean	Minimum	Maximum	Median	Soft	Moderately hard	Hard	Very Hard
1	73.26	12	200	61	7	6	1	1
2	23.11	3	63	10	15	1	0	0
3	19.91	3	51	14.5	12	0	0	0
4	25	11	41	23	3	0	0	0
Piedmont	84.25	35	190	70	8	3	1	1

Nitrite plus nitrate as N, mg/L

Aquifer	Mean	Minimum	Maximum	Median	Total n	n > MCL
1	1.78	0.10	11	1	15	1
2	1.95	.10	14	0.30	17	2
3	3.61	.10	12	1.80	12	1
4	.35	.10	0.6	0.35	2	0
Piedmont	.27	.07	0.8	0.10	8	0

3 MCL = 10 mg/L.

Chloride, mg/L

Aquifer	Mean	Minimum	Maximum	Median	Total n	n > SMCL
1	28.98	1.7	110	16	15	0
2	13.55	1.7	73	6.6	17	0
3	7.76	1.8	24	5.8	12	0
4	4.46	2.5	7.4	3.5	3	0
Piedmont	20.45	1.4	140	3	8	0

4 SMCL = 250 mg/L.

Iron, total, µg/L [5]

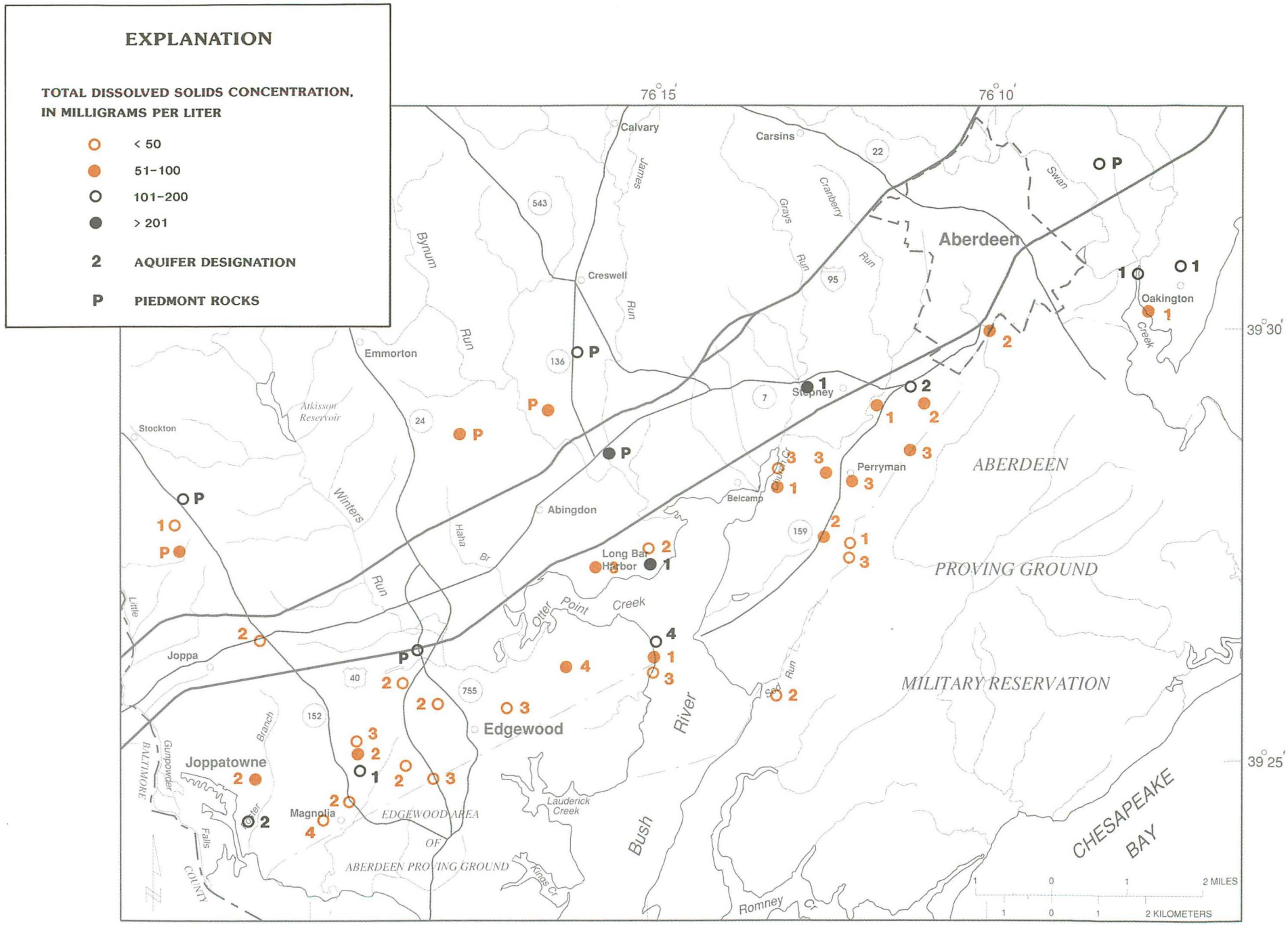
Aquifer	Mean	Minimum	Maximum	Median	Total n	n > SMCL
1	3,503	60	16,000	200	14	6
2	1,165	10	13,000	70	17	4
3	600	10	3,300	75	12	3
4	5,093	580	7,700	7,000	3	3
Piedmont	12,070	30	88,000	515	8	5

5 SMCL = 300 µg/L.

Manganese, total, µg/L [6]

Aquifer	Mean	Minimum	Maximum	Median	Total n	n > SMCL
1	762	10	4,800	185	14	11
2	79	10	350	30	17	6
3	30	10	90	20	12	2
4	113	40	190	110	3	2
Piedmont	705	10	3,600	125	8	4

6 SMCL = 50 µg/L.



Base map from U.S. Geological Survey, 1:100,000

Figure 76.—Total-dissolved-solids concentrations in ground water.

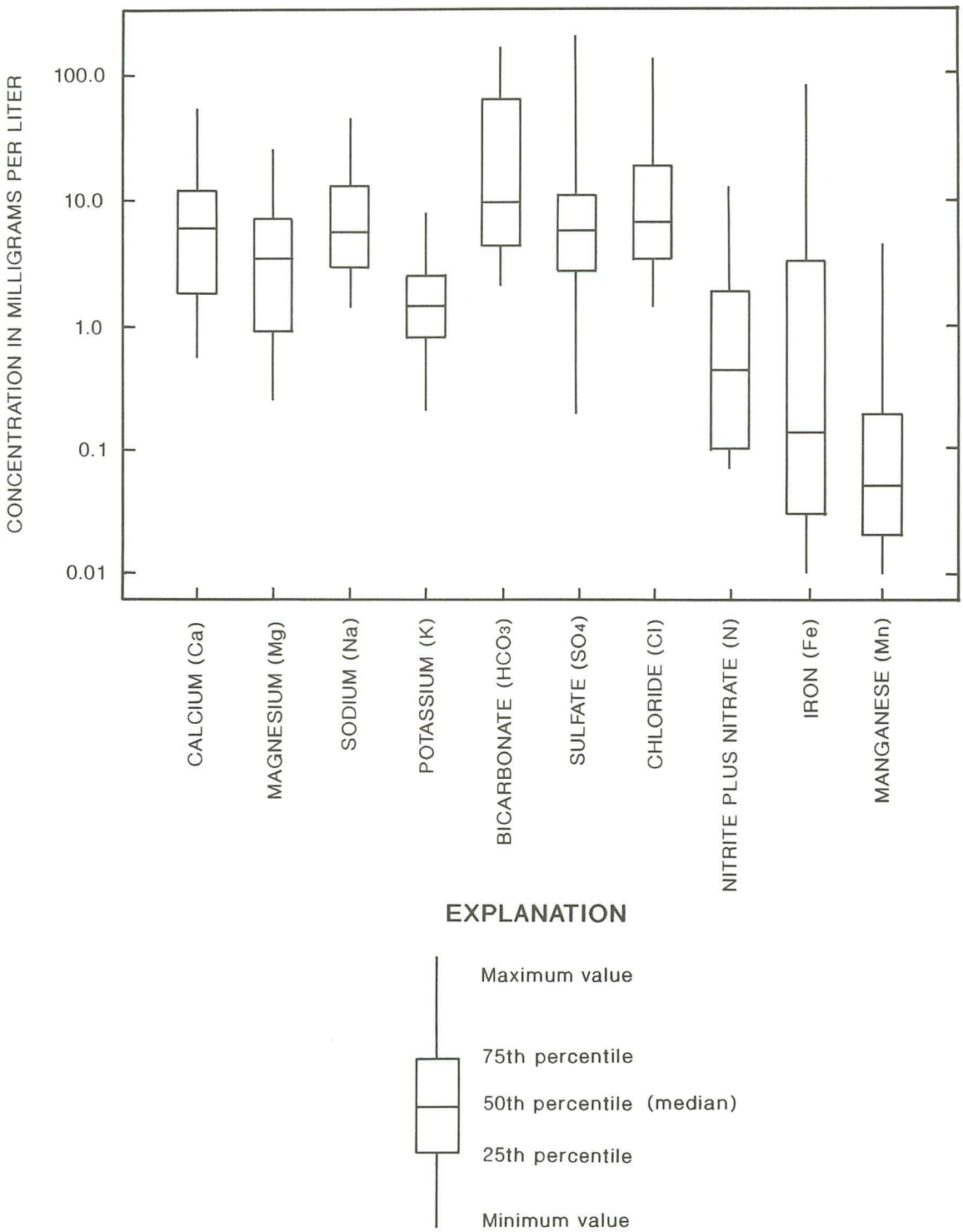


Figure 77.—Descriptive statistics on concentrations of major ions in ground water.

water from several wells, to 26 mg/L in well HA Ed 49; the mean concentration was 4.0 mg/L. Magnesium concentrations in water from Piedmont wells (mean concentration, 6.0 mg/L) were slightly higher than in Coastal Plain wells, possibly because of the relative abundance of magnesium-bearing minerals in Piedmont rocks. Magnesium is derived from weathering of minerals, such as amphiboles, chlorite, and dark micas (Hem, 1985).

Sodium concentrations in water from Coastal Plain wells ranged from 1.4 mg/L in well HA Ed 40 to 38 mg/L in well HA Dd 92; the mean was 9.6 mg/L. Dissolved sodium could be derived from the dissolution of sodium feldspars (Hem, 1985). Sodium could also be added to the ground-water system through anthropogenic sources, such as road-salt contamination, irrigation and fertilization, and brackish-water intrusion (Hem, 1985). Cation exchange can contribute sodium to solution, in which calcium and magnesium replace sodium on mineral surfaces (Krauskopf, 1979). No water-quality regulations have been established for sodium; however, the USEPA recommends a limit of 20 mg/L. Water from three Coastal Plain wells (HA Dd 92, HA De 169, HA Ec 23) and one Piedmont well (HA Ec 13) exceeded this concentration.

Potassium concentrations in water from Coastal Plain wells ranged from 0.2 mg/L in well HA Dd 75 to 8.0 in well HA De 128; the mean was 1.7 mg/L. Potassium is generally derived through dissolution of potassium feldspars and micas (Hem, 1985). It could also be added to solution by the decomposition of plant matter in the soil zone.

Sulfate ($SO_4^{=}$), the oxidized form of elemental sulfur, was present in relatively low concentrations in most Coastal Plain ground waters. Sulfate concentrations in water from Coastal Plain wells ranged from 0 at several wells to 210 mg/L in well HA Ed 49; the mean was 14.6 mg/L. Possible sources of sulfate include weathering of sulfur-containing minerals such as pyrite (Hem, 1985) and rainfall. Cleaves and others (1974) reported an average sulfate concentration of 3.74 mg/L in precipitation at a site 12 mi north of Baltimore, Md. Sulfate in rainfall is attributable to the burning of fossil fuels; such rainfall is referred to as "acid rain." The poorly buffered ground water in the Coastal Plain could reflect the effect of sustained additions of sulfate-enriched rainfall with high sulfate concentrations and low pH. Sulfate was the major anion in three samples taken at different times from well HA Ed 49 (210, 110, and 45 mg/L). Other ions showed similar variability. The source of elevated sulfate and the reason for the variability in this shallow well are unknown. A former gravel pit adjacent to the well site could affect the chemistry of the shallow ground water there.

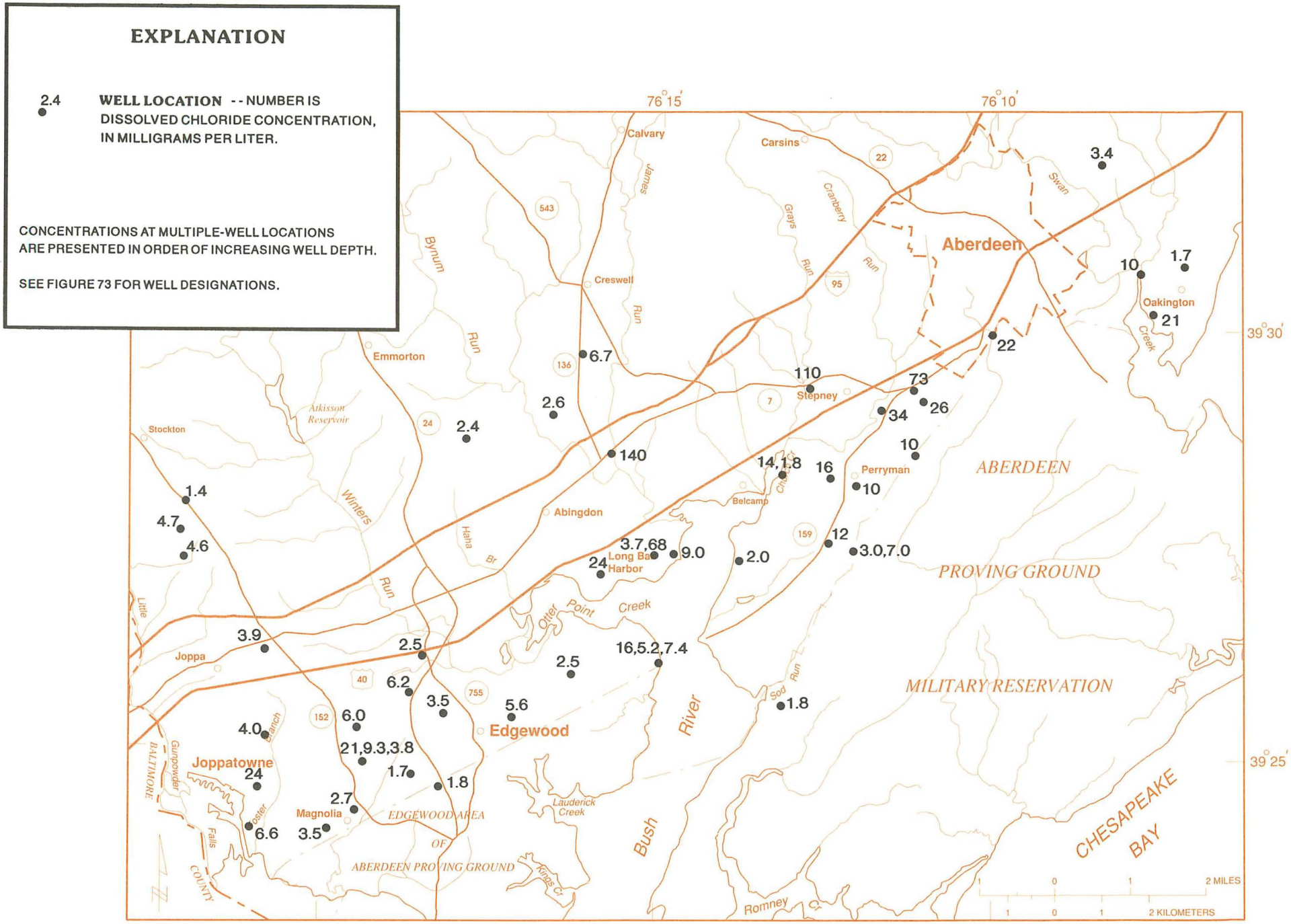
Chloride was a major ionic constituent in water from many Coastal Plain aquifers. Chloride concentrations in water from Coastal Plain aquifers ranged from 1.7 mg/L in wells HA Cf 115 and HA Ed 36 to 110 mg/L in well HA De 180; the mean was 16.4 mg/L. The maximum concentration in water from Piedmont wells was 140 mg/L, in well HA Dd 86. Concentrations of chloride in water from many of these wells exceeded what could be considered a background concentration of 10 mg/L; however, none of the concentrations exceeded the USEPA SMCL of 250 mg/L. Chloride concentrations in Maryland rainfall are generally lower than concentrations in ground water in the Harford County Coastal Plain. Cleaves and others (1974) reported an average chloride concentration in rainfall of 0.38 mg/L. Figure 78 shows the locations of wells where chloride concentrations in ground water were measured. Wells HA Dd 86 (140 mg/L), HA De 180 (110 mg/L), and HA De 169 (73 mg/L) are shallow wells located near major roads. The proximity of these wells to major roads indicates that these concentrations were probably caused by infiltration of road salt. Moderately high concentrations in other waters could result from the mixing of freshwater and road-salt contaminated water in the aquifers. Elevated chloride concentrations (above 10 mg/L) could also result from brackish-water intrusion in areas near estuaries such as the Bush River. Well HA Dd 92 is near the Bush River at Long Bar Harbor, and water from the well had a chloride concentration of 68 mg/L. Nutter (1977) documented a rise in chloride concentration in well HA Ec 13 between 1968 and 1976, concurrent with increased pumpage in the Joppatowne area and dredging in a local marina. He ascribed the increase in chlorides to brackish-water intrusion caused by the removal of confining sediments during dredging of the marina and by an increase in hydraulic gradients caused by pumping.

Fluoride was a minor anionic solute in water from Coastal Plain aquifers. Fluoride concentrations ranged from below the detection limit (0.1 mg/L) to 0.9 mg/L in well HA Ed 49. Possible mineral sources for fluoride include apatite, amphiboles, and some micas.

Silica concentrations in water from Coastal Plain aquifers ranged from 5.6 mg/L in well HA Dc 118 to 41 mg/L in well HA De 180. The median silica concentration in water from aquifer 1 (12.0 mg/L) is somewhat higher than the median in water from the deeper confined aquifers (10.0 mg/L). Water from Piedmont wells has a median silica concentration of 28 mg/L, which is significantly higher than that in water from Coastal Plain wells. Dissolved silica probably is derived from the dissolution of silicate minerals.

Phosphorus concentrations in water from Coastal Plain wells are low because of the low solubility of phosphorus. Phosphorus concentrations in water from Coastal Plain wells ranged from below the detection limit of 0.01 mg/L in numerous wells to 0.32 mg/L in well HA De 168. The median value for water from all Coastal Plain aquifers is at the detection limit. A primary mineral source of phosphorus is apatite. Phosphate from fertilizers could leach into ground water, but the low mobility of phosphorus in soils and sediments (Hem, 1985) makes this unlikely. Elevated concentrations of phosphorus also could indicate leakage from septic tanks.

Nitrogen concentrations represent the total of two dissolved species, nitrate (NO_3) and nitrite (NO_2). Nitrate is generally the more common form. Nitrogen concentrations in water from Coastal Plain wells ranged from below the detection limit of 0.1 mg/L in waters from several wells to 14.0 mg/L in water from well HA De 190. The USEPA has set a maximum contaminant



Base map from U.S. Geological Survey, 1:100,000

Figure 78.—Concentrations of chloride in ground water.

level (MCL) of 10.0 mg/L for dissolved nitrate (reported as nitrogen), because high concentrations have been shown to cause methemoglobinemia ("blue-baby syndrome") in infants. This level was equaled or exceeded in water from 4 of the 46 Coastal Plain wells (HA De 73, HA De 190, HA De 195, and HA De 198). Median nitrogen concentrations were less than 1 mg/L in all aquifers except aquifer 3, water from which had a median nitrogen concentration of 1.8 mg/L.

Nitrogen in ground water usually indicates contamination from animal wastes, leakage of septic systems, infiltration of fertilizers, or decomposition of organic material. Figure 79 shows the distribution of nitrogen concentrations in ground water. Nitrogen concentrations were highest in water from wells in the heavily farmed Perryman area in aquifers 1, 2, and 3. Water from shallow wells would be the first to show the effects of nitrogen contamination; the presence of high concentrations in confined aquifers indicates that nitrate moves downward into the confined aquifers in the Perryman area, probably because of high flow gradients caused by pumping at the Perryman well field and leakage through confining units.

Total-iron concentrations ranged from 4 μg/L to 16,000 μg/L in water from Coastal Plain wells and from 30 to 88,000 μg/L in water from Piedmont wells. Iron concentrations exceeded the USEPA SMCL of 300 μg/L in 35 percent of the Coastal Plain samples. Elevated iron concentrations in ground water are undesirable because they could cause an irony taste and staining of plumbing fixtures. The source of iron in Coastal Plain ground water is probably the dissolution of iron-bearing minerals in the aquifer matrix, including pyrite, goethite, hematite, and amphiboles.

Manganese chemistry is similar to iron chemistry in Coastal Plain ground water. Total-manganese concentrations in water from Coastal Plain wells ranged from less than 10 μg/L in water from several wells to 4,800 μg/L in water from well HA Ed 49. The USEPA SMCL of 50 μg/L was exceeded in water from 52 percent of Coastal Plain wells (tab. 9). The SMCL was set because manganese has a propensity for leaving a black stain on plumbing fixtures; no health risks are known to be associated with excessive manganese. Sources of manganese include the dissolution of manganese-bearing minerals in the aquifer matrix and riverbed sediments. Nutter (1977, p. 31) related elevated manganese concentrations in ground water to brackish-water intrusion from the Gunpowder River near Joppatowne.

Trace-element analyses were performed on water from wells HA Dd 86, HA De 64, HA De 179, and HA Ec 13. The following elements were found in detectable quantities: aluminum, arsenic, barium, beryllium, chromium, cobalt, copper, mercury, nickel, selenium, strontium, and zinc. Their presence indicates dissolution of minerals bearing these metals. The trace metals could also indicate leaching from a contaminant source such as a waste-disposal site or contaminant spill, or from dissolution of well casings and screens. Mercury concentrations (0.2 μg/L) above the USEPA MCL of 0.1 μg/L were found in water from wells HA Dd 86 and HA Ec 13; however, these concentrations are probably the result of contamination during sample processing rather than from ground-water contamination. No other elements were detected in concentrations that exceeded a USEPA MCL.

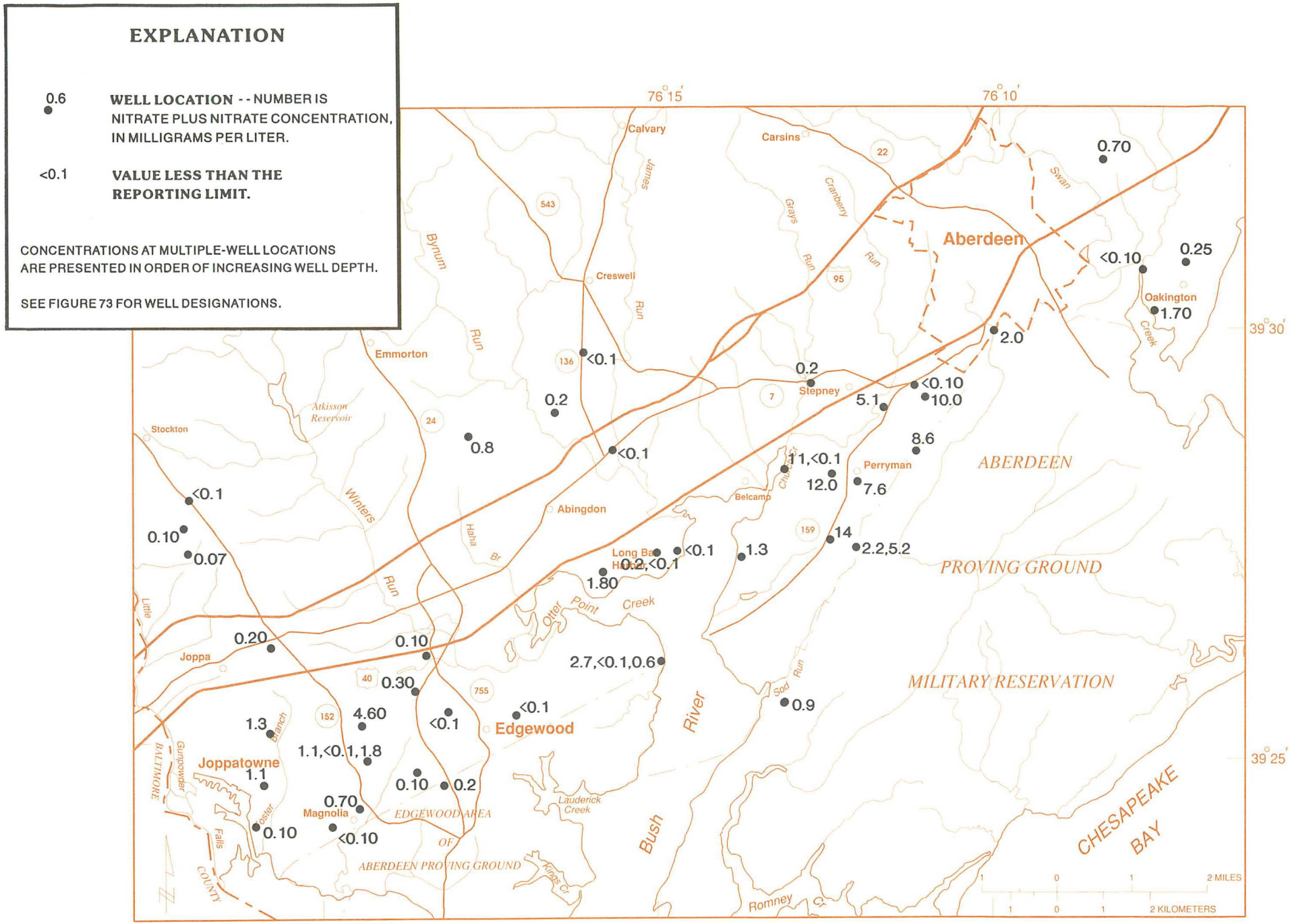
Results of a trace-element analysis of water from well HA Dd 86 (a shallow well screened in alluvial sediments about a mile from the Fall Line) was markedly different from results of other analyses. Strontium, copper, and zinc were present in water from well HA Dd 86 in much higher concentrations than in water from wells in the Coastal Plain. Aluminum, chromium, cobalt, and nickel were present in low concentrations in all Coastal Plain water samples, but were undetectable in water from well HA Dd 86. No large differences in trace-element concentrations were detected in water samples from the Coastal Plain wells.

Stable- and radioactive-isotope analyses were performed on samples from eight wells and one stream. Analyses of the stable isotopes of carbon, hydrogen, and oxygen are presented in table 14. $\delta^{13}C$ values ranged from −21.50 per mil at well HA De 181 to −13.30 per mil at well HA Dd 86. Deuterium ($\delta^{2}H$) values ranged from −43.0 per mil at well HA Dd 86 to −45.5 per mil at well HA Dd 71. $\delta^{18}O$ values ranged from −7.50 per mil at wells HA Dd 71 and HA De 64 to −7.10 per mil at well HA Dd 86. These values are within the expected range for isotopes in ground water at this geographic location. ^{14}C values from wells HA De 64 (101 percent modern) and HA Ec 13 (105 percent modern) indicate that at least a part of these waters entered the flow system after 1945 (when atmospheric nuclear-bomb testing began, which caused radioactive isotopes in precipitation recharge to exceed natural levels). The low tritium concentration of 1.28 picocuries per liter (pCi/L) in water from well HA Dd 106 in aquifer 4 indicates that this water entered the flow system as precipitation recharge before 1945.

Hydrochemical Facies and Water Types

The major ionic constituents in water of the Coastal Plain aquifers display a high degree of variability. Relative concentrations of these constituents can be used to characterize waters in terms of hydrochemical facies and water types (Back, 1966), which reflect recharge (precipitation) chemistry, the mineralogy of the aquifer system, and anthropogenic solutes in the ground water. Hydrochemical facies characterize water chemistry in terms of the anions and cations (for example, a sodium-bicarbonate hydrochemical facies). Water types characterize water chemistry in terms of predominant cations or anions (for example, a calcium magnesium water type or a chloride water type).

Hydrochemical facies can be depicted by use of trilinear plots, known as Piper diagrams. Piper (1944) developed this technique for ion analysis in which the relative ionic percentages are plotted on two triangular matrices, one for cations and one for anions (figs. 80–84). Cations include calcium, magnesium, sodium, and potassium. Anions include chloride, sulfate, bicarbonate, nitrate, and nitrite. In natural waters, positive and negative ions are present in equal ionic concentrations. Ionic concentrations, measured as a percentage of total cations or anions,



Base map from U.S. Geological Survey, 1:100,000

Figure 79.—Concentrations of nitrite plus nitrate in ground water.

