MARYLAND GEOLOGICAL SURVEY

CONVERSION FACTORS AND ABBREVIATIONS

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

Multiply inch-pound unit	By	To obtain metric unit
acre	4,047	square meter (m^2)
inch (in)	25.4	millimeter (mm)
inch per year (in/yr)	25.4	millimeter per year (mm/yr)
foot (ft)	0.3048	meter (m)
foot per mile	0.1894	meter per kilometer
foot per second (ft/s)	0.3048	meter per second (m/s)
foot squared per day (ft^2/d)	0.0929	meter squared per day (m^2/d)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per second per square mile [(ft^3/s)/mi^2]	0.01093	cubic meter per second per square kilometer [(m^3/s)/km^2]
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
gallon (gal)	3.785	liter (L)
gallon per minute (gal/min)	0.06308	liter per second (L/s)
gallon per minute per foot [(gal/min)/ft]	0.2070	liter per second per meter [(L/s)/m]
gallon per day (gal/d)	0.003785	cubic meter per day (m^3/d)
million gallons (Mgal)	3,785	cubic meter (m^3)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
million gallons per day per square mile [(Mgal/d)/mi^2]	1,460	cubic meter per day per square kilometer [(m^3/d)/km^2]

Chemical concentration in water is expressed in milligrams per liter (mg/L) or micrograms per liter (μg/L); 1,000 μg/L = 1 mg/L. The unit milliequivalents per liter takes into account the ionic charge and combining weight of an ion, so that ionic concentrations of all ions are chemically equivalent. (See Hem, 1985, p. 56 for explanation and conversion factors.)

Specific electrical conductance of water is expressed in microsiemens per centimeter (μS/cm) at 25°C. This unit is identical to micromhos per centimeter at 25°C.

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

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

BULLETIN 34

WATER RESOURCES AND ESTIMATED EFFECTS OF GROUND-WATER DEVELOPMENT, CECIL COUNTY, MARYLAND

by

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and the
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ABSTRACT

This report describes the results of a study of the ground- and surface-water resources of Cecil County, northeastern Maryland. Because of geologic differences, the county has two distinct types of terrane—the Piedmont and the Coastal Plain—that affect its water resources.

The crystalline rock in the Piedmont of Cecil County, Maryland, is highly indurated and contains free water only where the rock has been fractured or decomposed by weathering. Permeability of fractured rock depends on the number of fractures, the size of the fracture openings, and the interconnection of the fractures. Weathering increases the size of fracture openings, but is most significant in Cecil County because it has produced a mantle of unconsolidated, weathered rock at the land surface. The major significance of the weathered mantle is as a storage reservoir that supplies water to the fracture systems that supply water to wells. The median yield of wells in crystalline rock is 10 gallons per minute (gal/min). Median well yields for various topographic positions in the Piedmont are: flood plain and valley flat, 20 gal/min; upland draw, 14 gal/min; hilltop, 9 gal/min; and hillside, 8 gal/min.

The Coastal Plain sediments of Cecil County consist of unconsolidated stratified layers of clay, silt, sand, and gravel. The maximum thickness of Coastal Plain sediments is in the extreme southeastern corner of the county and is estimated to be about 1,600 feet (ft). Water occurs between grains in the sediments, and saturated sand and gravel constitute the aquifers. Interspersed in and grading laterally into the sand are clay and silt that act chiefly as confining and semiconfining layers. The major aquifers in Cecil County are the upper and lower Potomac aquifers. Yields of wells in the Potomac aquifers range from 0.5 to 703 gal/min and the median is 30 gal/min. The Magothy aquifer is the second most productive water-bearing unit in the county. Reported yields of 50 wells range from 7 to 270 gal/min; the median is 30 gal/min. The Monmouth is a major aquifer east of the Elk River and south of the Chesapeake and Delaware Canal. Reported yields of 25 wells producing from the Monmouth aquifer range from 8 to 42 gal/min; the median is 20 gal/min.

Decline in the water table in the Piedmont area caused by ground-water withdrawals tends to be local. By contrast, pumping from the Potomac aquifers causes widespread lowering of water level. Pumping of the Potomac aquifers has caused water levels to gradually decline; about 10 ft of decline has been measured in an observation well since 1967. A pronounced decline since 1983 has occurred near Elkton, Maryland, where about 20 ft of decline was measured in less than 3 years. Water levels near Elkton show effects of the intensive pumping from the Elkton well field and from another well field a few miles east in Delaware.

Generally, ground water in Cecil County is suitable for most uses except where it is contaminated. Dissolved-solids concentrations are generally low; only three ground-water samples had concentrations above 500 milligrams per liter (mg/L). Common chemical-quality problems are excessive iron concentrations and low pH. Iron concentrations range from less than 3 to 24,000 micrograms per liter (μg/L). The median for crystalline rock is 12 μg/L; for the Potomac aquifers, 120 μg/L; and for other Coastal Plain aquifers, 87 μg/L. The pH ranges from 4.2 to 8.1. The median for crystalline rock is 6.0; for the Potomac aquifers, 5.6; and for other Coastal Plain aquifers, 5.8.

Streamflow data were measured at 10 continuous-record and 27 partial-record stations. Flow duration for five unregulated streams in Cecil County ranges from 3.1 to 4.8 cubic feet per second per square mile [$(ft^3/s)/mi^2$] at the 5-percent exceedance level and from 0.31 to 0.39 $(ft^3/s)/mi^2$ at the 95-percent exceedance level. The 7-day, 10-year, low-flow frequency for 31 continuous- or partial-record sites ranges from 0.01 to 0.44 $(ft^3/s)/mi^2$. The 7-day, 2-year, low-flow frequency for the same sites ranges from 0.02 to 0.68 $(ft^3/s)/mi^2$.

Stream water-column samples were collected at 29 sites during base-flow periods, in either August or November 1982. Dissolved-solids concentration of these base-flow samples ranges from a minimum of 39 mg/L to a maximum of 256 mg/L; the median is 92 mg/L. The pH ranges from a minimum of 5.8 to a maximum of 9.1; the median is 7.3.

Synthetic organic compounds were detected at 6 of the 10 streambed-sediment sampling sites that were analyzed for these compounds. The most frequently detected compounds were the organochlorine insecticides; none of the more soluble pesticides were detected.

Water-budget estimates for Piedmont basins show about 10 inches per year (in/yr) of ground-water runoff, 10 in/yr of storm runoff, and 22 in/yr of evapotranspiration. Total runoff is about 20 in/yr.

Ground-water flow models were constructed for three areas in Cecil County. Maximum drawdowns of more than 30 ft were projected under unsewered, non-drought conditions in the Elkton-Chesapeake City area; maximum drawdowns of 5 to 10 ft were simulated for the same conditions in the Rising Sun and Highlands-Meadow View areas. Maximum drawdowns of more than 40 ft were projected under sewered, drought conditions in the Elkton-Chesapeake City area; maximum drawdowns of more than 20 ft were simulated in the other two areas for the same conditions.

INTRODUCTION

PURPOSE AND SCOPE

This report describes the results of a study of the ground- and surface-water resources of Cecil County, Md. It updates an earlier assessment of the water resources of the county published in 1958 (Overbeck and others, 1958). The report describes the occurrence and chemical quality of ground water in the Piedmont and Coastal Plain aquifers in Cecil County and also describes the flow characteristics and base-flow chemical quality of the surface water. The report also discusses the water budget and presents an evaluation of the effects of ground-water development in three selected areas of the county.

Eleven test wells at nine sites were drilled during the study. Construction records, detailed logs, and core descriptions of the test wells are presented in the appendix (tables 28, 29, and 30). Periodic or continuous water-level records were obtained on 15 wells. Samples for chemical analysis were collected from 72 wells and springs. Low flows were evaluated at 37 stream sites. Water-quality samples were obtained during a low-flow period at 29 sites. Streambed sediments at 20 sites were analyzed for trace elements. Samples from 10 of these sites also were analyzed for synthetic organic compounds. Hydrologic effects of future pumping under average annual and drought conditions were estimated for three areas using a ground-water flow model.

Hydrologic data on which many of the interpretations and conclusions in this report are based are presented in a separate basic data report (Willey and others, 1987). This basic data report includes maps giving locations of data-collection sites and includes detailed data regarding well and spring records, streamflow, water quality, water levels, well logs, and water appropriations.

LOCATION

Cecil County lies in the northeastern corner of Maryland (fig. 1). It is bordered on the north by Pennsylvania and on the east by Delaware. Kent County, Md., lies to the south and Harford County to the west. The Susquehanna River, Chesapeake Bay, and the Sassafras River mark its western and southern boundaries. The northeast transportation corridor linking Boston, New York, Philadelphia, Baltimore, and Washington, D.C., passes through the county providing it with a major interstate highway (Route I-95) and important rail facilities. In addition, the Chesapeake and Delaware Canal (C and D Canal) provides a water link for commercial and recreational traffic between the Chesapeake and Delaware Bays.

PREVIOUS INVESTIGATIONS

Hydrologic data collected for this study were published by Willey and others (1987). The water resources of Cecil County are described by Overbeck and others (1958, p. 1–365) as part of an investigation of Cecil, Kent, and Queen Annes Counties. More recent studies of the hydrogeology have examined the Coastal Plain part of the county in a regional context. Hansen (1972a, b) provided a guide to the Coastal Plain aquifers of Maryland. Cushing, Kantrowitz, and Taylor (1973) discussed the water resources of the Delmarva Peninsula; Otton and Mandle (1984) provided new data on the Coastal Plain aquifers of the upper Chesapeake Bay area, especially the aquifers in the Potomac Group; and Bachman and Wilson (1984) studied the Columbia aquifer south of the C and D Canal. In addition, the Coastal Plain east of the Elk River has been reviewed as part of a ground-water flow model of the freshwater segment of the Potomac aquifers in Delaware (Martin, 1984).

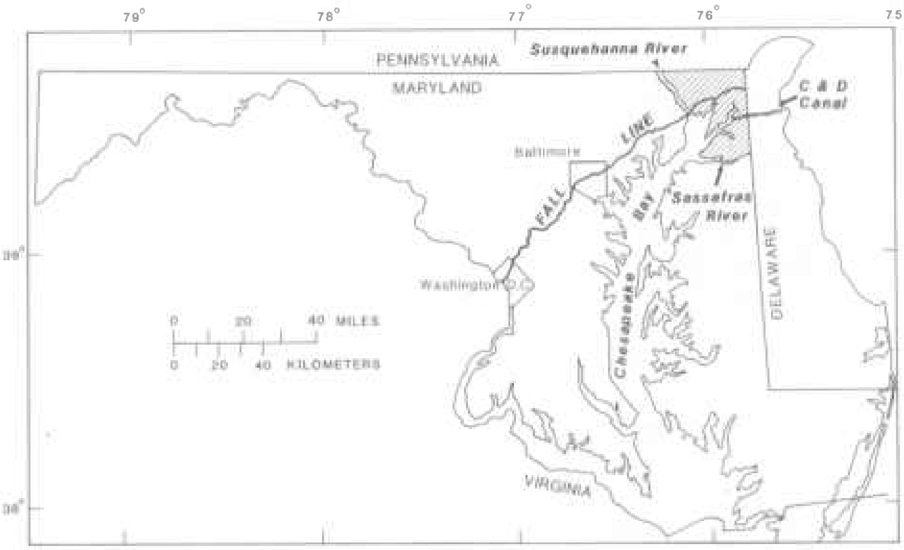

FIGURE 1. Location of study area.

Streamflow characteristics of the major rivers and selected smaller streams in northeastern Maryland have been recently studied by Carpenter (1983). The geology of the county has been mapped by Higgins and Conant (1986). Additional geologic data are contained in Edwards and Hansen (1979). General information on the geography and economy of Cecil County is given by Vokes and Edwards (1974).

WELL-IDENTIFICATION SYSTEM

Wells and test borings are identified in this report in accordance with the Maryland Geological Survey numbering system. Each identifier consists of two pairs of letters followed by a number (for example, CE Bf 59). The first pair of letters indicates the county (CE for Cecil); the second pair designates one of the 5-minute quadrangles of latitude and longitude into which each county has been subdivided (fig. 2). The number identifies a specific well or spring site within a 5-minute quadrangle.

ACKNOWLEDGMENTS

This report is the result of a water-resources investigation by the U.S. Geological Survey and the Maryland Geological Survey in cooperation with the Cecil County Board of Commissioners. Thanks are due to the various public officials of Cecil County for their support and assistance, which were coordinated through the Office of Planning and Economic Development, Michael Pugh, Director. Members of the Cecil County Environmental Health unit are also due thanks for their assistance in furnishing well records from their files. Records of ground-water appropriation permits and quantities used were provided by the Maryland Water Resources Administration in Annapolis, Md. Laurence J. McGreevy of the U.S. Geological Survey coordinated preparation of the report and edited it for publication.

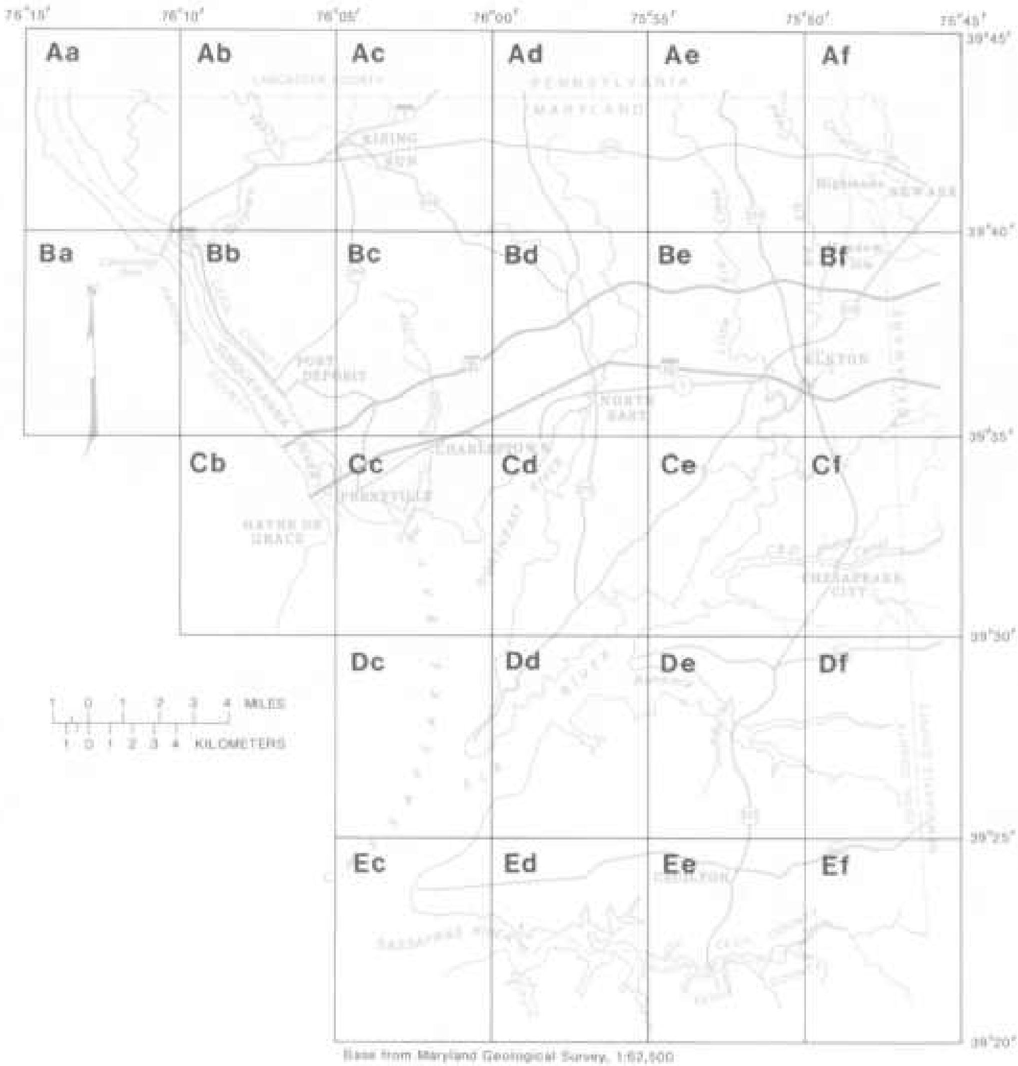

FIGURE 2. Index map of 5-minute quadrangles for well identification system.

DESCRIPTION OF STUDY AREA

POPULATION

The 1980 population of Cecil County was 60,430. The county is subdivided into nine election districts. Figure 3 shows rural and municipal population by election district from 1930 through 1980. Much of the population is concentrated along a central east-west belt (election

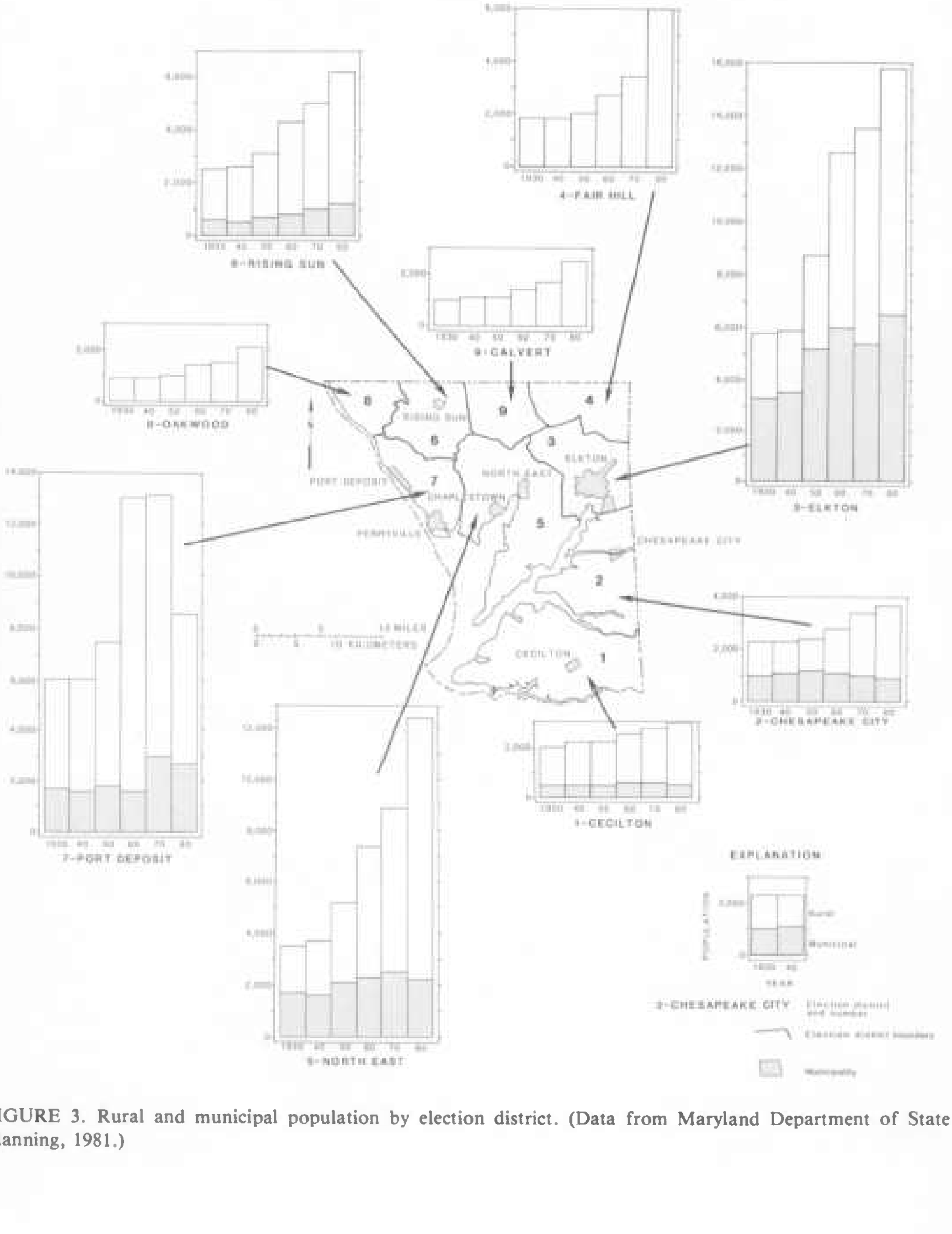

FIGURE 3. Rural and municipal population by election district. (Data from Maryland Department of State Planning, 1981.)

districts 3, 5, and 7) of the county. Historically, these districts have been the most populous and contained the largest towns. During 1970–80, most growth took place in the rural areas of all districts except district 7. District 7 showed a population decline of about 4,500 during 1970–80, because of the closing of the Bainbridge Naval Training Center near the town of Port Deposit. Municipal population in this same period increased in Elkton, Rising Sun, and Port Deposit, while it declined or remained about the same in other towns. Population projections for the county are estimated to be 67,900 for 1990, and 73,400 for the year 2000 (Maryland Department of State Planning, 1987, p. 15). Much of this growth will probably continue to be in rural areas near the shores of Chesapeake Bay and in the northeastern part of the county.

WATER USE

Total water withdrawals in Cecil County in 1985 were estimated to be 8.542 Mgal/d (million gallons per day), of which 59 percent was derived from ground-water sources (Moore and others, 1987, p. 11). The largest ground-water use was for domestic self-supplied households. This use amounted to 2.869 Mgal/d in 1985, with an estimated per capita use of 75 gal/d (gallons per day) (Moore and others, 1987, p. 14 and 22). Of the 41 percent of withdrawals from surface-water sources, the major users were the public water suppliers at Elkton, North East, Perryville, and the Perry Point Veterans Administration Hospital.

Ground-water withdrawals increased by 31 percent during the 5-year period 1980–85 (table 1). Surface-water use declined by about 16 percent during the same period. Surface-water use by the town of Elkton decreased 25 percent, from 0.751 to 0.562 Mgal/d, between 1980 and 1985. This may have been due to the use of a supplemental ground-water supply by 1985. A substantial decrease was also recorded at the Bainbridge Naval Training Center in Port Deposit; use declined from 0.906 Mgal/d in 1980 to 0.231 Mgal/d in 1985 because the training center was deactivated during the period.

A comparison of ground-water withdrawals by aquifer for 1980 and 1985 is summarized below. These data include only withdrawals by large users (pumping 0.01 Mgal/d or more) that are required to report pumpage to the Maryland Water Resources Administration (Herring, 1983, p. 9; Moore and others, 1987, p. 9). Domestic, livestock watering, farm irrigation, and nonreporting appropriated uses are not included. (See geologic unit names in tables 2 and 8).

Source of water	Pumpage (million gallons per day)		Percent change
	1980	1985	
Magothy aquifer	0.052	0.081	+ 56
Potomac aquifers	.650	.862	+ 33
Crystalline-rock aquifers	.273	.429	+ 57
Total	0.975	1.372	+ 41

TABLE 1

CHANGE IN WATER USE, 1980-85, CECIL COUNTY, MD.

[Source: Herring, 1983, and Moore and others, 1987.]

[Mgal/d = million gallons per day.]

User type	1980 Mgal/d	1985 Mgal/d	Percent change
Surface water			
Public water supplies	2.675	1.853	- 31
Commercial (also includes golf-course watering)	No data	.041	
Industrial, self-supplied (includes mining)	1.112	1.302	+ 17
Agriculture (includes irrigation and livestock watering)	.330	.281	- 15
Total	4.117	3.477	- 16
Ground water			
Public water supplies	0.843	1.221	+ 45
Domestic, self-supplied 1/	2.320	2.869	+ 24
Commercial (also includes golf-course watering)	.411	.512	+ 25
Industrial, self-supplied (includes mining)	.101	.198	+ 96
Agriculture (includes irrigation and livestock watering)	.200	.265	+ 32
Total	3.875	5.065	+ 31

1/ Estimated by taking the total county population for each year and subtracting the estimated population served by public water suppliers. The difference was then multiplied by 75 gallons per person per day (Herring, 1983, p. 10).

The four largest public-supply ground-water users and their average 1985 use are:

Town or system	Pumpage (million gallons per day)	Source of water
Elkton[1]	0.460	Potomac aquifers
Meadow View Utilities	.122	Potomac aquifers
Chesapeake City	.136	Potomac aquifers
Rising Sun	.113	Crystalline rock aquifers

[1]Elkton also supplied by surface water.

PRECIPITATION

No long-term weather stations have been maintained in Cecil County, but precipitation and temperature records are available from a station at the University Farm, University of Delaware, Newark, Del. Figure 4 is a graph of the annual precipitation at the University Farm during the period 1941–86. The 1951–80 normal (mean) annual precipitation is 42.59 in. (inches). The driest year was 1965 when precipitation totaled slightly more than 27 in.; the wettest year was 1952 when precipitation was slightly less than 55 in.

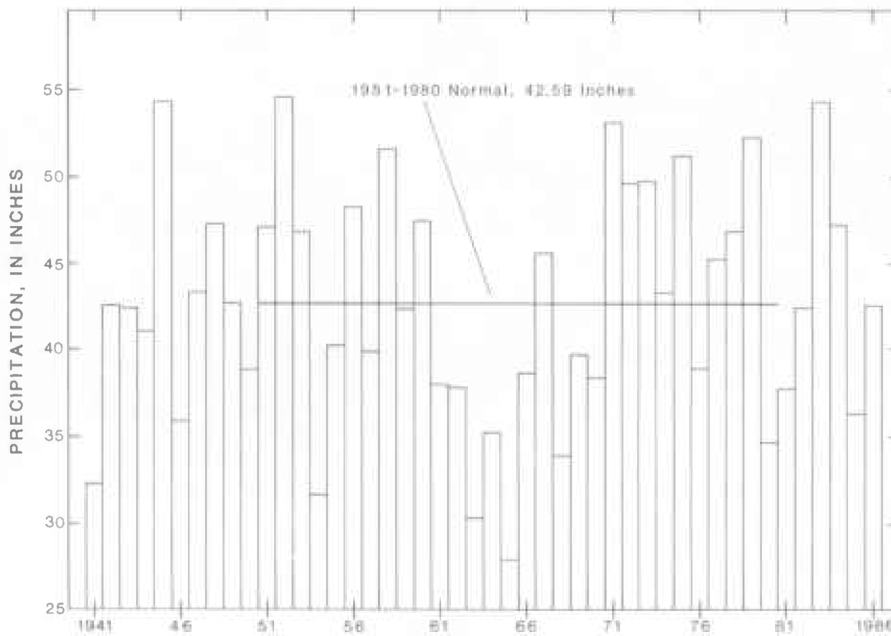

FIGURE 4. Annual precipitation at the University Farm, Newark, Del., 1941–86. (Data from National Oceanic and Atmospheric Administration.)

PHYSIOGRAPHY

Because of geologic differences, Cecil County has two distinct types of terrane—the Piedmont and Coastal Plain. In the Piedmont of the northern third of the county, crystalline igneous and metamorphic rock occurs at the surface. In the southern two-thirds of the county, the surface of the crystalline rock slopes southeastward beneath a progressively thicker cover of unconsolidated sedimentary strata. The sediments of the Coastal Plain consist chiefly of sand, gravel, silt, and clay. Figure 5, a geologic section, shows a topographic profile and the relation of the crystalline rock and younger Coastal Plain sediments. (See also tables 2 and 8.)

Drainage in both the Piedmont and the Coastal Plain is well-developed, except for a few places along the tidewater. Stream gradients along some Piedmont streams are on the order of 100 to 150 ft/mi (feet per mile) (2- to 3-percent grade).

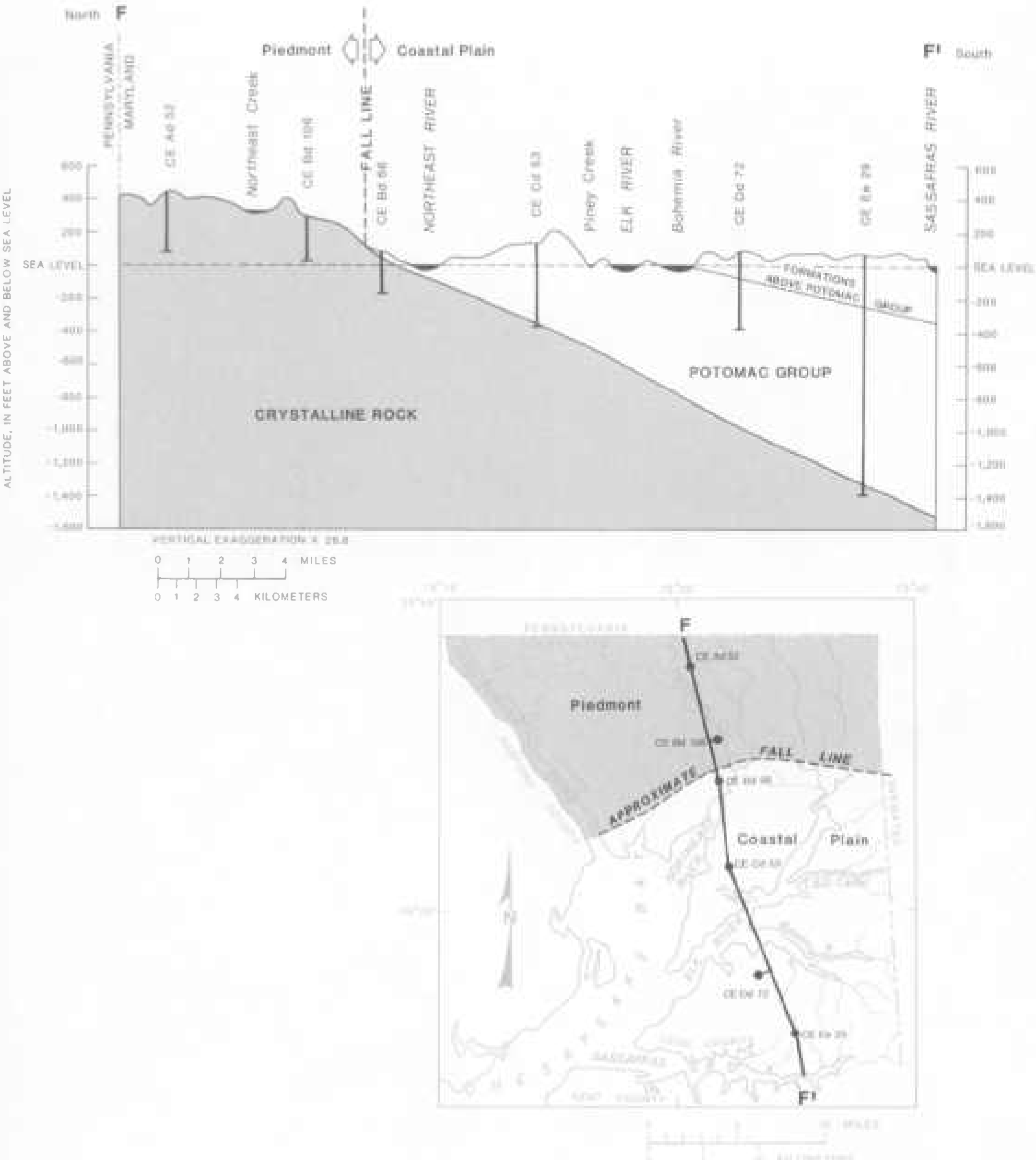

FIGURE 5. North-south geologic section across Cecil County, Md.

The greatest relief in the county is in the Piedmont where the elevation ranges from near sea level at the mouth of Octoraro Creek to a maximum of 535 ft at Rock Springs, about one-half mile south of the Pennsylvania State line on U.S. Route 222.

LAND USE

Cecil County is basically a rural county with about 25 percent of its land developed, 41 percent in agricultural use, and 34 percent in forest and other undeveloped use (Susan

McPheeters, Cecil County Office of Planning and Development, written commun., 1987). The total land area of the county is about 352 mi^2 (square miles). Most of the concentration of agricultural land is in the northwestern and southeastern parts of the county. Forested land is most prevalent along the Route I-95 to U.S. Route 40 corridor bisecting the county from northeast to southwest and along the Elk Neck peninsula where some of the largest forest stands occur.

Both natural and manmade factors markedly influence the pattern of land use. Most of the farmland is in areas of fertile, well-drained soils, and most of the woodland is along stream valleys and along steep or rocky slopes. Gravel pits and rock quarries occur where a suitable type of material is present.

Urbanization in the county tends to follow the location of highways and accessibility to railroad transportation. Prior to the development of good roads in this century, navigable waterways influenced urbanization more than at present. However, the existence of the tributaries of the Chesapeake Bay has influenced some development of seasonal residences in the southern part of the county.

GROUND-WATER RESOURCES

The source of freshwater in Cecil County is precipitation. Some water from precipitation runs across the ground into streams; some water soaks into the ground and some of it evaporates. Much of the water that soaks into the ground is held in the soil and used by plants. Excess water in the soil moves downward to the water table and recharges the ground-water reservoir.

Almost all ground-water movement in the Piedmont part of the county is between interstream drainage divides and the adjacent streams. In the Coastal Plain part of the county, deeper interbasin flow is also significant. The streams in the county, with rare exceptions, act as drains for the ground-water reservoir. Ground-water discharge to streams is the source of the base flow that sustains streamflow between precipitation events. Higher streamflows are produced by overland runoff during and following storms.

A large percentage of the water derived from precipitation is returned to the atmosphere through evaporation and transpiration (collectively called evapotranspiration). Most evapotranspiration is from soil moisture, but where the water table is near the land surface, evapotranspiration may come directly from ground water (ground-water evapotranspiration).

Ground-water conditions differ considerably between the Piedmont and the Coastal Plain. In the Piedmont, water occurs in openings in the crystalline rock caused by fracturing and weathering of the rock. Although water within an individual fracture may be confined by the adjacent rock, the system functions on a somewhat larger scale as a water-table system. In the Coastal Plain, water occurs between grains in the sediments. Except in outcrop areas, these units generally function as confined aquifers.

PIEDMONT

Crystalline rock of the Maryland Piedmont is exposed in the northern one-third of Cecil County. A generalized geologic map of the crystalline-rock outcrop area is shown on plate 1. The rock units consist chiefly of schist, gneiss, granofels, gabbro, amphibolite, serpentinite, and diamictite. Table 2 describes the geologic units in the Piedmont of Cecil County and table 3 correlates geologic names used in this report with those of other pertinent reports. The crystalline rock extends to great, unknown depths and forms the basement beneath the geologically younger sedimentary strata of the Coastal Plain. Contours on top of the crystalline rock beneath the Coastal Plain sediments are shown on plate 1.

Fractures and Weathering

The availability of ground water in the crystalline rock of the Piedmont depends on the nature and distribution of secondary openings resulting from fracturing and weathering. Figure 6 is a schematic section showing the occurrence of ground water in the Piedmont. Crystalline rock is highly indurated and contains free water only in openings where the rock has been fractured or decomposed by weathering. Permeability of fractured rock depends on the number of fractures, the size of the fracture openings, and the interconnection of the fractures.

Various stresses have produced complex systems of fractures oriented at numerous angles including horizontal and vertical. A group of closely spaced vertical fractures may sometimes result in a linear feature that can be mapped. Where these fractures result in a weakened or otherwise altered zone in the rock, they may show up in the field or on aerial photographs as a straight stream segment or as a linear variation in topography, vegetation,

TABLE 2

GEOLOGIC UNITS IN THE PIEDMONT OF CECIL COUNTY, MD.

[Geology based on Higgins and Conant, 1986.]

Erathem	System	Geologic unit		Description
Mesozoic	Juressic and Triessic	Dikes		Diebese dikes, derk grey to greenish black
Upper and Middle Peleozoic		Dikes, veins, end sills		Quartz veins, pegmatite dikes, end amphibolite dikes and sills. Maximum thickness ebout 100 ft
Lower Peleozoic end Upper Precambrian		James Run Formation	Upper members	Felsite, granofels, schist, and amphibolite
			Gilpins Falls Member	Greenstone, greenschist, metebaselt, amphibolite, end schist
			Lower members	Grenofels, amphibolite, and diamictite
		Port Deposit Gneiss		Granodiorite gneiss and grenofels
		Gneiss et Gerrett Island, Elkton, end Rolling Mill		Biotite-quartz-plagioclese gneiss
		Conowingo diamictite		Gneiss and grenofels with uniform matrix and included rock fragments
		Sykesville Formation		Diamictite: gneiss end grenofels. A significent portion of the included rock fregments are of ultramafic rock
		Pelitic facies	Pelitic schist	Quartz-biotite-plegioclese-muscovite schist
			Pelitic schist with amphibo-lite	Quertz-biotite-plegioclese-muscovite schist with thin layers of amphibolite
			Pelitic gneiss	Muscovite-biotite-quartz-plegioclase gneiss
		Metegraywacke		Metegraywacke end schist, interbedded. Includes thin leyers of amphibolite west of Northeest Creek
		Baltimore Complex	Gabbro	Gebbro, generally massive
			Serpen-tinite	Serpentinite end soapstone. Conteins sporadic messes of chromite grains
		Gabbro and serpentinite at Grays Hill		Gabbro and serpentinite. Commonly covered with weethering rind of iron silicates
		Gebbro et Appleton end Gerrett Island		Gebbro and amphibolite

TABLE 3
APPROXIMATE CORRELATION OF NAMES USED FOR GEOLOGIC UNITS OF THE PIEDMONT OF CECIL COUNTY, MD.

This report and Higgins and Conant (1986)		Cleaves and others (1968)	Overbeck and others (1958, pl. 5)
James Run Formation	Upper members	Port Deposit Gneiss. Some mapped as Wissahickon Formation	Granodiorite Schist
	Gilpins Falls Member	Volcanic Complex of Cecil County. Amphibolite mapped with Baltimore Gabbro Complex	Metadacite Gabbro
	Lower members	Port Deposit Gneiss	Granodiorite
Port Deposit Gneiss			
Gneiss at Garrett Island, Elkton, and Rolling Mill			
Conowingo diamictite			
Sykesville Formation		Wissahickon Formation	Schist
Pelitic facies	Pelitic schist	Wissahickon Formation. Some mapped as Baltimore Gabbro Complex or Port Deposit Gneiss	Schist Gabbro Granodiorite
	Pelitic schist with amphibolite		
	Pelitic gneiss		
Metagraywacke		Wissahickon Formation	Schist
Baltimore Complex	Gabbro	Baltimore Gabbro Complex	Gabbro
	Serpentinite	Ultramafic rock	Serpentinite
Gabbro and serpentinite at Grays Hill		Baltimore Gabbro Complex	Gabbro Serpentinite
Gabbro at Appleton		Wissahickon Formation	Schist
Gabbro at Garrett Island		Baltimore Gabbro Complex	Gabbro

or soil. Identification of linear features is often used as a prospecting tool for locating potential drilling sites for wells in crystalline rock areas. The assumption is that the linear feature identifies a zone where the rock has been weakened by fracturing and weathering, and the amount of fracture opening likely to be encountered by drilling in such a zone should be greater than average. Generally, this tool is helpful and yields are improved (Nutter, 1977, p. 16; McGreevy and Sloto, 1977, p. 26).

Weathering increases the size of fracture openings, but is most significant in Cecil County because of the saprolite zone it produces. The mechanical and chemical breakdown of rock by air, water, temperature, and biological activity has created a mantle of unconsolidated, weathered rock (saprolite) at the land surface. The process works progressively downward from the surface. This unconsolidated zone grades from a soil at the land surface, to decomposed rock, to crumbly gravel-like material where pieces of rock remain in place in a clayey matrix. Below the unconsolidated zone, the rock is generally solid, but some minerals are weathered along the fractures.

The major significance of the weathered mantle is as a storage reservoir that provides water to the fracture systems that supply water to wells. Recharge moves readily into this unconsolidated zone and discharge moves out to streams and to evapotranspiration. A large volume of water remains in storage in this unconsolidated zone.

Because most wells in the Piedmont have casings set in the upper few feet of solid rock, casing depth usually indicates the approximate thickness of the unconsolidated zone. Based

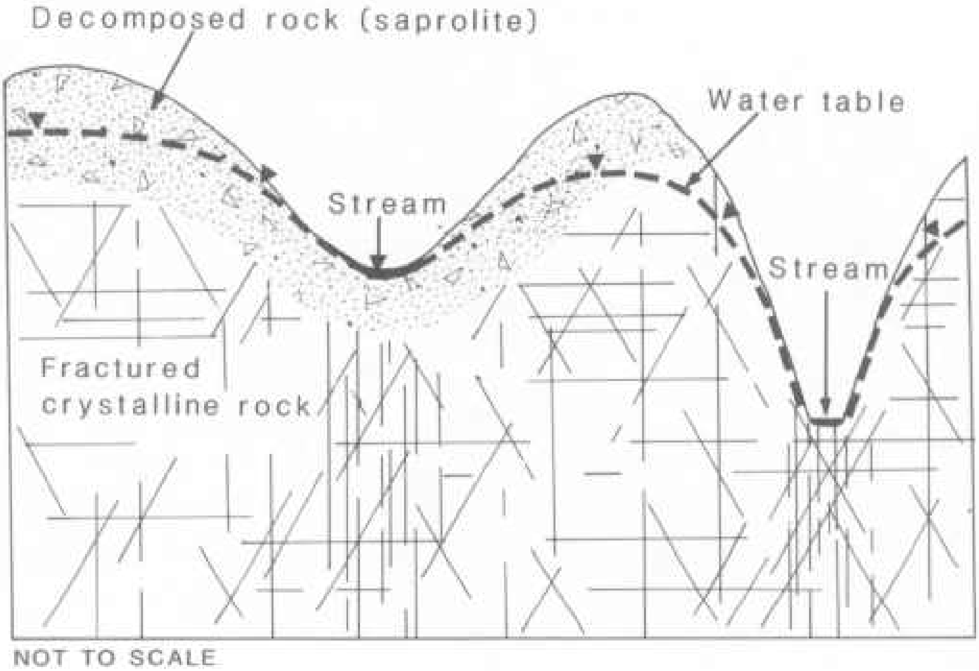

FIGURE 6. Occurrence of ground water in the Piedmont.

on the median (50 percent) casing depth for wells in all Piedmont units (table 4), the thickness of the unconsolidated zone averages about 41 ft. The saturated thickness of this zone, based on the median depth to water [20 ft (table 5)], is about 21 ft.

Specific-yield estimates from various studies listed in Willey and Achmad (1986, p. 19) indicate that the specific yield of the unconsolidated zone is about 0.08, and the specific yield of the solid rock below is probably one or two magnitudes less. (An average specific yield for the upper 200 ft of material of 0.05 is used in the models developed in later sections of this report.) A 21-ft mantle of saturated unconsolidated rock with a specific yield of 0.08 would contain at least 1.7 ft of water, which amounts to about 354 Mgal of water in storage per square mile.

Topographic Position

The most productive wells in the Piedmont commonly are located in valleys and draws and the least productive are on hilltops or hillsides. Consequently, when alternative sites for drilling are available, topographic position should be considered. Because topographic lows often form where the rock has been weakened by relatively intense fracturing and weathering, wells in such positions are likely to penetrate more and larger openings. Also, because the water table tends to be at a shallower depth in a topographic low, more unconsolidated weathered material will be saturated so that more storage is available to sustain the yield.

The distribution of reported yield and specific capacity according to topographic position is given in table 6. As the table indicates, flood plain and valley flat sites are most productive with a median yield of 20 gal/min. Upland draws are also relatively productive with a median yield of 14 gal/min. Least productive are hilltop and hillside sites where the median yield is 9 and 8 gal/min, respectively.

TABLE 4
SUMMARY OF DEPTH OF WELL AND DEPTH OF CASING FOR WELLS IN THE PIEDMONT OF CECIL COUNTY, MD.

Geologic unit	Depth of well (feet below land surface)							Depth of casing (feet below land surface)						
	Number of wells	Range	Depth equaled or exceeded by indicated percentage of wells					Number of wells	Range	Depth equaled or exceeded by indicated percentage of wells				
			90	80	50	20	10			90	80	50	20	10
James Run Formation														
Upper members	36	18-475	36	43	117	215	226	30	11-107	18	24	40	60	71
Gilpins Falls Member	69	16-430	33	49	90	185	241	64	10- 68	18	20	30	45	55
Lower members	152	15-575	30	46	88	175	242	140	10-206	20	25	40	61	79
Port Deposit Gneiss	45	24-300	36	45	90	145	200	41	16-103	20	23	40	63	73
Gneiss at Garrett Island, Elkton, and Rolling Mill	50	14-440	28	30	100	198	280	47	14-117	17	24	34	63	80
Conowingo diamictite	78	19-271	30	44	59	84	128	62	4-271	15	19	35	55	85
Pelitic schist and pelitic schist with amphibolite	106	17-400	26	39	83	120	152	94	18-175	23	28	63	98	116
Pelitic gneiss	24	13-225	20	40	60	102	114	20	13- 94	17	23	40	65	73
Metagraywacke	34	20-400	28	41	60	105	116	28	20- 96	28	30	43	59	71
Baltimore Complex														
Serpentinite	28	17-246	30	40	62	104	145	26	7-131	15	17	31	77	97
Gabbro	52	11-173	30	39	64	122	154	49	6-120	20	25	44	55	81
Gabbro and serpentinite at Grays Hill	44	21-450	65	85	156	230	390	40	8-181	41	59	90	120	135
All Piedmont units	718	11-575	30	43	82	152	210	641	4-271	20	24	41	71	94
Public-supply wells in Piedmont units	64	25-430	60	75	120	200	280	60	10-149	20	23	40	59	68

TABLE 5

SUMMARY OF DEPTH TO WATER FOR WELLS IN THE PIEDMONT OF CECIL COUNTY, MD.

Geologic unit	Number of wells	Depth to water (feet): Range	Depth equaled or exceeded by indicated percentage of wells: 90	80	50	20	10
James Run Formation:							
Upper members	34	4- 64	7	14	24	40	50
Gilpins Falls Member	65	3- 52	8	14	20	30	35
Lower members	131	6-200	10	13	21	32	44
Port Deposit Gneiss	44	4- 64	6	10	20	36	40
Gneiss at Garrett Island, Elkton, and Rolling Mill	46	3- 80	10	12	26	40	52
Conowingo diamictite	73	3- 60	8	10	15	30	35
Pelitic schist	96	4- 46	8	10	18	25	30
Pelitic gneiss	19	4- 43	6	7	15	35	36
Metagraywacke	31	6- 64	8	12	20	30	31
Baltimore Complex:							
Serpentinite	27	3- 50	7	9	17	30	40
Gabbro	48	3- 50	6	10	20	30	35
Gabbro and serpentinite at Grays Hill	37	1-150	5	8	25	38	50
All Piedmont units	651	1-200	8	11	20	30	40

TABLE 6

REPORTED YIELD AND SPECIFIC CAPACITY BY TOPOGRAPHIC POSITION IN THE PIEDMONT OF CECIL COUNTY, MD.

[—, percentage not computed for less than 20 values; (gal/min)/ft = gallon per minute per foot.]

Topographic position	Reported yield (gal/min): Number of wells	Range	Yield equaled or exceeded by indicated percentage of wells: 90	80	50	20	10	Specific capacity [(gal/min)/ft]: Number of wells	Range	Value equaled or exceeded by indicated percentage of wells: 90	80	50	20	10
Hilltop	92	0.5-200 a/	2	4	9	16	30	72	<0.1-10	<0.1	<0.1	0.2	0.8	2.5
Hillside	161	.8-200	3	5	8	15	25	116	<.1-20	<.1	.1	.4	1.5	2.4
Upland flat	253	.1-200	3	5	10	20	35	173	<.1-20	<.1	<.1	.2	1.0	1.9
Upland draw	34	3 -100	6	9	14	22	40	21	<.1-20	<.1	.2	.4	1.0	3.3
Flood plain and valley flat	20	2 - 74	4	6	20	50	60	12	<.1- 4.4	--	--	1.3	--	--

a/ One well reportedly yielded 500 gal/min, but data were not verified.

Well Information

Basic information on many wells in Cecil County is contained in Willey and others (1987, table 7). Much of this information for wells in the Piedmont will be evaluated in this section. Reported yields and specific capacities are summarized in table 7. Well and casing depths are summarized in table 4, and depths to water in table 5.

