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

REPORT OF INVESTIGATIONS NO. 68

HYDROGEOLOGY, SIMULATION OF GROUND-WATER FLOW, AND GROUND-WATER QUALITY OF THE UPPER COASTAL PLAIN AQUIFERS IN KENT COUNTY, MARYLAND

by

David D. Drummond

Prepared in cooperation with the
United States Department of the Interior
Geological Survey

1998

CONVERSION FACTORS, VERTICAL DATUM, AND WATER-QUALITY UNITS

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

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

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."

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

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

$$°F = 1.8\ (°C) + 32°$$

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

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KEY RESULTS

Ground water is the sole source of drinking water in Kent County and is vulnerable to environmental problems, such as lowered water levels, contamination from agricultural chemicals, and brackish-water intrusion.

Five major aquifers supply ground water to users in Kent County. (p. 6)

- The Columbia aquifer is the shallowest aquifer and extends over most of Kent County. It is used for small domestic supplies. Water levels in the Columbia aquifer vary seasonally, but show no long-term trends.
- The Aquia aquifer underlies the Columbia aquifer in most of the southeastern part of Kent County and is semi-confined in most of that area. Water levels in the Aquia aquifer vary seasonally, but also show a response to pumpage by large ground-water users.
- The Monmouth aquifer underlies the Aquia aquifer and is confined in most of Kent County. It is used for domestic and small commercial supplies in the central part of the county. Water levels in the Monmouth aquifer respond to pumpage by nearby large ground-water users, but show very little seasonal or long-term trends.
- The Magothy aquifer underlies the Monmouth aquifer and is used for small commercial and domestic supplies in the northwestern part of Kent County where the Aquia is absent, and for large community supplies elsewhere in the county. Water levels in the Magothy aquifer respond to pumpage by large ground-water users and show a steady decline of about one-half foot per year.
- The Upper Patapsco aquifer underlies the Magothy aquifer and is hydraulically connected to it in parts of Kent County. The two aquifers act as a single hydraulic unit.

Flow-model simulations show that the modest increases in pumpage projected for Kent County will not create significant water-level declines. (p. 32)

- Pumpage scenarios which simulate projected population growth from 1993 to 2012 indicate regional drawdowns of less than 5 feet in all aquifers.
- Pumpage scenarios which simulate projected increases in irrigation pumpage indicate regional drawdowns of as much as 20 feet in the Aquia aquifer and 7 feet in the Magothy and Upper Patapsco aquifers.

Water quality is generally good in all of the major aquifers in Kent County, but each aquifer shows minor water-quality problems. (p. 53)

- The Columbia and Aquia aquifers are vulnerable to brackish-water intrusion and contamination from nitrate and pesticides because they are shallow.
- Water from the Monmouth aquifer has the highest concentrations of radon of any aquifer in Kent County.
- High iron and manganese concentrations cause problems in all five aquifers in Kent County, but they are most severe in the Magothy and Upper Patapsco aquifers. Water from these aquifers is often unusable without treatment.

INTRODUCTION

PURPOSE AND SCOPE

This report presents the results of a study of the hydrogeology of the upper Coastal Plain aquifers in Kent County, Maryland. It refines the hydrogeologic framework, documents water-level and water-quality conditions in each of the major aquifers, and provides estimates of the consequences of projected pumpage increases. The results of the study may provide state and county officials with a better understanding of the hydrogeologic system and with an estimate of potential problems caused by future ground-water development.

The hydrogeologic framework was evaluated by inventorying about 300 existing wells, from which data were collected on lithology, water levels, aquifer characteristics, pumpage amounts, and water quality. Twelve test wells were drilled at five sites, and hydrologic data, geophysical logs, and core samples were collected. Water levels were measured in about 220 wells during three synoptic measurements, and stream discharge was measured at 10 sites. Ground-water flow was simulated using a quasi-three dimensional finite-difference flow model. The model was calibrated using data from prepumping to 1992 and was used to simulate the effects of projected pumpage on ground-water levels.

LOCATION OF STUDY AREA

The Kent County study area is on the upper Eastern Shore of Maryland (fig. 1) and lies entirely within the Coastal Plain physiographic province. Kent County is bounded on the north by the Sassafras River, on the east by Delaware, on the south by the Chester River, and on the west by the Chesapeake Bay. Cecil County lies across the Sassafras River to the north; Queen Anne's County lies across the Chester River to the south; and Harford, Baltimore, and Anne Arundel Counties lie across the Chesapeake Bay to the west. The ground-water flow-model area extends into the neighboring counties, Delaware, and the Chesapeake Bay. Kent County comprises 251 mi^2 (square miles), and the ground-water flow-model area comprises 984 mi^2.

WATER USE

Historical Pumpage

The first ground water used in Kent County was probably obtained from small springs. The only spring of large volume reported by Clark, Mathews, and Berry (1918) was at Betterton and flowed at about 25 gpm (gallons per minute). Public water systems began supplying ground water around the turn of the century at Chestertown and Tolchester (Clark, Mathews, and Berry, 1918).

The population of Kent County increased from 13,677 in 1950 to 17,842 in 1990. Ground-water pumpage of large users (greater than 10,000 gallons per day [gal/d]) increased from 200,000 gal/d in 1900 to 808,000 gal/d around 1950 to 2,287,000 gal/d in 1990 (Wheeler and Wilde, 1987), (Tompkins, Cooper, and Drummond, 1994). Total ground-water use in 1950 and 1980 was estimated to be about 1.4 million gallons per day (Mgal/d) and 3.5 Mgal/d by Wheeler and Wilde (1987).

The Aquia aquifer supplied the majority of ground water (79 percent of large-users' withdrawals in 1990). The Magothy aquifer supplied approximately 11 percent, the Upper Patapsco about 7 percent, and the Monmouth about 3 percent of large-users' withdrawals in 1990.

1992 Pumpage

Ground-water withdrawals by large users (greater than 10,000 gal/d as a yearly average) in 1992 totaled about 2.5 Mgal/d. Large users were the only users required by the state to report their pumpage. Although some irrigation pumpers may have withdrawn more than 10,000 gal/d, they were excluded from the reporting requirement until 1996, and their pumping totals are undocumented. Total ground-water use in Kent County for 1992 was estimated to be 5.59 Mgal/d (oral commun., J. C. Wheeler, U. S. Geological Survey, 1994). Wheeler estimated irrigation pumpage from aerial photographs showing total acreage being irrigated, and approximations of additional water per acre required to supplement rainfall for typical cropland.

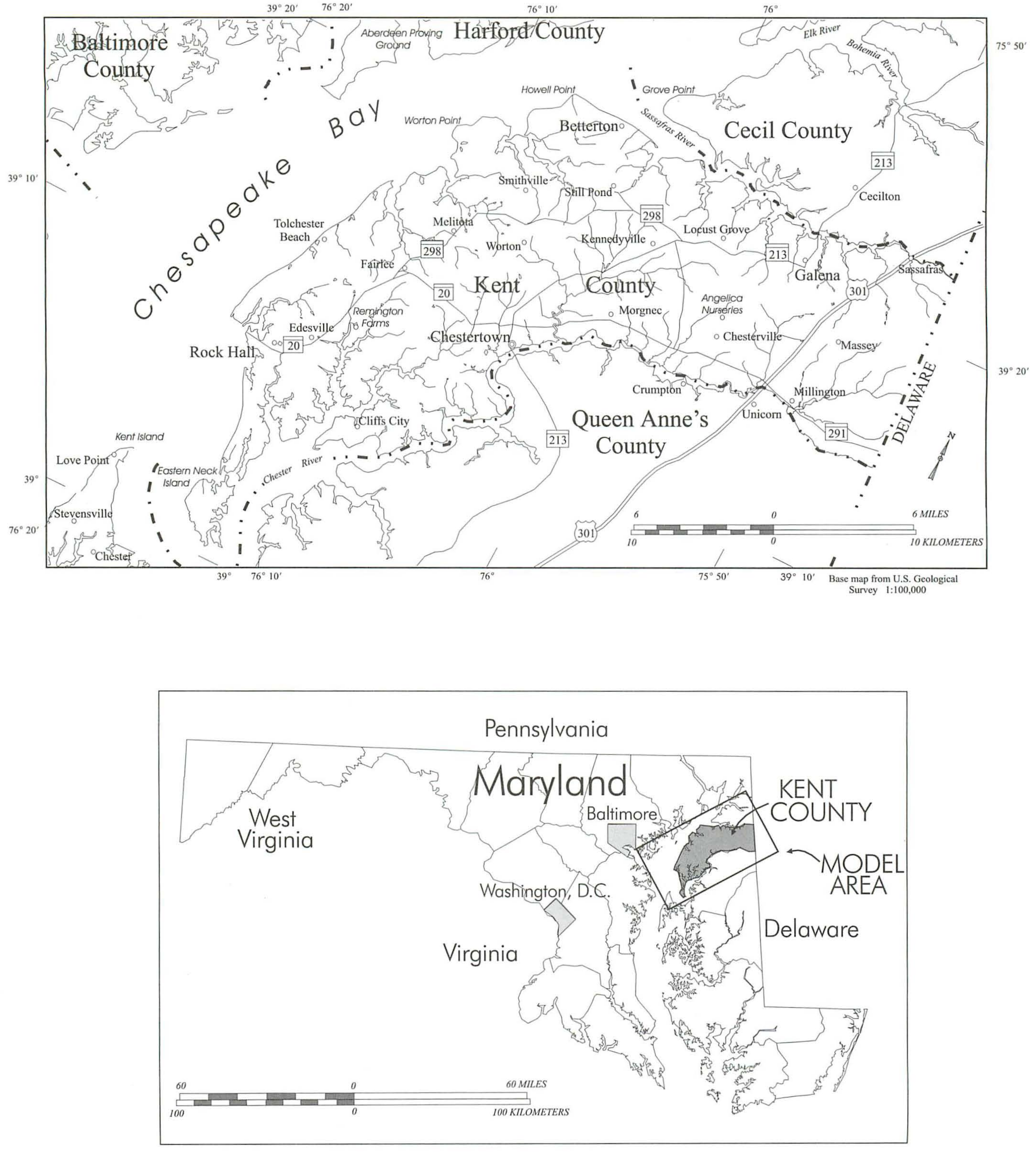


Figure 1.—Location of study area and flow-model area.

The largest users in 1992 were Angelica Nurseries (0.95 Mgal/d), Chestertown (0.702 Mgal/d), Campbell Soup Company[1] (0.32 Mgal/d), and Rock Hall (0.203 Mgal/d). Locations of major users in Kent County are provided in the flow-modeling section of this report.

Future Pumpage

Modest population increases are projected for Kent County through the next few decades, and ground-water pumpage is expected to increase concomitantly. The Maryland Office of Planning estimates that the county population will increase from 17,842 in 1990 to 18,600 in 2000, 19,100 in 2010, and 19,500 in 2020.

METHODS OF INVESTIGATION

The hydrogeology of Kent County was investigated by first compiling hydrologic data from published and file sources. These data, and data collected during the course of this project, were published in a Basic Data Report (Tompkins, Cooper, and Drummond, 1994). The basic data report includes well and spring records; chemical analyses from wells, springs, and stream sites; streamflow measurements and characteristics; chloride concentrations and specific conductance measurements from estuaries; ground-water appropriation and withdrawal data; hydrographs; geophysical logs; lithologic descriptions; and well-location maps.

One core hole and 12 test wells were drilled to obtain lithologic and stratigraphic data at 5 sites throughout the county. Geophysical logs were run on the uncased bore holes, and aquifer tests were performed on nine of the completed wells. Water samples were collected from the test wells for chemical analysis. Automatic water-level recorders were installed on 18 wells (including some privately-owned wells) to record water-level fluctuations and to produce hydrographs.

Synoptic water-level measurements were conducted during the fall of 1990, April 1991, October and November 1991, and April 1992. The measured water levels were used to construct potentiometric maps for each aquifer. The measuring points of most wells used in the synoptic measurements were estimated from topographic maps and have accuracies of about 5 feet (ft). The accuracy of the potentiometric maps constructed from the synoptic measurements is also considered to be ± 5 ft. Only the test wells drilled for the project were surveyed to an accuracy of 1 ft. Low-flow streamflow measurements were made at eight sites on May 4, 1993 to determine base flow from the ground-water system into streams.

A ground-water flow model was developed to simulate the regional flow system and evaluate the effects of stresses on the hydrologic system such as pumpage increases, droughts, and brackish-water intrusion. The flow model included all of Kent County, parts of neighboring counties and part of Delaware. It was calibrated to 1992 conditions and was used to simulate future conditions up through 2012. The U.S. Geological Survey's Modular Flow Model (McDonald and Harbaugh, 1988) was used for all simulations.

The ground-water quality of Kent County was investigated by sampling about 57 wells for major ions, nutrients, organic carbon, and radon. Chemical analyses from wells sampled during other projects were compiled and used for interpretations. The ground-water quality of each of the five major aquifers was described through the use of Piper diagrams, Stiff diagrams, and statistical analysis.

PREVIOUS INVESTIGATIONS

Darton (1896) first described the hydrogeology of the Coastal Plain region of Maryland and Delaware, but included scant information about Kent County. Clark, Mathews, and Berry (1918) provided a description of the aquifers that underlie Kent County including data from several deep wells. Miller (1926) provided the first detailed description of the geology underlying Kent County. Anderson (1948) studied the Cretaceous and Tertiary subsurface geology of the entire Eastern Shore based largely on three deep test wells on the lower Eastern Shore. Overbeck and Slaughter (1958) gave a detailed description of the hydrogeology of the upper Eastern Shore. They included a description of the major aquifers in the area, a listing of inventoried wells and their construction characteristics, a series of lithologic logs, and a description of water quality in the major aquifers. Rasmussen and Andreasen (1959) studied the Beaverdam Creek basin near Salisbury and determined a hydrologic budget for the basin. Glaser (1969)

[1] Changed ownership to Chestertown Foods, Inc. in October 1996.

examined the petrology and origin of Potomac and Magothy sediments in the Middle Atlantic Coastal Plain.

A user's guide for Coastal Plain aquifers was written by Hansen (1972) which described aquifer characteristics and water quality. Minard (1974) mapped the geology in the Betterton quadrangle and described the stratigraphy and origin of the sediments in the shallow subsurface. Otton and Mandle (1984) described the hydrogeology of the Potomac Group in the upper Chesapeake Bay area. A listing of historical ground-water use throughout Maryland was provided by Wheeler and Wilde (1987). Drummond (1988) described the hydrogeology of the Kent Island area in Queen Anne's County and analyzed the problem of brackish-water intrusion in a setting similar to Kent County. Hansen (1992) described the stratigraphy of a core hole near Chesterville, with an interpretation of the regional stratigraphic relationships. Tompkins, Cooper, and Drummond (1994) compiled a report of ground-water and surface-water data for Kent County as a part of the current study.

ACKNOWLEDGMENTS

Research for this project was funded by a joint agreement between the Maryland Geological Survey and the U.S. Geological Survey. The author expresses gratitude to Remington Farms, Angelica Nurseries, Tolchester Marina, the Kent County Department of Public Works, and the Kent County Department of Parks and Recreation for allowing observation wells to be installed on their property. Thanks also go to the many homeowners, businesses, farmers, and municipalities for allowing water-level measurements and water-quality sampling of their wells. Field work for this study was conducted by Michael D. Tompkins and Barbara F. Cooper of the Maryland Geological Survey, and James J. Manning of the U.S. Geological Survey. Observation wells were drilled by Darwin Fehely and Mark Filar of the former Maryland Water Resources Administration.

HYDROGEOLOGY

Kent County is underlain by Coastal Plain sediments of Pleistocene, Tertiary, and Cretaceous ages (tab. 1), (fig. 2). These sediments form a wedge-shaped body which becomes thicker to the southeast. The Coastal Plain sediments are underlain by crystalline bedrock of Paleozoic and Precambrian age, the surface of which increases in depth to the southeast from 1,121 ft below sea level at Still Pond to 2,059 ft below sea level at Massey (Otton and Mandle, 1984). This report focuses on aquifers in the upper Coastal Plain sediments, which supply all of the ground water in Kent County. Included are (from shallowest to deepest): the Columbia, Aquia, Monmouth, Magothy, and Upper Patapsco aquifers. Although aquifers are present in sands of the Potomac Group deeper than the Upper Patapsco (Otton and Mandle, 1984), they are not currently used for water supply due to their depth and, in places, poor water quality.

AQUIFER DESCRIPTIONS

The hydrogeologic units of Kent County subcrop and outcrop in a series of southwest- to northeast-trending bands (fig. 3). The older units are to the northwest and progressively younger units subcrop to the southeast. The depths and thicknesses of these units are shown in a series of hydrogeologic sections, the locations of which are shown in figure 4. Section A-A' (fig. 5) runs through the long axis of the county from Eastern Neck Island to Massey and is roughly parallel to regional strike. Sections B-B' (fig. 6), C-C' (fig. 7), and D-D' (fig. 8) cut across section A-A' in successively eastward locations and are roughly perpendicular to strike. The sections were constructed from gamma logs and lithologic logs of test wells and other deep wells that were available for logging. Only partial logs are shown for wells KE Ac 20, KE Bg 33, and QA Be 15; complete logs for these wells are included in Otton and Mandle (1984). Hydraulic properties of each of the major aquifers are listed in table 2.

Columbia Aquifer

The Columbia aquifer is a surficial, unconfined aquifer that blankets most of Kent County. As defined in this report, it is composed of sediments of the

Table 1--Generalized hydrogeology and stratigraphy of Kent County

[Stratigraphy modified from Owens and Denny (1979) and Hansen (1992); ft = feet]

System	Series	Hydro-geologic unit	Strati-graphic unit	Approximate thickness (ft)	Lithology	Water-bearing properties
Quaternary	Pleistocene	Columbia aquifer	Kent Island Formation	0-35(?)	Loose, light-colored, medium to coarse sand, and dark-colored, massive silt-clay.	Functions as an unconfined or semi-confined aquifer.
Tertiary	? Pliocene(?) and/or Upper Miocene(?) ?		Pensauken Formation	0-145(?)	Orange to reddish brown, fine to coarse sand and gravelly sand.	Functions as an unconfined or semi-confined aquifer. Yields moderate amounts of water to shallow wells.
	Miocene	Calvert confining unit	Calvert Formation	0-15(?)	Light brown and gray clay and silt, and white and gray, very fine to fine sand.	Functions as a leaky confining unit in parts of eastern Kent County.
	Oligocene	Aquia aquifer	Old Church(?) Formation	0-5(?)	Dusky brown, clayey, fine to medium, glauconitic sand.	Not an important unit due to its limited extent.
	Eocene(?)		Nanjemoy(?) Formation	0-30(?)	Greenish gray, clayey, fine to medium, glauconitic sand.	Not an important unit due to its limited extent.
	Paleocene		Aquia Formation	0-200	Olive brown to greenish gray, clayey, fine to medium, glauconitic sand.	An important confined and semi-confined aquifer throughout much of Kent County.
			Hornerstown Formation	0-100	Olive brown to grayish, fine to medium, glauconitic sand.	
Cretaceous	Upper Cretaceous	Severn confining unit	Severn Formation	0-40	Dark gray, clayey, glauconitic, fine sand.	Functions as a leaky confining unit.
		Monmouth aquifer	Mt. Laurel Formation	0-100	Light to medium gray, fine to coarse, clayey, glauconitic sand.	Functions as a fair aquifer in some parts of the county.
		Matawan confining unit	Matawan Group (undivided)	0-155	Dark to olive gray, silty clay and fine sand.	Functions as a confining unit throughout most of the county, but yields small amounts of water in some places.
		Magothy aquifer	Magothy Formation	0-55	Yellow-brown and light gray, fine to very coarse, quartz sand and gray to black, lignitic clay.	An important aquifer where the sandy facies is present.
	? Lower Cretaceous	Upper Patapsco aquifer / undifferentiated	Potomac Group (undivided)	1,150-2,500	Light-colored, fine to very coarse sand, and variegated silty clay.	Sandy units function as aquifers; clay units function as confining units.
Paleozoic			Basement Complex		Various types of crystalline rock and saprolite.	Not used for water supply in Kent County.

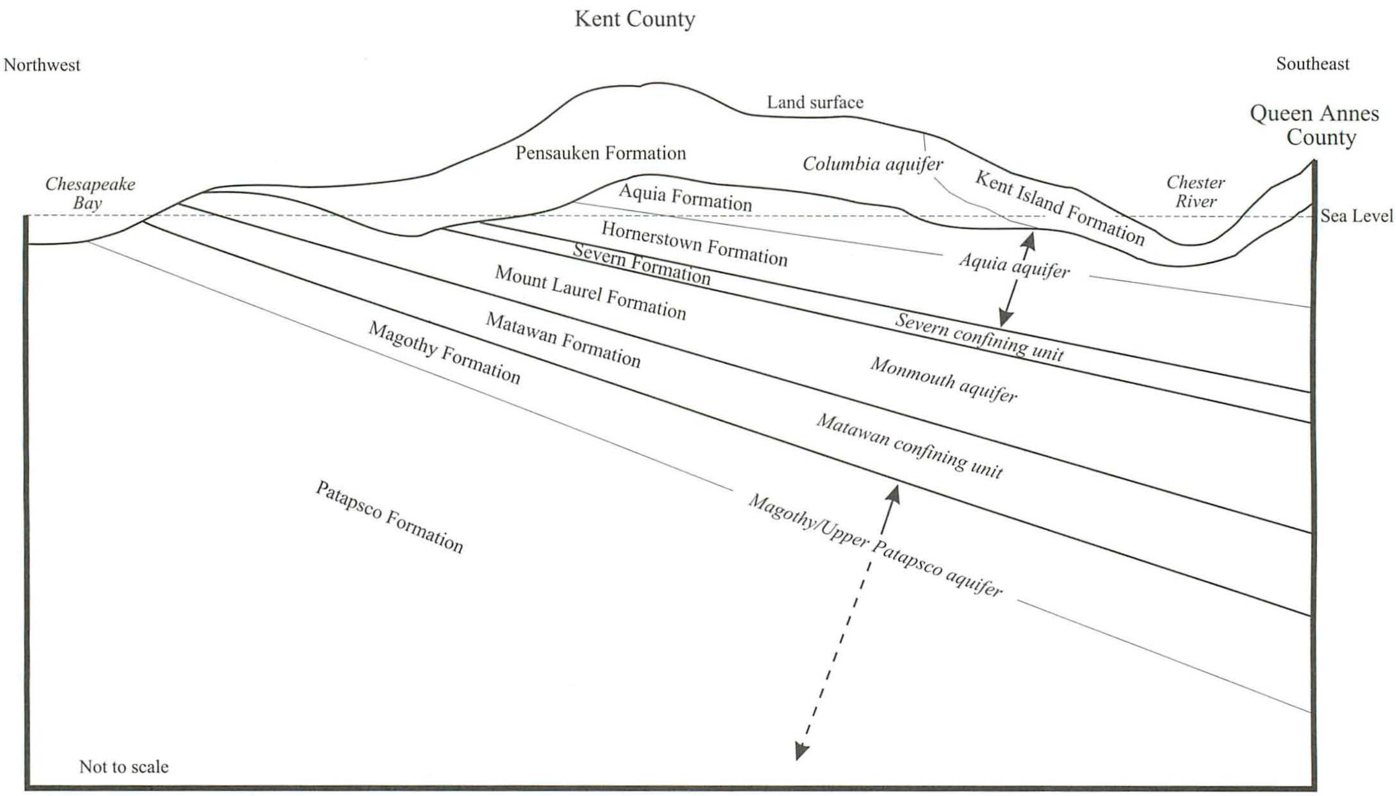


Figure 2.—Generalized cross section showing major hydrogeologic units in Kent County.

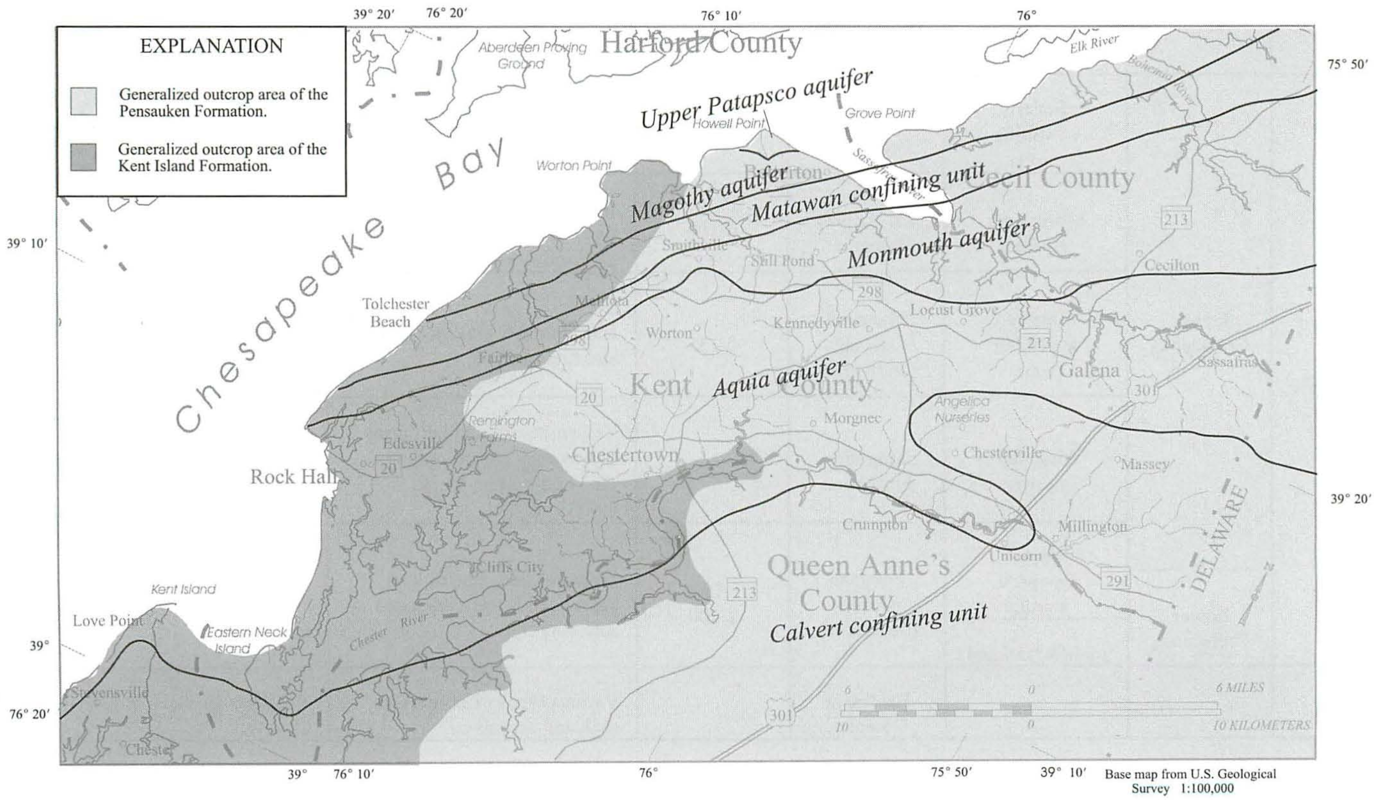


Figure 3. –Generalized outcrop and subcrop areas of hydrogeologic units in Kent County.

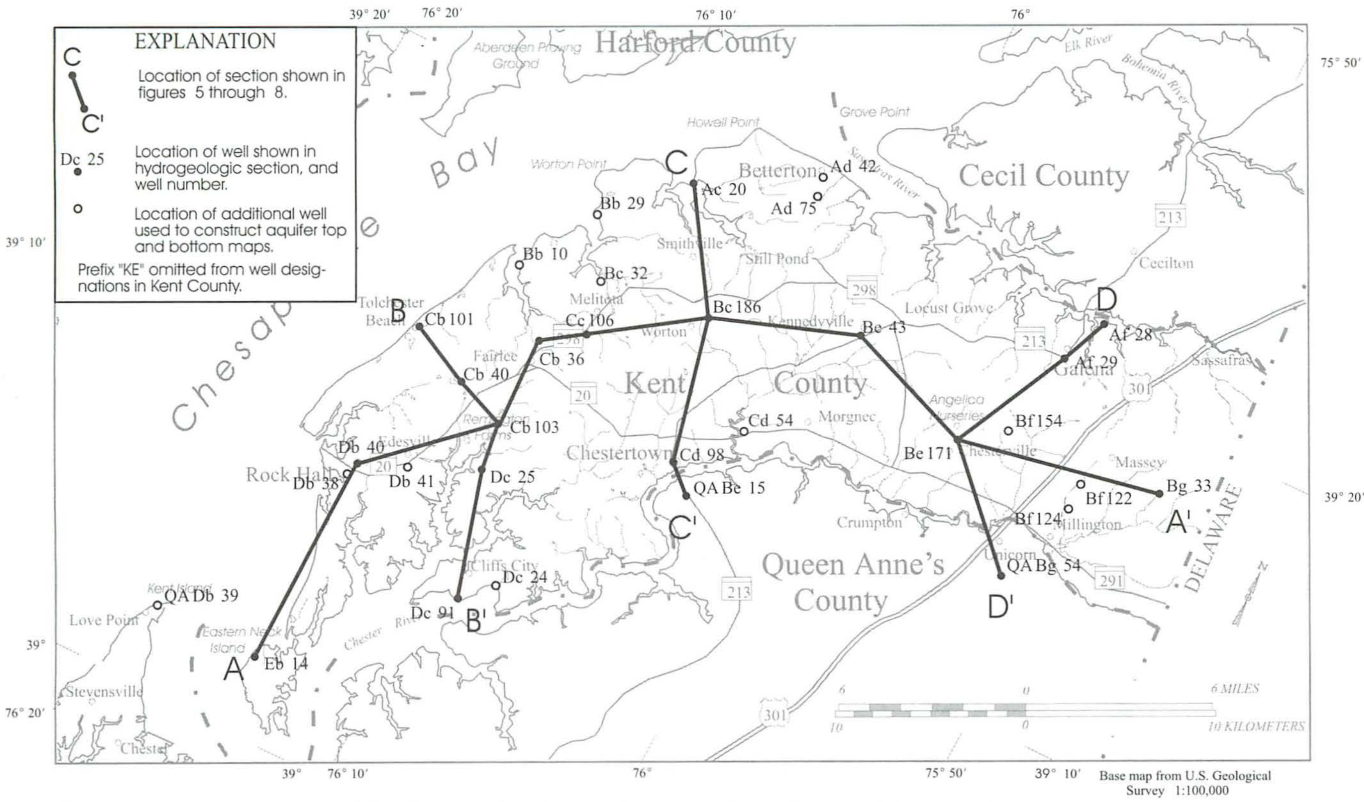


Figure 4.—Locations of hydrogeologic sections and wells used to construct aquifer top and bottom maps.

Pensauken Formation and Kent Island Formation. This usage differs from that used by Bachman (1984), who did not include sediments of the Kent Island Formation in the Columbia aquifer. Pensauken sediments occupy the uplands in the central and eastern part of the county, and Kent Island sediments occupy the lowlands to the southwest. The Kent Island Formation was included in the Columbia aquifer so that the Columbia aquifer would comprise all surficial sediments in the study area.

Extent

The Columbia aquifer extends over most of the county, and is absent only in the bottom of stream valleys and on bluffs overlooking the Sassafras River and the Chesapeake Bay where it was removed by erosion. It ranges in thickness from 0 ft to over 100 ft near Betterton, where it apparently infilled a post-Tertiary channel. Generally in Kent County, the Columbia aquifer is about 20 to 40 ft thick (Bachman, 1984, pl. 5).

Technically, the top of the Columbia aquifer is the water table, the altitude of which varies with time. For convenience, the top of the Columbia aquifer is shown as the land-surface elevation in figure 9, which is the highest elevation the water table could attain. This elevation ranges from sea level at the shoreline to slightly more than 100 ft above sea level near Still Pond. The central and eastern portions of the county form an upland plain generally 60 to 85 ft above sea level that is incised by numerous small creeks. The western portion of the county forms a lowland plain about 10 to 30 ft above sea level that is incised by several swampy tidal creeks. The bottom of the Columbia aquifer ranges from 80 ft below sea level near Still Pond to 90 ft above sea level near Smithville (fig. 10). It is bounded on the bottom by older hydrologic units which subcrop beneath it.

Lithology

Where the Columbia aquifer is composed of Pensauken sediments, it is an orange to reddish-brown

(Text continued on p. 16.)

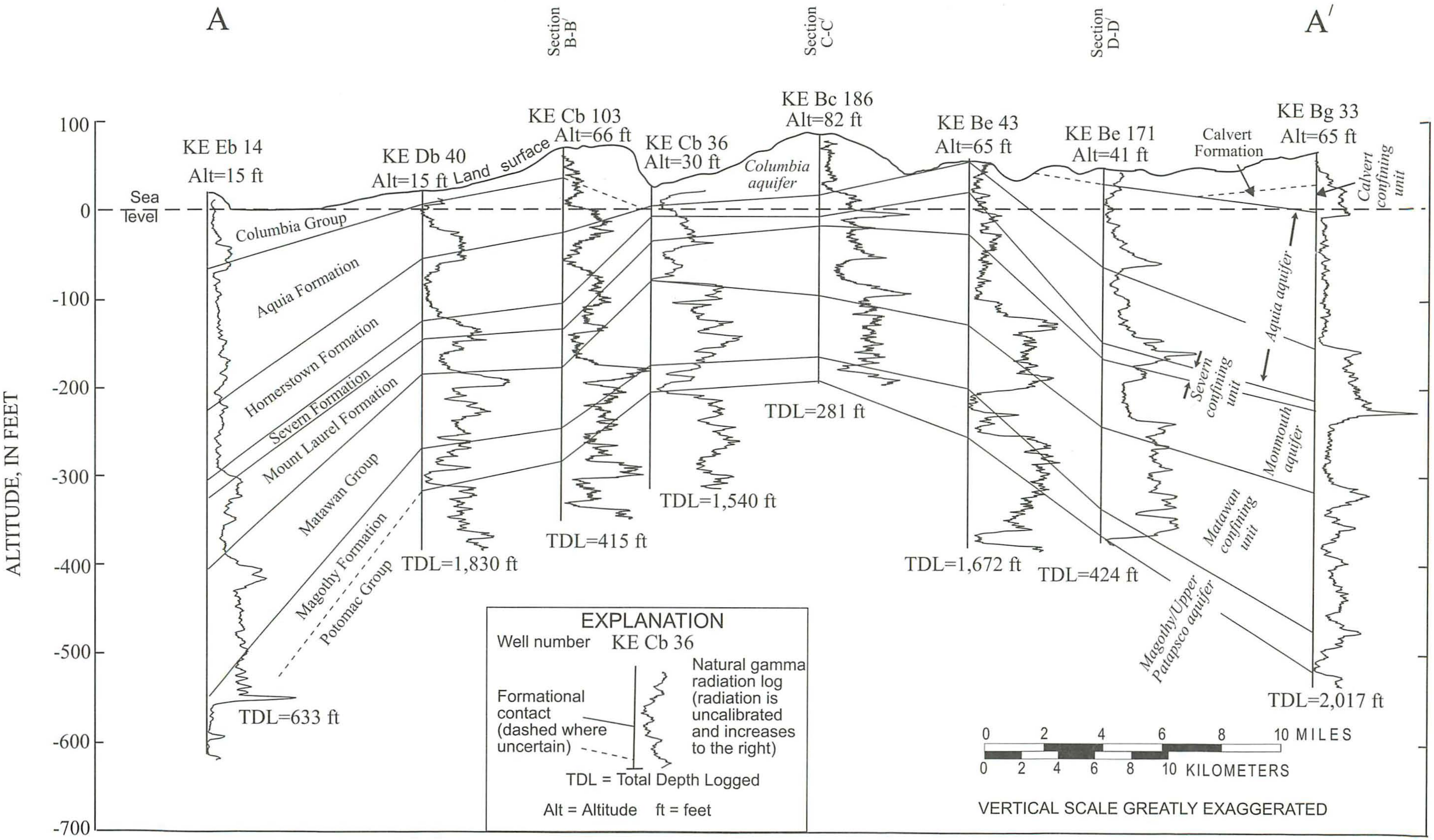


Figure 5.—Hydrogeologic section A-A' showing major hydrogeologic units in the upper Coastal Plain of Kent County.

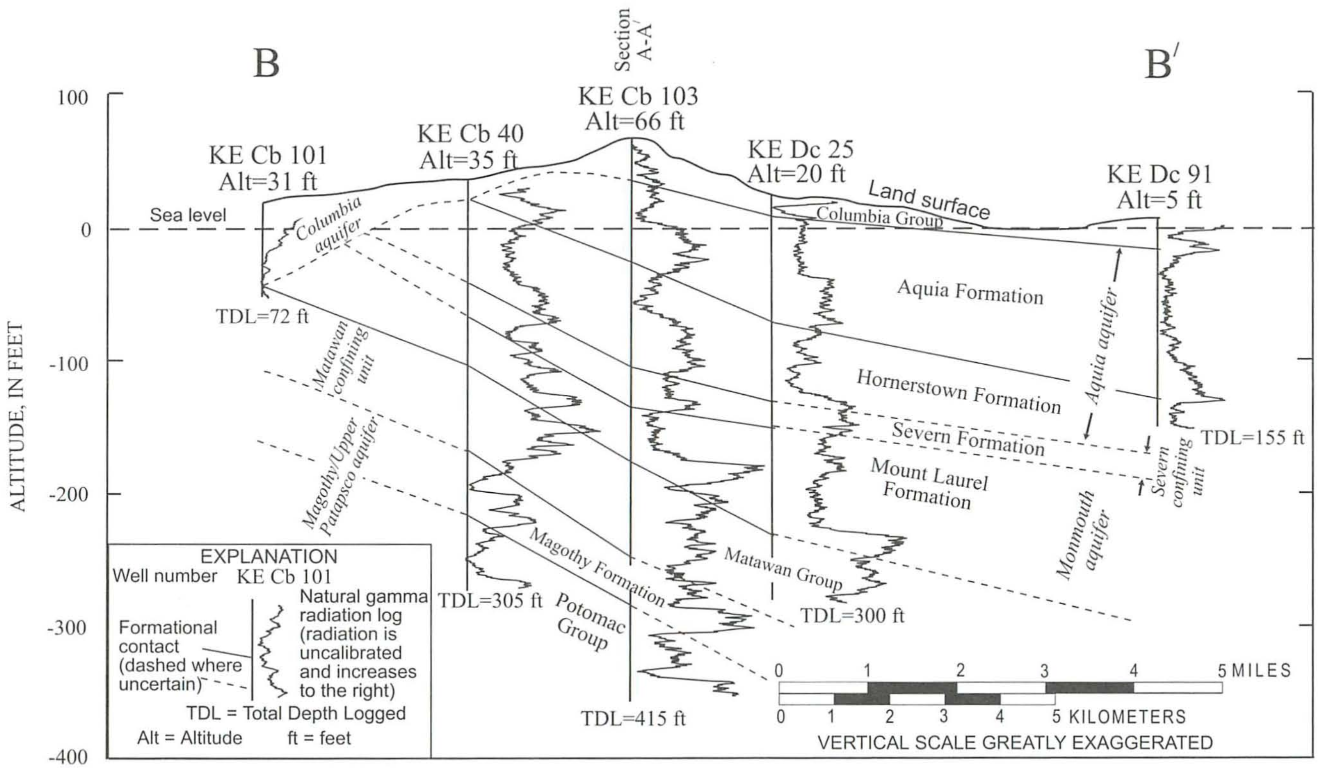


Figure 6.—Hydrogeologic section B-B′ showing major hydrogeologic units in the upper Coastal Plain of Kent County.

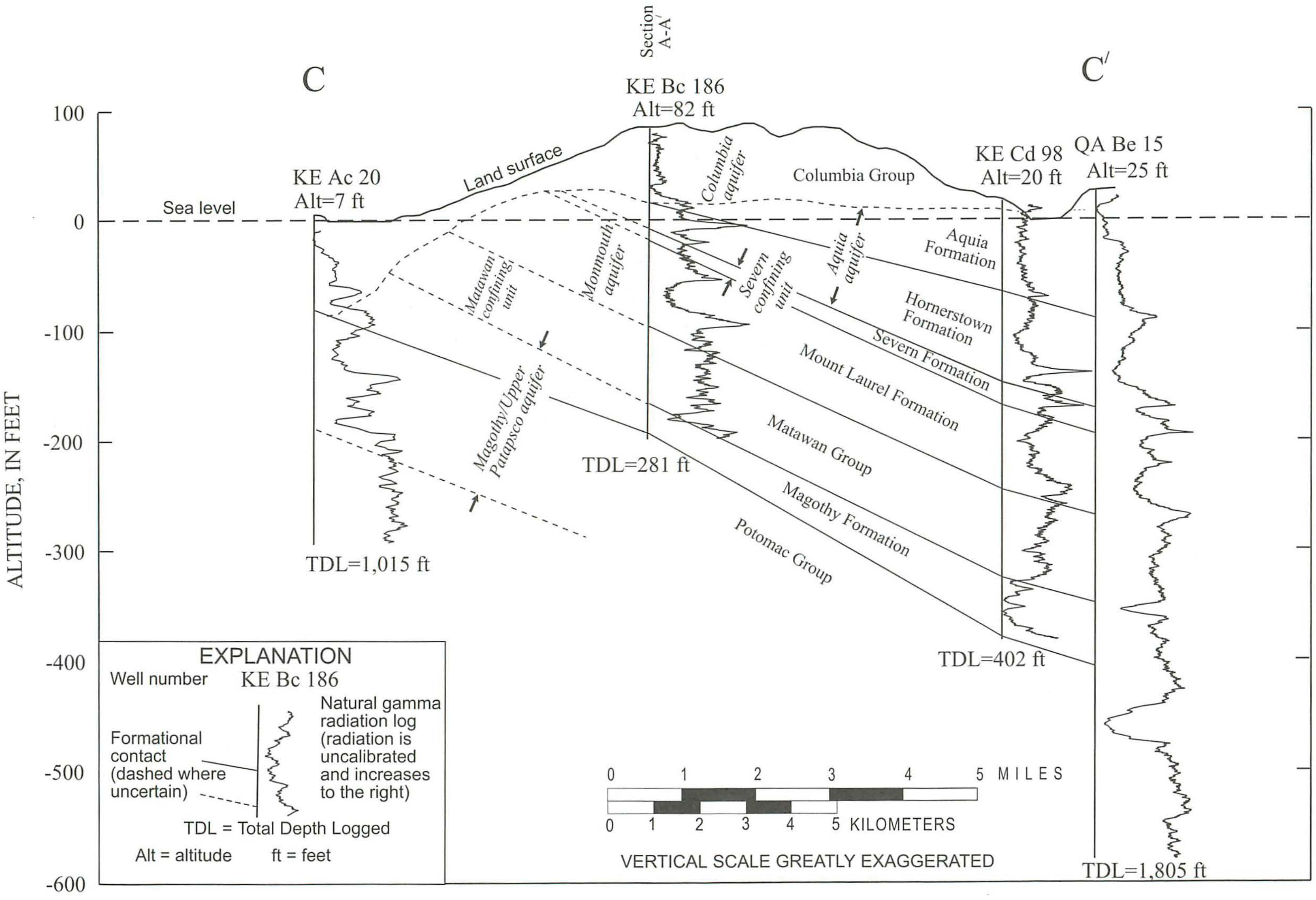


Figure 7. —Hydrogeologic section C-C′ showing major hydrogeologic units in the upper Coastal Plain of Kent County.