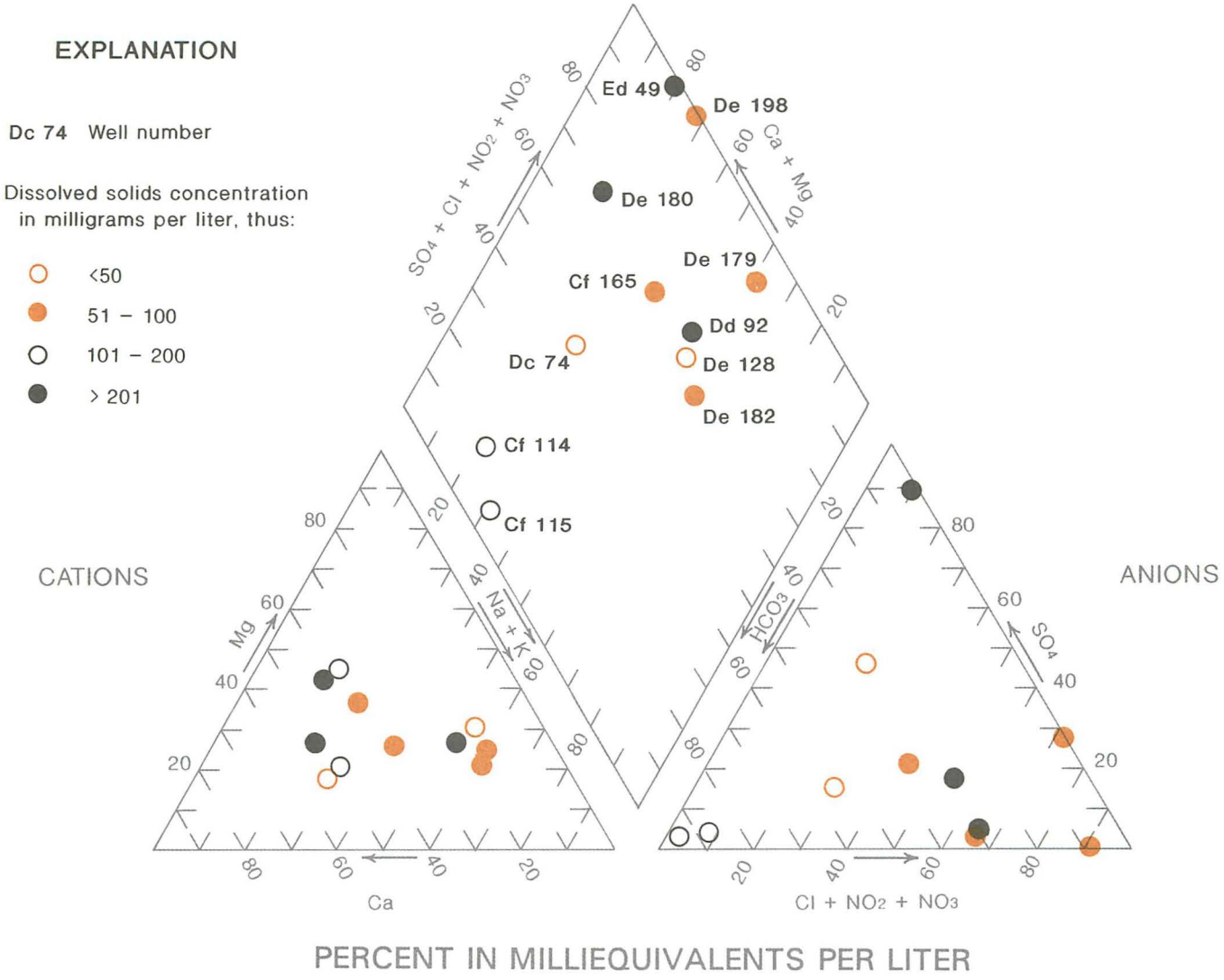


Figure 80.—Hydrochemical facies of water from wells in aquifer 1.

are plotted in the matrix, and the radius of the symbol represents the TDS of the water sample. Each corner of the triangles represents 100-percent composition for an individual ion or group of ions. The positions of the symbols in the cation field characterize the cation type, and the positions in the anion field characterize the anion type. The projection of the points onto the diamond-shaped plotting field represents the hydrochemical facies of the water sample. Piper diagrams in this report group sodium and potassium together as one component, and chloride and nitrate plus nitrite as one component.

Hydrochemical facies presented in this manner display chemical processes, such as chemical evolution (in which the progression of a chemical reaction plots as a pathline) and mixing of waters (in which a mixture of two waters plots between the source waters). A scattering of points indicates a variety of chemical processes that precludes the classification of waters into hydrochemical facies.

The hydrochemical facies for the Coastal Plain aquifers in Harford County (figs. 80–83) were similar to the facies described by Back (1966, p. A15) for the Cretaceous aquifers in southern Maryland. The cation types varied from predominantly sodium to a mix of 50-percent calcium and 50-percent magnesium. The anion type in Harford County was predominantly bicarbonate chloride nitrate with some sulfate, whereas the water in southern Maryland was predominantly the bicarbonate type and some sulfate type. The trend toward the chloride nitrate-type water in Harford County is probably due largely to the introduction of fertilizers and road salt to the ground-water environment.

The hydrochemical facies of ground water from aquifer 1 (fig. 80) was different from the facies in the deeper Coastal Plain aquifers. Water from wells HA Cf 114, HA Cf 115, and HA Dc 74 was a calcium bicarbonate facies, which was the dominant facies in Piedmont waters (fig. 84). This could result from

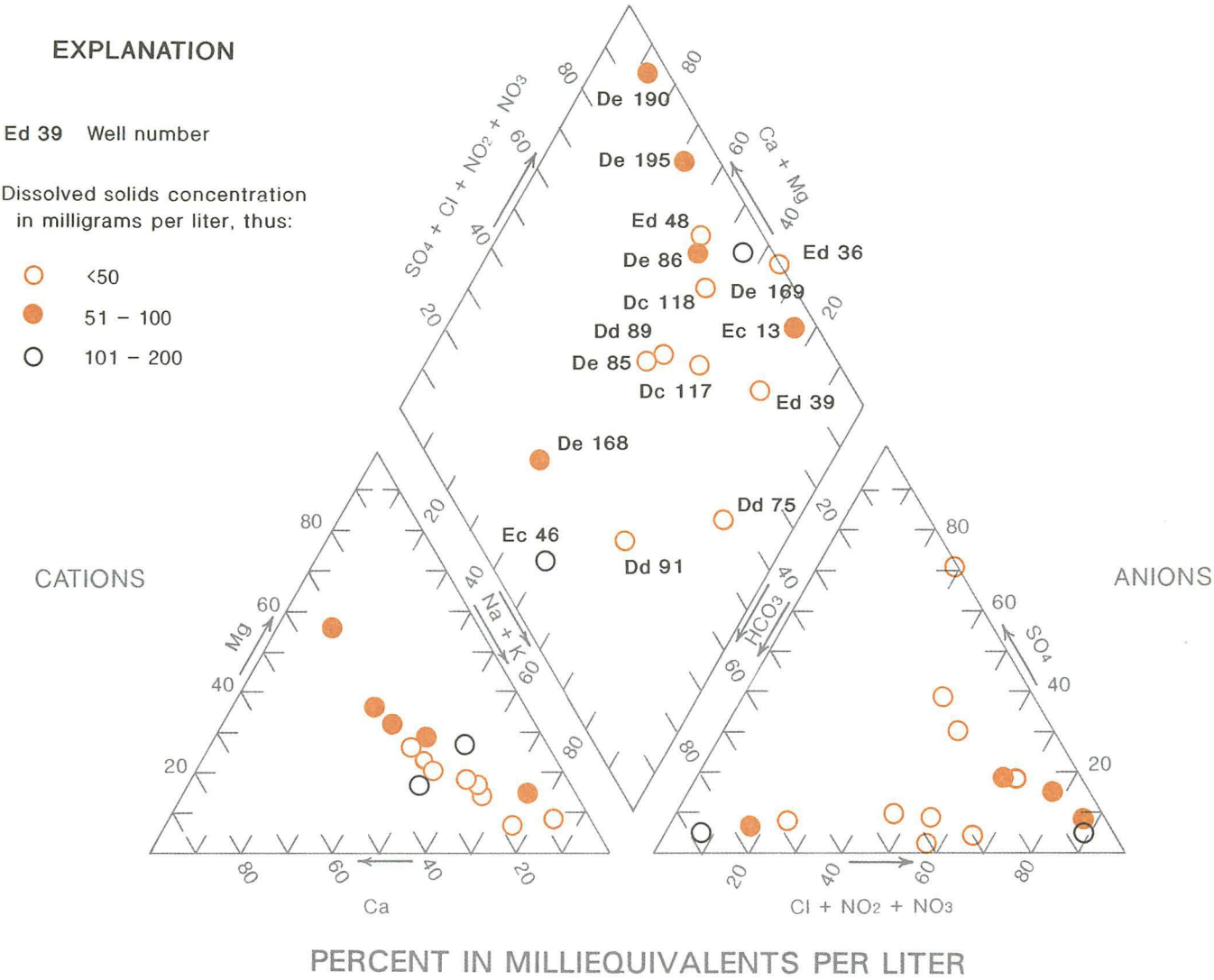


Figure 81.—Hydrochemical facies of water from wells in aquifer 2.

the mixing of waters from Piedmont aquifers and aquifer 1 or from the dissolution of alumnosilicate minerals in aquifer 1. The water from well HA Ed 49 was a sulfate type and probably indicates contamination. Waters from the Piedmont aquifers (fig. 84) were the calcium magnesium and bicarbonate facies that probably reflect weathering of alumnosilicate minerals in the Piedmont rocks. Water from well HA Ed 86 (in the Piedmont) was a chloride nitrate type that probably reflects road-salt contamination and septic-tank leakage.

STREAM WATER

Water samples were collected from streams in the Coastal Plain during base-flow conditions and analyzed to document stream-water quality during periods unaffected by recent precipitation or storm runoff. Stream base flow is derived solely from ground-water inflow, and stream-water chemistry should reflect the chemistry of the contributing ground-water system. Although all stream sites are located within the boundaries of the Coastal Plain, the Piedmont drainage area contributes water to several streams (Winters Run, Bynum Run, James Run, and Cranberry Run). Three streams, Winters Run, James Run, and Cranberry Run, were each sampled at two locations to document changes in stream chemistry between the sampling sites (fig. 73). Samples were collected in August 1987, April and August 1988, and June 1989, and analyzed to document seasonal variability in base-flow chemistry. Results of field and laboratory analyses are presented in tables 13, 14, and 15, and locations of the sampling sites are shown in figure 73. Because of the limited scope of the stream-chemistry investigation, some constituents that could affect stream-water quality, such as suspended sediments, organic compounds, and biological organisms, are not considered in this discussion. The water quality of the five Coastal Plain streams was generally similar to the ground-water

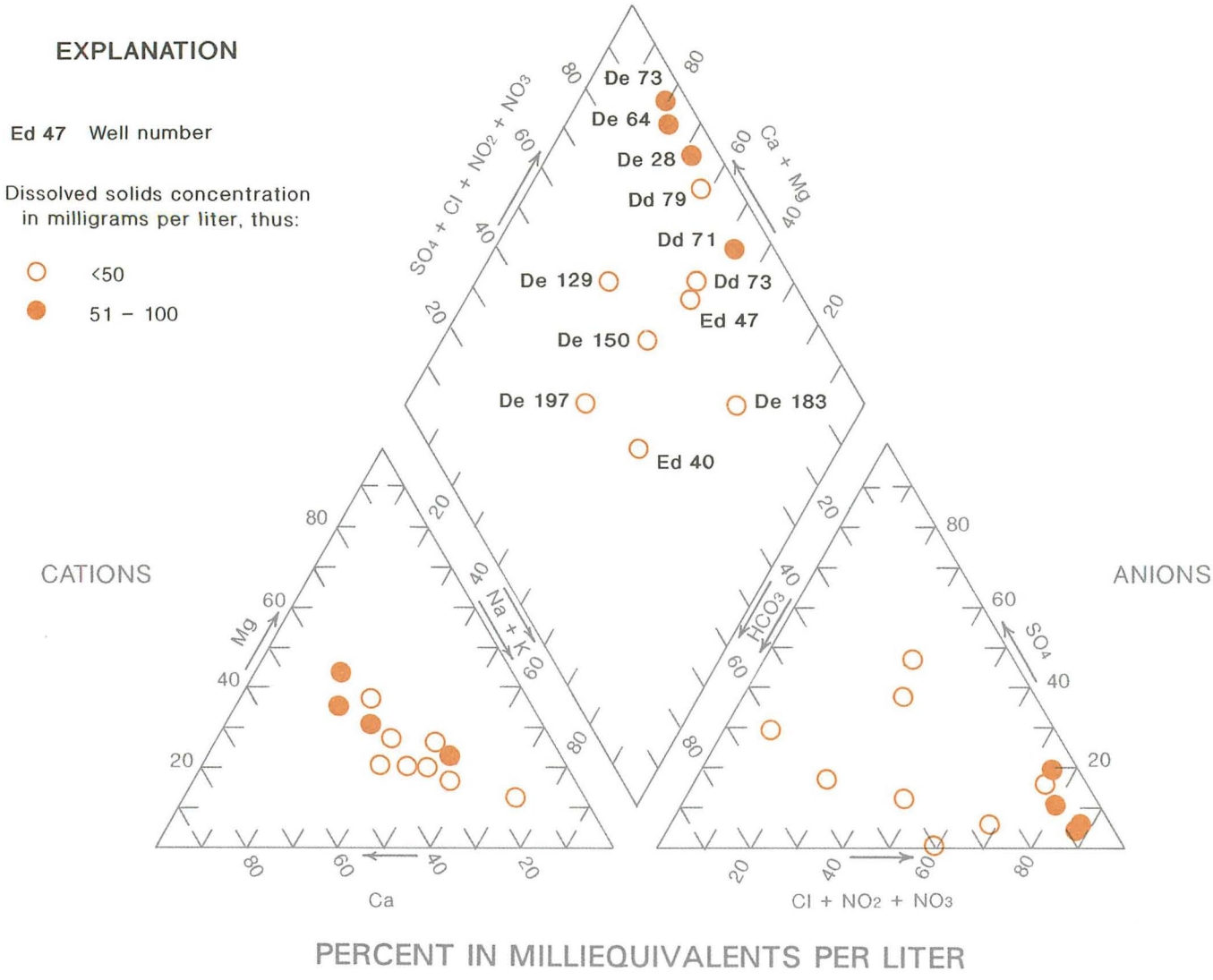


Figure 82.—Hydrochemical facies of water from wells in aquifer 3.

quality in the contributing drainage areas. All stream-water samples contained moderate levels of TDS, which ranged from 64 mg/L at Haha Branch to 133 mg/L at James Run at Bush. These concentrations correspond with concentrations in ground water in aquifer 1 and the Piedmont aquifers. Surface water in James Run showed seasonal variations in TDS, whereas samples in the late summer contained higher concentrations (126 and 133 mg/L) than in the spring (108 mg/L). Surface water from other sites showed little or no seasonal change in dissolved-solids concentrations.

The pH of stream water ranged from 6.4 at Cranberry Run at Aberdeen to 9.2 at Winters Run. The pH values on Winters Run were anomalously high and could have been caused by anthropogenic activity or algal respiration at Atkisson Reservoir, which is located a few miles upstream from the sampling sites (fig. 73). The pH of most Coastal Plain streams was slightly higher than the pH of contributing ground water, probably because of degassing of carbon dioxide from ground water as it equilibrated with the atmospheric conditions in the stream environment. Biological activity could also raise stream-water pH during periods of photosynthesis.

Hardness of stream water ranged from 19 mg/L at Haha Branch (soft) to 80 mg/L at James Run (moderately hard). All water samples from the two sites on James Run were moderately hard; all other samples were classified as soft.

Nitrogen (nitrite plus nitrate) concentrations in stream water ranged from 0.1 mg/L in Haha Branch to 5.3 mg/L in Cranberry Run (tab. 13). The high concentrations in Cranberry Run reflect high nitrogen concentrations in ground water in the Perryman area. Nitrogen is an essential nutrient for plant growth and enters the stream from treatment plant discharges, waste water from septic tanks, fertilizer runoff, and ground-water transport. High nitrogen concentrations in the stream environment could lead to eutrophication followed by oxygen depletion

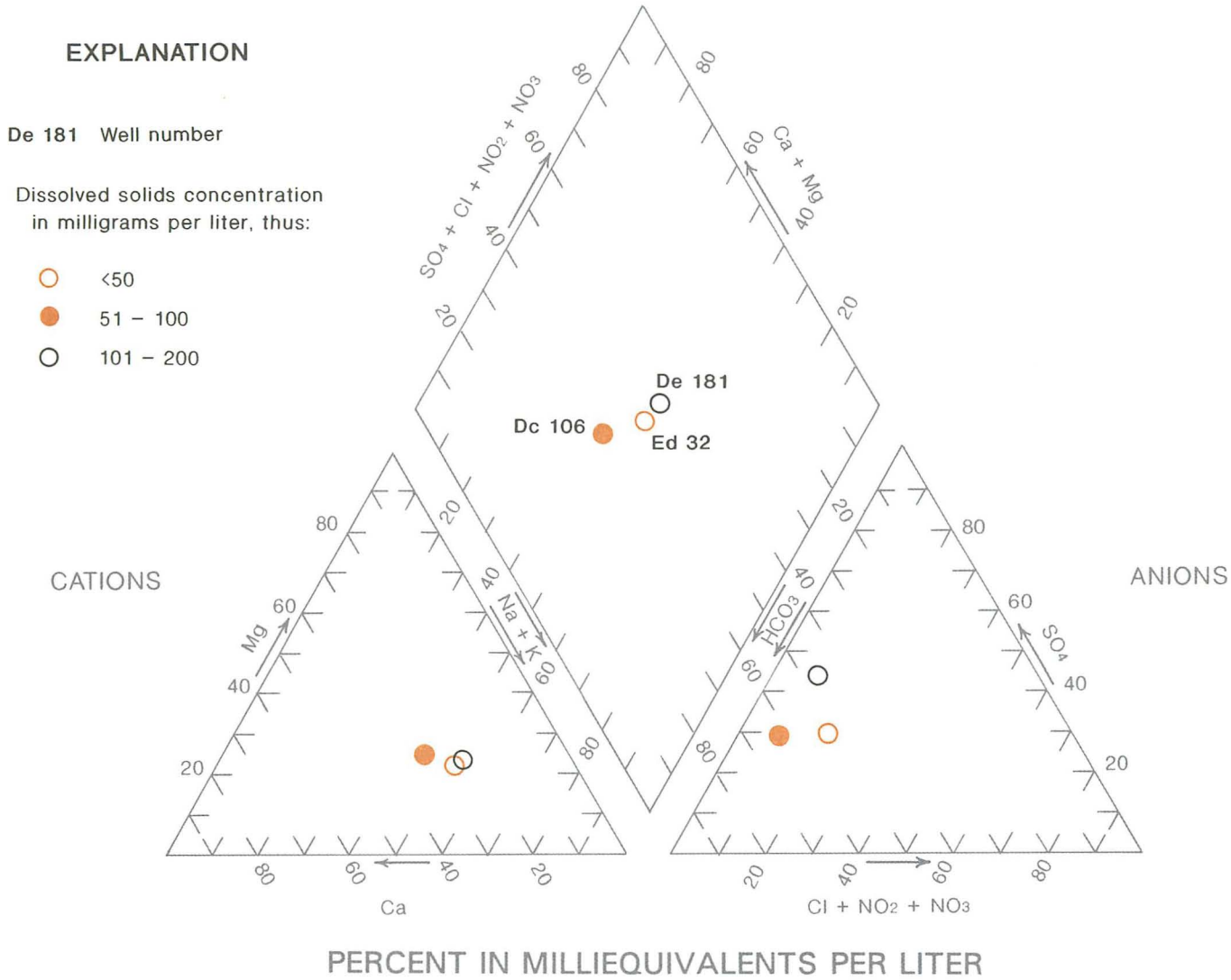


Figure 83.—Hydrochemical facies of water from wells in aquifer 4.

with bacterial decay of plant matter. Dissolved-oxygen concentrations in all samples were greater than the State water-quality minimum concentration of 5.0 mg/L for these streams, however. This indicates that eutrophication is not a serious problem in Coastal Plain streams.

The chemical facies of water in the five sampled streams reflect the chemical facies of ground water in the contributing drainage areas (fig. 85). Sites 1657 and 1658, on Cranberry Run, show the effect of elevated sodium, chloride, and nitrogen concentrations in ground water in the Perryman area on stream quality. Haha Branch (site 1671) and Fosters Branch (site 5072), both of which drain the Coastal Plain, show chemical facies that are similar to that of water from well HA Dd 118 (fig. 81), which is screened in aquifer 2 and is located approximately 2 mi upstream from the stream-sampling sites. Water samples from James Run (sites 1650 and 1651) and Winters Run (sites 1754 and 1755) are a calcium magnesium bicarbonate facies, similar to the water facies in Piedmont wells (fig. 84). Because the drainage upstream from the sampling locations is predominantly underlain by Piedmont rock, the stream-water quality shows no effect of inflow of ground water from the Coastal Plain.

GROUND-WATER-STREAM INTERACTIONS

As discussed previously, the chemical quality of the five streams sampled appears closely related to the ground-water quality of the contributing drainage areas. The actual composition of ground water entering a stream is difficult to determine directly, however, and can vary with local flow systems. If in-stream processes (such as chemical reactions and biological activity) affecting water chemistry are assumed to be negligible, the theoretical average composition of ground water entering a stream can be estimated by calculating the mass balance of upstream and downstream samples.

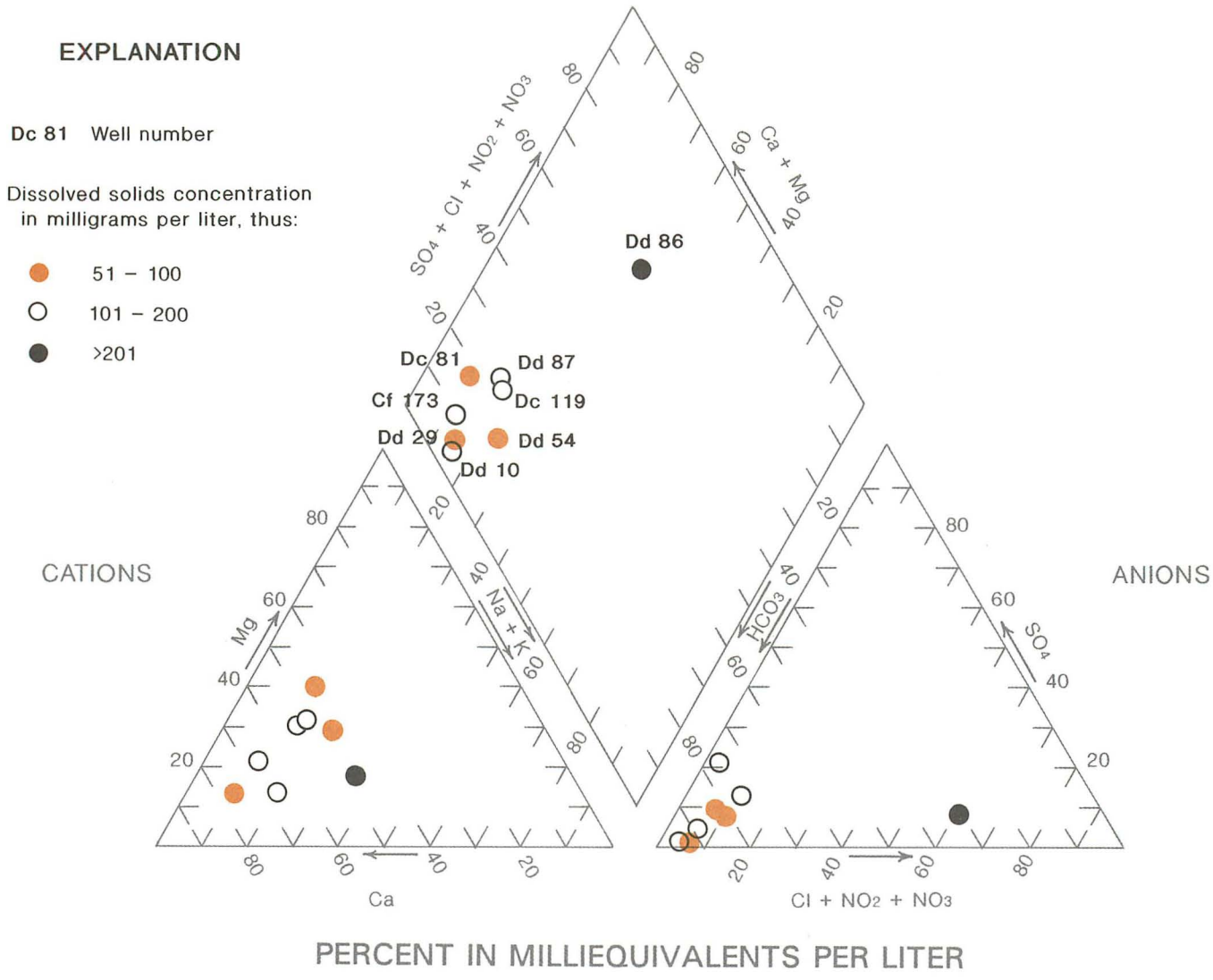


Figure 84.—Hydrochemical facies of water from wells in Piedmont aquifers.

The mass-balance equation for stream discharge is:

$$q_1 + q_2 = q_3, \qquad (6)$$

where q_1 and q_3 are the upstream and downstream discharges, and q_2 is the rate of ground-water inflow. The mass-balance equation can be modified to account for constituent loads by multiplying the discharges by the constituent concentrations, as follows:

$$c_1q_1 + c_2q_2 = c_3q_3, \qquad (7)$$

where c_1, c_2, and c_3 are the concentrations of the discharges. The two equations can be rewritten to determine the concentration of ground-water inflow, c_2, in the following manner:

$$c_2 = (c_3q_3 - c_1q_1) / (q_3 - q_1). \qquad (8)$$

Equation 8 was used to compute ground-water inflow concentrations for both Cranberry Run and Winters Run (tab. 10). Because the accuracy of the discharge measurements are subject to many variables, not all downstream sample pairings were used for mass-balance computation. For example, the discharge measurements at James Run indicated little or no change in discharge, and in August 1987, the measured discharge declined along the stream reach. Ground-water inflow concentrations were calculated for three water analyses from Cranberry Run and one analysis from Winters Run for those samples that showed sufficient increases in discharge along the stream reach and changes in stream-quality characteristics. These values represent average concentrations of chemical constituents in water entering the stream from the ground-water system. Although the discharge increased significantly along Winters Run in August 1987, the chemical concentrations changed only slightly and the calculated ground-water inflow was nearly identical to the stream water.

Table 10.—Estimated chemical composition of ground-water inflow to Coastal Plain streams

[mg/L = milligrams per liter; µg/L = micrograms per liter]

Date of sample collection	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Bicarbonate (mg/L as HCO_3)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Silica, dissolved (mg/L as SiO_2)	Solids, sum of constituents, dissolved (mg/L)	Nitrogen NO_2 + NO_3 total (mg/L as N)	Iron, dissolved (µg/L as Fe)	Manganese, dissolved (µg/L as Mn)
					Cranberry Run Basin							
08-26-87	8.6	5.1	9.6	3.0	19	9.3	12	7.9	66	4.87	23	20
04-25-88	9.4	5.3	13.0	2.2	10	9.9	28	6.7	79	4.74	49	22
08-17-88	9.1	6.1	11.3	2.5	16	8.8	22	7.4	76	5.57	24	3
					Winters Run Basin							
08-27-88	11.7	6.2	7.2	2.7	44	10.3	14	8.3	82	1.3	2	49

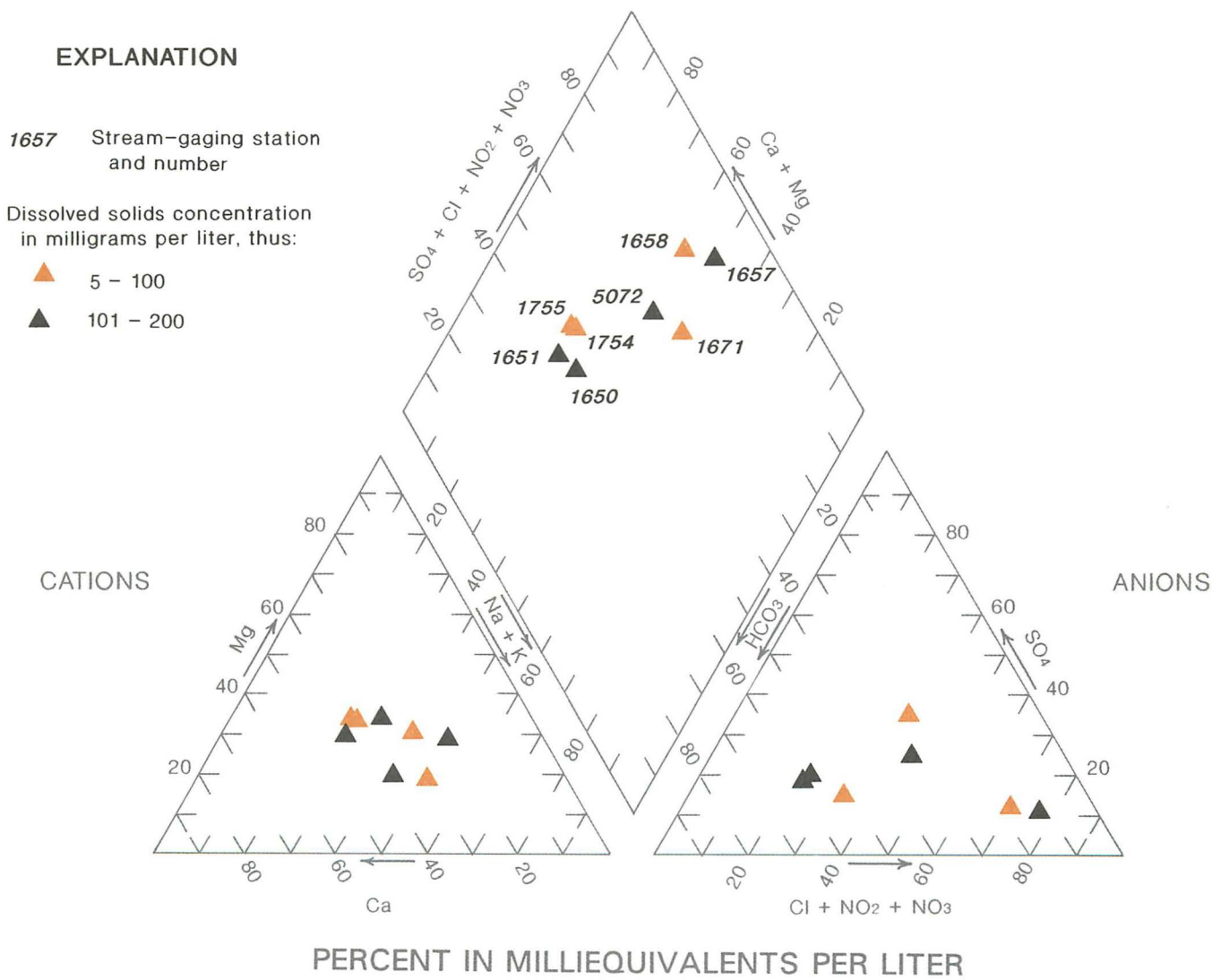


Figure 85.—Hydrochemical facies of stream water, August 1987.

