MARYLAND GEOLOGICAL SURVEY

CONVERSION FACTORS, ABBREVIATIONS, VERTICAL DATUM, AND WATER-QUALITY UNITS

Multiply	By	To obtain
inch (in.)	25.40	millimeter (mm)
inch per year (in/yr)	25.40	millimeter per year (mm/yr)
foot (ft)	.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
acre	.4047	hectare (ha)
foot squared per day (ft^2/d)	.09290	meter squared per day (m^2/d)
gallon per minute (gal/min)	.06309	liter per second (L/s)
gallon per minute per foot [(gal/min)/ft]	.2070	liter per second per meter [(L/s)/m]
gallon per day (gal/d)	.003785	cubic meter per day (m^3/d)
million gallons per day (Mgal/d)	.04381	cubic meter per second (m^3/s)
million gallons per day per square mile [(Mgal/d)/mi^2]	.01693	cubic meter per second per square kilometer [(m^3/s)/km^2]
cubic foot per second (ft^3/s)	.02832	cubic meter per second (m^3/s)
cubic foot per second per square mile (ft^3/s)/mi^2	.01093	cubic meter per second per square kilometer [(m^3/s)/km^2]
ton (t)	907.2	kilogram (kg)

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

Chemical concentration is given in milligrams per liter (mg/L), micrograms per liter (μg/L), micrograms per gram (μg/g), or micrograms per kilogram (μg/kg), except as noted. Concentrations in milligrams per liter are equivalent to concentrations in parts per million for values less than 7,000 mg/L.

Radioactivity is expressed in disintegrations per second, regardless of radionuclide species [1 picoCurie per liter (pCi/L) = 3.7×10^{-2} disintegrations per second].

Specific electrical conductance of water is expressed in microsiemens per centimeter at 25 degrees Celsius (μS/cm). This unit is equivalent to and replaces micromhos per centimeter at 25 degrees Celsius (μmho/cm).

Temperature in degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) using the following equation:

$$°F = 1.8(°C) + 32.$$

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

BULLETIN 38

WATER RESOURCES OF HOWARD COUNTY, MARYLAND

by

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U.S. Geological Survey

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Prepared in cooperation with the
United States Department of the Interior
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and the
Howard County Department of Public Works
Bureau of Environmental Services

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WATER RESOURCES OF HOWARD COUNTY, MARYLAND

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ABSTRACT

Howard County is located in central Maryland between the metropolitan centers of Baltimore and Washington, D.C. The county population increased from 62,394 in 1970 to 187,328 in 1990, and, accompanied by growing commercial and industrial development, has placed an increasing demand on the water resources of the county. This report describes the water resources of Howard County, Maryland.

Ground water is found primarily in joints and fractures of the igneous and metamorphic rocks of the Piedmont physiographic province, within which most of Howard County lies, and in the intergranular spaces of the sediments of the Coastal Plain, which includes the eastern part of the county. Reported yields of more than 2,000 wells in the county range from 2 to 101 gallons per minute in the Coastal Plain, and from 0 (dry hole) to 100 gallons per minute in the Piedmont; reported well depths in the county range from 13 to 750 feet. Transmissivity (estimated from specific capacity) ranges from 165 to 3,453 feet squared per day for 17 Coastal Plain wells, and from less than 1 to greater than 5,000 feet squared per day for 1,760 wells in the Piedmont. The geologic unit in which a well is completed appears to be the most important site factor affecting yield. Water levels fluctuate through a range inversely proportional to overburden thickness. The water is generally acidic, but chemical concentrations are mostly within safe drinking-water criteria. Radon concentrations in ground water range from less than 80 to 40,000 picoCuries per liter.

Thirty–two stream basins that range in area from 0.54 to 285 square miles were studied. Streamflow characteristics were determined for 11 gaging stations with continuous records of flow. Mean annual streamflows range from 23.9 to 412 cubic feet per second (ft^3/s), 100–year peak flows range from 10,400 to 181,000 ft^3/s, and 7-day, 10-year low flows range from 2.8 to 11 ft^3/s. Peak flows at three gaging stations in Howard County were simulated with the HEC-1 rainfall-runoff model; at a 100-year recurrence interval, flows ranged from 6,820 to 15,700 ft^3/s for a rainfall duration of 24 hours. Quality of stream water during base flow is similar to quality of ground water adjacent to the stream. Eight pesticides, DDD and DDE, polychlorinated biphenols (PCB), and 9 trace elements were detected in stream-bottom materials, but 11 other organic compounds were undetected.

The average annual hydrologic budget for that portion of Howard County located in the Piedmont Province is precipitation (42 inches) equals overland runoff (5 inches) plus ground-water runoff (9 inches) plus evapotranspiration (28 inches).

INTRODUCTION

The population of Howard County, Md., has increased considerably from 1970 to 1990, accompanied by increased residential and commercial development. The strategic location of Howard County between Baltimore and Washington, D.C., makes it desirable for suburban development. The population of the county increased from 62,394 to 118,572 during the period 1970–80, and by 1990 it had increased to 187,328 (Frese, 1991, p. 3). Howard County has had the greatest annual growth rate of all Maryland counties (6.6 percent during 1970–80 and 4.4 percent during 1980–90) and is expected to remain one of the fastest-growing counties in the 1990's (Maryland Office of Planning, 1992).

As a result of this growth, water use in Howard County has also increased significantly, from about 12.9 Mgal/d during 1980 (Herring, 1983), to about 20 Mgal/d during 1990 (Wheeler, 1994). Public water supplies, drawing from reservoirs operated by Baltimore City and by the Washington Suburban Sanitary Commission (WSSC), provide water to most of the eastern half of the county. Homes and businesses in the western half of the county, and in a few small areas in the eastern half of the county that are not served by public water systems, are supplied by individual wells. State and county administrators require accurate data upon which to base water-use and water-resource-protection policy decisions necessitated by growth and changing conditions.

PURPOSE AND SCOPE

This report assesses the availability and quality of ground water and surface water in Howard County, and is intended as a resource for State and local officials who plan, develop, and manage these resources, as well as others interested in the hydrology of the county.

The hydrologic analyses in this report are based on data collected and compiled by Dine and others (1992). Well yield and specific-capacity information is based on drillers' completion reports for 2,484 wells, and more than 80 wells (and several springs) were sampled for ground-water-quality analyses. Streamflow characteristics are based on flow records, base-flow measurements, and physical characteristics of 24 basins, and peak flows were simulated for 3 streams using the HEC-1 rainfall-runoff model (U.S. Army Corps of Engineers, 1987). Surface-water-quality evaluation (including analyses of bottom materials) is based on samples collected at 24 sites. Hydrologic budgets were estimated using annual precipitation records and interpretation of hydrographs for six stream gaging stations for which long-term data are available.

DESCRIPTION OF STUDY AREA

Howard County is located in central Maryland and lies between Baltimore, Md., and Washington, D.C. (fig. 1). The county is bounded by two major streams. On the northern border of the county, the South Branch Patapsco River and the Patapsco River separate Howard County from Carroll and Baltimore Counties. The Patuxent River is the southern border, separating Howard County from Montgomery and Prince Georges Counties. The southeastern boundary with Anne Arundel County coincides with the CSX railroad right-of-way and Deep Run. Parrs Spring, in extreme western Howard County, is a boundary point shared with three other counties—Carroll, Frederick, and Montgomery—and is the only point in Maryland where four counties meet.

Howard County is the second smallest county in Maryland, having an area of 253.51 mi^2 (162,246 acres) of which 2.51 mi^2 (1,606 acres) is water. The county seat is Ellicott City, located approximately 6 mi west of Baltimore and 22 mi northeast of Washington, D.C. (fig. 1). Most of the communities in the county are unincorporated; Columbia, the largest, is located approximately 9 mi southwest of Baltimore and 17 mi northeast of Washington, D.C. Development of Columbia, a comprehensively planned community, be-

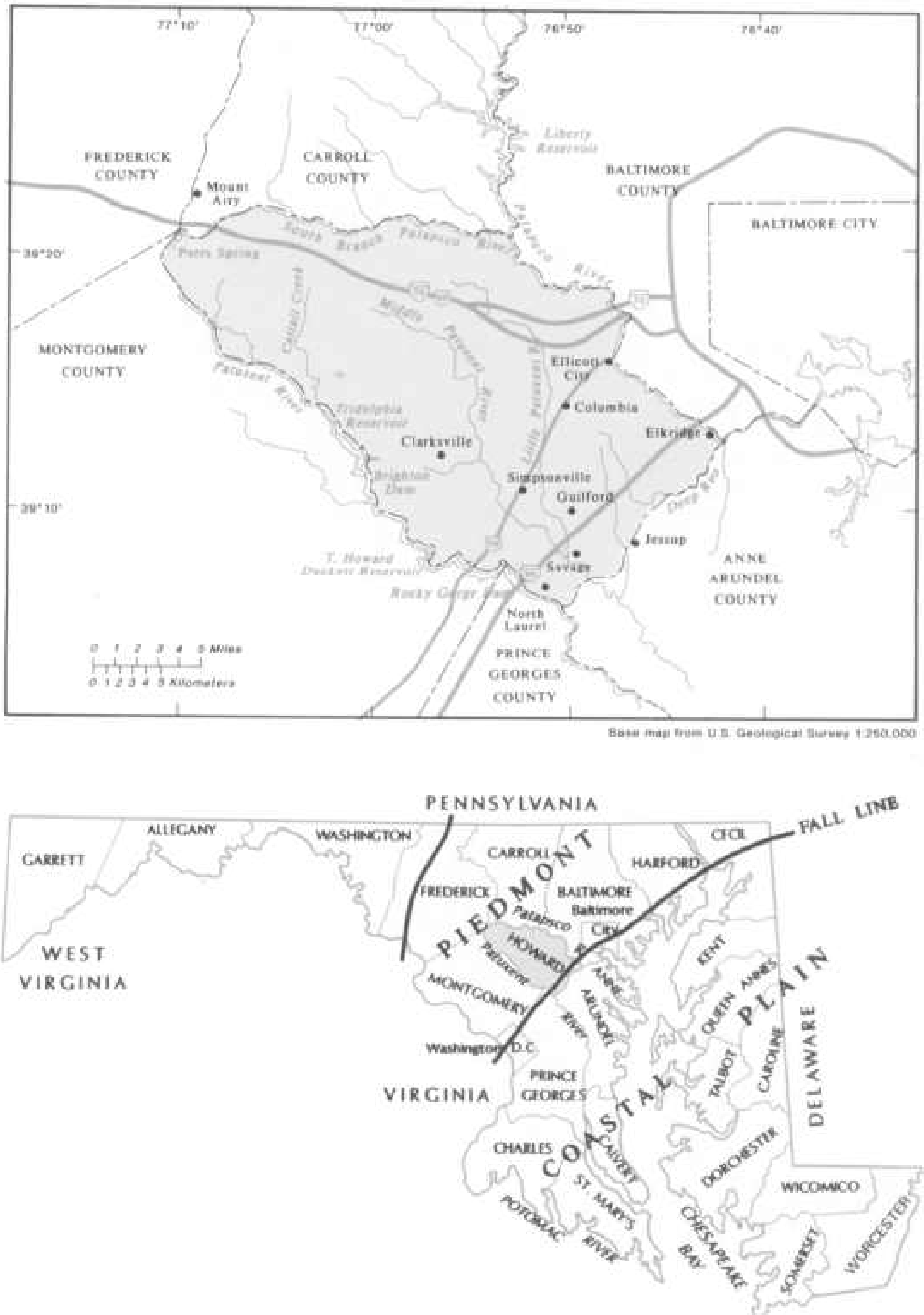


FIGURE 1.—Location of Howard County.

gan in 1965 and was largely completed by 1992. Other major communities are Elkridge, Guilford, Jessup, and Savage, located in the eastern portion of the county; and Clarksville, located in the central part. Numerous small communities and residential developments are also located in the central and western parts of the county.

Population

In 1990 the population of Howard County was 187,328 (Frese, 1991, p. 3), which is an average of 746 persons per square mile (table 1). The county population has increased during every decade since 1950. The most significant increase (90 percent) was between 1970 and 1980, which corresponds to the development of the city of Columbia. Development, stimulated by the establishment of Columbia, has spread to surrounding areas. The population density of Howard County was well under that of the State of Maryland during 1950–70, but, in 1980, the population density of the county surpassed that of the State and is projected to be almost double the state density by the year 2010.

The two largest communities in Howard County, Columbia and Ellicott City, account for 63 percent of the county population. The 1990 populations of selected communities in Howard County are (Maryland Office of Planning, 1990):

Community	*1990 Population*
Columbia	75,883
Elkridge	12,953
Ellicott City	41,396
North Laurel	15,008
Savage/Guilford	9,659
Jessup (Howard County part)	1,213
Remaining county population	31,216
Total	187,328

Water Supply and Wastewater Treatment

During 1990, Howard County used approximately 20.1 Mgal/d of water. Of this amount, about 3.1 Mgal/d was supplied from sources within the county by private systems (2.7 Mgal/d from ground water and about 0.4 Mgal/d from surface water; Wheeler, 1994). The other 17 Mgal/d of water (or almost 85 percent of the county's needs) was delivered by the Baltimore City and Washington Suburban Sanitary Commission (WSSC) systems from sources outside the county. Water appropriations and withdrawals in 1989 are listed in Dine and others (1992, table 21).

Approximately 159,230 people in Howard County (about 85 percent of the total population) received water from Baltimore City and WSSC public supplies during 1990. Baltimore City is the primary supplier and transferred approximately 14.1 Mgal/d of water from Liberty Reservoir in Carroll County on the Patapsco River for public-supply use in Howard County during 1990. WSSC transferred approximately 3.0 Mgal/d for public-supply use from the T. Howard Duckett Reservoir (fig. 1) on the Patuxent River.

About 28,100 people (15 percent of total population) used 2.3 Mgal/d of ground water from individual wells for domestic water supply during 1990 (table 2). This amount is estimated by the Maryland Water Resources Administration assuming an average individual

TABLE 1
POPULATION OF HOWARD COUNTY AND MARYLAND, WITH POPULATION SUMMARY STATISTICS AND PROJECTIONS TO THE YEAR 2010

	Howard County			Maryland	
Year	Population	Population increase during each decade (percent)	Density (persons/mi^2)	Population	Density (persons/mi^2)
1950	23,119	35	92	2,343,001	237
1960	36,152	56	144	3,100,689	314
1970	62,394	73	249	3,923,897	397
1980	118,572	90	472	4,216,933	427
1990	187,328	58	746	4,781,468	484
2000	228,400	22	910	5,326,200	539
2010	269,000	18	1,072	5,744,800	582

Sources: 1950-90 data from Maryland Office of Planning, 1992; projections to 2010 from Baltimore Regional Council of Governments, 1991.

water use of 80 gal/d. Self-supplied withdrawals for domestic use account for approximately 87 percent of ground-water withdrawals in Howard County.

Domestic use was 75 percent of self-supplied water withdrawn from ground- and surface-water sources in Howard County during 1990; commercial, industrial, agricultural, and irrigation water uses accounted for the remaining water withdrawals. Water used for commercial purposes (which include service and wholesale/retail businesses and educational institutions) amounted to 0.2 Mgal/d from self-supplied ground-water sources and 0.04 Mgal/d from surface-water sources within the county, and was 7.8 percent of the total water withdrawals. Industrial water is used by businesses that manufacture or process goods, such as washing and separation processes, cooling, boiler make-up, and dust control. In 1990, water withdrawn from county sources for industrial purposes included 0.05 Mgal/d from ground water and 0.2 Mgal/d from surface water, or 8.5 percent of the total water withdrawals from sources in the county. Livestock watering, dairy operations, and other agricultural activities used 0.08 Mgal/d of ground-water and 0.1 Mgal/d of surface-water in 1990, which equalled 5.9 percent of the total water withdrawals in the county. In 1990, irrigation, which includes water used for irrigating farm crops; commercial, municipal, and institutional lawns and parks; golf courses; and nursery plants, totalled 0.02 Mgal/d of ground water and 0.07 Mgal/d of surface water, or 2.9 percent of the total water withdrawn from Howard County sources.

TABLE 2
ESTIMATED WATER USE IN HOWARD COUNTY DURING 1990

[All quantities in million gallons per day]

Water source	Domestic	Commercial	Industrial	Agricultural	Irrigation	Total
Self-supplied withdrawals						
Ground water	2.3	0.2	0.1	0.1	0.0	2.7
Surface water	0.0	0.0	.2	.1	.1	.4
Total withdrawals	2.3	.2	.3	.2	.1	3.1
Public water supply						
Baltimore City	—	—	—	—	—	14.1
WSSC[1]	—	—	—	—	—	3.0
Total deliveries	14.9	1.7	.5	0.0	0.0	17.1
Total water use	17.2	1.9	.8	.2	.1	20.2

Source: Wheeler (1994)
[1]Washington Suburban Sanitary Commission.

Wastewater collected by sanitary sewers is treated by the Little Patuxent River Treatment Plant in Howard County and the Patapsco River Treatment Plant in Baltimore City. The Little Patuxent Treatment Plant has a designed capacity of 15 Mgal/d, but averaged 12.2 Mgal/d during 1990 (Maryland Department of the Environment, unpub. data, 1991). The treated effluent is discharged into the Little Patuxent River several miles downstream from the plant, in Anne Arundel County. Approximately 5 Mgal/d of sewage from Howard County was treated at the Patapsco River Treatment Plant and discharged into the tidal reach of the Patapsco River in 1991. The Mount Airy and the Freedom Wastewater Treatment Plants, which do not provide service to Howard County customers, discharged a combined 2.1 Mgal/d of treated effluent into the South Branch Patapsco River on the northern border with Howard County during 1990.

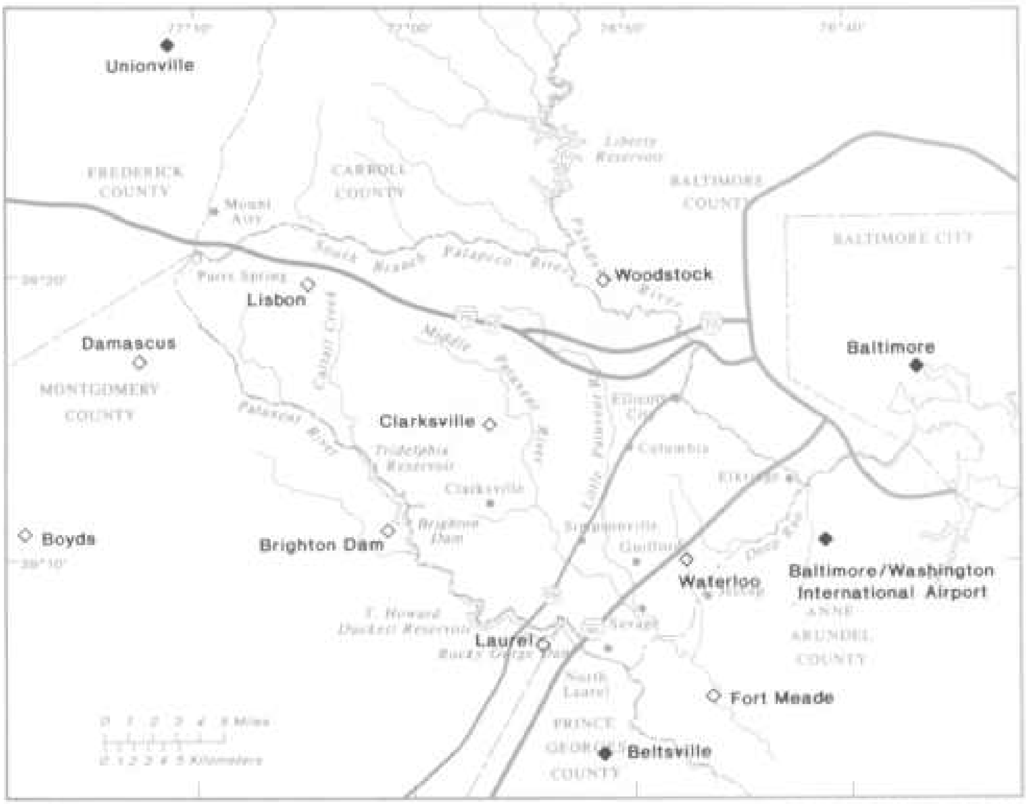
Land Use

Undeveloped land accounts for 106,015 acres, or 66 percent of Howard County (Howard County Department of Planning and Zoning, 1990a). Farmland, which is included in the undeveloped land category, was once the dominant land use but now occupies about 43,000 acres, or 27 percent of the total (Howard County Department of Planning and Zoning, 1990b). Farmland is mainly in the western part of the county. Parks, designated "open space," and other undeveloped areas account for the remaining 63,015 acres of undeveloped land and make up about 39 percent of the total land area. Much of the park land lies along the two major rivers and is part of the Patapsco Valley and Patuxent River State Parks.

Developed land accounts for the remaining 54,625 acres (34 percent of Howard County), with residential areas occupying 37,525 acres (23 percent of the total area), and commercial, industrial, institutional, road and utility right-of-ways, and other miscellaneous areas occupying the remaining 17,100 acres (9 percent of the total area). Most of the developed area is in the eastern half of the county along the major transportation routes connecting Baltimore and Washington, D.C.

Climate

The climate of Howard County is moderately humid and temperate. Long-term (1951–90) precipitation and temperature data are available from Brighton Dam (precipitation only) in Howard County, and from four stations located just outside of the county (tables 3 and 4). These stations, along with additional stations in Howard County for which short-term records are available, are shown in figure 2. The precipitation and temperature



EXPLANATION

Climatological stations

◇ Daily precipitation records

◆ Hourly precipitation records

FIGURE 2.—Locations of climatological stations in and near Howard County.

TABLE 3
PRECIPITATION NORMALS

[Precipitation in inches. --, record incomplete. All normals based on period 1951-80]

Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
						Baltimore-Washington International Airport						
3.00	2.98	3.72	3.35	3.44	3.76	3.89	4.62	3.46	3.11	3.11	3.40	41.84
						Laurel						
2.87	2.69	3.66	3.40	4.06	3.89	3.88	4.17	3.38	3.13	3.40	3.34	41.87
						Brighton Dam						
2.96	2.72	3.73	3.47	3.93	3.89	3.54	4.13	3.69	3.12	3.17	3.41	41.76
						Unionville						
2.76	2.41	3.38	3.51	3.67	4.08	3.59	3.76	3.51	2.93	3.09	3.30	39.99
						Woodstock						
3.14	2.76	3.94	3.62	3.77	4.03	3.56	3.98	4.00	3.12	3.28	3.52	42.72

Source: U.S. National Oceanic and Atmospheric Administration, 1970-92

TABLE 4
TEMPERATURE NORMALS

[Temperatures in degrees Fahrenheit. Based on period 1951-80]

Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
						Baltimore-Washington International Airport						
32.7	34.7	43.3	54.0	63.4	72.2	76.8	75.6	68.9	56.9	46.3	36.5	55.1
						Laurel						
33.4	35.7	44.2	55.2	64.4	72.6	77.2	76.2	69.6	58.2	47.5	36.9	55.9
						Unionville						
29.5	31.9	40.9	51.5	60.9	69.3	73.6	72.2	65.3	53.8	43.2	33.4	52.1
						Woodstock						
31.4	33.5	42.1	52.9	62.4	70.3	74.9	73.5	66.8	55.2	44.7	35.2	53.5

Source: U.S. National Oceanic and Atmospheric Administration, 1988-90 normals are averages for the 30-year period 1951–80 (U.S. National Oceanic and Atmospheric Administration, 1988–90). Annual precipitation in Howard County averages about 42 in., with slightly higher amounts falling in the late spring and summer months than during the rest of the year. The annual temperature normal is almost 4°F higher at Laurel than at Unionville.

Physiography

Parts of two physiographic provinces are present in Howard County—the Coastal Plain, which occupies approximately 25 mi^2 (10 percent) in the extreme eastern part of the county, and the Eastern division of the Piedmont, which occupies approximately 226 mi^2 (90 percent) in the rest of the county (fig. 1). The Fall Line is the boundary between these provinces, and is actually a zone where streams on the older, higher Piedmont surface descend quickly onto the Coastal Plain and contain numerous rapids. The Coastal Plain is a region of low relief underlain by unconsolidated sand, gravel, and clay deposited on the older surface of eastward-dipping crystalline rocks. Outliers of Cretaceous sediments remain near the Fall Line. The Piedmont Province is characterized by an undulating surface with a few ridges that rise above the general land surface and with deep, narrow stream valleys with relatively steep gradients. The Piedmont is underlain mostly by Precambrian and early Paleozoic crystalline rocks in Howard County.

The highest elevations are in the far western part of the county. The western boundary of the county and the ridge south of Parrs Spring (fig. 1) are more than 880 ft above sea level. There is a regional slope to the southeast, where elevations along the eastern boundary range from 100 to 200 ft above sea level. The lowest point, just a few feet above sea level, is along the Patapsco River where it leaves Howard County.

Drainage is good throughout Howard County. The northern part of the county is drained by small streams that flow northeast to the Patapsco River, which drains approximately 25 percent of the county. The Patuxent River drains most of the rest. Larger tributaries of the Patuxent originate in the central part of the county and flow southeast to the Patuxent River. One of these, the Little Patuxent River, joins the Patuxent River in Anne Arundel County.

Geologic Setting

Geologic units in Howard County range in age from Precambrian to Quaternary (pl. 1, fig. 3). Precambrian and early Paleozoic crystalline rocks underlie the Piedmont part of the county and are cut by diabase dikes of Triassic–Jurassic age; Upper Cretaceous and Quaternary sediments underlie the Coastal Plain. Understanding of the stratigraphic and structural relations in the Maryland Piedmont has evolved considerably, and the terminology has been revised many times. The Baltimore Gneiss "represents a pile of predominantly felsic volcaniclastic rocks that were deposited, metamorphosed, folded, and intruded by a granite in the late Precambrian" (Crowley, 1976, p. 21). These are the oldest rocks in Maryland and are exposed as the cores of domes or anticlinorial domes in several locations in the eastern division of the Piedmont.

The Glenarm Supergroup lies unconformably on the Baltimore Gneiss (fig. 3) and consists of a series of metamorphosed clastic and carbonate sediments. The basal unit is the Setters Formation, which, in Howard County, is mostly schist with quartzite and gneiss. The phlogopitic metalimestone member of the Cockeysville Marble overlies the Setters

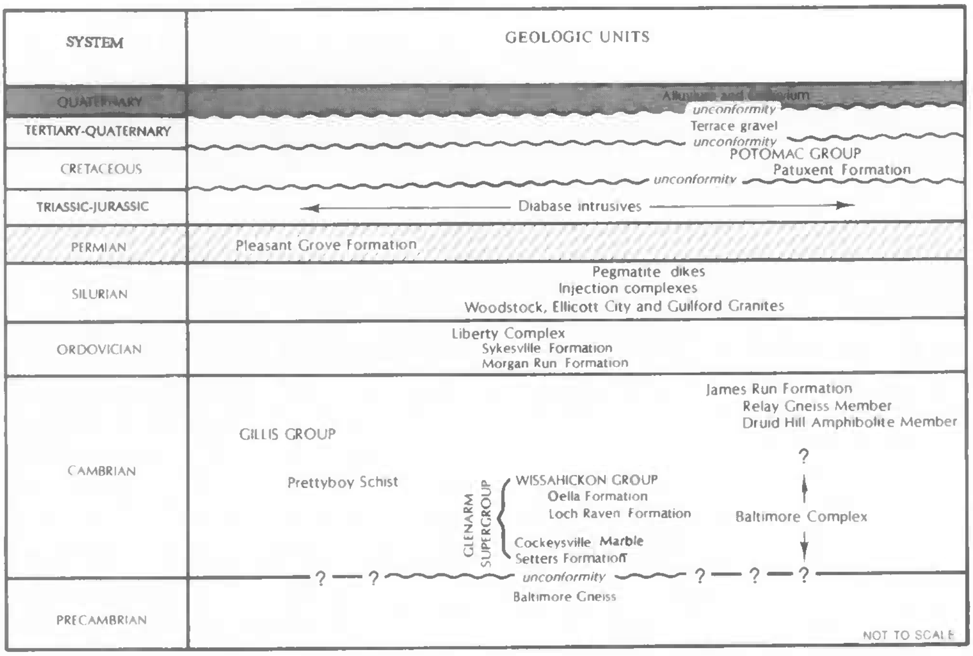


FIGURE 3.—Stratigraphic column of Howard County. NB: The Pleasant Grove Formation was not deposited during Permian time, but rather includes older rock units that have been deformed by shearing and emplacement that probably occurred during Permian time. (Geologic interpretation by J. Edwards, Maryland Geological Survey, written communication; for descriptions of geologic units, refer to plate 1).

Formation. Above the Cockeysville Marble is the Wissahickon Group, which consists of two metasedimentary units, the Loch Raven and the Oella Formations. The Morgan Run and the Sykesville Formations are part of the Liberty Complex (Muller and others, 1989) which was thrust over the Loch Raven and Oella Formations. The Morgan Run Formation is a schist interlayered with metagraywacke, and the Sykesville Formation is mostly gneiss with a schist member present in the county. The Pleasant Grove Formation appears to be a displaced unit; it apparently was thrust over the Prettyboy Schist and the Gillis Group[1] (Muller, 1991). The Gillis Group, which consists mostly of phyllites and represents the top of the crystalline-rock stratigraphic section, conformably overlies the Prettyboy Schist. The domal structure results in these units being exposed sequentially away from the Baltimore Gneiss except where the stratigraphic sequence is interrupted by faulting, non-deposition, or erosion.

Two metavolcanic units, the James Run Formation and the Baltimore Complex, occur in eastern Howard County (fig. 3). The James Run Formation contains a felsic member and a mostly mafic member (the Relay Gneiss and the Druid Hill Amphibolite, respectively). The Baltimore Complex is a plagioclase-hornblende gneiss, mapped as Mount Washington Amphibolite in Baltimore County. The Baltimore Complex is an allochthon (Crowley, 1976) that was emplaced by Ordovician time (Hanan and Sinha, 1989). It apparently is part of a larger, central Appalachian ophiolite that originated during an earlier period of plate convergence (Crowley, 1976; Drake and Morgan, 1981).

[1]Listed as Gillis Formation in Dine and others (1992).

Several distinct igneous intrusions are found in Howard County. The Ellicott City Granite and the Guilford Granite occur in plutons and also as injection complexes, comprising numerous small granitic masses (fig. 3). The Woodstock Granite occurs in a small area in the northeastern part of the county as an injection complex. Triassic–Jurassic diabase dikes cut through the county in the west and east-central part; in both areas the dikes trend north-northeast to south-southwest.

The old erosional surface of the crystalline rocks continues to the southeast where it dips downward and is covered by sands and clays of the Patuxent Formation. These sediments originally extended farther to the northwest but erosion has left the remaining sediments mainly in interfluves. In eastern Howard County, the Patuxent Formation attains a thickness of approximately 140 ft. (Dingman and others, 1954, p. 12).

Coarse, bouldery terrace gravels of Tertiary and Quaternary age are found in the vicinity of the lower reaches of some of the streams in southeastern Howard County. Quaternary alluvium is present in the stream valleys, but is only sufficiently thick and extensive to be mappable along the lower reaches of the larger streams. Some colluvium, not mapped, could interfinger with the alluvium at or near hillslope bases.

The structural geology of Howard County is complex because of the presence of multiple terranes and episodes of deformation. The crystalline rocks have been folded, faulted, intruded by magma, and joined by an allochthon. Primary structural features include original stratification, foliation and lineation, cleavage, and folding. Many of the linear trends are northeast-southwest. The core of the Baltimore-Washington Anticlinorium, which runs through the center of Howard County (Cloos and others, 1964), is exposed in the Woodstock, Mayfield, and Clarksville Domes. Few major faults are shown on older maps (Cloos and others, 1964), although a number of minor normal faults are found in the vicinity of the domes. More recently, some of the contacts have been reinterpreted as thrust faults pre-dating metamorphism (plate 1). The Baltimore Complex, an assemblage of metamorphosed mafic and ultramafic intrusive rocks, was thrust into its present location (Crowley, 1976; Drake and Morgan, 1981; Hanan and Sinha, 1989; Gates and others, 1991). The crystalline rocks are all jointed, with three major strike directions: parallel, perpendicular, and horizontal to major fold axes (Cloos and others, 1964).

PREVIOUS INVESTIGATIONS

The geology of Howard County was originally mapped by Cloos and Broedel (1940). Cloos and others (1964) described the lithology and structural geology of Howard and Montgomery Counties. Crowley (1976) described the evolution of the crystalline rocks of the eastern Piedmont of Maryland. The geology of the Ellicott City quadrangle was mapped by Crowley and Reinhart (1980). Muller and others (1989) described the development and tectonics of the Liberty Complex; Hanan and Sinha (1989) discussed the Baltimore Mafic Complex. Further refinements of the stratigraphy of various formations of the eastern Maryland Piedmont were proposed by Gates and others (1991). The geologic map of Howard County has been revised by Edwards and is included in this report (plate 1).

The water resources of Howard County were first described by Clark and others (1918), followed by a comprehensive study of Howard and Montgomery Counties by Dingman and others (1954). Studies in the Maryland Piedmont described the occurrence of ground water (Nutter and Otton, 1969) and factors that affect ground-water movement and yields (Richardson, 1982). Duigon (1983) compiled a Hydrogeologic Atlas for the Ellicott City quadrangle, and three atlases for the western part of the county (in press). Otton and Hilleary (1985) included eight Howard County springs in a report that described characteristics of Maryland springs. Streamflow characteristics of Maryland streams, including several in Howard County, were described by Darling (1962), Walker (1971), and Carpenter (1983). Willey and Achmad (1986) developed a model of ground-water flow in the Cattail Creek basin to determine availability of ground water. McFarland (1989) examined the effects of recharge variations and evapotranspiration on nitrogen transport at a site in the Piedmont of Howard County. Data on well construction and well yield, ground-water levels, streamflow, and water quality in Howard County are presented by Dine and others (1992).

SITE-IDENTIFICATION SYSTEM

Wells and springs in Maryland are identified and located by an alphanumeric system. The first two letters identify the county in which the site is located (HO for Howard County); the next two letters correspond to the row and column of a 5-minute by 5-minute grid superposed on the county. The first of these (in upper case) indicates the position of the row of that quadrangle from the north; the second letter (in lower case) indicates the position of the column of that quadrangle from the west. Wells and springs in each 5-minute quadrangle are numbered sequentially. For example, HO Bd 120 is the 120th well inventoried in the quadrangle located in the second row from the north, the fourth column from the west, in Howard County.

Surface-water stations are identified by a consecutive downstream 8-digit numbering system. The station farthest upstream is assigned the lowest identification number, and each successive station in the downstream direction is assigned a progressively higher number. Stations on a tributary that enters upstream from a mainstream station are assigned numbers lower than the mainstream station. For example, 01590800 identifies the Mullinix station as the farthest upstream station on the Patuxent River. The numbers 01591200 to 01591500 are assigned to stations on Cattail Creek, a tributary that enters the Patuxent River downstream of the Mullinix station, but is upstream of 01591610, the Patuxent River below Brighton Dam near Brighton.

ACKNOWLEDGMENTS

This report is the culmination of a study conducted in cooperation with the U.S. Geological Survey and the Howard County Department of Public Works. Appreciation is extended to the many property owners who permitted hydrologic measurements and collection of water samples from their wells and springs. Michael Tompkins, Maryland Geological Survey, assisted in much of the data collection and processing.

GROUND-WATER RESOURCES

Ground water plays a vital role in the environment and in meeting human needs: ground-water discharge sustains streamflow during dry periods, and springs and wells supply ground water to homes and businesses. Ground water is more important as a source of drinking water in the western part of Howard County than in the eastern part, where water is drawn from surface-water sources for most of the population. The crystalline-rock aquifers of the Piedmont are therefore more important for the supply of ground water in

Howard County than are the Coastal Plain sediments; less than two percent of the wells inventoried in the county were completed in Coastal Plain aquifers.

GROUND-WATER-SITE AND WELL DATA-COLLECTION METHODS

Information on 2,484 wells and 29 springs in Howard County was compiled from inventories conducted for this study as well as for previous studies (Dine and others, 1992). The information includes well location, depth, casing length, water level, yield, drawdown, topographic setting, and geologic unit and was obtained from site visits and well driller's reports. Water levels were measured monthly at 53 wells using a steel tape. Eleven of the wells were equipped with analog water-level recorders for up to 4 years. Discharge and temperature were measured at three springs.

HYDROGEOLOGY AND GROUND-WATER FLOW

In Howard County, ground water occurs in intergranular pore spaces in unconsolidated sediments, and fractures in the crystalline rocks of the Piedmont (fig. 4). Fractures may be classified as joints (negligible displacement) or faults (large displacements). Discontinuous layers of low permeability clay in the Patuxent Formation form confining beds in some areas of the Coastal Plain, forming artesian aquifers. In other areas the aquifer is unconfined. The water level in a well that is constructed in an unconfined aquifer corresponds to the water table, if there is no significant vertical flow in the vicinity of the well.

Ground-water-flow divides generally coincide with surface-water drainage divides in Howard County. Precipitation that infiltrates the soil and percolates downward until it reaches the saturated zone recharges the aquifer. Ground water flows from areas of high

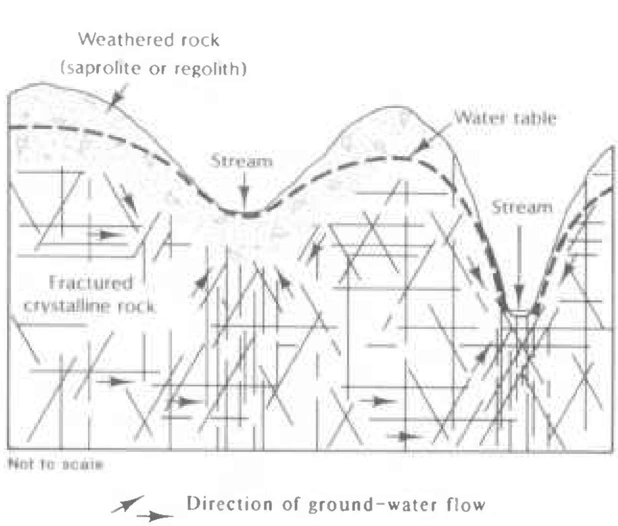


FIGURE 4.—Ground-water occurrence in the Piedmont. The zone of weathered rock may include additional unconsolidated material such as alluvium or colluvium, depending on location (adapted from Otton and others, 1988, fig. 6).

hydraulic head (height of the water level) to areas of low hydraulic head and usually discharges to streams through seeps, springs, and through the stream bed. Geological heterogeneities, such as due to fractures and joints, affect the occurrence of ground water and its flow paths in the Piedmont. Flow rates probably range from a few feet per day to a few feet per year (Richardson, 1982, p. 17) but could be greater in fractures where permeability and hydraulic gradients are large. In fractured rock, ground-water yield from a well depends on the number and size of water-bearing fractures and joints intersected by the borehole and the size of the ground-water reservoir. Soil and overburden covering the fractured bedrock makes locating fractures (and therefore the most productive water supplies) a difficult task.

Local topographic relief in the county is less than 100 ft, and total relief is approximately 500 ft. Most ground-water circulation takes place within 400 ft of land surface. Water flowing in deep (300 to 400 ft) fractures in the crystalline-rock aquifers could be part of a regional system in which ground water very slowly flows to the east-southeast. Deep fractures are much less common than are shallow fractures, however, so this sort of deep circulation, if it occurs, must consist of very circuitous paths.

Water-Table and Water-Level Fluctuations

Water-level data are published in Dine and others (1992). Water-level data from more than 400 of the inventoried wells and locations of 27 springs and the surface-water drainage system were used to construct a water-table-altitude map (plate 2). Water levels measured during either prolonged wet or dry periods, which do not represent average conditions, were excluded. Average water levels were determined from well HO Ce 38, which has 37 years of data (fig. 5); water levels in the range of 33 to 35 ft below land surface at this well are considered average. Dates corresponding to water levels in that range at well HO Ce 38 were noted, and all water levels recorded on those dates for other wells used in the analysis were assumed to represent average conditions and were used to prepare the water-table map.

The water table corresponds with land-surface topography (but with less relief) and, like the land surface of Howard County, has a regional slope toward the east. Depth to the water table ranges from 0 to more than 100 ft below land surface, and is deepest beneath hilltops and shallowest beneath valleys. Ground-water flow paths are directed toward decreasing head, but may not be perpendicular to the water-table contours (equipotentials) in some areas owing to the orientation of fractures and other aquifer heterogeneities.

Precipitation recharges ground water, thereby raising the water table. Although shallower wells and wells hydraulically connected to the land surface can be affected by individual rainfalls, ground-water levels generally respond only slightly, if at all, to individual precipitation events. Long-term variations in ground-water levels commonly are related to long-term variations in precipitation (fig. 5): higher levels occur during years of greater annual precipitation (1971–73 in the figure) and lower levels occur during years of less annual precipitation (1980–82 in the figure).

Water levels fluctuate in response to seasonal effects (fig. 6), declining during periods of evapotranspiration (June through September), and rising when little water is lost through evapotranspiration. The amplitude of seasonal water-level fluctuations is greatest in HO Bb 26 and least in HO Ce 38. Differences in response to the same seasonal conditions are caused by differences in local characteristics such as lithology, fracture location, or saprolite thickness.

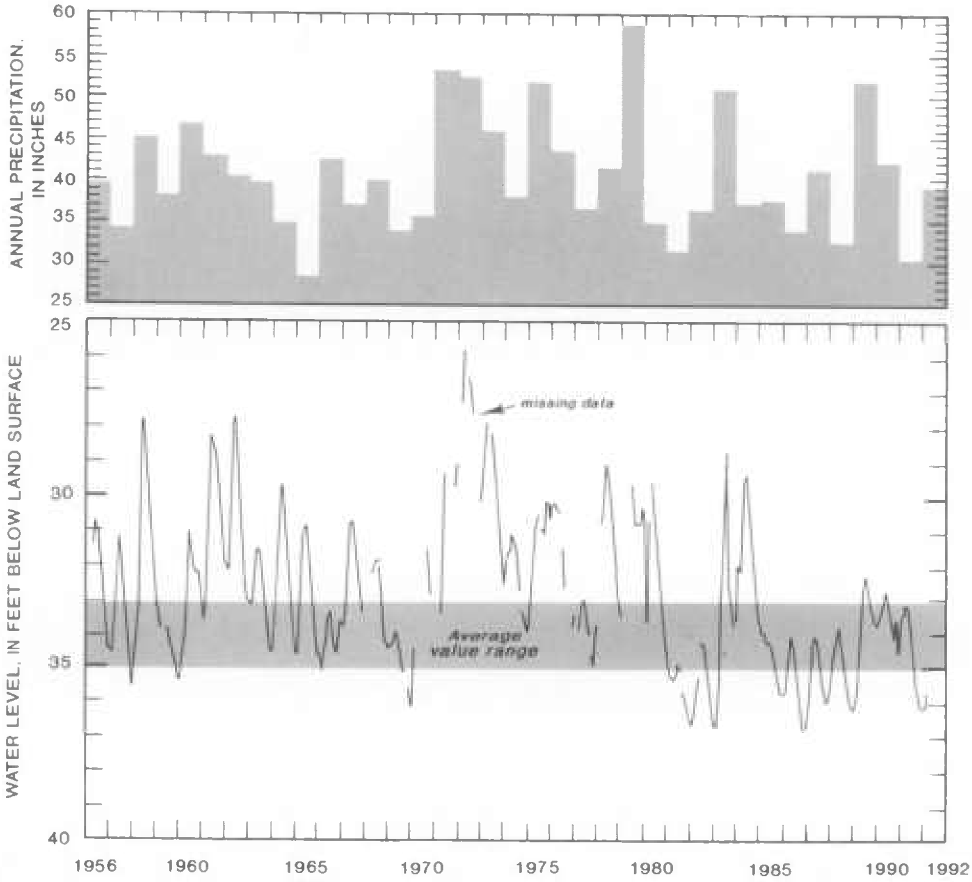


FIGURE 5.—How dates of typical water-level conditions were selected. The shaded area between 33 and 35 feet represents average conditions for well HO Ce 38. Water levels at other sites are assumed to be average if the dates they were measured correspond to dates that water levels at well HO Ce 38 were within the shaded region. Annual precipitation is shown for Baltimore–Washington International Airport (U.S. Weather Bureau, 1956–69; U.S. National Oceanic and Atmospheric Administration, 1970–92).