Well yield

Well yields commonly reflect the types of water use, particularly where the aquifers are crystalline rock. Drilling in this type of setting generally continues only until a sufficient yield is obtained for the desired use. Most of the reported yields in table 7 pertain to household wells that require only small to moderate yields that may not be the maximum available. Consequently, where sufficient area is available for exploration and with proper exploration techniques, yields greater than the median (50 percent) can probably be obtained from the crystalline rock units in most of the area. The median reported yield of 61 public-supply wells tapping the crystalline rock of Cecil County is 15 gal/min compared to the median for all wells, which is 10 gal/min. The reported yield of 20 percent of those public-supply wells is 30 gal/min or more.

The permeability of unfractured, fresh, crystalline rock is generally near zero. Water moves through crystalline rock only where the rock is weathered or fractured, and the yield of a well depends primarily on the amount of fracture openings penetrated by the well. Rock type influences the yield of wells by affecting the way the rock weathers and fractures. The yield data in table 7, however, show only minor differences between the mapped units in Cecil County. The median yield of all units is 10 gal/min, except for the upper and lower members of the James Run Formation which have a median yield of only 6 gal/min.

Specific capacity

Specific capacity relates well yield to drawdown and is expressed in gallons per minute per foot [(gal/min)/ft] of drawdown. At a constant pumping rate, the drawdown of a well increases at a gradually diminishing rate; hence, the specific capacity gradually decreases accordingly. Specific-capacity data, mostly reported by drillers, were obtained for 394 wells. The data are contained in Willey and others (1987, table 7) and are summarized in table 7.

Specific capacity can be used to estimate aquifer transmissivity. The relation of specific capacity to transmissivity depends on several factors such as well construction, length of pumping period, and effective well radius. (See Heath, 1983, p. 60–61). For the crystalline rock of Cecil County, transmissivity (in feet squared per day) is roughly about 100 to 300 times the specific capacity (in gallons per minute per foot). Figure 7 shows that 95 percent of the wells have a specific capacity greater than 0.02 (gal/min)/ft and only 5 percent are greater than 4.7 (gal/min)/ft. Using these figures to estimate transmissivity for the crystalline rock in Cecil County gives a range of about 2 ft^2/d (feet squared per day) (100×0.02) to 1,400 ft^2/d (300×4.7). This range is comparable to values given for a small basin in Chester County, Pa. [4 to 1,700 ft^2/d (McGreevy and Sloto, 1980, p. 14)], and for a small basin in Howard County, Md. [7 to 2,000 ft^2/d (Willey and Achmad, 1986, p. 20)]. Median specific capacity for the 394 Piedmont wells is 0.3 (gal/min)/ft. Use of the same factors (100 and 300) would put the median transmissivity in the range of 30 to 90 ft^2/d.

TABLE 7

SUMMARY OF REPORTED YIELD AND SPECIFIC CAPACITY OF WELLS IN THE PIEDMONT OF CECIL COUNTY, MD.

[—, percentage not computed for less than 20 values; (gal/min)/ft = gallon per minute per foot.]

Geologic unit	Reported yield (gal/min)							Specific capacity [(gal/min)/ft])						
	Number of wells	Range	Yield equaled or exceeded by indicated percentage of wells					Number of wells	Range	Value equaled or exceeded by indicated percentage of wells				
			90	80	50	20	10			90	80	50	20	10
James Run Formation														
Upper members	31	1 -200	1	3	6	20	42	21	<0.1-20	<0.1	<0.1	0.1	0.5	0.7
Gilpins Falls Member	58	3 -200	4	5	10	20	30	37	<.1-10	<.1	<.1	.2	1.0	3.0
Lower members	122	.1-100 a/	2	3	6	15	30	78	<.1- 6.0	<.1	<.1	.1	.8	1.3
Port Deposit Gneiss	43	2 -100	3	5	10	20	35	32	<.1- 4.0	<.1	<.1	.2	1.2	2.1
Gneiss at Garrett Island, Elkton, and Rolling Mill	36	1 - 60	2	5	10	20	30	31	<.1- 4.6	<.1	<.1	.2	1.0	1.9
Conowingo diamictite	74	1 - 74	4	7	10	20	30	50	<.1- 8.0	.2	.3	.8	2.1	3.0
Pelitic schist and pelitic schist with amphibolite	70	1 -100	4	5	10	20	35	44	<.1- 6.0	<.1	.1	.2	.8	3.0
Pelitic gneiss	12	3 -200	--	--	10	--	--	9	<.1- 2.0	--	--	.2	--	--
Metagraywacke	20	1 -100	1	5	10	20	25	16	<.1- 5.0	--	--	.4	--	--
Baltimore Complex														
Serpentinite	23	2 -200	5	5	10	20	100	19	<.1-20	--	--	.3	--	--
Gabbro	35	3 -100	4	6	10	25	30	27	<.1-17	<.1	<.1	.4	1.7	5.0
Gabbro and serpentinite at Grays Hill	36	1 - 50	3	3	10	25	39	30	<.1- 2.5	<.1	<.1	.1	.5	1.0
All Piedmont units	560	.1-200 a/	3	5	10	20	30	394	<.1-20	<.1	<.1	.3	1.3	2.5
Public-supply wells in Piedmont units	61	2 -100	3	6	15	30	45	40	<.1-10	<.1	.1	.2	1.3	3.3

a/ One well reportedly yielded 500 gal/min, but data were not verified.

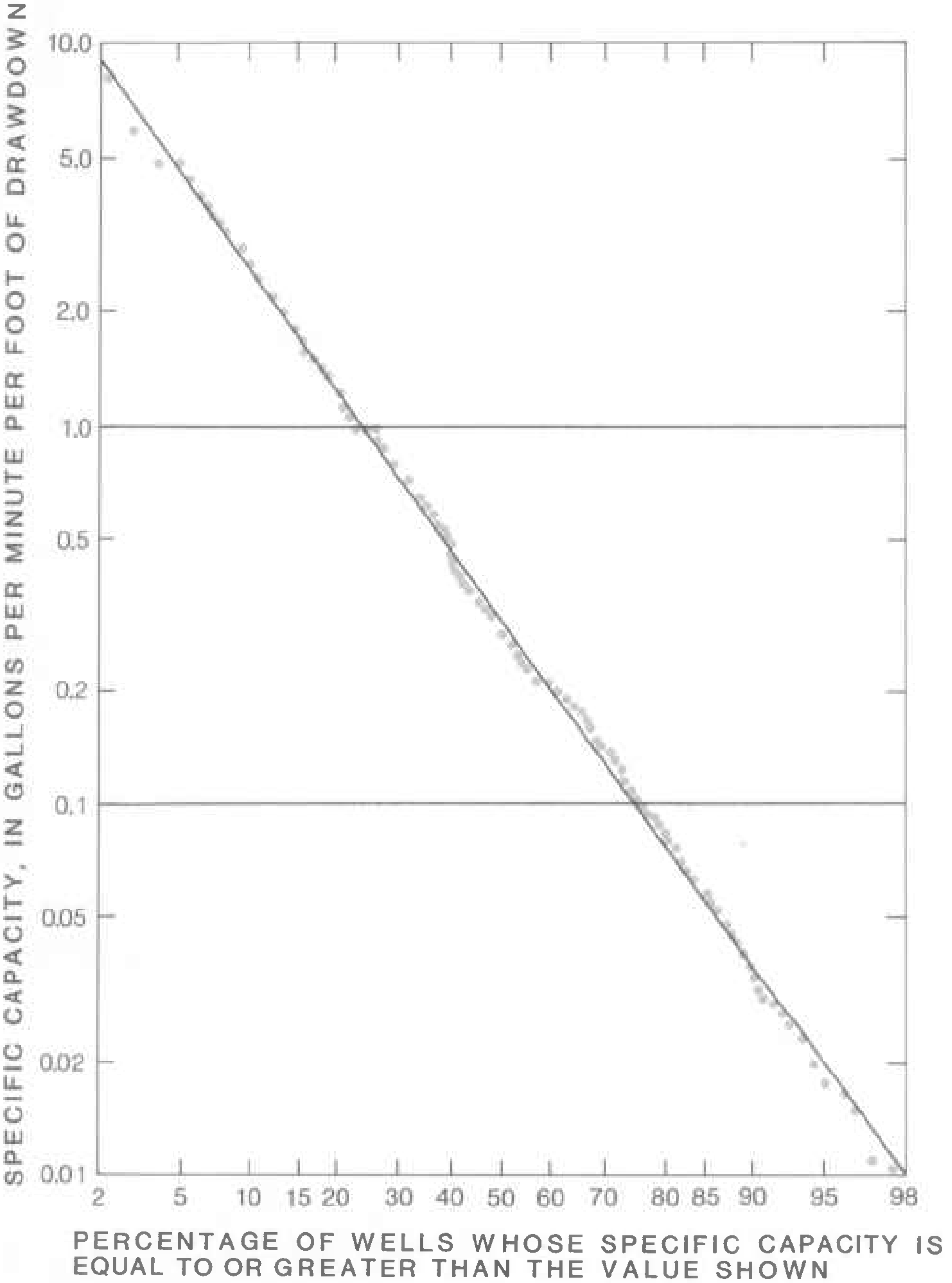

FIGURE 7. Specific capacity distribution for 394 wells in the Piedmont of Cecil County, Md.

Depth of well

Well depths range from 11 to 575 ft and the median is 82 ft (table 4). Because most of these are domestic wells, this gives an indication of the large range in depth needed to obtain sufficient supply for household use. The range in depth for 64 public-supply wells is 25 to 430 ft with a median of 120 ft. Generally, in the crystalline rock of Cecil County, if sufficient yield is not obtained by a depth of about 300 ft, testing another site may be more productive than drilling deeper.

COASTAL PLAIN

The Coastal Plain sediments consist of unconsolidated, stratified layers of clay, silt, sand, and gravel that rest on a sloping basement of crystalline rock. The basement surface slopes southward at a rate of about 100 ft/mi (pl. 1). The maximum thickness of the Coastal Plain sediments is in the extreme southeastern corner of the county and is estimated to be about 1,600 ft. The maximum known thickness is about 1,390 ft in a deep test well drilled at Cecilton in 1978 (well CE Ee 29). Geologic units of the Coastal Plain of Cecil County are described in table 8, and correlation of the geologic names used in this report with those of other pertinent reports is shown in table 9.

Potomac Aquifers and Confining Units

The major aquifers in Cecil County are the upper and lower Potomac aquifers. The thick sequence of sediments comprising the Cretaceous Potomac Group in Cecil County was divided into three hydrogeologic units: (1) the upper Potomac aquifer, (2) the middle Potomac confining unit, and (3) the lower Potomac aquifer. These units are shown in geologic sections A-A′ through E-E′ on plate 2. The lower Potomac aquifer is about 520 ft thick at Cecilton (well CE Ee 29, section C-C′). The unit thins updip (northward), and near Elkton (well CE Bf 82, section C-C′) it is only about 180 ft thick. The lower aquifer is present throughout most of the southern two-thirds of the county. Above the lower unit is a series of mostly clayey and silty beds that comprise the middle Potomac confining unit. Some water-bearing sand occurs within the confining unit, but finer-grained materials are predominant. This unit is about 325 ft thick at Cecilton (well CE Ee 29, section E-E′). Near Chesapeake City, the confining unit is only about 230 ft thick (well CE Ce 55, section C-C′). Lying above the confining unit is the upper Potomac aquifer which is about 235 ft thick in well CE Ee 29 at Cecilton. As the geologic sections (pl. 2) indicate, erosion has removed the upper Potomac aquifer from much of the area and it remains only in the southern one-third of the county.

The hydrologic subdivisions of the Potomac Group used in this report are not intended to infer stratigraphic correlation or uniform lithology[1]. All of the units have a high degree of

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[1]Generally speaking, the lower Potomac Group aquifer includes beds assigned to microfloral zones I, IIA, and IIB of Early Cretaceous age (Barremian (?), Aptian, and Albian stages). The middle Potomac Group confining bed can be largely assigned to microfloral zone IIC (Albian stage), but may extend into microfloral zone III (Cenomanian stage). The upper Potomac Group aquifer consists of microfloral zone III beds of Late Cretaceous age. Elsewhere in Maryland, where the Potomac Group is subdivided into formations, the Patuxent Formation and the Arundel Formation are assigned to microfloral zone I. The Patapsco Formation contains microfloral assemblages assigned to zones IIA, IIB, IIC, and III. Upper Patapsco beds containing zone IIC and zone III microfloras are sometimes referred to as the "Elk Neck beds of the Patapsco Formation" (Edwards and Hansen, 1979, p. 10–15). The Raritan Formation of Maryland, mentioned in earlier reports (for example, Overbeck, Slaughter, and Hulme, 1958), is now more properly assigned to the Elk Neck beds of the Patapsco Formation (microfloral zone III).

TABLE 8

GEOLOGIC UNITS AND CORRESPONDING AQUIFERS IN THE COASTAL PLAIN OF CECIL COUNTY, MD.

[Geology based on Higgins and Conant, 1986.]

Erathem	System	Series	Geologic unit	Description	Hydro-geologic unit
Cenozoic	Quaternary	Holocene	Tidel-marsh depoaits	Sand, silt, clay, end organic matter. Thickness generelly less then 20 ft	
			Alluvium	Sand, silt, clay, and gravel with aome orgenic meterial. Thickness generally less then 40 ft	
		Pleistocene	Talbot Formation	Coarse-grained facies: Coarse aand and gravel at base with aome boulders. Finer aand and loam in upper part. Thicknesa 25 to 50 ft. Finer-grained faciea: Silt and fine sand. Thickness 25 to 50 ft	Columbia aquifer
	Tertiary	Miocene	Pensauken Formation	Grevel and aand with some bouldera overlain with send end loam. Thickness generally between 15 and 90 ft	
			Uplend grevel	Gravel and aand with local lenses of clay. Thickness generelly less than 75 ft.	
		Paleocene	Aquie Formation	Sand, clayey, glauconitic; green and yellow. Only the lowest 70 ft present in Cecil County	Aquie-Hornerstown equifer
			Hornerstown Formation	Sand, about 90 percent glauconite, with glauconitic interstitial clay; green. Thickness generelly 20 ft	
Mesozoic	Cretaceous	Upper Cretaceous	Monmouth Group Unnamed upper unit	Sand, glauconitic, and silty sand. Thickness about 80 ft	Monmouth equifer
			Mount Laurel Sand	Sand, glauconitic, locally contains shell fregments. Thickness about 80 ft	
			Matawan Group Marshelltown Formation	Send, glauconitic, clayey, and silty, greenish black	Matawan confining unit
			Englishtown Formation	Sand, cleyey end silty, with lignite grains; dark gray to black where unweathered. Thickness about 15 to 20 ft	
			Merchantville Formetion	Sand, silty and clayey, micaceous and glauconitic, black. Thickness about 45 ft	
			Megothy Formation	Sand and clay, lignitic; black, gray, and white. Thicknesa about 35 ft	Magothy equifer
		Upper Cretaceous Lower Cretaceous	Potomac Group	Sand, gravelly sand, silt, and clay. Consists generally of elongate sand bodies within a matrix of silt and clay. Sand bodies are more preva-lent in the upper and lower parts of the unit while the middle part is predominantly silt and clay.	Upper Potomac aquifer Middle Potomac confining unit Lower Potomac equifer

TABLE 9

CORRELATION OF GEOLOGIC NAMES OF THE COASTAL PLAIN OF CECIL COUNTY, MD.

<table>
<tr><th colspan="5">Cecil County, Maryland</th><th>Delaware</th></tr>
<tr><th colspan="2">This report and Higgins and Conant (1986)</th><th>Cleaves and others (1968)</th><th colspan="2">Overbeck and others (1958, p. 25-94)</th><th>Spoljaric (1985, 1986)</th></tr>
<tr><td colspan="2">Tidal-marsh deposits</td><td rowspan="3">Lowland deposits</td><td colspan="2"></td><td></td></tr>
<tr><td colspan="2">Alluvium</td><td rowspan="4">Columbia Group</td><td rowspan="2">Talbot Formation</td><td rowspan="4">Columbia Formation</td></tr>
<tr><td colspan="2">Talbot Formation</td></tr>
<tr><td colspan="2">Pensauken Formation</td><td>Upland deposits (Eastern Shore)</td><td>Wicomico Formation</td></tr>
<tr><td colspan="2" rowspan="3">Upland gravel</td><td rowspan="3">Upland deposits (Western Shore)</td><td>Sunderland Formation</td></tr>
<tr><td colspan="2">Brandywine Gravel</td><td rowspan="2"></td></tr>
<tr><td colspan="2">Bryn Mawr Gravel</td></tr>
<tr><td colspan="2">Aquia Formation</td><td rowspan="2">Aquia Formation</td><td rowspan="2">Pamunkey Group</td><td rowspan="2">Aquia Greensand</td><td>Vincentown Formation</td></tr>
<tr><td colspan="2">Hornerstown Formation</td><td>Hornerstown Formation</td></tr>
<tr><td rowspan="2">Monmouth Group</td><td>Unnamed upper unit</td><td rowspan="2">Monmouth Formation</td><td colspan="2" rowspan="2">Monmouth Formation</td><td></td></tr>
<tr><td>Mount Laurel Sand</td><td>Mount Laurel Formation</td></tr>
<tr><td rowspan="3">Matawan Group</td><td>Marshalltown Formation</td><td rowspan="3">Matawan Formation</td><td colspan="2" rowspan="3">Matawan Formation</td><td>Marshalltown Formation</td></tr>
<tr><td>Englishtown Formation</td><td>Englishtown Formation</td></tr>
<tr><td>Merchantville Formation</td><td>Merchantville Formation</td></tr>
<tr><td colspan="2">Magothy Formation</td><td>Magothy Formation</td><td colspan="2">Magothy Formation</td><td>Magothy Formation</td></tr>
<tr><td colspan="2" rowspan="3">Potomac Group</td><td rowspan="3">Potomac Group</td><td colspan="2">Raritan Formation</td><td rowspan="3">Potomac Formation</td></tr>
<tr><td rowspan="2">Potomac Group</td><td>Patapsco Formation</td></tr>
<tr><td>Patuxent Formation</td></tr>
</table>

variability, both vertically and horizontally. Somewhat arbitrary boundaries are drawn between units based on predominance, or not, of water-bearing lithologies—sand and gravel. Martin (1984, pl. 1 and fig. 11) divided the Potomac Group in adjacent New Castle County, Del., into three aquifers and two intervening confining units. Martin's lower Potomac aquifer is approximately equivalent to that of this report.

The total thickness of the Potomac Group ranges from zero at the Fall Line to nearly 1,200 ft in the southeastern corner of the county (pl. 1 and fig. 8). Sediments are predominantly fine-grained and include sand, silt, and clay. Interspersed irregularly throughout the section are layers of coarse-grained materials (medium to coarse sand and gravel) that vary greatly in thickness and lateral extent. Sand layers are white to orange-brown, crossbedded, moderately well sorted, and mostly quartzose. Gravel is almost entirely quartz or quartzite clasts, usually less than 3 in. in diameter. Some larger cobbles are found in the lower part of the unit. Localized iron-cemented layers occur throughout the section, varying from fractions of an inch to a few feet in thickness. Clay may be silty and runny, or tough, compact, and almost dry in places. The colors of fine materials range from white and yellow to deeper shades of red, purple, and dark gray. Localized occurrences of lignite and pyrite are common.

The Potomac Group is present throughout most of the southern two-thirds of the county. Figure 8 shows the outcrop area of the Potomac Group in Cecil County and the altitude of the top of the unit. The top of the unit dips to the southeast at a rate of approximately 50 ft/mi. At Cecilton, the top of the Potomac Group lies about 240 ft below sea level.

Yields of wells in the Potomac aquifers range from 0.5 to 703 gal/min and the median is 30 gal/min (table 10). Specific capacities range from less than 0.1 to 40 (gal/min)/ft and the median is 1.1 (gal/min)/ft. The most productive wells commonly are large-diameter wells

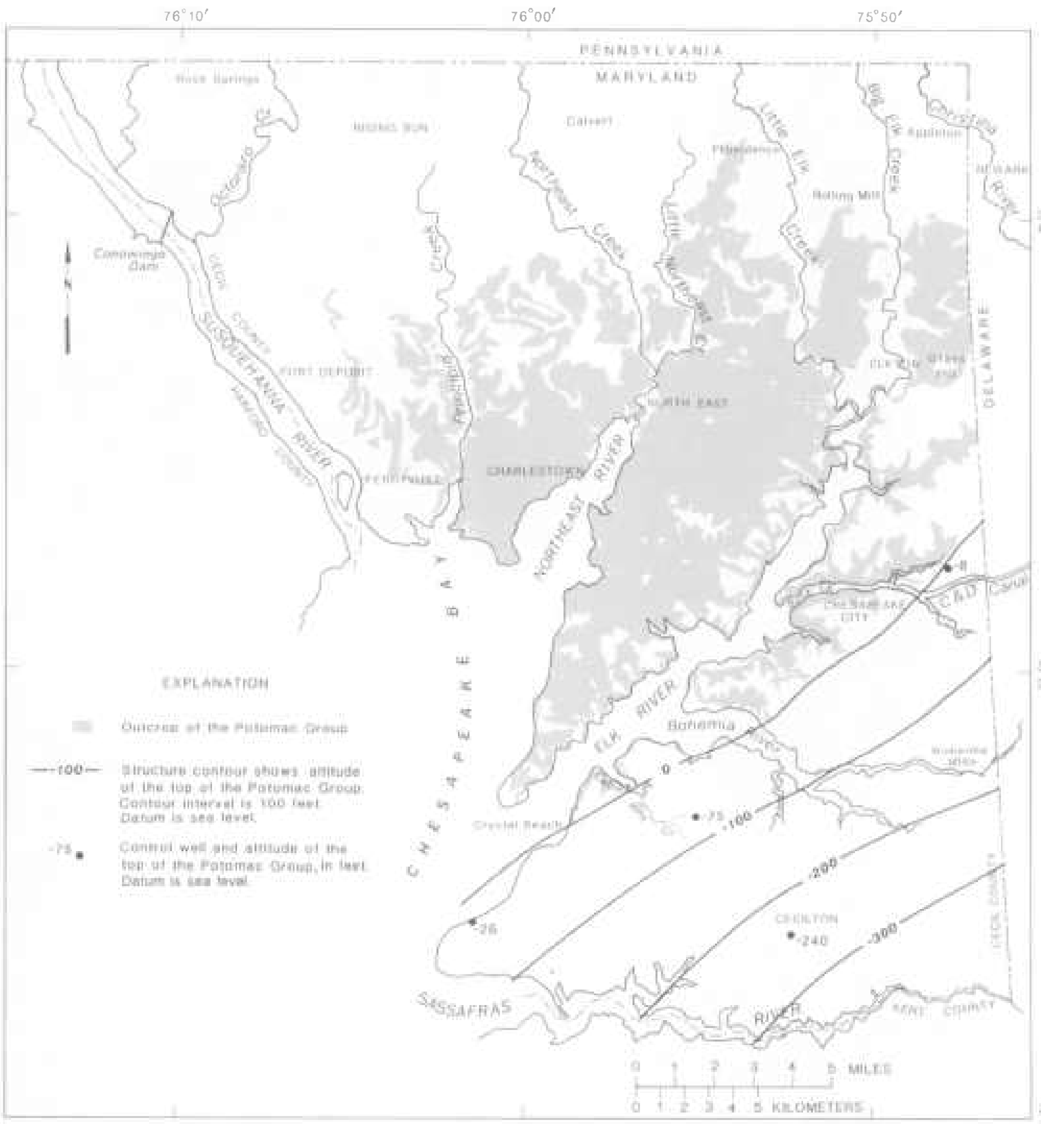


FIGURE 8. Outcrop area and altitude of the top of the Potomac Group.

drilled for municipal, commercial, or industrial supplies. Based on the records of 379 wells in the Potomac Group tabulated for this study, the following five wells are the most productive:

Well no.	Depth (ft)	Screen Diameter (in.)	Screen Length (ft)	Owner	Yield (gal/min)	Specific capacity [(gal/min)/ft]
CE Bf 59	157	12	31	Town of Elkton	703	12.3
CE Cf 51	443	8	20	Chesapeake City	410	4.1
CE Cf 74	267	10	20	Chesapeake City	302	3.5
CE Cf 50	226	8	10	Chesapeake City	300	4.2
CE Cf 5	147	8	23	Losten's Dairy	300	7.1

Well CE Bf 59 is located about 2.5 mi southeast of Elkton and was formerly owned by the Holly Hall Utilities Corporation. The well is screened opposite a sand zone in the lower Potomac aquifer from a depth of 126 to 157 ft. During 1984, the well is reported to have been pumped at the rate of 600,000 gal/d and was an important part of the Elkton water supply.

TABLE 10

SUMMARY OF REPORTED YIELD AND SPECIFIC CAPACITY OF WELLS IN THE COASTAL PLAIN OF CECIL COUNTY, MD.

[—, percentage not computed for less than 20 values; gal/min = gallon per minute; (gal/min)/ft = gallon per minute per foot.]

Geologic unit	Reported yield (gal/min): Number of wella	Range	Yield equaled or exceeded by indicated percentage of wells: 90	80	50	20	10	Specific capacity [(gal/min)/ft]: Number of wells	Range	Value equaled or exceeded by indicated percentage of wells: 90	80	50	20	10
Pensauken Formation and upland gravel	5	7 - 20	--	--	10	--	--	3	0.4- 2.5	--	--	2.0	--	--
Monmouth Group	25	8 - 42	8	12	20	30	35	24	.2- 3.8	0.2	0.2	.5	1.3	2.2
Matawan Group	4	7 - 40	--	--	20	--	--	4	.2- 1.9	--	--	1.2	--	--
Magothy Formation	50	7 -270	12	20	30	40	75	46	.3- 5.6	.3	.4	.9	1.7	2.3
Potomac Group	379	0.5-703	8	15	30	50	75	321	<.1-40	.4	.6	1.1	2.2	3.9
All Coastal Plain units	463	.5-703	8	15	30	50	70	398	<.1-40	.3	.5	1.1	2.1	3.7

The hydraulic properties of transmissivity (T) and storage (S) of the sand in which a well is completed determine in part the quantities of water that can be withdrawn by the well. These properties can be estimated by aquifer tests or by the relation of specific capacity to transmissivity. Estimates of hydraulic properties for sand in the Potomac aquifers at 25 wells are in table 11. Most of the transmissivity values in table 11 are estimated from specific-capacity data using an iterative solution of the Theis equation (Lohman, 1972, p. 8, formula

TABLE II

HYDRAULIC PROPERTIES OF SAND IN THE POTOMAC AQUIFERS

[Transmissivity estimated from specific capacity unless otherwise noted; ft = feet; ft^2/d = feet squared per day.]

Well no.	Location	Aquifer	Tranmissivity (ft^2/d)	Storage coefficient	Well depth (ft)	Screened interval (ft)
CE Be 28	Elkton	lower	210	-	80	75- 80
CE Be 43	Elkton	lower	60	-	85	-
CE Be 56	Elkton	lower	1/ 740	0.0001	104	99-104
CE Be 59	Elkton	lower	400	-	75	35- 47 52- 63
CE Be 66	Elkton	lower	270	-	118	108-118
CE Be 67	Elkton	lower	670	-	111	101-111
CE Be 81	Elkton	lower	130	-	75	70- 75
CE Be 90	Elkton	lower	200	-	82	77- 82
CE Be 92	Elkton	lower	160	-	80	75- 80
CE Be 95	Elkton	lower	1,400	-	95	75- 95
CE Be 98	Elkton	lower	210	-	244	232-244
CE Be 104	Elkton	lower	140	-	134	129-134
CE Bf 20	Elkton	lower	220	-	84	79- 84
CE Bf 41	Elkton	lower	220	-	124	119-124
CF Bf 55	Elkton	lower	700	-	47	41- 47
CF Bf 56	Elkton	lower	1,400	-	76	59- 74
CF Bf 59	Elkton	lower	3,900	-	157	126-157
CE Bf 64	Elkton	lower	510	-	114	94-114
CE Bf 95	Elkton	lower	2,400	-	42	20- 42
CE Bf 101	Elkton	lower	440	-	43	38- 43
CE Cd 35	Elk Neck (Camp Rodney)	lower	1/ 3,200	-	178	163-178
CE Cf 49	Chesapeake City	lower	2/ 2,500	.0001	410	390-410
CE Dd 73	Veazey Neck (Earleville)	upper	214	.00005	315	275-315
CE Ee 29	Cecilton	upper	3/ 1,500	-	547	515-525
Da 44 5	East of Elkton	lower	4/ 1,600	.004	235	160-186 222-232

1/ From aquifer test reported in Overbeck and others (1958, p. 47-49).

2/ From aquifer test reported in Sundstrom and others (1967, p. 51).

3/ From aquifer test reported in Otton and Mandle (1984, p. 16).

4/ From aquifer test data shown in figure 9.

19; W. B. Fleck, U.S. Geological Survey, written commun., 1986). Values of transmissivity range from 60 to 3,900 ft^2/d, with the median value being 440 ft^2/d. Four values of the storage coefficient (S) of the aquifers range from 0.00005 to 0.004.

Figure 9 shows how data obtained from an aquifer test on a well are used to compute the transmissivity and coefficient of storage. Well Da 44-5, the pumped well, is a 232-ft-deep well located 1,700 ft east of the Maryland-Delaware State line and 500 ft south of U.S. Route 40. The well is screened in a sand in the lower Potomac aquifer. The well was pumped in June 1981 for 48 hours (2,880 minutes), but only the first 1,000 minutes of drawdown are shown on the graph. The test results indicate the aquifer transmissivity at the site is about 1,600 ft^2/d and the coefficient of storage is 0.004. The storage value is based on measurements in a 2-in.-diameter observation well located 15 ft from the pumped well.

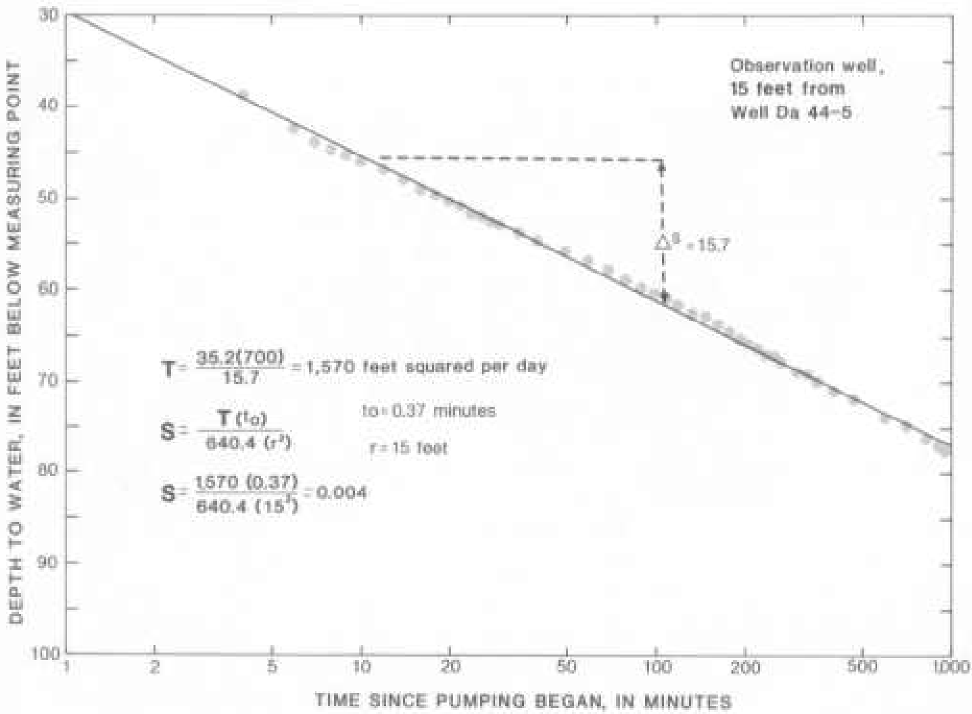
Magothy Aquifer

The Magothy aquifer is the Cretaceous Magothy Formation. It consists of black, dark gray, and white, fine to coarse, quartzose sand and clay. Coarse materials are usually light-colored and alternate with dark-colored clay or silty clay. Some outcrops contain lignitic sand in such abundance that the sand appears black until the lignite is removed by washing. Siderite, pyrite, and marcasite are present locally as are iron-stained and iron-cemented zones. The unit occurs in Cecil County in the area south of the C and D Canal and southeast of the Elk River. Exposures of the unit can be seen at Crystal Beach, along the bluffs at Cabin John Creek, and at other locations extending as far north as the C and D Canal. Figure 10 shows outcrop areas and structure contours on the top of the unit. The unit dips to the southeast at an average rate of about 30 to 40 ft/mi. At Cecilton, the top of the aquifer lies about 160 ft below sea level. The relation of the Magothy to other units is shown in sections B-B′, C-C′, and E-E′ on plate 2.

The Magothy aquifer is the second most productive water-bearing unit in the county. Reported yields of 50 wells range from 7 to 270 gal/min; the median is 30 gal/min. Reported specific capacities for 46 wells range from 0.3 to 5.6 (gal/min)/ft, with a median value of 0.9 (gal/min)/ft. (See table 10.) Table 12 lists estimates of hydraulic properties of the aquifer. Most of the values were estimated from specific-capacity data (W. B. Fleck, U.S. Geological Survey, written commun., 1986). Values of transmissivity range from 290 to 3,300 ft^2/d, with the median value being 490 ft^2/d. Only two values of the storage coefficient are available—0.00006 and 0.0001. Several of the wells in the table are domestic wells where only 5 ft of screen was used and the aquifer was only partially penetrated. Thus, the values of transmissivity estimated from the specific-capacity measurements may be low.

Matawan Confining Unit

The Cretaceous Matawan Group, which makes up the Matawan confining unit, contains three mappable formations. From oldest to youngest these are the Merchantville, Englishtown, and Marshalltown Formations, whose combined thickness ranges up to 90 ft. The Merchantville Formation is primarily indistinctly stratified, silty and clayey, gray to black, very fine to medium, micaceous sand, with some glauconite. Lignite and siderite concretions occur locally. The Englishtown Formation consists of well-stratified, dark gray to black clay, and silty, very fine to fine micaceous and lignitic sand. The glauconite content is less than that of the Merchantville Formation. The Marshalltown Formation is a poorly sorted, unstratified, green to black, silty and clayey, fine to medium sand with fine-grained glauconitic sand. Locally, this formation is richly fossiliferous and mica is less abundant



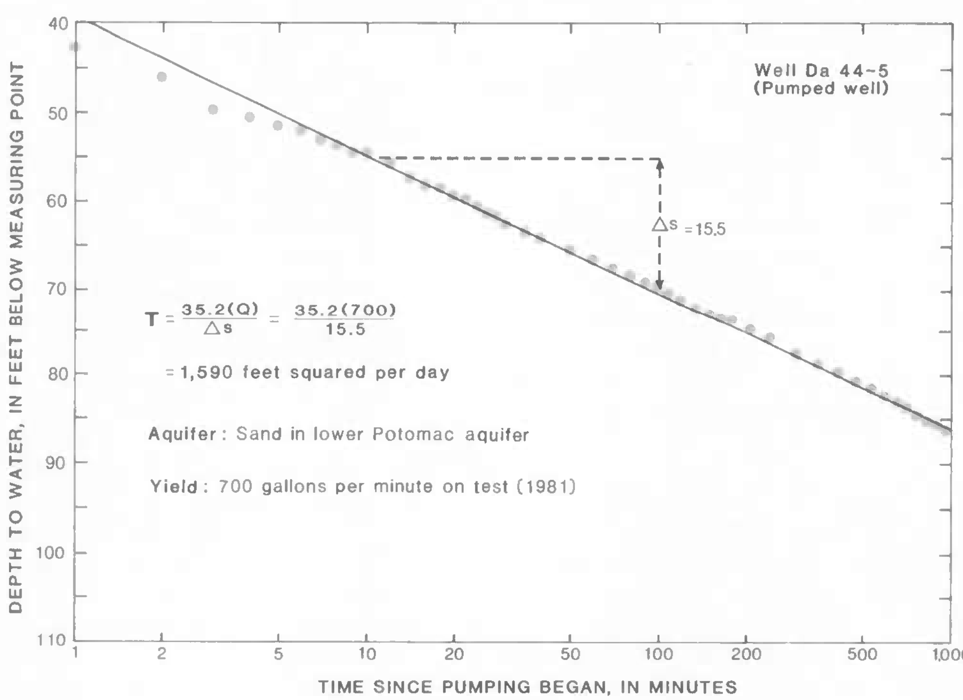


FIGURE 9. Drawdown and computation of transmissivity and storage in two Delaware wells located east of Elkton, Md.

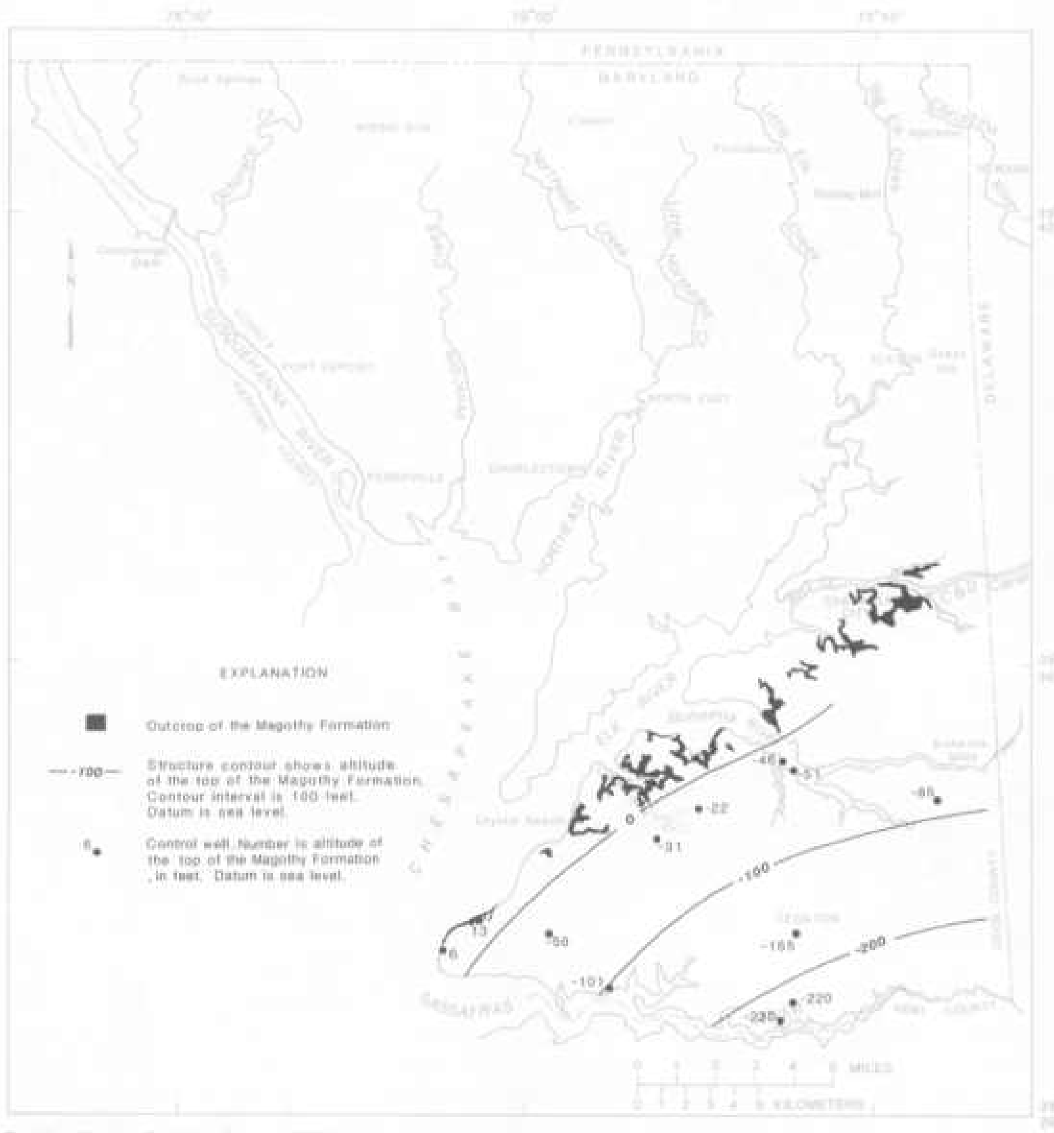


FIGURE 10. Outcrop area and altitude of the top of the Magothy Formation.

than in the underlying two formations. The relation of the Matawan confining unit to other units is shown in sections B-B′, C-C′, and E-E′ on plate 2.

Although the Matawan Group is primarily a confining unit in Cecil County, it is an important water-bearing unit in Kent County (Overbeck and others, 1958, table 10). Four wells in Cecil County had reported yields ranging from 7 to 40 gal/min (table 10). Specific capacities for these wells varied from 0.2 to 1.9 (gal/min)/ft.

TABLE 12

HYDRAULIC PROPERTIES OF SAND IN THE MAGOTHY AQUIFER

[Transmissivity estimated from specific capacity unless otherwise noted; ft = feet; ft^2/d = feet squared per day.]

Well no.	Location	Transmissivity (ft^2/d)	Storage coefficient	Well depth (ft)	Screened interval (ft)
CE Cf 77	Chesapeake City	290	-	44	39- 44
CE Dd 51	East of Crystal Beach	920	-	158	153-158
CE Dd 83	South of Crystal Beach	300	-	130	122-130
CE De 2	Hack Point	490	-	65	61- 65
CE De 55	Southeast of Hack Point	340	-	275	265-275
CE Ec 20	Grove Neck	290	-	73	68- 73
CE Ee 11	Cecilton	1/ 3,300	0.0001	274	262-274
CE Ee 28	Cecilton	310	-	289	284-289
CE Ee 34	Southwest of Cecilton	490	-	278	253-278
CE Ee 35	Southwest of Cecilton	430	-	278	253-278
CE Ee 42	Fredericktown	1,000	-	310	280-310
CE Ee 45	Cecilton	730	-	297	277-287
Lake Street Water Plant	Middletown, Del.	2/ 540	.00006	-	287-297

1/ From aquifer test reported in Overbeck and others (1958, p. 58).

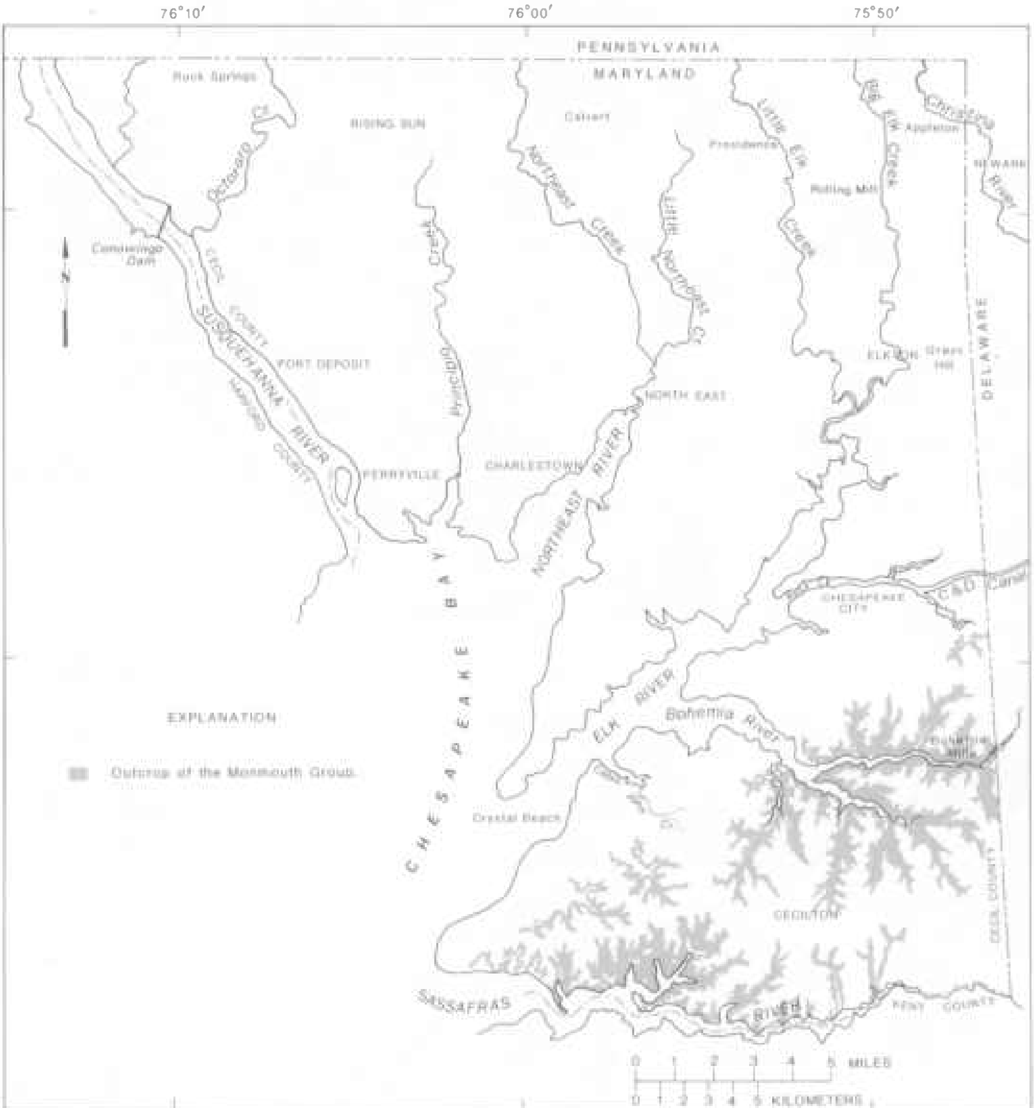
2/ From aquifer test reported in Rima and others (1964, p. 25-26).

Monmouth Aquifer

The Monmouth aquifer is in the Cretaceous Monmouth Group as used in Higgins and Conant (1986). The Monmouth Group primarily consists of a fine to medium, silty or clayey quartz sand. Weathered sections are buff to brown and red in color. Unweathered glauconite-rich layers may be dark green to black, while other layers with less glauconite may exhibit a "salt-and-pepper" appearance. Iron-cemented zones, siderite concretions, and calcareous zones occur locally. The Monmouth Group consists of a lower formation, the Mount Laurel Sand, which is about 80 ft thick, and an overlying unnamed upper unit of roughly the same thickness that may correlate with the Severn Formation of Minard and others (1977). The contact with the underlying Matawan Group is gradational.

The Monmouth is a major aquifer east of Elk River and south of the C and D Canal. The outcrop areas are shown in figure 11. Isolated deposits that occur on Elk Neck are either dry or have perched water tables and are not a dependable source of water. In most of the area where the Monmouth aquifer occurs, it is the first dependable aquifer encountered when drilling a water well.

Records of 25 wells tapping the Monmouth aquifer show that well yields range from 8 to 42 gal/min and have a median yield of 20 gal/min (table 10). Specific capacities range from



Base from Maryland Geological Survey, 1:62,500

FIGURE 11. Outcrop area of the Monmouth Group.

0.2 to 3.8 (gal/min)/ft and the median is 0.5 (gal/min)/ft. Well CE Df 29, located 3.5 mi southwest of Bohemia Mills, has the maximum reported specific capacity. The well is screened from 115 to 125 ft and yielded 30 gal/min when tested for 3 hours in 1967.

The hydraulic properties of sand in the Monmouth aquifer are listed in table 13. Values of transmissivity of the aquifer in Cecil County range from 100 to 730 ft^2/d, with the maximum value for well CE Df 29; the median is 270 ft^2/d. Most of the values were estimated from specific capacity (W. B. Fleck, U.S. Geological Survey, written commun., 1986). Three values of the storage coefficient are available, but none from Cecil County. The values are based on aquifer tests in Kent County and in Delaware, and range from 0.0002 to 0.0012.

TABLE 13
HYDRAULIC PROPERTIES OF SAND IN THE MONMOUTH AQUIFER
[Transmissivity estimated from specific capacity unless otherwise noted; ft = feet; ft^2/d = feet squared per day.]