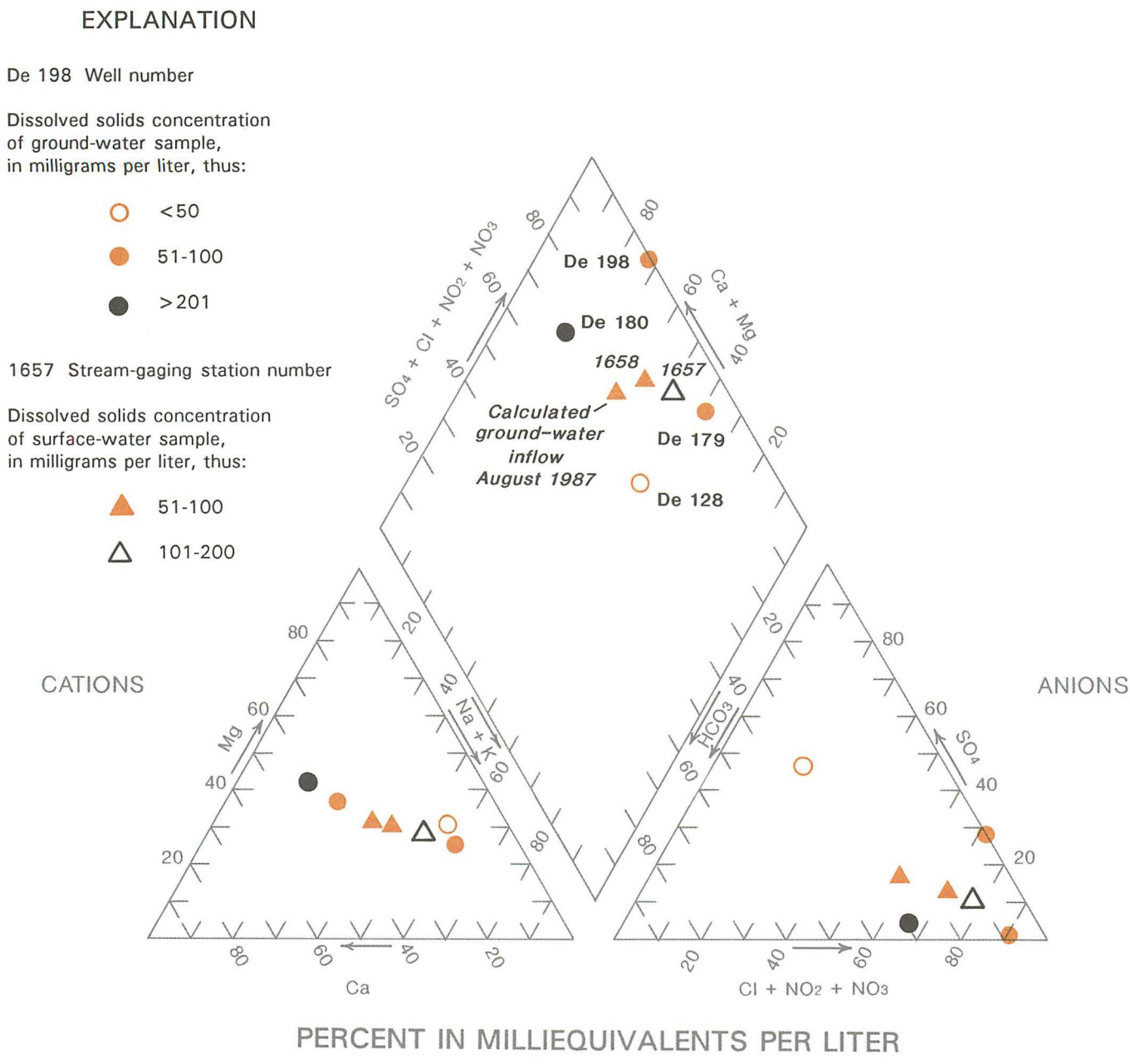


Figure 86.—Hydrochemical facies of calculated ground-water composition at Cranberry Run, with selected stream-water and ground-water analyses.

Chemical analyses from the Cranberry Run sites indicated increases in potassium, bicarbonate, and nitrate from upstream to the downstream site, and decreases in chloride, sodium, magnesium, and silica from the upstream to downstream sites. Higher chloride concentrations in the stream at the upstream site reflected the inflow of ground water that contained elevated chlorides in the upstream drainage area. This area includes the town of Aberdeen and extends northward to Interstate 95, where chloride concentrations in ground water are likely to be elevated as a result of applications of road salt. Higher nitrate concentrations in the stream at the downstream site resulted from inflow of ground water containing elevated nitrate concentrations caused by fertilizer application in the farmed lower part of the basin.

Chemical facies of calculated ground-water inflow, stream water at upstream and downstream sites, and water from wells HA De 128, HA De 179, HA De 180, and HA De 198 are shown in figure 86. Although the facies of calculated ground water differs from actual ground-water analyses, calculated inflow water is an average of the facies of ground-water samples. Stream-water facies indicate a trend towards a dilute calcium magnesium nitrate-type water at the downstream site.

SUMMARY AND CONCLUSIONS

A study was conducted to investigate the hydrogeology of the Coastal Plain aquifers of Harford County, Maryland. The study refined the hydrogeologic framework, documented ground-water-chemical quality, and assessed the potential for the aquifer system to meet projected pumpage requirements.

The Coastal Plain aquifer system of Harford County comprises a wedge-shaped body of sediments that dips and thickens to the southeast and is underlain by hard crystalline bedrock. The sediments comprise three lithostratigraphic units—the Talbot Formation of Pleistocene age, the upland gravels of Late Tertiary age, and the Potomac Group of Early Cretaceous age. The Talbot Formation consists of a shallow silty clay facies up to 20 ft thick and a deeper gravelly sand facies up to 35 ft thick that is interbedded with dark clay layers that are up to 24 ft thick.

The upland gravels form isolated patches of intercalated sand and gravel, and thin lenses of silty clay, which cap some of the higher hills near the Fall Line. The upland gravels are up to 40 ft thick and overlie Potomac Group sediments in some places and Piedmont rocks in other places.

The Potomac Group consists of sand and gravel units intercalated with multicolored clay lenses and ranges in thickness from 0 ft to 300 ft in the study area; it is as much as 627 ft thick at Spesutie Island. The Potomac Group has been subdivided into the Patuxent, Arundel, and Patapsco Formations in the Baltimore area to the southwest, but the distinction between the units is less certain in the Harford County Coastal Plain.

The types of bedrock underlying the Coastal Plain sediments are poorly documented but probably consist predominantly of the Piedmont units observed in outcrops northwest of the Fall Line. These units include schists, gneisses, amphibolites, and metagabbros of Early Paleozoic age, and the Baltimore Gneiss of Precambrian age.

For the purposes of the study reported here, the Coastal Plain sequence was divided into four aquifers and three intervening confining units. The aquifer boundaries do not generally coincide with the lithostratigraphic boundaries. The aquifers were designated aquifers 1, 2, 3, and 4, and the confining units were designated as confining units 1, 2, and 3. This aquifer division is somewhat arbitrary and, in places, poorly defined.

Aquifer 1 is the shallow unconfined aquifer and includes much of the Talbot Formation, the upland gravels, and shallow parts of the Potomac Group. It extends throughout the entire study area. Hydraulic conductivities range from 2.0 to 630 ft/d, and storativities are probably about 0.1. The water-table altitude reflects a subdued reflection of the topography of the area; altitudes range from 200 ft above sea level in the northwest to sea level near the estuaries. Hydrographs of water levels in wells that tap aquifer 1 indicate a variety of responses to water-table conditions, including rapid responses to recharge events, tidal fluctuations, and interaction with nearby streams. Confining unit 1 is between aquifers 1 and 2, and was arbitrarily assigned a thickness of 1 ft. Hydraulic conductivities of confining unit 1 range from 5×10^{-4} to 5×10^{-1} ft/d.

Aquifer 2 is the confined and semiconfined aquifer that underlies aquifer 1, and includes some of the deeper sands and gravels of the Talbot Formation and part of the Potomac Group. It extends throughout most of the study area except in some areas near the Fall Line. The top of the aquifer ranges in altitude from about 25 ft above sea level to about 75 ft below sea level, and the bottom ranges from about 10 ft above sea level to about 160 ft below sea level in the study area. The aquifer consists predominantly of sand and gravel but contains some layers and lenses of clay and silt. Estimated horizontal hydraulic conductivities range from about 20 to 1,600 ft/d, and transmissivities range from 1,000 to 40,000 ft^2/d. Water levels in aquifer 2 range from about 42 ft above sea level in the upland parts of the aquifer's extent to about 5 ft above sea level near the estuaries. Hydrographs of water levels in wells screened in aquifer 2 show fluctuations that are indicative of confined and semiconfined conditions. Confining unit 2 is between aquifers 2 and 3, and its vertical hydraulic conductivity ranges from 4×10^{-5} to 2×10^{-3} ft/d.

Aquifer 3 is the confined aquifer that underlies aquifer 2 and consists entirely of Potomac Group sediments. It extends to the Fall Line in places but is truncated southeast of the Fall Line in other places. The southeastern extent of aquifer 3 is uncertain because of the paucity of well logs in that area. The top of the aquifer ranges from about 30 ft above sea level to about 200 ft below sea level, and the bottom ranges from about 10 ft above sea level to about 225 ft below sea level in the study area. The aquifer consists predominantly of sand and gravel but contains some layers and lenses of clay and silt. Estimated horizontal hydraulic conductivities range from about 8.9 to 870 ft/d, and transmissivities range from 300 to 35,000 ft^2/d. Water levels in aquifer 3 range from about 30 ft above sea level in the upland parts of the aquifer's extent to about sea level near the Bush River. Hydrographs of water levels in wells screened in aquifer 3 show fluctuations indicative of confined conditions. Confining unit 3 is between aquifers 3 and 4, and its vertical hydraulic conductivity ranges from 6.3×10^{-8} to 6.3×10^{-7}.

Aquifer 4 is the confined aquifer that underlies aquifer 3 and consists entirely of Potomac Group sediments. It forms an elongate lens of sand that is approximately parallel to regional strike. It is bounded updip and downdip by clayey units. Its boundaries along strike are uncertain because of the lack of deep-well logs in those areas. The top of the aquifer ranges in altitude from about 70 ft to 400 ft below sea level, and the bottom ranges from about 70 ft to 500 ft below sea level in the study area. It includes predominantly silty sand, but contains some coarse sand and lenses of clay and silt. Estimated horizontal hydraulic conductivities range from about 0.2 to 20 ft/d, and transmissivities range from 5 to 150 ft^2/d. Water levels in aquifer 4 range from

about 5 to 10 ft above sea level. A hydrograph from a well screened in aquifer 4 shows fluctuations indicative of confined conditions.

Base-flow measurements were made at several points along each of the seven major streams that drain the study area to estimate the amount of ground water that discharges into the surface-water system. Measurements were made during the spring and late summer for 2 years to determine seasonal ranges in base flow. Two continuously recording stream gages were constructed on Cranberry Run to relate stream-stage fluctuations with ground-water-level fluctuations in a nearby well. Discharge measurements ranged from 0 to 79.4 ft^3/s, and flux calculations ranged from -4.7×10^{-3} to 11.7×10^{-3} ft/d, with a weighted average of 1.4×10^{-3} ft/d.

Almost all recharge to the regional ground-water system comes from precipitation, although a small amount could also derive from losing reaches of streams and from brackish-water intrusion from the estuaries. The water then flows through the aquifer system; flow is controlled by aquifer properties, confining-unit properties and head gradients. The components of the regional-flow system include recharge (18 to 23 in/yr), ground-water evapotranspiration (10.6 in/yr), base flow (6.2 in/yr), estuarine discharge (3.2 in/yr), and pumpage (2.9 in/yr).

A quasi-three-dimensional, finite-difference areal ground-water flow model was developed to simulate the response of water levels to projected pumping in the Coastal Plain aquifers. The modeled area includes the entire Coastal Plain of Harford County and parts of the Piedmont terrain. The model was calibrated primarily to 1989 conditions because data to describe hydrologic conditions at this time were considered complete and reliable. The effect of projected pumping on water levels was evaluated by model simulation; simulations were conducted for various scenarios through the year 2000 for average recharge conditions. Additional simulations were made with recharge reduced by 35 percent for 1 year (year 2001) and 3 years (for years 2001 and 2003) to evaluate the effect on water levels of a drought similar to the drought in the mid-1960's.

A simulation in which 1989 pumpage was continued until the year 2000 showed no significant additional drawdown from 1989 potentiometric surfaces. A simulation in which 1989 pumpage was increased by 20 percent showed additional drawdowns of 4 ft in aquifer 2 at the Aberdeen well field, and 4 ft in aquifer 3 at the Perryman well field. The greatest simulated drawdowns occurred in the safe-yield simulation, in which pumpage at the Perryman well field was increased until simulated pumping water levels were reduced to 80 percent of available drawdown. (Available drawdown is the difference between altitudes of the potentiometric surface and the top of the aquifer.) This simulation produced additional drawdowns of 18, 18, 49, and 0 ft in aquifers 1, 2, 3, and 4 for average recharge conditions, and 23, 39, 49, and 0 ft for drought conditions. Total safe-yield pumpage at the Perryman well field was 9.2 and 8.3 Mgal/d for average recharge and drought conditions, or 3.0 and 2.7 times the pumpage for 1989. Other simulations were made to simulate alternative pumping scenarios, such as the addition of a well field at Trimble Road, the addition of a well field at a power plant near Perryman, the addition of a well field at a bleach-bottling plant near Perryman, permitted pumpage under average and maximum ground-water appropriations, and additional wells at the Perryman well field. The drought simulations indicate that water levels in aquifers 1, 2, and 3 generally would be about 5 ft deeper for a 1-year drought than for average recharge conditions, and about 14, 11, and 8 ft deeper, respectively, for a 3-year drought. Water levels in aquifer 4 were only slightly deeper in the drought simulations than under average recharge conditions. Streamflow was not seriously affected by any of the projected pumpage simulations run with average recharge conditions. The greatest streamflow decrease, 3 percent, was observed in the safe-yield simulation. The 1-year and 3-year drought simulations indicated streamflow decreases of 22 percent and 35 percent as compared to 1989 streamflow.

Particle-tracking analysis and examination of head gradients and fluxes were used to evaluate the potential for brackish-water intrusion and contaminant migration to pumping centers as a result of projected pumpage. The analysis indicated that the most probable projected pumping scenarios are not likely to result in brackish-water intrusion but could result in contaminant migration.

Chemical analyses of water from 43 wells indicate that the water is suitable for most domestic and industrial supply needs. Ground water in Coastal Plain aquifers is relatively unmineralized because the aquifer material is predominantly quartz, which is a nonreactive mineral under most ground-water chemical conditions. Dissolved-solids concentrations range from 22 to 295 mg/L. Higher concentrations are found in water from the unconfined aquifer as a result of dissolution of an unstable mineral assemblage of the Talbot Formation and anthropogenic effects. Ground water in the Coastal Plain aquifers is mildly acidic and poorly buffered; the pH of 86 percent of ground-water samples was lower than the USEPA SMCL of 6.5. Alkalinity is low in water from all Coastal Plain aquifers; alkalinities are higher in water from aquifer 1 than in deeper aquifers.

Concentrations of chloride and nitrate in water from aquifer 1 indicate the effects of road salt and fertilizer application. Concentrations of chloride and nitrate in water from the confined aquifers near Aberdeen and Perryman indicate that, in places, the aquifers could be interconnected and that contamination in unconfined aquifers could be transported through breached confining units. Other regional water-quality problems include the presence of iron and manganese in concentrations that exceed the USEPA SMCL's.

The chemical quality of ground water is variable throughout the Coastal Plain. Aquifers 1, 2, and 3 contain a variety of water types that are affected in places by high concentrations of nitrate and chloride. Water from aquifer 4 is relatively stable chemically and is a calcium magnesium bicarbonate type. Analysis of carbon-14 in water from aquifer 2 in the Perryman area indicates that ground-water residence time is relatively short—less than 50 years. Analysis of tritium in water from aquifer 4 indicates

that ground-water residence time in the deeper confined system exceeds 43 years.

Water quality in four Coastal Plain streams is generally similar to that of ground water. Water from James Run and Winters Run shows chemical facies similar to facies seen in ground water in the Piedmont. Water from Fosters Branch, Haha Branch, and Cranberry Run is chemically similar to Coastal Plain ground water. Discharge measurements and water sampling was conducted at upstream and downstream sites of three streams to document changes in chemistry caused by ground-water inflow. The discharge and water chemistry of James Run and Winters Run indicated little change along the stream reaches. Increases in discharge and chemical changes in Cranberry Run permitted mass-balance calculation of the theoretical concentration of ground-water inflow. The calculated chemistry of ground-water inflow is an average of the chemistry of waters from the unconfined aquifer.

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SUPPLEMENTAL DATA

Compiled by Brenda L. Feit
U.S. Geological Survey

This section contains supplemental data collected during the course of the project. It includes tables 11 through 24, figure 87, and eight maps showing well locations.

Table 11.—Records of selected wells in Harford County

[ft = feet; ls = land surface; gal/min = gallons per minute; (gal/min)/ft = gallons per minute per foot; other abbreviations are found at the end of the table]

WELL NUMBER	STATE PERMIT NUMBER	OWNER	CONTRACTOR	DATE WELL CON-STRUCTED	ALTI-TUDE (ft)	DEPTH OF WELL (ft)	WELL DIAMETER (in.) CASING	WELL DIAMETER (in.) SCREEN	TOP OF SCREEN BELOW LS (ft)	TOTAL SCREEN LENGTH (ft)
HA Ce 117	HA-73-6869	WARFIELD, CHARLES	HAMILTON, C.	01-06-82	122	300	6	--	--	--
HA Ce 118	HA-73-1163	RAMMING, GEORGE	FRANK'S DRLG	--	80	--	--	--	--	--
HA Cf 2	--	J.M. HUBER CORP	ARTESIAN WELL CO	10- -43	45	58	10	10	28	30
HA Cf 30	HA-01-0405	TOWN OF ABERDEEN	SHANNAHAN CO	06-26-52	72	69	16	--	47	22
HA Cf 32	HA-01-5239	TOWN OF ABERDEEN	SHANNAHAN CO	06-18-54	65	65	10	10	45	20
HA Cf 65	HA-69-0201	HAWKINS, JOHN	A C REIDER	10-29-68	420	75	6	--	--	--
HA Cf 114	HA-73-1181	WARFIELD, WILBUR	NELSON DRLG	10-10-73	28	90	6	--	--	--
HA Cf 115	HA-73-1182	SPEIGHTS, NATHAN	VERNON KIRK	10-31-73	15	115	6	6	110	5
HA Cf 116	HA-72-0827	STYDOL, ROBERT	PRESTON & HAMILTON	06-23-72	20	120	4	--	115	5
HA Cf 124	HA-73-0618	SCATTERGOOD, JOSEPH	VERNON KIRK	08-17-73	40	75	6	6	70	5
HA Cf 125	HA-67-0419	POTTER, J. WALTER	PRESTON & HAMILTON	03-31-68	20	77	6	--	72	5
HA Cf 126	HA-67-0110	RADMOND, ROBERT	PRESTON & HAMILTON	08-25-66	20	62	6	--	57	5
HA Cf 127	HA-73-0473	REDMOND, OTIS	VERNON KIRK	01-18-73	20	75	6	6	70	5
HA Cf 165	HA-05-2729	SWAN CREEK COUNTRY CLUB	PRESTON & HAMILTON	07-15-63	40	63	6	4	58	5
HA Cf 169	HA-73-5987	CONJOUR, LEON	FRANK'S DRLG	03-27-80	43	62	4	2	52	10
HA Cf 170	HA-81-0090	ASHLEY INC	SCHULTES	04-20-82	45	139	6	8	129	10
HA Cf 171	HA-81-0091	ASHLEY INC	SCHULTES	04-22-82	42	142	6	8	132	10
HA Cf 172	HA-81-2559	BELINKA, ROGER	DIFILIPPO	02-15-86	41	65	6	6	59	6
HA Cf 173	HA-81-2575	WARNER, DENNIS	HAMILTON, C.	03-19-86	125	270	--	--	--	--
HA Cf 174	HA-81-1139	TOWN OF ABERDEEN	SHANNAHAN CO	02-08-84	71.82	71	2	2	60	11
HA Dc 1	--	FORNEY, ARTHUR	HARR SONS	08- -44	145	290	6	--	--	--
HA Dc 46	HA-67-0137	NAUMAN, KEN	H S RAWLE	09-26-66	230	40	36	--	--	--
HA Dc 47	HA-67-0268	WEBER, BENJAMIN	H S RAWLE	11-07-66	220	40	36	--	--	--
HA Dc 74	--	KRAMER, WILLIAM	H S RAWLE	- -67	240	30	36	--	--	--
HA Dc 81	HA-67-0718	CEGIELSKI, MILTON	H S RAWLE	07-18-67	230	35	36	--	--	--
HA Dc 101	HA-73-5746	CORVIN, JAMES	LEONARD DRLG	09-27-79	120	200	6	--	--	--
HA Dc 102	HA-81-1351	WIDMANN, JOHN	HAMILTON, C.	08-23-84	160	300	6	--	--	--
HA Dc 103	HA-81-1537	RICHICK, ROBERT	JONES DRLG	09-14-84	181	175	6	--	--	--
HA Dc 104	HA-73-5933	BROCKMEYER, CHARLES	DIFILIPPO	01-27-80	175	163	6	--	--	--
HA Dc 105	HA-73-4084	MARANTO, DANA	HARR SONS	08-03-77	107	200	6	--	--	--
HA Dc 106	HA-81-1541	DAIL, DANIEL	FRANK'S DRLG	10-04-84	62	55	4	4	47	8
HA Dc 107	HA-73-4789	WALDRON, BEN	FRANK'S DRLG	04-25-78	98	105	4	2	100	5
HA Dc 108	HA-81-2373	HOLLENBECK, GEORGE	FRANK'S DRLG	01-13-86	62	200	6	--	--	--
HA Dc 109	HA-81-2387	LEIZEAR, STANLEY	CASWELL DRLG	11-20-85	387	300	6	--	--	--
HA Dc 110	HA-81-0613	MURROW, WILLIAM	HARR SONS	04-25-83	117	175	6	--	--	--
HA Dc 111	HA-73-6465	HOVANEC, JOSEPH	JONES DRLG	03-16-81	168	200	6	--	--	--
HA Dc 112	HA-73-6296	KEMMERZELL, JACK	JONES DRLG	10-23-80	93	150	6	--	--	--
HA Dc 113	HA-73-0454	BURTON & ELLER	A C REIDER	01-13-73	145	200	6	--	--	--
HA Dc 114	HA-73-1774	BAROCH, JAMES	NELSON DRLG	09-02-74	131	375	6	--	--	--
HA Dc 115	HA-73-5714	MCKENNY, MICHAEL	LEONARD DRLG	09-23-79	98	325	6	--	--	--
HA Dc 116	HA-70-0526	NAGY, DAVID	HAMILTON, C.	07-11-70	133	253	6	--	--	--
HA Dc 117	HA-81-2034	SCRIVENER, GWYNN	FRANK'S DRLG	05-10-85	168.95	85	4	2	75	10
HA Dc 118	HA-81-1981	VACEK JR, LOUIS	FRANK'S DRLG	05-08-85	84	90	4	2	80	10
HA Dc 119	HA-73-6349	SULLIVAN, WAYNE	A C REIDER	03-26-81	390	350	6	--	--	--
HA Dd 4	--	ALTWATER & SCHOENHALS	BALT ARTESIAN WELL CO	04- -05	90	126.5	3	--	--	--
HA Dd 5	--	BAUER, F.	BALT ARTESIAN WELL CO	05- -05	90	116	6	--	--	--
HA Dd 10	HA-00-6183	HUDSON GARAGE	H & H DRLG	07-07-50	25	166	6	--	--	--
HA Dd 15	HA-01-1760	MARTIN, RICHARD	H & H DRLG	12-01-53	20	62	6	--	--	--
HA Dd 29	HA-00-5244	COOK, JOHN	H & H DRLG	02-02-50	140	47	6	--	--	--
HA Dd 46	HA-68-0359	HA CO DPW	SHANNAHAN CO	01-18-68	20	126	8	8	105	17
HA Dd 47	HA-67-0540	HA CO DPW	SHANNAHAN CO	05-02-67	15	--	--	--	--	--
HA Dd 48	HA-67-0604	HA CO DPW	SHANNAHAN CO	07-18-67	10	--	--	--	--	--
HA Dd 49	HA-66-0268	HA CO DPW	SHANNAHAN CO	10-13-65	19	109	8	8	98	11
HA Dd 50	HA-66-0267	HA CO DPW	SHANNAHAN CO	11-02-65	20	111	8	8	100	11
HA Dd 54	HA-66-0866	VAUGHT, JAMES	C.D. POAGE	06-27-66	115	72	6	--	--	--
HA Dd 55	HA-67-0624	WINSKOWSKI, M.	C.D. POAGE	07-15-67	20	233	6	--	--	--
HA Dd 70	HA-73-4515	CAMPBELL, ROBERT	LEONARD DRLG	12-29-77	24	53	4	2	48	5
HA Dd 71	HA-81-1166	WILLETT, RAYMOND	FRANK'S DRLG	05-02-84	67	107	4	2	97	10
HA Dd 73	HA-81-2452	BROWN, DONALD	FRANK'S DRLG	05- -86	49	125	4	2	117	8
HA Dd 74	HA-73-4100	SEDBERRY, MARION	LEONARD DRLG	08-22-77	160	200	6	--	--	--

PUMPING TEST DATA

WATER-BEARING FOR-MATION[1]	WATER LEVEL BELOW LS (ft)	DATE MEASURED	WATER LEVELS BELOW LAND SURFACE (ft) STATIC	PUMPING	DATE REPORTED	YIELD (gal/min)	HOURS PUMPED	SPECIFIC CAPACITY (gal/min)/ft	USE OF WATER[2]	REMARKS[3]	LOCAL WELL NUMBER
300MBAB	35.10	12-05-86	30	300	01-06-82	3	3	0.01	H	Cased to 105 ft.	HA Ce 117
--	189.5	12-31-86	--	--	--	--	--	--	H		HA Ce 118
112TLBT	28.25	11-01-43	28.25	29.7	11-01-43	100	1	68.96	U		HA Cf 2
112TLBT	--	--	17	23.5	06-26-52	150	8	23.08	P	Drilled to 116 ft.	HA Cf 30
112TLBT	--	--	20.5	32	06-18-54	250	8	21.74	P	Drilled to 85 ft.	HA Cf 32
300MBAB	--	--	8	73	10-29-68	60	1	0.92	H		HA Cf 65
112TLBT	33.93	08-26-86	22	75	10-10-73	10	3	0.19	H	QW	HA Cf 114
112TLBT	--	--	25	70	10-31-73	15	5	0.33	H		HA Cf 115
112TLBT	--	--	--	--	--	15	2	--	H		HA Cf 116
112TLBT	--	--	25	45	08-17-73	20	6	1.0	H		HA Cf 124
112TLBT	--	--	30	--	03-31-68	40	--	--	H		HA Cf 125
112TLBT	--	--	40	--	08-25-66	20	--	--	H		HA Cf 126
112TLBT	--	--	28	55	01-18-73	10	2	0.37	H		HA Cf 127
112TLBT	--	--	42	--	07-15-63	30	--	--	R	QW	HA Cf 165
112TLBT	37.60	08-29-86	38	48	03-27-80	10	1	1.00	H		HA Cf 169
217PTMC	44.81	12-05-86	45	70	04-20-82	40	--	1.60	T	Drilled to 144 ft.	HA Cf 170
217PTMC	45.11	07-28-86	44	70	04-22-82	35	--	1.35	T	Drilled to 144 ft.	HA Cf 171
112TLBT	35.45	04-22-87	46	--	02-15-86	7	6	--	H		HA Cf 172
300MBAB	2.87	11-13-86	5	270	03-19-86	15	3	0.06	H	QW	HA Cf 173
112TLBT	--	--	41	45	02-08-84	12	1	3.00	U	Drilled to 85 ft.	HA Cf 174
300LPLC	--	--	60	240	08- -44	4	1	0.02	H	Cased to 160 ft.	HA Dc 1
217PTMC	22	09- -85	18	--	09-26-66	--	--	--	U		HA Dc 46
217PTMC	--	--	18	--	11-07-66	--	--	--	H		HA Dc 47
217PTMC	--	--	--	--	--	--	--	--	H	QW	HA Dc 74
300PRDP	--	--	--	--	--	--	--	--	H	QW	HA Dc 81
300LPLC	--	--	18	118	09-27-79	3	6	0.03	H	Cased to 26 ft.	HA Dc 101
300PRDP	32.85	11-18-86	20	300	08-23-84	10	1	0.04	H	Cased to 69 ft.	HA Dc 102
300PRDP	24.79	11-18-86	39	170	09-14-84	10	2	0.08	H	Cased to 85 ft.	HA Dc 103
300PRDP	33.52	11-19-86	40	80	01-27-80	20	6	0.50	H	Cased to 101 ft.	HA Dc 104
300LPLC	44.90	11-18-86	34	180	08-03-77	5	4	0.03	H	Cased to 64 ft.	HA Dc 105
217PTMC	17.68	11-17-86	14	21	10-04-84	30	3	4.28	H		HA Dc 106
217PTMC	60.60	11-17-86	65	75	04-25-78	15	2	1.50	H		HA Dc 107
300JMSR	27.09	04-22-87	28	200	01-13-86	0.75	2	0.00	H	Cased to 90 ft.	HA Dc 108
300PRDP	--	--	96	235	11-20-85	2.16	7	0.02	H	Cased to 153 ft.	HA Dc 109
300PRDP	5.20	12-12-86	2	167.5	04-25-83	2.4	6	0.01	U	Cased to 40 ft.	HA Dc 110
300PRDP	--	--	33	200	03-16-81	5	2	0.03	H	Cased to 105 ft.	HA Dc 111
300LPLC	--	--	27	150	10-23-80	50	2	0.41	H	Cased to 118 ft.	HA Dc 112
300LPLC	--	--	73	198	01-13-73	4	1	0.03	U	Cased to 113 ft.	HA Dc 113
300LPLC	--	--	90	250	09-02-74	30	5	0.19	H	Cased to 100 ft.	HA Dc 114
300PRDP	--	--	48	250	09-23-79	2	6	0.01	H	Cased to 82 ft.	HA Dc 115
300PRDP	--	--	120	--	07-11-70	4	1	--	H	Cased to 167 ft.	HA Dc 116
217PTMC	58.73	02-13-87	57	68	05-10-85	10	3	0.91	H	QW	HA Dc 117
217PTMC	51.70	04-22-87	52	64	05-08-85	20	3	1.67	H	QW	HA Dc 118
300PRDP	--	--	83	166	03-26-81	6	6	0.07	H	QW Cased to 162 ft.	HA Dc 119
217PTMC	--	--	--	--	--	3	--	--	U		HA Dd 4
217PTMC	--	--	16	26	--	50	--	5.00	U		HA Dd 5
300LPLC	--	--	25	150	07-07-50	2.5	2	0.02	C	QW Cased to 128 ft.	HA Dd 10
217PTMC	--	--	23	50	12-01-53	30	1	1.11	H	Cased to 59 ft.	HA Dd 15
300JMSR	--	--	7	35	02-02-50	10	1	0.36	H	QW Cased to 46 ft.	HA Dd 29
217PTMC	--	--	46.25	69.67	01-18-68	60	30	2.56	P	GAM	HA Dd 46
--	--	--	--	--	--	--	--	--	U	Test hole to 104 ft.	HA Dd 47
--	--	--	--	--	--	--	--	--	U	Test hole to 149 ft.	HA Dd 48
217PTMC	15.17	08-03-73	15.17	48	10-13-65	102	30	3.11	P	Drilled to 118 ft.	HA Dd 49
217PTMC	--	--	13.92	44	11-02-65	104	30	3.46	P	Drilled to 118 ft.	HA Dd 50
400BLMR	--	--	20	72	06-27-66	8	2	0.15	H	QW Cased to 46 ft.	HA Dd 54
300JMSR	--	--	20	228	07-15-67	5	2	0.02	U	Cased to 177 ft.	HA Dd 55
217PTMC	16.92	08-27-86	15	25	12-29-77	25	2	2.50	H		HA Dd 70
217PTMC	52.57	04-22-87	53	76	05-02-84	20	3	0.87	H	QW	HA Dd 71
217PTMC	37.17	12-22-86	56	65	05- -86	20	3	2.22	H	QW	HA Dd 73
300JMSR	5.22	12-05-86	2	100	08-22-77	30	2	0.31	N	Cased to 50 ft.	HA Dd 74