Spring Discharge and Temperature

Variations in spring flow and temperature (fig. 7) can provide some information about the ground-water flow system. Discharge increases seasonally as a result of recharge from about December to June, and decreases because of evapotranspiration during the rest of the year. Temperature fluctuations are related to depth of the water source as well as to seasonal variations in atmospheric temperature. The range of temperature fluctuations in springs in the Piedmont is inversely proportional to the flow depth of the water (Otton and Hilleary, 1985); in other words, water from deep systems generally has longer flow paths and residence times than water from shallow sources. The narrow range of temperatures at spring HO Cd 240 (12 to 14°C) indicates a deeper origin, longer flowpath, and greater residence time of ground water for this spring than for spring HO Bc 176, where the temperature ranges from 7 to 20°C. Water temperatures at spring HO Bc 264 range from 9 to 14°C, intermediate between the other two (fig. 7).

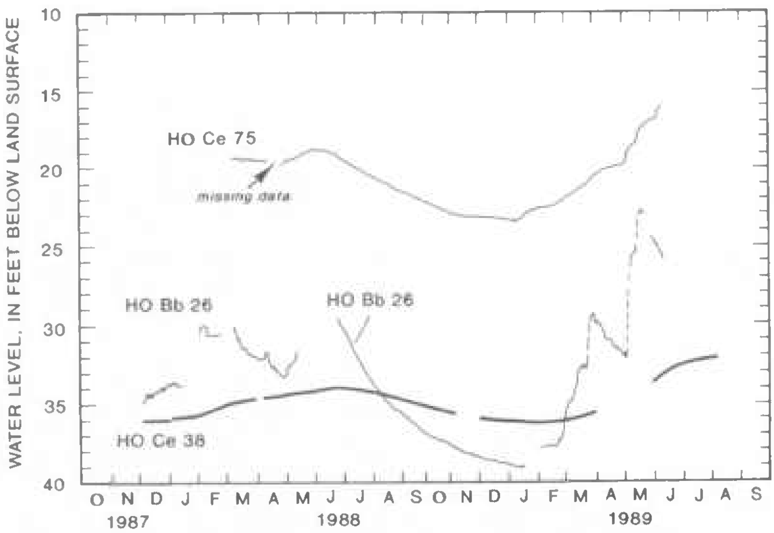


FIGURE 6.—Seasonal water-level fluctuations in three wells. Well HO Ce 75 is located in an upland draw; wells HO Bb 26 and HO Ce 38 are located on hilltops.

Aquifer Characteristics

Understanding the properties of aquifers that determine ground-water flow and storage is important for making best use of the resource and for protecting it. The aquifer characteristics used for hydrogeologic analysis include geometry, porosity, permeability, and storage.

Geometry includes location of the aquifer top, bottom, and lateral boundaries, as well as any other relevant geometric descriptors such as joint orientation or geologic contacts. For most of Howard County, the water table marks the aquifer top. The bottom is more difficult to determine, owing to geologic heterogeneity and the tendency for fractures to become less numerous and less open with depth. Lateral boundaries generally do not coincide with geologic outcrop boundaries (because of the fractured nature of all of the crystalline rocks in the county), but can be assumed on the basis of ground-water head and flow directions, with appropriate allowance for aquifer anisotropy.

Porosity is the amount of space between granules, solid fragments, or rock, expressed as percent of total volume. Aquifer porosity can be intergranular (primary) or result from fracturing or solutional enlargement of joints (secondary). Porosity of the Coastal Plain sediments in the eastern part of Howard County and of the saprolite, alluvium, colluvium, and terrace gravels is primary; porosity of the crystalline rocks of the Piedmont is predominantly secondary. The porosity of weathered crystalline rock is greater than that of unweathered rock. Porosity of the saprolite near the land surface can be high (34 to 60 percent for 34 samples of saprolite from Maryland and Georgia), but decreases with depth (Nutter and Otton, 1969, p. 27).

Permeability is the ability of a material to transmit water, and depends on the interconnection of the voids that provide porosity. High porosity does not necessarily lead to high permeability. Other factors contribute to permeability. *Hydraulic conductivity* (K) is the term used when fluid viscosity is included as a factor, and is reported in units of

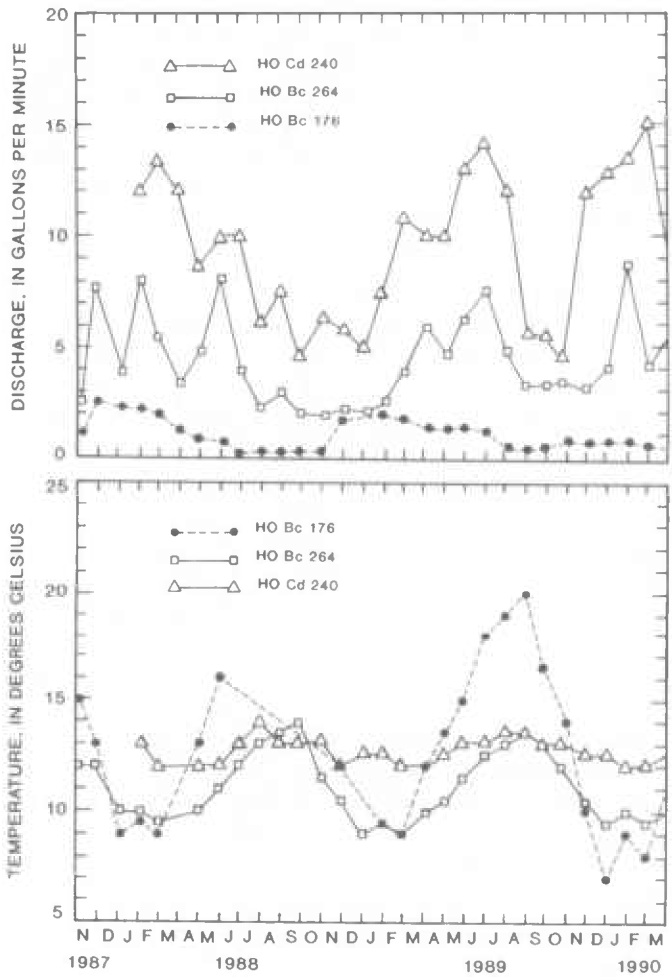


FIGURE 7.—Seasonal variations in discharge and water temperature of springs HO Bc 176, HO Bc 264, and HO Cd 240.

length/time. *Transmissivity* (T) equals hydraulic conductivity multiplied by saturated thickness, and has the units length^2/time. Transmissivity of an unconfined aquifer changes as the water table (and therefore aquifer thickness) falls and rises.

Storage coefficient (S) is the volume of water a porous medium will take in or release from storage per unit surface area per unit change in head (Fetter, 1980, p. 105), and is dimensionless. Storage coefficients generally are larger for unconfined aquifers (commonly 0.02 to 0.3) than for confined aquifers (typically 0.005 or less). In unconfined aquifers, the region of water-table fluctuation changes from saturated to unsaturated (or vice versa) conditions as water is stored or released. *Specific yield* (S_y) is the ratio of the volume of water that can be drained by gravity from the saturated medium to the total saturated volume, assuming complete drainage.

Hydraulic properties of aquifers are commonly estimated by field tests, in which water levels are measured while a well is pumped. Few aquifer tests have been conducted in the crystalline rocks of Howard County. Duigon (1992, p. 10) compiled values of T and S from pumping tests conducted in crystalline rocks in Maryland, including some of the geologic units that are found in Howard County. T.H. Slaughter (Maryland Geological Survey, written commun., 1963) and Otton (1955, p. 17) give results of two tests performed near Columbia and Simpsonville (fig. 1). All wells were drilled into the Guilford Granite (plate 1). Aquifer transmissivity at well HO Ce 42, near Columbia, was estimated to be 67 ft^2/d. Transmissivities at three wells near Simpsonville were calculated to be 348 ft^2/d for well HO Ce 39, 1,163 ft^2/d for well HO Ce 22, and 682 ft^2/d for well HO De 16.

A 28-hour aquifer test was conducted in central Howard County (Hydro-Terra, Inc., 1988). A well was pumped at increasing rates of 5.0, 7.5, 10.0, and 15.0 gal/min while simultaneously observing water levels in the pumped well and in two wells approximately 300 to 500 ft from the pumped well. The pumped well was completed in the Baltimore Gneiss, and the observation wells were both completed in the Oella Formation. Approximately 16,000 gal of water were pumped, but no drawdown was observed in either observation well. Water levels were only measured for 15 minutes during the recovery (S.N. Hau, Hydro-Terra, Inc., written commun., 1992). Analysis of recovery data for the pumped well indicated a transmissivity of 38 ft^2/d.

An aquifer test was conducted at two wells in the Loch Raven Formation. Well HO Cc 38 was pumped for 2 hours at a rate of 6 gal/min while water levels were measured in well HO Cc 37, 70 ft away. Transmissivity and storage coefficient were estimated using the Jacob semi-logarithmic method (Cooper and Jacob, 1946). Recovery data were analyzed using the residual drawdown method (Driscoll, 1986). Transmissivity was estimated as 78 ft^2/d from the pumping data, and as 30 ft^2/d from the recovery data. The storage coefficient was estimated as 0.001 and 0.0004 from the pumping and recovery data, respectively.

At another site, in the Sykesville Formation, well HO Bc 246 was pumped for 1 hour at a rate of 4.5 gal/min. Water levels were measured in well HO Bc 247, at a distance of only 13 ft, but no drawdown was observed in the observation well.

Transmissivity was estimated from specific-capacity data (well yield per foot of drawdown) for 1,760 wells in the Piedmont of Howard County using a computer program (Bradbury and Rothschild, 1985) based on the Theis and others (1963) method of estimating T from specific capacity. The program allows correction for well loss and partial penetration, but assumes a homogeneous, isotropic, confined aquifer; deviation from these assumptions introduces an undetermined error. Aquifer thickness was assumed to be 400 ft and storage coefficient was assumed to be 0.1. A single value for well-loss coefficient was assumed for all wells. These additional assumptions introduce more uncertainty, with the program being most sensitive to aquifer thickness. Effective aquifer thickness depends on fracture distribution, which is highly variable and difficult to quantify. Nevertheless, the spectrum of transmissivity estimates may be useful for providing input to ground-water models and other applications.

Resulting transmissivity ranges from less than 1 to greater than 5,000 ft^2/d. The mean is 313 ft^2/d and the median is 33 ft^2/d. Wells from which high transmissivities were calculated are near wells from which low transmissivities were calculated, evidence of the heterogeneity of the crystalline rocks of the Piedmont. Only one out of the five T estimates from pumping tests discussed above is close to the value estimated from specific capacity (table 5); in the absence of the test data, it is not possible to determine which estimates are more accurate.

The program was also used to estimate transmissivity for 17 Coastal Plain wells completed in the Patuxent Formation. Aquifer thickness was assumed to be equal to well-screen intervals, obtained from well drillers' logs. The aquifer was assumed to be uncon-

TABLE 5
COMPARISON OF TRANSMISSIVITY ESTIMATED FROM PUMPING TESTS AND FROM SPECIFIC-CAPACITY DATA

[Values are in feet squared per day. Transmissivity estimated from specific capacity was calculated using method of Bradbury and Rothschild (1985)]

Well	Transmissivity estimated from	
	Pumping test	Specific-capacity data
HO Cc 38	30 - 78	15
HO Ce 22	1,163	828
HO Ce 39	348	73
HO Ce 42	67	72
HO De 16	682	1,915

fined and the storage coefficient was set to 0.3. Resulting transmissivity estimates range from 165 to 3,453 ft^2/d; the mean is 1,056 ft^2/d, and the median is 700 ft^2/d.

Factors Affecting Well Productivity

Relations between site characteristics (well depth, overburden thickness, topographic setting, and geology) and well productivity (well yield and specific capacity) were evaluated from completion-report data for 2,354 wells drilled in Howard County (fig. 8, table 6). Specific capacity, defined as well yield divided by drawdown, is used here as the measure of well productivity because wells pumped at the same rate could have quite different drawdowns, and greater drawdown indicates lower productivity (and higher costs). The data are predominantly from 6-inch diameter wells; more than 71 percent of the wells supply water for domestic use, approximately 22 percent supply water for institutional use, and just under 3 percent supply water for commercial use. This distribution among water uses indicates that the vast majority of wells were drilled to meet only modest demands, and analyses of well yields may therefore underestimate potential well productivity. Nevertheless, the comparisons made in this section are valid for assessing relative well productivity.

Depth

Dingman and others (1954, p. 27–29) report that for the crystalline rocks of Howard County average well yields for 50-ft increments of well depth tend to increase "considerably" with well depth down to about 350 ft. For wells deeper than 400 ft the average yield

TABLE 6
SPEARMAN'S RANK CORRELATION COEFFICIENTS FOR WELL PRODUCTIVITY AND CONSTRUCTION FACTORS

Spearman's r number significance	Reported yield	Specific capacity	Well depth	Water level	Casing length
Reported yield	—	0.88 1998 0.000	-0.49 2161 0.000	-0.20 1980 0.000	-0.01 1952 0.661
Specific capacity	0.88 1998 0.000	—	-0.60 1955 0.000	-0.24 1804 0.000	-0.01 1800 0.604
Well depth	-0.49 2161 0.000	-0.60 1955 0.000	—	0.28 2041 0.000	0.17 1980 0.000
Water level	-0.20 1980 0.000	-0.24 1804 0.000	0.28 2041 0.000	—	0.16 1962 0.000
Casing length	-0.01 1952 0.661	-0.01 1800 0.604	0.17 1980 0.000	0.16 1962 0.000	—

A NOTE REGARDING STATISTICS: In this report, statistics are used to describe groups of data, to compare variables in different groups, and to relate variation in one variable to variation in one or more other variables. In many cases a *statistic*, such as Spearman's rank correlation coefficient, is computed, and the significance of the value of that statistic is reported. The *statistical significance* used here is the probability that the statistic could have such a magnitude simply due to chance sampling (an indication of the reliability of the statistic). A probability of 0.05 is considered herein as significant; if the reported significance is greater than 0.05, the magnitude of the correlation coefficient, Kruskal-Wallis H, or other statistic could be due to chance and the null hypothesis should not be rejected. The null hypothesis is the proposition being tested, generally a statement to the effect that variables do not vary dependently, treatments (groups) are not different, and so on.

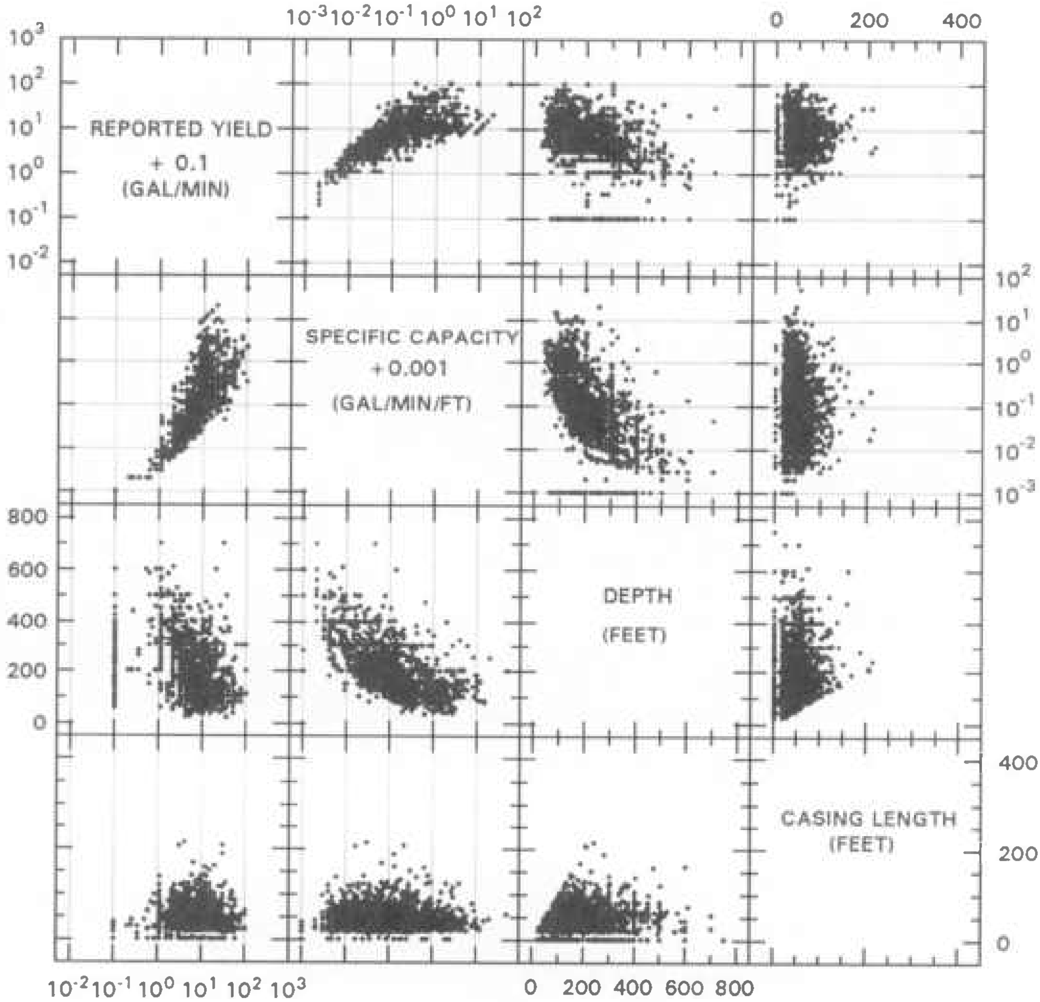


FIGURE 8.—Scatterplot matrix of well productivity and construction factors. Reported yield and specific capacity were coded by adding 0.1 and 0.001 to data to allow plotting on logarithmic scale. Casing length provides an approximation of overburden thickness.

is less than the average yields of wells 250 to 400 ft deep. This conclusion may be based, in part, on the small number of wells deeper than 149 ft (82 out of the total of 397 wells in their analysis). Results of the present study indicate that deeper wells tend to be less productive; the average yield of wells grouped by 50-ft intervals peaks at 14 gal/min for the interval 100–149 ft and decreases for deeper intervals (fig. 9). For the present study, 1,438 out of a total of 2,212 wells in the analysis are deeper than 149 ft. The two depth intervals for which both studies report similar average yields are those for which the earlier study had the most samples (173 and 113 wells for the intervals 50–99 and 100–149 ft). The difference in yield-depth relations between this study and the earlier study stems from the small sample size of the latter, which allowed a few large values to affect the average yields used to represent depth intervals. The inverse correlation (Spearman's r; Statsoft,

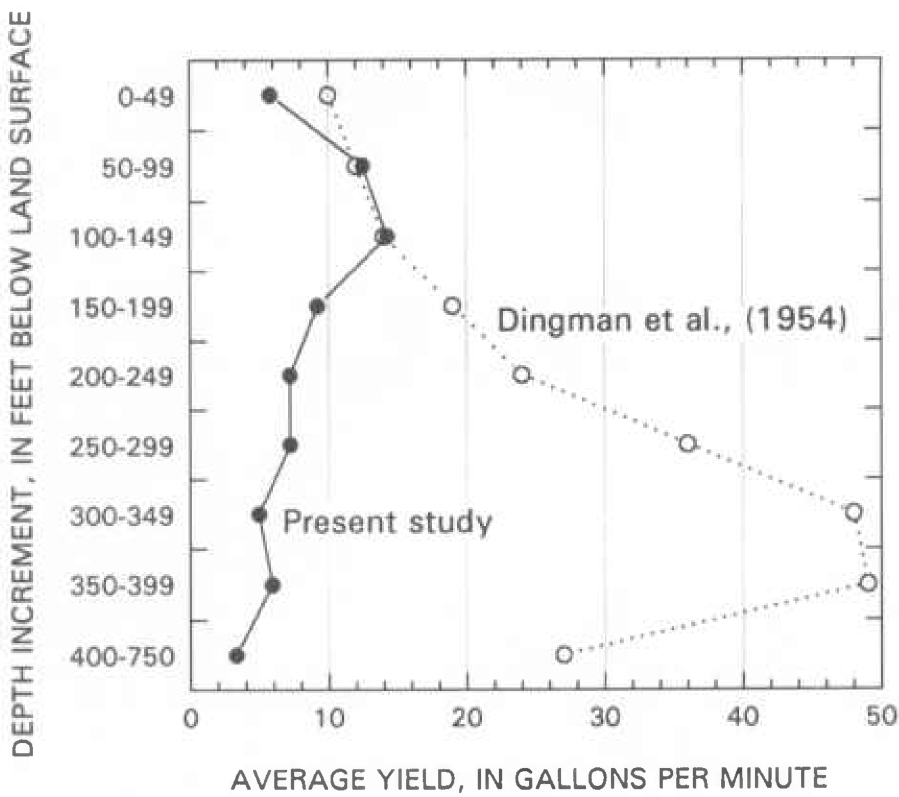


FIGURE 9.—Average well yields for fifty-foot increments of well depth. The average yield of wells grouped into 50-ft incremental depth categories is plotted. There were 2,212 wells analyzed in the present study, compared to 397 wells analyzed by Dingman and others (1954, p. 27). Compare this figure with the reported yield versus depth scatterplot in figure 8, in which individual data pairs are plotted.

1991) with well depth is slightly stronger for specific capacity than for reported yield (fig. 8; table 6), which is to be expected because well depth limits the available drawdown. Generally speaking, fractures tend to be fewer in number and less open at greater depths. Wells that initially have low yields at shallow depths are commonly drilled deeper in an attempt to obtain sufficient water; the tendency of wells deeper than 400 ft to have low yields is evidence that water-bearing fractures are uncommon below this depth, at least in areas where the upper few hundred feet produce little.

To investigate the possibility that the well-yield–well-depth relationship might vary according to topographic setting, the data were segregated by topographic setting and the correlations were recalculated for each setting. Well yield is moderately correlated with depth in all topographic settings except for hillsides, where the correlation is low, showing a tendency to decrease with increasing depth (table 7). The analysis was repeated, this time with the data segregated by geologic unit, to determine if this factor affected the productivity-depth relationship (table 8). The correlations are low to moderate for most groups; some of these correlations are not significant owing to small sample size.

TABLE 7
SPEARMAN'S RANK CORRELATION COEFFICIENTS FOR SPECIFIC CAPACITY AND DEPTH, WELLS GROUPED BY TOPOGRAPHIC SETTING

	Topographic setting				
	Hilltop	Hillside	Valley	Upland draw	Flat
Spearman's r	-0.65	-0.54	-0.67	-0.69	-0.67
Number of wells	905	883	41	44	84
Significance (p)	0.000	0.000	0.000	0.000	0.000

Overburden thickness

Overburden in Howard County comprises saprolite (weathered crystalline rock), alluvium and colluvium, and Coastal Plain sediments (Patuxent Formation). Overburden thickness in Howard County was mapped by Roen and Froelich (1978). Depth of well casing is a fair approximation of overburden thickness in the Piedmont because casing is generally seated into hard bedrock, sealing off the loose and weathered material above. Complicating factors include State well regulations, which specify a minimum casing length of 20 ft, seated at least 2 ft into bedrock; as well as weathered fracture zones at depth that may be cased off. Dingman and others (1954, p. 32) reported " . . . a small but fairly consistent increase in average yield with increased depth of weathering up to about 100 ft . . . " but no relationship is evident from the 1,798 wells analyzed herein (fig. 8, table 6). Correlations were very low for specific capacity and overburden thickness with topographic setting held constant (table 9), and very low to moderate with geologic unit held constant (table 10), except for a high (0.83) correlation for six wells drilled in the Druid Hill Amphibolite Member of the James Run Formation.

Areal variations in overburden permeability and porosity, in addition to thickness, can affect well productivity. A clay-rich saprolite can retard recharge because vertical hydraulic conductivity is low (Richardson, 1982, p. 24). In addition, well-yield and specific-capacity data are generally from short duration (1 to 6 hours) pumping tests; water initially withdrawn from the well is largely derived from rock fractures, rather than from the overburden, so thick overburden might not have a major short-term effect on well productivity. Analysis of long-term well productivity necessitates gathering additional information regarding the well site and the aquifer properties.

Topographic setting

Productivity of wells in the Maryland Piedmont varies with topographic setting (Dingman and others, 1954; Nutter and Otton, 1969; Duigon and Dine, 1987; and Otton and others, 1988). Zones of weakness can develop where fractures and faults are concentrated in the crystalline rocks, and land-surface topography is shaped in part by facilitated erosion along these weak zones. Stream channels commonly develop in areas of concentrated fractures and faults, forming valleys and draws; for this reason fractures frequently are

TABLE 8
SPEARMAN'S RANK CORRELATION COEFFICIENTS FOR SPECIFIC CAPACITY AND DEPTH, WELLS GROUPED BY GEOLOGIC UNIT

	Geologic unit						
	Baltimore Gneiss	Setters Fm.	Cockeys-ville Marble	Loch Raven Raven-Oella Fms. (undiff.)	Loch Raven Fm.	Oella Fm.	Prettyboy Schist
Spearman's r	-0.58	-0.49	0.34	-0.43	-0.50	-0.71	-0.66
Number of wells	277	52	8	471	38	79	85
Significance (p)	0.000	0.000	0.414	0.000	0.001	0.000	0.000

	Geologic unit					
		Morgan Run Fm.		Sykesville Fm.		
	Gillis Gp.	Schist	Ultramafic and mafic rock	Gneiss	Schist Member	Pleasant Grove Fm.
Spearman's r	-0.25	-0.62	-0.40	-0.54	-0.69	-0.35
Number of wells	105	269	33	280	38	18
Significance (p)	0.012	0.000	0.023	0.000	0.000	0.157

	Geologic unit					
		James Run Fm.				
	Baltimore Complex	Druid Hill Amphibolite Member	Relay Gneiss	Ellicott City Granite	Guilford Granite	Patuxent Fm.
Spearman's r	-0.62	-0.77	-0.62	-0.50	-0.63	-0.41
Number of wells	114	6	13	3	35	16
Significance (p)	0.000	0.072	0.025	0.667	0.000	0.114

TABLE 9
SPEARMAN'S RANK CORRELATION COEFFICIENTS FOR SPECIFIC CAPACITY AND OVERBURDEN THICKNESS, WELLS GROUPED BY TOPOGRAPHIC SETTING

	Topographic setting				
	Hilltop	Hillside	Valley	Upland draw	Flat
Spearman's r	-0.05	-0.00	0.23	0.24	0.02
Number of wells	854	785	39	38	82
Significance (p)	0.116	0.999	0.159	0.148	0.831

more numerous beneath stream valleys than beneath ridges and hilltops, making valleys and draws generally favorable locations for wells. Most wells are constructed on hilltops and hillsides, however, because these are the desirable locations for homesites in Howard County. The predominance of hilltops and hillsides as well sites holds true for all geologic units except the Cockeysville Marble and the Relay Gneiss Member of the James Run Formation, in which valley well sites outnumber hilltop well sites; and the Patuxent and Pleasant Grove Formations, in which sites in flat settings are almost as common as sites on hilltops or hillsides (table 11).

Most of the wells inventoried in Howard County are located in two topographic settings: 45 percent on hilltops and 45 percent on hillslopes. The remaining 10 percent of the wells are located in flats, valleys, or upland draws. Wells in valleys and flats tend to produce more water than wells on hilltops, hillsides, or in upland draws in Howard County (table 12; fig. 10), although there is much variability in each setting. Despite that variability, results of a nonparametric analog of analysis of variance (the Kruskal-Wallis test) permit the conclusion that all of the variables summarized in table 12 are affected differentially by topographic setting. The median specific capacity for wells in valleys is 0.154 (gal/min)/ft, compared to 0.057 (gal/min)/ft for wells on hilltops. The median specific capacity of 46 wells constructed in upland draws is 0.074 (gal/min)/ft. This middling productivity is not what one would expect, based on the references cited in the previous paragraph; no adequate explanation can be inferred from the available data.

Geologic unit

Well-construction characteristics and productivity in the various geologic units of Howard County are highly variable (table 13; fig. 11); median specific capacity ranges over approximately two orders of magnitude. All five variables included in table 13 show statistically significant effects due to geologic unit, as determined from the Kruskal-Wallis test. The four highest median specific capacities are from wells in the Patuxent and Pleasant Grove Formations, Cockeysville Marble, and the Sykesville Formation and Relay Gneiss Member of the James Run Formation (the last two are tied). The four lowest median specific capacities are from wells in the Gillis Group, the Druid Hill Amphibolite

(Text continues on p. 33.)

TABLE 10
SPEARMAN'S RANK CORRELATION COEFFICIENTS FOR SPECIFIC CAPACITY AND OVERBURDEN THICKNESS, WELLS GROUPED BY GEOLOGIC UNIT

	Geologic unit					
	Baltimore Gneiss	Setters Fm.	Cockeysville Marble	Loch Raven-Oella Fms. (undiff.)	Loch Raven Fm.	Oella Fm.
Spearman's r	-0.02	0.00	-0.44	0.07	0.05	-0.10
Number of wells	259	50	8	387	36	77
Significance (p)	0.793	0.980	0.272	0.198	0.766	0.393

	Geologic unit					
			Morgan Run Fm.		Sykesville Fm.	
	Prettyboy Schist	Gillis Gp.	Schist	Ultramafic and mafic rock	Gneiss	Schist Member
Spearman's r	-0.17	0.09	-0.06	0.14	-0.02	0.06
Number of wells	83	86	263	34	273	38
Significance (p)	0.117	0.423	0.294	0.434	0.758	0.729

	Geologic unit					
			James Run Fm.			
	Pleasant Grove Fm.	Baltimore Complex	Druid Hill Amphibolite Member	Relay Gneiss	Guilford Granite	Patuxent Fm.
Spearman's r	-0.12	-0.06	0.83	-0.01	0.09	-0.23
Number of wells	19	108	6	13	34	16
Significance (p)	0.638	0.531	0.042	0.964	0.628	0.402

TABLE 11
CROSSTABULATION OF INVENTORIED WELLS,
TOPOGRAPHIC SETTING BY GEOLOGIC UNIT

[Numbers of wells in each geologic unit, topographic setting, and combination thereof]

		Topographic setting					
		Hilltop	Hillside	Valley	Flat	Upland draw	Other
Geologic unit	2354	1057	1069	61	113	52	2
Saprolite	2	0	1	0	1	0	0
Patuxent Formation	28	8	9	3	7	1	0
Pegmatite	1	1	0	0	0	0	0
Guilford Granite	48	24	17	1	5	1	0
Ellicott City Granite	5	3	1	1	0	0	0
Relay Gneiss Member	26	4	12	9	1	0	0
Druid Hill Amphibolite Member	10	3	7	0	0	0	0
Baltimore Complex	164	76	69	3	14	2	0
Pleasant Grove Formation	34	12	12	0	10	0	0
Sykesville Formation (gneiss)	337	158	145	7	21	6	0
Sykesville Formation (Schist Member)	43	18	23	0	0	2	0
Morgan Run Formation	329	167	143	2	14	2	1
Ultramafic and mafic rocks	37	22	14	0	1	0	0
Gillis Group	128	59	59	5	0	5	0
Prettyboy Schist	98	48	44	0	5	1	0
Oella Formation	107	48	51	3	2	2	1
Loch Raven Formation	42	14	24	0	4	0	0
Loch Raven-Oella Formations (undiff.)	525	217	274	7	9	18	0
Cockeysville Marble	11	1	4	4	2	0	0
Setters Formation	61	25	33	3	0	0	0
Baltimore Gneiss	309	144	125	12	16	12	0
Not assigned	9	5	2	1	1	0	0

TABLE 12
SUMMARY STATISTICS ON WELL CONSTRUCTION AND PRODUCTIVITY FOR TOPOGRAPHIC SETTINGS

Topographic setting	Depth (feet below land surface)				Depth to water (feet below land surface)				Casing length (feet from land surface)			
	Number	Median	Minimum	Maximum	Number	Median	Minimum	Maximum	Number	Median	Minimum	Maximum
Hilltop	1011	200	24.7	700	978	40	4	245	923	42.1	5	159
Hillside	1019	180	28	750	918	35	.6	240	868	41	4	214
Valley	60	133.8	22	400	48	16	5	75	47	41.1	10	78
Flat	108	145	35.5	600	107	35	4.9	450	98	46.5	8	161
Upland draw	50	200	49	493	43	26	4	64	42	37.5	13	152

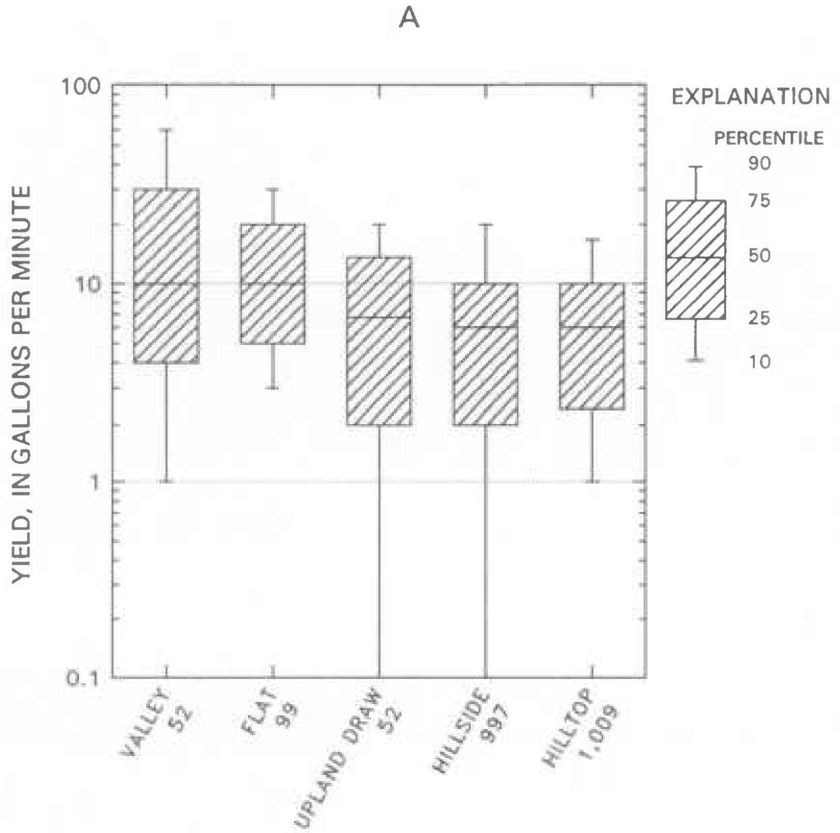


FIGURE 10.—Productivity of wells grouped by topographic setting. The number of wells in each group is shown beneath the group label. For some settings, the 10th percentile is less than the axis minimum. A, reported yield; B, specific capacity.

TABLE 12—CONTINUED

Reported yield (gallons per minute)				Specific capacity (gallons per minute per foot)				Topographic setting
Number	Median	Minimum	Maximum	Number	Median	Minimum	Maximum	
1005	6	0	75	917	0.057	0	15	Hilltop
997	6	0	100	908	.059	0	50	Hillside
52	10	0	100	41	.155	0	3.18	Valley
99	10	0	60	84	.13	0	12	Flat
52	6.75	0	101	46	.074	0	9.18	Upland draw

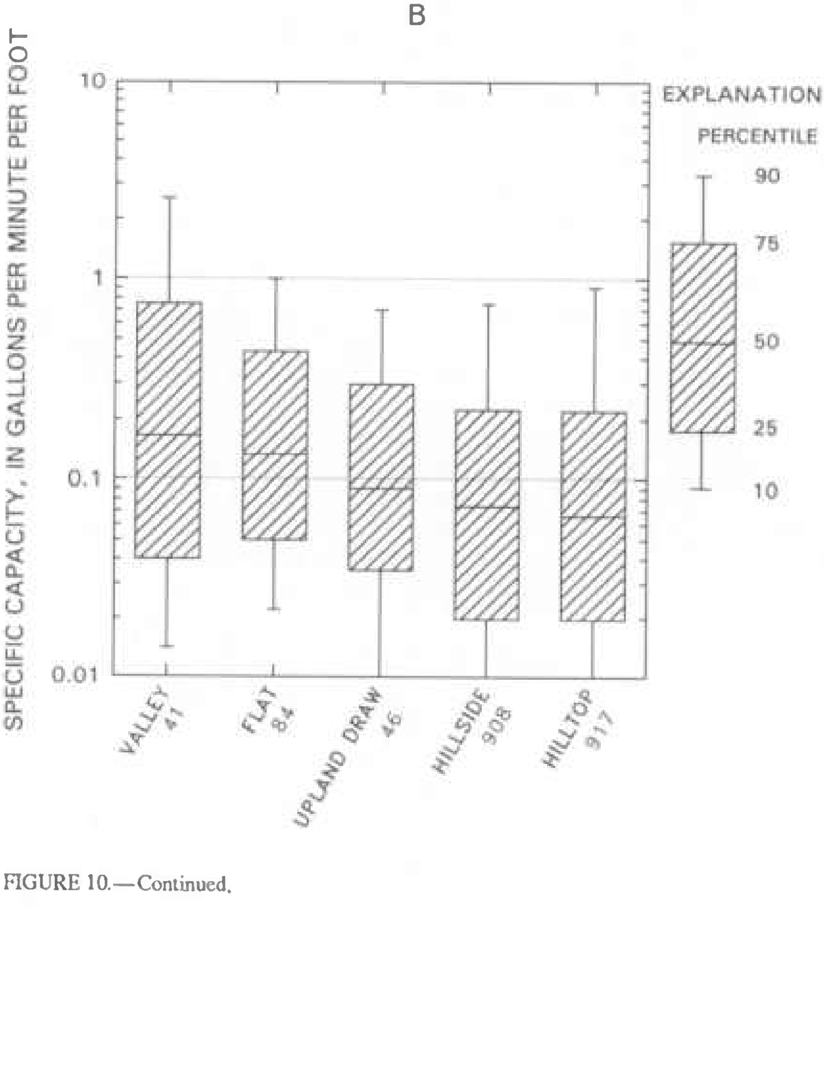


FIGURE 10.—Continued.

TABLE 13
SUMMARY STATISTICS FOR WELL CONSTRUCTION AND PRODUCTIVITY OF THE GEOLOGIC UNITS

Geologic unit	Depth (feet below land surface)				Depth to water (feet below land surface)				Casing length (feet)			
	Number	Median	Minimum	Maximum	Number	Median	Minimum	Maximum	Number	Median	Minimum	Maximum
Saprolite	2	48.5	48	48	1	38.4	38.4	38.4	2	48.5	48	48
Patuxent Fm.	26	80	37	150	25	50	4	100	20	61.5	24.4	145
Pegmatite	1	–	124	124	1	–	60	60	1	–	30	30
Guilford Granite	48	162	36	377	47	25	5	100	45	31	7	207
Ellicott City Granite	4	225	26	325	5	30	6.6	85	4	26.5	21	40
Relay Gneiss Member	26	110.5	58	800	19	21.7	.8	450	17	60	11	166
Druid Hill Amphibolite Member	10	203.5	38	580	8	45	10	65	8	40.5	18	58
Baltimore Complex	159	162	47	750	144	31.1	4	139	131	44	5	141
Pleasant Grove Fm.	28	115	50	240	33	30	6.1	50	24	35.5	18	79
Sykesville Fm. (gneiss)	329	145	24.7	700	322	36	4	187	309	38	14.5	123
Sykesville Fm. (Schist Member)	43	175	82	400	42	40	4	84	42	38.5	8	88
Morgan Run Fm.	285	170	50	500	312	40	.6	215	278	48	8	128
Ultramafic and mafic rocks	38	200	60	400	38	30	8.4	83.8	35	37	18	88
Gillis Gp.	120	200	60	610	85	45	8	175	82	31	13	87
Prettyboy Schist	82	187.5	33	500	85	40	5	60	88	36.5	18	110
Oella Fm.	105	180	39	500	102	30.5	5.5	65	91	43	14	105
Loch Raven Fm.	42	216	66	453	36	40.6	5	65	38	64	20	103
Loch Raven-Oella Fms. (undiff.)	467	260	22	600	411	40	1	245	402	48	4	166
Cockeysville Marble	11	200	38	400	10	24.7	12.6	90	9	30	12	72
Setters Fm.	80	212.5	85	480	58	40	14	185	58	39	18	214
Baltimore Gneiss	308	200	28	800	296	32	1	100	283	36	11	208

TABLE 13—CONTINUED

Reported yield (gallons per minute)				Specific capacity (gallons per minute per foot)				Geologic unit
Number	Median	Minimum	Maximum	Number	Median	Minimum	Maximum	
0	–	–	–	0	–	–	–	Saprolite
24	12.5	2	101	17	2.0	0.07	9.2	Patuxent Fm.
1	10	10	10	1	.33	.33	.33	Pegmatite
45	9	0	40	35	.08	0	2.1	Guilford Granite
4	3.25	1	5	3	.025	.004	.03	Ellicott City Granite
18	25	1	100	13	.133	.004	2.2	Relay Gneiss Member
10	3.75	1	30	6	.014	.002	.10	Druid Hill Amphibolite Member
146	9	0	100	117	.10	0	10	Baltimore Complex
25	10	2	50	19	.214	.01	9	Pleasant Grove Fm.
318	10	0	100	282	.145	0	20	Sykesville Fm. (gneiss)
42	5.5	1	75	38	.074	.004	3.8	Sykesville Fm. (Schist Member)
291	7	0	80	274	.090	0	8	Morgan Run Fm.
36	8	.5	40	34	.09	.01	2	Ultramafic and mafic rocks
128	2	0	30	114	.013	0	10	Gillis Gp.
91	6	0	60	88	.075	0	5.0	Prettyboy Schist
98	8	0	80	79	.077	0	3.0	Oella Fm.
40	5	0	15	38	.033	0	3.5	Loch Raven Fm.
513	3	0	100	497	.019	0	50	Loch Raven-Oella Fms. (undiff.)
10	8.75	.15	40	8	.23	.001	2	Cockeysville Marble
59	6.7	0	50	53	.052	0	1.4	Setters Fm.
305	8	0	80	278	.085	0	10	Baltimore Gneiss

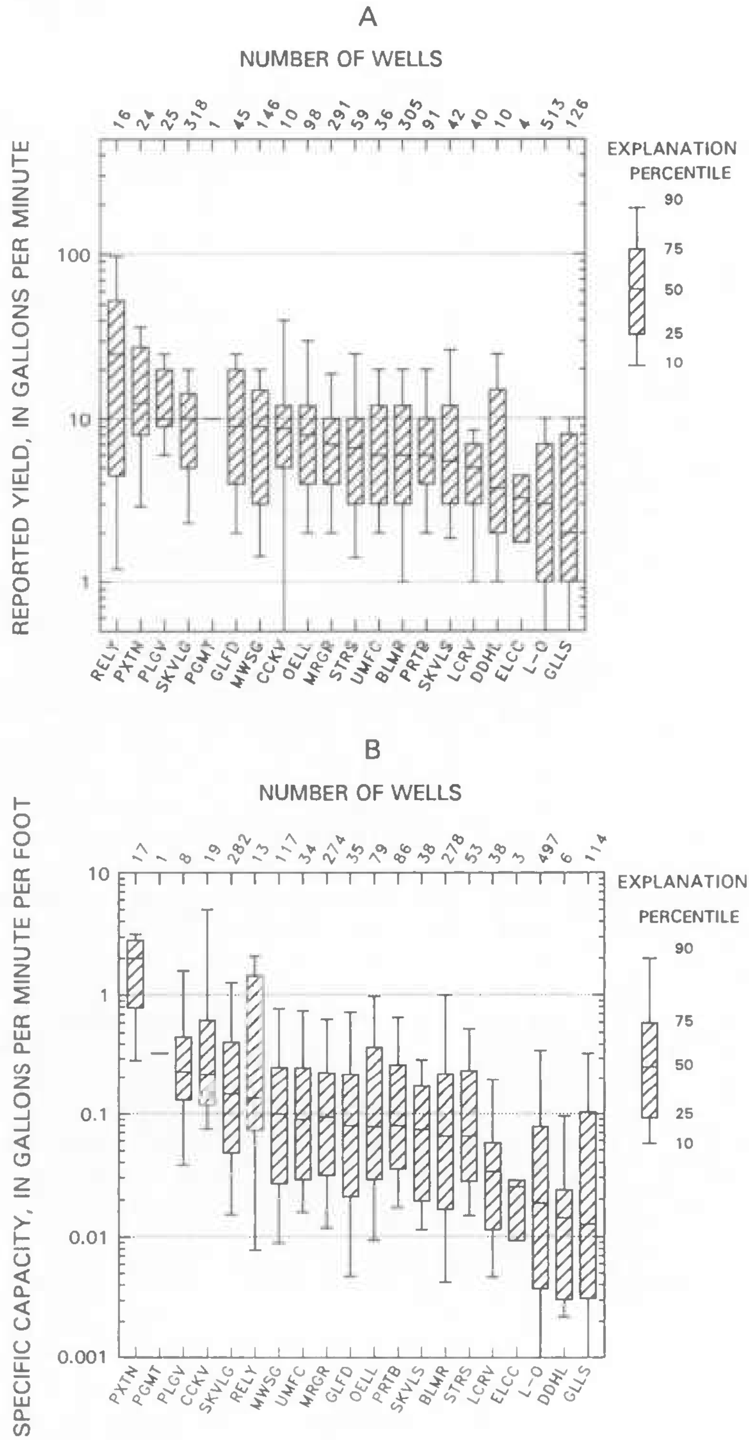


FIGURE 11.—Productivity of wells grouped by geologic unit. For some geologic units, the 10th percentile is less than the axis minimum. A, reported yield; B, specific capacity.