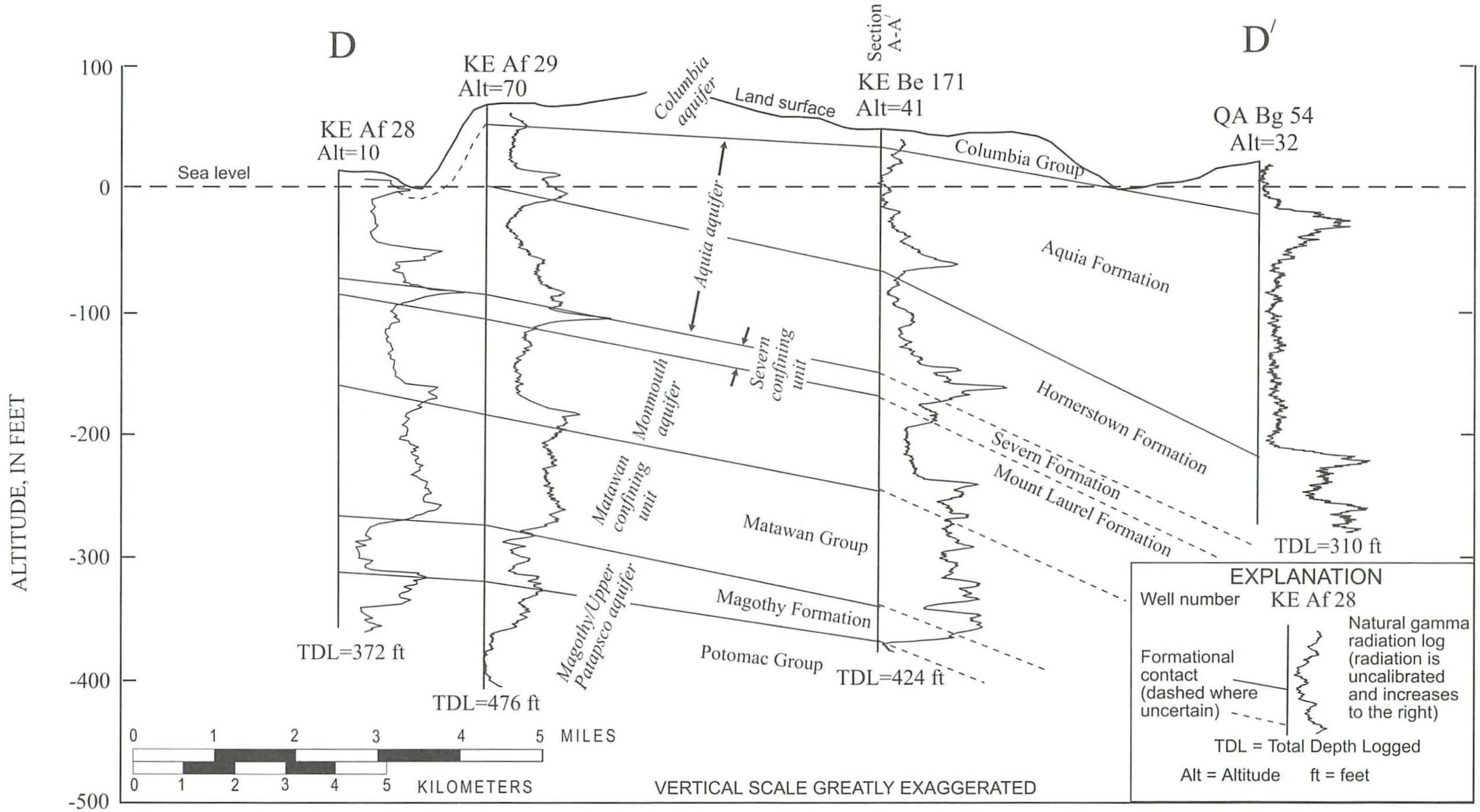


Figure 8. —Hydrogeologic section D-D/ showing major hydrogeologic units in the upper Coastal Plain of Kent County.

Table 2.–Hydraulic properties of aquifers in Kent County and adjacent areas

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

Well	Location	Transmissivity (ft^2/d)	Storativity	Source
Columbia aquifer				
KE Dc 89	Cliffs City	470	–	1
Aquia aquifer				
KE Bg 20	Massey	800	0.0004	2
KE Cb 99	Remington Farms	850	–	1
KE Cd *	Chestertown	3,200	–	3
KE Cd 50	Chestertown	500	.0003	2
KE Cd 95	Chestertown	10,000	–	4
KE Dc *	Walnut Point	630	.0005	5
KE Dc 91	Cliffs City	1,700	–	1
QA Ed 36	Queenstown	4,500	.0003	3
Monmouth aquifer				
KE Be 30	Kennedyville	300	.0012	2
KE Bg 26	Massey	740	–	2
KE Cb 98	Remington Farms	220	–	1
KE Db 3	Rock Hall	670	.0003	2
Magothy aquifer				
CE Ee 11	Cecilton	3,300	.0001	3
KE Eb 14	Eastern Neck Island	2,300	–	6
Upper Patapsco aquifer				
CE Dd 73	Earleville	210	.00005	7
CE Ee 29	Cecilton	1,500	–	2
KE Bc 186	Worton	32	–	1
KE Be 171	Angelica Nurseries	1,500	–	1
KE Cb 39	Fairlee	2,700	.0003	8
KE Cb 103	Remington Farms	86	–	1

1 This study
2 Otton and Mandle (1984)
3 Overbeck and Slaughter (1958)
4 Earth Data, Inc. (1990)
5 Earth Data, Inc. (1989)
6 Mark Schultz Associates (1992)
7 Otton and others (1988)
8 Earth Data, Inc. (1992)

* Average value from several aquifer tests.

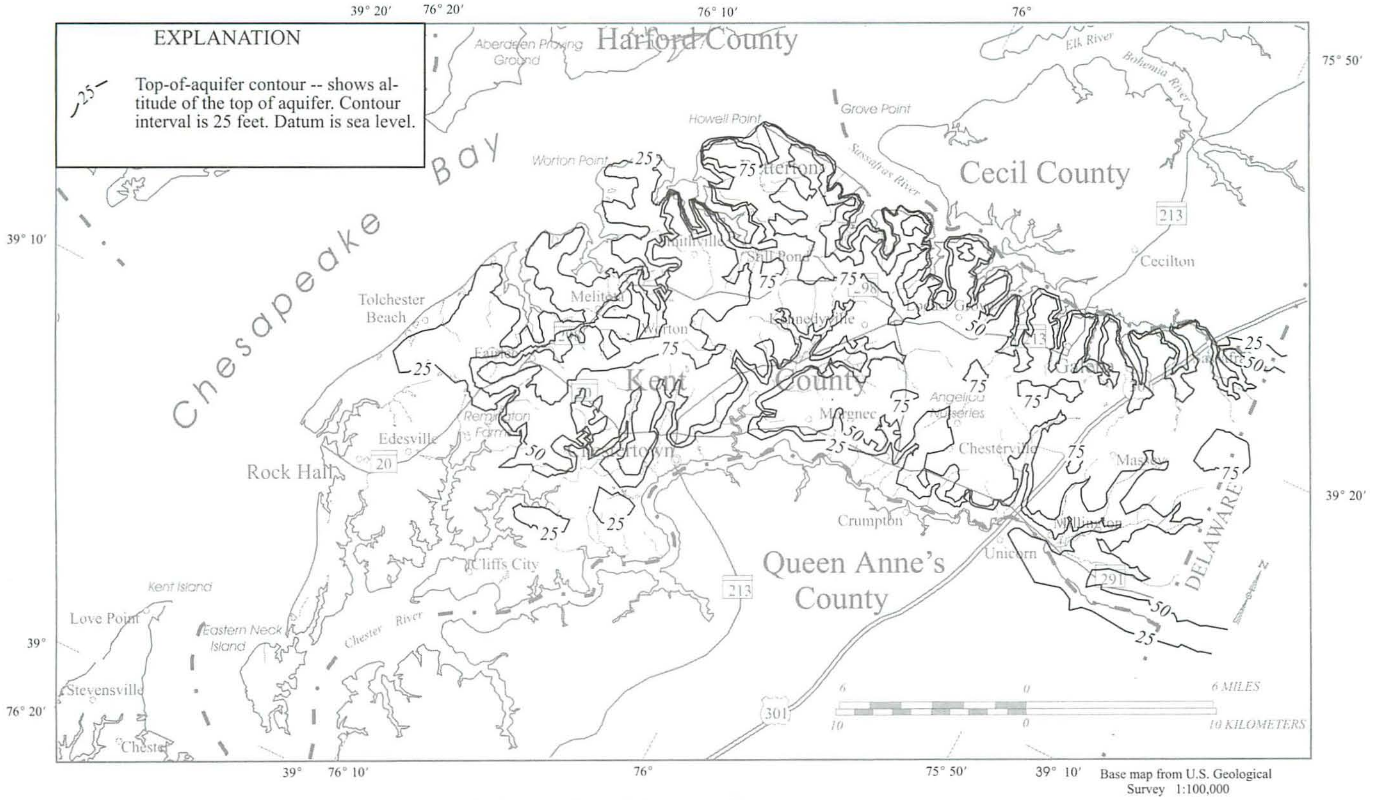


Figure 9.—Altitude of the top of the Columbia aquifer.

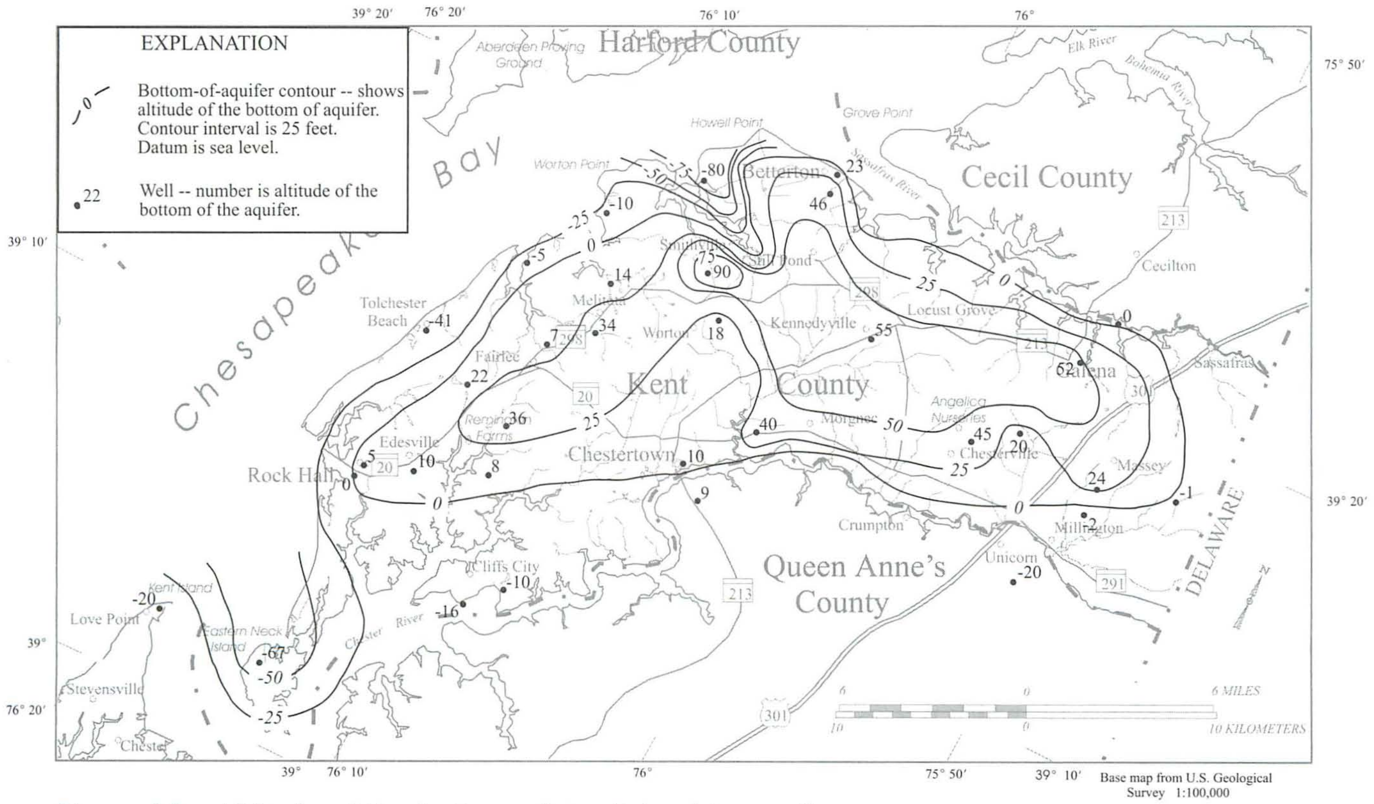


Figure 10.—Altitude of the bottom of the Columbia aquifer.

gravelly sand, mostly quartz and feldspar, with abundant heavy minerals of an immature suite. In places, the gravelly sand is overlain by 5 to 20 ft of medium brown and gray sandy clay. Where the Columbia aquifer is composed of Kent Island sediments, it is a light colored sand that overlies dark massive to thinly-laminated clay-silt (Owens and Denny, 1979). In places, the Columbia aquifer contains beds of coarse gravel and cobbles up to several inches in diameter, which are polylithic and contain clasts of sandstone, fossiliferous limestone, and schist.

Hydraulic Properties

Few data for hydraulic properties are available for the Columbia aquifer in Kent County. An aquifer test performed on well KE Dc 89 at Cliffs City (in the Kent Island Formation) yielded a transmissivity of 470 feet squared per day (ft^2/d) and, using an aquifer thickness of 10 ft, a hydraulic conductivity of 47 feet per day (ft/d) (tab. 2). Bachman (1984) reported hydraulic conductivity values from aquifer tests of 80 and 200 ft/d in Queen Anne's County (in the Pensauken Formation). Hydraulic conductivity values are probably higher in the Pensauken than in the Kent Island Formation, based on lithologic characteristics of the units.

Water Levels

Water levels in wells screened in the Columbia aquifer represent the water table. Water-level measurements and the contoured water-table altitude for April 1992 are shown in figure 11. The water table ranges from about sea level near the shoreline to 67 ft above sea level in the upland central part of the county.

Hydrographs for three wells screened in the Columbia aquifer are shown in figure 12. The period of record displayed is from February 16 to March 25, 1993. Well Bc 185 is located near Worton, in the upland part of the county. Water levels in this well show a steady increase throughout the period and a small increase on March 14, which is a response to a storm. These trends indicate that the upland is a recharge area for the regional flow system. The lack of a barometric fluctuation indicates the aquifer is completely unconfined in this area. Water levels in well KE Cb 101, located at Tolchester Beach on the Chesapeake Bay, do not show the steady rise in water levels displayed in KE Bc 185, indicating that this is not a regional recharge area. A slight barometric fluctuation indicates that the Columbia aquifer is semi-confined in this area. Water levels in well KE Dc 89 primarily show a semidiurnal tidal fluctuation caused by the well's proximity to the Chester River.

Long-term hydrographs for these same wells (Tompkins, Cooper, and Drummond, 1994, figure 2) show seasonal fluctuations caused by the annual recharge/discharge cycle, but no long-term trends.

Confining Units

The Columbia aquifer is not overlain by any significant confining units and, thus, is generally unconfined. Locally, however, clayey units near the top of the aquifer may create confined conditions. The Columbia overlies various other hydrogeologic units (figs. 2 and 3). Roughly from northwest to southeast, it overlies the Upper Patapsco aquifer, the Magothy aquifer, the Matawan confining unit, the Monmouth aquifer, the Severn confining unit, the Aquia aquifer, and the Calvert confining unit. Where the Columbia overlies an aquifer, unconfined conditions will prevail locally in that aquifer. Where the Columbia overlies a confining unit, the aquifers below are confined.

Aquia Aquifer

The Aquia is the most widely used aquifer in Kent County. The Aquia aquifer comprises several geologic units, which act as a single hydraulic unit. This includes, from shallowest to deepest, the Old Church(?), Nanjemoy, Aquia, and Hornerstown Formations (Hansen, 1992). The Nanjemoy and Old Church Formations are of minor importance, as they occur only locally, in the extreme southwestern and southeastern parts of the county, respectively. In earlier studies, such as Overbeck and Slaughter (1958), the lower part of the Aquia aquifer (for instance, from 55 to 125 ft below sea level at well KE Db 40 in figure 5) was included in the Monmouth aquifer based on lithologic data. Hansen (1992), however, determined that this section is early Paleocene in age, based on paleontologic data, and included it in the Hornerstown Formation. Hansen's

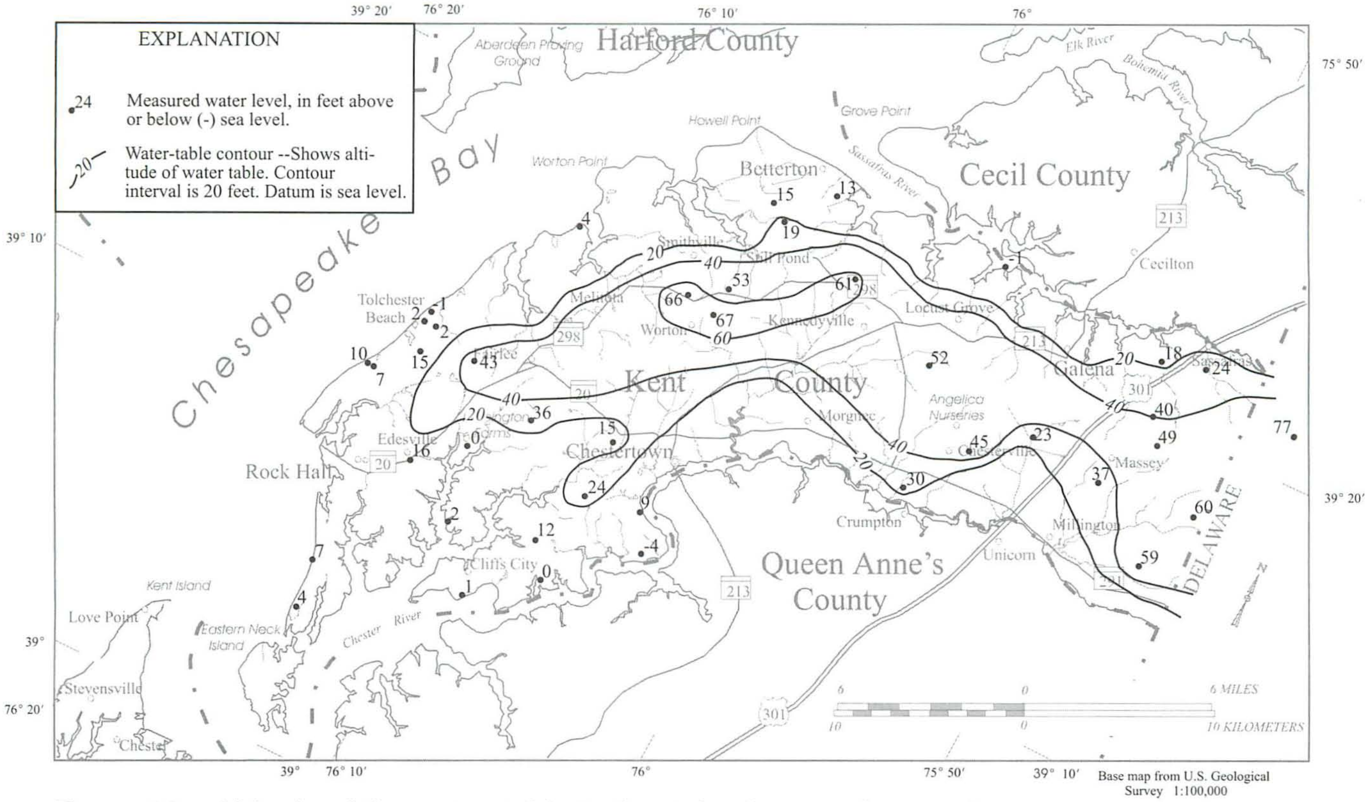


Figure 11.—Altitude of the water table in the Columbia aquifer, April 1992.

usage is retained in this study, and sediments of the Hornerstown Formation are included in the Aquia aquifer.

Extent

The Aquia aquifer subcrops beneath the Columbia aquifer in a band extending from Eastern Neck Island in the southwest to Sassafras in the northeast. Southeast of its subcrop area, the Aquia is overlain by the Calvert confining unit, and becomes progressively deeper. The top of the Aquia aquifer ranges from about 50 ft above sea level near Sassafras to nearly 100 ft below sea level on the southern tip of Eastern Neck Island (fig. 13). The bottom of the Aquia ranges from about 40 ft above sea level near Smithville to about 400 ft below sea level on Eastern Neck Island (fig. 14). The thickness of the Aquia aquifer ranges up to about 300 ft on Eastern Neck Island and at Massey. The Aquia aquifer is bounded on the bottom by the Severn confining unit which separates it from the Monmouth aquifer below.

Lithology

The Aquia aquifer is a fine to coarse, glauconitic quartz sand which locally contains clayey layers, shell beds, cemented zones, and highly weathered zones. It is olive-brown to grayish-olive with a "salt and pepper" aspect where unweathered, and dark reddish brown where weathered. The quartz grains are fine to coarse sand, generally clear and colorless but commonly stained green or brown. Glauconite constitutes from 10 to 80 percent of the sand fraction, is generally ovoid or polylobate, and ranges in color from dark green and black where unweathered, to light green and dark reddish brown where weathered. Clay beds within the Aquia aquifer range up to 50 ft in thickness and are green to gray, silty and sandy, and highly glauconitic. They seem to occupy various stratigraphic positions within the Aquia aquifer. Calcareous beds occur in the lower part of the Aquia aquifer and consist of abundant shell material and chalky calcite cement. A layer containing the brachiopod *Oleneothyris harlani* widely occurs in the basal few feet of the Aquia Formation near the contact with the Hornerstown Formation.

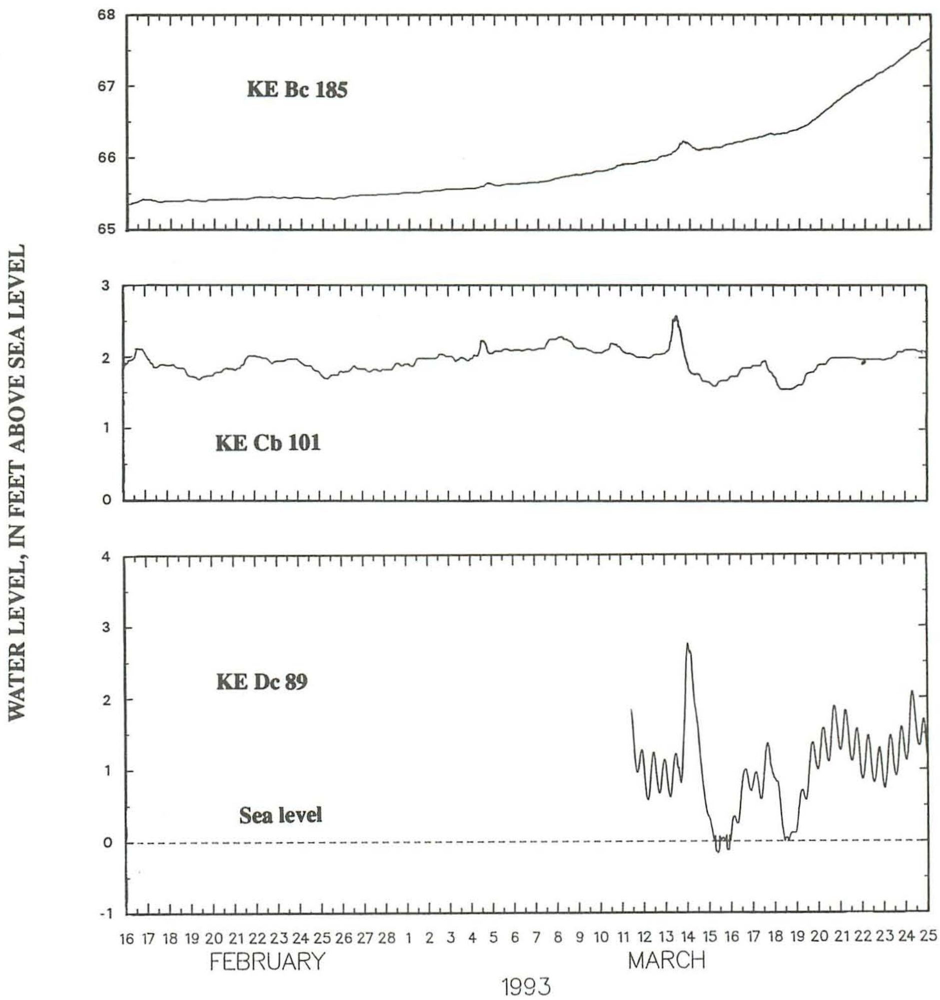


Figure 12.—Water levels in wells screened in the Columbia aquifer, February 16 to March 25, 1993.

Hydraulic Properties

Transmissivities calculated from six aquifer tests of the Aquia aquifer range from 500 to 10,000 ft^2/d (tab. 2). Storativity values from aquifer tests at Massey and Queenstown (in Queen Anne's County) are 0.0004 and 0.0003. No areal trends in the transmissivity values are apparent.

Water Levels

Water levels in the Aquia aquifer are similar to those in the Columbia aquifer because the two are partially hydraulically connected throughout much of the county. Water levels measured in the Aquia aquifer in April 1992 (fig. 15) range from approximately sea level in the southern lowland part of the county and along the Chester River to about 65 ft above sea level in the central part of the county.

Hydrographs from six wells screened in the Aquia aquifer are shown in figure 16. Water levels in wells KE Bf 93, KE Bf 154, KE Cb 99, and KE Cb 100 show the same general trend: a steady rise throughout the period shown, with sudden increases in response to storms, and varying degrees of barometric fluctuation. Water levels in well KE Cd 53 in Chestertown fluctuate greatly (note the greater vertical scale than the other hydrographs shown) in response to pumpage from the nearby Chestertown well field, which withdraws water principally from the Aquia aquifer. Water levels in well KE Dc 91 show a strong

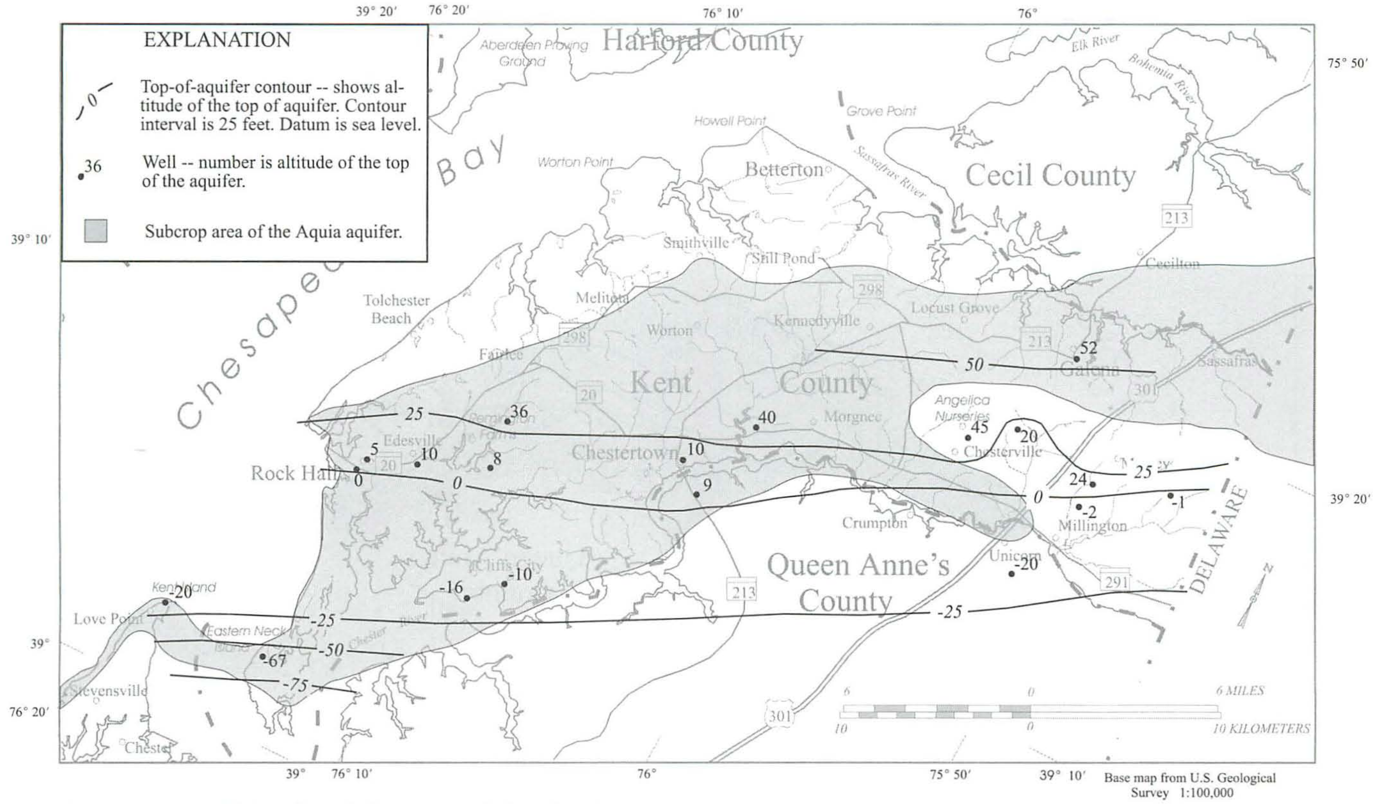


Figure 13.—Altitude of the top of the Aquia aquifer.

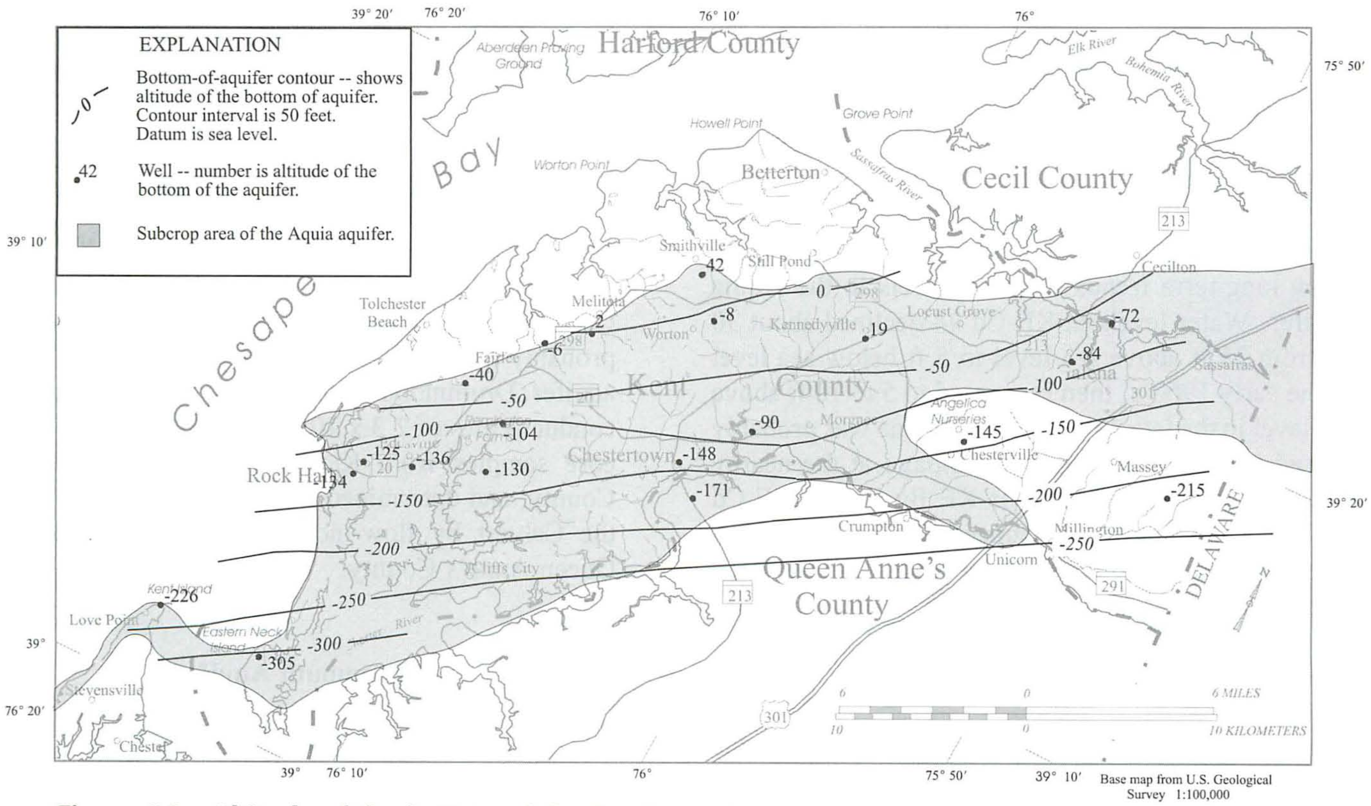


Figure 14.—Altitude of the bottom of the Aquia aquifer.

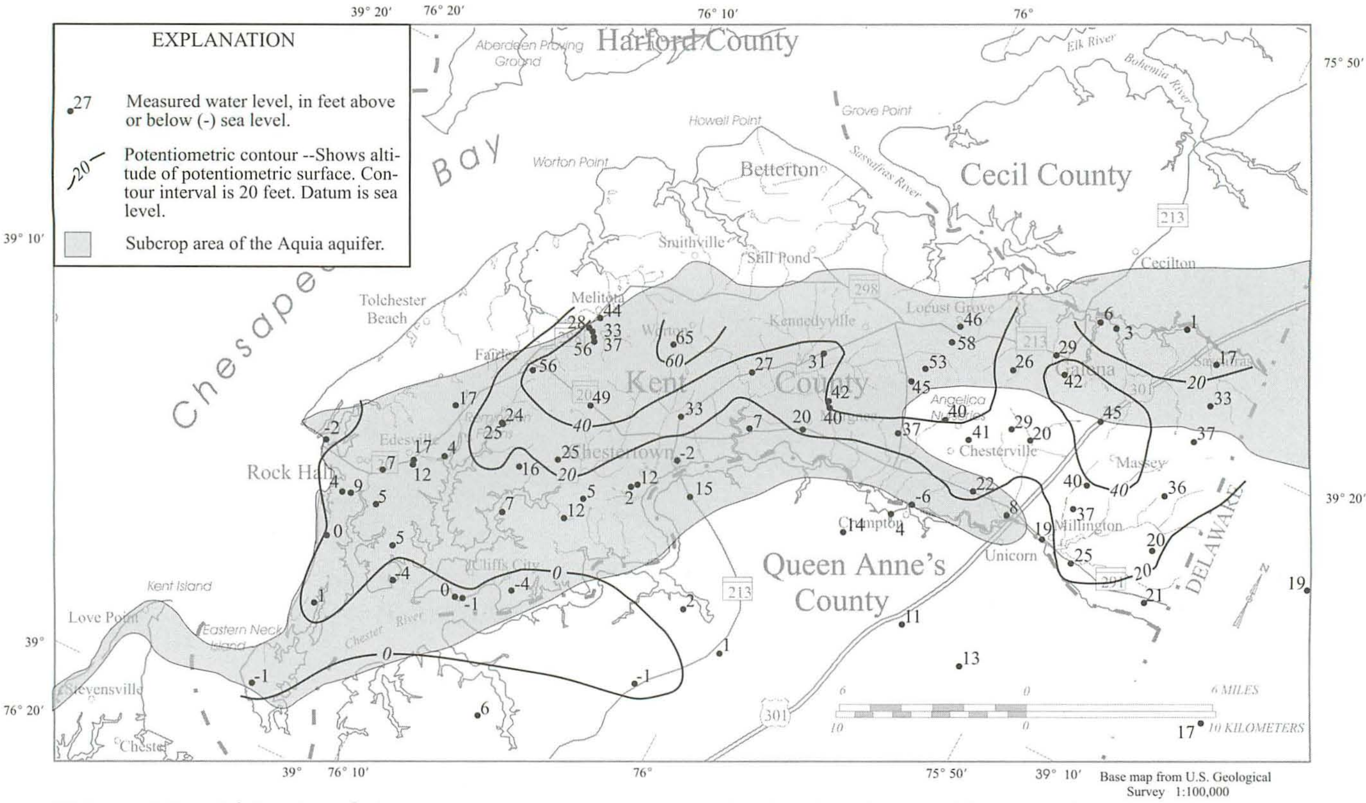


Figure 15.—Altitude of the potentiometric surface in the Aquia aquifer, April 1992.

tidal fluctuation superimposed on a longer-term barometric fluctuation. This well is located beside well KE Dc 89 at Cliffs City, by the Chester River. Water-level fluctuations in these two wells are nearly identical, although levels in KE Dc 91 are about 0.8 ft deeper than in KE Dc 89.

Hydrographs for wells KE Bg 34 and KE Cd 44 (Tompkins, Cooper, and Drummond, 1994, fig. 3) show long-term trends in water levels in the Aquia aquifer. Water levels in KE Cd 44 declined about 30 ft, from 25 ft above sea level to 5 ft below sea level in the early 1960's, then recovered to 5 to 10 ft above sea level in the late 1960's. This decline was probably caused by a drought and by pumpage at the nearby Chestertown well field. Wells KE Bg 34 and KE Cd 44 both show a less pronounced decline of about 5 feet in the late 1970's and early 1980's.

Confining Units

The Aquia aquifer is directly overlain by the Columbia aquifer throughout much of Kent County and is, thus, unconfined or semiconfined in that area. Clay layers within the Aquia aquifer may locally produce confined conditions in sands below the clay layers, as in the Chestertown area (Overbeck and Slaughter, 1958). In the southeastern part of Kent County, the Aquia aquifer is overlain by the Calvert confining unit, which comprises sediments of the Calvert Formation of Miocene age. The Calvert confining unit is a medium-gray sandy clay, and ranges in thickness up to about 50 ft at well KE Bg 33 near Massey. No hydraulic data are available for the Calvert in Kent County, but, based on its lithology, it probably acts as a leaky confining unit for the Aquia aquifer. Drummond (1988) reported vertical hydraulic conductivities of 2.3×10^{-3} and 2.0×10^{-2} ft/d for two core samples from Kent Island in Queen Anne's County, and determined a leakance of 3×10^{-6} d^{-1} for the Calvert by flow-model calibration in northern Queen Anne's County.

Monmouth Aquifer

The Monmouth aquifer is primarily used in the area northwest of the subcrop area of the Aquia aquifer where the Aquia is absent (fig. 3). It supplies water for the town of Kennedyville and for the Huls

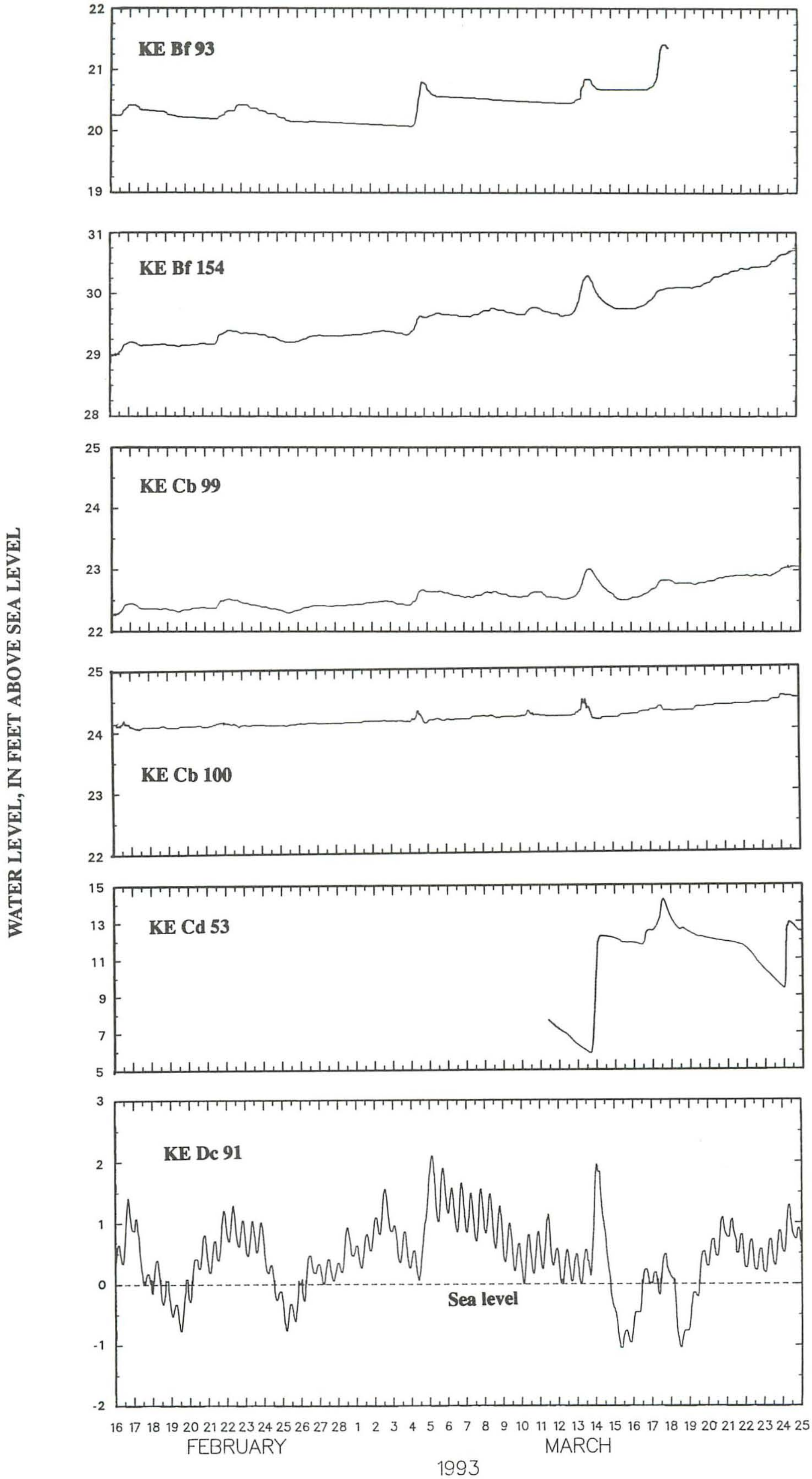


Figure 16.—Water levels in wells screened in the Aquia aquifer, February 16 to March 25, 1993.

America plant near Worton. The Monmouth aquifer comprises sediments of the Mount Laurel Formation, which was formerly labeled the Monmouth Formation, as in Overbeck and Slaughter (1958). Sandy units in the Matawan Formation produce water for small supplies in some areas, such as near Worton. These sandy units are assigned to the Monmouth aquifer in this report.

Extent

The Monmouth aquifer subcrops beneath the Columbia aquifer in a band extending from Rock Hall in the southwest to Galena in the northeast. Southeast of the subcrop area it is overlain by the Severn confining unit and is underlain by the Matawan confining unit throughout its extent. The altitude of the top of the Monmouth ranges from about 400 ft below sea level on Eastern Neck Island and near Millington to about 15 ft above sea level near Melitota (fig. 17). The altitude of the bottom of the Monmouth ranges from about 450 ft below sea level to about 45 ft above sea level near Betterton (fig. 18). The Monmouth attains its greatest thickness in well KE Be 43 near Kennedyville where it is about 100 ft thick.