Well no.	Location	Transmissivity (ft^2/d)	Storage coefficient	Well depth (ft)	Screened interval (ft)
CE Dd 80	North of Earleville	160	-	73	63- 73
CE De 5	Southeast of Hack Point	100	-	95	90- 95
CE Df 29	Southwest of Bohemia Mills	730	-	125	115-125
CE Df 32	North of Bohemia Mills	270	-	70	60- 70
CE Ee 8	Southwest of Cecilton	250	-	56	51- 55
CE Ee 10	West of Cecilton	170	-	141	136-141
CE Ee 33	Cecilton	490	-	100	-
CE Ee 40	East of Cecilton	160	-	68	59- 68
CE Ee 49	West of Cecilton	420	-	110	98-110
CE Ef 1	Southeast of Warwick	450	-	31	26- 31
KE Be 30	Kennedyville (Kent County)	1/ 290	0.0012	190	-
KE Bg 26	Massey (Kent County)	1/ 670	.0002	197	-
Unknown	Middletown, Del.	2/ 240	.0002	-	-

1/ From aquifer test reported in Overbeck and others (1958, p. 65-66).
2/ From aquifer test reported in Rima and others (1964, p. 34).

Aquia-Hornerstown Aquifer

The Aquia-Hornerstown aquifer includes the Paleocene Aquia and Hornerstown Formations. The contact between the Aquia Formation and the underlying Hornerstown Formation is gradational and the two units are considered a single aquifer in Cecil County. These units are found only in the extreme southeastern corner of the county where their combined thickness may be as much as 90 ft. The Hornerstown Formation is about 20 ft thick and is commonly a grayish-green to dark green, fine to coarse glauconite sand, with green clay and varying amounts of quartz sand. Glauconite content is approximately 80 to 90 percent of the sand fraction. The Aquia Formation is primarily a fine to medium, light-green and yellow, glauconitic quartz sand, with some coarse sand. Glauconite content is sometimes less than 5 percent, but locally may be as much as 50 percent. Clay in the formation is usually dark gray to black. Calcareous material is locally abundant.

The Aquia-Hornerstown aquifer is a potential source of water in a small area in the southeastern corner of the county where there is a sufficient saturated thickness of coarse material to supply limited quantities of water to wells. To the south in Kent County, the aquifer supplies water to the city of Chestertown and to a nearby commercial food-processing plant. The outcrop area of the aquifer is shown on plate 3.

Columbia Aquifer

The Miocene upland gravel and Pensauken Formation and the Pleistocene Talbot Formation are lumped into the Columbia aquifer. The name "Columbia aquifer" has been used on the Delmarva Peninsula for convenience, to include most surficial aquifer materials above a significant late Miocene erosional discontinuity. Bachman and Wilson (1984, p. 8–10) discuss the history of the name "Columbia."

As an aquifer, the Columbia generally is of minor importance in Cecil County and little data are available on its water-bearing properties within the county. South of Cecil County, however, the Columbia aquifer is a principal source of water for domestic, irrigation, and public-supply use (Bachman and Wilson, 1984, p. 4). Mapped units (Higgins and Conant, 1986) included in the Columbia aquifer are described below.

Upland Gravel

The deposits mapped as upland gravel are fluvial in origin and range in thickness up to 80 ft. This unit is chiefly a quartzitic gravel with interbedded, cross-stratified sand. Locally, intermittent layers of clay occur. Near-surface gravel beds are locally iron-stained and iron-cemented conglomerates.

The unit is found in numerous topographically high areas on Elk Neck and north and west of the town of North East (pl. 3). Individual deposits constitute a largely unsaturated veneer. Where portions of these deposits are water saturated, it is usually indicative of localized perched water-table conditions. The low saturated thickness and restricted areal extent of the gravel severely limits its use as an aquifer.

Pensauken Formation

The Pensauken Formation occupies nearly all of the upland areas east of the Elk River and south of Grays Hill and includes some terrace-like deposits on the east side of Elk Neck (pl. 3). The thickness of the formation is highly variable; it may be as much as 120 ft thick in paleochannels, but is less than 60 ft thick in most areas. The Pensauken Formation consists mainly of sand, gravelly sand, bouldery gravel, and loam. Quartz and quartzite clasts predominate, but rock fragments of many Piedmont formations are present. The sand fraction contains appreciable amounts of feldspar. Overbeck and others (1958, p. 25) reported this unit to be a widely used aquifer at the time of their study (1956). However, wells located at new construction sites and replacement wells for existing facilities are now commonly finished in the deeper underlying formations. In some places, the Pensauken has insufficient saturated thickness of coarse-grained materials to be a dependable source of supply during dry periods. It also is susceptible to local pollution. Water levels, especially in the deposits on Elk Neck, frequently indicate perched water-table conditions. In areas where the saturated thickness of coarse-grained materials is sufficient and where water-use demands are low, this unit may satisfy domestic and small commercial requirements. Few yield and specific-capacity data are available for this unit in Cecil County (table 10). The saturated thickness of this unit is greater south of Cecil County where it provides irrigation supplies.

Talbot Formation

The thickness of the Talbot Formation is variable, but probably does not exceed 50 ft. This unit includes Pleistocene deltaic and flood-plain deposits. Poorly sorted, coarse-grained deposits of the Talbot are found at Perryville, Charlestown, North East, in the lower valley of Big Elk Creek, and along the shores of the Elk River (pl. 3). Sediment sizes in these deposits range from boulders to clay. Finer-grained deposits occur along the C and D Canal and south along the Elk and Bohemia Rivers. Most of these deposits contain insufficient coarse materials and too much clay to yield large quantities of water. Wells in the Talbot Formation near the shore of the Chesapeake Bay may be susceptible to brackish-water intrusion.

Alluvium and Tidal-Marsh Deposits

Alluvium occurs intermittently along the streams in major valleys in the Piedmont and in the northern part of the Coastal Plain. Elsewhere in the Coastal Plain, alluvium is found at or near sea level along a few of the stream valleys. Tidal marshes dot the shoreline of the Chesapeake Bay; the largest marsh-deposit area is at the mouth of Big Elk Creek. These units are generally not used as aquifers in Cecil County.

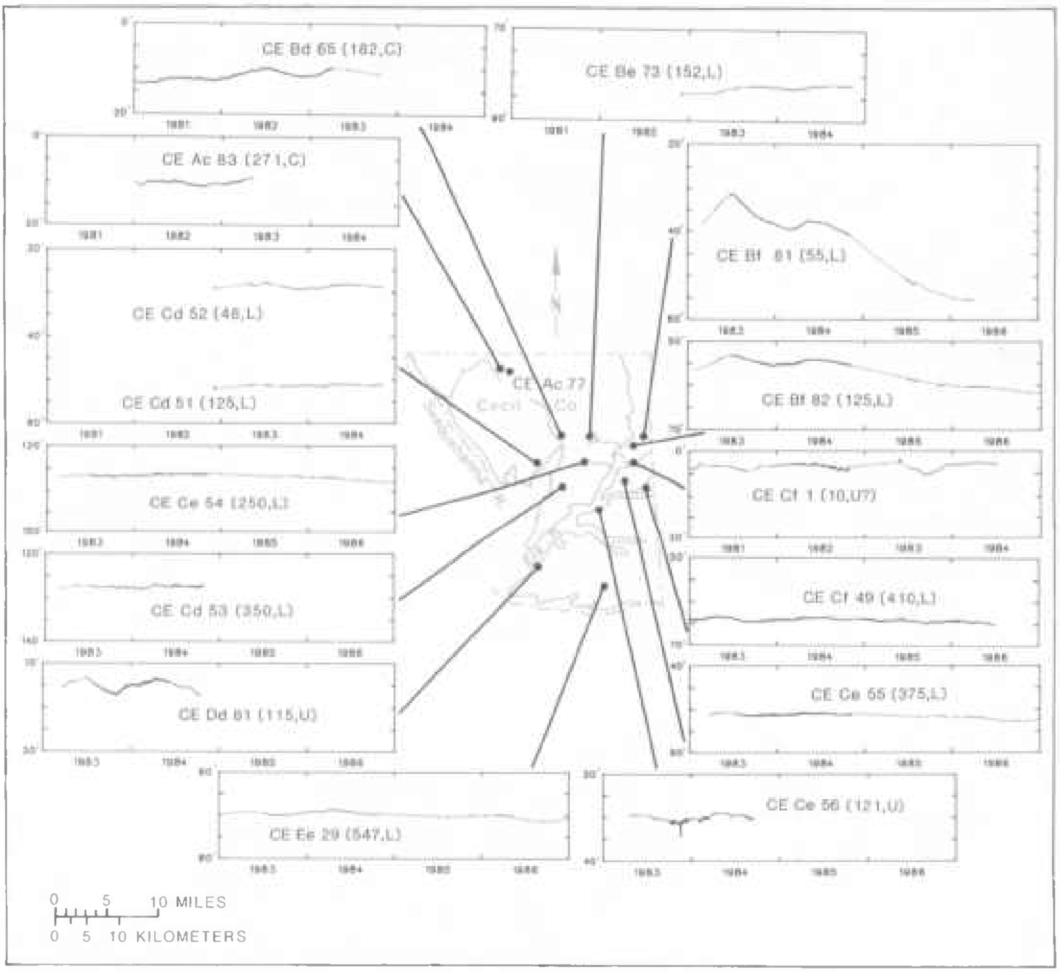
WATER-LEVEL FLUCTUATIONS

Water-level records for 15 wells measured during this study are shown graphically in figure 12 and long-term records for 5 wells are shown in figure 13. Most of the hydrographs in these figures show seasonal fluctuations in water level. Seasonal fluctuations are mostly influenced by evapotranspiration and precipitation, or by seasonal variations in pumping. Longer-term fluctuations caused by climatic variations can be seen in the hydrographs for wells CE Ac 77 and CE Bd 65 (fig. 13); these water-table wells tap crystalline rock of the Piedmont. Their hydrographs show generally lower levels in the 1960's, a relatively dry period, and generally higher levels in the early 1970's, a relatively wet period. (See fig. 4, annual precipitation.) Water levels in well CE Cf 1 (fig. 13), which is a water-table well influenced to some degree by a nearby stream, show a similar but subdued climatic variation.

Long-term water-level declines caused by pumping of the Potomac aquifers can be seen in the hydrographs for wells CE Cf 49 and CE Ee 29. The hydrograph of well CE Cf 49 in figure 13 shows a decline of about 10 ft since 1967. Pumping in New Castle County, Del. (Martin and Denver, 1982, p. 18; Martin, 1984, p. 13), is a major factor in this decline. (Note: Well CE Cf 49 is identified as well Ea33-1 in Martin and Denver, 1982; and Martin, 1984.)

Several hydrographs in figure 12 show declines in water level in the lower Potomac aquifer during 1983–86. A pronounced decline since 1983 is indicated by the hydrographs for wells CE Bf 81 and 82 (fig. 12). About 20 ft of decline in well CE Bf 81 took place in less than 3 years. These wells near Elkton show effects of the heavy pumping from the Elkton well field and from another well field a few miles east in Delaware near the State line (fig. 30).

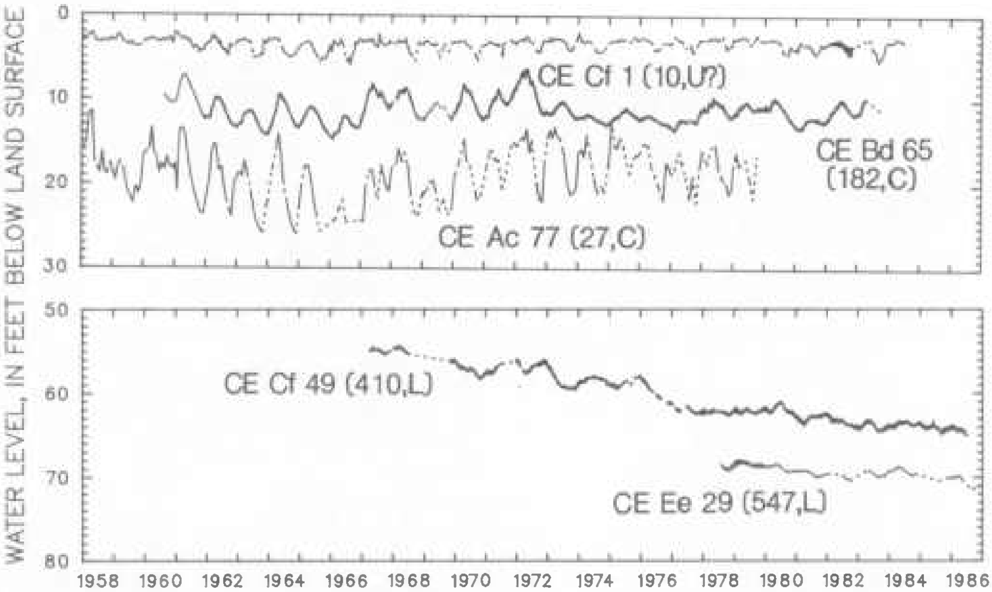
Decline in the water table in the Piedmont caused by pumping tends to be local and will not appear in an observation well that is distant from a pumping center. Water-table declines tend to intercept streamflow, which helps to localize the effects. Hydrographs of wells in crystalline rock of the Piedmont, which are water-table wells, show mostly climatic variations in water level. By contrast, pumping from the Potomac aquifers, which are confined in most of the area, causes widespread reduction in water level. Several of the hydrographs in figures 12 and 13 appear to indicate a general but moderate decline in water level in the lower Potomac aquifer east of the Elk River.



EXPLANATION

•	Observation well	--------	Data not available
CE Cd 53	Well number	0′–20′	Scale indicates depth to water, in feet below land surface
(350,L)	Number in parentheses is depth of well in feet below land surface. Letter indicates aquifer :		
	C-crystalline rock aquifer L-lower Potomac aquifer U-upper Potomac aquifer		Hydrograph for well CE Ac 77 (not shown here) is shown on figure 13.

FIGURE 12. Location of observation wells and hydrographs of water levels, 1981-86.



EXPLANATION

CE Cf 49 Well number

--------- Data not available.

(410,L) Number in parentheses is depth of well in feet below land surface. Letter indicates aquifer.

L lower Potomac aquifer

C crystalline-rock aquifer

U upper Potomac aquifer

FIGURE 13. Water levels in long-term observation wells, 1958–86.

CHEMICAL QUALITY

The chemical character of ground water is an important factor in determining its use. Generally, the ground water in Cecil County is suitable for most uses except where it is contaminated. Common natural chemical-quality problems are excessive iron concentrations and low pH. During this and earlier studies, 84 wells were sampled and analyzed for common chemical constituents. During 1980–83, 72 wells were sampled for this study. Results of analyses of 14 samples collected during 1953–55 and one sample collected in 1978 were also evaluated. These data and well locations are reported in Willey and others (1987, table 10, and fig. 4). Established sampling procedures described in the "National Handbook of Recommended Methods for Water Data Acquisition" (U.S. Geological Survey, 1977) were followed in the field collection and preservation of all water samples collected during this study. Analytical laboratory determinations of chemical constituents were done by the U.S.

Geological Survey Central Laboratory using standard analytical laboratory methods described in Skougstad and others (1979).

Three of the wells sampled in 1954–55 were resampled in 1983. Samples of water from two of the wells had little change in composition. One well, CE Ad 39, is located about 2 mi east of Calvert, Md.; it is 114 ft deep and taps crystalline rock. The second well, CE Df 11, is located near the Delaware State line about a mile south of Bohemia Mills, Md.; it is 87 ft deep and taps the Monmouth aquifer. Samples from the third well, CE Be 18, had an increase in dissolved-solids concentration from 23 to 132 mg/L (milligrams per liter) and an increase in chloride concentrations from 4 to 42 mg/L. This well is located about a mile west of Elkton, Md., where the aquifer may be affected by highway salting. The well is 63 ft deep and taps the lower Potomac aquifer.

One of the wells (CE Dd 81) sampled during the study is located near the edge of a dredge-disposal site for the C and D Canal. Although the well is screened in a sand of the upper Potomac aquifer at a depth of 110 to 115 ft, the water does not represent natural water in the aquifer. Water from this well had abnormally large concentrations of many constituents; results of the analysis are given in Willey and others (1987, table 10). Because the water quality is related to unusual local contamination, this analysis is not considered in the following discussions.

The following paragraphs briefly describe the common chemical constituents that may concern water users. For comparison of constituent concentrations, the aquifers are categorized as crystalline-rock aquifers, Potomac aquifers, and other Coastal Plain aquifers.

Dissolved solids—The dissolved-solids concentration represents the quantity of dissolved mineral matter in a water sample. Dissolved solids in water may be estimated from the specific conductance of the sample, which is much easier to measure. Based on the relationship shown in figure 14, a good approximation of the dissolved-solids concentration in Cecil County ground water can be obtained by multiplying specific conductance by 0.75. For public water supplies, the recommended limit for dissolved-solids concentration is 500 mg/L (U.S. Environmental Protection Agency, 1977b, p. 17 and 146). As figure 14 shows, dissolved-solids concentration of only three samples exceeds 500 mg/L.

The distribution of the dissolved-solids concentrations in water samples from wells in Cecil County is shown in figure 15. Also shown in the figure are distributions of concentrations for the major dissolved ions and other selected water-quality constituents that characterize the water. The ranges and median concentrations of dissolved solids by aquifer category are:

Aquifer	Dissolved-solids concentration (milligrams per liter)	
	Range	Median
Crystalline-rock aquifers	41 - 1,170	111
Potomac aquifers	16 - 439	42
Other Coastal Plain aquifers	56 - 353	160

Hardness—Hardness affects the use of water. Hard water consumes more soap than soft water and causes the formation of an objectionable curd. The curd is difficult to remove from fabrics and from containers where it may be deposited. Scale may also be deposited

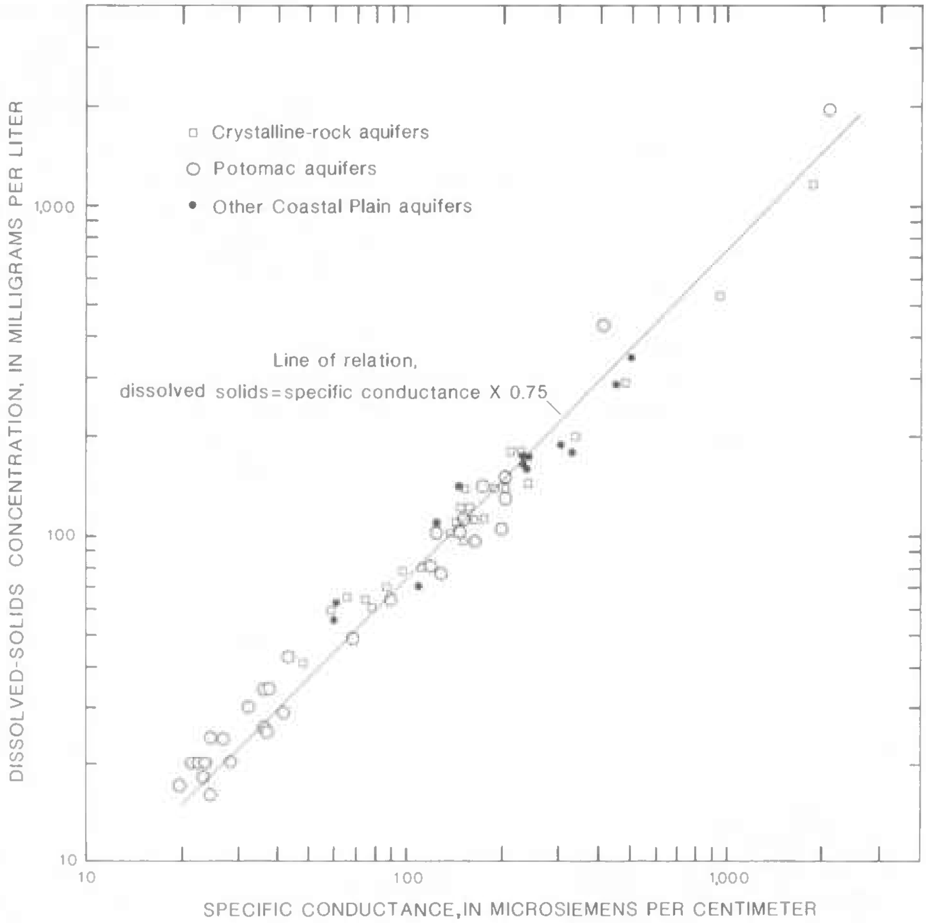


FIGURE 14. Relation of dissolved-solids concentration to specific conductance in ground water in Cecil County, Md.

and cause a special problem in steam boilers. The main cause of hardness is the solution of calcium and magnesium, although iron, manganese, silica, and aluminum may contribute.

Most of the ground water in Cecil County is soft (concentration 60 mg/L or less as $CaCO_3$) to moderately hard (concentration 61-120 mg/L as $CaCO_3$) (Hem, 1985) (see fig. 15). The ranges and median values are:

Aquifer	Hardness (milligrams per liter as $CaCO_3$)	
	Range	Median
Crystalline-rock aquifers	14 - 410	52
Potomac aquifers	2 - 74	12
Other Coastal Plain aquifers	9 - 180	68

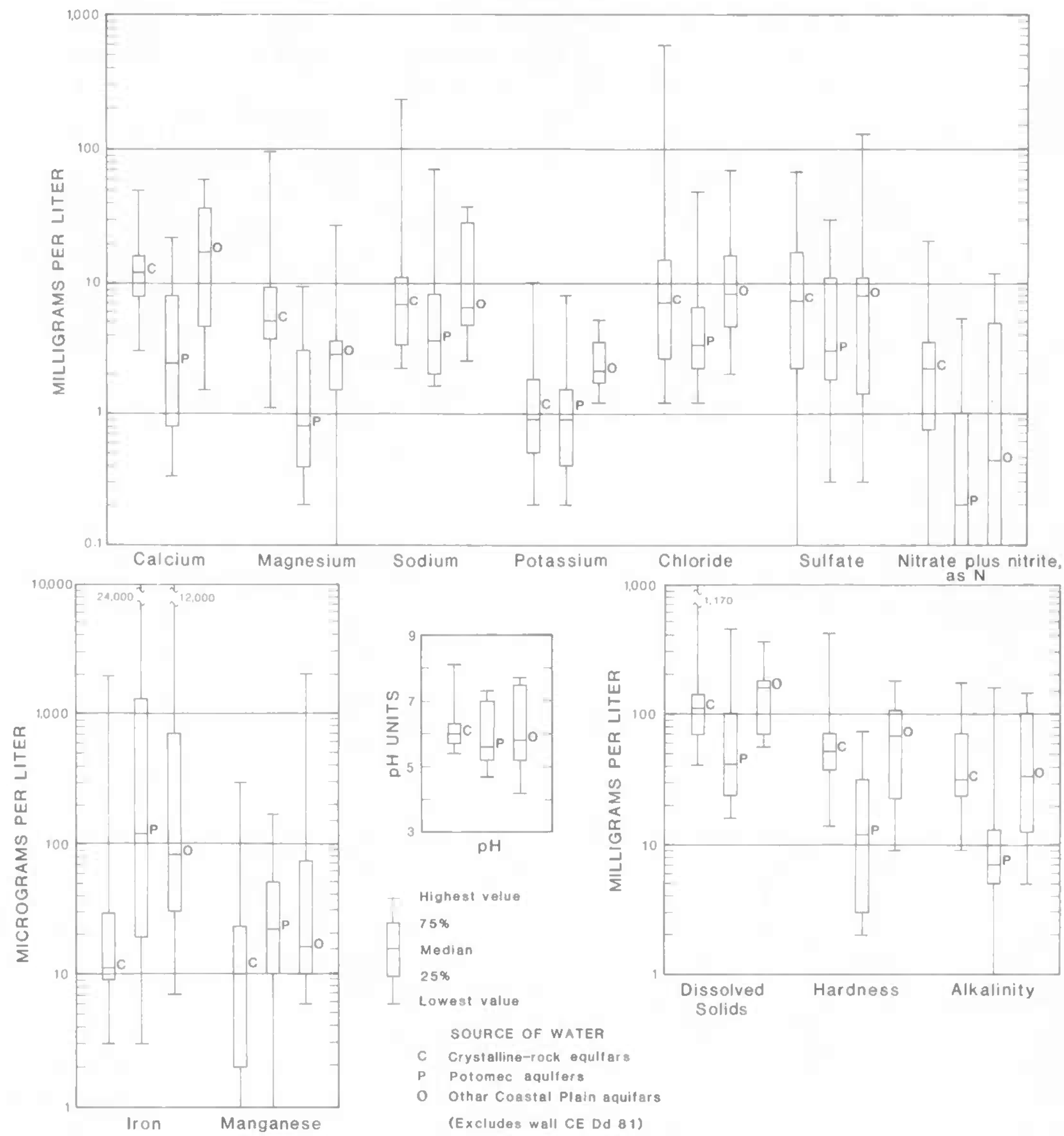


FIGURE 15. Distribution of the concentrations of selected water-quality constituents in ground-water samples.

The well having the highest hardness (410 mg/L) was CE Ab 66 near Rock Springs. The well is 70 ft deep and taps the serpentinite in the Baltimore Complex. Two wells having the lowest hardness are CE Cd 44 and CE Cd 59 (2 mg/L each). Well CE Cd 44 is in the Elk Neck State Forest and is screened opposite a sand in the lower Potomac aquifer at a depth of 204 to 214 ft. Well CE Cd 59 is on the eastern side of the Northeast River and is screened opposite a sand in the lower Potomac aquifer at a depth of 75 ft.

Hydrogen-ion concentration (pH)—The hydrogen-ion concentration of a water sample is indicated by the pH, which is the negative logarithm of the hydrogen-ion concentration, in moles per liter of water. The pH is a measure of the extent to which the water sample is acidic or alkaline: a pH of 7 indicates a neutral condition; less than 7, acidic; and greater than 7, alkaline. Water having a low pH is particularly significant because it may corrode well casings, pumps, and plumbing fixtures and may dissolve copper, iron, lead, or zinc from this equipment.

The range in pH for 86 water samples is from 4.2 to 8.1 and only a small percentage of samples have a pH above 7.0 (fig. 15). The lowest pH (4.2) was measured in well CE Ed 15, a 48-ft deep well in the Monmouth aquifer along the Grove Neck Peninsula. The highest pH (8.1) was measured in well CE Bf 77, located just east of Elkton. This well is 201 ft deep and taps gabbro and serpentinite below 135 ft. The ranges and median values of pH are:

Aquifer	pH	
	Range	Median
Crystalline-rock aquifers	5.4 - 8.1	6.0
Potomac aquifers	4.7 - 7.3	5.6
Other Coastal Plain aquifers	4.2 - 7.7	5.8

Iron—Iron is dissolved in water in small concentrations in nearly all aquifers. Water can be rendered unsuitable for many uses where the iron concentration exceeds a few hundred micrograms per liter (μg/L). Concentrations of iron in excess of 300 μg/L (0.3 mg/L) (U.S. Environmental Protection Agency, 1977b, p. 17 and 146; recommended limit for domestic water supply) cause stains on plumbing fixtures, cooking utensils, and fabrics. The iron concentration of water usually can be reduced by relatively simple treatment.

The concentrations of dissolved iron in 80 water samples range from less than 3 μg/L in wells CE Af 30 and CE Cd 48, to as high as 24,000 μg/L in well CE Cf 74 (fig. 15). Well CE Af 30 is 155 ft deep in the pelitic facies near Appleton in the extreme northeastern section of the county. Well CE Cd 48 is 174 ft deep at Elk Neck State Forest. It is screened in a sand in the lower Potomac aquifer. Well CE Cf 74 is screened opposite a sand of the upper Potomac aquifer at a depth of 247 to 267 ft. In general, the data indicate that wells in the crystalline rock may be expected to have the lowest concentration of dissolved iron. The range and median values of iron concentration are given below:

Aquifer	Iron (micrograms per liter)	
	Range	Median
Crystalline-rock aquifers	<3 - 1,900	11
Potomac aquifers	<3 - 24,000	120
Other Coastal Plain aquifers	7 - 12,000	83

Manganese—Manganese is a common dissolved constituent in ground water and its occurrence is often coincident with that of iron. Concentrations of manganese in excess of 200 μg/L can cause formation of a dark brown or black stain on porcelain fixtures or on fabrics. The U.S. Environmental Protection Agency's (1977b, p. 17 and 144) recommended limit for manganese for domestic water supply is 50 μg/L. Manganese concentrations in 77 water samples ranged from less than 1 to 2,000 μg/L (fig. 15). The maximum value was in water from well CE Dd 70, which is 34 ft deep and apparently taps the Magothy aquifer. The range and median values of manganese concentration are:

Aquifer	Manganese (micrograms per liter)	
	Range	Median
Crystalline-rock aquifers	<1 - 300	10
Potomac aquifers	<1 - 170	22
Other Coastal Plain aquifers	6 - 2,000	16

Nitrate plus nitrite as N—Most of the nitrate ions in natural ground water appear to be derived from decomposition of organic matter in the soil, although small amounts may result from the decomposition of igneous rocks. Medical studies have indicated that nitrate concentrations exceeding 10 mg/L as N in drinking water may contribute to, or be the main cause of a condition in infants known as methemoglobinemia (infant cyanosis or "blue babies"). The maximum contaminant level for nitrate in drinking water is 10 mg/L as N (U.S. Environmental Protection Agency, 1986).

Figure 15 shows the distribution of nitrate plus nitrite concentration for 86 analyses. The ranges and median values are:

Aquifer	Nitrate plus nitrite as N (milligrams per liter)	
	Range	Median
Crystalline-rock aquifers	< 0.1 - 21	2.2
Potomac aquifers	< .1 - 5.3	.2
Other Coastal Plain aquifers	< .1 - 12	.44

The Potomac aquifers have the lowest median nitrate plus nitrite concentration and also the narrowest range of values of this constituent. The maximum value of nitrate plus nitrite was found in well CE Ac 82, based on a sample collected in 1981. This well is located about 1 mi north of Rising Sun and taps the gabbro in the Baltimore Complex. A high value for hardness (282 mg/L) and a relatively high total organic carbon concentration (3.0 mg/L) suggest that the well may be contaminated.

A histogram showing the distribution of the logarithm of the nitrate values is shown in figure 16. (Water-quality data often exhibit a log normal distribution for a population.) Bachman (1984, p. 21) shows a similar graph in which he identifies a bimodal distribution of nitrate data for the Columbia aquifer in the central Delmarva Peninsula, Md. Bachman interprets this to show a mixture of two log normally distributed populations. One represents naturally occurring nitrate and has values mostly below about 0.5 mg/L; the other, with mostly higher values, is affected by man's activities. The Cecil County nitrate data plotted in figure 16 appear to show a similar distribution although the values in the secondary population tend to be lower than those in Bachman's data. A probable interpretation is that naturally occurring nitrate concentrations in Cecil County ground water tend to have values below about 0.6 mg/L, and few of the higher values are greater than 10 mg/L.

Chloride—Chloride is present in almost all natural water. Even precipitation commonly contains chloride in concentrations greater than 1 mg/L (Hem, 1985, p. 119). Chloride concentrations in water in excess of 250 mg/L may impart a slightly salty taste to the water (U.S. Environmental Protection Agency, 1977b, p. 17 and 144).

Figure 15 shows the distribution of chloride concentration for 86 analyses. The ranges and median values are:

Aquifer	Chloride (milligrams per liter)	
	Range	Median
Crystalline-rock aquifers	1.2 - 590	6.9
Potomac aquifers	1.2 - 48	3.3
Other Coastal Plain aquifers	2 - 69	8.2

The highest chloride concentration (590 mg/L) occurred in a 230-ft well ending in the James Run Formation. This well, CE Bd 72, is located along U.S. Highway I-95 (Willey and others, 1987, p. 137). It also has a high sodium concentration (230 mg/L), which indicates possible contamination by road salt at the time of sampling in 1983.

Fluoride—Fluoride, which is a minor constituent of most ground water, is commonly derived from the solution of the minerals fluorite or apatite. Minerals of the mica group may also contribute fluoride to water. Fluoride in excessive concentrations is undesirable in water used for drinking. Fluoride concentrations of about 1.0 mg/L are beneficial for teeth, and many public water suppliers add appropriate levels of fluoride to drinking water.

The range in fluoride concentration in 78 ground-water samples from Cecil County is from less than 0.1 to 0.9 mg/L, with the median value being less than 0.1 mg/L. The water having the maximum fluoride concentration is from well CE Ee 29 at Cecilton, which is screened opposite a sand of the upper Potomac aquifer at a depth of 515 to 525 ft.

Boron—Boron is an important element in plant growth. A small amount of boron is essential for plants; however, high concentrations in soil and irrigation water can be harmful. For some plants, such as citrus trees, the toxic concentration is as low as 1,000 μg/L (Hem, 1985, p. 129).

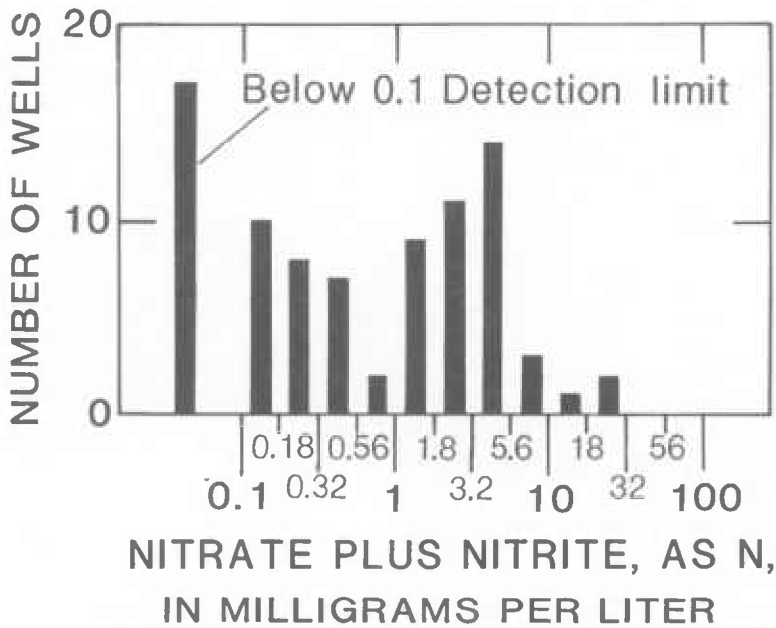


FIGURE 16. Distribution of the logarithm of nitrate plus nitrite concentrations in samples of water from wells in Cecil County, Md.

Boron is found in treated sewage effluent and may be an indicator of contamination. The major sources of boron in sewage are detergents and other cleansing agents. Human wastes and household and industrial chemicals may add some boron to the sewage. The boron concentration in 65 water samples from wells in Cecil County ranged from less than 10 to 200 μg/L, with the median value being 20 μg/L.

Silica—Silica is dissolved from quartz, feldspar, and other siliceous minerals in the rocks, and is a common constituent in ground water. Silica has little effect on domestic use, but for some industrial uses it contributes to the formation of boiler scale. The silica concentration in 78 water samples from wells in Cecil County ranges from 3.2 to 54 mg/L, with a mean value of 17 mg/L and a median value of 13 mg/L. The range of concentration of silica most commonly found in natural water is from 1 to 30 mg/L (Hem, 1985, p. 73).

Sulfate—Sulfate may be present in water from igneous rocks as a result of solution of the minerals of the feldspathoid group. Many sedimentary rocks contain pyrite and other sulfide minerals that oxidize upon solution to form sulfates. Whereas sulfate in water in moderate concentrations is not known to have a harmful effect on humans, the presence of the sulfate ion can have a laxative effect at concentrations above a few hundred mg/L. Sodium or magnesium sulfate in concentrations of 300 to 400 mg/L may impart an undesirable taste to water and coffee. The U.S. Environmental Protection Agency (1977b, p. 17 and 146) recommends a maximum level of 250 mg/L for sulfate in drinking water.

Sulfate normally is not a problem in ground water of the study area. The distribution of sulfate concentrations for 86 samples of ground water in Cecil County is shown in figure 15. Concentrations range from 0.1 to 130 mg/L and the median value is 6 mg/L. The maximum value was in water from well CE Dd 70 which taps the Magothy aquifer at a depth of 34 ft. Water from this well, which is near a dredge-disposal site, is not typical of the aquifer. The range and median concentrations of sulfate are:

Aquifer	Sulfate (milligrams per liter)	
	Range	Median
Crystalline-rock aquifers	0.1 - 67	7.2
Potomac aquifers	.3 - 30	3.0
Other Coastal Plain aquifers	.3 - 130	8.0

Calcium and Magnesium—Calcium and magnesium are dissolved from almost all soils and rocks, especially limestone, dolomite, and gypsum. The distribution of the concentrations of calcium and magnesium for 85 samples of ground water from Cecil County is shown in figure 15. The range and median values are:

Aquifer	Calcium (milligrams per liter)	
	Range	Median
Crystalline-rock aquifers	3.0 - 49	12
Potomac aquifers	.33 - 22	2.4
Other Coastal Plain aquifers	1.5 - 59	17

Aquifer	Magnesium (milligrams per liter)	
	Range	Median
Crystalline-rock aquifers	1.1 - 95	5.0
Potomac aquifers	.20 - 9.4	.80
Other Coastal Plain aquifers	.10 - 27	2.8

Sodium and Potassium—Sodium and potassium are also dissolved from almost all rocks and soils and are common elements in brines, sea water, and sewage effluent. Moderate quantities of these elements have little effect on the usefulness of water for most purposes. Sodium salts may cause foaming in steam boilers. Some individuals are limited in their dietary sodium intake for health reasons.

The distribution of the concentrations of sodium and potassium for 83 water samples is shown in figure 15. The range and median values are:

Aquifer	Sodium (milligrams per liter)	
	Range	Median
Crystalline-rock aquifers	2.2 - 230	6.7
Potomac aquifers	1.6 - 70	3.6
Other Coastal Plain aquifers	2.5 - 37	6.3

Aquifer	Potassium (milligrams per liter)	
	Range	Median
Crystalline-rock aquifers	0.20 - 10	0.9
Potomac aquifers	.20 - 8	.9
Other Coastal Plain aquifers	1.2 - 5.1	2.1

The high value (230 mg/L) of sodium is of interest as this water is from well CE Bd 72, which may have been contaminated with road salts. (See discussion of chloride.)

Aluminum—Small concentrations of aluminum are present in nearly all ground water. Aluminum is derived largely from the weathering of feldspathic rocks. Aluminum appears to go into solution more readily in acidic water (Hem, 1985, p. 73) than in alkaline water. The aluminum concentrations of 81 water samples from wells in Cecil County ranged from 60 to 3,500 μg/L, and the median is 100 μg/L. The anomalously high value of 3,500 μg/L is from a 136-ft well in the lower Potomac aquifer. The well, CE Cc 34, is located about 1 mi east of Principio Creek on the south side of U.S. Route 40.

Cadmium—Cadmium concentrations in natural ground water are extremely low, but cadmium may be introduced into water from zinc-galvanized iron in which cadmium is a contaminant, and from other sources of pollution. Concentrations of cadmium in water from 59 wells in Cecil County range from less than 1 to 2 μg/L. The maximum contaminant level for cadmium in water systems established by the U.S. Environmental Protection Agency (1986) is 10 μg/L.

Chromium—Chromium in ground water may be present in trace amounts when dissolved from chrome-bearing rocks. Chromite ores are present in the northwestern corner of the county (Pearre and Heyl, 1960). Concentrations of chromium in 64 ground-water samples range from less than 10 to 50 μg/L, with the median value being less than 10 μg/L. The maximum allowable level of chromium in public drinking-water supplies is 50 μg/L (U.S. Environmental Protection Agency, 1986). The only sample at this maximum level was from well CE Cf 3. This 100-ft well is along the bank of the C and D Canal at Chesapeake City. It yields water from a sand in the upper Potomac aquifer.

Lead—Lead may occur in rocks as lead sulfide (galena), or it may be present in the minerals aragonite and potassium feldspar. It may be dissolved from these minerals by percolating acidic ground water. Lead may also be dissolved by acidic water from solder used to join copper pipes in household distribution systems, or it may be present in soils near major highways as a result of its presence in automobile exhaust and its accumulation over several decades.

Lead is toxic and may present a special hazard to young children; for this reason, the Federal regulatory agency has a mandatory limit for drinking-water supplies of 50 μg/L (U.S. Environmental Protection Agency, 1986).

The lead concentration in 58 water samples from wells in Cecil County ranges from less than 10 to 30 μg/L. The median value is less than 10 μg/L. The maximum value is from well CE Df 31, which is located about 2 mi north of Bohemia Mills and 0.2 mi west of the Delaware State line. No information is available concerning its depth or diameter, although it is reported to yield water from the Monmouth aquifer.

Mercury—Very little natural water contains detectable concentrations of mercury (Hem, 1970, p. 19–24). However, mercury may be introduced into water through disposal of mining, metallurgical, or other industrial wastes. Mercury may also be introduced into the hydrologic environment through its use as a fungicide or a slimicide. Mercury poisoning may result from the ingestion of small amounts of mercury during an extended period of time (U.S. Environmental Protection Agency, 1977a, p. 77). The mercury concentration in 59 water samples from wells in the study area ranges from less than 0.1 to 0.7 μg/L, with the median value being less than 0.1 μg/L. The maximum value of 0.7 μg/L occurred in wells CE Cd 48 and CE Df 31. Well CE Cd 48, which is 174 ft deep, is located in the Elk Neck State Forest and produces from a sand in the lower Potomac aquifer. Well CE Df 31, mentioned in the discussion of lead, reportedly taps the Monmouth aquifer. None of the wells had concentrations approaching the limit of 2 μg/L, established by the U.S. Environmental Protection Agency (1986).

SURFACE-WATER RESOURCES

Historically, the surface-water resources of Cecil County have been plentiful and of good quality. Streams in most of the county drain southward or westward toward the Chesapeake Bay. Only a small area in the northeastern corner of the county drains eastward to the Delaware River and Delaware Bay (fig. 17). Eight major streams and the C and D Canal drain the study area. These streams are the Susquehanna, Northeast, Christina, Elk, Bohemia, and Sassafras Rivers, and Principio and Octoraro Creeks.

Surface water supplied about 41 percent of all the water used in the county in 1985 (table 1); municipal water supply accounts for most use. The primary users and their sources are the towns of Elkton (Elk River), North East (Northeast River), and Perryville (Susquehanna River). The Perry Point Veterans Administration Hospital also is a major user of water from the Susquehanna River. Irrigation is the other principal use of surface water, particularly for those areas of the county north of the C and D Canal.

STREAMFLOW CHARACTERISTICS

Streamflow data for this study were measured at 10 continuous-record and 27 partial-record stations. The continuous-record stations measure and record the flow of selected streams and rivers on a systematic and continuous basis. Records for eight continuous-record stations within the county and two located in adjoining counties were used. Five of these have more than 20 years of record. Twenty-seven partial-record stations, two of which are in adjoining counties, provide broad geographic coverage for estimation of low-flow frequency characteristics. The locations of all stations are shown in figure 17.

Streamflow-measurement sites used in this study are listed in table 14. Site numbers (first column of the table) are temporary numbers used to identify sites for this report. Station numbers (second column of the table) are permanent numbers assigned by the U.S. Geological Survey and are based on a nationwide, downstream-order numbering system.

Flow Duration

Flow-duration data were evaluated for seven of the continuous-record stations having no regulation and for the unregulated period of record for Octoraro Creek near Rising Sun (site 39). The period of record through water year 1979 was used to be consistent with work done by Carpenter (1983). Duration of daily flow for these stations is given in table 15.

The flow-duration curve is a cumulative-frequency curve that shows the percentage of time specified discharges were equaled or exceeded during a given period (Searcy, 1959). The shape of a flow-duration curve is related to the composite hydrologic and geologic characteristics of the drainage basin and can be used to compare basins. A steep slope (Northeast Creek, fig. 18) usually indicates a basin with highly variable flow, little surface- or ground-water storage, and a relatively large amount of direct runoff. A flatter slope (Big Elk Creek, fig. 18) usually indicates a basin with a more uniform flow, larger amounts of surface- or ground-water storage, and a larger percentage of ground-water discharge.

The slope of the Big Elk Creek (site 7) duration curve compares very favorably with the data for Basin Run (site 41), Octoraro Creek [site 39 (unregulated period)], Little Elk Creek (site 10), and Principio Creek (site 30). At the 5-percent exceedance level, runoff for these five streams ranged from 3.1 to 4.8 $(ft^3/s)/mi^2$ and at the 95-percent exceedance level from

(Text continues on p. 53)

TABLE 14

STREAMFLOW-MEASURING SITES AND SELECTED LOW-FLOW FREQUENCY CHARACTERISTICS OF STREAMS

[Station Class: C = continuous-record gaging station; P = partial-record site; R = affected by regulation; ° = degree; ′ = minute; ″ = second; mi^2 = square mile; ft^3/s = cubic feet per second.]

Site no.	Station no.	Station name	Station Class	Latitude Longitude (o ' ")	Drainag area (mi^2)
				Delaware River basin	
1	01477850	Christina River near Newark, Del.	P	39 42 02 75 47 18	3.76
2	01477860	West Branch Chriatina River near Newark, Del.	P	39 39 20 75 47 00	4.20
3	01478000	Chriatina River at Coochs Bridge, Del.	C,R	39 38 16 75 43 46	20.5
				Cheater River basin	
4A	01493500	Morgan Creek near Kennedyville, Md.	C	39 16 48 76 00 54	12.7
				Sasaafras River basin	
4	01494450	Sasaafras River tributary at Ginna Corner, Md.	P	39 23 23 75 46 47	3.81
5	01494480	Duffy Creek near Cecilton, Md.	P	39 23 45 75 49 32	1.45
				Elk River basin	
6	01494995	Gramies Run at Elk Mills, Md.	P	39 40 11 75 50 51	3.05
7	01495000	Big Elk Creek at Elk Milla, Md.	C	39 39 26 75 49 20	52.6
8	01495480	Little Elk Creek at Rock Church, Md.	P	39 42 03 75 53 12	17.8
10	01495500	Little Elk Creek at Childs, Md.	C	39 38 30 75 52 00	26.8
11	01495520	Laurel Run near Elkton, Md.	P	39 37 45 75 52 29	3.87
12	01495525	Dogwood Run at Elkton, Md.	P	39 37 00 75 50 58	1.62
14	01495540	Mill Creek neer Elkton, Md.	P	39 36 03 75 51 47	4.12
15	01495550	Perch Creek near Elkton, Md.	P	39 34 16 75 48 53	5.46
16	01495800	Long Creek near Chesepeake City, Md.	C,P	39 33 15 75 47 18	4.36
17	01495805	Long Creek (formerly Branch) near Chesapeake City, Md.	P	39 33 05 75 47 33	5.2
19	01495925	Sandy Branch at Bohemia Creek, Md.	P	39 27 36 75 46 28	2.58
20	01495935	Little Bohemia Creek near Warwick, Md.	P	39 26 05 75 48 25	2.45
21	01495950	Scotchman Creek tributary near Cecilton, Md.	P	39 25 15 75 53 15	1.40

TABLE 14—*Continued*

Average discharge period of record analyzed (ft^3/s)	Period of record analyzed (water years)	Annual low flow, in (ft^3/s)/mi^2, for 7 consecutive days and for indicated recurrence interval, in years: 2	10	Station used for correlation	Coefficient of determination	Number of measurements
-	1981-83	0.37	0.16	01495000	0.99	3
-	1981-83	.22	.13	01495000	.97	4
28.5	1943-79	.19	.07	N/A	N/A	N/A
10.7	1951-79	.24	.12	-	-	-
N/A	1982-83	.24	.09	01493500	.98	3
-	1968-71 1982	.45	.21	01493500	.85	6
-	1981-83	.31	.16	01495000	.80	5
70.3	1932-79	.38	.19	-	-	-
-	1981-83	.31	.15	01495000	.99	4
38.2	1949-58	.34	.17	01495000	-	-
-	1982-83	1/	-	-	-	-
-	1982-83	.02	.01	01496000	.99	4
-	1968-70 1982-83	.16	.08	01496000	.91	10
-	1964-75 1978-80	.16	.07	01495000	.92	14
-	1979-82	.06	.01	01493500	.61	6
-	1968-70	.13	.09	01493500	.95	5
-	1968-71 1982	.68	.44	01493500	.90	7
-	1953-54	.49	.29	01493500	2/	-
-	1982-83	.16	.06	01493500	.88	4

TABLE 14—*Continued*

STREAMFLOW-MEASURING SITES AND SELECTED LOW-FLOW FREQUENCY CHARACTERISTICS OF STREAMS

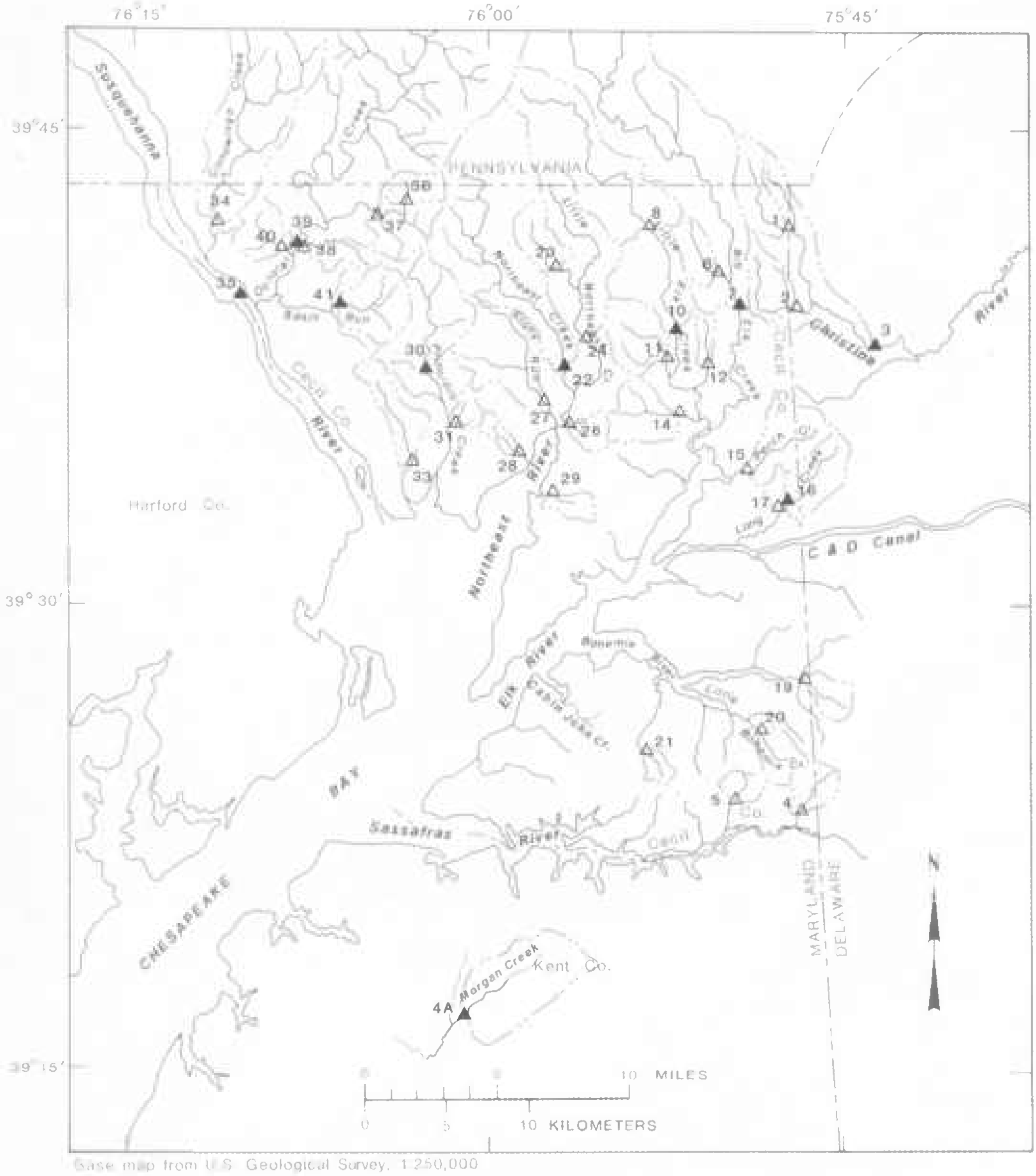
[Station Class: C = continuous-record gaging station; P = partial-record site; R = affected by regulation; ° = degree; ′ = minute; ″ = second; mi^2 = square mile; ft^3/s = cubic feet per second.]