Table 11.—Records of selected wells in Harford County—Continued

[ft = feet; ls = land surface; gal/min = gallons per minute; (gal/min)/ft = gallons per minute per foot; other abbreviations are found at the end of the table]

WELL NUMBER	STATE PERMIT NUMBER	OWNER	CONTRACTOR	DATE WELL CON-STRUCTED	ALTI-TUDE (ft)	DEPTH OF WELL (ft)	WELL DIAMETER (in.) CASING	WELL DIAMETER (in.) SCREEN	TOP OF SCREEN BELOW LS (ft)	TOTAL SCREEN LENGTH (ft)
HA Dd 75	HA-73-3900	WICKMAN, WILLIAM	LEONARD DRLG	06-01-77	95.6	89	4	2	84	5
HA Dd 76	HA-73-6380	RIVERI, JOHN	JONES DRLG	12-18-80	25	173	6	--	--	--
HA Dd 77	HA-73-1772	HARRIS, JAMES	NELSON DRLG	10-18-74	80	140	6	--	--	--
HA Dd 78	HA-73-6421	SHUNK, WILLIAM	JONES DRLG	03-14-81	91	116	6	--	--	--
HA Dd 79	HA-81-2954	PLITT, RICHARD	FRANK'S DRLG	08-05-86	123	140	4	2	130	10
HA Dd 80	HA-73-2412	UNITED METHODIST CHURCH	BARBER DRLG	09-17-75	68	200	6.25	--	--	--
HA Dd 81	HA-73-6889	SOUL, LOUIS	FRANK'S DRLG	01-08-82	10	65	4	2	55	10
HA Dd 82	HA-71-0670	MCDOWELL, FRANK	HARR SONS	07-14-71	90	290	6	--	--	--
HA Dd 84	HA-70-0525	FUTTY, CHARLES	HAMILTON, C.	07-30-70	135	283	6	--	--	--
HA Dd 85	HA-73-4058	SPALDING, CHARLES	JONES DRLG	08-02-77	137	300	6	--	--	--
HA Dd 86	--	--	--	--	10	12	42	--	--	--
HA Dd 87	HA-81-0704	BRAUN, JOHN	BARBER DRLG	05- -83	163	--	--	--	--	--
HA Dd 88	HA-81-4163	HA CO DPW	CZ ENTERPRISES	12-30-87	79.91	155	6	6	120	35
HA Dd 89	HA-81-4130	MD GEOLOGICAL SURVEY	WC SERVICES	12-08-87	99.05	150	4	4	96	10
								4	120	10
HA Dd 90	HA-81-4168	HA CO DPW	CZ ENTERPRISES	04-26-88	80.91	157	10	10	137	20
HA Dd 91	HA-81-4136	MD GEOLOGICAL SURVEY	WC SERVICES	01-28-88	19.73	78	4	4	58	10
HA Dd 92	HA-81-4137	MD GEOLOGICAL SURVEY	WC SERVICES	02-05-88	20.06	38	4	4	18	10
HA Dd 93	HA-81-4169	HA CO DPW	CZ ENTERPRISES	05-20-88	85	137	10	10	117	20
HA Dd 94	HA-81-3994	U.S. ARMY	ARMY CORPS OF ENGRS	08-09-87	23.60	44	4	4	34	10
HA Dd 95	HA-81-3995	U.S. ARMY	ARMY CORPS OF ENGRS	08-17-87	24.47	113	4	4	108	5
HA Dd 96	HA-81-3205	U.S. ARMY	ARMY CORPS OF ENGRS	10-02-86	10.00	39	4	4	29	10
HA Dd 97	HA-81-3206	U.S. ARMY	ARMY CORPS OF ENGRS	10-07-86	10.10	128	4	4	118	10
HA Dd 98	HA-81-3989	U.S. ARMY	ARMY CORPS OF ENGRS	08-01-87	28.45	45	4	4	35	10
HA Dd 99	HA-81-3990	U.S. ARMY	ARMY CORPS OF ENGRS	08-11-87	28.31	145	4	4	135	10
HA Dd 100	HA-81-4166	HA CO DPW	CZ ENTERPRISES	04-07-88	95.16	157	10	10	137	20
HA Dd 101	HA-81-4167	HA CO DPW	CZ ENTERPRISES	04-05-88	85	140	4	4	120	20
HA Dd 102	HA-81-4130	MD GEOLOGICAL SURVEY	WC SERVICES	12-04-87	99.05	--	--	--	--	--
HA Dd 103	HA-81-3204	U.S. ARMY	ARMY CORPS OF ENGRS	09-17-86	10.00	14	4	4	4	10
HA Dd 106	HA-81-4522	MD GEOLOGICAL SURVEY	WC SERVICES	06-28-88	33.89	210	4	4	190	10
HA De 6	--	U.S. ARMY	LAYNE-ATL CO	- - 42	53.5	83	10	--	73	10
HA De 7	--	U.S. ARMY	LAYNE-ATL CO	- - 42	59.0	81	10	--	71	10
HA De 19	--	U.S. ARMY	--	--	45	251.5	--	--	--	--
HA De 20	HA-00-9875	LONGLEY, L.	G. RINIER	04-21-52	20	68	6	--	63	5
HA De 28	HA-02-4175	INTERPACE CORP	SHANNAHAN CO	08-23-56	40	127	10	8	81	11
							8	8	116	11
HA De 56	HA-67-0088	HA CO DPW	SHANNAHAN CO	11-29-66	10	104	4	4	94	10
HA De 57	HA-67-0604	HA CO DPW	SHANNAHAN CO	07-07-67	10	115	4	4	104	11
HA De 58	HA-68-0657	HA CO DPW	LAYNE-ATL CO	07-17-68	45	138.5	8	8	93.5	45
HA De 59	HA-70-0086	HA CO DPW	LAYNE-ATL CO	12-11-69	45	144	10	--	96	48
HA De 60	HA-70-0377	BALT GAS & ELEC	SHANNAHAN CO	08-01-70	28	207	10	10	92	8
								10	160	20
								10	194	13
HA De 62	--	BALT GAS & ELEC	SHANNAHAN CO	01-01-70	28.80	206	2	2	96	14
							2	2	174	5
							2	2	201	5
HA De 63	--	HA CO DPW	SHANNAHAN CO	09- -70	35	166	4	--	--	--
HA De 64	HA-71-0164	HA CO DPW	SHANNAHAN CO	11-20-70	35	91	8	--	60	31
HA De 65	--	HA CO DPW	SHANNAHAN CO	09-15-70	39.74	166	4	4	91	16
							4	4	149	17
HA De 66	HA-69-0394	HA CO DPW	SHANNAHAN CO	01-14-69	67.75	66	4	4	45	21
HA De 67	HA-71-0165	HA CO DPW	SHANNAHAN CO	11-16-70	45	137	16-8	--	112	25
HA De 68	HA-69-0393	HA CO DPW	SHANNAHAN CO	01-09-69	55	43	4	4	33	10
HA De 69	HA-69-0395	HA CO DPW	SHANNAHAN CO	01-20-69	50	50	4	4	44	6

WATER-BEARING FOR-MATION[1]	WATER LEVEL BELOW LS (ft)	DATE MEASURED	WATER LEVELS BELOW LAND SURFACE (ft) STATIC	PUMPING	DATE REPORTED	YIELD (gal/min)	HOURS PUMPED	SPECIFIC CAPACITY (gal/min)/ft	USE OF WATER[2]	REMARKS[3]	LOCAL WELL NUMBER
			PUMPING TEST DATA								
217PTMC	67.66	12-01-86	65	75	06-01-77	8	--	0.80	H	QW	HA Dd 75
300JMSR	--	--	19	26	12-18-80	15	6	2.14	C	Cased to 23 ft.	HA Dd 76
300JMSR	74.48	11-19-86	18	115	10-18-74	20	6	0.21	H	Cased to 85 ft.	HA Dd 77
300JMSR	42.05	11-25-86	40	100	03-14-81	4	3	0.07	H	Cased to 100 ft.	HA Dd 78
217PTMC	88.92	04-22-87	88	99	08-05-86	15	3	1.36	H	QW	HA Dd 79
300JMSR	25.85	04-23-87	30	175	09-17-75	4	6	0.03	T	Cased to 88 ft.	HA Dd 80
217PTMC	4.22	12-31-86	5	15	01-08-82	30	3	3.00	H		HA Dd 81
217PTMC	--	--	70	280	07-14-71	7	4	0.03	U	Cased to 238 ft.; destroyed.	HA Dd 82
300--	--	--	100	--	07-30-70	4	3	--	U	Cased to 215 ft.; destroyed.	HA Dd 84
300LPLC	--	--	60	150	08-02-77	3	4	0.03	H	Cased to 127 ft.	HA Dd 85
110ALVM	6.48	09-03-87	--	--	--	--	--	--	H	QW	HA Dd 86
300JMSR	--	--	--	--	--	--	--	--	H	QW	HA Dd 87
217PTMC	49.79	05-16-88	52	75	12-30-87	151	8	6.56	U	GAM,SPE,MPE Drilled to 276 ft.	HA Dd 88
217PTMC	68.77	05-12-88	63	93.7	12-04-87	15	4	0.49	U	QW,GAM,SPE,MPE Drilled to 270 ft.	HA Dd 89
217PTMC	65.35	05-16-88	67	132	04-26-88	162	24	2.49	U	GAM,SPE,MPE	HA Dd 90
112TLBT	12.97	05-13-88	--	--	--	--	--	--	U	QW,GAM,SPE,MPE Drilled to 184 ft.	HA Dd 91
112TLBT	10.60	05-13-88	13.7	26.6	02-05-88	7.5	4	0.58	U	QW Drilled to 50 ft.	HA Dd 92
217PTMC	--	--	53	114	05-20-88	104	14	1.70	P	GAM,SPE,MPE Drilled to 180 ft.	HA Dd 93
112TLBT	18.73	05-16-88	--	--	--	--	--	--	U		HA Dd 94
217PTMC	19.83	05-16-88	--	--	--	--	--	--	U	Drilled to 131 ft.	HA Dd 95
112TLBT	5.15	05-16-88	6.3	13.3	10-02-86	4	2	0.57	U		HA Dd 96
217PTMC	5.90	05-16-88	6.6	21.5	10-07-86	6	3	0.40	U	Drilled to 132 ft.	HA Dd 97
112TLBT	25.30	05-16-88	--	--	--	--	--	--	U	Drilled to 65 ft.	HA Dd 98
217PTMC	--	--	--	--	--	--	--	--	U	Drilled to 147 ft.	HA Dd 99
217PTMC	--	--	67	131	04-07-88	162	24	2.53	P	Drilled to 180 ft.	HA Dd 100
217PTMC	--	--	55	120	04-05-88	50	8	0.77	U	Drilled to 180 ft.	HA Dd 101
217PTMC	--	--	63	93.7	12-04-87	15	4	0.49	U	Orig. designated HA Dd 88; destroyed; drilled to 160 ft.	HA Dd 102
112TLBT	1.95	05-02-89	6.3	11	09-17-86	3	2	0.64	U	Drilled to 24 ft.	HA Dd 103
217PTMC	28.00	07-14-88	31	43	06-28-88	3	2	0.25	U	QW,GAM,SPE,MPE Drilled to 260 ft.	HA Dd 106
112TLBT	24.94	05-03-89	29	67	-42	260	--	6.84	U		HA De 6
112TLBT	28.35	05-03-89	27	69	-42	253	--	6.02	U	Drilled to 121 ft.	HA De 7
217PTMC	--	--	--	--	--	--	--	--	U		HA De 19
112TLBT	--	--	25	--	04-21-52	12	7	--	H		HA De 20
217PTMC	--	--	15	29	08-23-56	96	24	6.86	N	QW	HA De 28
217PTMC	--	--	24.5	60	11-29-66	5	6	0.14	U	GAM Drilled to 105 ft.	HA De 56
217PTMC	--	--	32	53	07-07-67	7.5	6	0.36	U	GAM,SPE; destroyed Drilled to 126 ft.	HA De 57
217PTMC	29.96	07-24-86	19	83	07-17-68	201	24	3.14	P	GAM Drilled to 146 ft.	HA De 58
217PTMC	--	--	21	44	12-11-69	450	24	19.56	P	GAM Drilled to 155 ft.	HA De 59
217PTMC	--	--	20	60	08-01-70	336	48	8.40	U	SPE Drilled to 246 ft.	HA De 60
217PTMC	16.31	12-19-73	--	--	--	--	--	--	U	Drilled to 210 ft.	HA De 62
217PTMC	--	--	--	--	--	--	--	--	-	GAM,SPE	HA De 63
217PTMC	--	--	10	43	11-20-70	350	24	10.61	U	QW; GAM Drilled to 100 ft.	HA De 64
217PTMC	22.89	04-22-87	--	--	--	--	--	--	U	Drilled to 207 ft.	HA De 65
112TLBT	28.15	04-21-87	28.5	31.4	01-14-69	15	4	5.17	U	GAM Drilled to 135 ft.	HA De 66
217PTMC	--	--	17	72	11-16-70	350	24	6.36	P	Drilled to 147 ft.	HA De 67
112TLBT	--	--	18	20	01-09-69	15	4	7.50	U	Drilled to 135 ft.	HA De 68
112TLBT	--	--	12	28	01-20-69	7.5	4	0.47	U	Drilled to 135 ft.	HA De 69

Table 11.—Records of selected wells in Harford County—Continued

[ft = feet; ls = land surface; gal/min = gallons per minute; (gal/min)/ft = gallons per minute per foot; other abbreviations are found at the end of the table]

WELL NUMBER	STATE PERMIT NUMBER	OWNER	CONTRACTOR	DATE WELL CON-STRUCTED	ALTI-TUDE (ft)	DEPTH OF WELL (ft)	WELL DIAMETER (in.) CASING	WELL DIAMETER (in.) SCREEN	TOP OF SCREEN BELOW LS (ft)	TOTAL SCREEN LENGTH (ft)
HA De 70	HA-69-0284	HA CO DPW	SHANNAHAN CO	12-17-68	45	--	--	--	--	--
HA De 73	HA-66-0814	HA CO DPW	SHANNAHAN CO	07-28-66	40	103	8	8	94	9
HA De 75	HA-66-0813	HA CO DPW	SHANNAHAN CO	08-15-66	40	133	8	8	112	21
HA De 76	--	HA CO DPW	SHANNAHAN CO	11-23-70	41	89	10	8	58	9
								8	74	15
HA De 77	--	HA CO DPW	SHANNAHAN CO	11-04-70	41	107	10	8	77	30
HA De 79	HA-69-0392	HA CO DPW	SHANNAHAN CO	02-05-69	40	--	--	--	--	--
HA De 80	HA-05-6658	HA CO DPW	SHANNAHAN CO	03-23-64	20	--	--	--	--	--
HA De 81	HA-05-6657	HA CO DPW	SHANNAHAN CO	03-18-64	20	81	4	4	66	15
HA De 82	HA-05-6659	HA CO DPW	SHANNAHAN CO	03-19-64	15	--	--	--	--	--
HA De 83	HA-69-0397	HA CO DPW	SHANNAHAN CO	01-31-69	50	50	4	4	34	16
HA De 85	HA-68-0131	HA CO DPW	SHANNAHAN CO	07-20-67	32	118	6	4	103	15
HA De 86	HA-01-0406	TOWN OF ABERDEEN	SHANNAHAN CO	08- -52	60	61	10	--	39?	20?
HA De 87	HA-02-8021	TOWN OF ABERDEEN	SHANNAHAN CO	10-15-57	55	54.5	10	10	28	26.5
HA De 88	HA-65-0540	TOWN OF ABERDEEN	SHANNAHAN CO	03-26-65	60	46	2	2	37	5
HA De 89	HA-65-0540	TOWN OF ABERDEEN	SHANNAHAN CO	03-27-65	60	59	2	2	49	5
HA De 91	HA-65-0540	TOWN OF ABERDEEN	SHANNAHAN CO	03-29-65	60	64	2	2	42	5
HA De 92	HA-65-0540	TOWN OF ABERDEEN	SHANNAHAN CO	03-24-65	60	64	2	2	40	5
HA De 94	HA-67-0604	HA CO DPW	SHANNAHAN CO	07-28-67	50	109	2	2	99	10
HA De 117	HA-65-0039	HA CO DPW	SHANNAHAN CO	06-25-64	45	--	--	--	--	--
HA De 120	--	U.S. GEOLOGICAL SURVEY	U.S. GEOL SURVEY	12-04-74	38.66	38	1.25	--	34	--
HA De 122	--	HA CO DPW	SHANNAHAN CO	09-11-70	40	87	4	--	--	--
HA De 123	--	HA CO DPW	SHANNAHAN CO	09- -70	35	87	4	--	--	--
HA De 124	HA-73-2531	HA CO DPW	SHANNAHAN CO	01-30-76	40	218	4	4	147	20
							4	4	208	10
HA De 125	HA-73-2533	HA CO DPW	SHANNAHAN CO	02-04-76	39.47	228	2	2	150	5
							2	2	223	5
HA De 126	HA-73-2530	HA CO DPW	SHANNAHAN CO	02-10-76	38.94	143	2	2	134	9
HA De 127	HA-73-2532	HA CO DPW	SHANNAHAN CO	02-12-76	34.95	161	2-1	1	151	10
HA De 128	HA-73-2534	HA CO DPW	SHANNAHAN CO	02-18-76	38.35	66	4	4	40	10
							4	4	55	11
HA De 129	HA-73-2535	HA CO DPW	SHANNAHAN CO	02-19-76	38.16	165	4	4	125	15
							4	4	155	10
HA De 136	HA-81-0953	GERAGHTY & MILLER	HARDIN-HUBER	01-10-84	33.90	125	4	4	115	10
HA De 137	HA-81-0957	GERAGHTY & MILLER	HARDIN-HUBER	01-16-84	34.07	45	2	2	35	10
HA De 138	HA-81-0950	GERAGHTY & MILLER	HARDIN-HUBER	01-10-84	29.87	152	4	4	140	10
HA De 139	HA-81-0946	GERAGHTY & MILLER	HARDIN-HUBER	02-08-84	29.71	65	2	2	55	10
HA De 140	HA-81-0949	GERAGHTY & MILLER	HARDIN-HUBER	01-05-84	29	75	2	2	65	10
HA De 141	HA-81-0951	GERAGHTY & MILLER	HARDIN-HUBER	01-05-84	28.65	212	4	4	200	10
HA De 142	HA-81-1242	MD DEPT NAT RSRC	ENGR DRILL CO	04-29-84	14	260	2	2	250	10
HA De 143	HA-81-1243	MD DEPT NAT RSRC	ENGR DRILL CO	05-02-84	13	114	2	2	104	10
HA De 144	HA-81-1247	MD DEPT NAT RSRC	ENGR DRILL CO	04-19-84	36.31	90	2	2	80	10
HA De 145	HA-81-1246	MD DEPT NAT RSRC	ENGR DRILL CO	04-19-84	36.22	181	2	2	170	10
HA De 146	--	FELS	--	--	34	--	36	--	--	--
HA De 147	--	HORN	--	--	31	--	36	--	--	--
HA De 148	--	VAN VALKENBURGH	--	--	14	20	48	--	--	--
HA De 149	HA-73-6303	FUTTY, CHARLES	FRANK'S DRLG	10-28-80	32	45	4	2	38	7
HA De 150	HA-73-5780	CLINE, HOWARD	FRANK'S DRLG	08-07-79	23	100	4	2	95	5
HA De 151	HA-81-0952	GERAGHTY & MILLER	HARDIN-HUBER	01-11-84	31.74	180	4	4	168	10
HA De 152	HA-81-0948	GERAGHTY & MILLER	HARDIN-HUBER	01-11-84	32.55	95	2	2	85	10
HA De 153	HA-81-0955	GERAGHTY & MILLER	HARDIN-HUBER	01-16-84	14.74	138	4	4	126	10
HA De 154	HA-81-0956	GERAGHTY & MILLER	HARDIN-HUBER	01-16-84	14.41	70	2	2	60	10
HA De 155	HA-81-0954	GERAGHTY & MILLER	HARDIN-HUBER	01-16-84	38.84	122	4	4	110	10
HA De 156	HA-81-0947	GERAGHTY & MILLER	HARDIN-HUBER	01-09-84	38.66	50	2	2	40	10
HA De 157	HA-81-0960	GERAGHTY & MILLER	HARDIN-HUBER	01-09-84	33.83	40	2	2	30	10
HA De 158	HA-81-1251	MD DEPT NAT RSRC	ENGR DRILL CO	04-29-84	23.76	105	2	2	95	10
HA De 159	HA-81-1250	MD DEPT NAT RSRC	ENGR DRILL CO	04-25-84	22.92	190	2	2	180	10
HA De 160	HA-81-1245	MD DEPT NAT RSRC	ENGR DRILL CO	04-10-84	28.19	47	2	2	40	7

WATER-BEARING FOR-MATION[1]	WATER LEVEL BELOW LS (ft)	DATE MEASURED	WATER LEVELS BELOW LAND SURFACE (ft) STATIC	PUMPING	DATE REPORTED	PUMPING TEST DATA YIELD (gal/min)	HOURS PUMPED	SPECIFIC CAPACITY (gal/min)/ft	USE OF WATER[2]	REMARKS[3]	LOCAL WELL NUMBER
--	--	--	--	--	--	--	--	--	U	Test hole to 185 ft.	HA De 70
217PTMC	--	--	7	32	07-28-66	130	24	5.20	P	QW	HA De 73
217PTMC	--	--	20	66	08-15-66	164	24	3.57	P		HA De 75
112TLBT	--	--	14	29	02-05-71	1,000	24	66.67	P		HA De 76
217PTMC	--	--	14	--	02-05-71	400	3	--	P	SPE Drilled to 192 ft.	HA De 77
--	--	--	--	--	--	--	--	--	U	Test hole to 135 ft. Destroyed.	HA De 79
--	--	--	--	--	--	--	--	--	U	Test hole to 134 ft; destroyed.	HA De 80
112TLBT	--	--	20	32	03-18-64	23	4	1.92	U	Test hole to 117 ft; destroyed.	HA De 81
--	--	--	--	--	--	--	--	--	U	Test hole to 120 ft; destroyed.	HA De 82
112TLBT	--	--	25	27	01-31-69	10	4	5.00	U	GAM Drilled to 135 ft; destroyed.	HA De 83
217PTMC	27.89	08-14-86	25	30	07-20-67	42	6	8.40	N	QW Drilled to 126 ft.	HA De 85
112TLBT	--	--	5	16	08- -52	160	8	14.54	P	QW	HA De 86
112TLBT	--	--	15	16.5	10-15-57	30	4	20.00	P	Drilled to 70 ft.	HA De 87
112TLBT	--	--	23	26	03-26-65	2	2	0.67	U		HA De 88
112TLBT	--	--	25	29	03-27-65	3	2	0.75	U	GAM	HA De 89
112TLBT	--	--	17	21	03-29-65	10	2	2.50	U	GAM	HA De 91
112TLBT	--	--	13	17	03-24-65	10	2	2.50	U	GAM	HA De 92
217PTMC	24.84	07-24-86	17	30	07-28-67	25	4	1.92	U	Drilled to 143 ft.	HA De 94
--	--	--	--	--	--	--	--	--	U	Test hole to 115 ft; destroyed.	HA De 117
112TLBT	24.03	07-24-86	20	--	12-04-74	--	--	--	U		HA De 120
112TLBT	--	--	--	--	--	--	--	--	U	GAM Drilled to 116 ft; destroyed.	HA De 122
112TLBT	--	--	--	--	--	--	--	--	U	GAM Destroyed.	HA De 123
217PTMC	24.31	04-22-87	21.10	28.37	01-30-76	56	4	7.70	U	GAM,SPE Drilled to 328 ft.	HA De 124
217PTMC	23.07	04-22-87	19	30	02-04-76	20	2	1.82	U	GAM Drilled to 233 ft.	HA De 125
217PTMC	23.09	04-22-87	18.7	30	02-10-76	17	2	1.50	U	GAM Drilled to 253 ft.	HA De 126
217PTMC	19.20	04-22-87	13.2	20	02-12-76	10	2	1.47	U	GAM Drilled to 296 ft.	HA De 127
112TLBT	19.91	04-22-87	16.01	18.19	02-18-76	38	3	17.43	U	QW; GAM	HA De 128
217PTMC	23.29	04-22-87	19.91	26.27	02-19-76	56	3	8.80	U	QW; GAM Drilled to 250 ft.	HA De 129
217PTMC	23.10	11-03-86	--	--	01-10-84	1	1	--	U		HA De 136
217PTMC	19.50	11-03-86	--	--	01-16-84	2	1	--	U		HA De 137
217PTMC	20.94	11-03-86	--	--	01-10-84	20	1	--	U	GAM	HA De 138
217PTMC	18.92	11-03-86	--	--	02-08-84	1	1	--	U		HA De 139
217PTMC	--	--	--	--	01-05-84	2	1	--	U		HA De 140
217PTMC	22.12	11-03-86	--	--	01-05-84	20	1	--	U		HA De 141
217PTMC	11.69	12-12-86	7	--	04-29-84	25	1	--	U		HA De 142
217PTMC	11.63	12-12-86	--	--	05-02-84	25	1	--	U	Destroyed.	HA De 143
217PTMC	21.60	04-22-87	--	--	04-19-84	15	1	--	U	Drilled to 181 ft.	HA De 144
217PTMC	25.20	04-22-87	--	--	04-19-84	20	1	--	U		HA De 145
112TLBT	Dry	08-12-86	--	--	--	--	--	--	U		HA De 146
112TLBT	8.84	08-12-86	--	--	--	--	--	--	U		HA De 147
217PTMC	--	--	--	--	--	--	--	--	U		HA De 148
112TLBT	19.27	08-26-86	17	27	10-28-80	25	2	2.50	H		HA De 149
217PTMC	19.29	08-27-86	17	29	08-07-79	25	2	2.08	H	QW	HA De 150
217PTMC	25.00	08-13-86	--	--	01-11-84	20	1	--	U	GAM	HA De 151
217PTMC	26.18	04-21-87	--	--	01-11-84	2	1	--	U		HA De 152
217PTMC	8.98	11-03-86	--	--	01-16-84	5	2	--	U		HA De 153
217PTMC	10.97	11-03-86	--	--	01-16-84	2	1	--	U	Drilled to 75 ft.	HA De 154
217PTMC	26.86	11-03-86	--	--	01-16-84	3	1	--	U		HA De 155
217PTMC	23.71	11-03-86	--	--	01-09-84	2	1	--	U		HA De 156
217PTMC	22.12	11-03-86	--	--	01-09-84	1	1	--	U		HA De 157
217PTMC	16.83	04-21-87	--	--	04-29-84	30	1	--	U	GAM Drilled to 120 ft.	HA De 158
217PTMC	15.44	04-21-87	--	--	04-25-84	35	1	--	U		HA De 159
217PTMC	15.38	12-12-86	--	--	04-10-84	20	1	--	U	Drilled to 60 ft.	HA De 160

Table 11.—Records of selected wells in Harford County—Continued

[ft = feet; ls = land surface; gal/min = gallons per minute; (gal/min)/ft = gallons per minute per foot; other abbreviations are found at the end of the table]

