MARYLAND
GEOLOGICAL SURVEY

CONVERSION FACTORS AND ABBREVIATIONS

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

Multiply inch-pound unit	By	To obtain SI units
inch (in.)	25.40	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
acre	0.4047	hectare (ha)
gallon (gal)	3.785	liter (L)
million gallons (Mgal)	3,785	cubic meter (m^3)
acre-foot (acre-ft)	0.001233	cubic hectometer (hm^3)
foot squared per day (ft^2/d)	0.09290	meter squared per day (m^2/d)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
gallon per day (gal/d)	0.003785	cubic meter per day (m^3/d)
gallon per minute per foot [(gal/min)/ft]	0.2070	liter per second per meter [(L/s)/m]
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per second per square mile [$(ft^3/s)/mi^2$]	0.01093	cubic meter per second per square kilometer [$(m^3/s)/km^2$]
ton	907.2	kilogram (kg)

Chemical concentration is expressed in milligrams per liter (mg/L) or micrograms per liter (μg/L). Water temperature in degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) using the following equation:

$$°F = 1.8\,(°C) + 32$$

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

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

BULLETIN 33

WATER RESOURCES OF FREDERICK COUNTY, MARYLAND

by

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and

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Prepared in cooperation with the
United States Department of the Interior
Geological Survey
and the
Frederick County Board of Commissioners
1987

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WATER RESOURCES OF FREDERICK COUNTY, MARYLAND

by

Mark T. Duigon and James R. Dine

ABSTRACT

The water resources of Frederick County, Maryland, were assessed in order to provide the hydrologic background necessary for planning, developing, and other activities. Twenty-five drainage basins (including two that drain into the county) ranging in size from 3.04 to 968 square miles were delineated.

Ground water occurs primarily under unconfined or semiconfined conditions in fractures in metamorphic and sedimentary rocks; its circulation is generally controlled by local topography. Aquifer diffusivity ranges from 6,400 to 74,000 feet squared per day, and transmissivity rarely exceeds 1,000 feet squared per day.

Reported yields of 1,582 wells range from 0 to 950 gallons per minute, with a median of 10 gallons per minute. About 5 percent of these wells were reported to yield less than 1 gallon per minute, and about 11 percent yielded less than 2 gallons per minute. Specific capacities of 1,177 of these wells ranged from 0 to 262.5 gallons per minute per foot of drawdown, with a median of 0.15 gallon per minute per foot. More than 60 percent of these wells were drilled for domestic use and were not located to provide maximum yield. Wells may be grouped by various factors such as topographic setting or geologic unit, but within-group variation in yield remains large. Yields of individual wells generally cannot be accurately predicted.

Streamflow characteristics are described for 26 stations on 19 streams. Seven-day, 10-year low flows range from 0 to 0.170 cubic foot per second per square mile. The greatest values tend to occur in the southern basins and the least occur in the northern basins.

Most of the ground water is calcium-magnesium-bicarbonate type, ranging from soft to very hard. Incidents of ground-water contamination have occurred, but were very localized. Stream water, sampled under base-flow conditions, has chemistry similar to that of the surrounding ground water. Stream-bottom materials were analyzed for trace elements or pesticides, some of which were present at low levels in some of the samples.

The average annual hydrologic budget for the county is: Precipitation (48 inches) + Incoming Streamflow and Underflow (13 inches) = Surface Runoff (25 inches) + Subsurface Runoff (11 inches) + Underflow Leaving the County (0 inches) + Evapotranspiration (25 inches) + Change in Storage (0 inches). Budgets were also estimated for individual basins. Areal draft-storage relations were developed based on the low-flow characteristics of nine gaging stations in the county. The total water resource is vast but not uniformly available, a factor that will influence growth and development in Frederick County.

INTRODUCTION

LOCATION AND SIZE

Frederick County is located in north-central Maryland, bounded by Pennsylvania on the north and by Virginia on the southwest (fig. 1). It is the largest county in the State, encom-

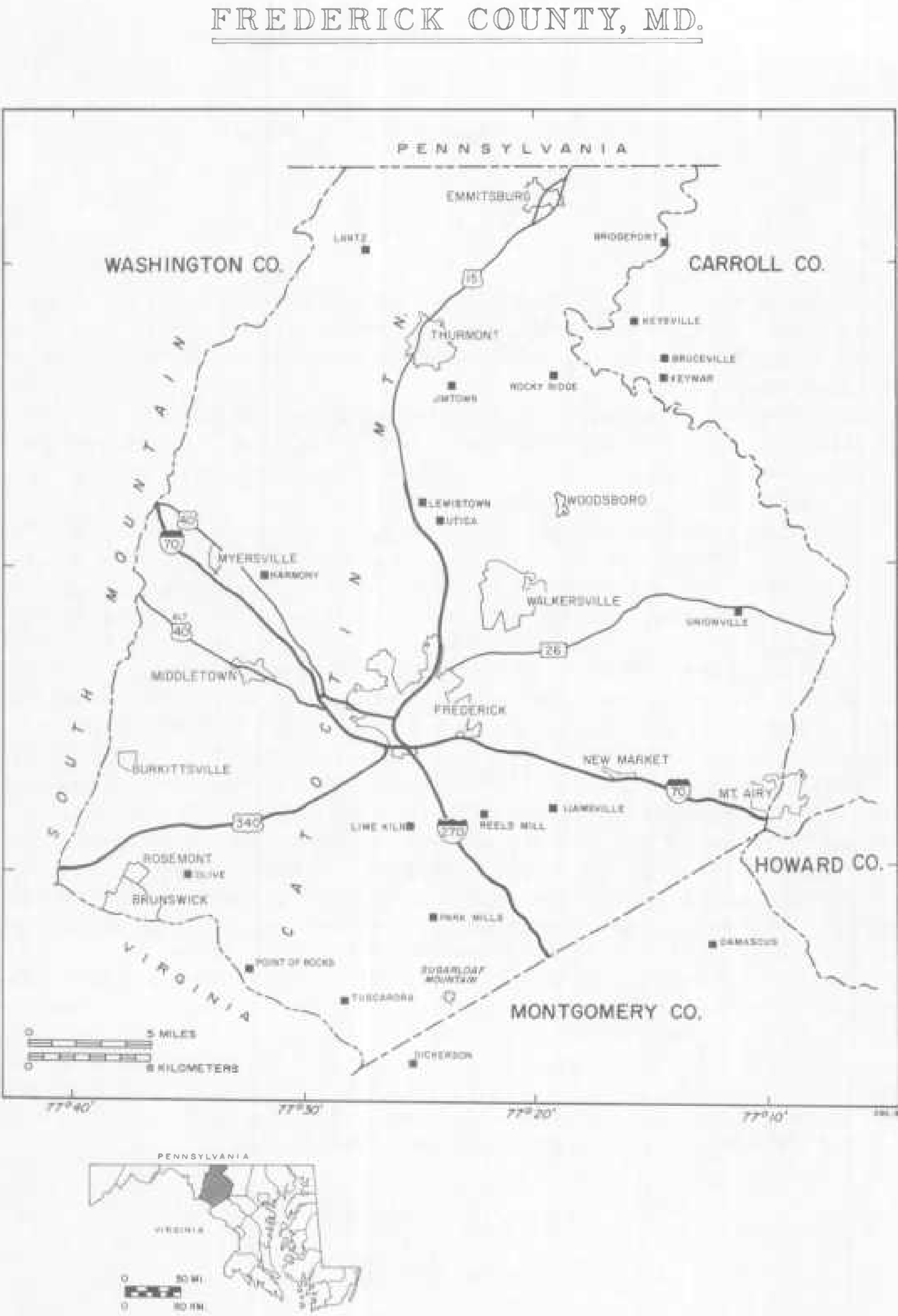


FIGURE 1. Location of Frederick County.

passing a land area of 664.8 mi^2, or 425,472 acres. The county seat is located in the city of Frederick, which is in the south-central part of the county. Frederick is 44 mi west of Baltimore and 42 mi northwest of Washington, D.C.

PURPOSE AND SCOPE

The growth in population and industry in Frederick County over the last two decades has resulted in increased demands for adequate water supplies while maintaining protection of the water resources from pollution. Individual wells and springs supply water to more than half of the population and several municipalities obtain their public water supplies from wells. The city of Frederick obtains its water from four surface-water sources: the Monocacy River, Linganore Creek, Tuscarora Creek, and Fishing Creek.

The purpose of this report is to provide an updated assessment of the water resources of Frederick County. This includes analyses of the availability of water, water quality, and the hydrologic flow system, with emphasis on ground-water and surface-water interactions. Twenty-five drainage basins (or subbasins) were delineated; these are drained by 19 streams. Hydrologic conditions and characteristics were evaluated for these basins.

GEOGRAPHIC SETTING

Frederick County includes portions of two physiographic provinces: the western, or Lowlands, division of the Piedmont in the east and the Blue Ridge in the west (fig. 2). The Piedmont is characterized by gently rolling hills with some deeply cut valleys. Land-surface altitudes are generally between 400 and 700 ft above sea level, tending to be higher in the north and east. This landscape is interrupted near the county's southern border where Sugarloaf Mountain, an erosional remnant, rises to an altitude of 1,282 ft. The broad, north-south trending Frederick Valley lies between the low Piedmont ridges to the east and the higher Catoctin Mountain of the Blue Ridge in the west. The Monocacy River, the major drainageway of Frederick County, flows through the Frederick Valley and into the Potomac River, receiving drainage from most of the county plus large areas to the north and east.

The Blue Ridge province in the western part of Frederick County includes two high ridges, South Mountain and Catoctin Mountain, which are separated by Middletown Valley. The highest point in the county is 1,917 ft above sea level, located 5 mi west of Thurmont. The border with Washington County follows the crest of South Mountain; it coincides with the western drainage divides of the Catoctin Creek and Little Catoctin Creek basins, which drain to the Potomac River.

The climate of Frederick County is moderately-humid temperate. Long-term precipitation and temperature records are available for two stations in the county (table 1), and shorter-term records are available for five additional stations (U.S. National Oceanic and Atmospheric Administration, 1961–82). The locations of these stations are shown in figure 3. The mean annual precipitation at the Frederick WFMD station (based on the period 1941–70) is 37.63 in., and 39.01 in. at Unionville (39.99 in. at Unionville is the 30-year normal for 1951–80; the Frederick WFMD station was moved during this period, so an updated 30-year normal is unavailable). Precipitation at Frederick has ranged from 19.84 in. in 1930 to 53.16 in. in 1948. Snowfall averages 27.1 in. annually in the county but melts fairly quickly, although greater amounts may fall in the mountains and remain longer. The mean annual temperature at Frederick is 53.3°F. The frost-free period is approximately 180 days, commencing (on the average) April 19.

Differences in rock type, drainage, and other soil-forming factors in Frederick County have produced a wide variety of soils, which are described in the Soil Survey of Frederick

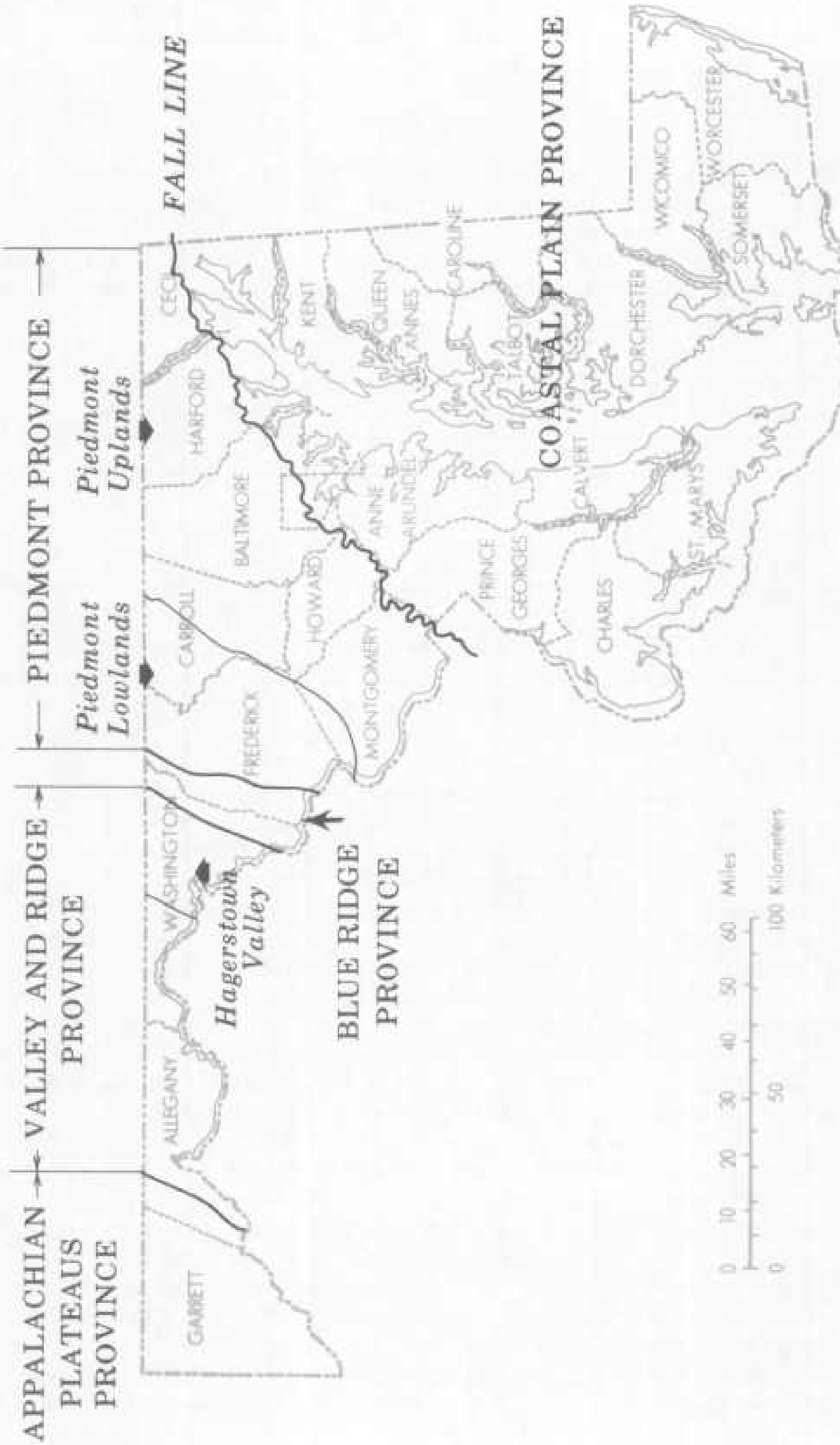


FIGURE 2. Physiographic provinces and their divisions in Maryland.

TABLE 1

PRECIPITATION AND TEMPERATURE DATA FOR FREDERICK COUNTY

[Temperatures are given in degrees Fahrenheit; precipitation is given in inches.]

Frederick WFMD temperature means for period 1951-70

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
Maximum	39.4	42.6	51.3	64.7	74.0	82.6	86.8	84.9	78.3	67.3	53.9	42.1	64.0
Minimum	22.3	24.4	30.3	41.4	50.1	59.1	63.9	62.2	54.8	43.2	34.0	25.1	42.5
Mean	30.9	33.5	40.8	52.9	62.1	70.9	75.3	73.5	66.6	55.3	44.0	33.6	53.3

Unionville temperature normals for period 1951-80

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
Maximum	39.2	42.4	52.4	64.6	73.8	81.7	85.6	84.1	77.7	66.6	54.3	43.1	63.8
Minimum	19.8	21.4	29.3	38.3	48.1	56.9	61.5	60.3	52.8	41.0	32.0	23.6	40.4
Mean	29.5	31.9	40.9	51.5	60.9	69.3	73.6	72.2	65.3	53.6	43.2	33.4	52.1

Frederick WFMD precipitation normals for period 1941-70

Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
2.44	2.45	3.40	3.30	3.67	3.31	3.87	3.66	3.03	2.56	2.96	2.98	37.63

Frederick WFMD precipitation means for period 1951-70

Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
2.17	2.57	3.43	3.52	3.28	3.25	3.71	3.57	2.82	2.30	2.92	2.87	36.41

Unionville precipitation normals

Period	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
1951-80	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
1941-70	2.57	2.35	3.28	3.28	3.86	3.69	4.23	3.81	2.90	2.68	3.16	3.20	39.01

National Oceanic and Atmospheric Administration, 1977, Climate of Frederick, Md., Asheville, N.C.

National Oceanic and Atmospheric Administration, 1982, Monthly normals of temperature, precipitation, and cooling degree days, 1951-80, Asheville, N.C.

County (Matthews, 1960). A generalized map of the soils from that report is reproduced in figure 4. The units on this map correspond well to the major physiographic and geologic features of the county.

Approximately 50 percent of Frederick County land is devoted to agriculture. Corn is the chief crop, but much of the agricultural land is in pasture. Approximately 13 percent of the land in Frederick County is woodlands, forested areas, and national, State, and municipal parks. About 25 percent is undeveloped. Hardwood forests, predominantly oak, occur on the mountains and along streams, and numerous small timber stands are scattered throughout the county. The remaining 12 percent of the land is used for commercial, industrial, and residential development.

The perennial streams were attractive for construction of water-powered mills, contributing to the settlement of the county. Numerous low dams were constructed during the 19th century. Some of these remain intact, but most have deteriorated because of floods and lack of maintenance, leaving only ruins to mark the sites of pioneer industry.

The 1980 population of Frederick County was 114,792 (Maryland Department of State Planning, 1981)—an increase of 35 percent from 1970. This growth rate was considerably greater than the rates of the previous two decades, which were 15.5 and 18 percent, respectively. In terms of density, the population increased from 127.6 to 172.7 persons per square mile during the decade 1970-80. The population projected by the Maryland Department of

State Planning (1981) for 1990 is 142,000 (a 24-percent increase since 1980), and 156,900 for the year 2000 (an increase of 10.5 percent for that decade).

FIGURE 3. Locations of precipitation-measurement stations.

GEOLOGIC SETTING

Frederick County is underlain by a variety of rock types. The stratigraphic and structural relations of the geologic units and their regional relations are still not fully understood and revision of nomenclature is ongoing. The stratigraphic nomenclature used in this report follows that of the State geologic map compilation (Cleaves and others, 1968) which is the most recent map to include the entire county; it does not necessarily follow usage of the U.S. Geological Survey, nor does it reflect the most recent, unpublished, findings of the Maryland Geological Survey.

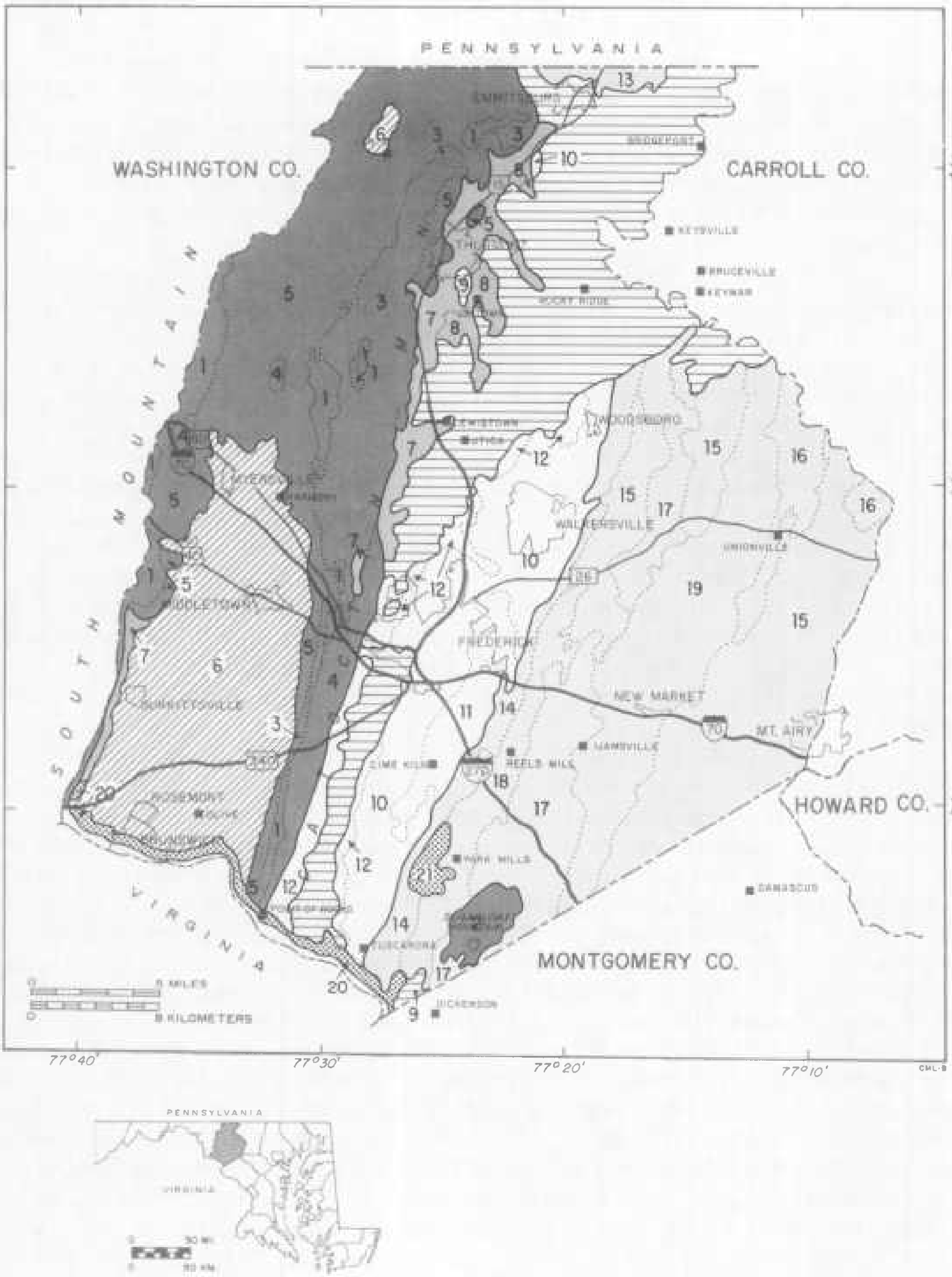
The rocks of Frederick County (pl. 1) may be grouped into four basic sequences: 1) the oldest sequence, composed of Precambrian gneiss, phyllite, and metabasalt, forms the core of the South Mountain anticlinorium and is exposed in the area between South Mountain and Catoctin Mountain (Middletown Valley); 2) a sequence of lower Paleozoic clastic and carbonate sedimentary rocks flank this core and underlie Frederick Valley; 3) metasediments and metavolcanics of the western Piedmont lie to the east of Frederick Valley and probably represent (for the most part) facies changes from the second sequence (Scotford, 1951; Edwards, 1986); 4) Triassic conglomerates, sandstones, siltstones, shales, and diabase intrusions form a band on the western edge of Frederick Valley and broaden northward where they form uplands. Overlying the rocks in most areas of the county is a variable thickness of unconsolidated overburden composed of alluvium, colluvium, and (or) residual material.

The first (and so far, only) geologic map of Frederick County was produced by Jonas and Stose (1938). The Frederick County portion of the State geologic map (Cleaves and others, 1968) reproduced as plate 1 was compiled from this map plus revisions of Stose and Stose (1946), Thomas (1952), Whitaker (1955), and E. Cloos (personal commun. to compilers, 1966).

Stose and Stose (1946) reassigned some areas in the Middletown Valley that they had previously mapped as Loudoun Formation to Swift Run Tuff. Scotford (1951) disputed the Stose and Stose (1946) interpretation that the structure of the Sugarloaf Mountain area was synclinal, arguing instead that it represented an overturned anticlinal dome. He also mapped the Sugarloaf Mountain Quartzite and Urbana Phyllite in this area as Weverton Quartzite and Harpers Phyllite, respectively. Thomas (1952) agreed that the structure was anticlinal, but disagreed in detail with Scotford; Thomas retained the names Urbana Phyllite and Sugarloaf Mountain Quartzite. Tucker and Pilant (1983) interpreted magnetic anomalies as indicating a doubly plunging, overturned anticlinorium, and confirmed the correlation of the Sugarloaf Mountain Quartzite to the Weverton Quartzite.

Whitaker (1955) reinterpreted the structure and stratigraphy of the South Mountain–Catoctin Mountain area, arguing that it represented an overturned anticlinorium, rather than a pair of synclines. Under this interpretation, he reassigned what Jonas and Stose (1938) had mapped as Loudoun Formation on the eastern flank of Catoctin Mountain to basal Harpers and uppermost Weverton Formations. The personal communication of Cloos to the compilers of the State map referred to two small areas along the crest of South Mountain.

More recent work includes remapping of the Frederick Valley by Reinhardt (1974), who renamed the Antietam Quartzite on the east side of the Frederick Valley the Araby Formation. He placed the Tomstown Dolomite as mapped by Jonas and Stose (1938) and Whitaker (1955) into the base of the Frederick Formation (which he subdivided into three members), with no Araby/Frederick hiatus. Reinhardt agreed with Rasetti's (1961) interpretation placing the belts of massive limestone west of Frederick within the Frederick Formation rather than the Grove; but he defined the Frederick Formation to include some of the Grove Limestone containing Upper Cambrian fossils which had been described by Rasetti (1959).



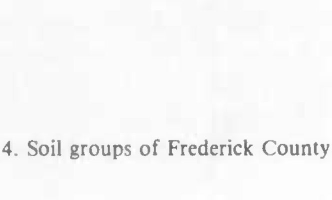


FIGURE 4. Soil groups of Frederick County (from Matthews, 1960).

EXPLANATION

STONY OR STEEP, SHALLOW SOILS OF MOUNTAIN AND ELEVATED INTERMOUNTAIN AREAS:

1. Dekalb-Clymer
2. Edgemont-Dekalb.
3. Edgemont-Chandler-Dekalb.
4. Chandler-Talladega
5. Highfield-Fauquier

ROLLING SOILS OF INTERMOUNTAIN VALLEYS:

6. Myersville-Fauquier-Catoctin.

SOILS OF COLLUVIAL FOOT SLOPES:

7. Braddock-Thurmont-Augusta.
8. Norton

MOSTLY SHALLOW SOILS OF VALLEYS OF RED SHALE AND SANDSTONE:

9. Penn-Readingtan-Crotan

SOILS OF LIMESTONE VALLEYS:

10. Duffield-Hagerstown
11. Sequatchie-Hagerstawn.
12. Athal

SOILS OF THE PIEDMONT PLATEAU:

13. Montalto-Lehigh-Watchung
14. Cardiff.
15. Manor-Glenelg.
16. Canestaga-Manor
17. Manar-Edgemant-Brandywine.
18. Manor-Linganare-Montalta.
19. Manar-Linganore-Urbana.

SOILS OF RIVER TERRACES AND FLOOD PLAINS:

20. Waynesboro-Captina-Huntington
21. Elk-Captina-Huntington

Fauth (1977) lumped metabasalt, metarhyolite, and phyllite into the Catoctin Formation, having nine mapping units in the Catoctin Furnace and Blue Ridge Summit quadrangles; some of the contacts were somewhat modified from previous mapping. He continued this scheme into the Myersville quadrangle (1981). Fisher (1978) mapped the New Windsor quadrangle, which lies mostly in Carroll County, but includes a very small wedge of Frederick County. Fisher changed the name of Sams Creek Metabasalt to Sams Creek Formation, but this has no real effect on interpretations of Frederick County geology.

Interpretations of the geology of the eastern part of Frederick County are much less certain. These rocks differ from the metavolcanics and metasediments in the west because of facies changes and differences in metamorphic and tectonic history, obscuring their relations to other areas. The Libertytown Metarhyolite may be an oxidized part of the Sams Creek Metabasalt, which is probably correlative with the Catoctin Metabasalt (Edwards, 1986).

Some of these units (Marburg, Ijamsville and Urbana) have been considered to belong to the Glenarm Group of the Piedmont Uplands to the east. However, their relations to the eastern Piedmont rocks have been obscured by severe deformation (which includes allochthonous transport of these units) along with poor exposures; a relationship to the Glenarm Group cannot be demonstrated. They may be correlative with the Harpers-Antietam-Frederick succession to the west (Edwards, 1984, 1986). Where these metasedimentary phyllitic units cannot be differentiated, they have been assigned to a new unit, the Gillis Formation (Edwards, 1984; Muller and Edwards, 1985; Edwards, 1986).

Assignment of water wells to particular geologic units is thereby tenuous in many cases owing to differences in stratigraphic and structural interpretations and nomenclature, and to vague or erroneous descriptions of well cuttings. The water-bearing characteristics of most of the geologic units ("aquifers"), however, are similar. This topic is discussed in the sections "Aquifer Properties" and "Factors Influencing the Yields of Wells." Aspects of the relation of ground-water quality and geologic unit are discussed in the section "Ground-Water Quality."

The geologic structure of Frederick County is complex. The rocks of the Middletown Valley (sequence 1 described above) are the exposed core of a large, overturned anticline (the South Mountain anticlinorium). East of the anticline, the Frederick syncline (in sequence 2) contains the Grove Limestone along its axis. Part of the synclinal unit was covered by sediments (of sequence 4) and downfaulted. After deposition of those sediments, igneous activity resulted in the intrusion of numerous diabase dikes throughout the county and some diabase sills in the northern edge of the county. The Triassic sedimentary rocks are found in the Newark-Gettysburg Basin (extending from near Frederick to north of New York City) and the Culpeper Basin (reaching from south of Frederick almost to Charlottesville, Va.). The two basins are separated by a mile-wide area of rocks of sequence 2, probably because of faulting and erosion. Minor thrusting of the crystalline schists and related rocks of the western Piedmont (sequence 3) upon the carbonate rocks of sequence 2 occurs along the eastern edge of the Frederick Valley. This thrust, the trace of which has previously been called the Martic Line, is covered by the Triassic rocks northeast of the Frederick Valley. Within the crystalline-rock terrane, large-scale overthrusting of the Sams Creek Metabasalt over the Urbana, Ijamsville, and Marburg formations has been demonstrated (Edwards, 1984, 1986).

The Frederick and Grove Limestones are the basis of most of the mineral industry in Frederick County. Several operations within the county produce portland and masonry cement, industrial and agricultural lime, and crushed stone. The Wakefield Marble is also quarried in Frederick County to supply a portland cement plant located in Carroll County. Clay and shale are produced for the manufacture of portland cement and bricks (Frederick County was the State's leading clay producer in 1979); lightweight aggregate has been produced by expanding shale and some phyllite. Aluminum produced by the Eastalco plant near Adamstown is made from imported alumina.

PREVIOUS INVESTIGATIONS

A report on the water resources of Carroll and Frederick Counties (Meyer and Beall, 1958) includes basic data and an interpretive report on ground water (Meyer) and a summary report on surface water (Beall). Earlier studies of geology and water resources are cited therein.

The Maryland State Planning Department, with the Maryland Geological Survey and the U.S. Geological Survey, published "Ground-Water Aquifers and Mineral Commodities of Maryland" in 1969. This report was based on the county water-resources bulletins of the Maryland Department of Geology, Mines and Water Resources (now the Maryland Geological Survey) and work done by Nutter and Otton (1969), who reported on ground water in the Maryland Piedmont. Nutter (1974) included some well data from Frederick County in his report on bedrock aquifers of the State. Hydrology of the carbonate aquifers of Maryland was studied by Otton and Richardson (1958) and by Nutter (1973), who restricted his study to the Frederick and Hagerstown Valleys. LaRiccia and Rauch (1977) studied the relation of well productivity and drawdown with photo-lineaments in the limestones of the Frederick Valley. Nutter (1975) investigated the hydrology of the Triassic rocks in Frederick, Carroll, and Montgomery Counties. Hydrology of the Triassic rocks of western Montgomery County (just south of eastern Frederick County) was studied by Otton (1981). Richardson (1980) described ground-water occurrence in the central Maryland Piedmont; that study included part of southeastern rederic County. Otton discussed geohydrologic factors pertinent to the disposal of liquid (1970) and solid (1972) wastes in Maryland. These reports identified areas within Frederick County having differing characteristics that affect waste disposal.

Trainer and Watkins (1974 and 1975) investigated base flow of the Potomac River basin and used base-flow recession to estimate areal transmissivities. Trainer (1969) also investigated estimations of base flow from drainage density in that portion of the Potomac River basin between Point of Rocks in Frederick County and Washington, D.C.

Maryland streamflow characteristics were presented by Darling (1962) and updated by Walker (1971) and Carpenter (1983). Flood-hazard information has been published by the U.S. Department of Agriculture, Soil Conservation Service, for the Little Catoctin Creek basin (1978), and by the U.S. Army Corps of Engineers for the Monocacy River (1971) and the Potomac River, Frederick County portion (1975). Taylor (1970) investigated traveltime of a soluble dye in the Monocacy River. The U.S. Geological Survey publishes annual reports containing streamflow and water-quality data (U.S. Geological Survey, 1967–71, 1972–75, 1976–85).

Reconnaissance investigations of water quality were performed for Maryland streams (Thomas, 1966; Maryland Department of Natural Resources, Water Resources Administration, 1977) and for ground water (Woll, 1978). Thomas and Heidel (1969) gathered water-quality data from municipal supplies (serving populations of 1,000 or more). These data include analyses of raw and treated water, and information concerning water sources, quantities of water used, and methods of treatment. A report on water quality of the Monocacy River basin (DeRose, 1966) included analyses of 21 sites that were sampled monthly during the period March–December 1966.

Related materials published since 1958 include the Frederick County Soil Survey (Matthews, 1960) and a land use and cover map for 1974–76 (U.S. Geological Survey, 1981, scale 1:250,000). The Board of County Commissioners of Frederick County compiled a Master Plan for water and sewerage (1977) and update it periodically. An informative compilation of facts about the county was made by the League of Women Voters of Frederick County (1980). Basic hydrologic data were compiled as part of the present study and published separately (Dine and others, 1985).

ACKNOWLEDGMENTS

This investigation was performed by the Maryland Geological Survey in cooperation with the U.S. Geological Survey, Water Resources Division; and with the Board of County Com-

missioners of Frederick County. The Frederick County Planning Department, particularly Carole Larsen, assisted in communicating the needs and plans of the county. Well drillers and property owners provided much information on wells and well locations and permitted field personnel to measure water levels and collect water samples.

DATA-COLLECTION NETWORK

Twenty-five drainage basins (or subbasins) were delineated. Two of these drain into the country from the east; 16 are independent basins; and seven include one or more of the other basins within their boundaries. Significant portions of some of the basins lie outside of Frederick County, but were included for study because of their contributions to the county's water resources. Selection was based on basin size and availability of streamflow data. The drainage basins range in size from 3.04 to 968 mi^2. The total drainage area under consideration is 1,092 mi^2, which exceeds the area of Frederick County by 427 mi^2. The basins provide units for analyses of water budgets, water availability, and areal distribution of water and water-bearing characteristics. Each of the basins is characterized by heterogeneous geology. Variations in rock type and structure affect the availability of water within the basins, as will be discussed in a later section of this report.