Site no.	Station no.	Station name	Station Class	Latitude Longitude (° ′ ″)	Drainage area (mi^2)
				Northeast River basin	
22	01496000	Northeast Creek at Leslie, Md.	C	39 37 38 75 56 40	24.3
23	01496030	West Brench Little Northeast Creek at Zion, Md.	P	39 40 52 75 57 07	3.32
24	01496050	Littla Northeast Creek at Mechanic Valley, Md.	P	39 38 26 75 55 49	14.0
26	01496055	Northeast River tributary at North Eaat, Md.	P	39 35 43 75 56 36	1.55
27	01496060	Stony Run near North Eeat, Md.	P	39 36 24 75 57 33	8.23
28	01496085	Northeast River tributary at Charlestown, Md.	P	39 34 50 75 59 51	1.03
29	01496100	Hance Point Creek at Hance Point, Md.	P	39 33 30 75 57 19	1.36
				Principio Creek basin	
30	01496200	Principio Creek near Principio Furnace, Md.	C	39 37 34 76 02 27	9.03
31	01496225	Principio Creek tributary et Belvedere, Md.	P	39 35 30 76 01 19	2.08
				Mill Creek basin	
33	01496250	Mill Creek at Jackson, Md.	P	39 34 29 76 03 22	3.73
				Susquehanna River basin	
34	01578300	Conowingo Creek at Oakwood, Md.	P	39 42 01 76 11 22	34.4
35	01578310	Suaquehanna River at Conowingo, Md.	C,R	39 39 31 76 10 28	27,000
36	01578475	Stone Run neer Riaing Sun, Md.	P	39 42 38 76 03 29	2.24
37	01578480	Stone Run at Rising Sun, Md.	P	39 42 21 76 04 40	6.71
38	01578490	Love Run at Richardsmere, Md.	P	39 41 23 76 07 38	3.55
39	01578500	Octoraro Creek near Rising Sun, Md.	C,R	39 41 24 76 07 43	193
40	01578515	Octoraro Creek tributery at Richardsmere, Md.	P	39 41 09 76 08 32	3.27
41	01578900	Basin Run at Liberty Grove, Md.	C	39 39 30 76 06 10	5.31

1/ Observed zero flow for 2 weeks, August 1983.
2/ Value not reported in Cushing and others, 1973, p. 17,18.

TABLE 14—*Continued*

Average discharge period of record analyzed (ft^3/s)	Period of record analyzed (water years)	Annual low flow, in $(ft^3/s)/mi^2$, for 7 consecutive days and for indicated recurrence interval, in years		Station used for correlation	Coefficient of determination	Number of measurements
		2	10			
36.3	1949-79	0.23	0.11	-	-	-
-	1981-83	.16	.09	01496000	0.92	6
-	1964-69	.20	.08	01496000	2/	-
-	1982-83	.04	.01	01496000	.92	5
-	1982-83	.11	.04	01496000	.98	6
-	1981-83	-	-	-	-	-
-	1983	.02	.01	01496000	.92	4
14.1	1967-79	.31	.21	-	-	-
-	1982-83	.48	.38	01496200	.86	4
-	1982-83	.43	.29	01496200	.97	6
-	1981-83	.17	.06	01496000	.96	5
44,820	1968-79	.25	.14	-	-	-
-	1982-83	-	-	-	-	-
-	1982-83	.18	.09	01496000	.96	5
-	1982-83	.26	.13	01496000	.98	4
270	1932-58 1969-79	.48	.28	-	-	-
-	1982-83	.20	.08	01496000	.93	6
6.74	1949-58	.34	.17	01495000	-	-



EXPLANATION

▲ Streamflow continuous-record site

△ Low-flow partial-record site

27 Site number

—·—·— Drainage divide

FIGURE 17. Location of streamflow-measurement sites and drainage divides.

TABLE 15

DURATION OF DAILY FLOW AT CONTINUOUS-RECORD GAGING STATIONS

[mi^2 = square mile.]

Site no.	Station name	Period of record analyzed (water years)	Drainage area (mi^2)	Flow, in cubic feet per second, which was exceeded for indicated percentage of time								
				1	5	10	25	50	75	90	95	99
3	Christina River at Coochs Bridge, Del.	1944-79	20.5	354	98	48	23	13	7.6	4.5	3.1	1.2
4A	Morgan Creek near Kennedyville, Md.	1951-79	12.7	97	30	17	9.3	6.1	4.2	3.0	2.5	1.7
7	Big Elk Creek at Elk Mills, Md.	1932-79	52.6	510	180	120	74	48	32	21	17	10
10	Little Elk Creek at Childs, Md.	1949-58	26.8	370	120	64	38	24	15	11	8.2	5.8
22	Northeast Creek at Leslie, Md.	1949-79	24.3	430	130	59	30	18	11	6.4	4.6	2.9
30	Principio Creek near Principio Furnace, Md.	1967-79	9.03	140	43	22	13	8.2	5.1	3.5	3.0	2.2
39	Octoraro Creek near Rising Sun, Md.	1932-50	193	1,400	590	420	270	190	130	98	76	53
	Octoraro Creek near Rising Sun, Md. 1/	1951-58, 1969-77	193	1,500	670	460	290	180	100	60	45	34
41	Basin Run at Liberty Grove, Md.	1949-58	5.31	59	18	12	7.0	4.5	2.8	2.0	1.7	1.1

1/ Flow values affected by regulation.

0.31 to 0.39 ($ft^3/s)/mi^2$. Data for low flows indicate that the rate at which ground water discharges into these particular streams is similar. Each stream drains a portion of the Piedmont. The drainage basins of both Principio Creek and Basin Run are located entirely within Cecil County, while much of the basins of Little Elk (45 percent), Octoraro (90 percent), and Big Elk (78 percent) Creeks are located in Pennsylvania.

Northeast Creek (site 22) also drains the Piedmont; however, its duration curve has a much steeper slope than that of Big Elk Creek (fig. 18). At the 5-percent exceedance level, runoff was 5.4 $(ft^3/s)/mi^2$, and at the 95-percent level, runoff was 0.19 $(ft^3/s)/mi^2$. Possible explanations for its steeper slope include man's activities such as (1) pumping ground water for irrigation or municipal use, (2) pumping from the creek during low-flow periods for irrigation, and (3) storage in ponds or reservoirs. All of these might reduce streamflow during low-flow periods.

Morgan Creek (site 4A), located entirely within the Coastal Plain, has a duration curve (fig. 18) which is similar in shape to Big Elk Creek (site 7), but at a lower flow. At the 5-percent exceedance level, runoff was 2.4 $(ft^3/s)/mi^2$, and at the 95-percent level, runoff was 0.20 $(ft^3/s)/mi^2$. The lower flow indicates that the shallow ground-water divide may not coincide with the surface-water divide, and some ground water moves out of the basin to adjacent streams or to deeper aquifers.

Flood Frequency

Floods in the study area occur often as a result of heavy thundershowers during the summer. Streams in the Piedmont tend to have higher discharges per square mile during floods than streams in the Coastal Plain. Flood hydrographs of streams in the Piedmont are charac-

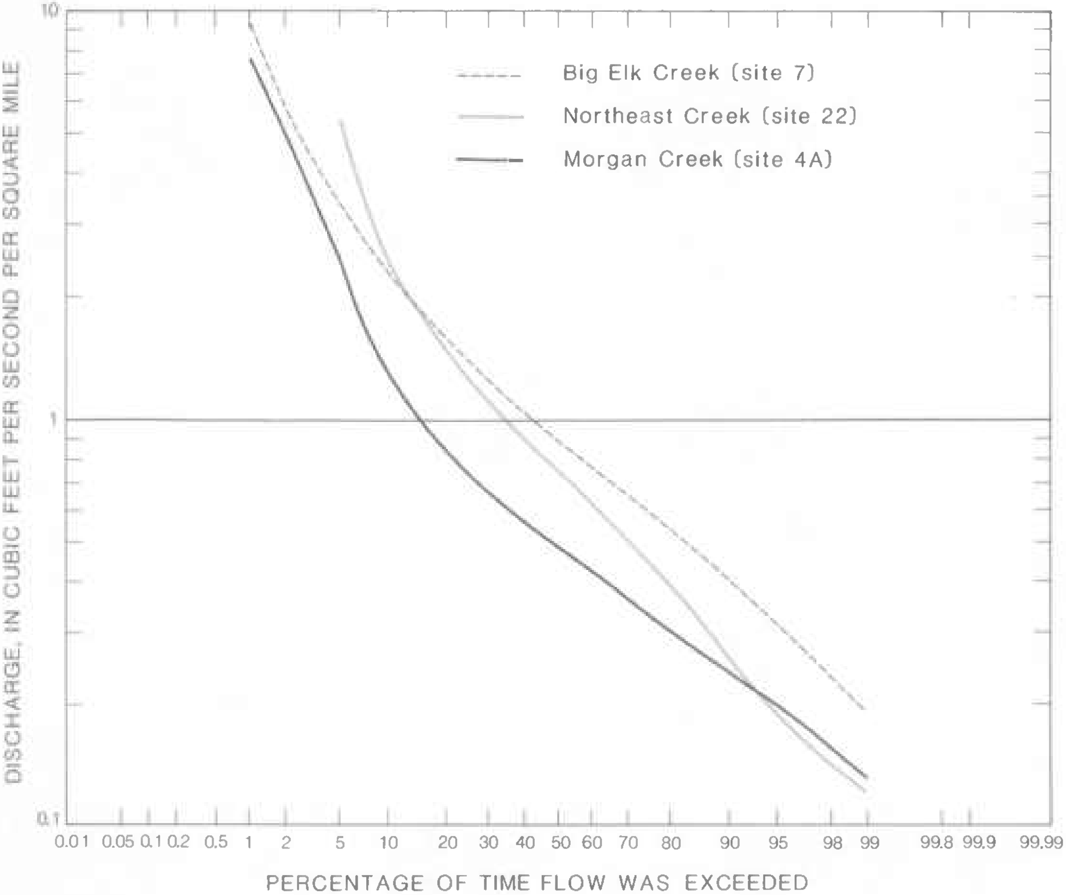


FIGURE 18. Duration of daily flow for Big Elk Creek (site 7), Northeast Creek (site 22), and Morgan Creek (site 4A).

terized by sharp rises and rapid recessions. Flood hydrographs of streams in the Coastal Plain tend to be characterized by slow rises, rounded peaks, and long recessions.

Flood-frequency characteristics are presented in table 16 for continuous-record stations having at least 10 years of record. In addition to the peak-flow discharges, discharges for the annual maximum daily flow and the 3-day and 7-day high flows are presented. The frequency of a given high flow is a measure of the average number of times the given flow will be exceeded during a specified period of years. The recurrence interval is the average time, in years, between occurrences of a given flow extreme. It is also the reciprocal of probability. For example, a "50-year flood peak of 1,000 ft^3/s" means that in any 1 year, there is a 2-percent chance of a discharge event exceeding 1,000 ft^3/s. A 7-day, 10-year high-flow discharge of 1,000 ft^3/s means that a discharge of 1,000 ft^3/s (average over the highest 7 consecutive days in a year) will be exceeded at that site (on the average) once every 10 years.

Peak-flow magnitudes and frequencies were computed by fitting the observed annual peak discharges to a log-Pearson type III distribution and developing flood-frequency curves as recommended by the U.S. Water Resources Council (1981). High-flow characteristics were obtained from frequency curves developed by fitting the log-Pearson type III distribution to records of observed annual-maximum average flow for 1, 3, and 7 consecutive days.

TABLE 16

MAGNITUDE AND FREQUENCY OF ANNUAL HIGH FLOWS AT CONTINUOUS-RECORD GAGING STATIONS

[mi^2 = square mile; — = data not collected.]

Site no.	Station name	Drainage area (mi^2)	Annual maximum	Discharge, in cubic feet per second, for indicated recurrence intervals, in years: 2	5	10	25	50
3	Christina River at Coochs Bridge, Del. (based on period Oct. 1, 1944, to Sept. 30, 1979)	20.5	Peak flow	1,700	2,370	2,900	3,650	4,290
			Daily flow	651	909	1,103	1,379	1,607
			3-day flow	288	416	534	731	919
			7-day flow	161	232	291	382	464
4A	Morgan Creek near Kennedyville, Md. (based on period Oct. 1, 1951, to Sept. 30, 1979, except peak flow; water years 1951-75)	12.7	Peak flow	374	756	1,150	1,900	2,680
			Daily flow	215	451	699	1,160	1,650
			3-day flow	103	202	302	485	675
			7-day flow	54	100	145	224	302
7	Big Elk Creek at Elk Mills, Md. (based on period Oct. 1, 1932, to Sept. 30, 1979, except peak flow; water years 1884, 1932-35, 1937-77)	52.6	Peak flow	2,930	4,870	6,550	9,230	11,700
			Daily flow	1,090	1,660	2,090	2,690	3,180
			3-day flow	548	821	1,030	1,320	1,570
			7-day flow	316	456	558	696	806
10	Little Elk Creek at Childs, Md. (based on period Oct. 1, 1948, to Sept. 30, 1958)	26.8	Peak flow	1,720	2,550	3,230	4,260	5,170
			Daily flow	572	750	884	--	--
			3-day flow	257	380	506	--	--
			7-day flow	151	225	296	--	--
22	Northeast Creek at Leslie, Md. (based on period Oct. 1, 1948, to Sept. 30, 1979, except peak flow; water years 1949-77)	24.3	Peak flow	1,510	2,400	3,160	4,350	5,440
			Daily flow	775	1,210	1,560	2,070	2,500
			3-day flow	380	576	734	970	1,170
			7-day flow	213	314	393	505	600
30	Principio Creek near Principio Furnace, Md. (based on period Oct. 1,1967, to Sept. 30, 1979, except peak flow; water years 1967-77)	9.03	Peak flow	1,260	2,290	3,280	5,020	6,770
			Daily flow	291	488	665	--	--
			3-day flow	150	243	314	--	--
			7-day flow	81	117	143	--	--
41	Basin Run at Liberty Grove, Md. (based on period Oct. 1, 1948, to Sept. 30, 1958, except peak flow; water years 1949-58, 1965-76)	5.31	Peak flow	720	1,350	1,980	3,130	4,350
			Daily flow	94	127	147	--	--
			3-day flow	45	56	61	--	--
			7-day flow	25	34	42	--	--

Data for the period of record through the water year 1979 were used to be consistent with work done by Carpenter (1983). High-flow characteristics for recurrence intervals of 2, 5, 10, 25, and 50 years are presented in table 16. Characteristics are not furnished for recurrence intervals beyond twice the length of available record because such extension may be unreliable.

High-flow data were not collected at partial-record sites. At such sites, however, high-flow characteristics may be estimated from regionalized estimating techniques. Carpenter (1983) describes such a method of estimating high flows with recurrence intervals from 2 to 100 years for natural drainage basins (without urban development or regulated flow) in Maryland. The method employs multiple-regression techniques to derive regionalized estimating equations in which drainage-basin and climatic characteristics are used to obtain high-flow discharges. The accuracy of the results that can be obtained using the equations is indicated to some extent by the standard errors of estimate of the equations, which range between 37 and 49 percent. Information on the development of the estimating equations and their application to predicting high-flow discharges on ungaged streams are provided by Carpenter (1983).

Low-Flow Frequency

The adequacy of streamflow to supply requirements for disposal of liquid wastes, municipal supplies, and to maintain adequate habitat for fish and wildlife is commonly evaluated in terms of low-flow frequencies. The frequency characteristic most widely used in relation to established water-quality standards is the 7-day, 10-year low flow (7Q10). This characteristic is defined as the lowest average flow over a period of 7 consecutive days that has a 10-percent chance of not being exceeded during any 1 year.

The low-flow frequency data presented in tables 14 and 17 are from two types of stations: (1) continuous-record stations having at least 10 years of record, and (2) low-flow partial-record stations. The low-flow partial-record stations are established sites where a number of base-flow discharge measurements were made over a period of several years.

For the continuous-record stations, low-flow frequencies are based on curves developed using the log-Pearson type III analysis. Discharges for periods of 7, 14, 30, 60, and 120 consecutive days for recurrence intervals of 2, 5, 10, and 20 years were determined from the curves and are listed in table 17. Curves for Northeast Creek (site 22) are shown in figure 19 as examples.

For the partial-record stations, relationships with continuous-record stations were obtained by correlating measurements of instantaneous flow with concurrent daily discharge from a nearby continuous-record station. As an example, figure 20 shows the relation between measurements at the partial-record station on Stony Run (site 27) and concurrent daily flows at the nearby continuous-record station on Northeast Creek (site 22).

TABLE 17

MAGNITUDE AND FREQUENCY OF ANNUAL LOW FLOWS AT CONTINUOUS-RECORD GAGING STATIONS

[mi^2 = square mile; — = data not collected.]

Site no.	Station name	Drainage area (mi^2)	Period (consecutive days)	Annual low flow, in cubic feet per second, for indicated recurrence interval, in years			
				2	5	10	20
3	Christina River at Coocha Bridge, Del. (based on period Apr. 1, 1944, to Mar. 31, 1979)	20.5	7	3.8	2.2	1.5	1.1
			14	4.3	2.6	1.9	1.4
			30	5.1	3.1	2.3	1.8
			60	6.6	4.2	3.3	2.6
			120	10.1	6.1	4.7	3.7
4A	Morgan Creek near Kennedyville, Md. (based on period Apr. 1, 1952, to Mar. 31, 1979)	12.7	7	3.0	1.9	1.5	1.2
			14	3.2	2.1	1.6	1.3
			30	3.6	2.3	1.8	1.4
			60	4.3	2.8	2.2	1.8
			120	5.6	3.7	2.9	2.3
7	Big Elk Creek at Elk Mills, Md. (based on period Apr. 1, 1932, to Mar. 31, 1979)	52.6	7	20	13	9.9	7.8
			14	21	14	11	8.4
			30	24	16	12	9.7
			60	29	19	15	12
			120	36	24	19	16
22	Northeast Creek at Leslie, Md. (based on period Apr. 1, 1949, to Mar. 31, 1979)	24.3	7	5.5	3.4	2.6	2.0
			14	6.0	3.7	2.8	2.2
			30	6.8	4.2	3.2	2.6
			60	8.7	5.5	4.3	3.4
			120	12.6	7.7	5.8	4.6
30	Principio Creek near Principio Furnace, Md. (based on period Apr. 1, 1968, to Mar. 31, 1979)	9.03	7	2.8	2.1	1.9	--
			14	2.9	2.3	2.1	--
			30	3.3	2.6	2.4	--
			60	4.2	3.5	3.3	--
			120	5.7	4.6	4.3	--
39	Octoraro Creek near Rising Sun, Md. (based on unregulated period Apr. 1, 1933, to Mar. 31, 1950)	193	7	92	67	55	45
			14	97	70	57	47
			30	107	78	64	53
			60	125	92	76	64
			120	153	111	91	75

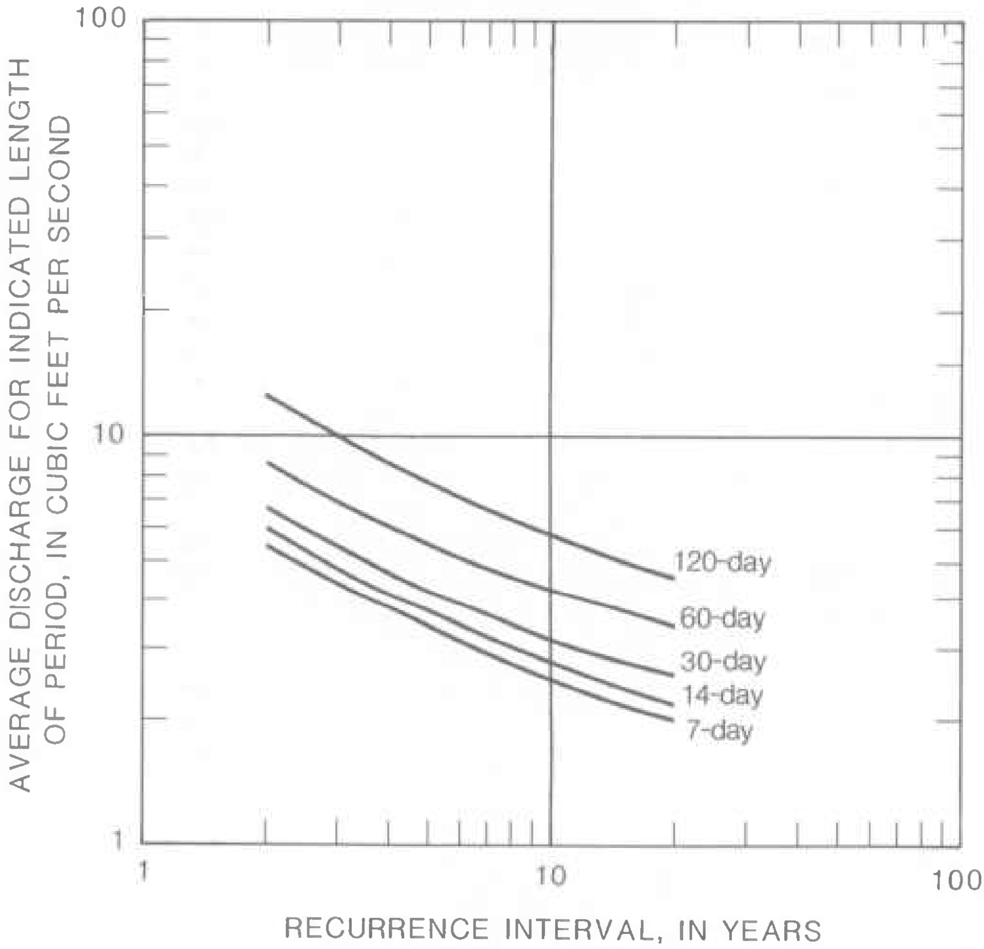


FIGURE 19. Magnitude and frequency of annual low flow for Northeast Creek at Leslie, Md. (site 22), 1949–79.

Table 14 gives the 7-day low-flow discharges for the 2- and 10-year recurrence intervals for those partial-record stations that could be correlated with continuous-record stations. These discharges are given in flow per square mile to enable comparisons between stations.

The 7-day low-flow discharge for the 2-year recurrence interval ranges from 0.02 to 0.68 $(ft^3/s)/mi^2$, and for the 10-year recurrence interval, 0.01 to 0.44 $(ft^3/s)/mi^2$ (table 14). The highest values are for Sandy Branch (site 19), and the lowest values that could be correlated are for Dogwood Run (site 12) and Hance Point Creek (site 29). Figures 21 and 22 show general areal patterns of the 7-day, 2-year and 7-day, 10-year low flows, respectively. Data are not available for areas along the Elk, Bohemia, and Sassafras Rivers because most of the streams in these areas are marshy or affected by tide and cannot be measured. The low-flow maps may be useful as a reconnaissance tool in finding streams with high sustained yields, but the determination of specific flow characteristics at an ungaged site will require additional measurements of flow.

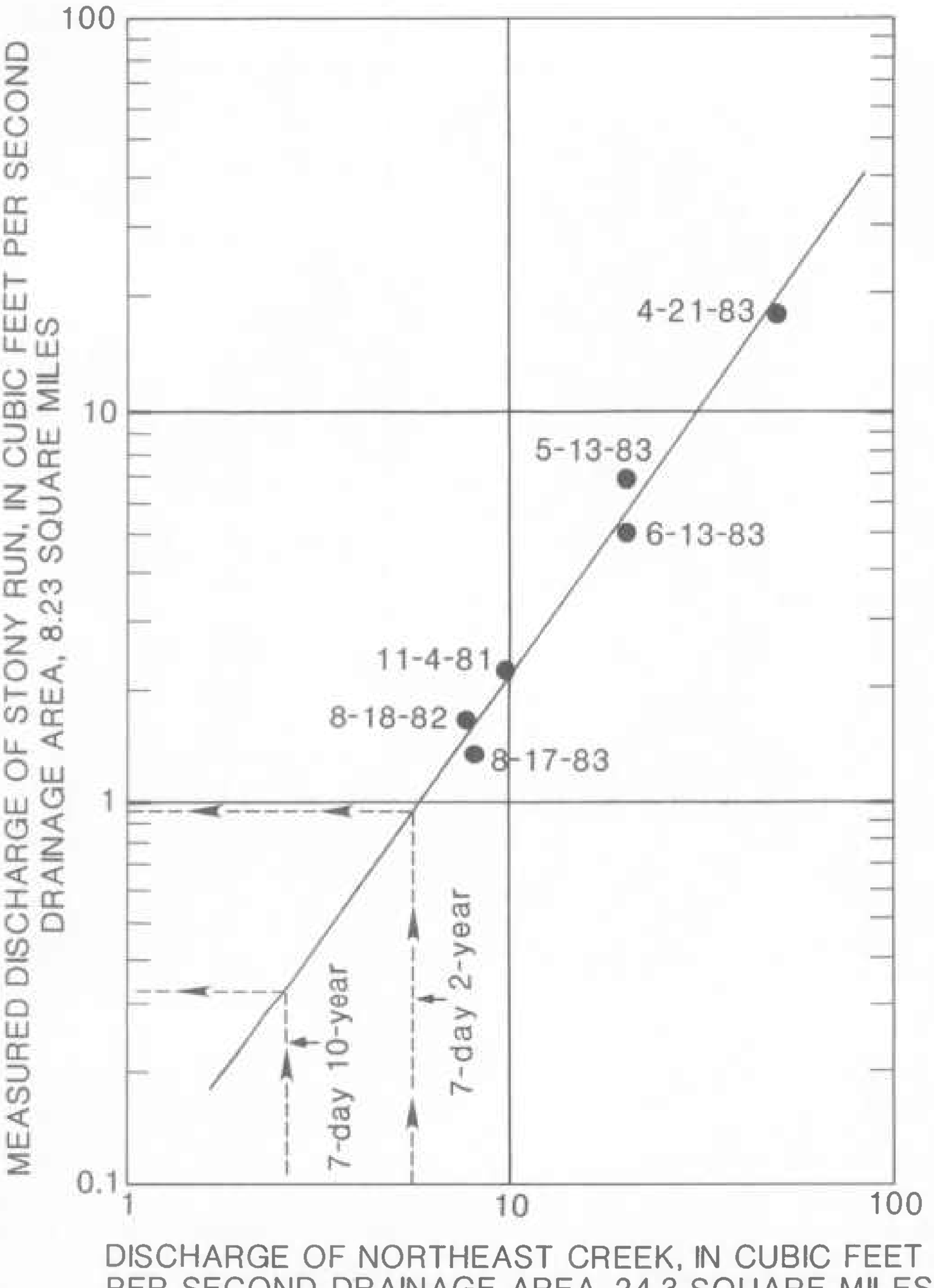
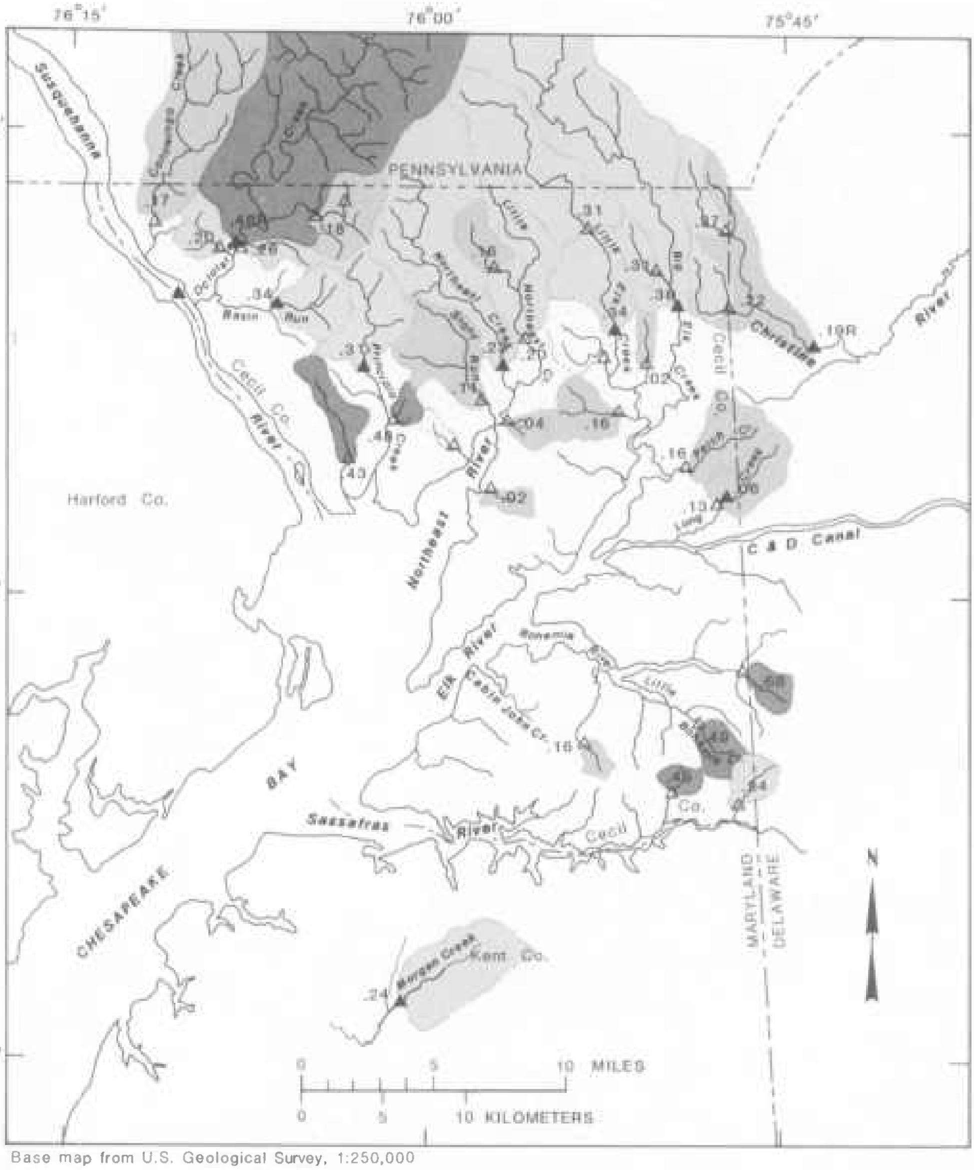


FIGURE 20. Relation between low-flow measurements of Stony Run near North East, Md. (site 27), and concurrent daily flows of Northeast Creek at Leslie, Md. (site 22).



EXPLANATION

.31 Annual 7-day, 2-year low flow, in cubic feet per second per square mile. (R - Indicates that discharge is affected by regulation.)

Less than 0.2

0.2 to 0.4

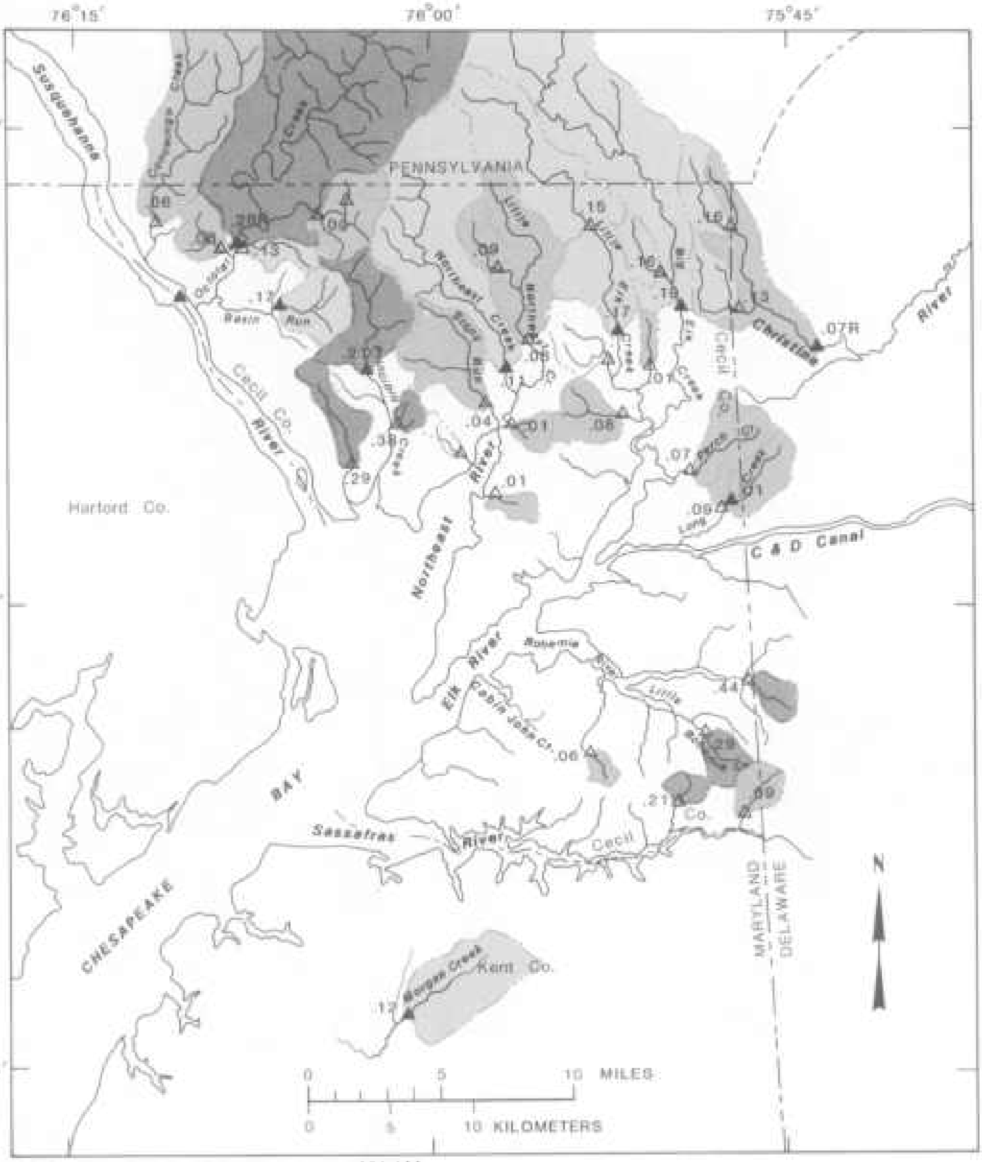
More than 0.4

▲ Streamflow continuous-record site

△ Low-flow partial-record site

Drainage divide

FIGURE 21. Pattern of estimated 7-day, 2-year annual low flow.



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

EXPLANATION

.01 Annual 7-day, 10-year low flow, in cubic feet per second per square mile. (R - Indicates that discharge is affected by regulation.)

Less than 0.1

0.1 to 0.2

More than 0.2

▲ Streamflow continuous-record site

△ Low-flow partial-record site

Drainage divide

FIGURE 22. Pattern of estimated 7-day, 10-year annual low flow.

CHEMICAL QUALITY

Stream-water-column and streambed-sediment samples were collected from 35 sites during low-flow periods in August and November 1982. Storm-runoff quality is too highly variable to quantify with the limited sampling effort of this study; consequently, no storm samples were collected. Figure 23 shows the locations of the stream-quality sampling sites and the type of sample (water-column or bed-sediment) collected at each site.

The surface-water-quality data from laboratory analytical determinations of water-column and bed-sediment samples collected at all the stream-sampling sites are presented by Willey and others (1987, tables 4, 5, and 6). Laboratory analytical results reported for 29 water-column samples include the concentrations of 10 common dissolved ions, 4 dissolved nutrient species, total dissolved solids, hardness and alkalinity, total organic carbon, and total and suspended iron and manganese. Field-water-quality measurements reported at the time of stream sampling include water temperature, pH, specific conductance, and dissolved oxygen. Analytical results of streambed-sediment samples include the concentrations of 9 trace elements at 20 sites, and the concentrations of 27 synthetic organic compounds comprising three groups of pesticides and 2 other compounds at 10 sites.

Stream sampling was conducted concurrently with low-flow stream-discharge measurements. Definition of streamflow rate, at the time of sampling, enables the constituent concentrations and discharge rate to be related to daily mean streamflow conditions at nearby representative long-term gages.

Established sampling procedures, described in the "National Handbook of Recommended Methods for Water Data Acquisition" (U.S. Geological Survey, 1977) were followed in the field collection and preservation of all water-column and streambed-sediment samples. Analytical laboratory determinations of chemical constituents were done by the U.S. Geological Survey Central Laboratory using standard analytical laboratory methods described in Skougstad and others (1979).

Ground water is the primary source of base flow in streams in Cecil County. Consequently, base-flow water quality generally reflects the nature and chemical-quality characteristics of the ground-water source. The chemical quality of ground water discharged into streams typically is controlled by the aquifer's lithology and the geochemical reactions occurring in the aquifer system. Upon discharge to the surface, numerous changes and chemical reactions occur as the water adjusts to the atmospheric and biospheric conditions of the stream environment.

Concentrations of commonly occurring dissolved inorganic ions in the base flow of Cecil County streams are generally within ranges suitable for most uses with ordinary treatment. However, many industrial, urban, and agricultural activities can change stream-water quality by introducing organic compounds, trace metals, and nutrients. These constituents are often introduced erratically and their presence in a basin might not be detected by one or two samplings of stream water. Some of these constituents sorb onto and accumulate in the streambed sediment; consequently, streambed sediments also were analyzed to detect their presence.

Base Flow

Representative width- and depth-integrated composite samples of the water column were collected at 29 sampling sites (fig. 23) primarily to determine the concentration of the commonly occurring dissolved inorganic ions. All stream-water-column samples were collected

EXPLANATION

21 Site number

Stream water-column and streambed-sediment sampling site

Stream water-column sampling site

Streambed-sediment sampling site

FIGURE 23. Location and type of stream chemical-quality sampling sites.

during base-flow periods in either August or November 1982. The average flow duration at six long-term gaging stations in Cecil County was approximately 85 percent at the time of sampling in August and approximately 80 percent during the sampling conducted in November, indicating that all samples were probably collected under similar base-flow conditions.

Figure 24 shows the distribution of the concentration of selected water-quality constituents from 29 stream-water-column samples. The concentration of total dissolved solids ranges from a minimum of 39 mg/L at site 29, to a maximum of 256 mg/L at site 2. The median dissolved-solids concentration for the 29 sites is 92 mg/L. Specific conductance ranges nearly an order of magnitude, with a minimum of 46 μS/cm (microsiemens per centimeter) at site 29, to a maximum of 451 μS/cm at site 2. The median specific conductance for 29 sites is 130 μS/cm. The hydrogen-ion concentration, expressed and measured in pH units, ranges from a minimum of 5.8 to a maximum of 9.1; the median is 7.3. Hardness, expressed as an equivalent concentration of calcium carbonate ($CaCO_3$), ranges from a minimum of 8 mg/L at site 6, to a maximum of 99 mg/L at site 21. The median hardness for 29 sites is 47 mg/L.

Stiff diagrams in figure 25 show graphically the concentrations of 7 major dissolved ions in the 29 base-flow samples. The majority (18) of the sites are on streams that predominantly drain the crystalline rock of the Piedmont, whereas the remaining 11 sites are on streams that drain the sedimentary deposits of the Coastal Plain. Widths of the Stiff diagrams indicate

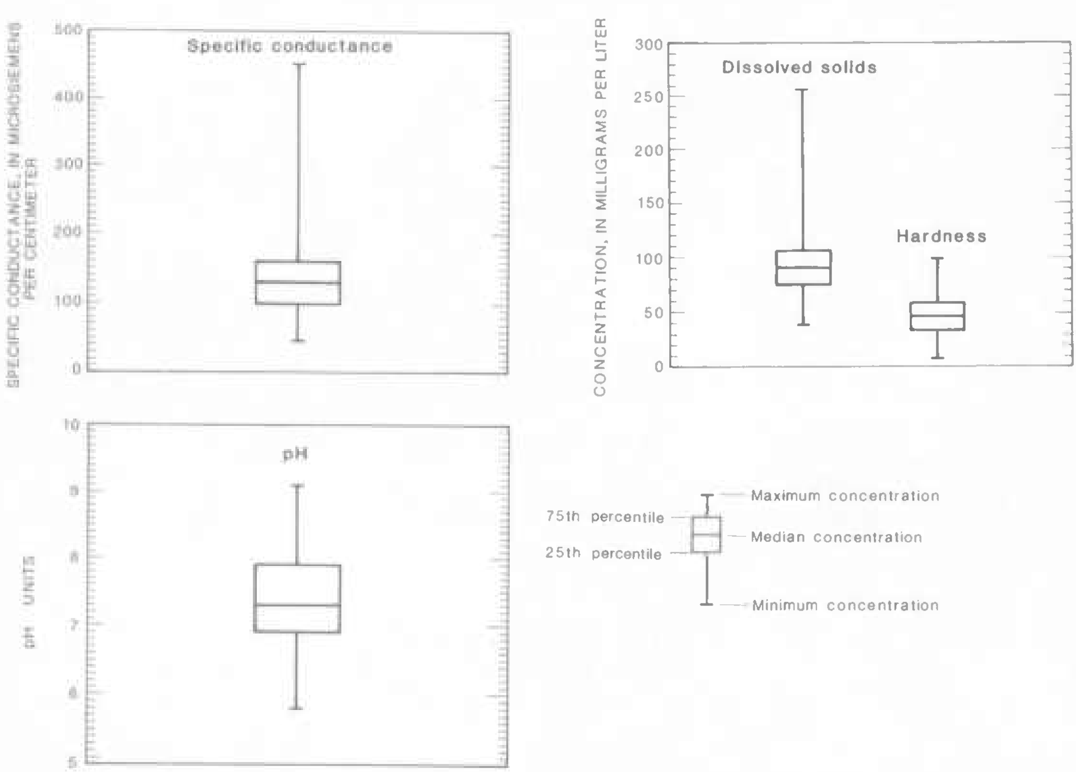


FIGURE 24. Distribution of the concentration of selected water-quality constituents from 29 base-flow samples collected in 1982.

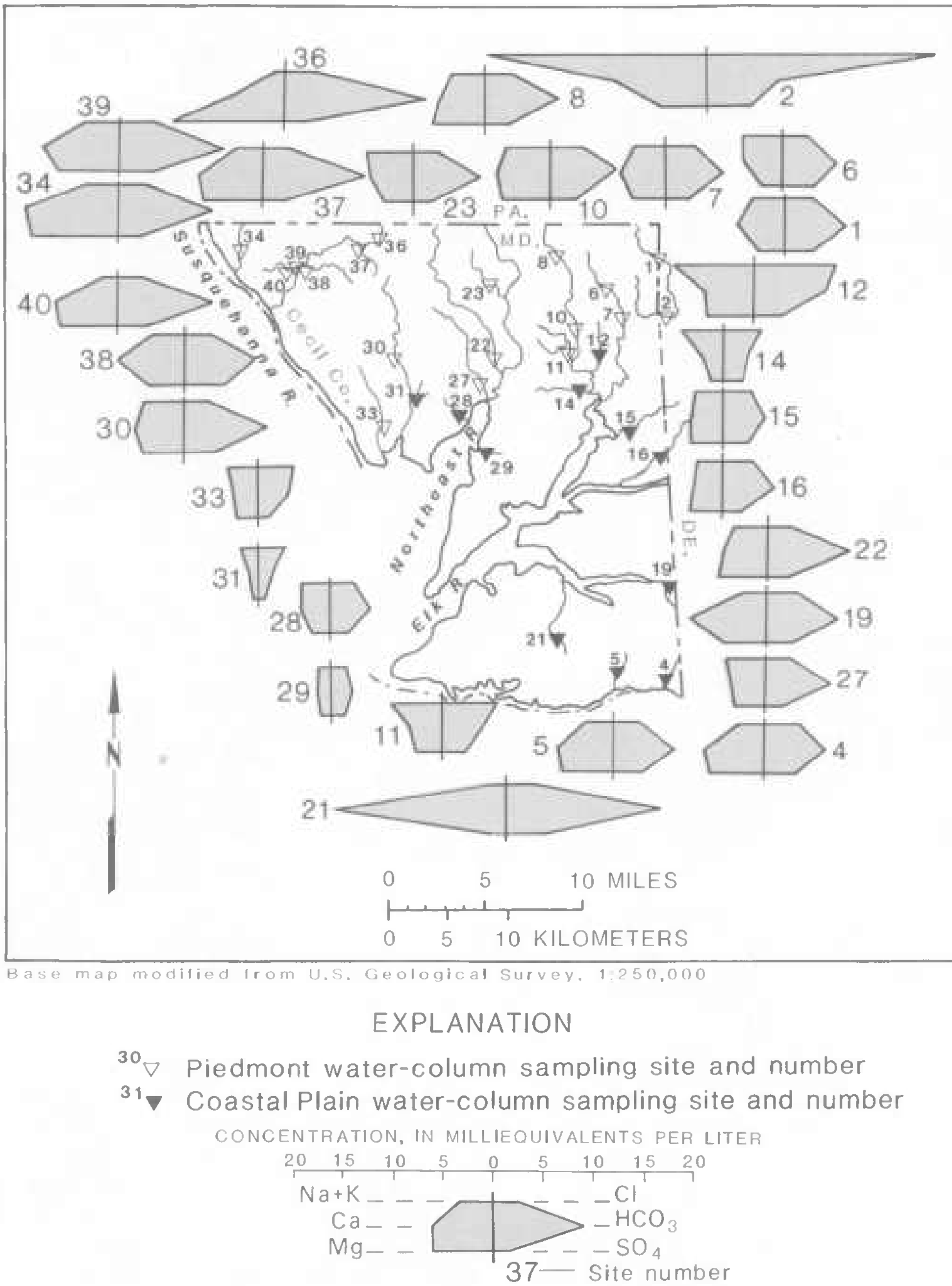


FIGURE 25. Stiff diagrams representing concentrations of 7 major ions in 29 base-flow samples collected in 1982.

concentrations in milliequivalents per liter. The shapes of the diagrams reflect the relative concentration of the major ions and indicate similarities or differences in type of water. A comparison of diagrams shows that the highest concentrations are in samples from sites 2 and 21. The municipal sewage-treatment plant upstream from site 2 probably accounts for the high sodium and chloride concentrations of the sample. The lowest concentrations are in samples from sites 29 and 31, which are on streams that drain very small basins (1.36 and 2.08 mi^2, respectively) in the Coastal Plain.