WELL NUMBER	STATE PERMIT NUMBER	OWNER	CONTRACTOR	DATE WELL CON-STRUCTED	ALTI-TUDE (ft)	DEPTH OF WELL (ft)	WELL DIAMETER (in.) CASING	WELL DIAMETER (in.) SCREEN	TOP OF SCREEN BELOW LS (ft)	TOTAL SCREEN LENGTH (ft)
HA De 161	HA-81-1244	MD DEPT NAT RSRC	ENGR DRILL CO	04-06-84	27.87	140	2	2	130	10
HA De 162	HA-81-1249	MD DEPT NAT RSRC	ENGR DRILL CO	04-24-84	30.69	79	2	2	69	10
HA De 163	HA-81-1248	MD DEPT NAT RSRC	ENGR DRILL CO	04-20-84	29.96	165	2	2	155	10
HA De 164	HA-73-3141	FENDER, MARILYN	LEONARD DRLG	07-28-76	57	120	4	2	115	5
HA De 165	HA-73-6437	ROSCHEL, JAMES	KIRK DRLG	04-10-81	20	158	6	6	153	5
HA De 166	HA-81-2322	WELCH, MILES	FRANK'S DRLG	11-12-85	17	140	4	2	131	9
HA De 167	HA-73-6822	SPIES, WILLIAM	JONES DRLG	11-21-81	70	250	6	--	--	--
HA De 168	HA-81-1055	PASTA, SAL	BRANHAM CONTRS	07-25-84	38	50	4	2	42	8
HA De 169	HA-81-1729	HOLECHECK, F.	FRANK'S DRLG	12-11-84	63	60	4	2	50	10
HA De 170	HA-81-0458	KILBY, ALLEN	PRESTON & HAMILTON	01-14-83	47	350	6	--	--	--
HA De 171	HA-81-3181	BATA SHOE CO	ATEC ASSC.	11-13-86	80	77	4	4	62	15
HA De 172	HA-81-0381	REEVES, HARRIS	BARBER DRLG	11-21-82	33	149	6	--	--	--
HA De 173	HA-73-6439	NO MD SOC AID RET CH	FRANK'S DRLG	02-11-81	105	275	6	--	--	--
HA De 174	HA-81-0051	STOUT, BRYAN	FRANK'S DRLG	04-14-82	38	48	4	2	41	7
HA De 177	HA-81-0870	WILLIAMS, RIAL	JONES DRLG	09-08-83	125	175	6	--	--	--
HA De 178	HA-73-6436	COLLIER, CHARLES	KIRK DRLG	03-09-81	62	65	6	6	60	5
HA De 179	--	--	--	--	30	--	--	--	--	--
HA De 180	--	--	--		20	--	--	--	--	--
HA De 181	HA-81-4134	MD GEOLOGICAL SURVEY	WC SERVICES	12-17-87	12.22	280	4	4	264	5
							4	4	275	5
HA De 182	HA-81-4135	MD GEOLOGICAL SURVEY	WC SERVICES	12-22-87	12.29	40	4	4	30	10
HA De 183	HA-81-4577	MD GEOLOGICAL SURVEY	WC SERVICES	12-19-87	12.53	165	4	4	155	10
HA De 184	HA-81-0978	MITCHELL, F. O. & BRO.	SHANNAHAN CO	03-22-84	39	189	12	12	87	13
							8	8	147	10
							8	8	170	19
HA De 185	--	HA CO DPW	--	--	34.79	60	--	--	--	--
HA De 186	--	HA CO DPW	--	--	38.63	62	--	--	--	--
HA De 187	--	MD GEOLOGICAL SURVEY	U.S. GEOL SUR	- -87	5.08	--	--	--	--	--
HA De 188	--	HA CO DPW	--	--	39.26	50	--	--	--	--
HA De 189	--	HA CO DPW	--	--	40	44	--	--	--	--
HA De 190	HA-73-4568	MITCHELL, F. O. & BRO.	KIRK DRLG	05-30-78	40	50	6	6	45	5
HA De 193	--	MITCHELL, FRED	--	- -12	40.18	50	--	--	--	--
HA De 195	HA-81-4142	MD GEOLOGICAL SURVEY	WC SERVICES	01-20-88	52.70	45	4	4	35	10
HA De 197	HA-81-4140	MD GEOLOGICAL SURVEY	WC SERVICES	01-22-88	19.08	85	4	4	75	10
HA De 198	HA-81-4141	MD GEOLOGICAL SURVEY	WC SERVICES	01-21-88	18.92	19	4	4	9	10
HA De 199	HA-81-4576	MD GEOLOGICAL SURVEY	WC SERVICES	01-22-88	20.10	29	4	4	9	10
HA De 200	HA-81-1463	U.S. ARMY	N.F. ENGR	11-30-84	49.30	44	4	4	7	37
HA De 201	--	ERM	HARDIN-HUBER	02-02-87	36.32	40	2	2	30	10
HA De 202	HA-81-3518	ERM	HARDIN-HUBER	01-20-87	24.4	35	2	2	25	10
HA De 203	HA-81-3514	ERM	HARDIN-HUBER	02-02-87	27.75	40	2	2	30	10
HA De 204	HA-81-3515	ERM	HARDIN-HUBER	01-27-87	32.47	27	2	2	17	10
HA De 206	--	HA CO DPW	--	--	42.78	106	4	4	70	5
							--	4	75	20
HA Df 3	--	U.S. ARMY	--	- -18	12	135	10-8	8	125	10
HA Df 4	--	U.S. ARMY	--	- -18	16	147	10-8	8	137	10
HA Df 17	--	U.S. ARMY	--	--	31.5	165	--	--	--	--
HA Df 22		U.S. ARMY	--	--	58	105	--	--	--	--
HA Df 27	HA-65-0540	TOWN OF ABERDEEN	SHANNAHAN CO	12-06-66	60	45	2	2	39	5
HA Df 29	HA-73-2481	TOWN OF ABERDEEN	SHANNAHAN CO	01-20-76	65	64	4	4	54	10
HA Df 30	HA-73-2482	TOWN OF ABERDEEN	SHANNAHAN CO	12-17-75	65	80	4	4	50	30
HA Df 31	HA-73-2483	TOWN OF ABERDEEN	SHANNAHAN CO	12-15-75	65	72	4	4	57	15
HA Df 32	HA-73-2484	TOWN OF ABERDEEN	SHANNAHAN CO	12-11-75	55	64	4	4	49	15
HA Df 33	HA-73-2485	TOWN OF ABERDEEN	SHANNAHAN CO	12-10-75	55	75	4	4	55	20
HA Df 34	HA-73-2486	TOWN OF ABERDEEN	SHANNAHAN CO	12-03-75	55	42	4	4	32	10
HA Df 40	HA-81-1641	U.S. ARMY	A C SCHULTES	04-01-85	24	431	2	2	421	10
HA Df 44	HA-81-1460	ARMY CORPS OF ENGRS	N.F. ENGR.	11-30-84	59.57	71	4	4	24	47

WATER-BEARING FOR-MATION[1]	WATER LEVEL BELOW LS (ft)	DATE MEASURED	PUMPING TEST DATA: WATER LEVELS BELOW LAND SURFACE (ft) STATIC	PUMPING	DATE REPORTED	YIELD (gal/min)	HOURS PUMPED	SPECIFIC CAPACITY (gal/min)/ft	USE OF WATER[2]	REMARKS[3]	LOCAL WELL NUMBER
217PTMC	20.43	12-12-86	--	--	04-06-84	20	1	--	U		HA De 161
217PTMC	16.26	12-12-86	--	--	04-24-84	20	1	--	U		HA De 162
217PTMC	18.91	12-12-86	--	--	04-20-84	25	1	--	U	GAM	HA De 163
217PTMC	58.88	12-04-86	60	70	07-28-76	19	2	1.90	H		HA De 164
217PTMC	17.88	12-04-86	17	60	04-10-81	16	4	0.37	H		HA De 165
217PTMC	11.22	12-04-86	17	27	11-12-85	30	3	3.00	H		HA De 166
300MBAB	20.91	11-19-86	75	89	11-21-81	15	6	1.07	H	Cased to 47 ft.	HA De 167
112TLBT	34.35	11-25-86	32	40	07-25-84	18	3	2.25	H	QW	HA De 168
217PTMC	28.98	11-21-86	24	33	12-11-84	15	3	1.67	N	QW	HA De 169
300MBAB	--	--	25	350	01-14-83	1	4	0.00	H	Cased to 73 ft.	HA De 170
217PTMC	64.16	12-23-86	65	72	11-13-86	10	5	1.43	U	GAM Drilled to 81 ft.	HA De 171
300MBAB	17.53	04-23-87	20	124	11-21-82	4	6	0.04	H	Cased to 106 ft.	HA De 172
300MBAB	--	--	--	170	02-11-81	20	2	--	N	Cased to 121 ft.	HA De 173
217PTMC	23.20	12-23-86	22	32	04-14-82	10	3	1.00	H		HA De 174
300MBAB	--	--	32	92	09-08-83	12	3	0.20	H	Cased to 57 ft.	HA De 177
217PTMC	15.64	12-23-86	20	30	03-09-81	12	3	1.20	H		HA De 178
112TLBT	--	--	--	--	--	--	--	--	H	QW	HA De 179
217PTMC	--	--	--	--	--	--	--	--	H	QW	HA De 180
217PTMC	7.15	05-12-88	7.25	72.7	12-17-87	20	3.5	0.30	U	QW,GAM,SPE,MPE Drilled to 317 ft.	HA De 181
112TLBT	8.59	05-13-88	11.4	15.2	12-22-87	8	4	2.24	U	QW Drilled to 60 ft.	HA De 182
217PTMC	9.36	05-13-88	--	--	--	--	--	--	U	QW Drilled to 180 ft.	HA De 183
217PTMC	--	--	22	27	03-22-84	94	4	18.80	I		HA De 184
217PTMC	15.12	04-22-87	--	--	--	--	--	--	U		HA De 185
217PTMC	19.20	04-22-87	--	--	--	--	--	--	U		HA De 186
110ALVM	2.81	05-04-89	--	--	--	--	--	--	U		HA De 187
112TLBT	20.91	04-22-87	--	--	--	--	--	--	U		HA De 188
112TLBT	22.54	04-22-87	--	--	--	--	--	--	U		HA De 189
112TLBT	24.48	02-02-87	20	30	05-30-78	25	4	2.50	N	QW	HA De 190
112TLBT	23.49	05-15-89	--	--	--	--	--	--	U		HA De 193
112TLBT	12.85	05-16-88	--	--	--	--	--	--	U	QW,GAM,SPE Drilled to 164 ft.	HA De 195
217PTMC	--	--	--	--	--	--	--	--	U	QW Drilled to 140 ft.	HA De 197
112TLBT	6.91	05-13-88	--	--	--	--	--	--	U	QW Drilled to 35 ft.	HA De 198
112TLBT	8.51	07-14-88	--	--	--	--	--	--	U	Drilled to 35 ft.	HA De 199
112TLBT	12.52	11-13-87	10	10	11-30-84	10	2	0.00	U		HA De 200
112TLBT	20.99	04-21-87	--	--	--	--	--	--	-	Drilled to 47 ft.	HA De 201
112TLBT	15.72	04-21-87	--	--	--	--	--	--	U		HA De 202
112TLBT	16.94	04-21-87	--	--	--	--	--	--	U		HA De 203
112TLBT	23.88	04-21-87	--	--	--	--	--	--	U	Drilled to 37 ft.	HA De 204
217PTMC	26.54	04-22-87	--	--	--	--	--	--	-		HA De 206
112TLBT	1.03	05-03-89	23	--	--	--	--	--	-		HA Df 3
112TLBT	4.74	05-03-89	28	--	--	--	--	--	-		HA Df 4
--	--	--	--	--	--	--	--	--	-		HA Df 17
--	--	--	--	--	--	--	--	--	-		HA Df 22
112TLBT	--	--	31	34	12-06-66	2	1	0.67	U	GAM Drilled to 48 ft.	HA Df 27
112TLBT	--	--	31	32.25	01-20-76	20	10	16.00	U	GAM Drilled to 207 ft.	HA Df 29
112TLBT	--	--	33.25	34.08	12-17-75	30	2	36.14	U	Drilled to 203 ft; destroyed.	HA Df 30
112TLBT	35.84	03-01-76	38.67	39.92	12-15-75	15	2	12.00	U	GAM Drilled to 208 ft.	HA Df 31
112TLBT	--	--	34.33	38.33	12-11-75	10	2	2.50	U	Drilled to 187 ft; destroyed.	HA Df 32
112TLBT	--	--	30.58	32.50	12-10-75	14	2	7.29	U	Drilled to 195 ft.	HA Df 33
112TLBT	--	--	32	33	12-03-75	0.50	1	0.50	U	Drilled to 183 ft; destroyed.	HA Df 34
217PTMC	24.77	05-03-89	28	30	04-01-85	1	2	0.50	U	GAM,SPE	HA Df 40
112TLBT	31.22	11-13-87	25	39	11-30-84	10	2	0.71	U	Drilled to 72 ft.	HA Df 44

Table 11.—Records of selected wells in Harford County—Continued

[ft = feet; ls = land surface; gal/min = gallons per minute; (gal/min)/ft = gallons per minute per foot; other abbreviations are found at the end of the table]

WELL NUMBER	STATE PERMIT NUMBER	OWNER	CONTRACTOR	DATE WELL CON-STRUCTED	ALTI-TUDE (ft)	DEPTH OF WELL (ft)	WELL DIAMETER (in.) CASING	WELL DIAMETER (in.) SCREEN	TOP OF SCREEN BELOW LS (ft)	TOTAL SCREEN LENGTH (ft)
HA Df 45	HA-81-1461	ARMY CORPS OF ENGRS	N.F. ENGR.	11-30-84	53	42	4	4	17	24
HA Df 46	HA-81-1459	ARMY CORPS OF ENGRS	N.F. ENGR.	11-30-84	71.32	62	4	4	30	31
HA Df 47	HA-81-1462	ARMY CORPS OF ENGRS	N.F. ENGR.	11-30-84	67.32	50	4	4	34	15
HA Ec 4	HA-04-2505	HA CO DPW	LAYNE-ATL CO	05-06-61	33	100	6	6	80	20
HA Ec 6	HA-04-3679	HA CO DPW	LAYNE-ATL CO	08-07-61	18.5	87	6	6	67	20
HA Ec 11	HA-04-7211	HA CO DPW	LAYNE-ATL CO	05-16-62	11.7	68	6	2	63	5
HA Ec 12	HA-04-6966	HA CO DPW	LAYNE-ATL CO	06-15-62	36.0	97	8	8	57	40
HA Ec 13	HA-04-6967	HA CO DPW	LAYNE-ATL CO	06-20-62	66.5	133	8	8	113	20
HA Ec 14	HA-04-6968	HA CO DPW	LAYNE-ATL CO	08-06-62	77.6	166	8	8	146	20
HA Ec 19	HA-04-9214	HA CO DPW	LAYNE-ATL CO	10-12-62	69.8	--	--	--	--	--
HA Ec 22	HA-04-9556	HA CO DPW	LAYNE-ATL CO	11-02-62	11.3	--	--	--	--	--
HA Ec 27	HA-05-0335	HA CO DPW	LAYNE-ATL CO	01-17-63	93.8	--	--	--	--	--
HA Ec 33	HA-05-1170	HA CO DPW	LAYNE-ATL CO	05-06-63	84.64	154	8	8	129	25
HA Ec 40	HA-65-0113	HA CO DPW	LAYNE-ATL CO	08-26-64	72	--	--	--	--	--
HA Ec 43	HA-72-0609	HA CO DPW	LAYNE-ATL CO	07-06-72	15	116	8	8	91	25
HA Ec 44	HA-81-0919	O'QUINN, ALMA	FRANK'S DRLG	09-29-83	23	57	4	2	50	7
HA Ec 45	HA-72-0026	ELLIS, CLAUDE	JONES DRLG	07-20-71	77	78	6	--	--	--
HA Ec 46	HA-81-4124	MD GEOLOGICAL SURVEY	WC SERVICES	11-20-87	23.16	85	4	4	65	10
HA Ec 47	HA-81-4125	MD GEOLOGICAL SURVEY	WC SERVICES	11-21-87	23.30	20	4	4	3	10
HA Ed 24	--	U.S. ARMY	LAYNE-ATL CO	- -41	12.8	135	18-10	10	120	15
HA Ed 32	HA-69-0685	HARFORD SANDS INC	LAYNE-ATL CO	11-07-69	42	243	8	8	200	20
								8	228	15
HA Ed 33	HA-73-1146	MAGNOLIA SCHOOL	FRANK'S DRLG	09-20-73	115	138	4	8	133	5
HA Ed 34	HA-81-2915	DAY, FRED	FRANK'S DRLG	07-31-86	92	112	4	2	102	10
HA Ed 35	HA-81-2244	LEWIS, RUSSELL	FRANK'S DRLG	09-03-85	42	90	4	2	80	10
HA Ed 36	HA-81-0141	HEINE, DONALD	FRANK'S DRLG	05-04-82	70	120	4	2	110	10
HA Ed 37	HA-73-4545	COLEMAN, HAROLD	FRANK'S DRLG	12-15-77	116	165	4	2	160	5
HA Ed 38	HA-73-4968	UNDERWOOD, JAMES	FRANK'S DRLG	06-12-78	29	85	4	2	80	5
HA Ed 39	HA-73-4147	MCKAUGHAN, MITCHELL	FRANK'S DRLG	08-17-77	47	110	4	2	105	5
HA Ed 40	HA-81-0693	CROWDER, LEO	FRANK'S DRLG	05-28-83	47	185	4	2	175	10
HA Ed 41	HA-73-6326	PANOWICZ, RAPHAEL	FRANK'S DRLG	11-10-80	108	192	4	2	182	10
HA Ed 43	HA-73-5234	CASTEEL, MARION	FRANK'S DRLG	10-06-78	50	100	4	2	95	5
HA Ed 44	HA-81-0497	BEERS, LAWRENCE	FRANK'S DRLG	02-22-83	60	140	4	2	130	10
HA Ed 45	HA-73-1875	TOBASH, THOMAS	LEONARD DRLG	10-07-74	86	210	4	2	200	10
HA Ed 46	HA-81-4165	HA CO DPW	CZ ENTERPRISES	01-18-88	72.89	140	4	4	120	20
HA Ed 47	HA-81-4128	MD GEOLOGICAL SURVEY	WC SERVICES	02-29-88	90.50	200	4	4	190	10
HA Ed 48	HA-81-4578	MD GEOLOGICAL SURVEY	WC SERVICES	03-17-88	91.20	128	4	4	118	10
HA Ed 49	HA-81-4129	MD GEOLOGICAL SURVEY	WC SERVICES	03-21-88	91.89	23	4	4	13	10
HA Ed 50	HA-81-4521	HA CO DPW	CZ ENTERPRISES	05-10-88	60	167	4	4	147	20

[1]WATER-BEARING FORMATION

110ALVM = Quaternary Alluvium
112TLBT = Talbot Formation
217PPSC = Patapsco Formation
217PTMC = Potomac Group
400BLMR = Baltimore Gneiss
300JMSR = James Run Formation
300LPLC = Lower Pelitic Schist of Wissahickon Formation
300MBAB = Metagabbro and Amphibolite
300PRDP = Port Deposit Gneiss

[2]USE OF WATER

C = Commercial
H = Domestic
I = Irrigation
N = Industrial
P = Public supply
R = Recreation
T = Institutional
U = Unused

[3]REMARKS

QW = Collected ground-water samples for water quality data

Geophysical Logs: GAM = Gamma ray log
SPE = Single-point electric log
MPE = Multi-point electric log

HA CO DPW = Harford County Department of Public Works
ERM = Environmental Resources Management

WATER-BEARING FOR-MATION[1]	WATER LEVEL BELOW LS (ft)	DATE MEASURED	WATER LEVELS BELOW LAND SURFACE (ft) STATIC	PUMPING	DATE REPORTED	YIELD (gal/min)	HOURS PUMPED	SPECIFIC CAPACITY (gal/min)/ft	USE OF WATER[2]	REMARKS[3]	LOCAL WELL NUMBER
			PUMPING TEST DATA								
112TLBT	24.51	11-13-87	23	24	11-30-84	8	2	8.00	U		HA Df 45
112TLBT	40.19	11-13-87	35	35	11-30-84	5	2	--	U		HA Df 46
112TLBT	41.72	11-13-87	37	39	11-30-84	10	2	5.00	U		HA Df 47
217PTMC	--	--	24.5	72	05-06-61	175	120	3.68	U	Drilled to 180 ft; destroyed.	HA Ec 4
217PTMC	--	--	6	64	08-07-61	150	120	2.59	U	Drilled to 175 ft; destroyed.	HA Ec 6
217PTMC	6.38	04-22-87	1	--	05-16-62	40	3	--	U	Drilled to 85 ft.	HA Ec 11
217PTMC	--	--	29	57.75	06-15-62	225	48	7.83	P	Drilled to 106 ft.	HA Ec 12
217PTMC	--	--	59	74.5	06-20-62	250	48	16.13	P	QW Drilled to 146 ft.	HA Ec 13
217PTMC	--	--	92.71	133.79	08-06-62	300	72	7.30	P	Drilled to 187 ft.	HA Ec 14
--	--	--	--	--	--	--	--	--	U	SPE; test hole to 239 ft; destroyed.	HA Ec 19
--	--	--	--	--	--	--	--	--	U	Test hole to 145 ft; destroyed.	HA Ec 22
--	--	--	--	--	--	--	--	--	U	Test hole to 191.5 ft; destroyed.	HA Ec 27
217PTMC	68.39	04-22-87	74.67	122.33	05-06-63	280	72	5.87	P	Drilled to 161 ft.	HA Ec 33
--	--	--	--	--	--	--	--	--	U	Test hole to 209 ft; destroyed.	HA Ec 40
217PTMC	--	--	36	91	07-06-72	201	8	3.65	P	Drilled to 123.5 ft.	HA Ec 43
217PTMC	29.53	11-17-86	28	38	09-29-83	10	3	1.00	H		HA Ec 44
217PTMC	--	--	45	59	07-20-71	15	4	1.07	H		HA Ec 45
217PTMC	16.08	05-13-88	--	--	--	--	--	--	U	QW; GAM,SPE,MPE Drilled to 180 ft.	HA Ec 46
112TLBT	18.17	05-12-88	9	--	11-21-87	--	--	--	U		HA Ec 47
217PPSC	9.78	08-08-88	--	--	--	--	--	--	U		HA Ed 24
217PTMC	--	--	37	185	11-07-69	250	12	1.69	N	QW Drilled to 277 ft.	HA Ed 32
217PTMC	--	--	87	97	09-20-73	10	1	1.00	U		HA Ed 33
217PTMC	75.80	11-17-86	76	85	07-31-86	12	3	1.33	H		HA Ed 34
217PTMC	32.67	11-17-86	34	43	09-03-86	25	3	2.78	H		HA Ed 35
217PTMC	52.78	04-21-87	48	58	05-04-82	30	3	3.00	H	QW	HA Ed 36
217PTMC	95.46	12-01-86	110	120	12-15-77	25	2	2.50	H		HA Ed 37
217PTMC	17.20	11-17-86	17	27	06-12-78	60	2	6.00	H		HA Ed 38
217PTMC	32.77	11-17-86	32	42	08-17-77	20	2	2.00	H	QW	HA Ed 39
217PTMC	31.46	01-08-87	32	42	05-28-83	50	3	5.00	H	QW	HA Ed 40
217PTMC	93.90	01-13-86	94	104	11-10-80	12	2	1.20	H		HA Ed 41
217PTMC	40.30	04-21-87	30	40	10-06-78	30	2	3.00	H		HA Ed 43
217PTMC	47.47	04-21-87	47	57	02-22-83	30	3	3.00	H		HA Ed 44
217PTMC	69.80	04-22-87	71	100	10-07-74	60	2	2.07	U		HA Ed 45
217PTMC	47.80	05-16-88	47	120	01-18-88	25	8	0.34	U	GAM,SPE,MPE Drilled to 240 ft.	HA Ed 46
217PTMC	71.94	08-03-88	74.6	101.7	02-29-88	7	4	0.26	U	QW; GAM,SPE,MPE Drilled to 277 ft.	HA Ed 47
217PTMC	61.69	06-28-88	65	95.7	03-17-88	15	4	0.49	U	QW Drilled to 140 ft.	HA Ed 48
112TLBT	12.63	05-12-88	15	18.2	03-21-88	9	4	2.81	U	QW Drilled to 32 ft.	HA Ed 49
217PTMC	--	--	47	135	05-10-88	125	4	1.42	U	GAM,SPE,MPE	HA Ed 50

Table 12.—Chemical analyses of major dissolved constituents and nutrients in ground water from selected wells in the Coastal Plain and Piedmont aquifers of Harford County, Maryland

[µS/cm = microsiemens per centimeter; µg/L = micrograms per liter; mg/L = milligrams per liter; deg C = degrees Celsius; < = less than; * = analysis performed on filtered sample and lab value used in place of field; -- = data not collected; 110ALVM = Quaternary Alluvium; 112TLBT = Talbot Formation; 217PTMC = Potomac Group; 300JMSR = James Run Gneiss; 300MBAB = Metagabbro and Amphibolite; 300LPLC = Lower Pelitic Schist of Wissahickon Formation; 300PRDP = Port Deposit Gneiss; 400BLMR = Baltimore Gneiss]

Well number	Aquifer	Geologic unit	Date	Specific conductance (µS/cm)	pH (standard units)	Temperature water (deg C.)	Color (platinum-cobalt units)	Oxygen, dissolved (mg/L)	Hardness total (mg/L as CaCO3)	Hardness, noncarbonate, total (mg/L as CaCO3)	Calcium, dissolved (mg/L as Ca)
HA Cf 114	1	112TLBT	05-08-87	270	6.80	14.0	3	<0.1	110	0	28
HA Cf 115	1	112TLBT	05-06-74	195	8.20	--	2	--	75	0	21
HA Cf 165	1	112TLBT	07-19-74	142	7.20	--	0	--	33	19	7.5
HA Cf 173	P	300MBAB	08-31-87	246	7.69	15.0	--	3.0	130	16	38
HA Dc 74	1	217PTMC	02-12-74	52	5.80	--	--	--	15	3	4.5
HA Dc 81	P	300PRDP	04-19-74	122	6.40	--	2	--	53	5	18
HA Dc 117	2	217PTMC	05-29-87	25	5.20	14.5	1	5.7	3	1	.72
HA Dc 118	2	217PTMC	05-18-87	56	4.89	15.0	1	8.0	5	2	1.2
HA Dc 119	P	300PRDP	09-01-87	163	6.95	17.0	--	<.1	67	4	22
HA Dd 10	P	300LPLC	03-19-54	180	7.30	8.5	25	--	80	0	20
HA Dd 29	P	300JMSR	10-05-54	115	7.20	12.5	2	--	46	0	9.7
HA Dd 54	P	400BLMR	05-24-74	103	6.80	--	100	--	35	0	8.5
HA Dd 71	3	217PTMC	09-03-87	115	4.76	15.0	--	7.5	23	19	4.6
HA Dd 73	3	217PTMC	06-10-87	64	5.12	15.0	--	.3	13	8	2.5
HA Dd 75	2	217PTMC	05-29-87	44	5.30	18.0	2	1.2	3	0	.55
HA Dd 79	3	217PTMC	05-18-87	68	5.14	28.0	1	6.7	16	13	3.5
HA Dd 86	P	110ALVM	09-03-87	444	6.26	18.0	--	.8	190	96	55
HA Dd 87	P	300JMSR	09-04-87	155	6.94	14.0	--	<.1	73	12	18
HA Dd 89	2	217PTMC	04-20-88	42	5.51	14.0	4	8.2	7	3	1.5
HA Dd 91	2	112TLBT	04-15-88	73	6.22	14.0	2	2.3	6	0	1.3
HA Dd 92	1	112TLBT	04-07-88	292	6.11	14.0	2	<.1	61	3	9.8
HA Dd 92	1	112TLBT	07-19-88	360	6.09	15.0	--	--	71	16	12
HA Dd 92	1	112TLBT	01-17-89	361	5.90	16.0	--	--	74	24	13
HA Dd 106	4	217PTMC	06-30-88	96	6.45	17.0	17	<.1	23	0	5.2
HA De 28	3	217PTMC	03-04-74	112	5.30	--	--	--	30	29	6.6
HA De 64	3	217PTMC	09-04-87	140	5.36	12.0	--	7.9	51	49	9.3
HA De 73	3	217PTMC	06-03-87	127	5.32	14.0	1	6.5	51	47	11
HA De 85	2	217PTMC	05-08-87	27	5.50	13.5	1	3.8	6	2	1.3
HA De 86	2	112TLBT	06-10-87	135	5.24	13.0	--	4.6	31	23	5.9
HA De 86	2	112TLBT	10-01-73	118	5.60	--	--	--	30	21	5.8
HA De 128	1	112TLBT	02-18-76	--	--	--	1	--	12	5	1.5
HA De 129	3	217PTMC	02-18-76	--	--	--	2	--	21	13	4.0
HA De 150	3	217PTMC	05-07-87	31	5.48	13.0	1	7.5	7	2	1.7
HA De 168	2	112TLBT	05-18-87	129	6.33	14.0	2	--	30	0	5.9
HA De 169	2	217PTMC	05-06-87	293	4.70	15.0	1	4.6	60	53	9.7
HA De 179	1	112TLBT	09-03-87	150	5.15	13.0	--	4.0	26	21	3.9
HA De 180	1	217PTMC	09-03-87	428	6.56	16.0	--	<.1	180	110	36
HA De 181	4	217PTMC	04-13-88	186	6.60	7.0	2	.9	41	0	8.2
HA De 182	1	112TLBT	03-31-88	138	5.65	15.0	3	2.8	24	5	4.3
HA De 183	3	217PTMC	04-19-88	46	5.32	14.0	4	<.1	5	0	1.1
HA De 190	2	112TLBT	06-10-87	166	5.34	14.0	--	7.2	63	59	9.2
HA De 195	2	112TLBT	04-12-88	178	5.56	14.0	2	7.5	58	51	11
HA De 197	3	217PTMC	04-06-88	49	6.12	13.5	1	.1	11	0	2.8
HA De 198	1	112TLBT	08-25-88	177	4.47	15.0	25	7.7	60	59	12
HA Ec 13	2	217PTMC	06-03-87	93	4.85	13.0	1	7.1	10	8	1.6
HA Ec 13	2	217PTMC	09-04-87	--	4.96	--	--	--	--	--	--
HA Ec 46	2	217PTMC	08-23-88	207	7.10	14.0	<1	1.2	56	0	15
HA Ed 32	4	217PTMC	06-11-87	54	5.79	14.0	1	.2	11	0	2.4
HA Ed 36	2	217PTMC	05-07-87	33	4.51	13.0	1	2.7	3	2	.61
HA Ed 39	2	217PTMC	09-01-87	29	5.00	--	--	--	5	2	1.3
HA Ed 40	3	217PTMC	05-06-87	18	5.23	14.0	1	6.9	3	0	.65
HA Ed 47	3	217PTMC	03-30-88	40	5.45	14.0	2	7.1	8	4	1.8
HA Ed 48	2	217PTMC	04-27-88	34	5.13	13.0	3	8.2	17	15	3.6
HA Ed 49	1	112TLBT	03-29-88	400	4.95	12.0	2	.4	200	200	37
HA Ed 49	1	112TLBT	07-19-88	315	4.64	13.0	--	--	110	100	19
HA Ed 49	1	112TLBT	01-19-89	174	4.69	13.0	--	--	48	44	9.3

Table 12.—Chemical analyses of major dissolved constituents and nutrients in ground water from selected wells in the Coastal Plain and Piedmont aquifers of Harford County, Maryland—Continued

[µS/cm = microsiemens per centimeter; µg/L = micrograms per liter; mg/L = milligrams per liter; deg C = degrees Celsius; < = less than; * = analysis performed on filtered sample and lab value used in place of field; -- = data not collected; 110ALVM = Quaternary Alluvium; 112TLBT = Talbot Formation; 217PTMC = Potomac Group; 300JMSR = James Run Gneiss; 300MBAB = Metagabbro and Amphibolite; 300LPLC = Lower Pelitic Schist of Wissahickon Formation; 300PRDP = Port Deposit Gneiss; 400BLMR = Baltimore Gneiss]