The basin outlets were monitored at either continuous-record stations or partial-record stations (fig. 5; table 2). Long-term, continuous records were available for 11 stations, including two stations whose operations were discontinued prior to this study. Seven stations had partial records obtained for previous studies, and nine new stations were chosen for this study. Basic data obtained at these sites are reported separately (Dine and others, 1985). Flows measured at the non-instrumented sites were correlated with flows at long-term instrumented stations in order to develop the flow characteristics needed for further analyses. Water-quality samples were collected at all of these sites with the exception of Monocacy River at Jug Bridge near Frederick, for which samples were collected approximately 1.2 mi downstream from the gage at Reich's Ford Bridge.

Water levels were measured periodically in 56 wells located throughout the county. Analog-type water-level recorders were placed on four of these wells to provide continuous records of water-level fluctuations. The water-level data are tabulated in Dine and others (1985, table 3). In addition to providing depth to water values for those locations, the data may be used to estimate areal variability of depths to water, ranges in water-level fluctuations, and certain aquifer properties.

Water samples for chemical analysis were collected from 12 wells also used as water-level-measuring sites, from 130 wells where water levels were not periodically measured, and from 24 springs. Figure 6 shows the locations of water-level and ground-water-quality data sites.

The identification numbers of these sites are based on a Statewide system in which each county (designated by a two-letter prefix) is divided into grids drawn at every fifth minute of latitude and longitude. The quadrangles formed by the grid are lettered from north to south and from west to east, and wells and springs are numbered consecutively as they are inventoried. Thus, well FR EF 49 is the 49th well inventoried in the fifth tier from the north, sixth column from the west, in Frederick County. Locations of all inventoried wells and pertinent ground-water data are reported by Dine and others (1985).

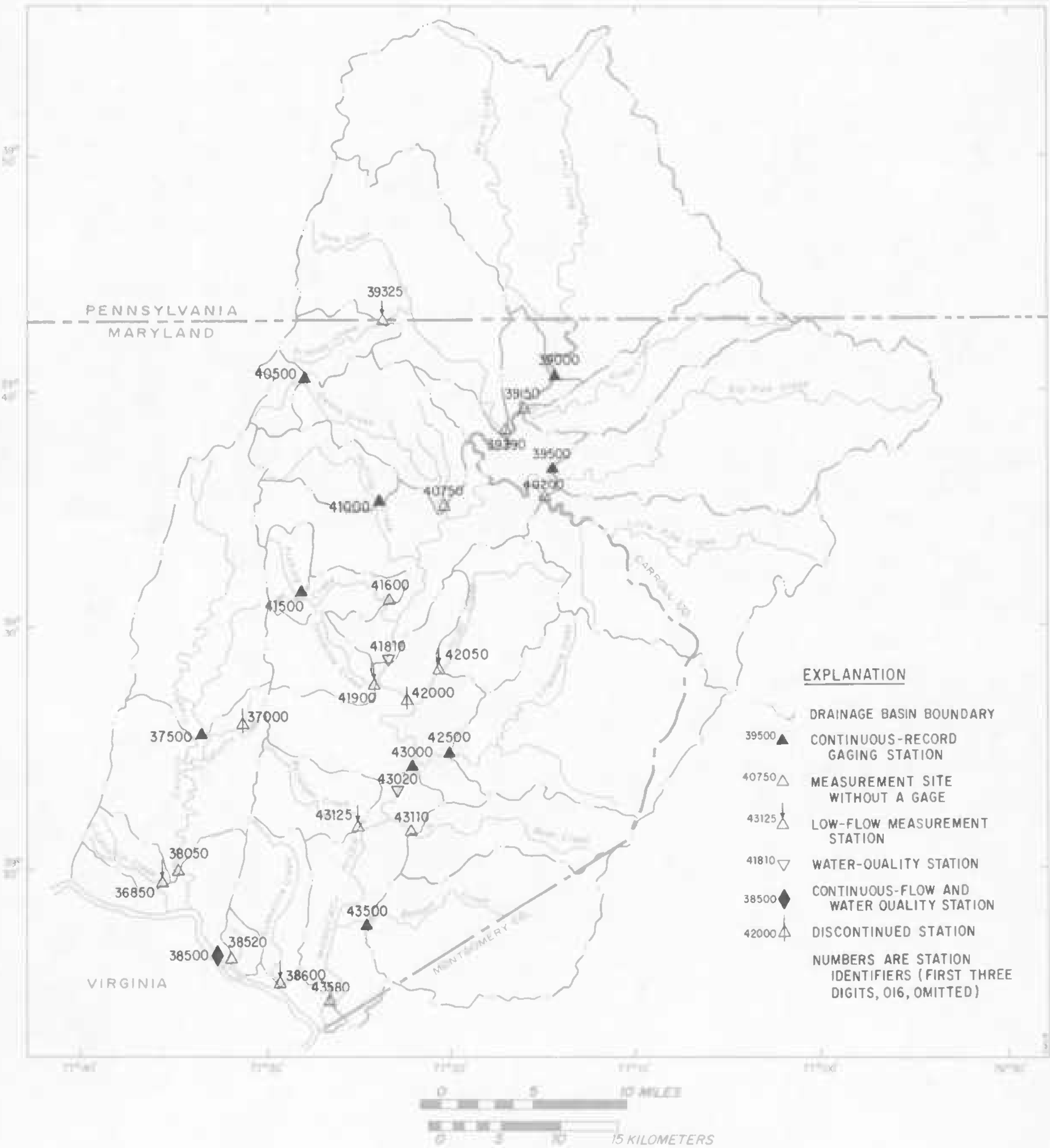


FIGURE 5. Locations of drainage basins and surface-water stations.

TABLE 2
STREAM DATA-COLLECTION STATIONS AND BASIN CHARACTERISTICS

Stetion no.	Station name	Type of record	Latitude (dagree	Longitude minute second)	Drainege area (mi^2)	Period of record
01636850	Little Catoctin Creek near Brunswick	P	39 19 25	77 35 35	8.64	May 1977 - Sept. 1983
01637000	Little Catoctin Creek at Harmony	C	39 28 55	77 32 20	8.83	July 1947 - Oct. 1958, Oct. 1967 - Sept. 1968
01637500	Catoctin Craek near Middletown	C	39 25 35	77 33 25	66.9	Aug. 1947 - present
01638050	Catoctin Creek at Olive	S	39 19 56	77 34 45	112	Mar. 1982 - Sept. 1983
01638500	Potomac River at Point of Rocks	C Q	39 16 25	77 32 35	9651	Feb. 1895 - presant Oct. 1960 - present
01638520	Potomac River Tributary at Point of Rocks	S	39 16 23	77 31 31	3.04	Mar. 1982 - Sept. 1983
01638600	Tuscarora Creak at Tuscarora	P	39 15 06	77 28 49	20.3	Aug. 1975 - Sept. 1983
01639000	Monocacy River at Bridgeport	C	39 40 43	77 14 06	173	May 1942 - present
01639150	Piney Creek near Keysville	S	39 39 19	77 15 54	34.4	Mer 1982 - Sept. 1983
01639325	Friends Creek near Emmitsburg	P	39 43 03	77 23 35	12.2	May 1977 - Sept. 1983
01639390	Toms Creek near Keysville	S	39 28 23	77 16 55	88.1	Mar. 1982 - Sept. 1983
01639500	Big Pipe Creek at Bruceville	C	39 36 45	77 14 10	102	Oct. 1947 - present
01640200	Little Pipe Creek at Keymar	S	39 35 28	77 14 35	80.0	Mar. 1982 - Sept. 1983
01640500	Owens Creek at Lantz	C	39 40 36	77 27 50	5.93	Oct. 1931 - Sept. 1983
01640750	Owens Creek neer Rocky Ridge	S	39 35 07	77 20 08	38.8	Mar. 1982 - Sept. 1983
01641000	Hunting Creek at Jimtown	C	39 35 40	77 23 50	18.4	Oct. 1949 - present
01641500	Fishing Creek near Lewistown	C	39 31 35	77 28 00	7.29	Oct. 1947 - Sept. 1983
01641600	Fishing Creek near Utica	S	39 30 41	77 23 07	17.9	Mar. 1982 - Sept. 1983
01641810	Monocacy River near Walkersville	S	39 28 47	77 23 18	637	Aug. 1982 - July 1983
01641900	Tuscarora Creek near Frederick	P	39 27 52	77 24 11	16.5	Nov. 1974 - Sept. 1983
01642000	Monocacy River near Frederick	C	39 27 09	77 22 16	665	Aug. 1896 - Sept. 1930
01642050	Israel Creek near Walkersville	P	39 28 27	77 20 26	28.4	Aug. 1964 - Sept. 1983
01642500	Linganore Creek near Frederick	C	39 24 55	77 20 00	82.3	Nov. 1931 - Mar. 1932, Sapt. 1934 - Sept. 1982
01643000	Monocacy River at Jug Bridge near Frederick	C	39 24 13	77 21 58	817	Oct. 1929 - prasent
01643020	Monocacy River at Reich's Ford Bridge neer Frederick	Q1/	39 23 16	77 22 40	--	Oct. 1960 - present
01643110	Bush Craek at Reels Mill	S	39 21 37	77 22 08	29.7	Mar. 1982 - Sept. 1983
01643125	Ballenger Craak near Lima Kiln	P	39 21 52	77 25 01	20.2	May 1977 - Sept. 1983
01643500	Bennatt Creek at Park Milla	C	39 17 40	77 24 30	62.8	July 1948 - Sept. 1958, Aug. 1966 - present
01643580	Monocacy River at Dickerson	W	39 14 11	77 26 25	968	Oct. 1974 - Sept. 1983

Typa of record codes
- C - Continuous-record gaging station
- P - Partial-record low-flow station
- Q - Long-term water-quality station
- S - Station established for this study
- W - Meryland Water Resources Administration site
  Period of record, Oct. 1949 to Sapt. 1971

Artificial influance codes
- N - Negligible
- S - Slight
- M - Some
- D - Considerable

1/ Flow valuas uaed are from Jug Bridge station, 1.2 mi upstream.

TABLE 2—*Continued*

Artificial influence on flow	Main channel length (mi)	Altitude (ft) At 10% stream length	Altitude (ft) At 85% stream length	Mean basin altitude (ft)	Slope of main channel (ft/mi)	Slope of main channel (percent)	Area of lakes and ponds (percent)	Forested area (percent)	Station no.
N	6.7	325	510	523	36.8	0.70	0.158	12	01636850
N	5.10	555	1,445	1,010	232.7	4.41	.006	48	01637000
S	23.9	410	1,250	1,110	46.9	.89	.163	46	01637500
S	35.8	285	1,005	851	26.8	.51	.090	30	01638050
D	271	290	1,150	1,356	4.2	.080	.044	59	01638500
N	3.12	235	515	379	119.7	2.27	.089	29	01638520
N	12.7	220	415	396	20.5	.39	.111	19.4	01638600
M	31.5	350	810	597	19.5	.37	.26	24.0	01639000
S	21.7	360	595	558	14.5	.27	.12	14.5	01639150
N	8.01	630	1,300	1,196	111.5	2.11	.05	62	01639325
S	20.8	345	1,010	826	42.6	.81	.20	49	01639390
N	28.0	363	600	625	12.8	.24	.020	17.0	01639500
N	22.3	350	560	559	12.6	.24	.091	12.9	01640200
N (pre-1959)	4.10	1,010	1,620	1,455	198.4	3.76	.00	71	01640500
N	16.9	315	1,165	860	67.1	1.27	.097	52	01640750
M	8.8	385	1,280	1,100	135.6	2.57	.336	77	01641000
N	4.2	850	1,655	1,450	255.6	4.84	.20	100	01641500
M	12.9	310	1,470	933	119.9	2.27	.657	61	01641600
M	58.4	270	565	669	6.74	.13	.14	31.6	01641810
M	5.82	285	450	741	37.8	.72	.12	44.8	01641900
N	57.9	270	565	731	6.79	.13	.144	36	01642000
N	11.9	290	480	483	21.3	.40	.085	16.4	01642050
M	20.1	290	590	576	19.9	.38	.36	20	01644250
N	64.7	250	535	621	5.87	.11	.155	33	01643000
-	69.7	--	--	--	--	--	--	--	01643020
N	14.3	290	570	537	26.1	.49	.097	24.5	01643110
N	10.6	250	490	419	30.2	.57	.099	13	01643125
N	15.6	265	545	521	23.9	.45	.087	26	01643500
M	83.5	240	540	613	4.79	.09	.148	30.5	01643580

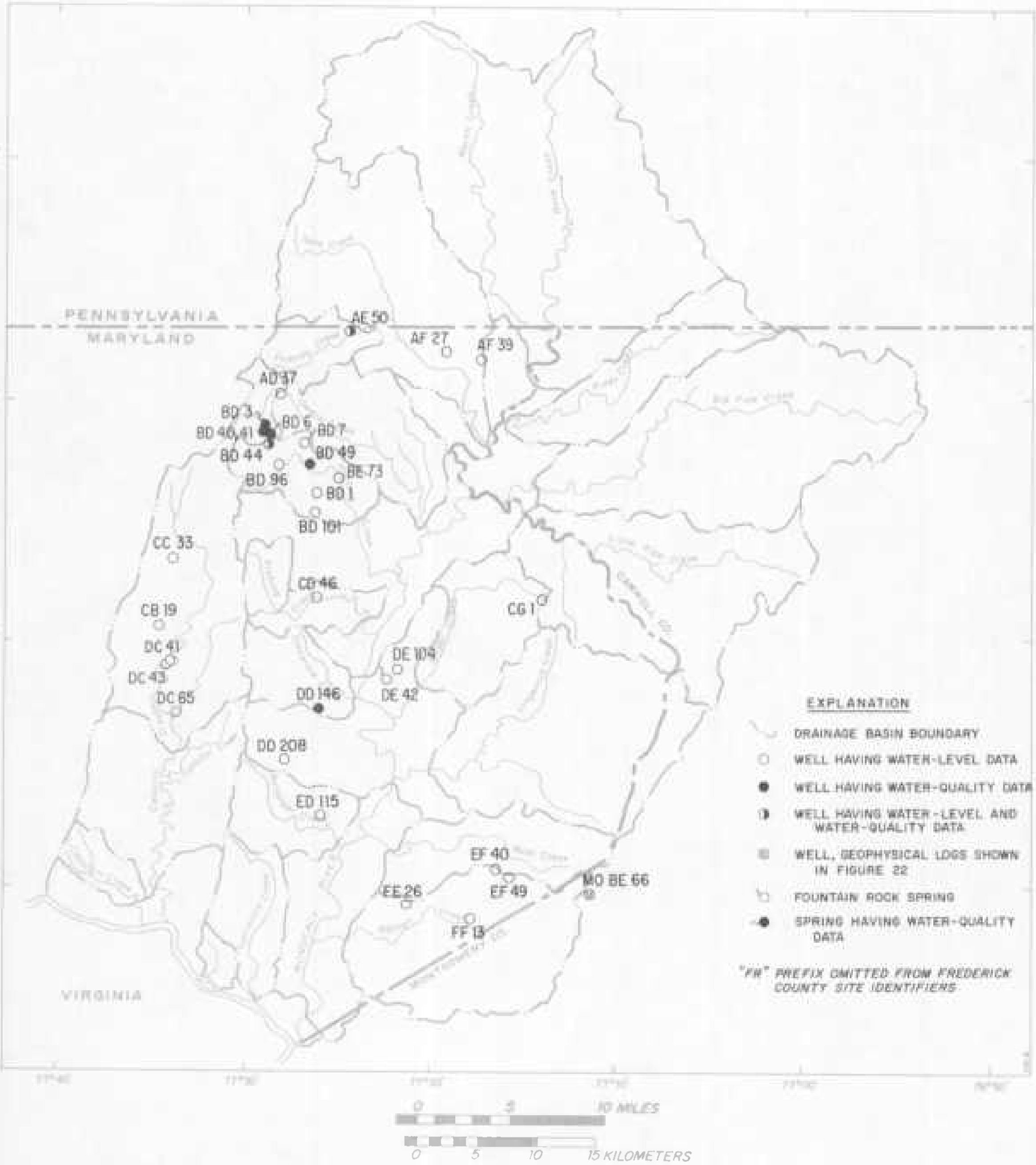


FIGURE 6. Locations of wells and springs referred to in this report. Additional locations are shown in the basic-data report (Dine and others, 1985).

GROUND-WATER RESOURCES

SOURCES OF WATER

Most ground water in Frederick County originates locally from precipitation, a portion of which infiltrates into the ground. Water that has descended to the zone of saturation does not move very far horizontally (a few miles at most) before being discharged to one of the numerous streams in the county. Water may evaporate directly or be transpired through plant leaves, re-entering the atmosphere and completing the hydrologic cycle (fig. 7).

As suggested by the concept of the hydrologic cycle, ground water is intimately related to surface water, and vice versa (some water-table and stream relations are shown in figure 8). Under some circumstances, a well may induce water from a nearby stream to replenish water pumped from the aquifer. Indeed, all of the factors of the hydrologic cycle interact, each exerting some influence on total water availability; from the hydrologic cycle we may develop a hydrologic budget for more quantitative analysis. The hydrologic budgets for various drainage basins of Frederick County are discussed in a later section of this report.

The boundaries of a ground-water system may be difficult to identify. The upper boundary of a ground-water system may be a zone of relatively impermeable geologic material, or it may be the top of the zone of saturation. The lower boundary may also be a zone of impermeable material; in Frederick County this boundary is commonly indistinct, due to the gradual decrease in the number and width of rock fractures with depth. The individual geologic formations underlying Frederick County are not simple, distinct aquifers because the water-bearing fractures may cut across contacts between lithologies having similarly low primary permeabilities, and intraformational differences may be as hydrologically significant as differences between formations. Individual ground-water flow systems in this area are more commonly bounded areally by ground-water divides which generally correspond to the local topography. In some areas (limestone terranes are noted for this), the ground-water and surface-water divides may not coincide.

Ground water may occur under unconfined or confined conditions. The upper boundary of an unconfined aquifer is the top of the saturated zone. This surface, the water table, is the locus of points where water pressure is atmospheric. In the fractured-rock terrane characteristic of Frederick County, water-table conditions prevail where the fractures are numerous and well-connected; this is the case for most of the county. In some areas, however, the distribution of fractures may be such that zones of unfractured rock effectively confine ground-water flow, and wells tapping such confined fractures are "artesian wells" because their water levels rise above the level of the intersected fractures. If the altitude of the well is below the altitude of the potentiometric surface, the well is a "flowing artesian well" (fig. 9).

RECHARGE AND DISCHARGE

Because the aquifers of Frederick County generally exist under water-table conditions and precipitation falls across the entire county, some amount of recharge can occur almost anywhere in the county. Weather and antecedent soil-moisture conditions are two important factors governing what percentage of precipitation reaches the ground-water body; this percentage ranges from approximately 12 to 30 percent in Frederick County. Water from other sources can enter an aquifer. For example, when surface runoff causes a stream to rise, some water may move from the channel into the streambanks; or (in the case of a perched stream), a streambed may be somewhat but not completely impermeable and surface runoff

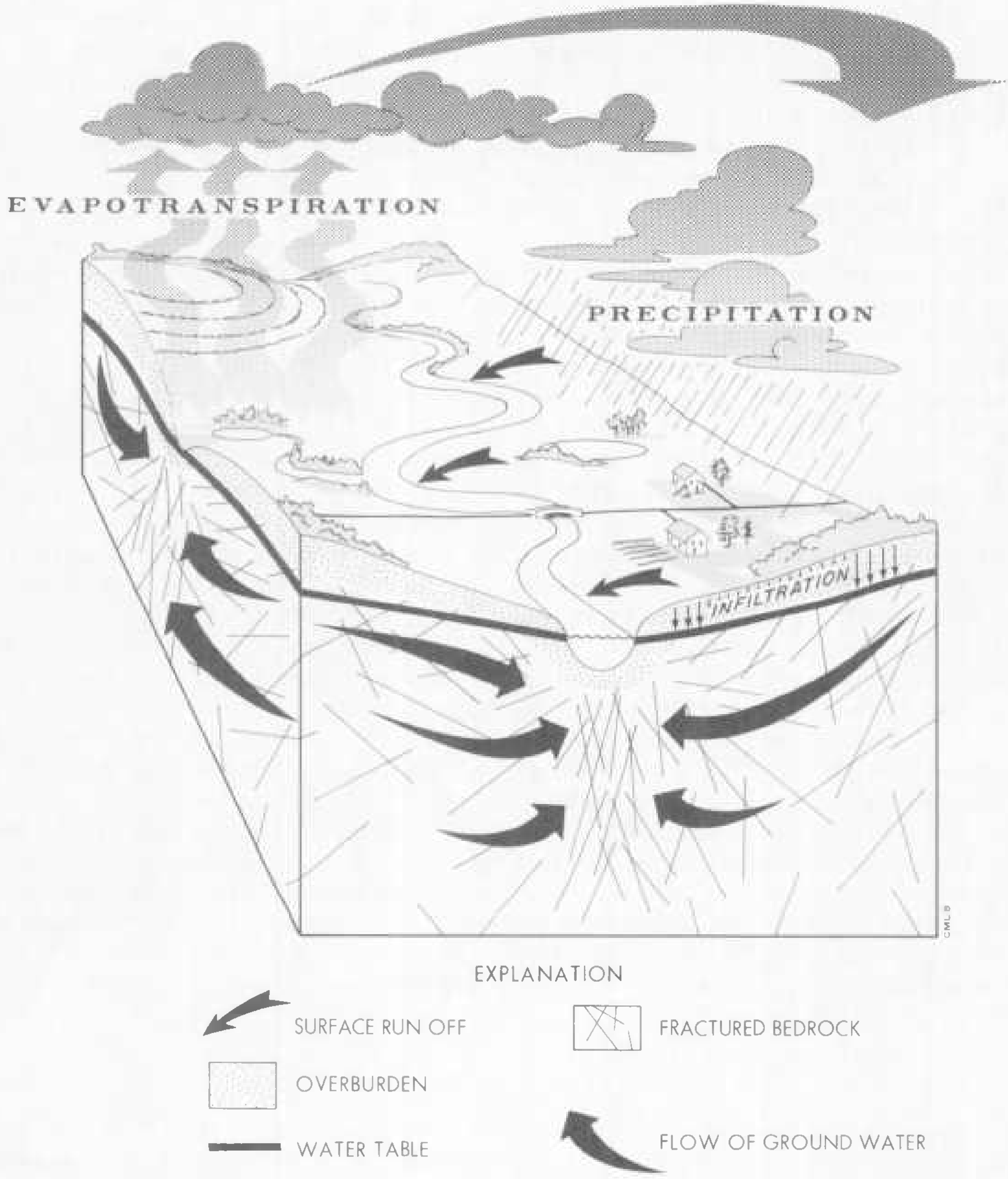


FIGURE 7. The hydrologic cycle.

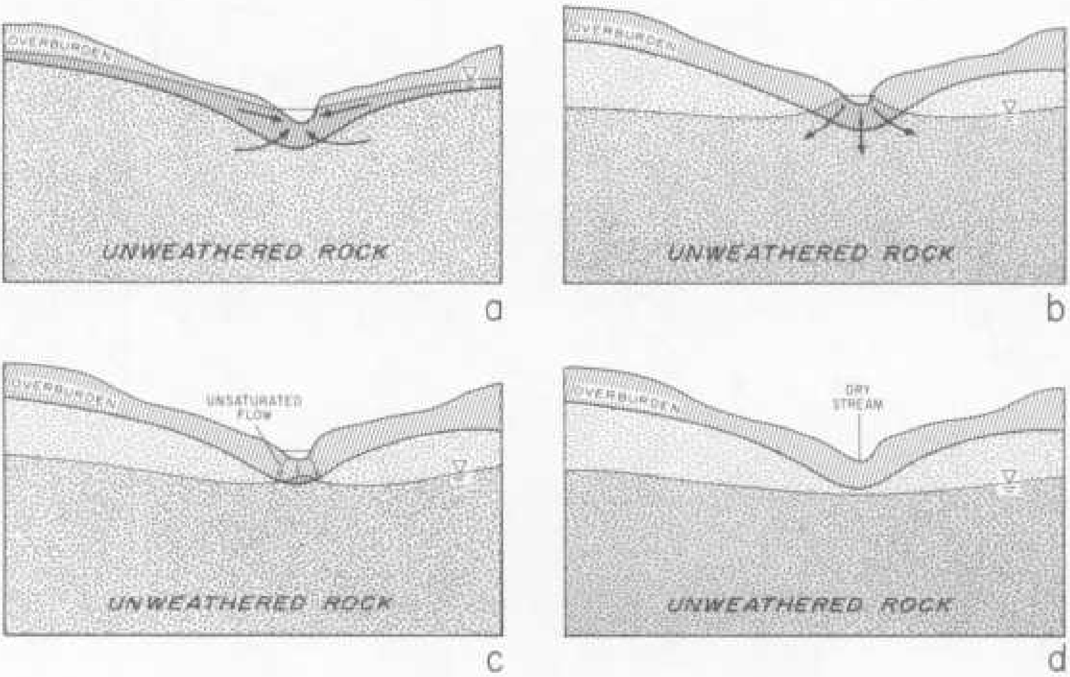


FIGURE 8. Stream and water-table relations. a) Ground water discharges to stream (gaining, or effluent stream); b) Stream loses water to shallow saturated zone (losing, or influent stream; c) Stream loses water, which moves as unsaturated flow toward deeper water table; d) During severe drought, water table is well below dry stream channel.

may leak through the bed and percolate downward. Another mechanism of recharge important in some areas is the return of water to the ground via septic-tank waste-disposal systems.

Ground-water discharge in Frederick County occurs primarily along stream channels. Discharge into streams is generally diffuse in the noncarbonate terranes, but in the Frederick Valley, many streams can be traced to springs discharging from the Frederick or Grove Limestones, which supply nearly all of the streamflow during base-flow periods (Nutter, 1973, p. 16). The sustained, or base, flow of a stream is derived from ground-water discharge and, in Frederick County, may be more than half of a stream's annual flow. The ground-water gradients, as implied by the potentiometric map (pl. 2), slope toward the streams draining into Catoctin Creek and the Monocacy River. Thus, much of the ground water in Frederick County eventually drains to the Potomac River.

Some of the numerous springs can be utilized in public water-supply systems. The spring at Fountain Rock, FR DE 42, is the largest in the county and has a discharge that exceeds 1,000 gal/min; it has been used to provide water for raising trout. (The land surrounding this spring was purchased by the county in 1983 to make it available as a public-supply source, if needed). In some areas, springs are more diffuse and are frequently referred to as seepage springs or seeps. For a more detailed discussion of Maryland springs, see Otton and Hilleary (1985). Subsurface water is also lost to the atmosphere by evaporation and plant transpiration. These processes generally involve soil moisture and unsaturated conditions, but evapotranspiration from the saturated zone can be significant, particularly along streams, where the saturated zone is closest to land surface.

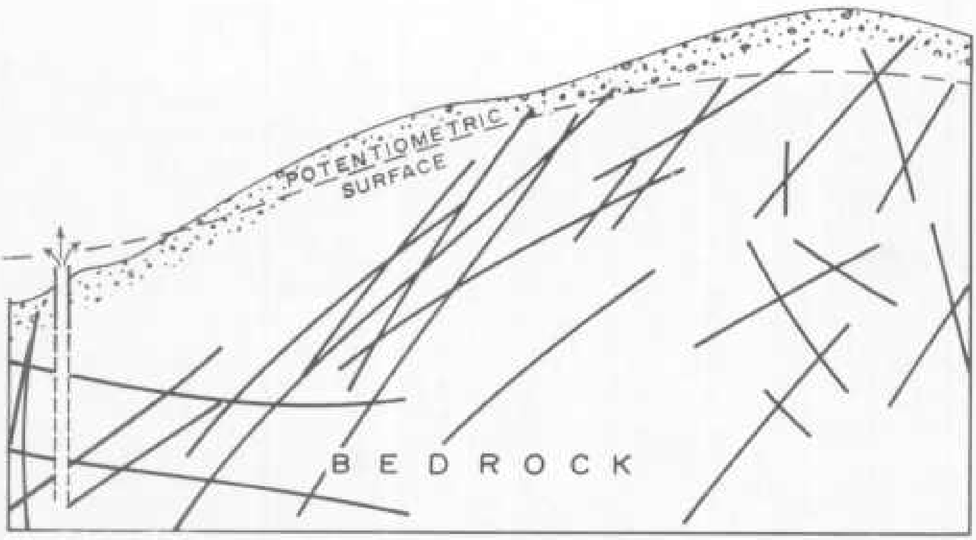


FIGURE 9. Artesian conditions in a fractured-rock aquifer. Ground-water flow (toward the left) is effectively confined by the unfractured rock (where lines indicating fractures are lacking). The well intersects fractures containing water under pressure and is, therefore, a flowing artesian well.

Withdrawal of water from wells is another means of ground-water discharge. The impact of pumping on a ground-water system depends on the pumping rate and the location of the well. If the well is located near a recharge zone, it may increase the rate of recharge by increasing the gradient near that zone. The fate of the water after being pumped may affect recharge or discharge of an aquifer, depending on whether it is returned to the aquifer or exported beyond. A computer-modeling study of possible recharge/discharge scenarios involving water-supply systems in the Piedmont province of Maryland may be found in Willey and Achmad (1986).

The rate of discharge is also dependent upon the weather and soil moisture, and antecedent conditions. As streams fall from storm crests, water that moved into the banks returns to the channels. During prolonged dry periods, as ground water is discharged from storage, the potentiometric surface tends to flatten out, producing a lesser gradient, and, consequently, a slower rate of discharge. In extreme situations, some streams and even some reliable springs may cease to flow as the potentiometric surface lowers. Ground-water recharge and discharge in relation to total basin runoff are discussed in the section "Hydrologic Budgets and Water Availability."

WATER LEVELS

Water levels in shallow wells drilled into unconfined ground-water systems will be at approximately the level of the water table. The location of a well's intake, in relation to the ground-water flow system, can affect the level of water in the well (fig. 10). In an area of recharge, there is a downward component of flow; hence, water levels are lower in deeper wells. In an area of discharge, such as along a stream, there is an upward component of flow, so water levels are higher in deeper wells. Flowing artesian wells may thus be found where

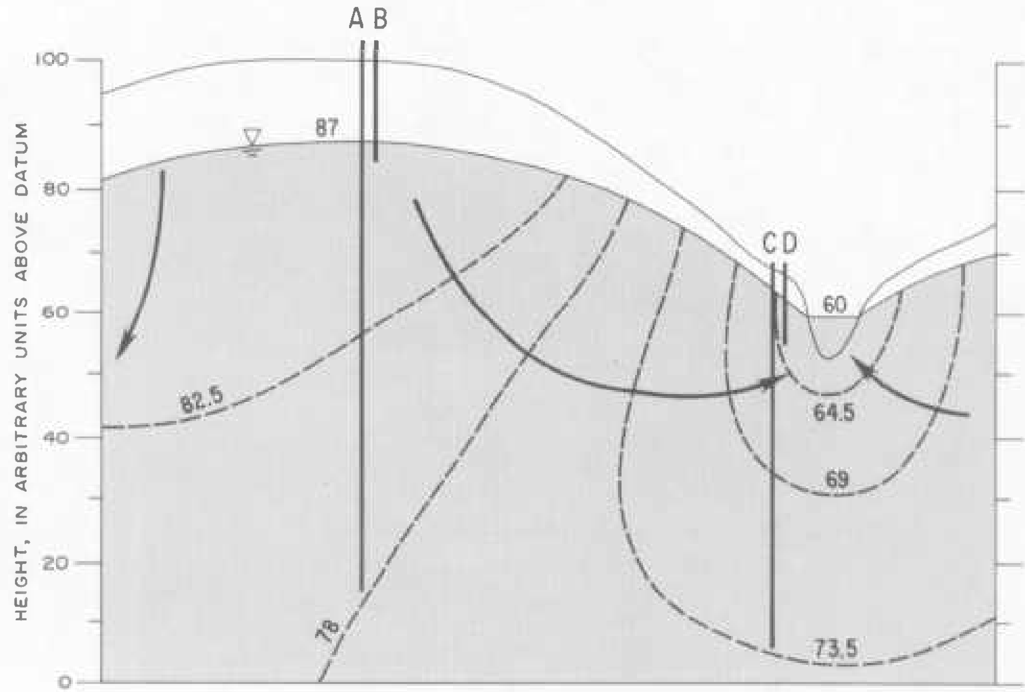


FIGURE 10. Effect of well depth on water levels in wells. The scale is in arbitrary units of length and wells are open-bottomed, acting as piezometers. Each equipotential (dashed) line represents a head drop of 1/6 of the total decline in head from the beginning of a flow path (87 units) to the final head (60 units), which is controlled by the water level in the stream. The water levels in wells A and B are approximately 78 and 86; there is a downward component of flow. The water levels in wells C and D are approximately 73.5 and 64 (well C is a flowing well, because its altitude is 67); there is an upward component of flow at this site.

confining zones are absent. Observation wells FR AE 50, FR AF 27, FR BD 7, and FR DC 43 are examples of wells wherein water levels fluctuated above and below land surface (Dine and others, 1985).

The altitude of the potentiometric surface (which, under unconfined conditions, is the water table) varies from place to place and from time to time; in Frederick County, it averages about 30 ft below land surface. Seasonal variations in water levels, caused by seasonal distribution of precipitation and consumption of water by evapotranspiration, can vary from feet to tens of feet, depending on the topographic setting and the weather for the year (fig. 11). Pumping and dewatering cause localized depression of the potentiometric surface. The amount of drawdown decreases away from the well or dewatered region at a rate depending on properties of the aquifer.

Long-term records of measured water levels are available for two wells in Frederick County: FR BD 1, in Thurmont, measured from 1946 until it was destroyed in 1977; and FR CG 1, in Johnsville, measured since 1946. The median water level in the former is approximately 14 ft below land surface; the median level in the latter is about 38 ft. One can see in these hydrographs not only the seasonal changes that occur each year, but also year-to-year variations. The lowest recorded water level at FR CG 1 is 42.02 ft below land surface, measured on October 5, 1982 (the well is 43 ft deep). The water level was high in 1983, and even higher in

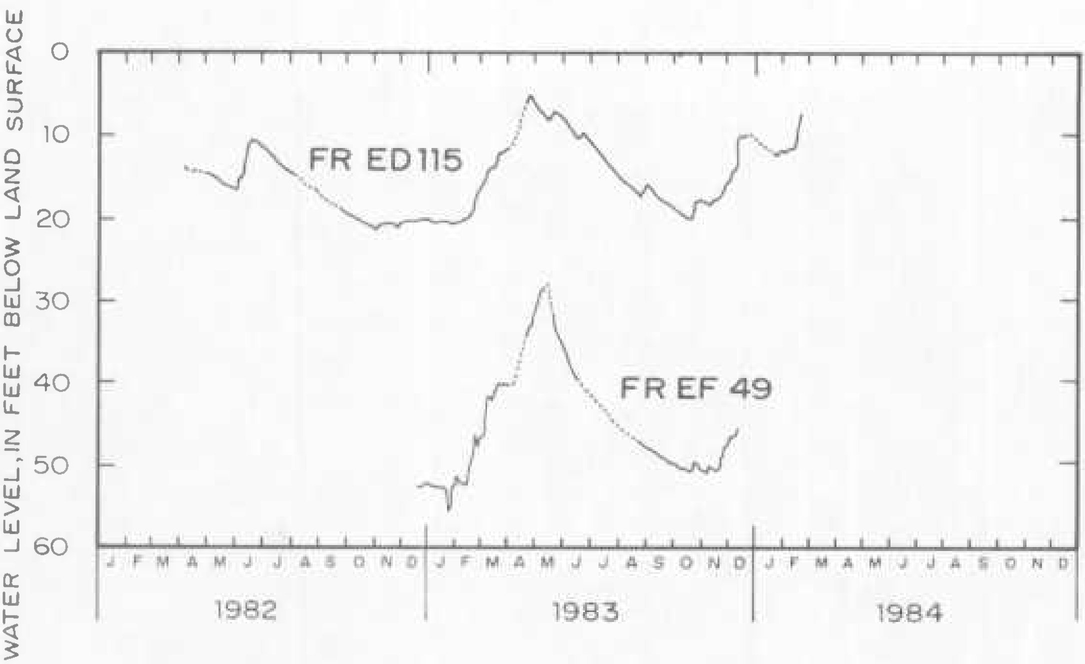


FIGURE 11. Seasonal fluctuations of ground-water levels. Well locations are shown in figure 6.