EXPLANATION OF GEOLOGIC CODES

RELY	Relay Gneiss Member of the James Run Formation	UMFC	Ultramafic and mafic rocks of the Morgan Run Formation
PXTN	Patuxent Formation	BLMR	Baltimore Gneiss
PLGV	Pleasant Grove Formation	PRTB	Prettyboy Schist
SKVLG	Sykesville Formation (gneiss)	SKVLS	Sykesville Formation (Schist Member)
PGMT	Pegmatite		
GLFD	Guilford Granite	LCRV	Loch Raven Formation
MWSG	Mount Washington Amphibolite Member of the Baltimore Complex	DDHL	Druid Hill Amphibolite Member of the James Run Formation
		ELCC	Ellicott City Granite
CCKV	Cockeysville Marble	L-O	Loch Raven-Oella Formations (undifferentiated)
OELL	Oella Formation		
MRGR	Morgan Run Formation	GLLS	Gillis Group
STRS	Setters Formation		

FIGURE 11.—Continued.

Member of the James Run Formation, the Loch Raven-Oella Formations (undifferentiated), and the Ellicott City Granite. These results are consistent with Duigon's (in press, Map 4 of each quadrangle atlas) analysis for central and western Howard County. Duigon also noted that in areas where the Oella Formation is mapped as consisting of up to 50 percent pegmatite and (or) granite injections, well yields tend to be higher than in areas of Loch Raven-Oella Formations (undifferentiated) not intruded. The results differ somewhat with previous studies in the Maryland Piedmont (Dingman and others, 1954; Nutter and Otton, 1969; Duigon and Hilleary, 1981a and 1981b; Richardson, 1982; Duigon, 1983; Duigon and Crowley, 1983; Duigon and Dine, 1987) owing to changes in stratigraphic nomenclature and the availability of more well data. About 72 percent of the wells which have been assigned geologic units are in the Loch Raven-Oella, Sykesville, and Morgan Run Formations, and Baltimore Gneiss; these geologic units underlie a correspondingly large proportion of the county.

GROUND-WATER QUALITY

Dine and others (1992) compiled field and laboratory ground-water-quality data. The topographic and geologic distribution of 117 ground-water sampling sites (112 wells and 5 springs) is shown in table 14. Most sites were on hilltops and slopes, and about 68 percent of the sites were in the Oella, Loch Raven, and Sykesville Formations, the Baltimore Gneiss, and the Baltimore Complex.

The fractured-rock aquifers of the Piedmont generally are more susceptible to surface contamination than are the unconsolidated aquifers of the Coastal Plain, owing to their lower adsorption capabilities. Adsorption of contaminants is a function of available surface area; consequently, much less adsorption can take place in rock fractures than in intergranular pore spaces (Fetter, 1980, p. 372). In fractured rocks, contaminants are generally transported along fractures or faults, but determination of the location and orientation of open and interconnected fractures (which is important to predict the movement of the contaminant) is difficult. Where soil and saprolite are thin, rapid recharge and transport of contaminants to the saturated zone can occur before chemical breakdown or adsorption of the contaminants.

TABLE 14
CROSSTABULATION OF GROUND-WATER SAMPLING SITES, TOPOGRAPHIC SETTING BY GEOLOGIC UNIT

[Numbers of sampling sites in each geologic unit, topographic setting, and combination thereof]

		Topographic setting					
		Hilltop	Hillside	Valley	Flat	Upland draw	Other
Geologic unit	117	38	52	7	6	12	2
Patuxent Formation	1	0	0	0	1	0	0
Saprolite	6	0	5	0	0	1	0
Guilford Granite	2	0	1	1	0	0	0
Ellicott City Granite	1	0	0	1	0	0	0
Relay Gneiss Member	4	1	1	1	1	0	0
Druid Hill Amphibolite Member	1	0	1	0	0	0	0
Baltimore Complex	12	6	4	1	0	1	0
Pleasant Grove Formation	2	0	2	0	0	0	0
Sykesville Formation (gneiss)	16	5	7	1	2	1	0
Sykesville Formation (Schist Member)	2	1	1	0	0	0	0
Morgan Run Formation	9	4	4	0	0	0	1
Ultramafic and mafic rocks	1	1	0	0	0	0	0
Gillis Group	6	2	3	1	0	0	0
Prettyboy Schist	2	0	2	0	0	0	0
Oella Formation	12	5	5	0	1	0	1
Loch Raven-Oella Formations (undifferentiated)	23	9	8	1	0	5	0
Cockeysville Marble	1	0	0	0	1	0	0
Setters Formation	2	1	0	0	0	1	0
Baltimore Gneiss	14	3	8	0	0	3	0

Methods of Sample Collection and Analysis of Ground Water

Water samples were collected during December 1988–July 1989 and during November 1989– June 1990. They were collected and preserved in the field according to methods prescribed by the U.S. Geological Survey (U.S. Geological Survey, 1977), and were analyzed by the U.S. Geological Survey Central Laboratory using standard methods described by Fishman and Friedman (1989) and Wershaw and others (1987). Additional analyses were available for samples collected prior to December, 1988 (Dine and others, 1992). Most ground-water samples were collected from domestic wells, and all samples were from untreated sources. For samples collected during 1988–90, field measurements of specific conductance, temperature, and dissolved-oxygen concentrations were made with a flow-through chamber (fig. 12), in order to minimize contact between the sample and the atmosphere and prevent degassing of the sample; flow and pH were measured at the discharge port of the chamber. Field-measured properties were monitored at 10-minute intervals to observe any fluctuations in the values. Samples were collected after three well volumes of water were pumped, or a minimum pumping period of one hour had elapsed, and all field measurements were stabilized.

Samples for analysis of major ions (dissolved), nutrients (total), and trace elements (dissolved) were collected from a spigot on the inflow side of the flow-through chamber (fig. 12); samples for radon analysis were extracted from the inflow hose using a syringe. Samples for analysis of pesticides, volatile organic compounds, total organic carbon, and tritium were collected directly from the spigot or bibcock at which the site was sampled. Samples for bacterial analysis were collected after disinfection of the bibcock with a dilute chlorine-bleach solution. Sites that tested positive on an immunoassay test for pesticides

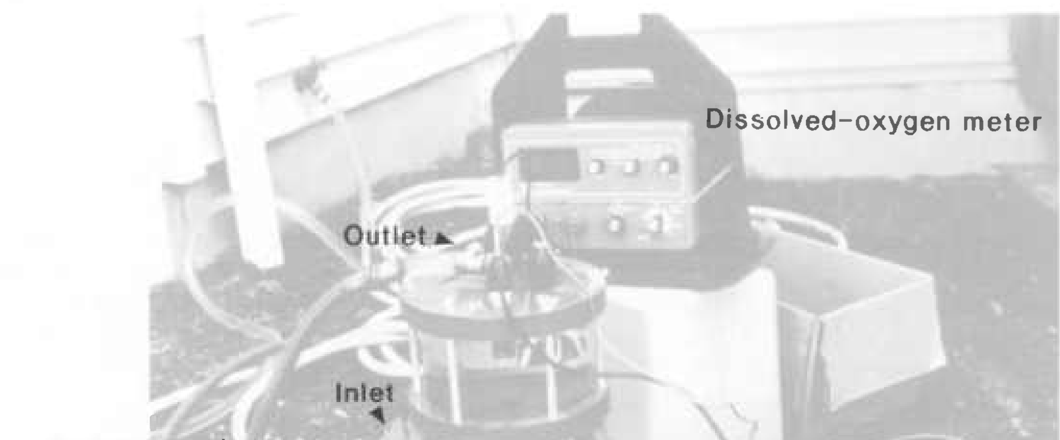


FIGURE 12.—Flow-through chamber and associated field equipment used for well sampling during 1988–90.

and one half of the sites having negative results were sampled for laboratory analysis of pesticides.

Sampling precision and accuracy were ensured by providing the laboratory with duplicate water samples from some of the sites, and by analyzing the distilled water used to rinse the field equipment between samples. Ionic balances of all samples were within 10 percent.

Physical and Chemical Characteristics

Ground-water quality varies considerably throughout Howard County (table 15), owing to the geologic variation of the county and differences in the hydrologic regimes of the separate ground-water flow systems. It is also affected by land use, waste-disposal, and other human activities. The quality of ground water from 19 geologic units is summarized in table 16. Some of these units were sampled only once, whereas others are represented by several samples. Table 16 shows that ground-water quality varies about as much within the geologic units as between all the different units sampled in Howard County.

Under the authority of the Safe Drinking Water Act of 1986, the U.S. Environmental Protection Agency (USEPA) established National Primary Drinking Water Regulations, setting criteria for contaminant limits in public drinking water. Maximum Contaminant Levels (MCL's) were set for contaminants that can cause adverse effects on human health, based on the contaminant level that could result in an acceptable level of risk during a lifetime of exposure. Secondary Maximum Contaminant Levels (SMCL's) were established for contaminants that can adversely affect the odor or appearance of water and result in limited or discontinued use of the water. MCL's are enforceable, health-based standards, whereas SMCL's are non-enforceable, aesthetically based standards. The State of Maryland prescribes these same criteria. MCL's and SMCL's for the inorganic water-quality parameters discussed in this report, as well as common sources or causes of the parameters and their significant effects, are listed in table 17.

Specific conductance and total dissolved solids

Specific conductance is a measure of the ability of a liquid to conduct an electrical current, which is a function of the ionic concentration of the sample (Hem, 1985, p. 66). Pure water has a low specific conductance; as the concentration of dissolved ions in solution increase, specific conductance increases. Specific conductance is easily measured and can be used to estimate total-dissolved-solids concentration based on the linear relationship (fig. 13). Undissociated chemical species that contribute to measured total dissolved solids, but not to specific conductance, produce much of the scatter about the least squares regression line in figure 13. Total dissolved solids in a sample from well HO Bd 403 in the Loch Raven-Oella Formations (undifferentiated) exceeded the USEPA SMCL of 500 mg/L (U.S. Environmental Protection Agency, 1991a).

pH

The negative logarithm of the effective concentration, or activity, of hydrogen ions in solution defines the pH of that solution. The pH of most ground water ranges from 6.0 to

(Text continues on p. 47.)

TABLE 15
SUMMARY STATISTICS OF GROUND-WATER QUALITY

[Concentrations are in milligrams per liter; μS/cm, microsiemens per centimeter; °C, degrees Celsius]

Property or constituent	Minimum	Maximum	Median	Mean	Number of sites	Drinking-water standards[1]	
						MCL[1]	SMCL[2]
Specific conductance (μS/cm at 25°C)	24.3	920	77.75	150.0	116	—	—
pH	4.7	8.5	5.9	6.12	117	—	6.5-8.5
Water temperature (°C)	10.5	18.5	13.0	13.23	109	—	—
Dissolved oxygen	.0	14.6	7.4	6.26	101	—	—
Calcium, dissolved	.04	53	7.9	11.85	116	—	—
Magnesium, dissolved	.50	29	3.38	4.46	115	—	—
Sodium, dissolved	1.13	70	5.7	8.58	116	—	—
Potassium, dissolved	.20	6.4	1.7	1.93	116	—	—
Total alkalinity (as $CaCO_3$)	4	156	23	34.2	114	—	—
Sulfate, dissolved	< .1	59	2.1	7	117	—	250
Chloride, dissolved	.80	250	5.7	13.9	117	—	250
Fluoride, dissolved	< .05	.8	.1	.1	116	4.0	—
Silica, dissolved	4.43	45	16	19.42	116	—	—
Nitrate + nitrite, total (as N)	< .10	13	2.1	2.8	98	10	—
Phosphorus, total	< .01	1.8	.02	.07	89	—	—
Total organic carbon (as C)	.1	15.5	.2	.58	98	—	—

[1] U.S. Environmental Protection Agency, 1991a.

[2] Maximum Contaminant Levels (MCL) are the maximum permissible concentration of a contaminant in water which is delivered to any user of a public water system. MCL's are enforceable and based on effects on human health.

[3] Secondary Maximum Contaminant Levels (SMCL) are non-enforceable limits of constituents that affect water taste or odor, based on aesthetic considerations.

TABLE 16
SUMMARY OF BASIC WATER CHEMISTRY OF THE GEOLOGIC UNITS

[Where multiple samples were obtained at a site, the mean value was used; bracketed statistics reflect uncertainty due to values less than detection limits. µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter]

Geologic unit[1]	Specific conductance (µS/cm at 25°C)					pH					Hardness (mg/L as $CaCO_3$)				
	Number	Minimum	Maximum	Median	Mean	Number	Minimum	Maximum	Median	Mean	Number	Minimum	Maximum	Median	Mean
PTXN	1	61	61	61	61	1	7.3	7.3	7.3	7.3	1	14	14	14	14
SAPR	6	24.3	92.2	46.5	52.6	6	5.1	6.0	5.45	5.48	6	4.8	27	13.2	14.8
GLFD	2	90	124	107	107	2	6.4	7.5	6.95	6.95	2	14	30.5	22.25	22.25
ELCC	1	258	258	258	258	1	6.6	6.6	6.6	6.6	1	93	93	93	93
RELY	4	174	367	249.5	260	4	5.9	8.4	6.45	6.80	4	16	63	49.5	44.5
DDHL	1	255	255	255	255	1	8.5	8.5	8.5	8.5	1	100	100	100	100
BLMC	12	77	410	168.5	187.8	12	5.6	7.5	6.6	6.58	12	22	170	72	80.3
PLGV	2	103	155	129	129	2	5.8	6.7	6.25	6.25	2	31	63	47	47
SKVL	16	33	272	102	125.1	16	4.9	6.9	5.6	5.75	16	7	86	31	35.5
SKVLS	2	31	31.5	31.25	31.25	2	6.1	6.35	6.22	6.22	2	6	9	7.5	7.5
MRGR	9	26	240	89	94.7	9	5.0	6.4	5.8	5.80	9	5	60	28	33.2
UMFC	1	193	193	193	193	1	6.0	6.0	6.0	6.0	1	89	89	89	89
GLLS	6	32	114	74	74.0	6	5.1	5.9	5.33	5.38	6	9.5	43	20	20.8
PRTB	2	64	109	86.5	86.5	2	5.1	5.7	5.4	5.4	2	21	32	26.5	26.5
OELL	12	42	306	94	137.6	12	5.1	7.6	5.95	6.12	12	13	100	31.5	44.3
LO	22	28	920	126.0	180.0	23	4.7	8.36	5.9	6.23	21	0	250	33.3	57.3
CCKV	1	263	263	263	263	1	7.8	7.8	7.8	7.8	1	130	130	130	130
STRS	2	109	179	144	144	2	5.5	5.6	5.55	5.55	2	33	51	42	42
BLMR	14	53	637	198	203.8	14	5.5	7.4	5.9	6.17	14	10	230	59.5	64.4

[1]See explanation of geologic codes at end of table.

TABLE 16—CONTINUED

Geologic unit[1]	Calcium (mg/L)					Magnesium (mg/L)					Sodium (mg/L)				
	Number	Minimum	Maximum	Median	Mean	Number	Minimum	Maximum	Median	Mean	Number	Minimum	Maximum	Median	Mean
PTXN	1	2.8	2.8	2.8	2.8	1	1.6	1.6	1.6	1.6	1	3.0	3.0	3.0	3.0
SAPR	6	1.0	5.53	2.28	2.84	6	.57	3.66	1.70	1.85	6	1.13	3.36	1.93	2.02
GLFD	2	4.1	7.9	6.0	6.0	2	1.0	2.65	1.83	1.83	2	5.45	19	12.23	12.23
ELCC	1	27	27	27	27	1	6.2	6.2	6.2	6.2	1	9.5	9.5	9.5	9.5
RELY	4	3.7	16	11.1	10.5	4	1.6	5.9	5.05	4.40	4	7.7	70	30	34.4
DDHL	0	—	—	—	—	0	—	—	—	—	0	—	—	—	—
BLMC	12	5.1	45	18.5	20.88	12	2.3	14	6.2	6.68	12	3.4	15	5.8	7.25
PLGV	2	6.5	20	13.25	13.25	2	3.2	3.5	3.35	3.35	2	4.4	5.8	5.1	5.1
SKVL	16	1.6	28	6.1	8.34	16	.60	7.15	3.35	3.55	16	2.7	32	5.48	8.48
SKVLS	2	1.6	2.1	1.85	1.85	2	.50	1.0	.75	.75	2	2.15	2.7	2.43	2.43
MRGR	9	.85	14	5.2	7.27	9	.61	7.3	3.2	3.60	9	2.15	11	5.0	5.37
UMFC	1	11	11	11	11	1	15	15	15	15	1	2.3	2.3	2.3	2.3
GLLS	6	1.55	12	3.65	4.61	6	1.35	3.1	2.25	2.26	6	1.5	8.7	3.3	4.32
PRTB	2	5.8	6.7	6.25	6.25	2	1.5	3.7	2.6	2.6	2	3.2	6.0	4.6	4.6
OELL	12	2.6	28	8.15	11.7	12	1.4	7.0	2.9	3.57	12	2.7	18	6.75	8.81
LO	23	.04	52	8.4	13.9	22	.82	29	3.39	5.42	23	2.4	56	5.4	10.2
CCKV	1	45	45	45	45	1	5.3	5.3	5.3	5.3	1	2.0	2.0	2.0	2.0
STRS	2	8.3	13	10.7	10.7	2	3.0	4.4	3.7	3.7	2	7.7	8.6	8.15	8.15
BLMR	14	2.5	53	14.5	15.5	14	.92	23	5.2	6.14	14	4.35	20	6.4	8.99

[1]See explanation of geologic codes at end of table.

TABLE 16—CONTINUED

Geologic unit[1]	Potassium (mg/L)					Total alkalinity (mg/L as $CaCO_3$)					Sulfate (mg/L)				
	Number	Minimum	Maximum	Median	Mean	Number	Minimum	Maximum	Median	Mean	Number	Minimum	Maximum	Median	Mean
PTXN	1	1.4	1.4	1.4	1.4	1	21	21	21	21	1	8.5	8.5	8.5	8.5
SAPR	6	1.0	3.7	1.54	1.97	6	4.0	17.5	7.69	8.72	6	(a)	4.18	(b)	1
GLFD	2	1.2	1.25	1.23	1.23	2	28	52	40	40	2	< .2	(c)	(d)	(e)
ELCC	1	1.4	1.4	1.4	1.4	1	76	76	76	76	1	32	32	32	32
RELY	4	2.5	4.6	3.25	3.40	4	64	156	112.5	111.25	4	7.9	41	14.5	19.5
DDHL	0	—	—	—	—	1	105	105	105	105	1	20	20	20	20
BLMC	12	.30	3.2	2.65	2.13	12	16	130	58	64.4	12	1.1	59	10.1	16.6
PLGV	2	.30	.80	.55	.55	2	10	55	32.5	32.5	2	2.3	3.2	2.75	2.75
SKVL	16	.60	2.4	1.5	1.45	15	4.0	80	12	19.2	16	< .2	21	1	4
SKVLS	2	.20	.50	.35	.35	2	10	15	12.5	12.5	2	.10	.15	.125	.125
MRGR	9	.40	4.6	.60	1.26	9	5.0	39	12	19.9	9	< .2	9.4	< 1	(f)
UMFC	1	1.0	1.0	1.0	1.0	1	50	50	50	50	1	31	31	31	31
GLLS	6	.45	1.0	.80	.758	5	4.0	29	7.0	10.6	6	< 1.0	3.2	< 1.0	(g)
PRTB	2	.60	1.0	.80	.80	2	4.0	16	10	10.0	2	< 1.0	< 1.0	< 1.0	< 1.0
OELL	12	.80	2.9	1.85	1.92	12	11	75	34	32.9	12	< 1.0	51	< 1.0	11
LO	23	.25	6.4	2.43	2.55	23	5.5	133	17	28.9	23	< .2	17	4.0	5
CCKV	1	2.6	2.6	2.6	2.6	1	119	119	119	119	1	17	17	17	17
STRS	2	2.0	2.4	2.2	2.2	2	12	35	23.5	23.5	2	2.0	2.6	2.3	2.3
BLMR	14	1.1	5.4	2.03	2.50	13	10.5	90	30	34.2	14	< .80	32	2.05	8

[1]See explanation of geologic codes at end of table.

(a) 0.23 < minimum < 0.5
(b) 0.50 < median < 0.78
(c) 0.2 < maximum < 1
(d) 0.1 < median < 0.6
(e) 0.1 < mean < 0.6
(f) 1.5 < mean < 2.2
(g) 0.70 < mean < 1.37

TABLE 16—CONTINUED

Geologic unit[1]	Chloride (mg/L)					Fluoride (mg/L)					Nitrate + nitrite (mg/L as N)				
	Number	Minimum	Maximum	Median	Mean	Number	Minimum	Maximum	Median	Mean	Number	Minimum	Maximum	Median	Mean
PTXN	1	1.3	1.3	1.3	1.3	1	0.1	0.1	0.1	0.1	1	< 0.1	< 0.1	< 0.1	<
SAPR	6	1.02	9.55	2.90	4.03	6	(h)	.13	.1	.1	6	(i)	3.26	1.8	1.8
GLFD	2	3.5	5.15	4.33	4.33	2	< .1	.1	(j)	(k)	1	2.5	2.5	2.5	2.5
ELCC	1	5.2	5.2	5.2	5.2	1	< .05	< .05	< .05	< .05	0	—	—	—	—
RELY	4	3.0	7.5	5.8	5.53	4	.2	.8	.4	.45	4	< .1	< .1	< .1	< .1
DDHL	1	5.0	5.0	5.0	5.0	0	—	—	—	—	0	—	—	—	—
BLMC	12	1.0	42	4.2	9.54	12	< .05	.5	.1	(l)	9	< .1	2.8	.8	1.0
PLGV	2	7.8	11	9.4	9.4	2	< .1	.2	(m)	(n)	2	1.2	6.1	3.65	3.65
SKVL	16	1.0	65	7.7	14.6	16	< .05	.1	< .1	(o)	14	.70	8.0	2.9	3.62
SKVLS	2	2.0	2.9	2.45	2.45	2	.1	.1	.1	.1	0	—	—	—	—
MRGR	9	.8	45	4.0	9.11	9	< .1	(p)	< .1	(q)	9	< .1	8	2.6	3.29
UMFC	1	3.4	3.4	3.4	3.4	1	.1	.1	.1	.1	1	1.9	1.9	1.9	1.9
GLLS	6	2.85	11	5.55	6.13	6	< .1	.1	.1	.1	5	1.4	6.6	3.6	4.02
PRTB	2	3.0	14	8.5	8.5	2	.1	.1	.1	.1	2	2.3	4.7	3.5	3.5
OELL	12	1.6	37	5.85	9.65	12	< .1	.4	.1	.1	11	< .1	9.6	1.3	2.7
LO	23	1.0	250	8.2	24.7	23	< .05	.3	.1	.1	17	< .1	13	1	3.2
CCKV	1	3.0	3.0	3.0	3.0	1	.1	.1	.1	.1	0	—	—	—	—
STRS	2	4.4	30	17.2	17.2	2	< .1	< .1	< .1	< .1	2	2.5	5.0	3.75	3.75
BLMR	14	2.1	160	7.65	23.0	14	< .1	.2	.1	.1	12	< .1	7.5	2.9	3.65

[1]See explanation of geologic codes at end of table.

(h) 0.06 < minimum < 0.10
(i) 0.06 < minimum < 0.6
(j) 0.05 < median < 0.1
(k) 0.05 < mean < 0.1
(l) 0.12 < mean < 0.15
(m) 0.10 < median < 0.15
(n) 0.10 < mean < 0.15
(o) 0.03 < mean < 0.09
(p) 0.10 < maximum < 0.15
(q) 0.04 < mean < 0.11

TABLE 16—CONTINUED

Geologic unit[1]	Silica (mg/L)					Total dissolved solids (residue at 180°C, mg/L)					Radon (pCi/L)				
	Number	Minimum	Maximum	Median	Mean	Number	Minimum	Maximum	Median	Mean	Number	Minimum	Maximum	Median	Mean
PTXN	1	11	11	11	11	1	41	41	41	41	1	< 80	< 80	< 80	< 80
SAPR	6	7.38	14.7	10.1	10.6	1	62.7	62.7	62.7	62.7	1	700	700	700	700
GLFD	2	22	28.5	25.25	25.25	2	78.5	86	82.25	82.25	1	3600	3600	3600	3600
ELCC	1	39	39	39	39	1	184	184	184	184	0	—	—	—	—
RELY	4	13	38	28.5	27.0	4	84	226	163	159	3	1600	2700	2500	2267
DDHL	0	—	—	—	—	0	—	—	—	—	0	—	—	—	—
BLMC	12	21	45	32.5	33.5	12	70	294	127	139.9	8	97	40,000	4000	11,125
PLGV	2	12	14	13	13	2	87	96	91.5	91.5	2	1700	1800	1750	1750
SKVL	16	7.9	29	14.5	14.7	16	27	173	70.5	82.8	12	1450	3700	2850	2871
SKVLS	2	9.1	11	10.1	10.1	2	26	26.5	26.3	26.3	0	—	—	—	—
MRGR	9	6.1	27	11	14.3	9	20	186	66	74.4	8	2700	6900	3550	3788
UMFC	1	19	19	19	19	1	116	116	116	116	1	170	170	170	170
GLLS	6	5.9	9.3	7.55	7.68	6	11	82	54.5	82	5	2500	7300	3100	3760
PRTB	2	7.6	11	9.3	9.3	2	41	84	62.5	62.5	2	3400	4100	3750	3750
OELL	12	15	38	25.5	25.1	12	32	212	75.5	99.3	12	1600	23,000	6875	8021
LO	23	4.43	30	15	16.1	17	26	554	101	139.5	16	860	20,000	3000	5516
CCKV	1	15	15	15	15	1	166	166	166	166	0	—	—	—	—
STRS	2	21	28	24.5	24.5	2	79	123	101	101	2	3300	15,000	9150	9150
BLMR	14	14.5	32	27.3	24.9	14	50.5	446	127.5	134.6	10	3500	25,000	9600	11,700

[1]EXPLANATION OF GEOLOGIC CODES

PTXN Patuxent Formation
SAPR Saprolite
GLFD Guilford granite
ELCC Ellicott City Granite
RELY Relay Gneiss Member
DDHL Druid Hill Amphibolite Member
BLMC Baltimore Complex
PLGV Pleasant Grove Formation
SKVL Sykesville Formation (gneiss)
SKVLS Sykesville Formation (Schist Member)
MRGR Morgan Run Formation
UMFC Ultramafic and mafic rocks
GLLS Gillis Group
PRTB Prettyboy Schist
OELL Oella Formation
LO Loch Raven-Oella Formations (undifferentiated)
CCKV Cockeysville Marble
STRS Setters Formation
BLMR Baltimore Gneiss

TABLE 17
SOURCE OR CAUSE AND SIGNIFICANCE OF DISSOLVED MINERAL CONSTITUENTS AND PROPERTIES OF WATER

[Sources: Durfor and Becker, 1964; Brown, Skougstad, and Fishman, 1970; Hem, 1985; U.S. Environmental Protection Agency, 1990, 1991a, 1991b, 1991c. Standards are in mg/L except pH. MCL, Maximum Contaminant Level; MCLG, Maximum Contaminant Level Goal; SMCL, Secondary Maximum Contaminant Level; TT, best available treatment technique to reduce concentration]

Constituent	Source	Significance	Standard
Specific conductance	Dissolved ions.	Varies with concentration of dissolved ions, so can be used as guide to mineral content.	—
pH	Hydrogen ion concentration.	Indicates acidity (pH < 7) or alkalinity (pH > 7) of a solution (pH = 7 is neutral). Corrosiveness generally increases with decreasing pH, but excessively alkaline water can also attack metals.	SMCL=6.5-8.5
Dissolved oxygen	Atmosphere is main source; also produced by photosynthesizing aquatic organisms and consumed by decomposition of organic material.	Required for survival of aquatic animals and for aerobic bacterial activity.	—
Hardness	Mostly due to dissolved calcium and magnesium.	Soap and detergent are required in greater quantities to be effective in hard water.	—
Total alkalinity	Almost all alkalinity in natural waters is produced by dissolved bicarbonate and carbonate.	The capacity to neutralize acid. The degree of alkalinity reflects buffer strength.	—
Calcium, Magnesium	Ubiquitous mineral components, supplied in particularly large amounts by marble.	The cause of most hardness and scale formation in natural waters. Low levels are required for water used for electroplating, tanning, dyeing, and textile manufacturing. Small amounts help prevent corrosion.	—
Sodium, Potassium	Ubiquitous mineral components; also components of sewage and industrial waste. Potassium may also be derived from fertilizers.	Concentrations greater than 50 mg/L of sodium and potassium in the presence of suspended matter causes foaming in boilers, which accelerates scale formation and corrosion. Sodium concentrations greater than 65 mg/L can cause problems in commercial ice manufacture.	—

TABLE 17—CONTINUED

Constituent	Source	Significance	Standard
Sulfate	Sulfide minerals, industrial wastes (including deposition of atmospheric sulfur waste compounds and reaction products).	In the presence of calcium, forms hard scale in steam boilers. In high concentrations, can give water a bitter taste or produce a laxative effect. Some calcium sulfate is beneficial for brewing.	SMCL=250
Chloride	Local high concentrations can result from road deicing; a component of sewage and industrial waste. Minerals are a minor source.	Concentrations exceeding 100 mg/L produce a salty taste. High concentrations increase corrosiveness. Treatment methods are not currently economical for most uses.	SMCL=250
Fluoride	Small amounts may be due to dissolution of minor fluoride minerals. Added to many public supplies for dental benefits.	Aids in the prevention of dental caries, but when in excess of 8.0 mg/L causes mottling and disfiguration of teeth.	MCL=4.0
Silica	Weathering of silicate minerals.	With calcium and magnesium, silica forms a heat-insulating scale. Inhibits deterioration of zeolite-type water softeners and may be added to soft water to inhibit corrosion of iron pipes.	—
Total dissolved solids (residue on evaporation)	Comprises all dissolved species plus some water of crystallization that remains bound in the residue.	Water having concentrations greater than 500 mg/L are undesirable for drinking; other uses vary in levels that are tolerable.	SMCL=500
Nitrate plus nitrite	Fertilizer, sewage, decaying organic matter, nitrogen fixation by soil bacteria, deposition of atmospheric pollutants.	Promotes growth of algae and other organisms leading to eutrophication of surface-water bodies, undesirable odor and taste; concentrations greater than 10 mg/L (as N) can cause methemoglobinemia in infants.	MCL=10 (as N)
Phosphorus	Leached from soil; fertilizer, sewage, decomposing organic matter, and industrial effluents.	Promotes eutrophication.	—
Iron	Weathering of ferromagnesian minerals, pyrite; corrosion of plumbing and equipment in contact with water; industrial wastes.	Stains laundry and porcelain; imparts an objectionable taste; industrial uses vary in tolerance, but generally require less than 0.1 mg/L.	SMCL=0.3

TABLE 17—CONTINUED

Constituent	Source	Significance	Standard
Manganese	Solution of manganese oxide and hydroxide nodules and grain coatings; common component of minerals; can be concentrated by some vegetation and released upon decay.	Water containing more than 0.5 mg/L can form deposits on cooked food, laundry, and plumbing fixtures; fosters growth in reservoirs, filters, and distribution systems; can impart an objectionable taste; industrial uses generally require less than 0.2 mg/L.	SMCL=0.05
Total organic carbon	Decomposition of plant or animal material; industrial effluents, accidental spills or leakages of fuels, oils, cleaning fluids, and other organic compounds.	Can impart color, which is undesirable for potable water. The term includes a broad spectrum of compounds, some of which can have adverse health effects.	—
Arsenic	Pesticides, industrial effluent, fallout from fossil-fuel combustion.	Long-term consumption of water with concentrations of about 0.2 mg/L may lead to poisoning.	MCL=0.05
Barium	Industrial wastes.	Above-average concentrations affect the circulatory system.	MCL=2
Cadmium	Industrial waste; corrosion of alloys; motor oil.	Toxic.	MCL=0.005
Chromium	Minor amounts derived from weathering of chromite associated with serpentinites; industrial wastes, pigments, treated cooling water.	Affects the liver and kidneys.	MCL=0.1
Copper	Corrosion of copper pipes, industrial wastes, brake linings, anti-algal salts.	Objectionable taste, staining of porcelain, causes gastric disturbances at higher doses than nutritional requirements.	MCLG=1.3; MCL=TT; SMCL=1
Lead	Corrosion of plumbing and solder joints; industrial discharges; paints and dyes; automotive leaded fuel; fossil-fuel combustion.	Retards neurologic development in children and causes other adverse effects; probable carcinogen.	MCLG = 0 MCL=TT
Lithium	Minor amounts may be derived from weathering of pegmatites; industrial effluents, batteries, grease, swimming-pool chlorine mixtures.	Potentially toxic to plants.	—

TABLE 17—CONTINUED

Constituent	Source	Significance	Standard
Mercury	Industrial waste, fossil-fuel combustion, fungicides; used in the manufacture of paint.	Affects the central nervous system and kidneys.	MCL=0.002
Strontium	A minor substitution cation in igneous-rock minerals; various industrial uses.	No apparent health effects.	—
Zinc	Corrosion of galvanized steel and brass; pigment, tires, road salt; industrial wastes.	Imparts a noticeable taste.	SMCL=5
Radon	Part of the radioactive decay series of uranium, radon is the daughter product of radium; members of the series are widely dispersed, particularly in granitic rocks.	An alpha emitter, causes cancer.	MCL=300 (proposed); MCLG=0

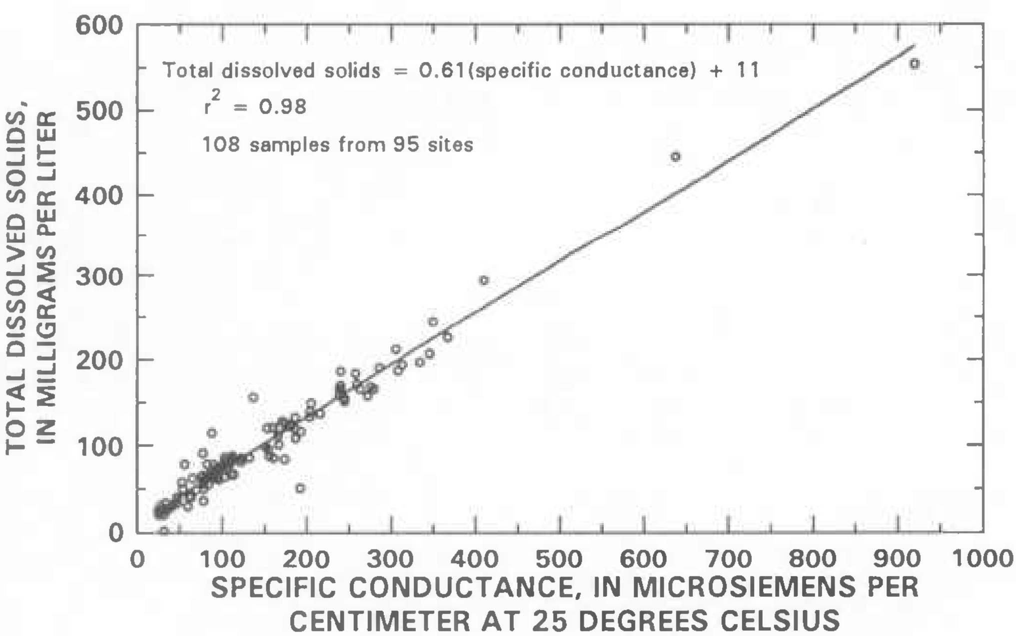


FIGURE 13.—Relation of specific conductance and total dissolved solids content (residue at 180 degrees Celsius) of ground water sampled from 116 sites in Howard County.

8.5 (Hem, 1985). Acidic water, that is, water having pH less than 7, can result in corroded plumbing, stained laundry, and an unpleasant taste. The USEPA (1991a) established a SMCL for pH of 6.5 to 8.5; the pH was lower than the SMCL in 124 of 179 samples in the county (fig. 14).

Moderate to high correlations exist between pH and alkalinity, silica, dissolved oxygen, and nitrate concentrations (fig. 15 and table 18). In the case of alkalinity (fig. 15), the relation is due primarily to the thermodynamics of carbonate equilibrium reactions. The solubility of silica increases slightly with increasing pH, but the increase is insignificant for the range of pH in Howard County; the strength of the correlation may be due to a simultaneous increase in pH (owing to hydrolysis of silicate minerals) and increase in silica concentration (because the same minerals provide a more soluble form of silica than do quartz and clays). Similarly, pH tends to be slightly higher in the eastern part of Howard County (fig. 16), because marble and mafic rocks are more common there than in the western part of the county. Reaction with the ferrous-iron bearing minerals simultaneously depletes dissolved oxygen, thereby accounting for the correlation of pH and dissolved oxygen.

TABLE 18
SPEARMAN'S RANK CORRELATION COEFFICIENTS OF SELECTED GROUND-WATER-QUALITY MEASURES

Spearman's r Number of wells Significance (p)	pH	Alkalinity	Silica	Dissolved oxygen	Nitrate
pH	—	0.78 114 0.000	0.47 116 0.000	-0.58 101 0.000	-0.61 96 0.000
Alkalinity	0.78 114 0.000	—	0.64 113 0.000	-0.62 98 0.000	-0.46 94 0.000
Silica	0.47 116 0.000	0.64 113 0.000	—	-0.36 101 0.000	-0.32 96 0.001
Dissolved oxygen	-0.58 101 0.000	-0.62 98 0.000	-0.36 101 0.000	—	0.42 94 0.000
Nitrate	-0.61 96 0.000	-0.46 94 0.000	-0.32 96 0.001	0.42 94 0.000	—

(Text continues on p. 50.)

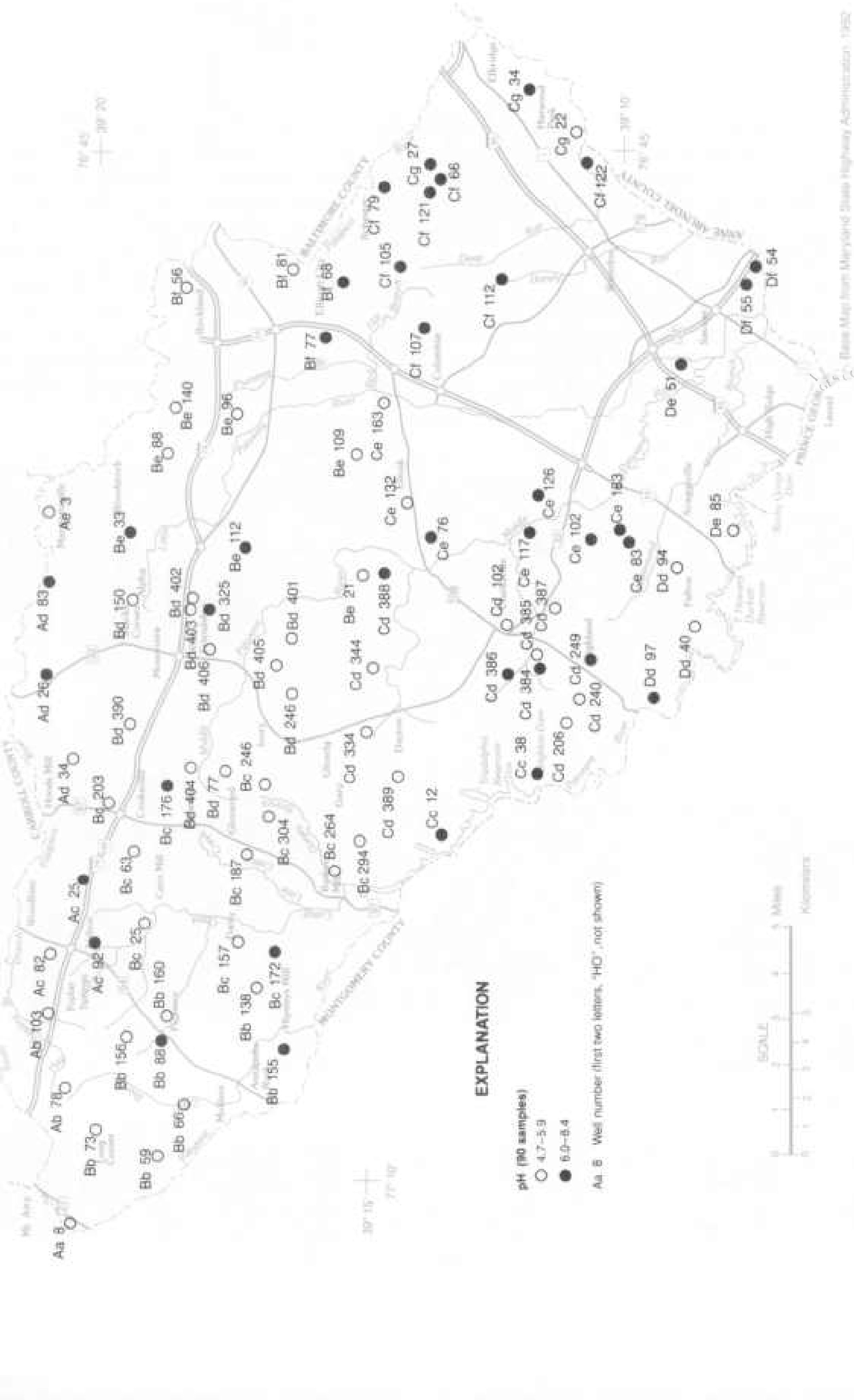


FIGURE 14.—Areal variation of pH in ground water.

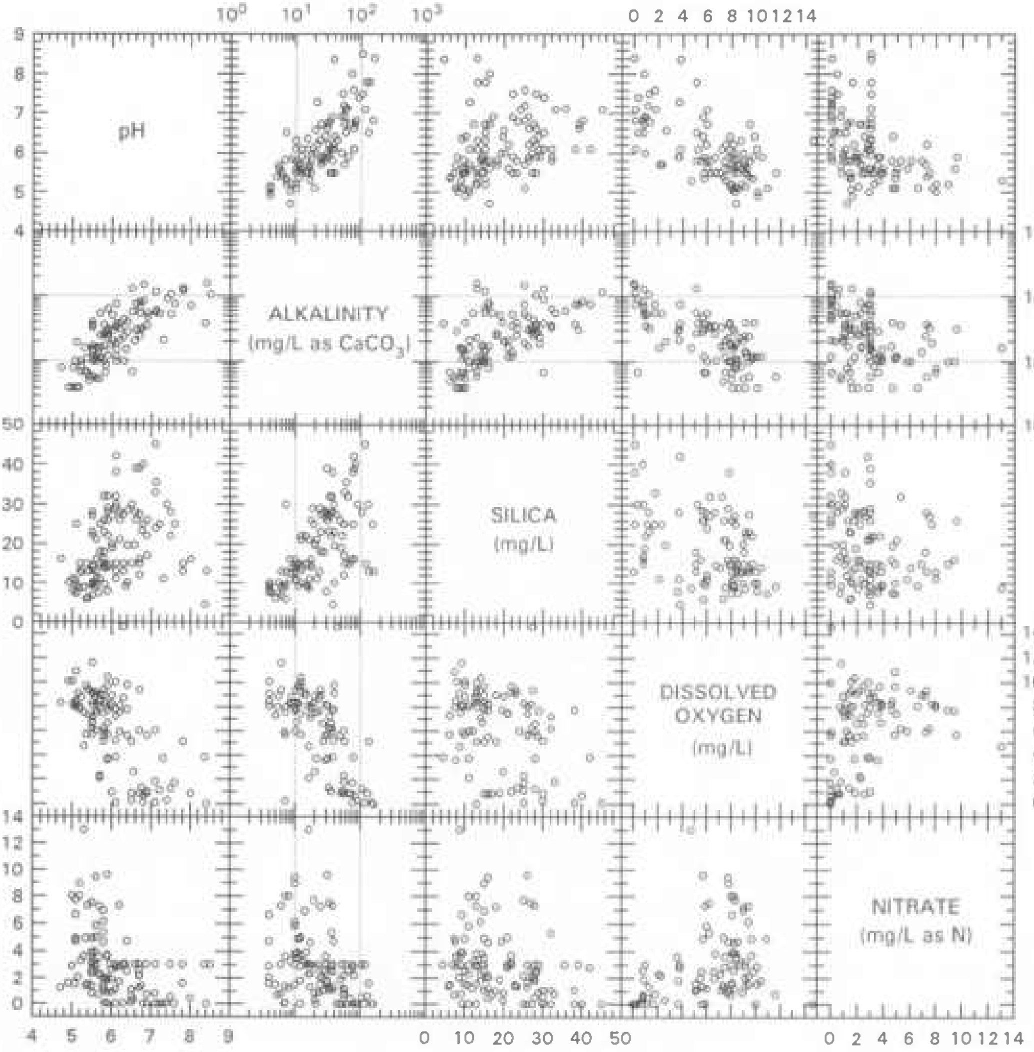


FIGURE 15.—Scatterplot matrix of pH and other selected water-quality indicators in Howard County ground water.