Streambed Sediments

Because of the large surface areas that silt, clay, and organic particles provide for sorption, sediment suspended in stream water is commonly the major transport mechanism for several chemical constituents (Feltz, 1980, p. 1). Suspended-sediment particles tend to settle out of the water column when streamflow velocities drop below a critical threshold of about 2 ft/s. The suspended-sediment particles with their sorbed chemical constituents are deposited in slack-water areas of the streambed, susceptible to resuspension whenever flow velocities reach or exceed the critical threshold velocity.

The transport rate of sediment through a stream basin is generally more sporadic and more discharge dependent than the transport rate of the dissolved inorganic constituents. Relatively large portions of a streambed's fine sediment material may be resuspended and translocated by the few relatively infrequent flooding events that might occur in a given year. Lang (1982, p. 54) supports earlier researchers who concluded that stream discharges on the Susquehanna River at Conowingo Dam that are greater than about 400,000 ft^3/s resuspend and translocate large amounts of the bed sediments accumulated upstream of the dam. Additional water-quality data for the Susquehanna River at Conowingo Dam are presented in U.S. Geological Survey annual reports entitled "Water Resources Data for Maryland and Delaware."

Representative samples of surficial streambed sediments were collected on August 16-18, 1982, at 20 sampling sites (fig. 23). The samples were analyzed in the laboratory to determine the presence of nine trace elements commonly associated with streambed sediments. The samples from 10 of these sites also were analyzed to determine the presence and concentration of 27 different synthetic organic compounds—PCB, PCN, and 25 pesticides.

Trace Elements—Table 18 lists the concentrations of the various trace elements that were detected in streambed-sediment samples analyzed for these elements. Figure 26 shows the distribution of the concentrations of several trace elements detected in samples from the 20 bed-sediment sampling sites. Laboratory analytical detection limits for trace elements range from a low of 0.01 $\mu g/g$ (microgram/gram) for mercury, to 10 $\mu g/g$ for lead. Neither mercury nor arsenic were present in detectable quantities at any of the sampling sites, and cadmium was detected only at site 1. This stream site also had the highest concentration of four other trace elements (copper, zinc, iron, and lead). Iron and manganese were detected at all sites reflecting their ubiquitous occurrence in the natural hydrogeologic system of Cecil County. Moderately high concentrations of chromium at sites 34 and 40 may be attributable to the occurrence of chromite ores in the northwestern corner of the county (Pearre and Heyl, 1960).

Synthetic organic compounds—Samples of the surficial streambed sediments, particularly that portion of the mineral and organic sediments smaller than 0.062 mm (millimeter), commonly provide a long-term record of the presence and transport of many synthetic organic

TABLE 18

TRACE ELEMENTS IN STREAMBED SEDIMENTS AT SELECTED STREAM SITES

[All concentrations in micrograms per gram.]

Site no.	Station no.	Date of sample	Time	Arsenic total (as As)	Cadmium (as Cd)	Chromium (as Cr)	Copper (as Cu)	Iron (as Fe)	Lead (as Pb)	Manganese (as Mn)	Mercury (as Hg)	Zinc (as Zn)
1	01477850	82-08-18	0900	<1	1	5	16	4,200	80	220	< 0.01	60
2	01477860	82-08-18	0950	<1	<1	2	1	580	<10	130	< .01	7
5	01494480	82-08-17	1125	<1	<1	2	1	2,700	<10	100	< .01	7
9	01495050	82-08-18	1035	<1	<1	2	1	1,200	<10	190	< .01	5
13	01495530	82-08-18	1140	<1	<1	5	<1	1,800	10	200	< .01	17
14	01495540	82-08-16	1600	<1	<1	3	2	760	<10	27	< .01	5
15	01495550	82-08-18	1200	<1	<1	1	<1	690	<10	27	< .01	7
18	01495850	82-08-17	1530	<1	<1	3	6	2,900	10	91	< .01	18
19	01495925	82-08-17	1340	<1	<1	2	1	2,900	<10	120	< .01	7
21	01495950	82-08-17	0930	<1	<1	6	1	3,700	<10	70	< .01	10
25	01496053	82-08-18	0900	<1	<1	4	5	2,400	50	190	< .01	12
26	01496055	82-08-18	0945	<1	<1	1	2	650	10	6	< .01	5
27	01496060	82-08-18	1115	<1	<1	1	1	430	<10	90	< .01	5
31	01496225	82-08-16	1530	<1	<1	1	1	820	10	87	< .01	6
32	01496230	82-08-18	1200	<1	<1	7	1	2,500	<10	200	< .01	9
33	01496250	82-08-16	1645	<1	<1	5	4	940	10	230	< .01	16
34	01578300	82-08-17	0915	<1	<1	30	2	2,700	<10	460	< .01	9
37	01578480	82-08-17	1345	<1	<1	9	2	1,400	10	96	.01	8
39	01578500	82-08-17	1200	<1	<1	6	3	2,700	10	150	.01	12
40	01578515	82-08-17	1030	<1	<1	20	7	3,500	<10	290	< .01	10

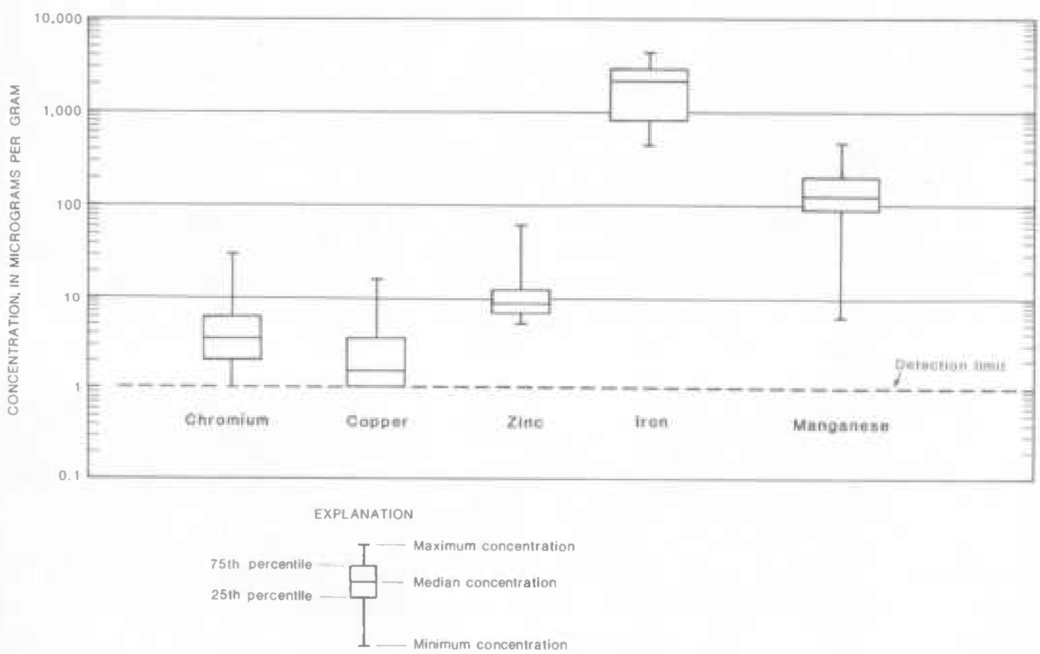


FIGURE 26. Distribution of the concentration of selected trace elements in streambed sediments collected August 16-18, 1982.

compounds. Most of the synthetic organic compounds are hydrophobic (low aqueous solubilities) and tend to associate with particulate surfaces (Hem, 1985, p. 154). Hence, if present in a hydrologic system, these organic compounds frequently occur at more detectable concentrations in the streambed sediments.

Table 19 lists the concentrations of the eight synthetic organic compounds that were detected at 6 of the 10 bed-sediment sampling sites that were analyzed for these compounds. Figure 27 shows the location of the sampling sites. The compounds detected do not occur naturally and are found in rivers and streams only as a result of their use, disposal, or manufacture (Gilliom and others, 1985, p. 4). Compounds that were not detected in the 10 samples are PCN, aldrin, diazinon, ethion, heptachlor, heptachlor epoxide, lindane, malthion, methylparathion, methyltrithion, methoxychlor, parathion, perthane, silvex, toxaphene, trithion, 2-4-D, 2-4-DP, and 2-4-5-T.

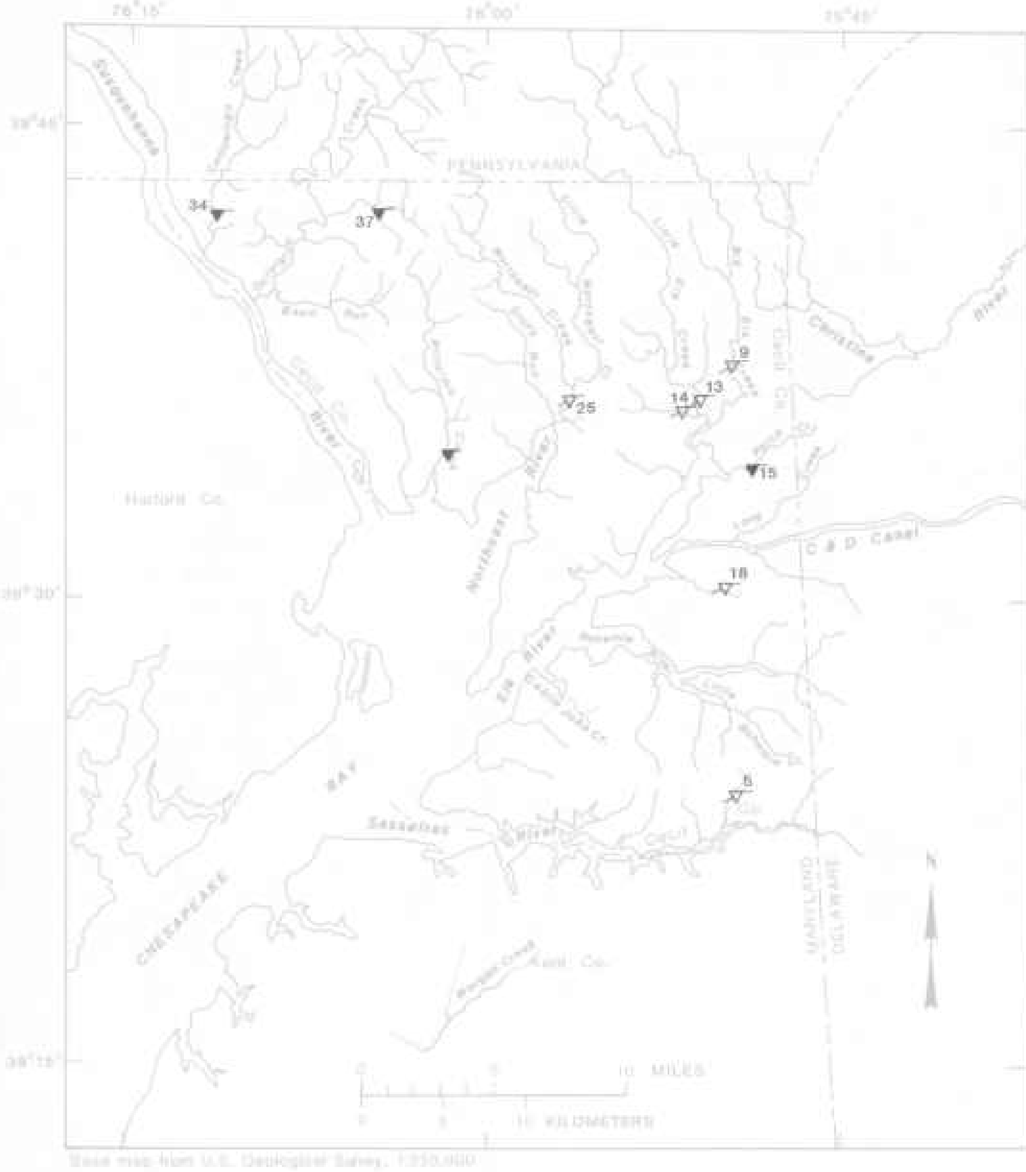
Some general patterns exist in the occurrence and detection of synthetic organic compounds in Cecil County, primarily due to differing uses and applications of these chemicals, coupled with differing chemical characteristics such as aqueous solubility and persistence in the environment. The most frequently detected compounds were the organochlorine insecticides (table 19); none of the more soluble pesticides were detected. Federal prohibitions against the manufacture or use of DDT were enacted in 1972. However, DDT or its metabolites DDD and DDE were detected in bed sediments at five of the sampling sites. The continued presence of residues of this pesticide group after 10 years of presumed nonuse indicates that these compounds can persist in the fluvial environment.

Although the scope of the sampling effort was very limited, results are consistent with the expected relation of land use above a site to the normal use of the detected compound. Those compounds that may be associated with urban or industrial areas (PCB, chlordane) were detected only in streams receiving drainage from such areas (sites 13 and 25). DDT, which

TABLE 19

CONCENTRATIONS OF SYNTHETIC ORGANIC COMPOUNDS DETECTED IN STREAMBED-SEDIMENT SAMPLES, AUGUST 16–18, 1982

	Organochlorine insecticides (micrograms per gram)							
Site no.	Chlordane	DDD	DDE	DDT	Dieldrin	Endosulfan	Endrin	Gross PCB
5	<1	2.4	1.1	2.7	<0.1	<0.1	<0.1	<1
9	<1	<.1	<.1	<.1	<.1	<.1	<.1	<1
13	4	5.3	<.1	12.0	.3	.1	.3	58
14	<1	.7	.3	<.1	<.1	<.1	<.1	<1
18	<1	.9	.3	.3	<.1	<.1	<.1	<1
25	3	<.1	<.1	.4	<.1	<.1	<.1	<1



EXPLANATION

37 Site number

Streambed-sediment sampling site where synthetic-organic compounds were detected.

Streambed-sediment sampling site where synthetic-organic compounds were not detected.

FIGURE 27. Location of streambed-sediment sampling sites for synthetic organic compounds.

was formerly used in a variety of land-use areas, and its metabolites were detected in the bed sediments of several streams, which collectively drain a variety of land-use areas. Chlordane, which is used extensively for termite control in residential dwellings, was detected in the bed sediments of two streams (sites 13 and 25) that drain relatively high-density residential areas. PCB, which is a class of chlorinated hydrocarbons used primarily in a variety of industrial applications, was found in bed sediment of a stream (site 13) that drains an area that includes industrial land use.

The U.S. Geological Survey established an interim alert system in 1979 to identify and flag any laboratory determinations of excessively high concentrations of chemical constituents present in samples processed in U.S. Geological Survey Central Laboratories. The alert limit for all the synthetic organic compounds listed in table 19 was arbitrarily set at 20 μg/g (micrograms per gram) under this system.

Bed-sediment samples collected in August 1982 from Little Elk Creek at Elkton (site 13) had a PCB concentration of 58 μg/g. This resulted in the issuance of an alert message to notify the Maryland Department of Health and Mental Hygiene (MDHMH). The MDHMH conducted a subsequent investigation on December 9, 1982, in which bed-sediment samples were collected from nine locations along the length of the main stem of Little Elk Creek. Measurable quantities of PCB (79 μg/g) were detected at only one site, and no PCB was detected at site 13 (George Harmon, MDHMH, written commun., 1983). The site at which MDHMH detected PCB is approximately 7 mi upstream from site 13. Nondetection of PCB at site 13 may be the result of resuspension and translocation of sediment particles and their sorbed organic compounds by high flows. Inspection of published daily-flow records from the long-term gages in the area shows that four significant storm-runoff events occurred between the two sampling dates—high daily flows occurred on September 27, October 26, and November 15 and 29, 1982.

The limited sampling effort of this study gives only a preliminary indication of the occurrence of synthetic organic compounds in the streambed sediments of Cecil County. The results, however, show that such compounds do occur at some sites in the county. The fact that they were detected by this limited sampling implies that they are likely to be present elsewhere as well.

WATER BUDGET

Water into a basin equals water out of a basin plus or minus change in storage. This can be expressed as a water budget:

$$P = GR + SR + ET \pm DIV \pm GU + Q \pm CS,$$

where

P = precipitation;

GR = ground-water runoff (base flow);

SR = storm runoff;

ET = evapotranspiration;

DIV = diversions into or out of a basin (public-supply systems, canals, drainage ditches, sewers, and so forth);

GU = ground-water underflow (Ground water that moves into or out of the basin across the drainage divide; includes water moving in the sediments beneath a stream that would not be measured as streamflow);

Q = ground-water withdrawals; and

CS = change in storage (ground-water storage, ponds, reservoirs, channel storage, soil-moisture storage, and so forth).

Table 20 shows major budget elements for three basins for which ground-water runoff (base flow) was estimated separately from total streamflow. These streams primarily drain the Piedment where stream-drainage divides approximate the ground-water divides, although some Coastal Plain deposits are present at higher elevations in these basins. The table shows results for the 1961–80 period for two streams and for the 1971–80 period for three streams. Results are average amounts for the periods shown, and all assume that diversions, ground-water underflow, pumpage, and change in storage are negligible. (Most pumpage in these basins is returned to the system within the basin through septic systems or local treatment facilities, so the net loss of water can be considered negligible at the rough scale of this analysis.) Ground-water runoff and storm-runoff components of measured streamflow were estimated visually from streamflow hydrographs. The evapotranspiration estimate is the quantity required to balance the equation.

Figure 28 shows the annual variation of ground-water runoff, storm runoff, and precipitation for the Big Elk Creek drainage basin above site 7 at Elk Mills, Md., for water years 1961–80. The variability from dry years (early 1960's) to wet years (early 1970's) is evident. During dry years there generally is a net loss in storage as water levels decline, and during wet years storage is replenished as water levels recover. (See hydrographs for wells CE Ac 77 and CE Bd 65, fig. 13.)

The estimates in table 20 indicate that evapotranspiration remained about the same during both wet (1971–80) and dry (1961–70) periods, while runoff figures differed significantly. For the 20-year period 1961–80, which included both wet and dry years, estimates of ground-water runoff shown for the two basins averaged about 10 in/yr; storm runoff, 10 in/yr; and evapotranspiration, 22 in/yr. These values are assumed to be representative of average conditions in the Piedmont basins of Cecil County, although the estimates in the table also indicate moderate variability between basins.

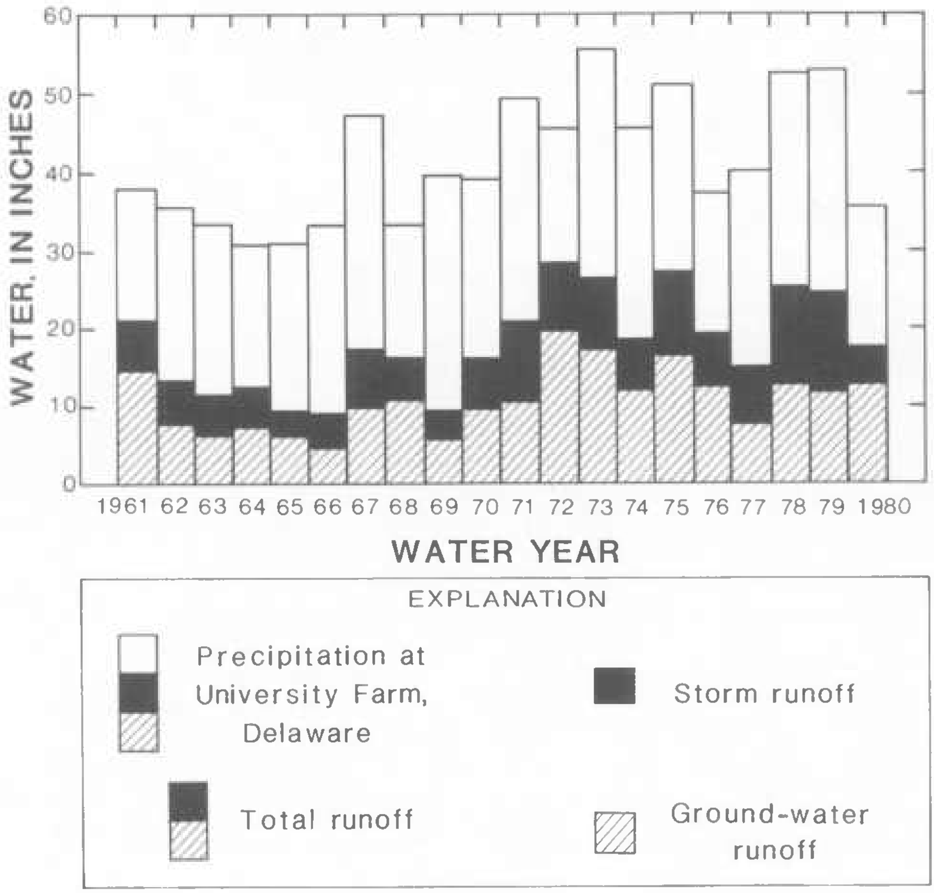


FIGURE 28. Relation of annual ground-water runoff, storm runoff, and precipitation, Big Elk Creek basin above site 7, water years 1961–80.

Budgets for small basins in the Coastal Plain may differ significantly from Piedmont basins because stream-drainage divides are less likely to coincide with ground-water divides. On a regional scale, however, evapotranspiration and total runoff (unaffected by pumping) would be about the same as in the Piedmont. The ground-water part of the runoff would likely be larger than in the Piedmont because Coastal Plain soils tend to be more permeable and more of the precipitation will likely infiltrate into the ground.

The total water available in a basin on a renewable basis is approximately equal to the total runoff if other elements of the water budget are negligible. Based on the previous analysis, the total renewable resource in Cecil County (unless special means are devised to modify evapotranspiration) is about 20 in/yr, or 1 (Mgal/d)/mi^2. Ground-water pumpage that is not returned to the system is ultimately derived from either storage (with declining water levels) or runoff (with reduced streamflow).

TABLE 20

MAJOR WATER-BUDGET ELEMENTS FOR SELECTED BASINS

[Water units are in million gallons per day per square mile (inches/year).]

Basin (Site location in fig. 17)	Drainage area (mi^2)	Precipitation 1/	Runoff		Evapotranspiration 3/
			Ground water 2/	Storm 2/	
			Water years 1961-80		
Big Elk Creek above site 7	52.6	1.97 (41.34)	0.51 (10.8)	0.34 (7.1)	1.12 (23.5)
Northeast Creek above site 22	24.3	1.97 (41.34)	.41 (8.6)	.56 (11.8)	1.00 (21.0)
			Water years 1961-70		
Big Elk Creek above site 7	52.6	1.72 (36.08)	0.39 (8.3)	0.25 (5.2)	1.08 (22.6)
Northeast Creek above site 22	24.3	1.72 (36.08)	.33 (7.0)	.37 (7.8)	1.02 (21.3)
			Water years 1971-80		
Big Elk Creek above site 7	52.6	2.22 (46.60)	0.63 (13.2)	0.43 (9.0)	1.16 (24.4)
Northeast Creek above site 22	24.3	2.22 (46.60)	.49 (10.3)	.75 (15.7)	.98 (20.6)
Principio Creek above site 30	9.03	2.22 (46.60)	.50 (10.6)	.57 (12.0)	1.14 (24.0)

1/ Measured at University Farm, Newark, Del.
2/ Estimated from streamflow hydrographs.
3/ Precipitation minus runoff. Assumes other variables are neligible.

ESTIMATED EFFECTS OF GROUND-WATER DEVELOPMENT IN THREE SELECTED AREAS

The development of a ground-water resource for water-supply purposes is necessarily accompanied by declines of ground-water levels and ground-water base flow to surface-water bodies in the areas of development. The purpose of this section is to estimate the magnitudes of these declines for hypothetical ground-water development plans in three areas in Cecil County. The three areas—Elkton-Chesapeake City, Rising Sun, and Highlands-Meadow View (fig. 29)—were selected to include some of the current major population centers in the county as well as some of the regions where rapid residential and commercial growth is projected to occur. The Elkton-Chesapeake City area covers about 54 mi^2 in eastern Cecil County and northwestern Delaware, and includes the major population centers of Elkton and Chesapeake City. The Rising Sun area in the northern part of the county includes the town of Rising Sun and covers about 8 mi^2. The third area, the Highlands-Meadow View area in northeastern Cecil County, includes the rapidly growing western suburbs of the city of Newark, Del., and covers about 11.5 mi^2.

The three areas are representative of the range of hydrogeologic conditions found in Cecil County. The Elkton-Chesapeake City area lies in the Coastal Plain and derives its ground-water supplies mainly from the sediments of the Potomac Group. The Rising Sun area is in the Piedmont where ground water is obtained from weathered and fractured crystalline rock. Most of the Highlands-Meadow View area also is in the Piedmont; however, the extreme southern part of the area is underlain by sediments of the Coastal Plain.

Estimates of the effects of ground-water development were obtained through the construction, adjustment, and use of three digital ground-water flow models (one for each of the three areas). The models were used under both steady-state and transient conditions to estimate the relative declines of ground-water levels and base flows caused by two hypothetical development plans under two different climatic conditions. The hypothetical development plans were (1) projected nondomestic and domestic ground-water pumpage without sewers, and (2) projected nondomestic and domestic ground-water pumpage with sewers. The two climatic conditions that were simulated were (a) long-term average ground-water recharge, and (b) short-term drought recharge.

It was not within the scope of the study to collect the hydrogeologic data necessary to fully calibrate the digital models. Instead, the models were constructed and used in a manner similar to standard analytical solutions. The results of the models are therefore not as reliable as those of a fully calibrated model. Accordingly, the simulated ground-water level and base-flow declines need to be viewed as gross estimates. Nevertheless, the results are more reliable than those that could have been obtained through the use of standard analytical methods because digital models allow the specification of more flexible boundary conditions and the inclusion of all available data. The location and type of lateral aquifer boundaries and stream-aquifer boundaries can be incorporated into digital models, whereas analytical solutions typically assume either no boundary conditions (infinite aquifer assumptions) or simplified uniform boundary conditions (equidistant boundaries, linear stream boundaries). Another advantage of digital models over analytical solutions is that they can incorporate all the possible interactive components of a ground-water flow system, whereas analytical solutions generally address only two or three components at a time. Also, digital models facilitate the estimation of the effects of geometrically complex pumpage distributions, whereas analytical solutions typically are restricted to one pumpage at a time and must be solved and summed many times to account for numerous interfering pumpages.

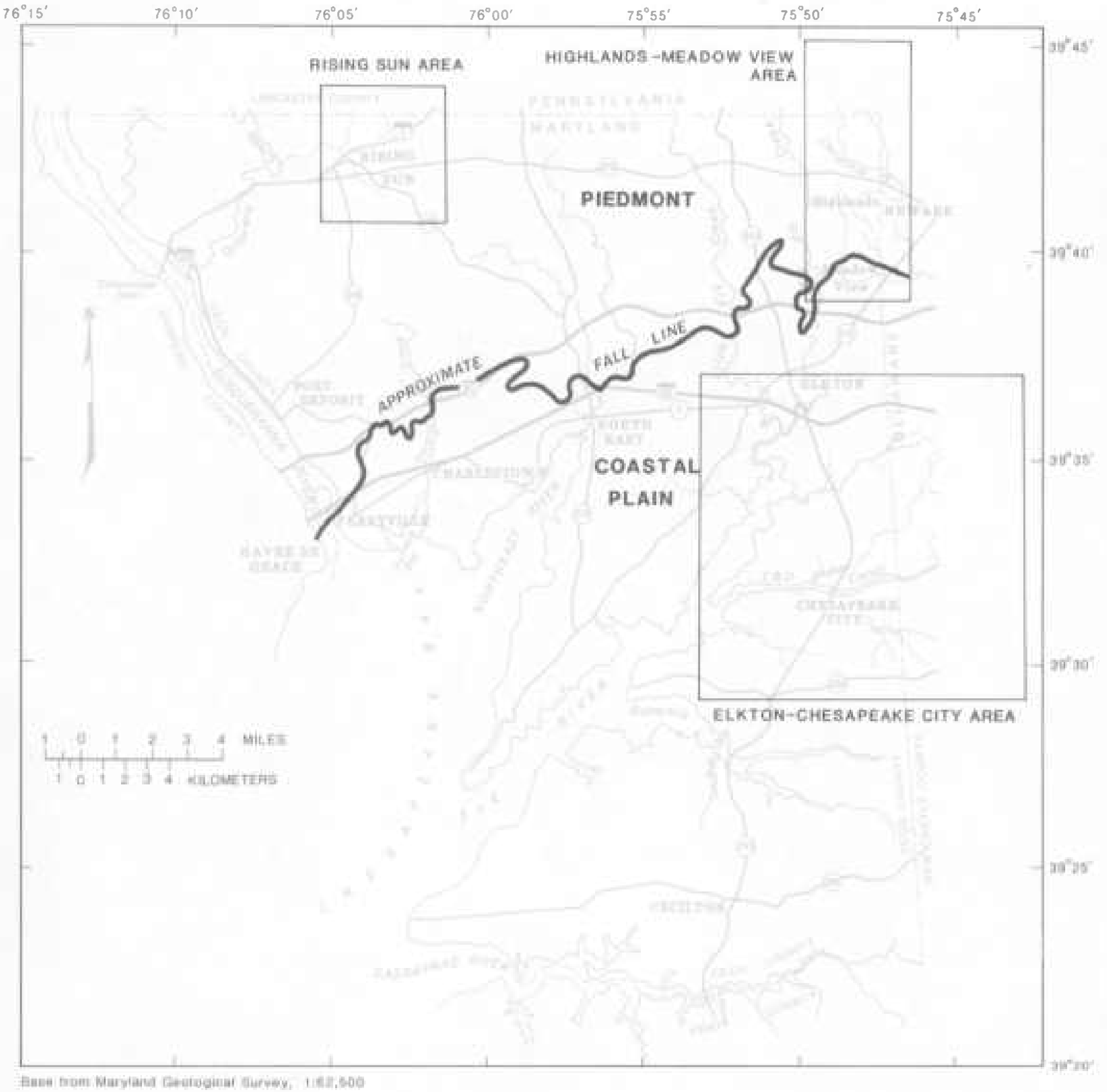


FIGURE 29. Location of three modeled areas in Cecil County, Md.

MODEL DESCRIPTION

The digital model used in this study was the U.S. Geological Survey modular, three-dimensional, finite-difference, ground-water flow model. The reader is referred to McDonald and Harbaugh (1984) for a detailed description of the features and mathematics of the model.

The model uses finite-difference methods to approximate the partial differential equation of ground-water flow. A rectangular grid is superimposed on a map of a study area. For each cell of the grid, estimates are made of aquifer thickness, hydraulic properties, natural ground-water recharge and discharge rates, ground-water/surface-water relations, and ground-water pumpages. These estimates are entered into the model computer program where a finite-difference approximation of the governing partial differential equation is formulated for each cell. Each of these approximation equations contains an unknown variable—the ground-water level in the aquifer for that cell. These equations are then solved simultaneously in an iterative procedure to obtain the ground-water level in each cell that is compatible with the estimates of aquifer characteristics that were entered for each cell. If the entered estimates are based on sufficient hydrogeologic data, and the resulting model-generated ground-water levels compare favorably with ground-water levels actually observed in the aquifer under a range of hydrologic conditions, then the model is considered calibrated. A calibrated model may be used to estimate the response of the aquifer to hypothetical stresses such as increased ground-water pumpage and drought.

The grids selected for use in the three modeled areas of this study consisted of square cells 0.2 mi on a side. The positioning of the grids on the three modeled areas is shown in figure 30. The divisions labeled on the northern and western edges of the maps indicate the locations of the grids relative to each area. For the sake of map clarity, only those cells corresponding with surface-water bodies are shown in the figure. The grid for the Elkton-Chesapeake City area consists of two layers of cells to account for two different aquifers, while the grids for the Rising Sun and Highlands-Meadow View areas have only one layer. Any particular cell can be referred to by its "layer, row, and column number." For example, cell 1, 7, 8 is the first-layer cell in the seventh row and eighth column. The Elkton-Chesapeake City grid contains 46 rows and 46 columns of cells; the Rising Sun grid, 19 rows and 18 columns; and the Highlands-Meadow View grid, 36 rows and 15 columns.

CONCEPTUAL MODELS

The translation of the complex hydrogeological relationships of an actual ground-water flow system into a simplified form capable of being mathematically simulated results in a conceptual model of the ground-water flow system. Two different conceptual models (figs. 31 and 32) were necessary to simulate the three areas modeled in this study. The conceptual model for the Coastal Plain sediments was applied to the Elkton-Chesapeake City area. The Piedmont conceptual model was used in the Rising Sun area and the Highlands-Meadow View area.

Two model layers were necessary to adequately simulate ground-water flow in the Coastal Plain sediments in the Elkton-Chesapeake City area (fig. 31). The top layer (layer 1) is modeled as a water-table aquifer; it includes, where present, the upper Potomac aquifer, the Magothy aquifer, the Matawan confining unit, the Monmouth aquifer, and the overlying surficial deposits. Some of the sands included in the water-table aquifer may actually be locally semiconfined or confined aquifers; however, for the purposes of modeling, it was assumed that all the sands in the top layer of the model are unconfined aquifers. The bottom layer (layer 2) is modeled as a confined aquifer that represents the lower Potomac aquifer. The two layers are separated by a confining unit of lower permeability than either of the aquifer layers. The confining unit is modeled as a single, areally extensive unit. It is a simplification of the many smaller, discontinuous confining units that occur at about the same stratigraphic position throughout the area and are called the middle Potomac confining unit. This confining unit dips to the southeast; thus, the modeled thickness of the overlying units varies from less than 50 ft in the northwestern part of the Elkton-Chesapeake City area to about 300 ft in the southeastern part.

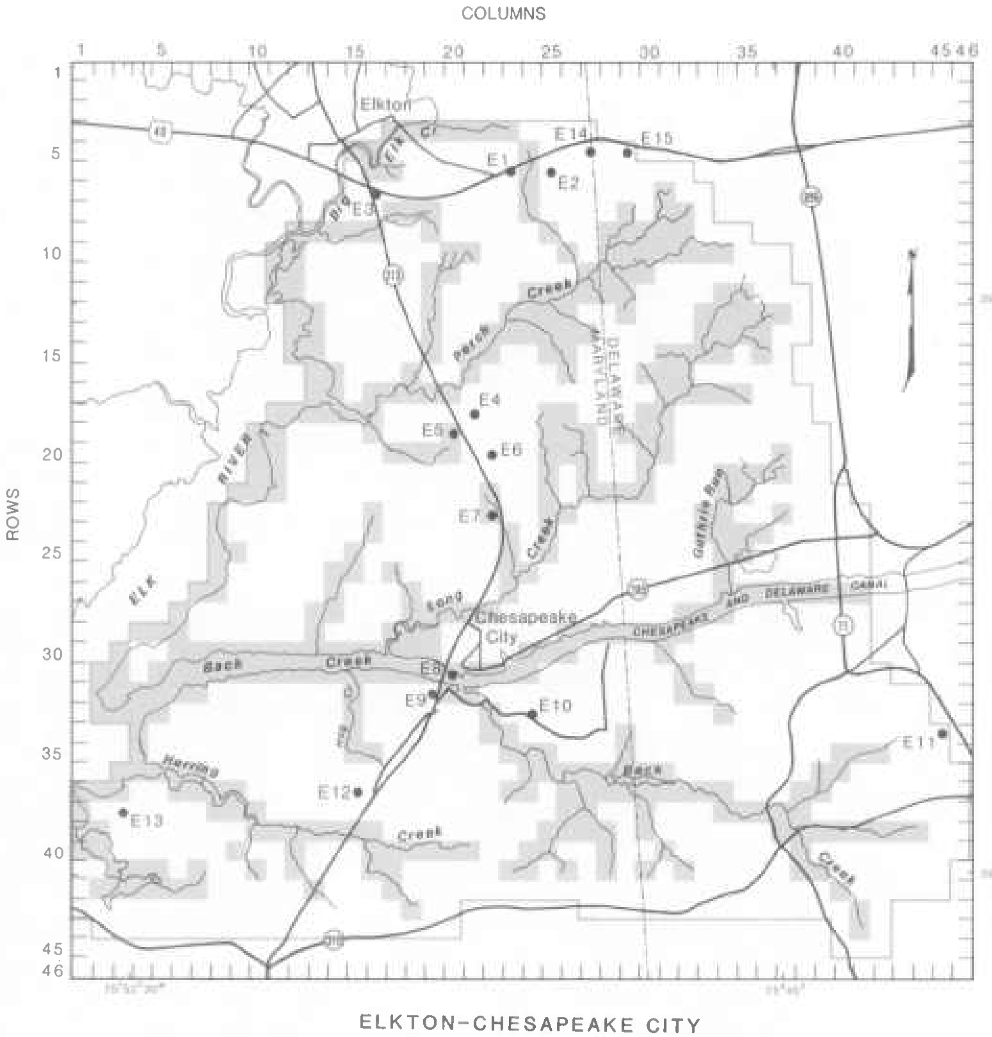


FIGURE 30. Location of model boundaries, surface-water cells, and nondomestic pumpage cells in three modeled areas.

The Piedmont conceptual model (fig. 32) consists of only the water-table aquifer (layer 1). This layer includes the saprolite and the upper part of the fractured crystalline rock and is assumed to extend from land surface to a depth of 200 ft. For purposes of simulation, the water-table aquifer is assumed to be only 200 ft thick because the most permeable part of the flow system, and therefore the majority of ground-water flow, generally occurs in the upper 200 ft. This assumption results in a water-table aquifer of uniform thickness mantling the relatively unproductive bedrock that is 200 ft below land surface.

Both conceptual models are bounded on the bottom by relatively impermeable bedrock, which is treated as a no-flow boundary in the models. Also treated as no-flow boundaries are the lateral model boundaries, the locations of which were selected to coincide approximately with surface-drainage divides as delineated on U.S. Geological Survey 7½-minute

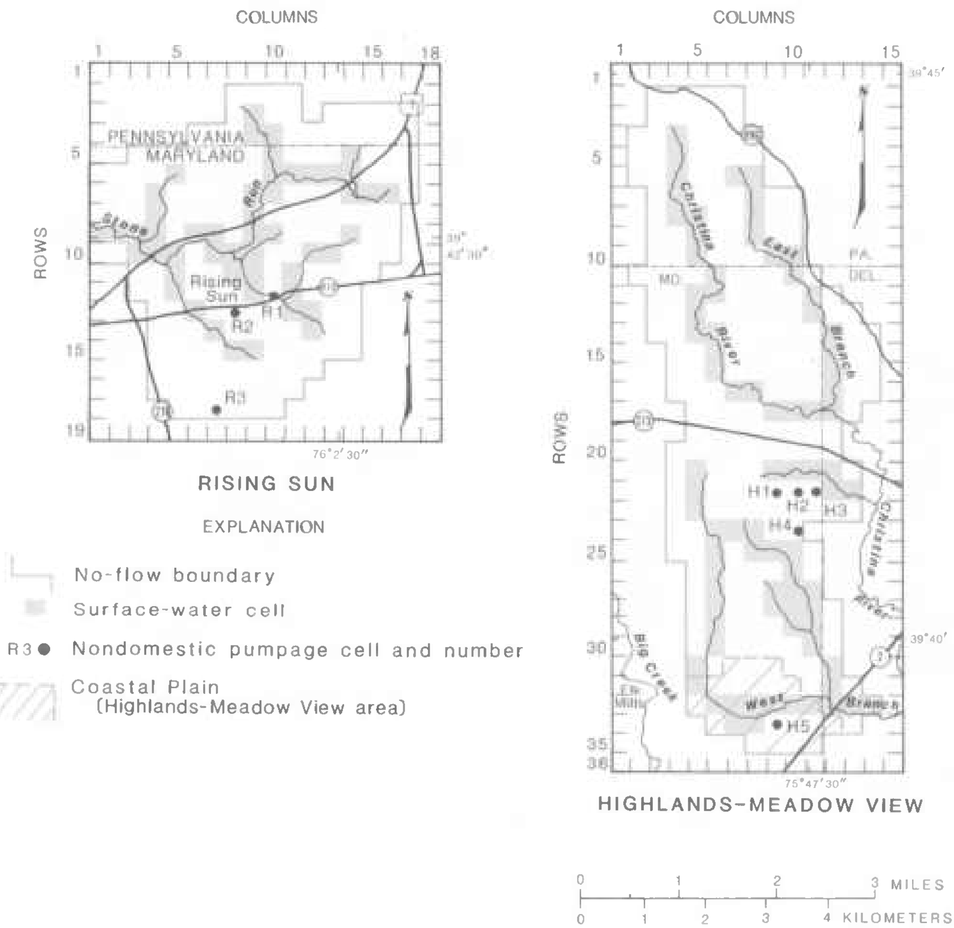


FIGURE 30.—*Continued.*

topographic maps. The assumption that ground-water divides coincide with surface-water divides is probably valid for the water-table aquifers, but is not valid for the confined aquifer in the Coastal Plain conceptual model, especially under heavy pumping conditions. The effect of this assumption on the simulated effects of ground-water development will be evaluated in a later section of this report.

The upper boundary in both conceptual models is the water table. In both models, the water table and the potentiometric surface slope toward the low-lying areas, which generally are occupied by surface-water bodies such as streams, estuaries, canals, and lakes. These surface-water bodies are considered to represent the water table and their stage is held constant in the models.

The water-table aquifers in both conceptual models are recharged by infiltration of precipitation. Ground water in the water-table aquifer flows laterally within the aquifer to discharge at surface-water bodies as base flow. Additionally, in the Coastal Plain conceptual model, it may move vertically through the confining unit as downward leakage into the confined aquifer in those areas where the water table is above the potentiometric surface of the confined aquifer. Ground water in the confined aquifer also flows toward major surface-

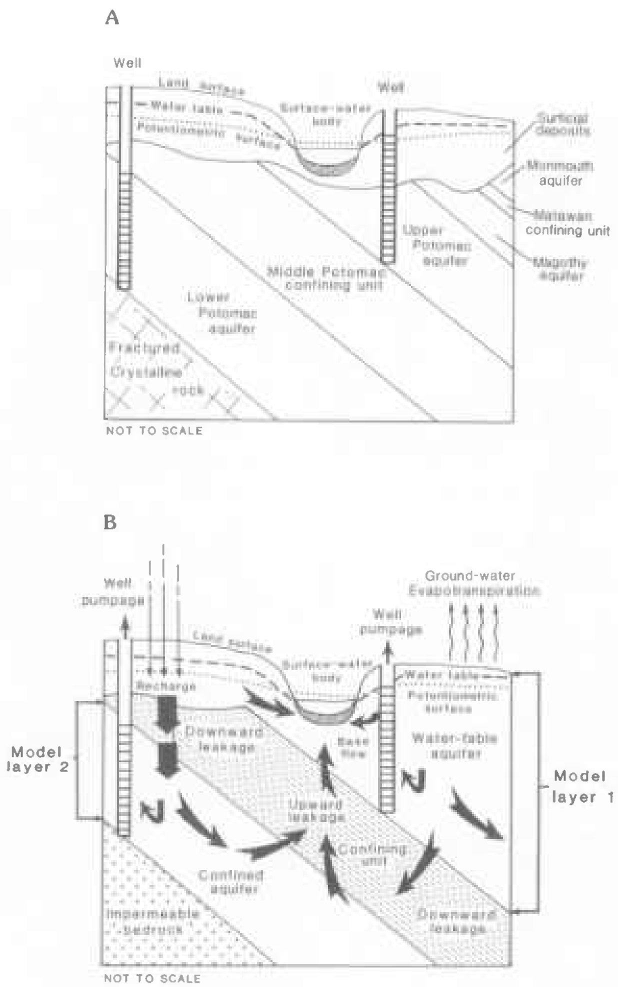
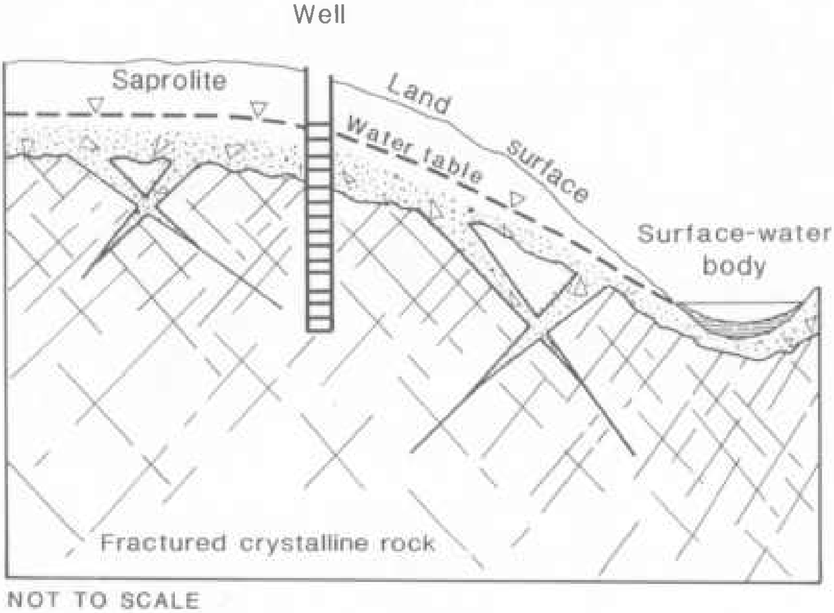


FIGURE 31. Schematic hydrogeologic section of the actual Coastal Plain ground-water flow system (A), and the simplified representation used in the Coastal Plain conceptual model (B).

water bodies and leaks upward through the confining unit and back into the water-table aquifer in areas where the potentiometric surface is above the water table. Another possible ground-water discharge mechanism in the conceptual models is ground-water evapotranspiration. This occurs where the water table is near the land surface, which generally is in the vicinity of surface-water bodies.