Well number	Aquifer	Geologic unit	Date	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Bicarbonate, field (mg/L as HCO3)	Sulfate dissolved (mg/L as SO4)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO2)	Solids, residue at 180 deg. C dissolved (mg/L)
HA Cf 114	1	112TLBT	05-08-87	8.7	13	2.4	170	5.7	10	0.20	12	152
HA Cf 115	1	112TLBT	05-06-74	5.4	15	1.4	110	3.0	1.7	.20	13	--
HA Cf 165	1	112TLBT	07-19-74	3.4	9.6	.70	17	1.5	21	<.10	23	--
HA Cf 173	P	300MBAB	08-31-87	7.6	6.9	1.8	130	4.9	3.4	.10	28	163
HA Dc 74	1	217PTMC	02-12-74	.90	2.3	1.0	15	3.4	4.7	.10	8.7	--
HA Dc 81	P	300PRDP	04-19-74	2.0	2.0	1.6	59	4.4	4.6	.10	9.3	--
HA Dc 117	2	217PTMC	05-29-87	.37	2.0	.40	3	.40	3.9	<.10	6.6	15
HA Dc 118	2	217PTMC	05-18-87	.53	2.2	.50	3	<5.0	4.0	<.10	5.6	21
HA Dc 119	P	300PRDP	09-01-87	2.9	5.5	3.3	77	17	1.4	.20	49	128
HA Dd 10	P	300LPLC	03-19-54	7.2	5.9	1.9	110	1.0	2.5	<.05	43	140
HA Dd 29	P	300JMSR	10-05-54	5.4	3.2	1.1	66	.80	2.4	.10	19	80
HA Dd 54	P	400BLMR	05-24-74	3.3	3.6	2.6	49	4.3	2.6	<.10	25	--
HA Dd 71	3	217PTMC	09-03-87	2.7	11	1.2	4	4.5	24	.10	8.8	64
HA Dd 73	3	217PTMC	06-10-87	1.6	5.1	.80	6	11	5.6	<.10	8.4	44
HA Dd 75	2	217PTMC	05-29-87	.39	6.9	.20	10	1.8	6.2	<.10	7.5	29
HA Dd 79	3	217PTMC	05-18-87	1.7	3.9	1.0	3	<5.0	6.0	<.10	7.5	45
HA Dd 86	P	110ALVM	09-03-87	13	45	2.5	120	23	140	.10	19	380
HA Dd 87	P	300JMSR	09-04-87	6.9	4.9	3.5	74	10	6.7	.30	41	129
HA Dd 89	2	217PTMC	04-20-88	.70	2.6	.70	4	0.80	3.5	.10	7.4	28
HA Dd 91	2	112TLBT	04-15-88	.55	4.2	.80	20	1.9	3.7	.10	7.5	29
HA Dd 92	1	112TLBT	04-07-88	8.9	35	1.0	71	23	55	.20	34	209
HA Dd 92	1	112TLBT	07-19-88	9.9	34	1.5	67	20	63	.30	33	--
HA Dd 92	1	112TLBT	01-17-89	10	38	1.1	60	29	68	.20	34	--
HA Dd 106	4	217PTMC	06-30-88	2.5	7.6	1.1	*30	11	2.5	.10	9.4	47
HA De 28	3	217PTMC	03-04-74	3.4	5.6	1.7	3	2.7	10	.20	9.1	--
HA De 64	3	217PTMC	09-04-87	6.8	4.5	2.1	3	11	10	.10	11	90
HA De 73	3	217PTMC	06-03-87	5.8	5.4	2.8	6	3.7	16	<.10	9.9	114
HA De 85	2	217PTMC	05-08-87	.64	2.2	.40	5	0.30	1.8	<.10	12	25
HA De 86	2	112TLBT	06-10-87	4.0	11	1.6	10	9.5	24	<.10	15	93
HA De 86	2	112TLBT	10-01-73	3.7	9.5	1.5	11	6.7	19	.30	14	--
HA De 128	1	112TLBT	02-18-76	1.9	1.8	8.0	8	9.0	3.0	.10	6.5	--
HA De 129	3	217PTMC	02-18-76	2.7	3.3	1.2	10	2.5	7.0	.10	9.0	--
HA De 150	3	217PTMC	05-07-87	.62	2.2	.60	6	<.20	2.0	<.10	9.2	30
HA De 168	2	112TLBT	05-18-87	3.7	7.4	.80	69	<5.0	9.0	<.10	39	105
HA De 169	2	217PTMC	05-06-87	8.6	32	2.7	8	6.1	73	<.10	13	205
HA De 179	1	112TLBT	09-03-87	4.0	17	2.2	7	.60	34	.10	10	96
HA De 180	1	217PTMC	09-03-87	22	16	1.7	84	10	110	.10	41	305
HA De 181	4	217PTMC	04-13-88	4.9	20	1.4	57	43	7.4	.10	15	119
HA De 182	1	112TLBT	03-31-88	3.1	16	1.8	23	11	16	.10	17	92
HA De 183	3	217PTMC	04-19-88	.57	3.2	.50	7	7.7	5.2	.10	8.5	34
HA De 190	2	112TLBT	06-10-87	9.7	2.6	2.2	4	6.1	12	<.10	9.6	128
HA De 195	2	112TLBT	04-12-88	7.3	9.7	3.4	8	14	26	.10	13	128
HA De 197	3	217PTMC	04-06-88	.87	2.6	.90	19	7.3	1.8	.10	9.4	31
HA De 198	1	112TLBT	08-25-88	7.2	8.3	3.1	--	22	14	.10	9.2	123
HA Ec 13	2	217PTMC	06-03-87	1.4	13	.60	2	2.7	24	<.10	8.1	55
HA Ec 13	2	217PTMC	09-04-87	--	--	--	--	--	--	--	--	--
HA Ec 46	2	217PTMC	08-23-88	4.5	23	4.9	130	5.9	6.6	.30	15	126
HA Ed 32	4	217PTMC	06-11-87	1.3	5.1	.70	16	7.2	3.5	<.10	9.0	35
HA Ed 36	2	217PTMC	05-07-87	.31	2.0	.30	--	5.7	1.7	<.10	7.6	21
HA Ed 39	2	217PTMC	09-01-87	.31	2.4	6.7	3	3.8	2.7	.10	7.3	22
HA Ed 40	3	217PTMC	05-06-87	.25	1.4	.30	6	1.5	1.8	<.10	7.5	15
HA Ed 47	3	217PTMC	03-30-88	.73	2.9	.80	5	1.1	3.8	.10	7.7	31
HA Ed 48	2	217PTMC	04-27-88	1.9	5.6	.70	2	3.5	9.3	.20	21	60
HA Ed 49	1	112TLBT	03-29-88	26	15	4.0	4	210	21	.90	11	355
HA Ed 49	1	112TLBT	07-19-88	14	5.3	2.7	2	110	8.7	.70	9.6	--
HA Ed 49	1	112TLBT	01-19-89	6.0	3.0	4.2	5	45	4.6	.20	9.1	--

Table 12.—Chemical analyses of major dissolved constituents and nutrients in ground water from selected wells in the Coastal Plain and Piedmont aquifers of Harford County, Maryland—Continued

[µS/cm = microsiemens per centimeter; µg/L = micrograms per liter; mg/L = milligrams per liter; deg C = degrees Celsius; < = less than; * = analysis performed on filtered sample and lab value used in place of field; -- = data not collected; 110ALVM = Quaternary Alluvium; 112TLBT = Talbot Formation; 217PTMC = Potomac Group; 300JMSR = James Run Gneiss; 300MBAB = Metagabbro and Amphibolite; 300LPLC = Lower Pelitic Schist of Wissahickon Formation; 300PRDP = Port Deposit Gneiss; 400BLMR = Baltimore Gneiss]

Well number	Aquifer	Geologic unit	Date	Solids, sum of constituents, dissolved (mg/L)	Nitrogen, NO_2+ NO_3 total (mg/L as N)	Phosphorus total (mg/L as P)	Carbon, organic total (mg/L as C)	Iron, total recoverable (µg/L as Fe)	Iron, dissolved (µg/L as Fe)	Manganese, total recoverable (µg/L as Mn)	Manganese, dissolved (µg/L as Mn)
HA Cf 114	1	112TLBT	05-08-87	166	<0.100	0.160	0.1	7,100	1,900	180	180
HA Cf 115	1	112TLBT	05-06-74	118	.250	<.010	--	6,400	--	190	--
HA Cf 165	1	112TLBT	07-19-74	83	1.70	.010	--	100	--	130	--
HA Cf 173	P	300MBAB	08-31-87	157	.700	.010	< .1	30	6	<10	<1
HA Dc 74	1	217PTMC	02-12-74	33	.100	--	--	90	--	30	--
HA Dc 81	P	300PRDP	04-19-74	71	.070	.010	--	30	--	40	--
HA Dc 117	2	217PTMC	05-29-87	16	.200	<.010	.3	<10	4	<10	8
HA Dc 118	2	217PTMC	05-18-87	--	1.30	.010	<.1	10	6	20	18
HA Dc 119	P	300PRDP	09-01-87	142	<.100	.010	.1	3,200	3,000	200	210
HA Dd 10	P	300LPLC	03-19-54	138	*.100	--	--	680	--	50	--
HA Dd 29	P	300JMSR	10-05-54	75	*.800	--	--	88,000	--	1,400	--
HA Dd 54	P	400BLMR	05-24-74	75	.200	.020	--	170	--	40	--
HA Dd 71	3	217PTMC	09-03-87	59	1.80	<.010	.3	70	43	30	29
HA Dd 73	3	217PTMC	06-10-87	38	<.100	.030	.3	80	70	90	97
HA Dd 75	2	217PTMC	05-29-87	28	.300	<.010	2.1	70	55	<10	5
HA Dd 79	3	217PTMC	05-18-87	--	4.60	.050	<.1	80	16	20	19
HA Dd 86	P	110ALVM	09-03-87	360	<.100	<.010	1.6	350	250	3,600	3,900
HA Dd 87	P	300JMSR	09-04-87	132	<.100	.010	.2	4,100	4,200	300	320
HA Dd 89	2	217PTMC	04-20-88	19	<.100	<.010	<.1	90	58	20	24
HA Dd 91	2	112TLBT	04-15-88	30	.200	<.010	<.1	140	170	20	22
HA Dd 92	1	112TLBT	04-07-88	208	.100	.160	1.5	6,600	6,300	180	180
HA Dd 92	1	112TLBT	07-19-88	214	<.100	.040	--	6,300	7,000	200	200
HA Dd 92	1	112TLBT	01-17-89	230	<.100	.020	--	5,700	6,500	190	190
HA Dd 106	4	217PTMC	06-30-88	61	--	--	--	7,000	6,800	110	120
HA De 28	3	217PTMC	03-04-74	75	7.60	--	--	60	--	20	--
HA De 64	3	217PTMC	09-04-87	57	8.60	.010	.2	<10	7	40	30
HA De 73	3	217PTMC	06-03-87	58	12.0	.030	1.0	20	29	20	17
HA De 85	2	217PTMC	05-08-87	21	.900	<.010	2.1	10	5	20	4
HA De 86	2	112TLBT	06-10-87	76	1.90	.020	.4	30	7	180	180
HA De 86	2	112TLBT	10-01-73	75	2.10	--	--	150	--	100	--
HA De 128	1	112TLBT	02-18-76	36	2.20	.010	--	150	--	<10	--
HA De 129	3	217PTMC	02-18-76	35	5.20	.010	--	110	--	<10	--
HA De 150	3	217PTMC	05-07-87	--	1.30	.010	.2	<10	6	<10	<1
HA De 168	2	112TLBT	05-18-87	--	<.100	.320	.9	13,000	15,000	260	300
HA De 169	2	217PTMC	05-06-87	149	<.100	<.010	<.1	<10	8	30	31
HA De 179	1	112TLBT	09-03-87	76	5.10	<.010	.1	130	100	20	18
HA De 180	1	217PTMC	09-03-87	295	.200	<.010	.2	16,000	17,000	340	340
HA De 181	4	217PTMC	04-13-88	136	.600	<.010	<.1	7,700	8,000	190	200
HA De 182	1	112TLBT	03-31-88	81	2.70	<.010	4.4	250	260	100	130
HA De 183	3	217PTMC	04-19-88	34	<.100	<.010	.2	3,300	3,500	30	40
HA De 190	2	112TLBT	06-10-87	54	14	.020	.9	730	330	50	50
HA De 195	2	112TLBT	04-12-88	89	10	.110	.1	230	190	120	130
HA De 197	3	217PTMC	04-06-88	38	<.100	.120	.8	3,100	2,600	70	72
HA De 198	1	112TLBT	08-25-88	77	11.0	<.010	1.3	--	23	--	60
HA Ec 13	2	217PTMC	06-03-87	53	1.10	.020	1.1	<10	5	70	51
HA Ec 13	2	217PTMC	09-04-87	--	--	--	--	--	20	--	70
HA Ec 46	2	217PTMC	08-23-88	142	.100	<.010	5.2	3,300	2,800	350	350
HA Ed 32	4	217PTMC	06-11-87	38	<.100	.020	.7	580	590	40	44
HA Ed 36	2	217PTMC	05-07-87	19	.100	<.010	<.1	<10	45	<10	46
HA Ed 39	2	217PTMC	09-01-87	26	.700	<.010	.1	20	17	20	27
HA Ed 40	3	217PTMC	05-06-87	17	.200	.020	.2	<10	6	<10	9
HA Ed 47	3	217PTMC	03-30-88	22	1.80	<.010	.1	360	510	10	28
HA Ed 48	2	217PTMC	04-27-88	49	<.100	.010	8.0	2,000	2,400	50	80
HA Ed 49	1	112TLBT	03-29-88	332	1.10	<.010	2.1	80	22	4,800	4,900
HA Ed 49	1	112TLBT	07-19-88	173	1.00	.010	--	90	6	3,100	2,400
HA Ed 49	1	112TLBT	01-19-89	85	1.00	<.010	3.0	60	16	1,200	1,300

Table 13.—Chemical analyses of dissolved trace metals in ground water from selected wells in the Coastal Plain and Piedmont aquifers of Harford County, Maryland.

[μg/L = micrograms per liter; -- = data not collected; < = less than]

Well number	Date	Aluminum (μg/L as Al)	Antimony (μg/L as Sb)	Arsenic (μg/L as As)	Barium (μg/L as Ba)	Beryllium (μg/L as Be)	Cadmium (μg/L as Cd)	Chromium (μg/L as Cr)	Cobalt (μg/L as Co)
HA Dd 86	09-03-87	<10	<1	<1	110	8	<1	<1	<1
HA De 64	09-04-87	20	<1	<1	110	<.5	<1	1	3
HA De 179	09-03-87	20	<1	<1	76	<.5	<1	1	2
HA Ec 13	09-04-87	80	<1	3	<100	<10	<1	4	10

Well number	Date	Copper (μg/L as Cu)	Lead (μg/L as Pb)	Mercury (μg/L as Hg)	Molybdenum (μg/L as Mo)	Nickel (μg/L as Ni)	Selenium (μg/L as Se)	Silver (μg/L as Ag)	Strontium (μg/L as Sr)	Zinc (μg/L as Zn)
HA Dd 86	09-03-87	57	<5	.2	<1	<1	<1	<1	220	1,100
HA De 64	09-04-87	4	<5	<.1	<1	15	<1	<1	72	60
HA De 179	09-03-87	4	<5	<.1	<1	10	<1	<1	47	350
HA Ec 13	09-04-87	12	<5	.2	<1	10	1	<1	30	40

Table 14.—Chemical analyses of isotopes in ground water from selected wells in the Coastal Plain and Piedmont aquifers of Harford County, Maryland.

[-- = data not collected]

Well number	Date	$\delta^{13}C$ stable isotope ratio per mil	$\delta^{2}H$ stable isotope ratio per mil	$\delta^{18}O$ stable isotope ratio per mil	Carbon-14 percent modern	Tritium, picocuries per liter
HA Dd 71	09-03-87	-14.90	-45.5	-7.50	--	--
HA Dd 86	09-03-87	-13.30	-43.0	-7.10	--	--
HA Dd 106	06-30-88	-21.00	--	--	--	1.28
HA De 64	09-04-87	-21.00	-45.0	-7.50	101	--
HA De 179	09-03-87	-21.20	-44.0	-7.35	--	--
HA De 181	04-13-88	-21.50	--	--	--	--
HA De 183	04-19-88	-21.30	--	--	--	--
HA Ec 13	09-04-87	--	-45.0	-7.40	105	--

Table 15.—Chemical analyses of major dissolved constituents and nutrients in surface water from selected streamflow-gaging stations in the Coastal Plain of Harford County, Maryland

[μS/cm = microsiemens per centimeter at 25° Celsius; deg. C = degrees Celsius; mg/L = milligrams per liter; μg/L = micrograms per liter; -- = data not collected; < = less than]

Date	Discharge, instantaneous cubic feet per second	Specific conductance (μS/cm)	pH (units)	Temperature (deg. C)	Temperature (deg. C)	Color (platinum-cobalt units)	Oxygen dissolved (mg/L)	Hardness total (mg/L as $CaCO_3$)	Hardness noncarbonate (mg/L as $CaCO_3$)
			01581650 James Run at Bush, Maryland						
08-27-87	0.64	214	7.01	19.0	23.0	--	7.7	70	8
04-26-88	8.2	--	7.38	10.0	11.0	--	12.8	61	23
08-17-88	1.0	238	7.21	23.5	28.5	1	7.0	83	23
			01581651 James Run Bynum Run at Bush, Maryland						
08-27-87	0.51	209	7.33	19.0	21.0	--	7.6	80	15
04-26-88	8.3	--	7.37	10.0	11.0	--	11.6	61	21
08-17-88	1.0	230	7.22	23.0	28.5	2	6.9	83	22
			01581657 Cranberry Run at Aberdeen, Maryland						
08-26-87	0.19	212	7.07	17.5	23.5	--	9.6	49	37
04-25-88	1.9	200	7.38	11.0	14.0	--	13.1	49	24
08-17-88	0.23	250	6.44	22.0	31.5	2	8.2	52	39
			01581658 Cranberry Run at Perryman, Maryland						
04-30-87	2.2	210	6.98	14.0	17.0	--	12.0	49	30
08-26-87	0.56	153	7.78	17.0	22.0	--	8.9	45	30
04-25-88	2.8	204	6.94	12.5	15.0	--	14.4	48	28
08-17-88	0.83	207	6.64	21.5	31.5	1	9.0	51	37
			01581671 Haha Branch near Abingdon, Maryland						
04-30-87	--	119	6.76	14.0	19.0	--	10.8	19	12
08-26-87	17	102	6.51	17.5	21.5	--	8.5	23	8
04-25-88	0.70	123	7.34	9.5	14.0	--	11.1	22	10
08-17-88	0.20	118	6.69	21.0	24.0	32	7.0	26	7
			01581754 Winters Run near Edgewood, Maryland						
08-27-87	8.5	136	8.26	23.0	29.0	--	9.6	46	10
08-27-87	8.5	136	8.26	23.0	30.0	--	9.3	49	13
04-25-88	53	141	8.70	16.5	17.0	--	11.9	43	18
08-17-88	14	145	9.18	29.0	32.0	3	10.7	46	15
			01581755 Winters Run at Route 7 near Edgewood, Maryland						
08-27-87	14	140	7.03	23.0	30.0	--	9.3	51	14
04-25-88	53	141	8.36	15.0	17.0	--	14.6	43	19
08-17-88	13	152	8.71	28.0	31.5	1	9.7	50	16
			01585072 Foster Branch at Joppatowne, Maryland						
04-30-87	0.19	214	6.85	13.0	13.0	--	9.9	53	23

Table 15.—Chemical analyses of major dissolved constituents and nutrients in surface water from selected streamflow-gaging stations in the Coastal Plain of Harford County, Maryland—Continued

[µS/cm = microsiemens per centimeter at 25° Celsius; deg. C = degrees Celsius; mg/L = milligrams per liter; µg/L = micrograms per liter; -- = data not collected; < = less than]

Date	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as as K)	Bicarbonate, field (mg/L as HCO3)	Sulfate, dissolved (mg/L as SO 4)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO 2)
				01581650 James Run at Bush, Maryland					
08-27-87	14	8.5	14	2.6	76	20	16	0.10	20
04-26-88	14	6.3	9.1	1.3	46	17	15	.10	10
08-17-88	20	8.1	12	2.7	73	22	16	.10	12
				01581651 James Run above Bynum Run at Bush, Maryland					
08-27-87	19	7.9	12	2.6	79	19	16	.10	10
04-26-88	14	6.4	9.1	1.2	49	16	14	.10	9.9
08-17-88	20	8.0	11	2.8	74	23	16	.10	12
				01581657 Cranberry Run at Aberdeen, Maryland					
08-26-87	8.5	6.8	21	2.3	15	10	46	.10	11
04-25-88	10	5.9	16	1.0	31	16	31	.10	10
08-17-88	9.2	7.1	21	2.2	16	6.7	46	<.10	11
				01581658 Cranberry Run at Perryman, Maryland					
04-30-87	9.9	5.8	15	1.8	23	11	32	<.10	8.6
08-26-87	8.6	5.6	13	2.8	18	9.5	22	.10	8.8
04-25-88	9.8	5.7	15	1.4	24	14	30	.10	8.9
08-17-88	9.7	6.4	14	2.4	16	8.2	29	<.10	8.4
				01581671 Haha Branch near Abingdon, Maryland					
04-30-87	4.4	2.0	12	1.2	9	13	20	<.10	6.9
08-26-87	5.8	2.1	9.7	2.4	18	17	13	.20	6.9
04-25-88	5.0	2.2	12	1.1	14	14	17	.10	7.2
08-17-88	6.2	2.6	11	1.5	23	10	16	.10	7.7
				01581754 Winters Run near Edgewood, Maryland					
08-27-87	10	5.1	6.7	2.3	44	10	13	.10	8.1
08-27-87	11	5.3	7.0	2.4	44	9.5	12	.10	8.5
04-25-88	9.5	4.8	7.3	1.5	32	11	12	.10	8.9
08-17-88	10	5.2	7.5	2.2	38	9.2	13	.10	8.6
				01581755 Winters Run at Route 7 near Edgewood, Maryland					
08-27-87	11	5.6	7.0	2.5	44	10	13	.10	8.3
04-25-88	9.5	4.8	7.6	1.6	30	11	13	.10	8.8
08-17-88	11	5.5	7.3	2.4	42	8.7	13	.10	7.4
				01585072 Foster Branch at Joppatowne, Maryland					
04-30-87	14	4.3	16	3.0	36	21	26	.10	5.2

Table 15.—Chemical analyses of major dissolved constituents and nutrients in surface water from selected streamflow-gaging stations in the Coastal Plain of Harford County, Maryland—Continued

[µS/cm = microsiemens per centimeter at 25° Celsius; deg. C = degrees Celsius; mg/L = milligrams per liter; µg/L = micrograms per liter; -- = data not collected; < = less than]

Date	Solids, residue at 180 deg. C dissolved (mg/L)	Solids, sum constituents dissolved (mg/L)	Nitrogen, $NO_2 + NO_3$ total (mg/L as N)	Phosphorus total (mg/L as P)	Carbon, organic total (mg/L as C)	Iron, total recoverable (µg/L as Fe)	Iron, dissolved (µg/L as Fe)	Manganese, total recoverable (µg/L as Mn)	Manganese, dissolved (µg/L as Mn)
			01581650 James Run at Bush, Maryland						
08-27-87	126	133	0.900	0.030	2.7	290	21	90	3
04-26-88	108	96	1.60	.010	--	120	44	20	20
08-17-88	133	129	1.30	.030	3.3	470	110	140	120
			01581651 James Run above Bynum Run at Bush, Maryland						
08-27-87	136	126	.800	.030	2.6	500	72	100	86
04-26-88	107	95	1.50	.010	--	210	82	40	42
08-17-88	140	130	1.00	.030	3.4	980	210	210	170
			01581657 Cranberry Run at Aberdeen, Maryland						
08-26-87	156	113	4.30	.020	1.9	360	66	80	70
04-25-88	113	106	.800	<.010	3.2	340	170	50	58
08-17-88	153	111	4.60	.020	2.0	740	93	130	76
			01581658 Cranberry Run at Perryman, Maryland						
04-30-87	123	96	2.60	.050	--	430	240	50	52
08-26-87	105	80	4.70	<.010	1.8	--	36	--	35
04-25-88	118	97	2.10	.010	3.4	320	130	40	46
08-17-88	122	86	5.30	.030	1.8	230	43	30	23
			01581671 Haha Branch near Abingdon, Maryland						
04-30-87	75	64	.200	.020	--	530	170	60	59
08-26-87	60	66	.200	.030	6.2	2,100	120	60	64
04-25-88	76	66	.300	.020	3.8	660	230	70	82
08-17-88	82	67	.100	.030	5.5	2,700	160	70	39
			01581754 Winters Run near Edgewood, Maryland						
08-27-87	88	77	1.30	.010	2.6	250	26	30	18
08-27-87	84	77	1.30	.020	2.5	250	23	40	18
04-25-88	80	71	2.20	.020	--	370	76	40	29
08-17-88	88	75	1.60	.020	2.7	270	68	40	10
			01581755 Winters Run at Route 7 near Edgewood, Maryland						
08-27-87	89	79	1.30	.020	2.6	340	15	40	31
04-25-88	84	72	2.20	.020	2.5	380	78	50	31
08-17-88	93	76	1.70	.020	2.7	300	81	40	21
			01585072 Foster Branch at Joppatowne, Maryland						
04-30-87	109	108	.800	.020	--	1,000	530	100	100

Table 16.—Chemical analysis of dissolved trace metals in surface water from station 01581658 Cranberry Run at Perryman in the Coastal Plain of Harford County, Maryland

[μg/L = micrograms per liter; -- = data not collected; < = less than]

Date	Aluminum (μg/L as Al)	Antimony (μg/L as Sb)	Arsenic (μg/L as As)	Barium (μg/L as Ba)	Beryllium (μg/L as Be)	Cadmium (μg/L as Cd)	Chromium (μg/L as Cr)	Cobalt (μg/L as Co)	Copper (μg/L as Cu)
08-26-87	<10	<1	<1	74	<0.5	<1	40	<1	1

Date	Lead (μg/L as Pb)	Mercury (μg/L as Hg)	Molybdenum (μg/L as Mo)	Nickel (μg/L as Ni)	Selenium (μg/L as Se)	Silver (μg/L as Ag)	Strontium (μg/L as Sr)	Zinc (μg/L as Zn)
08-26-87	<5	0.1	<1	6	<1	<1	70	75

Table 17.—Chemical analysis of isotopes in surface water from station 01581658 Cranberry Run at Perryman in the Coastal Plain of Harford County, Maryland

Date	$\delta^{13}C$ stable isotope ratio per mil	$\delta^{2}H$ stable isotope ratio per mil	$\delta^{18}O$ stable isotope ratio per mil
08-26-87	-15.20	-38.5	-6.70

Table 18.—Lithologic descriptions of drill cuttings from test wells in the Coastal Plain of Harford County, Maryland

Joppatowne
HA Ec 46, 47

Depth, in feet	Description
	Talbot Formation
0- 10	Sand, medium- to coarse-grained, with lithic fragments; some coarse, lithic gravel
	Potomac Group (Patuxent and Arundel Formations)
10- 30	Clay, white, pink and yellowish, silty
30- 35	Sand (?) (no recovery)
35- 55	Clay, medium gray, massive, micaceous, silty
55- 65	Clay, medium gray, with some mottling, red-brown, yellow, white, purple
65- 85	Sand, fine to medium, with some coarse sand and gravel; some fragments of iron-cemented sandstone
85- 95	Clay, mottled pink, white, brown, yellow, silty
95-105	Sand (?) cemented, very hard (no recovery)
105-135	Clay, yellow, white, gray, reddish brown
	Basement Complex (Wissahickon Formation (?))
135-170	Saprolite, greenish-yellow clay with abundant coarse muscovite
170-180	Rock, muscovite, quartz, staurolite, garnet, chlorite, biotite; some hard greenish and brown rock fragments

Edgewood
HA Dd 89, 102

Depth, in feet	Description
	Talbot Formation
0- 20	Sand, gravel (fill?)
	Potomac Group (Patapsco Formation)
20- 40	Silt, clay, white and pink
40- 42	Sand
42- 50	Clay, red, yellow, white, hard
50-100	Silt and clay, white, some yellow, soft; some reddish tan 85-95 ft
100-135	Sand, fine to medium, some white silt-clay
	(Patuxent Formation (?))
135-150	Silt, medium gray, clayey, abundant muscovite
150-200	Clay, mottled gray, red, yellow, white, brown; hard drilling; sandy layers at 165-168 ft, and 184-185 ft
200-240	Clay, medium gray, silty, abundant lignite, muscovite
	Basement Complex (James Run Gneiss(?))
240-257	Saprolite, medium to dark greenish-gray clay, sandy; abundant muscovite, chlorite
257-270	Rock, greenish-black chips

Willoughby Beach
HA De 181, 182, 183

Depth, in feet	Description
	Talbot Formation
0- 8	Clay, medium brown, some gray, silty
8- 10	Sand, coarse
10- 30	Clay, medium gray, reddish; silty; with lignite, peat
30- 41	Gravel, sand, quartz, iron-stained orange, greenish frosted grains, some feldspathic lithic fragments

Table 18.—Lithologic descriptions of drill cuttings from test wells in the Coastal Plain of Harford County, Maryland—Continued

Willoughby Beach--Continued
HA De 181, 182, 183

Depth, in feet	Description
	Potomac Group (Patapsco Formation(?))
41-107	Clay, red, some white and gray, yellow
	(Patuxent Formation)
107-170	Sand, reddish tan, fine, silty, clayey, massive, with abundant muscovite
170-175	Clay, mottled, white to light gray, tan, pink, silty
175-180	Clay, olive green, yellow
180-195	Clay, mottled red, yellow, white, olive
195-205	Clay, medium to dark gray, no silt, hard
205-210	Clay, mottled pink, white, yellow, gray
210-230	Clay, medium-dark gray, abundant lignite, muscovite
230-263	Clay, mottled red, white, yellow, brown, olive
263-280	Sand, white, coarse; streaks of clay
280-300	Clay, mottled gray, red, white, yellow
	Basement Complex (James Run Gneiss (?))
300-305	Saprolite, light and dark green clay with abundant muscovite and chlorite
305-317	Rock, greenish-black rock fragments