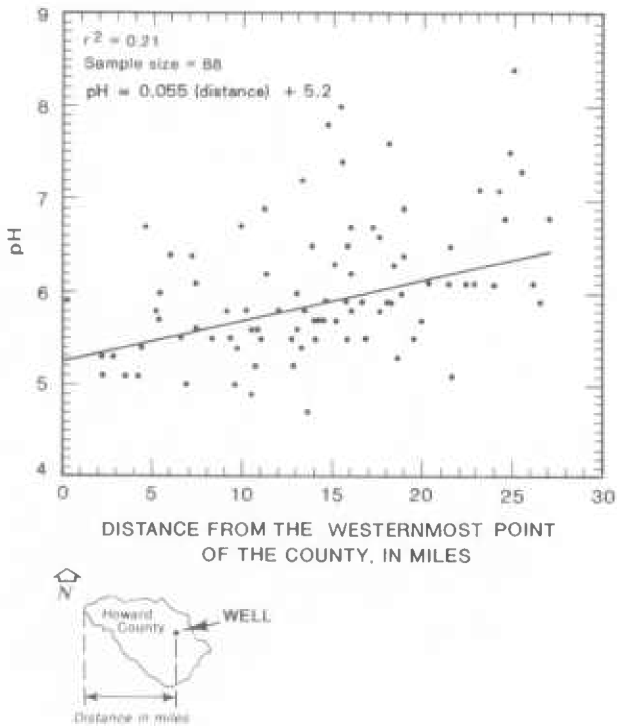


FIGURE 16.—East-west variation of ground-water pH.

Similarly, the correlation of pH and nitrate likely is due to pH increase, and simultaneous nitrate decrease, with depth.

Temperature

Temperatures of shallow ground water are approximately equal to mean annual air temperature, but the temperature of deep ground water is related to the geothermal gradient. Below the zone of seasonal water-level fluctuation, temperature increases with depth at a rate of about 0.3 to 0.5°C per 100 feet in Piedmont rocks (Duigon and Dine, 1987, p. 39). Water temperatures in Howard County ranged from 8.5 to 19.0°C, whereas mean annual air temperature ranges from 11.2 to 13.3°C.

Dissolved oxygen

The primary source of dissolved oxygen in ground water is the atmosphere. Oxygen is consumed by aerobic decomposition of organic material in soil. Additional oxygen is lost by oxidation of such minerals as magnetite in the Prettyboy Schist or the ferromagnesian minerals in the Baltimore Complex, the mafic and ultramafic rocks of the Morgan Run Formation, and other geologic units.

Dissolved oxygen concentrations are generally highest in the central part of the county and lowest in the deeply incised valleys of the Patuxent and Patapsco Rivers (fig. 17). Dissolved oxygen is also low in areas of the eastern part of Howard County where the clay-silt facies of the Patuxent Formation confines the underlying fractured-rock aquifer.

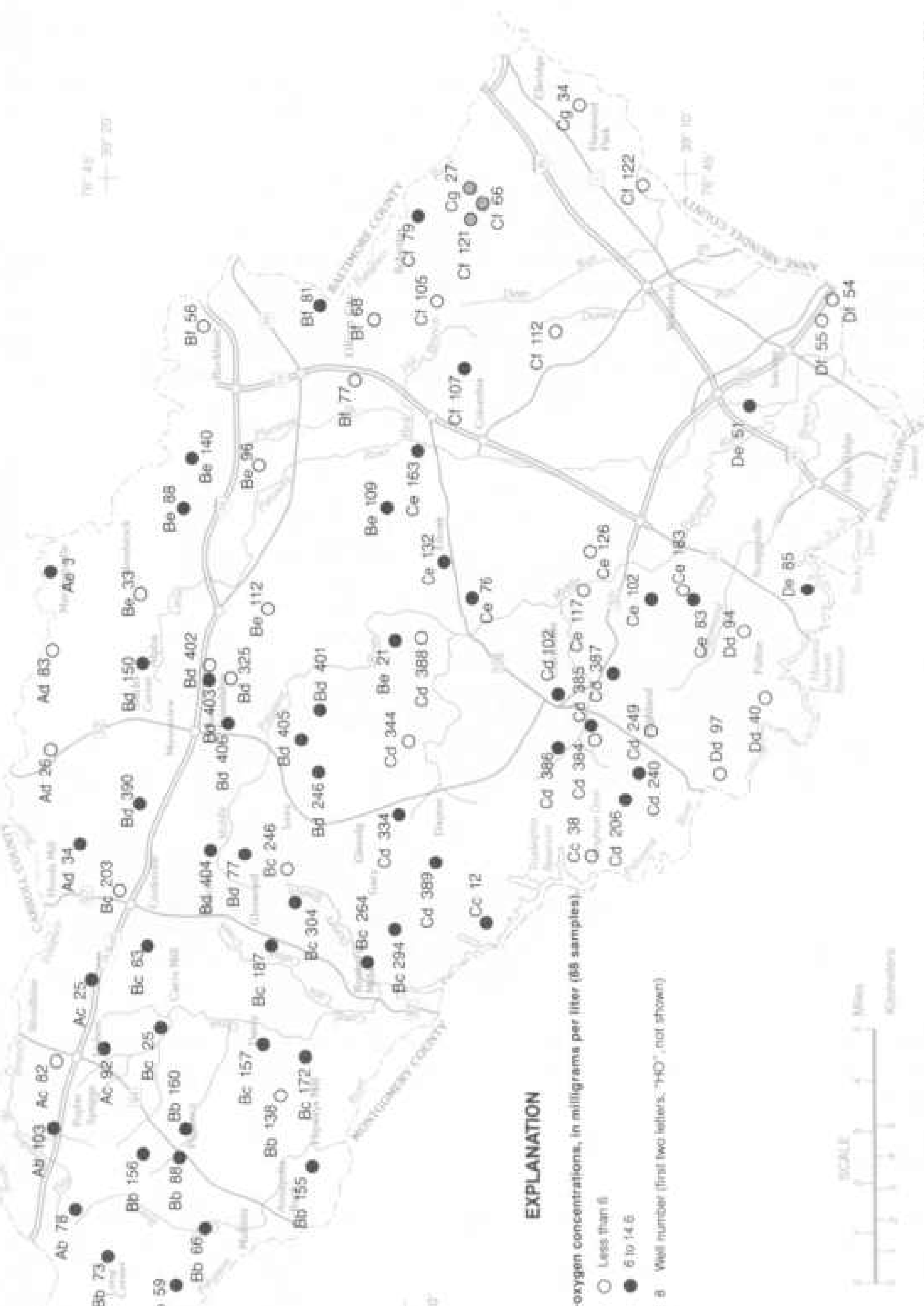


FIGURE 17.—Areal distribution of dissolved oxygen in ground water.

Bacteria

Coliform bacteria are common in the environment and are also found in the intestines of warm-blooded animals. Fecal coliform bacteria are limited to the intestines (and feces) of warm-blooded animals, and, although not harmful themselves, their detection in water indicates the possible presence of other pathogenic organisms transmitted through animal and human wastes. The USEPA (1991a) established an MCL of 0 colonies per 100 ml for fecal coliform bacteria in drinking water.

Twenty-five ground-water samples were analyzed for fecal and total coliform bacteria by the Maryland State Department of Environmental Health laboratory. Fecal coliform bacteria were not detected in any of the samples, but total coliform bacteria were detected in seven samples. Subsequent resampling and testing of water from the seven sites again found total coliform at three sites (Gregory Mellon, Maryland State Department of Environmental Health, oral commun., 1991).

Total organic carbon

Small concentrations of total organic carbon (TOC) in ground water can be derived from soil organic matter, but large concentrations may result from contamination, such as from septage or landfill leachate. Organic carbon is readily adsorbed onto soil or aquifer media and can also form complexes with metal ions (Hem, 1985, p. 151). Ninety-eight sites were sampled for TOC; of these, 92 were obtained from wells completed in bedrock and 6 from wells completed in saprolite. The median TOC concentration for the 98 sites is 0.2 mg/L (table 15). Median concentration in the saprolite (6 sites) is 1.7 mg/L, whereas the median concentration in bedrock is 0.2 mg/L. The number of samples obtained from wells completed in the saprolite is too small for rigorous analysis, but the difference in median concentrations is expected, consistent with shallow sources of organic carbon.

Optical brighteners

Optical brighteners are fluorescent dyes used in paper manufacturing, the clothing industry, and most laundry detergents used to whiten cellulose. Their presence in ground water indicates contamination because the dyes do not occur naturally (Glover, 1972). Optical brighteners were detected in only 1 well (HO Bf 51) of 20 wells sampled. The likely source is a domestic wastewater-septic system, considering the rural agricultural nature of the area. Most of the dye traps accumulated a red stain, probably an iron precipitate; dissolved iron is a known interference (Glover, 1972) and thus it is possible that some of the negative test results could be false.

Major ions

The cations Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+} are common in the ground water of Howard County, being readily derived from rock minerals. The anions HCO_3^-, Cl^-, SO_4^{2-}, NO_3^-, and F^- are also common in the ground water of the county. Carbon dioxide from the atmosphere or unsaturated subsurface reacts with water to produce carbonic acid, which subsequently dissociates into hydrogen and bicarbonate ions; the resulting carbonate system is responsible for most of the buffering capacity of natural waters. Dissolution of carbonate minerals (the primary minerals of the Cockeysville Marble) and silicate minerals, particularly feldspars, (common minerals in most of the rocks of Howard County) increases the concentration of bicarbonate in solution, thereby raising the pH and increasing alkalinity. Alkalinity is a measure of the buffering capacity, or ability of a solution to neutralize acid. Noncarbonate contributions to alkalinity come from complexes that are the result of weathering, including hydroxides and silica; phosphate and organic ligands may also contribute. Chloride, sulfate, nitrate, and fluoride are not common constituents of minerals in Howard County, and high concentrations of these in ground water are more likely related to human activity. Chloride concentrations are inversely correlated with well-casing length, suggestive of a surface or near-surface source such as road salt or septic system/sewage effluent.

The major-ion composition of ground-water samples obtained from 112 sites representing 18 geologic units (fig. 18) does not show a correspondence between geologic unit and ground-water composition (Only mafic [Baltimore Complex and the ultramafic and mafic rocks of the Morgan Run Formation] and other units [everything else, including the Patuxent Formation and saprolite] are differentiated in the diagram). The points fall into four fields, irrespective of geologic unit. Most points are in fields I and II, which are characterized by sodium plus potassium comprising less than 60 percent of the cations (in milliequivalents per liter). Chloride and sulfate are the dominant anions in field I, but in field II, bicarbonate dominates. Fields III and IV are characterized by sodium plus potassium comprising more than 60 percent of the cations; bicarbonate is the dominant anion in field III and chloride is the dominant anion for the single point in field IV.

The lack of correspondence of major-ion composition with geologic unit likely results from 1) large variation in the mineralogy of each geologic unit as well as 2) anthropogenic effects, such as road salting or waste disposal. The differentiation of fields I and II on the basis of anion content supports the second conjecture.

The USEPA has set permissible levels of three major anions in drinking water. The SMCL's for chloride and sulfate are 250 mg/L (U.S. Environmental Protection Agency, 1991a), and the MCL for fluoride is 4.0 mg/L (U.S. Environmental Protection Agency, 1991a). Chloride concentrations greater than the SMCL can impart undesirable taste; high concentrations of sulfate can have a laxative effect. Low concentrations of fluoride are beneficial to tooth structure and resistance to dental caries, but higher levels cause pronounced mottling and disfiguration of teeth; the optimum concentration is dependent upon water temperature.

Major-ion concentrations are highest in central and eastern Howard County (plate 3), but no samples exceeded the drinking-water regulations for chloride, sulfate, or fluoride. High chloride concentrations were found in wells HO Bd 403, near West Friendship (250 mg/L) and HO Cd 387, near Clarksville (160 mg/L). Sulfate and fluoride concentrations at approximately two-thirds of the sites sampled were below detection limits.

Silica

Dissolved silica in ground water is derived mainly from weathering of silicate minerals. The silicate minerals least resistant to reaction with water are the ferromagnesian silicates because of their structure. Silica concentrations generally are greater in the eastern and southeastern parts of the county (fig. 19), where these minerals occur in rocks such as the Baltimore Complex and the Druid Hill Amphibolite Member of the James Run Formation. Higher silica concentrations in Howard County ground water also are found in samples

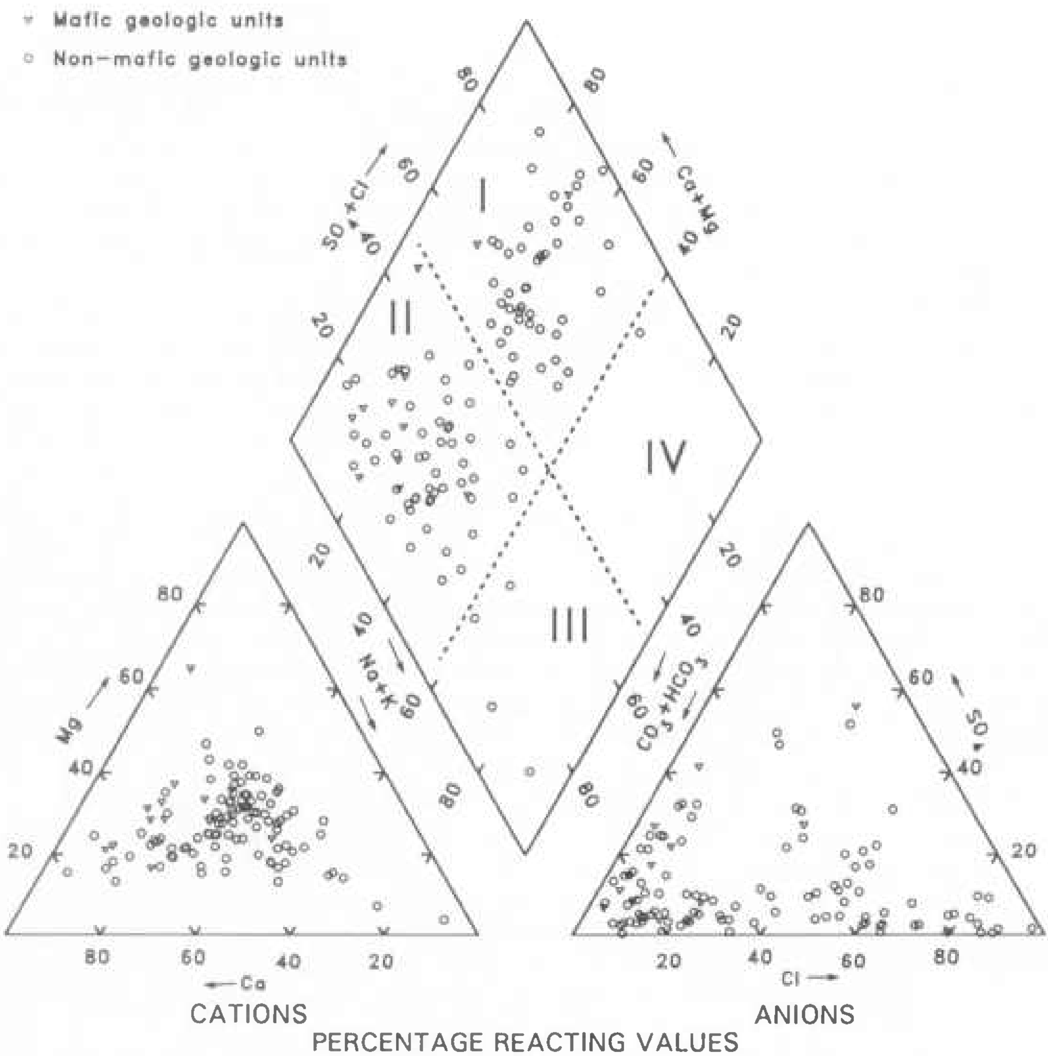


FIGURE 18.—Major-ion percentages in Howard County ground water. Mafic geologic units are the Baltimore Mafic Complex and ultramafic and mafic rocks in the Morgan Run Formation (13 sites); non-mafic units are all other geologic units sampled (99 sites). For sites having multiple samples, the average value was used. Concentrations of sulfate below detection limits (1.0 or 0.2 mg/L, depending on method) were set equal to the detection limit to allow calculation of anion percentages.

from the Ellicott City Granite, Relay Gneiss, and Oella Formation; biotite and plagioclase (sodium-calcium feldspar) may be the source minerals.

Nutrients

Nitrate is the most common form of nitrogen in ground water; ammonia and nitrite may be present in small amounts in reducing environments. Nitrate in soil and ground water results from atmospheric deposition, microbiological activity, and land-use practices such as animal and human waste disposal and fertilizer application. Because these are surface or

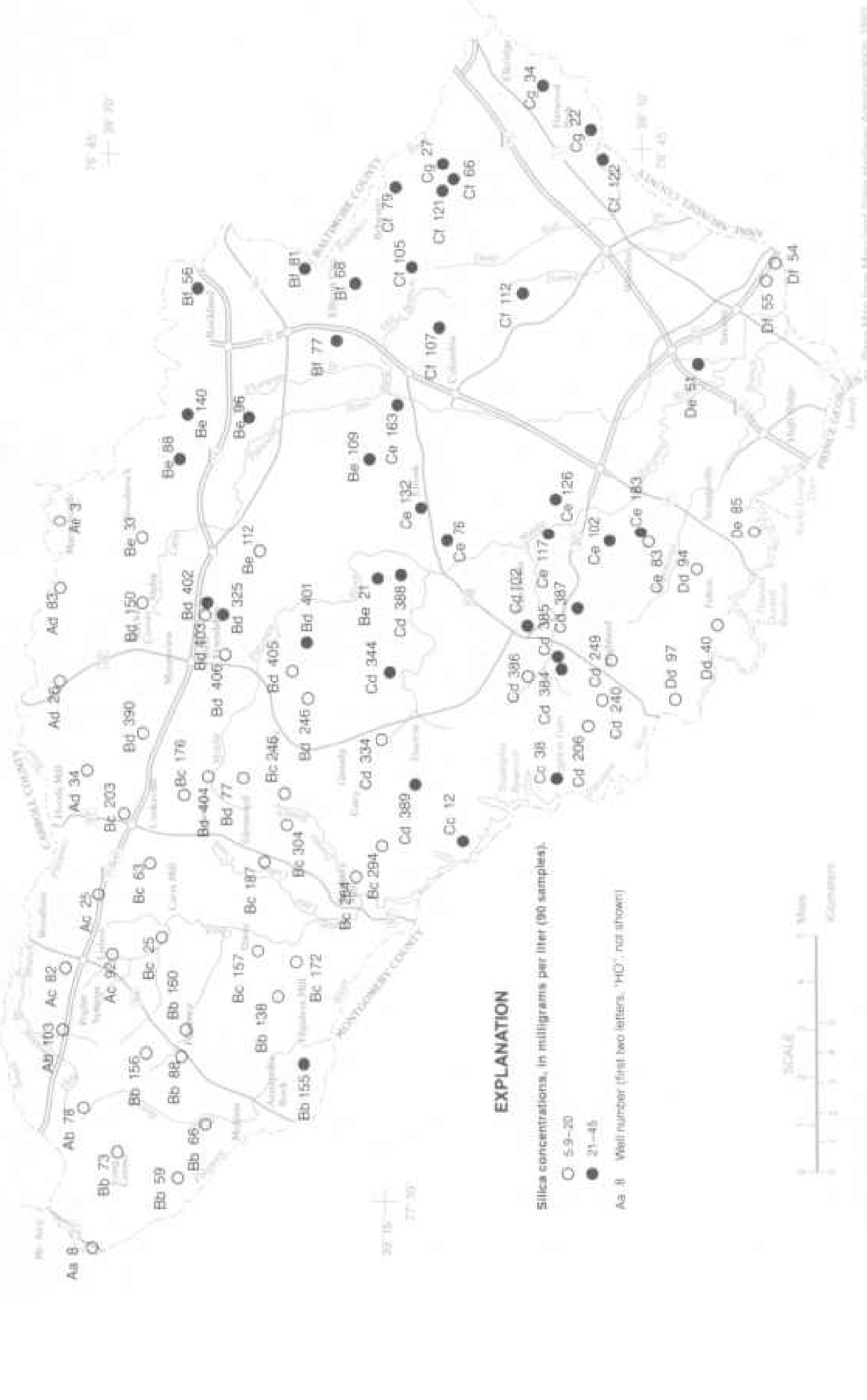


FIGURE 19.—Areal distribution of silica in ground water.

near-surface sources, nitrate concentrations tend to be higher in samples from shallower wells, and highest in soil (McFarland, 1989, discusses nitrate concentrations and transport in soil and ground water at a Howard County site in detail). The MCL's for nitrate and for nitrite plus nitrate in drinking water are both 10 mg/L as N (U.S. Environmental Protection Agency, 1991a); the MCL was exceeded in one sample (well HO Dd 94), which had a concentration of 13 mg/L nitrate plus nitrite. Nitrate concentrations greater than the MCL can cause methemoglobinemia, or "blue baby," disease in infants. Nitrate concentrations greater than 3 mg/L (as N) are more common in western and central Howard County, where agriculture is the major land use and individual wastewater septic systems are common, than in the eastern part of the county where land use is primarily urban and suburban with community wastewater-collection systems (fig. 20).

Although phosphorus is a constituent of some rock-forming minerals, dissolution is only a minor source of phosphorus in ground water. Natural concentrations are generally less than 0.1 mg/L (as P) because phosphates and other phosphorus compounds are readily adsorbed by soil or react with cations to form insoluble material. Common sources include fertilizers, sewage, and (formerly) phosphate detergents.

Trace elements

Trace elements are commonly defined (with respect to natural waters) as those substances typically present in concentrations less than 1.0 mg/L (Hem, 1985, p. 129). Detectable levels of most of these elements usually result from contamination by spills, motor vehicles, or by leaching of copper plumbing and solder joints. Ground-water samples were analyzed for 17 trace elements (Dine and others, 1992, table 11). Concentrations of 10 of these (aluminum, beryllium, cadmium, chromium, cobalt, lead, molybdenum, nickel, silver, and vanadium) were below detection limits in most samples. Only barium, copper, iron, lithium, manganese, strontium, and zinc were detected in a large percentage of the samples (table 19).

Iron concentrations greater than the SMCL (300 μg/L) impart an objectionable taste to water, can stain laundry or plumbing fixtures, and can precipitate when exposed to air, causing turbidity. Samples from nine wells in Howard County exceeded the SMCL. Manganese at concentrations greater than the SMCL (50 μg/L) is objectionable for the same reasons as high iron concentrations. Samples from 19 wells exceeded the SMCL for manganese. No ground-water samples contained concentrations of trace elements that exceeded the standards for barium (MCL = 2 mg/L), copper (MCLG = 1.3 mg/L), or zinc (SMCL = 5 mg/L).

Radon

Radon, a product of the radioactive decay of radium, is an alpha-particle-emitting noble gas. Radon-222 has a half-life of 3.8 days and is the only isotope of radon abundant in the environment. Radon is soluble in water, but readily dissipates upon exposure of the water to air. Only three sites sampled did not exceed the proposed MCL of 300 pCi/L (U.S. Environmental Protection Agency, 1991d).

Dissolved-radon concentrations of ground water sampled from 85 sites in Howard County range from less than 80 to 40,000 pCi/L, with a median concentration of 3,400 pCi/L (table 16; well HO Cg 27 produced samples having concentrations of 38,000 and 42,000 pCi/L in December 1988 and May 1989, respectively). Most of the radon concen-

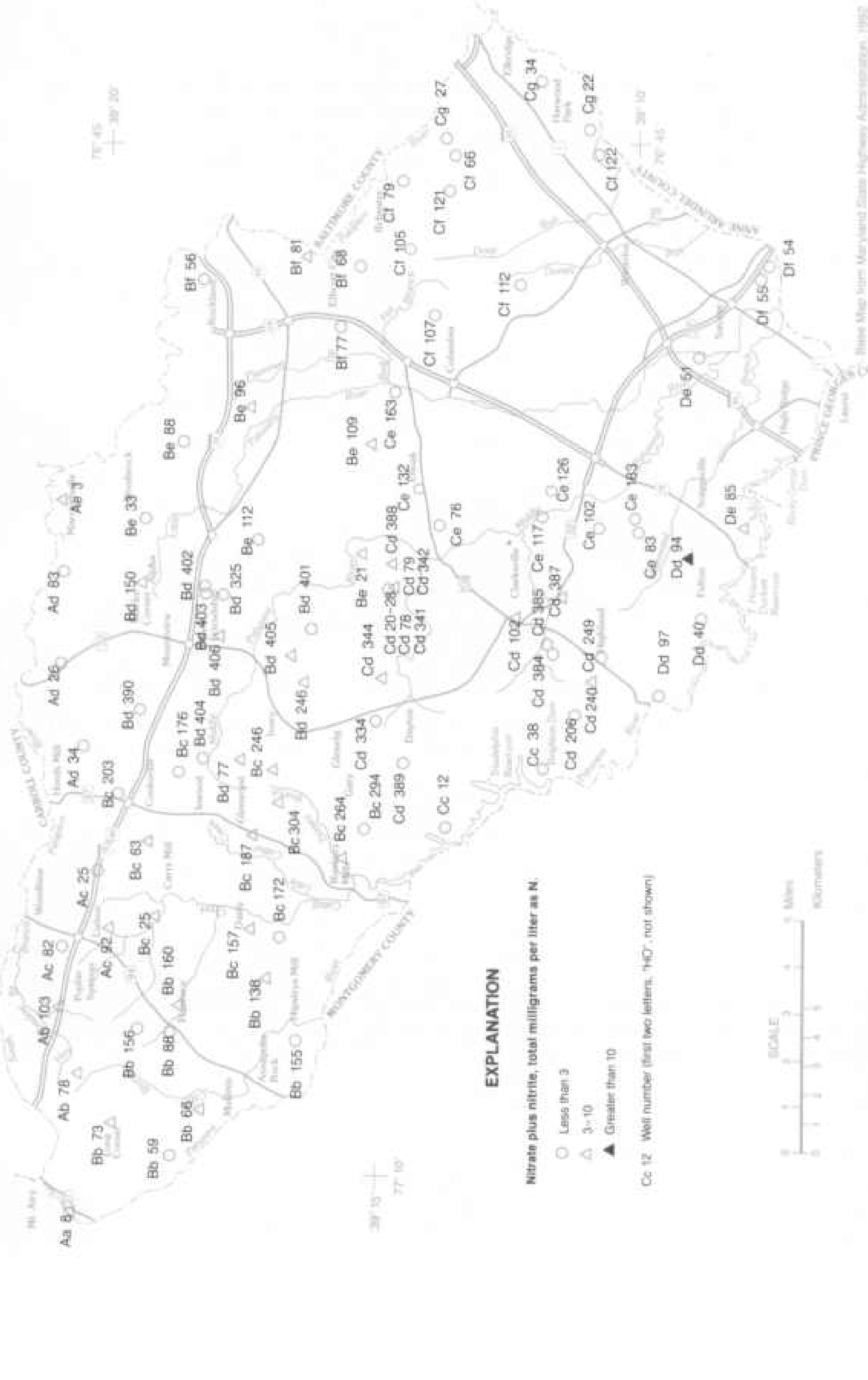


FIGURE 20.—Areal distribution of nitrate plus nitrite in ground water.

TABLE 19
SUMMARY STATISTICS OF CONCENTRATIONS OF
TRACE ELEMENTS IN GROUND WATER

[All concentrations are in micrograms per liter except for radon, which is expressed in picocuries per liter. For sites having multiple samples, average values were used. USEPA, U.S. Environmental Protection Agency. Bracketed means reflect uncertainty due to values less than detection limits. Where dashed, MCL or SMCL has not been established]

						USEPA drinking-water standards	
Trace element	Number of sites	Minimum	Maximum	Median	Mean	MCL[1]	SMCL[2]
Barium	88	< 2	380	26.5	46	2,000	—
Copper	88	< 1	170	20	(a)[3]	[4]1,300	—
Iron	99	< 3	18,000	10	325	—	300
Lithium	88	< 4	26	< 4	(b)[3]	—	—
Manganese	99	< 1	2,400	11	66	—	50
Strontium	89	1	670	68	105.1	—	—
Zinc	88	< 3	310	8	(c)[3]	—	5,000
Radon	85	< 80	40,000	3,400	6,160	[4]300	—

[1] Maximum Contaminant Level (MCL) is the maximum permissible concentration of a contaminant in water which is delivered to any user of a public water system and is based on effects on human health.
[2] Secondary Maximum Contaminant Level (SMCL) is a non-enforceable level at which a constituent can adversely affect the odor or appearance of water, and is based on aesthetic considerations.
[3] (a) 27.6 < mean < 30.3; (b) 4.2 < mean < 6.6; (c) 14.8 < mean < 15.5
[4] Proposed.

trations greater than 7,000 pCi/L are in central Howard County, in an area roughly corresponding to the outcrop of the Baltimore Gneiss (fig. 21). No relation between radon concentration and well depth is apparent.

Tritium

Tritium (^3H) is a radioactive isotope of hydrogen with a half-life of 12.3 years produced by bombardment of the atmosphere by cosmic rays. Above-ground testing of nuclear weapons in the 1950's and 1960's produced considerable additional quantities of tritium in the atmosphere. Atmospheric tritium is incorporated in precipitation and some eventually

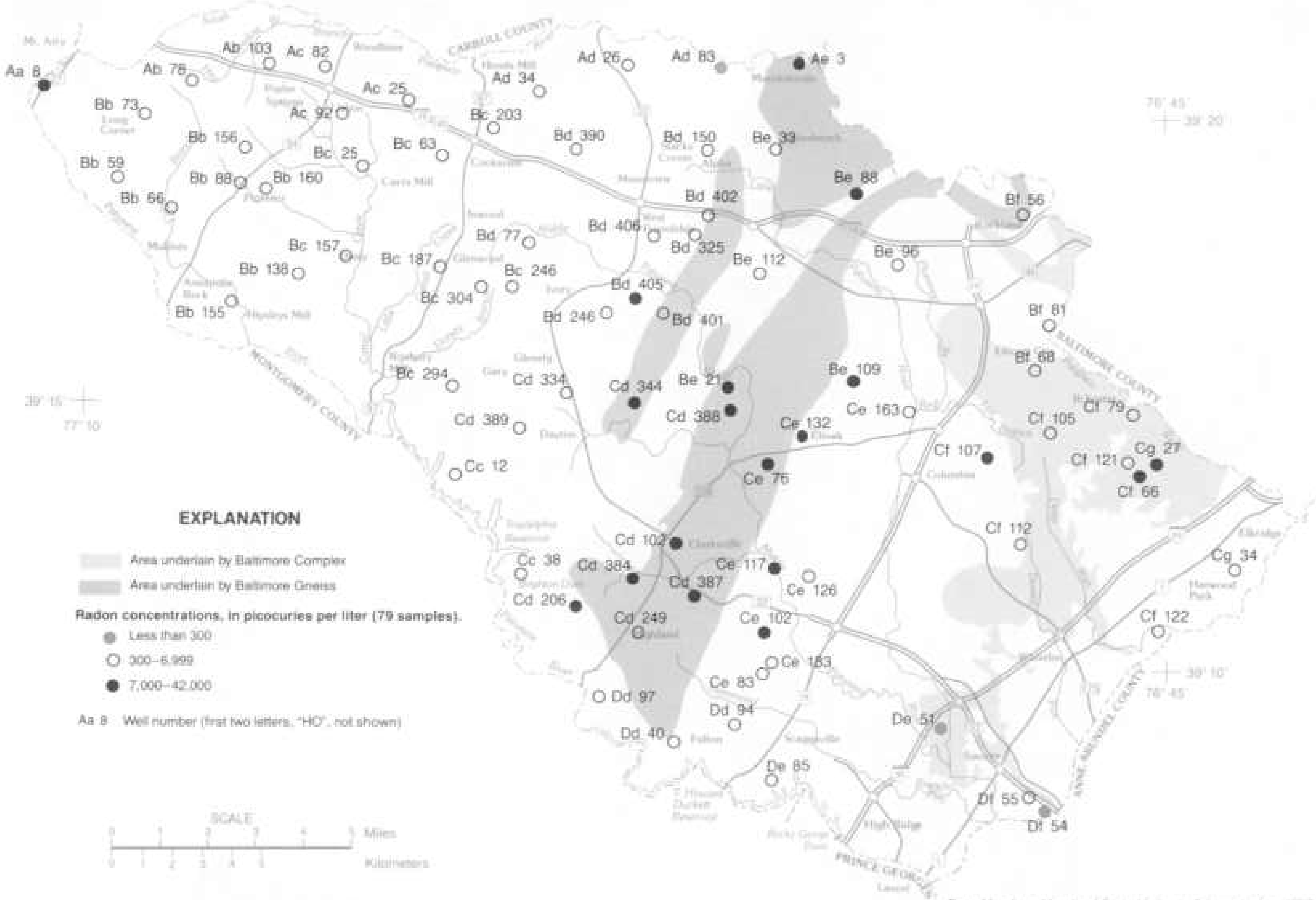


FIGURE 21.—Areal distribution of radon in ground water.

reaches ground water as recharge. Because the era of atomic weapons testing is known, measurement of tritium can be used to estimate the age (i.e., the time since last contact with the atmosphere) of ground water, at least in a qualitative way. Concentrations in the range of 10–100 tritium units (TU) are typical for ground water that is less than about 40 years old, and concentrations in the range of 2–10 TU is typical for ground water at least 25 years old (Hendry, 1988, p. 411). Dating of ground water comprising a mixture of water from sources of different ages is more difficult to evaluate.

Nineteen of 22 sites sampled contained tritium in concentrations ranging from about 10 to 30 TU, suggesting that most ground water in Howard County has been underground for less than about 40 years. However, tritium concentration can vary vertically owing to zonation of ground water of varying ages, and most of these wells have long open-hole intervals. The extent of mixing of waters of different ages during sampling cannot be determined, adding to the uncertainty of the age estimates. Ground water sampled from two wells in eastern Howard County, HO Cf 121 and HO Cg 34, which are cased through the Coastal Plain sediments, might be quite old, but the detection limit of the analytical method used was 6 TU, which is not sensitive enough to identify pre-nuclear testing ground waters. Also, both of these wells have more than 200 ft of open hole and therefore uncertainty due to possible mixing is added to the age estimate. A sample from well HO Cd 20 had a tritium concentration of 3.9 TU, suggesting a ground-water age of at least 25 years, but this well has an open interval of 70 ft. Three wells and one spring nearby had concentrations ranging from 16 to 30.4 TU. Two of these wells have open intervals of only 5 ft; tritium concentrations in these wells were 29 and 30.4 TU.

Pesticides

Sixty-eight ground-water samples from 61 wells in Howard County were analyzed for two groups of pesticides—triazines and carbamates (Dine and others, 1992, tables 12–13). The triazine compounds include the herbicides atrazine, cyanazine, prometone, and simazine; the acetanilide herbicides alachlor and metolachlor were also analyzed in this group. The carbamate compounds include the insecticides aldicarb, carbaryl, carbofuran, and methomyl, and the herbicide propham.

Triazine compounds detected in 12 ground-water samples include atrazine (the most common, in 8 of 68 samples), metolachlor, prometone, and simazine. The rest of the compounds listed in the previous paragraph were not present in detectable (0.1 μg/L) concentrations. Atrazine concentrations ranged from less than 0.1 to 0.3 μg/L. The highest pesticide concentration measured was of metolachlor—1.8 μg/L in water from well HO Bb 88. The MCL of 3 μg/L for atrazine (U.S. Environmental Protection Agency, 1991a) was not exceeded in any of the samples.

Concentrations of carbamate pesticides were below the detection limit of 0.5 μg/L in all but one ground-water sample. Carbofuran concentration in a sample from well HO Cd 387 was 0.7 μg/L, which is considerably below the MCL of 40 μg/L (U.S. Environmental Protection Agency, 1991a).

Volatile organic compounds

Volatile organic compounds (VOC's) are synthetic organic compounds used primarily for industrial purposes or manufacturing. Many of the compounds are toxic and MCL's have been set (U.S. Environmental Protection Agency, 1991a). Eleven wells in Howard

County were sampled for VOC's in ground water (Dine and others, 1992, table 14). Only three VOC's were present in concentrations above the detection limit of 0.2 μg/L. Methylene chloride (0.20 μg/L) and 1,2-dichloroethane (0.30 μg/L) were detected in a sample from well HO Cd 102 and dichlorodifluoromethane (3.4 μg/L) was present in a sample from well HO Ce 117. Both wells are located in south-central Howard County; well HO Ce 117 is a few feet from the bank of the Middle Patuxent River. These concentrations did not exceed MCL's.

SURFACE-WATER RESOURCES

Surface water of Howard County is used for public-water supply, to assimilate and dilute municipal and industrial wastewater, and to provide recreation. In 1990, approximately 3.9 Mgal/d of water was withdrawn from the T. Howard Duckett Reservoir (fig. 1) for public water supply. About 70 mi^2 (53 percent) of the reservoir watershed lies within Howard County. The South Branch Patapsco River received an average of 2.1 Mgal/d of treated wastewater from two municipal sewage-treatment plants in 1990 and transported the treated wastewater to the Chesapeake Bay. The Patapsco Valley and Patuxent River State Parks, and several lakes created in the Columbia area, are used for recreation.

STREAMFLOW DATA-COLLECTION METHODS

Streamflow data were collected at 13 continuous-record gaging stations that operated in the county during various periods, 8 of which were in operation in 1990 (fig. 22, table 20). The network of continuous-record stations is augmented by partial-record stations, at which periodic measurements of low flow or peak flow have been made. Current-meter flow measurements were made at 18 sites using methods described by Rantz and others (1982) during dry conditions when all streamflow was assumed to be derived from ground-water discharge (base flow). Three crest-stage stations provided peak-flow data. Drainage areas and forested areas were obtained by planimeter measurements on 1:24,000-scale topographic maps (with green overprint indicating forested areas). The drainage areas of these basins range from 0.54 to 285 mi^2; forested areas range from 1 to 51 percent.

MEASUREMENT AND REGULATION OF STREAMFLOW

Streamflow is monitored as part of a national network of gaging stations established by the U.S. Geological Survey; locations of stations in Howard County are shown in figure 22. Selected streamflow information collected at 13 continuous-record, 18 low-flow partial-record, and 3 peak-flow partial-record gaging stations is listed in table 20. Record high and average streamflows in table 20 are based on records from 1897–1908 and 1933–92. Maximum instantaneous discharge was recorded on June 22, 1972, at seven of nine continuous-record and peak-flow stations operating at that time, resulting from runoff from tropical storm Agnes. Minimum instantaneous discharge was recorded for several days preceding September 12, 1966, at the three stations with the longest periods of record.

Regulation from large reservoirs and streamflow diversions affect the natural flow of two streams in Howard County. Liberty Reservoir, an impoundment on the Patapsco River

(Text continues on p. 66.)

TABLE 20
CHARACTERISTICS OF STREAMFLOW AND DRAINAGE BASINS

[DMS, degrees, minutes, seconds; mi^2, square miles; ft^3/s, cubic feet per second; K, peak flow; L, low flow; Q, water quality; C, continuous; R, regulated. Period of record reported in water year, October 1 to September 30. ---, not determined]

Station no.	Station name	Period of record	Type of record	Latitude Longitude (DMS)		
01587050	Hay Meadow Branch tributary at	1966-76	K	39	20	55
	Poplar Springs			77	06	02
01587070	South Branch Patapsco River at	1975-79, 1988-90	L	39	21	44
	Woodbine	1989-90	Q	77	04	55
01587500	South Branch Patapsco River at	1948-80	C	39	21	05
	Henryton	1954-55, 1960, 1963-80, 1989	Q	76	54	50
		1988-90	L			
01588500	Patapsco River at Woodstock	1897-1908	C	39	19	54
				76	52	18
01589000	Patapsco River at Hollofield	1944-91	C	39	18	36
		1970-83, 1989	Q	76	47	34
		1954-91	R			
01589040	Rockburn Branch at Elkridge	1988-90	L	39	13	30
		1989-90	Q	76	43	12
01589080	Deep Run at Hanover	1975-79, 1988-90	L	39	11	24
		1989-90	Q	76	43	12
01590800	Patuxent River at Mullinix	1988-90	L	39	17	40
		1989-90	Q	77	08	42
01590900	Cabin Branch near Florence	1975-79, 1988-90	L	39	16	36
		1989-90	Q	77	06	20
01591000	Patuxent River near Unity	1944-92	C	39	14	18
		1985-91	Q	77	03	23
01591200	Cattail Creek tributary at Carrs	1956-66, 1988-90	L	39	18	57
	Mill	1989-90	Q	77	03	41
01591350	Cattail Creek near Cooksville	1977-81	C	39	18	50
		1988-90	L	77	03	15
		1989-90	Q			
01591375	Cattail Creek tributary at Daisy	1977-82, 1988-90	L	39	17	58
		1989-90	Q	77	03	52

TABLE 20—CONTINUED

Drainage area (mi²)	Forested area[1] (percent)	Instantaneous discharge of record (ft³/s)				Average discharge (ft³/s)	Station no.
		Maximum	Date	Minimum	Date		
0.54	1	630	9/11/71	---	---	---	01587050
11.4	29	---	---	---	---	---	01587070
64.4	26	26,900	6/22/72	0.40	9/9-12/66	75	01587500
251	--	11,000	2/26/08	---	---	373	01588500
285	--	80,600	6/22/72	6.0	9/ 6/44	---	01589000
3.69	42	---	---	---	---	---	01589040
18.0	52	---	---	---	---	---	01589080
10.7	28	---	---	---	---	---	01590800
8.36	27	---	---	---	---	---	01590900
34.8	35	21,800	9/11/71	.20	9/10-12/66	38.9	01591000
3.93	13	---	---	---	---	---	01591200
8.37	17	2,460	9/ 6/79	1.2	9/21-22/77	11.8	01591350
3.12	21	---	---	---	---	---	01591375

TABLE 20—CONTINUED

Station no.	Station name	Period of record	Type of record	Latitude Longitude (DMS)		
01591400	Cattail Creek near Glenwood[2]	1978-92 1989-90	C Q	39 77	15 03	21 05
01591475	Dorsey Branch near Knollwood	1964, 1988-90 1989-90	L Q	39 77	15 02	41 17
01591500	Cattail Creek at Roxbury Mills	1944-56	C	39 77	15 02	17 43
01591610	Patuxent River below Brighton Dam near Brighton	1981-92. 1989	C,R Q	39 77	11 00	31 16
01592000	Patuxent River near Burtonsville	1911-12 1913-45	C	30 76	07 55	47 04
01592500	Patuxent River near Laurel	1945-91	C,R	39 76	06 52	56 27
01593200	Little Patuxent River at Pine Orchard	1956-66, 1988-90 1989-90	L Q	39 76	16 51	42 11
01593300	Red Hill Branch near Columbia	1988-90 1989-90	L Q	39 76	14 50	44 43
01593350	Little Patuxent River tributary at Guilford Downs	1966-76	K	39 76	13 50	39 41
01593500	Little Patuxent River at Guilford	1932-92 1989	C Q	39 76	10 51	04 07
01593600	Middle Patuxent River near West Friendship	1956-66, 1988-90 1989-90	L Q	39 76	17 57	14 33
01593650	Middle Patuxent River tributary near Dayton	1977-82	L	39 76	14 56	12 27
01593675	Middle Patuxent River tributary near Columbia	1988-90 1989	L Q	39 76	14 55	02 04
01593700	Middle Patuxent River tributary near Clarksville	1977-82, 1988-90 1989-90	L Q	39 76	12 55	00 12
01593710	Middle Patuxent River near Simpsonville	1988-92 1989	C Q	39 76	11 53	48 59

TABLE 20—CONTINUED

Drainage area (mi²)	Forested area[1] (percent)	Instantaneous discharge of record (ft³/s)				Average discharge (ft³/s)	Station no.
		Maximum	Date	Minimum	Date		
22.9	20	4,040	2/12/85	1.7	8/19/91	24.7	01591400
3.78	18	---	---	---	---	---	01591475
27.7	18	10,100	7/21/56	2.9	8/26/44 9/ 8/44	28.6	01591500
78.6	--	17,800	6/22/72	1.2	12/3/85	---	01591610
127	--	11,000	8/24/33	4.6	10/9-10/42	124	01592000
132	29	26,000	6/22/72	.05	7/18/85	---	01592500
7.03	25	---	---	---	---	---	01593200
5.98	10	---	---	---	---	---	01593300
.95	2	620	6/22/72	---	---	---	01593350
38.0	19	12,400	6/22/72	0.0	9/6-12/66	43.1	01593500
11.4	19	---	---	---	---	---	01593600
4.25	30	---	---	---	---	---	01593650
9.12	25	---	---	---	---	---	01593675
6.24	21	---	---	---	---	---	01593700
48.4	26	2,340	1/20/88	6.4	8/ 6/91	51.6	01593710

TABLE 20—CONTINUED

Station no.	Station name	Period of record	Type of record	Latitude Longitude (DMS)		
01594000	Little Patuxent River at Savage	1940-58	C	39	08	06
		1976-80		76	48	58
		1986-92				
		1959-66, 1968, 1972, 1975	K			
		1985-91	Q			
01594100	Hammond Branch at Scaggsville	1956-66	L	39	09	13
				76	53	35
01594200	Hammond Branch near Laurel	1988-90	L	39	07	23
		1989	Q	76	49	31
01594395	Dorsey Run at Jessup	1964, 1989-91	L	39	08	57
		1989	Q	76	47	14

[1]Measured from U.S. Geological Survey topographic maps, revised 1971-79, scale 1:24,000.