Lithology

The Monmouth aquifer is a fine- to medium-grained glauconitic quartz sand with clayey layers and calcareous beds. The sandy intervals are light olive-gray, and the clayey layers are medium- to dark-greenish gray. The quartz component is 65 to 80 percent and commonly stained green or reddish brown. Glauconite is 15 to 35 percent, dark green to black, and generally polylobate. Calcareous beds occur in the top and bottom of the Monmouth and consist of weakly cemented layers and leached shells.

Hydraulic Properties

Transmissivity values calculated from aquifer tests range from 220 to 740 ft^2/d. Storativity values from two aquifer tests are 0.0003 and 0.0012. The latter value, from a well at Kennedyville, indicates semiconfined conditions. This location is near the subcrop area of the Monmouth aquifer (fig. 3).

Water Levels

Water levels in wells screened in the Monmouth aquifer represent the potentiometric surface where the aquifer is confined, but may represent the water table in the subcrop area. Water levels measured in April 1992 range from about sea level to 60 ft above sea level (fig. 19). The general pattern shown by the potentiometric contours is the same as in the Aquia aquifer, but water levels are generally 5 to 15 ft lower in the Monmouth than in the Aquia.

Hydrographs for wells KE Bc 50 and KE Cb 98, screened in the Monmouth aquifer, are shown in figure 20. Water levels in these wells show a general rise, with a slight barometric fluctuation, and rapid responses to rain storms. No long-term hydrographs are available for wells screened in the Monmouth aquifer.

Confining Units

The Monmouth aquifer is overlain by the Severn confining unit, which comprises sediments of the Severn Formation of Upper Cretaceous age. The Severn is a clayey, glauconitic, fine to very fine sand which is generally 15 to 20 ft thick. It is easily recognized on geophysical logs by its high gamma-ray spike (figs. 5-8). No hydraulic data are available for the Severn confining unit in Kent County, but based on its lithology, it probably acts as a tight confining unit between the Aquia and Monmouth aquifers.

Magothy Aquifer

The Magothy aquifer is used for domestic supplies in the northwestern part of Kent County and for large municipal and commercial supplies throughout the county. It provides water for the towns of Betterton, Edesville, and Rock Hall. The Magothy aquifer comprises sands of the Magothy Formation. Historically, the uppermost non-glauconitic sand below the Matawan Formation has been called the Magothy aquifer; however, Hansen (1992) showed that the Magothy Formation consists of a clayey facies at Angelica Nurseries, and the first sand below the Matawan is in the Potomac Group. Because of the similar appearance of Magothy and Potomac sands, some Potomac sands have been assigned to the

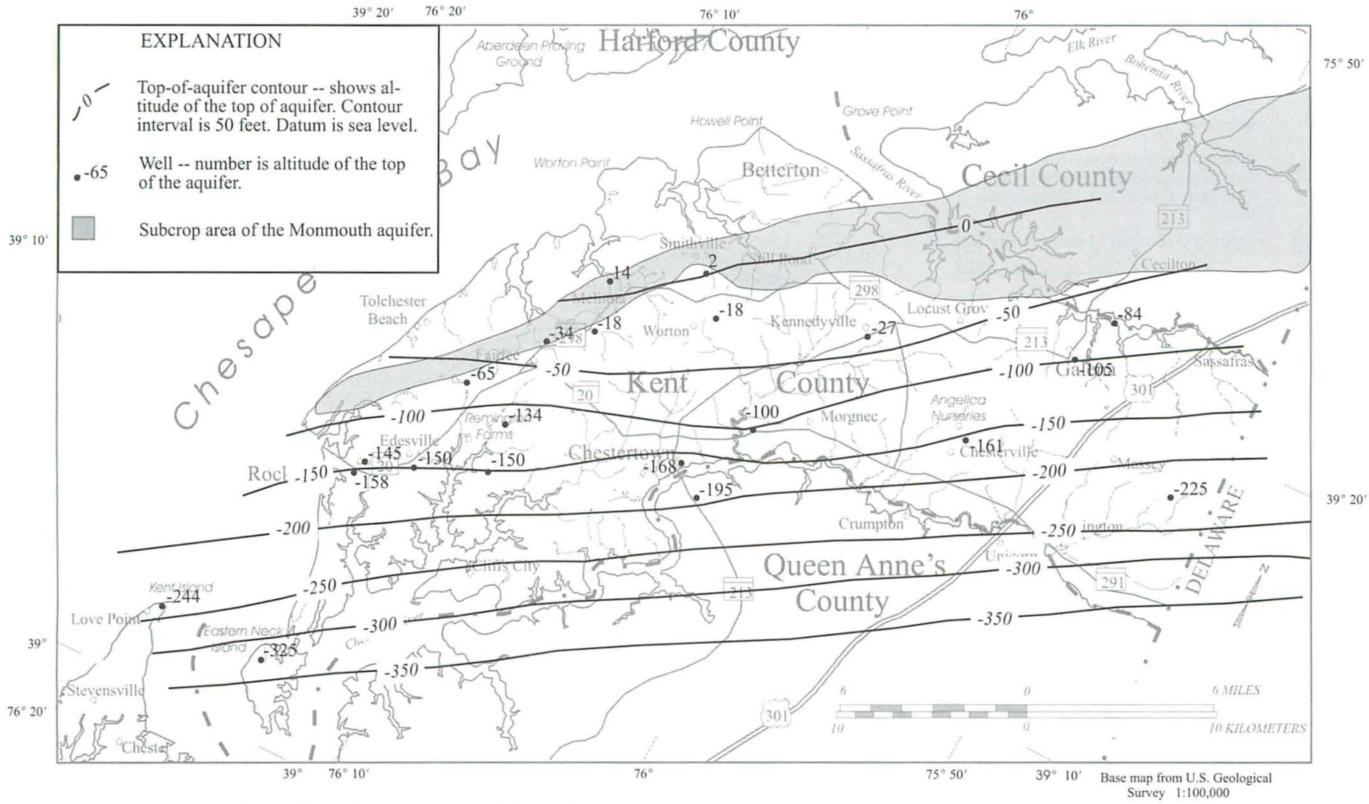


Figure 17.—Altitude of the top of the Monmouth aquifer.

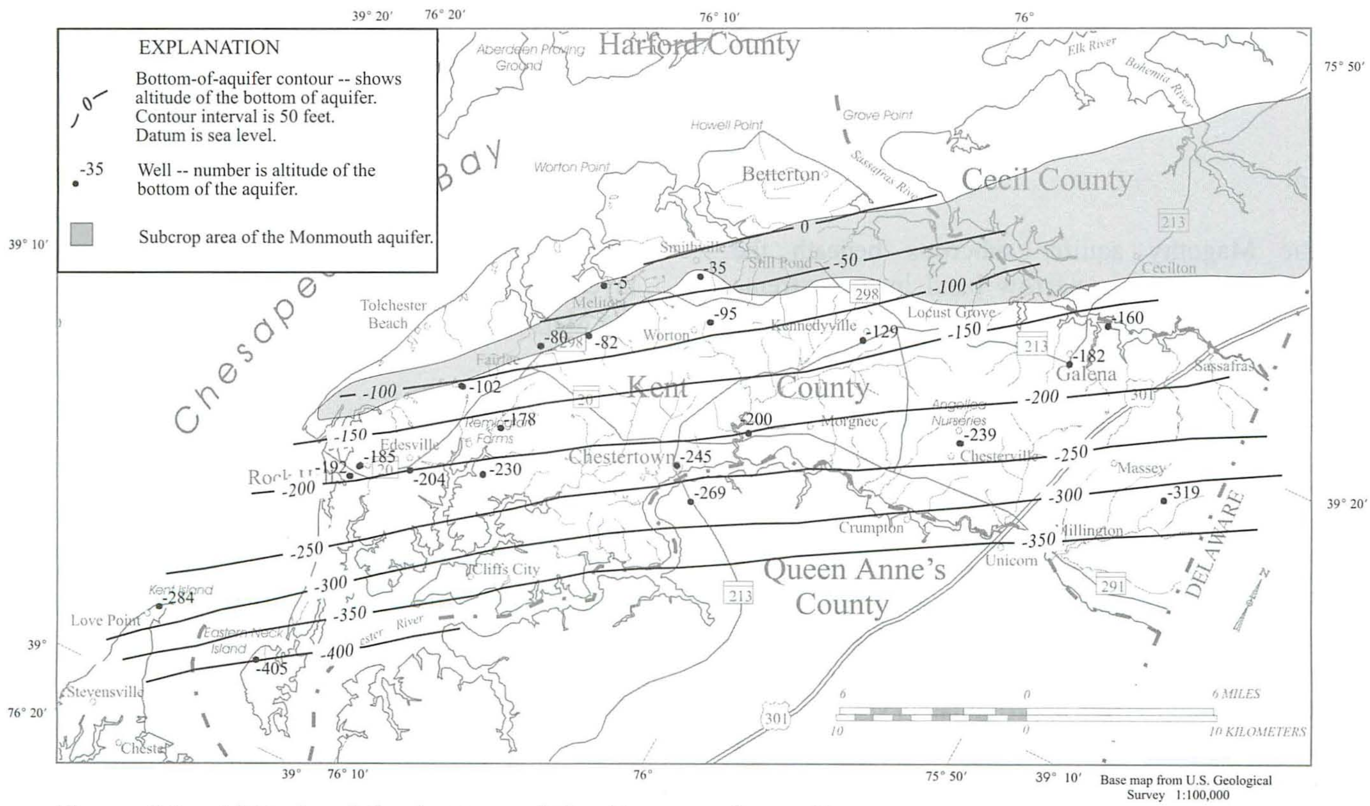


Figure 18.—Altitude of the bottom of the Monmouth aquifer.

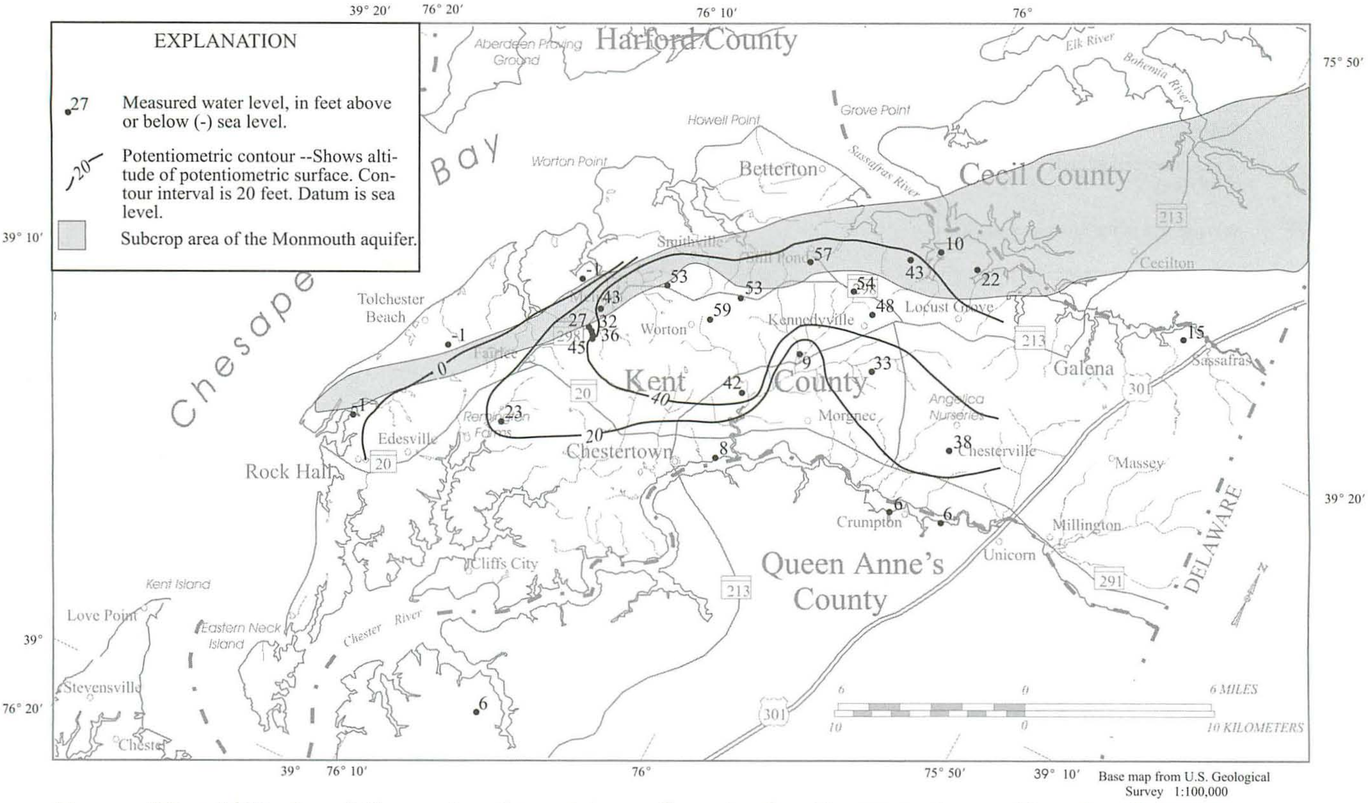


Figure 19.—Altitude of the potentiometric surface in the Monmouth aquifer, April 1992.

Magothy aquifer in the past (for instance, at Galena and Chestertown).

Extent

The Magothy aquifer subcrops beneath the Columbia aquifer in a narrow band in the extreme northwestern part of Kent County, on Stillpond Neck and near Worton Point. It outcrops in the cliffs near Betterton and along Stillpond Creek and the Chesapeake Bay. Southeast of the subcrop area the Magothy is overlain by the Matawan confining unit. The Magothy is underlain by the Upper Patapsco aquifer throughout Kent County.

The top of the Magothy aquifer ranges from approximately 30 ft above sea level in the cliffs near Betterton to 550 ft below sea level on Eastern Neck Island and near Millington (fig. 21). The bottom of the Magothy ranges from approximately sea level near Betterton to 600 ft below sea level on Eastern Neck Island and near Millington (fig. 22). The thickness ranges up to about 55 ft at Chestertown.

Lithology

The Magothy Formation comprises two lithofacies in Kent County, a light-colored lignitic sand and a light- to dark-gray carboniferous silt-clay. The sand is white to yellowish brown, fine to coarse grained quartz. The clay-silt occurs as thin horizontal layers which interfinger with the sandy layers, to massive layers which in places occupy the entire thickness of the Magothy.

Hydraulic Properties

Two aquifer tests performed on Magothy sands indicate transmissivities of 2,200 and 3,300 ft^2/d on Eastern Neck Island and at Cecilton (in Cecil County), respectively.

Water Levels

Water levels in the Magothy aquifer measured in April 1992 range from about 10 ft below sea level

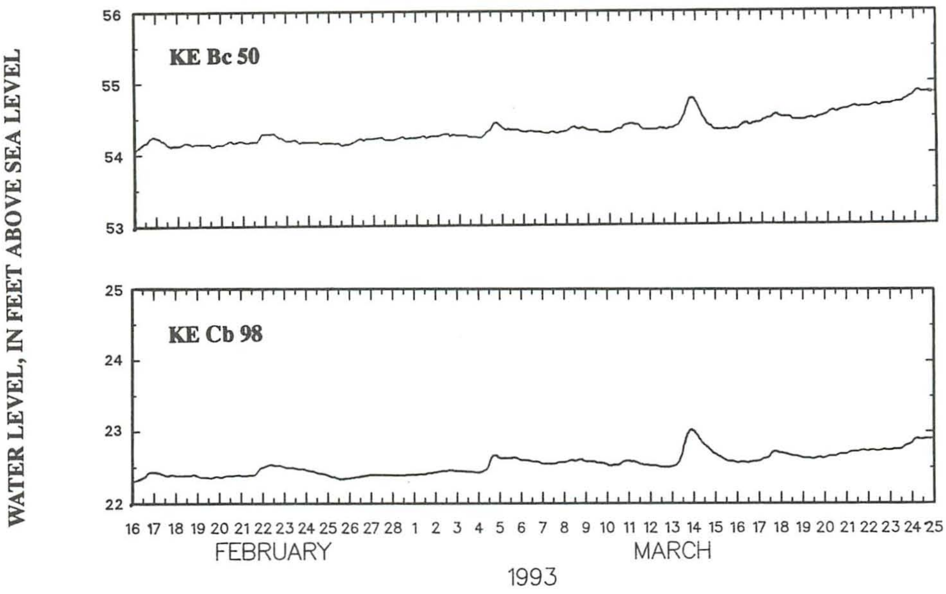


Figure 20.— Water levels in wells screened in the Monmouth aquifer, February 16 to March 25, 1993.

near the shoreline to 50 ft above sea level near Worton (fig. 23). Several pumping centers near the shore form cones of depression where heads have declined below sea level. Low heads near Rock Hall and Eastern Neck Island are probably caused by pumping centers at Rock Hall and at Kent Island, which is southwest of Eastern Neck Island.

Hydrographs for two wells screened in the Magothy aquifer are shown in figure 24. Water levels in well KE Be 43 show a cyclic response to pumpage from the production well for Kennedyville, which is screened in the Monmouth aquifer and is located less than 100 ft to the south. The fluctuation in well KE Be 43 is a direct response to pumpage in the Monmouth aquifer and indicates a leaky confining unit separating the aquifers. Water levels in well KE Cb 97, at Remington Farms, show a barometric fluctuation typical of confined aquifers in Kent County. The long-term hydrograph for well KE Be 43 shown in Tompkins, Cooper, and Drummond (1994, fig. 3) shows a general decline in water levels of about 10 ft from 1977 to 1993. This decline is probably caused by pumpage at Kennedyville and from wells in Cecil County to the north.

Confining Units

The Magothy aquifer is overlain by the Matawan confining unit except where the Magothy subcrops beneath the Columbia aquifer. Although no hydraulic-test data are available for the Matawan, it is estimated from its lithology that it acts as a tight confining unit throughout most of Kent County. In the central part of the county, however, the Matawan appears to be significantly sandier than in other areas and is even screened for small domestic-supply wells. In this central area, the Matawan probably acts as a leaky confining unit. Clayey layers at the base of the Magothy Formation may act as local confining units which separate sands in the Magothy aquifer from sands in the underlying Upper Patapsco aquifer.

Where the Magothy aquifer overlies clayey sediments of the Potomac Group, those clays form a confining unit between the Magothy and the Upper Patapsco aquifers. Where Potomac Group clays are absent, the Magothy aquifer directly overlies the Upper Patapsco aquifer, and the two are hydraulically connected.

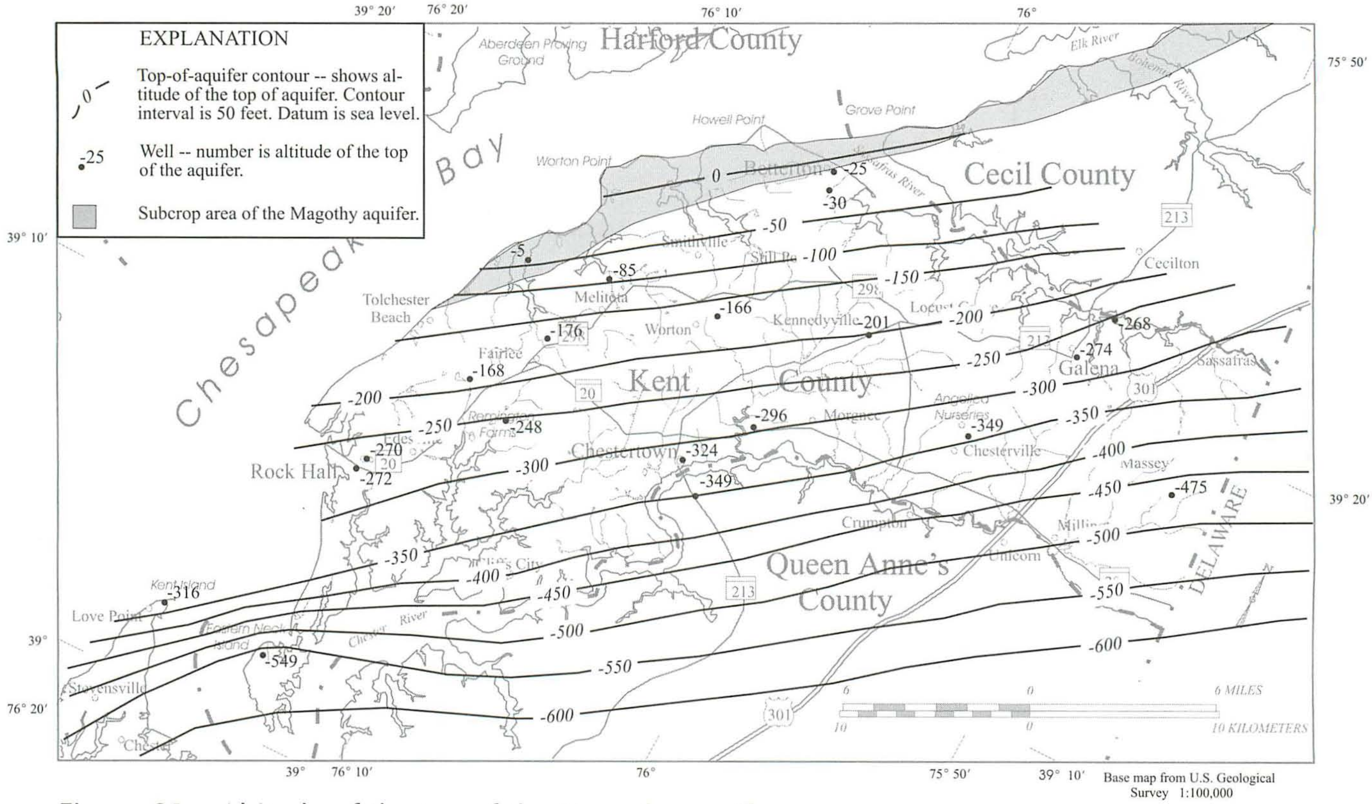


Figure 21.—Altitude of the top of the Magothy aquifer.

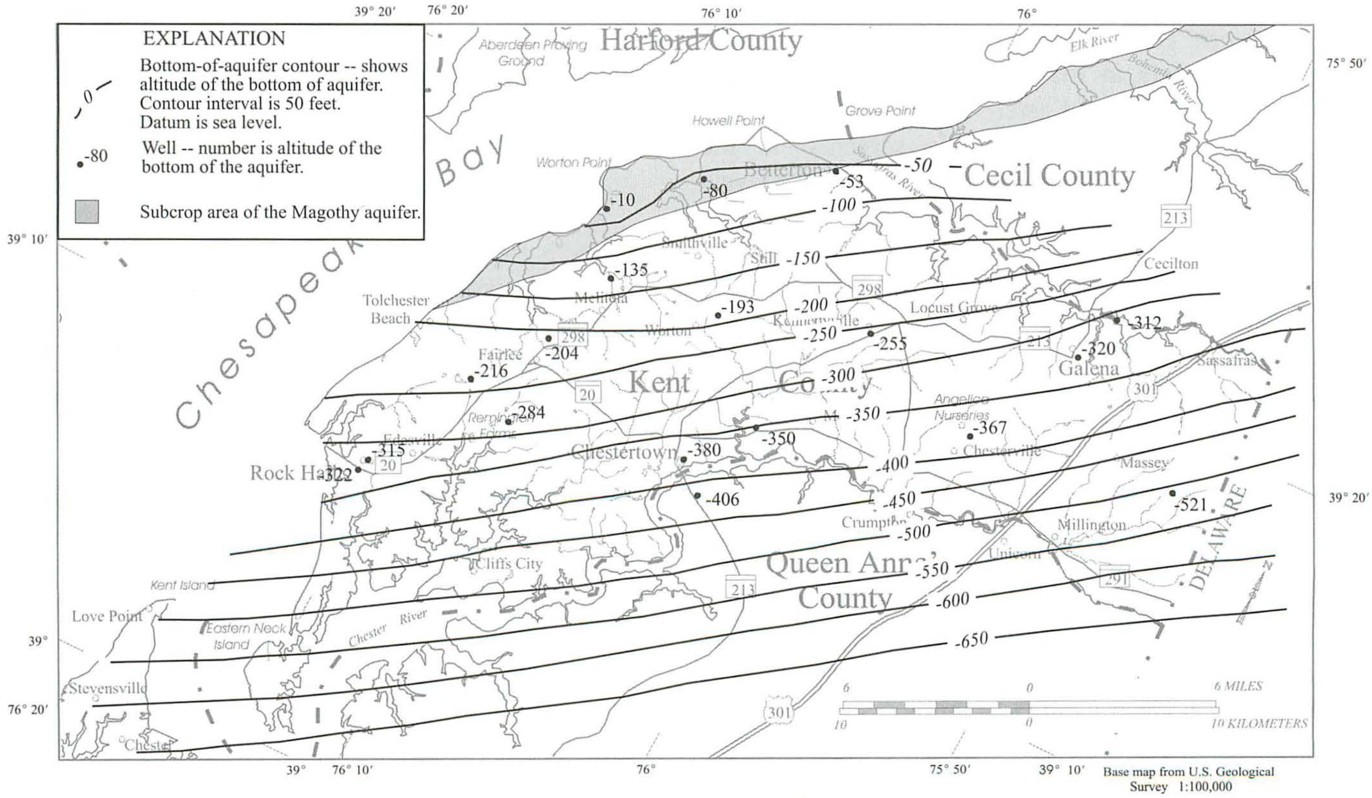


Figure 22.—Altitude of the bottom of the Magothy aquifer.

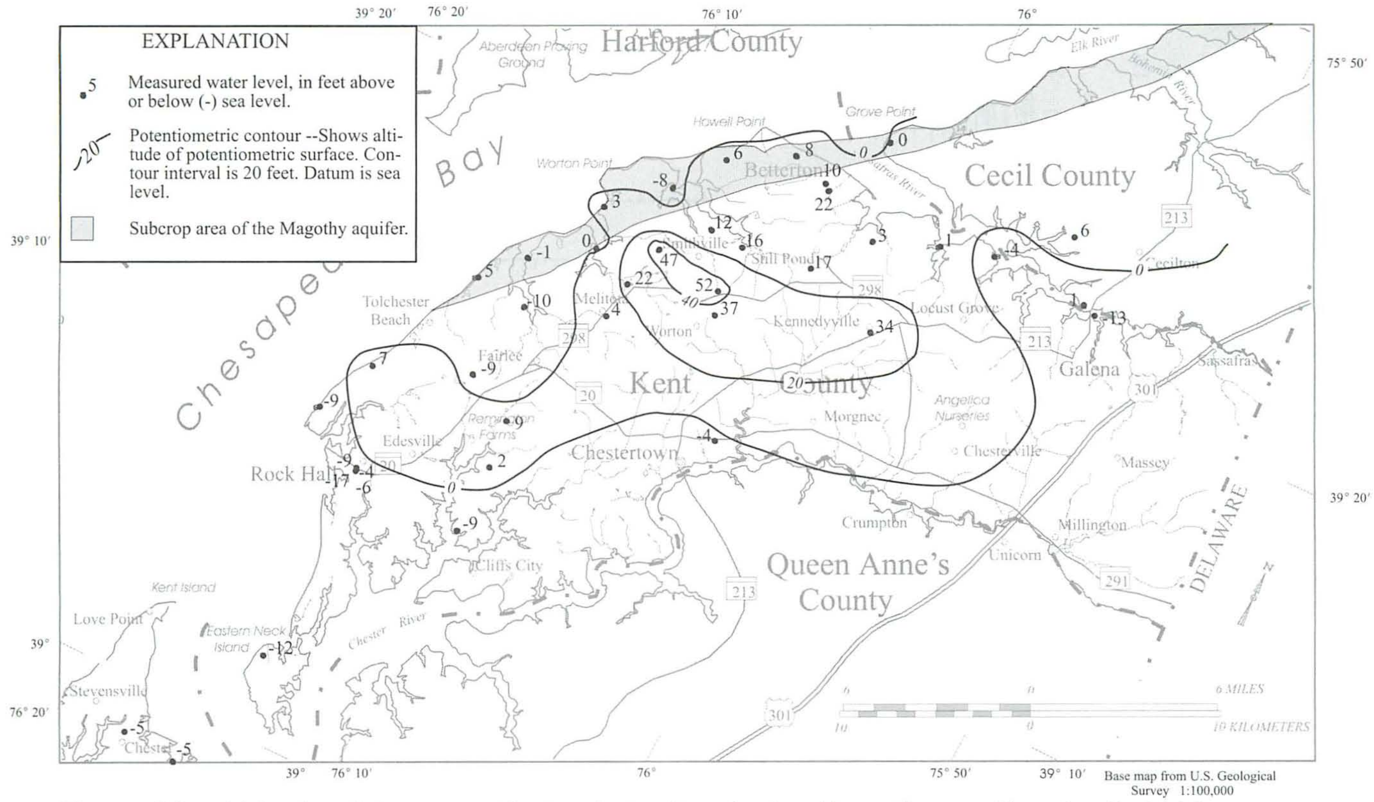


Figure 23.—Altitude of the potentiometric surface in the Magothy aquifer, April 1992.

Upper Patapsco Aquifer

The Upper Patapsco aquifer is used for small domestic supplies in the northwestern part of Kent County where the shallower aquifers are absent, and for large commercial and public supplies throughout the county. It supplies water for Galena, Fairlee, and Chestertown. The Upper Patapsco aquifer comprises sands in the uppermost part of the Potomac Group. These sands occur at different stratigraphic positions within the Patapsco Formation and may not be hydraulically continuous with one another.

Extent

The Upper Patapsco aquifer underlies all of Kent County. It subcrops beneath the Columbia aquifer only in the northwesternmost part of the county, in the bluffs near Betterton and at Worton Point. The top of the Upper Patapsco aquifer coincides with the bottom of the Magothy aquifer and ranges from approximately sea level near Betterton to about 600 ft below sea level on Eastern Neck Island and near Millington (fig. 22). The bottom of the Upper Patapsco aquifer is not a well defined surface, but the thickness of Upper Patapsco sands range up to approximately 35 ft. The Upper Patapsco aquifer occurs near the top of the Potomac Group. Sediments which comprise the Potomac Group in Kent County exceed 1,150 ft in thickness (tab. 1).

Lithology

The Upper Patapsco aquifer is a light-colored quartz sand, with some feldspar, lignite, and associated pyrite. The color of the sand ranges from white to light pinkish-gray and brownish gray. The grain size ranges from very fine sand and silt to coarse gravel and pebbles. The sand layers are generally 2 to 35 ft thick and are interlayered with variegated silty clay layers.

Hydraulic Properties

Transmissivities calculated from aquifer tests in the Upper Patapsco aquifer range from 30 ft^2/d to 2,700 ft^2/d, and average 1,000 ft^2/d (tab. 2). One

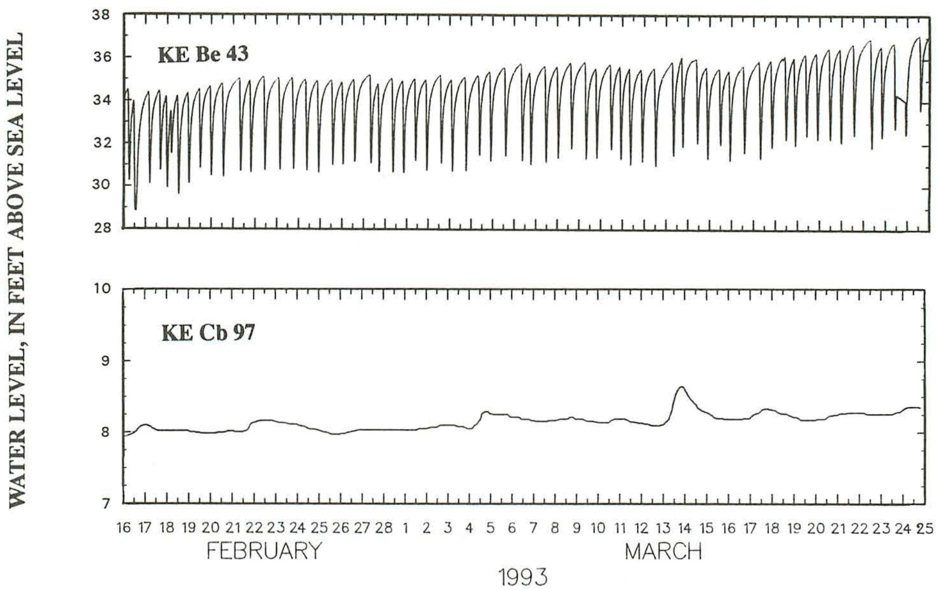


Figure 24.— Water levels in wells screened in the Magothy aquifer, February 16 to March 25, 1993.

aquifer test at Earleville in Cecil County yielded a storativity value of 0.00005. The wide range in values of transmissivity for the Upper Patapsco aquifer reflect the variable nature of the sandy units which compose the aquifer. The higher transmissivities are in the southwestern part of the county near Rock Hall, whereas the lower values are in the central part of the county near Worton. A pumping test of well KE Db 40, which is screened in the Lower Patapsco Formation near Rock Hall indicated a transmissivity of 5,500 ft^2/d.

Water Levels

Water levels in the Upper Patapsco aquifer measured in April 1992 range from about 10 ft below sea level at Chestertown to 30 ft above sea level near Worton (fig. 25). Water levels are below sea level in the lowland part of the county and along the entire shoreline.

Hydrographs for five wells screened in the Upper Patapsco aquifer are shown in figure 26. Water levels in well KE Ac 20 show a strong tidal fluctuation in response to tides in the Chesapeake Bay, located only several feet from the well. Water levels in wells KE Bc 186, KE Be 171, and KE Cb 103 show a barometric fluctuation typical of confined aquifers in Kent County. The hydrograph for KE Cb 36, near Fairlee, is quite flat at this time scale, but does show long-term fluctuations, as shown in Tompkins, Cooper, and Drummond (1994, figs. 2 and 3). The reason for the lack of a barometric fluctuation in this well is unclear, as the aquifer is over 200 ft deep and confined by several overlying clayey units.

All of the long-term hydrographs for wells in the Upper Patapsco aquifer shown in Tompkins, Cooper, and Drummond (1994, fig. 3) show general water-level declines. These declines range from 0.07 ft/yr (feet per year) for well KE Ac 20 at Still Pond Neck to 0.4 ft/yr for KE Bg 33 near Massey. In addition, water levels in wells CE Ee 29 at Cecilton (in Cecil County) and QA Eb 111 near Chester (in Queen Anne's County) show water level declines of 0.3 and 0.9 ft/yr, respectively. These declines could not be caused solely by pumpage in Kent County because there is no pumpage from the Upper Patapsco aquifer in the vicinity of the well at Massey. The declines are probably caused by a combination of pumpage in Kent, Cecil, and Anne Arundel Counties, and from Delaware.

Confining Units

The Upper Patapsco aquifer is confined in nearly all of Kent County due to clay beds in the overlying Magothy and Matawan Formations; however, sands in

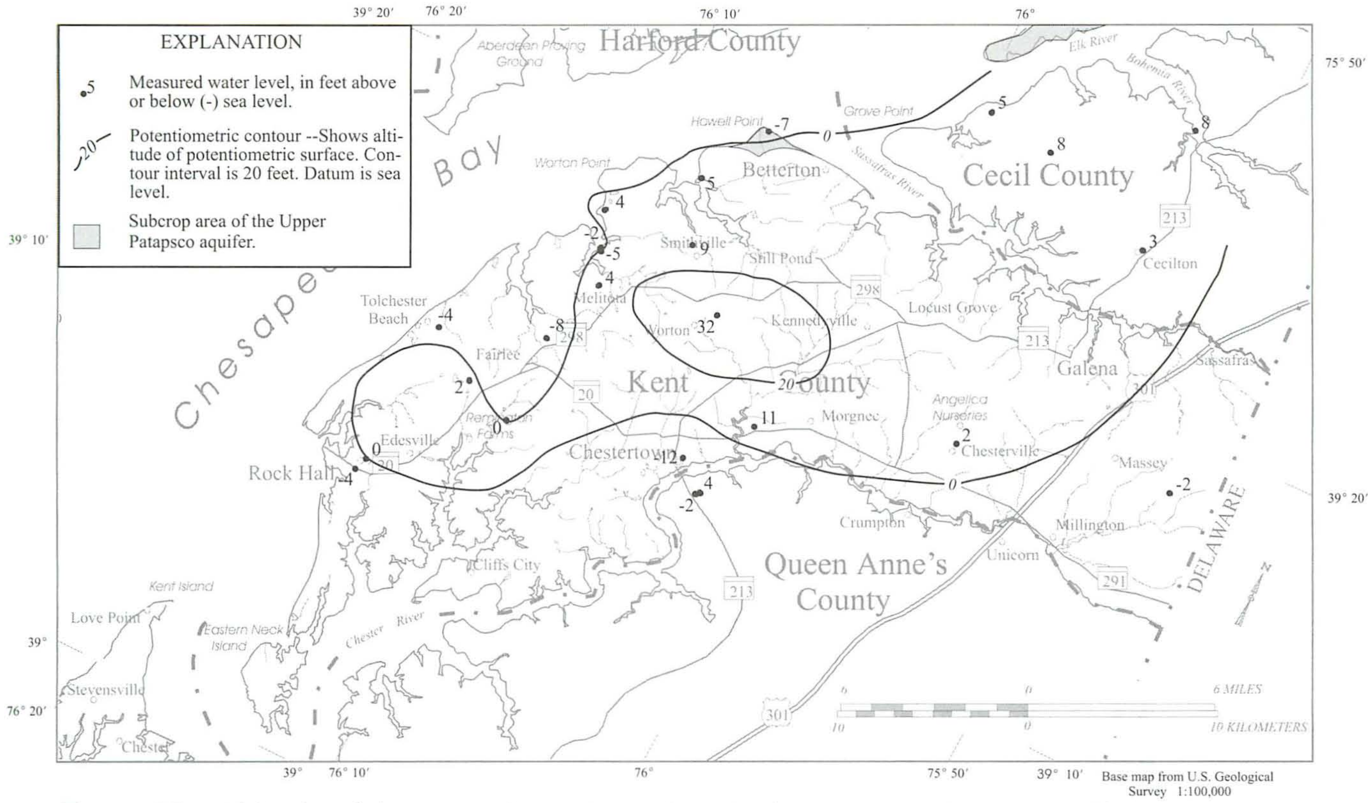


Figure 25.—Altitude of the potentiometric surface in the Upper Patapsco aquifer, April 1992.

the Magothy aquifer are probably hydraulically connected to Upper Patapsco sands where an intervening confining unit is absent. In fact, because of the discontinuous nature of the Magothy sands and the discontinuous nature of interceding confining beds, the Magothy probably functions as a sand within the Upper Patapsco aquifer. Thick clay beds below the Upper Patapsco aquifer create a tight confining unit and probably prevent significant flow to or from sands deeper in the Potomac Group.

REGIONAL FLOW SYSTEM

The regional ground-water flow system can be deduced from water-table and potentiometric-surface maps shown in figures 11, 15, 19, 23, and 25. The general pattern shown on all of these maps is of high water levels in the central upland part of the county and low water levels (around sea level) near the shores of the Chesapeake Bay and the Sassafras and Chester Rivers. In the central part of the county, water levels are highest in the Columbia aquifer and become progressively lower in the deeper aquifers. This pattern indicates that the regional flow system is mainly recharged through the Columbia aquifer in the central part of the county. Ground water then flows downward into the deeper aquifers and toward the shoreline, then discharges into tidal estuaries (fig. 27).

Some ground water in the deeper aquifers may also flow beneath the Sassafras and Chester Rivers into Cecil and Queen Anne's Counties. It is also possible that ground water may flow toward Kent County under the Chesapeake Bay from the western shore, but this is not likely due to the low head gradient observed in the Upper Patapsco and shallower aquifers (Drummond and Blomquist, 1993). The bay probably acts as a regional discharge area, and ground water flows into it from both sides of the bay. Ground water also discharges into streams, is removed as evapotranspiration, and is pumped out for water supply by humans. Although the ground-water flow system is mostly recharged by precipitation, small amounts may also be derived from losing stream reaches and from brackish-water intrusion from tidal estuaries near pumping centers.

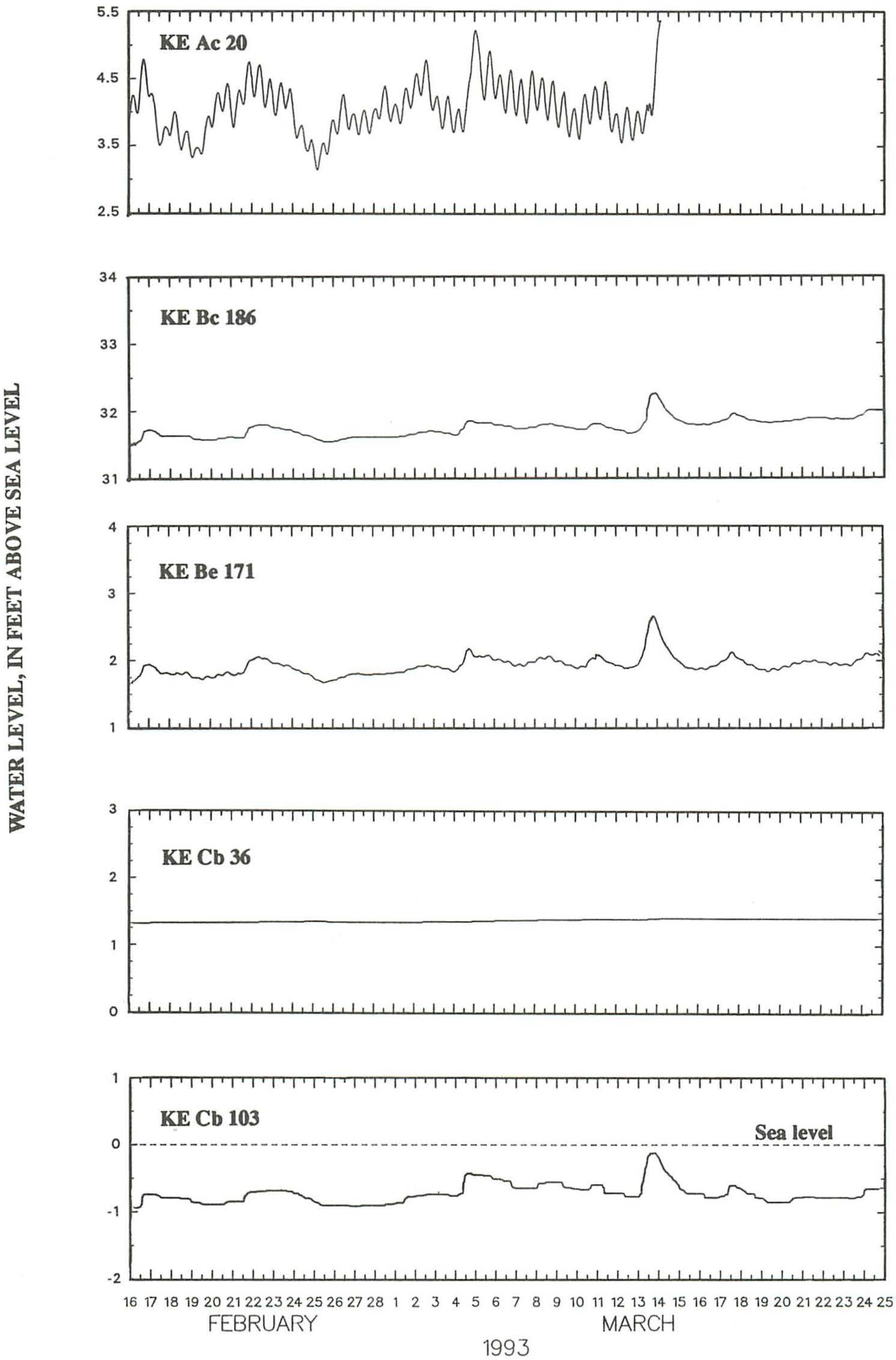


Figure 26.– Water levels in wells screened in the Upper Patapsco aquifer, February 16 to March 25, 1993.