1984. These water-level fluctuations correspond with the slightly subnormal precipitation of 1982 and the greater than normal precipitation of 1983 (compared to the 1941-70 normal precipitation at Unionville—see table 1). The hydrograph of FR BD 1 shows greater year-to-year variation in water levels than does FR CG 1 (fig. 12). This may reflect local differences in hydrogeological setting and climatic variability; FR BD 1 is located next to a stream, where the stream debouches from Catoctin Mountain, whereas FR CG 1 is located on a broad upland, about 12 mi southeast of FR BD 1.

Areal variation in the altitude of the potentiometric surface is shown on plate 2. This map was prepared from water levels reported from 632 wells over a 30-year period. Only water levels reported for the months of May through August were used in order to filter out seasonal extremes and to produce a map indicating "average" conditions. Altitudes of 125 springs supplemented the well data. The potentiometric surface correlates with land surface, but has less relief. Significant ground-water divides underlie Catoctin and South Mountains. All ground-water discharge ultimately flows to the Potomac River, primarily by way of the Monocacy and Catoctin drainage systems.

Several factors preclude construction of a more detailed or absolute potentiometric-surface map from the data that are readily available. Most of the wells were constructed for water supply, not water-level measurements, and have long open-hole intervals. The water level in such a well depends on the head distribution along the open interval; unless flow is horizontal, the amount of head varies with depth and whether the vertical component is upward or downward (such variation was seen in fig. 10). Another factor is time dependence, the effects of which are seen in the hydrographs of figures 11 and 12; ideally, all observation wells should be measured simultaneously. The uneven distribution of rock fractures can also produce irregularities in the water table.

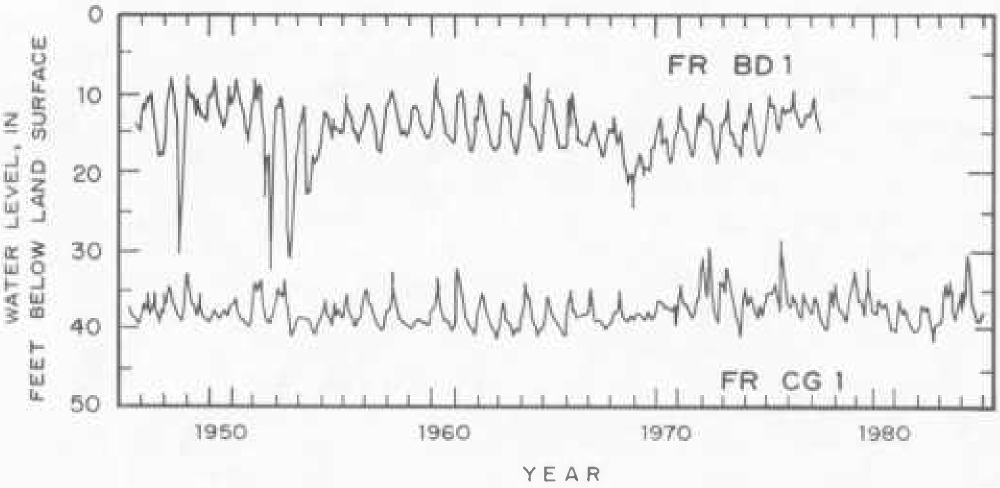


FIGURE 12. Seasonal and year-to-year fluctuations of ground-water levels. Well locations are shown in figure 6.

GROUND-WATER FLOW

Subsurface flow is not as easily traced and predictable as surface-water flow. To do so requires an understanding of topography, geologic structure, and other geohydrologic properties of the rock units. Flow directions may be inferred from measured water levels. The contours of the water-level map (pl. 2) are lines of equal potential; ground-water flow paths may be drawn orthogonally to them, producing a flow net. On a regional scale this may be accurate, but on a finer scale, the potential surface will show numerous, local highs and lows not shown on the plate. Flow rates may be estimated if the hydraulic gradient along a flow path and the aquifer properties can be estimated. Ground-water flow rates in Frederick County probably do not commonly exceed a few tens of feet per day, although higher rates may be more common in those areas underlain by limestone with large solution conduits.

AQUIFER PROPERTIES

Flow of ground water is controlled by properties of the aquifer that, once evaluated, may allow useful predictions to be made concerning well yields, water-level declines, well interference, and other aspects of ground-water behavior. The heterogeneity of the geologic materials in Frederick County results in large variability of these properties even within relatively small areas, however, so that site-specific data are necessary for accurate analyses of particular locations.

Porosity is the amount of void space in a geologic material, expressed in percent. The voids may or may not be filled with water. Unconsolidated formations in Frederick County, such as alluvium and mountain wash, have the greatest porosities, perhaps in excess of 50 percent. The consolidated and the crystalline rocks generally have very little intergranular, or primary, porosity because the voids have been filled with cementing minerals, or the rock is of igneous origin or has been metamorphosed to some extent resulting in interlocking growth of minerals. Much of the void space in these rocks is due to open joints and fractures created by brittle response of the rock to geologic stresses. This secondary porosity may be increased by the solutional action of circulating ground water. Limestones, such as the Frederick and Grove Limestones, are composed chiefly of calcite, a relatively soluble mineral. Groundwater circulation has enlarged fractures and joints in these rocks to the extent that they behave as extensive, interconnected conduits. Such solutional enlargement is responsible for development of spectacular caverns in many areas of the world, but only a handful of small caves of solutional origin are reported from Frederick County in the Frederick and Grove Limestones and the Wakefield Marble (Davies, 1950; Franz and Slifer, 1971).

Rock weathering results in a mantle of unconsolidated material, or residuum, which may possess considerable porosity. Samples of residuum derived from the New Oxford Formation near Hansonville (about 2 mi northwest of Walkersville) had measured values of effective porosity (effective porosity includes only the interconnected voids and, hence, is somewhat less than total porosity) ranging from 24 to 42 percent (Nutter, 1975, p. 9); a sample of arkosic sandstone from the same formation, obtained a few miles to the south, had an effective porosity of only 7.6 percent. Additional porosity values for the New Oxford Formation range from 0 to 6 percent (Nutter, 1975, p. 9). Residuum derived from the Frederick Limestone, sampled near Adamstown, had porosity values ranging from 47.5 to 53.2 percent (Nutter, 1973, p. 32).

Porosity of undisturbed samples (such as cores) can be measured in the laboratory, but sample porosity may not be representative of the bulk porosity of the site because of fracture density and spacing and other heterogeneities. Porosity of larger, more representative "samples" can be estimated *in situ* by geophysical means such as caliper, resistivity, or neutron logging of wells. A caliper tool uses extendable fingers to measure hole diameter; it can detect and, to an extent, measure open fractures and voids. The resistivity tool measures electrical resistance, which is dependent on the resistivity of the rocks and the amount of pore space filled with fluid of a different resistivity. The neutron device responds to water-filled pores; in unsaturated zones it may be used (with proper calibration) to measure degree of saturation. The porosity values cited in table 4 were obtained from laboratory analysis of cores and from geophysical logs.

Although porosity may indicate how much water may be stored in a saturated material, not all of this water is available to wells. Under unconfined conditions and gravity drainage, some water remains clinging to the soil or rock material, and only a portion of the water drains. The ratio of (1) the volume of water that drains by gravity to (2) the original total volume of saturated material is called the specific yield (S_y) of the material; it generally ranges from about 10 to 30 percent for nonindurated sediments. A figure obtained for specific yield assumes complete gravity drainage following complete saturation, a situation difficult to obtain in the field.

An approximation, called gravity yield (Rasmussen and Andreasen, 1959, p. 83), may be made where water-level and streamflow data are available. The approximation is the ratio of the inches of water (as determined by separating the base-flow component of streamflow) drained from the basin during a period of recession to the water-level decline measured in observation wells in the basin. Gravity-yield values determined for several of the Frederick County basins (table 3) were quite lower than the general range of specific yield mentioned above; however, values similar to those in table 3 were obtained by Olmsted and Hely (1962, p. A17) for a Piedmont area in Pennsylvania, and by Trainer and Watkins (1975, p. 25) for fractured-rock terrane of the Upper Potomac River basin. The range of values shown in table 3 is a reflection of the heterogeneity of the hydrogeologic system and cannot be simply

TABLE 3

SELECTED VALUES OF GRAVITY YIELD IN BASINS IN FREDERICK COUNTY

Subbasin	Well	Water-level decline (inches)	Cumulative base flow (inches)	Period	Gravity yield (percent)	Average (percent)
Catoctin Creek near Middletown	FR CB 19	31.8	0.33	7/28-8/25/82	1	8
	FR CC 33	6.84	.50	7/13-8/25/82	7	
	FR DC 41	15.96	.50	7/13-8/25/82	3	
	FR DC 43	1.80	.50	7/13-8/25/82	28	
	FR DC 65	29.76	.33	7/28-8/25/82	1	
Owens Creek at Lantz	FR AD 37	22.20	5.05	5/23-8/22/83	23	--
Hunting Creek at Jimtown	FR BD 1	55.32	1.75	7/19-9/28/72	3	1.2
	FR BD 7	14.28	.27	7/27-8/22/83	2	
	FR BD 44	30.84	.27	7/27-8/22/83	.9	
	FR BD 96	148.80	.59	7/15-9/10/83	.4	
	FR BD 101	94.56	.58	7/27-9/26/83	.6	
	FR BE 73	122.52	.28	7/27-8/23/83	.2	
Fishing Creek near Lewistown	FR CD 46	18.96	3.95	6/15-9/18/82	21	--
Monocacy River at Jug Bridge near Frederick	FR DD 208	47.88	.91	6/23-9/26/83	1.9	1.6
	FR DE 104	71.88	.93	6/20-9/28/83	1.3	
Bennett Creek at Park Mills	FR EF 40	36.72	3.45	5/24-8/23/83	9	6.3
	FR EF 49	161.88	3.52	5/25-8/30/83	2	
	FR FE 26	33.36	3.45	5/24-8/23/83	10	
	FR FF 13	90.12	3.45	5/24-8/23/83	4	

related to factors such as distance from the observation well to the stream or depth to the water table at the onset of the decline.

In confined aquifers, the saturated volume remains saturated; nevertheless, water may still be released from storage as a result of compression of the aquifer and expansion of the water itself. The storage coefficient (S) is defined as the volume of water per surface area of an aquifer that is taken into or released from storage in that aquifer per unit change in head. The storage coefficient of confined aquifers generally ranges from about 10^{-5} to 10^{-3}, and is dimensionless. In unconfined aquifers, very little of the water released from storage is due to compression of the aquifer or expansion of the water, and, thus, the storage coefficient of such an aquifer is approximately the same as the specific yield. The smaller the storage coefficient, the more rapid will be the spread of the cone of depression of a pumping well, all else being equal. The storage coefficient is commonly determined from the results of aquifer (pumping) tests where drawdown is measured in one or more observation wells. Several values are shown in table 4. The storage coefficient is infrequently calculated for Frederick County aquifers because suitable observation wells are not commonly available; most of the pumping tests are single-well tests.

Permeability is the ability to transmit a fluid through the void spaces of a medium. Most ground-water flow to wells in Frederick County occurs through the jointed and fractured bedrock and is thus termed "secondary permeability." Properties of the fluid itself influence its movement through the medium; when the combined effects of the fluid and the medium are considered, the term "hydraulic conductivity" is used. Hydraulic conductivity is expressed in terms of length per time, such as feet per day or centimeters per second. Although

TABLE 4

SELECTED ESTIMATES OF AQUIFER PROPERTIES

[Sources: (1) Slaughter, 1962; (2) Nutter, 1973; (3) Nutter, 1975.]

Aquifer	Porosity (percent)	Hydraulic conductivity (ft/d)	Transmissivity (ft^2/d)	Storage coefficient
Residuum (New Oxford Formation)	24 - 42 (3)	.046 - .36 (3)	--	--
Residuum (Frederick Limestone)	47.5 - 53.2 (2)	0.001 - 0.027 (2)	--	--
Gettysburg Shale	--	--	2,700 (3)	--
New Oxford Formation	<1 - 7.6 (3)	.00028 (3)	110 - 460 (3)	--
Grove Limestone	--	--	130 (2)	--
Tomstown Dolomite	--	--	4 - 2433 (1) 1200 - 1600 (2)	--
Harpers Formation	--	--	67 (1)	--
Catoctin Metabasalt	--	--	241 - 588 (1)	.002 - .004 (1)

[Porosity and hydraulic conductivity for Frederick Limestone residuum and New Oxford Formation residuum were determined from cores; hydraulic conductivity for the New Oxford Formation was determined from cores; porosity for New Oxford Formation was determined from both core and geophysical log analyses; transmissivity and storage coefficients for all units shown were determined from pumping tests.]

these terms are the same as used to express velocity, the seepage velocity (V_s), or average velocity of a particle of ground water, is calculated from hydraulic conductivity (K), gradient (dh/dL, dimensionless) and effective porosity (n_e, dimensionless decimal):

$$V_s = K\,(dh/dL)\,(1/n_e).$$

Reported values of hydraulic conductivity of rocks in and near Frederick County are listed in table 4.

Hydraulic conductivity may not be uniform in all directions or at all depths in an aquifer. In the fractured-rock terrane of Frederick County, the direction of maximum permeability is controlled by the orientation and spacing of sets of fractures. One consequence of this is that the cone of depression of a pumping well spreads more rapidly in the direction of greater permeability; this in turn affects interpretation of pumping tests with only a few observation wells.

The transmissivity of an aquifer is its hydraulic conductivity multiplied by its saturated thickness; a physical interpretation of transmissivity is shown in figure 13. Transmissivity is commonly determined from the results of aquifer (pumping) tests. However, a few narrow zones may control water flow in a thick rock unit, resulting in misleading interpretations based on values calculated from averages. For example, from table 4, the value of transmissivity for the New Oxford Formation divided by the value shown for hydraulic conductivity yields an unreasonably high thickness. In this case, the hydraulic conductivity was determined by laboratory analysis of a core sample, whereas the transmissivity was calculated

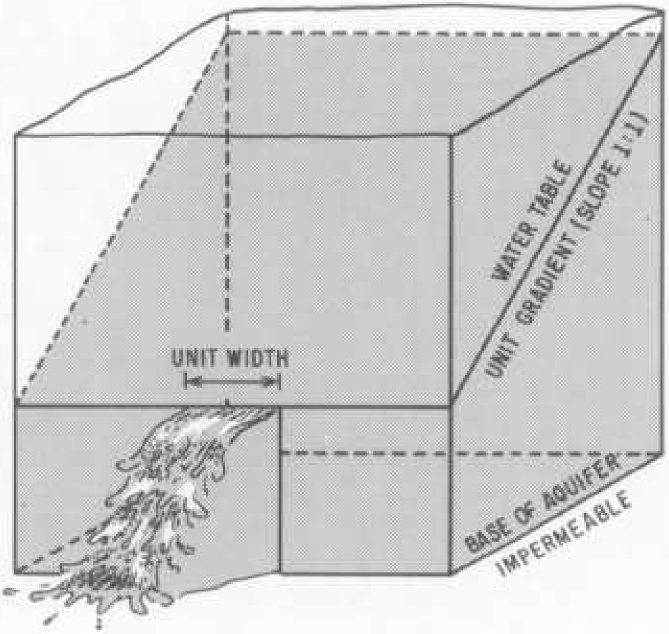


FIGURE 13. A physical interpretation of transmissivity. Transmissivity is the rate at which water is discharged across a strip of unit width that is the entire saturated thickness of the aquifer, under the impetus of a unit hydraulic gradient (100 percent slope). It was formerly expressed as "gallons per day per foot" [(gal/d)/ft], but present usage is in reduced terms, "feet squared per day" (ft^2/d).

from pumping-test results; the core volume tested did not include significant fractures and therefore underestimated the large-scale, or bulk, hydraulic conductivity.

The cone of depression in an aquifer of high transmissivity spreads farther, but to lesser depths than that of an aquifer of low transmissivity, other factors being equal. Transmissivities estimated from water-level fluctuations, streamflow, and estimates of storage coefficient are listed in table 5. These values represent basin-wide averages, but are comparable to values obtained from pumping tests.

Aquifer diffusivity (T/S) can be evaluated from natural water-level fluctuations measured in observation wells without the necessity of pumping (Rorabaugh, 1960), or from streamflow data (Rorabaugh, 1964). By assuming values for S or T, the other value can be estimated.

Using the natural water-level fluctuations in well FR EF 49, aquifer diffusivity can be calculated for an area mostly underlain by the Ijamsville Formation. Following recharge in the spring of 1983, the water level in this well declined steadily until October (fig. 14). This well is located nearly on the drainage divide, and the datum may be assumed to be about 56 ft below land surface, corresponding to the lowest recorded water level. Using Rorabaugh's (1960) equation (5) for a recession slope drawn on a logarithmic scale:

$$T/S = 0.933a^2 \log (h_1/h_2)/(t_2 - t_1)$$

TABLE 5

AQUIFER DIFFUSIVITY VALUES FOR SELECTED BASINS

Site No.	Basin	Recession slope (days/tenfold head decrease)	Aquifer diffusivity T/S (ft^2/d)	Assumed S	T = S(T/S) (ft^2/d)	Primary geologic units
01637500	Catoctin Creek near Middletown	57	55,000	0.001	55	Catoctin Metabasalt
				.01	550	
				.1	5,500	
01640500	Owens Creek at Lantz	71	23,000	.001	23	Catoctin Metabasalt
				.01	230	
				.1	2,300	
01641000	Hunting Creek at Jimtown	85	6,400	.001	6	Weverton Formation, Catoctin Metabasalt, Gettysburg Shale, mountain wash
				.01	64	
				.1	640	
01642500	Linganore Creek near Frederick	250	8,000	.001	8	Ijamsville Formation, Marburg Schist, Sams Creek Metabasalt, metarhyolite, metaandesite
				.01	80	
				.1	800	
FR AF 39	Toms Creek	154	74,000	.001	74	Gettysburg Shale, Catoctin Metabasalt, diabase, Weverton Formation, Loudoun Formation
				.01	740	
				.1	7,400	
FR EF 49	Bennett Creek	139	16,000	.001	16	Urbana Formation, Ijamsville Formation, Marburg Schist
				.01	160	
				.1	1,600	

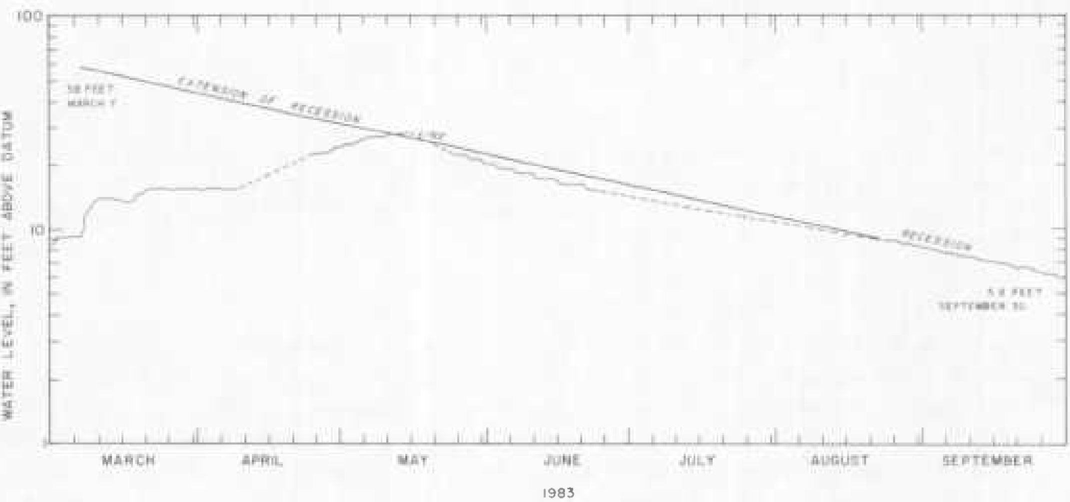


FIGURE 14. Water-level recession in well FR EF 49. Well location is shown in figure 6.

where a is the distance from the divide to the discharge line, in feet; and h_1 and h_2 are the heads, in feet, measured at times t_1 and t_2 (days),

$$T/S = [(0.933)\ (1{,}900\ ft)^2\ (1)]/(207\ d) = 16{,}271\ ft^2/d$$

(rounded to 16,000 ft^2/d).

The critical time for the water-level decay to become exponential is about 25 days in this example. If S is estimated as 0.01, then T takes on the value of 160 ft^2/d. If T could be obtained from previous pumping tests in the area, then a value of S could be derived.

This example demonstrates not only a method of obtaining transmissivity values but also indicates some of the difficulties in application: water-level data must be available for a relatively long period; the validity of the equation used is affected by the geometry of the setting; and to obtain a value for transmissivity, the storage coefficient must be estimated. Aquifer diffusivities for other areas of the county are shown in table 5.

Aquifer tests suitable for the accurate determination of aquifer properties are performed infrequently in Frederick County. In some cases this may be due to inadequate testing procedure, but, commonly, the setting and construction of the well do not match the assumptions of the testing theories, and observation wells may not be available. Some of the theoretical assumptions may be violated without significant consequences (especially if the results are used for comparative, rather than predictive, purposes). However, hydrologic predictions must be viewed with a certain amount of skepticism as the analytical methods used do not account for deviations from ideal conditions. Well yield and specific capacity (discharge divided by drawdown, fig. 15) are useful for making comparisons and, to some extent, for estimating ground-water availability. Discharge and drawdown data for the county are abundant, but care must be exercised in interpretation. For example, most of the wells were constructed for domestic use and, therefore, required minimum yields; the depth and topographic setting are less critically chosen than for wells where higher yields are required.

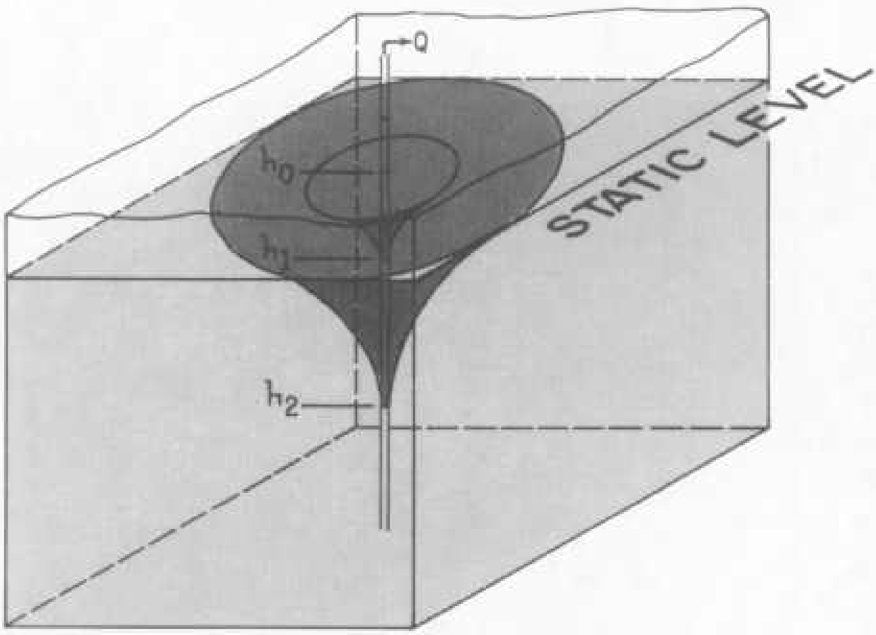


FIGURE 15. Definition of specific capacity. A well having a water level at h_0 above datum is pumped at a rate Q. The water level in the well drops to h_1 (the lowest part of the cone of depression). The specific capacity is $Q/(h_0-h_1)$. This function is time-dependent, however; if pumping continues, the water level continues to fall. The diagram also shows the cone of depression for a later time, for which the specific capacity is $Q/(h_0-h_2)$. Note that the later cone of depression has spread over a broader area. Specific capacity is typically expressed as "gallons per minute per foot of drawdown" [(gal/min)/ft].

FACTORS INFLUENCING THE YIELDS OF WELLS

Reported discharges for 1,582 wells inventoried in Frederick County range from 0 to 950 gal/min; the median is 10 gal/min. The distribution is shown in figure 16 as a plot of cumulative frequencies (percentage of observations less than or equal to the value shown). Specific capacities for 1,177 of these wells range from 0.00 to 262.5 (gal/min)/ft, with a median value of 0.15 (gal/min)/ft. The distribution of specific capacity values is a skewed one, having larger numbers of low values (fig. 17). The distribution appears nearly normal because the specific capacities are plotted on a logarithmic scale. Note that, whereas the median is 0.15 (gal/min)/ft, the mean is 1.46 (gal/min)/ft; the occurrence of a few very high values tends to raise the mean.

Many factors influence the amounts of water available from wells constructed in the complex hydrogeologic system found in areas underlain by crystalline rock. The majority of wells (about 60 percent) examined in the present study were constructed for household use. Sites for such wells are usually chosen to accommodate minimum distances specified by regulations and to be uphill from onsite waste-disposal systems, if present. Within these restrictions, the sites are usually chosen to be as convenient to the house as possible. Furthermore, the wells are generally constructed to meet the relatively low yields required; once a sufficient yield is obtained and the minimum depth required by well regulations is met, drilling usually ceases. The homesites themselves are selected with other factors pre-empting consideration of maximum well yields (factors such as nice view, road construction, drainage, or availability of a building lot). Therefore, analysis of yields of domestic wells may underestimate the potential yield of an aquifer.

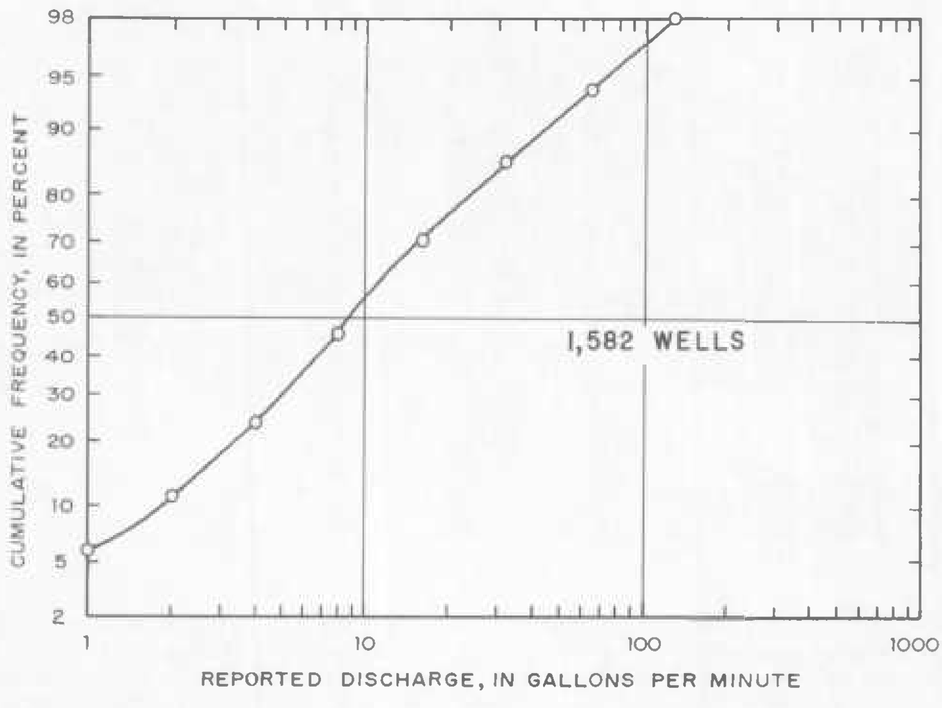


FIGURE 16. Cumulative frequencies of yields of wells inventoried in Frederick County.

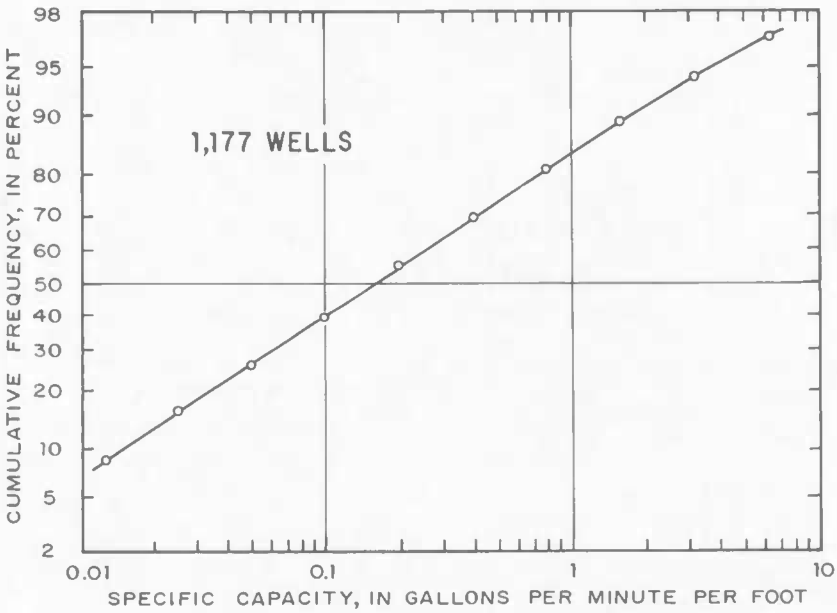


FIGURE 17. Cumulative frequencies of specific capacities of wells inventoried in Frederick County.

On the other hand, public-supply wells must meet greater demands and are more commonly located and constructed to produce more water. Approximately 4 percent of the wells inventoried in the county were constructed for public-supply systems. Industrial, institutional, and public-supply wells generally have higher reported yields than domestic wells, although in terms of specific capacity, the two categories are quite similar except for the low and high extremes of their distributions (fig. 18). The distribution of 1,881 inventoried wells among various water-use categories is shown in table 6.

For some purposes, specific capacity is a better measure of well productivity than is discharge. A well can be pumped at any rate, at least for a short time; dividing the discharge by the drawdown gives an indication of the ability of an aquifer to produce at a given rate. Ideally, specific capacity values for tests of nearly equal or of lengthy duration should be used for comparisons. In large samples, if all groups have relatively equal mixes of lengthy and short tests, comparisons will remain valid. The amount of drawdown also depends on the efficiency of the constructed well; most of the wells included for analysis were drilled and finished as open-hole wells in hard rock, so well efficiency probably does not vary significantly in the sample. Another shortcoming of specific capacity as a value used for making comparisons may occur in situations that depart from the ideal. In an isotropic medium, an increase in discharge results in an increase in drawdown, so that the ratio remains constant. In crystalline-rock aquifers, water-bearing fractures may intersect only the upper portion of the well; when the water level falls below such fractures, the maximum head gradient in that fracture has been obtained and, consequently, the maximum rate of flow of water from the fracture into the well. In this case, an increase in discharge merely results in a decrease in specific capacity.

The geohydrologic properties of the local bedrock exert considerable control over the yields of wells drilled in an area, chiefly owing to variations in secondary permeability.

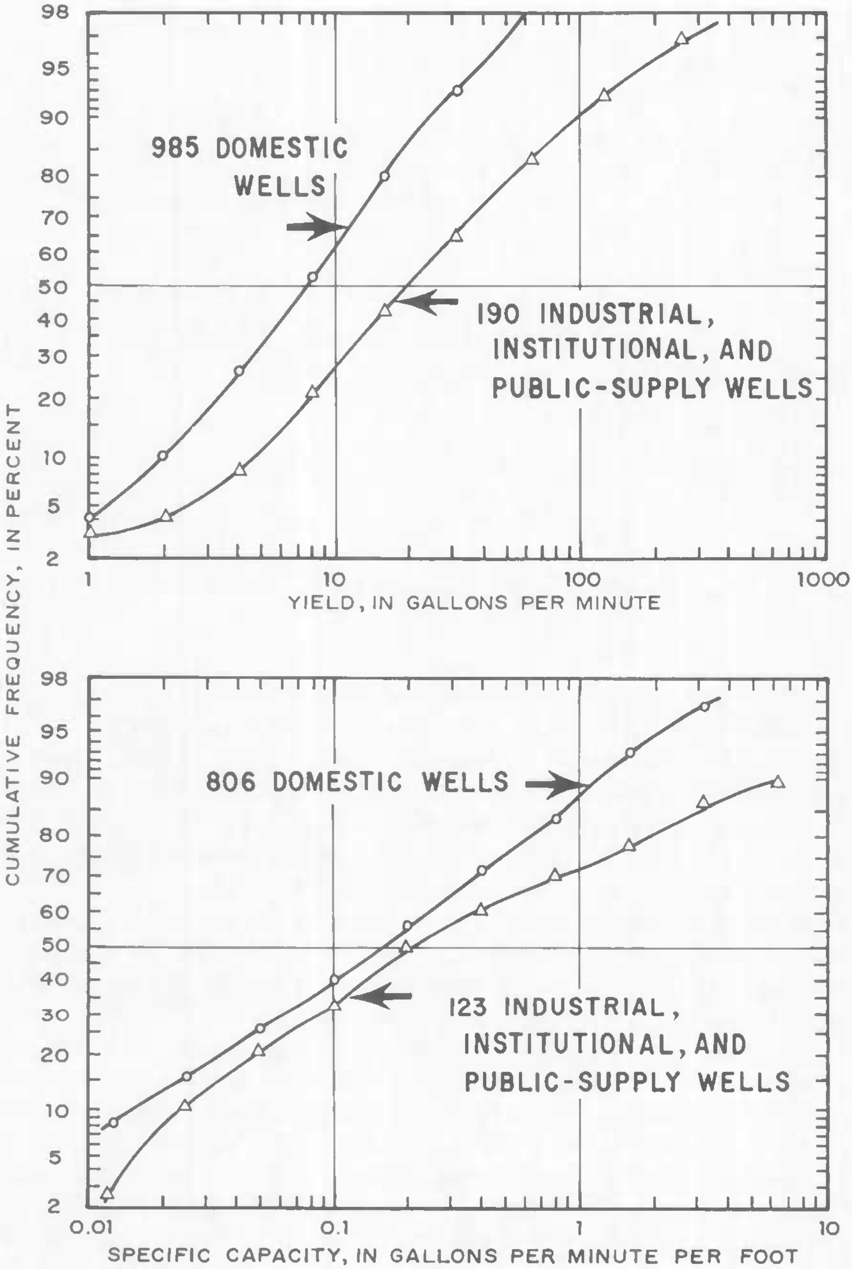


FIGURE 18. Comparison of performance of industrial, institutional, and public-supply wells and domestic wells.