[2]From 1978-83, published as Cattail Creek at Roxbury Mills Road at Roxbury Mills, Md.

in Baltimore and Carroll Counties (fig. 1), was constructed in 1954. Combined diversions from Liberty Reservoir for public-water supply to Baltimore and from Cranberry Branch (a tributary of the Patapsco River upstream of Liberty Reservoir) for public-water supply to Westminster averaged 136 ft^3/s during Water Year[1] 1992. Spillway management to maintain this withdrawal regulates downstream flow. Two reservoirs affect streamflow in the Patuxent River: Triadelphia Reservoir, behind Brighton Dam, constructed in 1942; and the T. Howard Duckett Reservoir, behind Rocky Gorge Dam, constructed in 1954 downstream from Brighton Dam. Diversions from the T. Howard Duckett Reservoir for public-water supply averaged 64.25 ft^3/s during Water Year 1992.

STREAMFLOW CHARACTERISTICS

Streamflow exhibits considerable variation over time (fig. 23) in response to climatic factors. Dry periods are indicated by extended recession slopes that are shown on the figure for December, early March, June, and early September. The effects of evapotranspiration on the hydrologic system show up in the figure as diminished streamflow during the growing season (April to September).

The water flowing in a stream channel has several sources, all of which are ultimately derived from precipitation. Contributions from the major sources sometimes can be evaluated by decomposition of a streamflow hydrograph (fig. 24) into a rapid contribution

[1] Water year is the 12-month period October 1 through September 30. The water year is designated by the calendar year in which it ends and which includes 9 of the 12 months. Thus, the year ending September 30, 1989, is called "Water Year 1989."

TABLE 20—CONTINUED

Drainage area (mi²)	Forested area[1] (percent)	Instantaneous discharge of record (ft³/s)				Average discharge (ft³/s)	Station no.
		Maximum	Date	Minimum	Date		
98.4	24	35,400	6/22/72	7.0	9/19/43	107	01594000
3.01	16	---	---	---	---	---	01594100
6.83	26	---	---	---	---	---	01594200
6.59	25	---	---	---	---	---	01594395

termed overland flow, or surface runoff; and a prolonged contribution termed subsurface runoff, base flow, or ground-water runoff (Barnes, 1939; Daniel, 1976; Pilgrim and others, 1979). The mechanisms involved in runoff generation are incompletely understood, however, and this leads to uncertainty in how the hydrograph should be decomposed and exactly what the graphical components represent (Hall, 1968; Freeze, 1972a, 1972b; Gregory and Walling, 1973, p. 118 and following).

Precipitation reaching the ground may flow overland, infiltrate the soil, or be detained in storage. The most important rapid contribution to streamflow after the onset of precipitation, which produces the greatest part of the hydrograph peak, comes from local areas along the channel and along valley floors and the lower parts of adjacent slopes (as well as precipitation directly on the channel). In these areas the water table is close to land surface and reacts quickly to precipitation. Rainfall of sufficient duration causes the water table to rise above land surface, resulting in overland flow to the stream channel (Dunne and Black, 1970). In some settings, however, infiltrating rainfall may move rapidly through soil macropores or fractured-rock zones and travel to the channel through the subsurface, with little overland flow occurring (Sklash and Farvolden, 1979; Pearce and others, 1986). After precipitation ceases, surface runoff is depleted. The hydrograph response is not immediate, however, because of the distances and flow velocities involved. The difference is termed the lag time, measured as the time period from the centroid of precipitation to the centroid of streamflow. Eventually, nearly all the streamflow consists of base flow, which decreases exponentially in the absence of recharge.

Streamflow characteristics discussed in this section describe discharge by use of summary statistics, probabilities, and frequencies of the fluctuation extremes, and include mean monthly and mean annual flows, flow durations, flood frequencies, and low-flow frequencies.

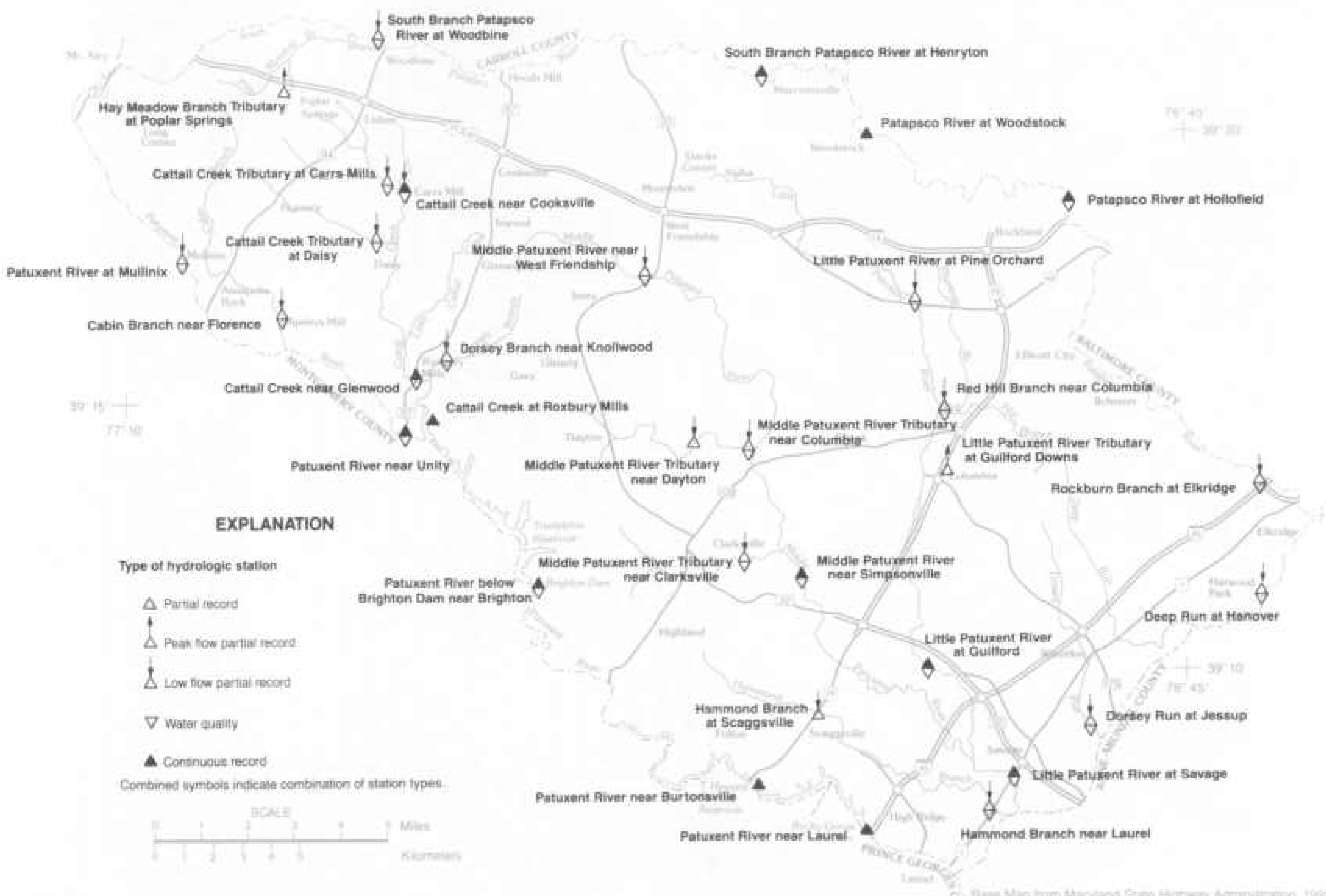


FIGURE 22.—Locations of streamflow-gaging and surface-water-quality stations.

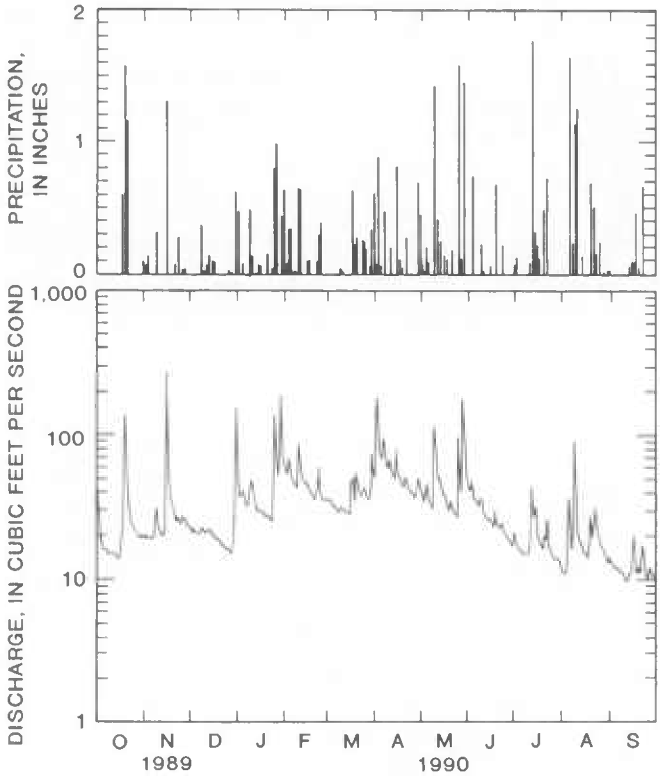


FIGURE 23.—Seasonal variation in streamflow, Patuxent River near Unity. Precipitation shown for Clarksville (U.S. National Oceanic and Atmospheric Administration, 1970–92).

Monthly Mean and Annual Mean Streamflow

Daily mean flow, or "daily flow," is the average flow of a day. Monthly mean flow is the average of daily flows for a 1-month period, and annual mean flow is the average of all daily flows for a year. Mean monthly flow is the average of monthly mean flows for a particular month (at least 10 years of record for that month for a reliable estimate), and mean annual flow is the average of all annual mean flows for the period of record. The magnitude of variability of monthly mean flow (table 21) is about as great over the years (for any one month) as it is throughout any year (for twelve months). That is to say, seasonal variation is substantial, but so is long-term variation. Flows per unit area are similar at all of the unregulated streams (table 22), due to relative homogeneity of geologic and hydrologic characteristics of the drainage basins.

The lowest minimum monthly mean flows listed in table 21 occurred during September at five stations and during August at two stations; highest minimum monthly mean flows occurred during February and March. Maximum monthly mean streamflows at four stations occurred in June (as a result of tropical storm Agnes in 1972), and three occurred during February. Maximum monthly mean streamflows occurred during May, September, and December at other stations, indicating that the highest monthly mean streamflow can occur at any season.

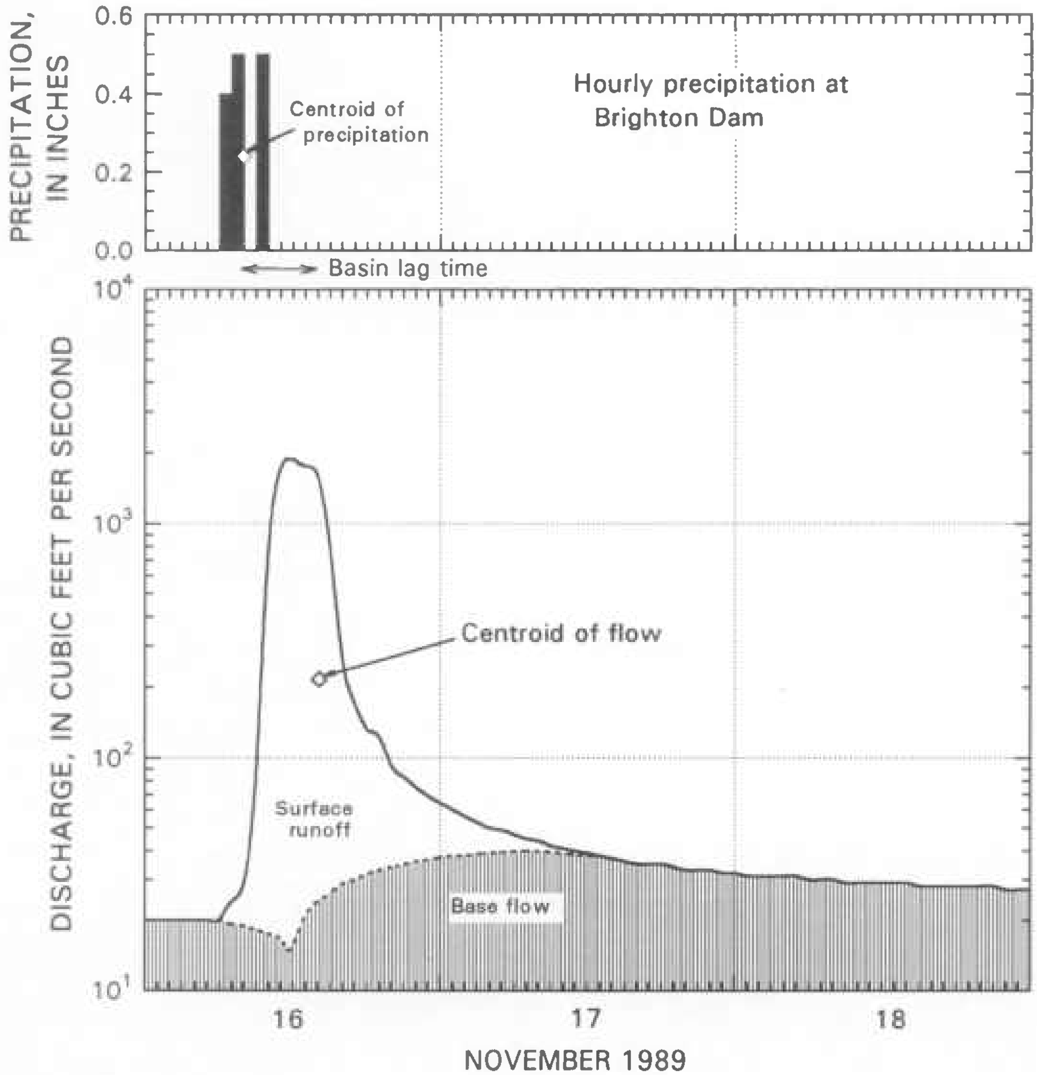


FIGURE 24.—Hydrograph of Cattail Creek near Glenwood showing separation of streamflow components. Hourly precipitation shown for Brighton Dam (U.S. National Oceanic and Atmospheric Administration, 1970–90).

Monthly mean streamflows are greater at the Patuxent River near Burtonsville than at the Laurel station, which is downstream (and has an additional 5 mi^2 of drainage area). This reversal of the expected discharge-drainage area relationship is due primarily to diversion of water by WSSC for public-water supply since 1954, after the Burtonsville station had been discontinued; almost half of the record of the Laurel station includes the period of withdrawals. Diversions also account in part for the differences between recorded streamflow of the Patapsco River at Woodstock and at Hollofield, although the periods of record and the methods of data collection contribute to the difference: stage was observed twice daily at Woodstock and daily mean discharge was computed from the average for water years 1897–1908.

TABLE 21
MONTHLY MEAN AND ANNUAL MEAN STREAMFLOW STATISTICS
AT CONTINUOUS-RECORD GAGING STATIONS

[All values are in cubic feet per second; water year is October 1 to September 30]

Station: **01587500 South Branch Patapsco River at Henryton**
Period of record: August 1948 to September 1980

	October	November	December	January	February	March	April
Minimum	12.8	16.8	16.3	17.8	43.8	55.0	42.4
25th percentile	24.5	32.8	37.6	51.4	63.3	81.9	61.9
Mean	47.7	53.2	72.6	88.6	103	113	105
Medien	31.9	39.1	57.5	62.4	87.2	114	101
75th percentile	47.1	60.9	104	120	125	136	130
Maximum	253	139	176	236	258	184	254

	May	June	July	August	September	Annual
Minimum	32.3	21.3	10.6	6.82	8.98	34.5
25th percentile	54.9	37.8	21.4	24.6	19.0	51.7
Mean	88.9	75.4	50.9	47.6	55.4	74.9
Median	76.3	59.9	44.1	34.2	36.6	65.6
75th percentile	129	78.5	58.3	57.8	50.1	96.3
Maximum	254	521	162	180	343	163

Station: **01588500 Patapsco River at Woodstock**
Period of record: August 1896 to March 1909

	October	November	December	January	February	March	April
Minimum	137	136	156	200	234	332	189
25th percentile	146	167	211	293	344	514	374
Mean	256	258	414	420	619	667	497
Median	174	250	372	410	520	613	449
75th percentile	297	287	512	511	786	804	626
Maximum	830	558	906	902	1,340	1,160	982

	May	June	July	August	September	Annual
Minimum	145	120	174	114	106	257
25th percentile	287	274	209	178	124	312
Mean	381	374	355	390	213	412
Median	368	290	298	331	226	407
75th percentile	514	367	482	531	255	451
Maximum	575	1,270	766	1,090	383	799

Station: **01589000 Patapsco River at Hollofield**
Period of record: May 1944 to September 1990

	October	November	December	January	February	March	April
Minimum	14.7	35.2	32.7	33.3	92.0	74.3	85.3
25th percentile	49.1	69.1	68.7	94.3	125	154	123
Mean	120	144	192	218	268	285	285
Median	65.6	95.5	139	166	172	238	214
75th percentile	134	155	242	295	401	407	391
Maximum	857	590	675	770	724	804	1,070

	May	June	July	August	September	Annual
Minimum	58.3	33.5	22.4	20.1	19.4	64.3
25th percentile	111	74.2	56.2	43.6	38.4	97.2
Mean	260	228	155	120	141	202
Median	218	146	89.9	76.2	80.4	153
75th percentile	398	248	195	158	126	269
Maximum	1,100	2,020	601	516	1,490	524

TABLE 21—CONTINUED

Station: **01591000 Patuxent River near Unity**
Period of record: July 1944 to September 1992

	October	November	December	January	February	March	April
Minimum	4.19	9.09	8.51	10.0	19.6	23.9	21.6
25th percentile	10.7	16.3	18.9	24.0	35.5	42.9	36.3
Mean	21.7	27.4	38.4	45.1	54.3	58.1	56.3
Median	14.3	21.0	29.5	37.4	49.6	55.0	48.8
75th percentile	20.3	33.9	53.2	57.9	65.5	71.8	66.5
Maximum	150	82.8	106	135	152	104	150

	May	June	July	August	September	Annual
Minimum	15.2	8.75	4.15	2.79	4.51	19.8
25th percentile	26.6	18.9	12.1	8.73	8.80	25.8
Mean	49.6	36.7	26.6	22.0	26.6	38.5
Median	40.8	29.6	22.9	14.6	15.9	35.5
75th percentile	60.2	44.3	34.9	24.6	23.0	48.5
Maximum	141	206	102	120	214	82.3

Station: **01591400 Cattail Creek near Glenwood**[1]
Period of record: June 1978 to September 1992

	October	November	December	January	February	March	April
Minimum	3.73	5.96	9.24	8.38	14.6	14.5	14.9
25th percentile	6.56	12.2	13.4	13.7	21.4	20.9	19.3
Mean	18.7	19.6	24.7	27.4	37.6	32.3	32.9
Median	10.1	17.8	18.7	22.2	27.6	27.5	26.0
75th percentile	20.2	26.9	29.6	35.1	51.0	44.6	36.5
Maximum	76.6	37.9	83.1	83.0	103	58.7	90.6

	May	June	July	August	September	Annual
Minimum	14.1	6.96	4.23	4.63	4.43	13.1
25th percentile	14.5	12.9	11.6	6.05	5.76	15.3
Mean	32.0	21.3	16.3	12.2	15.1	23.9
Median	23.9	17.9	15.9	8.92	8.54	23.2
75th percentile	45.5	28.9	21.5	16.6	14.1	29.2
Maximum	92.5	38.4	31.5	30.7	81.6	42.0

Station: **01591500 Cattail Creek at Roxbury Mills**
Period of record: July 1944 to September 1956

	October	November	December	January	February	March	April
Minimum	7.09	9.72	14.8	11.1	17.2	24.6	16.8
25th percentile	9.88	14.5	15.8	22.3	33.0	29.9	24.1
Mean	15.5	23.6	30.8	34.0	41.2	38.8	33.7
Median	15.7	21.9	27.0	33.5	41.6	37.3	29.4
75th percentile	19.7	29.4	45.0	42.7	47.3	43.9	37.4
Maximum	25.9	51.0	59.3	70.3	64.8	70.1	76.8

	May	June	July	August	September	Annual
Minimum	11.3	10.2	6.93	5.73	4.16	18.1
25th percentile	19.7	17.0	16.9	11.9	10.5	20.4
Mean	32.9	29.6	25.9	20.3	16.3	28.6
Median	29.1	25.0	20.3	17.8	15.2	26.6
75th percentile	40.1	42.2	39.7	26.9	20.4	37.6
Maximum	80.4	59.8	57.9	51.6	36.0	41.8

[1] From 1978-83, published as Cattail Creek at Roxbury Mills Road at Roxbury Mills, Maryland.

TABLE 21—CONTINUED

Station: **01591610 Patuxent River below Brighton Dam near Brighton**
Period of record: October 1980 to September 1992

	October	**November**	**December**	**January**	**February**	**March**	**April**
Minimum	7.87	17.1	14.9	9.33	10.1	8.90	8.49
25th percentile	25.0	26.8	26.8	16.9	29.2	63.2	78.3
Mean	57.5	45.1	80.5	63.3	68.2	87.0	114
Median	48.7	38.6	52.5	45.4	58.5	80.4	97.3
75th percentile	88.4	67.6	91.5	107	101	104	133
Maximum	117	82.1	373	183	142	205	261

	May	**June**	**July**	**August**	**September**	**Annual**
Minimum	8.63	22.4	46.7	18.1	26.1	47.5
25th percentile	41.8	47.9	53.1	55.0	48.3	57.5
Mean	97.7	74.4	58.7	64.3	75.9	73.9
Median	67.6	56.6	58.1	64.0	63.0	63.8
75th percentile	165	88.1	65.9	83.8	88.0	89.4
Maximum	229	170	66.9	86.4	205	134

Station: **01592000 Patuxent River near Burtonsville**
Period of record: July 1913 to February 1945

	October	**November**	**December**	**January**	**February**	**March**	**April**
Minimum	11.0	19.4	35.1	40.4	36.8	64.6	73.2
25th percentile	45.6	58.9	77.7	101	117	145	135
Mean	81.7	97.3	106	148	193	183	181
Median	69.2	88.3	108	142	168	164	163
75th percentile	104	125	136	169	257	202	232
Maximum	273	266	170	375	414	347	341

	May	**June**	**July**	**August**	**September**	**Annual**
Minimum	62.6	45.4	20.9	10.4	9.37	51.7
25th percentile	90.2	69.9	49.7	46.9	32.3	99.1
Mean	138	109	88.7	96.7	74.0	124
Median	125	89.9	79.7	73.4	59.9	121
75th percentile	157	132	106	139	101	153
Maximum	319	351	247	352	231	201

Station: **01592500 Patuxent River near Laurel**
Period of record: October 1944 to September 1990

	October	**November**	**December**	**January**	**February**	**March**	**April**
Minimum	7.76	7.21	8.45	7.84	7.92	7.88	7.47
25th percentile	12.1	12.7	13.9	14.0	20.4	57.1	56.6
Mean	43.5	53.5	76.6	104	120	126	137
Median	19.1	18.3	37.8	65.3	79.4	113	121
75th percentile	60.3	65.4	110	161	199	180	192
Maximum	379	272	390	480	462	373	444

	May	**June**	**July**	**August**	**September**	**Annual**
Minimum	9.04	7.88	7.81	5.72	4.91	9.09
25th percentile	30.8	17.6	15.8	16.0	15.2	38.2
Mean	120	91.8	63.2	51.6	67.1	87.7
Median	91.5	57.0	31.4	24.2	19.8	75.2
75th percentile	185	110	95.8	76.2	54.1	130
Maximum	397	822	280	226	587	241

TABLE 21—CONTINUED

Station: **01593500 Little Patuxent River at Guilford**
Period of record: April 1932 to September 1992

	October	November	December	January	February	March	April
Minimum	5.90	9.31	11.6	12.9	19.7	24.9	21.0
25th percent	14.1	19.3	23.4	34.5	40.5	46.2	36.1
Mean	26.2	36.0	43.9	51.3	60.8	61.9	58.5
Median	18.5	29.3	36.2	45.2	55.6	58.1	49.1
75th percentile	31.9	47.7	55.4	59.5	73.3	76.4	67.0
Maximum	107	108	119	145	147	123	160

	May	June	July	August	September	Annual
Minimum	15.7	9.32	6.66	4.91	3.88	23.3
25th percentile	28.3	20.1	15.0	13.3	11.4	31.4
Mean	49.6	38.5	29.7	27.5	31.1	43.1
Median	41.5	29.7	25.2	19.8	18.2	39.9
75th percentile	63.2	41.1	37.4	34.4	35.2	50.8
Maximum	197	265	119	130	214	93.7

Station: **01594000 Little Patuxent River at Savage**
Period of record: October 1939 to September 1958, October 1975 to September 1980, and May 1985 to September 1992

	October	November	December	January	February	March	April
Minimum	14.7	22.5	35.8	34.0	57.7	85.3	60.0
25th percentile	37.6	50.7	57.5	79.5	99.8	118	96.9
Mean	72.1	91.1	112	142	139	152	136
Median	49.2	83.4	97.7	125	129	135	123
75th percentile	80.9	118	142	173	164	164	152
Maximum	336	228	260	386	375	308	351

	May	June	July	August	September	Annual
Minimum	39.5	25.5	21.9	15.1	12.8	59.3
25th percentile	73.6	58.4	43.4	31.6	34.5	77.3
Mean	127	94.0	76.8	64.0	67.2	106
Median	113	74.2	65.7	46.0	43.6	94.6
75th percentile	164	104	87.6	82.6	69.8	134
Maximum	367	294	312	315	432	196

Monthly mean and annual mean flows of the Patuxent River are more variable at Laurel, which is regulated by the Triadelphia and T. Howard Duckett Reservoirs, than at the Unity station, which is located upstream from the reservoirs (fig. 25). Also, the basin above the Unity station is not affected by development. The month-to-month uniformity of minimum monthly mean flows at the Laurel station are due to flow regulation by the reservoirs.

Flow Durations

Cumulative frequency of streamflows, or flow duration, is the percentage of time specified discharges are equaled or exceeded (Searcy, 1959). Differences in climate and drainage-basin characteristics result in variability of flow durations among streams (table

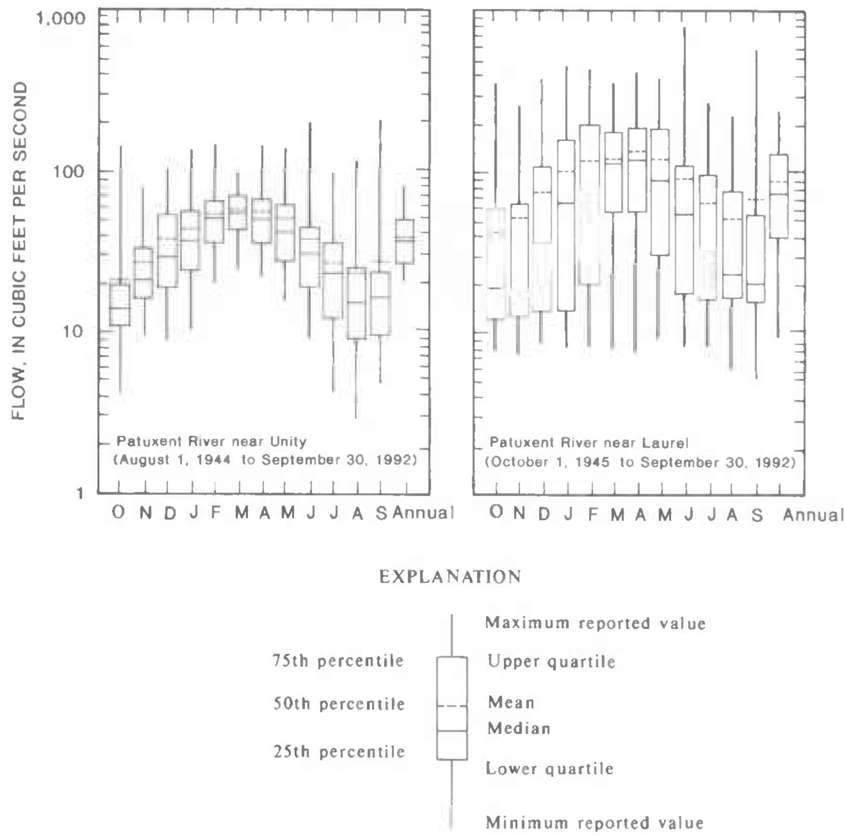


FIGURE 25.—Box-whisker plots of monthly mean and annual mean flows of the Patuxent River at an unregulated station near Unity and at a regulated station near Laurel.

23). More variable flow, indicated by steeper slopes of the duration curves, may be due to greater climatic variability as well as little water storage and a larger proportion of runoff being surface runoff in the basin than in basins represented by less steep curves. Slopes of the flow duration curves drawn for eight Howard County stations that monitored unregulated streamflow for at least 10 years (fig. 26) are similar, evidence that the hydrologic characteristics of the basins are similar. The magnitudes of the flows differ in relation to the sizes of the drainage basins, which range from 22.9 to 251 mi^2 (reporting streamflow per unit area of drainage basin removes this source of variability, and is used for comparing certain hydrologic properties of drainage basins).

The effect of streamflow regulation can be seen in the flow-duration curves for two stations on the Patuxent River (fig. 27): unregulated flow conditions prevail upstream from the gage near Unity, but flow past the gage near Laurel is regulated by the Rocky Gorge Dam, which forms the T. Howard Duckett Reservoir (fig. 1). The reservoir is used to store a portion of the water during periods of high runoff and, during periods of low runoff, reservoir releases augment flow.

The three curves for the Patuxent River near Unity shown in figure 27 also illustrate the effect of climatic variations. Major droughts in Maryland occurred in calendar years

TABLE 22
MEDIAN VALUES OF MONTHLY AND ANNUAL MEAN AREAL STREAMFLOWS AT CONTINUOUS-RECORD GAGING STATIONS

[All flows in cubic feet per second per square mile]

Station no.	Station name	Period of record (water years)	Area (square miles)	Oct.	Nov.	Dec.
01587500	South Branch Patapsco River at Henryton	1948-80	64.4	0.50	0.61	0.89
01591000	Patuxent River near Unity	1944-90	34.8	.41	.60	.85
01591400	Cattail Creek near Glenwood[1]	1978-90	22.9	.44	.78	.82
01591500	Cattail Creek at Roxbury Mills	1944-56	27.7	.57	.79	.97
01592000	Patuxent River near Burtonsville	1914-44	127	.54	.70	.85
01593500	Little Patuxent River at Guilford	1932-90	38.0	.49	.77	.95
01594000	Little Patuxent River at Savage	1940-58, 1976-80, 1986-90	98.4	.50	.85	.99

[1]From 1978-83, published as Cattail Creek at Roxbury Mills Road at Roxbury Mills, Md.

TABLE 23
DURATIONS OF DAILY STREAMFLOWS AT CONTINUOUS-RECORD GAGING STATIONS

Station no.	Station name	Discharge (cubic feet per second) equaled or exceeded for indicated percent of time				
		0.5	1	2	5	10
01587500	South Branch Patapsco River at Henryton	631	453	318	191	138
01588500	Patapsco River at Woodstock	4,190	2,990	2,000	1,070	678
01591000	Patuxent River near Unity	364	245	165	101	72
01591400	Cattail Creek near Glenwood[1]	330	148	93	52	39
01591500	Cattail Creek at Roxbury Mills	240	172	110	70	51
01592000	Patuxent River near Burtonsville[2]	1,100	792	544	319	219
01593500	Little Patuxent River at Guilford	539	374	247	121	72
01594000	Little Patuxent River at Savage	1,080	773	519	285	185

[1]Formerly published as Cattail Creek at Roxbury Mills Road at Roxbury Mills, 1978-83.
[2]Based on nonregulated period, 1914-42.

TABLE 22—CONTINUED

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Annual	Station no.
0.97	1.35	1.77	1.57	1.18	0.93	0.68	0.53	0.57	1.02	01587500
1.07	1.43	1.58	1.40	1.17	.85	.66	.42	.46	1.02	01581000
.97	1.21	1.20	1.14	1.04	.78	.69	.39	.37	1.01	01591400
1.21	1.50	1.35	1.06	1.05	.90	.73	.64	.55	.96	01591500
1.12	1.32	1.29	1.28	.98	.71	.63	.58	.47	.95	01592000
1.19	1.46	1.53	1.29	1.09	.78	.66	.52	.48	1.05	01593500
1.27	1.31	1.37	1.25	1.15	.75	.67	.47	.44	.96	01594000

TABLE 23—CONTINUED

Discharge (cubic feet per second) equaled or exceeded for indicated percent of time											Station no.
20	30	50	70	80	90	95	98	99	99.5	99.9	
100	79	51	34	27	19	14	11	8.2	6.8	3.0	01587500
485	393	283	20	163	126	102	77	65	57	51	01588500
51	40	26	17	13	9.0	6.7	4.8	4.0	3.3	1.7	01591000
28	23	16	12	8.7	6.3	4.8	3.7	3.2	2.9	2.5	01591400
36	29	21	16	13	10	8.1	5.4	4.3	3.9	3.4	01591500
159	131	92	62	49	35	23	16	10	8.0	6.0	01592000
50	39	27	18	14	11	8.1	6.0	4.8	4.0	2.7	01593500
127	103	72	49	38	28	21	15	13	10	8.8	01594000

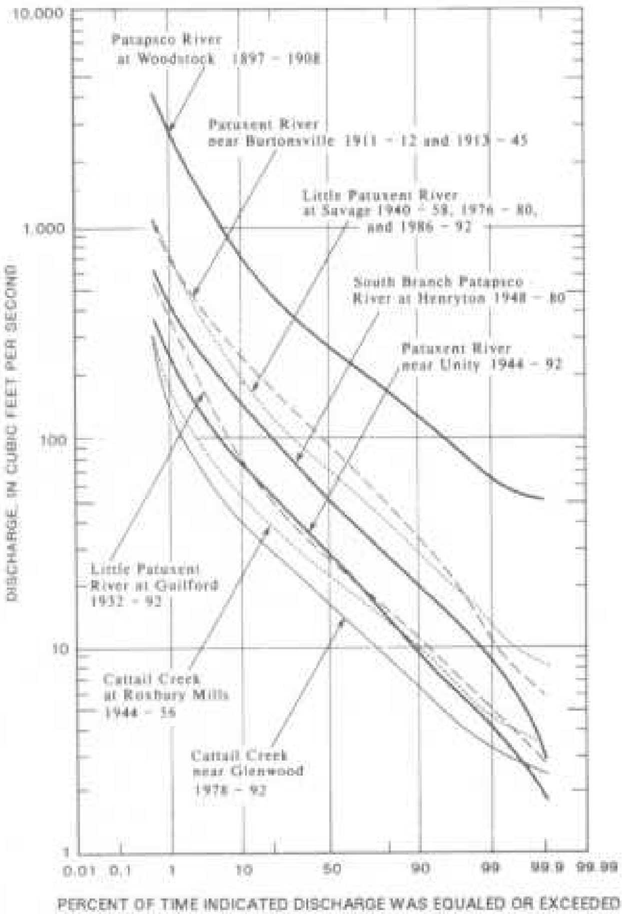


FIGURE 26.—Flow durations of streams having continuous-record gaging stations. Periods of record (water years) for each station are shown.

1953–56, 1958–71, 1980–83, and 1984–88 (Paulson and others, 1991, p. 324). The entire record of the station spans water years 1944–92. The curve for the period 1944–55 shows little effect of drought, but the curve for water years 1956–92 (corresponding to the period of operation of the reservoir) shows lower flows, particularly over the interval of 50 to 99 percent exceedence, as a consequence of drought.

Streamflow in the Little Patuxent River has been modified by development in the vicinity of Columbia beginning in the late 1960's (fig. 28). Much of this region was transformed from rural-agricultural use to moderately dense commercial-residential use. Flow duration curves for the pre-development period (1933–60) and the post-development period (1970–90) are similar throughout most of the range in flow, but at the low-flow end (flows exceeded 95 percent of the time), the post-development curve steepens, owing to decreased base flows. The records for water years 1961–69 were excluded because of extremely low streamflows due to drought. The difference between the two curves at the 99.9 percent exceedence level is 0.7 ft^3/s.

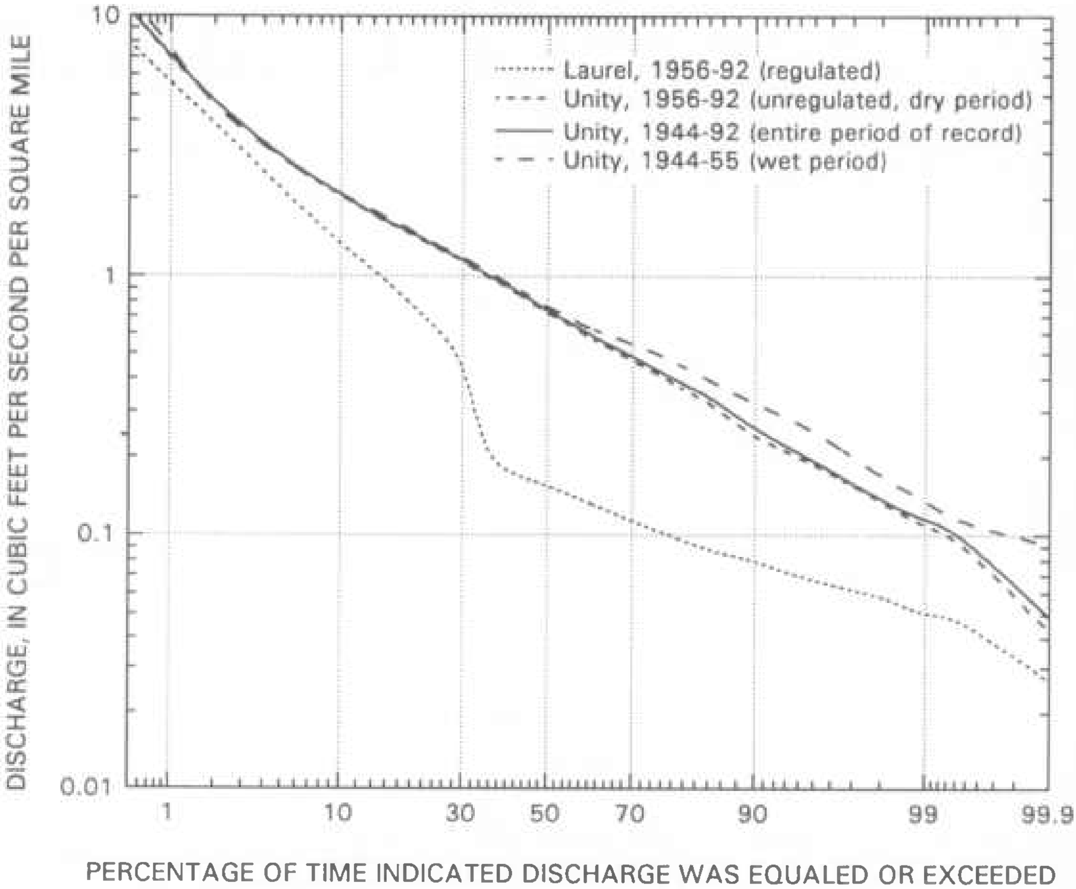


FIGURE 27.—Flow durations at unregulated and regulated stations on the Patuxent River. The T. Howard Duckett Reservoir began operation in water year 1956, regulating flow past the Laurel station. Climatic effects on flows also can be seen in the curves for the station at Unity (several major droughts occurred during 1956–92).

Duration curves for pre-1961 and post-1969 flows measured in the Patuxent River near Unity, a watershed which remained undeveloped, are included in figure 28 as a control for climatic effects. Low flows are similar for both periods in this basin, in contrast to the difference seen in the Little Patuxent River at Guilford, implying that development, not climate, is responsible for the decreased flows.

Flood Frequency

Runoff in Howard County is quickly transported to stream channels because there are few lakes, swamps, or other impediments to overland flow; consequently, streamflow increases rapidly in response to storms. Commercial and residential development such as has occurred in Howard County tends to increase the proportion of the watershed underlain by impermeable surfaces and provides conduits (storm sewers and drains) that allow storm runoff to be transported directly to streams. This results in increased peak-flow volume, shortened basin lag time, and diminished ground-water recharge. Major floods in

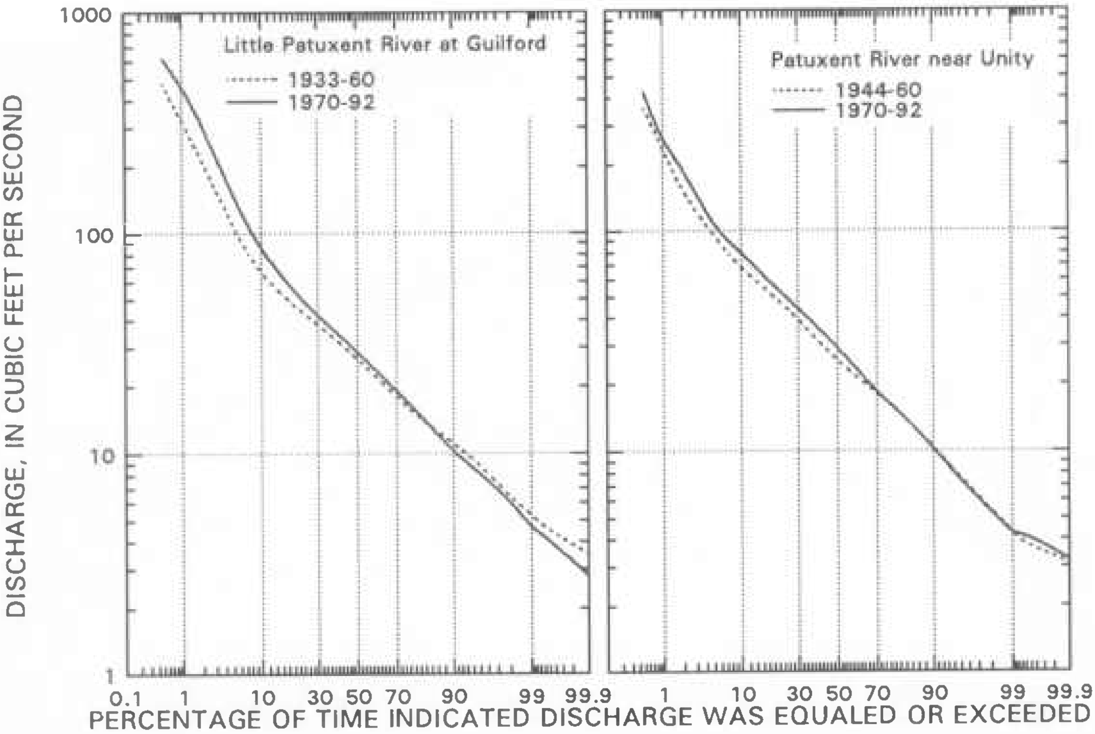


FIGURE 28.—Pre-development and post-development flow durations, Little Patuxent River at Guilford and Patuxent River near Unity. The area around Columbia was developed from mostly agricultural to commercial-residential use beginning in the late 1960's (solid lines show post-development flow durations).