Ground-water recharge, base flow, and evapotranspiration (as well as vertical leakage for the Coastal Plain conceptual model) are the natural ground-water flow components that are included in the conceptual models. They approach dynamic equilibrium under natural conditions, with ground-water sources balancing ground-water sinks. However, when ground water is pumped for water supplies, this equilibrium is disrupted. In the conceptual models, A



B

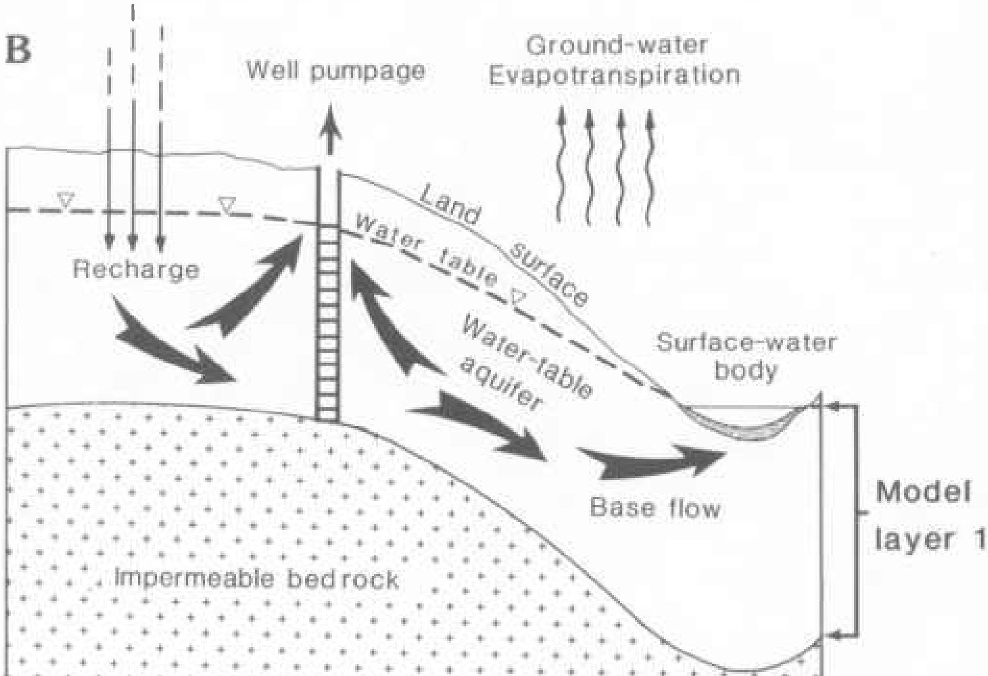


FIGURE 32. Schematic hydrogeologic section of the actual Piedmont ground-water flow system (A), and the simplified representation used in the Piedmont conceptual model (B).

pumping can occur either in the water-table or confined aquifer and, in effect, represents an interception of ground water as it flows from natural recharge to natural discharge areas (figs. 31 and 32). Pumping from the water-table aquifer will result in a lowering of the water table in the vicinity of the pumping, a decrease in ground-water evapotranspiration and base flow, and, in the Coastal Plain case, a net decrease in the amount of water moving downward into the confined aquifer. Pumping from the confined Coastal Plain aquifer will result in a lowering of the potentiometric surface in the vicinity of the pumping and a net increase in the amount of water moving downward through the confining unit. Also, an eventual result of pumping from the confined aquifer may be a lowering of the water table in the vicinity of the pumping, plus consequent decreases in ground-water evapotranspiration and base flow. Because the digital models for these three areas are based on these concepts, the above effects of pumping can be quantified by entering estimates of natural sources and sinks into the models, along with hypothetical ground-water development plans that specify the locations and rates of pumping.

MODEL INPUTS

Ground-Water Recharge

Long-term average ground-water recharge is generally considered to be equal to the sum of long-term average base flow and average ground-water evapotranspiration. For the Piedmont aquifers in Cecil County and adjacent counties, several studies (Dingman and Ferguson, 1956; Nutter and Otton, 1969; Gerhart and Lazorchick, 1984) obtained long-term average base flows ranging from 11 to 12 in/yr. Annual ground-water evapotranspiration rates are not available from these studies, but McGreevy and Sloto (1980, p. 27) estimated the sum of long-term average base flow and ground-water evapotranspiration to be 14.3 in/yr in the crystalline rocks of Chester County, Pa. Based on these results, a long-term average ground-water recharge rate of 15 in/yr (base flow plus ground-water evapotranspiration) was selected for use in the Piedmont parts of the three modeled areas of this study (table 21).

Ground-water recharge typically is higher in the shallow Coastal Plain aquifers. Johnston (1973, 1977) and Fleck (U.S. Geological Survey, written commun., 1985) used average base flows of 13.7, 14.0, and 15.0 in/yr, respectively. Rasmussen and Andreasen (1959) and Grufron Achmad determined the average sum of base flow and ground-water evapotranspiration to be 21 and 20.5 in/yr, respectively. Therefore, a long-term average ground-water recharge rate of 20 in/yr was selected for use in the Coastal Plain parts of the modeled areas (table 21).

Nearly all of the model simulations were based on these long-term average recharge rates. However, in order to evaluate the effects of prolonged below-average ground-water recharge on ground-water levels and base flow, two simulations were made with reduced recharge rates. Recharge rates of one-half the long-term averages (7.5 in/yr in the Piedmont, and 10 in/yr in the Coastal Plain) were used in these simulations, which were made for a 2-year period (table 21). These drought-recharge conditions were selected to approximate a severe drought such as the one that occurred in Maryland in the mid-1960's.

Ground-Water Evapotranspiration

Evapotranspiration from the water-table aquifer was permitted to occur in the models wherever the water table was within 10 ft of the land surface. The rate at which this ground-

TABLE 21
MODEL INPUTS FOR THREE MODELED AREAS
[—, not applicable.]

Inputs	Elkton-Chesapeake City (Coastal Plain)	Rising Sun (Piedmont)	Highlands-Meadow View (Coastal Plain)	Highlands-Meadow View (Piedmont)
For all simulations				
Hydraulic conductivity of water-table aquifer (ft/d)	17	1	17	0.5
Transmissivity of confined aquifer (ft^2/d)	1,730	---	---	---
Leakance of confining bed (d^{-1})	.0005	---	---	---
Vertical hydraulic conductivity of streambeds (ft/d)	.1	.5	.1	.5
Maximum evapotranspiration rate (in/yr)	18	12	18	12
Maximum depth of evapotranspiration (ft)	10	10	10	10
For average recharge simulations				
Recharge (in/yr)	20	15	20	15
For drought recharge simulations				
Recharge (in/yr)	10	7.5	10	7.5
Specific yield of water-table aquifer	.15	.05	.15	.05
Storage coefficient of confined aquifer	.0005	---	---	---

water evapotranspiration occurred in each cell was determined by a linear relationship between a minimum of 0 in/yr at a depth of 10 ft and a maximum of 12 in/yr at land surface in the Piedmont, and 18 in/yr at land surface in the Coastal Plain (table 21). For example, if the water table were 5 ft below land surface in a Piedmont cell, the ground-water evapotranspiration rate in that cell would be 6 in/yr. The selection of these maximum rates was based on results of studies in similar areas in adjoining counties. For the Piedmont areas, the maximum rate of 12 in/yr estimated by McGreevy and Sloto (1980) was used. For the Coastal Plain aquifers near Glen Burnie, Md., Grufron Achmad used a maximum rate of 16 in/yr. This rate was adjusted during model calibration in this study to 18 in/yr for the Coastal Plain parts of the three modeled areas. The assumption of a linear decline in evapotranspiration rate with increasing depth may result in an overestimation of the amount of ground-water evapotranspiration that can be captured by lowering the water table. However, in the absence of the data necessary to define the actual relationship between evapotranspiration rate and depth, the simpler linear relationship was used.

Hydraulic Properties

Initial values for the hydraulic conductivity of the water-table aquifers (layer 1) in the three modeled areas were estimated from data collected during this study and were refined during model calibration. A hydraulic conductivity of 1 ft/d was used for the Piedmont water-table aquifer in the Rising Sun area (table 21). A lower hydraulic conductivity of 0.5 ft/d was used for the water-table aquifer in the Piedmont part of the Highlands-Meadow View area (table 21). This difference was based on higher reported specific capacities for wells in the Rising Sun area, and assumes that the water-table aquifers are equally thick in the two areas. A hydraulic conductivity of 17 ft/d was used for the water-table aquifer in the Elkton-Chesapeake City area and the Coastal Plain part of the Highlands-Meadow View area (table 21). This order-of-magnitude difference between Piedmont and Coastal Plain hydraulic conductivities was based on an approximately similar difference in median specific capacities of water-table wells in those areas, again assuming approximately equally thick water-table aquifers.

The transmissivity of the confined aquifer (layer 2) in the Elkton-Chesapeake City area was set equal to 1,730 ft^2/d (table 21), and was based on the range of transmissivities presented earlier in this report (60 to 3,900 ft^2/d), as well as on slight adjustments made during model calibration.

The leakance of the confining unit separating the water-table aquifer (layer 1) from the confined aquifer (layer 2) in the Elkton-Chesapeake City area was set at $5 \times 10^{-4}/d$ (table 21). This value was derived mainly through model calibration and falls within the wide range of such values ($1 \times 10^{-8}/d$ to $1 \times 10^{-2}/d$) reported by Martin (1984) for similar sediments in Delaware.

For the transient simulations under drought-recharge conditions, storativities of the aquifers were necessary model inputs. Specific yields of 0.05 and 0.15 were used for the water-table aquifers in the Piedmont and Coastal Plain parts of the three modeled areas, respectively (table 21). A storage coefficient of 0.0005 was used for the confined Coastal Plain aquifer (layer 2) in the Elkton-Chesapeake City area (table 21). These values were based on those reported by various workers in Cecil County and in similar settings in nearby counties and were not adjusted during model calibration.

Ground-Water/Surface-Water Relations

Ground water flows toward and discharges mainly to surface-water bodies (streams, estuaries, canals, lakes). In order to simulate the interaction of ground water with these surface-water bodies, several model inputs were required. Average surface-water stage for each cell containing a surface-water body (see fig. 30 for locations) was determined from U.S. Geological Survey 7½-minute topographic maps and was held constant in the simulations. Also determined from the same maps and entered into the models was the approximate area of each cell that is occupied by surface-water bodies. The average depth of surface water was necessary in order to determine when the water table drops below the bottom of a surface-water body during simulation, resulting in desaturation. An average depth of 2 ft was used for all streams depicted as single lines on the topographic maps, and an average depth of 4 ft was used for all other surface-water bodies (larger streams, canals, lakes). The final model input necessary to simulate ground-water/surface-water relations was the vertical hydraulic conductivity of the materials lining the bottom of the surface-water bodies (the thickness of these materials was assumed to be 1 ft). This property is virtually unknown in the three modeled areas because of its extreme variability and the difficulty of measuring it. However, it is likely that on the average, it is lower than aquifer hydraulic conductivity because of the tendency for fine-grained sediment and organic debris to accumulate on the bottom of surface-water bodies. It is also likely that it is lower in the Coastal Plain because the lower stream velocities there probably cause more fine sediment to accumulate. Vertical hydraulic conductivities of 0.5 and 0.1 ft/d were selected for use in the Piedmont and Coastal Plain parts of the three modeled areas, respectively (table 21). These values were based mainly on model calibration, but they do fall in the same general range as similar values (0.11 ft/d) for the Piedmont rocks of northern Cecil County used by Gerhart and Lazorchick (1984) in their modeling study of the lower Susquehanna River basin.

MODEL ADJUSTMENTS

The scope of the study precluded the detailed calibration of the digital models. Simulated ground-water levels and base flows were not systematically compared to observed water levels and base flows. In addition, hydraulic properties and other model inputs were assumed to be uniform throughout hydrogeologically similar areas. Finally, no attempt was made to calibrate the models under transient conditions. However, the models were calibrated in a limited, general fashion by comparing the gross characteristics of the simulated and observed flow systems using steady-state simulations of prepumping and 1980 pumpage conditions.

Prepumping Simulations

The steady-state simulation of average recharge, prepumping conditions was used to refine the initial model inputs by slight uniform adjustments until the following five acceptance criteria were met.

(1) The relative magnitudes of the simulated ground-water sinks were in general agreement with those of ground-water budget studies in Cecil County and nearby, similar areas. The simulated prepumping ground-water budgets for the three modeled areas are shown in table 22. All budget terms are reported in inches per year; therefore, the differences in areal extent of the three areas are normalized. Also, in this way the budget terms may be readily compared to annual precipitation totals. The only natural source of ground water in all three areas is recharge from precipitation (assumed to be 15 in/yr in the Piedmont and 20 in/yr in the Coastal Plain). The only natural ground-water sinks are base flow (discharges to surface-water bodies) and evapotranspiration. In the Piedmont metamorphic rocks in Chester County, Pa., McGreevy and Sloto (1980) estimated average base flow to be about 82 percent of a total recharge of 14.3 in/yr. Johnston (1973), in the shallow Coastal Plain sediments of Delaware, estimated that base flow is about 11.7 in/yr, or about 85 percent of a total recharge of 13.7 in/yr. For the shallow Coastal Plain sediments in the vicinity of Glen Burnie, Md., Grufron Achmad determined that of a total recharge of about 20.5 in/yr, about 16 in/yr or 78 percent leaves as base flow. Based on these studies, it was decided that in the average recharge, prepumping simulation for each area, ground-water base flow should equal about 80 percent of ground-water recharge in order for the simulations to be acceptable. The final simulated percentages calculated from data in table 22 are 85, 75, and 68, respectively, in the Elkton-Chesapeake City, Rising Sun, and Highlands-Meadow View areas.

(2) Directions of ground-water flow were reasonable. The simulated water-table and potentiometric-surface maps are shown on plate 4. The water-table contours reflect the

TABLE 22

GROUND-WATER BUDGETS FOR THREE MODELED AREAS UNDER PREPUMPING AND 1980 PUMPAGE CONDITIONS

[Amounts of water in inches per year.]

	Elkton-Chesapeake City		Rising Sun		Highlands Meadow View	
	Prepumping	1980	Prepumping	1980	Prepumping	1980
Sources						
Recharge	20.0	20.0	15.0	15.0	15.4	15.4
Sinks						
Base flow	17.0	16.7	11.2	10.9	10.5	10.4
Ground-water evapotranspiration	3.0	3.0	3.8	3.8	4.9	4.6
Pumpage	0	.3	0	.3	0	.4

topography and the influence of the streams and other surface-water bodies. The contours indicate that ground-water recharge and discharge are occurring in the expected locations within each modeled area. The potentiometric-surface contours for the confined aquifer in the Elkton-Chesapeake City area indicate that ground-water flow directions in this deeper aquifer are similar to those in the water-table aquifer. Also, the distribution of the areas of downward and upward leakage through the confining unit in the Elkton-Chesapeake City area is reasonable.

(3) The simulated water table and potentiometric surface were at approximately the same depth below land surface as observed in the undeveloped parts of the modeled areas. This was qualitatively assessed by comparing the simulated depths below land surface to water levels measured as part of this study. Water levels were generally within about 10 ft of the typically observed depths for the appropriate topographic settings. Water levels near the mouths of major streams and near the C and D Canal were within a few feet of land surface.

(4) All streams were gaining streams. The simulated water table in cells containing streams was above the average stream stage in nearly all cases. In the Elkton-Chesapeake City area, some stream reaches in the headwaters of several small streams were simulated as being losing reaches. It was beyond the scope of the study to field check those reaches to determine whether or not they were perennial; therefore, losing conditions were assumed to be reasonable for those reaches.

(5) The occurrence of ground-water evapotranspiration was reasonably distributed. By analyzing the difference between the simulated water table and the average land-surface altitude in each cell, it was determined that ground-water evapotranspiration was occurring in broad bands adjacent to the major surface-water bodies.

Simulation of 1980 Pumpage

For each of the three areas, a model simulation was made which superimposed estimated ground-water pumpage for 1980 on average recharge, prepumping conditions. This was done by adding the estimated nondomestic and domestic pumpage to those cells in which it was occurring in 1980. Estimates of nondomestic pumpage (public supply, commercial, and industrial) were obtained from the Maryland Water Resources Administration and are listed in table 23. Locations of cells with nondomestic pumpage are shown in figure 30.

It was assumed that all domestic pumpage and nondomestic pumpage for unsewered users were disposed of in septic systems that returned 90 percent of the total pumpage to the local ground-water system; only 10 percent was actually consumed or lost to the ground-water system. Most of the nondomestic pumpage in 1980 was not returned to local ground-water systems, but instead was delivered by way of sewers to surface-water bodies after its use. Therefore, nearly all nondomestic pumpage was lost from the ground-water flow system.

Nondomestic pumpage for 1980 is given in table 23, along with identifying information and locations in the model. In 1980, there were 13 nondomestic ground-water users in the Elkton-Chesapeake City area, 3 in the Rising Sun area, and 5 in the Highlands-Meadow View area. The total nondomestic pumpages used in the 1980 pumpage simulations were about 830,000, 100,000, and 205,000 gal/d, respectively, in the three modeled areas. Most of the nondomestic pumpage in each area occurred in only one or two cells.

Domestic pumpage was assumed to come from the water-table aquifer and was estimated based on the number of houses in areas without public-water supply. The number of houses was obtained from the most recent U.S. Geological Survey 7½-minute topographic maps and from aerial photographs provided by the Cecil County Planning Office. The number of houses in each cell was multiplied by 3 (the estimated average number of residents per house) and then by 75 (the estimated average number of gallons of water used per day per capita) to obtain the total domestic ground-water pumpage for each cell. These total domestic pumpages were then multiplied by 10 percent to obtain the net pumpage assumed to be lost from the ground-water system in each cell.

Net domestic pumpage used in the models for 1980 is given in table 24. In the Elkton-Chesapeake City area, 40,000 gal/d was lost from the ground-water flow system. This represents 10 percent of the ground water pumped in the approximately 1,800 self-supplied houses that were in the area in 1980. Similarly, the 11,500 gal/d net pumpage in the Rising Sun area was based on about 500 houses and the 23,200 gal/d net pumpage in the Highlands-Meadow View area was based on about 1,000 houses. When total area is taken into account, these rates of ground-water loss due to domestic pumpage in the three areas are low, ranging from about 1.2 to 3.2 (gal/d)/acre.

The results of the 1980 pumpage simulations in the three modeled areas are shown in terms of ground-water budgets in table 22. The pumpage in 1980 ranged from about 0.3 to 0.4 in/yr, or from about 1.5 to 2.5 percent of ground-water recharge. In the Elkton-Chesapeake City and Rising Sun areas, all the pumpage was balanced by decreases in base flow; in the Highlands-Meadow View area, most of the pumpage was balanced by a reduction in ground-water evapotranspiration.

The results of the 1980 pumpage simulations are shown in terms of water-level drawdowns from prepumping levels on plate 4. The drawdowns shown are average drawdowns over the area of each cell and provide an estimate of the regional drawdowns that could be expected from the estimated 1980 pumpages. They do not reflect the drawdowns that would actually occur in the individual wells providing pumpage; the actual drawdowns in wells would be significantly greater. On plate 4, drawdowns of 1 ft or more occur only at nondomestic pumpage cells. In the confined aquifer (layer 2) in the Elkton-Chesapeake City area, drawdowns of more than 20 ft are caused by pumping at the Elkton well field, and drawdowns of less than 5 ft are caused by the lesser Chesapeake City pumpages. The water

TABLE 23

NONDOMESTIC PUMPAGE FOR 1980 AND PROJECTED PUMPING CONDITIONS IN THREE MODELED AREAS

Modeled area	Identification No. [1]	Owners	Model cell (layer)	Model cell (row)	Model cell (column)	Pumpage, in gallons per day: 1980 Average total	1980 Model [2]	Projected Average total	Projected Model [2] Unsewered	Projected Model [2] Sewered
Elkton-Chesapeake City	E 1	Sentaman Liquors, American Tennis, Hollywood Diner Ciampoli Motel	2	6	23	4,900	490	9,000	900	9,000
	E 2	Elkton	2	6	25	600,000	600,000	700,000	700,000	700,000
	E 3	Elkton	2	7	16	85,000	85,000	100,000	100,000	100,000
	E 4	Brantwood Country Club	2	18	21	2,000	2,000	4,500	4,500	4,500
	E 5	Baker Restaurant	2	19	20	2,000	200	3,000	300	3,000
	E 6	Brantwood Country Club	2	20	22	2,000	200	4,500	450	4,500
	E 7	Hall Trailer Park	2	23	22	1,600	160	2,500	250	2,500
	E 8	Chesapeake City	2	31	20	70,000	70,000	95,000	95,000	95,000
	E 9	Chesapeake City	2	32	19	70,000	70,000	95,000	95,000	95,000
	E 10	Chesapeake Estates	2	33	24	4,500	450	6,000	600	6,000
	E 11	Summit Airfield	1	34	45	800	80	800	800	800
	E 12	Bohemia Manor High School	2	37	15	1,700	1,700	1,700	1,700	1,700
	E 13	Harbor View, Inc.	2	38	3	550	55	100,000	100,000	100,000
	E 14	Artesian Watar Co.	2	5	27	0	0	576,000	576,000	576,000
	E 15	Artesian Water Co.	2	5	29	0	0	288,000	288,000	288,000
		Total				845,050	830,335	1,986,000	1,963,500	1,986,000
Rising Sun	R 1	Rising Sun	1	12	10	83,300	83,300	183,300	183,300	183,300
	R 2	Rising Sun	1	13	8	16,700	16,700	36,700	36,700	36,700
	R 3	Rising Sun Elementary School	1	18	7	1,400	140	1,400	140	1,400
		Total				101,400	100,140	221,400	220,140	221,400
Highlands-Meadow View	H 1	Highlands Water Supply	1	22	9	9,500	9,500	10,000	10,000	10,000
	H 2	Highlands Water Supply	1	22	10	9,500	9,500	10,000	10,000	10,000
	H 3	Highlands Water Supply	1	22	11	9,500	9,500	10,000	10,000	10,000
	H 4	Highlands Sewage Treatment Plant	1	24	10	[4] --	[3] -8,550	[3] -9,000	[3] -9,000	[3] -9,000
	H 5	Meadow View Utilities	1	34	9	185,000	185,000	684,000	684,000	684,000
		Total				213,500	204,950	705,000	705,000	705,000

[1] Locations shown in figure 30.

[2] Net pumpage used in the model. Assumes that 90 percent of total pumpage for unsewered users is returned to the ground-water system through septic systems.

[3] Amount returned to ground-water flow system (negative pumpage) at spray irrigation fields (30 percent of model pumpage in three Highlands Water Supply pumpage cells).

[4] --, data not available.

table (layer 1) is lowered by more than 5 ft in the vicinity of the Elkton well field as a result of increased downward leakage through the confining unit to balance the pumpage from the confined aquifer. In the Highlands-Meadow View area, drawdowns of about 5 ft are caused by pumpage from the Highlands well field, and drawdowns of less than 5 ft are caused by the much greater pumpage of the Meadow View well field. The hydraulic conductivity of the Coastal Plain sediments in the Meadow View area is much higher than the hydraulic conduc-

TABLE 24
NET DOMESTIC PUMPAGE USED IN MODELS FOR 1980 AND
PROJECTED PUMPAGE CONDITIONS

Modeled area	Net pumpage, in gallons per day					
	1980		Projected			
	Unsewered 1/		Unsewered 1/		Sewered	
	Total	Per acre	Total	Per acre	Total	Per acre
Elkton-Chesapeake City	40,000	1.2	558,300	16.2	5,582,500	162.3
Rising Sun	11,500	2.2	106,600	20.5	1,066,200	205.2
Highlands-Meadow View	23,200	3.2	116,400	15.8	1,163,600	158.4

1/ For unsewered simulations, assumes that 90 percent of total domestic pumpage is returned to the ground-water system through septic systems.

tivity of the Piedmont crystalline rocks in the Highlands area; hence, the disproportionately lower drawdowns in the Meadow View well field. In the Rising Sun area, the Rising Sun well-field pumpages cause drawdowns of less than 5 ft.

The simulations of 1980 pumpages were used to further refine the models through gross comparison of simulated drawdowns in pumpage cells to observed drawdowns in pumping wells. The hydraulic properties of the aquifers (and the confining unit in the Elkton-Chesapeake City area) were the only model inputs adjusted during this calibration step. For each modeled area, a cell containing a well with a high 1980 pumping rate was selected for analysis. In the Highlands-Meadow View area, two cells were selected—one in the Piedmont and one in the Coastal Plain. In the Elkton-Chesapeake City area, only a cell in the confined aquifer was selected because there were no high pumpages in the water-table aquifer in 1980. The average simulated drawdown in each of these cells was converted to the drawdown that would occur in a single well in the center of each cell if all that cell's pumpage was occurring in that well. This was accomplished by using the following equation (modified from Trescott, Pinder, and Larson, 1976, p. 10):

$$s = s_1 + \frac{2.3Q}{2\pi T} \log \frac{r_c}{4.81 r_w} ,$$

where

s = drawdown in a single well in the center of the cell, in feet;

s_1 = simulated drawdown in the cell, in feet;

Q = pumping rate in the cell, in cubic feet per day;

T = transmissivity of the cell, in feet squared per day;

r_c = cell dimension, in feet; and

r_w = radius of well in the center of the cell, in feet.

This calculation assumes that the well penetrates the full thickness of the aquifer, that well losses are negligible, and that saturated thickness is constant. The radii of the actual production wells in which the pumpage occurred were used for r_w.

The results of this analysis are shown in table 25. Drawdowns of 12 to 67 ft were obtained for the four cells. These drawdowns were then converted to specific capacities by dividing the cell pumping rate (in gallons per minute) by the calculated drawdown. Results at the four selected cells were compared to the observed drawdowns in the wells in those four cells and to the median specific capacities of all wells in each model area. The model hydraulic conductivities and transmissivities were considered reasonable if the calculated specific capacity was within or near the range of the observed specific capacities for the pumping wells in the selected cell (table 25). Specific capacity is a function of well construction and testing procedures as well as aquifer hydraulic properties. Specific capacities measured in inadequately constructed, developed, or tested wells can mask high hydraulic conductivity and transmissivity. Therefore, in addition to adjusting hydraulic conductivity and transmissivity until calculated specific capacity was within the range of those observed in wells in the cell, further adjustments were made so that calculated specific capacity was higher than the median specific capacity for each area. In this way, the resulting hydraulic conductivities and transmissivity should be more representative of actual aquifer properties, and less affected by possible inadequate well-construction and testing methods. Through this gross comparison, the initial values of hydraulic conductivity and transmissivity, which were evaluated under prepumping conditions, were adjusted and refined under 1980 pumpage conditions.

TABLE 25

CONVERSION OF CELL DRAWDOWNS TO WELL DRAWDOWNS FOR SELECTED PUMPAGE CELLS IN THREE MODELED AREAS, AND COMPARISON OF RESULTING SPECIFIC CAPACITIES TO OBSERVED SPECIFIC CAPACITIES

[gal/d = gallon per day; (gal/min)/ft = gallon per minute per foot; ft = feet.]

Area (province)	Location in model (layer, row, column)			Pumpage for 1980 (gal/d)	Average drawdown in cell (ft)	Calculated drawdown in well (ft)	Calculated specific capacity [(gal/min)/ft]	Observed specific capacities in wells in cell [(gal/min)/ft]	Median specific capacity in area [(gal/min)/ft]
Elkton-Chesapeake City (Coastal Plain)	2	6	25	600,225	22	67	6.2	1.0 12.3	1.5
Rising Sun (Piedmont)	1	12	10	83,300	4	65	.9	1.7 3.8	.3
Highlands - Meadow View (Coastal Plain)	1	34	9	185,000	3	12	10.7	1.1 4.3 4.4 5.1 12.0 12.5	4.3
Highlands - Meadow View (Piedmont)	1	22	10	8,700	6	20	.3	.1	.2

EFFECTS OF DEVELOPMENT

The adjusted models were used to simulate the effects of the following four combinations of hypothetical conditions:

(1) Average recharge and projected pumpage without sewers;

(2) Average recharge and projected pumpage with sewers;

(3) Drought recharge and projected pumpage without sewers; and

(4) Drought recharge and projected pumpage with sewers.

The two average recharge simulations were made under steady-state model conditions. In other words, aquifer storage was not considered and the resulting effects are those that would eventually occur if the projected pumpages were to continue long enough for the ground-water flow systems to reach new dynamic equilibrium conditions. To determine how long it would take the systems to reach new equilibriums, a test simulation was made for each modeled area using aquifer storage. The Coastal Plain parts of the modeled areas would approach equilibrium after about 15 years; in the Piedmont parts, it would take about 10 years. However, most of the effects of projected pumpages would occur shortly after pumpage began. In the Coastal Plain parts of the modeled areas, about 75 percent of the eventual effects would occur in the first 2 years; in the Piedmont parts, about 60 percent of the eventual effects would occur in the first 2 years.

It is fairly likely that a particular pumpage situation would continue for periods of several years or more, so steady-state simulations were thought to be appropriate for the two average recharge simulations. The two drought recharge simulations, on the other hand, were made under transient model conditions. Droughts are not likely to persist for the 10 to 15 years necessary for the ground-water flow systems to approach new equilibrium conditions. Consequently, these two simulations were based on a hypothetical 2-year drought and included aquifer storage terms. Drought recharge was assumed to be one-half of average recharge, making the hypothetical drought similar in duration and severity to the mid-1960's drought that affected much of the mid-Atlantic area. As the drought simulations begin, ground water comes out of storage in the aquifers (ground-water levels fall) to balance the decrease in recharge. As the simulations progress through time, increasingly less ground water comes out of storage (ground-water levels begin to stabilize) and more of the decrease in recharge is balanced by decreases in base flow and ground-water evapotranspiration. At the end of the 2-year simulated drought period, ground-water levels in the three modeled areas are still falling in response to the decreased recharge, but have experienced about 60 to 75 percent of their eventual declines. If average recharge were to resume at the end of the 2 years, ground water would begin to go back into storage (ground-water levels would begin to recover) and base flow and ground-water evapotranspiration would begin to increase.

Average Recharge Simulations

Projected pumpage without sewers

Projected pumpage rates for nondomestic ground-water users were assumed to equal the maximum average daily ground-water appropriation for the highest pumpage month. As with the nondomestic pumpage for 1980, only that fraction not returned to aquifers by on-site septic systems was used as pumpage in the models. The projected nondomestic ground-water users were the same as in 1980 for the three modeled areas (table 23; fig. 30), except for the addition of two wells owned by the Artesian Water Company in the Elkton-Chesapeake City area. Total projected nondomestic pumpages used in the models were 1,962,800, 220,140, and 705,000 gal/d in the Elkton-Chesapeake City, Rising Sun, and Highlands-Meadow View areas, respectively (table 23). These totals are about 2 to 3 times greater than the corresponding nondomestic pumpage totals for 1980.

Estimates of projected domestic pumpage for each cell were made in a manner similar to that for 1980. Parts of the modeled areas not likely to be developed (steep slopes, flood plains, and zoned open spaces) and planned public water-supply and sewer-service areas were assigned no domestic pumpage. The development density for the remaining area in each cell was determined from zoning maps on file at the Cecil County Planning Office and current zoning regulations (Stottler, Stagg, and Associates, Inc., 1974). The agricultural, low-density residential, commercial, and light industrial areas were projected to be developed with a density of one house per acre. Medium-density residential zones were projected to have two houses per acre and mobile-home zones were projected to have eight units per acre. As with the 1980 domestic pumpage, total projected domestic pumpage was calculated by multiplying the number of houses per cell by the average number of residents per house (three) and the average per capita water use (75 gal/d). In all currently unsewered areas, 90 percent of the total projected domestic pumpage was considered to be returned to the ground-water system, so only 10 percent of the total pumpage was used in the models. These same estimation methods were used for those parts of Pennsylvania and Delaware that are included in the three modeled areas. All domestic pumpage was assumed to come from the water-table aquifer.

Based on the above estimating methods, the projected net domestic pumpage used in the model for the Elkton-Chesapeake City, Rising Sun, and Highlands-Meadow View areas was 558,300, 106,600, and 116,400 gal/d, respectively (table 24). The corresponding projected number of houses in each area was about 24,800, 4,700, and 5,200, respectively. These estimates represent domestic pumpage increases of about 1,400, 900, and 500 percent in the Elkton-Chesapeake City, Rising Sun, and Highlands-Meadow View areas, respectively.

The results of the simulation of projected pumpage without sewers are shown in terms of ground-water budgets in table 26. The total projected pumpage in the three modeled areas ranges from 0.9 to 1.5 in/yr, or about 5 to 10 percent of ground-water recharge. About 60 to 90 percent of the pumpage comes from decreased base flow; the remainder comes from decreased ground-water evapotranspiration. Base flow in the three areas is decreased by about 5 to 9 percent from prepumping conditions.

The simulated ground-water-level declines caused by the projected pumpages are shown on plate 5. They represent drawdowns from prepumping water levels and are average drawdowns over the area of each cell. As with the drawdowns caused by 1980 pumpages (pl. 4), only those cells containing significant nondomestic pumpage experience any appreciable drawdown. Drawdowns of more than 30 ft occur in the Elkton well field and Artesian Water Company pumpage cells in the confined aquifer in the Elkton-Chesapeake City area. Drawdowns in major pumpage cells in the Rising Sun and Highlands-Meadow View area range from about 5 to 10 ft. Because most of the projected nondomestic pumping rates are higher than 1980 rates, the drawdowns are generally 5 to 10 ft greater than in the 1980 pumpage simulation (pl. 4). The greatest drawdowns per unit of pumping rate occur in the Piedmont parts of the three modeled areas where the assigned aquifer hydraulic conductivities are lowest. The least drawdown per unit of pumping rate occurs in the confined Coastal Plain aquifer in the Elkton-Chesapeake City area. Even at pumping rates significantly higher than the 1980 rates, domestic pumpage causes drawdowns of less than 1 ft throughout most of the areas. This is largely due to the fact that domestic pumpage is fairly uniformly distributed, rather than concentrated in well fields.

TABLE 26

GROUND-WATER BUDGETS FOR THREE MODELED AREAS UNDER PREPUMPING, PROJECTED PUMPAGE AND AVERAGE RECHARGE, AND PROJECTED PUMPAGE AND DROUGHT RECHARGE CONDITIONS

[Amounts of water in inches per year.]

	Prepumping	Projected pumpage and average recharge		Projected pumpage and drought recharge	
		Unsewered	Sewered	Unsewered	Sewered
Elkton-Chesapeake City					
Sources					
Recharge	20.0	20.0	20.0	10.0	10.0
Storage	0	0	0	2.5	3.1
Sinks					
Base flow	17.0	16.2	14.6	9.7	8.4
Ground-water evapotranspiration	3.0	2.8	2.4	1.8	1.7
Pumpage	0	1.0	3.0	1.0	3.0
Rising Sun					
Sources					
Recharge	15.0	15.0	15.0	7.5	7.5
Storage	0	0	0	1.2	1.8
Sinks					
Base flow	11.2	10.4	9.0	6.1	4.7
Ground-water evapotranspiration	3.8	3.7	2.7	1.7	1.3
Pumpage	0	.9	3.3	.9	3.3
Highlands-Meadow View					
Sources					
Recharge	15.4	15.4	15.4	7.7	7.7
Storage	0	0	0	1.4	1.9
Sinks					
Base flow	10.5	9.6	8.7	6.0	5.0
Ground-water evapotranspiration	4.9	4.3	3.3	1.6	1.2
Pumpage	0	1.5	3.4	1.5	3.4

Projected pumpage with sewers

When hypothetical sewerage systems are added to the projected pumpage simulation, total projected nondomestic pumpages in the modeled areas remain the same or are only slightly higher (table 23). This is because most nondomestic pumpage was already discharged through sewers in 1980.

Projected domestic pumpage used in the model is 10 times greater in the sewered situation because, instead of only 10 percent of the total pumpage being lost from the ground-water flow system, 100 percent is lost. As a result, the total projected domestic pumpages with sewers are about 5.6, 1.1, and 1.2 Mgal/d for the Elkton-Chesapeake City, Rising Sun, and Highlands-Meadow View areas, respectively (table 24). These total domestic pumping rates, when converted to pumpage per unit area, yield pumpages of about 150 to 200 (gal/d)/acre.

The ground-water budgets for the three modeled areas for this simulation are shown in table 26. Total pumpages in the three areas range from 3.0 to 3.4 in/yr, or about 15 to 22 percent of ground-water recharge. About 55 to 80 percent of the pumpage comes from decreased base flow and the remainder from decreased ground-water evapotranspiration. Base flows in the three areas are reduced about 14 to 20 percent from prepumping conditions.

The drawdowns from prepumping water levels that are caused by projected pumpage conditions with sewers are shown on plate 5. The tenfold increase in domestic pumpage causes drawdowns of at least 1 ft to occur over most of the three modeled areas. The drawdowns due to nondomestic pumpage are about 5 to 10 ft greater near the well fields than in the unsewered case (pl. 5), probably due to interference from surrounding domestic pumpage. Drawdowns in the Elkton well field and Artesian Water Company areas of the Elkton-Chesapeake City area range from about 30 ft to more than 40 ft. (These are average cell drawdowns; drawdown at pumped wells would be much greater.) Drawdowns in the other well fields in the three modeled areas are generally 10 ft to less than 20 ft.

Drought Recharge Simulations

Projected pumpage without sewers

For this transient simulation, a 2-year drought of one-half average recharge was superimposed on projected pumpage without sewers. The resulting ground-water budgets for the three areas at the end of the 2-year period are shown in table 26. The drought causes a reduction in base flow of about 40 percent in each area; that is, a 50-percent decrease in recharge for 2 years results in a 40-percent decrease in base flow. The remaining 10 percent of the recharge decrease is balanced by a decrease in ground-water evapotranspiration and by a release of ground water from storage in the aquifers. The significance of the aquifer-storage term is that a new dynamic equilibrium has not yet been reached at the end of 2 years and ground-water levels are still falling. These storage changes would approach zero after about 10 to 15 years, at which time decreases in base flow and ground-water evapotranspiration would balance the decreases in recharge.

The drawdowns from prepumping water levels that are caused by the combination of projected pumpage without sewers and the 2-year drought are shown on plate 6. At least one-half of each area has more than 5 ft of drawdown. Drawdowns of more than 20 ft occur at several major pumpage cells, with a maximum of more than 40 ft in the confined aquifer in the northern part of the Elkton-Chesapeake City area. An examination of the differences in drawdowns between plate 6 and plate 5, for those areas containing no major nondomestic pumpages, indicates that the drought causes a uniformly distributed decrease in ground-water levels of about 5 ft in the Elkton-Chesapeake City area and about 5 to 10 ft in the Rising Sun and Highlands-Meadow View areas. Additional drought-caused drawdowns of up to 5 ft occur near major-pumpage cells in the Rising Sun and Highlands-Meadow View areas due to interference of the drought and pumpage stresses. In the relatively shallow water-table aquifer in these two areas, large drawdowns cause significant reductions in saturated aquifer thickness, lowering the aquifer transmissivities and thereby causing increasingly greater drawdowns per unit of pumpage. The influence of surface-water bodies is very apparent in the drawdown contours for all three areas, with drawdowns of less than 5 ft occurring in the vicinity of the Elk Creek shoreline, the C and D Canal, and most streams. In the absence of major pumpages, drawdowns increase with increasing distance from surface-water bodies to maximums under hilltops and near ground-water divides.

Large drawdowns in areas near brackish surface-water bodies can create the potential for intrusion of brackish water into aquifers. If aquifer water levels fall below sea level in the Elkton-Chesapeake City area, brackish water from Elk Creek and the C and D Canal could begin to intrude into the water-table aquifer. The model used in this study does not permit accurate delineation of where this may occur. However, assuming that simulated water levels could be off by as much as 5 ft in the vicinity of Elk Creek and the C and D Canal, areas where simulated water levels in the water-table aquifer are less than 5 ft above sea level are shown on plate 6 as a zone of potential brackish-water intrusion. The zone includes the shore of Elk Creek (especially near the mouth of Back Creek), the banks of the C and D Canal (especially near Chesapeake City), and areas near the mouths of Perch and Herring Creeks.

Projected pumpage with sewers

The 2-year drought also was superimposed on projected pumpage conditions with sewers. The resulting ground-water budgets (table 26) for the three areas show that the drought would cause base-flow reductions of about 45 percent at the end of 2 years, or about 5 percent more than in the simulation of projected pumpage without sewers. Also, the rate at which ground water is leaving aquifer storage at the end of 2 years would be higher and ground-water levels after 2 years would be falling at a faster rate. Base flows at the end of the 2-year drought in the three areas would be decreased by about 50 to 60 percent from prepumping base flows, and ground-water evapotranspiration would be decreased by about 45 to 75 percent (table 26). These reductions in ground-water evapotranspiration may be too large due to the assumption of a linear relationship between evapotranspiration rate and depth. If the actual evapotranspiration reductions are less than the models estimate, the base-flow reductions would be proportionally greater.

The drawdowns from prepumping water levels that would be caused by the combination of projected pumpage with sewers and the 2-year drought are shown on plate 6. Comparing plate 6 with plate 5 indicates that the drought causes drawdowns of about 5 ft in those parts of the Elkton-Chesapeake City area not affected by major nondomestic pumpage. In the Rising Sun and Highlands-Meadow View areas, drawdowns of up to about 15 ft would be caused by the drought in areas away from major pumpage cells. Additional drought-caused drawdowns of about 5 to 10 ft would occur near the major nondomestic pumpage cells in the Rising Sun and Highlands-Meadow View areas. The drawdowns from prepumping conditions that would be caused by this combination of projected pumpage with sewers and drought conditions would be as much as about 50 ft in major pumpage cells in the confined aquifer in the northern part of the Elkton-Chesapeake City area, and about 30 ft in the water-table aquifer in the same area. Water levels in the Rising Sun and Highlands-Meadow View areas would be about 20 ft lower than prepumping levels near major pumpage cells and on hilltops. Surface-water influence would be again very evident in the drawdown contours. The zone of potential brackish-water intrusion would be about the same as in the unsewered case (pl. 6) except for the addition of 12 more cells along Elk Creek and the C and D Canal.

RELIABILITY OF MODEL RESULTS

Because the models were not rigorously calibrated, the simulated drawdowns shown on plates 4 to 6 are only rough estimates. If the model inputs for a cell were estimated poorly, the drawdowns simulated for that cell would not be accurate. Consequently, the reader needs to view the results as rough, general approximations.

An evaluation of the reliability of the model results is necessary to provide the appropriate perspective from which to evaluate the simulated drawdowns. For the three modeled areas in this study, sensitivity analysis was used to estimate model reliability. The approach was to globally change selected major model inputs, one at a time, and rerun the simulations, keeping all other inputs set at the values shown in table 21. By analyzing the drawdown differences between each of these sensitivity simulations and a base simulation, the relative sensitivity of the models to changes in selected model inputs was determined.

The simulations of projected pumpage without sewers and 2-year drought conditions were used as the base simulations for all three modeled areas. The model inputs for which sensitivity was analyzed were aquifer hydraulic conductivity, aquifer transmissivity, aquifer specific yield, aquifer storage coefficient, confining unit leakance, vertical hydraulic conductivity of streambeds, and maximum ground-water evapotranspiration rate. Each input was changed by a factor of two in the sensitivity simulations.

The greatest changes in water levels caused by changing inputs would occur in and adjacent to cells containing pumpage. The approximate range of the water-level changes in the vicinity of pumpage cells in each of the three modeled areas is given in table 27. As an example of how to use this table, consider the effects of halving hydraulic conductivity in the water-table aquifer (layer 1) in the Elkton-Chesapeake City area. The water-level changes resulting from this change in hydraulic conductivity would range from approximately -5 to -10 ft. In other words, if the hydraulic conductivity in the Elkton-Chesapeake City area were in reality only one-half that used in the model, the resulting drawdowns would be no more than about 5 to 10 ft greater than those shown on plates 4 to 6 for the Elkton-Chesapeake City area. Conversely, and as a general rule, if the hydraulic conductivity were in reality twice that used to calibrate the model, the resulting drawdowns would be no more than about 5 to 10 ft less than those shown on plates 4 to 6. The drawdowns in the nonpumpage cells in the area would be different by much less than 5 to 10 ft.

As seen in table 27, the greatest change in simulated water levels for all three modeled areas would be caused by changing aquifer hydraulic conductivity or transmissivity. The maximum water-level change would be about 10 ft for the Elkton-Chesapeake City and Highlands-Meadow View areas, and about 15 ft for the Rising Sun area. Although the sensitivity tests imply that the input values used are within 50 percent of the real values, the actual accuracy of these values are not known. Further, the interaction of changing several input factors that might have additive effects were not tested.

Inappropriate model boundary conditions also can lead to inaccurate simulated results. The lateral boundary conditions used to calibrate each of the three models were no-flow

TABLE 27

SENSITIVITY OF SIMULATED DRAWDOWNS TO CHANGES IN SELECTED MODEL INPUTS

[Negative change indicates increase in drawdown; —, not applicable.]

Change in model input	Approximate range of water-level change in the vicinity of pumpage cells, in feet			
	Elkton - Chesapeake City		Rising Sun	Highlands-Meadow View
	Layer 1	Layer 2		
0.5 x hydraulic conductivity	-5 to -10	---	-10 to -15	-5 to -10
0.5 x transmissivity	---	-5 to -10	---	---
0.5 x specific yield	-3 to -7	---	-2 to -5	-3 to -7
0.5 x storage coefficient	---	-3 to -7	---	---
0.5 x confining bed leakance	2 to 3	-3 to -7	---	---
0.5 x vertical hydraulic conductivity of streambeds	1 to 2	---	1 to 2	1 to 2
2 x maximum evapotranspiration rate	-1 to -2	---	-1 to -2	-1 to -2

boundary conditions. Their location was based on estimated ground-water divides. No ground water was permitted to enter or leave the modeled areas across these boundaries. Under prepumping conditions, this assumption was probably fairly realistic. However, as the aquifers in the modeled areas were progressively stressed during the projected pumpage and drought simulations, the assumption of no ground-water flow across these boundaries became less reasonable. If the only stresses on the aquifers had been domestic pumpage and drought conditions, the no-flow boundaries probably still would have been realistic. This is because similar domestic pumpage and drought conditions probably would have been occurring outside the boundaries as well as inside. Therefore, the ground-water divides would have remained near their prepumping locations and no-flow boundaries would have been appropriate. However, where major nondomestic pumpage is located just inside the boundaries, the assumption of stable ground-water divides is not realistic. Use of the no-flow boundary condition in these areas probably caused exaggerated drawdowns. Examples of such areas in the three modeled areas are the Elkton well field and the Artesian Water Company wells in the Elkton-Chesapeake City area, and the Highlands Water Supply and Meadow View Utilities wells in the Highlands-Meadow View area. There is no major nondomestic pumpage near the boundaries of the Rising Sun area.

The sensitivity of the models to the type of lateral boundary conditions was determined by replacing the no-flow boundaries for the three modeled areas with constant-head boundaries. Constant-head boundaries assume that the ground-water levels at the boundary will not change, even when the aquifers are stressed. In effect, a constant-head boundary acts as an inexhaustible supply of ground water. Clearly, this assumption is just as unrealistic as the no-flow assumption for those areas where major pumpage is located near the boundaries. Use of constant-head boundaries in these areas will cause lesser drawdowns than would actually occur, rather than the exaggerated drawdowns caused by the no-flow boundaries. Therefore, the actual drawdowns that would be expected to occur lie between the drawdowns on plates 4 to 6 (based on no-flow boundaries) and the drawdowns resulting from the use of constant-head boundaries. When constant-head boundaries were used, the simulated drawdowns were a maximum of about 20 ft less than those shown on plates 4 to 6 for the Elkton well field and the Artesian Water Company pumpage cells, and a maximum of about 10 ft less for the Highlands Water Supply and Meadow View Utilities pumpage cells.

To summarize the results of the sensitivity analysis, changing input values by a factor of two would change most drawdowns on plates 4 to 6 by less than about 5 ft. The greater drawdowns in the figures would change by about 10 ft in the Elkton-Chesapeake City and Highlands-Meadow View areas, and about 15 ft in the Rising Sun area. In addition, due to unrealistic boundary conditions, the drawdowns on plates 4 to 6 for the Elkton well field and the Artesian Water Company pumpage cells may be a maximum of about 20 ft greater than they should be; the drawdowns for the Highlands Water Supply and Meadow View Utilities pumpage cells may be a maximum of about 10 ft greater than they should be.

SUMMARY AND CONCLUSIONS

Because of geologic differences, Cecil County has two distinct types of terrane—the Piedmont and the Coastal Plain. In the Piedmont of the northern one-third of the county, crystalline igneous and metamorphic rock occurs at the surface. In the southern two-thirds of the county, the surface of the crystalline rock slopes southeastward beneath a progressively thicker cover of unconsolidated sand, gravel, silt, and clay.

Ground-water conditions differ considerably between the Piedmont and the Coastal Plain of Cecil County. In the Piedmont, water occurs in openings in the crystalline rock caused by fracturing and weathering of the rock. In the Coastal Plain, water occurs between grains in the sediments.

The crystalline rock in the Piedmont is highly indurated and contains free water only in openings where the rock has been fractured or decomposed by weathering. Permeability of fractured rock depends on the number of fractures, the size of the fracture openings, and the interconnection of the fractures. Weathering increases the size of fracture openings, but is most significant in Cecil County because it has produced a mantle of unconsolidated, weathered rock at the land surface.