TABLE 6

DISTRIBUTION OF 1,881 WELLS AMONG WATER-USE CATEGORIES

Water-use category	Percent of wells
Aquaculture	0.3
Commercial	7.4
Dewatering	.1
Domestic	60.6
Fire	.3
Industrial	2.2
Industrial (cooling)	.1
Institutional	4.7
Irrigation	.3
Public-supply	3.9
Recreational	1.5
Stock	2.8
Unused	15.5
Other uses	.3
Total	100.0

Development of secondary permeability depends, in part, on the strength and brittleness of the rock and the minerals it contains. Weathering processes can increase permeability by increasing the mechanical fragmentation of the rock; solution by circulating water can enlarge void space, especially in relatively soluble carbonate rocks. These processes are generally most active near land surface, which explains why well productivity commonly does not increase proportionately with depth.

Twenty-four "aquifers" were associated with 1,890 of the wells inventoried in the county (fig. 19). Fourteen of these wells were drilled through geologic contacts and derive some of their water from each of two geologic units; these were classified as "multiple aquifers." Four wells could not be assigned to any aquifer.

It is not entirely correct to speak of these geologic units as distinct aquifers. The geologic units correspond to the mapping units of various geologic maps, and, in some cases, different mapping units reflect revisions in the interpretation of stratigraphy. Hydrologic boundaries may not correspond with the mapping-unit boundaries because the hydrologic properties of adjacent mapping units may be identical, or nearly so. In addition, ground-water flow systems within an area underlain by a single geologic unit may be local and independent, their boundaries defined by topographic and structural features.

Well characteristics vary considerably within geologic units as well as between the units (table 7). The variation in well performance is more readily seen graphically, as in figure 20, where specific capacity statistics are grouped by geologic unit and arranged in descending order by median value. The carbonate units appear to be better producers; however, the difference between the Marburg Schist and Frederick Limestone (in terms of specific capacity) is much less than the difference between the Frederick Limestone and the basal limestone

TABLE 7

WELL CHARACTERISTICS OF THE GEOLOGIC UNITS

Geologic unit	Discharge (gallons per minute)					Specific Capacity (gallons per minute per foot)					Depth (feet below land surface)				
	Number	Minimum	Maximum	Mean	Median	Number	Minimum	Maximum	Mean	Median	Number	Minimum	Maximum	Mean	Median
ALVM	0	--	--	--	--	0	--	--	--	--	1	50	50	50	50
ANTM	23	0.5	20	8.1	10	10	0.029	4.00	0.673	0.164	28	40	220	100.4	93.5
CONG	25	5	160	40.1	25	13	.29	7.50	1.799	1.02	29	28	305	107.8	95
CTCN	201	0	160	16.4	10	160	.00	21.3	.573	.128	230	21	675	187.4	150
DIBS	10	1	100	19.1	8	9	.00	1.82	.421	.071	13	25	433	146.9	125
FDCK	236	0	300	23.8	10	135	.00	43.3	1.585	.25	274	11	954	170.9	116
GBGG	4	5	10	8.3	9	2	1.60	2.00	1.800	1.80	6	19	129	59.3	54
GBRG	195	.5	830	27.8	10	178	.00	240	2.011	.118	223	22	520	166.0	150
GROV	130	0	950	58.9	20	84	.00	262	8.153	.50	158	15	868	205.6	152.5
HRPR	70	.5	103	11.6	5	60	.00	12.5	.625	.096	80	23	996	196.7	155
IJMV	123	0	110	8.9	5	99	.00	10.0	.365	.070	140	18	505	165.4	122.5
LBRN	12	0	15	7.9	9	8	.00	1.43	.287	.068	17	11	442	183.5	100
LUDN	31	1	30	8.0	6	24	.01	2.00	.216	.083	35	27	500	161.5	104
MNWS	17	2	20	7.4	5	11	.04	5.00	.978	.571	17	15	114	45.6	45
MRBG	50	1	284	22.4	10	48	.01	30.0	1.678	.160	58	29	350	138.2	120
MTRL	92	1	74	15.7	10	69	.01	3.00	.389	.161	101	9	400	130.2	115
NOXF	178	1	150	17.9	10	133	.01	9.00	.433	.150	211	19	525	135.1	115
PCMB	72	2	100	10.6	7	61	.01	4.00	.430	.192	76	37	537	132.6	100
SGFM	2	24	30	27.0	27	0	--	--	--	--	2	59	70	64.5	64.5
SMCK	21	1	20	6.8	5	17	.01	2.00	.283	.167	29	9	302	118.1	100
TMSN	5	10	50	31.0	30	2	.08	1.00	.542	.542	6	64	423	231.7	219
URBN	50	2	100	15.7	10	33	.01	5.00	.500	.167	64	29	500	160.6	103.5
WKFD	2	8	25	16.5	16.5	0	--	--	--	--	4	36	349	142.3	92
WVRN	18	1	80	13.0	8	14	.00	17.6	1.463	.127	23	21	1000	258.8	175

Explanation of geologic unit codes

ALVM Quaternary alluvium
ANTM Antietam Formation
CONG Basal limestone conglomerate of New Oxford Formation and Gettysburg Shale
CTCN Catoctin Metabasalt
DIBS Diabase sills and dikes
FDCK Frederick Limestone
GBGG Granodiorite and biotite granite gneiss
GBRG Gettysburg Shale
GROV Grove Limestone
HRPR Harpers Formation
IJMV Ijamsville Formation
LBRN Libertytown Meterhyolite
LUDN Loudoun Formation
MNWS Alluvial cones of mountain wash
MRBG Marburg Schist
MTRL Metarhyolite and associated pyroclastic sediments
NOXF New Oxford Formation
PCMB Undifferentiated Precambrian rocks
SGFM Sugarloaf Mountain Quartzite
SMCK Sams Creek Metabasalt
TMSN Tomstown Dolomite
URBN Urbana Formation
WKFD Wakefield Marble
WVRN Weverton Formation

TABLE 7—*Continued*

Casing Depth (feet below lend surface)					Static Water Level (feet below land surface)					Geologic unit
Num-ber	Mini-mum	Maxi-mum	Mean	Medien	Num-ber	Mini-mum	Maxi-mum	Mean	Median	
1	9	9	9	9	0	--	--	--	--	ALVM
24	8	220	38.9	26	21	6	60	36.3	38	ANTM
27	12	157	38.6	30	26	6	46	23.9	23.7	CONG
208	7	307	39.8	33	218	-1	325	29.3	23.5	CTCN
11	17	40	24.9	22	13	13	45	25.5	22	DIBS
221	2.5	235	36.5	31	229	1.98	100	27.8	28	FDCK
5	8	56	34.2	40	6	8	44	22.8	20	GBGG
203	2	209	40.6	36	220	0	100	29.7	30	GBRG
130	7	182	46.4	38.5	122	-1.70	153	40.2	35	GROV
67	9	615	54.4	40	74	0	85	26.4	25	HRPR
116	6	126	35.1	28	132	5	100	37.5	35	IJMV
13	10	80	34.4	29.2	14	10	105	32.2	29	LBRN
34	6	154	43.4	34.5	36	3	100	33.5	32.5	LUDN
16	8	74	34.3	36	16	7	50	18.7	15	MNWS
51	7	92	40.8	40	54	3.50	67	37.4	40	MRBG
96	9	137	36.6	33	100	2	72	28.5	27.9	MTRL
181	5	134	31.3	23	197	1	70	31.4	30	NOXF
71	9	165	38.0	33	75	5	60	27.7	30	PCMB
1	49	49	49	49	2	10	26	18.0	18	SGFM
19	4	112	31.8	22	25	1	95	28.9	24.7	SMCK
4	21	75	43.3	38.5	5	9	63	29.5	25	TMSN
50	6	77	32.2	24	57	1	86	33.3	30	URBN
1	17	17	17	17	1	18	18	18	18	WKFD
20	12	96	36.8	30	21	2	160	36.5	30	WVRN

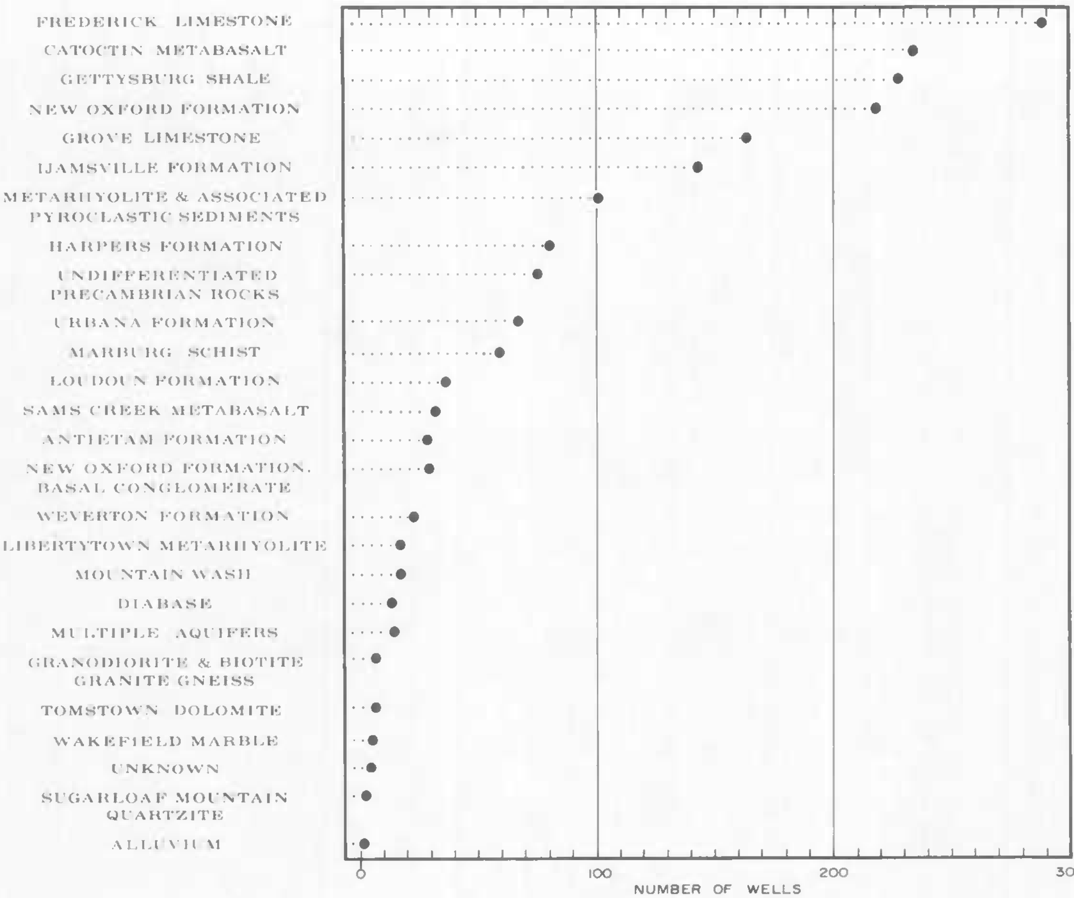


FIGURE 19. Distribution of wells among geologic units.

conglomerate of the Gettysburg Shale and the New Oxford Formation. Most of the boxes in figure 20 are asymmetric. This is because the distribution of specific capacities in these groups is skewed to the right, very strongly in some cases. Using the arithmetic mean as a representative well yield may be misleading because a single high value can result in a high mean. It may therefore be more desirable to use the median (50 percent value) or another percentage when referring to likely individual well yields, and the mean for estimating the total yield from a group of wells.

Structural features can affect well yields. A fault zone may contain brecciated material, which could increase well yields, or it may contain clayey fault gouge, tending to decrease well yields. Both factors may be present (as in the fault between the Tomstown Dolomite and the Grove Limestone, described by Hoy and Schumacher, 1956). Data from the Frederick County well inventory are insufficient for analysis of the effects of fault zones on well yields.

High-angle fracture zones may have surficial expression as rather straight alignments, or narrow, linear zones of soil-tonal variations, stream segments, sinkholes, or other naturally occurring features. Techniques for identifying these lineaments on aerial photographs are well documented, along with the relation of lineaments and well yields (Blanchet, 1957; Latt-

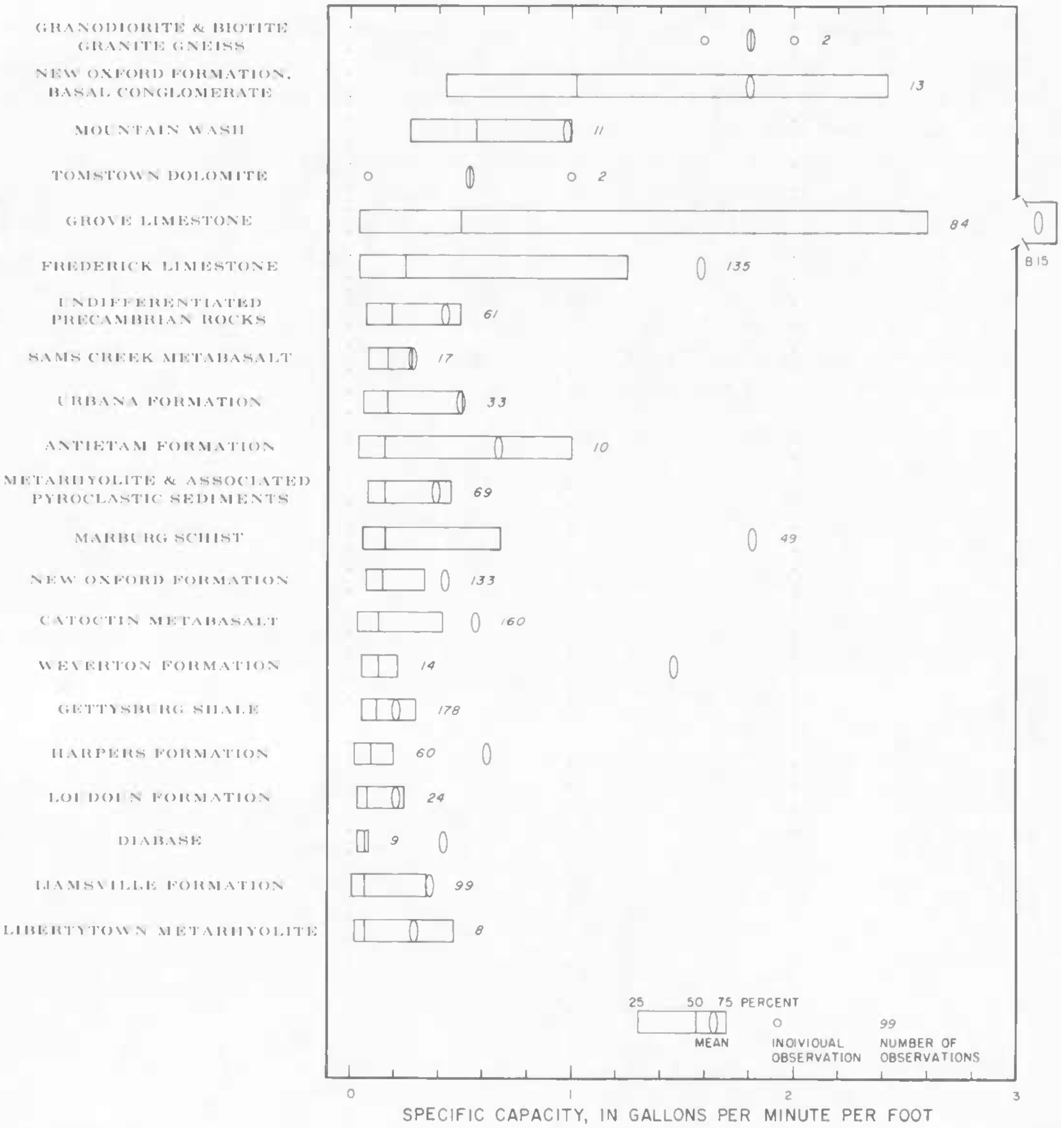


FIGURE 20. Box plots of specific capacities of wells in Frederick County grouped by geologic unit.

man, 1958; Lattman and Parizek, 1964; Sharpe and Parizek, 1979). LaRiccia and Rauch (1977), in a study of lineaments in the Frederick Valley, concluded that photo-lineament analysis is a useful technique for locating higher yielding wells in the carbonate-rock terrain of that area. They found that well yields were significantly higher in wells that were within 100 to 200 ft of a mapped fracture trace.

In areas underlain by carbonate rocks, zones of greater permeability commonly develop along bedding planes if there are solubility differences between beds. In some cases, slippage along bedding planes during folding may affect permeability at the plane. Other planar structural features that may affect well yields in areas underlain by crystalline rocks are schistosity and rock cleavage. Sever (1964) reported that such planar conduits played a more important role in ground-water circulation than did joints in an area underlain by schist, but insufficient data are available to determine which geologic features exert greater control over ground-water flow in the schists of Frederick County.

Topographic features are commonly related to the strength of rocks and their resistance to erosion, which may be affected by fracturing. For example, a valley or draw may coincide with a zone of denser fracture concentration, whereas a hilltop may represent a much less fractured rock mass. Furthermore, depth to water beneath a hilltop is generally greater than beneath a valley or draw, so that near-surface fractures that may exist under a hilltop are not saturated and will not produce water. The distribution of specific capacities of wells grouped by topographic setting (fig. 21) supports this interpretation, indicating that hilltop and hillside wells are generally the lowest producers.

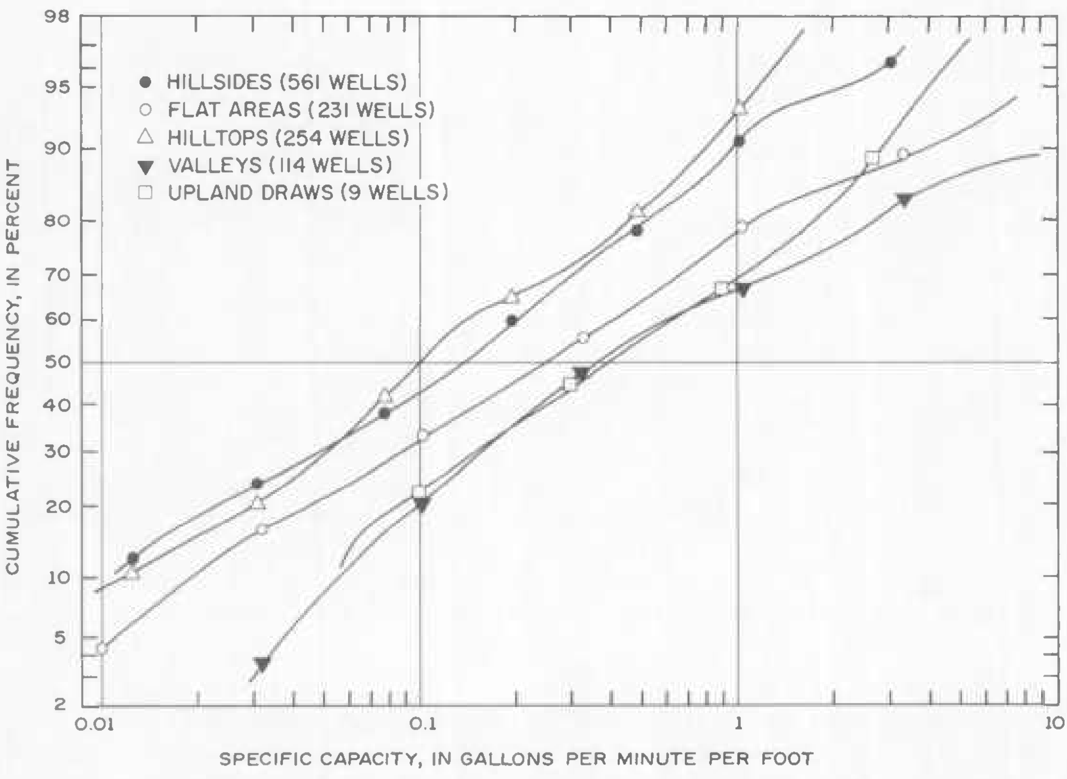


FIGURE 21. Cumulative frequencies of specific capacities of wells in Frederick County grouped by topographic setting.

GROUND WATER AS A SOURCE OF GEOTHERMAL ENERGY

The rising costs of fossil fuels in recent years has prompted the development of renewable energy resources, especially for space heating. Ground water, because of its relatively uniform temperature throughout the year and water's high specific heat, can be used with a heat pump to both heat during winter and cool during summer. Not only is the ground-water heat source renewable, but the heat-pump system may be more efficient and cleaner than fossil-fuel sources. An energy-efficiency and cost comparison of a home in Dayton, Ohio, demonstrated that a ground-water heat pump was more efficient than the original natural-gas furnace (Keller, 1983).

A temperature log from a 1,008-ft well (MO BE 66) drilled for a ground-water source heat pump in adjacent Montgomery County several miles southwest of the town of Mt. Airy shows the vertical temperature distribution of the water in the well (fig. 22; other geophysical logs are included). The temperature trace grades linearly from 54.2°F near the top of the water to 59.4°F at the bottom of the well, for an average geothermal gradient of 0.54°F/100 ft. The geothermal gradient in the Piedmont province in the Maryland area has been variously reported as 0.86°F/100 ft in quartz-mica schists (mean of three holes; Diment and Werre, 1964, p. 2143); 0.54°F/100 ft (average) in 20 wells located throughout the Maryland Piedmont (Nutter and Otton, 1969, p. 43–45); 0.85°F/100 ft for the depth interval 835 to 927 ft in a well in the lower Paleozoic Baltimore Gabbro (Costain and Glover, 1980, p. B-157); 0.90 and 0.20°F/100 ft in wells in Harford and Cecil Counties, respectively (Otton and Hilleary, 1985, p. 23). Obviously, although some increase in temperature may be obtained by drilling deeper, one will not be able to locate hot ground water in Frederick County.

There are basically three types of ground-water heat-pump sources (fig. 23): 1) a well for water withdrawal, with discharge to a stream, sewer, or recharge well; 2) a single well utilized by a closed-loop system; and 3) a closed loop buried horizontally in the ground. The first type is the most efficient, but the other two types offer an advantage where well yields are too low and disposal of the "used" water may be a problem or prohibited by regulations. Regardless of its source, the heat-containing ground water passes through an exchanger, transferring its heat to air, which is then circulated through the building. In summer, the exchanger operates in reverse, with the cool water absorbing heat from the air in the building.

The minimum well yield required for a ground-water source heat pump depends on the size of the heating system, whether any water from the well will be used for other purposes, and if the system is open or closed. A typical heat pump requires 1 to 3 gal/min per 12,000 BTU (Gass, 1980a, p. 37), and may run for 8 hours per day. Such a demand may require provision for storage if an open system is installed.

The environmental impact of ground-water source heat pumps is likely to be minimal, affecting the heat content of ground water in the immediate area of the return well, if one is used (Gass, 1980b, p. 28). The degree to which such effects develop depends on the quantities of water involved, the temperature differences, and whether the system is used for both heating and cooling.

Fourteen ground-water appropriation permits for residential heat-pump use of ground water in Frederick County were in effect in 1985. Water was to be provided from seven geologic units in permitted quantities ranging from 100 to 18,400 gal/d (average daily use during month of greatest demand; unpublished data from Maryland Water Resources Administration).

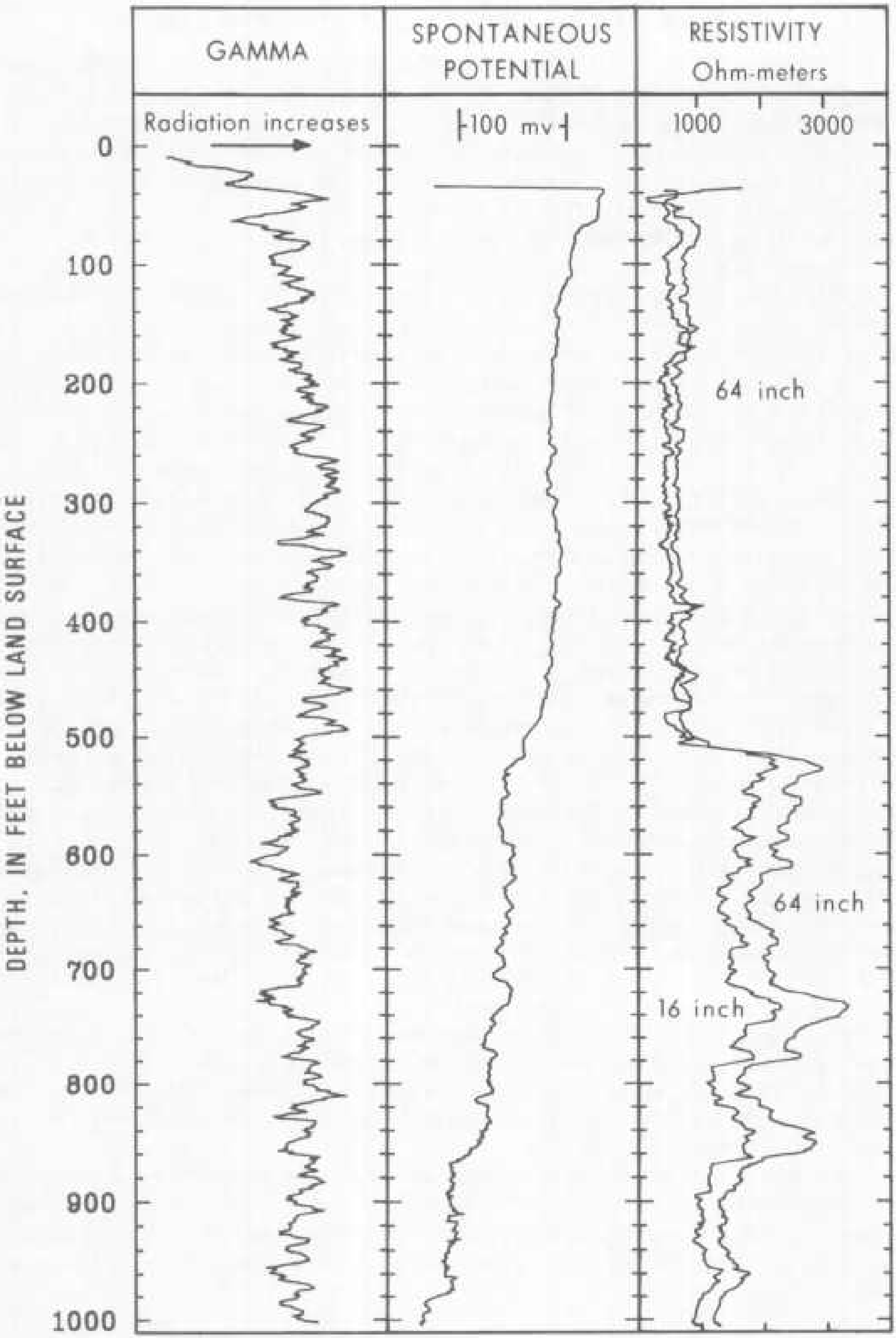


FIGURE 22. Geophysical logs of well MO BE 66. Location of well is shown in figure 6.

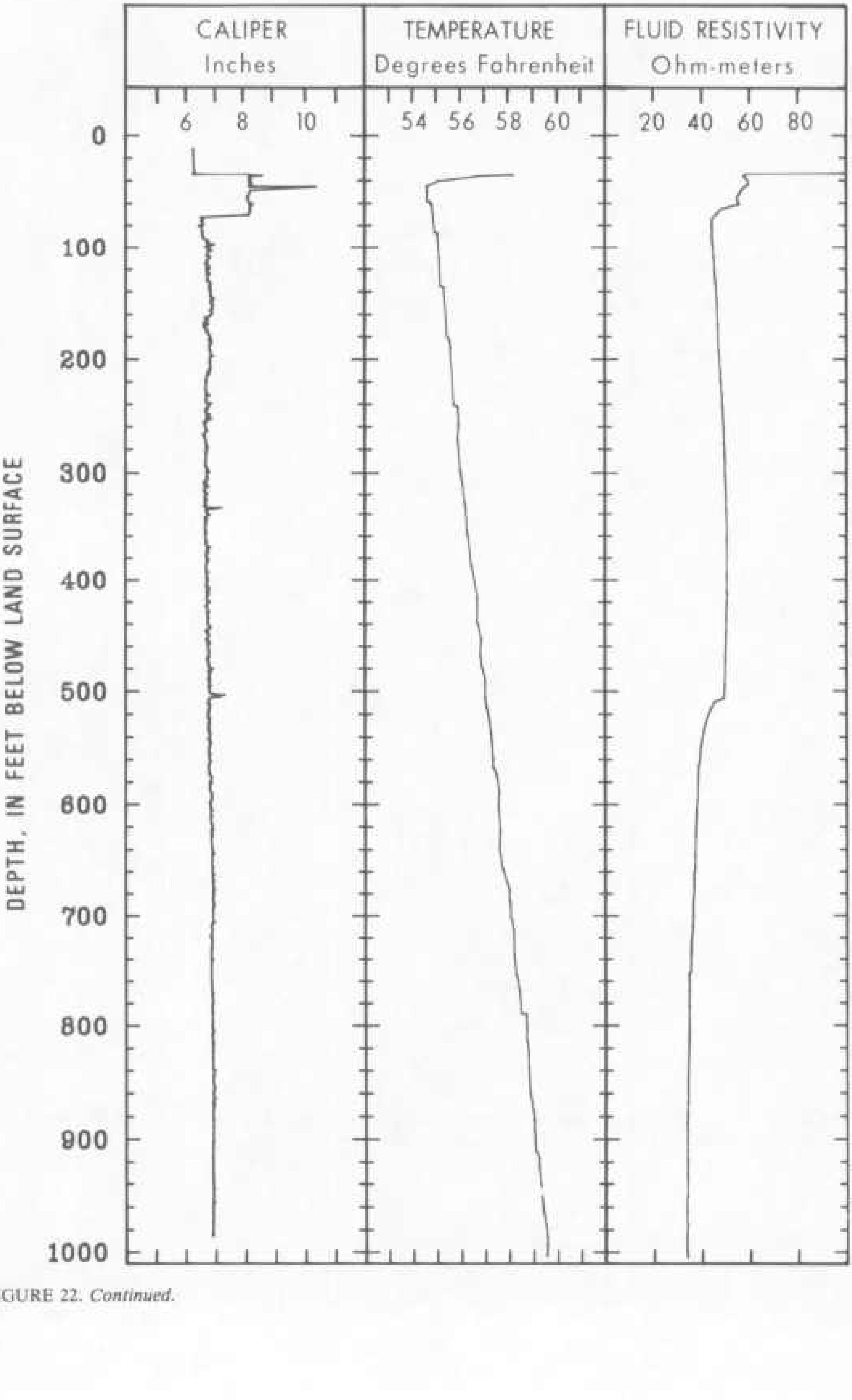


FIGURE 22. *Continued.*

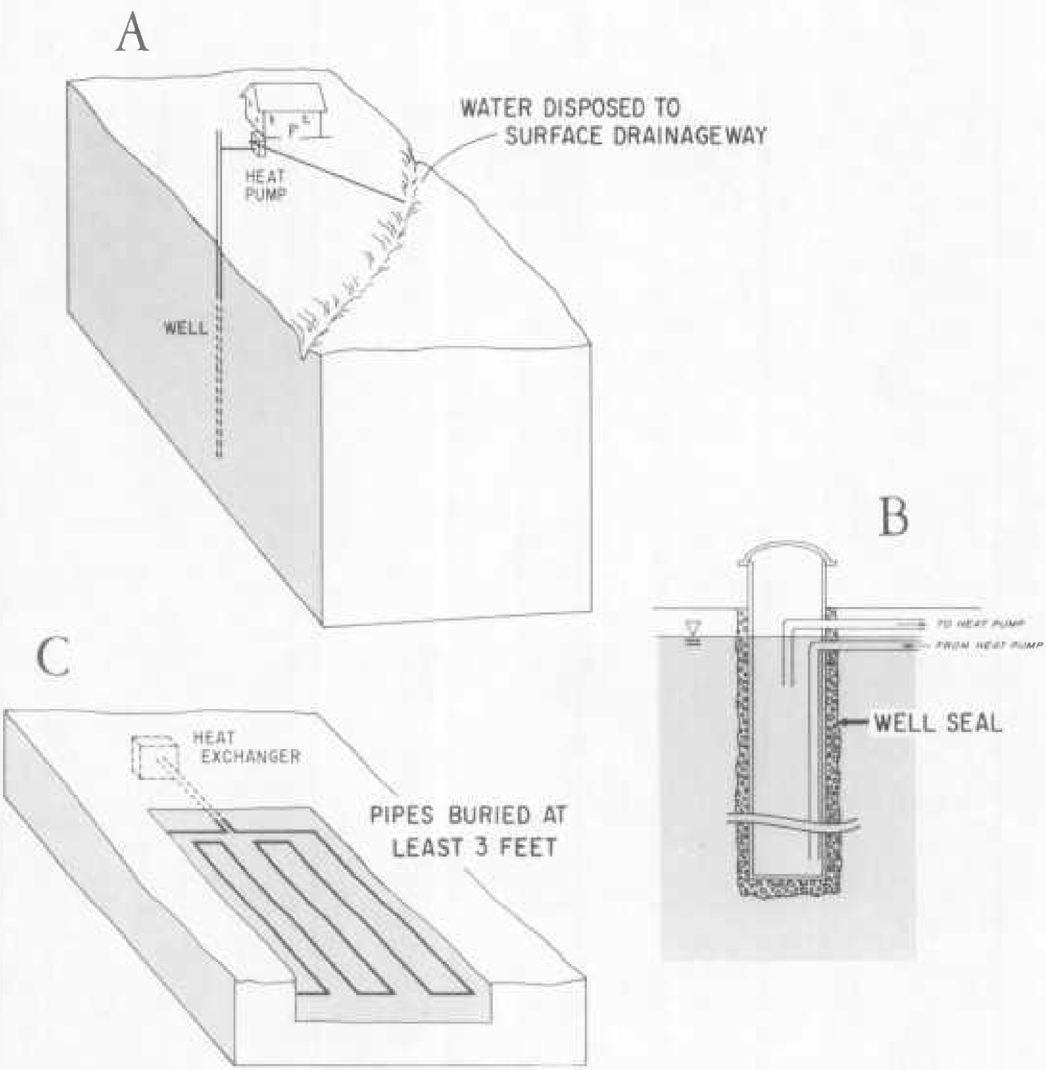


FIGURE 23. Three main types of coupling systems for ground-water heat pumps: A) Extraction well with disposal to surface; B) Closed-loop "well"; C) Earth-coupled closed loop.