Howard County usually are produced by heavy rainfall associated with hurricanes. Hurricanes caused record peaks at nine gaging stations in Howard County, and rainfall from tropical storm Agnes in June 1972 caused record peaks at seven of these stations (table 20).

Magnitudes and frequencies of annual peak flows and flood volumes at nine continuous-record gaging stations are presented in table 24. These flows were computed using the log-Pearson type III distribution (U.S. Water Resources Council, 1981). Peak flows are instantaneous flows and were estimated using annual maximum instantaneous-discharge data; flood volumes are average flows occurring over a specified period, and were estimated using daily flows (means for the day). The average interval of time during which a given flow is equaled or exceeded once is called the recurrence interval. The reliability of the flow estimates decreases as the recurrence interval increases; only frequency characteristics for recurrence intervals less than two times the length of the period of record are considered reliable. Because of their importance, however, estimates of annual maximum-peak flow are also provided. Peak flows at partial-record stations and at continuous-record gaging stations where insufficient record length (less than 10 years) precludes accurate estimation from a log-Pearson type III distribution were estimated using multiple-regression equations that express discharge as a function of basin area, forest cover, and precipitation intensity (Carpenter, 1983, p. 16–28; table 25).

TABLE 24
MAGNITUDE AND FREQUENCY OF ANNUAL MAXIMUM STREAMFLOW AT CONTINUOUS-RECORD GAGING STATIONS

[--, Period of record insufficient for reliable estimate]

Station no.	Station name (Period of record)	Annual maximum	Discharge, in cubic feet per second for indicated recurrence interval					
			2-year	5-year	10-year	25-year	50-year	100-year
01587500	South Branch Patapsco River at Henryton (Oct. 1, 1948, to Sept. 30, 1980)	Instantaneous peak flow	2,670	5,440	8,420	14,100	20,300	28,700
		1-day flow	939	1,890	2,890	4,790	6,820	--
		3-day flow	498	946	1,410	2,290	3,210	--
		7-day flow	311	551	779	1,170	1,550	--
01588500	Patapsco River at Woodstock (Oct. 1, 1897, to Sept. 1908)	Instantaneous peak flow	13,300	20,600	26,200	34,100	40,600	47,600
		1-day flow	6,710	10,000	12,700	--	--	--
		3-day flow	3,070	4,150	5,030	--	--	--
		7-day flow	1,750	2,390	2,870	--	--	--
01589000	Patapsco River at Hollofield[1] (Oct. 1, 1944, to Sept. 30, 1989; except peak flow, water years 1933, and 1945-89)	Instantaneous peak flow	10,000	24,400	41,800	77,600	120,000	181,000
		1-day flow	2,080	4,620	7,610	13,800	21,000	--
		3-day flow	1,190	2,550	4,030	6,920	10,100	--
		7-day flow	768	1,560	2,360	3,790	5,230	--
01591000	Patuxent River near Unity (Oct. 1, 1944, to Sept. 30, 1992)	Instantaneous peak flow	1,530	3,560	5,880	10,600	15,900	23,400
		1-day flow	546	1,040	1,490	2,230	2,920	--
		3-day flow	279	509	724	1,090	1,440	--
		7-day flow	176	298	402	566	714	--
01591400	Cattail Creek near Glenwood[2] (Oct. 1, 1978, to Sept. 30, 1992)	Instantaneous peak flow	2,000	3,610	4,920	6,850	8,480	10,300
		1-day flow	638	1,120	1,400	--	--	--
		3-day flow	263	449	573	--	--	--
		7-day flow	137	225	288	--	--	--
01591500	Cattail Creek at Roxbury Mills (Oct. 1, 1944, to Sept. 30, 1956)	Instantaneous peak flow	833	1,720	2,700	4,640	6,800	9,800
		1-day flow	360	595	778	--	--	--
		3-day flow	191	292	359	--	--	--
		7-day flow	124	171	194	--	--	--
01592000	Patuxent River near Burtonsville[3] (Oct. 1, 1913, to Sept. 30, 1944; except peak flow, water years 1911-44)	Instantaneous peak flow	2,530	3,930	5,100	6,910	8,530	10,400
		1-day flow	1,310	2,070	2,730	3,750	4,670	--
		3-day flow	807	1,210	1,520	1,970	2,340	--
		7-day flow	518	725	866	1,050	1,180	--
01593500	Little Patuxent River at Guilford (Oct. 1, 1932, to Sept. 30, 1992)	Instantaneous peak flow	1,350	2,490	3,620	5,650	7,710	10,400
		1-day flow	688	1,190	1,680	2,530	3,380	4,460
		3-day flow	351	582	788	1,130	1,450	1,830
		7-day flow	203	319	417	568	702	858
01594000	Little Patuxent River at Savage (Oct. 1, 1939, to Sept. 30, 1958 Oct. 1, 1975, to Sept. 30, 1980, and Oct. 1, 1986, to Sept. 30, 1992; except peak flow, water years 1933, 1940-1966, 1968, 1972, 1975-80, and 1986-92)	Instantaneous peak flow	3,090	4,970	6,580	9,120	11,400	14,100
		1-day flow	1,390	2,330	3,160	4,490	5,710	--
		3-day flow	740	1,200	1,580	2,150	2,640	--
		7-day flow	439	685	833	1,180	1,430	--

1 Flow regulated by Liberty Reservoir since July 22, 1954.

2 From 1978-83, published as Cattail Creek at Roxbury Mills Road at Roxbury Mills, Md.

3 Flow regulated by Triadelphia Reservoir since June 27, 1942.

TABLE 25
MAGNITUDE AND FREQUENCY OF ANNUAL PEAK STREAMFLOW AT PARTIAL-RECORD AND SHORT-TERM CONTINUOUS-RECORD STREAMFLOW-GAGING STATIONS

Station no.	Station name	Discharge, in cubic feet per second, for indicated recurrence interval					
		2 yr	5-year	10-year	25-year	50-year	100-year
01587050	Hay Meadow Branch tributary at Poplar Springs[1]	104	190	270	408	544	710
01587070	South Branch Patapsco River at Woodbine	696	1,260	1,770	2,650	3,490	4,560
01589040	Rockburn Branch at Elkridge	295	575	848	1,340	1,830	2,480
01589080	Deep Run at Hanover	918	1,750	2,550	3,960	5,360	7,200
01590800	Patuxent River at Mullinix	670	1,210	1,710	2,560	3,380	4,410
01590900	Cabin Branch near Florence	563	1,020	1,440	2,170	2,860	3,740
01591200	Cattail Creek tributary at Carrs Mill	363	667	953	1,450	1,940	2,560
01591350	Cattail Creek near Cooksville[2]	816	1,420	1,970	2,900	3,840	5,020
01591375	Cattail Creek tributary at Daisy	282	518	740	1,120	1,490	1,960
01591475	Dorsey Branch near Knollwood	342	641	928	1,430	1,930	2,580
01593200	Little Patuxent River at Pine Orchard	522	990	1,440	2,240	3,050	4,090
01593300	Red Hill Branch near Columbia	540	1,030	1,510	2,380	3,260	4,410
01593350	Little Patuxent River tributary at Guilford Downs[1]	135	255	372	581	795	1,060
01593600	Middle Patuxent River near West Friendship	772	1,430	2,050	3,130	4,200	5,580
01593650	Middle Patuxent River tributary near Dayton	338	633	911	1,390	1,870	2,480
01593675	Middle Patuxent River tributary near Columbia	633	1,200	1,740	2,700	3,670	4,910
01593700	Middle Patuxent River tributary near Clarksville	495	941	1,370	2,150	2,920	3,930
01593710	Middle Patuxent River near Simpsonville	2,180	4,030	5,790	8,880	11,900	15,900
01594100	Hammond Branch at Scaggsville	308	603	900	1,440	1,990	2,730
01594200	Hammond Branch near Laurel	516	998	1,470	2,330	3,200	4,350
01594395	Dorsey Run at Jessup	507	983	1,450	2,300	3,160	4,290

1 Peak-flow partial-record streamflow-gaging station and estimates were computed by Log-Pearson type III distribution from 11 years of annual peak-discharge record during 1966-76, adjusted by regional long-term/short-term flood-frequency-curve ratios (Carpenter, 1980, p. 34).

2 Continuous-record streamflow-gaging station and estimates were computed by log-Pearson type III distribution from four years of continuous record during 1978-81, weighted by peak-flow estimation equations (Carpenter, 1983, p. 20).

Maps showing flood-prone areas of Howard County were completed in 1973 using a step-backwater method of analysis (Carrigan, 1974) in response to a recommendation by the U.S. Congress for minimizing flood losses. Although the exact position of flood boundaries cannot be predicted, the maps serve as a useful guide to potential flood hazards.

Low Flow

A comprehensive understanding of low streamflows is essential for planning public and industrial water supplies, instream dilution and disposal of wastewater, and maintenance of suitable habitat for aquatic biota. Many water-quality standards are based on the 7-day, 10-year low-flow ($7Q_{10}$), defined as the lowest average of daily mean flows during 7 consecutive days, having a recurrence interval of 10 years. Daily mean flows can be equal to or less than the $7Q_{10}$ value more frequently than once every 10 years, but those flows are not sustained for 7 consecutive days.

Low-flow data that were collected for at least 10 years at continuous-record gaging stations on nonregulated streams were fitted to the log-Pearson type III distribution to obtain discharges for duration periods of 7, 14, 30, 60, and 120 consecutive days and for recurrence intervals of 2, 5, and 10 years, and, when possible, for 20 and 50 years (table 26). Differences in low flows among the stations in table 26 are due mainly to differences in watershed area, but hydrogeologic factors and land use are also factors governing the availability and transmission of ground water to the streams. The values in table 26 may be graphed as in figure 29, which shows the magnitude and frequency of annual low flows in the Little Patuxent River at Guilford.

Low-flow characteristics for partial-record gaging stations are obtained by regressing measured base flows at the partial-record station against concurrent streamflows at a nearby continuous-record station (Riggs, 1972) as in figure 30 (The linear regression is only valid for the base-flow regime). The necessary statistical parameters of the flow-frequency distribution at the partial-record site are derived from those at the continuous-record site using the regression relationship (Stedinger and Thomas, 1985) and the desired low-flow characteristics are computed. In the case of Dorsey Branch near Knollwood, shown in figure 30, the same result (0.4 ft^3/s) is obtained from the regression equation, setting X equal to $7Q_{10}$ of the continuous-record station as by the procedure used; however,

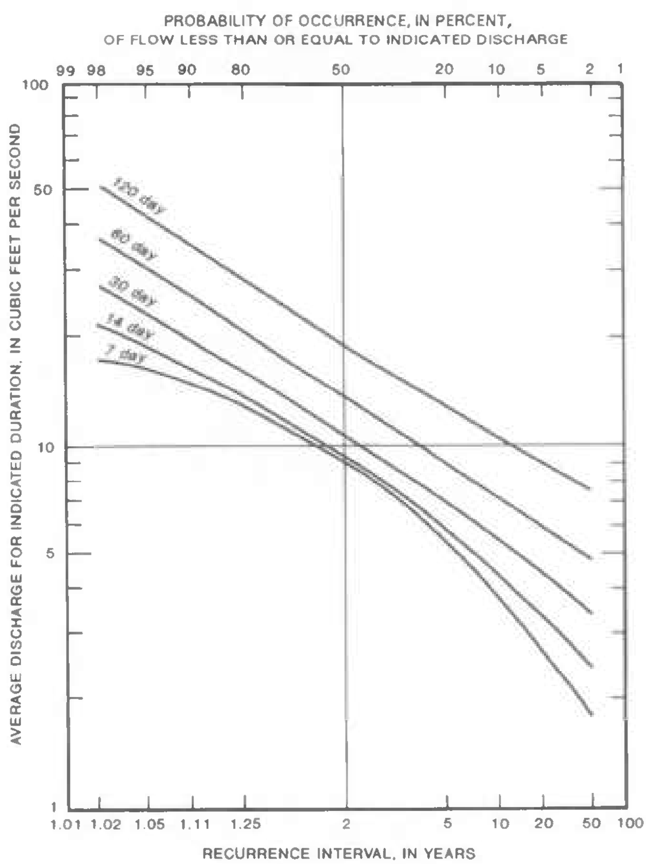


FIGURE 29.—Magnitude and frequency of annual low flows of the Little Patuxent River at Guilford, water years 1933–91. Period of record is water years 1933–90.

TABLE 26
MAGNITUDE AND FREQUENCY OF ANNUAL LOW FLOW AT CONTINUOUS-RECORD GAGING STATIONS

[--, Period of record insufficient for reliable estimate]

Station no.	Station name (period of record)	Annual minimum n-day flow	Discharge, in cubic feet per second, for indicated recurrence interval				
			2-year	5-year	10-year	20-year	50-year
01587500	South Branch Patapsco River at Henryton (April 1, 1950, to March 31, 1980)	n = 7	20	9.3	5.3	3.0	--
		14	20	10	6.7	4.4	--
		30	21	12	8.9	6.7	--
		60	26	16	12	9.3	--
		120	32	22	17	15	--
01591000	Patuxent River near Unity (April 1, 1946, to March 31, 1992)	n = 7	8.4	4.4	2.8	1.8	--
		14	8.7	4.9	3.4	2.5	--
		30	9.4	5.8	4.5	3.6	--
		60	11	7.2	5.6	4.5	--
		120	15	10	8.2	6.9	--
01591400	Cattail Creek near Glenwood[1] (April 1, 1980, to March 31, 1992)	n = 7	5.2	3.4	2.7	--	--
		14	5.7	3.7	3.0	--	--
		30	6.2	4.1	3.4	--	--
		60	7.2	4.9	4.1	--	--
		120	9.6	6.4	5.2	--	--
01591500	Cattail Creek at Roxbury Mills (April 1, 1946, to March 31, 1956)	n = 7	9.1	5.8	4.5	--	--
		14	9.6	6.2	4.8	--	--
		30	11	7.2	5.6	--	--
		60	13	8.8	6.9	--	--
		120	17	12	9.1	--	--
01592000	Patuxent River near Burtonsville (April 1, 1914, to March 31, 1942; flow regulated by Triadelphia Reservoir since June 27, 1942)	n = 7	31	16	11	7.6	--
		14	34	18	12	8.3	--
		30	43	23	16	11	--
		60	52	29	20	14	--
		120	66	39	28	20	--
01593500	Little Patuxent River at Guilford (April 1, 1933, to March 31, 1992)	n = 7	9.0	5.3	3.7	2.7	1.7
		14	9.3	5.7	4.3	3.3	2.4
		30	10	6.8	5.3	4.3	3.4
		60	14	8.9	7.1	5.9	4.8
		120	19	13	10	8.8	7.3
01594000	Little Patuxent River at Savage (April 1, 1941, to March 31, 1958, April 1, 1977, to March 31, 1980, and April 1, 1987, to March 31, 1992)	n = 7	22	14	11	9.2	--
		14	24	15	12	10	--
		30	28	18	14	11	--
		60	35	23	18	15	--
		120	48	32	26	21	--

[1]From 1978-83, published as Cattail Creek at Roxbury Mills Road at Roxbury Mills, Md.

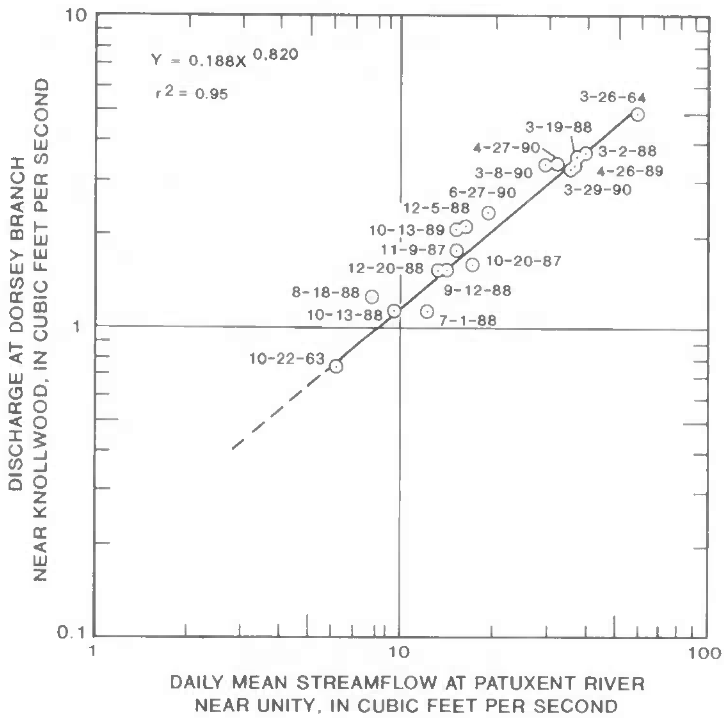


FIGURE 30.—Relation of base flow at Dorsey Branch near Knollwood and concurrent daily mean flow of the Patuxent River near Unity. Dates of flow measurements of Dorsey Branch are shown with points.

Stedinger and Thomas reported that simple regression frequently overestimates estimates of low flows. Estimates of 7-day low flows for reeurrence intervals of 2 ycars ($7Q_2$) and 10 years ($7Q_{10}$) at the partial-reeord stations are listed in table 27.

The number of base-flow measurements used to estimate low flow at the partial-rccord stations ranges from 12 to 28. Precision of estimates can be improved with additional measurements at the stations, but additional improvement becomes negligible with more than 20 measurements (Stedinger and Thomas, 1985, p. 18). Precision is also affected by the distanee of extrapolation from the minimum observed diseharge to thc $7Q_2$ and $7Q_{10}$.

The greatest (on a unit-area basis) $7Q_{10}$ flows, ranging from 0.162 to 0.057 (ft^3/s)/mi^2, occur in streams in the Cattail Creek and Middle Patuxent River basins, located in central Howard County (fig. 31). The lowcst low flows oceur in basins in the eastern part of thc county, where $7Q_{10}$ ranges from 0.113 to 0.0 (ft^3/s)/mi^2. In the western part of the eounty $7Q_{10}$ ranges from 0.074 to 0.029 (ft^3/s)/mi^2. The distribution of 7-day, 2-year low flows is similar, if not quite as pronouneed.

The small magnitude of low flows in eastern Howard County is primarily related to geologieal faetors, but may also refleet the effects of urban development (fig. 32). Post-development $7Q_2$ and $7Q_{10}$ of the Little Patuxent River at Guilford deereased from 0.241 and 0.130 (ft^3/s)/mi^2, respeetively, to 0.234 and 0.111 (ft^3/s)/mi^2. This reduetion of ground-water diseharge (for that is what provides most of the streamflow during the low-flow periods) also steepens the flow-duration curve, as already discussed and shown in figurc 28.

TABLE 27
ESTIMATED 7-DAY, 2-YEAR AND 7-DAY, 10-YEAR LOW FLOWS
AT PARTIAL-RECORD STATIONS

[ft^3/a, cubic feet per aecond; $(ft^3/a)/mi^2$, cubic feet per aecond per aquare mile]

Station no.	Station name	7-day, 2-year low flow (ft^3/a)	7-day, 2-year low flow $[(ft^3/s)/mi^2]$	7-day, 10-year low flow (ft^3/a)	7-day, 10-year low flow $[(ft^3/a)/mi^2]$
01587070	South Branch Patapaco River at Woodbine	3.0	0.264	0.8	0.067
01589040	Rockburn Branch at Elkridge	.4	.111	0.0	0.000
01589080	Deep Run at Hanover	2.1	.119	.6	.032
01590800	Patuxent River at Mullinix	1.5	.143	.3	.029
01590900	Cabin Branch naar Florence	2.4	.293	.6	.074
01591200	Cattail Creek tributary at Cerra Mill	1.2	.309	.5	.129
01591350	Cattail Creek near Cooksville[1]	2.7	.221	.9	.110
01591375	Cattail Creek tribuary at Daiay	1.0	.327	.4	.141
01591475	Dorsey Branch near Knollwood	1.1	.288	.4	.115
01593200	Littla Pauxent River at Pine Orchard	2.3	.327	.8	.113
01593300	Rad Hill Branch near Columbia	1.0	.172	.2	.037
01593600	Middle Patuxent River naar West Friendship	3.5	.311	1.6	.138
01593650	Middle Patuxent River tributary near Dayton	1.2	.282	.6	.141
01593675	Middle Patuxent River tributary near Columbia	2.2	.247	.5	.057
01593700	Middle Patuxent River tributary near Clarkavilla	1.6	.251	.4	.072
01593710	Middle Patuxent River near Simpaonvilla[2]	13.0	.272	3.6	.075
01594100	Hammond Branch near Scaggsville	.8	.260	.3	.109
01594200	Hammond Branch near Laurel	1.1	.162	.3	.046
01594395	Doraey Run at Jeaaup	.4	.060	.1	.019

[1] Opereted as a continuous-record gaging station.

[2] Opereted aa e continuoua-record geging station.

STREAMFLOW SIMULATION

Simulation of peak streamflow based on real or hypothetical rainfall data can facilitate flood evaluation through analysis of the timing of concentration of tributary runoff, or the effects of changes in the watershed or main channel. By providing a means of predicting peak streamflow behavior, the simulation models help planners to mitigate flood damage.

Rainfall–Runoff Model

The HEC-1 (Hydrologic Engineering Center) model (U.S. Army Corps of Engineers, 1987) was used to simulate the surface-runoff response of three river basins—the South Branch Patapsco River at Henryton, the Patuxent River near Unity, and the Little Patuxent River at Guilford (fig. 22)—to design rainfall durations of selected frequencies from 2 to 100 years. Homogeneity of those basin characteristics that can affect peak flows and basin response to rainfall was assumed; infiltration rates and rainfall were considered to be evenly distributed within the basin and were modeled as basin averages. The model components are based on mathematical relations representing individual meteorologic, hydrologic, and hydraulic processes that result in surface runoff.

Precipitation amounts (hyetographs) were calculated for individual storms from rainfall records and used as input for runoff calculations. Rainfall not contributing to runoff (con-

TABLE 27—CONTINUED

Continuous-record gaging station used for regression analysis	Coefficient of determination (r^2)	Number of measurements	Minimum observed discharge used in the regression analysis (ft^3/s)	Partial-record gaging station no.
South Branch Patapsco River at Henryton	0.94	21	2.14	01587070
Do.	.94	15	.33	01589040
Little Patuxent River at Guilford	.93	19	.78	01589080
Patuxent River near Unity	.93	15	1.32	01590800
South Branch Patapsco River at Henryton	.94	20	1.50	01590900
Do.	.94	23	.16	01591200
Patuxent River near Unity	.96	367	1.40	01591350
Do.	.85	23	.52	01591375
Do.	.95	18	.75	01591475
South Branch Patapsco River at Henryton	.88	20	1.01	01593200
Do.	.91	14	.93	01593300
Patuxent River near Unity	.93	26	.64	01593600
Northwest Branch Anacostia River near Colesville	.96	9	.69	01593650
South Branch Patapsco River at Henryton	.92	15	1.80	01593675
Do.	.94	19	1.10	01593700
Do.	.89	17	10.00	01593710
Little Patuxent River at Guilford	.93	13	.27	01594100
Do.	.91	15	.57	01594200
Little Patuxent River at Savage	.88	8	.93	01594395

sidered lost) was calculated by a precipitation-loss subroutine that simulated interception, depression storage, and infiltration. The difference between total rainfall and precipitation loss is rainfall excess. The hyetograph of rainfall excess is transformed by the model (which assumes linear storage) into a discharge hydrograph using the instantaneous unit-hydrograph method (Clark, 1945). A unit hydrograph is a hydrograph showing a volume of 1 in. of storm runoff that results from a rainstorm of specified duration that occurs uniformly over a drainage basin. For rainfalls of similar magnitude and duration falling on different drainage basins, differences in the unit hydrographs are due to differences in physical characteristics of the basins. Clark's method assumes the unit hydrograph is characteristic for a basin and is not storm-dependent, and that runoff caused by precipitation excess from different storms can be linearly superposed.

Input

Data required by the model include hourly streamflow for the observed peak and recession period, hourly rainfall from the storm responsible for the peak, and basin characteristics obtained from topographic maps of the watershed. Daily discharges at the three gaging stations were reviewed to select runoff events for calibration. The period from mid–November to March was excluded to avoid complications caused by frozen ground, river ice, and snowmelt. Model simulations are limited to a single storm, because no provision is made for soil-moisture recovery from the first storm, which diminishes initial

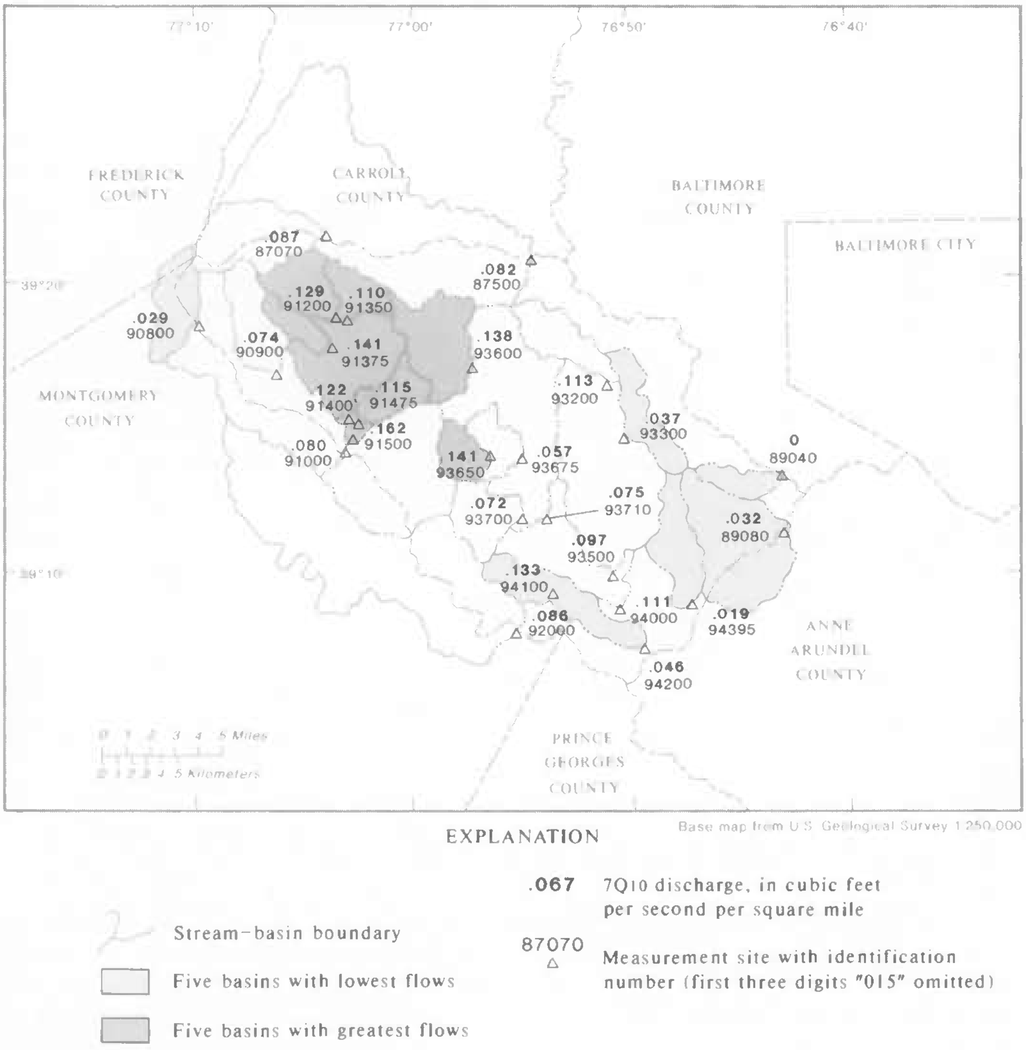


FIGURE 31.—Areal variation of 7-day, 10-year low flows (based on discharge per square mile; values from table 27). The five basins having the highest and the five basins having the lowest flows are highlighted.

loss at the start of the second storm. A flow chart (fig. 33) shows the input and output of the HEC-1 model.

Rainfall data were obtained from the Climatological Data and Hourly Precipitation Data publications of the U.S. Department of Commerce (U.S. Weather Bureau, 1955–69b; U.S. National Oceanic and Atmospheric Administration, 1970–90). Representative precipitation stations were selected from the stations shown in figure 2. The stations are weighted, and the weights adjusted to obtain a match between the computed and the observed hydrographs. Rainfall of short duration and moderate to high intensity is optimum for modeling purposes.

The time-area record defines the cumulative area that contributes runoff to the basin outlet over time and provides a means to translate runoff from subareas to the basin outlet.

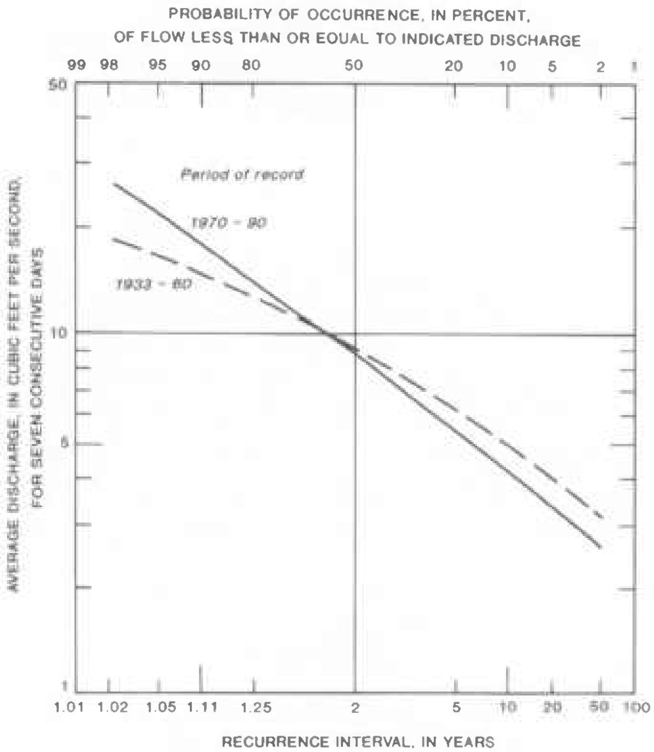


FIGURE 32.—Effect of development of the Columbia area on low flow in the Little Patuxent River at Guilford. The pre-development period includes water years 1933–60, and the post-development period includes water years 1970–90.

Each basin was divided into zones representing equal traveltime to the basin outlet. The area of each zone was measured on 1:24,000-scale topographic maps and tabulated cumulatively from the gage to the basin divide.

Initial base flow, recession base flow, and the recession constant are determined from separation of the total runoff hydrograph. Initial base flow is the discharge at the time of hydrograph rise; recession base flow is the discharge at the time when base flow once more becomes the dominant component of streamflow. The recession constant is the exponential decay rate that is assumed to be representative of the basin.

The Clark (1945) unit-hydrograph method for generating synthetic streamflows is included as a part of the HEC-1 model. This method uses time of concentration (Tc) and a storage coefficient (R), in addition to the time-area record, to define an instantaneous unit hydrograph. Time of concentration is the time required for runoff from the most distant portion of the drainage basin to reach the basin outlet. The storage coefficient is a time-related proportionality constant relating storage in the basin and discharge at the basin outlet, thus indicating channel-storage capacity.

The parameters for the Clark synthetic unit hydrograph (initial loss, STRTL; constant loss rate, CNSTL; time of concentration, Tc; and storage coefficient, R) are determined by the model during the calibration process and are then used to model hypothetical rainfalls. The initial and uniform method was used in this study; this method uses STRTL and

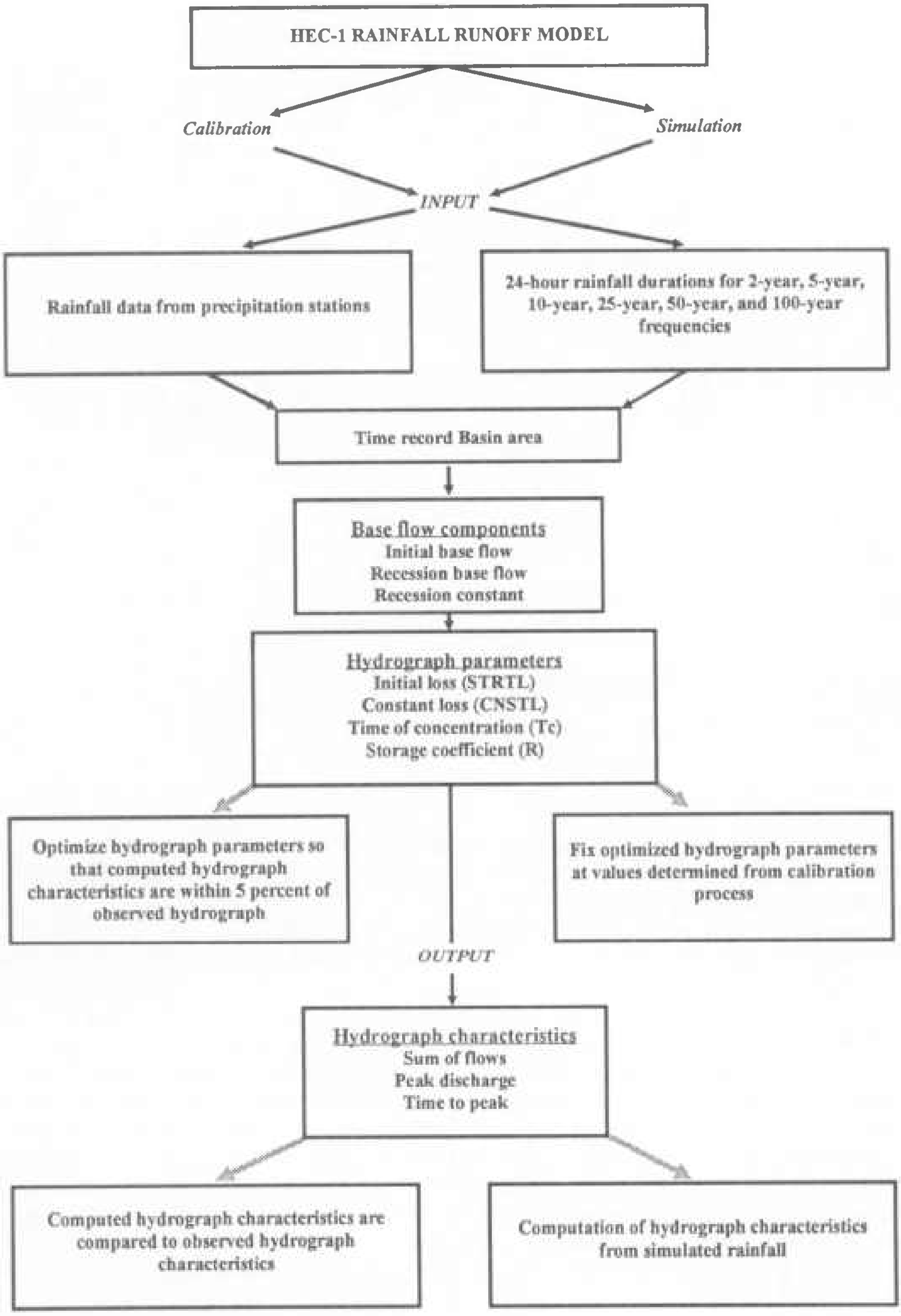


FIGURE 33.—Flow chart of HEC-1 rainfall-runoff model.

CNSTL to calculate precipitation loss. All precipitation is diverted from the hydrograph until initial loss is satisfied. After the initial loss is satisfied, a portion of the precipitation is diverted from the hydrograph at the specified constant rate, CNSTL. Precipitation excess is the remainder after losses are deducted from total precipitation.

Output

Output from the HEC-1 model consists of optimized values of the hydrograph parameters STRTL, CNSTL, Tc, and R; a tabulation of the computed outflow-discharge hydrograph, including sum of flows and peak discharge compared to the observed discharge hydrograph; and a graphic display of the computed hydrograph superimposed on the observed hydrograph (fig. 34). Accuracy of the modeled hydrograph was evaluated by

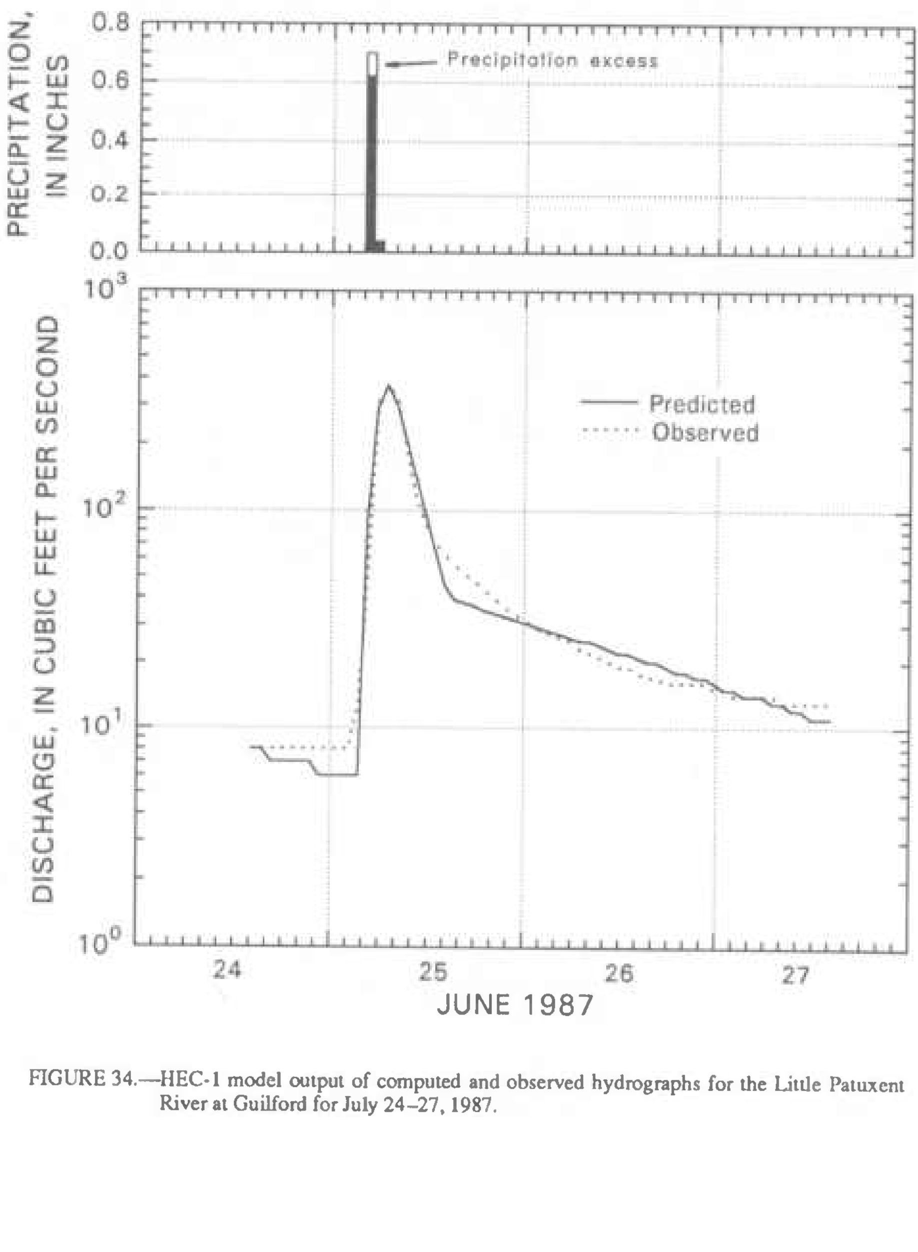


FIGURE 34.—HEC-1 model output of computed and observed hydrographs for the Little Patuxent River at Guilford for July 24–27, 1987.

means of three computed hydrograph characteristics—sum of flows (V), peak discharge (Qp), and time to peak (Tp)—and visual comparison of the hydrographs. The sum of flows represents the summation of incremental discharges during the modeled time period and indicates the total volume of flow during the period.

Calibration

Precipitation and streamflow data for six rainfall events at each station were used to calibrate the model. Observed discharge hydrographs that were chosen for calibration were isolated events that exhibited single peaks. Acceptable values of STRTL, CNSTL, Tc, and R for each observed rainfall-runoff event were obtained from the model. Parameter values were then adjusted manually and held constant until the computed sum of flows and the peak discharge were within 5 percent of observed conditions and time-to-concentration deviation from the observed was minimized. Median parameter values for the six rainfall-runoff events were then used as starting points to estimate average values for the basin. The model was used to adjust parameter values until computed cumulative flows were within 5 percent of observed cumulative flows. The final computed basin-average parameters, the percentage of error in flows, and differences in time to peak are presented in table 28.

Results of Simulations

The HEC-1 model was used to synthesize hydrographs for the three streams for selected rainfall frequencies of 2 to 100 years and rainfall duration of 24 hours, using the basin-

TABLE 28
HEC-1 MODEL HYDROGRAPH PARAMETERS AND DIFFERENCES BETWEEN OBSERVED AND COMPUTED VALUES

[STRTL, initial loss (inches); CNSTL, constant loss rate (inches per hour); Tc, time of concentration (hours); R, storage coefficient; V, sum of flows; Qp, peak discharge; Tp, time to peak]

Station name	STRTL	CNSTL	Tc	R	Percent error		
					V	Qp	Tp
South Branch Patapsco River at Henryton	1.62	0.15	9.50	4.05	1.05	1.07	1.25
Patuxent River near Unity	1.98	.18	5.45	3.19	-.65	-.90	3.44
Little Patuxent River at Guilford	1.38	.11	9.46	9.26	.10	-.12	-6.77

average parameters determined during calibration. Data for rainfall frequency and duration were from the U.S. Weather Bureau (1961) and the U.S. National Oceanic and Atmospheric Administration (1977). Estimated 24-hour rainfall depths are:

Frequency (years)	*Depth (inches)*
2	3.2
5	4.2
10	5.1
25	5.5
50	6.3
100	7.2

Results of the simulation are presented in table 29.

Peak flows produced by the HEC-1 model (table 29) are similar to the observed flows (table 24) for recurrence intervals of 2, 5, and 10 years, but are lower than the observed flows at recurrence intervals of 25, 50, and 100 years. Several factors may contribute to this disparity. The HEC-1 model is based on both rainfall distributions and relations between rainfall and runoff, whereas peak flows in table 24 were estimated from a log-Pearson type III frequency distribution of observed annual peak flows. The peak-flow frequency distribution could include observed annual-peak flows generated from storms of a greater magnitude than the 100-year rainfall recurrence interval, which are systematically excluded from HEC-1 peak-flow simulations; the storm of June 21–23, 1972, had a rainfall recurrence interval estimated to exceed 100 years. Similarly, some of the observed annual-peak flows were generated by storms that produced rainfall for periods longer than 24 hours, whereas a 24-hour duration was used for the simulation. For example, the duration of precipitation from the storm of June 21–23, 1972, ranged from 49 to 52 hours at three climatological stations near Howard County, and the duration of rainfall from the storm of September 22–26, 1975, ranged from 36 to 53 hours. Another possible source of difference between modeled and observed peak-flows is that the isolated peaks used to calibrate the model occurred under comparatively dry soil conditions that enhanced ab-

TABLE 29
PEAK DISCHARGE AT THREE CONTINUOUS-RECORD STREAMFLOW-GAGING STATIONS SIMULATED BY THE HEC-1 RAINFALL-RUNOFF MODEL

Station name	Discharge, in cubic feet per second, for indicated recurrence interval					
	2-year	5-year	10-year	25-year	50-year	100-year
South Branch Patapsco River at Henryton	2,480	6,010	8,740	11,000	13,500	15,700
Patuxent River near Unity	2,210	4,970	7,080	8,790	10,800	12,400
Little Patuxent River at Guilford	1,160	2,640	3,910	4,860	5,780	6,820

sorption of rainfall and, consequently, decreased the quantity of runoff available for simulated flow peaks.