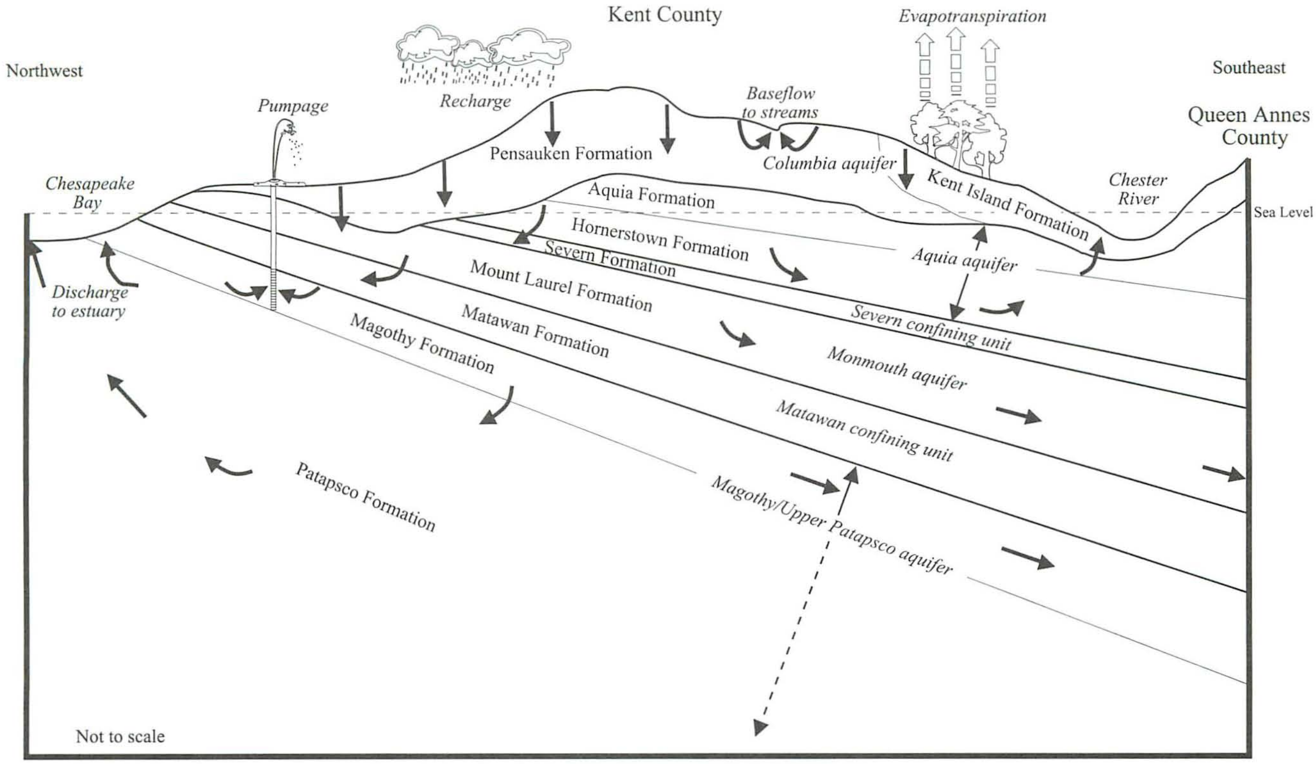


Figure 27. —Schematic cross section showing generalized ground-water flow components in the subsurface of Kent County.

ESTIMATION OF FLOW COMPONENTS

Hydrologic flow components were calculated for the Beaverdam Creek basin for the period April 1950 to March 1952 by Rasmussen and Andreasen (1959). The Beaverdam Creek basin is a small watershed near Salisbury Maryland, about 60 miles (mi) south-southeast of Kent County, with hydrologic conditions similar to those of the Kent County study area. They measured (or calculated from measurements) precipitation (41.4 inches per year [in./yr]), recharge (21.3 in./yr), base flow to streams (10.7 in./yr), change in storage (0.9 in./yr), and ground-water evapotranspiration (9.7 in./yr). Values they calculated for recharge and evapotranspiration are probably similar for Kent County.

Stream-discharge measurements were made at nine sites on May 4, 1993 after a week without rain (tab. 3). These discharges represent base flow of ground water to the streams at a time when base flow is somewhat higher than the annual or long-term average. Specific discharges were calculated by dividing the instantaneous discharge measurements by the subbasin areas, and converting to units of inches per year to conform with other flow components. The weighted average (weighted by subbasin area) of these measurements for the nine subbasins in Kent County is 12.3 in/yr.

In order to extrapolate this value over the entire year, the 1993 hydrograph from the continuous-discharge gage at Morgan Creek near Kennedyville (James, Simmons, and Strain, 1993) was separated into base-flow and storm-flow components. The average base flow for the entire water year 1993 (5.3 cubic feet per second [ft^3/s]) was divided by the instantaneous base flow (8.0 ft^3/s) from May 4 of that year. The resultant ratio (0.66) was then multiplied by the specific discharge value (12.3 in./yr), previously calculated for the 9 subbasins in Kent County, to give an average specific discharge for all of Kent County in 1993 of 8.14 in./yr. The long-term average specific discharge can be estimated by comparing the annual mean instantaneous discharge from the gage on Morgan Creek near Kennedyville for 1993 (9.5 ft^3/s) to the mean from water years 1951 through 1997 (10.8 ft^3/s) (James, Helinsky, and Tallman, 1997).

Table 3.–Baseflow measurements on streams in Kent County, May 4, 1993

[ft^3/s = cubic feet per second; ft^2 = feet squared; in./yr = inches per year]

Site	Discharge (ft^3/s)	Basin area (ft^2)	Specific discharge (in./yr)
Chester River tributary near Crumpton	7.8	1.7×10^8	18
Cypress Branch near Millington	28	6.7×10^8	16
Herring Branch at Sassafras	4.5	1.2×10^8	14
Jacobs Creek near Sassafras	5.7	1.3×10^8	16
Langford Creek, East Branch near Langford	3.0	1.5×10^8	7.3
Langford Creek, East Branch tributary, near Langford	4.3	1.5×10^8	11
Mills Branch near Millington	4.3	2.6×10^8	6.2
Mill Creek near Galena	1.9	0.62×10^8	11
Morgan Creek near Kennedyville	7.7	3.5×10^8	8.3

Multiplying the resultant ratio of 1.1 by the average specific discharge for 1993 (8.14 in./yr) yields a long-term average specific discharge of 8.9 in./yr.

SIMULATION OF GROUND-WATER FLOW

GROUND-WATER FLOW MODEL

Ground-water flow in the subsurface of Kent County was simulated using the U.S. Geological Survey three-dimensional finite-difference ground-water flow model (MODFLOW) (McDonald and Harbaugh, 1988). This model simulates aquifers as active layers, and confining units as leakance terms. The model area was divided into a finite-difference grid, and values for hydraulic parameters were input for each grid cell in each layer. Boundary conditions were specified where they occur naturally or at the edges of the model area. The model calculates hydraulic heads and intercell flows for each cell in each aquifer layer. Model results are output at specified time intervals and may be used to calibrate the model, simulate projected future pumpage scenarios, and to evaluate various influences on the

hydrogeologic system. The flow model that was developed is not unique, and other hydrologic conditions might have been used to calibrate the flow model.

Conceptualization

The hydrogeologic framework of the Kent County area was translated into the flow-model terms by designating a model layer for each hydraulically distinct aquifer (fig. 28). Layer 1 was assigned to the water-table aquifer, which includes all of the Columbia aquifer and unconfined portions of the older aquifers. Tidal estuaries were simulated as specified-head cells in layer 1, and surficial fluxes, such as recharge, evapotranspiration, and base flow to streams, were simulated entirely in layer 1.

Layers 2 and 3 were assigned to the Aquia and Monmouth aquifers, respectively. Layer 4 was assigned to the combined Magothy and Upper Patapsco aquifers, which are referred to in this section of the report as the "Magothy/Upper Patapsco aquifer." The Magothy and Upper Patapsco aquifers were simulated as a single model layer because of the discontinuous nature of Magothy sands, the difficulty in distinguishing between the two aquifers, and the absence of an intervening confining unit in some parts of the study area.

Confining units were simulated as leakance terms between the active model layers. Leakance of each confining unit was estimated from lithologic characteristics, and refined during model calibration. A very high value of leakance was entered where a confining unit is absent between two aquifer layers.

Pumping centers that are appropriated to withdraw an average of 10,000 gal/d or more were simulated with the well package of MODFLOW. Domestic pumpage and commercial users appropriated to pump less than 10,000 gal/d were not simulated. Preliminary model runs showed that the relatively small pumpage from these sources does not have a significant impact on regional water levels.

An initial 10-year model simulation was run without pumpage to produce steady-state head arrays with which to start subsequent model simulations. No prepumping head data are available with which to compare model results, so the head distributions from the prepumping simulation were only checked for reasonableness. A 10-year transient simulation was then made using 1992 pumpage amounts, and model-calculated heads were compared to measured heads from April 1992. Model-calculated flow components were also compared to measured values. This 1992 pumpage simulation was the basis for model calibration. Although the 10-year pumping simulation was run in transient mode, the simulation time was long enough that hydraulic heads had stabilized by the end, and the model reached steady-state conditions.

Although some long-term water-level trends have been documented, a transient calibration of the flow model was not attempted. The steady declines in water levels in the Magothy and Upper Patapsco aquifers are caused primarily by pumpage outside of the model area, and simulation of these declines would merely involve adjusting heads at the lateral model boundaries. Long-term head declines in the Aquia aquifer appear to be caused by variations in precipitation and by pumpage changes that have not been documented in sufficient detail for model calibration.

The calibrated flow model was used to estimate future head distributions in response to projected-pumpage increases for the year 2012. The same values were used in the projected-pumpage for recharge, ET, boundary heads, and aquifer characteristics as in the calibrated flow model. Projected-pumpage amounts were estimated from population projections, planning documents, and interviews with well-field operators. Although the projected-pumpage simulations were run in transient mode, the time period of 20 years was sufficiently long that, by the end of the period, storage changes were minimal, and heads reached steady-state conditions. Because the model was not calibrated to transient stresses and head changes, it was not used to estimate rates of head declines in response to pumpage increases.

Model Description

Grid Design

The model area was divided into a grid with 24 rows and 41 columns, for a total of 984 cells (fig. 29). The cells are each 1 mi by 1 mi. The model grid was oriented with the long dimension approximately east-northeast to take advantage of the natural hydrologic boundary of the Chesapeake Bay.

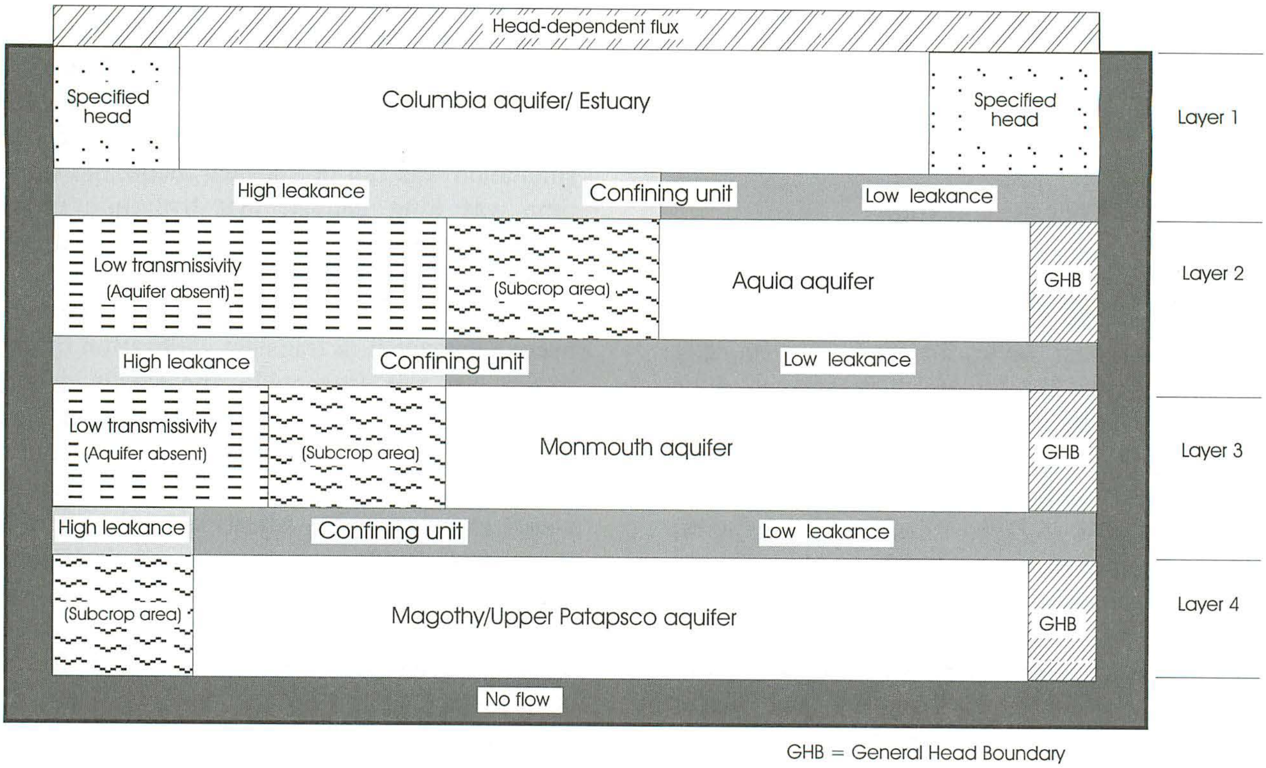


Figure 28. — Conceptualization of the ground-water flow model.

Boundary Conditions

The water table is the upper flux boundary of the model. Water enters the model through this boundary as recharge, from losing reaches of streams, and as brackish-water intrusion from estuaries, which are simulated as specified-head cells with heads at sea level. Tidal fluctuations cause short term variations of head in the estuaries, but average out to a constant value at sea level in the long term. Water leaves the model through the upper boundary as ground-water evapotranspiration, base flow to streams, and submarine discharge to estuaries. The water-table aquifer was simulated with active cells in Kent County, but the subaerial parts of surrounding areas were simulated as specified-head cells with heads at the water-table altitude to simplify the model configuration (fig. 30). Water-table altitudes for surrounding areas were derived from Bachman (1984) and Fleck and Vroblesky (1996). Although the water table fluctuates seasonally in these surrounding areas, it does not vary significantly in the long term. Because these areas are outside the area of main interest, the use of specified heads is justified. Water could enter or leave the model depending on relative heads in the model and at the boundary.

The lower boundary of the model was simulated as no-flow. The thick Potomac Group clays underlying the Upper Patapsco aquifer probably do not allow significant leakage to or from deeper aquifers in the Potomac Group.

The updip truncations of layers 2 and 3 were simulated as no-flow boundaries (figs. 31, 32, and 33). Where layers 2, 3, and 4 extend beneath the Chesapeake Bay, a no-flow boundary was placed at the center of the bay, with the assumption that the bay acts as a discharge boundary, and water will not flow beneath it, to or from the western shore (fig. 33). General Head Boundary (GHB) cells were placed at the model edges in layers 2, 3, and 4 where the aquifers extend beyond the model edges. Conductance values at GHB cells were calculated from cell dimensions and aquifer transmissivities. Head values at GHB cells were estimated from potentiometric maps. Heads at GHB cells in layers 2 and 3 were held constant throughout the simulation, because no regional head declines have been documented in the boundary areas of the Aquia or Monmouth aquifers. In layer 4, however, heads at GHB cells were decreased with time to simulate the regional head

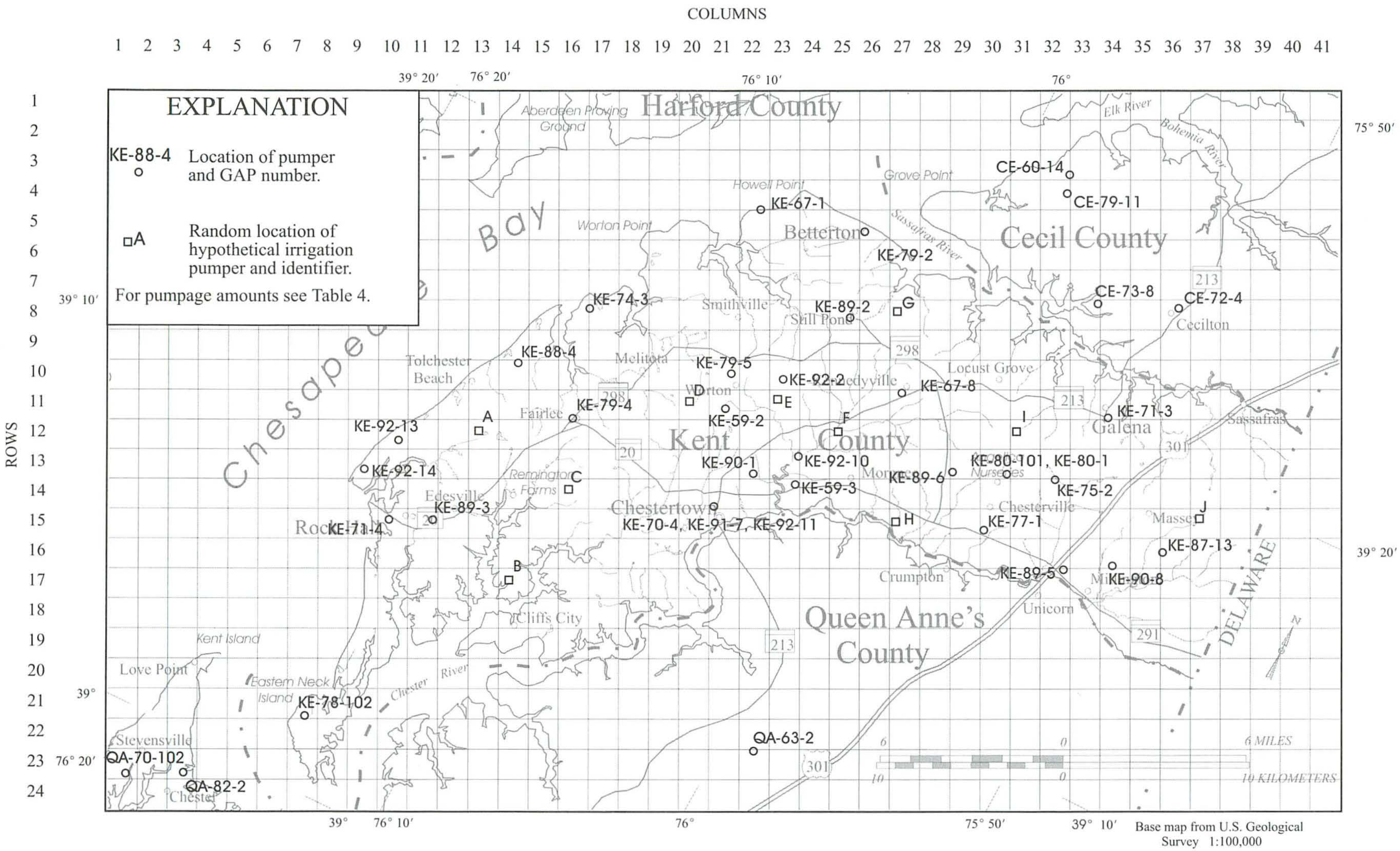


Figure 29.—Finite-difference grid and pumping locations simulated in the ground-water flow model.

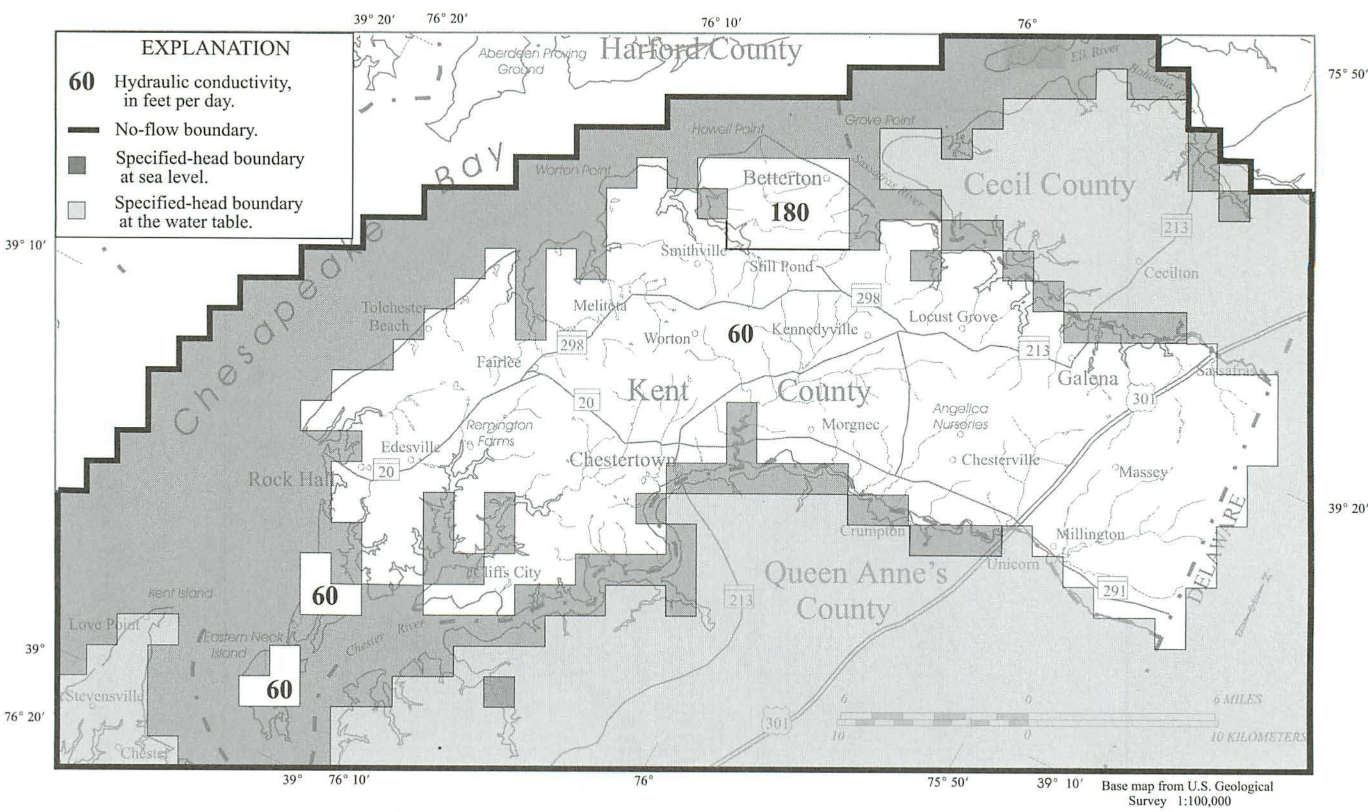


Figure 30.—Simulated boundaries and hydraulic conductivity of layer 1.

declines caused by pumpage outside the model area. These heads were estimated from hydrographs and from regional aquifer simulations (Fleck and Vroblesky, 1996).

Input Data

Input data to the flow model consists of data for surficial processes such as recharge, ET, and stream-bed characteristics; and hydraulic data for each layer, including horizontal hydraulic conductivity and aquifer-bottom altitude for layer 1, transmissivity for layers 2, 3, and 4, confining-unit leakance for layers 1, 2, and 3, and storativity for all layers. Pumpage data were also entered for each aquifer. These data were described in the Hydrogeology section of this report and are described here as they were translated into model input.

Recharge is the volumetric flux reaching the top of the water table in model layer 1. It equals precipitation minus surface runoff and soil ET (soil ET is the amount of water removed from the unsaturated zone by evaporation to the atmosphere and by transpiration of plant roots in the unsaturated zone). A value of 0.0048 ft/d (21 in./yr) was entered for recharge (Rasmussen and Andreasen, 1959).

Ground-water ET (referred to henceforth only as ET) is the volumetric flux that is removed from the ground-water system by evaporation to the unsaturated zone and by transpiration of plant roots in the saturated zone. ET was withdrawn from each cell in the model according to the simulated depth of the water table below land surface. No ET was withdrawn from a cell if the depth to water table in that cell was greater than 8 ft; a maximum of 0.0028 ft/d (12 in./yr) was withdrawn if the depth to water table was 3 ft or less; and a linear relation was used to calculate ET withdrawal if the depth to water table was between 3 ft and 8 ft.

Base flow to a stream is the amount of water flowing from the ground-water system into the stream, and depends on the altitude of the water table relative to the stage in the stream and the conductance of the stream bed. Water may also flow from the stream into the water table if the stream stage is higher than the water table. Stream-bed conductance for each cell was calculated with the equation (McDonald and Harbaugh, 1988)

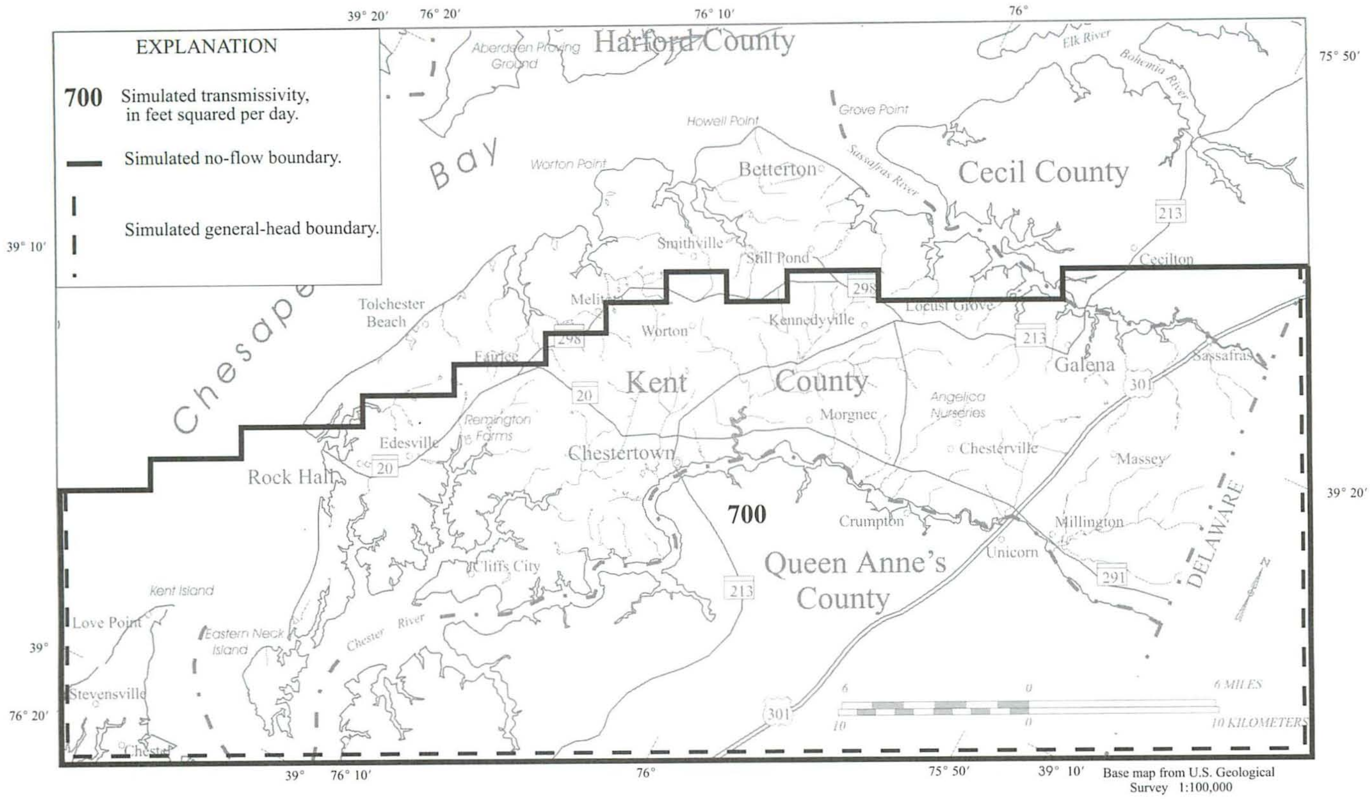


Figure 31.—Simulated boundaries and transmissivity of layer 2.

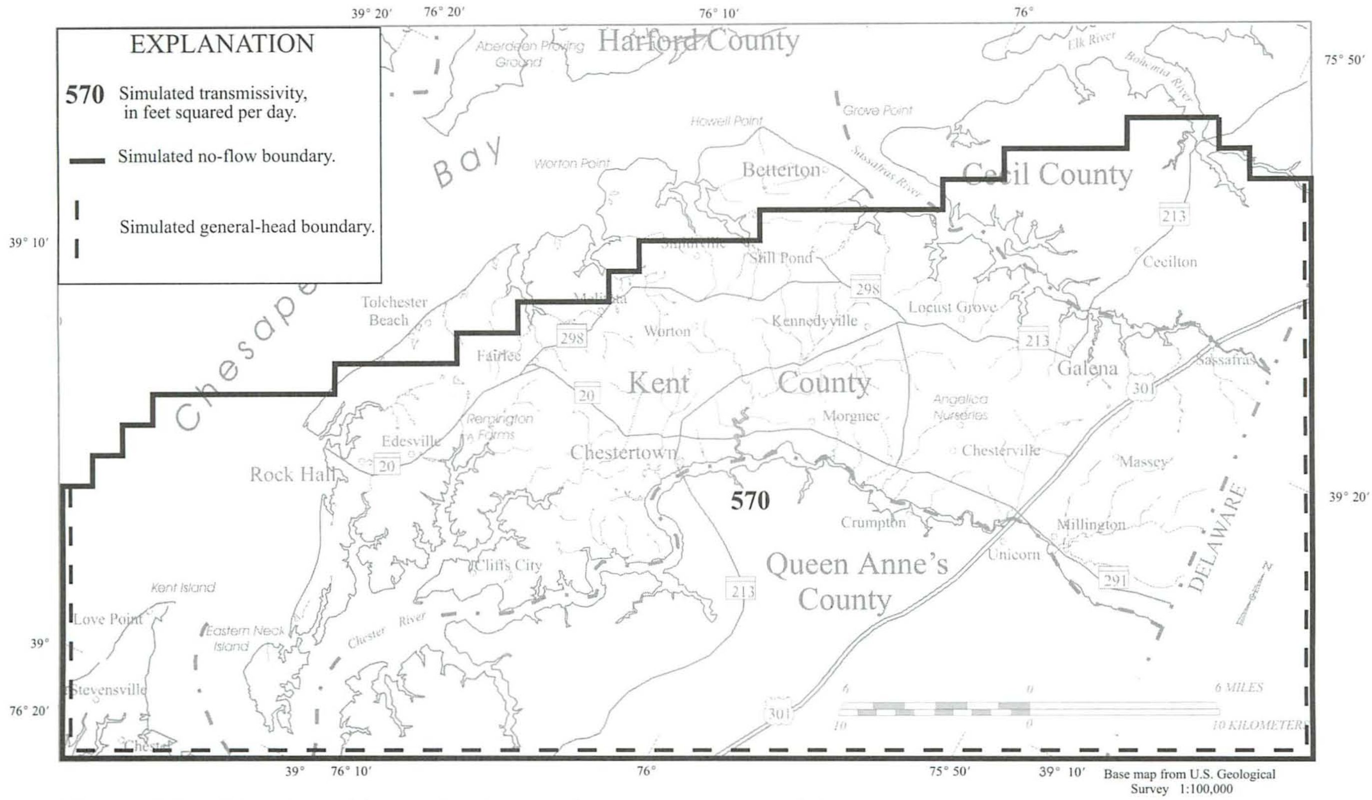


Figure 32.—Simulated boundaries and transmissivity of layer 3.

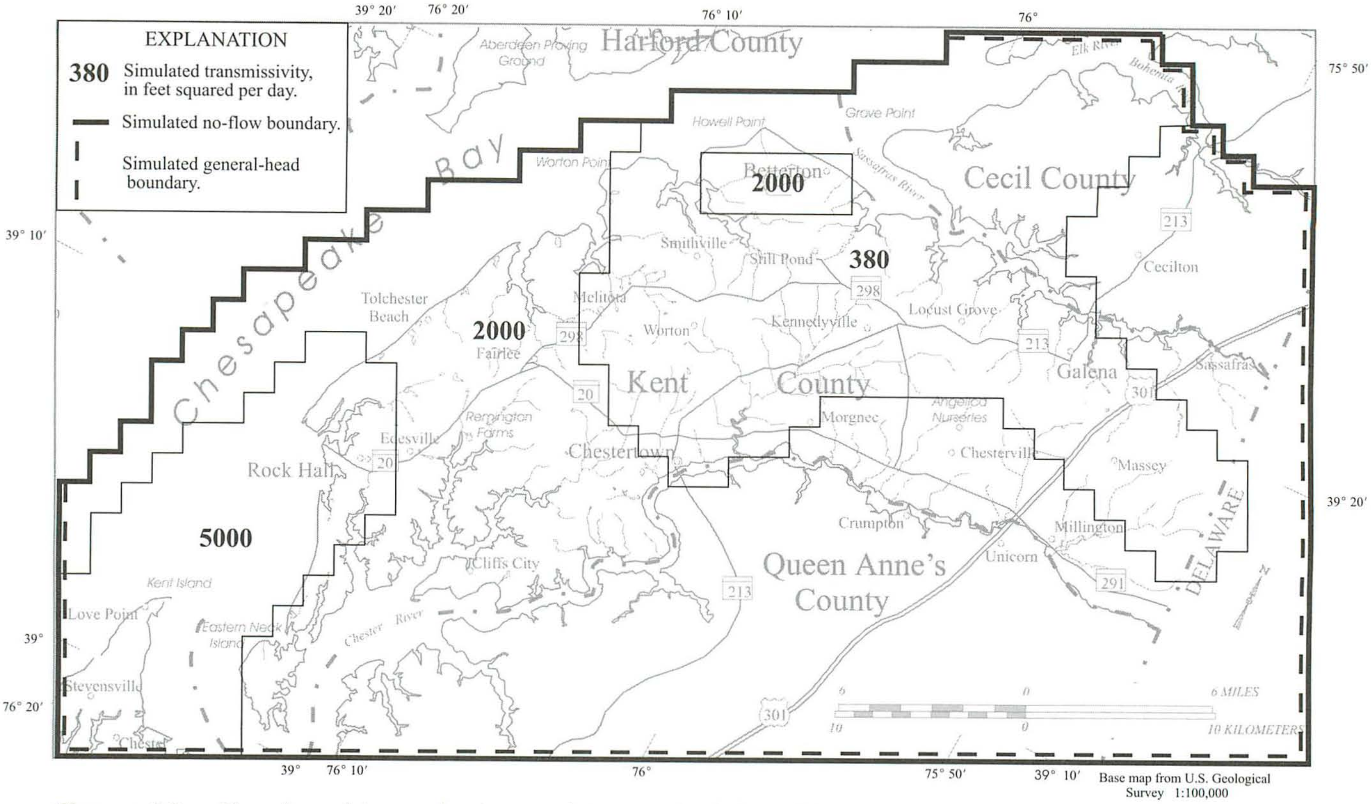


Figure 33.—Simulated boundaries and transmissivity of layer 4.

$$C = KLW/M$$

where

C = conductance (ft^2/d),

K = hydraulic conductivity of the streambed material (ft/d),

L = sum of lengths of stream reaches in each cell (ft),

W = average width of stream reaches in each cell (ft), and

M = average thickness of streambed (ft).

The average stream width and total length of all stream reaches in each cell were estimated from topographic maps. Thickness of all stream beds was estimated to be 2 ft, and the hydraulic conductivity of all stream-bed material was determined from model calibration to be 0.4 ft/d. The average stage for all stream reaches in each cell was estimated from topographic maps.

Pumpage was simulated with the well package by entering pumpage for each major ground-water user at the appropriate layer, row, and column. Simulated pumpage for the calibration period (1992) was compiled from records at the Maryland Department of Environment (Water Rights Division) and is shown in table 4. Projected pumpage amounts for future scenarios are also shown in table 4.

Hydraulic conductivity for layer 1 was specified at 60 ft/d throughout most of Kent County (fig. 30). Where the Columbia aquifer directly overlies the Magothy/Upper Patapsco aquifer in the northeastern part of the county, hydraulic conductivity was set to 180 ft/d. In this area, layer 1 partially represents coarse sands of the Magothy and Upper Patapsco aquifers which have a higher hydraulic conductivity than other sediments in the Columbia aquifer. A storativity value of 0.1 was entered for layer 1, which is typical for unconfined aquifers.

A transmissivity value of 700 ft^2/d was entered for layer 2 throughout the area where the Aquia aquifer is active (fig. 31). This value is considerably lower than the average value calculated from available pump tests for the Aquia (2,800 ft^2/d), but is within the range of those values (tab. 2). A transmissivity value of 570 ft^2/d was entered for layer 3 throughout the area where the Monmouth aquifer is active (fig. 32). This value is close to the average value calculated

Table 4.–Pumpage amounts simulated in the Kent County flow model

Pumping center	Ground-Water Appropriation Permit[1]	Layer	Row	Col-umn	Pumpage in thousand gallons per day: 1992 Cali-bration	Simulation (1993-2012): 1	2	3	4	5
Huls America, Inc.	KE-59-002	3	11	21	73	73	88	100	73	100
Campbell Soup Co.	KE-59-003	2	14	24	321	321	385	700	321	700
YMCA Camp Tockwogh	KE-67-001	4	5	22	9	9	11	15	9	15
Town of Kennedyville	KE-67-008	3	11	27	18	18	22	18	18	18
Town of Chestertown	KE-70-004	2	14	21	435	435	522	600	435	600
Town of Galena	KE-71-003	4	11	34	53	53	64	90	53	90
Town of Rock Hall	KE-71-004	4	15	10	203	203	243	230	203	230
Angelica Nurseries	KE-75-002	2	14	32	22	22	27	500	27	500
Eastern Neck NWR	KE-78-102	4	21	7	5	5	6	18	5	18
Town of Betterton	KE-79-002	4	5	26	47	47	56	50	47	50
Fairlee Service Area	KE-79-004	4	11	16	97	97	117	146	97	146
Worton Service Area	KE-79-005	2	10	21	54	54	65	40	54	40
Angelica Nurseries	KE-80-001	2	13	31	464	464	557	1,435	557	575
Angelica Nurseries	KE-80-001	2	14	30	464	464	557	1,435	557	575
Angelica Nurseries	KE-80-101	4	13	31	0	0	0	0	0	860
Angelica Nurseries	KE-80-101	4	14	30	0	0	0	0	0	860
Edesville Service Area	KE-89-003	4	15	11	2	2	2	24	2	24
Town of Chestertown	KE-91-007	4	14	21	267	267	320	375	267	375
Town of Crystal Beach	CE-60-014	4	3	33	32	32	38	32	32	32
Town of Cecilton	CE-72-004	4	8	36	48	48	58	48	48	48
Indian Acres Campground	CE-73-008	4	7	34	49	49	59	49	49	49
Holly Hills Nursery	CE-79-011	4	4	33	67	67	80	67	67	67
Eastern Correctional Camp	QA-63-002	2	23	22	28	28	33	28	28	28
Thompson Creek Service Area	QA-70-102	4	23	1	58	58	70	58	58	58
Queens Landing Service Area	QA-82-002	2	23	3	24	24	29	24	24	24
Great Oak Landing	KE-74-003	4	8	17	0	0	0	11	0	11
Owings Farm	KE-77-001	4	15	30	0	0	0	36	0	36
DeCoster Farm	KE-87-013	2	16	36	0	0	0	43	52	43
Bohn Farm	KE-88-004	4	10	14	0	0	0	23	0	23
Speakman Nursery	KE-89-002	4	8	25	0	0	0	90	108	90
VanSant Farm	KE-89-005	2	17	32	0	0	0	14	0	14
Messer Farm	KE-89-006	2	13	29	0	0	0	165	198	165
Sommers Farm	KE-90-001	2	13	22	0	0	0	19	0	19
Wick Nursery	KE-90-008	2	16	34	0	0	0	300	360	300
Kent & Queen Annes Hospital	KE-91-007	2	14	21	0	0	0	150	0	150
Priapi Farm	KE-92-002	4	10	23	0	0	0	11	13	11
Peace Farm	KE-92-010	1	13	24	0	0	0	54	65	54
Warthen Farm	KE-92-013	2	12	10	0	0	0	30	36	30
Warthen Nursery	KE-92-014	2	13	9	0	0	0	12	14	12
Hypothetical Irrigator A		4	12	13	0	0	0	0	189	0
Hypothetical Irrigator B		2	17	14	0	0	0	0	211	0
Hypothetical Irrigator C		2	14	16	0	0	0	0	63	0
Hypothetical Irrigator D		2	11	20	0	0	0	0	42	0
Hypothetical Irrigator E		2	11	22	0	0	0	0	105	0
Hypothetical Irrigator F		2	12	25	0	0	0	0	84	0
Hypothetical Irrigator G		4	8	27	0	0	0	0	105	0
Hypothetical Irrigator H		2	15	27	0	0	0	0	211	0
Hypothetical Irrigator I		2	12	31	0	0	0	0	169	0
Hypothetical Irrigator J		2	15	37	0	0	0	0	147	0
Totals					2,840	2,840	3,408	7,040	5,201	7,040

[1]For GAP locations, see figure 29.

from available pump tests (480 ft^2/d) for the Monmouth. The calibrated transmissivity distribution for layer 4 (fig. 33) includes areas of 380, 2,000, and 5,000 ft^2/d. These distinct areas reflect lithologic variations in the sands that compose the Magothy and Upper Patapsco aquifers, and are corroborated by aquifer tests which show a similar pattern (tab. 2).

The leakance array for the confining unit underlying layer 1 is shown in figure 34. Leakance values range from 10^{-6} d^{-1} in the southern part of the model area where the confining unit represents the Calvert Formation, to 10^{-1} d^{-1} in the northern part of the model area where the confining unit is absent. Leakance is 10^{-2} d^{-1} in most of the southern part of Kent County where the Aquia aquifer subcrops beneath the Columbia aquifer, and the two aquifers are in close hydraulic connection. A value of 10^{-5} d^{-1} was assigned to the confining unit in the southeastern part of Kent County where it represents the Old Church Formation (Hansen, 1992) and a sandy facies of the updip Calvert Formation. All leakance values were derived primarily through model calibration.

Leakance values for the confining unit underlying layer 2 is shown in figure 35. A value of 5 x 10^{-1} d^{-1} was assigned to the confining unit in the northwestern part of Kent County where the Monmouth aquifer subcrops beneath the Columbia aquifer. Elsewhere in the model area, a value of 5 x 10^{-6} d^{-1} was assigned to the confining unit where it represents the Severn Formation which is a tight sandy clay.

Leakance values for the confining unit underlying layer 3 are shown in figure 36. These values range from 1.4 x 10^{-9} d^{-1} in the southeastern part of the model area where the unit represents the thick impermeable clays of the Matawan Formation, to 1.4 x 10^{1} d^{-1} where the Magothy and Upper Patapsco aquifers outcrop in the bluffs along the Chesapeake Bay and the Sassafras River. A value of 1.4 x 10^{-2} d^{-1} was entered for the confining unit where the Magothy and Upper Patapsco aquifers subcrop beneath the Columbia aquifer, and the Matawan Formation becomes thin near its updip truncation. A value of 1.4 x 10^{-5} was assigned where the Matawan Formation is somewhat sandier than in downdip areas.