GROUND-WATER QUALITY

Water samples from 142 wells and 25 springs were analyzed in the field for temperature, specific conductance, pH, and alkalinity, and in the laboratory for common ions and trace elements. Additional data were obtained from U.S. Geological Survey files. These data may be found in Dine and others (1985) and are summarized in table 8.

TABLE 8
SUMMARY OF GROUND-WATER QUALITY
Physical Properties and Common Ions
[All analyses reported in milligrams per liter unless otherwise specified.]

Constituent or property	Number	Minimum	Maximum	Meen	Median
Conductivity (μS/cm)	168	25.1	1,800	281	220
pH	168	5.51	8.3	6.79	6.6
Temperature (°C)	136	8.0	27.0	14.1	13.0
Color (Platinum cobelt units)	46	0	65	6.0	5
Fecal coliform becteria (Colonies/100 ml)	26	<1	>60	--	<1
Fecel streptococci (Colonies/100 ml)	26	<1	>200	--	14
Herdness (es $CeCO_3$)	106	6.3	495	120	83
Noncerbonate hardness (as $CaCO_3$)	106	0	170	26.2	18.7
Calcium (Dissolved)	92	1.53	160	32	20
Magnesium (Dissolved)	91	.5	30	9.0	6.4
Sodium (Dissolved)	88	.6	61	7.9	5.9
Potassium (Dissolved)	88	.10	13.1	1.42	.80
Iron (Dissolved)	44	<.003	.468	.047	.008
Alkelinity, Field (mg/L es $CaCO_3$)	82	2	509	116	125
Alkelinity, Lab (mg/L es $CeCO_3$)	56	9.6	350	71	34
Sulfate (Dissolved)	105	.1	115	15.7	10
Chloride (Dissolved)	106	.40	110	12.2	7.3
Fluoride (Dissolved)	84	< .05	.4	< .1	< .1
Silice (Dissolved)	83	6.1	44	16.7	16
Sum of dissolved constituents	80	31.5	590	165	148
Nitrete (Dissolved)	122	.02	40	4.8	3.6
Nitrete plus nitrite (Dissolved, as N)	55	.045	20	2.9	2.1
Ammonie plus organic nitrogen (Dissolved, as N)	48	< .10	5.0	.35	.20
Phosphorus	25	< .01	.21	.5	.05
Orthophosphate (Dissolved, es P)	54	< .01	.20	.04	.03

Note: For sites heving multiple observations, the mean value was used.

Water-quality criteria for drinking water were promulgated by the U.S. Public Health Service (1946), and updated and amended in 1962. These regulations were superseded by those of the U.S. Environmental Protection Agency (USEPA, 1977), and more recent updates have appeared in the Federal Register. The standards set by USEPA are generally applicable to public water-supply systems and are based on health aspects of the water consumed. Water for other uses may have to be treated to remove scale-forming substances which clog pipes; acidity, which corrodes plumbing and equipment; chemicals that cause undesirable reactions in processes requiring a mix with water; or to reduce other objectionable qualities. Standards have also been developed to meet the requirements of various commercial and industrial uses.

The quality of ground water is determined by several factors, primary of which is the chemical and mineralogic makeup of the geologic matrix through which the water circulates. Water from the carbonate rocks has the highest median values of specific conductance, likely owing to the relatively greater solubility of calcite and dolomite. The Triassic shales and sandstones have the next highest values (fig. 24). Values from the rest of the units are quite scattered, except in the case of the Weverton Formation (a quartzite) which has the lowest median specific conductance. Considerable mineralogic variation may occur within geologic mapping units, and mineralogy was not examined at each sampling site.

Another indication of the variability in ground-water quality may be seen in the distribution of total dissolved solids concentration (fig. 25), although the particular dissolved species are not identified. Because the ability of water to conduct an electrical current is dependent upon ions in solution, specific conductance is an indirect measure of total dissolved solids (fig. 26). Based on 159 analyses of ground water sampled throughout Frederick County (wherein specific conductance was measured, and total dissolved solids was determined as the sum of the concentrations of the dissolved ions that were determined), the total dissolved solids content of a sample of ground water may be estimated as:

$$\text{TOTAL DISSOLVED SOLIDS} = (0.53 \times \text{SPECIFIC CONDUCTANCE}) + 14.3$$

Although there are differences in quantity of total dissolved minerals, calcium, magnesium, and bicarbonate are the dominant ions (fig. 27). These ions dominate water from the noncarbonate rocks as well as the carbonate rocks because of the prevailing influence of atmospheric carbon dioxide (increased by soil biologic respiration) and the greater mobility of calcium and magnesium ions. Deviations from this composition include a few sites where relative concentrations of sodium and chloride were higher (in some cases, dominant). Such samples were obtained from the metarhyolite and associated rocks in the western part of the county, the Catoctin Metabasalt, and the Marburg Schist. These samples reflect the immixture of septic-tank effluents or roadside runoff containing a dissolved load of deicing salts. One sample (FR AE 50) from the Catoctin Metabasalt had a calcium-magnesium-sulfate composition. The Catoctin Metabasalt does contain some pyrite, which may add to the sulfate concentration, but the possibility that sulfate was introduced into the ground-water system by other avenues cannot be discounted.

The variation in water quality seen in figure 27 is somewhat limited and is not closely related to rock type (at the detail of mapping). Water samples from the carbonate rocks (fig. 27E) are more uniformly calcium-magnesium type. These are also characterized by higher pH values (fig. 28), but values greater than 7.0 were also measured in wells completed in areas mapped as the New Oxford Formation (sandstone and shale), Ijamsville Formation, Libertytown Metarhyolite, and others. On the other hand, low pH (<6.0) was reported from wells completed in metarhyolite, metaandesite, quartzite of the Weverton Formation, Catoctin Metabasalt, and Gettysburg Shale. The last two showed a wide range; however, some samples from these units had high pH. Although of little direct concern to health, water having low pH may permit undesirable chemical reactions to occur in water-supply lines and food-processing ingredients. The range in pH can affect the treatment of water required for some special uses.

(Text continued on page 54.)

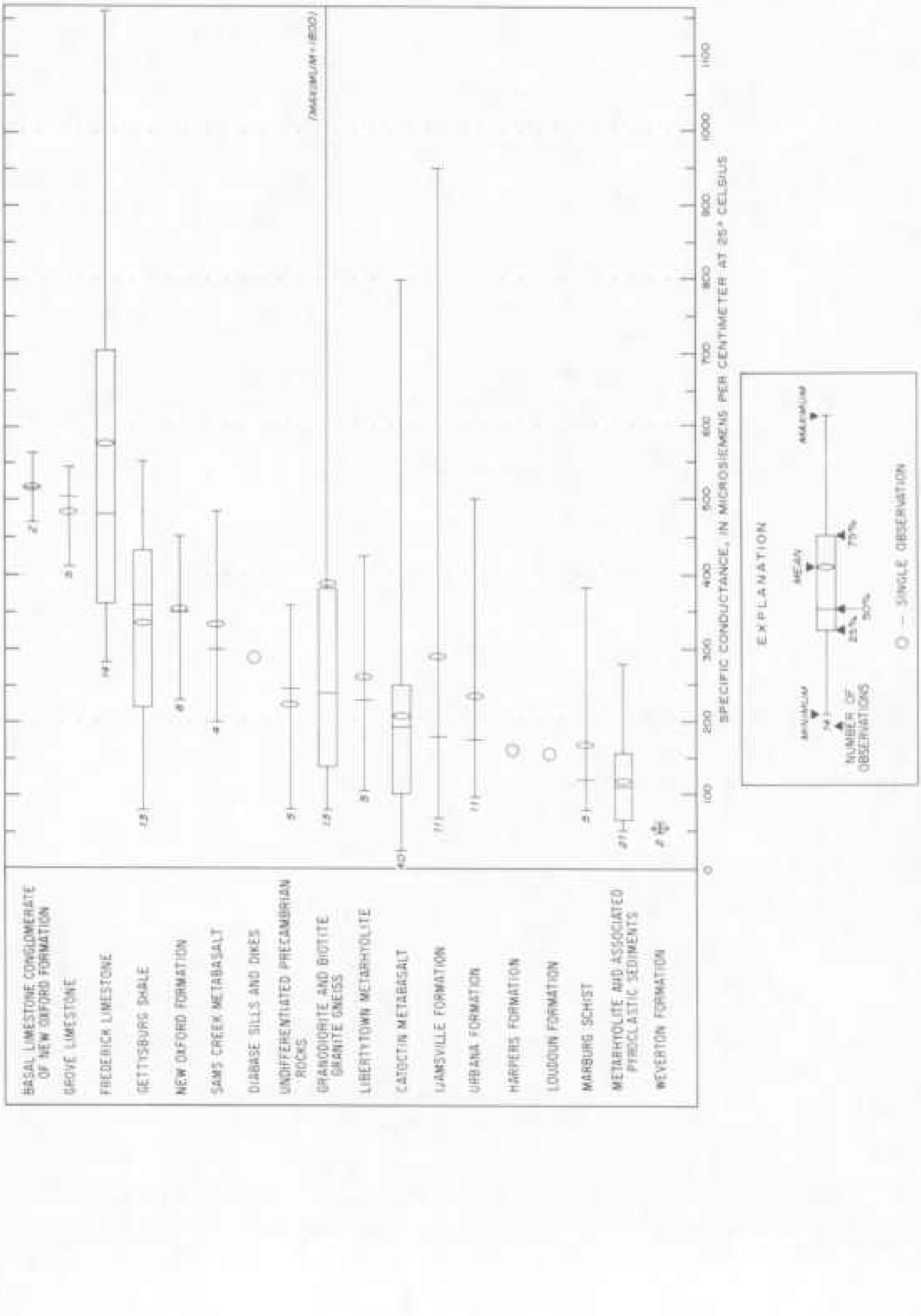


FIGURE 24. Box-whisker plots of specific conductances of water from wells open to various geologic units.

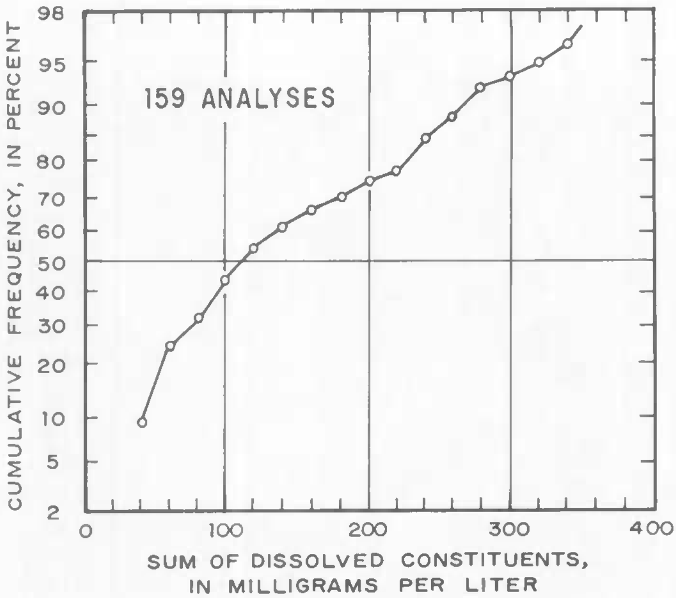


FIGURE 25. Cumulative frequencies of total dissolved solids (sum of dissolved ions analyzed) in ground-water samples.

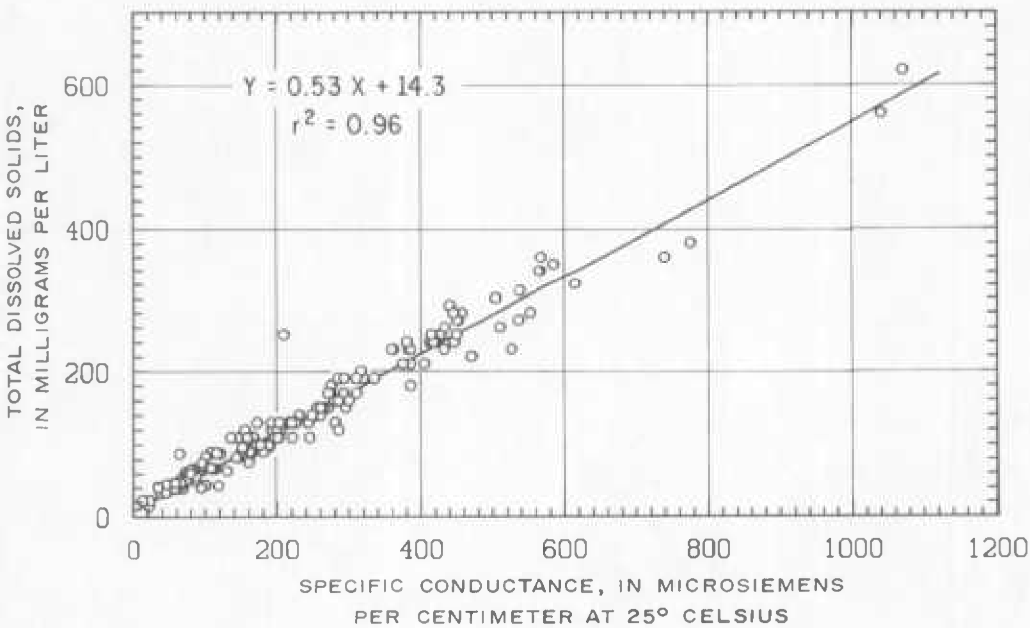


FIGURE 26. Relation of total dissolved solids (sum of dissolved ions analyzed) and specific conductance of ground water in Frederick County.

A

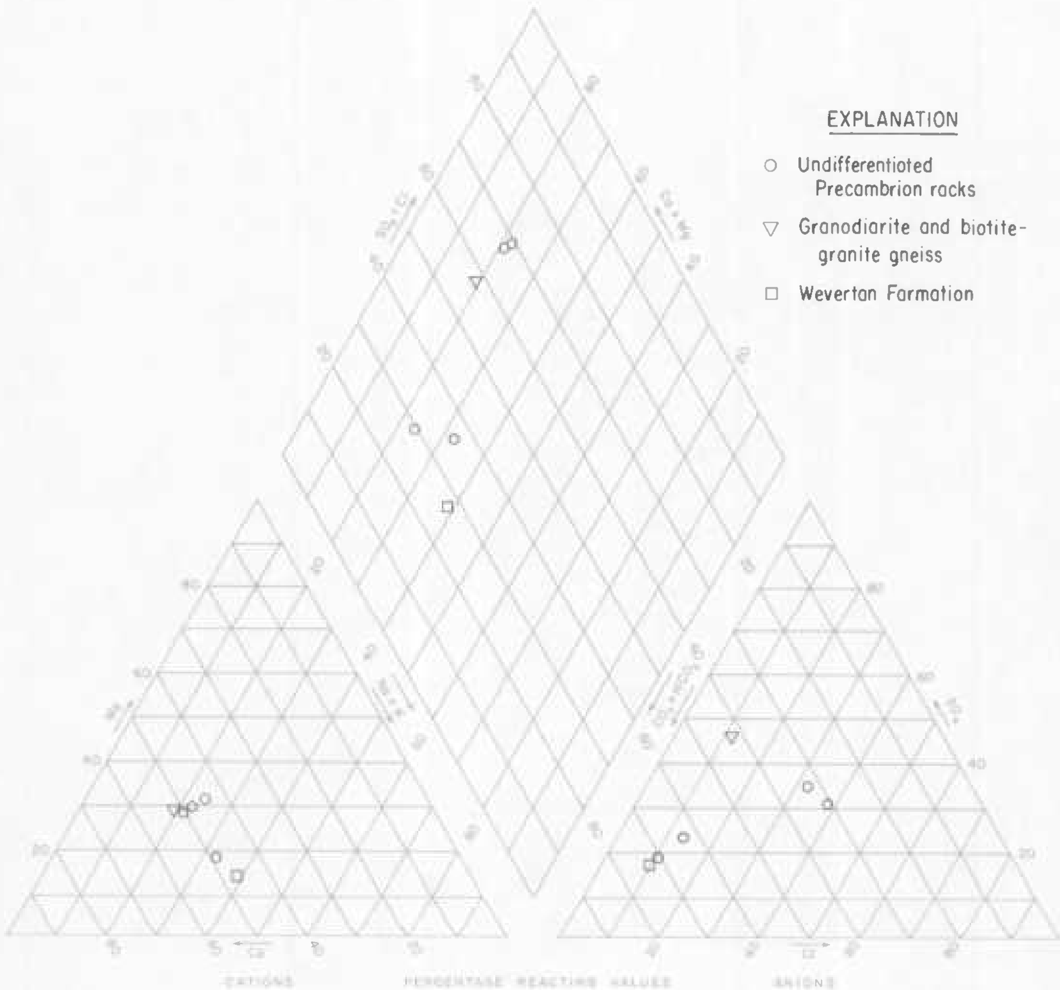
FIGURE 27. Percentages of major ions in ground-water samples from selected geologic units. Where multiple samples for a site were analyzed, average values were used.

B

FIGURE 27. *Continued.*

C

FIGURE 27. *Continued.*

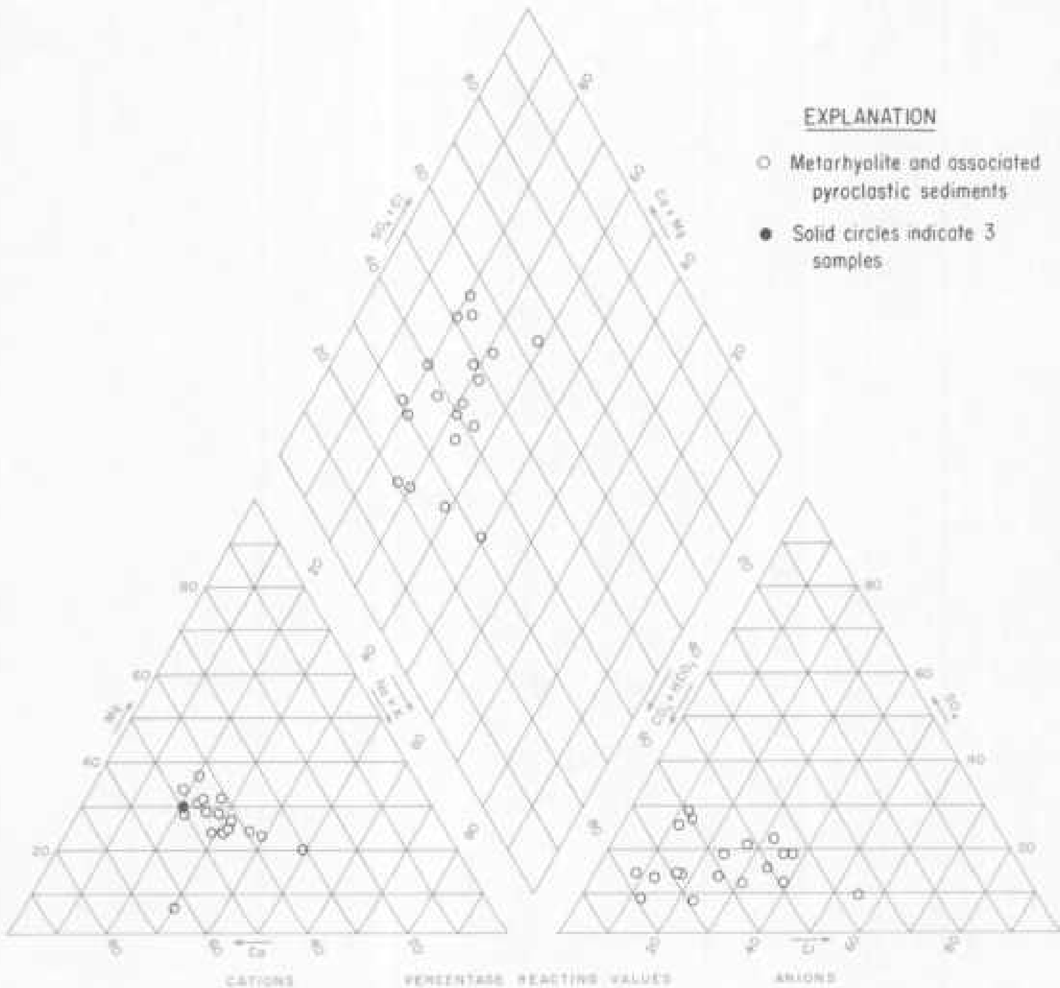


D

FIGURE 27. *Continued.*

E

FIGURE 27. *Continued.*



F

FIGURE 27. *Continued.*

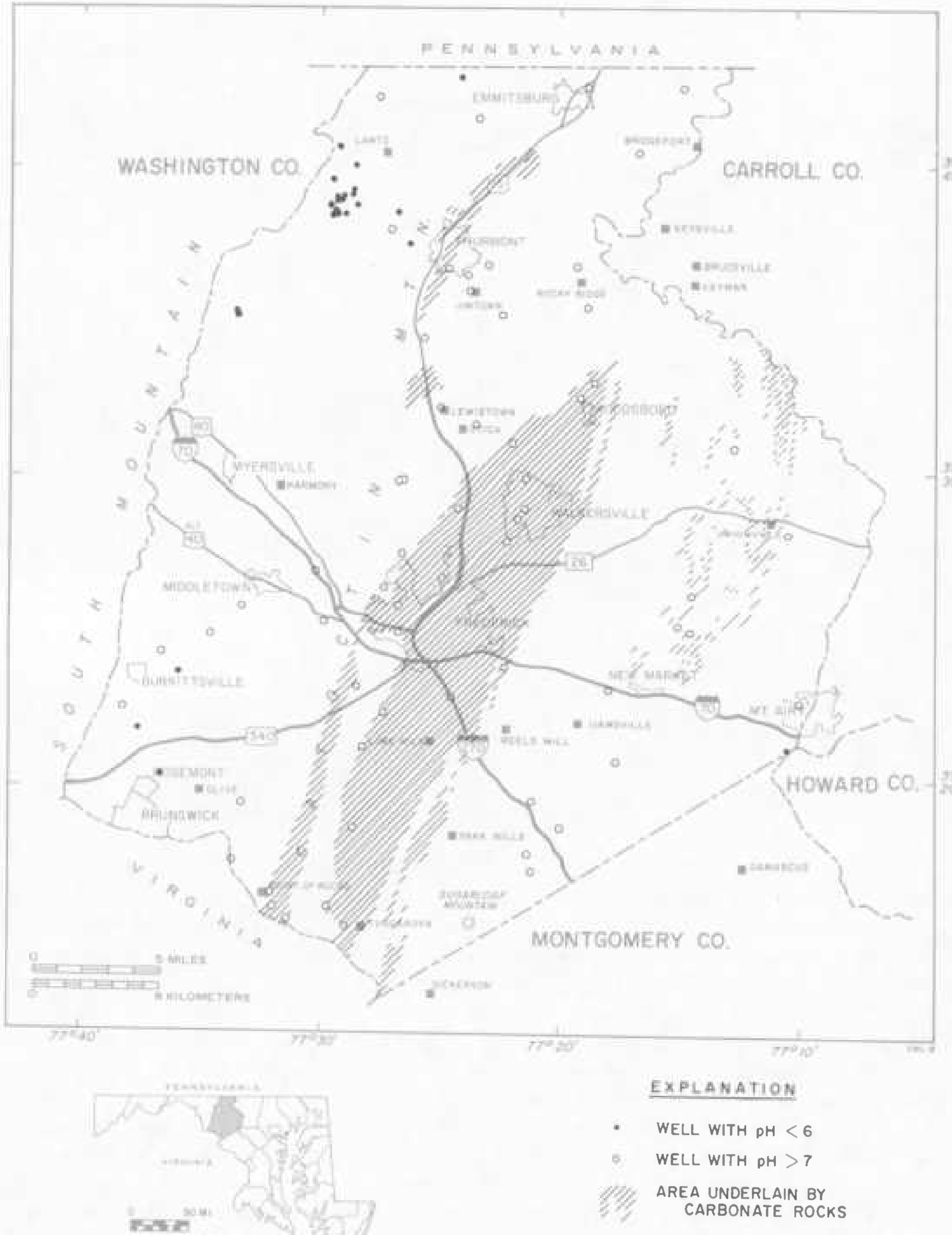


FIGURE 28. Areal distribution of high and low pH in ground water in Frederick County.

TABLE 9

OLD AND NEW ANALYSES OF GROUND-WATER QUALITY

Site No.	Date of sample	Geologic unit	Specific conductance (μS)	pH	Temperature (°C)	Hardness (mg/L as $CaCO_3$)	Hardness, noncarbonate (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)
FR BD 3	52-07-30	Metarhyolite	58	6.2	--	19	0	4.6	1.8	3.7	0.70
	83-04-11		90	6.3	7.0	--	--	--	--	--	--
	83-06-01		80	6.3	9.0	30	6	7.1	2.9	3.9	.84
FR BD 6	55-06-06	Catoctin	73	6.7	--	31	0	8.0	2.7	1.7	1.7
	83-04-26	Metabasalt	150	5.8	9.0	68	50	14	8.2	13	1.0
	83-06-06		245	5.8	9.0	66	47	13	8.2	16	.84
FR BD 40	66-03-17	Catoctin	56	7.0	10.0	24	0	6.4	2.0	2.2	.30
	83-05-02	Metabasalt	72	6.0	9.5	27	0	6.8	2.3	2.7	.57
	83-06-13		71	6.1	10.5	26	1	6.7	2.2	2.4	.35
	83-07-18		71	5.8	10.0	28	1	7.3	2.4	2.7	.53
	83-11-03		65	6.3	12.0	29	0	7.5	2.4	2.7	.40
	84-03-08		61	6.1	9.0	28	3	7.2	2.4	2.1	.40
	84-05-09		67	6.0	10.0	27	1	7.0	2.4	2.1	.40
	84-08-09		70	6.4	11.0	29	0	7.8	2.4	2.1	.40
FR BD 41	66-03-22	Catoctin	74	6.8	10.0	32	0	7.4	3.2	3.2	.50
	83-05-02	Metabasalt	79	6.2	9.5	31	0	7.2	3.3	3.7	.75
	83-06-13		84	6.3	10.5	32	0	7.4	3.4	3.0	.57
	83-07-18		85	5.9	11.0	32	0	7.4	3.4	3.9	.65
FR BD 44	66-05-16	Catoctin	37	7.0	10.5	11	0	2.9	1.0	2.2	1.1
	83-04-27	Metabasalt	33	5.6	11.0	10	0	2.5	.88	2.3	.84
	83-06-07		27	5.7	11.0	10	4	2.4	.88	2.4	.84
FR BD 49	71-04-07	Weverton	43	5.9	--	12	0	3.4	.80	2.7	1.7
	81-08-21	Formation	21	5.9	15.0	1	0	.20	.10	.90	1.0
	83-04-18		44	6.3	10.0	12	0	3.6	.75	2.6	1.1
	83-06-06		50	5.6	13.0	13	0	3.9	.75	3.0	1.8
	83-07-13		55	5.8	13.0	15	0	4.6	.81	3.8	1.8
	83-11-04		55	6.2	10.0	18	0	5.6	.95	3.8	1.6
	84-03-07		50	6.3	10.0	16	0	4.8	.88	2.8	1.6
	84-05-09		52	6.2	12.0	16	0	4.9	.83	2.9	1.6
	84-08-08		54	5.9	13.5	15	0	4.7	.81	2.7	1.5
FR DD 146	72-08-04	New Oxford	362	8.5	--	170	45	54	8.0	8.9	.60
	82-10-05	Formation	405	7.8	14.0	170	57	55	8.8	9.2	.60
	83-04-12		385	7.5	12.5	180	48	57	8.9	9.7	.90

Human factors, such as improper disposal of waste and careless handling of various substances, also affect the quality of ground water, sometimes to a greater degree than natural processes. Buried steel fuel tanks eventually rust, and may leak for some time before being detected; not only does this result in contamination of ground water, but it can also result in explosive conditions where gasoline is pumped out of the ground by a water well (such a situation occurred at a gasoline station near New Market in 1976).

Natural protection of ground-water quality in Frederick County is afforded to some extent by such means as filtration by and adsorption on geologic materials. Most renovation of contaminated water occurs in the unconsolidated material overlying bedrock, especially in the shallower portion, which is biologically more active and contains much clay-size material which provides greater surface area and electrostatic attraction; however, the presence of organic material (chiefly fulvic acid) may decrease virus removal (Bixby and O'Brien, 1979). Open fractures provide little opportunity for renovation; solutionally enlarged joints, fractures, and bedding planes have no renovation capacity, and can act as conduits for pollution migration. The Grove and Frederick Limestones are the geologic units most likely to allow conduit flow in Frederick County; consequently, areas underlain by these units require special safeguarding. Proper location and construction of a well can prevent many contamination problems, and this is reflected in State and local regulations.

TABLE 9—*Continued*

Alkalinity, field (mg/L as $CaCO_3$)	Alkalinity, lab (mg/L as $CaCO_3$)	Carbon dioxide, dissolved (mg/L as CO_2)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Solids, residue at 180 °C dissolved (mg/L)	Solids, sum of constituents, dissolved (mg/L)	Nitrate, dissolved (mg/L as N)	NO_2+NO_3, dissolved (mg/L as N)	Site No.
20	--	24	2.0	2.9	<.05	17	47	47	.47	--	FR BD 3
--	--	23	--	--	--	--	--	--	--	--	
--	24	23	6.1	2.1	--	--	--	--	1.1	1.1	
33	--	13	.0	.60	<.05	13	55	50	.68	--	FR BD 6
--	18	58	5.9	32	--	--	--	--	--	1.2	
--	19	60	6.0	20	--	--	--	--	--	1.2	
25	--	4.9	.6	.80	.20	17	48	46	.38	--	FR 8D 40
--	25	56	.3	2.1	--	--	--	--	--	1.7	
--	25	38	.9	1.5	--	--	--	--	--	1.7	
--	26	83	.3	2.9	--	--	--	--	--	1.5	
--	30	29	.5	3.7	<.10	16	49	51	--	<.10	
--	26	38	.3	1.7	<.10	16	49	45	--	1.7	
--	25	51	.6	1.3	<.10	15	58	45	--	1.6	
--	28	24	1.8	1.5	<.10	16	52	51	--	1.4	
36	--	11	1.2	.70	.20	19	58	58	.18	--	FR BD 41
--	32	40	.2	1.8	--	--	--	--	--	1.3	
--	34	33	.8	2.7	--	--	--	--	--	1.5	
--	34	86	.1	2.8	--	--	--	--	1.2	1.3	
16	--	3.0	1.4	1.0	.10	14	36	33	--	--	FR BD 44
--	11	60	.6	2.1	--	--	--	--	--	.59	
--	11	22	.2	2.1	--	--	--	--	--	.38	
16	--	38	3.2	1.0	.10	10	28	33	.09	--	FR BD 49
--	3.0	7.3	2.2	1.1	<.10	6.5	16	14	--	--	
--	13	12	3.4	1.6	--	--	--	--	--	.06	
--	16	68	3.9	1.7	--	--	--	--	--	.08	
--	--	58	3.3	2.5	--	--	--	--	--	.02	
--	23	31	4.3	1.8	<.10	11	39	44	--	.96	
--	20	21	3.8	1.3	<.10	10	41	39	--	.20	
--	19	22	4.1	1.3	.10	10	41	37	--	.17	
--	19	44	4.4	1.3	<.10	10	39	38	--	.11	
123	--	.7	26	12	.10	24	--	230	5.1	--	FR DD 146
165	117	3.6	26	14	<.10	24	234	210	--	5.0	
157	131	8.0	30	22	<.10	25	257	230	--	5.6	

Six wells and one spring that had been sampled prior to 1973 were resampled in 1983 or 1984 (table 9). Two wells, FR BD 6 (first sampled in 1955) and FR DD 146 (first sampled in 1972), show increased dissolved solids, particularly sodium, calcium, and chloride, which may be the result of contamination by road-deicing salt (or perhaps septic-tank effluent). Additional discussion of ground-water contamination by septic-tank effluent and road salt in the vicinity of the Catoctin Mountain National Park may be found in Trombley and Zynjuk (1985). Although incidents of contaminated wells have occurred over the years, a general degradation of ground-water quality in Frederick County is not apparent.

SURFACE-WATER RESOURCES

Streamflow may vary over several orders of magnitude. Planning and design considerations require estimates of flow magnitudes and frequencies and their probabilities of occurrence. Streamflow characteristics for 26 stations along 19 streams flowing through or into Frederick County (fig. 5) are discussed in this section.

MONTHLY AND ANNUAL MEAN FLOWS

Monthly mean flows (the average of the daily flows of a month) and annual mean flows (the mean of the average daily flows of a year) for 12 continuous-record streamflow gaging stations are shown in figure 29. Highest average flows generally occur in March or April. Lowest average flows occur in August through October. As shown in the figure, monthly flows can vary by more than an order of magnitude over the years. Monthly flows are, on the average, lower in the summer than in the winter, owing to additional water loss through evapotranspiration.

FLOW DURATIONS

A cumulative frequency of streamflows, or flow-duration, curve (Searcy, 1959) provides a means of characterizing streamflow variability and of comparing stream basins. The periods of records used for comparisons should be nearly the same, or at least of sufficient length, so that rare, extreme events do not strongly affect the shape of the curve. Because short-term unusual conditions (such as several years of below-normal precipitation) may affect the duration curve, it is generally better to use extreme frequency distributions to obtain estimates of high or low flows. Flow durations were determined for 10 continuous-record stations using the complete period of record for each station, except where natural flows have been altered by construction of reservoirs (table 10).

TABLE 10

DURATIONS OF DAILY FLOWS AT CONTINUOUS-RECORD STATIONS

Station No.	Station name	Flow, in cubic feet per second,				
		0.5	1	2	5	10
01637000	Little Catoctin Creek at Harmony	97	64	45	30	23
01637500	Catoctin Creek near Middletown	780	580	420	260	180
01639000	Monocacy River at Bridgeport	3,400	2,500	1,800	870	440
01640500	Owens Creek at Lantz	84	62	46	30	22
01641000	Hunting Creek at Jimtown[1/]	210	160	120	75	54
01641500	Fishing Creek near Lewistown	75	59	47	35	27
01642000	Monocacy River near Frederick	12,000	9,900	7,000	3,600	2,100
01642500	Linganore Creek near Frederick[2/]	790	560	380	220	160
01643000	Monocacy River at Jug Bridge near Frederick	11,000	7,900	5,500	3,200	2,000
01643500	Bennett Creek at Park Mills	740	530	350	200	140

1/ Based on period April 1, 1950, to March 31, 1971.

2/ Based on period April 1, 1935, to March 31, 1971.

The shape of the flow-duration curve is determined by the characteristics of the drainage basin, and is useful for comparing basins (fig. 30). A curve having a steep slope (Monocacy River at Bridgeport) may indicate a basin with highly variable flow, little storage of water in the basin, and a relatively large amount of direct runoff. A curve with flatter slope (Fishing Creek near Lewistown) indicates a basin with fairly uniform flow, large amounts of storage, and a large proportion of base flow or ground-water discharge. The curves shown in figure 30 illustrate the extremes in duration-curve slopes for the 10 continuous-record gaging stations (table 10); curves for the remaining stations plot between these two.