The major significance of the weathered mantle is as a storage reservoir that provides water to the fracture systems that supply water to wells. Recharge moves readily into this unconsolidated zone and discharge moves out to streams and to evapotranspiration. A large volume of water remains in storage in this unconsolidated zone.

Because topographic lows often form where the rock has been weakened by relatively intense fracturing and weathering, wells in such positions are likely to penetrate more and larger openings and be more productive. Also, because the water table tends to be at a shallower depth in a topographic low, more unconsolidated weathered material is saturated so that more storage is available to sustain the yield. Median well yields for various topographic positions are: flood plain and valley flat, 20 gal/min; upland draw, 14 gal/min; hilltop, 9 gal/min; and hillside, 8 gal/min.

The median yield of wells in all crystalline rock units in the Piedmont is 10 gal/min, except for the upper and lower members of the James Run Formation which have a median yield of only 6 gal/min. Where sufficient area is available for exploration and with proper exploration techniques, yields somewhat greater than the median for all wells can probably be obtained in most of the area. The median reported yield of 61 public-supply wells tapping the crystalline rock of Cecil County is 15 gal/min.

Specific capacities of 95 percent of 394 wells in crystalline rock are greater than 0.02 (gal/min)/ft and only 5 percent are greater than 4.7 (gal/min)/ft; the median is 0.3 (gal/min)/ft.

The Coastal Plain sediments of Cecil County consist of unconsolidated, stratified layers of clay, silt, sand, and gravel that rest on a sloping basement of crystalline rock. The basement slopes southward at a rate of about 100 ft/mi. The maximum thickness of Coastal Plain sediments is in the extreme southeastern corner of the county and is estimated to be about 1,600 ft.

The major aquifers in Cecil County are the upper and lower Potomac aquifers. The thick sequence of sediments comprising the Potomac Group in Cecil County was divided into three hydrogeologic units: (1) the upper Potomac aquifer; (2) the middle Potomac confining unit; and (3) the lower Potomac aquifer. Yields of wells in the Potomac aquifers range from 0.5 to 703 gal/min, and the median is 30 gal/min. Specific capacities range from less than 0.1 to 40 (gal/min)/ft, and the median is 1.1 (gal/min)/ft.

The Magothy aquifer is the second most productive water-bearing unit in the county. Reported yields of 50 wells range from 7 to 270 gal/min; the median is 30 gal/min. Reported specific capacities for 46 wells range from 0.3 to 5.6 (gal/min)/ft, with a median value of 0.9 (gal/min)/ft.

The Monmouth is a major aquifer east of Elk River and south of the C and D Canal. Reported yields of 25 wells tapping the Monmouth aquifer range from 8 to 42 gal/min; the median is 20 gal/min. Specific capacities range from 0.2 to 3.8 (gal/min)/ft, and the median is 0.5 (gal/min)/ft.

Seasonal fluctuations in ground-water levels are influenced mostly by evapotranspiration and precipitation or by seasonal variations in pumping. Longer-term fluctuations caused by climatic variations show generally lower levels in the 1960's, a relatively dry period, and generally higher levels in the early 1970's, a relatively wet period.

Decline in the water table in the Piedmont caused by pumping tends to be local and does not show up in a well that is distant from a pumping center. Water-table declines tend to intercept streamflow, which helps to localize the effects. By contrast, pumping from the Potomac aquifers, which are confined in most of the area, causes widespread reduction in water level.

Pumping of the Potomac aquifers has caused water levels to gradually decline; the hydrograph of well CE Cf 49 shows a decline of about 10 ft since 1967. A more pronounced decline since 1983 has occurred near Elkton, Md., where about 20 ft of decline took place in less than 3 years. Water levels near Elkton show effects of the heavy pumping from the Elkton well field and from another well field a few miles east in Delaware.

Generally, ground water in Cecil County is suitable for most uses except where it is contaminated. Dissolved-solids concentrations are generally low; only three ground-water samples had concentrations above 500 mg/L. Common chemical-quality problems are excessive iron concentrations and low pH. Iron concentrations range from less than 3 to 24,000 μg/L. The median for crystalline rock is 12 μg/L; for the Potomac aquifers, 120 μg/L; and for other Coastal Plain aquifers, 87 μg/L. The pH ranges from 4.2 to 8.1. The median for crystalline rock aquifers is 6.0; for the Potomac aquifers, 5.6; and for other Coastal Plain aquifers, 5.8.

Surface water supplied about 41 percent of all the water used in the county in 1985; municipal water supply accounts for the highest usage. Streamflow data were collected at 10 continuous-record and 27 partial-record stations. Records are available for eight continuous-record stations within the county and two located in adjoining counties. Five of these have more than 20 years of record. Twenty-seven partial-record stations, two of which are in adjoining counties, provide broad geographic coverage for the estimation of low-flow frequency characteristics.

Flow duration for five unregulated streams in Cecil County ranges from 3.1 to 4.8 $(ft^3/s)/mi^2$ at the 5-percent exceedance level, and from 0.31 to 0.39 $(ft^3/s)/mi^2$ at the 95-percent exceedance level. The 7-day, 10-year, low-flow frequency for 31 continuous- or partial-record sites ranges from 0.01 to 0.44 $(ft^3/s)/mi^2$. The 7-day, 2-year, low-flow frequency for the same sites ranges from 0.02 to 0.68 $(ft^3/s)/mi^2$.

Stream-water-column samples were collected at 29 sites during base-flow periods in either August or November 1982. Dissolved-solids concentration of these base-flow samples range from a minimum of 39 mg/L to a maximum of 256 mg/L; the median is 92 mg/L. The pH ranges from a minimum of 5.8 to a maximum of 9.1; the median is 7.3.

Samples of streambed sediments were collected in August 1982 at 20 stream-sampling sites. The samples were analyzed in the laboratory to determine the presence of nine trace elements commonly associated with streambed sediments. The samples from 10 of these sites were also analyzed for 27 different synthetic organic compounds—PCB, PCN, and 25 pesticides.

Neither mercury nor arsenic was present in detectable quantities at any of the sampling sites, and cadmium was detected only at one site. This same site also had the highest concentration of four other trace elements (copper, zinc, iron, and lead). Iron and manganese were detected at all sites, reflecting their ubiquitous occurrence in the natural hydrogeologic system of Cecil County. Moderately high concentrations of chromium at two sites (20 and 30 μg/L) may be attributable to the occurrence of chromite ores in the northwestern corner of Cecil County.

Synthetic organic compounds were detected at 6 of the 10 sites which were analyzed for these compounds. The most frequently detected compounds were the organochlorine insecticides; none of the more soluble pesticides were detected. DDT or its metabolites DDD and DDE were detected in streambed sediments at five of the sampling sites.

Although the scope of the sampling effort was very limited, results are consistent with the expected relation of land use above a site to the normal use of the detected compound. Those compounds that may be associated with urban or industrial areas (PCB, chlordane) were detected only in streams receiving drainage from such areas. DDT, which was formerly used in a variety of land-use areas, and its metabolites were detected in the bed sediments of several streams that collectively drain a variety of land-use areas. Chlordane, which is used extensively for termite control in residential dwellings, was detected in the bed sediments of two streams that drain relatively high-density residential areas. PCB, which is a class of chlorinated hydrocarbons used primarily in a variety of industrial applications, was found in bed sediment of a stream that drains an area that includes industrial land use.

The limited sampling effort of this study gives only a preliminary indication of the occurrence of synthetic organic compounds in the streambed sediments of Cecil County. The results, however, show that such compounds do occur at some sites in the county. The fact that they were detected by this limited sampling implies that they are likely to be present elsewhere as well.

Water-budget estimates for the 20-year period 1961-80, which included both wet and dry years, show about 10 in/yr of ground-water runoff, 10 in/yr of storm runoff, and 22 in/yr of evapotranspiration. Ground-water runoff and storm-runoff components of measured streamflow were estimated visually from streamflow hydrographs for three basins that primarily drain the Piedmont where stream-drainage divides approximate the ground-water divides. The evapotranspiration estimate is the quantity required to balance inflow and outflow and assumes that other variables are negligible. The total water available in Cecil County on a renewable basis is approximately equal to the runoff, which is estimated to be about 20 in/yr or about 1 (Mgal/d)/mi^2. Ground-water pumpage that is not returned to the system is ultimately derived from storage (with declining water levels) or runoff (with reduced streamflow).

Digital ground-water flow models were constructed for three acres of Cecil County—the Elkton-Chesapeake City, Rising Sun, and Highlands-Meadow View areas. Two model layers were used in the Elkton-Chesapeake City area to simulate a water-table aquifer separated from an underlying confined aquifer by a confining unit. One layer was used in the Rising Sun and Highlands-Meadow View areas to simulate a water-table aquifer overlying relatively impermeable bedrock. Lateral model boundaries were located at estimated ground-water divides and were simulated as no-flow boundaries. Natural ground-water recharge was derived solely from infiltration of precipitation, and natural ground-water discharge was by ground-water base flow to surface-water bodies and ground-water evapotranspiration.

The models were initially adjusted by comparing the gross flow-system characteristics of prepumping steady-state simulations to observed characteristics. The model adjustments were refined by superimposing estimated 1980 pumpages on the prepumping steady-state simulations and comparing simulated specific capacities to observed specific capacities for selected pumpage cells. Simulated specific capacities were calculated by converting simulated average cell drawdowns to drawdowns in hypothetical single wells in the center of the selected pumpage cells.

Projected pumpage without sewers was superimposed on prepumping conditions for each modeled area. Ground-water base flows in the three areas were reduced by 5 to 9 percent from prepumping base flows. Maximum drawdowns of more than 30 ft occurred in pumpage cells in the confined aquifer in the Elkton-Chesapeake City area, whereas maximum drawdowns of 5 to 10 ft occurred in pumpage cells in the other two areas.

Projected pumpage with sewers was superimposed on prepumping conditions for each modeled area. Ground-water base flows were reduced by 14 to 20 percent. Maximum drawdowns of more than 30 ft to more than 40 ft occurred in pumpage cells in the confined aquifer in the Elkton-Chesapeake City area; maximum drawdowns of about 10 to 20 ft occurred in pumpage cells in the other two areas.

Simulation of a 2-year drought of one-half average recharge was superimposed on projected pumpage without sewers. Ground-water base flows were reduced by about 40 percent by the drought. The drought causes uniformly distributed drawdowns of about 5 ft in the Elkton-Chesapeake City area, and about 5 to 10 ft in the other two areas. Additional drought-caused drawdowns of about 5 ft occurred near major pumpage cells in the Rising Sun and Highlands-Meadow View areas. Simulated ground-water levels in the water-table aquifer in the Elkton-Chesapeake City area were less than 5 ft above sea level along the Elk Creek shoreline and the C and D Canal, indicating the potential for brackish-water intrusion into the water-table aquifer.

Simulation of a 2-year drought was also superimposed on projected pumpage with sewers. Ground-water base flows were reduced by about 45 percent by the drought, contributing to an overall 50 to 60 percent baseflow reduction from prepumping conditions in the three areas. Ground-water evapotranspiration was reduced by about 45 to 75 percent. The drought caused uniformly distributed drawdowns of about 5 ft in the Elkton-Chesapeake City area, and up to about 15 ft in the other two areas. Additional drought-caused drawdowns of about 5 to 10 ft occurred near major pumpage cells in the Rising Sun and Highlands-Meadow View areas. Total simulated drawdowns from prepumping conditions were more than 40 ft in pumpage cells in the Elkton-Chesapeake City area, and more than 20 ft in the other two areas. The zone of potential brackish-water intrusion in the Elkton-Chesapeake City area was slightly larger than in the unsewered case.

The relative sensitivity of the models to changes in model inputs was evaluated by increasing and decreasing input values, one at a time, by a factor of two. Results indicate a maximum simulated drawdown change for the three modeled areas of about 15 ft, while most drawdowns changed by less than about 5 ft. Analyses of sensitivity to boundary conditions indicate that simulated drawdowns in major pumpage cells near model boundaries may be 5 to 10 ft greater than they should be, due to unrealistic boundary conditions.

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APPENDIX

TABLE 28

RECORDS OF TEST WELLS DRILLED DURING THE PROJECT

[Geophysical logs: SP = spontaneous potential; E = single-point electric; M = multipoint electric; G = gamma; —, not applicable.]

Well no.	Location	Date completed	Altitude of land surface (feet)	Depth (feet below land surface) Hole	Well	Screened interval
CE Be 73 *	Y.M.C.A.	11/30/82	162	181	152	147-152
CE Be 74 *	Y.M.C.A.	11/30/82	162	181	115	110-115
CE Bf 81	Thompson Estates Elementary School	1/25/83	90	95	55	50- 55
CE Bf 82	Holly Hall Elementary School	2/03/83	70	285	125	120-125
CE Cd 51 *	Charlestown	11/29/82	70	159	125	120-125
CE Cd 52 *	Charlestown	11/29/82	70	156	48	43- 48
CE Cd 53	Black Hill, Elk Neck State Forest	12/08/82	135	495	350	345-350
CE Ce 54	Irish Town, Elk Neck State Forest	12/01/82	180	285	250	245-250
CE Ce 55	Elk Forest Road	1/10/83	55	624	375	370-375
CE Ce 56	Court House Point Road	2/02/83	38	420	121	116-121
CE Dd 81	Pond Neck Road	2/10/83	24	503	115	110-115

* Well cluster

TABLE 28—*Continued*

Diameter (inches) Casing	Screen	Static water level Depth (feet below land surface)	Date measured	Core sample depths (feet below land surface)	Geophysical logs	Well no.
2	2	84.20	11/30/82	43 60 110	SP, M, G	CE Be 73
2	2	84.35	11/30/82	-		CE Be 74
4	2	38.68	3/03/83	50 95	SP, E, M, G	CE Bf 81
4	2	56.37	2/03/83	60 100 160 200 285	SP, E, M, G,	CE Bf 82
2	2	51.76	11/29/82	15 45 89 120	SP, E, M, G	CE Cd 51
2	2	28.89	11/29/82	-		CE Cd 52
4	2	127.84	3/04/83	97 199 377 492	SP, E, M, G	CE Cd 53
4	2	136.79	3/04/83	60 171 266	SP, E, M, G	CE Ce 54
4	2	51.12	3/25/83	100 200 320 420 520 602 624	SP, E, M, G	CE Ce 55
4	2	29.63	4/27/83	50 100 120 200 220 400 420	SP, E, M, G	CE Ce 56
4	2	15.52	3/25/83	20 60 100 140 200 260 300 400 500	SP, E, M, G	CE Dd 81

TABLE 29

LITHOLOGIC LOGS OF TEST WELLS BASED ON CUTTING DESCRIPTIONS

[Cutting descriptions by J.M. Wilson, Maryland Geological Survey, October 1985.]

Cutting description	Thickness (feet)	Depth to base (feet)
CE Be 73		
Silt, very clayey, micaceous, grayish orange (10 YR 7/4)	5	5
Silt, some fine sand, very clayey, micaceous, dark yellowish orange (5 YR 6/4); with chips of very pale orange (10 YR 8/2), very fine, clayey silt	20	25
Sand, very fine and silty, clayey matrix, micaceous, white (N 9) and grayish orange pink (5 YR 7/2)	20	45
Silt, clayey with very fine sand, micaceous, pinkish gray (5 YR 8/2)	20	65
Silt, same as above	30	95
Sand, fine, silty, some medium, micaceous, grayish orange (10 YR 7/4)	25	120
Sand, as above; mixed with white (N 9), talc-like silt and small angular quartz pebbles	20	140
Sand and small pebbles, as above.	10	150
Pebbles, small (1/8 to 1/4 inch), subrounded to subangular, quartz pebbles, and hard, limonite cemented, clayey silt	5	155
Sand, fine to medium, silty, small pebbles common, micaceous, grayish orange (10 YR 7/4)	15	170
Pebbles, small, angular to subangular quartz pebbles; frosty and very pale orange (10 YR 8/2); with pale olive (10 Y 6/2), mica bearing, clayey silt. A few light olive gray (5 Y 6/1) chips of silt with shiny luster of micaceous minerals (muscovite, chlorite?), possibly saprolite.	5	175

TABLE 29—*Continued*

Cutting description	Thickness (feet)	Depth to base (feet)
CE Bf 81		
Sand, medium to coarse, some fines, mica bearing, very dark yellowish orange (10 YR 4/6)	5	5
Sand, medium, fine to coarse, a few small (1/8 inch) pebbles, mica bearing, feldspar bearing (weathered, chalky), grayish orange (10 YR 7/4); with a few chips of grayish black (N 2), clayey silt	15	20
Sand, medium, range fine to coarse, with a few small (1/4 inch) pebbles, mica bearing, feldspar bearing (weathered, chalky), grayish orange (10 YR 7/4)	15	35
Sand, as above; with small pebbles more common than above; chips of pale olive (10 Y 6/2) and yellowish gray (5 Y 7/2), micaceous, clayey silt	15	50
Sand, fine, silty, micaceous, feldspar bearing, dark yellowish orange (10 YR 6/6); with abundant granules and small quartz pebbles (dark yellowish orange, 10 YR 6/6); a few dark gray (N 3) "clastic", metamorphic rock fragments present	10	60
Sand, fine to medium, some coarse to very coarse, mica bearing, feldspar bearing, grayish orange (10 YR 7/4)	5	65
Silt, clayey, micaceous, medium light gray (N 6); mixed with sand, fine, silty, micaceous, yellowish gray (5 Y 7/2)	5	70
Silt, fine sand, micaceous, light gray (N 6); mixed with sand, fine to coarse, mostly medium, micaceous, feldspar bearing, pinkish gray (5 YR 8/2), and yellowish gray (5 Y 7/2)	12	82
Saprolite, silt, clayey, micaceous, pale olive (10 Y 6/2) with schist, chips of biotite, muscovite, and probably chlorite schist, greenish gray (5 G 6/1) with shiny luster	13	95

TABLE 29—*Continued*

Cutting description	Thickness (feet)	Depth to base (feet)
CE Bf 82		
Silt, clayey, micaceous, grayish orange (10 YR 3/4)	5	5
Sand, medium to coarse, some fines, mica bearing, dark yellowish orange (10 YR 6/6)	10	15
Silt, very clayey, micaceous, grayish orange (10 YR 7/4); mixed with small pebbles	5	20
Sand, fine and silty, light clayey matrix, micaceous, light olive gray (5 Y 6/1)	30	50
Sand, as above, mixed with pale reddish brown (10 R 5/4), clayey silt	5	55
Sand, fine, silty, clayey, micaceous, pale reddish brown (10 R 5/4)	15	70
Silt, fine, clayey, micaceous, pale red (10 YR 6/2) and light gray (N 7)	5	75
Sand, fine, silty, clayey matrix, micaceous, light brownish gray (5 YR 6/1); mixed with medium light gray (N 6), silty, micaceous clay	15	90
Silt, fine, very clayey, micaceous, medium light gray (N 6)	20	110
Sand, fine, silty, clayey, micaceous, light brownish gray (5 YR 6/1), with some very light gray (N 8), clayey silt	20	130
Sand, fine to medium, silty, some coarse, slightly clayey, mica bearing, pale to moderate yellowish brown (10 YR 6/2 to 10 YR 5/4); with chips of medium light gray clayey silt	20	150
Sand, fine, some silt, slightly clayey, micaceous, pale red (10 R 6/2), with chips of very pale orange (10 YR 8/2), fine, talc-like, clayey silt	20	170
Sand, fine, range silt to medium, slightly clayey, micaceous, light brown (5 YR 6/4)	20	190

TABLE 29—*Continued*

Cutting description	Thickness (feet)	Depth to base (feet)
CE Bf 82--Continued		
Sand, fine, silty, clayey, micaceous, light brown (5 YR 6/4); some chips of very pale orange (10 YR 8/2), clayey, talc-like silt	20	210
Sand, fine and silty, some medium, slightly clayey, micaceous, light brown (5 YR 6/1); some small chips of very pale orange (10 YR 8/2), clayey, talc-like silt	20	230
Sand, same as above	20	250
Sand, fine to medium, silty and clayey, micaceous, light brown (5 YR 6/4)	15	265
Sand, fine to coarse, very silty, slightly clayey, mica bearing, light brown (5 YR 6/1), coarse, books of muscovite, and white (N 9), chalky, talc-like, very fine, clayey silt	15	280
CE Cd 51		
Silt, fine sand, clayey, mica bearing, pale orange (10 YR 7/2)	5	5
Clay, silty, mica bearing, moderate reddish orange (10 R 6/6) and moderate red (5 R 4/6); with silt, clayey, mica bearing, grayish orange (10 YR 7/4)	5	10
Gravel, small pebbles and granules, with some pale red (10 R 6/2), clayey silt	5	15
Sand, fine, silty, ranges to coarse, some small pebbles, mica bearing, pale red (10 R 6/2)	15	30
Silt, very fine, clayey, mica bearing, pinkish gray (5 YR 8/1); with moderate red (5 R 4/6), silty clay	10	40
Sand, fine, silty and clayey, mica bearing, pale red (10 R 6/2); some small gravel present in sample (possibly from higher in hole)	10	50

TABLE 29—*Continued*

Cutting description	Thickness (feet)	Depth to base (feet)
CE Cd 51--Continued		
Sand, fine, silty, clayey, micaceous, pale red (10 R 6/2); mixed with moderate orange pink (5 YR 8/4), clayey silt and some small gravel (possibly from higher in hole)	15	65
Silt, very clayey, mica bearing, moderate reddish brown (10 R 4/6) and grayish orange pink (10 R 8/2)	5	70
Sand, fine, silty, micaceous, moderate reddish orange (10 R 6/6)	5	75
Silt, very clayey, some fine sand, micaceous, moderate red (5 R 5/4)	10	85
Silt, very clayey, micaceous, pale red purple (5 RP 6/2), and light red (5 R 6/6)	5	90
Silt, very clayey, micaceous, pale red (10 R 6/2), grayish pink (5 R 8/2) and moderate red (5 R 5/4)	15	105
**** Sample labeled 90 to 110 described below ****		
Sand, fine to very coarse, silty, mica bearing, coarse flakes of muscovite, light red (5 R 6/6) and grayish pink (5 R 8/2) (See logs to determine probable lithology for 90 to 110 ft interval)	(5? to 20?)	110
Sand, fine to medium, silty, micaceous, light red (5 R 6/6); with very clayey, micaceous, white (N 9) silt	10	120
Sand, fine to coarse, silty, mica bearing, moderate red (5 R 4/6); some white (N 9), clayey, micaceous, very fine silt	2	122
No samples for this interval (See geophysical log)	8	130
Gravel, small pebbles, and granules, moderate reddish orange (10 R 6/6); with pale red (10 R 6/2) to light olive gray (5 Y 6/1), clayey silt (possibly very weathered saprolite)	7	137

TABLE 29—*Continued*

Cutting description	Thickness (feet)	Depth to base (feet)
CE Cd 51--Continued		
Silt, very clayey, light bluish gray (5 B 7/1), probably weathered schist; mixed with small gravel, as above	8	145
Saprolite, greenish gray (5 G 6/1), muscovite, biotite, chlorite? bearing, clayey silt; a few chips of black (N 1) moderately weathered biotite, muscovite, chlorite? bearing schist in sample; greenish gray, clayey silt appear to be weathering products of schistose basement rock	14	159
CE Cd 53		
Silt, fine sand, very clayey, mica bearing, medium orange brown (5 YR 7/4)	5	5
Silt, very clayey, some fine sand, mica bearing, moderate reddish orange (10 R 6/6)	5	10
Silt, fine, very clayey, talc-like feel, pale red (10 R 6/2) and grayish orange pink (10 R 8/2)	25	35
Silt, fine, very clayey, grayish pink (5 R 8/2), mottled grayish red (5 R 4/2); also little dark yellowish orange (10 YR 6/6), clayey silt	10	45
Clay, silty, varicolored grayish pink (5 R 8/2), moderate orange pink (10 R 7/4) and moderate red (5 R 4/6)	5	50
Silt, fine sand, very clayey, mica bearing, light brown (5 YR 5/6)	25	75
Silt, very clayey, micaceous, grayish orange (10 YR 7/4), some medium gray (N 5), and moderate red (5 YR 4/6), clayey silt	20	95
Silt, same as above	20	115

TABLE 29—*Continued*

Cutting description	Thickness (feet)	Depth to base (feet)
CE Cd 53--Continued		
Silt, with a little fine sand, very clayey, micaceous, pale red (10 R 6/2); with some grayish pink (5 R 8/2), micaceous, clayey silt	20	145
Silt, a little fine sand, very clayey, micaceous, varicolored light olive gray (5 Y 6/1), light red (5 R 6/6) and grayish pink (5 R 8/2)	20	165
Silt, very clayey, micaceous, mostly medium gray (N 5) and medium light gray (N 6); varicolored light brown (5 YR 6/4) and very pale orange (10 YR 8/2)	20	185
Silt, clayey, same as above	20	205
Silt, clayey, same as above	20	225
Silt, very clayey, some very fine sand, micaceous, white (N 9); with pale yellowish brown (10 YR 6/2), fine, silty, clayey sand	15	240
Sand, fine, silty and clayey, micaceous, light brown (5 YR 5/6), and light brownish gray (5 YR 6/1)	20	260
Sand, fine, silty, same as above	25	285
Sand, fine, silty, same as above	20	305
Silt, some fine sand, very clayey, micaceous, medium gray (N 5), light brown (5 YR 5/6), and moderate red (5 R 4/6)	25	330
Silt, fine sand, same as above	10	340
Sand, fine, silty and clayey, ranges up to medium micaceous, light brown (5 YR 5/6)	10	350
Sand, fine to medium, ranges to coarse, silty, and clayey, micaceous, light brown (5 YR 5/6)	10	360
Sand, fine to coarse, silty, clayey, micaceous, light brown (5 YR 5/6); with sand, very coarse to granular quartz grains, appears to be bimodal sand size distribution in sample	15	375

TABLE 29—*Continued*

Cutting description	Thickness (feet)	Depth to base (feet)
CE Cd 53--Continued		
Sand, same as above, with a few chips of pale red purple (5 RP 6/2), clayey silt	5	380
Sand, fine, silty, clayey, micaceous, light brown (5 YR 5/6), with dark yellowish orange (10 YR 6/6) and moderate brown (5 YR 3/4), clayey, micaceous silt	10	390
Sand, same as above; with chips of hard, pale red purple (5 RP 6/2) and soft white (N 9), micaceous, clayey silt	10	400
Sand, fine, silty and clayey, micaceous; mostly light brown (5 YR 5/6); some chips of white (N 9), moderate red (5 R 4/6), and light olive gray (5 Y 6/1), micaceous, clayey silt	25	425
Sand, fine, some medium, very silty, clayey, micaceous light brown (5 YR 5/6)	15	440
Sand, fine, very silty, clayey, micaceous, light brown (5 YR 5/6); with some very light gray (N 8), clayey silt	5	445
Silt, very fine, clayey, micaceous, very light gray (N 8); mixed with light brown clayey silt and a fine sand	20	465
Sand, fine silty, clayey, micaceous, light brown (5 YR 5/6); some very light gray (N 8), clayey silt	25	490
Sand, fine, silty, clayey, micaceous, light brown (5 YR 5/6); with saprolite, dominantly micas (probably muscovite and chlorite, no biotite seen), talc-like feel, dusky yellow (5 Y 6/4); chips show alignment of micas, but sample is too weathered to be called weathered schist	5	495

TABLE 29—*Continued*

Cutting description	Thickness (feet)	Depth to base (feet)
CE Ce 54		
Sand, fine to coarse, silty, slightly clayey, some small quartz pebbles, dark yellowish orange (10 YR 6/6)	10	10
Sand, fine to coarse, small pebbles, dark yellowish orange (10 YR 6/6)	10	20
Sand, mostly fine, silty, some coarse to very coarse; some small quartz pebbles, grayish orange (10 YR 7/4); with chips of very pale orange (10 YR 8/2) clayey silt	15	35
Sand, fine, silty, slightly clayey, dark orange pink (5 YR 7/4); with chips of very pale orange (10 YR 8/2), clayey silt	20	55
Sand, fine, silty, some medium, mica bearing, dark yellowish orange (10 YR 6/6); with chips of very pale orange (10 YR 8/2) clayey silt	5	60
Silt, very clayey, with a little fine sand, moderate orange pink (5 YR 8/4); with chips of very pale orange (10 YR 8/2) clayey silt	10	70
Silt, clayey, very pale orange (10 YR 8/2) with light grayish orange (10 YR 8/4), fine, clayey, silty sand	10	80
Sand, fine, silty, clayey, grayish orange (10 YR 7/4); with large chips and pieces of very pale orange (10 YR 8/2), clayey silt	10	90
Sand, fine, some medium, silty with light clayey matrix, dark orange pink (5 YR 7/4); with a few chips of very pale orange (10 YR 8/2), clayey silt	5	95
Sand, fine, silty, very clayey, light brown (5 YR 5/6); with chips of moderate red (5 R 5/4) and grayish pink (10 R 8/2), silty clay	5	100
Clay, silty, moderate red (5 R 5/4) and grayish orange pink (10 R 8/2), with moderate orange pink (5 YR 8/4), fine, silty, and clayey sand	20	120

TABLE 29—*Continued*

Cutting description	Thickness (feet)	Depth to base (feet)
CE Ce 54--Continued		
Silt, clayey, yellowish gray (5 Y 8/1) and pale reddish brown (10 R 5/4); with light brown (5 YR 5/6), fine, silty, and clayey sand	20	140
Sand, fine, some medium, silty and slightly clayey, light brown (5 YR 5/6)	30	170
Sand, fine, silty, clayey, mica bearing, dark orange pink (10 YR 8/4); with chips of pinkish gray (5 YR 8/1), clayey silt	15	185
Silt, clayey, very light gray (N 5), with light brown (5 YR 6/4), fine, silty, and clayey sand	20	205
Silt, clayey, very light gray (N 8); with chips of light gray (N 7) to yellowish gray (5 Y 8/1), silty clay; some light brown (5 YR 5/6) to very dark red (5 R 2/6), iron oxide cemented, mica-bearing silt	20	225
Silt, very clayey, fine sand, micaceous, varicolored mostly light brown (5 YR 5/6); some pale purple (5 P 6/2), very pale orange (10 YR 8/2), and dark yellowish orange (10 YR 6/6); also some small chips of moderate red (5 R 4/6), iron cemented silt	20	245
Sand, fine, silty, clayey, mica bearing, light brown (5 YR 5/6); some very light gray (N 8), clayey silt, and moderate brown (5 Y 3/4), micaceous silt	20	265
Sand, fine, silty, clayey, mica bearing, light brown (5 YR 5/6); chips of very light gray (N 9), clayey silt; some chips of light olive gray (5 Y 5/2) and dusky yellow (5 Y 6/4), micaceous silt, mostly muscovite, but with some biotite, possibly saprolite	20	285
CE Ce 55		
Silt, fine sand, clayey, dark yellowish orange (10 YR 6/6)	5	5

TABLE 29—*Continued*

Cutting description	Thickness (feet)	Depth to base (feet)
CE Ce 55--Continued		
Silt, fine sand, clayey, moderate reddish orange (10 R 6/6)	5	10
Silt, some fine sand, clayey, mica bearing, pinkish gray (5 YR 8/1) and moderate orange pink (10 R 7/6); with some very light gray (N 8), clayey silt	5	15
Silt, some fine sand, clayey, mica bearing, pinkish gray (5 YR 8/1), and moderate orange pink (10 R 7/4)	10	25
Sand, fine, silty, clayey, micaceous, pinkish gray (5 YR 8/1) and moderate orange pink (10 R 7/4)	20	45
Silt, fine sand, clayey, micaceous, light gray (N 7) and pale red (10 R 6/2)	15	60
Silt, fine sand, clayey, micaceous, light gray (N 7) and pale red (10 R 6/2); with some chips of moderate red (5 R 5/4), silty clay	5	65
Sand, fine, silty, micaceous, pale red (10 R 6/2)	5	70
Sand, as above, with some light brownish gray (5 YR 6/1), clayey silt	5	75
Sand, fine, silty, clayey, micaceous, medium brownish gray (5 YR 5/7)	5	80
Sand, as above, varicolored pale red (10 R 6/2), grayish orange (10 YR 7/4), and brownish gray (5 YR 6/1)	10	90
Sand, fine silty, and clayey, micaceous, light brown (5 YR 5/6); with some fine, clayey silt, very light gray (N 8), and dark yellowish orange (10 YR 6/6)	40	130
Silt, fine sand, clayey, mica bearing, varicolored light brown (5 YR 5/6), light olive gray (5 Y 6/1), white (N 9), and grayish orange (10 YR 7/4)	20	150

TABLE 29—*Continued*

Cutting description	Thickness (feet)	Depth to base (feet)
CE Ce 55--Continued		
Clay, silty, light brown (5 YR 6/6), with light gray (N 7), clayey silt	15	165
Silt, very clayey, light brown (5 YR 6/4), with chips of white (N 9), dark yellowish orange (10 YR 6/6) and medium gray (N 5) silt	25	190
Silt, and fine sand, very clayey, light brown (5 YR 5/6), with some white (N 9), clayey silt	15	205
Silt, very clayey, moderate reddish orange (10 R 6/6), with some white (N 9) and olive gray (5 Y 5/1), clayey silt	20	225
Silt, and fine sand, clayey, light brown (5 YR 5/6), with chips of white (N 9) clayey silt	15	240
Silt, and some fine sand, clayey, light brown (5 YR 5/6), with chips of white (N 9) and light olive gray (5 Y 6/1), clayey silt common	80	320
Silt, and fine sand, clayey but less so than above, mica bearing, moderate orange pink (10 R 7/4), with chips of white (N 9), light olive gray (5 Y 6/1) and medium bluish gray (5 B 5/1), clayey silt common	60	380
Sand, fine and silty, clayey, mica bearing, pale red (10 R 6/2), with chips of white (N 9) and light olive gray (5 Y 6/1), clayey silt	50	430
Silt, clayey, mica bearing, pale red (10 R 6/2), with white (N 9) and medium light gray (N 6), clayey silt	15	445
Silt, some fine sand, clayey, mica bearing, pale red (10 R 6/2), medium light gray (N 6), clayey silt common	15	460
Sand, fine, very silty, clayey, mica bearing, pale red (10 R 6/2), with medium light gray (N 6), clayey silt common	55	515

TABLE 29—*Continued*

Cutting description	Thickness (feet)	Depth to base (feet)
CE Ce 55--Continued		
Silt, clayey, micaceous, light brown (5 YR 6/4); with chips of white (N 9) and medium light gray (N 6), clayey silt	20	535
Silt, as above, with some fine sand	35	570
Silt, with fine sand, micaceous, light brown (5 YR 6/4); some chips of very light to medium light gray, clayey silt (N 8 to N 6)	32	602
Silt, fine sand, some medium, clayey, micaceous, light to medium brown (5 YR 6/4 to 5 YR 4/4); chips of white (N 9) and light gray (N 7), clayey silt	15	617
Sand, fine, silty and clayey, ranges up to medium, micaceous, medium muscovite flakes common, light brown (5 YR 5/6), a few chips of white (N 9), talc-like, silty clay	5	622
CE Ce 56		
Silt, some fine sand, very clayey, mica bearing, grayish orange (10 YR 7/4) and light gray (N 7)	5	5
Sand, fine to coarse, some silt, few small pebbles, micaceous, yellowish gray (5 Y 7/2)	10	15
Sand, fine, silty, very clayey, micaceous, light gray (N 7) and grayish orange (10 YR 7/4)	5	20
Silt, and fine sand, very clayey, micaceous, light (5 YR 5/6)	15	35
Silt, fine sand, clayey, micaceous, light brown (5 YR 6/6)	20	55
Sand, fine, silty, clayey, micaceous, moderate reddish orange (10 R 6/6)	20	75
Sand, fine silty, less clayey than above, micaceous, moderate reddish orange (10 R 6/6)	20	95

TABLE 29—*Continued*

Cutting description	Thickness (feet)	Depth to base (feet)
CE Ce 56--Continued		
Sand, same as above	15	110
Sand, fine, silty, clayey, micaceous, moderate reddish orange (10 R 6/6); with chips of light gray (N 6) and pinkish gray (5 YR 8/1) clayey silt	20	130
Sand, same as above	25	155
Sand, fine, silty, some medium, clayey matrix, micaceous, light brown (5 YR 5/6)	20	175
Sand, same as above	20	195
Silt, clayey, micaceous, light brown (5 YR 6/4)	15	210
Sand, fine silty, some medium, micaceous, light brown (5 YR 5/6)	20	230
Sand, fine, silty and clayey, micaceous, light brown (5 YR 6/4)	20	250
Silt and fine sand, clayey, micaceous, light brown (5 YR 6/4)	20	270
Silt, and fine sand, same as above	20	290
Silt, and fine sand, same as above	20	310
Sand, fine, very silty, clayey, ranges to medium, micaceous, moderate brown (5 YR 4/4)	20	330
Sand, fine silty, clayey, micaceous, pale red (5 YR 6/4) and pale yellowish brown (10 YR 6/2)	20	350
Silt, some fine sand, clayey, micaceous, pale yellowish brown (10 YR 6/2) to light brown (5 YR 5/6)	20	370
Silt, some fine sand, clayey, micaceous, light brownish gray (5 YR 6/1) and light brown (5 YR 6/4)	20	390
Sand, fine, silty, clayey, micaceous, light brownish gray (5 YR 6/1) and light brown (5 YR 6/6)	20	410

TABLE 29—*Continued*

Cutting description	Thickness (feet)	Depth to base (feet)
CE Ce 56--Continued		
Sand, fine, silty, clayey, micaceous, mostly light brownish gray (5 YR 6/1), some light brown (5 YR 6/4). (No saprolitic material seen)	10	420
CE Dd 81		
Sand, fine to coarse, a few small pebbles, mica bearing, grayish orange (10 YR 7/4)	5	5
Sand, fine, silty, micaceous, grayish orange (10 YR 7/4); with silt, clayey, micaceous, medium light gray (N 6) and grayish orange (10 YR 7/4)	5	10
Silt, fine sand, micaceous, grayish orange (10 YR 7/4), dark yellowish orange (10 YR 6/6) and medium light gray (N 6); some chips of moderate yellowish brown (10 YR 5/4) to dark reddish brown (10 R 3/4), iron oxide cemented silt	15	25
Gravel, granules to small pebbles, angular to subangular, grayish orange (10 YR 7/4); with fine, silty, grayish orange (10 YR 7/4), micaceous sand; and a few chips of pinkish gray (5 YR 8/1), clayey silt	15	40
Gravel, as above, but with less grayish orange (10 YR 7/4), fine, silty sand	20	60
Sand, fine, silty, micaceous, grayish orange (10 YR 7/4); with a few small quartz pebbles and some very light gray, clayey silt	20	80
Silt, clayey, micaceous, very light gray (N 8) and light pinkish gray (5 YR 9/1); mixed with grayish orange (10 YR 7/4), fine, silty, micaceous sand	20	100
Silt, clayey, micaceous, medium gray (N 5); mixed with grayish orange (10 YR 7/4), fine, silty sand	20	120

TABLE 29—*Continued*

Cutting description	Thickness (feet)	Depth to base (feet)
CE Dd 81--Continued		
Sand, fine, silty, clayey, grayish orange (10 YR 7/4); with chips of medium gray (N 5), micaceous, clayey silt	10	130
Sand, fine, silty, clayey, grayish orange pink (5 YR 7/2) to moderate reddish brown (10 R 4/6); a few chips of medium gray (N 5), micaceous, clayey silt	10	140
Sand, fine silty, mica bearing, grayish orange (10 YR 7/4)	15	155
Sand, fine, silty, some clayey matrix, micaceous, grayish orange pink (5 YR 7/2)	25	180
Sand, fine, silty, some clayey matrix, micaceous, pale yellowish brown (10 YR 6/2)	20	200
Sand, as above; with rare, light brown, micaceous, iron oxide cemented silt	20	220
Sand, as above; no iron oxide cemented silt seen	20	240
Silt, very clayey, micaceous, medium gray (N 5); mixed with pale yellowish brown (10 YR 6/2), fine, silty, micaceous sand	20	260
Sand, fine, silty, moderately clayey, micaceous, pale yellowish brown (10 YR 6/2); mixed with silt, very clayey, micaceous, medium gray (N 5)	20	280
Sand, and clayey silt, as above; a few chips of moderate orange pink (10 R 7/4) to dusky red (5 R 3/4), very clayey silt	20	300
Sand, and clayey silt, as above: chips of moderate (5 R 4/6) to dusky red (5 R 3/4), very clayey silt more common than above	20	320

TABLE 29—*Continued*

Cutting description	Thickness (feet)	Depth to base (feet)
CE Dd 81--Continued		
Clay, silty, mica bearing, dusky red (5 R 3/4) and moderate red (5 R 4/6); mixed with silt, very clayey, micaceous, medium gray (N 5) and some pale reddish brown (10 R 5/4), mica bearing, fine, silty sand	20	340
Clay, silt, and sand, same as above but less sand present	20	360
Clay, silty, moderate red (5 R 4/6), moderate reddish orange (10 R 6/6); and silt, clayey, mica bearing, medium gray (N 5); mixed with pale reddish brown (10 R 5/4), mica bearing, silty sand (less sand present than above)	20	380
Clay, silty, mica bearing, medium gray (N 5), moderate red (5 R 4/6) and grayish pink (5 R 8/2)	20	400
Clay, silty, same as above	20	420
Clay, silty, same as above	20	440
Clay, silty, same as above; but with grayish orange pink (5 YR 7/2), very clayey, mica bearing silt	20	460
Clay, silty; silt, very clayey, same as above	20	480
Silt, very clayey, mica bearing, grayish orange pink (5 YR 7/2), some varicolored moderate red (5 R 4/6) to grayish pink (5 R 8/2), silty clay present	20	500

TABLE 30

DESCRIPTIONS OF CORES FROM TEST WELLS

[Descriptions by J.M. Wilson, Maryland Geological Survey, October 1985.]

CE Be 73

Core at 43 ft:	Recovery: 5 in.
0 to 5 in.	Silt, with a little fine sand, clayey matrix, well sorted, mica bearing, very light gray (N 8).
Core at 63 ft:	Recovery: 5 in.
0 to 5 in.	Silt, some clay matrix, micaceous, white with grayish cast.
Core at 89 ft:	Recovery: 9.25 in.
0 to 9 in.	Sand, very fine to fine, some silt, well sorted, mica bearing, trace opaques, pinkish gray (5 YR 8/1).
9 to 9.25 in.	Silt, very clayey, mica bearing, light grayish orange pink (5 YR 8/2).
Core at 112 ft:	Recovery: 8 in.
0 to 8 in.	Sand (loose), fine to coarse, some silt, small pebbles (1/8 to 3/8 in.), mica bearing, pale grayish orange (10 YR 8/4); with silt, very clayey, micaceous, chalky white with tan cast.

CE Bf 81

Core at 50 ft:	Recovery: 4 in.
0 to 4 in.	Sand, fine to medium, well sorted, mica bearing, trace opaques, pale graying orange (10 YR 8/4). (Note: Large quartz pebbles present in sample, probably from higher in hole.) Some very pale orange (10 YR 8/2), clayey, micaceous silt at base of sample.

TABLE 30—*Continued*

CE Bf 82

Core at 60 ft:	Recovery: 14 in.
0 to 1 in.	Silt, clayey, micaceous, medium light gray (N 6), and mottled light red (5 R 6/6) to dark red (5 R 3/6).
1 to 14 in.	Clay, silty, very light gray (N 8), mottled light red (5 R 6/6) to dark red (5 R 3/6).
(Section from 0 to 1 in. sampled for pollen.)	
Core at 100 ft:	Recovery: 10 in.
0 to 3 in.	Sand, fine silty, clayey matrix, mica bearing, dark yellowish orange (10 YR 6/6).
3 to 7 in.	Sand, fine, well sorted, mica bearing, dark yellowish orange (10 YR 6/6).
7 to 10 in.	Clay, dark browniah gray (5 YR 4/1), heavily oxidized to dark yellowiah orange in places, lignite bearing.
Core at 160 ft:	Recovery: 11 in.
0 to 2 in.	Clay, dark reddish brown (10 R 3/4).
2 to 5 in.	Sand, fine to medium, silty, mica bearing, grayish orange (10 YR 7/4).
5 to 11 in.	Silt, clayey, mica bearing, white (N 9).
Core at 200 ft:	Recovery: 10 in.
0 to 1.5 in.	Clay, medium dark gray (N 4), mottled in part to moderate reddish brown (10 R 4/6).
1.5 to 5 in.	Silt, clayey, mica bearing, pale yellowiah orange (10 YR 8/6).
5 to 10 in.	Silt, less clayey than above, micaceous, very pale orange (10 YR 8/2) with moderate yellowish brown (10 YR 5/4) specka.
(Dark gray portion aampled for pollen)	

TABLE 30—*Continued*

CE Cd 51

Core at 15 ft:	Recovery: 8 in.
0 to 8 in.	Gravel, amell to medium quartz pebbles with moderete red (5 R 4/6) silty cley, and greyish orenge pink (10 R 8/2), fine clayey silt.
Core at 45 ft:	Recovery: 10 in.
0 to 5.5 in.	Silt, very cleyey, miceceous, shiny lustre, aoepy feel, pele grayish orenge (10 YR 8/4). (Possibly seprolite material).
5.5 to 11 in.	Silt, clayey, mica beering, pele yellowish brown (10 YR 6/2).
Core at 89 ft:	Recovery: 3 in. (core broken up)
0 to 3 in.	Silt, very cleyey, micaceous, moderate pink (5 R 7/4) and white (N 9); some large (1 in.) well rounded quartz pebbles; soapy feeling to sediment; probebly very weethered aeprolitic material. (Pebbles mey not be in situ).

CE Cd 53

Core at 97 ft:	Recovery: 10 in. (core broken up)
0 to 1.5 in.	Clay, silty, moderate reddish brown (10 R 4/6).
1.5 to 7.5 in.	Silt, fine, very well sorted, e little cley metrix, greyish pink (5 R 8/2).
7.5 to 10 in.	Cley, slightly silty, mottled moderete reddish brown (10 R 4/6) and medium derk grey (N 4).

(Dark gray cley portion aampled for pollen).

Core at 199 ft:	Recovery: 8 in.
0 to 8 in.	Send, fine, silty, renges up to medium, moderately well sorted, mica bearing, light brown (5 YR 6/4).

TABLE 30—*Continued*

CE Cd 53--Continued

Core at 200 ft:	Recovery: 10 in.
0 to 10 in.	Clay, slightly silty, mottled pale yellowish orange (10 YR 8/6) and reddish brown (10 R 4/6).
Core at 377 ft:	Recovery: 9 in.
0 to 9 in.	Clay, slightly ailty, moderate to dark reddish brown (10 R 4/6 to 10 R 3/4) and grayish orange pink (10 R 8/2).

CE Ce 54

Core at 20 ft:	Recovery: 7 in.
0 to 3 in.	Sand, very fine and silty, very clayey, grayish orange (10 YR 7/4).
4 to 7 in.	Sand, fine to medium, silty with some clayey matrix, ranges up to coarae, moderately sorted, dark yellowish orange (10 YR 6/6)
Core at 60 ft:	Silt, clayey, mica bearing, pinkish gray (5 YR 8/1).
Core at 171 ft:	Recovery: 5 in.
	Sand, very fine, silty, some clayey matrix, well sorted, micaceous, white with slight gray cast.

CE Ce 55

Core at 100 ft:	Recovery: 10 in.
	Clay, aome ailt, very stiff, mottled moderate red (5 R 5/4), pale olive (10 Y 7/2), and yellowish gray (5 Y 7/2).

TABLE 30—*Continued*

CE Ce 55--Continued

Core at 320 ft:	Recovery: 5 in.
0 to 1.5 in.	Clay, silty, mottled reddish brown (10 R 6/6), mixed with silt, very clayey, mica bearing, lignite bearing, light gray (N 7). Thin bed of fine, silty sand, oxidized to dark yellowish orange (10 YR 6/6).
1.5 to 5 in.	Sand, fine, silty, well sorted, lignite bearing, mica bearing, very light to medium light gray (N 8 to N 6).
Second core at 320 ft:	Recovery: 8 in.
0 to 1 in.	Clay, silty, mottled moderate red (5 R 4/6) and medium gray (N 5).
1 to 6 in.	Sand, fine silty, well sorted, micaceous, lignitic, light gray (N 7).
6 to 8 in.	Lignite, thinly laminated, solid, brownish black (5 YR 2/1).