A storativity value of 2 x 10^{-4} (unitless) was used for layers 2, 3 and 4, which is typical for confined aquifers. As shown in the sensitivity analysis, the storativity values used had very little effect on model results because simulation times were sufficiently long to allow the system to reach hydrostatic equilibrium.

Initial Conditions

Initial conditions are required to start the model simulations. A steady-state simulation with no pumpage and average annual recharge and evapotranspiration conditions was run to generate starting-head arrays for predictive model simulations. These starting heads did not affect model results because the prepumping transient stress period was long enough to allow heads to reach equilibrium with prepumping conditions.

Calibration

Initial estimates of model inputs were adjusted within reasonable limits during model calibration so that model-generated heads and flow-budget components matched measured and estimated values. Model inputs that were adjusted during calibration include the hydraulic conductivity of river-bed sediments; heads at general-head-boundary cells; hydraulic conductivity of the Columbia aquifer; transmissivity of the Aquia, Monmouth, and Magothy/Upper Patapsco aquifers; and the leakance of all confining units.

The flow model was calibrated to heads measured in April 1992. Water levels fluctuate throughout each year and from year to year as a function of precipitation and evapotranspiration variations. The calibration period represents approximate average annual conditions, as judged from long-term ground-water hydrographs shown in Tompkins, Cooper, and Drummond (1994, pp. 125-128). Flow components calculated by the model were compared to components estimated in the Hydrogeology section of this report. The model was considered calibrated when the RMS (root-mean-square) error for calculated hydraulic head for the entire model was below 5.0 ft, and model-calculated flow components were reasonably close to estimated values. Flow components calculated by the flow model are listed in table 5.

The recharge value of 21 in./yr was set to the value estimated by Rasmussen and Andreasen (1959) and was not changed during calibration. The average base flow calculated for the entire model area was 8.4 in./yr. This value is close to the average base flow estimated for Kent County in 1993 of 8.1 in./yr and for the long-term extrapolated value of 8.9 in./yr. The

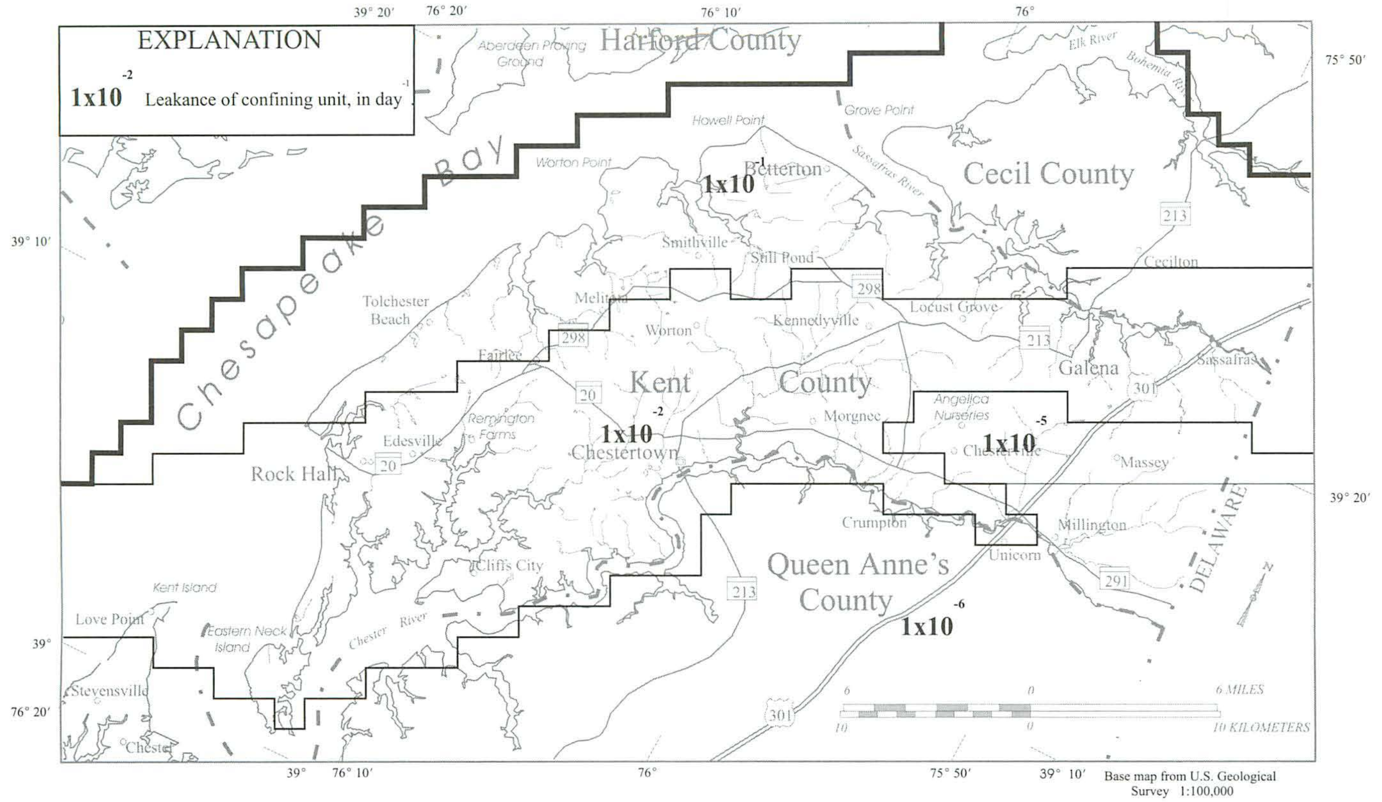


Figure 34.—Simulated leakance of layer 1.

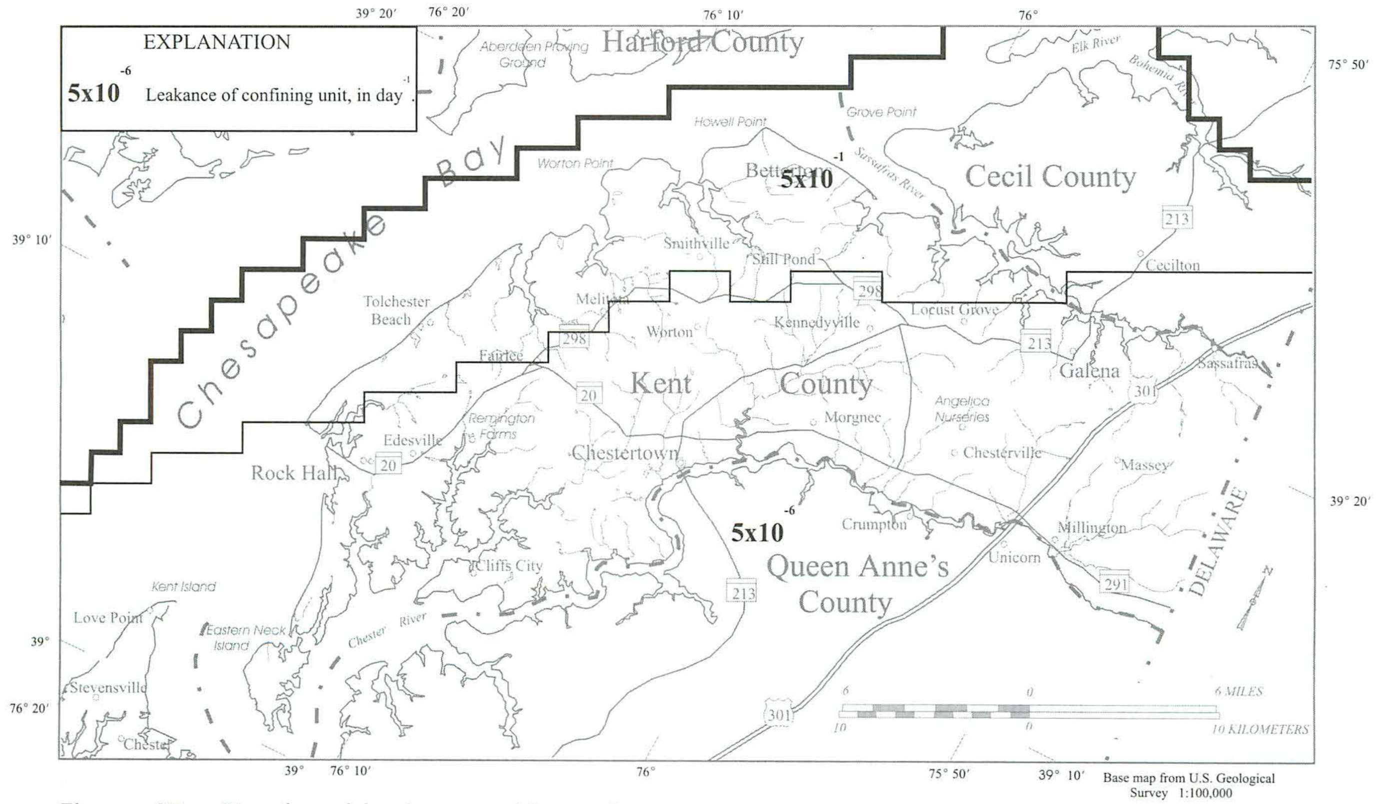


Figure 35.—Simulated leakance of layer 2.

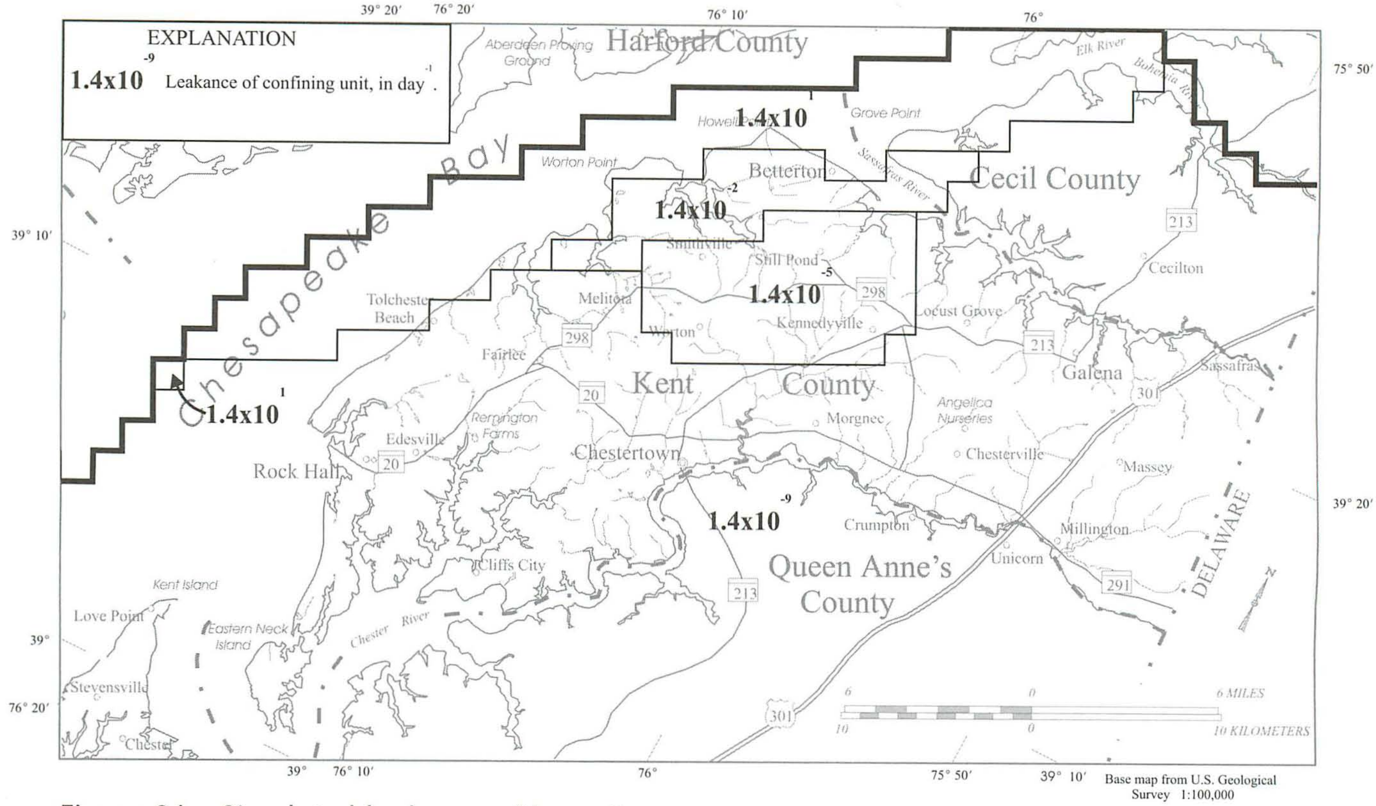


Figure 36.—Simulated leakance of layer 3.

model-calculated value is somewhat less than baseflow measured by Rasmussen and Andreasen (1959) in the Beaverdam Creek watershed. The model-calculated value for ET (8.7 in./yr) is also slightly less than the 9.7 in./yr measured by Rasmussen and Andreasen (1959). This discrepancy may be due to the higher baseflow in Kent County which would leave less water available for ET, or to differences in topography, vegetation, and pumpage between the two areas.

The majority (about 90 percent) of the flow in the budget shown in table 5 involves the constant-head-boundaries and general-head boundaries. This indicates that most of the water in the flow-model area enters and leaves through the lateral boundaries (general-head boundary), the land surface of areas outside of Kent County, and the estuaries (constant-head boundary). These flow components were not measured, and no data are available to compare with the model-calculated values. Of the other flow components (storage, pumpage, baseflow, ET, and recharge), inflow to the model is composed almost entirely of recharge, with insignificant contributions (less than 1 percent) from storage and baseflow (from losing stream reaches). Outflow from the model is composed of ET (50 percent), baseflow (49 percent), and pumpage (1 percent), with an insignificant component of storage.

Pumpage entered for the 1992 calibration period included only major users that has been documented by the Maryland Department of the Environment. This excludes domestic pumpage, small commercial users, and some irrigation pumpage. Domestic and small commercial pumpage is only about 17 percent of total pumpage. Most of this pumpage is withdrawn from the Aquia aquifer, which is unconfined or semiconfined throughout most of the study area, and much of this water would be returned to the Aquia through septic systems. For these reasons, the exclusion of domestic and small-commercial pumpage from the model is not expected to affect the model calibration significantly. To test this assumption, the calibrated flow model was run with domestic and commercial pumpage from the entire county entered into nine model cells in the Aquia aquifer. Drawdowns were less than 2 feet in those cells,

Table 5.–Flow budget for the ground-water flow model

[ft^3/d = cubic feet per day; ft/d = feet per day; in./yr = inches per year]

Flow component	ft^3/d	ft/d	in./yr
Inflow:			
Storage	222	0	0
Constant head	1.51×10^8	0.0198	86.8
Wells	0	0	0
Recharge	3.65×10^7	0.0048	21.0
Evapotranspiration	0	0	0
Base flow	7.38×10^4	9.7×10^{-6}	0.04
General head boundaries	1.43×10^8	0.0188	82.4
Total	3.30×10^8	0.0434	190.2
Outflow:			
Storage	24	0	0
Constant head	1.40×10^8	0.0184	80.6
Wells	3.73×10^5	4.90×10^{-5}	0.21
Recharge	0	0	0
Evapotranspiration	1.52×10^7	0.00199	8.72
Base flow	1.46×10^7	0.00192	8.41
General head boundaries	1.61×10^8	0.212	92.9
Total	3.30×10^8	0.0435	190.8

Flow values in ft/d were derived by dividing the flow values in ft^3/d by the total area of the active model grid (7.60×10^9 ft^2).

indicating that if that pumpage were distributed throughout the entire county, it would produce negligible drawdown.

Irrigation pumpage is seasonal and occurs during the months of June through September, after the April 1992 water-level measurement which was used to calibrate the flow model. Most of the irrigation water comes from the Aquia aquifer, and some of it is returned to the Aquia through infiltration. For these reasons the exclusion of some irrigation pumpage from the model is not expected to affect model calibration significantly. Irrigation pumpage causes water-level declines in the late summer, especially near the pumping wells. This effect coincides with the seasonal water-level declines caused by increased ET during the summer months.

The simulated water table in the Columbia aquifer is shown in figure 37, along with measured water levels for 1992. The simulated water table shows maximum values in the central part of the county approaching 70 ft above sea level and decreasing to sea level at the shoreline of the tidal estuaries.The simulated water table matches measured values reasonably well. Some differences are caused by local

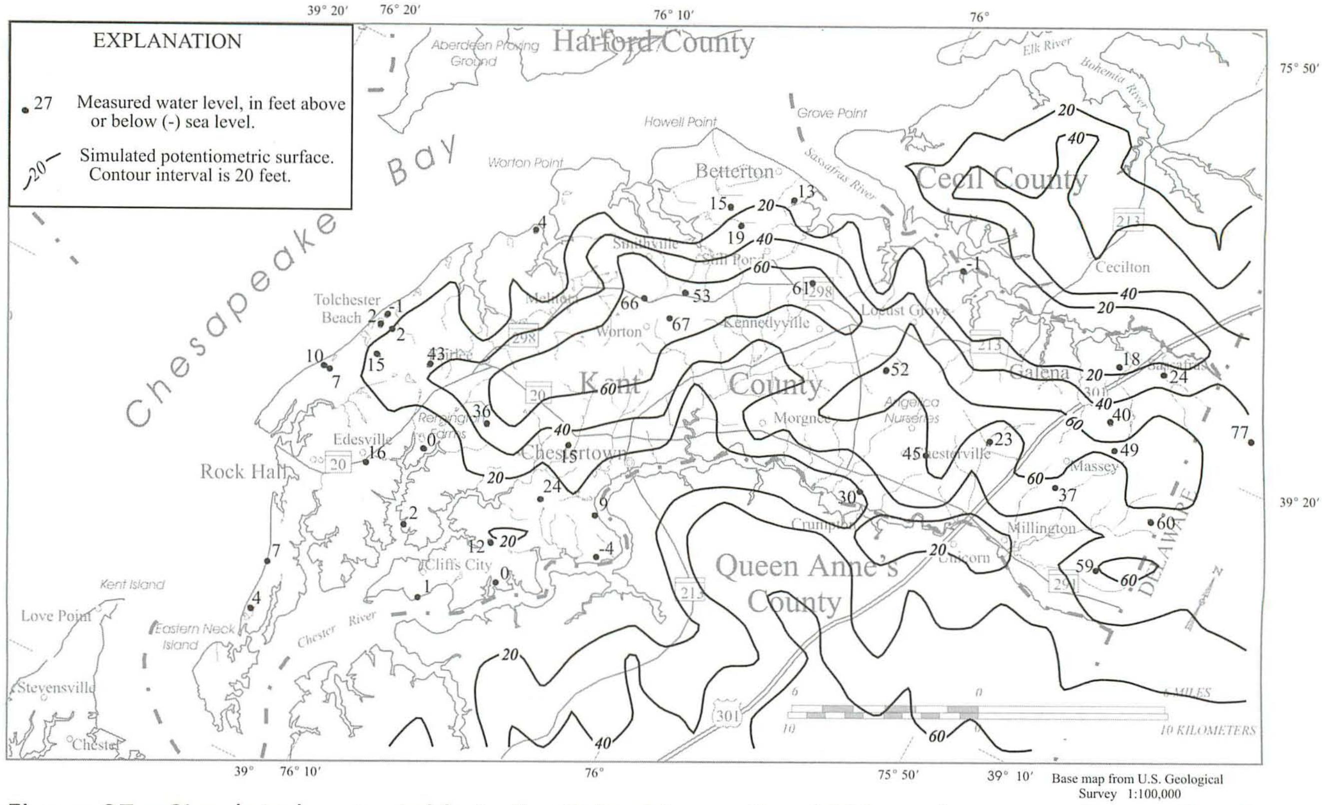


Figure 37.—Simulated water table in the Columbia aquifer, 1992, and measured water levels.

variations in the water table that could not be simulated with the relatively large scale of the flow model.

The simulated potentiometric surface in the Aquia aquifer is shown in figure 38, along with measured water levels for 1992. These contours show a similar pattern to the water-table contours shown in figure 37, with highs above 60 ft above sea level in the central part of the county, decreasing to sea level at the shoreline. Depressions in the potentiometric surface of the Aquia aquifer at Chestertown and Angelica Nurseries are caused by pumping at those sites. The potentiometric surface is below sea level in the southern part of the model area due to pumpage on Kent Island where the Aquia aquifer is confined. The simulated potentiometric surface in the Aquia aquifer matches measured water levels reasonably well, with slight discrepancies caused by local variations in the water table (the Aquia is unconfined or semi-confined throughout much of the model area) and by pumping.

The simulated potentiometric surface in the Monmouth aquifer is shown in figure 39, along with measured water levels for 1992. These contours show highs about 60 ft above sea level in the central part of the county, decreasing to below 20 ft above sea level in the southern part of the model area. The simulated potentiometric surface in the Monmouth aquifer matches measured water levels reasonably well, with slight discrepancies caused by local variations in the water table (the Monmouth is unconfined or semi-confined along the Sassafras River) and by pumping centers which were not simulated exactly due to the relatively coarse grid spacing.

The simulated potentiometric surface in the Magothy/Upper Patapsco aquifer is shown in figure 40, along with measured water levels for 1992. These contours show a high about 40 ft above sea level in the central part of the county, decreasing to sea level at the shoreline. The potentiometric surface is below sea level throughout much of the southern part of the model area, due to pumpage in southwestern Kent County and western Queen Anne's County. Cones of depression at Chestertown and Galena are caused by pumping at those sites. The simulated potentiometric surface in the Magothy/Upper Patapsco aquifer matches measured water levels reasonably well, with slight discrepancies caused by pumping.

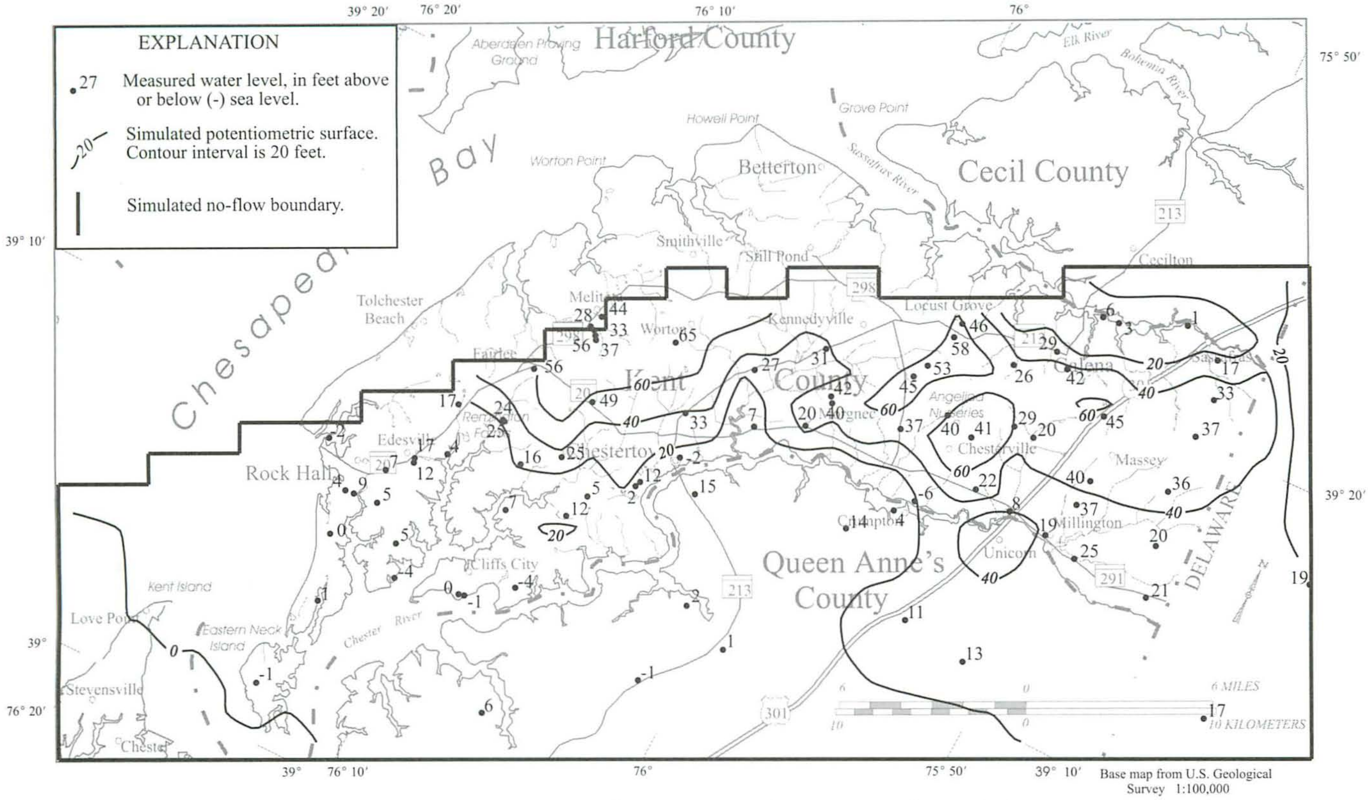


Figure 38.—Simulated potentiometric surface in the Aquia aquifer, 1992, and measured water levels.

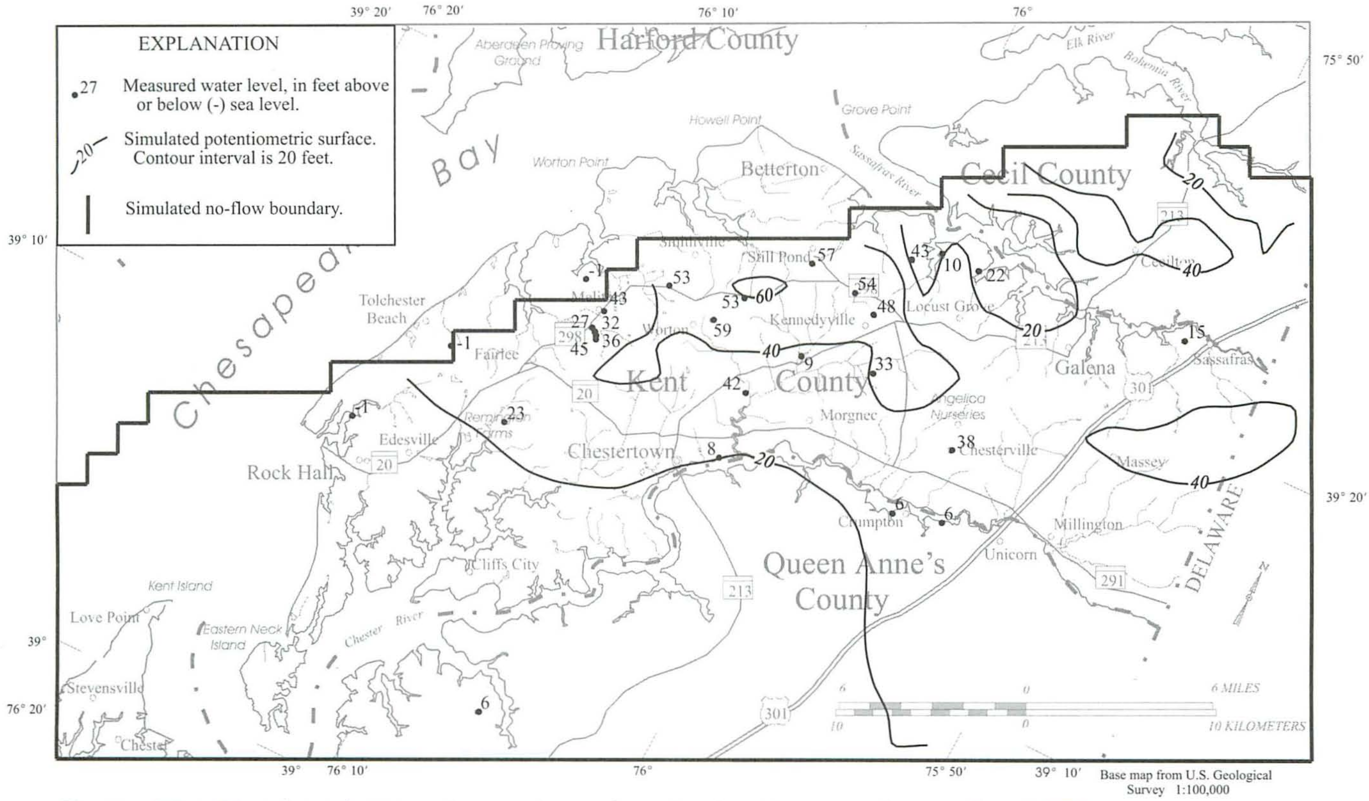


Figure 39.—Simulated potentiometric surface in the Monmouth aquifer, 1992, and measured water levels.

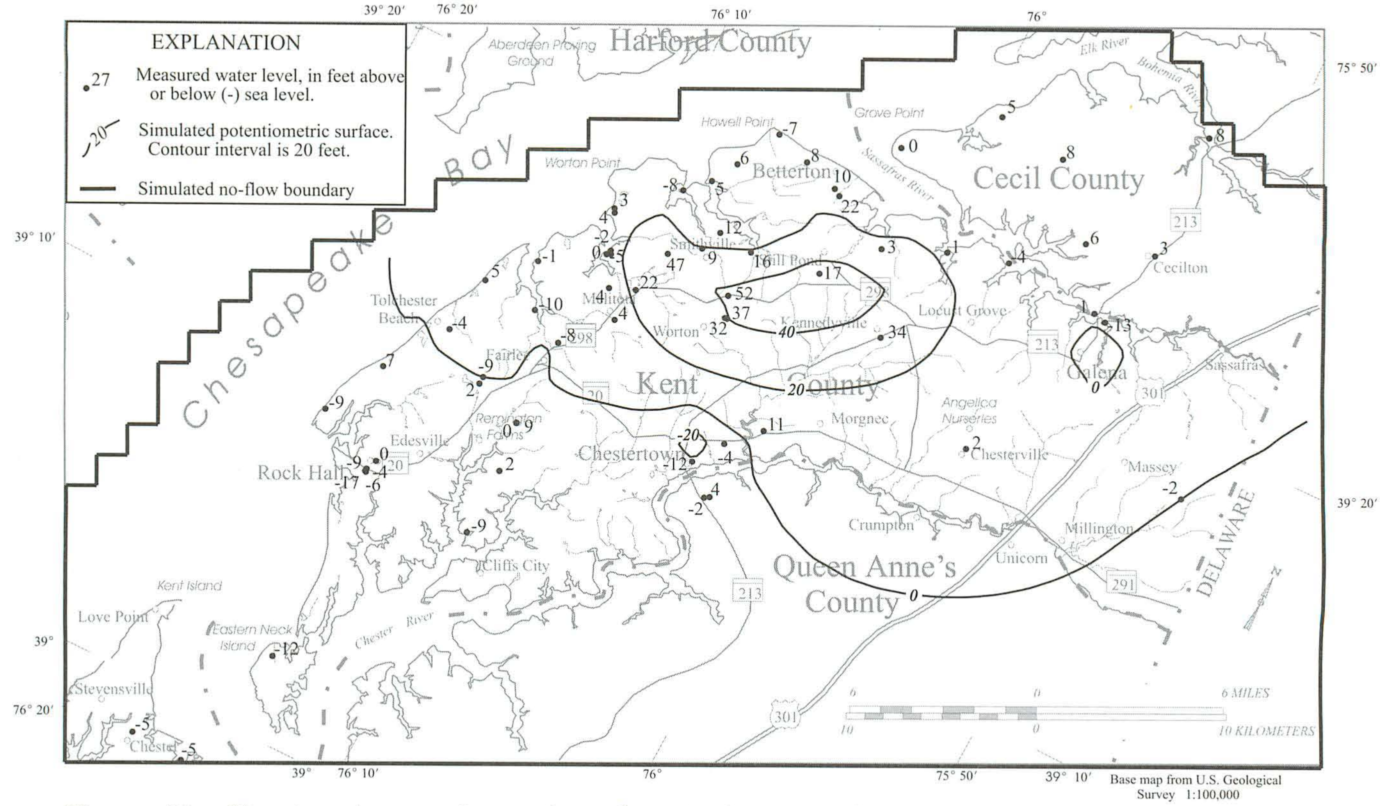


Figure 40.—Simulated potentiometric surface in the Magothy/Upper Patapsco aquifer, 1992, and measured water levels.

Sensitivity Analysis

A sensitivity analysis was performed on the calibrated flow model in order to determine the input values to which model results are most sensitive. The sensitivity analysis also provides an estimate of possible error in model results due to inaccuracies in model inputs. The analysis was performed by making a series of model runs, in which each model input was individually increased and then decreased by 50 percent from its calibration value. All other inputs were kept at their calibration values, and pumpage amounts for 1992 were used. For each sensitivity-analysis run, the change in RMS error and the maximum head change were recorded. Results of the sensitivity analysis are summarized in table 6. The model is considered most sensitive to inputs which, when changed by 50 percent, caused changes in RMS error of 0.5 ft or more. The model is considered moderately sensitive to inputs which, when changed by 50 percent, caused changes in RMS error between 0.05 and 0.5 ft. The model is considered least sensitive to inputs which, when changed by 50 percent, caused changes in RMS error of 0.05 ft or less.

The model is most sensitive to altitude of the ET surface, ET rate, recharge rate, and stage at river cells. The model is moderately sensitive to hydraulic conductivity of the Columbia aquifer, altitude of the bottom of the Columbia aquifer, transmissivity of the Aquia aquifer, leakance of the Monmouth aquifer, transmissivity of the Magothy/Upper Patapsco aquifer, head at general-head boundaries, conductance of the streambed at river cells, and altitude of the streambed in river cells. The model is least sensitive to leakance of the Columbia and Aquia aquifers, transmissivity of the Monmouth aquifer, storage coefficient of all aquifers, and the conductance at general-head boundaries.

The results of the sensitivity analysis give a general indication of the amount of error in model results that could be caused by errors in input data. The greatest head differences indicated by the sensitivity analysis are -47 ft in the Aquia aquifer and -35 ft in the Magothy aquifer, both of which resulted from decreasing the transmissivity of the respective aquifers by 50 percent. Both of these maximum head changes occurred at heavily pumping wells. These

Table 6.–Summary of results of sensitivity analysis

Change of input data	Maximum head difference (in feet)	Delta root mean square
Increase storage of the Columbia aquifer	0.00	0.000
Decrease storage of the Columbia aquifer	0.00	0.000
Increase hydraulic conductivity of the Columbia aquifer	-2.95	0.123
Decrease hydraulic conductivity of the Columbia aquifer	6.08	-0.223
Increase altitude of the bottom of the Columbia aquifer*	3.75	0.112
Decrease altitude of the bottom of the Columbia aquifer	3.20	-0.148
Increase leakance of the Columbia aquifer	3.42	0.000
Decrease leakance of the Columbia aquifer	-5.88	0.002
Increase storage of the Aquia aquifer	0.00	0.000
Decrease storage of the Aquia aquifer	0.00	0.000
Increase transmissivity of the Aquia aquifer	17.39	0.051
Decrease transmissivity of the Aquia aquifer	-46.52	-0.778
Increase leakance of the Aquia aquifer	3.98	-0.045
Decrease leakance of the Aquia aquifer	-5.62	0.028
Increase storage of the Monmouth aquifer	0.00	0.000
Decrease storage of the Monmouth aquifer	0.00	0.000
Increase transmissivity of the Monmouth aquifer	-3.15	0.013
Decrease transmissivity of the Monmouth aquifer	6.43	-0.034
Increase leakance of the Monmouth aquifer	4.47	-0.075
Decrease leakance of the Monmouth aquifer	-7.86	0.004
Increase storage of the Magothy/Upper Patapsco aquifer	0.00	0.000
Decrease storage of the Magothy/Upper Patapsco aquifer	0.00	0.000
Increase transmissivity of the Magothy/Upper Patapsco aquifer	11.82	0.079
Decrease transmissivity of the Magothy/Upper Patapsco aquifer	-35.14	-0.390
Increase altitude of the evapotranspiration surface	11.57	-1.703
Decrease altitude of the evapotranspiration surface	-11.68	0.706
Increase evapotranspiration rate	-4.39	0.255
Decrease evapotranspiration rate	5.21	-0.643
Increase recharge rate	5.72	-0.948
Decrease recharge rate	-5.61	0.636
Increase heads at general-head boundaries	20.00	-0.073
Decrease heads at general-head boundaries	-20.00	0.042
Increase conductance at general-head boundaries	-3.33	-0.001
Decrease conductance at general-head boundaries	5.91	0.002
Increase stage at river cells	8.67	-0.726
Decrease stage at river cells*	-12.66	0.408
Increase conductance of streambed in river cells	-3.69	0.173
Decrease conductance of streambed in river cells	5.28	-0.278
Increase altitude of streambed in river cells*	-11.48	0.196
Decrease altitude of streambed in river cells	2.73	0.014

* Change of input caused some cells to go dry

head differences are far greater than the estimated model error because, if the alternative values were used, other model inputs would have been changed to compensate, in order to achieve model calibration in those areas. A reasonable amount of error would be around 20 percent of the maximum head differences or about 10 ft.

Projected Pumpage

The effects of projected pumpage on the ground-water system were evaluated by developing several future pumpage scenarios, simulating those scenarios in the well module of MODFLOW, and analyzing the resultant heads and flow regimes. Projected pumpage simulations were run from 1993 through 2012 using the calibrated flow model. Contoured drawdowns are shown for simulations in which drawdown exceeded 5 ft. Results of the projected-pumpage simulations are shown in table 7. Total pumpage simulated in Kent County is shown in the table along with the greatest water-level change in the entire model area when compared with 1992 simulated water levels.

Drawdowns calculated by the flow model are cell averages, and drawdown near a pumping well can be significantly greater than that indicated by the model. Drawdowns in production wells can be even greater than drawdowns in the aquifer near the wells. The additional drawdown in a pumping well may be calculated using the following equation from Trescott and others (1976, p. 10):

$$s = \frac{2.3Q}{2\pi T} \times \log_{10} \frac{a}{4.18r_w}$$

where

s = additional drawdown in the well (ft),
Q = well pumping rate (cubic feet per day [ft^3/d]),
T = transmissivity of the aquifer (ft^2/d),
r_w = radius of the well (ft),
a = cell width (ft).

The amount of error in model-calculated drawdowns may be estimated from the sensitivity analysis and from the error criterion used in model calibration. The amount of error estimated for the calibration was 10 ft, which is about 20 percent of the greatest drawdown produced in the calibration simulation.

Simulation 1

Simulation 1 continues (through 2012) the 1992 pumpage rate that was used to calibrate the flow model. The total pumpage for Kent County in this scenario is 2.5 Mgal/d and for the entire model area is 2.8 Mgal/d. Nonappropriated irrigation pumpage is not included in this amount. Drawdown in all four aquifers is near zero for this simulation, indicating that the additional 20 years of pumping at 1992 rates caused no residual drawdown, and that water levels had attained equilibrium by 1992.

Simulation 2

Simulation 2 increases the pumpage amounts used in Simulation 1 by 20 percent, for all users in the model area. The total pumpage for Kent County in this scenario is 3.0 Mgal/d. Drawdown in the Aquia aquifer is 5 ft at Angelica Nurseries and near zero elsewhere in the model area (fig. 41). The minimal drawdowns in this simulation for the Aquia aquifer result from unconfined conditions throughout much of Kent County and the high storativity of the water-table aquifer. Drawdown in the Magothy/Upper Patapsco aquifer is about 7 ft at Chestertown and 2 ft at Angelica Nurseries and Galena (fig. 42). Drawdown in the Columbia and Monmouth aquifers is less than 5 ft for this simulation.

Simulation 3

Simulation 3 represents pumpage at the current (1992) average annual GAP (Ground-water Appropriation Permit) amounts for all large ground-water users in Kent County. Ground-water users are not allowed to exceed this rate as an annual average; that is, the total yearly pumpage divided by 365 days can not exceed the average GAP amount, in gal/d. The total pumpage for Kent County in this scenario is 6.7 Mgal/d.

Simulated drawdown in the Aquia aquifer shows a cone-of-depression centered at Angelica Nurseries with a maximum of 60 ft (fig. 43). Simulated pumpage at the Wick Nursery caused the formation of a smaller cone-of-depression with a maximum drawdown of about 20 ft. Both of these pumpers are located in the area where the Aquia aquifer is partially confined by the Calvert confining unit. The

Table 7.–Summary of results of projected-pumpage simulations

[Mgal/d = million gallons per day; ft = feet; GAP = Ground-Water Appropriation Permit]

Simulation	Description	Simulated pumpage in Kent County (Mgal/d)	Greatest simulated water-level change (ft)
1	Continue pumpage of 1992 calibration period	2.5	0
2	Increase pumpage of 1992 calibration period by 20%	3.0	-7
3	Use average GAP amounts in Kent County	6.7	-60
4	Increase irrigation pumpage to 3.4 Mgal/d by adding hypothetical pumpers	4.9	-20
5	Distribute half of pumpage at Angelica Nurseries to the Magothy/Upper Patapsco aquifer	6.7	-120

semi-confined conditions in this area cause greater drawdowns than in the area where the Aquia is unconfined.

Leakage from the Monmouth aquifer into the Aquia aquifer caused a cone-of-depression to form in the Monmouth aquifer with a maximum drawdown of about 15 ft (fig. 44). This cone-of-depression is centered at Angelica Nurseries, as is the cone-of-depression in the Aquia aquifer. Drawdown at the Huls America plant is 2 ft.

Simulated drawdown contours in the Magothy/Upper Patapsco aquifer show cones-of-depression at Chestertown (15 ft), Still Pond (6 ft), and Galena (6 ft) (fig. 45).

Simulation 4

The Kent County Department of Planning and Zoning expects irrigation pumpage to increase to as much as 3.4 Mgal/d during the 20-year simulation period. In Simulation 4, irrigation pumpage was increased to 3.4 Mgal/d by multiplying reported 1992 irrigation pumpage (Simulation 1) and average GAP amounts at non-reporting sites (Simulation 3) by a factor of 1.2. In addition, pumpage was simulated at ten hypothetical irrigation sites at randomly selected locations (fig. 29 and table 4) to attain the 3.4 Mgal/d pumping rate. Non-irrigation withdrawals were simulated using reported 1992 pumpage, as in Simulation 1.

Simulated drawdowns in the Aquia aquifer attain maximums of about 20 ft at the Wick Nursery and about 10 ft at Angelica Nurseries (fig. 46). Drawdown in the Monmouth aquifer attained a maximum of 6 ft at the Wick Nursery due to upward leakage into the Aquia aquifer. Simulated drawdowns in the Magothy/Upper Patapsco aquifer attain maximums of 9 ft at the Speakman Nursery and at Hypothetical User G, and 5 ft at Hypothetical User A (fig. 47). Drawdown in the Columbia aquifer was less than 5 ft for this simulation.