Cranberry Run Business Park
HA De 195

Depth, in feet	Description
	Talbot Formation
0- 14	Clay, medium brown, silt
14- 45	Sand, brown, medium- to coarse-grained; mostly brown quartz with abundant feldspar, chert, lithic fragments-well rounded; iron cemented at 32 ft; some very coarse gravel
	Potomac Group (Patuxent Formation(?))
45-114	Clay, mottled gray, reddish brown, yellow, purple; silty; with slickensides; layers of sand
114-130	Clay, mottled olive green to yellow, light medium-gray, some pink, red, white; thin layers of sand
130-135	Sand, coarse quartz
	Basement Complex (James Run Gneiss(?))
135-142	Saprolite, white and bluish gray silty clay; some quartz grains in matrix
142-164	Rock, greenish black, white rock fragments with quartz fragments

Long Bar Harbor
HA Dd 91, 92

Depth, in feet	Description
	Talbot Formation
0- 10	Clay, light brown and light gray; silty
10- 11	Sand
11- 20	Clay, medium bluish gray, abundant lignite
20- 38	Sand, medium to dark gray; medium- to very coarse-grained, gravel; abundant lignite, brown wood chunks
38- 64	Clay, dark gray; silty; abundant lignite; streaks of sand
64- 74	Sand, white; fine grained, silty; sparse lignite
	Potomac Group (Patuxent Formation)
74-125	Clay, mottled light gray and red; very hard; abundant muscovite, lignite; silty
125-137	Sand (?) (no recovery) abundant lignite some pyrite-cemented sandstone fragments
137-144	Clay, gray

Table 18.—Lithologic descriptions of drill cuttings from test wells in the Coastal Plain of Harford County, Maryland—Continued

Long Bar Harbor--Continued
HA Dd 91, 92

Depth, in feet	Description
	Basement Complex (James Run Gneiss(?))
144-184	Saprolite, weathered chlorite schist, light blue-green to gray with schistose structure; some harder areas, but mostly soft rock

Church Creek
HA De 197, 198, 199

Depth, in feet	Description
	Talbot Formation
0- 14	Clay, light brown, gray; silty, sandy
14- 19	Sand, coarse-grained to gravel, lignite
	Potomac Group (Patuxent Formation)
19- 21	Clay, pink, some medium gray
21- 30	Silt, clay, light gray
30- 50	Clay, red, mottled with light gray, yellow, reddish brown; sandy
50- 71	Sand, fine to medium; clayey, soft
71- 75	Clay, light gray and red; silty
75- 85	Lignite (?) no recovery
85-100	Clay, white and dark gray; sandy, hard
	Basement Complex (Setters Formation (?))
100-130	Saprolite, white clay with abundant (60 percent) muscovite, quartz grains
130-140	Rock, mica schist

Trimble Road
HA Ed 47, 48, 49

Depth, in feet	Description
	Talbot Formation
0- 30	Sand, gravel, bright yellow clay
	Potomac Group (Patapsco Formation(?))
30- 42	Clay, gray and red with sand streaks
42- 47	Gravel, and gray sandy clay
47- 70	Clay, mottled red, brown, white, and gray
70- 87	Sand, some clay
87-107	Clay, red, brown, white; tough; streaks of sand
	(Patuxent Formation(?))
107-133	Sand, medium to coarse
133-167	Clay, red, brown, dark gray, streaks of sand
167-202	Sand, white; fine; some gravel, coarse sand
202-237	Clay, mottled red, gray, white, brown, yellow; hard; some lignite, muscovite
237-251	Sand; fine, and gravel
	Basement Complex (James Run Gneiss (?))
251-265	Saprolite, clay, mixed; abundant muscovite
265-277	Rock, greenish-black fragments

Table 18.—Lithologic descriptions of drill cuttings from test wells in the Coastal Plain of Harford County, Maryland—Continued

Willoughby Woods
HA Dd 106

Depth, in feet	Description
	Talbot Formation
0- 20	Sand, brown and gravel
20- 38	Clay, light gray and tan, sandy; sand 23-28 ft
38- 48	Sand, coarse; sparse lignite
	Potomac Group (Patapsco Formation(?))
48-107	Clay, gray and red; sparse pyrite; some brown white, purple; sand layer 102-105 ft
	(Patuxent Formation(?))
107-130	Sand, fine
130-180	Clay, red and gray, some white and yellow; sandy layer 148-150 ft, 161-163 ft
180-240	Sand, white, coarse, clear; abundant lignite; clay layers at 205-207 ft, 218-222 ft, 228-230 ft, 238-240 ft
	Basement Complex
240-248	Saprolite, green to gray, abundant muscovite
248-260	Rock, greenish-black fragments

Table 19.—Lithologic descriptions of core samples from test wells in the Coastal Plain of Harford County, Maryland

Depth, in feet	Description
	Joppatowne **HA Ec 46, 47**
	Talbot Formation
5.0- 5.8	Sand, gravel, poorly sorted, very fine to coarse mostly fine; sand is quartz, clear, frosted, angular to sub-angular; gravel is quartz, cemented clasts, lithic fragments, sub-rounded to well-rounded; common muscovite, sparse pyrite
	Potomac Group (Patuxent and Arundel Formations)
40.0- 40.9	Silt, clayey, light gray, massive, some mottling with yellowish-brown; finely disseminated lignite
117.0-118.1	Clay, silty, mottled with light purplish-gray, reddish-brown, light gray, trace of yellow
	Edgewood **HA Dd 89, 102**
	Potomac Group (Patapsco Formation)
40.0- 41.0	Silt, sandy, white, with laminae (1-3 cm) of light pink, light purple and yellow; sand is fine, moderate sorting, sub-rounded to sub-angular; small (.5 cm) pyrite-cemented nodules
124.0-124.1	Sand, light brown, fine to medium-grained, sub-rounded to sub-angular; quartz, mostly frosted colorless, some yellow, some clear
	(Patuxent Formation (?))
140.0-140.5	Silt, clayey, medium gray, massive, with irregular pods of light gray silty clay; common muscovite, finely disseminated lignite
210.0-210.7	Silt, clayey, light gray mottled with streaks of yellow; finely disseminated lignite
	Willoughby Beach **HA De 181, 182, 183**
	Potomac Group (Patapsco Formation(?))
60.0- 61.9	Clay, silty, sandy, mottled dark reddish-brown, medium reddish-brown; clasts of white silt, about 1 cm in width; sand is very fine
	(Patuxent Formation)
120.0-121.2	Sand, light yellowish-brown with streaks of medium reddish-brown clay; fine to very fine grained, poorly sorted; quartz is clear, yellow iron stained, sub-rounded to sub-angular; common muscovite
180.0-180.5	Silt, sandy, light gray with some mottling of light olive, layers .5 cm thick of slightly darker, hard clay; sand is very fine, clear colorless, some frosted, sub-rounded to sub-angular; abundant dark minerals
220.4-220.5	Sand, silty, light gray, very fine to fine grained, poorly sorted; streaks of pink silt; quartz grains clear and frosted, colorless; sub-rounded to sub-angular; abundant muscovite, abundant lignite in large fragments up to 2 cm long
	Cranberry Run Business Park **HA De 195**
	Potomac Group (Patuxent Formation(?))
64.0- 65.2	Silt, clayey, sandy, some gravel, medium pink, mottled with reddish-brown, white, olive
114.0-115.2	Clay, silty, sandy, light gray, mottled with light pink, olive
	Basement Complex (James Run Gneiss(?))
135.0-135.8	Saprolite, greenish gray and white, in 1-cm layers; white layers are quartz and badly decomposed feldspar; gray layers are weathered chlorite

Table 19.—Lithologic descriptions of core samples from test wells in the Coastal Plain of Harford County, Maryland—Continued

Depth, in feet	Description
	Long Bar Harbor **HA Dd 91, 92**
	Talbot Formation
20.0- 21.0	Sand, clayey, dark brownish gray, very fine to silt, poorly sorted; quartz is clear colorless quartz, some yellow stained, angular to sub-angular; clayey layers 0.5 cm thick, gray, yellowish-brown; common muscovite
64.0- 65.0	Sand, silty, light gray, streaks of yellowish gray, very fine to coarse, poorly sorted; sand is clear, colorless quartz, some frosted, some yellow-stained, angular to sub-rounded; common dark minerals, sparse pyrite
	Potomac Group (Patuxent Formation)
124.0-124.8	Sand, silty, clayey, medium brownish-gray, mottled with light gray, fine to silt, poorly sorted, clear colorless quartz, angular to sub-angular; abundant dark minerals, pyrite, lignite and muscovite
	Church Creek **HA De 197, 198, 199**
	Talbot Formation
15.0- 16.4	Sand, light gray with layers 0.2-1.0 cm of medium yellow, fine, well sorted, clear colorless quartz, yellow staining in the yellow layers, angular to sub-rounded; abundant very fine dark minerals
	Potomac Group (Patuxent Formation)
25.0- 26.9	Silt, clayey, sandy, light gray with a dark brownish-gray sandy layer from 25.9 to 26.6; abundant lignite and muscovite
40.0- 41.5	Silt, clayey, medium reddish-brown, mottled with light gray, dark reddish-brown, yellow, olive
70.0- 71.0	Silt, clayey, light gray mottled with light pink, light salmon, medium reddish brown; abundant finely disseminated lignite
	Basement Complex (Setters Formation (?))
100.0-100.9	Saprolite, weathered muscovite-quartz schist; muscovite 90 percent, quartz clear, smokey, in 1-mm thick layers
	Willoughby Woods **HA Dd 106**
	Potomac Group (Patapsco Formation(?))
60.0- 60.9	Clay, silty, medium reddish-brown, mottled with brownish-yellow, light gray
	(Patuxent Formation(?))
160.0-160.9	Sand, light gray, interlayered with layers 1 mm to 3 cm thick of medium-gray, yellow, red, brownish-red clay; fine to very fine frosted colorless quartz, angular to sub-angular; common muscovite
	Basement Complex
240.0-241.4	Saprolite, medium greenish-gray mottled with white, purple, yellow; abundant chlorite, talc, quartz grains

Table 20.—Biostratigraphic analyses of test-well cores and outcrop samples from the Coastal Plain of Harford County, Maryland (by Gilbert J. Brenner)

[ACP = Atlantic Coastal Plain; ft = feet; -- = data not available]

Site name	Well number	Depth (ft)	Formation	Age	Paleoecology	Diagnostic species and discussion
Outcrop	(Hansen Road at Route 152)	0	--	--	--	BARREN
Joppatowne (Mariner Point Park)	HA Ec 47	117.0-118.0	--	--	--	BARREN
	HA Ec 46	40.0- 40.9	Patuxent and Arundel	Early Cretaceous (Barremian-Aptian, Zone I)	Nonmarine	**Diagnostic Spores and Pollen** / **Range ACP** / **Frequency**[1] Classopollis torosus / I - Paleocene / C Eucommiidites troedssonii / Zones I-II / C **Discussion:** The maceral residue has an abundance of carbonized wood. While the few palynomorphs present belong to only the two pollen types above, the association of these two species to the exclusion of all others is a common characteristic of Zone I assemblages.
Trimble Road	HA Ed 47	67.0- 67.3	--	--	--	BARREN
Edgewood (Elementary School)	HA Dd 89	210.0-210.7	--	--	--	BARREN
Willoughby Beach Boat Launch	HA De 181	220.0-220.4	Patuxent and Arundel	Early Cretaceous (Barremian-Aptian, Zone I)	Nonmarine	**Diagnostic Spores and Pollen** / **Range ACP** / **Frequency**[1] Alisporites bilateralis / Zones I-III / C Cicatricosisporites hallei / Zones I-II / A Classopollis parva / Zones I-II / R Cyathidites minor / Zones I-? / C Parvisaccites amplus / Zone I / A **Discussion:** Parvisaccites amplus is an easily recognizable index form for Zone I in the Potomac Group. It is an unusually large grain (ca. 110 micrometers long), and the exine of the bladders contains radially directed thickenings that form a poorly defined reticulum at the surface.

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

Table 20.—Biostratigraphic analyses of test-well cores and outcrop samples from the Coastal Plain of Harford County, Maryland—Continued

Site name	Well number	Depth (ft)	Formation	Age	Paleoecology	Diagnostic species and discussion
Long Bar Harbor	HA Dd 91	20.0- 21.0	--	--	--	BARREN
	HA Dd 91	64.0- 64.8	--	--	--	BARREN
	HA Dd 91	124.0-124.8	Patuxent and Arundel	Early Cretaceous (Barremian-Aptian, Zone I)	Nonmarine	**Diagnostic Spores and Pollen** / **Range ACP** / **Frequency**[1] Abietineaepollenites microreticulatus — Zones I-II — O Alisporites bilateralis — Zones I-III — C Classopollis torosus — I - Paleocene — C Cyathidites minor — Zones I-? — C Eucommiidites troedssonii — Zones I-II — C Ginkocycadophytus nitidus — Zones I-III — C Tiletes verrucatus — Zones I-II — R **Discussion:** The above association of long-ranging species is characteristic of Zone I assemblages.
Church Creek (at Ford's Lane)	HA De 198	25.0- 26.9	Patuxent and Arundel	Early Cretaceous (Barremian-Aptian, Zone I)	Nonmarine	**Diagnostic Spores and Pollen** / **Range ACP** / **Frequency**[1] Abietineaepollenites microreticulatus — Zones I-II — O Cicatricosisporites potomacensis — Zones I-II — R Cicatricosisporites australiensis — Zones I-III — O Classopollis torosus — I - Paleocene — R Cyathidites minor — Zones I-? — C Eucommiidites troedssonii — Zones I-II — A Ginkocycadophytus nitidus — Zones I-III — C Inaperturopollenites dubius — Zones I-II — A **Discussion:** There is no particular form in the above list that restricts this sample to Zone I; however, the absence of Zone II index forms, the association of numerous grains of Cyathidites minor, Eucommiidites troedssonni, Ginkocycadophytus nitidus, and Inaperturopollenites dubius are suggestive of Zone I.
	HA De 197	70.0- 70.8	--	--	--	BARREN
Cranberry Run Business Park	HA De 195	114.0-115.0	--	--	--	BARREN

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

Table 21.—Heavy mineral analyses of test-well cores from the Coastal Plain of Harford County, Maryland

Site name	Well number	Depth (feet)	Percent of heavy minerals in sample	Percent of total heavy minerals, excluding opaques												
				Hornblende	Rutile	Unknown	Zircon	Staurolite	Tourmaline	Muscovite	Cl-zo-ep[1]	Apatite	Kyanite	Brookite	Pyroxene	Sillimanite	Garnet
Joppatowne	HA Ec 47	5.0- 5.5	3.27	6.93	0.00	0.00	6.16	10.78	3.84	2.31	49.32	16.94	0.77	3.08	0.00	0.00	0.00
Edgewood (Elementary School)	HA Dd 102[2]	40.0- 41.0	2.28	5.89	1.47	1.47	19.11	2.94	27.94	1.47	5.89	33.83	0.00	0.00	0.00	0.00	0.00
	HA Dd 102[2]	124	2.55	4.30	0.00	0.00	4.30	4.30	3.44	1.73	67.24	12.92	1.73	0.00	0.00	0.00	0.00
Willoughby Beach Boat Launch	HA De 181	120.0-121.2	1.39	1.80	0.00	9.01	9.90	27.93	15.32	22.53	9.01	0.00	1.80	0.00	0.00	2.70	0.00
Long Bar Harbor	HA Dd 91	20.0- 21.0	17.61	78.54	0.00	0.00	2.74	0.46	0.00	6.85	1.37	3.19	0.00	0.00	4.56	1.82	0.46
	HA Dd 91	64.0- 64.8	7.21	65.80	0.00	1.29	3.87	0.00	1.29	12.90	12.26	0.00	0.00	0.00	0.00	1.94	0.65

[1]Clinozoisite-zoisite-epidote.

[2]Originally designated HA Dd 88.

Table 22.—Exchangeable cation analyses of test-well cores from the Coastal Plain of Harford County, Maryland

[meq = milliequivalents; gms = grams]

Site name	Well number	Depth, in feet	Exchangeable cations in meq/100 gms dry soil: Calcium	Magnesium	Sodium	Potassium	Strontium	Barium	Percent water content[1]
Joppatowne	HA Ec 47	5.0- 5.5	0.34	0.17	0.72	0.04	0.01	0.01	1.62
	HA Ec 46	40.0- 40.9	2.30	.20	.84	.11	.00	.01	12.50
	HA Ec 46	117.0-118.0	47.60	.83	.37	.15	.02	.02	11.07
Trimble Road	HA Ed 47	47.0- 47.3	3.62	.96	.71	.15	.00	.02	13.04
Edgewood (Elementary School)	HA Dd 102[2]	40.0- 41.0	1.05	.09	.78	.04	.00	.01	18.28
	HA Dd 102[2]	124	4.35	.12	.78	.04	.01	.02	5.76
	HA Dd 89	210.0-210.7	34.01	2.72	.68	.04	.01	.02	6.64
Willoughby Beach Boat Launch	HA De 181	60.9- 61.9	4.52	.57	.72	.08	.01	.02	11.53
	HA De 181	120.0-121.2	1.92	.12	.70	.06	.01	.02	9.00
Long Bar Harbor	HA Dd 91	20.0- 21.0	2.56	.25	.77	.04	.01	.02	11.60
	HA Dd 91	64.0- 64.8	7.18	1.33	.79	.06	.01	.02	9.03
Cranberry Run	HA De 195	114.0-115.0	7.26	.69	.76	.07	.01	.02	9.21

[1] Determined by air-drying samples in a convection oven for 24 hours.

[2] Originally designated HA Dd 88.

Table 23.—X-ray mineralogy analyses of test-well cores from the Coastal Plain of Harford County, Maryland

[% = percent]

Site Name	Well Number	Depth (feet)	Minerals Present (%)							Clay Minerals Present (%)						Comments [1]
			Quartz	Hematite	Goethite	Rutile	Mica	Feldspar	Amphiboles	Kaolinite	Smectite	Illite	Goethite	Margarite	Chlorite	
Joppatowne	HA Ec 47	5.0- 5.5	>50	0	0	0	0	0	0	33-50	33-50	5-20	0	0	0	
	HA Ec 46	40.0- 40.9	>50	0	0	0	0	0	0	>50	<5	33-50	0	0	0	
	HA Ec 46	117.0-118.0	>50	<5-20	0	0	0	0	0	>50	<5	<5	0	0	0	Clay fraction almost pure kaolinite (>90%).
Trimble Road	HA Ed 47	47.0- 47.3	>50	0	<5-20	0	0	0	0	33-50	0	33-50	<5	0	0	Illite may have <10% mixed-layering with smectite.
Edgewood (Elementary School)	HA Dd 102	40.0- 41.0	>50	0	0	<5	5-20	0	0	>50	0	5-20	0	5-20	0	Margarite is a brittle mica often associated with emery deposits and with tourmaline and staurolite in chlorite and mica schists. Also, a small amount of an unidentified mineral is present. Possibilities are a zeolite or a hydroxy-carbonate.
	HA Dd 102	124	>50	0	0	0	<5	0	0	>50	33-50	5-20	0	0	0	
	HA Dd 89	210.0-210.7	>50	0	0	0	0	0	0	>50	<5	0	0	0	20-33	The chlorite is degraded, perhaps weathering to vermiculite or present as a "chloritized vermiculite".
Willoughby Beach Boat Launch	HA De 181	60.9- 61.9	>50	<5	0	0	0	0	0	>50	<5	5-20	0	0	0	The illite is degraded and may contain some mixed-layered smectite.
	HA De 181	120.0-121.2	>50	0	<5	0	<5	0	0	>50	0	20-33	0	0	0	
Long Bar Harbor	HA Dd 91	20.0- 21.0	>50	0	0	0	<5	5-20	<5	>50	<5	0	0	0	20-33	The chlorite is degraded similar to sample Dd 89, 210.0-210.7.
	HA Dd 91	64.0- 64.8	>50	0	0	0	<5	0	5-20	33-50	33-50	5-20	0	0	5-20	Chlorite behaves more like "chloritized vermiculite" or vermiculite with Al-hydroxy interlayers.
Cranberry Run	HA De 195	114.0-115.0	>50	<5	<5	0	0	0	0	>50	0	0	5-20			

1 Richard April, Colgate University, written commun., 1988.

Table 24.—Stream data entered in the flow model of Harford County, Maryland

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

Row	Column	Stage (ft)	Streambed conductance (ft^2/d)
1	17	260	485
1	18	280	1,420
1	19	290	612
1	20	260	1,518
1	21	200	971
1	22	155	1,024
1	23	120	63,715
1	24	175	3,628
1	25	240	4,434
1	26	315	1,210
1	27	260	1,631
1	28	200	1,119
1	29	180	9,872
1	30	190	2,373
1	32	260	438
1	33	295	1,722
1	34	330	918
1	35	300	625
1	36	330	1,793
1	37	315	1,154
1	38	300	1,650
1	39	285	5,734
1	40	270	2,863
1	41	280	1,737
1	42	300	1,734
1	43	280	3,388
1	44	305	1,402
1	45	320	1,310
1	46	340	472
2	17	245	425
2	18	210	2,135
2	19	180	1,105
2	20	180	2,989
2	21	150	2,669
2	22	120	1,375
2	23	100	281,882
2	24	200	4,757
2	25	250	1,958
2	26	250	2,015
2	27	190	2,252
2	28	120	8,425
2	29	100	7,373
2	32	150	5,198
2	33	140	8,171
2	34	180	2,002
2	35	240	6,506
2	36	230	2,378
2	37	250	2,603
2	38	290	1,396
2	39	190	3,990
2	40	220	9,807
2	41	240	1,388
2	42	270	2,006
2	45	320	515
2	46	340	1,245
2	47	350	801
2	49	320	441
2	50	360	3,126
2	51	365	1,299
2	52	370	1,069
2	53	380	758
2	56	340	338
2	57	350	2,324
2	58	330	8,237
3	13	160	2,610
3	14	160	2,536
3	15	175	2,579
3	16	205	83
3	17	195	258
3	18	180	1,070
3	19	160	2,681
3	20	120	2,079
3	21	95	1,443
3	22	80	9,881
3	23	60	83,998
3	24	150	2,174
3	25	200	2,234
3	26	200	1,961
3	27	100	6,269
3	28	50	13,847
3	29	70	7,685
3	30	50	11,138
3	31	80	8,573
3	32	105	718
3	33	170	368
3	34	115	1,461
3	36	95	984
3	37	140	3,739
3	38	180	5,250
3	39	200	3,741
3	40	250	777
3	43	290	225
3	44	285	1,293
3	45	280	2,658
3	46	270	6,584
3	49	260	500
3	50	250	2,527
3	51	240	1,051
3	52	235	1,929
3	53	210	5,966
3	54	240	1,290
3	55	295	269
3	56	280	2,258
3	57	240	11,179
3	58	280	5,884
3	59	295	8,913
3	60	350	3,815
4	9	35	9,642
4	10	50	5,098
4	11	65	979
4	12	80	1,071
4	13	90	1,403
4	14	100	653
4	16	95	100
4	17	80	1,089
4	18	60	991
4	21	70	859
4	22	50	2,763
4	23	35	60,880
4	24	90	2,118
4	25	75	2,307
4	27	80	796
4	29	30	14,194
4	33	25	1,386
4	34	40	5,362
4	35	80	4,586
4	36	120	2,850
4	37	180	1,483
4	38	205	253
4	42	250	1,483
4	45	200	170
4	46	200	7,860
4	49	155	1,598
4	50	210	1,719
4	51	170	939
4	53	200	2,280
4	54	200	5,717
4	55	200	11,296
4	57	200	11,393
4	58	180	25,691
4	59	240	8,730
4	60	190	7,298
5	9	20	1,049
5	10	40	1,048
5	11	60	40
5	17	90	394
5	18	80	741
5	19	50	1,127
5	20	35	1,071
5	21	30	979
5	22	28	43,262
5	25	50	4,310
5	27	60	321
5	28	50	1,050
5	29	24	4,657
5	30	20	19,614
5	32	14	15,856
5	33	18	1,385
5	37	150	910
5	38	190	770
5	39	160	1,011
5	42	150	1,559
5	43	100	1,189
5	44	70	500
5	45	100	43,36
5	46	120	392
5	49	100	4,460
5	50	125	2,142
5	51	180	211
5	52	150	130
5	54	190	397
5	55	180	3,093
5	56	160	1,493
5	57	140	11,850
5	58	120	3,289
5	59	250	1,611
6	8	0	3,766
6	18	70	803
6	19	60	510
6	22	25	26,615
6	25	20	1,985
6	30	16	11,099
6	31	18	3,818
6	32	16	8,262
6	33	60	347
6	34	90	679
6	36	80	216
6	37	100	1,110
6	39	100	1,030
6	43	70	1,914
6	44	55	2,170
6	48	65	84
6	49	70	2,565
6	52	120	1,251
6	58	100	2,261
6	59	175	1,360
6	60	150	3,834
7	7	0	3,964
7	11	30	243
7	12	40	586
7	14	65	250
7	15	70	615
7	19	40	922
7	20	30	1,131
7	21	25	1,027
7	22	18	19,826
7	23	18	3,128
7	25	13	3,319
7	27	120	424
7	30	14	6,930

Table 24.—Stream data entered in the flow model of Harford County, Maryland—Continued

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

Row	Column	Stage (ft)	Streambed conductance (ft^2/d)
7	31	12	13,703
7	32	18	10,510
7	33	20	786
7	36	40	1,060
7	38	50	41
7	39	60	1,031
7	42	40	906
7	43	40	2,818
7	44	60	1,111
7	47	40	694
7	48	60	2,733
7	51	85	938
7	52	100	177
7	55	110	678
7	57	120	958
7	58	80	1,992
7	59	130	2,718
7	60	100	4,226
7	61	110	862
8	7	0	1,069
8	9	5	265
8	10	10	1,160
8	11	20	1,025
8	13	50	949
8	14	60	1,024
8	22	16	9,074
8	23	14	23,068
8	25	5	2,235
8	26	50	1,108
8	27	100	81
8	32	10	23,135
8	36	30	983
8	38	35	1,060
8	42	20	2,428
8	43	20	2,205
8	47	36	2,591
8	50	60	960
8	51	75	824
8	55	100	802
8	56	100	444
8	57	100	1,312
8	58	50	4,134
8	59	90	3,354
8	60	90	1,075
8	61	50	4,780
9	7	0	4,319
9	9	3	320
9	10	2	677
9	12	30	599
9	13	30	500
9	23	12	20,515
9	25	2	2,214
9	26	5	830
9	31	6	7,946
9	32	8	24,057
9	36	15	990
9	38	25	1,086
9	41	10	1,912
9	42	15	2,159
9	43	20	1,046
9	47	34	2,826
9	49	40	967
9	50	50	474
9	52	85	581
9	56	80	1,701
9	57	60	2,179
9	58	40	2,098
9	59	80	3,830
9	60	70	1,137
9	61	25	2,367
10	9	0	569
10	10	0	530
10	12	10	1,594
10	13	17	978
10	14	29	1,032
10	15	45	428
10	23	8	21,719
10	31	4	19,014
10	32	2	13,817
10	36	20	970
10	37	15	871
10	38	15	211
10	39	0	72
10	40	0	3,260
10	41	5	810
10	43	40	828
10	46	26	444
10	47	30	3,141
10	48	35	1,027
10	49	39	334
10	51	70	1,092
10	52	75	1,008
10	57	50	876
10	58	30	11,104
10	59	50	4,059
10	60	50	1,399
10	61	30	2,503
11	7	0	4,457
11	9	0	1,036
11	10	0	486
11	11	2	1,000
11	12	5	539
11	17	70	279
11	23	6	34,480
11	24	4	1,825
11	32	0	10,322
11	37	10	1,080
11	38	10	526
11	39	0	1,440
11	40	0	1,381
11	41	0	1,557
11	44	18	458
11	45	22	2,040
11	46	24	2,320
11	51	58	28
11	52	58	1,030
11	57	0	5,734
11	58	20	25,776
11	59	25	4,148
11	60	40	317
11	61	35	46
12	7	0	756
12	8	0	263
12	9	0	1,587
12	10	0	860
12	16	45	714
12	17	60	867
12	18	65	627
12	19	75	322
12	23	10	1,666
12	24	2	39,554
12	25	0	4,379
12	41	1	2,365
12	42	1	2,192
12	43	10	2,126
12	44	16	4,005
12	45	23	350
12	51	50	450
12	52	52	759
12	57	0	11,620
12	58	20	1,208
12	59	10	5,515
13	8	0	696
13	9	0	1,297
13	16	35	1,492
13	17	47	1,141
13	18	55	543
13	21	60	335
13	22	40	2,111
13	23	16	3,199
13	42	1	883
13	44	25	1,383
13	45	30	558
13	50	46	60
13	51	46	1,283
13	57	0	13,941
13	58	0	46,164
13	59	5	2,248
14	9	0	55
14	12	10	172
14	13	12	712
14	14	16	746
14	15	20	1,088
14	16	30	886
14	45	40	467
14	50	42	127
14	51	44	1,102
14	55	55	10
14	56	50	1,206
14	57	30	2,040
14	58	0	26,357
15	12	8	1,082
15	13	14	335
15	14	15	386
15	48	37	1,696
15	49	38	3,579
15	50	40	978
15	58	0	9,974
16	11	0	1,126
16	12	4	1,773
16	16	14	25
16	17	18	1,226
16	45	31	2,771
16	46	32	4,273
16	47	34	4,176
16	48	36	2,634
17	11	0	814
17	12	0	970
17	13	1	47
17	14	2	523
17	15	8	506
17	16	10	1,572
17	43	28	2,623
17	44	29	4,405
17	45	30	2,816
18	13	0	848
18	14	4	782
18	15	6	1,225
18	41	25	2,213
18	42	26	4,368
18	43	27	1,473
18	49	40	567
19	35	14	1,158
19	36	18	998
19	37	20	337
19	41	24	5,078
19	50	36	1,139
20	33	6	757
20	34	10	1,110
20	35	12	1,095

Table 24.—Stream data entered in the flow model of Harford County, Maryland—Continued