(Lignite sampled for pollen)

Core at 420 ft:	Recovery: 10 in.
0 to 10 in.	Clay, stiff, a little silt, moderate brown (5 YR 4/4) and grayish pink orange (5 YR 7/2), with thin, 1/8 to 1/4 in. thick, beds and pods of yellowish gray (5 Y 7/2) silt.
Core at 520 ft:	Recovery: 7.5 in.
	Clay, stiff, slightly silty, yellowish gray (5 Y 7/2), some very pale red (10 R 7/2) patches; some coarse limonite grains are interspersed throughout sample.
Core at 602 ft:	Recovery: 9 in. (Core appears to represent two attempts)
0 to 1 in.	Silt, clayey, light red (5 R 6/6) and grayish yellow (5 Y 8/4).

TABLE 30—*Continued*

CE Ce 55--Continued

1 to 9 in.	Saprolite, weathered micaceous achist, very light bluish gray (5 B 8/1). Fine clear, angular quartz with medium to coarse muscovite and fine to medium biotite in ailty (almost chalky) matrix. Some schistose atructure preserved in parta of sample.

CE Ce 56

Core at 100 ft:	Recovery: 1-in. plug
	Silt, clayey, white (N 9), moderate orange pink (10 R 7/4) and pale yellowish orange (10 YR 8/6).
Core at 120 ft:	Recovery: 8 in.
0 to 8 in.	Sand, medium to coarse, well aorted, light brown (5 YR 5/6).
Core at 150 ft:	Recovery: 11 in.
0 to 1 in.	Silt, fine, very clayey, light red (5 R 6/6).
1 to 11 in.	Silt, and fine sand, some clay matrix, well aorted, mica bearing, very light gray (N 8).
Core at 200 ft:	Recovery: 2 in.
	Silt, clayey, mica bearing, lignite bearing, light gray (N 7), some dark yellowiah orange (10 YR 6/6) patches.

(Pollen sample from light gray zone.)

Core at 220 ft:	Recovery: 7 in.
0 to 7 in.	Sand, fine and silty, well sorted, mica bearing, dark reddish brown (10 R 3/4) and moderate yellowiah brown (10 YR 5/4).
Core at 400 ft:	Recovery: 8 in.
0 to 1 in.	Sand, fine and silty, well sorted, mica bearing, light gray (N 7).

TABLE 30—*Continued*

CE Ce 56--Continued

1 to 4 in.	Clay, dark gray (N 3), some pods of light gray (N 7) silt.
4 to 6 in.	Clay, dark gray (N 3), interbedded (1/8 in. beds) with light brownish gray (5 YR 6/1) micaceous silt. (Pollen sample).
6 to 7 in.	Sand, fine to medium, silty, micaceous, light gray (N 7).
7 to 8 in.	Clay, silty, medium gray (N 5) and pods of light brownish gray silt (5 YR 6/1) with lignite.
Core at 420 ft:	Recovery: 12 in.
	Clay, some silt, mottled light gray (N 8), grayish orange pink (10 R 8/2), moderate yellow (5 Y 7/6), and dusky red (5 R 3/4).

CE Dd 81

Core at 20 ft:	Recovery: 10 in.
0 to 5 in.	Sand, fine to medium, micaceous, well sorted, dusky yellowish orange (10 YR 6/6), interbedded with very pale orange (10 YR 8/2) micaceous, fine, silty clay and grayish orange pink (5 YR 7/2) micaceous clay.
5 to 10 in.	Sand, fine, very well sorted, mica bearing, pinkish gray (5 YR 8/1).
Core at 60 ft:	Recovery: 6 in.
0 to 6 in.	Sand, fine and silty, well sorted, very pale orange (10 YR 8/2)
Core at 100 ft:	Recovery: 8.5 in.
	Silt, clayey, grayish pink (5 R 8/2), thinly laminated beds of slightly darker grayish pink and grayish pink clayey silt. Lower 2 in. of core are less clayey and coarser than upper 4 in. (some fine sand).

TABLE 30—*Continued*

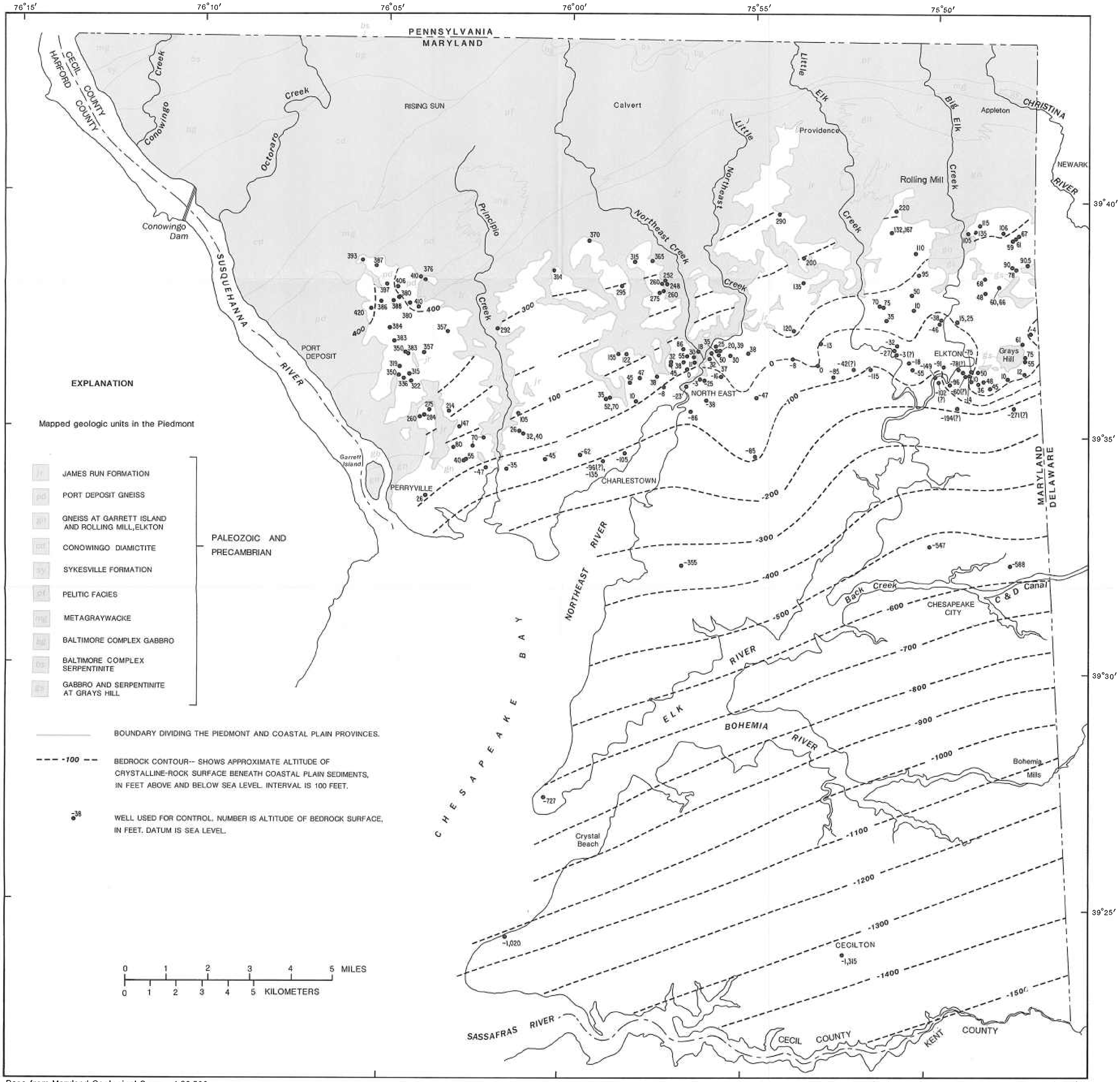
CE Dd 81--Continued

Core at 140 ft:	Recovery: 7 in.
0 to 7 in.	Clay, silty, light gray (N 7) with some moderate reddish orange patches (10 R 6/6).
Core at 140 ft (2nd attempt)	Recovery: 11 in.
0 to 11 in.	Clay, same as first attempt, above.
Core at 200 ft:	Recovery: 9.5 in.
0 to 3 in.	Clay, moderately dark red (5 R 3/6) and light gray (N 8).
3 to 9.5 in.	Silt, clayey, micaceous, pale yellowish brown (10 YR 6/2) with thin (1/4 in. thick) beds of brownish grey (5 YR 4/1) more clayey silt.
Core at 260 ft:	Recovery: 5 in. (core broken up)
0 to 5 in.	Sand, fine to medium, ranges to coarse, mica bearing, lignitic, pale yellowish brown (10 YR 6/2).
	Clay (2-in. plug), silty, mica beering, mottled pale red (5 R 6/2) and light brownish gray (5 YR 6/1).
Core at 300 ft:	Recovery: 8 in.
0 to 1.5 in.	Clay, silty, yellowish orange (10 YR 4/6) end moderete reddish brown (10 R 6/6).
1.5 to 8 in.	Clay, slightly silty, stiff, very light gray (N 8), pale yellowish orange (10 YR 8/6) and dusky red (5 R 3/4).
Core at 400 ft:	Recovery: 9.5 in.
	Silt, very clayey, medium light gray (N 6) beds of pinkish gray (5 YR 8/1), clayey silt (1/4 to 1/2 inch thick); becomes increesingly oxidized from 7 to 9.5 in. to mottled light brownish grey (5 YR 6/1) end moderate red (5 R 5/4) with beds of dark yellowish orenge (10 YR 6/6) silt.

TABLE 30—*Continued*

CE Dd 81--Continued

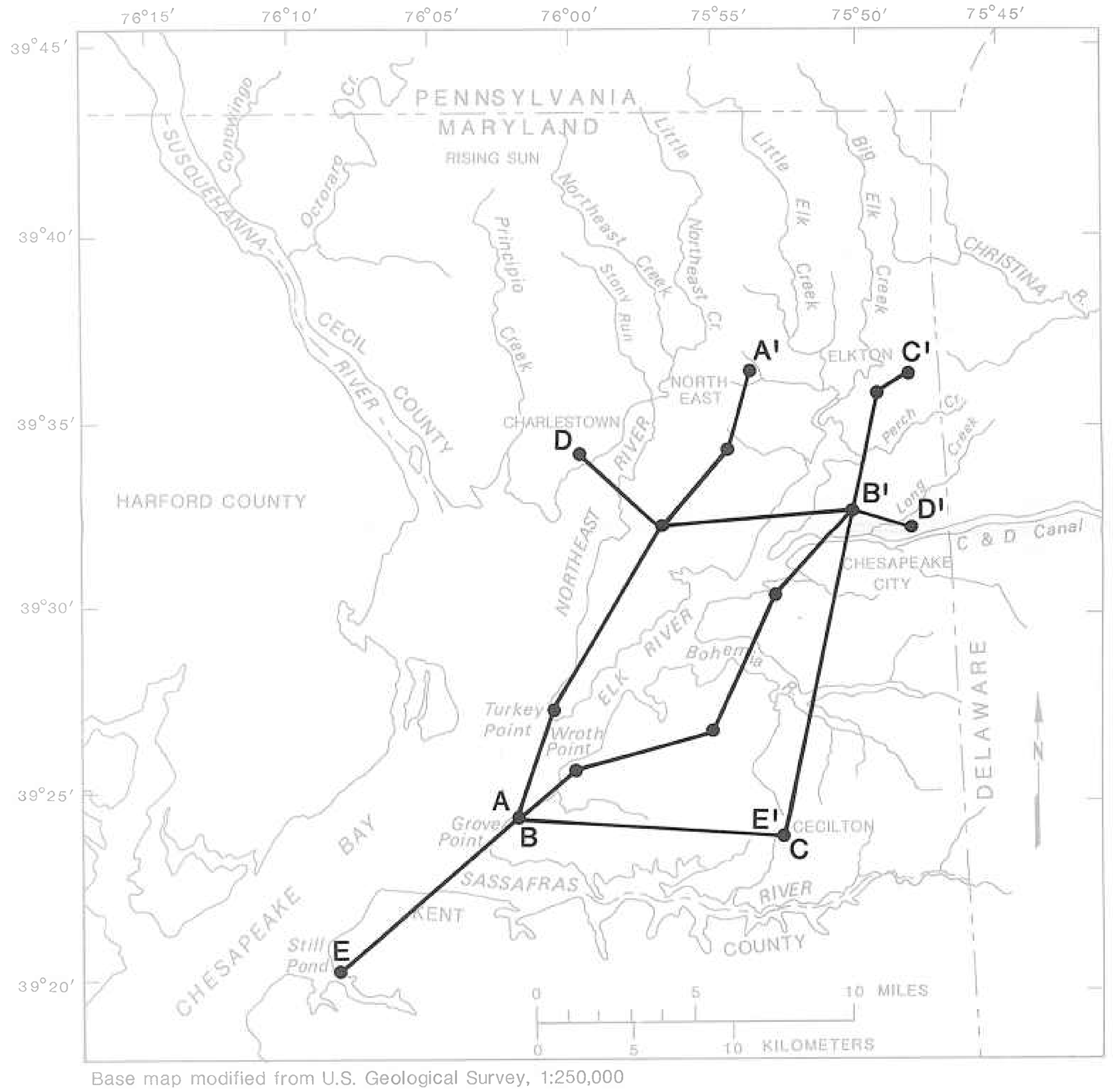
	(Pollen sample from gray clayey silt.)
Core at 500 ft:	Recovery: 11 in.
	Clay, slightly silty, mottled light gray (N 7), moderate brown (5 YR 3/4) and moderate reddish orange (10 R 6/6).

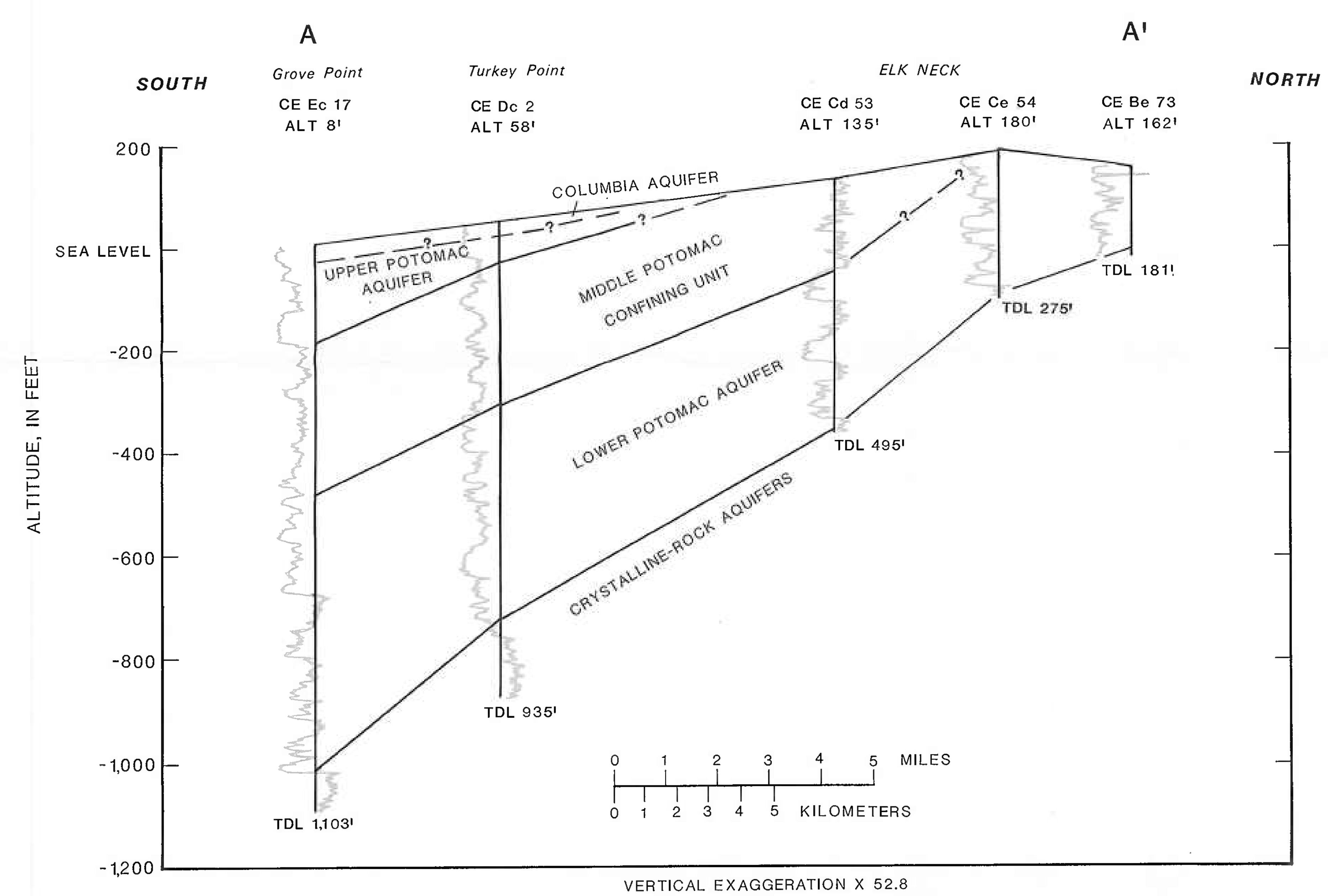


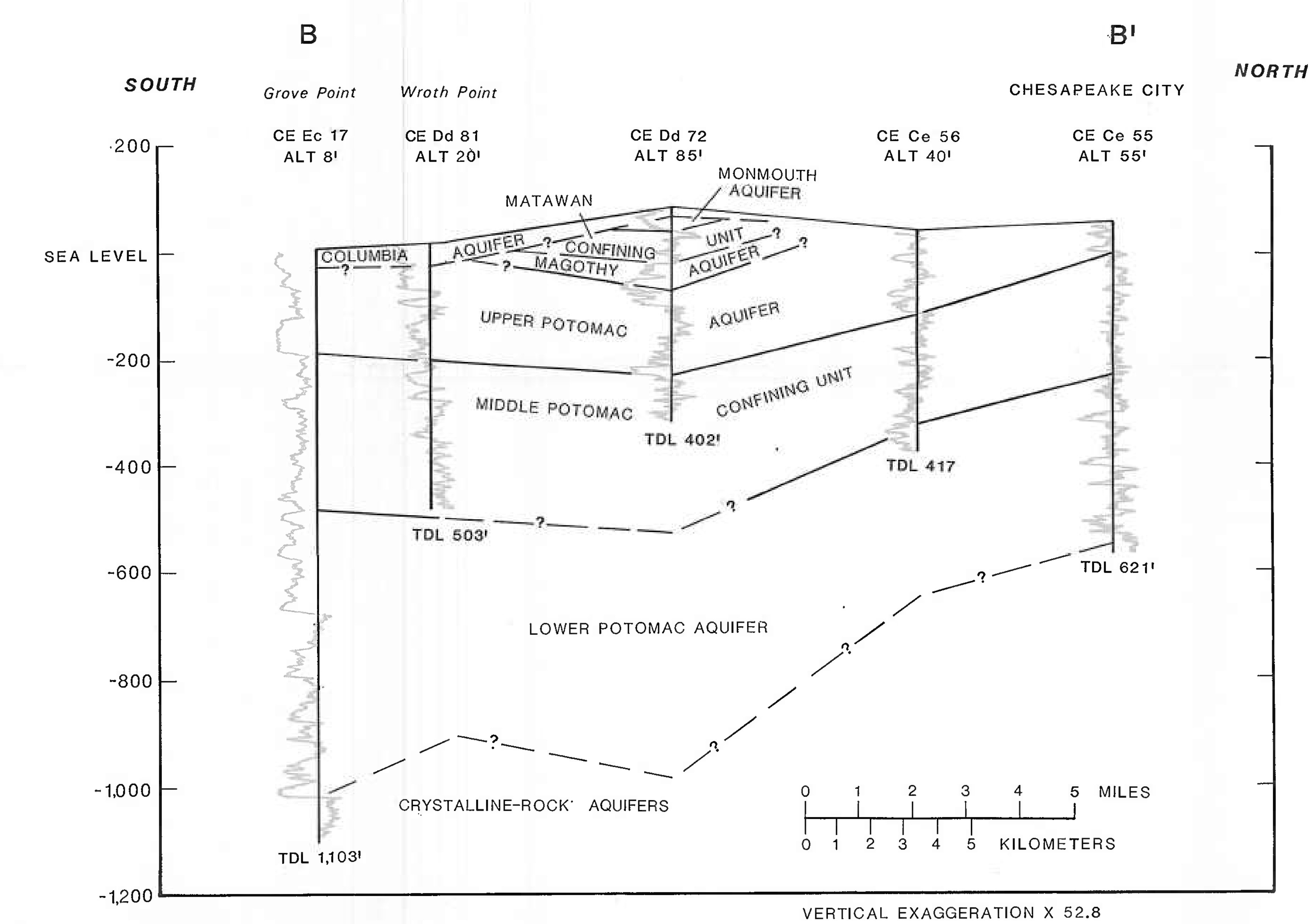
Base from Maryland Geological Survey, 1:62,500

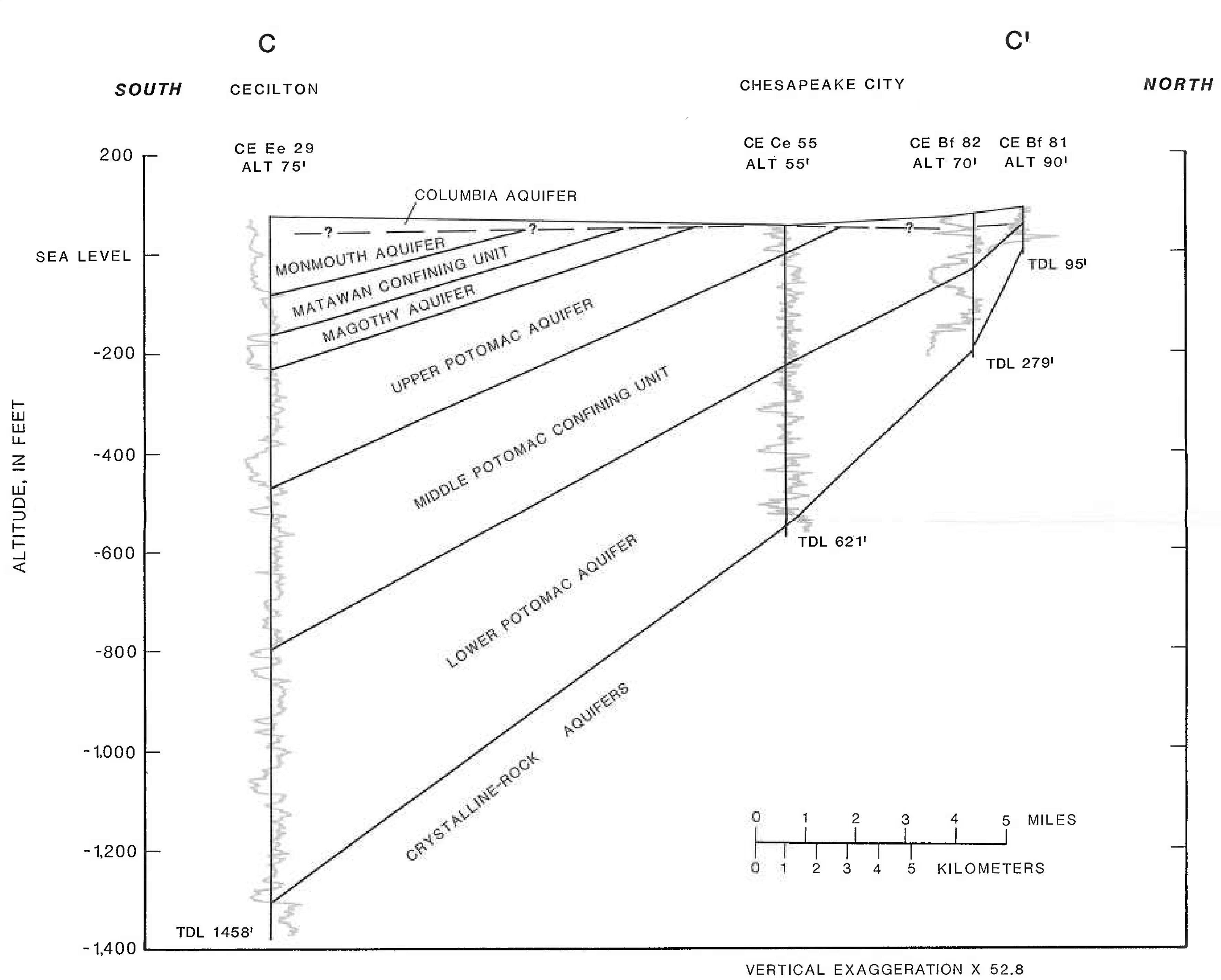
Geology modified from Higgins and Conant (1986). Contours on crystalline-rock surface modified from H.J. Hansen, Maryland Geological Survey (written commun., 1987).

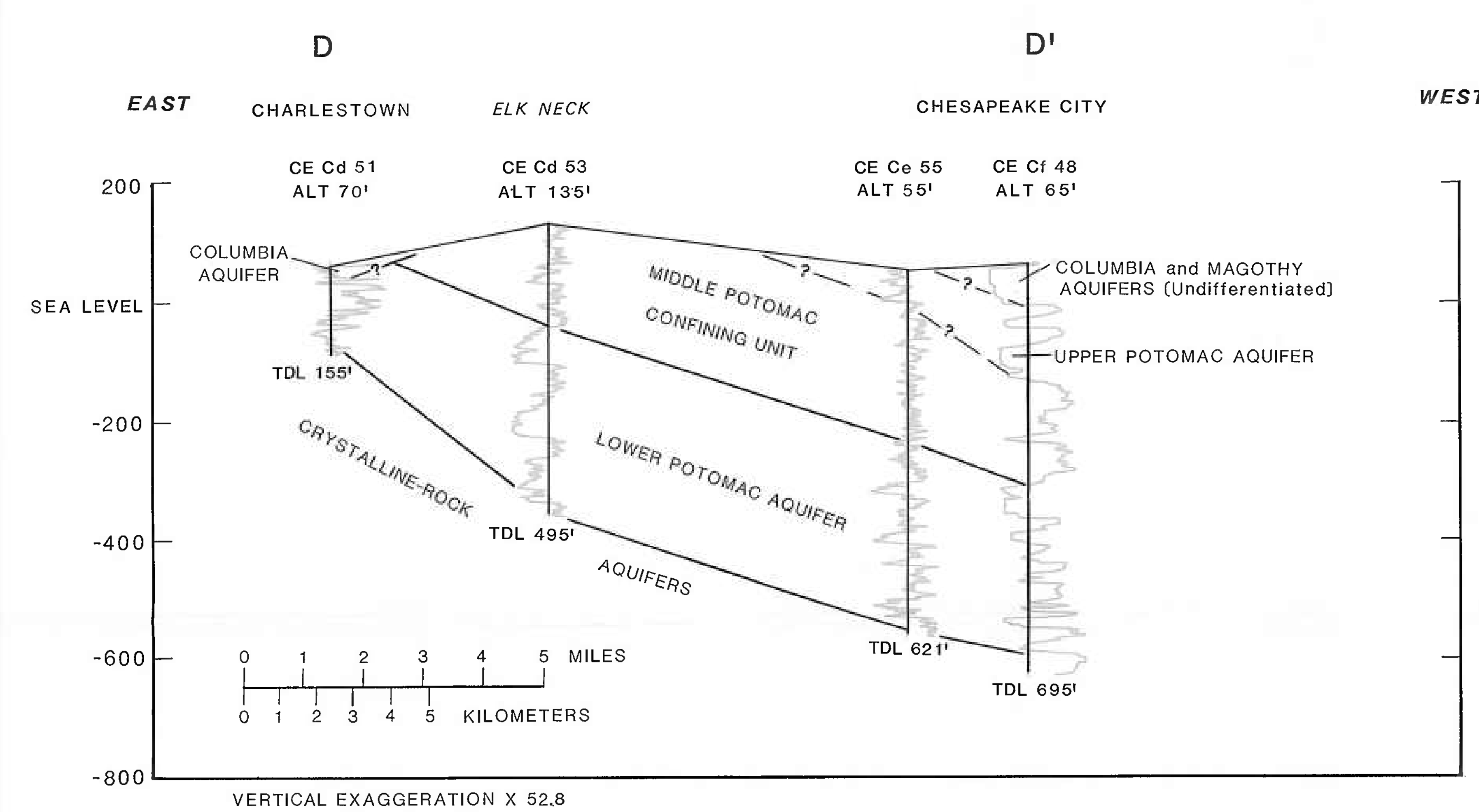
PLATE 1. Map showing geologic units in the Piedmont and contours on the crystalline rock surface beneath the Coastal Plain of Cecil County, Md.

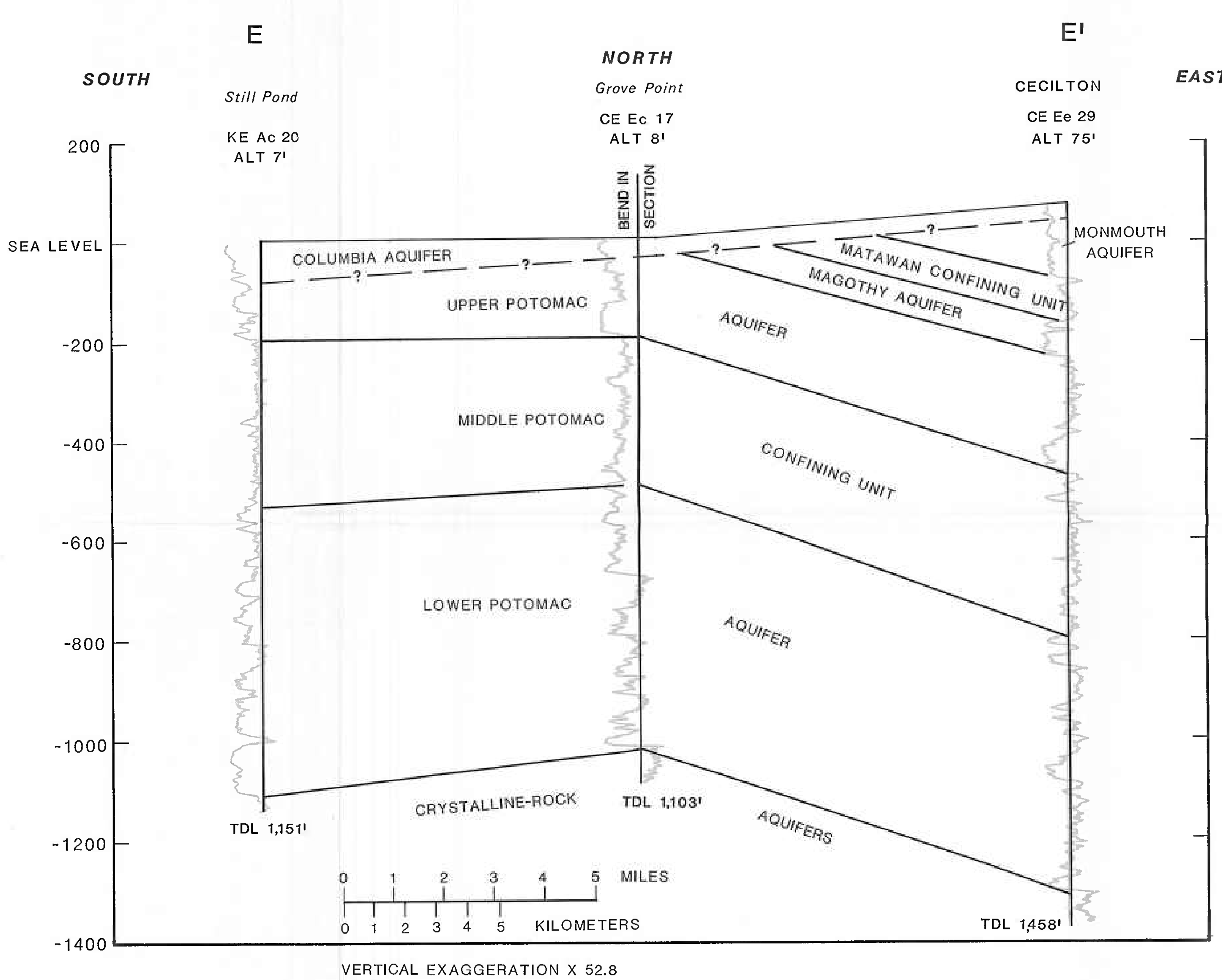












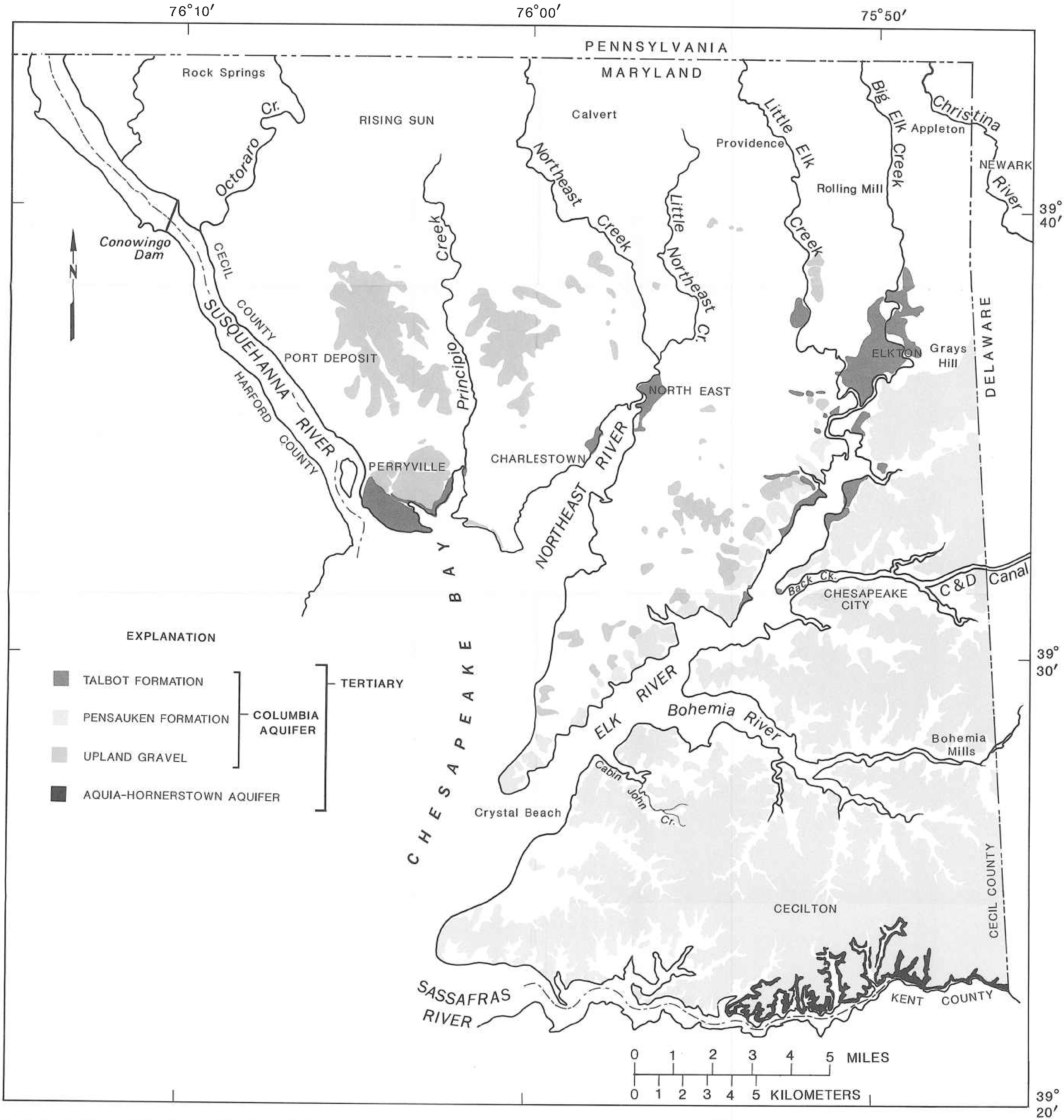
EXPLANATION

ALT 8' Altitude of well in feet.
TDL 95' Total depth logged of well in feet.

Geophysical logs are natural gamma radiation. Radiation increases to the right.

Geologic sections modified from H. J. Hansen, Maryland Geological Survey (written commun., 1986).

PLATE 2. Geologic sections of the Coastal Plain of Cecil County, Md.



Base from Maryland Geological Survey, 1:62,500

Geology modified from Higgins and Conant (1986)

PLATE 3. Map showing outcrop areas of the Aquia-Hornerstown and Columbia aquifers

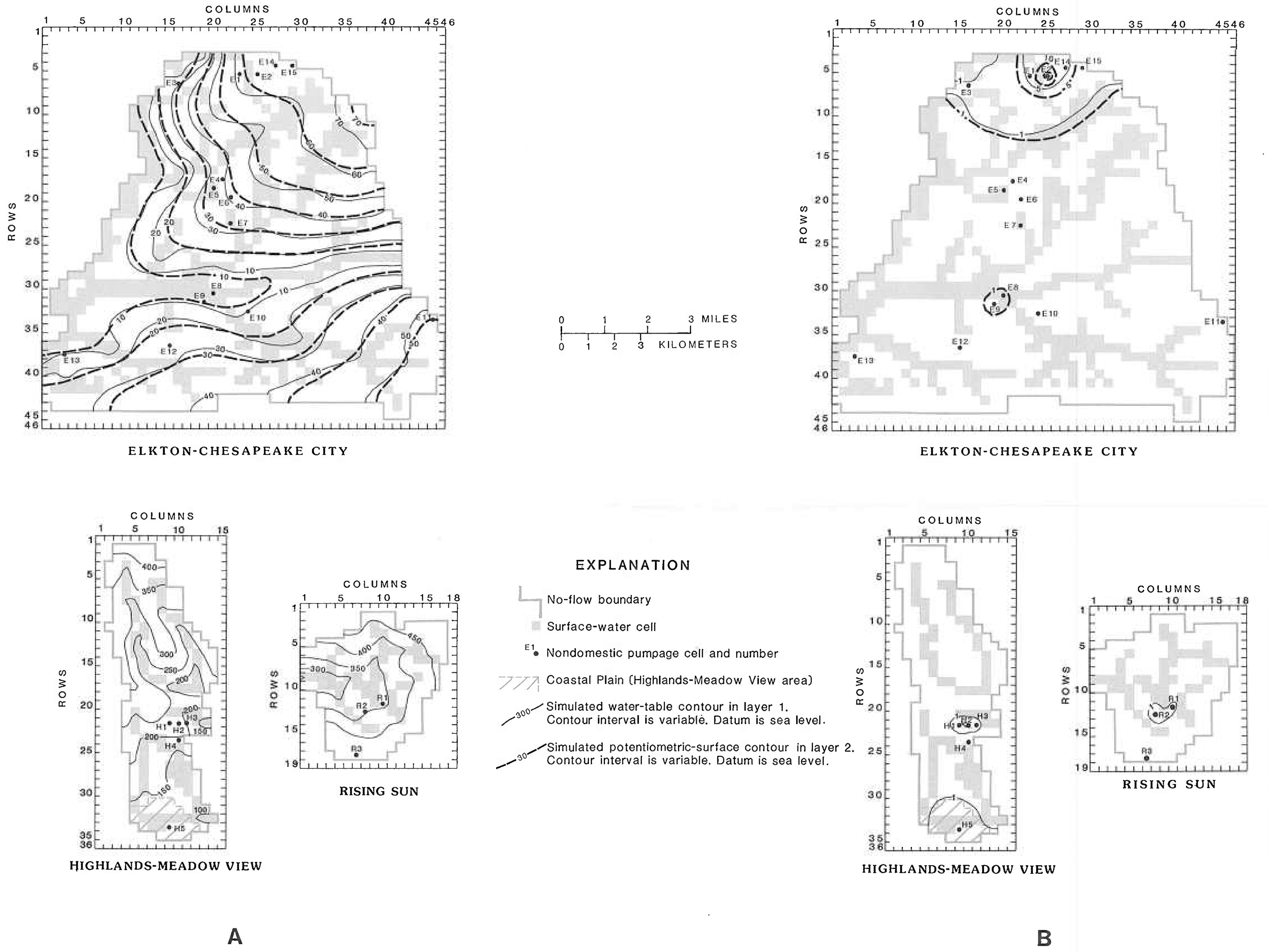


PLATE 4. Maps showing simulated water levels under (A) average-recharge prepumping conditions, and (B) simulated drawdowns caused by 1980 pumpages, in three modeled areas.

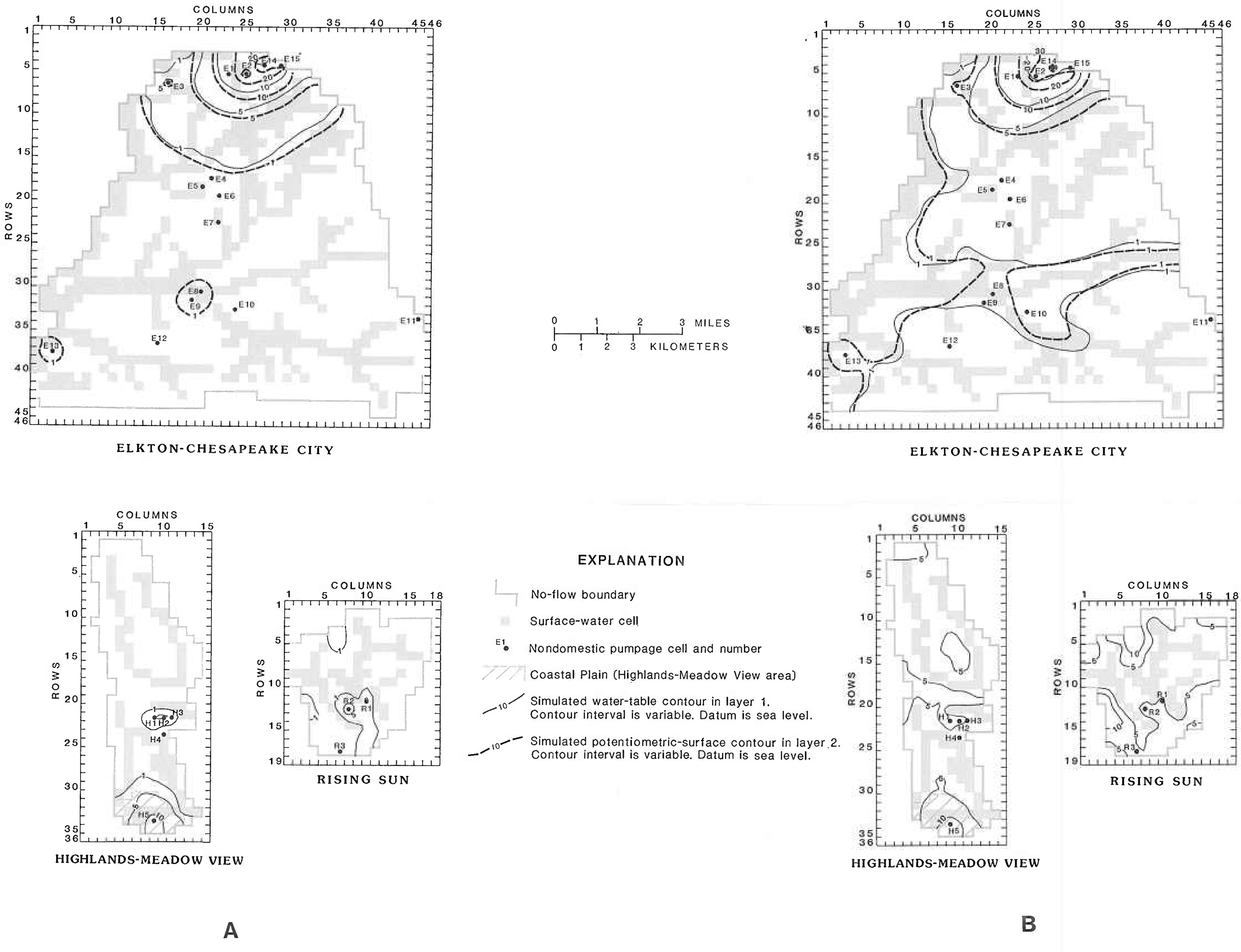
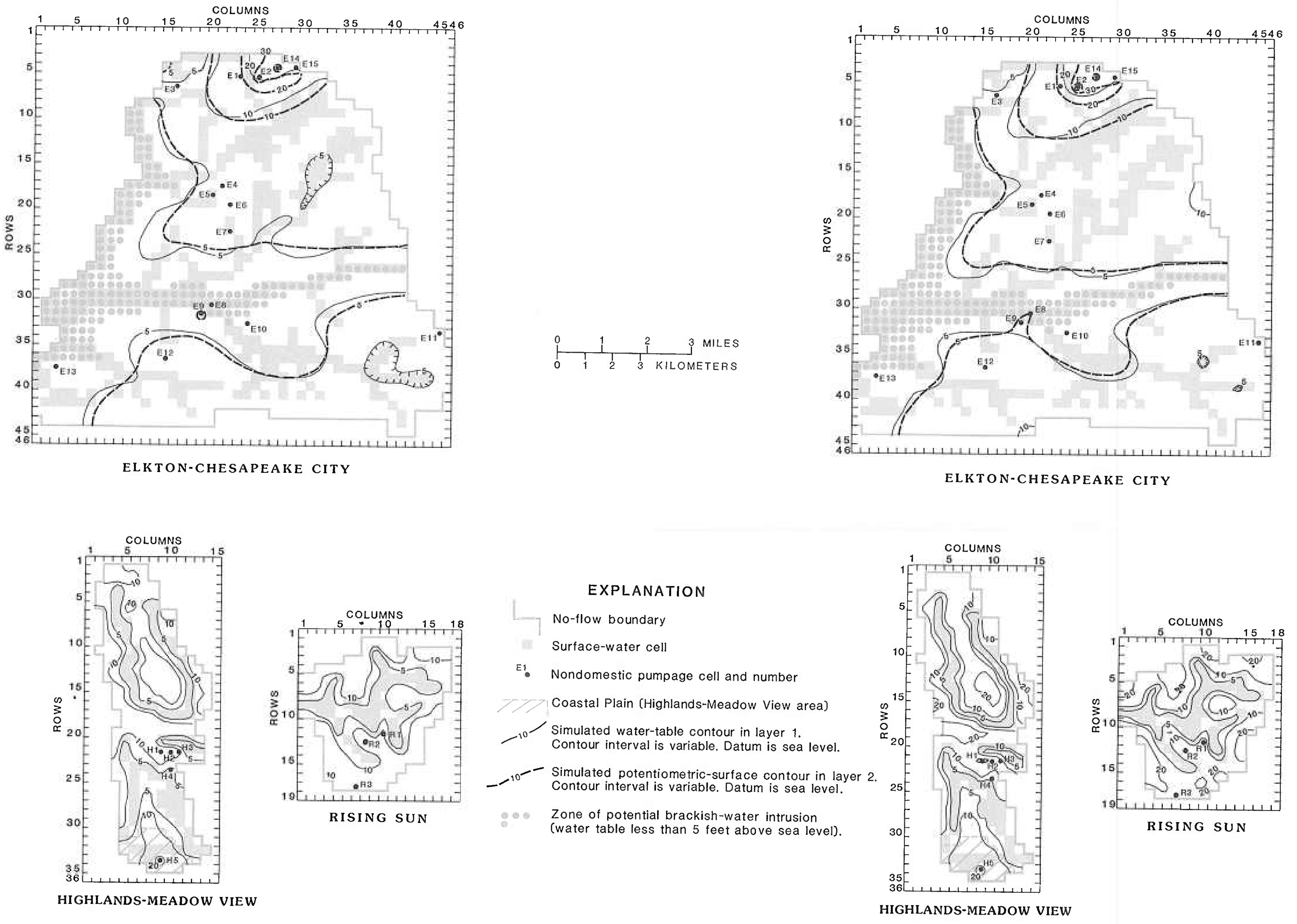


PLATE 5. Maps showing simulated drawdowns in three modeled areas caused by projected pumpage (A) without sewers and (B) with sewers.



A

B

PLATE 6. Maps showing simulated drawdowns in three modeled areas caused by projected pumpage and 2 year drought, (A) without sewers and (B) with sewers.