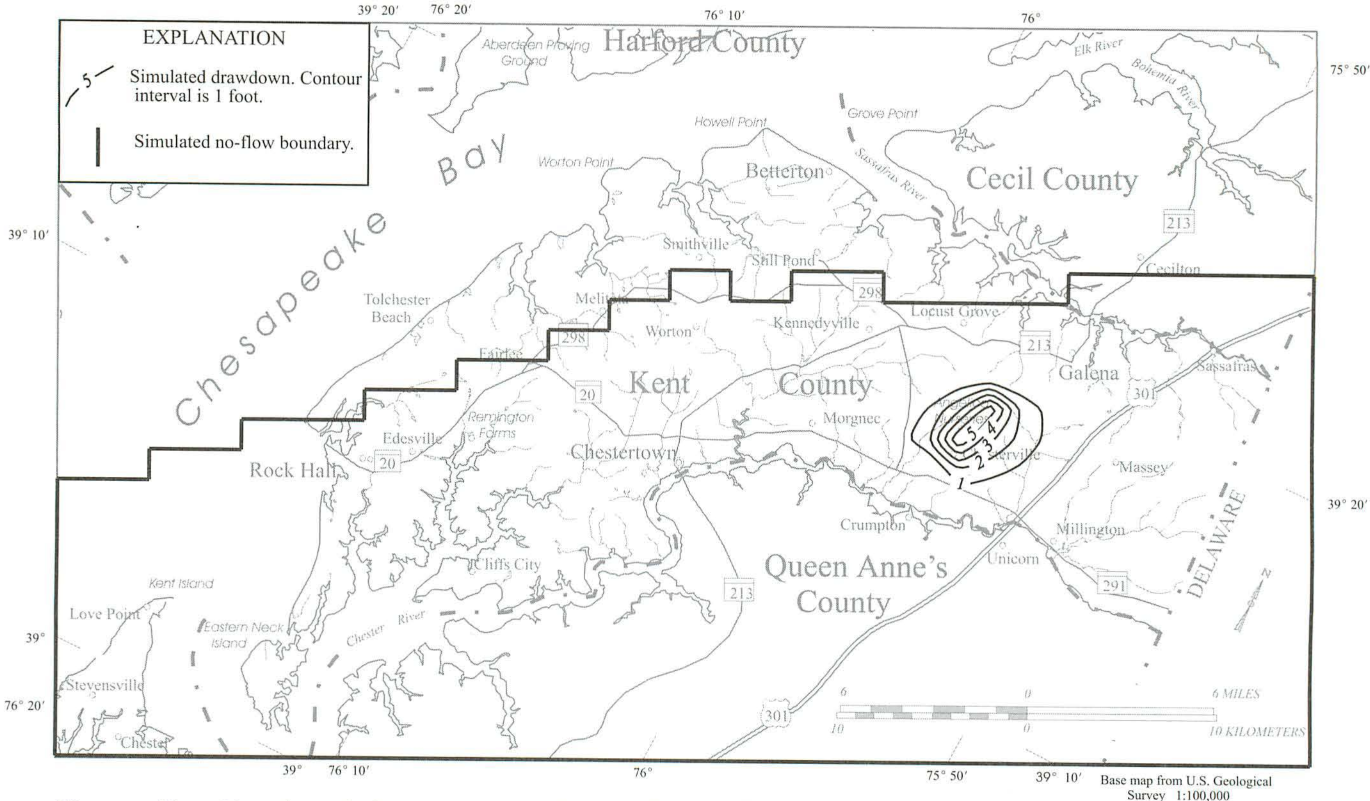


Figure 41.—Simulated drawdown in the Aquia aquifer, 1992-2012, based on Simulation 2.

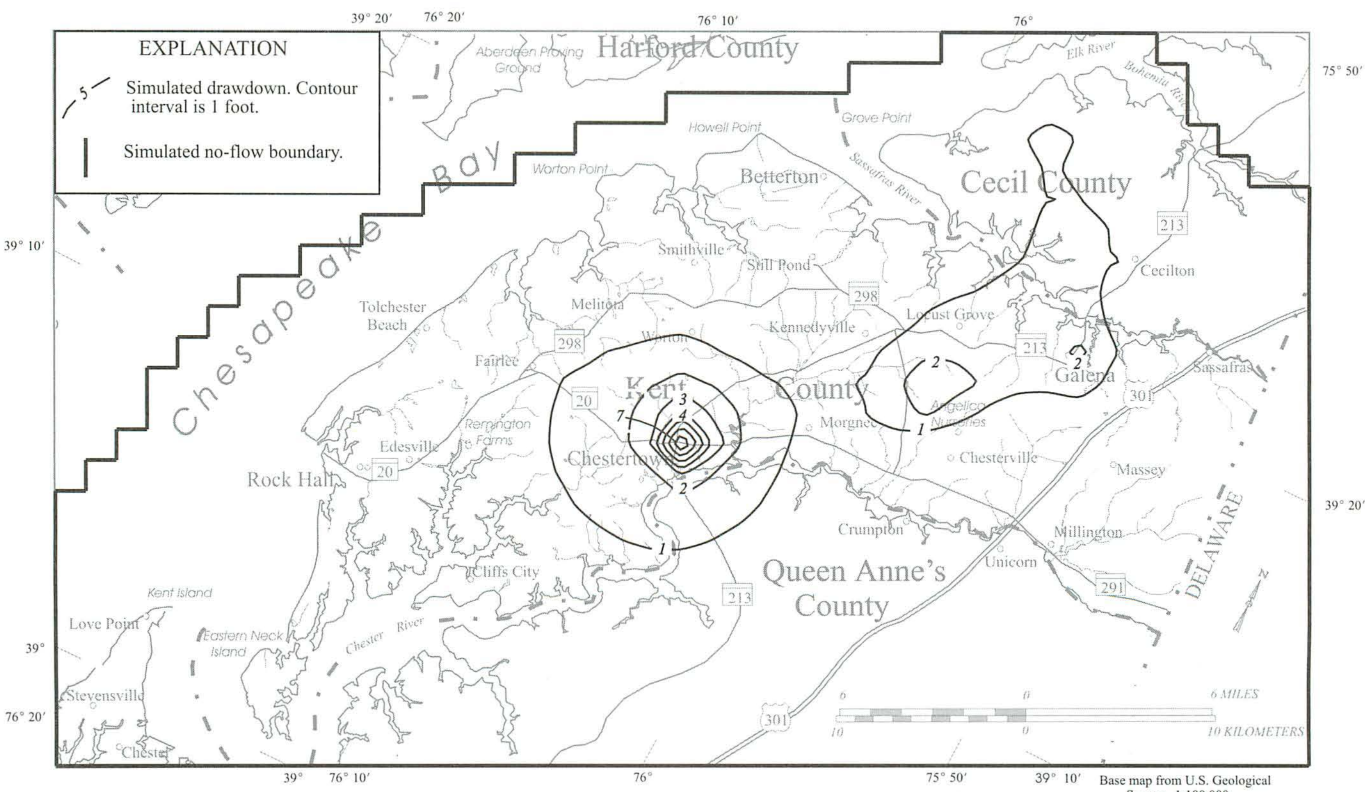


Figure 42.—Simulated drawdown in the Magothy/Upper Patapsco aquifer, 1992-2012, based on Simulation 2.

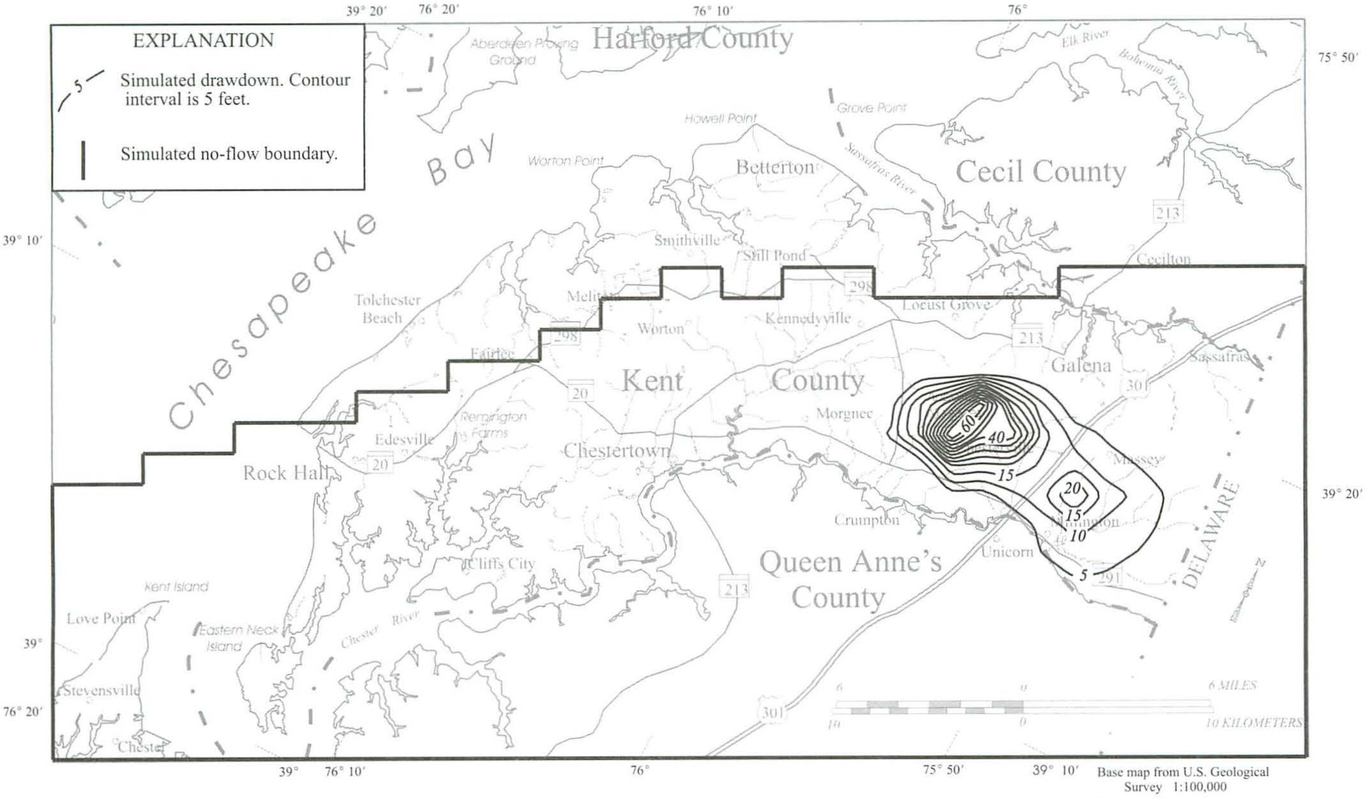


Figure 43.—Simulated drawdown in the Aquia aquifer, 1992-2012, based on Simulation 3.

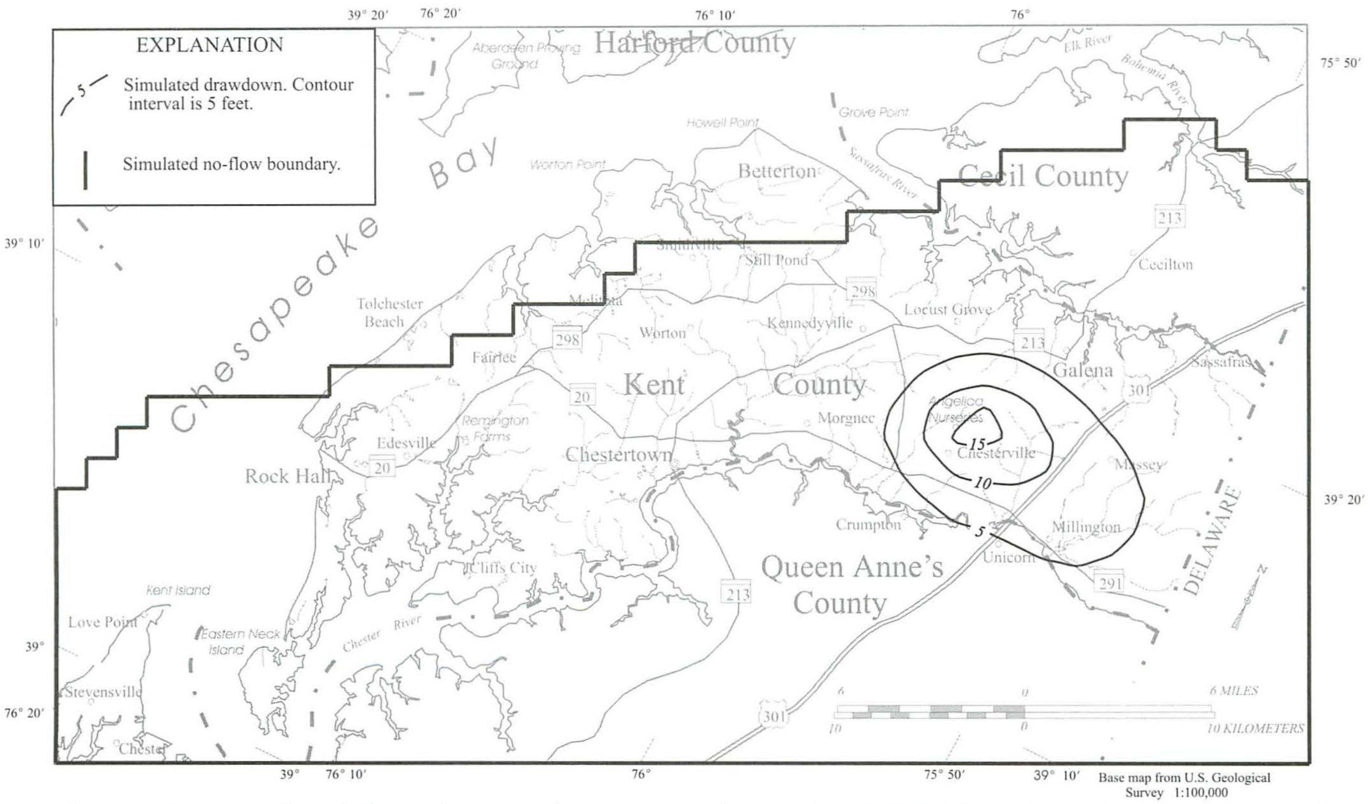


Figure 44.—Simulated drawdown in the Monmouth aquifer, 1992-2012, based on Simulation 3.

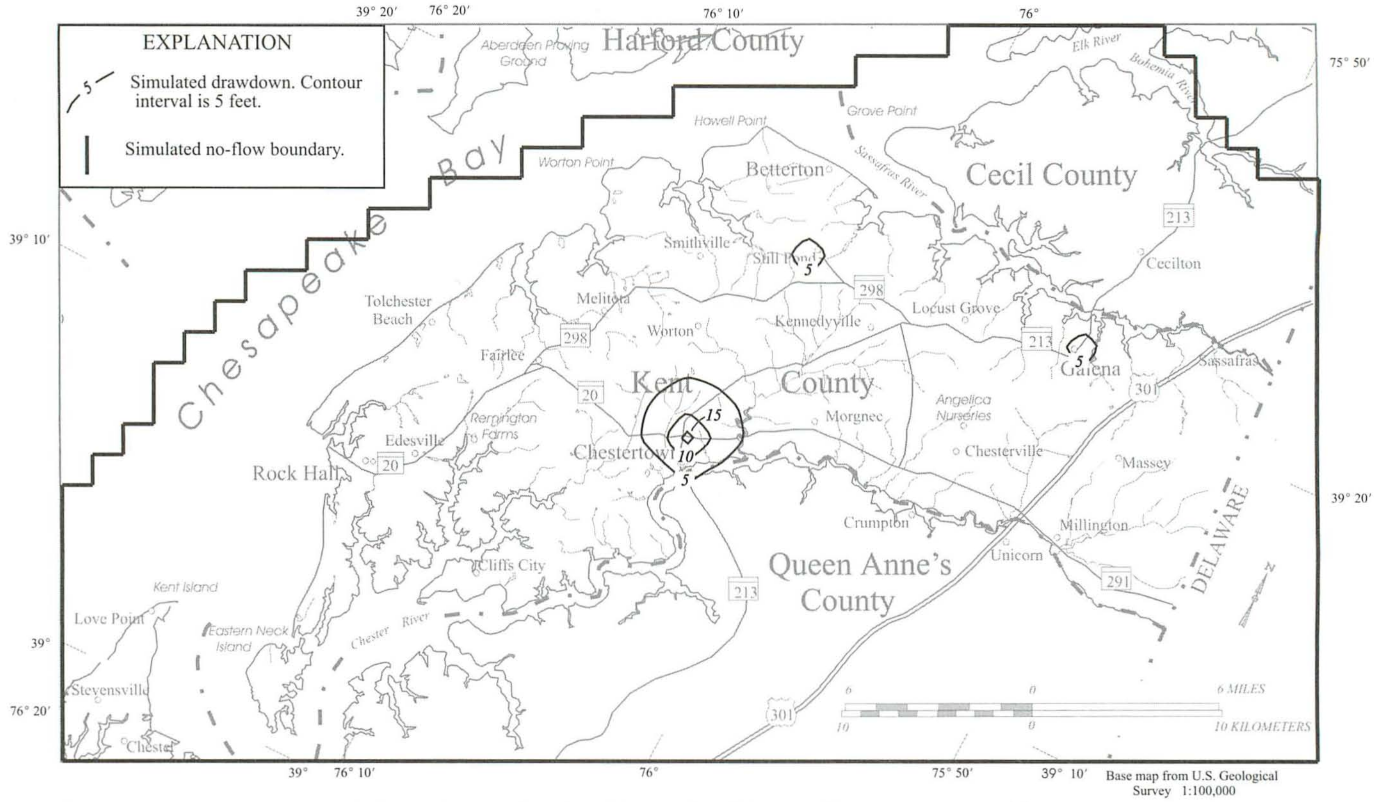


Figure 45.—Simulated drawdown in the Magothy/Upper Patapsco aquifer, 1992-2012, based on Simulation 3.

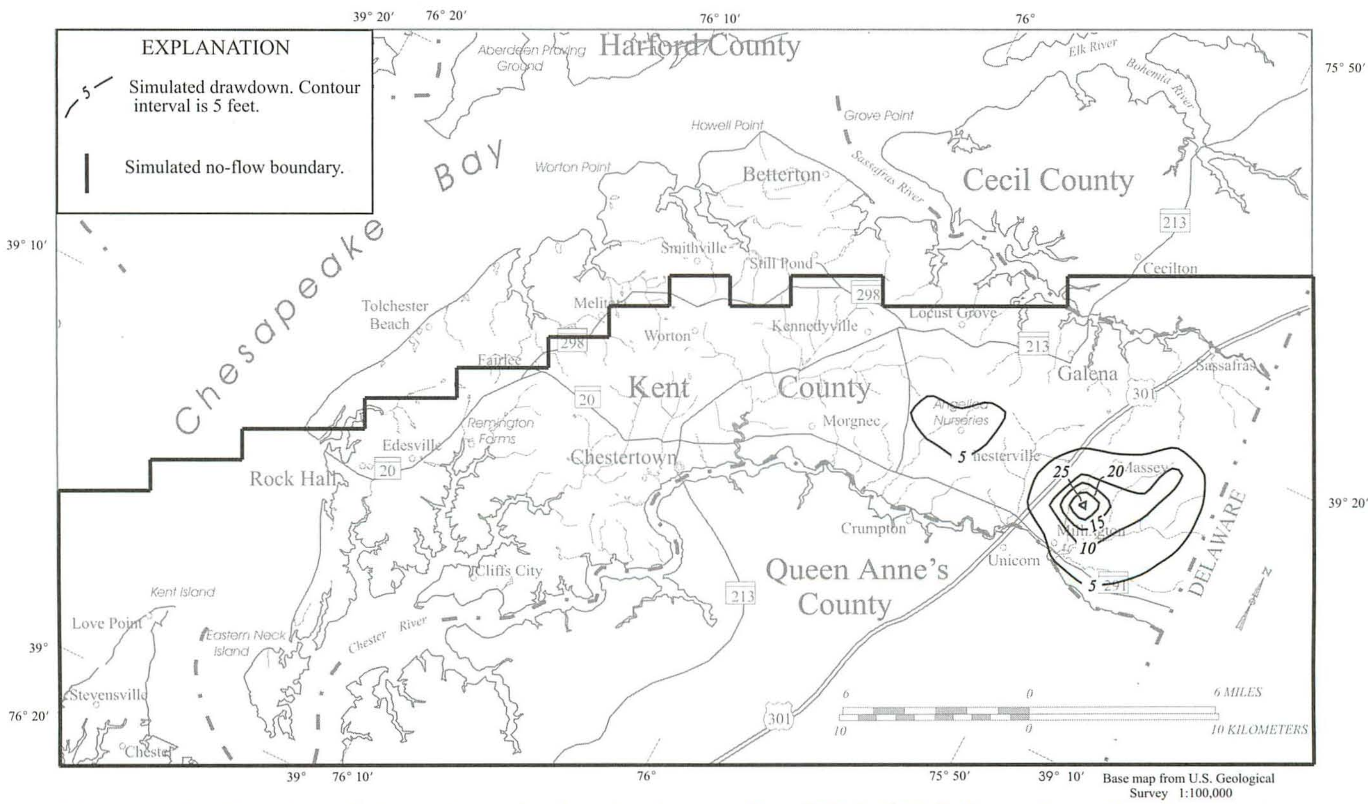


Figure 46.—Simulated drawdown in the Aquia aquifer, 1992-2012, based on Simulation 4.

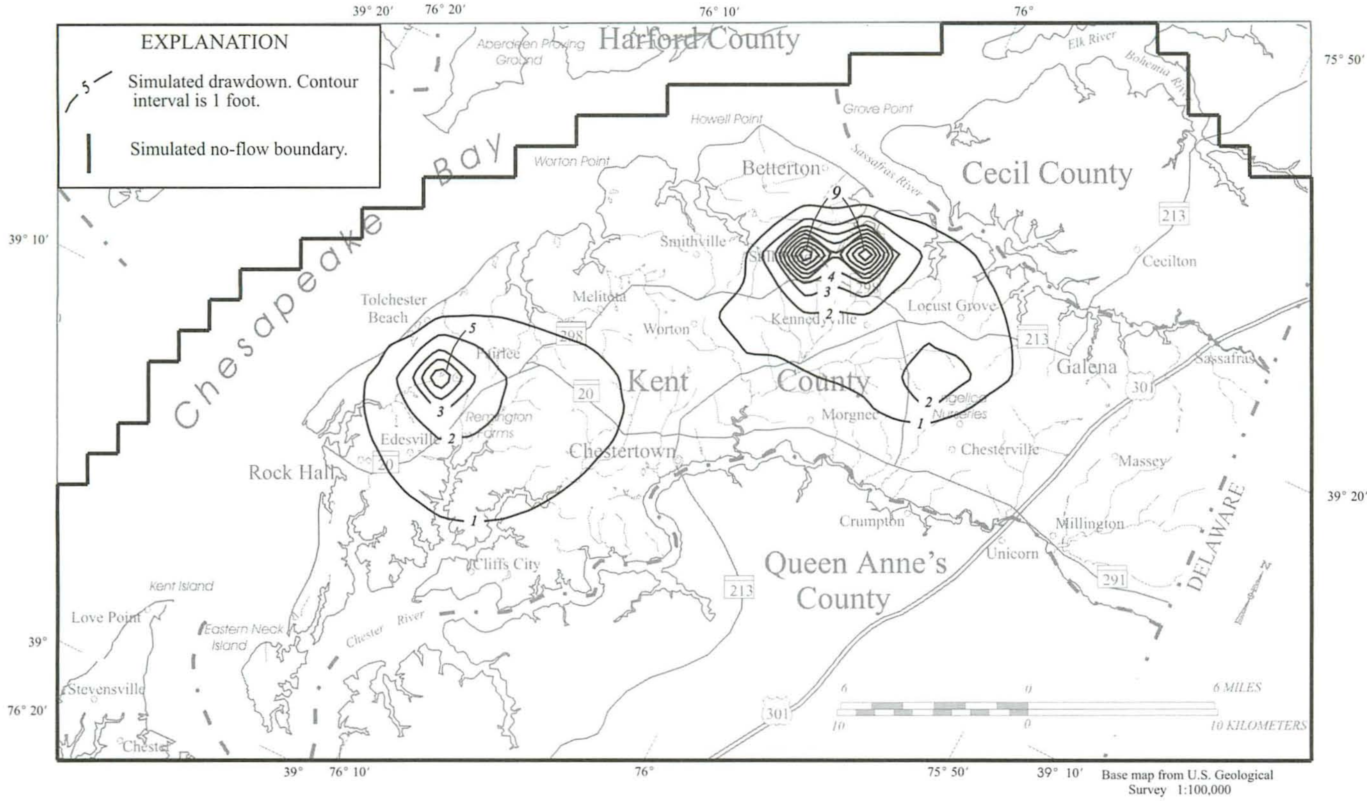


Figure 47.—Simulated drawdown in the Magothy/Upper Patapsco aquifer, 1992-2012, based on Simulation 4.

Simulation 5

Simulation 5 is identical to Simulation 3 except that 1.7 Mgal/d of pumpage was transferred from the Aquia aquifer to the Magothy/Upper Patapsco aquifer at Angelica Nurseries. This simulation demonstrates the results of redistributing pumpage from the Aquia aquifer to the Magothy/Upper Patapsco aquifer.

Maximum drawdown in the Aquia aquifer is 25 ft at Angelica Nurseries (fig. 48), which is about 35 ft less than in Simulation 3. The reduced drawdown is a result of 1.7 Mgal/d less pumpage in the Aquia than in Simulation 3. Maximum drawdown in the Magothy/Upper Patapsco aquifer is about 120 ft at Angelica Nurseries (fig. 49); there was no significant drawdown at this location in the Magothy/Upper Patapsco aquifer in Simulation 3. Although the transmissivity of the Magothy/Upper Patapsco aquifer (2,000 ft^2/d) is higher than in the Aquia aquifer (700 ft^2/d), the pumpage produces greater drawdown when it is placed in the Magothy/Upper Patapsco aquifer. This is caused by the confined conditions in the Magothy/Upper Patapsco aquifer, as opposed to semi-confined conditions in the Aquia aquifer.

GROUND-WATER QUALITY

The quality of ground water in the coastal plain aquifers of Kent County is generally good for most purposes, although some problem areas exist. Chemical analyses of 163 ground-water samples taken from 113 wells and springs were compiled by Tompkins, Cooper, and Drummond, 1994. Those analyses include major ions, nutrients, metals, pesticides, and volatile organic compounds. This section describes the ground-water quality of each aquifer in Kent County, provides summary statistics of ground-water analyses, and describes water-quality problems in each aquifer. Selected analyses from each

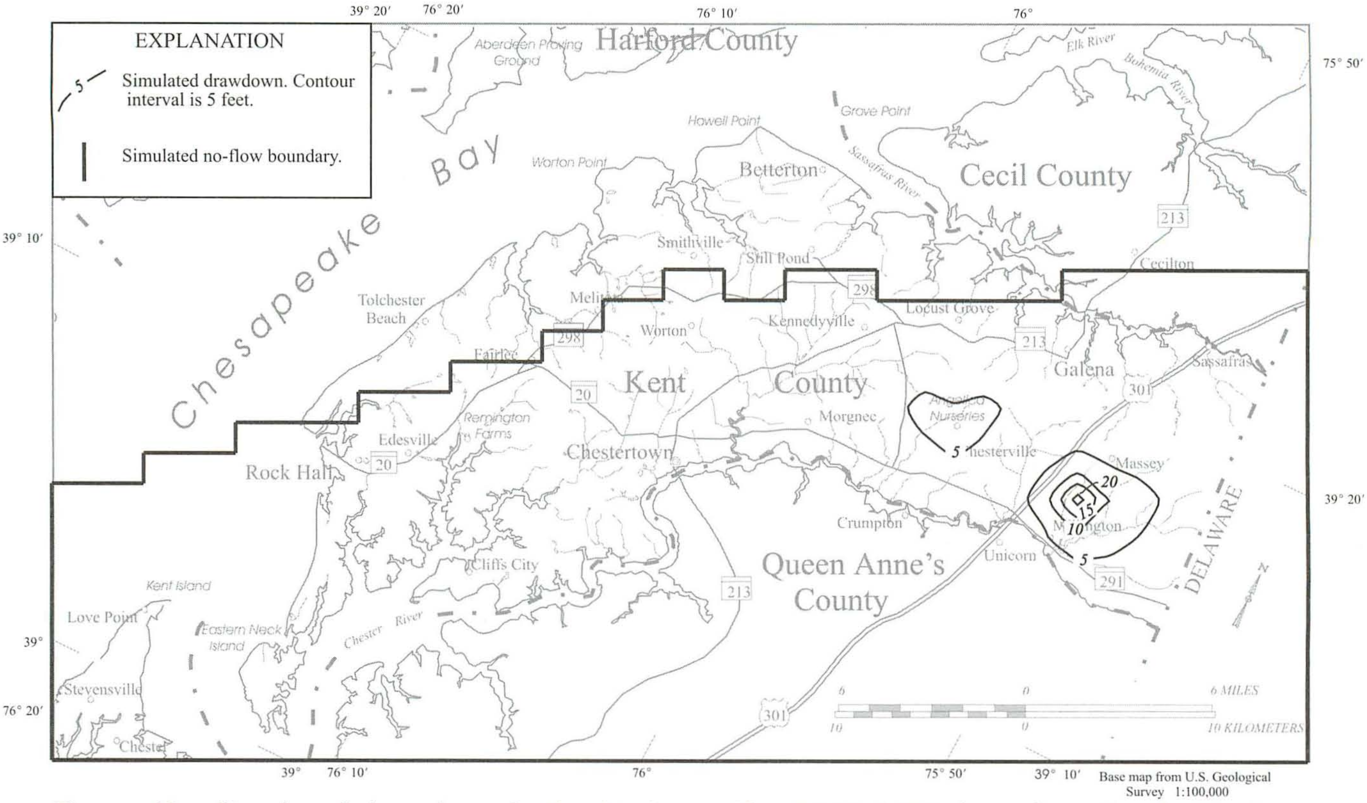


Figure 48.—Simulated drawdown in the Aquia aquifer, 1992-2012, based on Simulation 5.

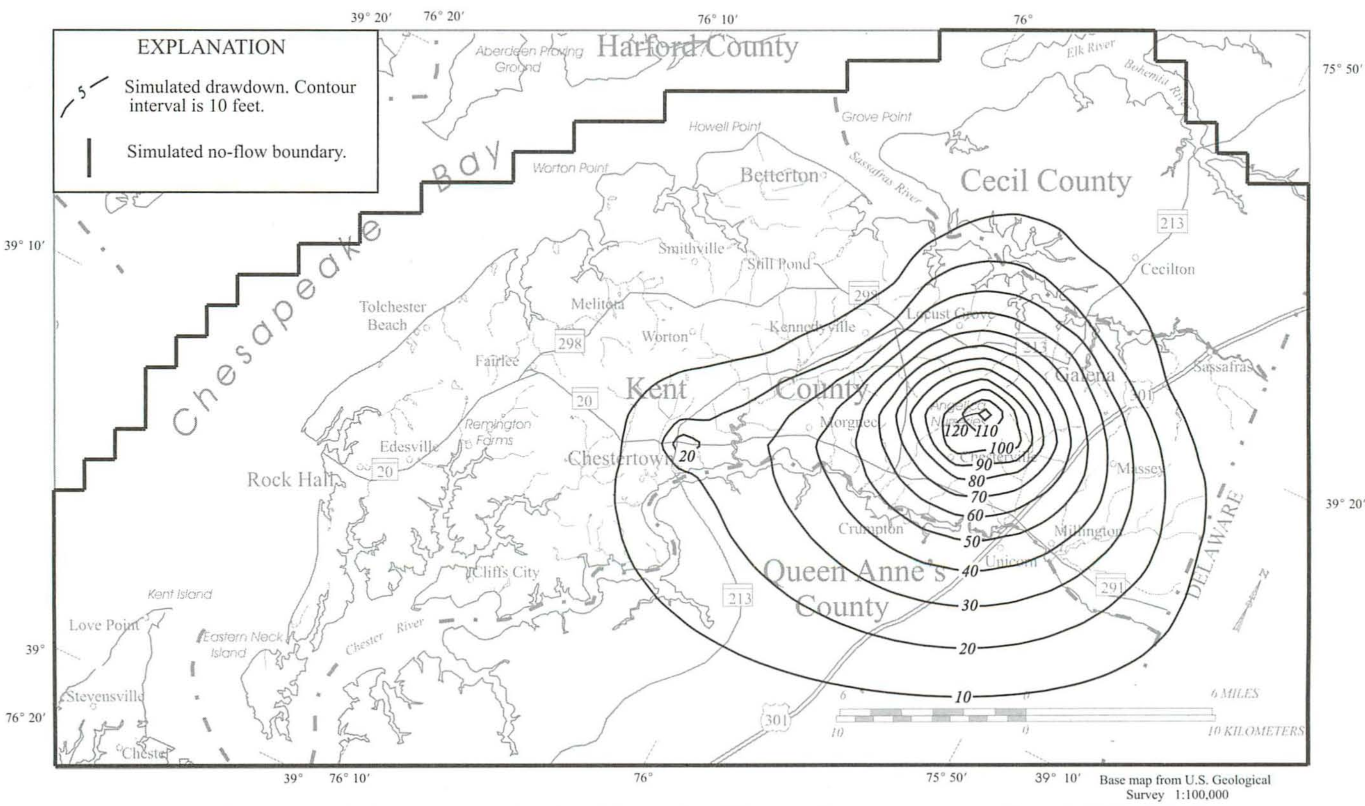


Figure 49.—Simulated drawdown in the Magothy/Upper Patapsco aquifer, 1992-2012, based on Simulation 5.

aquifer are provided in table 8 which represent typical water types and show variations of water quality in each aquifer. The locations of wells included in table 8 are shown in figure 50.

Many of the chemical analyses listed in Tompkins, Cooper, and Drummond (1994), and in this report, were obtained from a U.S. Geological Survey NAWQA (National Water Quality Assessment) study of a small watershed near Locust Grove (Hamilton and others, 1993). In that study, many water samples from the Columbia and Aquia aquifers were analyzed for major ions, nutrients, pesticides and pesticide residues, trace metals, and VOCs (volatile organic compounds). Because of this extensive sampling in the shallow aquifers of a relatively small portion of Kent County, some statistical results may be biased toward this area. For example, water from 9 of 16 wells sampled in the Aquia aquifer for pesticide residues showed detections, and water from one of those 16 exceeded the MCL (Maximum Contaminant Level) for atrazine. This does not necessarily indicate that water from half of the wells screened in the Aquia aquifer in Kent County are contaminated with pesticide residues, because all but one of the wells sampled for pesticides are in the Locust Grove watershed.

Ground-water quality problems in Kent County are associated with agricultural application of fertilizers and pesticides, brackish-water intrusion from the Chesapeake Bay and the Sassafras and Chester Rivers, and naturally occurring chemical constituents such as iron, manganese, and radon. None of the 10 wells sampled for VOCs showed detections. Of 22 trace metals analyzed in water from wells in Kent County, only aluminum, iron, and manganese exceeded SMCLs (Secondary Maximum Contaminant Levels), and none exceeded MCLs.

Concentrations of dissolved nitrate plus nitrite exceeded the MCL in water from 19 wells. In general, these wells are screened in the Columbia aquifer and the shallow unconfined portion of the Aquia aquifer. Water from 80 wells and springs exceeded SMCLs for pH, sulfate, chloride, total dissolved solids, aluminum, iron, and/or manganese. Water from 37 wells exceeded the proposed (but subsequently withdrawn) MCL for radon (300 picoCuries per liter [pCi/L]) (Stone, 1993). Of these wells, 5 are screened in the Columbia aquifer, 16 in the Aquia, 5 in the Monmouth, 2 in the Magothy, and 1 in the Upper Patapsco. No analyses exceeded 4,000 pCi/L, which is the maximum level recommended by the American Water Works Association (1997) for public-supply wells.

The chemical character of waters from each of the aquifers is shown on trilinear (Piper) diagrams. The relative ionic composition of each water sample is plotted on two triangular diagrams, one for cations and one for anions. These plots are projected onto a central diamond which displays the composite ionic character of each sample. The "water type" refers to the anionic or cationic character of a water, and the "hydrochemical facies" refers to the composite character of the water (Back, 1966). For example, a water of calcium-carbonate hydrochemical facies will have a calcium type and a bicarbonate type.

Four hydrochemical facies were identified in water samples from the aquifers studied in Kent County (fig. 51). Most water samples collected in the study area fall into one of these four facies or are transitional between two or more facies. A few water samples from each aquifer show a complete dominance of sodium in the cation type (calcium and magnesium less than 1 mg/L) and may have been inadvertently collected after the water passed through water-softening treatment systems.

Facies 1-- Soil reaction/silicate dissolution facies: This facies represents water that has been altered only slightly since entering the ground-water system as precipitation, by chemical reactions in the soil zone or dissolution of interstitial silicate minerals. Waters of this facies have low dissolved solids content (typically below 120 milligrams per liter [mg/L]), a mixed cation type which tends more toward calcium and sodium than magnesium, and a mixed-anion type which tends more toward sulfate and carbonate than chloride.

Facies 2-- Nitrate facies: This facies is similar to, and is transitional with Facies 1, but includes the presence of significant amounts of nitrate (typically more than 5 mg/L). Waters of this facies have a mixed cation type, and a nitrate/sulfate anion type with some chloride.

Facies 3--Calcite dissolution facies: Dissolution of calcite shell material produces water in this facies, with calcium and bicarbonate types. A trend toward sodium may be caused by cation exchange on interstitial glauconite. Alkalinities of waters in this facies are typically greater than 100 mg/L as $CaCO_3$.

Facies 4--Brackish-water intrusion facies: This facies represents the mixing of brackish water from nearby estuaries with ground water of the other facies.

(Text continued on p. 62.)