SURFACE–WATER QUALITY

Surface water serves a wide variety of purposes in Howard County, but the quality of the water can determine or limit its uses. Water-quality requirements for industrial uses commonly are less stringent than for potable supply. Two industries in the county use stream water to cool machinery and wash dairy equipment; the water is treated onsite before use. Where treated wastewater is discharged to streams, streamflow must be sufficient to provide adequate dilution and aeration in order to prevent degradation of the quality of the stream. Stream-water-quality data collected during the period 1988–89 are summarized in table 30. Maximum Contaminant Levels (MCL's) and Secondary Maximum Contaminant Levels (SMCL's) for public drinking water, as well as acute freshwater aquatic-life standards, are included in table 30. Freshwater aquatic-life standards are classified as acute (defined as the contaminant level at which stress to aquatic life begins) or chronic (defined as the contaminant level at which death of a species would occur).

Methods of Sample Collection and Analysis of Surface Water

Most of the discussion of surface-water-quality in this section is based on 72 samples collected at 24 stream sites during three base-flow periods: December 1988, April 1989, and September–October 1989 (fig. 35) and stream-bottom materials collected at 24 sites during September–October 1989. The drainage basins upstream of the sampling sites include both small tributaries and major streams with areas ranging from 3.12 to 285 mi^2. Seventeen of the basins are predominantly rural with low-density residential and agricultural areas, six are predominantly suburban residential, and the dominant land use upstream from Dorsey Run at Jessup is commercial and industrial. The discussion in this section is limited to base-flow conditions; characterization of storm-water quality is beyond the scope of this report. On the basis of flow-duration information for the gaging stations on the Patuxent River near Unity and the Little Patuxent River at Guilford (fig. 28), flow conditions during sampling were

Sampling date	*Flow-duration exceedence (percent)*
December 1988	80
April 1989	45
September–October 1989	75

Samples were collected and preserved in the field according to methods prescribed by the U.S. Geological Survey (1977) and were analyzed for commonly occurring dissolved inorganic ions and nutrients by the U.S. Geological Survey Central Laboratory using standard methods (Fishman and Friedman, 1989; Wershaw and others, 1987). Bottom materials dredged from the streambed and passed through a 2-millimeter sieve were analyzed for trace elements and pesticides. The data are presented by Dine and others (1992).

TABLE 30
SUMMARY STATISTICS OF STREAM-WATER QUALITY

[Based on analyses of 72 samples. Concentrations are in milligrams per liter. µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; --, no standard established]

Property or constituent	Minimum	Maximum	Median	Mean	Water-quality standards[1]		
					Drinking water		Freshwater aquatic life[4]
					MCL[2]	SMCL[3]	
Specific conductance (µS/cm at 25°C)	73	373	141	196	--	--	--
pH	6.4	9.1	7.2	7.2	--	6.5-8.5	6.5-9.0
Water temperature (°C)	0	22.5	13.0	11.1	--	--	--
Dissolved oxygen	6.4	14.8	11.1	10.9	--	--	<5.0
Hardness (as $CaCO_3$)	28	140	54	62	--	--	--
Total alkalinity (as $CaCO_3$)	13	100	34	41	--	--	<20
Calcium, dissolved	6.4	41.0	13.0	16.0	--	--	--
Magnesium, dissolved	2.9	8.5	5.2	5.2	--	--	--
Sodium, dissolved	4.6	50.0	9.4	11.7	--	--	--
Potassium, dissolved	1.2	16.0	2.2	2.4	--	--	--
Sulfate, dissolved	2.0	25.0	8.0	9.3	--	250	--
Chloride, dissolved	9.3	41.0	19.0	21.7	--	250	--
Fluoride, dissolved	<.1	.2	.1	.1	4.0	--	--
Silica, dissolved	.45	22.0	8.4	9.1	--	--	--
Total dissolved solids (residue at 180°C)	50	231	114	119	--	500	--
Nitrate plus nitrite, total (as N)	.1	7.5	2.5	2.7	10	--	--
Phosphorus, total (as P)	<.01	3.5	.02	.17	--	--	--
Iron, total	.03	4.50	.26	.40	--	--	--
Iron, dissolved	.01	.85	.07	.11	--	.3	1.0
Manganese, total	<.01	.40	.04	.06	--	--	--
Manganese, dissolved	.002	.37	.04	.06	--	.05	--
Total organic carbon (as C)	1.0	56.0	1.9	2.8	--	--	--

[1]Source: U.S. Environmental Protection Agency.
[2]Maximum Contaminant Level (MCL) is the maximum permissible concentration of a contaminant in water delivered to any user of a public water system. MCL's are enforceable and are based on effects on human health.
[3]Secondary Maximum Contaminant Levels (SMCL's) are established for constituents that can adversely affect the odor or appearance of water. SMCL's are not enforceable..
[4]Freshwater aquatic-life contaminant levels are the maximum concentrations of a contaminant in stream or lake water that will not have an adverse affect on aquatic life.

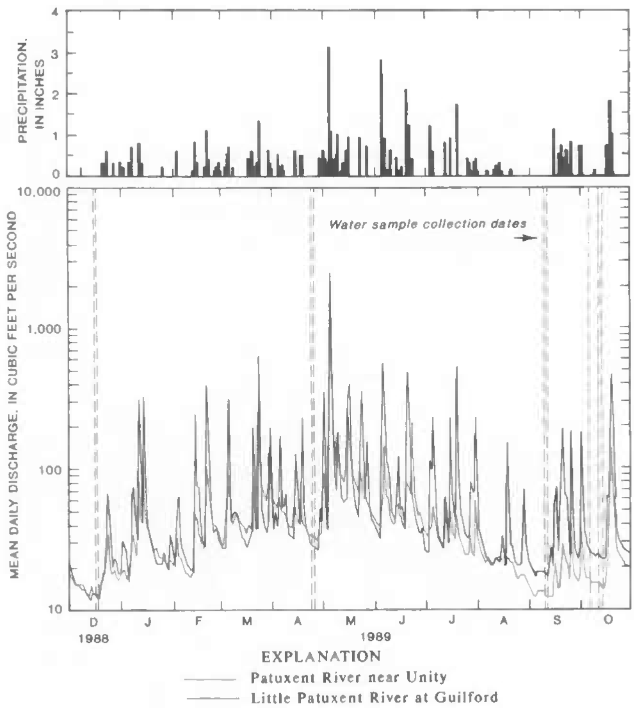


FIGURE 35.—Flow conditions during the December 1988 to October 1989 water-quality sampling period. Precipitation shown for Brighton Dam (U.S. National Oceanic and Atmospheric Administration, 1970–92).

Physical and Chemical Characteristics

Water quality of streams in Howard County depends to a large extent on the underlying geology and on land use and human activities. The water quality of the streams in the western part of Howard County differs from the quality of the streams in the eastern part of the county (figs. 36 and 37). The western group of sampling sites is characterized by agricultural and forested land with some residential development; the eastern group is characterized by commercial and urban-residential development. The sites were grouped as follows (see fig. 22 for locations):

Eastern Group	*Western Group*
Rockburn Branch at Elkridge	Patuxent River at Mullinix
Deep Run at Hanover	Cabin Branch near Florence
Red Hill Branch near Columbia	Patuxent River near Unity
Little Patuxent River at Pine Orchard	Cattail Creek tributary near Carrs Mill
Little Patuxent River at Guilford	Cattail Creek near Cooksville
Little Patuxent River at Savage	Cattail Creek tributary at Daisy
Hammond Branch near Laurel	Cattail Creek near Glenwood

Eastern Group—Continued

Dorsey Run at Jessup

Western Group—Continued

Dorsey Branch near Knollwood
Middle Patuxent River near West Friendship
Middle Patuxent River tributary near Columbia
Middle Patuxent River tributary near Clarksville
Middle Patuxent River near Simpsonville.

Sampling sites on the South Branch Patapsco River are not listed because the natural water quality has been altered by effluent discharged from sewage-treatment plants. Sites on regulated reaches of streams also are not listed.

The dissolved-mineral content is low in streams in the western part of the county and higher in streams in the eastern part, similar to the pattern for ground water. In contrast, concentrations of nitrate plus nitrite (as N), tend to be higher in the western streams, where agricultural fertilizers and individual septic systems are more prevalent.

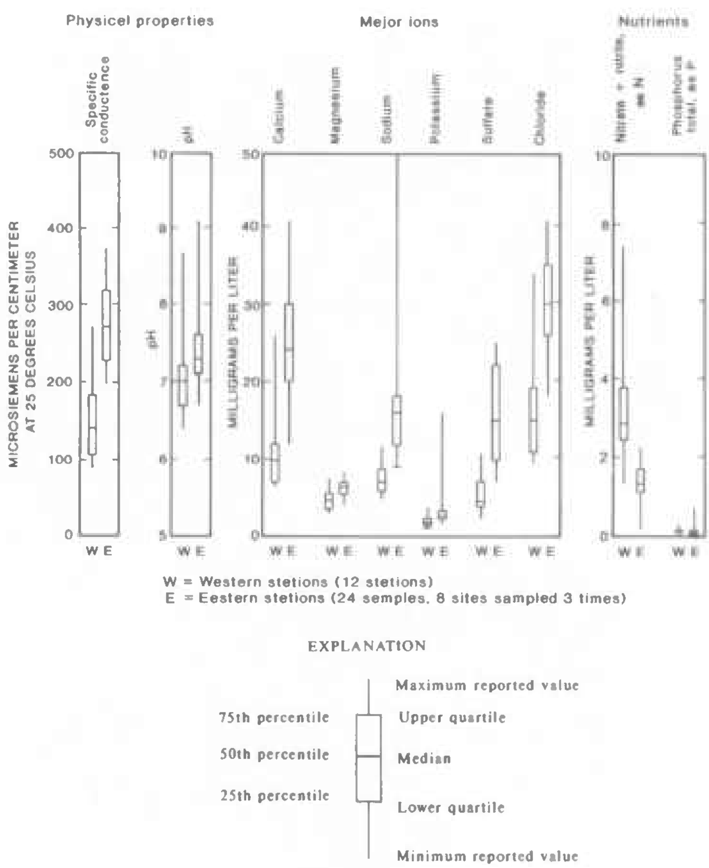
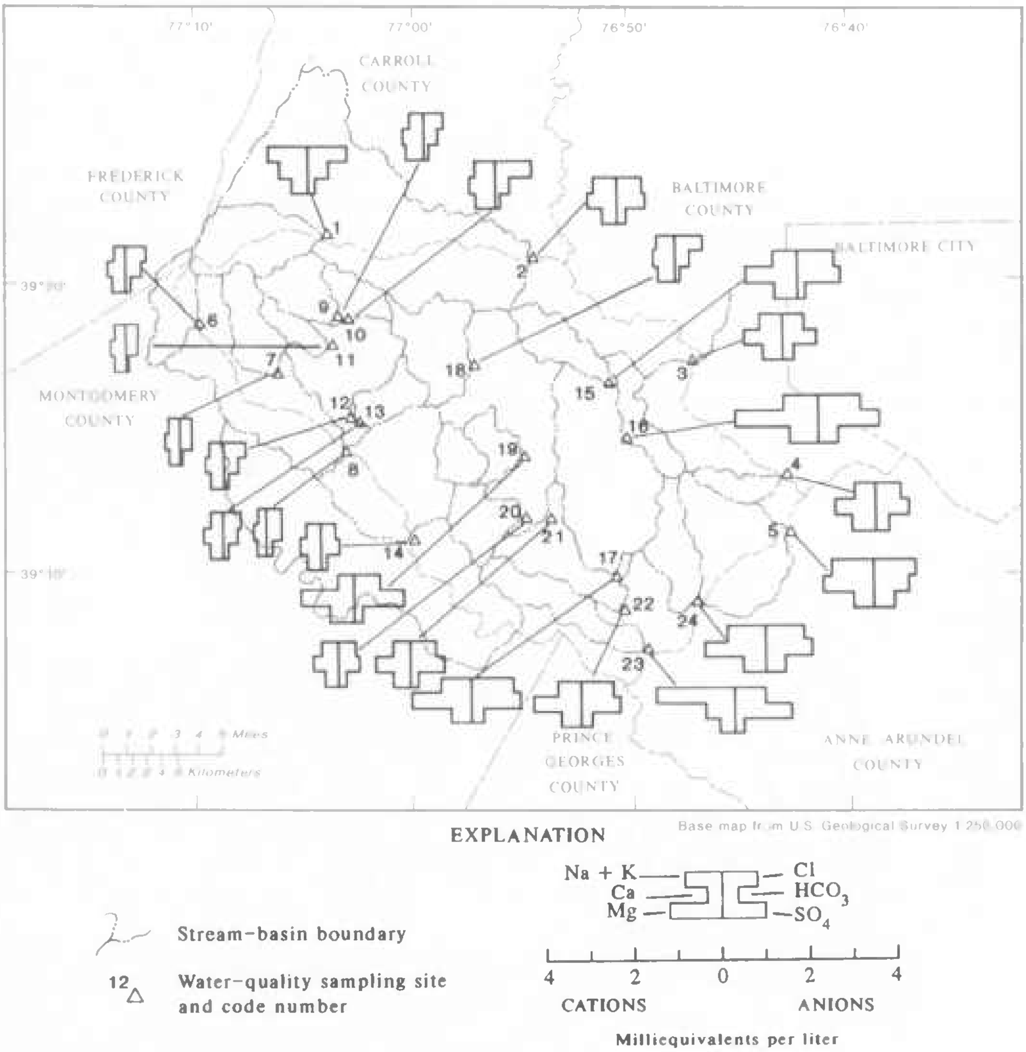


FIGURE 36.—Stream-water quality in eastern and western Howard County. Percentiles are for three samples collected at each of 8 eastern and 12 western groups (groups listed in text) during 1988–90.



CODE NUMBER	STATION NAME	CODE NUMBER	STATION NAME
1	South Branch Patapsco River at Woodbine	13	Dorsey Branch near Knollwood
2	South Branch Patapsco River at Henryton	14	Patuxent River below Brighton Dam near Brighton
3	Patapsco River at Hollofield	15	Little Patuxent River at Pine Orchard
4	Rockburn Branch at Elkridge	16	Red Hill Branch near Columbia
5	Deep Run at Hanover	17	Little Patuxent River at Guilford
6	Patuxent River at Mullinix	18	Middle Patuxent River near West Friendship
7	Cabin Branch near Florence	19	Middle Patuxent River tributary near Columbia
8	Patuxent River near Unity	20	Middle Patuxent River tributary near Clarksville
9	Cattail Creek tributary at Carrs Mill	21	Middle Patuxent River near Simpsonville
10	Cattail Creek near Cooksville	22	Little Patuxent River at Savage
11	Cattail Creek tributary at Daisy	23	Hammond Branch near Laurel
12	Cattail Creek near Glenwood	24	Dorsey Run at Jessup

FIGURE 37.—Major-ion concentrations in base flows. For each site, the median value of three samples collected during 1988–90 is shown.

Water from six small basins having somewhat uniform geology tends to be calcium-sodium-chloride-sulfate-bicarbonate type, except for the Little Patuxent River at Pine Orchard, which has a slightly lower percentage of sulfate and a slightly higher percentage of bicarbonate than the others (fig. 38). Analyses for ground-water sites within the basins are included in figure 38 for comparison. Not all of the ground-water points clump around the surface-water point; two factors may contribute to the differences. First, the geology underlying each basin is not completely homogeneous, and the ground-water quality may vary locally within the basin as a result. The quality of the water sampled at the stream station is a mix of ground-water sources. Second, the water chemistry may have evolved as the water traveled between the sampled well and the stream-sampling site, especially after discharging to the stream and entering different environmental conditions.

Specific conductance

Specific conductance is a function of the concentration of dissolved ions (fig. 39). The concentration normally varies with streamflow, because higher flows consist of a smaller proportion of base flow (ion-rich water, in comparison with storm runoff). Specific conductance is generally lower in streams in the western part of the county than in streams in the eastern part. Specific conductance ranges from 73 μS/cm in water from the Patuxent River below Brighton Dam near Brighton, to 373 μS/cm in water from the Red Hill Branch near Columbia.

pH

The pH of stream water ranges from 6.4 in the South Branch Patapsco River at Woodbine, Cabin Branch near Florence, and the Cattail Creek tributary at Daisy to 9.1 in Hammond Branch near Laurel. Precipitation is acidic, as measured over the period 1982–91 at Catoctin Mountain, Frederick County, ranging from 3.0 to 5.2 (Rice and others, 1993). Mineral solution in western Howard County is generally insufficient to completely neutralize acidic precipitation. In other areas of the county where the acid-neutralizing capacity of the rock and soil is higher, pH is 7, and in eastern Howard County it is even higher. The SMCL for pH is the range 6.5 to 8.5 for drinking water and 6.5 to 9.0 for freshwater aquatic life (U.S. Environmental Protection Agency, 1990, 1991a); most stream water in Howard County is within this range.

Dissolved oxygen

The dissolved oxygen concentration of water in contact with air and devoid of biological activity is a function of temperature and atmospheric pressure, and to a lesser degree, the concentration of other solutes. Chemical equilibrium frequently is not attained, however, because of biological activity: Organisms feeding on organic matter consume dissolved oxygen, and photosynthesizing flora replace it. All dissolved-oxygen concentrations measured in Howard County streams were above the freshwater aquatic-life standard minimum concentration of 5.0 mg/L (U.S. Environmental Protection Agency, 1991a).

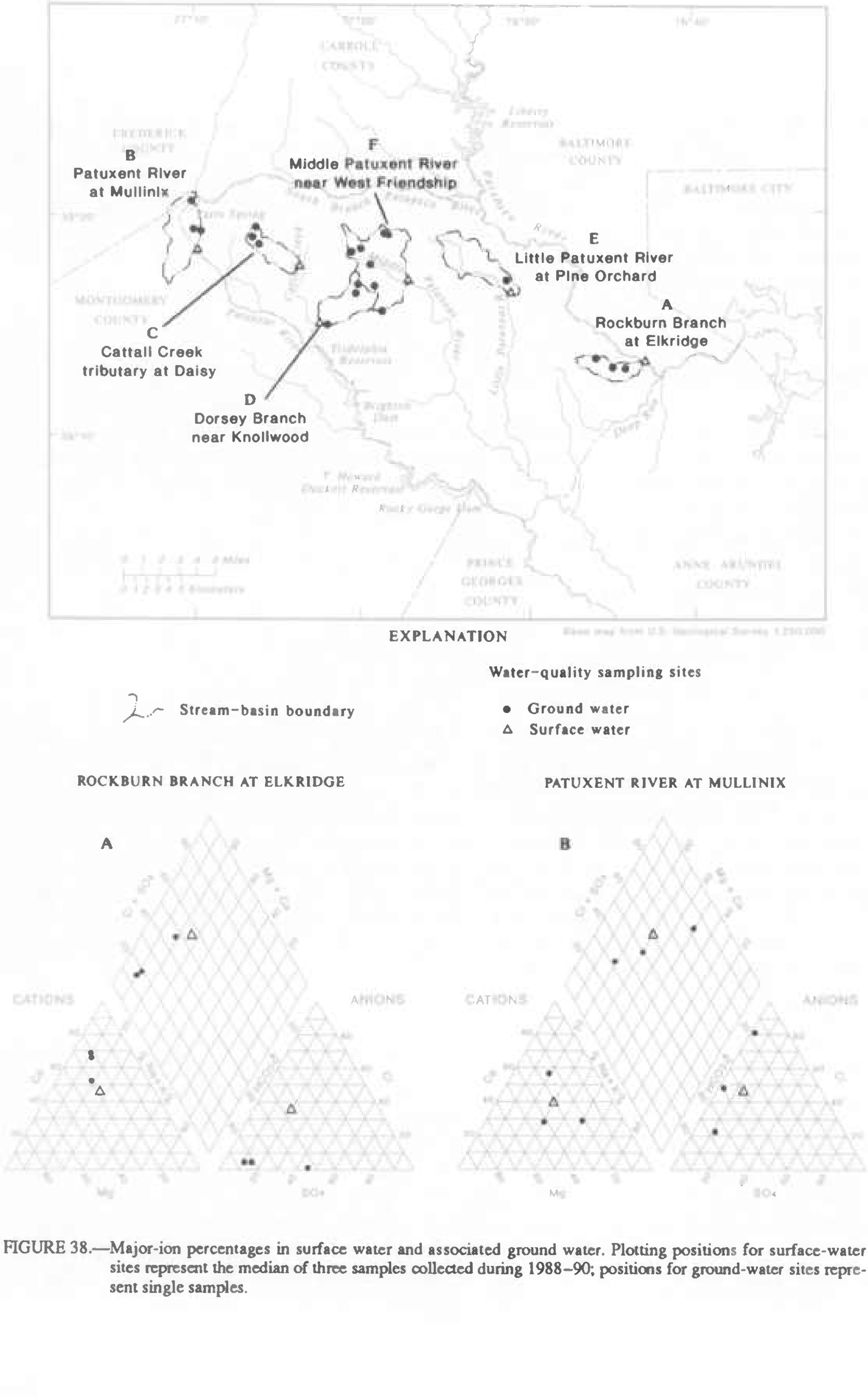


FIGURE 38.—Major-ion percentages in surface water and associated ground water. Plotting positions for surface-water sites represent the median of three samples collected during 1988–90; positions for ground-water sites represent single samples.

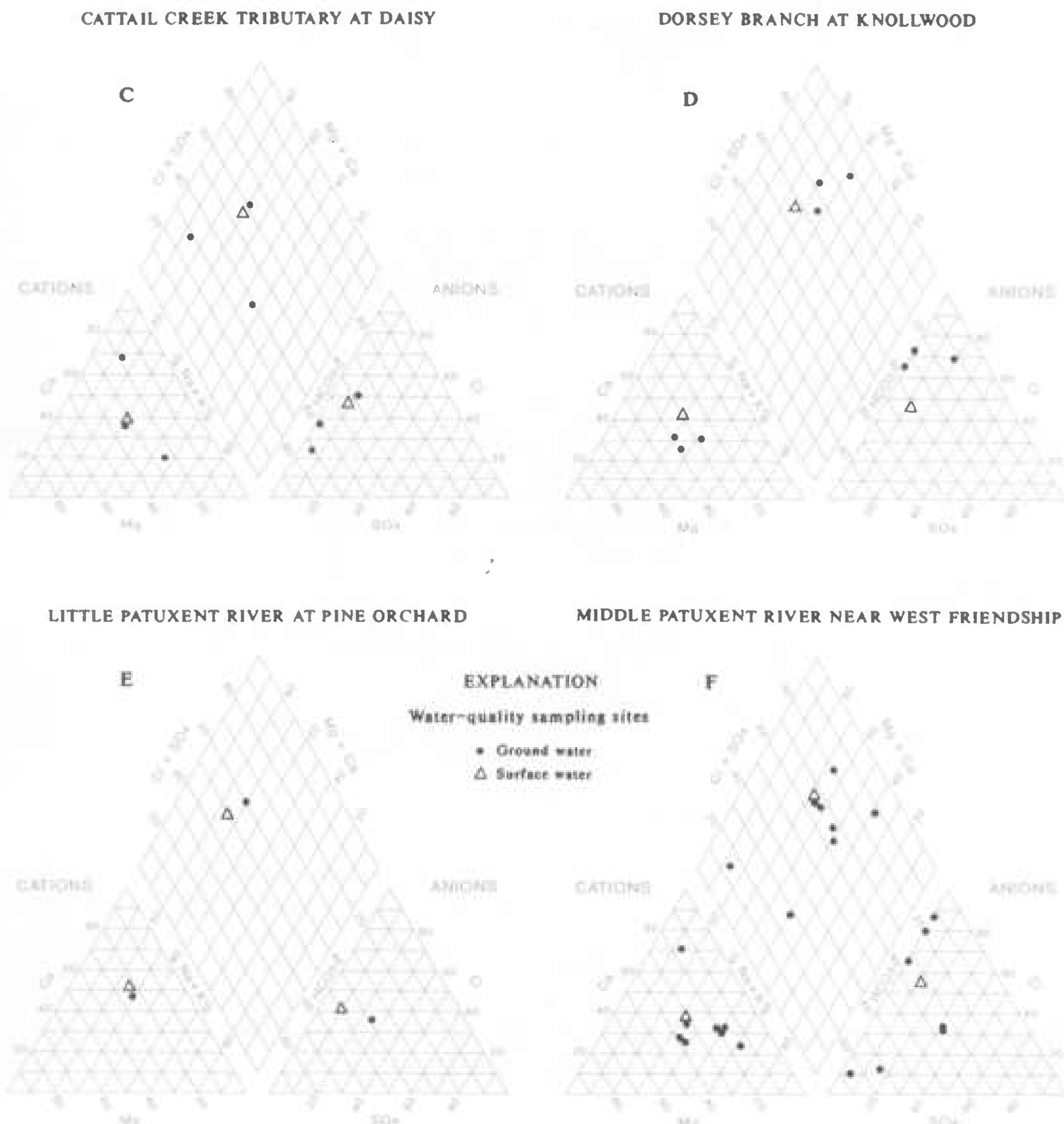


FIGURE 38.—Continued.

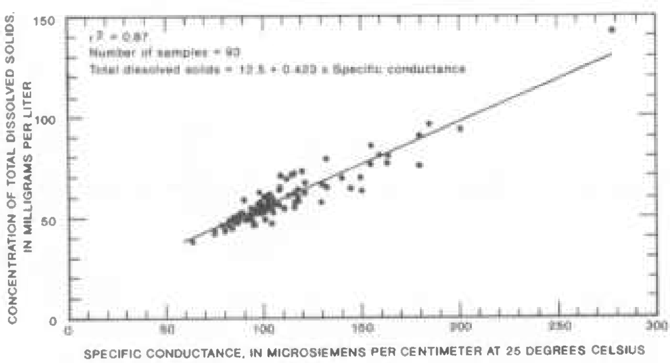


FIGURE 39.—**Relation between total dissolved solids concentration (sum of dissolved constituents) and specific conductance, South Branch Patapsco River at Henryton. Ninety-three measurements were made during the period 1954–1989.**

Hardness

Hard water can leave mineral deposits in pipes and plumbing fixtures, and requires additional soap for laundering. On the positive side, there is evidence that hard water provides some protection from heart disease (Neri and others, 1975). Hardness may be classified as (Collins and others, 1934):

Hardness, in mg/L $CaCO_3$	*Classification*
0 – 60	Soft
61 – 120	Moderately hard
121 – 180	Hard
Greater than 180	Very hard.

Hardness ranges from 28 mg/L in Cabin Branch near Florence, the Patuxent River near Unity, and the Cattail Creek tributary at Daisy to 140 mg/L in the Red Hill Branch near Columbia. Hardness of samples collected in the western part of the county, where mineral content of the water is low, was less than 50 mg/L, although three samples from the Middle Patuxent River tributary near Columbia averaged 96 mg/L, probably owing to the presence of the Cockeysville Marble located in the watershed. Hardness from water samples collected in the eastern part of the county exceeded 50 mg/L.

Alkalinity

Alkalinity is the capacity of water to react with and neutralize acid. Although several ions contribute to alkalinity, most is due to bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}), the latter becoming a larger proportion at higher pH. Analyses are reported as an equivalent concentration of $CaCO_3$. Streams in western Howard County have the lowest alkalinities. The lowest alkalinity, 13 mg/L as $CaCO_3$, is from Cabin Branch near Florence and at Cattail Creek near Cooksville, and the highest, 140 mg/L as $CaCO_3$, is from Hammond Branch near Laurel. Alkalinity of the Middle Patuxent River tributary near Columbia, where the Cockeysville Marble underlies part of the watershed, is higher than in neighboring stream basins.

Major ions

This group comprises calcium, magnesium, sodium, potassium, bicarbonate (discussed separately under alkalinity), chloride, sulfate, and fluoride. Concentrations of major ions and silica generally are lower in streams in the western part of the county than in streams in the eastern part. Chloride is present in all natural waters, but generally in low concentrations. The highest chloride concentrations (site averages ranging from 30 to 35 mg/L) are from Deep Run at Hanover, Cattail Creek near Cooksville, Little Patuxent River at Pine Orchard, Red Hill Branch near Columbia, and Dorsey Run at Jessup. The likely source of chloride in these streams is deicing salt applied to roads (fig. 40). The SMCL is 250 mg/L for sulfate and for chloride, and 500 mg/L for total dissolved solids; the MCL for fluoride is 4.0 mg/L (U.S. Environmental Protection Agency, 1991a). These limits were not exceeded at any sites.

Iron and manganese

Iron and manganese are common in the environment and are present in all of the streams in the county, but, under the prevailing pH-Eh conditions, most of the iron and manganese form insoluble oxides. The highest concentrations of dissolved iron and man-

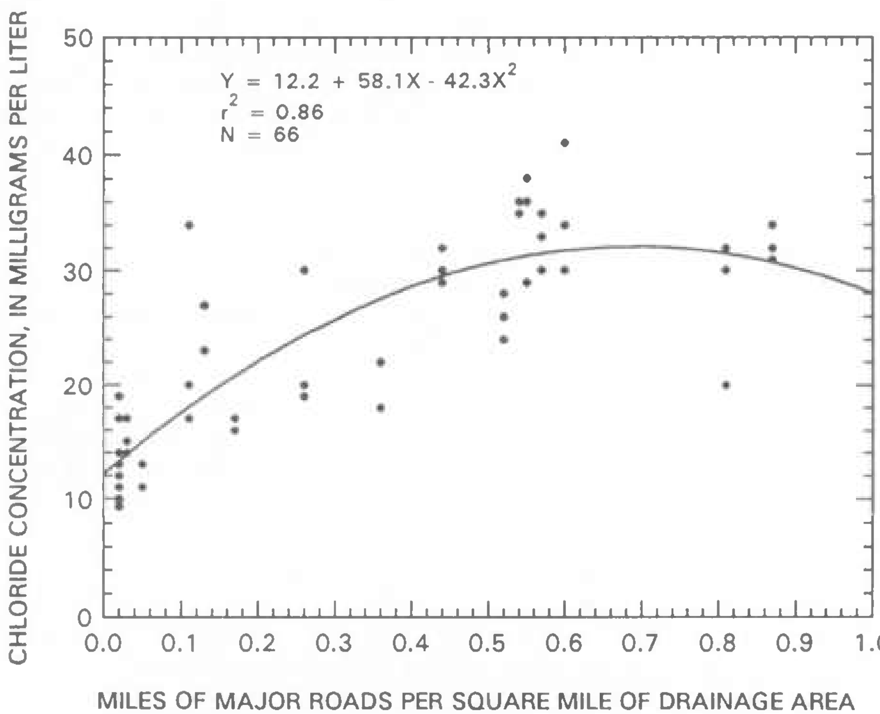


FIGURE 40.—The relation of chloride concentrations in streams and density of major roads in the drainage basins.

ganese are from Dorsey Run at Jessup (0.85 and 0.37 mg/L) and from Deep Run at Hanover (0.48 and 0.22 mg/L). The source of iron in these streams may be iron oxides and hydroxides in the Patuxent Formation, in addition to iron-bearing silicates in the Baltimore Complex and James Run Formation. The lowest concentrations of iron (0.02 mg/L) and manganese (0.007 mg/L), are from the South Branch Patapsco River at Woodbine. The SMCL's for dissolved iron and manganese in drinking water are 0.3 and 0.05 mg/L, respectively. The maximum limit of dissolved iron for freshwater aquatic life is 1.0 mg/L (U.S. Environmental Protection Agency, 1991a).

Total (unfiltered) iron and manganese concentrations are slightly lower in the western part of the county than in the eastern part. The lowest concentrations of total iron (0.03 mg/L) are in the South Branch Patapsco River at Woodbine, and the highest are in the Cattail Creek tributary at Carrs Mill (4.5 mg/L). The lowest concentrations of total manganese (0.010 mg/L) are in Rockburn Branch at Elkridge, and the highest are in Dorsey Run at Jessup (0.40 mg/L).

Total organic carbon

Concentrations of total organic carbon in most Howard County streams are less than 3 mg/L; concentrations higher than this amount may indicate contamination from organic material or chemicals. The highest concentration of total organic carbon is 56 mg/L from Dorsey Run at Jessup; concentrations averaging 3.4 mg/L were detected in Hammond Branch near Laurel.

Nutrients

Phosphorus and nitrogen are nutrients required for biological metabolism, and increased availability of them can have profound ecological effects. Phosphorus and nitrogen generally are present in various forms in natural waters in small concentrations but can be significantly increased by fertilizer application, improper waste disposal, and malfunctioning septic systems. Median concentrations of nitrate plus nitrite and phosphorus in Howard County streams during 1988–89 are listed in table 31.

Atmospheric nitrogen reaches stream water through biological pathways, beginning with bacterial fixation. Anthropogenic sources include nitrogen oxides originating from fossil-fuel combustion emissions, which are entrained in precipitation, and fertilizers. The most common aqueous form is nitrate (NO_3^-) which is stable over a wide range of conditions. Nitrite (NO_2^-) is readily oxidized to nitrate and if present, may indicate contamination by sewage or other organic waste. Ammonium (NH_4^+) is the primary aqueous form of nitrogen in precipitation as well as ammonia fertilizers; it is mostly adsorbed by soil grains or converted (via bacterial nitrification) to nitrite and then nitrate before reaching streams.

The highest concentration of nitrate plus nitrite is 7.5 mg/L from the Cattail Creek tributary at Carrs Mill, and the lowest is 0.5 mg/L from Deep Run at Hanover. Concentrations are greater in western streams than in eastern streams, owing to the more rural character of the western part of the county. Concentrations did not exceed the MCL, which is 10 mg/L nitrate plus nitrite as N (U.S. Environmental Protection Agency, 1991a).

Phosphorus is a common element in sediment and igneous rocks, but, because of its low solubility, concentrations in stream water generally do not exceed 0.025 mg/L (Meybeck, 1982), and because available phosphorus is readily taken up by biota (Hem, 1985, p. 126). The most common aqueous form of phosphorus is phosphate. During the 1950's and

TABLE 31
MEDIAN NITROGEN AND PHOSPHORUS CONCENTRATIONS IN STREAM WATER UNDER BASE-FLOW CONDITIONS, 1988–89

[All values in milligrams per liter; values are the median of three determinations at each site]

Station no.	Station name	Nitrate plus nitrite, total (as N)	Phosphorus, total (as P)
01587070	South Branch Patapsco River at Woodbine	4.6	0.21
01587500	South Branch Patapsco River at Henryton	3.4	.10
01589000	Patapsco River at Hollofield	2.8	.07
01589040	Rockburn Branch at Elkridge	1.7	<.01
01589080	Deep Run at Hanover	.7	.01
01590800	Patuxent River at Mullinix	2.6	.01
01590900	Cabin Branch near Florence	3.0	.02
01591000	Patuxent River near Unity	2.4	.01
01591200	Cattail Creek tributary at Carrs Mill	7.2	.14
01591350	Cattail Creek near Cooksville	5.4	.05
01591375	Cattail Creek tributary at Daisy	2.8	.01
01591400	Cattail Creek near Glenwood	3.7	.02
01591475	Dorsey Branch near Knollwood	4.6	.02
01591610	Patuxent River below Brighton Dam near Brighton	1.5	.02
01593200	Little Patuxent River at Pine Orchard	1.3	.01
01593300	Red Hill Branch near Columbia	1.4	.03
01593500	Little Patuxent River at Guilford	1.4	.02
01593600	Middle Patuxent River near West Friendship	3.2	.02
01593675	Middle Patuxent River tributary near Columbia	2.8	.01
01593700	Middle Patuxent River tributary near Clarksville	1.4	.01
01593710	Middle Patuxent River near Clarksville	2.7	.02
01594000	Little Patuxent River at Savage	1.7	.02
01594200	Hammond Branch near Laurel	1.3	2.8
01594395	Dorsey Run at Jessup	.7	.02

1960's, phosphates were used in cleansers and detergents, but incorporation of phosphates in such products was legally banned because phosphate wastes from these products lead to eutrophication of surface-water bodies and related environmental degradation. Sewage effluent and animal wastes remain important sources of phosphorus in surface water.

Total phosphorus exists in concentrations as high as a few hundredths of a milligram per liter (total phosphorus, as P) in streams throughout Howard County. Concentrations were high (averaging 2.5 mg/L) in three samples collected at Hammond Branch near Laurel and in one of three samples collected at Dorsey Run at Jessup (0.68 mg/L). A possible source of phosphorus at the Hammond Branch site is a large horse-stable complex upstream from the sampling site.

Bottom Materials

Nutrients, trace elements, and organic compounds can be adsorbed by bottom materials that are intermittently transported during infrequent higher than normal streamflow (U.S. Geological Survey, 1977, p. 5–14; Feltz, 1980). These materials can remain in the stream channel for a long time and can provide a source for the chemicals in the stream. Physical and chemical factors that affect the capacity of sediment to sorb such chemicals include grain size, surface area, electrical charge, cation-exchange capacity, particle composition of the sediment, phase associations, and chemical bonding (Horowitz, 1985). Concentrations of trace elements and organic chemicals adsorbed on bottom sediments can therefore vary widely and sediment analysis (particle size and organic carbon content) is necessary for full quantitative comparison of bottom materials. Even without a complete characterization of the sediments, bottom-materials analyses provide a qualitative indication of the occurrence of trace elements and selected organic compounds. Samples of stream-bottom materials were collected at 24 sites and analyzed for trace elements and pesticides (Dine and others, 1992, tables 19 and 20).

Trace elements

Bottom materials collected at 10 sites during September–October 1989 were analyzed for nine trace elements (table 32). Chromium, copper, iron, manganese, and zinc were detected in all samples. Concentrations of iron ranged from 3,300 to 11,000 μg/g and concentrations of manganese ranged from 90 to 620 μg/g. Most trace elements were detected in sediments from South Branch Patapsco River at Woodbine, where, in addition to the constituents listed above, arsenic, cadmium, lead, and mercury were detected. The stream receives agricultural runoff as well as effluent discharged from a wastewater treatment plant. Refer to table 17 for further information on sources of trace elements.

Arsenic was detected in bottom materials from five sites, in concentrations ranging from 1 to 3 μg/g. Pesticides are the likely source, owing to the prevalence of agriculture in the basin. Cadmium was detected only at the South Branch Patapsco River at Woodbine, and may have been introduced to the stream with effluent from the wastewater treatment plant. Chromite associated with serpentinite was sufficiently abundant at some localities to allow Maryland to be a leading producer of chromium in the last century. However, concentrations ranging from 3 to 10 μg/g in bottom materials of streams throughout the county are likely derived from paints, stains, and industrial salts. Copper was detected at all sites tested and ranges from 1 to 7 μg/g. Lead was detected at the South Branch Patapsco River at Woodbine and may have been a constituent of effluent from the wastewater

TABLE 32
TRACE ELEMENTS IN STREAM-BOTTOM MATERIALS

[Concentrations in micrograms per gram]

Station no.	Station name	Sampling date	Arsenic	Cad-mium	Chrom-ium	Copper	Iron	Lead	Man-ganese	Mercury	Zinc
01587070	South Branch Patapsco River at Woodbine	10-06-89	3	1	6	7	7,600	20	700	0.01	30
01589040	Rockburn Branch at Elkridge	09-12-89	<1	<1	10	7	11,000	<10	300	<.01	30
01590800	Patuxent River at Mullinix	10-06-89	2	<1	6	4	7,700	<10	620	.01	30
01591350	Cattail Creek tributary near Cooksville	10-16-89	1	<1	10	3	6,600	<10	520	<.01	20
01591400	Cattail Creek near Glenwood	10-13-89	<1	<1	6	6	7,200	<10	200	.01	30
01591475	Dorsey Branch near Knollwood	10-13-89	<1	<1	6	3	4,800	<10	170	<.01	20
01593500	Little Patuxent River at Guilford	09-12-89	<1	<1	3	1	3,300	<10	220	<.01	10
01593710	Middle Patuxent River near Simpsonville	09-11-89	1	<1	10	5	6,300	<10	310	<.01	20
01594000	Little Patuxent River at Savage	09-12-89	<1	<1	6	3	3,600	<10	210	<.01	10
01594395	Dorsey Run at Jessup	09-12-89	1	<1	4	3	3,700	<10	90	.03	20

treatment plant. Mercury was detected at three sites in the western part of the county and may be from an agrichemical source; mercury detected at Dorsey Run at Jessup may originate from industrial discharge. Zinc was detected at all sites tested, in concentrations ranging from 10 to 30 μg/g.

Pesticides

Bottom materials collected at 14 sites (fig. 22) during September–October 1989 were analyzed for 24 organic compounds: 15 organochlorine insecticides (and metabolites) as well as polychlorinated biphenyl (PCB), polychlorinated naphthalene (PCN), and 7 organophosphorus insecticides. Eleven pesticide chemicals that were detected from one or more sites are listed in table 33. Thirteen additional chemicals (endosulfan, endrin, ethion, heptachlor epoxide, malathion, methoxychlor, methyl trithion, mirex, parathion, PCN, perthane, toxaphene, and trithion) were below detection limits at all sites.

Organochlorine insecticides persist in aquatic ecosystems (Chau and others, 1981);

TABLE 33
PESTICIDES DETECTED IN STREAM-BOTTOM MATERIALS

[Concentrations in micrograms per kilogram]

Station no.	Station name	Sampling date	Aldrin	Chlordane	DDD
1587500	South Branch Patapsco River at Henryton	09-11-89	<0.1	<1.0	<0.1
1589000	Patapsco River at Hollofield	09-11-89	.6	20	<.1
1589080	Deep Run at Hanover	10-16-89	<.1	2.0	<.1
1590900	Cabin Branch near Florence	10-13-89	<.1	<1.0	<.1
1591000	Patuxent River near Unity	09-11-89	<.1	<1.0	<.1
1591200	Cattail Creek tributary at Carrs Mill	10-13-89	<.1	<1.0	<.1
1591375	Cattail Creek tributary at Daisy	10-13-89	<.1	1.0	<.1
1591610	Patuxent River below Brighton Dam near Brighton	09-11-89	<.1	<1.0	<.1
1593200	Little Patuxent River at Pine Orchard	10-16-89	<.1	5.0	.1
1593300	Red Hill Branch near Columbia	10-16-89	<.1	1.0	<.1
1593600	Middle Patuxent River near West Friendship	10-16-89	<.1	<1.0	<.1
1593675	Middle Patuxent River tributary near Columbia	09-12-89	<.1	<1.0	<.1
1593700	Middle Patuxent River tributary near Clarksville	10-16-89	<.1	<1.0	<.1
1594200	Hammond Branch near Laurel	09-12-89	<.1	5.0	<.1

eight were detected in Howard County. PCB's, which were used in industrial applications, and the organophosphorus insecticides diazinon and methyl parathion, also were detected. Federal regulations banned the use of dichloro-diphenyl-trichloroethane (DDT) in 1972, but DDT and its metabolites, dichloro-diphenyl-dichloroethane (DDD) and dichloro-diphenyl-dichloroethylene (DDE) were still detected at 9 of 14 sites.

Use of organophosphorus insecticides has expanded since the ban on DDT, and these have replaced the organochlorine insecticides, except for some special applications. This class of insecticides is much less persistent and more soluble in water than are organochlorine insecticides and are therefore less likely to accumulate in bottom materials. Diazinon was detected at three sites, and methyl parathion at one site.