Streamflow may not be generated uniformly throughout a basin, especially if the basin is large and diverse. Duration curves for two stations on the Monocacy River (at Bridgeport, drainage area 173 mi^2; and at Jug Bridge near Frederick, drainage area 817 mi^2; fig. 31) indicate greater variation in streamflow for the Bridgeport station, which is tributary to the Jug Bridge station. High flows past Jug Bridge are relatively lower owing to the distribution of precipitation during storms and the traveltimes for runoff to reach the station. Low flows past the Bridgeport station are relatively lower but the reasons are uncertain. A combination of geologic and topographic factors may be responsible.

Streamflow characteristics may be affected by flow regulation. A flow-duration curve using the entire period of record (unregulated and regulated intervals) would represent neither condition and thus be of little value. If the curve is to be used to define hydrologic and geologic characteristics of natural flow, only the unregulated period of record should be used. But, if the conditions as they exist under regulated conditions are required, only that period of record should be used. Duration curves for Hunting Creek at Jimtown have been plotted to illustrate the effects of regulation on streamflow (fig. 32). Curves for the periods before the lake impoundment at Cunningham Falls State Park (water years 1950–71) and after completion of the lake (water years 1972–83) are shown. The curve plotted from the later data indicates more discharge throughout the entire curve. This is due, in part, to the generally wetter conditions of the 1970's. At the 90-percent exceedance level, the curve representing the regulated period flattens rapidly. The break in slope occurs in base-flow conditions, and indicates augmented flow due to water released from the reservoir.

TABLE 10—*Continued*

which was equaled or exceeded for indicated percentage of time											Station No.
20	30	50	70	80	90	95	98	99	99.5	99.9	
16	12	5.7	2.6	1.9	1.3	1.0	0.7	0.6	0.6	0.4	01637000
110	78	38	17	10	5.7	3.8	2.5	1.6	.9	.1	01637500
220	140	61	25	15	7.7	4.8	2.7	1.7	.8	.1	01639000
15	11	5.3	2.3	1.4	.8	.5	.3	.2	.2	.1	01640500
35	25	12	5.4	3.7	2.5	1.9	1.5	1.3	1.1	.8	01641000
19	15	7.6	3.4	2.4	1.7	1.4	1.1	1.0	.9	.8	01641500
1,100	740	420	230	170	110	77	55	40	34	22	01642000
110	78	49	31	24	17	13	10	8.5	7.3	3.2	01642500
1,200	830	470	250	180	120	92	65	54	46	31	01643000
89	69	45	27	21	15	12	9.1	7.7	6.8	5.7	01643500

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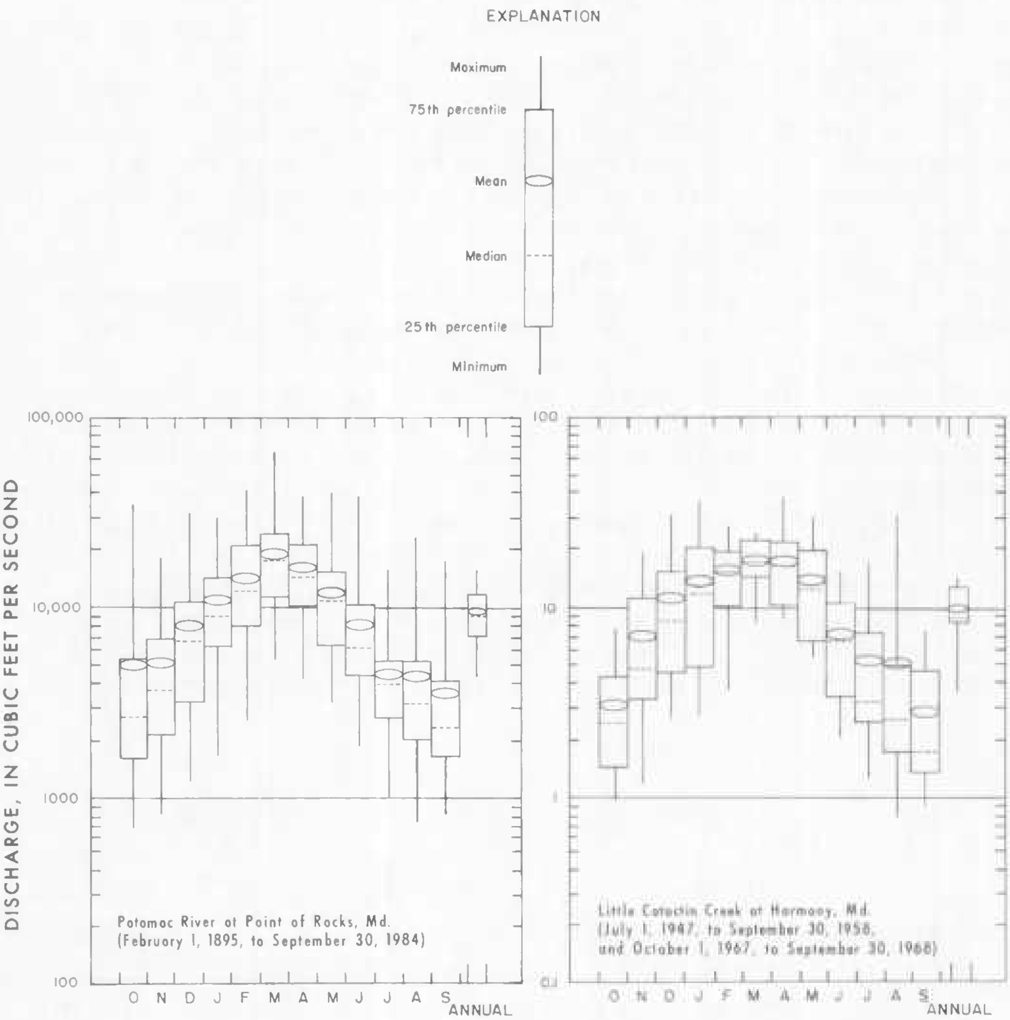

FIGURE 29. Monthly and annual streamflow statistics for stations having continuous records.

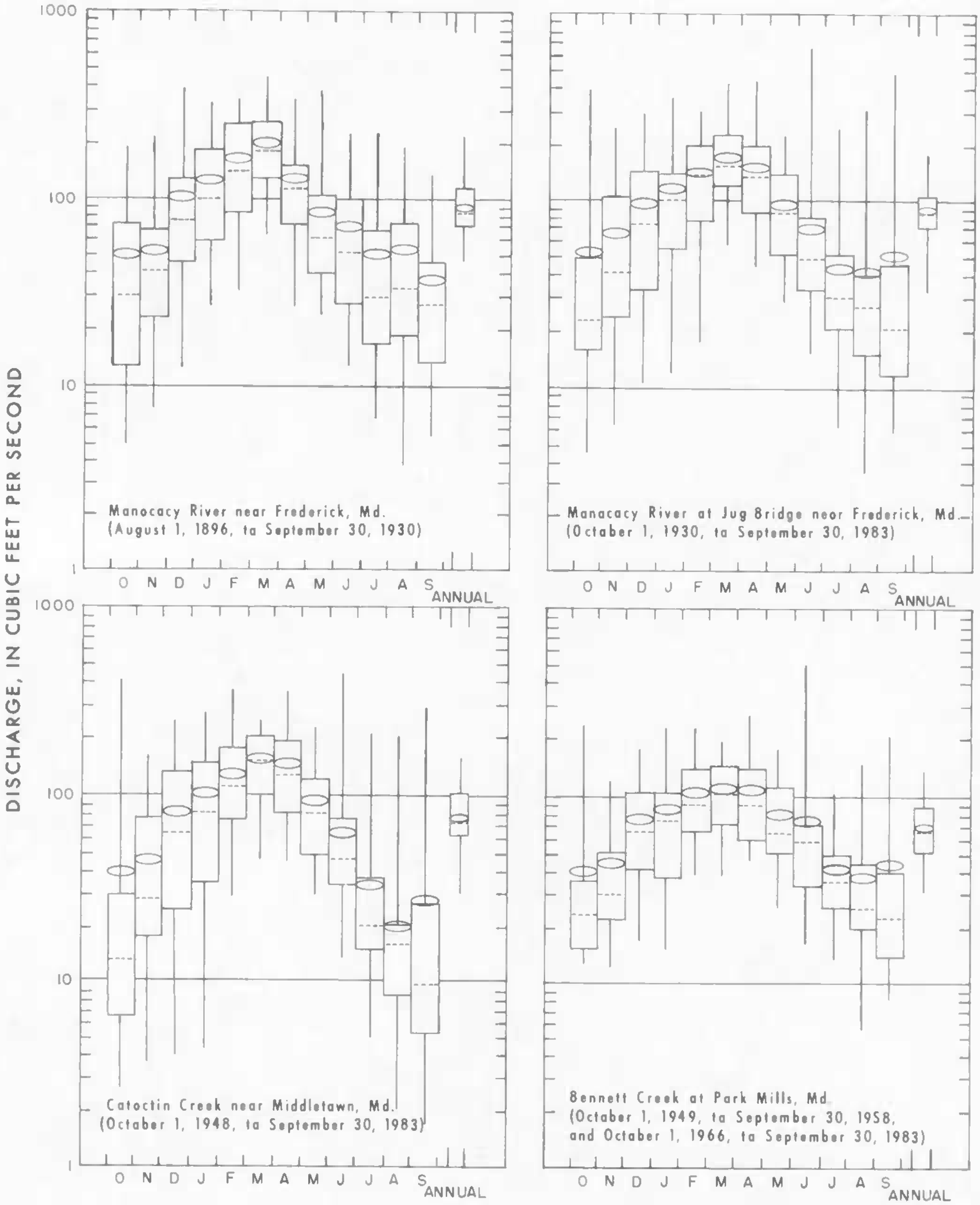

FIGURE 29. *Continued.*

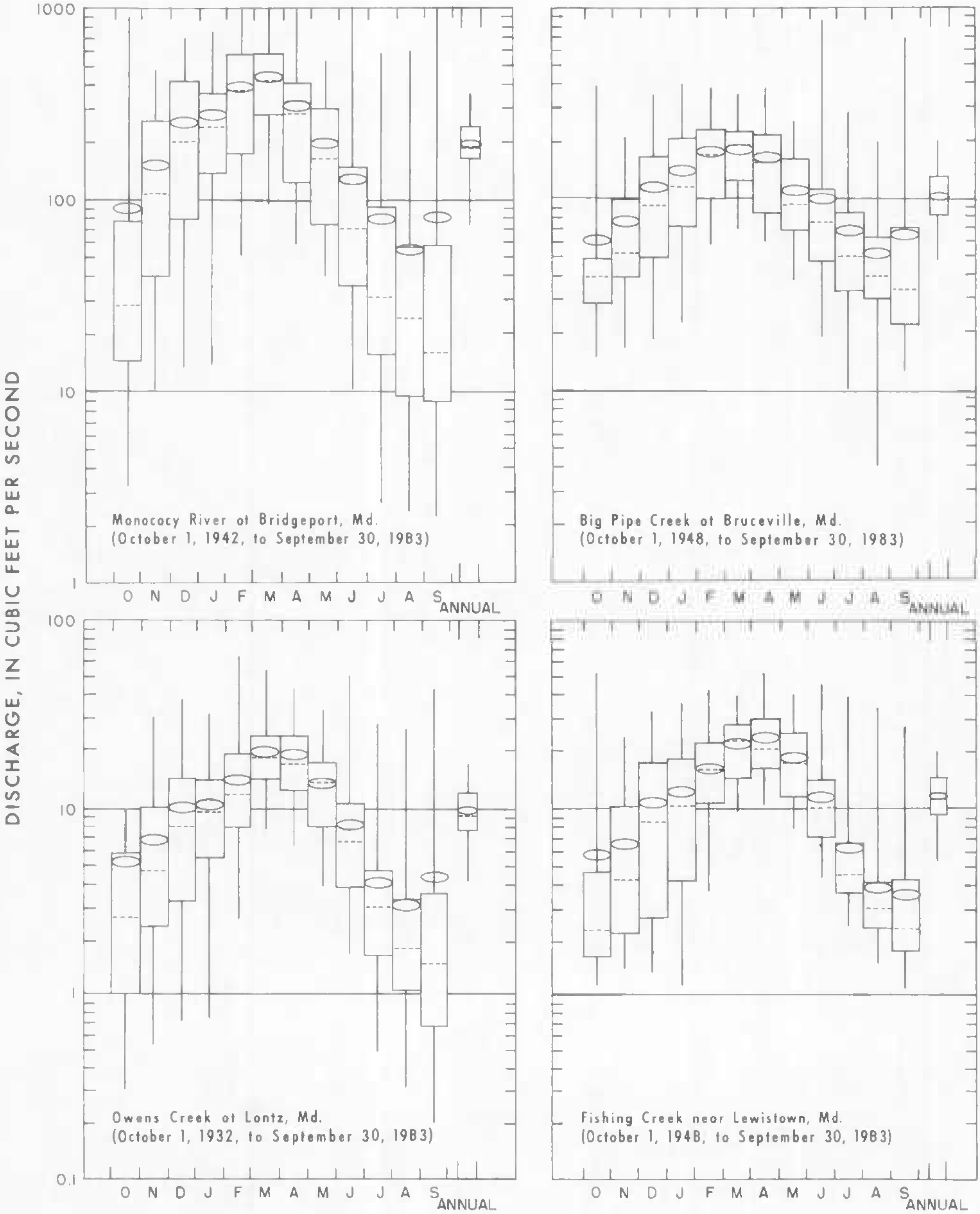

FIGURE 29. *Continued.*

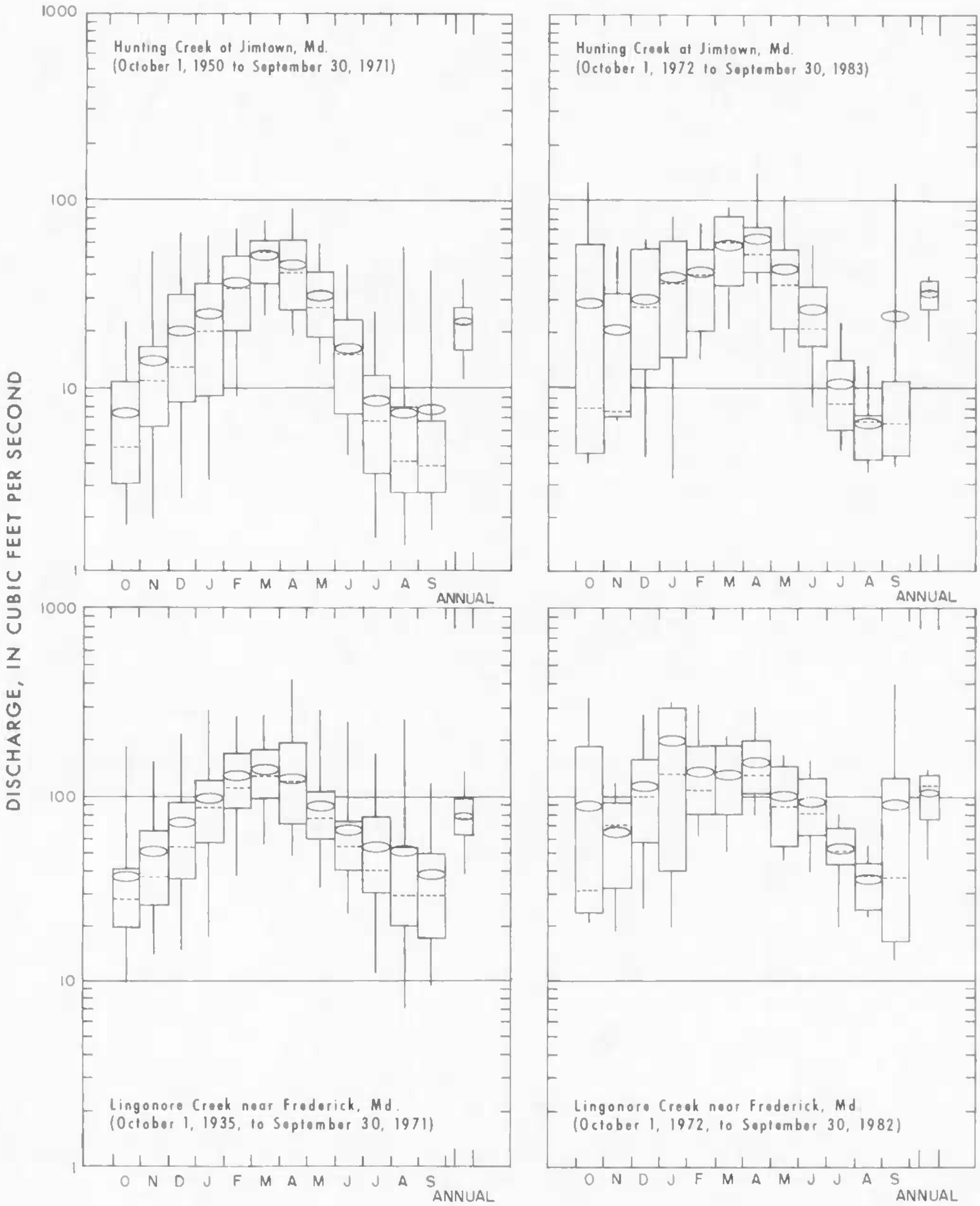

FIGURE 29. *Continued.*

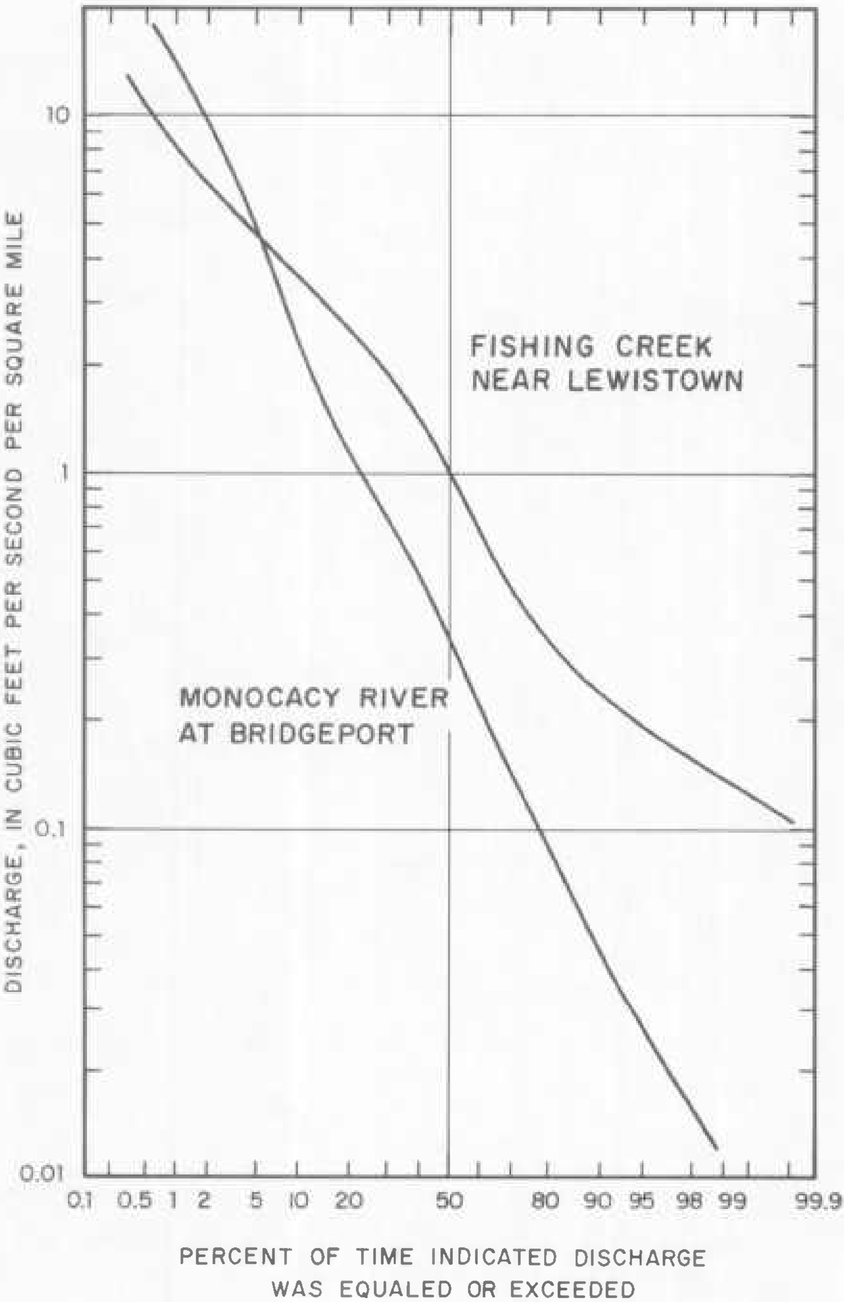

FIGURE 30. Durations of daily flows of Fishing Creek near Lewistown and Monocacy River at Bridgeport, 1947–83.

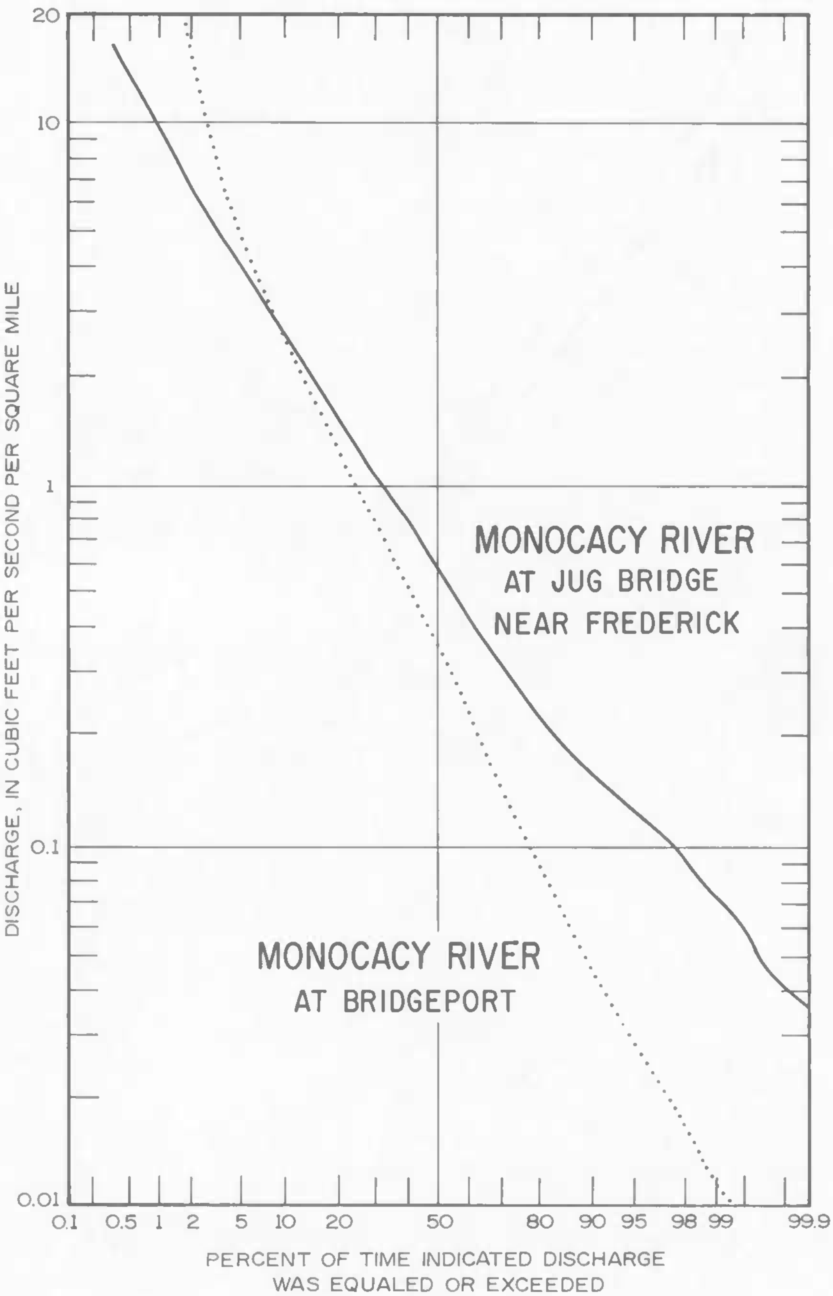

FIGURE 31. Durations of daily flows past two stations on the Monocacy River (at Bridgeport, drainage area 173 square miles; at Jug Bridge near Frederick, drainage area 817 square miles), for the period 1942–85.

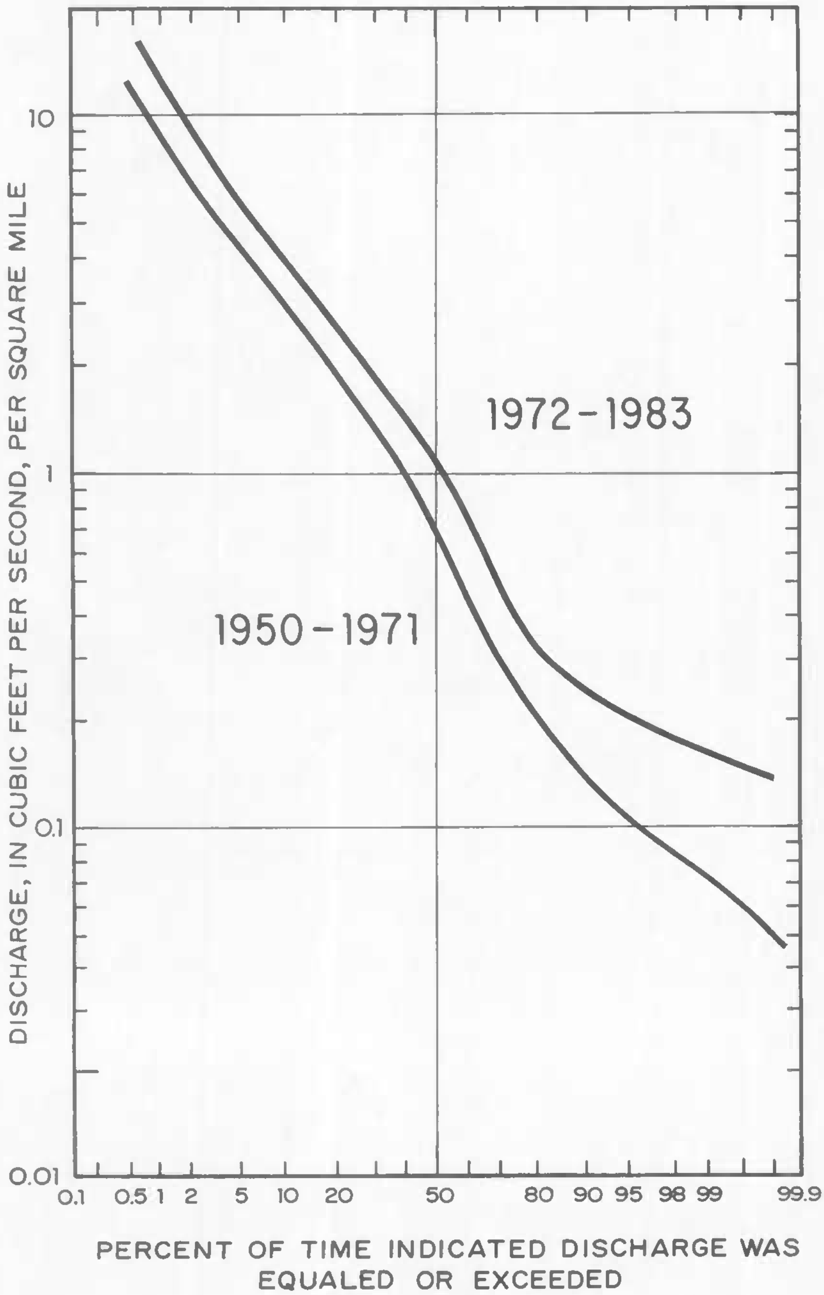

FIGURE 32. Durations of daily flows at Hunting Creek at Jimtown before and after impoundment.

FLOOD FREQUENCIES AT LONG-TERM STATIONS

Most major floods in Frederick County are caused by hurricanes. The rain associated with Hurricane Agnes (1972) caused record peaks at four continuous-record gaging stations in the county. Peaks of record at three other gaging stations occurred on October 9, 1976, from a storm which was the result of a continental low pressure system which moved into the area from the west. Most of the hydrographs covering that period show fast rises and sharp peaks; on the other hand, the Monocacy River, which receives contributions from numerous tributaries spread over a much larger area, reacts more slowly to storms resulting in an attenuated hydrograph.

High-flow frequencies at the sites in Frederick County having continuous records are shown in table 11. In addition to values for instantaneous peak discharge, values for annual maximum daily, 3-day, and 7-day flows are shown for various recurrence intervals ("recurrence interval" is the average period during which a given flow is exceeded once; the reciprocal of the recurrence interval is the probability that such a flow will be exceeded in any one year). The flood magnitude and frequency figures were computed using the log-Pearson type III distribution fitted to the streamflow records (U.S. Water Resources Council Hydrology Committee, 1981). Peak flows were estimated using annual maximum instantaneous discharges, whereas the average flows were estimated using all average daily flows for the years of record. The reliability of the estimates decreases with decreased exceedence probability; values for recurrence intervals greater than twice the period of record should be used with caution for this reason.

Basin-to-basin variability of high flows (discharge per square mile) is not very significant. Annual high flows are composed primarily of surface runoff; therefore, the geologic units do not play an important role in transmitting water to streams under high-flow conditions (although the infiltration capacity of the soil mantle does affect the amount of surface runoff). One important factor governing high-flow variability is the distribution of rainfall intensity throughout the county. Variability is affected to some extent by differences in other characteristics of the basins, such as forest cover (which may be an indirect measure of the amount of impermeable surfaces, such as parking lots or roofs, present in the basin) or slope of the land surface. Most of these factors are interrelated; forest cover, for example, is greater on more steeply sloping land because that land is less suited for farming or urbanization.

Carpenter (1983) determined the statistical relations between basin factors and peak flows of Maryland streams. Peak flows of various recurrence intervals for ungaged streams in Frederick County may be estimated using regression equations that express discharge as a function of basin area, forest cover, and precipitation intensity, all raised to various powers (details on the use of this method are given in Carpenter, 1983). Table 12 presents peak-flow discharges estimated using this method. The accuracy of the results, in percent error for each recurrence interval, are included in the table.

LOW-FLOW CHARACTERISTICS

Streams may be required to dilute and dispose of liquid wastes, provide municipal or industrial water supplies, provide water for irrigation, maintain suitable conditions for fish and aquatic communities, or any combination of these. Knowledge of low-flow distributions is necessary in order to plan for the successful operation of these functions. Many water-quality standards have been based on the 7-day, 10-year low-flow frequency ($7Q_{10}$), defined

TABLE 11

MAGNITUDES AND FREQUENCIES OF ANNUAL HIGH FLOWS AT CONTINUOUS-RECORD STATIONS

Station No.	Station name and Period of record	Annual maximum	Discharge, in cubic feet per second for indicated recurrence intervals, in years					
			2	5	10	25	50	100
01637000	Little Catoctin Creek at Harmony	Peak flow[1/]	506	1,150	1,860	3,230	4,690	6,670
	(Based on period Oct. 1, 1947,	Daily flow	135	204	246			
	to Sept. 30, 1958, except peak	3-day flow	82	118	137			
	flow; water years 1948-76)	7-day flow	55	78	90			
01637500	Catoctin Creek near Middletown	Peak flow	2,190	3,950	5,610	8,460	11,200	14,700
	(Based on period Oct. 1, 1947,	Daily flow[2/]	930	1,660	2,500	3,960	5,840	
	to Sept. 30, 1983)	3-day flow[2/]	650	1,010	1,460	2,230	3,290	
		7-day flow[2/]	442	675	840	1,180	1,570	
01639000	Monocacy River at Bridgeport	Peak flow	7,990	11,200	13,500	16,900	19,600	22,600
	(Based on period Oct. 1, 1942,	Daily flow[2/]	4,620	6,860	8,790	12,300	16,000	
	to Sept. 30, 1983, except peak	3-day flow[2/]	2,470	3,470	4,540	6,410	8,480	
	flow; water years 1933, 1943-83)	7-day flow[2/]	1,520	2,050	2,600	3,490	4,550	
01640500	Owens Creek at Lantz	Peak flow	367	850	1,380	2,380	3,460	4,910
	(Based on period Oct. 1, 1931,	Daily flow	115	210	298	447	589	765
	to Sept. 30, 1983)	3-day flow	71	121	165	235	310	378
		7-day flow	49	76	98	130	156	186
01641000	Hunting Creek at Jimtown[3/]	Peak flow	833	1,380	1,810	2,410	2,900	3,430
	(Based on period Oct. 1, 1949,	Daily flow	276	407	501	628		
	to Sept. 30, 1971, except peak	3-day flow	186	257	298	344		
	flow; water years 1950-83)	7-day flow	129	171	192	213		
01641500	Fishing Creek near Lewistown	Peak flow	128	292	482	865	1,300	1,920
	(Based on period Oct. 1, 1947,	Daily flow[2/]	74	163	242	366	474	
	to Sept. 30, 1983)	3-day flow[2/]	61	117	160	226	290	
		7-day flow	49	74	94	121	143	
01642000	Monocacy River near Frederick	Peak flow	16,800	22,400	26,500	32,100	36,500	41,300
	(Based on period Oct. 1, 1896, to	Daily flow	13,300	16,300	18,000	20,000	21,400	
	Sept. 30, 1930, except peak flow;	3-day flow	8,970	11,400	12,900	14,700	16,000	
	water years 1889, 1897-1930)	7-day flow	5,770	7,520	8,660	10,100	11,200	
01642500	Linganore Creek near Frederick[3/]	Peak flow	2,460	4,130	5,610	8,020	10,300	12,900
	(Based on period Oct. 1, 1934,	Daily flow	1,160	1,690	2,030	2,870		
	to Sept. 30, 1971, except peak	3-day flow	645	825	1,020	1,360		
	flow; water years 1933-82)	7-day flow	408	564	661	851		
01643000	Monocacy River at Jug Bridge near	Peak flow	18,000	27,700	35,300	46,300	55,600	65,900
	Frederick	Daily flow[2/]	13,900	22,500	30,300	43,000	54,000	
	(Based on period Oct. 1, 1929,	3-day flow[2/]	8,570	13,400	18,600	29,500	42,700	
	to Sept. 30, 1983, except peak	7-day flow[2/]	5,410	7,980	10,400	13,600	19,600	
	flow; water years 1889, 1929-83)							
01643500	Bennett Creek at Park Mills	Peak flow	2,230	4,150	6,170	9,980	14,100	19,600
	(Based on period Oct. 1, 1948, to	Daily flow	1,010	1,750	2,410	3,490	4,480	
	Sept. 30, 1958, and Oct. 1, 1966,	3-day flow	546	962	1,350	2,000	2,620	
	to Sept. 30, 1983)	7-day flow	352	577	764	1,050	1,300	

1/ Weighted with synthesized flood-frequency data from rainfall-runoff model (Carpenter, 1983).