Table 8.–Chemical analyses of ground water from selected wells in Kent County

WELL NUMBER	DATE	DEPTH OF WELL (FEET)	SPE-CIFIC CON-DUCT-ANCE (µS/CM)	PH FIELD (STAND-ARD UNITS)	TEMPER-ATURE WATER (DEG C)	OXYGEN, DIS-SOLVED (MG/L)	TOTAL DIS-SOLVED SOLIDS (MG/L)	CALCIUM, DIS-SOLVED (MG/L AS CA)	MAGNE-SIUM, DIS-SOLVED (MG/L AS MG)	SODIUM, DIS-SOLVED (MG/L AS NA)	POTAS-SIUM, DIS-SOLVED (MG/L AS K
Columbia aquifer											
KE Ad 20	05-26-92	--	214	5.5	13.0	8.0	137	12	6.0	16	4.7
KE Bb 38	04-16-92	58.00	199	5.1	12.0	2.0	127	7.2	3.5	23	1.5
KE Bc 185	05-05-92	55.00	55	5.2	13.5	7.9	47	2.4	1.7	2.7	2.1
KE Bd 42	09-07-88	27.00	235	--	21.0	5.7	172	23	7.7	9.0	2.9
KE Be 46	07-18-88	50.00	127	4.6	14.5	10.0	--	9.6	2.7	5.1	2.7
KE Be 47	06-09-92	24.00	303	5.9	14.0	9.1	112	21	14	6.2	3.1
KE Be 49	06-04-90	25.00	251	5.5	13.5	8.4	162	19	14	3.8	2.0
KE Be 50	05-28-91	22.00	397	5.4	15.0	10.1	262	27	20	8.9	1.7
KE Be 51	06-04-90	27.00	168	4.7	13.5	9.8	--	11	5.9	8.1	2.4
KE Be 52	03-04-91	36.00	197	5.0	13.5	10.0	--	11	8.3	4.6	2.7
KE Be 53	06-05-90	22.00	--	5.5	13.5	8.6	53	4.2	3.3	4.0	1.5
KE Be 64	05-28-91	16.00	180	5.3	13.5	9.9	118	10	8.8	4.4	3.0
KE Be 169	03-05-91	5.50	71	5.2	12.5	8.7	--	17	16	4.1	2.0
KE Be 170	03-05-91	6.90	260	6.1	12.0	3.2	70	3.9	1.6	4.4	1.9
KE Be 174	10-15-91	2.00	77	5.2	16.0	9.5	52	4.1	1.5	4.8	2.1
KE Bg 36	07-05-89	31.00	295	4.8	17.0	7.1	182	18	15	6.1	2.9
KE Cb 64	04-14-92	52.00	293	5.8	13.5	0.3	171	9.9	4.2	38	1.5
KE Cb 71	07-08-92	32.00	395	6.7	17.5	0.8	261	0.30	0.10	94	0.10
KE Cb 79	07-08-92	60.00	124	5.1	15.0	4.7	88	6.3	3.1	9.7	1.4
KE Cb 101	05-05-92	73.00	196	6.0	14.0	0	143	8.5	3.1	25	2.5
KE Cc 5	05-06-81	27.30	445	4.1	12.5	--	126	21	19	10	25
KE Db 96	07-07-92	40.00	168	4.6	16.0	3.0	143	8.2	1.7	16	3.6
KE Dc 73	05-21-92	73.00	294	6.2	16.0	0	212	7.9	4.4	17	1.6
KE Dc 89	12-18-91	29.00	7150	6.5	16.5	0	4380	140	180	1200	20
Aquia aquifer											
KE Af 56	05-27-92	119.00	366	7.3	14.0	0.5	242	72	1.7	3.2	2.6
KE Ag 20	07-28-93	70.00	343	7.0	14.5	0.2	127	9.7	2.4	4.8	3.6
KE Bc 174	07-29-93	65.00	84	5.4	18.0	0	79	2.3	1.8	2.8	4.5
KE Bd 39	06-13-89	38.50	68	4.9	16.0	0.6	54	1.1	1.2	3.7	3.3
KE Bd 147	12-06-91	3.00	100	6.5	7.5	0	81	3.5	0.88	2.7	1.5
KE Be 59	11-19-90	26.50	276	5.9	15.0	7.6	175	20	14	7.5	2.7
KE Be 60	06-07-90	26.50	96	5.0	16.0	10.0	--	7.3	3.1	3.4	2.2
KE Be 61	06-05-91	50.50	117	5.0	14.5	10.6	--	8.5	2.7	5.4	2.6
KE Be 62	03-04-91	25.50	246	5.6	12.5	9.0	146	17	12	3.7	2.4
KE Be 63	11-06-90	39.50	77	5.3	13.5	9.5	55	4.3	1.5	4.5	1.8
KE Be 64	11-06-90	16.00	180	5.0	15.5	8.4	118	9.9	8.8	4.7	3.3
KE Be 65	06-13-89	22.00	133	5.7	13.5	5.6	69	12	5.0	3.2	1.8
KE Be 158	12-05-91	34.00	224	5.3	12.5	9.8	132	12	11	3.1	8.8
KE Be 159	06-04-91	68.50	225	6.9	14.0	2.5	132	42	0.69	2.8	1.9
KE Be 160	03-05-91	38.00	57	5.3	14.0	10.0	--	3.4	1.0	4.1	1.8
KE Be 161	06-04-91	19.00	148	4.9	13.5	9.0	92	11	3.4	5.7	3.3
KE Be 162	03-04-91	67.00	53	5.3	13.5	10.4	--	3.6	0.89	3.4	1.5
KE Be 163	06-05-91	43.00	171	4.8	14.0	10.1	113	8.2	6.5	7.1	4.2
KE Be 164	11-19-90	48.00	146	5.5	13.5	9.2	--	12	3.8	4.6	2.8
KE Be 165	11-07-90	48.00	231	5.0	13.0	10.7	151	19	4.5	9.6	2.9
KE Be 166	11-07-90	28.00	229	5.0	14.0	10.4	137	14	10	4.0	3.7
KE Be 167	11-07-90	18.00	188	5.1	16.0	10.1	107	6.4	10	5.6	2.5
KE Be 172	10-10-91	4.30	217	7.3	17.0	--	134	36	2.4	3.3	2.9
KE Bf 1	01-10-55	105.00	265	7.5	14.5	--	155	41	7.0	2.9	1.3
KE Bf 9	05-20-92	130.00	258	6.9	--	0.3	178	55	2.0	2.4	2.1
KE Bf 58	05-27-92	192.00	274	7.1	14.0	0.4	186	56	1.1	2.7	2.3
KE Bf 91	07-28-93	164.00	239	7.4	15.0	1.8	157	46	1.3	2.8	2.2
KE Bf 138	05-20-92	227.00	285	6.9	--	4.3	168	50	2.7	3.1	2.9
KE Bf 183	05-20-92	100.00	270	6.6	--	1.8	165	54	1.5	2.6	1.3
KE Bg 34	10-26-78	186.00	295	7.1	14.0	--	173	52	1.9	3.0	1.9
KE Bg 91	07-28-93	179.00	364	7.5	16.0	0.1	178	42	6.7	4.2	3.3
KE Cb 41	07-29-93	96.00	70	5.9	17.0	0.8	77	0.19	0.01	13	0.5
KE Cb 58	07-20-93	67.00	137	6.0	15.5	0	93	5.4	3.6	3.7	3.4
KE Cb 99	05-06-92	134.00	124	6.2	14.0	0	113	6.4	1.5	2.3	6.0
KE Cb 100	12-11-91	67.00	36	5.4	18.5	8.2	31	2.0	0.62	2.9	1.4
KE Cc 45	07-21-93	115.00	155	6.2	14.5	0	102	11	1.9	3.7	3.3
KE Cc 61	07-16-92	100.00	248	7.1	17.5	0	155	37	5.9	5.2	2.4
KE Cd 2	07-15-92	82.00	124	5.6	15.5	7.6	75	12	2.2	6.6	2.2
KE Cd 15	12-21-54	141.00	197	7.8	14.5	--	129	34	1.0	2.6	2.6
KE Cd 33	06-29-93	95.00	895	5.6	16.5	2.7	487	44	10	110	3.7
KE Cd 99	06-29-93	127.00	130	5.4	16.0	6.9	86	12	2.7	7.4	2.8
KE Cd 100	06-29-93	116.00	235	5.4	15.5	6.4	135	16	4.3	17	2.7
KE Cd 101	06-29-93	120.00	262	5.4	15.0	7.4	150	21	5.7	17	3.2
KE Db 79	07-16-92	80.00	144	6.0	16.0	0	118	10	3.0	3.8	5.1
KE Db 94	07-21-93	150.00	144	5.6	16.0	0	95	6.4	0.95	4.8	1.6
KE Db 120	04-14-92	80.00	1880	7.0	14.5	0	1030	180	25	160	5.6
KE Dc 55	07-07-92	110.00	357	7.1	15.0	0.2	245	68	3.3	11	2.5
KE Dc 77	05-21-92	232.00	351	5.2	13.0	1.5	218	23	11	20	4.6
KE Dc 91	12-16-91	155.00	1220	6.3	14.5	0	8150	1000	230	1700	23
KE Dc 92	05-13-93	100.00	2	6.8	16.5	0	259	79	3.8	9.1	3.6
KE Dd 5	07-07-92	120.00	282	7.0	16.0	0.5	177	58	1.7	1.8	1.3
KE Eb 10	07-29-93	100.00	141	6.4	20.5	0	141	9.3	2.4	4.6	2.9
KE Eb 12	07-01-92	97.00	2780	6.7	17.5	0	2250	410	41	320	9.0
KE Eb 13	07-21-93	135.00	377	7.2	16.5	0	242	66	2.2	5.9	1.9

Table 8.–Chemical analyses of ground water from selected wells in Kent County–Continued

	ALKA-LINITY, TOTAL FIELD (MG/L AS $CACO_3$)	SULFATE, DIS-SOLVED (MG/L AS SO_4)	CHLO-RIDE, DIS-SOLVED (MG/L AS CL)	FLUO-RIDE, DIS-SOLVED (MG/L AS F)	BROMIDE, DIS-SOLVED (MG/L AS BR)	IODIDE, DIS-SOLVED (MG/L AS I)	SILICA, DIS-SOLVED (MG/L AS SIO_2)	IRON, DIS-SOLVED (µG/L AS FE)	MANGA-NESE, DIS-SOLVED (µG/L AS MN)	NITRO-GEN, NO_3 DIS-SOLVED (MG/L AS N)	PHOS-PHORUS ORTHO, DIS-SOLVED (MG/L AS P)	RADON 222 TOTAL (PCI/L)
Columbia aquifer												
KE Ad 20	19	13	34	0.30	0.050	0.004	15	4	5	5.50	<0.01	--
KE Bb 38	7	23	41	0.10	0.13	0.003	23	16	330	1.4	--	280
KE Bc 185	4	0.50	4.5	<0.10	0.030	<0.001	13	13	23	4.00	<0.01	--
KE Bd 42	68	11	25	0.10	--	--	18	10000	2200	4.80	0.04	<80
KE Be 46	2	<0.20	10	<0.10	--	--	13	7	8	8.40	<0.01	260
KE Be 47	18	24	22	<0.10	--	--	9.9	23	780	3.7	--	--
KE Be 49	10	25	19	0.40	0.030	--	10	200	310	14.0	<0.01	--
KE Be 50	3	1.1	52	<0.10	0.030	--	17	3	45	30.0	<0.01	--
KE Be 51	3	<1.0	16	<0.10	0.030	--	12	<5	24	13.0	<0.01	350
KE Be 52	3	<1.0	17	<0.10	0.030	--	12	4	48	13.0	<0.01	--
KE Be 53	10	4.3	7.4	<0.10	0.050	--	8.8	<3	4	3.10	<0.01	420
KE Be 64	2	5.5	16	<0.10	0.020	--	11	3	26	13.0	<0.01	--
KE Be 169	3	<23	12	<0.10	0.020	--	11	160	21	10.0	<0.01	--
KE Be 170	34	0.60	4.7	<0.10	0.020	--	10	8	5	5.00	<0.01	--
KE Be 174	3	0.50	5.6	<0.10	--	--	11	5	6	4.70	<0.01	--
KE Bg 36	3	11	24	<0.10	0.040	--	13	250	110	20.0	<0.01	110
KE Cb 64	17	30	56	<0.10	0.18	0.006	21	52	52	1.1	--	--
KE Cb 71	163	15	34	<0.10	0.10	0.008	16	<3	<1	0.75	0.03	430
KE Cb 79	9	22	11	<0.10	0.050	0.002	20	6	4	2.10	0.01	600
KE Cb 101	43	32	19	<0.10	0.060	0.012	17	5200	180	0.97	0.09	480
KE Cc 5	--	11	27	0.20	--	--	12	20	170	27.0	--	--
KE Db 96	1	27	27	<0.10	0.12	0.008	54	510	230	0.88	<0.01	270
KE Dc 73	92	2.3	37	0.10	0.080	0.015	45	39000	580	<0.05	<0.01	--
KE Dc 89	161	300	2400	1.4	--	--	19	24000	530	<0.05	<0.01	--
Aquia aquifer												
KE Af 56	154	33	9.6	0.50	0.020	0.005	26	920	12	<0.05	0.04	330
KE Ag 20	179	3.2	7.3	0.20	0.010	--	53	18000	160	0.21	<0.01	500
KE Bc 174	10	19	6.8	<0.10	0.080	0.002	30	5700	15	<0.05	0.01	--
KE Bd 39	1	16	5.7	0.10	0.050	--	19	3000	51	<0.10	<0.01	450
KE Bd 147	42	2.1	4.3	<0.10	--	--	22	17000	29	<0.05	0.15	--
KE Be 59	26	20	26	<0.10	0.020	--	11	47	390	13.0	<0.01	--
KE Be 60	12	<1.0	8.2	<0.10	0.040	--	10	<3	16	5.60	<0.01	260
KE Be 61	3	<0.10	7.6	<0.10	0.020	--	11	6	20	8.10	<0.01	--
KE Be 62	8	22	14	<0.10	0.030	--	7.8	<3	3	14.0	<0.01	--
KE Be 63	5	1.4	4.8	<0.10	0.020	--	11	<3	10	5.00	0.03	220
KE Be 64	3	2.9	16	<0.10	0.030	--	12	6	37	13.0	0.02	370
KE Be 65	23	17	5.7	0.10	<0.010	--	4.9	<11	4	1.30	0.01	210
KE Be 158	5	5.8	17	0.10	--	--	7.8	11	130	14.0	<0.01	--
KE Be 159	91	7.7	1.0	<0.10	0.010	--	18	9	<1	0.81	<0.01	--
KE Be 160	4	<1.0	3.3	<0.10	0.020	--	12	8	30	3.80	<0.01	--
KE Be 161	5	0.20	12	<0.10	0.020	--	10	10	80	9.80	<0.01	--
KE Be 162	5	<1.0	3.5	<0.10	0.020	--	13	<3	4	3.20	<0.01	--
KE Be 163	2	0.20	8.9	<0.10	0.030	--	10	13	16	15.0	<0.01	--
KE Be 164	4	<1.0	12	<0.10	0.030	--	12	26	20	11.0	<0.01	--
KE Be 165	3	2.9	18	<0.10	0.050	--	12	<3	29	18.0	0.03	280
KE Be 166	2	1.2	28	<0.10	0.030	--	12	<3	230	14.0	0.03	420
KE Be 167	4	31	17	<0.10	0.010	--	15	4	320	3.60	0.03	350
KE Be 172	89	4.9	8.2	0.30	--	--	21	2100	6	<0.05	0.03	--
KE Bf 1	134	3.5	0.80	0.10	--	--	18	--	--	0.02	--	--
KE Bf 9	139	6.2	2.5	<0.10	0.030	0.007	23	1200	69	<0.05	0.07	240
KE Bf 58	--	18	2.7	0.20	0.020	0.004	20	840	94	<0.05	0.02	350
KE Bf 91	121	13	2.2	0.20	0.020	0.003	20	260	9	<0.05	0.01	460
KE Bf 138	138	4.4	3.2	<0.10	0.040	0.005	18	350	24	<0.050	0.03	210
KE Bf 183	135	5.7	2.8	0.10	0.020	<0.001	16	450	23	<0.05	0.03	230
KE Bg 34	140	4.3	2.4	0.10	--	--	23	1100	70	<0.10	--	--
KE Bg 91	142	4.6	1.9	0.20	0.020	0.001	30	350	7	<0.05	0.02	270
KE Cb 41	11	15	5.0	<0.10	0.030	0.001	36	180	2	<0.05	0.01	--
KE Cb 58	54	10	3.7	0.60	0.040	0.005	29	15000	210	0.05	0.41	--
KE Cb 99	34	20	2.5	0.60	0.020	0.003	36	15000	220	<0.05	0.56	150
KE Cb 100	7	0.50	3.8	0.20	--	--	11	180	14	0.91	0.01	--
KE Cc 45	33	36	4.9	0.10	0.060	0.001	22	8300	43	<0.05	0.02	600
KE Cc 61	137	0.40	1.7	0.20	0.030	0.005	17	1000	43	<0.05	0.03	440
KE Cd 2	10	2.5	12	<0.10	0.040	0.002	13	6	7	4.20	0.01	400
KE Cd 15	84	7.5	2.8	<0.05	--	--	28	--	--	0.02	--	--
KE Cd 33	39	27	230	0.10	0.63	0.007	14	31	35	5.00	<0.01	370
KE Cd 99	17	1.8	16	<0.10	--	--	12	10	10	4.40	<0.01	380
KE Cd 100	22	4.1	42	<0.10	--	0.003	12	20	20	5.30	0.02	390
KE Cd 101	16	2.5	59	<0.10	--	0.002	12	10	20	4.20	<0.01	450
KE Db 79	54	9.3	6.0	0.40	0.22	0.002	30	14000	140	<0.05	1.30	350
KE Db 94	56	1.4	8.3	0.50	0.050	0.003	36	22000	170	<0.05	0.02	110
KE Db 120	167	43	480	0.30	1.9	0.022	28	1700	560	0.09	--	--
KE Dc 55	175	12	14	0.30	0.060	0.004	28	430	13	0.06	0.06	230
KE Dc 77	8	35	53	<0.10	0.090	0.006	18	28	63	11.0	<0.01	--
KE Dc 91	188	730	4300	1.7	--	--	26	21000	80	<0.05	0.01	--
KE Dc 92	275	25	9.4	0.20	0.060	0.011	37	1700	11	<0.05	0.07	190
KE Dd 5	136	11	4.9	<0.10	0.020	0.002	14	1000	27	0.41	<0.01	270
KE Eb 10	78	3.5	15	0.30	4.8	--	55	18000	160	<0.05	<0.01	--
KE Eb 12	152	140	1200	0.30	3.9	0.017	24	7300	<10	<0.05	<0.01	130
KE Eb 13	200	1.0	9.3	0.10	0.050	0.009	36	2700	76	<0.05	0.03	190

Table 8.–Chemical analyses of ground water from selected wells in Kent County–Continued

WELL NUMBER	DATE	DEPTH OF WELL (FEET)	SPE-CIFIC CON-DUCT-ANCE (µS/CM)	PH FIELD (STAND-ARD UNITS)	TEMPER-ATURE WATER (DEG C)	OXYGEN, DIS-SOLVED (MG/L)	TOTAL DIS-SOLVED SOLIDS (MG/L)	CALCIUM, DIS-SOLVED (MG/L AS CA)	MAGNE-SIUM, DIS-SOLVED (MG/L AS MG)	SODIUM, DIS-SOLVED (MG/L AS NA)	POTAS-SIUM, DIS-SOLVED (MG/L AS K
				Monmouth aquifer							
KE Ae 18	09-28-54	82.00	187	7.5	17.0	--	118	33	0.90	3.1	1.7
KE Ag 54	05-18-93	184.00	239	6.9	13.5	0.1	146	38	3.7	4.9	4.5
KE Bc 172	07-07-93	180.00	216	6.6	15.5	0	150	35	2.0	2.0	4.3
KE Bd 136	05-13-93	145.00	246	6.5	13.5	0	145	36	1.6	1.9	2.3
KE Be 5	12-21-54	150.00	316	7.4	12.0	--	187	61	1.3	2.5	2.2
KE Be 113	05-26-92	180.00	399	7.1	15.0	0.2	259	75	2.9	5.9	3.5
KE Be 151	05-18-93	263.00	240	7.6	14.0	0.1	--	0.05	<0.01	58	1.2
KE Cb 98	12-05-91	225.00	134	6.0	14.0	0	102	12	1.8	2.3	3.3
KE Cd 86	05-04-93	147.00	267	6.1	14.5	0	179	52	4.4	2.4	4.4
KE Da 15	07-07-93	112.00	271	6.6	16.0	0	--	0.25	0.03	67	0.4
				Magothy aquifer							
KE Ad 5	09-28-54	72.00	32	6.4	16.5	--	23	1.1	0.10	2.6	1.5
KE Ad 10	12-21-54	93.00	122	6.1	13.5	--	85	6.0	2.9	9.5	2.2
KE Ad 43	05-26-92	160.00	44	5.3	13.5	7.4	37	2.0	0.84	3.6	1.5
KE Bb 12	04-16-92	64.00	236	5.6	13.0	2.7	131	11	3.5	26	1.7
KE Bc 70	07-15-92	61.00	289	6.5	16.5	0.2	213	0.05	0.01	66	5.7
KE Be 43	12-07-78	297.00	290	7.1	16.0	--	168	44	4.5	6.8	3.9
KE Cb 88	07-08-92	80.00	71	5.3	14.5	3.2	56	3.9	1.1	6.3	1.1
KE Cb 97	05-06-92	285.00	223	6.5	15.0	0	136	15	3.8	17	4.2
KE Cd 50	03-25-68	397.00	160	7.3	--	--	93	18	5.3	3.6	6.4
KE Da 11	07-08-92	174.00	167	6.3	15.5	0	113	7.2	3.7	8.7	2.7
				Upper Patapsco aquifer							
KE Ac 20	12-02-77	600.00	--	--	--	--	1670	97	48	380	15
KE Bc 186	05-05-92	275.00	141	6.4	13.5	0	100	11	3.2	1.9	3.0
KE Be 171	12-20-91	440.00	222	7.5	15.5	0.1	138	11	3.0	31	7.2
KE Bg 33	10-25-78	710.00	435	8.1	20.5	--	254	4.7	1.0	90	4.1
KE Cb 36	04-20-78	650.00	280	--	14.0	--	--	6.0	--	50	2.9
KE Cb 103	12-09-91	404.00	133	6.6	16.5	0	89	9.9	4.2	3.1	4.2
KE Cd 104	07-15-92	428.00	153	6.3	18.0	0	96	12	3.5	9.2	5.5
KE Cd 137	06-30-93	413.00	202	6.5	15.5	0	113	23	5.4	2.3	5.4
KE Db 40	12-04-78	1030.00	163	5.6	19.0	--	93	4.8	2.8	16	5.0

Table 8.–Chemical analyses of ground water from selected wells in Kent County–Continued

Well	ALKA-LINITY, TOTAL FIELD (MG/L AS $CACO_3$)	SULFATE, DIS-SOLVED (MG/L AS SO_4)	CHLO-RIDE, DIS-SOLVED (MG/L AS CL)	FLUO-RIDE, DIS-SOLVED (MG/L AS F)	BROMIDE, DIS-SOLVED (MG/L AS BR)	IODIDE, DIS-SOLVED (MG/L AS I)	SILICA, DIS-SOLVED (MG/L AS SIO_2)	IRON, DIS-SOLVED (µG/L AS FE)	MANGA-NESE, DIS-SOLVED (µG/L AS MN)	NITRO-GEN, NO_3 DIS-SOLVED (MG/L AS N)	PHOS-PHORUS ORTHO, DIS-SOLVED (MG/L AS P)	RADON 222 TOTAL (PCI/L)
					Monmouth aquifer							
KE Ae 18	79	9.2	5.6	0.50	--	--	16	--	--	0.11	--	--
KE Ag 54	119	4.6	2.2	0.30	0.020	0.002	17	200	6	<0.05	<0.01	--
KE Bc 172	98	13	2.6	0.20	0.060	0.001	33	2000	20	<0.05	0.01	600
KE Bd 136	118	10	1.9	0.30	0.030	0.001	23	1000	16	<0.05	0.06	570
KE Be 5	156	5.3	2.0	<0.05	--	--	19	--	--	0.02	--	--
KE Be 113	172	6.2	38	0.20	0.040	0.001	19	5200	90	<0.05	<0.01	830
KE Be 151	117	11	1.7	0.20	0.020	0.005	13	9	1	<0.05	<0.01	790
KE Cb 98	48	10	2.7	0.30	--	--	29	11000	99	<0.05	0.22	--
KE Cd 86	122	12	6.6	0.10	0.030	--	24	360	11	<0.05	<0.01	590
KE Da 15	127	<0.10	15	0.20	0.050	0.007	37	220	4	<0.05	1.20	240
					Magothy aquifer							
KE Ad 5	4	5.6	2.6	0.10	--	--	6.9	--	--	0.11	--	--
KE Ad 10	8	0.30	12	<0.05	--	--	14	--	--	7.50	--	--
KE Ad 43	3	2.2	3.5	<0.10	0.020	0.003	12	21	10	2.10	<0.01	--
KE Bb 12	14	21	39	<0.10	0.10	0.003	20	16	5	5.10	--	370
KE Bc 70	101	0.80	41	0.40	0.14	0.018	37	14	6	<0.05	0.17	120
KE Be 43	140	8.8	2.4	0.10	--	--	11	2700	60	<0.10	--	--
KE Cb 88	9	2.4	8.6	<0.10	0.030	<0.001	19	6	<1	1.90	<0.01	340
KE Cb 97	96	8.7	6.9	0.30	0.020	0.019	9.8	12000	230	<0.05	<0.01	190
KE Cd 50	67	12	1.0	0.30	--	--	6.1	--	--	--	--	--
KE Da 11	81	0.80	6.6	<0.10	0.13	0.008	15	18000	210	<0.05	<0.01	<80
					Upper Patapsco aquifer							
KE Ac 20	54	5.9	1000	0.10	--	--	9.6	80000	3200	<0.10	--	--
KE Bc 186	60	8.1	2.4	0.30	0.010	0.001	18	15000	190	<0.05	0.10	340
KE Be 171	100	11	5.8	0.20	--	--	8.1	190	15	<0.05	0.02	--
KE Bg 33	150	8.6	47	0.60	--	--	9.1	860	20	<0.10	--	--
KE Cb 36	68	19	32	0.20	--	--	7.2	--	200	--	--	--
KE Cb 103	51	15	1.1	0.20	--	--	6.8	14000	200	<0.05	<0.01	--
KE Cd 104	64	12	2.3	0.20	0.030	0.003	7.5	4700	82	<0.05	0.02	140
KE Cd 137	94	12	1.7	0.20	0.030	0.003	7.4	5900	85	<0.05	<0.01	96
KE Db 40	35	14	11	0.20	--	--	10	7700	230	<0.10	--	--

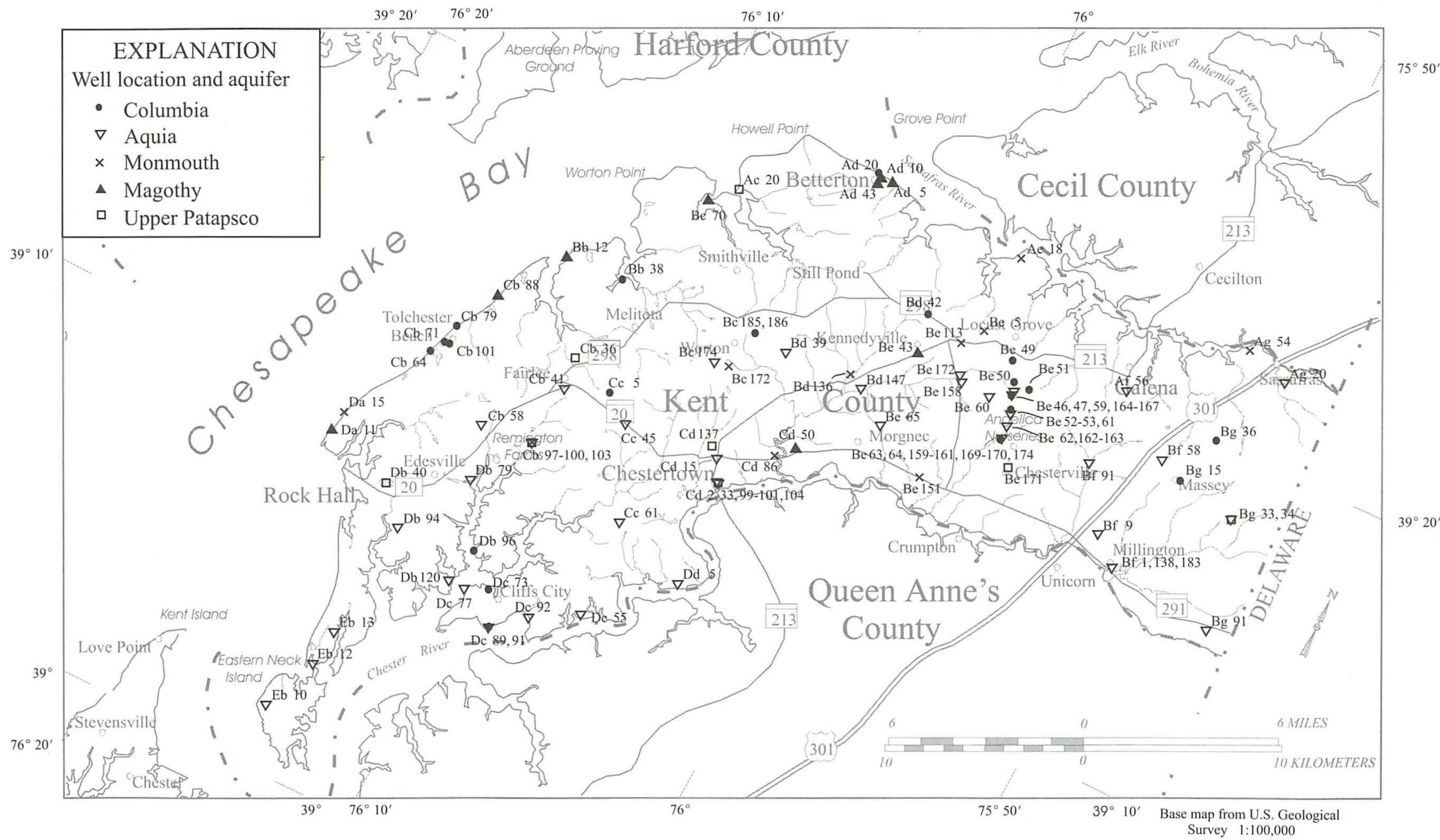


Figure 50.—Locations of wells with water-quality analyses.

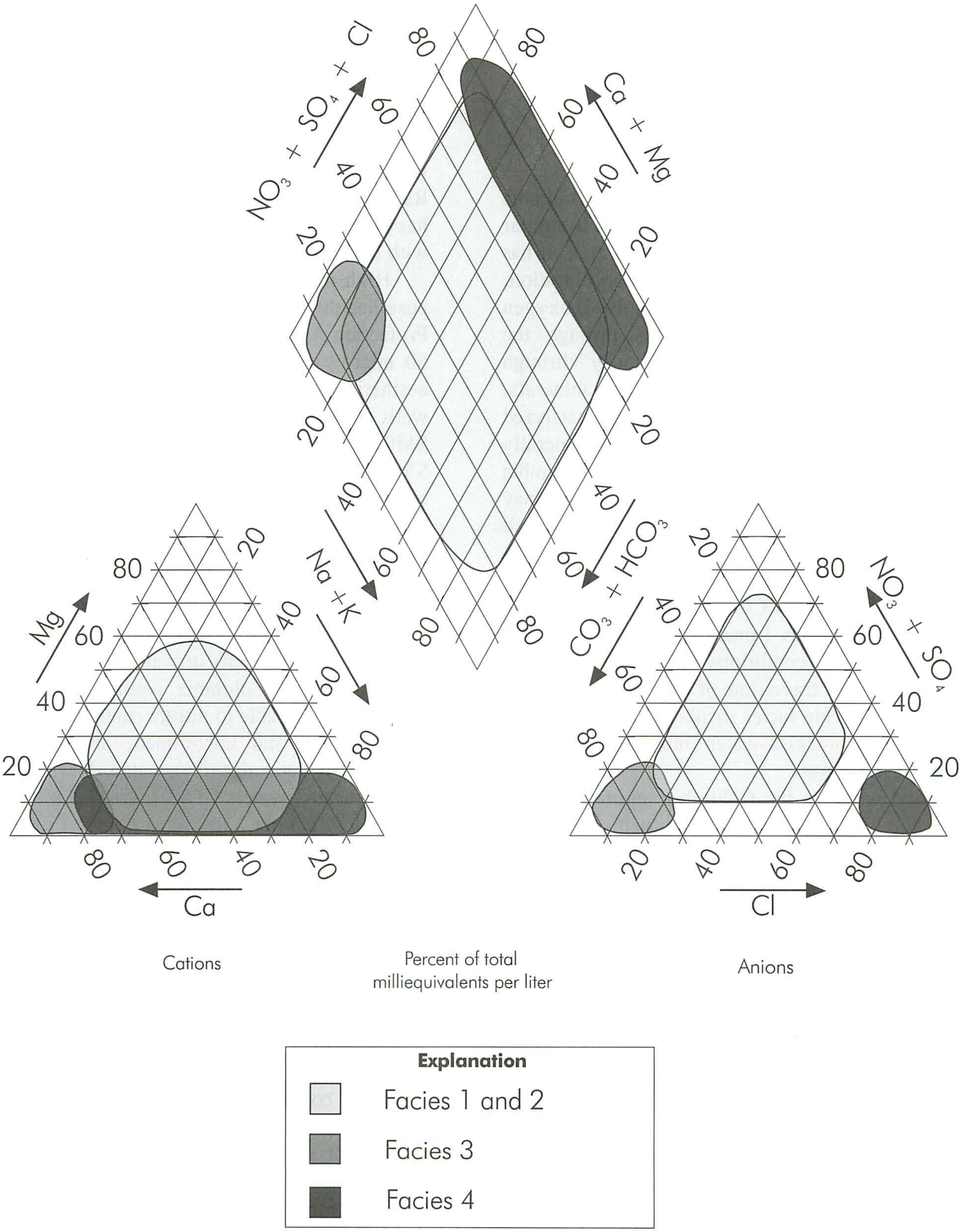


Figure 51.—Hydrochemical facies in the Coastal Plain aquifers in Kent County.

These waters are mixed calcium and sodium cation types, and chloride anion type. Although brackish bay water is predominantly sodium chloride, cation exchange in the glauconitic aquifers may cause a trend away from sodium toward calcium.

COLUMBIA AQUIFER

Most of the water recharging the Columbia aquifer enters as precipitation and initially is similar to average precipitation chemistry of the area. It has a low TDS (total dissolved solids) concentration, neutral to low pH, and a high dissolved oxygen concentration. As the water moves through the aquifer, it increases in TDS primarily through dissolution of chemically unstable silicate minerals, and oxygen is consumed by biologically catalyzed reactions. These chemical processes do not generally go to completion, as residence time in the Columbia aquifer is relatively short. Water in the Columbia may also be affected by anthropogenic contaminants such as nitrates and pesticides.

Hydrochemical facies for the Columbia aquifer are shown in figure 52. Columbia aquifer chemistry is dominated by Facies 1 and 2. These facies reflect shallow unconfined conditions in the Columbia and the relatively short traveltime of water in the aquifer. The sodium-chloride facies displayed in well KE Dc 89 represents brackish-water intrusion from the nearby Chester River.

Ground water in the Columbia aquifer shows a large range in most chemical constituents due to the different sources of water to the aquifer (fig. 53). Water from well KE Bc 185, at the low end of the range, has undergone only slight modification from soil reactions and silicate hydrolysis, with a TDS concentration of 47 mg/L. At the high end of the range, water from well KE Dc 89 is affected by brackish-water intrusion and displays a TDS concentration of 4,380 mg/L.

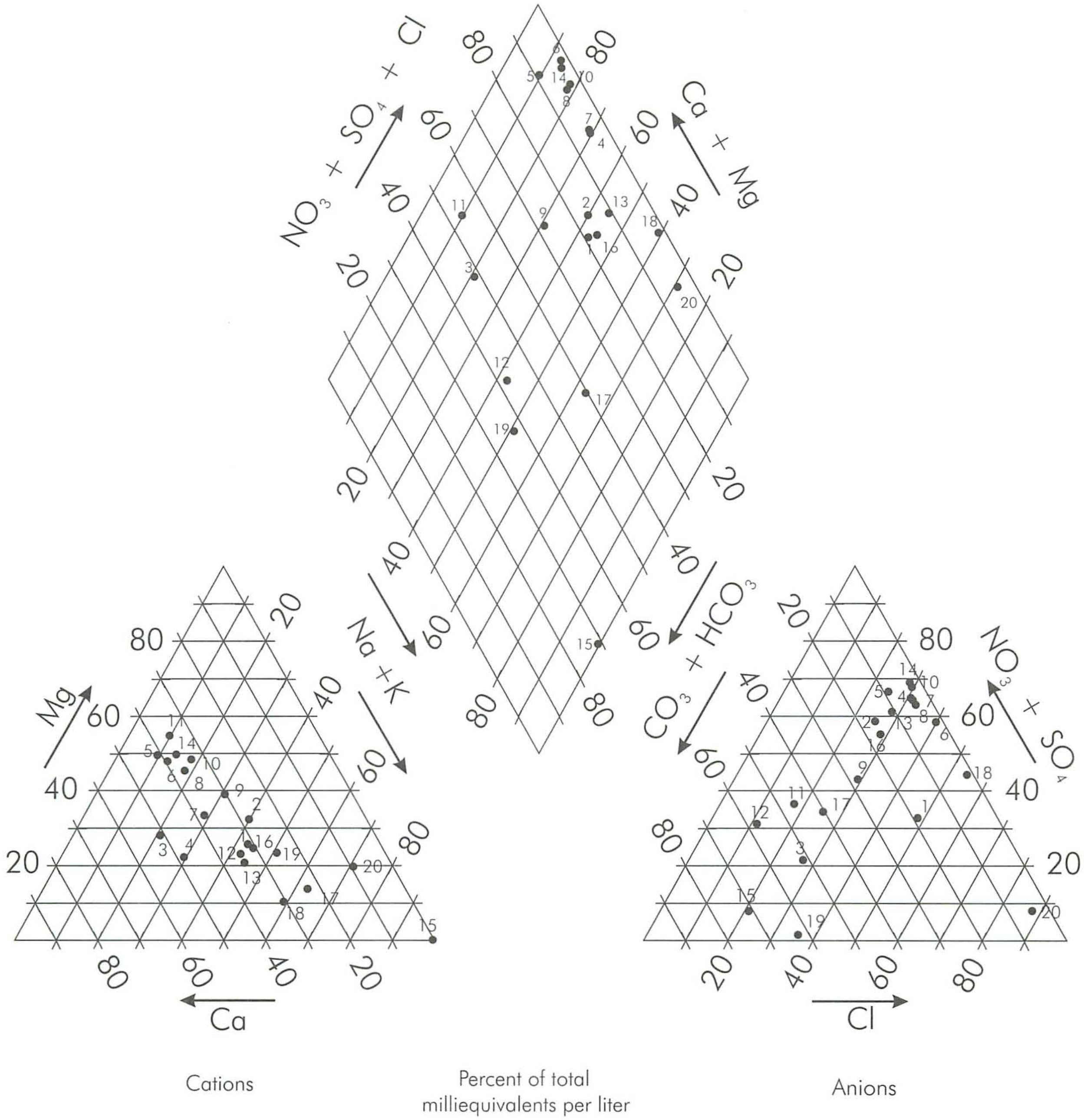
Documented water-quality problems in the Columbia aquifer in Kent County include brackish-water intrusion, the presence of radon, high concentrations of iron and manganese, and contamination with nitrate and pesticide residues. Although one well screened in the Columbia aquifer (KE Dc 89) indicates brackish-water intrusion, it is not considered an extensive problem in the study area. Brackish-water intrusion in the Columbia aquifer is limited to areas immediately adjacent to tidal water bodies (Webb and Heidel, 1970). Ground-water withdrawals from the Columbia are limited to small domestic wells, and regional head gradients are toward the estuaries. For these reasons, brackish water is not likely to migrate very far inland, and intrusion will most likely continue to be limited to isolated wells very near the shore.

Radon concentrations ranged up to 600 pCi/L in water from wells screened in the Columbia aquifer. Radon is a naturally-occurring radioactive gas which has been shown to pose a health risk when ingested with drinking water or inhaled.

High iron and manganese concentrations do not pose health risks; however, the U.S. Environmental Protection Agency (EPA) has set SMCLs of 300 and 50 micrograms per liter (μg/L), respectively, for aesthetic reasons. Water from 5 of the 24 sampled wells screened in the Columbia aquifer exceeded the SMCL for iron, and 11 of 24 samples exceeded the SMCL for manganese. The relatively low number of exceedences for iron and manganese is due to high dissolved oxygen content and moderate pH levels in most waters from the Columbia aquifer. Iron and manganese both have low solubilities in these conditions.

Nitrate concentrations exceeded the EPA MCL of 10 mg/L (as nitrogen) in water from 7 of 20 wells sampled in the Columbia aquifer. The Columbia aquifer is vulnerable to nitrate contamination because it is shallow and unconfined, and water in the Columbia is generally oxygenated. Nitrate is soluble in oxygenated waters. The source of nitrate in the Columbia aquifer in most cases is probably agricultural application of fertilizer; Kent County has been extensively farmed since the 1800's.

Of the 13 wells completed in the Columbia aquifer that were sampled for pesticide residues, 8 showed detections, but none exceeded MCLs or HALs (Health Advisory Levels). The substances for which detections were found include alachlor, atrazine, deethyl atrazine, deisopropyl atrazine, metolachlor, and simazine. The Columbia aquifer is vulnerable to pesticide contamination because it is shallow and unconfined. The fairly high percentage of Columbia wells with pesticide-residue detections reflects the agricultural land use of the area. It should be noted that all of the wells that showed pesticide-residue detections (and most of the wells sampled for pesticides) are in a relatively small section of the county near Locust Grove.



Explanation

1	KE Ad 20	11	KE Be 169
2	KE Bc 185	12	KE Be 170
3	KE Bd 42	13	KE Be 174
4	KE Be 46	14	KE Bg 36
5	KE Be 49	15	KE Cb 71
6	KE Be 50	16	KE Cb 79
7	KE Be 51	17	KE Cb 101
8	KE Be 52	18	KE Db 96
9	KE Be 53	19	KE Dc 73
10	KE Be 64	20	KE Dc 89

Figure 52.—Hydrochemical facies in the Columbia aquifer in Kent County.

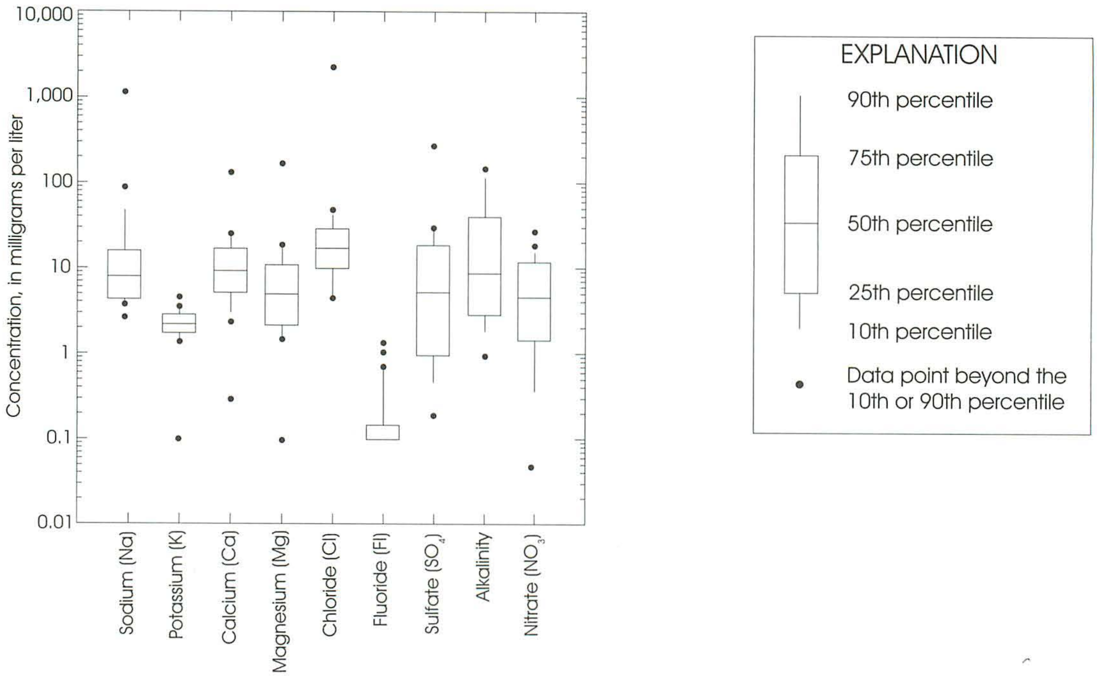


Figure 53.—Boxplot showing ranges of chemical constituents in the Columbia aquifer.

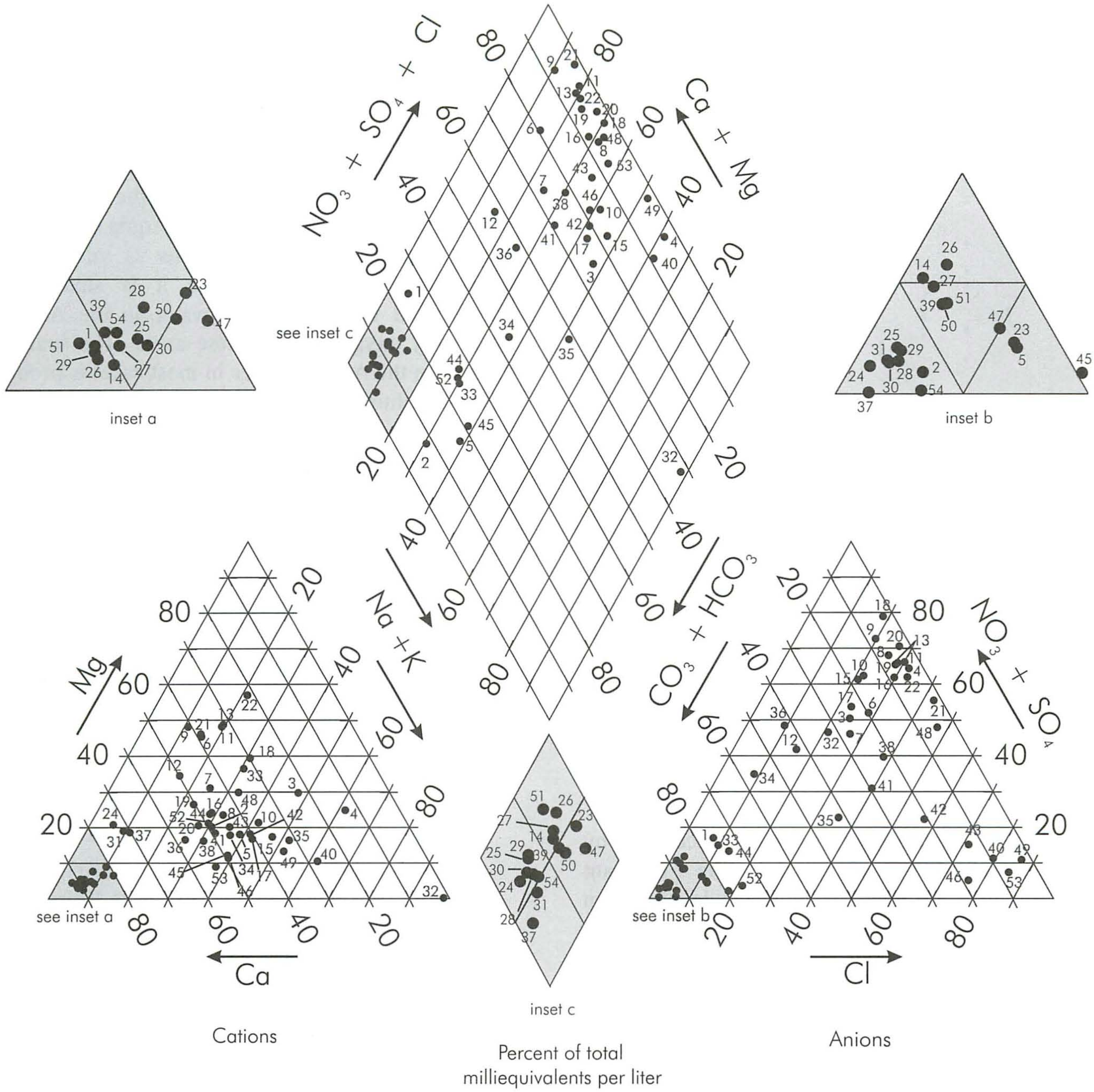
AQUIA AQUIFER

Water enters the Aquia aquifer either directly from precipitation recharge where the Aquia outcrops or as leakage from the Columbia aquifer where the Aquia subcrops beneath the Columbia. Some water may also enter the Aquia as upward leakage from deeper aquifers and as brackish-water intrusion. Consequently, Aquia water is initially similar to precipitation or water in the Columbia aquifer. As ground water moves through the Aquia aquifer, it may react with minerals, such as calcite and glauconite, to increase the dissolved solids content and to alter the proportions of chemical constituents. Aquia water is also affected in places by brackish-water intrusion and anthropogenic contaminants such as nitrate and pesticide residues.