Trends in Stream-Water Quality

Specific conductance, pH, and dissolved calcium and sodium in water sampled from the South Branch Patapsco River at Henryton increased during the period 1954–89, and total nitrate plus nitrite increased during the period 1973–89 (fig. 41). The upward trend can be

TABLE 33—CONTINUED

DDE	DDT	Diazinon	Dieldrin	Hepta-chlor	Lindane	Methyl parathion	PCB	Station no.
0.1	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<1	01587500
.5	.8	<.1	<.1	.3	<.1	<.1	<1	01589000
<.1	<.1	.1	.1	<.1	<.1	<.1	2	01589080
.1	<.1	<.1	<.1	<.1	<.1	<.1	<1	01590900
<.1	<.1	<.1	<.1	<.1	<.1	<.1	<1	01591000
.1	<.1	<.1	<.1	<.1	.4	<.1	<1	01591200
.1	<.1	<.1	<.1	<.1	<.1	.1	<1	01591375
.1	.1	<.1	<.1	<.1	<.1	<.1	<1	01591610
.1	.1	<.1	<.1	<.1	<.1	<.1	<1	01593200
.1	.1	<.1	.1	<.1	<.1	<.1	<1	01593300
<.1	<.1	.1	<.1	<.1	<.1	<.1	<1	01593600
<.1	<.1	<.1	<.1	<.1	<.1	<.1	<1	01593675
<.1	<.1	<.1	<.1	<.1	<.1	<.1	<1	01593700
.1	.4	.1	<.1	.2	<.1	<.1	1	01594200

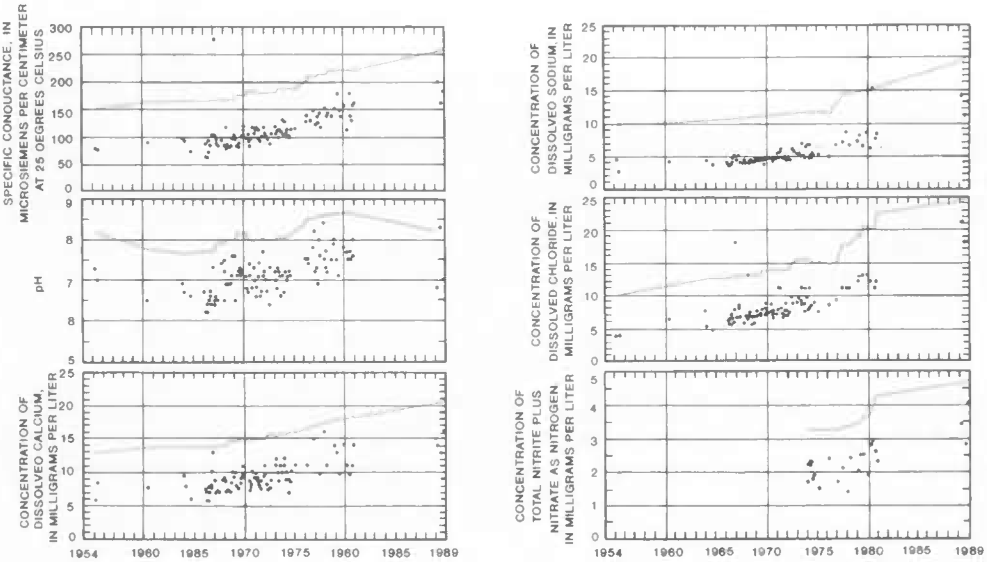


FIGURE 41.—Water-quality trends in the South Branch Patapsco River at Henryton, 1954–89. Smoothing lines are robust locally-weighted regression (lowess) lines.

detected despite the scatter of values using the Mann-Kendall ranked correlation test (table 34). The test statistic, Kendall's τ, measures the correlation between (in this case) each of the water-quality variables and the sample date (i.e., are successive values greater than, less than, or equal to all earlier values). The relationships with time are low to moderate, but all are statistically significant ($p < 0.01$). The trends shown in figure 41 are not adjusted for relative amounts of base flow or for seasonal variation, which are partly responsible for the amount of scatter.

TABLE 34
MANN-KENDALL TESTS FOR WATER-QUALITY TRENDS, SOUTH BRANCH PATAPSCO RIVER AT HENRYTON

[Sampled 1954–89 except for nitrate plus nitrite, collected 1973–89]

	Specific conductance	pH	Calcium (dissolved)	Sodium (dissolved)	Chloride (dissolved)	Nitrate plus nitrite (total, as N)
Kendall's τ	0.65	0.46	0.50	0.63	0.64	0.47
Number	109	109	93	92	94	24
Significance (p)	0.000	0.000	0.000	0.000	0.000	0.001

Two wastewater-treatment plants were constructed on the South Branch of the Patapsco River upstream from Henryton, in 1972 and 1974. The volume of wastewater discharged into the river has gradually increased over the period of operation (table 35); in 1991 the combined discharge from the two plants was 2.137 Mgal/d, or 17 percent of the total 2-year 7-day low flow and 63 percent of the total 10-year 7-day low flow at Henryton. Additional contributions to the increased dissolved-ion load may have come from urban and highway (road deicing salts) runoff as the watershed has been developed. Also, the total nitrate concentrations of many streams in the eastern United States have increased as a result of increased atmospheric deposition of nitrate, in addition to agricultural sources (Smith and others, 1987, p. 1612).

TABLE 35
AVERAGE ANNUAL WASTEWATER DISCHARGE TO THE SOUTH BRANCH PATAPSCO RIVER, 1980–81

Year	Discharge (Million gallons per day)
1980	0.828
1981	.964
1982	1.058
1983	1.462
1984	1.713
1985	1.444
1986	1.508
1987	1.698
1988	1.759
1989	2.191
1990	2.114
1991	2.137

HYDROLOGIC BUDGETS

The hydrologic budget shows the quantitative relations among the components of the hydrologic cycle. It is an account of the inflow to, outflow from, and storage within an area or hydrologic unit (basin or aquifer) for a particular interval and can be used to estimate the availability of water in that area. The hydrologic equation can be expressed as

$$P + I = R_G + R_S + ET + X + \Delta S,$$

where P is precipitation,
I is water imported into the area,
R_G is ground-water runoff,

R_S is surface-water runoff,
ET is evapotranspiration,
X is water exported from the area, and
ΔS is change in storage.

The primary source of water in Howard County is precipitation, which totals approximately 42 in. annually (table 3). About 17 Mgal/d of imported water is delivered to the county by public-supply systems, but most of this water is collected and transported to sewage-treatment plants and discharged outside of and downstream from the county; this imported water is therefore omitted from this analysis. Major outflows include runoff, evapotranspiration, and storage withdrawals that are not replaced. Runoff is divided into ground-water and surface-water components and is estimated from streamflow-hydrograph separation. Evapotranspiration is difficult to measure and is therefore commonly estimated as a residual term in the hydrologic budget equation; for the present analysis, evapotranspiration was also estimated by the method of Thornthwaite and Mather (1957) in order to substantiate the estimates from residuals. The Thornthwaite method incorporates temperature, precipitation, latitude, and soil-moisture-retention capability. Water can be stored in soils, aquifers, and surface-water bodies. Storage withdrawals in Howard County are relatively insignificant; no users withdraw large quantities, and domestic withdrawals are generally replaced through onsite septic systems. Ground water flows slowly from recharge areas to discharge to streams and is considered to be in storage during this time. Lakes, marshes, or other surface-water bodies have not formed naturally, because of the favorable drainage of the Piedmont. The T. Howard Duckett and Triadelphia Reservoirs, constructed along the Patuxent River, have a combined usable capacity of 11.8×10^9 gallons of fresh water.

HYDROLOGIC BUDGETS FOR BASINS WITH LONG-TERM CONTINUOUS-STREAMFLOW RECORDS

Hydrologic budgets were developed for six gaged basins on unregulated streams having at least 10 years of continuous streamflow record (table 36). These basins are distributed throughout the county and represent various combinations of land use and geologic and topographic setting. Basin divides were determined from topographic highs located from topographic maps (scale 1:24,000). The budgets were calculated using values of the components that were averaged over the period of record of each basin gaging station. The basins used in the analysis are unaffected by diversions or withdrawals; therefore, water imported (I) and exported (X) are equal to zero. Ground-water and surface-water runoff were estimated from automated separation of continuous-streamflow hydrographs (Pettyjohn and Henning, 1979). Long-term changes in basin storage (ΔS) were considered negligible. In view of these assumptions, the hydrologic-budget equation simplifies to

$$P = R_G + R_S + ET.$$

Precipitation was measured at 13 climatological stations in or near Howard County (fig. 2) over various periods. To obtain annual precipitation for the basins, the climatological stations having annual values for each year of gaging-station record were identified, and the median of the group of annual precipitation values was determined for each year. The

TABLE 36
AVERAGE ANNUAL HYDROLOGIC BUDGETS
FOR BASINS WITH LONG-TERM CONTINUOUS
STREAMFLOW RECORDS

[Values on first line are in inehes; on seeond line, as pereentage of preeipitation; on third line, in million gallons per day per square mile. P, precipitation; R_G, ground-water runoff; R_S, surface-water runoff; ET, evapotranspiration]

Station name at basin outlet	Period	P =	+ R_G	+ R_S	+ ET	
					Equation residual	Thornthwaite method
South Branch Patapsco River at Henryton	1949-80	41	10	4	27	28
		100	24	10	66	68
		1.9	.5	.2	1.2	1.3
Patuxent River near Unity	1945-90	41	9	4	28	28
		100	23	10	67	68
		1.9	.4	.2	1.3	1.3
Cattail Creek near Glenwood	1979-90	38	10	5	23	28
		100	26	12	62	74
		1.8	.5	.2	1.1	1.3
Cattail Creek near Roxbury Mills	1945-56	43	10	4	29	28
		100	23	9	68	65
		2.1	.5	.2	1.4	1.3
Little Patuxent River at Guilford	1933-90	41	8	6	27	29
		100	20	15	65	71
		2.0	.4	.3	1.3	1.4
Little Patuxent River at Savage	1940-58,	42	8	5	29	29
	1976-80,	100	19	12	69	69
	and 1986-89	2.0	.4	.2	1.4	1.4

mean of these values was then computed and represents the mean annual precipitation in the basin for the gaging station's period of record. Mean annual precipitation for the six basins (representing six different periods of reeord) ranges from 38 to 43 in. Surface-water runoff, estimated by hydrograph separation, ranges from 4 to 6 in., or 10 to 15 percent of mean annual precipitation; ground-water runoff ranges from 8 to 10 in., or 19 to 26 percent of mean annual precipitation. Evapotranspiration, estimated as the equation residual, ranges from 24 to 29 in., or 63 to 69 percent of mean annual precipitation. Evapotranspiration estimated using the Thornthwaite method ranges from 28 to 29 in., or 65 to 74 pereent of mean annual precipitation. A considerable amount of water, more than 60 percent of the mean annual precipitation, is consumed by evapotranspiration.

Evapotranspiration and total runoff are 66 and 34 percent of precipitation, respectively, for the three basins with the longest streamflow records—the South Branch Patapsco River at Henryton, the Patuxent River near Unity, and the Little Patuxent River at Guilford. These proportions result mainly from similar geologic and topographic settings of the six basins, and are representative of values for Howard County. An average hydrologic budget for the county can thus be presented as:

$$\begin{aligned} \text{Precipitation (42 in.)} = &\ \text{Surface Runoff (5 in.)} \\ &+ \text{Ground-Water Runoff (9 in.)} \\ &+ \text{Evapotranspiration (28 in.).} \end{aligned}$$

Ground-water recharge is the process whereby water (predominantly precipitation in Howard County) is added to the ground-water reservoir; ground-water discharge is the process by which water leaves the ground-water reservoir, usually by seepage into a nearby stream, discharge from a spring, or pumping from a well. Recharge and discharge affect ground-water availability and, in turn, are affected by hydraulic properties, climate, vegetation, and human activity.

Long-term ground-water discharge was assumed to be equivalent to the long-term recharge rate for the basins—that is, ground-water discharge and recharge were assumed to be under natural steady-state conditions. Computed recharge rates are for effective recharge (rates do not include water that is lost by transpiration or evaporation prior to replenishing ground-water storage; Pettyjohn and Henning, 1979). Effective recharge for the six basins ranges from 0.4 to 0.5 (Mgal/d)/mi^2, or 8.4 to 10.5 in/yr. These recharge rates are average values for each basin because of local differences in hydrogeologic characteristics of the basins, but they are not significantly different throughout the county.

Ground-water discharge by pumping wells can affect ground-water availability. The potential effects of ground-water pumping for residential development was simulated by Willey and Achmad (1986). Ground-water flow was modeled in the 8.37 mi^2 drainage area of upper Cattail Creek near Cooksville in western Howard County. One simulation, which included residential development on 3-acre lots with onsite wells and offsite sewer systems, predicted that ground-water levels would decline as much as 4.2 ft (typically water levels decline more under hilltops than in valleys). A simulation with development on 3-acre lots, public-supply wells, and onsite sewage disposal predicted that ground-water levels would increase as much as 3.6 ft, except near public-supply wells, where water levels would decline nearly 21 ft in model grids which contained the pumping wells. Simulation time in each case was 20 years.

Hydrologic budgets are affected by changes in land use and development in the basins. The budget for the basin upstream from the Little Patuxent River at Guilford for 1933–65 differs slightly from the budget for 1966–90 (table 37). Surface runoff increased, and evapotranspiration decreased, in this basin, probably owing to decreases in vegetated areas and increases in impermeable surfaces (buildings and pavements) associated with the development of Columbia.

HYDROLOGIC BUDGETS FOR BASINS WITH PARTIAL-STREAMFLOW RECORDS

Hydrologic budgets also were developed for basins having partial streamflow records (table 38). Ground-water runoff for these basins was estimated from annual base flows

TABLE 37
PRE- AND POST-DEVELOPMENT AVERAGE ANNUAL HYDROLOGIC BUDGETS
FOR THE LITTLE PATUXENT RIVER UPSTREAM FROM GUILFORD

[Values on first line are expressed in inches; on second line as percentage of precipitation; on third line in million gallons per day per square mile. P, precipitation; R_G, ground-water runoff; R_S, surface-water runoff; ET, evapotranspiration]

Period	P	=	R_G	+	R_S	+	ET
Pre-development	41		8		5		28
1933-65	100		20		12		68
	2.0		.4		.3		1.3
Post-development	40		8		7		25
1966-90	100		20		18		62
	2.0		.4		.3		1.3

calculated by hydrograph separation at continuous-record stations, using base-flow relations between stations developed from linear regressions in the low-flow analysis computed elsewhere in this report. This procedure assumes that annual base flow can be calculated using the same relations. Average annual hydrologic budgets were calculated for periods corresponding to the periods of record of the continuous-record gaging stations used to develop the base-flow relations: the South Branch Patapsco River at Henryton, the Patuxent River near Unity, and the Little Patuxent River at Guilford.

Average annual precipitation was set at 41 in. for most partial-record basins, but was set at 42 in. for the basin upstream from Dorsey Run at Jessup, for which flow was regressed with flow in the Little Patuxent River at Savage station. Evapotranspiration was assumed to be equal to the average evapotranspiration for the continuous-record stations, about 66 percent of precipitation (table 36). Surface-water runoff was computed as a residual.

Surface-water runoff in the ungaged basins ranges from 4 to 9 in., whereas ground-water runoff ranges from 5 to 10 in. Surface-water runoff was greatest, and ground-water runoff was least, in the basin upstream from Dorsey Run at Jessup. A large proportion of this basin is underlain by impervious surfaces.

Dingman and others (1954, p. 39) present a hydrologic budget for the Rock Creek basin which occupies a similar topographic and geologic setting in adjacent Montgomery County. Average annual precipitation was 43.5 in. Surface-water runoff was estimated as 4.1 in., or 9 percent of the annual precipitation, and ground-water runoff was estimated as 8.5 in., or 19.5 percent of annual precipitation. Estimated evapotranspiration was 30.9 in., or 71 percent of annual precipitation. Willey and Achmad (1986, p. 6) determined a hydrologic budget for the basin of Cattail Creek near Cooksville for a 15-month period. Total runoff was 40 percent of precipitation and evapotranspiration was 68 percent of precipitation (an 8 percent loss in storage occurred during the 15-month period). These hydrologic budgets are similar to the ones presented in this report.

TABLE 38
AVERAGE ANNUAL HYDROLOGIC BUDGETS FOR BASINS
WITH PARTIAL STREAMFLOW RECORDS

[All values in inches of water per year. P, precipitation; R_G, ground-water runoff; R_S, surface-water runoff; ET, evapotranspiration]

Station name at basin outlet	P	=	R_G	+	R_S	+	ET
South Branch Patapsco River at Woodbine	41		8		6		27
Rockburn Run at Elkridge	41		7		7		27
Deep Run at Hanover	41		6		8		27
Patuxent River at Mullinix	41		8		6		27
Cabin Branch near Florence	41		9		5		27
Cattail Creek tributary near Carrs Mill	41		9		5		27
Cattail Creek near Cooksville	41		10		4		27
Cattail Creek tributary at Daisy	41		9		5		27
Dorsey Branch near Knollwood	41		9		5		27
Little Patuxent River at Pine Orchard	41		8		6		27
Red Hill Branch at Columbia	41		6		8		27
Middle Patuxent River near West Friendship	41		7		7		27
Middle Patuxent River tributary near Columbia	41		8		6		27
Middle Patuxent River tributary near Clarksville	41		7		7		27
Middle Patuxent River near Simpsonville[1]	41		8		6		27
Hammond Branch at Scaggsville	41		8		6		27
Hammond Branch near Laurel	41		7		7		27
Dorsey Run at Jessup	42		5		9		28

[1]Continuous-record streamflow-gaging station, water years 1988-90.

SUMMARY

Howard County, located between Baltimore and Washington, D.C., has an area of 253.51 mi^2. The population of the county in 1990 was 187,328, which represents an increase of 200 percent since 1970. During 1990, approximately 20.1 Mgal/d of water was used in the county. Baltimore City and the Washington Suburban Sanitary Commission supplied 17 Mgal/d from sources outside of Howard County while 2.6 Mgal/d of ground water and 0.4 Mgal/d of surface water were withdrawn in the county.

The county includes parts of the Coastal Plain and Piedmont Physiographic Provinces. The Coastal Plain is underlain by unconsolidated layers of clay, sand, and gravel of Cretaceous (Patuxent Formation) and Tertiary-Quaternary (terrace gravels, alluvium, and colluvium) age deposited on a sloping basement of crystalline rock. The maximum thickness of Coastal Plain sediments in Howard County is about 140 ft. The Piedmont is underlain by fractured igneous and metamorphic rocks of Precambrian and early Paleozoic age with narrow diabase dikes of Triassic-Jurassic age; these rocks are covered by a variable thickness of soil and weathered rock, or saprolite.

Ground water flows through intergranular spaces of the Coastal Plain sediments. Impermeable clays confine the water-bearing sands and gravels in some areas, resulting in artesian conditions; unconfined, or water-table, conditions exist where confining clays are absent. The Coastal Plain is located in the eastern part of the county where the preponderance of commercial and residential development is located. The developed area is served by public-water distribution systems drawing from surface-water sources; consequently, fewer than 2 percent of the wells in Howard County are completed in the Patuxent Formation.

In the Piedmont, ground water flows through fractures in the crystalline rocks. Most ground-water circulation takes place in the uppermost several hundred feet because fracture frequency diminishes below this depth. Ground water is generally unconfined in the Piedmont and the water-table approximates the land surface, although with less relief. The water table and land surface both have a regional slope from west to east across the county.

Precipitation recharges ground water throughout the county at rates of 0.4 to 0.5 (Mgal/d)/mi^2. Water levels in wells and spring discharges fluctuate in response to seasonal evapotranspiration and ground-water recharge and discharge; temperatures of spring water also fluctuate seasonally.

Transmissivity estimated from one aquifer test and from specific-capacity data for 1,760 Piedmont wells ranges from less than 1 to more than 5,000 ft^2/d; the median is 33 ft^2/d. Transmissivity for 17 Coastal Plain wells ranges from 165 to 3,450 ft^2/d; the median is 700 ft^2/d. Well yield and specific capacity vary inversely with well depth because water-bearing fractures are less numerous with increasing depth. The chances of increasing the yield of a well by drilling deeper than 400 ft are negligible. Wells situated in valleys and flats tend to be more productive than wells situated on hilltops, hillsides, or upland draws. The Patuxent and Pleasant Grove Formations and the Cockeysville Marble are the most productive geologic units in Howard County (based on specific capacity). The Gillis Group, the Druid Hill Amphibolite Member of the James Run Formation, and the Loch Raven-Oella Formations (undifferentiated) are the least productive.

Ground-water quality is generally good, although the water is somewhat acidic; 83 of 124 sites sampled had pH below the U.S. Environmental Protection Agency's suggested maximum contaminant level (SMCL) range of 6.5 to 8.5. One site exceeded the maximum

contaminant level (MCL) for nitrate plus nitrite, nine sites exceeded the SMCL for iron, and 19 sites exceeded the SMCL for manganese. All but three of 85 sites sampled for radon had levels greater than the proposed MCL of 300 pCi/L; median radon concentration for these sites was 3,400 pCi/L. Higher values of temperature, pH, alkalinity, and concentrations of calcium, magnesium, potassium, sulfate, and silica tend to be found in the eastern part of Howard County. In contrast, dissolved oxygen and nitrate concentrations tend to be higher in the western part.

Most ground water in Howard County may have been underground for less than 40 years, based on tritium analysis of samples from 22 sites. Many of the wells sampled have long open intervals and could therefore have sampled mixed ground water of various ages; some of the ground water could be more than 40 years old.

Streamflow data were collected at 13 continuous-record and 19 partial-record streamflow-gaging stations in basins that ranged from 0.54 to 285 mi^2 in area. Eight of the continuous-record gaging stations were operating in 1990; three of these are located downstream from large reservoirs. Mean annual flows for 11 continuous-record streamflow-gaging stations range from 24.8 to 412 ft^3/s, or 0.66 to 1.16 $(ft^3/s)/mi^2$. Mean monthly flows are generally highest in March and April and lowest in August through October. Flows of seven nonregulated streams in Howard County range from 2.40 to 3.18 $(ft^3/s)/mi^2$ at the 5-percent exceedence level, and from 0.18 to 0.29 $(ft^3/s)/mi^2$ at the 95-percent exceedence level. One-hundred-year peak flows at nine stations with more than 10 years of streamflow records range from 10,400 to 181,000 ft^3/s. Seven-day, 10-year low flows of 7 nonregulated continuous-record gaging stations with more than 10 years of streamflow records range from 2.8 to 11 ft^3/s, or 0.08 to 0.11 $(ft^3/s)/mi^2$. Low flows were highest in the Cattail Creek basin and lowest at Rockburn Branch at Elkridge, Deep Run at Hanover, and Dorsey Run at Jessup in the eastern part of the county.

The HEC-1 rainfall-runoff model was used to simulate floods resulting from hypothetical rainfalls. Simulated peak flows past three stations, developed from the 100-year-rainfall frequency, range from 6,820 to 15,700 ft^3/s at South Branch Patapsco River at Henryton, Patuxent River near Unity, and Little Patuxent River at Guilford.

Streamwater samples for water-quality analysis were collected at 24 sites during base-flow conditions in December 1988, April 1989, and September–October 1989. Total dissolved solids concentrations ranged from 50 to 231 mg/L; the median was 114 mg/L. The pH ranged from 6.4 to 9.1; the median was 7.2. Concentrations of total dissolved solids, and most major ions, pH, and alkalinity gradually increase from the western part of the county to the eastern—a trend similar to that observed for ground-water quality. Nitrate plus nitrite concentrations are higher in the western part of the county where agricultural sources are likely. Concentrations of total dissolved solids, calcium, sodium, sulfate, and chloride, and pH gradually increased in the Patapsco River at Henryton from 1954 to 1989; this increase could be attributed to the discharge of treated wastewater into the stream.

All nine trace elements included in the laboratory analyses were detected in the stream-bottom-material sample collected at South Branch Patapsco River at Woodbine; five trace elements, the least number of trace elements detected at the 10 sites sampled, were found at Rockburn Branch at Elkridge, Dorsey Branch near Knollwood, and the Little Patuxent River sites at Guilford and Savage. Pesticides and related compounds were detected from stream-bottom samples at 11 of 14 sites. DDE, a metabolite of DDT, was most frequently detected, but DDT and chlordane were also prevalent. PCB's were found at Deep Run at Hanover and Hammond Branch near Laurel.

Hydrologic budgets were calculated for 6 drainage basins where continuous-record streamflow-gaging stations record basin outflow, and for 18 basins for which partial-streamflow records were available. An average budget, based on the six gaged basins and assuming steady-state conditions, is

Precipitation (42 in.) = Ground-Water Runoff (9 in.) + Surface Runoff (5 in.) + Evapotranspiration (28 in.).

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INDEX

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

GEOLOGIC MAP OF HOWARD COUNTY

Compiled by
Jonathan Edwards, Jr.
1993

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

EXPLANATION

SEDIMENTARY ROCKS

QUATERNARY

ALLUVIUM AND COLLUVIUM (Qal)
Interbedded gravel, sand, silt, and clay in tidal marshlands and in flood plains of perennial streams. Grades into colluvium at bases of slopes and in upland gathering areas. Mapped only in Coastal Plain.

unconformity

QUATERNARY/TERTIARY

TERRACE GRAVEL (Qt)
Very coarse gravel composed predominantly of boulders and cobbles of quartz and quartzite with matrix of sand and minor silt and clay. Sand layers locally abundant. Mapped only in Coastal Plain.

unconformity

LOWER CRETACEOUS

PATUXENT FORMATION (Kps, Kpc)
Medium to coarse quartz-cobble gravel, white to tan locally ferruginous cross-bedded sand, and white, gray, tan, and red clay.

Kps: Predominantly sand/gravel facies.
Kpc: Predominantly clay/silt facies.

unconformity

INTRUSIVE IGNEOUS ROCKS

JURASSIC

DIABASE (Jd)
Dark greenish-gray to black, fine- to medium-grained basalt and diabase. Occurs in steeply dipping to vertical dikes which range between 1 and 50 feet in thickness. Weathers to orange-red clayey soil with spheroidal residual boulders.

PEGMATITE (p)
Small to large pods and dikes of massive, coarse-grained to very coarse-grained, light-gray to pinkish-gray rock composed of mica (mostly muscovite), quartz, albite, and microcline-perthite.

Overprint indicates area of injection complex of small pegmatite dikes and sills within surrounding rock units.

GRANITIC ROCKS

SILURIAN

g — GUILFORD GRANITE
Uniform, massive, fine- to medium-grained, light gray-tan to medium gray, muscovite-biotite-microcline-quartz-plagioclase granite, locally devoid of biotite. Also occurs within surrounding rock units as an injection complex of up to 50% small dikes and sills.

e — ELLICOTT CITY GRANITE
Uniform, medium- to coarse-grained, medium gray, weakly foliated to massive epidote-microcline-biotite-quartz-plagioclase granite locally with subhedral to anhedral megacrysts of pink microcline ranging up to 4 cm in length. Also occurs within surrounding rock units as an injection complex of up to 25% small dikes and sills.

w — WOODSTOCK GRANITE
Uniform, medium-grained, light to medium gray-tan, massive epidote-muscovite-biotite-microcline-quartz-plagioclase granite. Not present in Howard County as a discrete pluton but occurs as an injection complex of up to 50% small dikes and sills.

Overprint patterns indicate areas of injection complexes.

EXTRUSIVE IGNEOUS ROCKS

CAMBRIAN

JAMES RUN FORMATION

jr — Relay Gneiss Member: Uniform, generally pinkish-gray, fine- to medium-grained, mica-poor biotite-quartz-plagioclase gneiss locally containing muscovite. Commonly contains abundant flattened to elongated grains of quartz up to 3 mm in length.

jdh — Druid Hill Amphibolite Member: Uniform, fine- to medium-grained, dark greenish-gray to black, plagioclase-hornblende amphibolite interlayered with felsic gneiss identical to the Relay Gneiss Member.

Crowley (1976) and Higgins and Conant (1990) show the James Run Formation to have been thrust westward upon the Baltimore Complex.

CAMBRIAN/PRECAMBRIAN (?)

BALTIMORE COMPLEX (bc)
Fine- to medium-grained, green to dark greenish-gray and black, poorly foliated to massive plagioclase-hornblende amphibolite, commonly with a spotted appearance due to clumping of coarser hornblende grains. Lenses or masses of serpentinite occur sporadically. Local textural variations include a strongly expressed foliation, the occurrence of porphyroblastic hornblende, and veins and patches of felsic rock.

The base of the Baltimore Complex in Baltimore, Harford, and Cecil Counties is a thrust fault (Crowley, 1976, Higgins and Conant, 1990).

METASEDIMENTARY ROCKS

PERMIAN (?)

PLEASANT GROVE FORMATION (pg)
A narrow, 1- to 3-mile wide belt of lustrous medium gray to green-gray, fine-grained chlorite-quartz-muscovite schist or phyllite and metagraywacke with a distinctive phacoidal parting, or "oyster-shell structure" caused by closely spaced, steeply dipping, intersecting cleavages. Minor isoclinal folds and pods of vein quartz occur.

Map unit is not a true lithostratigraphic formation but represents a tectonic zone where an older rock unit was thrust over the Prettyboy Formation prior to Taconic metamorphism, and has also experienced right-lateral shear during Alleghenian deformation (Muller and others, 1989).

ORDOVICIAN

LIBERTY COMPLEX

SYKESVILLE FORMATION (sy, sys)
Locally garnetiferous, fine- to medium-grained, light to medium gray, muscovite-biotite-plagioclase-quartz gneiss or fels, deceptively granite-like in appearance. Moderately well foliated to poorly foliated to massive. Contains cobble- to granule-size clasts and slabs of schist and vein quartz and less-abundant slabs and cobbles of fine-grained gneiss.

sys — Sykesville Schist Member: Well foliated, non-garnetiferous, fine- to medium-grained, medium gray to brownish-gray, biotite-plagioclase-quartz-muscovite schist. Clasts are more flattened than in the more gneissic Sykesville Formation, and are less abundant to absent.

MORGAN RUN FORMATION (mr, um)
Fine- to medium-grained, lustrous, silvery gray to greenish-gray, garnetiferous quartz-chlorite/biotite-muscovite schist. Interlayered zones of fine- to medium-grained metagraywacke may contain granules of detrital quartz and feldspar. Some layers locally exhibit graded bedding, clastic dikes, and probable soft-sediment slump folds.

um: Undifferentiated ultramafic and mafic rock. Discontinuous layers and lenses of fine- to medium-grained, gray to dark-green to black chlorite-amphibole schist and fels, chlorite-talc schist, talc schist, epidote-amphibolite, serpentinite, and foliated metagabbro.

In Baltimore and Carroll Counties, the Liberty Complex has been interpreted as an allochthonous mass that overlies the Loch Raven Formation on the east and the Pleasant Grove Formation on the west along a premetamorphic thrust fault (Muller, 1991; Muller and others, 1989).

GILLIS GROUP (gg)
Dark to light silvery gray-tan, and greenish-gray quartz-chlorite-muscovite phyllite with thin silty laminae. Zones of bluish-green muscovite-chlorite phyllite and reddish-purple to pale purplish-gray muscovite phyllite are also present. Thin quartzites and quartzitic phyllites occur locally.

CAMBRIAN

PRETTYBOY SCHIST (ps)
Greenish gray-tan to medium gray, fine-grained quartz-muscovite-chlorite schist. May contain abundant small porphyroblasts of albite. Magnetite crystals are also common. In places schist contains many lenses and pods of milky-white vein quartz.

GLENARM SUPERGROUP

WISSAHICKON GROUP

OELLA FORMATION (o)
Locally garnetiferous, medium-grained, medium gray, biotite-plagioclase-muscovite-quartz schist interlayered with fine-grained biotite-plagioclase-quartz gneiss.

LOCH RAVEN FORMATION (l-o, l, a, lr)
Uniform, medium-grained, medium to dark gray, biotite-plagioclase-garnet-muscovite-quartz schist, commonly bearing staurolite, and, locally, kyanite. Locally includes minor fine-grained biotite quartzite.

l-o: Interlayered Oella and Loch Raven lithologies, not separately mapped.

lr — Rush Brook Member: Schist similar in appearance and composition to the Loch Raven Formation, but includes more quartzite layers plus minor biotite schist and gneiss, and lacks staurolite and kyanite.

a: Discontinuous layers and lenses of fine- to medium-grained, dark-green to black epidote-amphibolite and amphibolite.

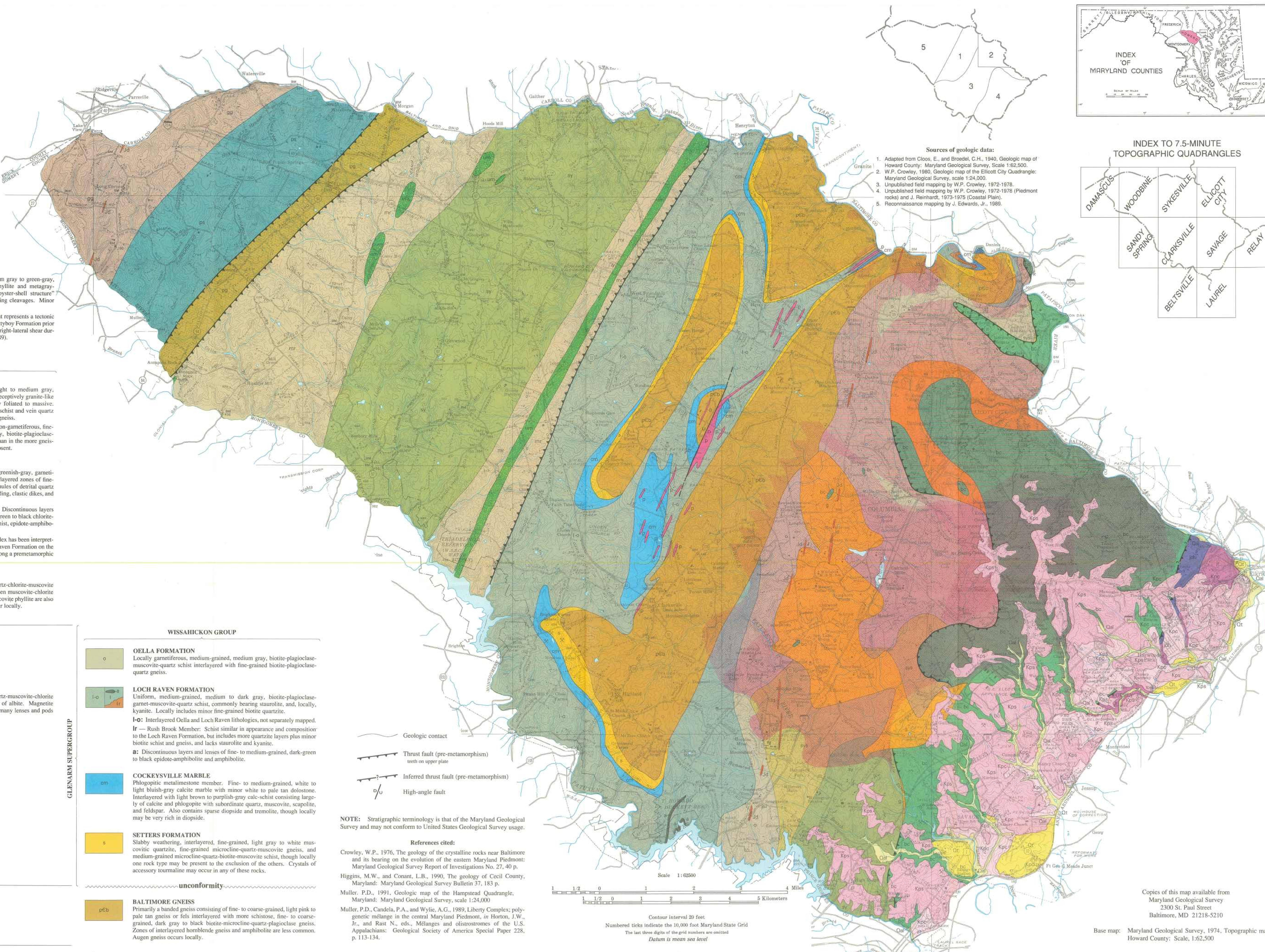
COCKEYSVILLE MARBLE (cm)
Phlogopitic metalimestone member. Fine- to medium-grained, white to light bluish-gray calcite marble with minor white to pale tan dolostone. Interlayered with light brown to purplish-gray calc-schist consisting largely of calcite and phlogopite with subordinate quartz, muscovite, scapolite, and feldspar. Also contains sparse diopside and tremolite, though locally may be very rich in diopside.

SETTERS FORMATION (s)
Slabby weathering, interlayered, fine-grained, light gray to white muscovitic quartzite, fine-grained microcline-quartz-muscovite gneiss, and medium-grained microcline-quartz-biotite-muscovite schist, though locally one rock type may be present to the exclusion of the others. Crystals of accessory tourmaline may occur in any of these rocks.

unconformity

PRECAMBRIAN

BALTIMORE GNEISS (p€b)
Primarily a banded gneiss consisting of fine- to coarse-grained, light pink to pale tan gneiss or fels interlayered with more schistose, fine- to coarse-grained, dark gray to black biotite-microcline-quartz-plagioclase gneiss. Zones of interlayered hornblende gneiss and amphibolite are less common. Augen gneiss occurs locally.



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3. Unpublished field mapping by W.P. Crowley, 1972-1978.
4. Unpublished field mapping by W.P. Crowley, 1972-1978 (Piedmont rocks) and J. Reinhardt, 1973-1975 (Coastal Plain).
5. Reconnaissance mapping by J. Edwards, Jr., 1989.

NOTE: Stratigraphic terminology is that of the Maryland Geological Survey and may not conform to United States Geological Survey usage.

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Copies of this map available from
Maryland Geological Survey
2300 St. Paul Street
Baltimore, MD 21218-5210

Base map: Maryland Geological Survey, 1974, Topographic map of Howard County: Scale, 1:62,500

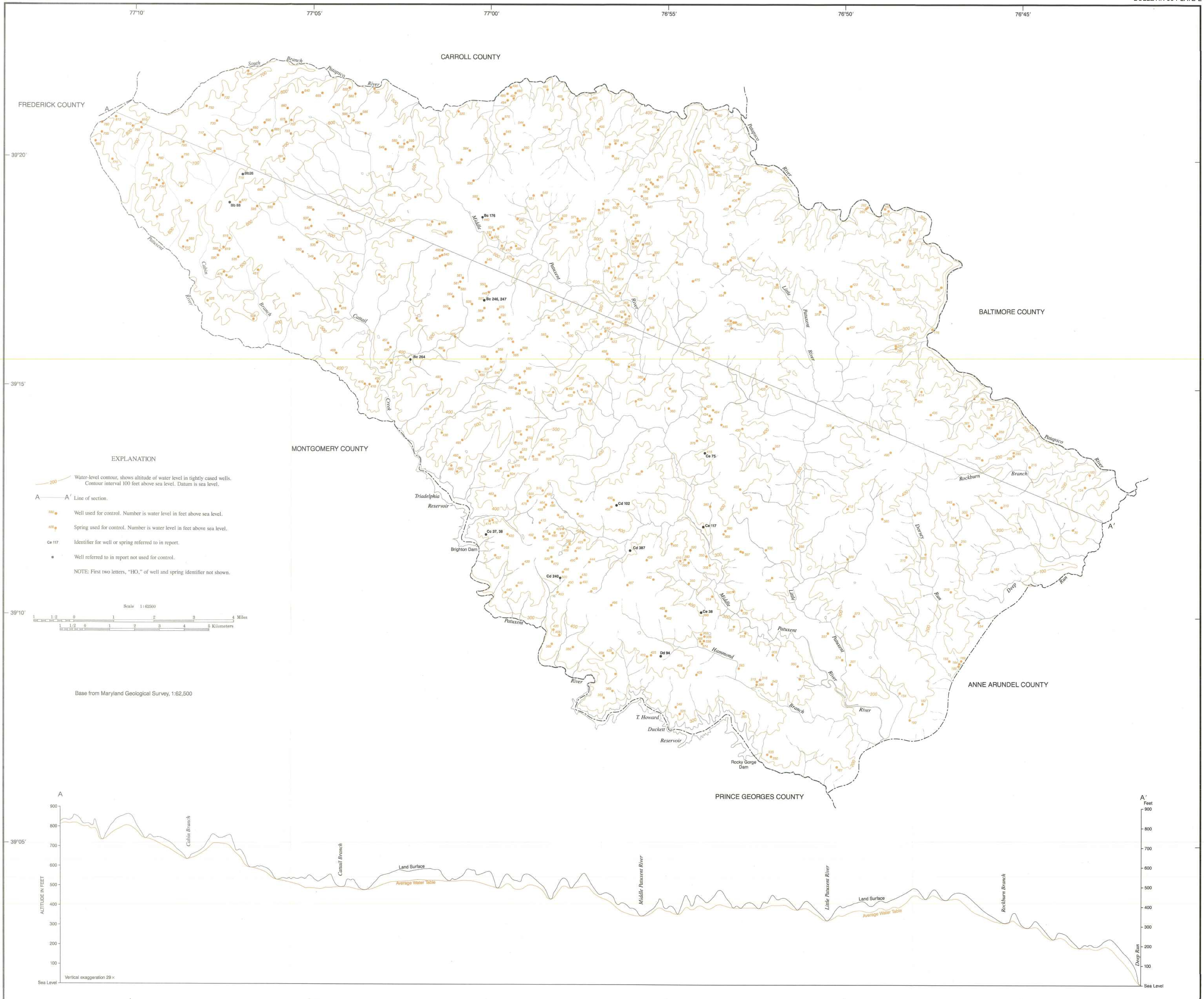
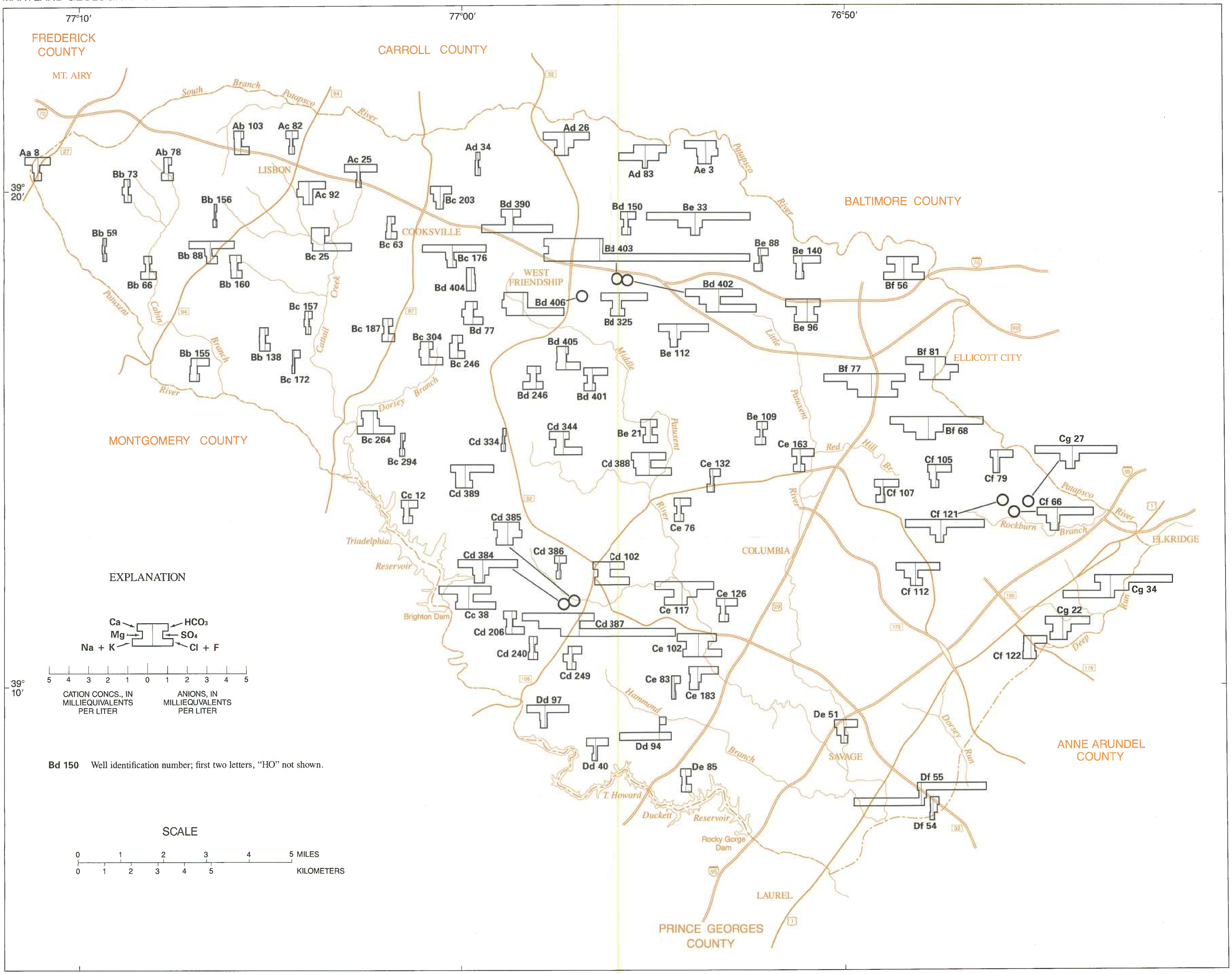


PLATE 2—GROUND-WATER LEVELS IN HOWARD COUNTY, MARYLAND, AND WELLS AND SPRINGS REFERENCED IN REPORT.



Base map from Maryland State Highway Administration, 1986, scale 1:100,000

PLATE 3—MAJOR CATION AND ANION CONCENTRATIONS IN GROUND-WATER SAMPLES FROM HOWARD COUNTY, MARYLAND.