2/ Curves adjusted to fit observed flow.

3/ Affected by regulation after 1971.

as the lowest mean daily flow over a period of 7 consecutive days, recurring once every 10 years. Low-flow characteristics at low-flow partial-record stations included in this report are based on 14 to 17 measurements; 3 to 8 measurements were used for sites established for this study.

Data collected at continuous-record gaging stations were fitted to the log-Pearson type III distribution. The resulting curves were adjusted to fit the data (fig. 33). Discharges for periods of 7, 14, 30, 60, and 120 consecutive days and for recurrence intervals of 2, 5, 10, 20, and (where possible) 50 years were determined from the curves and are listed in table 13.

TABLE 12

ESTIMATES OF MAGNITUDES AND FREQUENCIES OF ANNUAL PEAK FLOWS AT PARTIAL-RECORD STATIONS

Station No.	Station name	Discharga, in cubic feet per second, for indicated recurrence intervals, in yeers					
		2	5	10	25	50	100
01636850	Littla Cetoctin Creek naar Brunswick	663	1,200	1,710	2,600	3,460	4,550
01638050	Catoctin Creak et Olive	3,800	6,650	9,230	13,600	17,700	22,800
01638520	Potomac Rivar Tributary et Point of Rocks	260	479	683	1,030	1,370	1,790
01638600	Tuscarore Creek et Tuscarore	1,180	2,160	3,090	4,710	6,310	8,340
01639325	Friends Creek near Emmitsburg	607	1,070	1,480	2,140	2,760	3,520
01639390	Toms Creek naar Kaysville	2,800	4,800	6,550	9,400	12,000	15,300
01640200	Little Pipe Creek at Keymer	3,410	5,930	8,240	12,200	15,900	20,600
01640750	Owens Craek near Rocky Ridge	1,510	2,660	3,670	5,340	6,900	8,840
01641600	Fishing Creek near Utica	828	1,490	2,080	3,050	3,980	5,140
01641810	Monocecy River neer Walkeraville	14,200	20,500	27,200	36,000	43,700	52,600
01641900	Tuscerora Creek neer Frederick	837	1,500	2,110	3,120	4,080	5,290
01642050	Israel Creek near Walkarsville	1,530	2,730	3,850	5,760	7,610	9,940
01643110	Bush Creek at Reels Mill	1,490	2,680	3,790	5,690	7,520	9,850
01643125	Bellenger Creek naer Lime Kiln	1,250	2,260	3,220	4,880	6,520	8,600
01643580	Monocacy River at Dickerson	21,300	31,700	41,700	57,400	71,200	88,600
	Percent error of estimate	40	38	39	42	45	49

Streamflow at partial-record sites may be estimated from regression with data from nearby continuous-record stations. The regression equation is in the form $Y = a(X)^b$, where X is a known discharge at the recording station and Y is the discharge to be estimated at the nonrecording station; a and b are determined using the method of least squares. Certain low-flow characteristics of the partial-record station may thus be estimated from long-term records available for other sites (fig. 34); this statistical relation is only valid for estimating streamflow under base-flow conditions. The 7-day low-flow discharges for recurrence intervals of 2 years ($7Q_2$) and 10 years ($7Q_{10}$) are listed in table 14.

Because fewer measurements were made at the short-term sites established for this study, low-flow figures for these stations are less certain than those for the low-flow partial-record stations previously in operation. Only three measurements were used to correlate the Monocacy River near Walkersville site with the Monocacy River at Jug Bridge near Frederick continuous-record gaging station. In this case, where the short-term site is upstream from the continuous-record site, geologic and other variables governing streamflow overlap the sites and are not independent. Fewer measurements may, therefore, be sufficient to adequately describe the low-flow characteristics of the short-term site.

To augment its public water supply, the city of Frederick withdraws water from Fishing Creek and Tuscarora Creek from points upstream of the flow measurement sites. Flows of these streams were regressed with the natural flows of gaged streams, so the amounts of diverted flow were estimated and added to the measured flows and the totals were used.

A large range of low flow per square mile exists among the subbasins (fig. 35). Highest values of $7Q_{10}$ are found in the southwestern and the southeastern tributaries to the Monocacy, and the lowest values are found in the northern tributaries and in the Catoctin Creek drainage basin. The ratio $7Q_{10}$:$7Q_2$, expressed as a percentage, is proportional to the base-flow recession slope. Table 15 ranks the $7Q_{10}$ per square mile estimated for 25 stations (19 streams) and gives the $7Q_2$ per square mile and the $7Q_{10}$:$7Q_2$ per square mile ratio.

The greatest flow per square mile under low-flow conditions occurred at Bush Creek at Reels Mill (fig. 35). Carpenter (1983) obtained lower values by correlating Bush Creek at Ijamsville (located about 4 mi upstream from the Reels Mill station) with the gage on

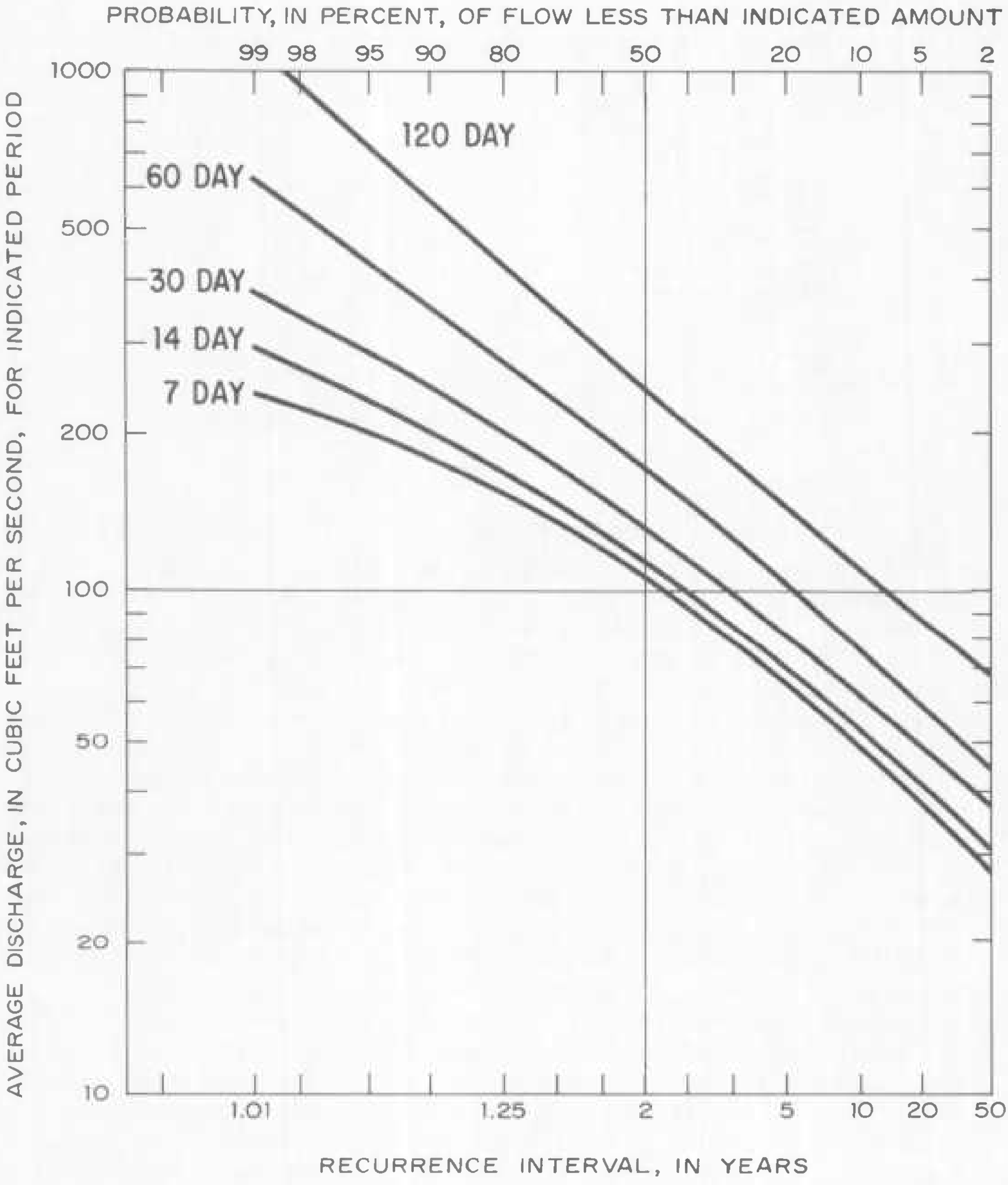

FIGURE 33. Magnitudes and frequencies of annual low flows of the Monocacy River at Jug Bridge near Frederick, 1931-83.

TABLE 13

MAGNITUDES AND FREQUENCIES OF ANNUAL LOW FLOWS AT CONTINUOUS-RECORD STATIONS

Stetion No.	Station name (period of record)	Annual minimum	Discharge, in cubic feet per second, for indicated recurrence intervel, in yeers				
			2	5	10	20	50
01637000	Little Cetoctin Creek et Hermony (Based on period Apr. 1, 1948, to Mar. 31, 1958)	7-dey flow	1.1	0.7	0.5	--	--
		14-day flow	1.2	.8	.6	--	--
		30-dey flow	1.4	.9	.8	--	--
		60-dey flow	1.8	1.2	1.0	--	--
		120-day flow	2.7	1.6	1.2	--	--
01637500	Catoctin Creek neer Middletown (Based on period Apr. 1, 1948, to Mar. 31, 1983)	7-day flow[1]	3.9	1.8	1.0	.5	--
		14-day flow[1]	4.6	2.2	1.3	.7	--
		30-dey flow	6.2	3.0	1.9	1.3	--
		60-dey flow	8.5	4.6	2.8	1.9	--
		120-day flow	14	7.9	5.8	4.5	--
01639000	Monocacy River at Bridgeport (Based on period Apr. 1, 1943, to Mer. 31, 1983)	7-dey flow	4.5	1.5	.7	.3	--
		14-day flow	5.7	2.3	1.2	.7	--
		30-dey flow	7.9	3.9	2.6	1.9	--
		60-day flow	13	6.0	4.3	3.2	--
		120-day flow	26	13	8.7	6.5	--
01640500	Owens Creek at Lantz (Based on period Apr. 1, 1932, to Mar. 31, 1983)	7-day flow	.5	.3	.2	.1	.0
		14-day flow	.7	.3	.2	.1	.1
		30-dey flow	.8	.4	.3	.2	.1
		60-dey flow	1.2	.6	.4	.3	.2
		120-dey flow	1.9	1.0	.7	.6	.4
01641000	Hunting Creek et Jimtown[2] (Based on period Apr. 1, 1950, to Mer. 31, 1971)	7-day flow	1.9	1.4	1.2	1.0	--
		14-day flow	2.1	1.5	1.2	1.1	--
		30-day flow	2.6	1.8	1.5	1.3	--
		60-dey flow	3.2	2.2	1.8	1.5	--
		120-dey flow	4.6	3.0	2.4	2.1	--
01641500	Fishing Creek near Lewistown (Besed on period Apr. 1, 1948, to Mer. 31, 1983)	7-day flow	1.5	1.1	.9	.8	--
		14-day flow	1.6	1.2	1.0	.8	--
		30-day flow	1.8	1.3	1.1	1.0	--
		60-dey flow	2.1	1.5	1.3	1.1	--
		120-dey flow	2.7	1.8	1.5	1.3	--
01642000	Monocacy River neer Frederick (Besed on period Apr. 1, 1897, to Mar. 31, 1930)	7-day flow	86	50	36	27	--
		14-day flow	96	57	43	33	--
		30-day flow	124	79	61	48	--
		60-day flow	173	109	84	68	--
		120-dey flow	272	161	120	93	--
01642500	Linganore Creek neer Frederick[2] (Based on period Apr. 1, 1935, to Mar. 31, 1971)	7-day flow	15	9.3	6.8	5.2	--
		14-day flow	16	10	7.5	5.6	--
		30-day flow	18	12	9.0	7.1	--
		60-day flow	22	14	11	9.2	--
		120-dey flow	29	20	16	14	--
01643000	Monocecy River at Jug Bridge near Frederick (Based on period Apr. 1, 1930, to Mar. 31, 1983)	7-dey flow	106	66	50	39	28
		14-day flow	114	71	53	41	31
		30-dey flow	133	83	63	49	37
		60-day flow	173	102	77	60	45
		120-day flow	247	145	110	88	69
01643500	Bennett Creek et Perk Mills (Based on period Apr 1, 1949, to Mer. 31, 1958 end Apr. 1, 1967, to Mer. 31, 1983)	7-dey flow	12	8.3	6.8	5.8	--
		14-day flow	13	8.9	7.4	6.4	--
		30-dey flow	15	10	8.7	7.6	--
		60-day flow	17	12	11	9.5	--
		120-dey flow	24	17	15	13	--

[1] Curves edjusted to fit observed flow.

[2] Affected by regulation after 1971.

TABLE 14

TWO-YEAR AND 10-YEAR 7-DAY LOW FLOWS

Station No.	Station name	$7Q_2$ (ft^3/s)	$7Q_2$ [(ft^3/s)/mi^2]	$7Q_{10}$ (ft^3/s)	$7Q_{10}$ [(ft^3/s)/mi^2]
01636850	Little Catoctin Creek near Brunswick	0.4	0.04	0.1	0.01
01637000	Little Catoctin Creek at Harmony	1.1	.12	.5	.06
01637500	Catoctin Creek near Middletown	3.9	.06	1.0	.02
01638050	Catoctin Creek at Olive	6.5	.06	1.7	.02
01638500	Potomac River at Point of Rocks	1,340	.14	860	.09
01638520	Potomac River Tributary at Point of Rocks	.01	.003	.00	.000
01638600	Tuscarora Creek at Tuscarora	3.9	.19	2.3	.11
01639000	Monocacy River at Bridgeport	4.5	.03	.7	.004
01639325	Friends Creek near Emmitsburg	.4	.03	.06	.005
01639390	Toms Creek near Keysville	6.3	.07	1.5	.02
01640200	Little Pipe Creek at Keymar	21	.26	7.5	.09
01640500	Owens Creek at Lentz	.5	.08	.2	.03
01640750	Owens Creek near Rocky Ridge	.9	.02	.3	.008
01641000	Hunting Creek at Jimtown[1/]	1.9	.10	1.2	.06
01641500	Fishing Creek near Lewistown	1.5	.21	.9	.12
01641600	Fishing Creek near Utica	1.8	.10	1.0	.06
01641810	Monocacy River near Walkersville	64	.10	26	.04
01641900	Tuscarora Creek near Frederick	2.2	.13	1.1	.07
01642000	Monocacy River near Frederick	86	.13	36	.05
01642050	Israel Creek near Walkersville	3.1	.11	.8	.03
01642500	Linganore Creek near Frederick[2/]	15	.18	6.8	.08
01643000	Monocacy River at Jug Bridge near Frederick	106	.13	50	.06
01643110	Bush Creek at Reels Mill	7.8	.26	5.1	.17
01643125	Ballenger Creek near Lime Kiln	4.8	.24	3.0	.15
01643500	Bennett Creek at Park Mills	13	.21	6.9	.11
01643580	Monocacy River at Dickerson	149	.15	72	.07

1/ Based on period April 1, 1950, to March 31, 1971.

2/ Based on period April 1, 1935, to March 31, 1971.

Linganore Creek near Frederick (which was discontinued before completion of the present study). The streams arising on the Piedmont upland and flowing west across schist, phyllite, and metabasalt generally have high $7Q_2$ discharges and maintain flow at $7Q_{10}$. The $7Q_{10}$ per square mile values tend to be greater in the more southerly subbasins.

The drainage basins of Ballenger Creek at Lime Kiln, Tuscarora Creek at Tuscarora, and Israel Creek near Walkersville include large portions of limestone bedrock. However, low flows of Ballenger Creek and Tuscarora Creek are noticeably greater than those of Israel Creek. This may be an indication of a greater degree of karst development in the area of Israel Creek; base flow intensities are not so much related to the amount of carbonate rock in a basin, but to the development of conduit-like ground-water flow systems which allow rapid drainage and provide lesser amounts of ground-water storage (White, 1977). The streams descending the eastern slope of Catoctin Mountain have increasing discharges per square mile from north to south, corresponding with increasing areal extent of the Weverton Formation. The drainage basin of Fishing Creek above Lewistown lies entirely within the Weverton Formation; this station ranks third in low-flow discharge.

Those basins associated with the Triassic Gettysburg Shale and the New Oxford Formation have the lowest flows per square mile under low-flow conditions and exhibit the largest decline in flow from the 2-year to 10-year recurrence level. Piney Creek near Keysville, in Carroll County, was included in table 15 as it is the only drainage basin studied that is completely underlain by these formations; this basin has the second lowest $7Q_{10}$. Many of these

TABLE 14—*Continued*

Continuous-record gaging station used for regression	Coefficient of determination (r^2)	Number of measurements used	Coefficients for regression equation $Y = a(x)^b$ a	b	Station No.
01637500	0.94	16	0.101	0.951	01636850
--	--	--	--	--	01637000
--	--	--	--	--	01637500
01637500	1.00	7	1.705	.987	01638050
--	--	--	--	--	01638500
01643500	.93	4	3.2×10^{-6}	3.215	01638520
01643500	.93	14	.391	.928	01638600
--	--	--	--	--	01639000
01637500	.98	17	.062	1.307	01639325
01639000	.98	7	1.917	.788	01639390
01639500	.96	6	.772	1.053	01640200
--	--	--	--	--	01640500
01640500	.99	5	2.123	1.234	01640750
--	--	--	--	--	01641000
--	--	--	--	--	01641500
01641500	1.00	8	1.088	1.192	01641600
01643000	.96	3	.256	1.183	01641810
01640500	.98	14	3.542	.709	01641900
--	--	--	--	--	01642000
01639500	.94	17	.041	1.376	01642050
--	--	--	--	--	01642500
--	--	--	--	--	01643000
01643500	.99	6	1.156	.770	01643110
01643500	.96	17	.607	.835	01643125
--	--	--	--	--	01643500
01643000	.99	13	1.580	.976	01643580

streams originate on the eastern slope of Catoctin Mountain or South Mountain in Pennsylvania where they develop substantial flows. However, flows accumulate at a lesser rate per square mile after the streams reach the valley where they encounter the Triassic rocks, as shown by Fishing Creek and Owens Creek (table 16).

Low flows of streams in Middletown Valley appear low compared to some other streams in the county. The northern portion of the valley is underlain by the Catoctin Metabasalt, whereas granodiorite and biotite granite gneiss underlie the southern part. The low-flow characteristics of the streams in these two areas are quite similar, indicating that the hydrologic effects at low-flow conditions are very similar for these formations.

The stations along the Monocacy River also show increasing low flows from north to south. The station farthest upstream, at Bridgeport, has a minimal low-flow discharge per square mile and a $7Q_{10}$:$7Q_2$ ratio of only 15 percent. Conversely, at Dickerson, the most southerly station along the river, low flows per square mile are greater and the $7Q_{10}$:$7Q_2$ ratio is nearly 50 percent. This may be a reflection of low contributions from the Triassic rocks which underlie a greater proportion of the northern part of the drainage basin.

The Potomac River Tributary at Point of Rocks, with a drainage area of 3.04 mi^2, is the smallest of the basins studied. The $7Q_{10}$ is 0 ft^3/s (no flow). The channel of this stream is not deeply entrenched and may be well above the water table during very dry weather (refer to fig. 8 in the section "Sources of Water").

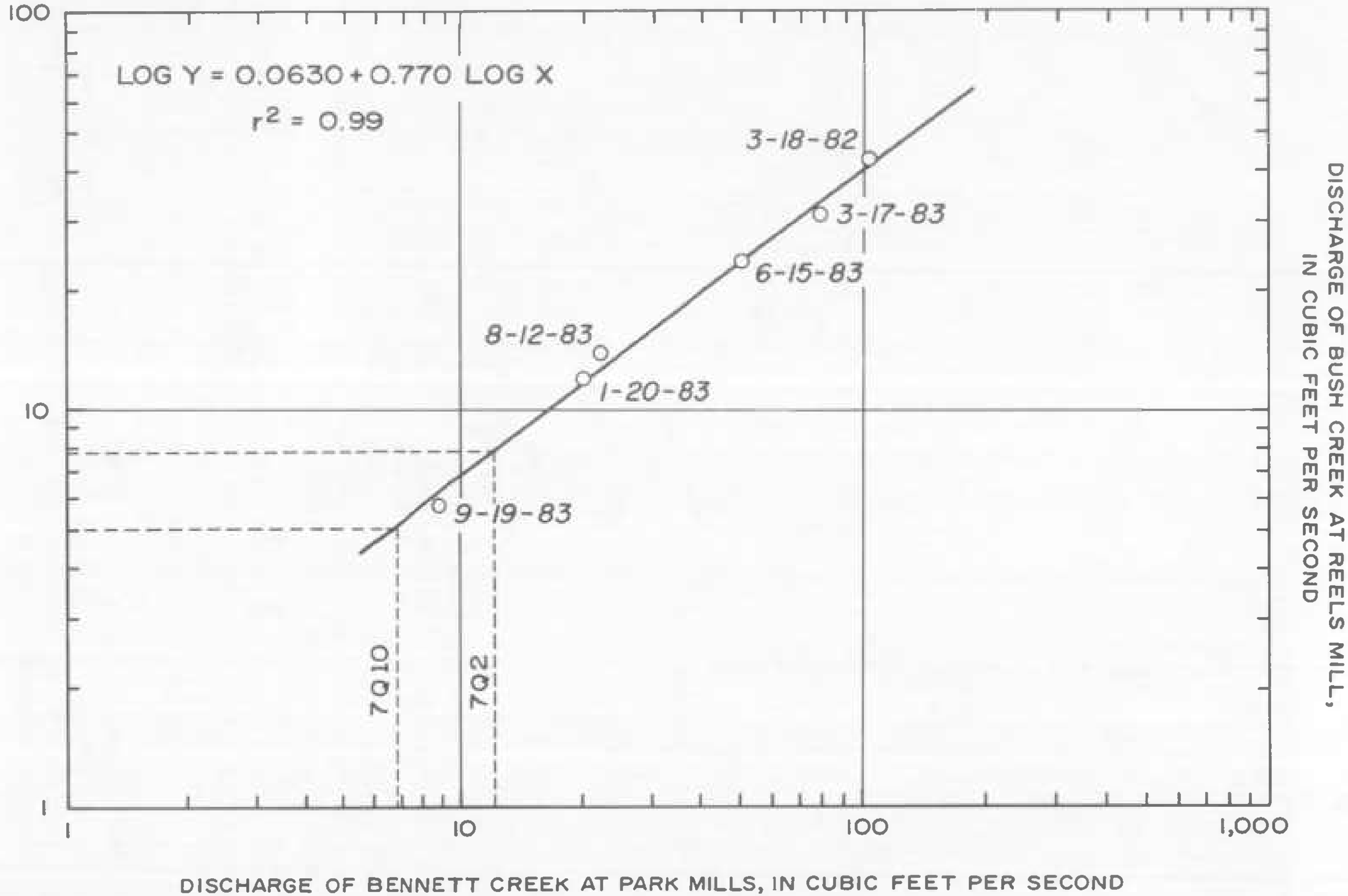

FIGURE 34. Relation of low flow at Bush Creek at Reels Mill and flow at Bennett Creek at Park Mills. Measurement dates are shown.

TABLE 15

RANKING OF STREAMFLOW-MEASUREMENT STATIONS BY 7-DAY, 10-YEAR LOW FLOW

Rank	Station No.	Station name	Discharge, in cubic feet per second per square mile, for a period of 7 consecutive days end for indicated recurrence interval, in years: 10	2	$7Q_{10}$:$7Q_2$ ratio (percent)
1	01643110	Bush Creek at Reels Mill	0.17	0.26	64
2	01643125	Ballenger Creek near Lime Kiln	.15	.24	62
3	01641500	Fishing Creek near Lewistown	.12	.21	60
4	01638600	Tuscarora Creek at Tuscarora	.11	.19	59
5	01643500	Bennett Creek at Park Mills	.11	.21	53
6	01640200	Little Pipe Creek at Keymar	.09	.26	36
7	01642500	Linganore Creek near Frederick[1/]	.08	.18	46
8	01643580	Monocacy River at Dickerson	.07	.15	47
9	01641900	Tuscarora Creek near Frederick	.07	.13	53
10	01641000	Hunting Creek at Jimtown[2/]	.06	.10	61
11	01643000	Monocecy River at Jug Bridge near Frederick	.06	.13	47
12	01637000	Little Catoctin Creek at Harmony	.06	.12	46
13	01641600	Fishing Creek near Utica	.06	.10	55
14	01641810	Monocacy River near Walkersville	.04	.10	41
15	01640500	Owens Creek at Lantz	.03	.08	40
16	01642050	Israel Creek near Walkersville	.03	.11	26
17	01639390	Toms Creek near Keysville	.02	.07	23
18	01637500	Catoctin Creek near Middletown	.02	.06	26
19	01638050	Catoctin Creek at Olive	.02	.06	26
20	01636850	Little Catoctin Creek near Brunswick	.01	.04	28
21	01640750	Owens Creek near Rocky Ridge	.008	.02	35
22	01639325	Friends Creek near Emmitsburg	.005	.03	17
23	01639000	Monocacy River at Bridgeport	.004	.03	15
24	01639150	Piney Creek near Keysville	.001	.01	10
25	01638520	Potomac River Tributary at Point of Rocks	.000	.003	--

1/ Period of record, Nov. 1931 to Mar. 1932, and Sept. 1934 to Sept. 1971

2/ Period of record, Oct. 1949 to Sept. 1971

TABLE 16

LOW FLOWS OF HEADWATER AREAS AND DOWNSTREAM AREAS, OWENS CREEK AND FISHING CREEK

	Miles upstream from mouth	$7Q_2$ (ft^3/s)	$7Q_2$ [(ft^3/s)/mi^2]	$7Q_{10}$ (ft^3/s)	$7Q_{10}$ [(ft^3/s)/mi^2]
Owens Creek at Lantz	14.2	0.5	0.08	0.2	0.03
Owens Creek near Rocky Ridge	.7	.9	.02	.3	.008
Fishing Creek near Lewistown	9.9	1.5	.21	.9	.12
Fishing Creek near Utica	1.3	1.8	.10	1.0	.06

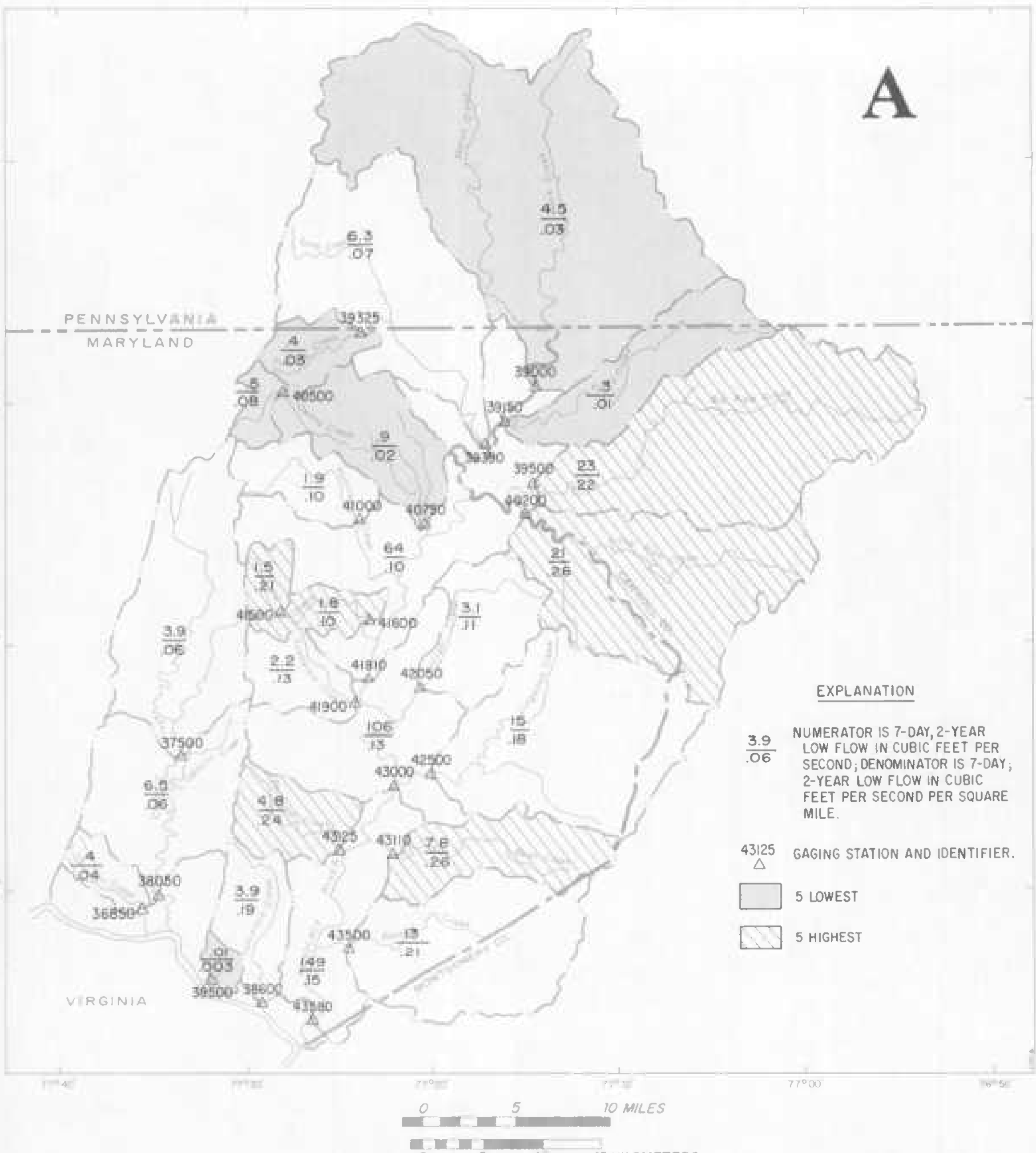

FIGURE 35. Areal distribution of low flows. A) 7-day, 2-year low flow; B) 7-day, 10-year low flow.

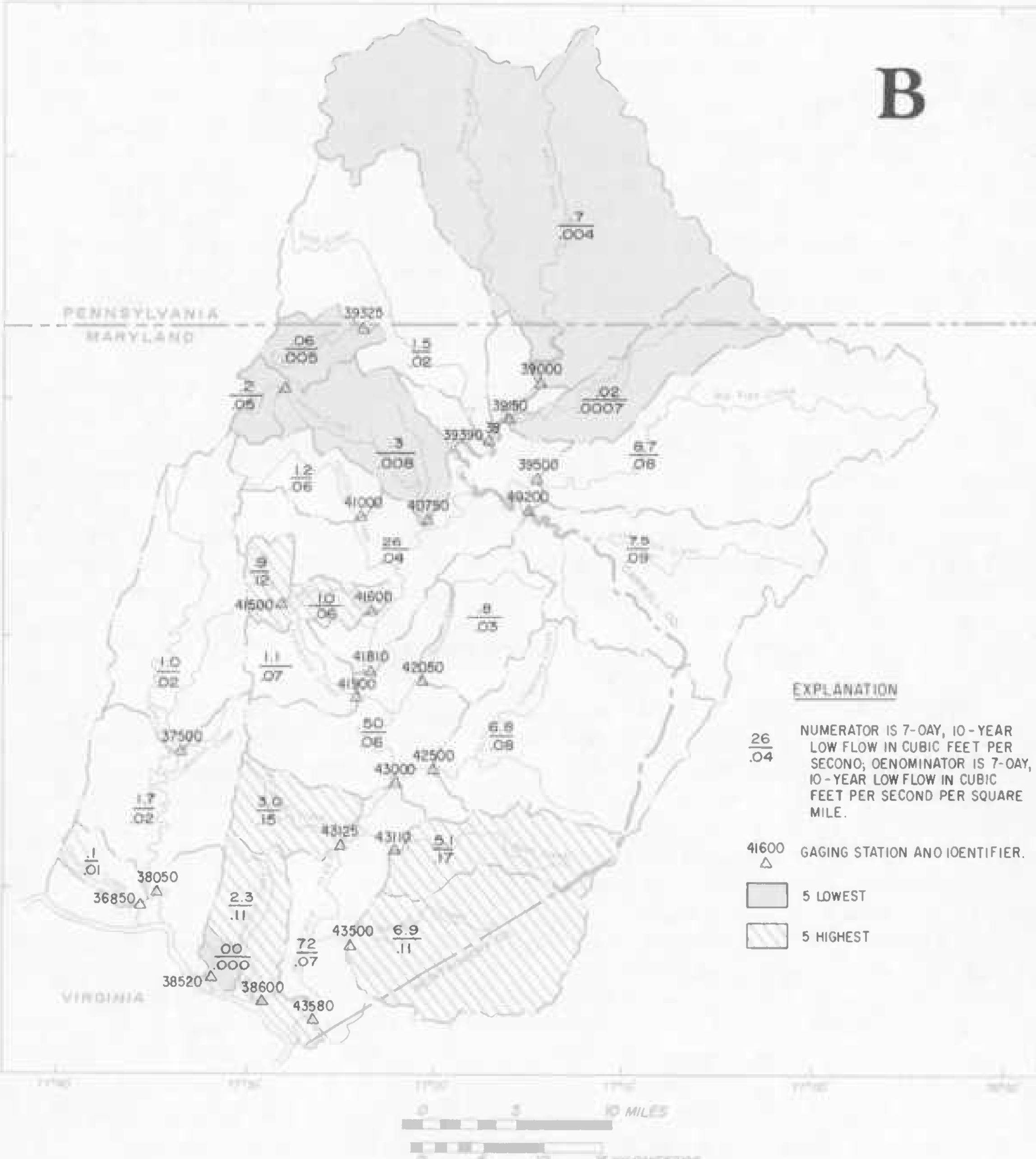

FIGURE 35. *Continued.*

SURFACE-WATER QUALITY

Basic surface-water-quality data collected from 27 sites in Frederick County are presented by Dine and others (1985). Analyses reported include field measurements of pH, specific conductance, temperature, and dissolved oxygen; dissolved species (common ions and trace elements); total recoverable quantities; concentrations of trace elements and pesticides in stream-bottom materials; and suspended sediments (total amounts and grain-size distributions). Most samples collected for this study were obtained during low flows, although some samples, obtained for other studies, were acquired at higher flows. Likewise, not all sites could be extensively and frequently sampled for analyses of trace elements and pesticides. As a means of reconnaissance for these constituents, stream-bottom materials were sampled and analyzed for either trace elements or pesticides, both of which have a tendency to be adsorbed on sediments. Furthermore, the sediments are not flushed through the basin as rapidly as the water is, so a record of previous inputs is provided by the sediments.