Water from the Aquia aquifer displays all four hydrochemical facies (fig. 54). The Aquia is shallow and unconfined or semiconfined throughout much of Kent County, and, consequently, many water samples in the Aquia display Facies 1 and 2. Abundant calcareous shell material in the Aquia dissolves to produce water of Facies 3. This calcium-bicarbonate water is typical of Maryland Coastal Plain aquifers of shallow marine origin. Facies 4 is displayed by several samples in the Aquia aquifer, with chloride concentrations exceeding 100 mg/L. The range of cation type in this facies between sodium and calcium is caused by exchange of calcium for sodium on exchange sites on interstitial glauconite.

Ground water in the Aquia aquifer shows the widest range in concentration of most constituents of any of the Coastal Plain aquifers in Kent County (fig. 55). This wide range reflects the various sources of water to the Aquia: from minimally altered rain water to mixing with brackish water from the Chesapeake Bay. TDS concentrations range from 31 to 8,150 mg/L. Chloride and sodium range from 0.8 to 4,300, and 1.8 to 1,700 mg/L, respectively. pH ranges from 4.8 to 7.8.

Water-quality problems in the Aquia aquifer include brackish-water intrusion, the presence of radon, high concentrations of iron and manganese, and contamination with nitrate and pesticide residues. Brackish-water intrusion is a more serious problem in the Aquia than in the Columbia because of greater pumpage in the Aquia. The problem is most acute in the low-lying southwestern part of the county where water-level elevations are naturally low (near sea level), and the Aquia subcrops beneath the Chesapeake Bay and the Chester River (fig. 56). A brackish-water wedge occurs naturally in the Aquia near the shoreline in this area, as evidenced in well



Explanation

1	KE Af 56	15	KE Be 160	29	KE Bf 183	42	KE Cd 100
2	KE Ag 20	16	KE Be 161	30	KE Bg 34	43	KE Cd 101
3	KE Bc 174	17	KE Be 162	31	KE Bg 91	44	KE Db 79
4	KE Bd 39	18	KE Be 163	32	KE Cb 41	45	KE Db 94
5	KE Bd 147	19	KE Be 164	33	KE Cb 58	46	KE Db 120
6	KE Be 59	20	KE Be 165	34	KE Cb 99	47	KE Dc 55
7	KE Be 60	21	KE Be 166	35	KE Cb 100	48	KE Dc 77
8	KE Be 61	22	KE Be 167	36	KE Cc 45	49	KE Dc 91
9	KE Be 62	23	KE Be 172	37	KE Cc 61	50	KE Dc 92
10	KE Be 63	24	KE Bf 1	38	KE Cd 2	51	KE Dd 5
11	KE Be 64	25	KE Bf 9	39	KE Cd 15	52	KE Eb 10
12	KE Be 65	26	KE Bf 58	40	KE Cd 33	53	KE Eb 12
13	KE Be 158	27	KE Bf 91	41	KE Cd 99	54	KE Eb 13
14	KE Be 159	28	KE Bf 138				

Figure 54.—Hydrochemical facies in the Aquia aquifer in Kent County.

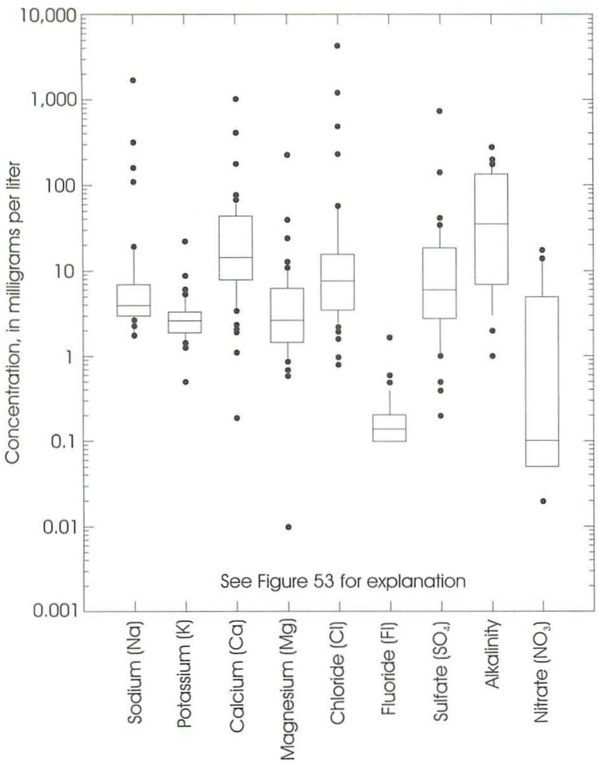


Figure 55.—Boxplot showing ranges of chemical constituents in the Aquia aquifer.

KE Dc 91. Brackish-water intrusion is exacerbated by pumpage in these areas, as the resultant cones-of-depression may draw water levels down below sea level and produce significant landward head gradients. Pumpage-induced intrusion is the probable cause of elevated chloride concentrations at the Chestertown well field. Chloride concentrations are highest in water from Chestertown production wells closest to the Chester River, and lowest in water from wells farthest from the river. Alternative water supplies should be sought in these areas of potential brackish-water intrusion.

Radon concentrations ranged up to 600 pCi/L in samples collected from wells in the Aquia aquifer. No areal trend is apparent in radon concentrations. The source of dissolved radon in water in the Aquia aquifer is probably interstitial glauconite, in which uranium substitutes for potassium in the chemical structure.

Dissolved iron concentrations exceeded the SMCL in water from 26 of 53 wells sampled in the Aquia aquifer. High iron concentrations occur in areas where the Aquia is confined and dissolved oxygen concentrations are low. In general, these areas are in the southern and eastern parts of the county. Dissolved manganese concentrations exceeded the SMCL in 19 of 53 wells sampled in the Aquia. Areas of high manganese concentrations follow the same trend as areas of high iron concentrations.

Nitrate concentrations exceeded the MCL in water from 9 of 50 wells sampled in the Aquia aquifer. Like the Columbia, the Aquia aquifer is vulnerable to nitrate contamination because it is shallow and unconfined in some areas; water in the Aquia is generally oxygenated in these areas. The source of nitrate in the Aquia aquifer in most cases is probably the agricultural application of fertilizer. It should be noted that eight of the nine wells with water that exceeded the MCL are in a relatively small part of Kent County, near Locust Grove.

Water from 9 of 16 wells sampled in the Aquia aquifer showed detections of pesticide residues. The substances that were detected include atrazine, deethyl atrazine, deisopropyl atrazine, metolachlor, and simazine. Water from one well, KE Be 65, exceeded the EPA MCL (10 μg/L) for atrazine, with a dissolved concentration of 11 μg/L (Tompkins, Cooper, and Drummond, 1994).

MONMOUTH AQUIFER

The Monmouth aquifer crops out in Kent County only along the banks of the Sassafras River and is confined or semiconfined throughout most of Kent County. The Monmouth receives recharge primarily as downward leakage from the overlying Columbia and Aquia aquifers. Thus, water entering the Monmouth is initially chemically similar to Aquia or Columbia water. As water flows through the Monmouth, it reacts with minerals in the aquifer, such as glauconite and calcite, to alter the water chemistry.

Water from wells screened in the Monmouth aquifer shows a minor influence of Facies 1, but is dominated by Facies 3, calcium dissolution (fig. 57). This dominance reflects the mineralogy of the aquifer, generally confined conditions, and long traveltimes of water in the Monmouth. No influence is evident of brackish-water intrusion or contamination from agricultural chemicals from the wells sampled.

Water in the Monmouth aquifer displays a relatively narrow range of constituents, which reflects the narrow range of conditions in the aquifer (fig. 58). TDS concentrations range from 102 to 259 mg/L, and pH ranges from 6.0 to 7.6. Iron and manganese

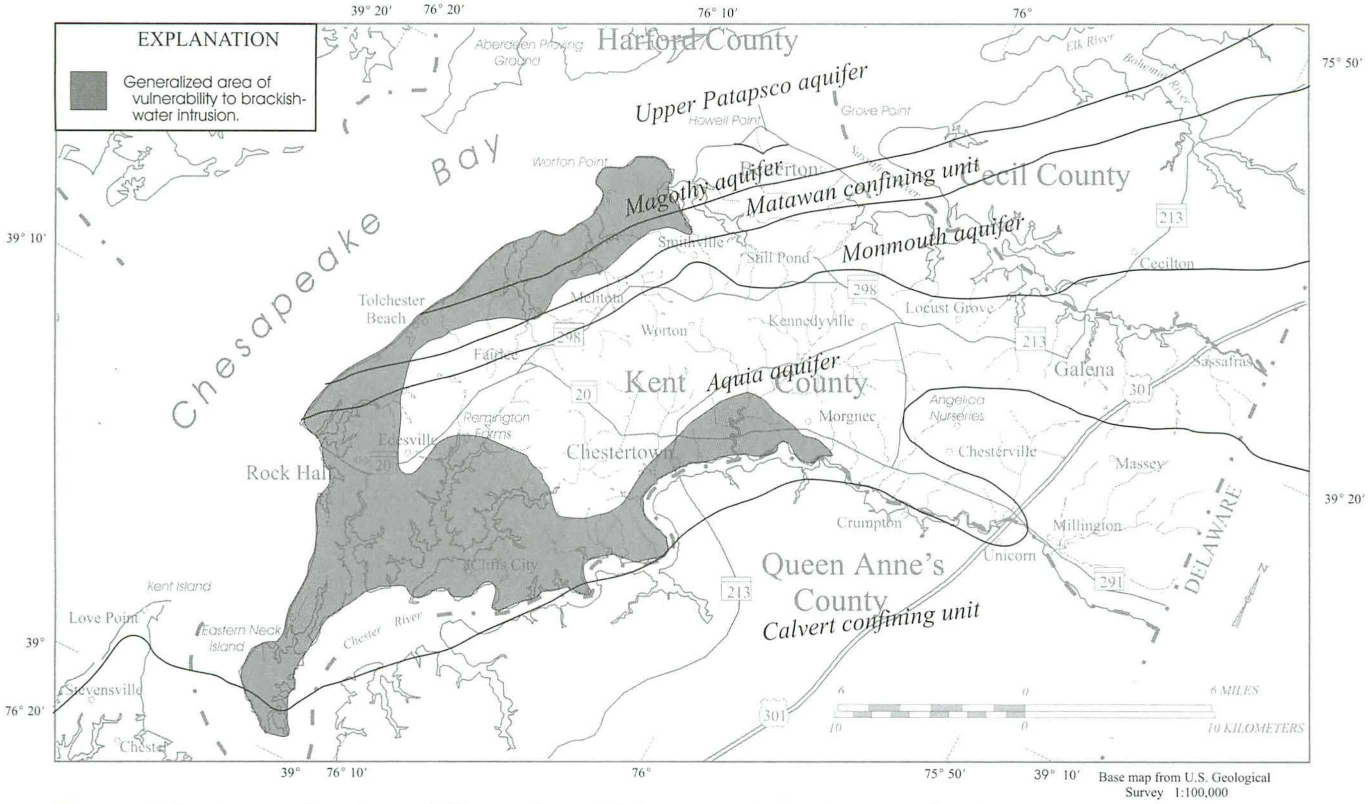


Figure 56.—Area of vulnerability to brackish-water intrusion, and subcrop areas of major hydrogeologic units.

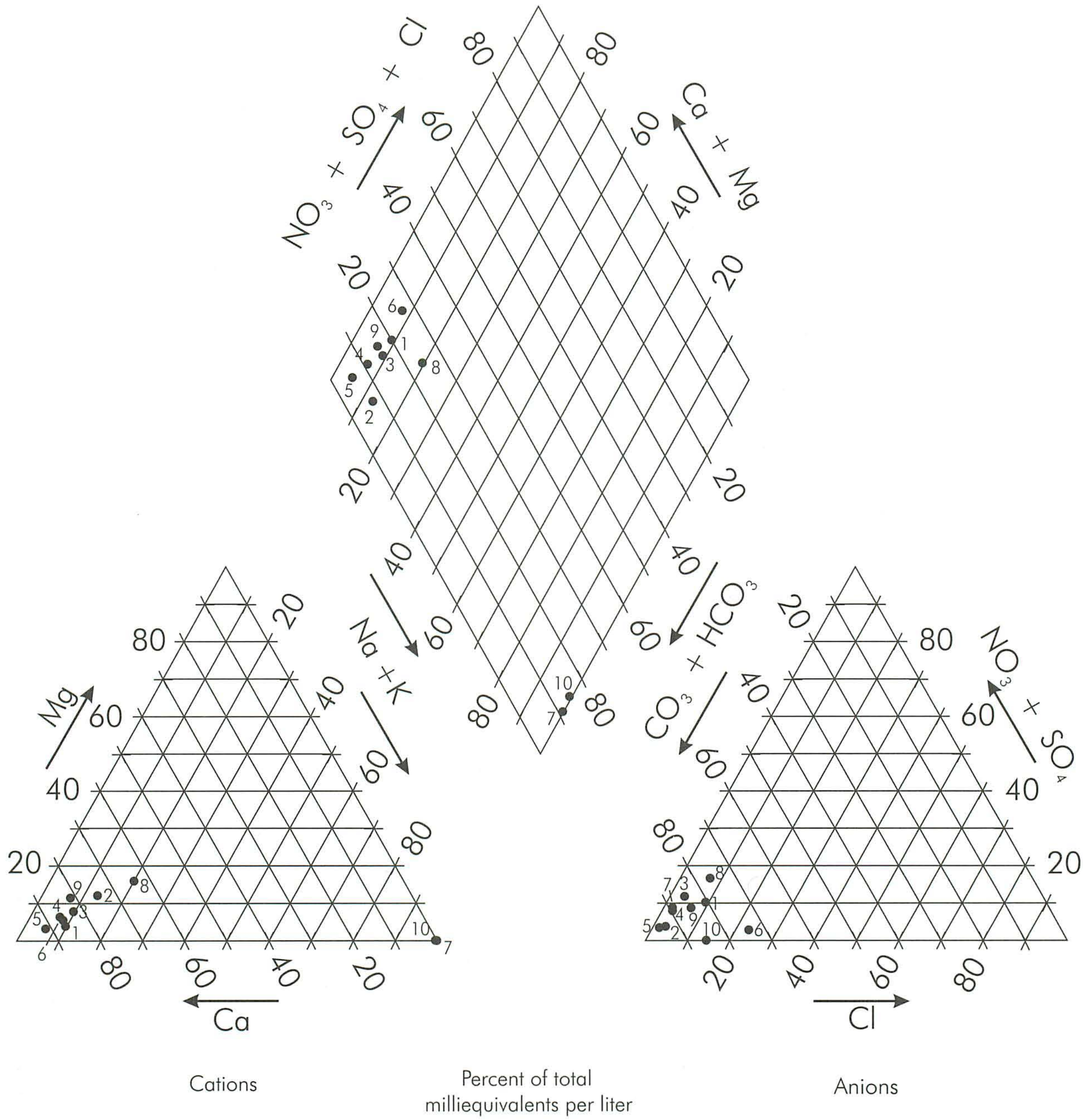
concentrations range from 9 to 11,000 μg/L and 1 to 99 μg/L, respectively.

Iron concentrations exceeded the SMCL in 5 of 8 wells sampled, and manganese concentrations exceeded the SMCL in 2 of 8 wells sampled. These exceedences reflect the generally confined conditions and low dissolved oxygen concentrations in all wells sampled. Radon concentrations ranged up to 830 pCi/L. The mean concentration of radon in the Monmouth aquifer is 603 pCi/L, the highest of any aquifer in Kent County. Abundant interstitial glauconite is the probable source of radon in the Monmouth, but the percentage of glauconite is generally higher in the Aquia aquifer, and it is unknown why radon concentrations tend to be higher in the Monmouth.

Nitrate concentrations in water from the Monmouth aquifer were low in all wells sampled and range only up to 0.11 mg/L. The absence of nitrate contamination is due to generally confined conditions in the aquifer and low redox conditions. No analyses for pesticide residues are available for the Monmouth aquifer, but, based on low nitrate concentrations and confined conditions, pesticide contamination is not likely to be a problem in the Monmouth. Although the Monmouth aquifer outcrops or subcrops beneath the brackish Sassafras River along the northern edge of Kent County, this area is primarily a discharge zone for the Monmouth, due to the relatively high land-surface elevations (as high as 80 ft above sea level) and, consequently, high water-table elevations along the river bank. This factor, combined with the generally low salinities of the Sassafras River (Tompkins, Cooper, and Drummond, 1994, p. 109), makes the potential for brackish-water intrusion into the Monmouth aquifer insignificant.

MAGOTHY AQUIFER

The Magothy aquifer crops out in Kent County only along the bluffs near Betterton, an area which is probably a discharge zone. Consequently, the Magothy receives recharge primarily as leakage from overlying aquifers in Kent County and perhaps some direct infiltration in its outcrop area in Cecil County to the north. Water entering the Magothy aquifer is initially chemically similar to water in the Columbia



Explanation

1	KE Ae 18	6	KE Be 113
2	KE Ag 54	7	KE Be 151
3	KE Bc 172	8	KE Cb 98
4	KE Bd 136	9	KE Cd 86
5	KE Be 5	10	KE Da 15

Figure 57.—Hydrochemical facies in the Monmouth aquifer in Kent County.

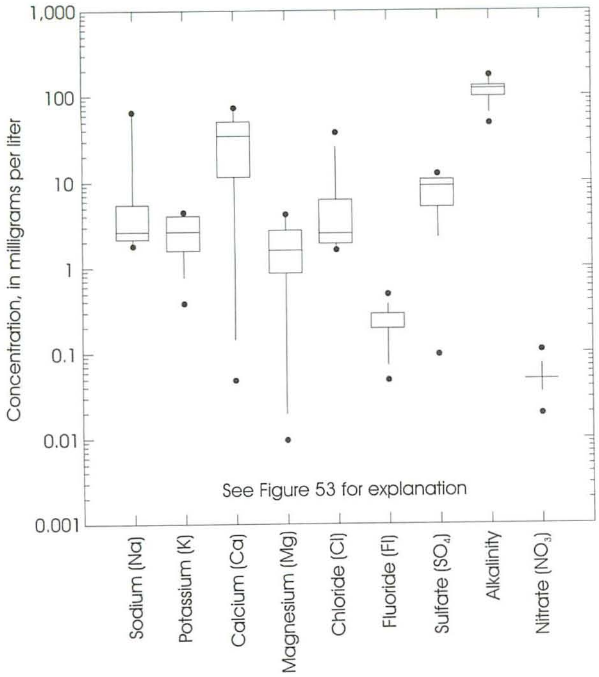


Figure 58.—Boxplot showing ranges of chemical constituents in the Monmouth aquifer.

or Monmouth aquifers and is altered slightly by reactions with interstitial minerals as it moves through the Magothy. The Magothy is predominantly a quartz sand with some clay, silt, and carbonaceous matter, and thus does not contain an abundance of reactive minerals.

Water in the Magothy aquifer is predominantly Facies 1 (soil reactions and silicate dissolution) with some influence of Facies 3 (calcite dissolution) (fig. 59). Facies 1 reflects the lack of reactive minerals in the Magothy and generally confined conditions. Facies 3 probably indicates leakage from the overlying Monmouth aquifer, as calcite is not present in the Magothy.

Water in the Magothy aquifer displays a fairly narrow range of chemical constituents, reflective of the narrow range of sources to the aquifer (fig. 60). TDS concentrations range from 23 to 213 mg/L, and pH ranges from 5.3 to 7.3. Chloride ranges up to 41 mg/L, and iron and manganese range up to 18,000 and 230 μg/L, respectively.

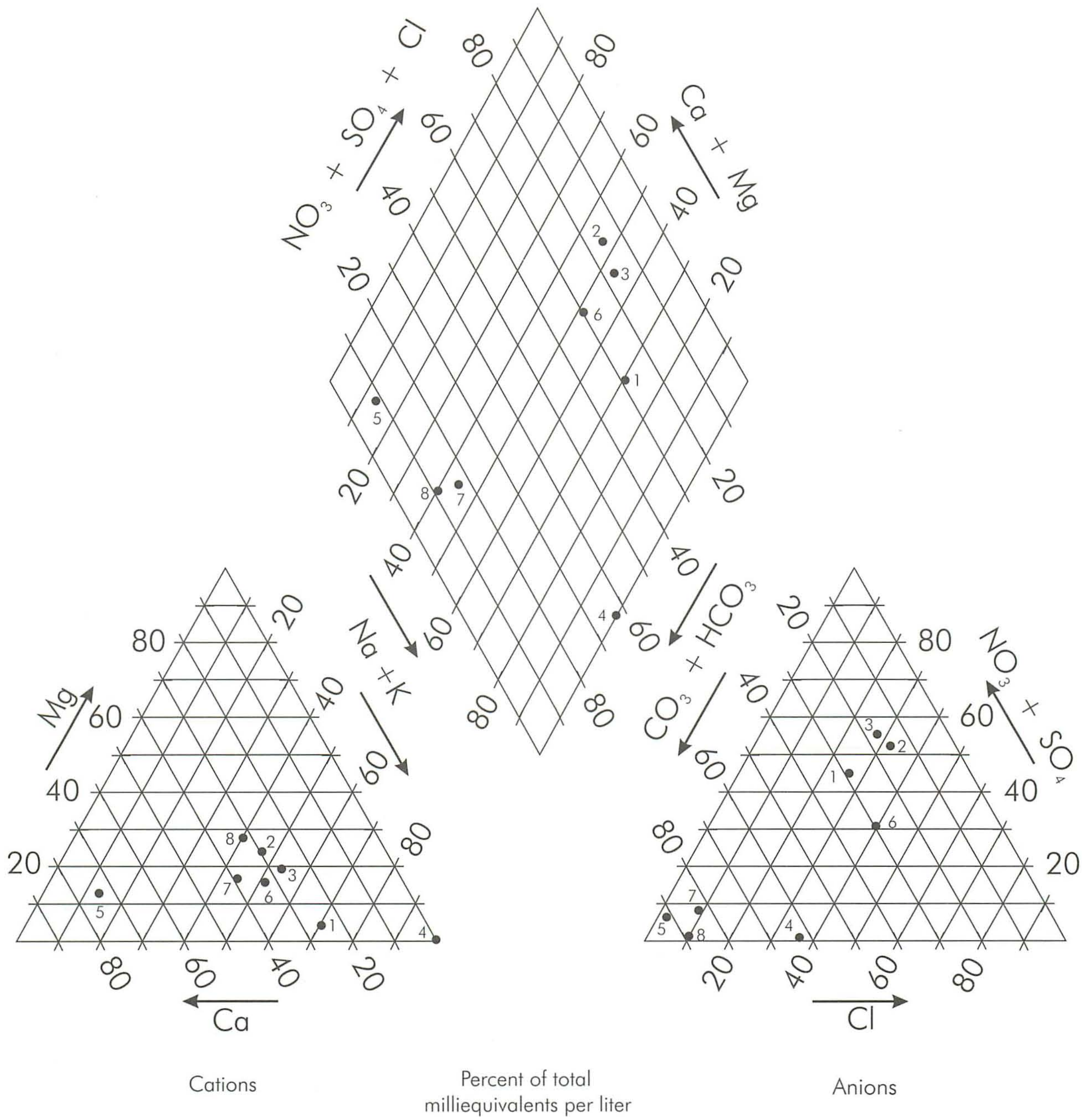
The only water-quality problems associated with the Magothy aquifer are high concentrations of iron and manganese, each of which exceeded the SMCL in water from three of the seven wells sampled. These high levels are caused by low dissolved oxygen concentrations in the confined parts of the aquifer. Finely disseminated pyrite, associated with carbonaceous lignite in clayey layers common in the Magothy, provides a source of iron.

Radon concentrations in water from the Magothy aquifer ranged up to 370 pCi/L. Brackish-water intrusion is not a significant problem in the Magothy aquifer and is not likely to become a problem, unless a large increase in pumpage causes water levels to fall below sea level. Although the Magothy crops out along the shore of the Chesapeake Bay near Betterton, heads were well above sea level in that area in 1992, and projected-pumpage scenarios do not indicate large head declines in the next few decades. Although water from two of the five wells sampled in the Magothy aquifer had elevated nitrate concentrations (1.9 and 2.1 mg/L), none were close to the MCL, and nitrate is not expected to become a problem in the Magothy because of generally confined conditions in Kent County. No pesticide-residue analyses are available for the Magothy aquifer, but pesticide contamination is not likely to be a problem in the Magothy for the same reasons as for nitrate contamination.

UPPER PATAPSCO AQUIFER

Water recharges the Upper Patapsco aquifer in Kent County primarily as downward leakage from the overlying Magothy and Columbia aquifers. Although the Upper Patapsco aquifer crops out on the bluffs along the Chesapeake Bay near Betterton, this is primarily a discharge zone for the Upper Patapsco. Water that enters the Upper Patapsco aquifer is initially chemically similar to water from the Columbia and Magothy aquifers. As the water flows through the Upper Patapsco aquifer it may react slightly with minerals in the aquifer. The Upper Patapsco is predominantly a quartz sand with some clay and silt, and does not contain an abundance of reactive minerals.

With the exception of water from well KE Ac 20, Upper Patapsco aquifer water is dominated by Facies 1 (fig. 61). This dominance reflects the confined conditions and the absence of reactive minerals in the Upper Patapsco. Water from well KE Ac 20 appears at first to represent brackish-water intrusion from the Chesapeake Bay, but several factors refute the bay as the source of salty water. Otton and Mandle (1984, pp. 33-35) display cross sections in which the



Explanation

1	KE Ad 5	5	KE Be 43
2	KE Ad 10	6	KE Cb 88
3	KE Ad 43	7	KE Cb 97
4	KE Bc 70	8	KE Da 11

Figure 59.—Hydrochemical facies in the Magothy aquifer in Kent County.

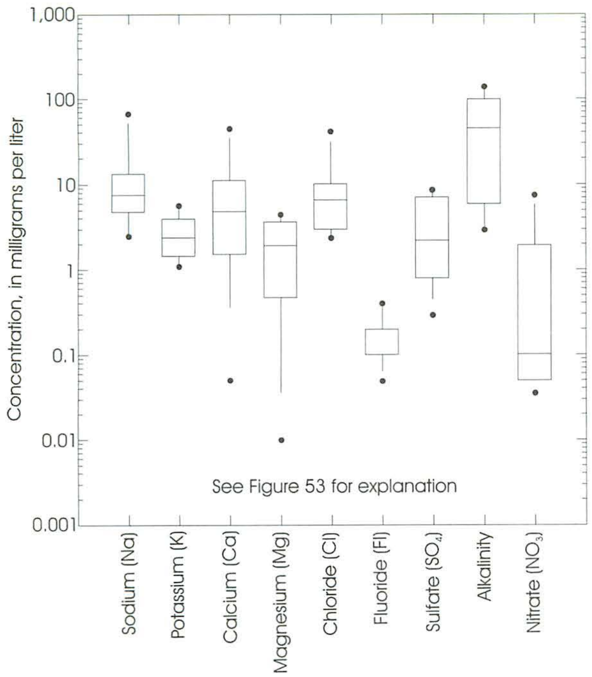


Figure 60. —Boxplot showing ranges of chemical constituents in the Magothy aquifer.

brackish water in KE Ac 20 at Still Pond is part of a regional body of brackish water that occupies the base of the Potomac Group beneath most of Kent County and parts of Queen Anne's County and Delaware. Potentiometric heads in the Upper Patapsco aquifer in 1992 were well above sea level (as high as 52 ft) and were probably even higher under prepumping conditions. These head conditions would tend to drive water out of the Upper Patapsco aquifer and into the Bay. The brackish-water body is more likely a relic of a previous high stand of sea level, in which brackish water invaded the Coastal Plain aquifers, and has subsequently been flushed out of most of the aquifers.

Water from the Upper Patapsco aquifer displays a fairly wide range in concentrations of chemical constituents, due primarily to one analysis (KE Ad 20) which is anomalously high in many constituents (fig. 62). TDS in water from the Upper Patapsco aquifer ranges from 89 to 1,670 mg/L, and pH ranges from 5.6 to 8.1. Iron and manganese concentrations range up to 80,000 and 3,200 μg/L, respectively, and dissolved oxygen was at or below detection limits in all samples. Nitrate concentrations were also below detection limits in all samples.

High iron and manganese concentrations are the only significant water-quality problems in the Upper Patapsco aquifer. Water from seven of eight wells sampled for iron in the Upper Patapsco aquifer exceeded the SMCL, and water from seven of nine wells sampled for manganese exceeded the SMCL. Prevailing anoxic and low pH conditions in the Upper Patapsco mobilize iron and manganese and generally render Upper Patapsco aquifer water unusable without treatment.

Radon concentrations in water from three wells screened in the Upper Patapsco aquifer were 96, 140, and 340 pCi/L. Brackish-water intrusion and contamination from nitrate and pesticide residues are not considered potential water-quality problems in the Upper Patapsco aquifer for the same reasons as for the Magothy aquifer.

EFFECTS OF INCREASED DEVELOPMENT ON WATER QUALITY

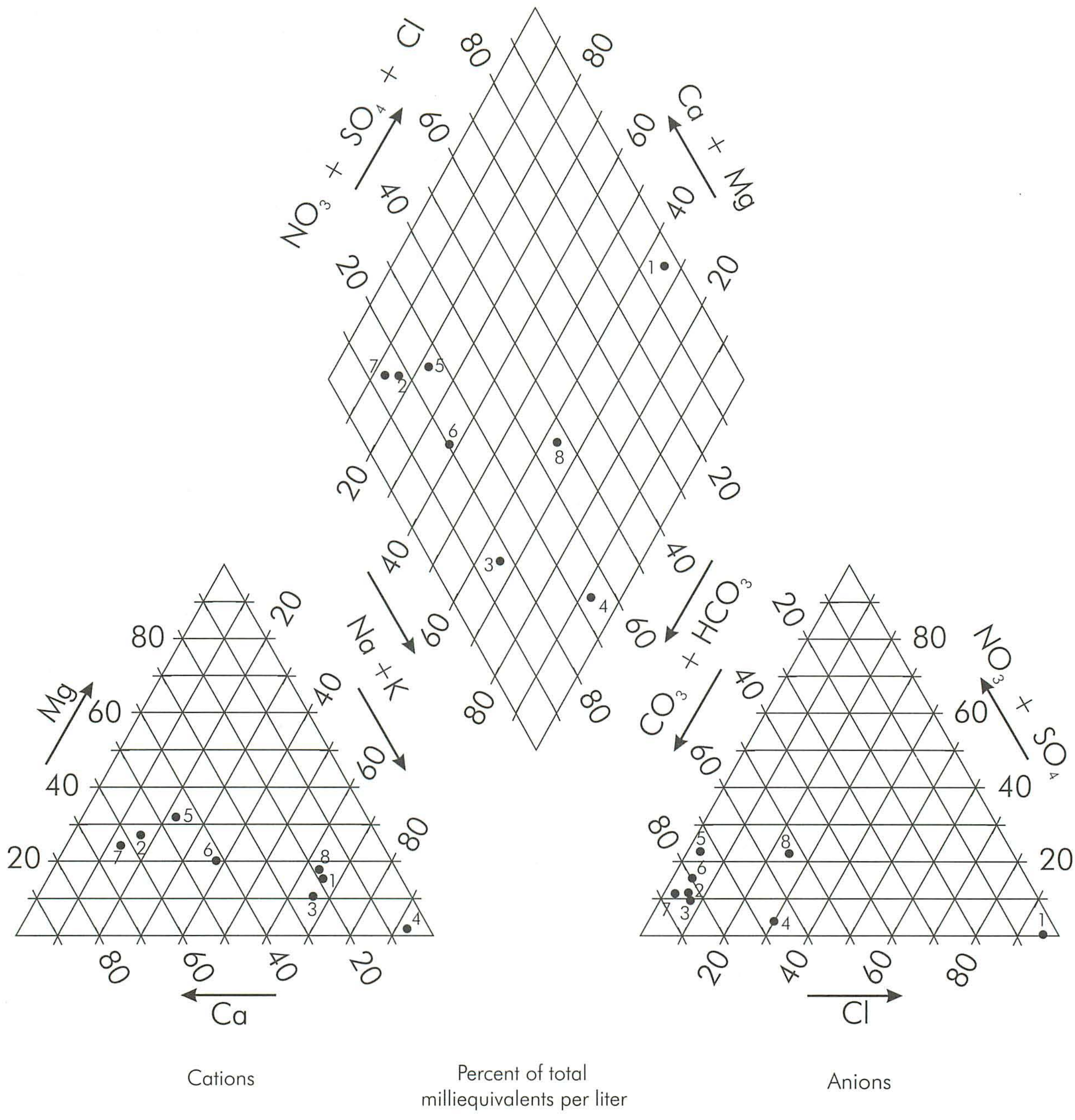
Brackish-Water Intrusion

Although brackish-water intrusion is not currently (1992) a widespread problem in Kent County, the potential exists for worsening the problem. If heads decline regionally below sea level, flow gradients may be reversed, and brackish water from the estuaries may flow into the aquifers. Most of the future pumpage scenarios, however, show drawdowns of only a few feet, and it is not anticipated that regional cones of depression will form near coastal areas.

Ground-water users that plan to pump large amounts of water in the area of brackish-water vulnerability (fig. 56) should be directed to aquifers deeper than the Aquia. Significant increases in pumpage from the Chestertown water plant should likewise be directed to the Magothy and Upper Patapsco aquifers.

Nitrate Migration

The migration of dissolved nitrate from the land surface to the water-table, and thence to deeper aquifers, is a potential threat to ground-water quality in Kent County and Queen Anne's County to the south. The generally unconfined conditions and substantial pumpage for irrigation and other purposes in the Aquia aquifer produce a downward flow path that transports solutes into the Aquia. The southward head gradient of about 10 ft per mile indicates that



Explanation

1	KE Ac 20	5	KE Cb 103
2	KE Bc 186	6	KE Cd 104
3	KE Be 171	7	KE Cd 137
4	KE Bg 33	8	KE Db 40

Figure 61.—Hydrochemical facies in the Upper Patapsco aquifer in Kent County.

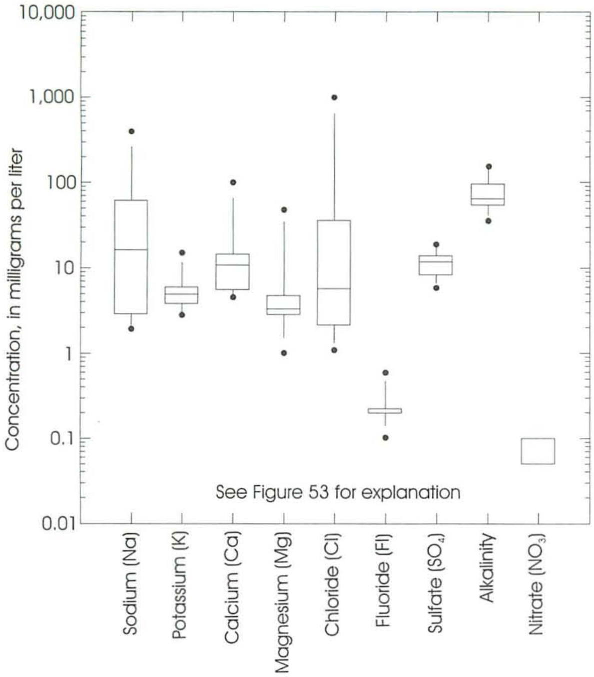


Figure 62.—Boxplot showing ranges of chemical constituents in the Upper Patapsco aquifer.

once dissolved nitrate has reached the Aquia aquifer, it may migrate southward into Queen Anne's County where the Aquia is confined by the Calvert Formation. Given a hydraulic conductivity of 14 ft/d, head gradient of 0.002, and porosity of 0.25, a non-reactive solute would travel southward at about 0.1 ft/d or about 36 ft/yr. This calculation neglects the effects of chemical degradation and dispersion.

The denitrification process would remove dissolved nitrate from ground water if anaerobic aquifer conditions prevail. The Aquia aquifer is unconfined or semi-confined throughout most of Kent County, but the overlying Calvert Formation creates confined conditions in the southeastern part of Kent County and most of Queen Anne's County. The confined conditions in this area may foster anaerobic chemical conditions; thus, dissolved nitrate may be removed from ground water as it flows into Queen Anne's County. The only dissolved oxygen concentration available for water from a well in the Aquia aquifer in northern Queen Anne's County is 0.5 mg/L from well QA De 30. Due to the sparse data on dissolved oxygen in water from the Aquia aquifer in northern Queen Anne's County, it is uncertain whether anaerobic conditions exist in this area and whether nitrate would be removed.

Although the aquifers beneath the Aquia (the Monmouth, Magothy, and Upper Patapsco aquifers) receive a substantial amount of leakage from the Aquia, they are anaerobic throughout Kent County, except in their outcrop areas. For this reason, it is unlikely that dissolved nitrate would migrate into these aquifers from the Aquia.

SUMMARY AND CONCLUSIONS

Ground water in Kent County, Maryland is the sole source of drinking water and is vulnerable to several potential problems, such as declining water levels, brackish-water intrusion from tidal estuaries, and contamination from anthropogenic sources. A study was conducted to investigate the hydrogeology of the Coastal Plain aquifers of Kent County and to assess the potential for these problems to affect the use of ground water in the area. The study refined the hydrogeologic framework, assessed the potential for the aquifer system to meet projected pumpage requirements, and documented ground-water chemical quality.

The Coastal Plain aquifer system of Kent County comprises a wedge-shaped body of sediments which dips and thickens to the southeast. These sediments form a series of aquifers which supply all of the drinking water in the county and most of the water for other purposes. The important aquifers underlying Kent County include (from shallowest to deepest): the Columbia, Aquia, Monmouth, Magothy, and Upper Patapsco. Deeper, unused aquifers include the Lower Patapsco and the Patuxent. Crystalline bedrock underlies the Patuxent aquifer at depths of 1,000 to 2,500 ft below sea level.

The Columbia aquifer is a surficial unconfined aquifer that blankets most of Kent County. It is used in a few places for small domestic water supplies, but is not extensively developed because it is shallow and vulnerable to contamination and excessive seasonal water-level fluctuations. The thickness of the Columbia aquifer ranges up to about 100 ft, but is generally 20 to 40 ft thick. An aquifer test yielded a transmissivity of 470 ft^2/d and a hydraulic

conductivity of about 47 ft/d.

The Aquia aquifer directly underlies the Columbia aquifer and is also unconfined throughout much of Kent County. It is extensively developed as a water supply for domestic, commercial, and irrigation uses. The thickness of the Aquia ranges from zero to about 300 ft, and measured transmissivity values range from 800 to 10,000 ft^2/d. Water levels in the Aquia aquifer range from around sea level in the southern part of Kent County near the Chester River to about 65 ft above sea level in the central part of the county.

The Monmouth aquifer underlies the Aquia aquifer and is used primarily in the area where the Aquia aquifer is absent. Thickness of the Monmouth ranges from zero to approximately 100 ft, and measured transmissivity values range from 200 to 700 ft^2/d. Water levels in the Monmouth range from about sea level to about 60 ft above sea level.

The Magothy aquifer underlies the Monmouth aquifer and is used for domestic supplies in the northwestern part of Kent County and for large municipal and commercial supplies throughout the county. Thickness of the Magothy aquifer ranges up to approximately 55 ft, and measured transmissivity is about 3,000 ft^2/d, but it is not present as an aquifer in parts of Kent County. Water levels in the Magothy range from about 10 ft below sea level to 50 ft above sea level in the central part of the county.

The Upper Patapsco aquifer underlies the Magothy aquifer and, in places, is hydraulically connected to the Magothy. It is used for small domestic and commercial supplies in the northwestern part of Kent County and for large municipal supplies throughout the county. The thickness of the Upper Patapsco aquifer is not well documented, but probably ranges up to about 100 ft, and the transmissivity ranges up to 2,600 ft^2/d. Water levels in the Upper Patapsco range from 10 ft below sea level to 30 ft above sea level in the central part of the county. Long-term hydrographs show a general decline in water levels of about 0.5 ft/yr.

A ground-water flow model was used to simulate future drawdowns in response to projected pumpage amounts. The model simulated four aquifer layers: the Columbia, Aquia, Monmouth, and Magothy/Upper Patapsco. The Magothy and Upper Patapsco aquifers were combined into one model layer because the two aquifers are hydraulically connected, and the Magothy functions as one of the sands within the Upper Patapsco aquifer. Model-calculated drawdowns are cell averages, and drawdowns in production wells could be greater than those calculated by the model.

Simulations of projected pumpage using a calibrated ground-water flow model indicate modest head declines for most pumpage scenarios. Pumpage scenarios which simulate projected population growth from 1993 to 2012 indicate drawdowns of less than 5 ft in all aquifers. Pumpage scenarios which simulate projected increases in irrigation pumpage indicate drawdowns of 20 ft in the Aquia aquifer and 7 ft in the Magothy/Upper Patapsco aquifer.

Ground-water quality in the coastal plain aquifers of Kent County is generally good. Minor water-quality problems are caused by brackish-water intrusion, agricultural application of fertilizers and pesticides, and naturally occurring concentrations of iron, manganese, and radon. Water from 19 wells screened in the Columbia and Aquia aquifers exceeded the MCL for dissolved nitrate plus nitrite. Water from 80 wells and springs exceeded the SMCLs for pH, sulfate, chloride, total dissolved solids, aluminum, iron, and/or manganese. Radon concentrations ranged up to 830 pCi/L, with the highest concentrations generally in water from the Monmouth aquifer.

Ground water in Kent County was classified into four hydrochemical facies: soil reaction/silicate dissolution, nitrate, calcite dissolution, and brackish-water intrusion. These facies indicate the source of water for each aquifer and the chemical reactions the ground water undergoes with aquifer material. Water in the Columbia aquifer is primarily precipitation which has undergone soil reactions and the addition of agricultural fertilizers and, in places, brackish-water intrusion. Water in the Aquia aquifer shows the influence of all four hydrochemical facies, indicating leakage from the Columbia aquifer, silicate hydrolysis, calcite dissolution, addition of nitrate, and brackish-water intrusion. Water chemistry of the Monmouth aquifer is dominated by calcite dissolution. Water in the Magothy aquifer shows the influence of silicate hydrolysis and leakage from the Monmouth aquifer. Water in the Upper Patapsco aquifer is dominated by silicate hydrolysis and leakage from the Magothy aquifer.

Ranges of important chemical constituents are displayed in box plots, which indicate the variance of each constituent and maximum and minimum values. Ground water in the Columbia aquifer shows a wide range of constituents due to the numerous sources of recharge to the aquifer. Water in the Columbia that is primarily precipitation that has only undergone soil reactions has very low concentrations of most

constituents, whereas water that has mixed with brackish water from estuaries has high concentrations of many constituents. Ground water in the Aquia aquifer also shows a wide range of most chemical concentrations due to multiple sources of recharge, additions of agricultural chemicals, and the dissolution of calcite. Chemical concentrations in the Monmouth, Magothy, and Upper Patapsco aquifers show narrower ranges, due to more restricted recharge sources, and fewer interaquifer chemical reactions.

The modest amount of development projected for Kent County through 2012 is not expected to cause major problems in ground-water quality. The Aquia aquifer is vulnerable to brackish-water intrusion in the southwestern part of the county, and large pumpers should be directed to deeper aquifers in this area. Pumpage throughout Kent County and in neighboring areas may cause movement of nitrate and pesticide residues toward pumping centers. Although concentrations of these contaminants generally are not above maximum contaminant levels, this is a potential problem that should be monitored in the future. The presence of iron, manganese, and radon is a natural occurrence, and future development is not expected to worsen problems associated with these constituents.

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