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

Row	Column	Stage (ft)	Streambed conductance (ft^2/d)
20	36	14	734
20	41	23	2,312
20	42	22	2,788
20	50	34	1,080
21	32	2	1,065
21	33	5	466
21	31	0	92
21	36	18	740
21	42	21	2,011
21	43	20	4,277
21	46	20	1,699
21	47	22	2,116
21	48	26	2,656
21	49	30	1,973
21	50	31	1,116
21	51	32	1,019
21	52	33	1,055
21	53	34	708
22	43	18	4,631
22	44	16	2,249
22	45	17	1,988
22	46	18	258
23	33	15	1,033
23	34	18	671
23	41	14	1,386
23	42	15	2,905
23	43	16	2,411
23	44	17	971
23	45	18	991
23	46	19	985
23	47	20	912
24	27	0	4,686
24	28	0	2,682
24	29	0	4,191
24	30	2	1,299
24	31	5	1,418
24	32	10	1,212
24	33	5	596
24	34	6	1,997
24	35	8	1,009
24	36	9	696
24	37	10	2,028
24	38	11	1,995
24	39	12	2,282
24	40	13	2,621
24	41	14	936
24	42	22	1,291
24	45	20	1,279
24	46	20	458
24	47	21	123
24	48	25	1,342
24	49	30	1,195
24	50	35	616
25	26	0	1,672
25	27	0	367
25	29	1	2,655
25	30	2	2,089
25	31	3	2,229
25	32	4	2,107
25	33	5	1,596
25	35	8	1,065
25	36	9	1,303
25	38	15	1,542
25	39	18	1,982
25	41	20	3,320
25	45	15	651
25	46	10	2,066
25	47	8	1,257
25	49	25	2,276
25	50	20	1,191
25	52	18	683
25	53	16	1,578
25	54	10	1,167
25	55	6	1,039
25	56	2	1,523
26	29	0	397
26	30	2	1,143
26	31	4	1,072
26	32	6	1,046
26	33	8	1,205
26	34	10	1,379
26	35	10	2,099
26	37	10	915
26	38	5	6,627
26	39	10	1,880
26	40	15	1,184
26	41	18	359
26	47	6	174
26	48	4	1,351
26	49	0	1,888
26	50	4	4,700
26	51	8	5,918
26	53	0	814
26	55	0	2,020
26	56	0	650
27	14	1	1,267
27	15	1	1,903
27	16	1	824
27	22	1	112
27	23	1	1,388
27	24	1	3,308
27	35	5	1,043
27	36	2	2,969
27	37	1	172
27	39	0	5,152
27	40	0	798
27	41	1	1,147
27	42	1	1,281
27	43	2	1,054
27	44	2	727
27	50	0	250
27	51	0	2,065
27	52	0	2,788

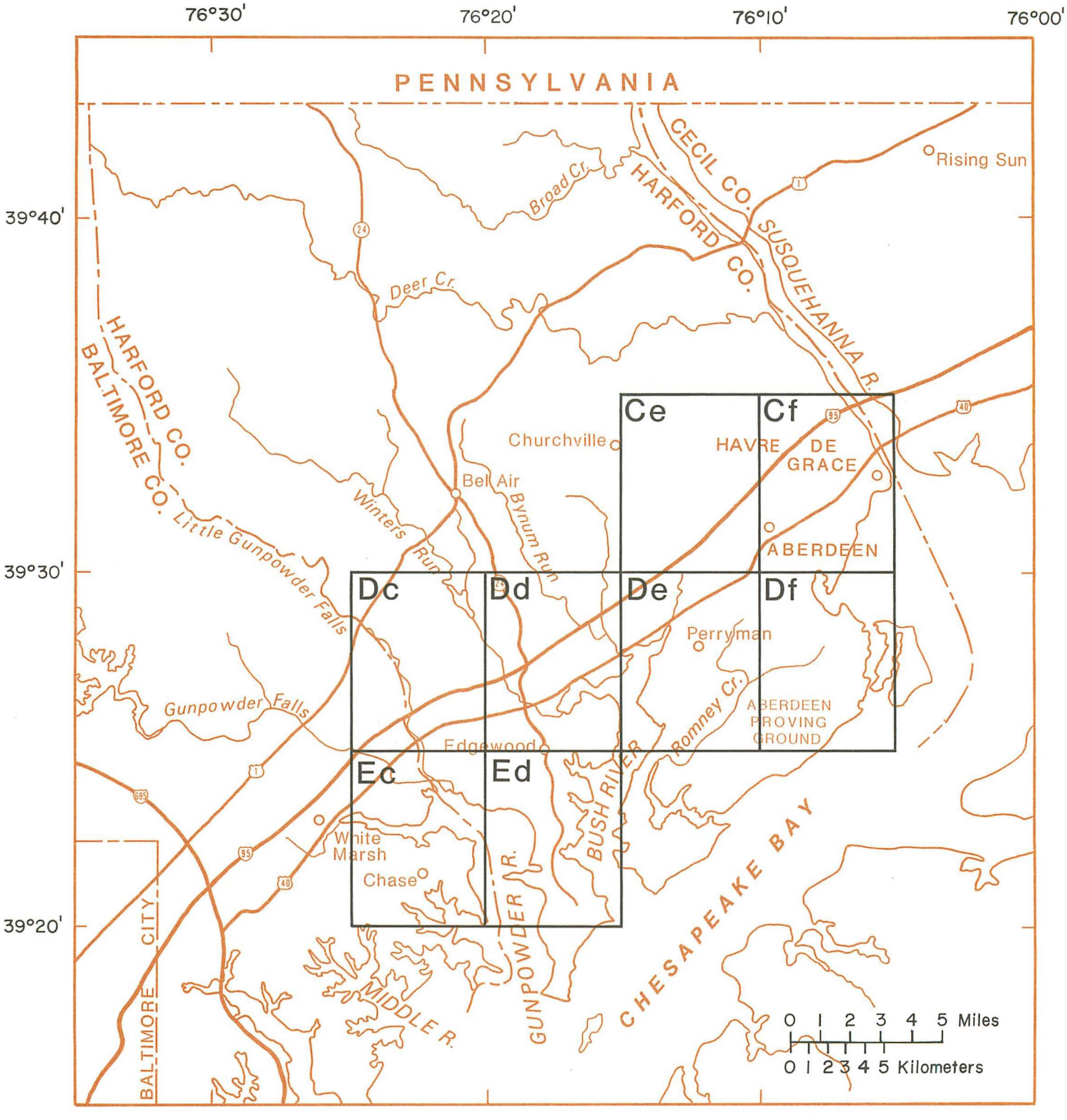


Figure 87.—Locations of 5-minute quadrangles.

Ce

Base modified from U.S. Geological Survey 7.5 minute quadrangles 1:24,000

1 ½ 0 1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

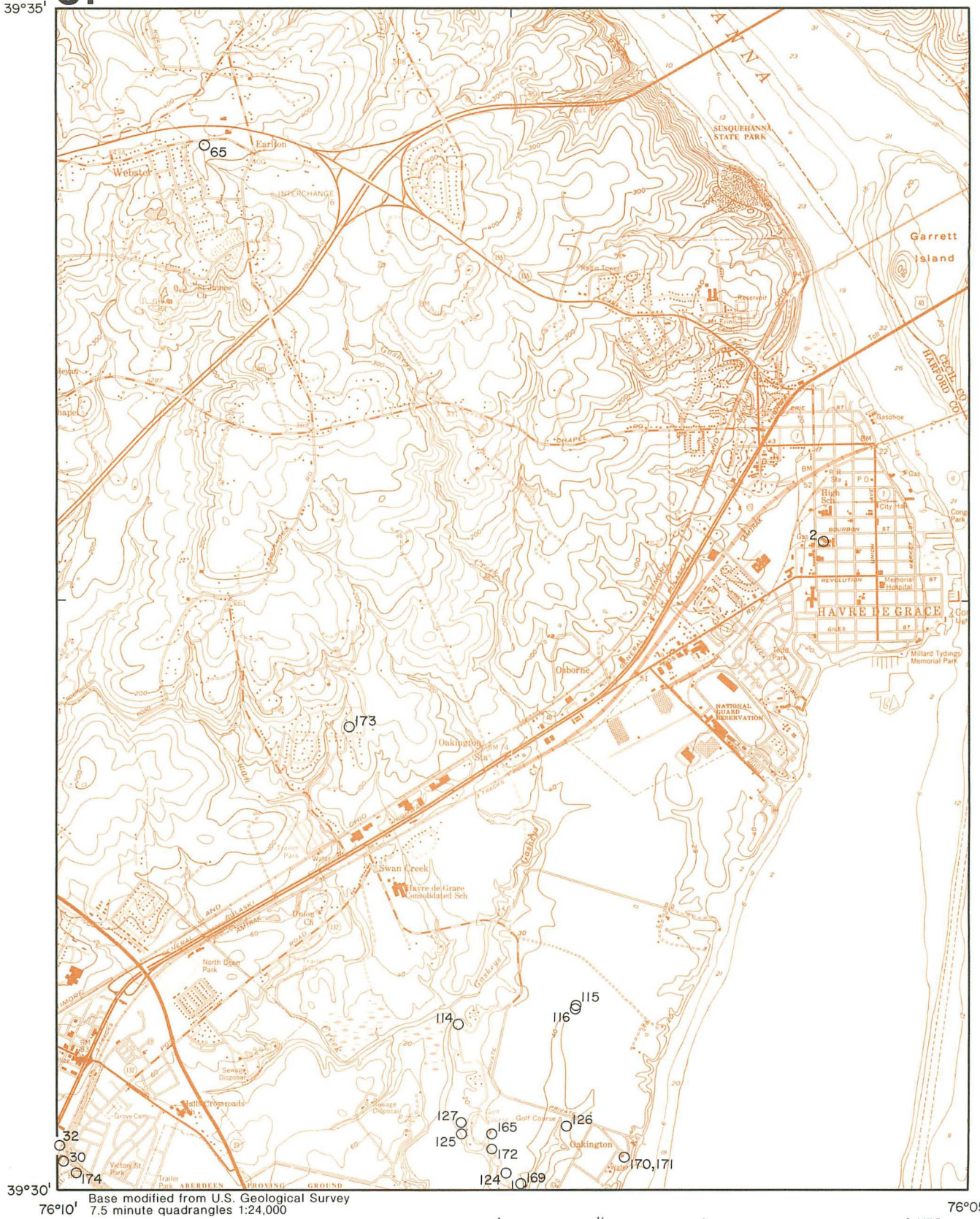
1 .5 0 1 KILOMETER

CONTOUR INTERVAL 20 FEET
DATUM IS NATIONAL GEODETIC VERTICAL DATUM OF 1929

EXPLANATION

○117 Well location and number

Cf



Base modified from U.S. Geological Survey
7.5 minute quadrangles 1:24,000

1 ½ 0 1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

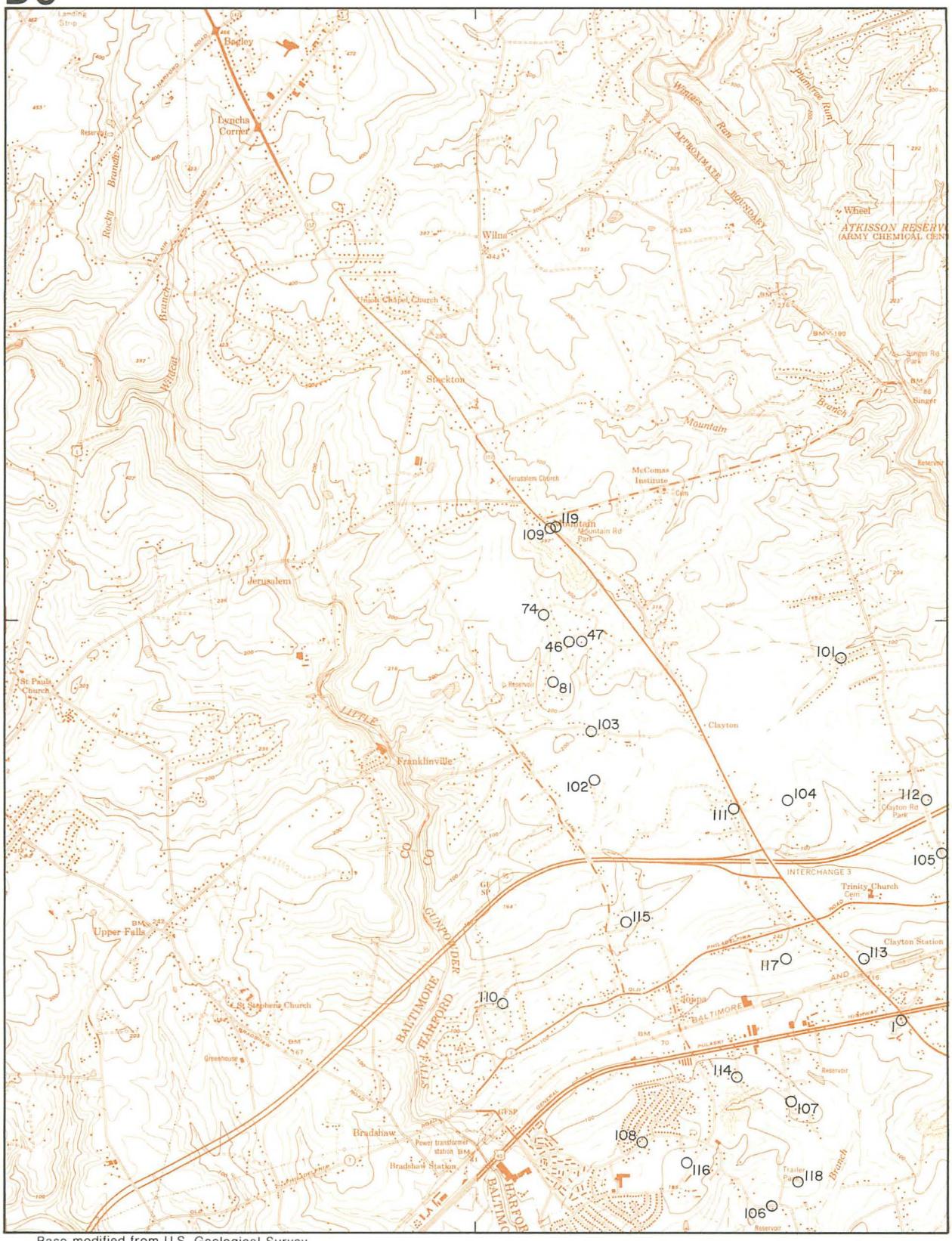
1 .5 0 1 KILOMETER

CONTOUR INTERVAL 20 FEET
DATUM IS NATIONAL GEODETIC VERTICAL DATUM OF 1929

EXPLANATION

○124 Well location and number

Dc



Base modified from U.S. Geological Survey
7.5 minute quadrangles 1:24,000

1 ½ 0 1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

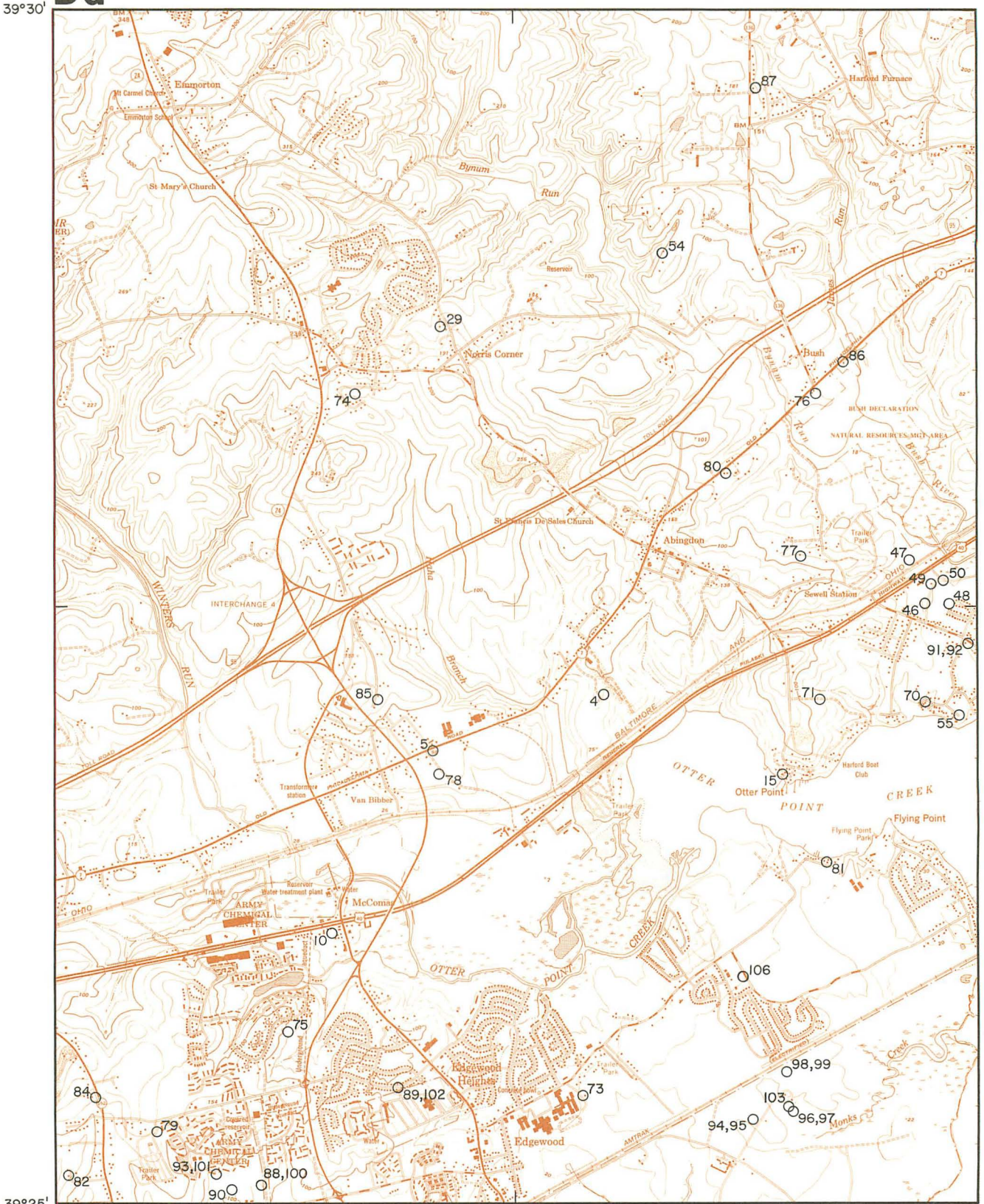
1 .5 0 1 KILOMETER

CONTOUR INTERVAL 20 FEET
DATUM IS NATIONAL GEODETIC VERTICAL DATUM OF 1929

EXPLANATION

○118 Well location and number

Dd



Base modified from U.S. Geological Survey 7.5 minute quadrangles 1:24,000

1 ½ 0 1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

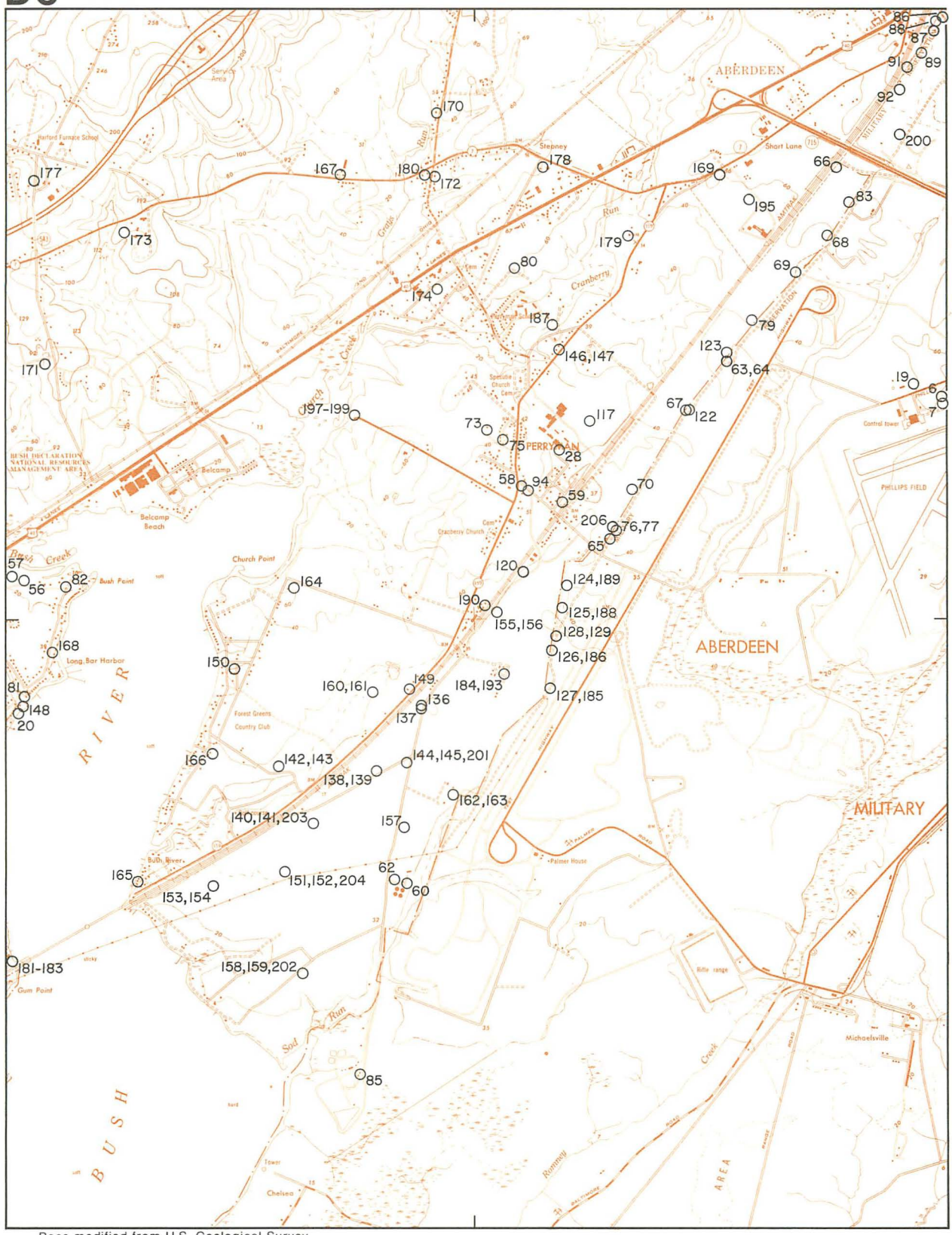
1 .5 0 1 KILOMETER

CONTOUR INTERVAL 20 FEET
DATUM IS NATIONAL GEODETIC VERTICAL DATUM OF 1929

EXPLANATION

○106 Well location and number

De



Base modified from U.S. Geological Survey 7.5 minute quadrangles 1:24,000

1 ½ 0 1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

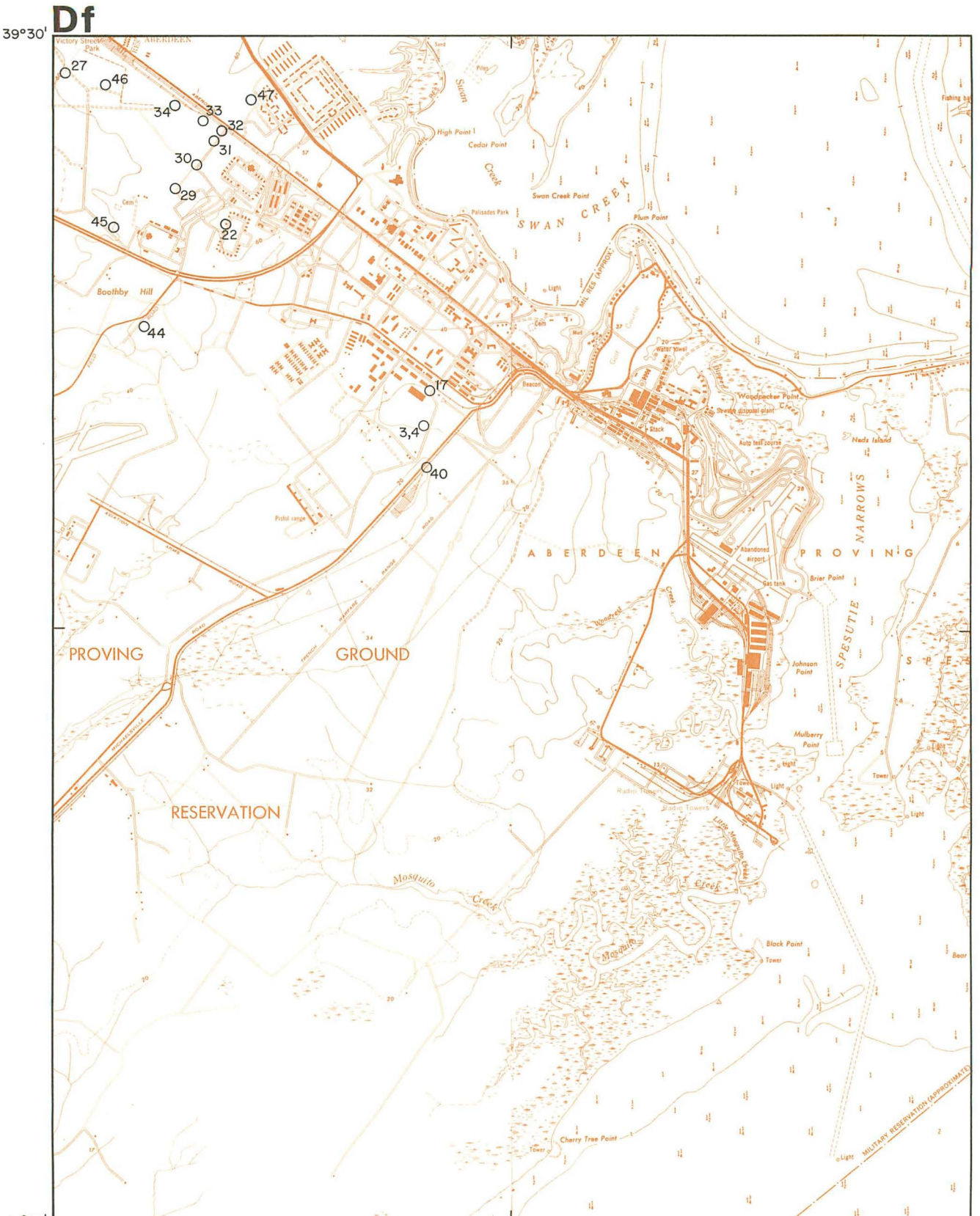
1 .5 0 1 KILOMETER

CONTOUR INTERVAL 20 FEET
DATUM IS NATIONAL GEODETIC VERTICAL DATUM OF 1929

EXPLANATION

○85 Well location and number

Df



Base modified from U.S. Geological Survey
7.5 minute quadrangles 1:24,000

1 ½ 0 1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 .5 0 1 KILOMETER

CONTOUR INTERVAL 20 FEET
DATUM IS NATIONAL GEODETIC VERTICAL DATUM OF 1929

EXPLANATION

○40 Well location and number

Ec

Base modified from U.S. Geological Survey 7.5 minute quadrangles 1:24,000

1 ½ 0 1 MILE

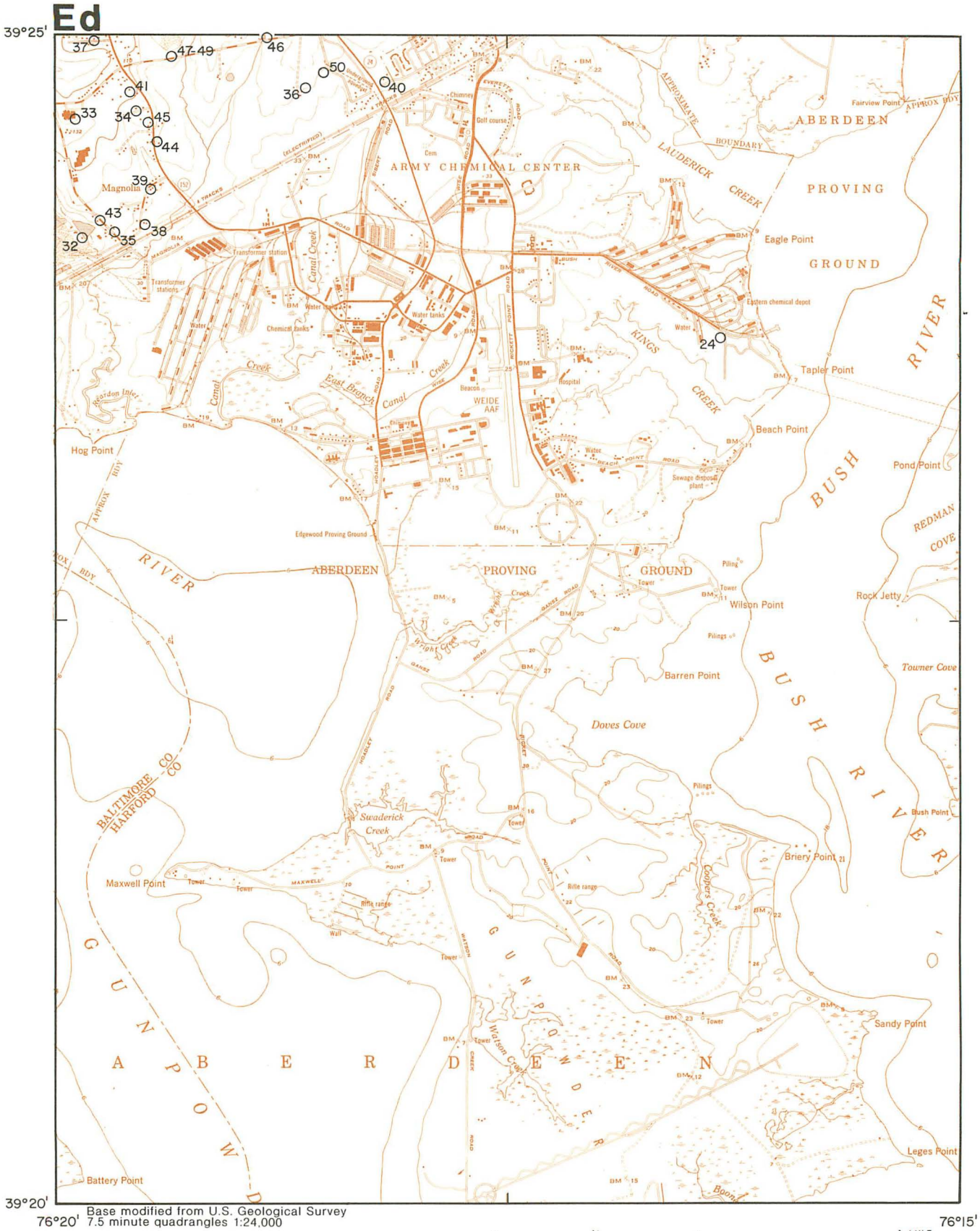
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 .5 0 1 KILOMETER

CONTOUR INTERVAL 20 FEET
DATUM IS NATIONAL GEODETIC VERTICAL DATUM OF 1929

EXPLANATION

○43 Well location and number



EXPLANATION

○38 Well location and number

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