The factors influencing surface-water quality are considerably more variable than those affecting ground-water quality. To begin with, a variable portion of total streamflow is generally composed of ground water; hence, the factors affecting ground-water quality discussed above apply. The ground-water (base-flow) contribution to total streamflow depends on coincident and antecedent weather conditions. The higher the portion of ground water, the more stream quality resembles that of the adjacent aquifers, and chemical quality of very low-flow stream samples may be indicative of the prevailing ground-water quality (fig. 36; cf. fig. 27). Once this water is exposed to the atmosphere, it is in thermodynamic disequilibrium and chemical reactions take place as it adjusts not only to atmospheric gases, but also to elements introduced into the stream channel by erosion, wet and dry precipitation, and biologic (including human) activity.

Stream-bottom sediments and suspended and colloidal materials modify stream-water quality through the processes of chemical reaction, adsorption, chelation, and cation exchange. Substances such as trace metals or pesticide residues may be present in the water column in minute or undetectable quantities, and yet be found in greater concentrations associated with particulate material. Concentrations of these substances in bottom materials are related to particle size and mineralogy and chemical composition of the sediments, and to the substance's affinity for the sediment particles.

Human activities that can have significant impacts on surface-water quality include accidental spills, agricultural pesticide runoff, erosion due to negligent construction practices, highway salting, and improper disposal of wastes. Federal and State regulations attempt to reduce the impact of these occurrences, but regulations cannot eliminate them altogether. Population growth with concomitant urbanization commonly leads to impairment of surface waters, becoming severe when 30 to 70 percent of the watershed is covered by impervious surfaces (Klein, 1979, p. 958). Such problems are not widespread in Frederick County, but the potential for their occurrence exists. Katz and others (1985), in a geochemical study of two small watersheds in the county, ascribed springtime concentrations of sodium and chloride to heavy use of road-deicing salt, and excess sulfate to dry deposition (from a source outside of the drainage basins, which could be fossil-fuel-burning power-generation plants).

Specific electrical conductance of stream water is related to dissolved mineral content. Figure 37 shows this relation for the Monocacy River at Bridgeport based on analyses of samples collected over the period 1969–83. Specific conductance also fluctuated seasonally (fig. 38), corresponding to fluctuations in discharge (fig. 39).

The water-quality diagram of figure 36 is based on content of dissolved major inorganic ions. Other constituents are also important, even though they may occur in much smaller

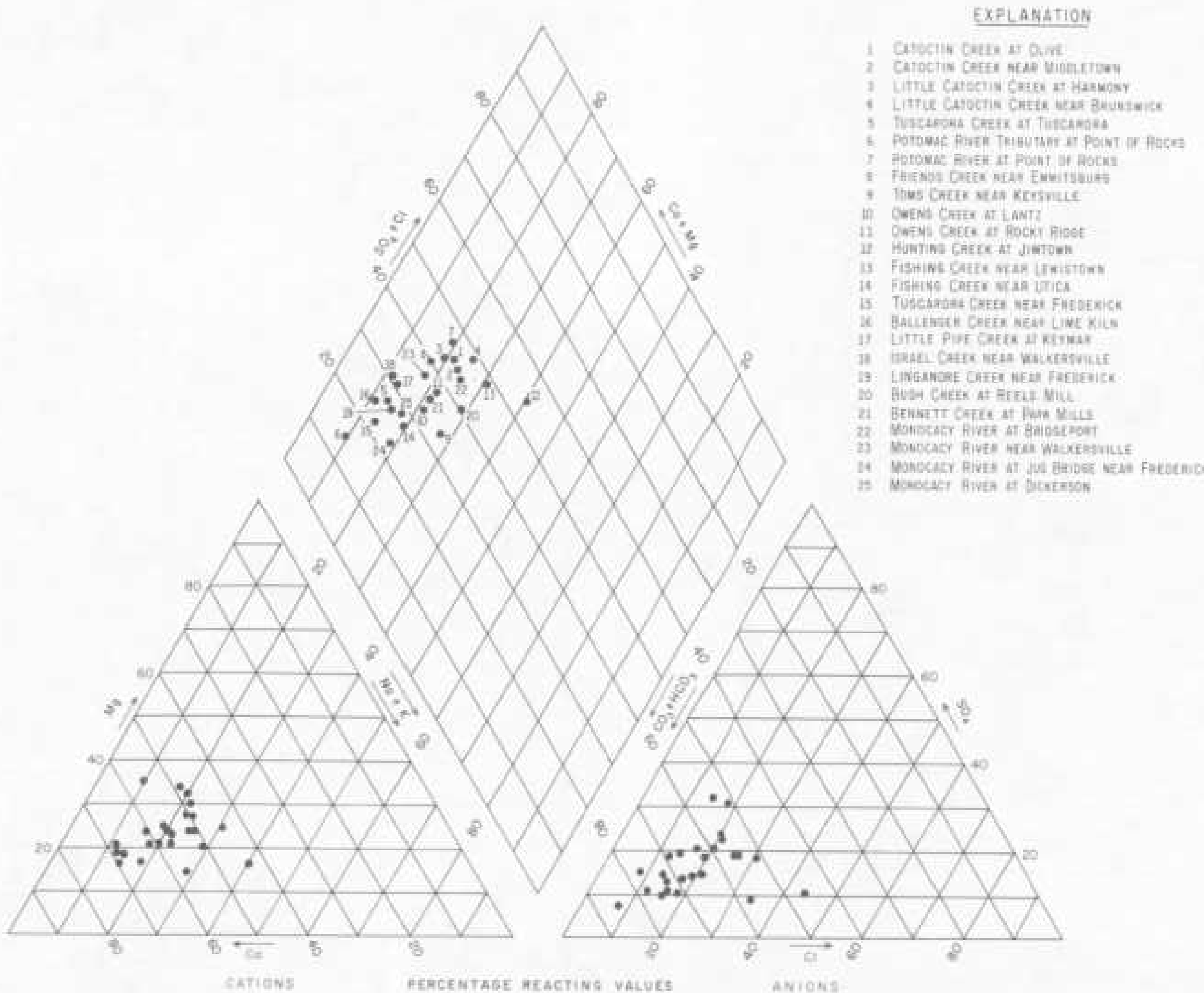

FIGURE 36. Percentages of major ions in stream samples. Where multiple samples for a site were analyzed, average values were used.

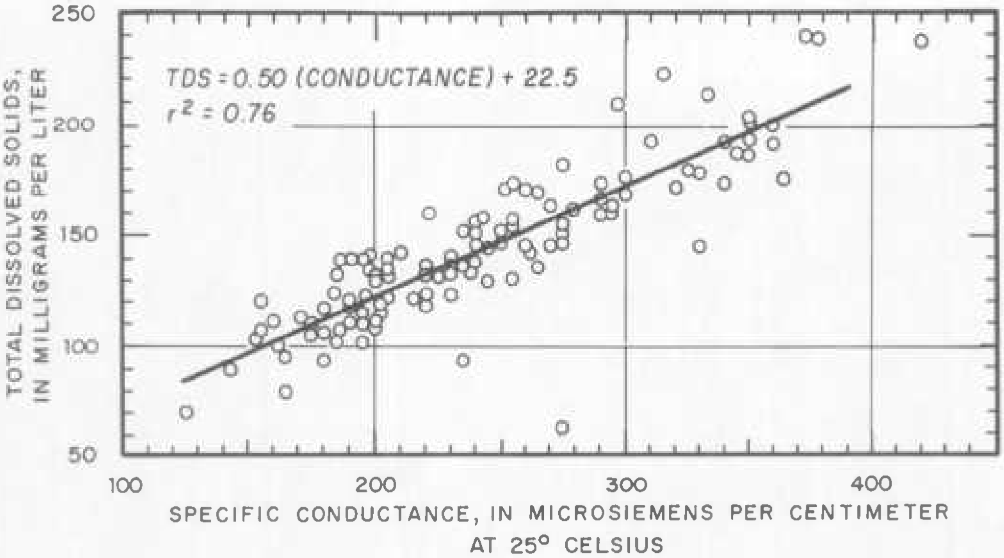

FIGURE 37. Relation of total dissolved solids (sum of analyzed ions) and specific conductance, Monocacy River at Bridgeport, 1968–75.

quantities. Nitrogen and, especially, phosphorus are commonly limiting factors in ecosystems. Additions of large quantities of these nutrients via fertilizer runoff or incompletely treated waste-water discharges can cause rapid increases in aquatic biomass, leading to eutrophication of water bodies. Average concentrations of total nitrogen and phosphorus for 24 stations are listed in table 17. Seasonal variations in nutrient concentrations (fig. 40) may be partly due to seasonal applications of fertilizer.

Samples from some of the stream stations were analyzed for trace metals (Dine and others, 1985). Dissolved forms were analyzed for five stations; dissolved plus suspended, or total recoverable, forms were determined for seven stations. The Monocacy River was sampled for trace metals numerous times beginning in 1969 at Reich's Ford Bridge near Frederick, and 1974 at Walkersville, continuing through 1979 (table 18). Analyses of stream-bottom materials provide a somewhat better indication of the presence or absence of trace metals at the 13 stations sampled for this form, although trace-element loads still cannot be calculated with confidence from the data. Iron, manganese, chromium, and zinc were detected in the bottom materials at all 13 stations; lead was found at 12 of the stations. Arsenic, cobalt, copper, and nickel were detected in bottom materials from the Potomac River at Point of Rocks and from the Monocacy River at Dickerson. Mercury was measured in material from the Potomac River at Point of Rocks. Cadmium was not detected in bottom materials from any of the stations.

Characterization of trace-metal distribution in the hydrologic environment of Frederick County requires additional and more detailed data. Sources of the constituents are diverse; factors affecting their distribution, such as land use, must be known in some detail in order to derive meaningful interpretations and models. Recognition of the major transport mechanisms is necessary to evaluate occurrences of trace metals; sediments moving along a stream bottom and in suspension carry much greater concentrations than what is carried in solution (Horowitz, 1984).

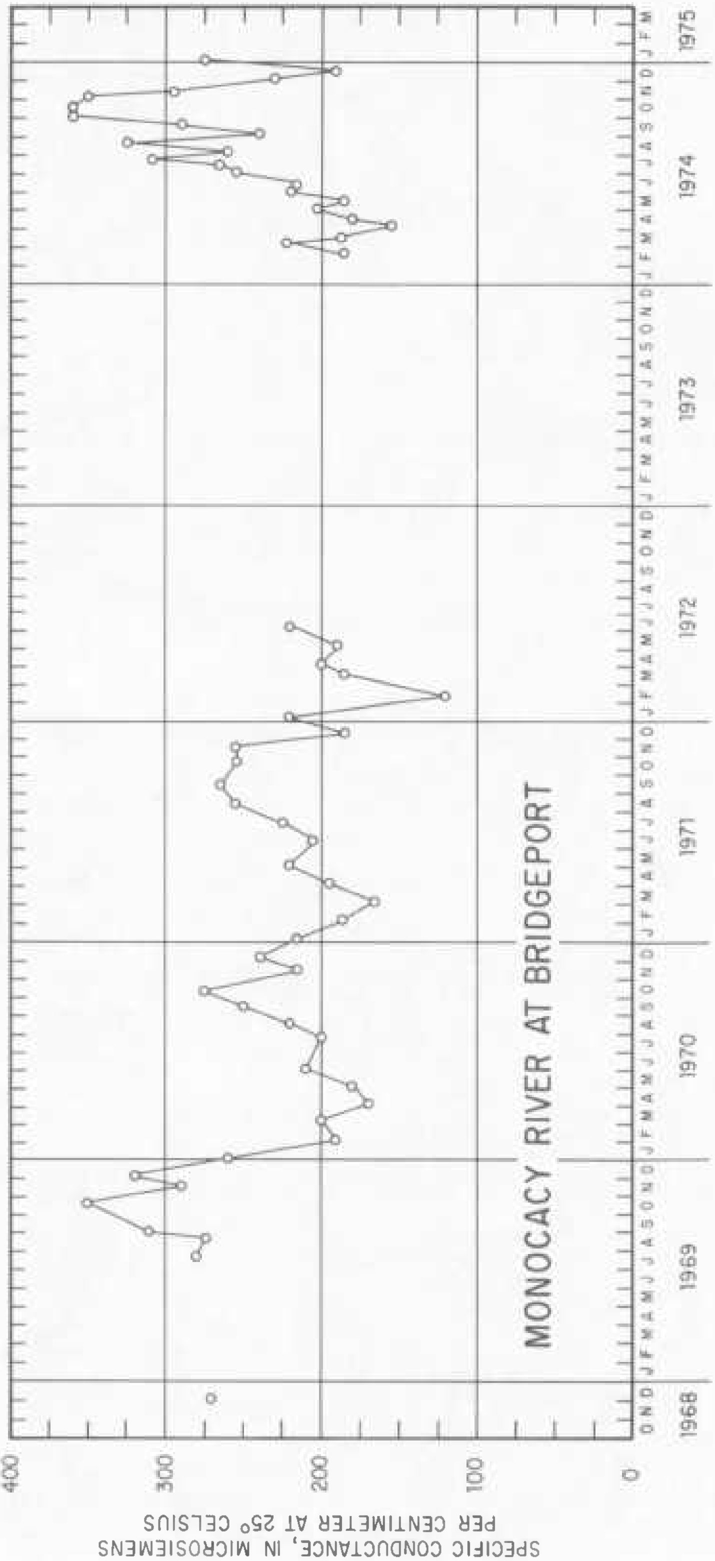

FIGURE 38. Specific conductance, Monocacy River at Bridgeport, 1968–75.

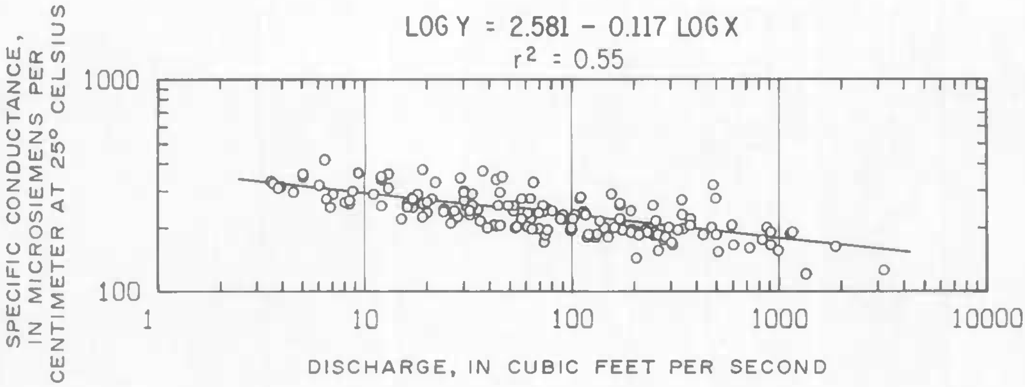

FIGURE 39. Relation of specific conductance and discharge, Monocacy River at Bridgeport, 1968-75.

TABLE 17
MEAN TOTAL NITROGEN AND PHOSPHORUS CONCENTRATIONS
IN FREDERICK COUNTY STREAMS

[All values in milligrams per liter; numbers in parentheses are numbers of samples.]

Station No.	Station name	Nitrogen	Phosphorus
01636850	Little Catoctin Creek near Brunswick	3.45 (2)	0.095 (4)
01637500	Little Catoctin Creek at Harmony	1.4 (1)	.160 (4)
01638050	Catoctin Creek at Olive	2.6 (2)	.095 (4)
01638500	Potomac River at Point of Rocks	.73 (1)	.094 (61)
01638520	Potomac River Tributary at Point of Rocks	4.35 (2)	.063 (3)
01638600	Tuscarora Creek at Tuscarora	6.1 (2)	.060 (4)
01639000	Monocacy River at Bridgeport	1.78 (122)	.221 (129)
01639325	Friends Creek near Emmitsburg	1.47 (3)	.023 (4)
01639390	Toms Creek near Keysville	1.57 (3)	.089 (4)
01640200	Little Pipe Creek at Keymar	4.87 (3)	.223 (4)
01640500	Owens Creek at Lantz	1.95 (2)	.021 (4)
01640750	Owens Creek near Rocky Ridge	1.57 (3)	.033 (4)
01641000	Hunting Creek at Jimtown	1.4 (1)	.290 (4)
01641500	Fishing Creek near Lewistown	1.1 (1)	.010 (4)
01641600	Fishing Creek near Utica	1.13 (3)	.050 (4)
01641810	Monocacy River near Walkersville	2.45 (120)	.146 (124)
01641900	Tuscarora Creek near Frederick	4.20 (3)	.090 (4)
01642050	Israel Creek near Walkersville	3.40 (2)	.053 (4)
01642500	Linganore Creek near Frederick	3.7 (1)	.068 (4)
01643020	Monocacy River at Reich's Ford Bridge near Frederick	2.89 (121)	.258 (140)
01643110	Bush Creek at Reels Mill	2.00 (2)	.040 (4)
01643125	Ballenger Creek near Lime Kiln	4.85 (2)	.040 (3)
01643500	Bennett Creek at Park Mills	2.6 (1)	.030 (7)
01643580	Monocacy River at Dickerson	2.85 (2)	.170 (3)

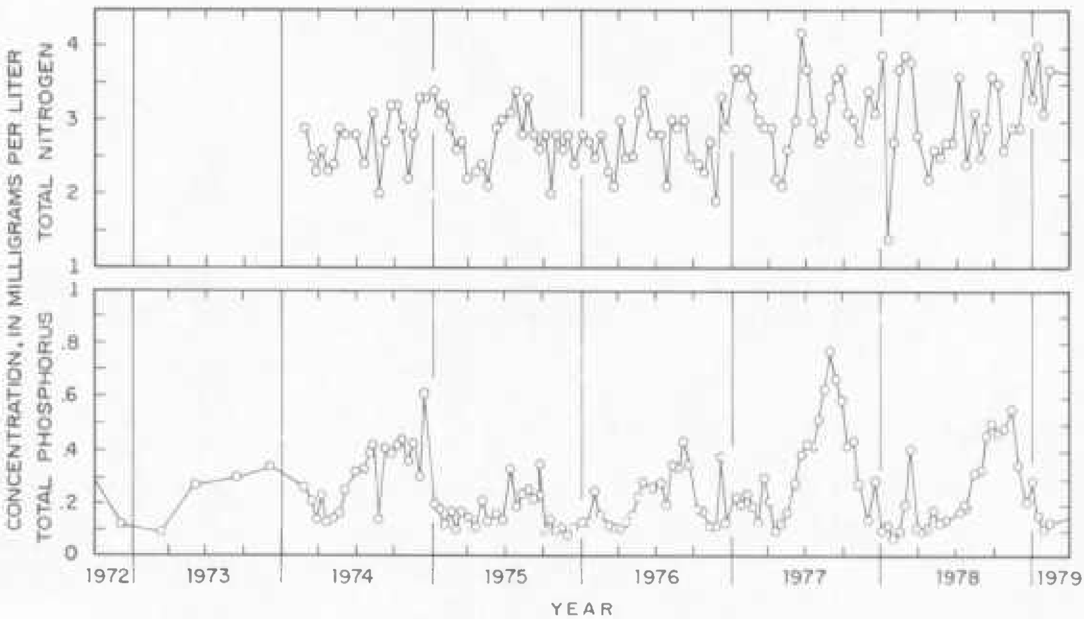

FIGURE 40. Seasonal variations in nutrient concentrations, Monocacy River at Reich's Ford Bridge near Frederick, 1972–79.

Bottom materials from 12 stations were analyzed for three types of pesticides (Dine and others, 1985, p. 195): chlorphenoxy acid herbicides; organochlorine insecticides and metabolites (including polychlorinated biphenols, or PCBs, and polychlorinated napthalene, or PCN); and organophosphorus insecticides. Of the 27 constituents that were analyzed, only the organochlorine insecticides DDT, DDD, DDE, and dieldrin were detected, and none of these exceeded 2 μg/kg (parts per billion) (fig. 41). The presence of small quantities of organochlorine insecticides is not surprising as they were in common use, applied against a broad spectrum of insect pests. Although applied in quantities that were sublethal to small fish and mammals, these compounds can persist in the environment for decades. Most of these compounds have been prohibited by Federal regulations, and, although data from Frederick County have not been collected over a sufficiently long period to reflect it, levels of these compounds in the environment generally have been declining. Geologic factors are probably of little importance in the observed areal distribution of detected substances.

Dine and others (1985, table 13) report suspended-sediment data for five stations in Frederick County. Excessive amounts of sediment carried by streams is undesirable because (1) resulting deleterious effects on aquatic biota and stream hydrology, (2) many water uses cannot tolerate high concentrations of sediment, and (3) the sediments provide a major transport mechanism for heavy metals, pesticides, and other contaminants. Agricultural areas and areas undergoing construction generally allow the greatest rates of sediment production; however, erosion-control measures developed over the past few years can help reduce sediment production. Suspended sediment in the Monocacy River at Reich's Ford Bridge near Frederick varied over more than two orders of magnitude during the period 1965–84 (fig. 42). Much of this variation correlates with discharge (fig. 43). The suspended-

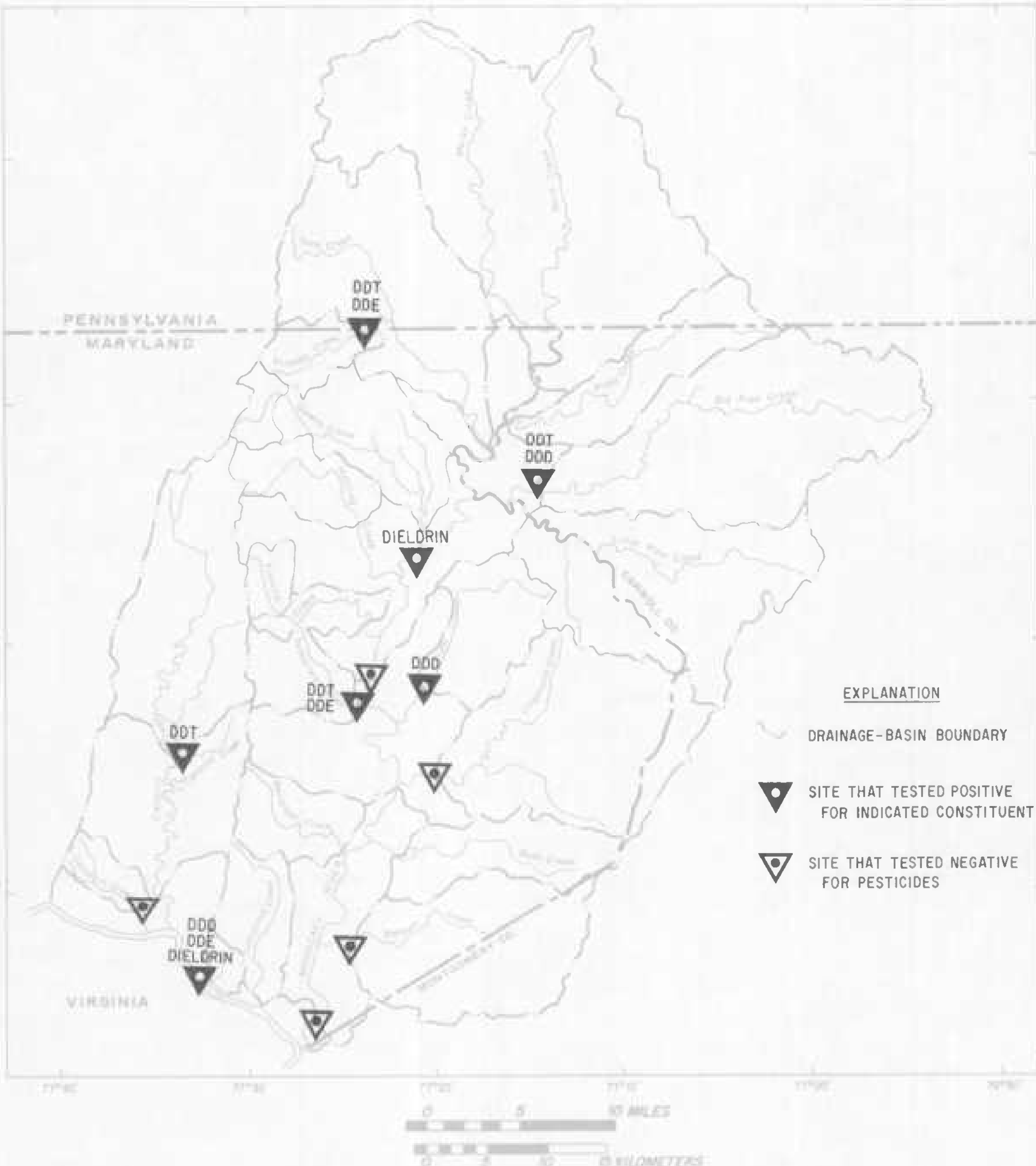

FIGURE 41. Sites where bottom materials were analyzed for pesticides.

TABLE 18

TRACE METALS IN THE MONOCACY RIVER AT WALKERSVILLE AND AT REICH'S FORD BRIDGE NEAR FREDERICK

[All analyses in micrograms per liter; ND, not detected.]

Trace metal	0161810 Walkersville 1974-1979					01643020 Reich's Ford Bridge near Frederick 1969-1979				
	Minimum	Maximum	Median	Mean	Number	Minimum	Maximum	Median	Mean	Number
Aluminum, total recoverable	10	7000	260	603	120	20	10000	280	695.4	123
Aluminum, dissolved	10	40	35	30	4	<100	100	--	--	11
Arsenic, total recoverable	0	3	1	1.2	110	<1	4	1	1.3	111
Cadmium, total recoverable	0	9	0	.9	120	0	5	0	.9	123
Cadmium, dissolved	--	--	--	--	--	0	1	0	.4	7
Chromium, total recoverable	0	40	20	16.8	120	0	30	20	15.4	127
Chromium, dissolved	--	--	--	--	--	ND	ND	--	--	2
Copper, total recoverable	0	60	4	7.5	120	0	30	4	6.5	123
Copper, dissolved	--	--	--	--	--	ND	19	--	--	7
Lead, total recoverable	0	35	6	8.4	120	0	48	7	10.2	123
Lead, dissolved	--	--	--	--	--	ND	12	--	--	7
Silver, total recoverable	0	3	0	.4	120	0	5	0	.5	121
Zinc, total recoverable	0	170	20	23.8	116	0	300	20	24.1	119
Zinc, dissolved	0	20	10	10.0	4	0	140	20	34.5	11

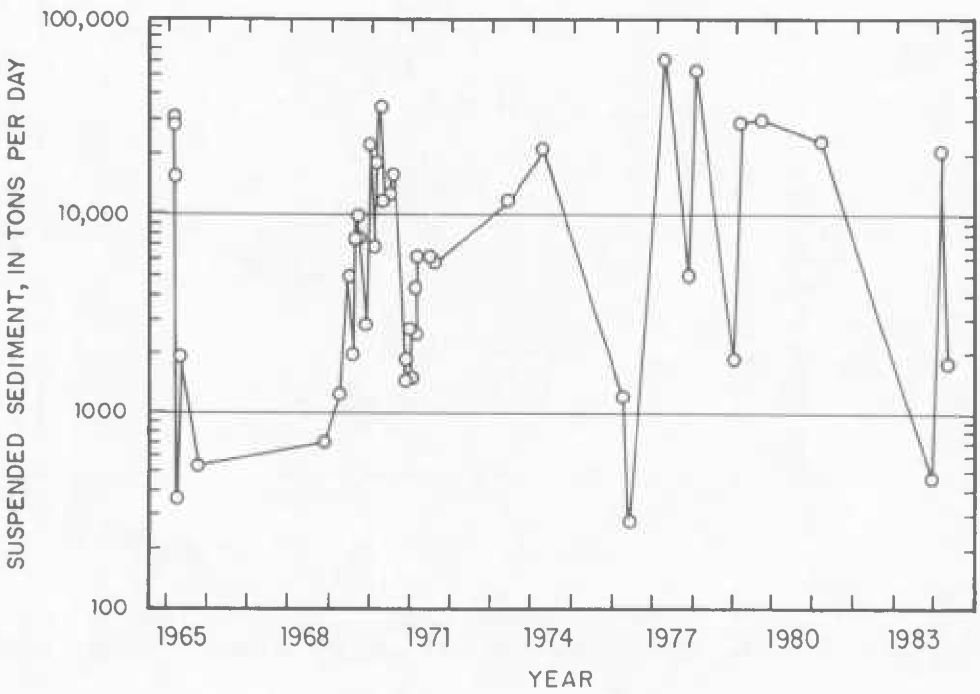

FIGURE 42. Variations in suspended-sediment loads, Monocacy River at Reich's Ford Bridge near Frederick, 1965–84.

sediment load of the Monocacy River at Reich's Ford Bridge is log-normally distributed (fig. 44), based on the 44 samples collected during the period 1965–84. The median load is about 5,500 tons/d.

The grain-size distribution of suspended sediment affects the sediment's efficacy as a contaminant transport vehicle. Finer particles provide greater surface area and may be more electrostatically active. Grain-size distributions are shown in figure 45 for samples obtained from Hunting Creek near Jimtown and Linganore Creek near Frederick, and for average values for the Monocacy River at Reich's Ford Bridge.

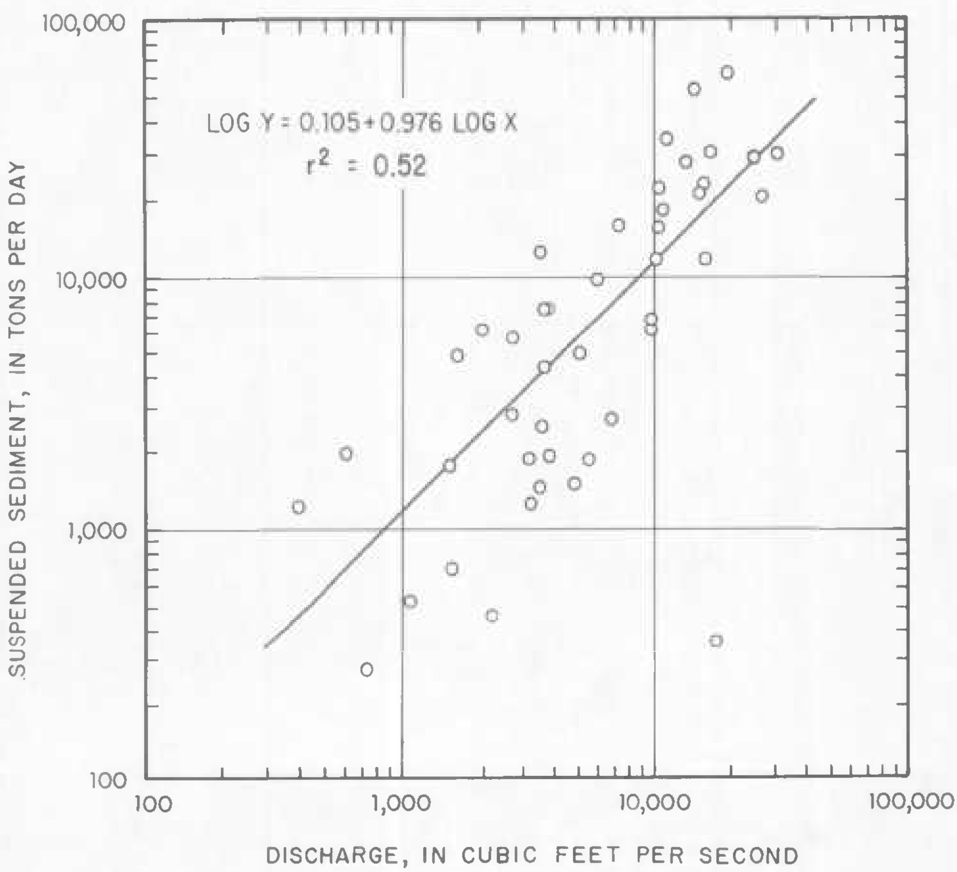

FIGURE 43. Relation of suspended sediment and discharge, Monocacy River at Reich's Ford Bridge near Frederick.

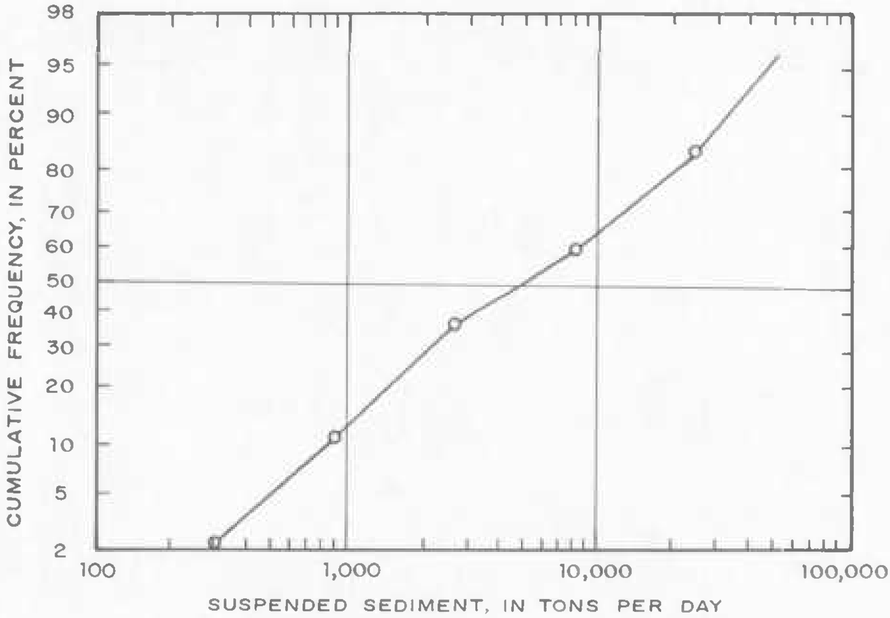

FIGURE 44. Cumulative frequencies of suspended sediment measured in the Monocacy River at Reich's Ford Bridge near Frederick. Forty-four samples were collected during 1982–84.

HYDROLOGIC BUDGETS AND WATER AVAILABILITY

HYDROLOGIC BUDGETS OF BASINS HAVING LONG-TERM RECORDS

The hydrologic cycle may be considered as a budget. Precipitation (P) is balanced by runoff (R_S, R_G), evapotranspiration (ET), and changes in storage (ΔS):

$$P = R_S + R_G + ET + \Delta S.$$

Precipitation data were obtained for stations at Catoctin Mountain National Park, Unionville, Gettysburg, Pa., and Frederick for the period 1971–80 (U.S. National Oceanographic and Atmospheric Administration, 1971–80). The precipitation values for this period are somewhat higher than the normals cited in the Introduction; the budget would have to be adjusted for evaluation of periods of lower precipitation. Mean annual values from the closest precipitation station were used; the accuracy of other factors considered in the budget evaluations did not justify application of sophisticated weighting techniques to precipitation data.

Total runoff (R) is simply the total streamflow passing the outlet of the basin; it consists of a surface-runoff component (R_S) and a subsurface component (R_G). Continuous records of streamflow are needed to determine R and to provide hydrographs for separating R_S and R_G; these were available for eight gaging stations in Frederick County (plus Big Pipe Creek in Carroll County) covering the period 1971–80. The hydrographs were separated using the method described by Kunkle (1962). Small quantities of ground water may depart basins as

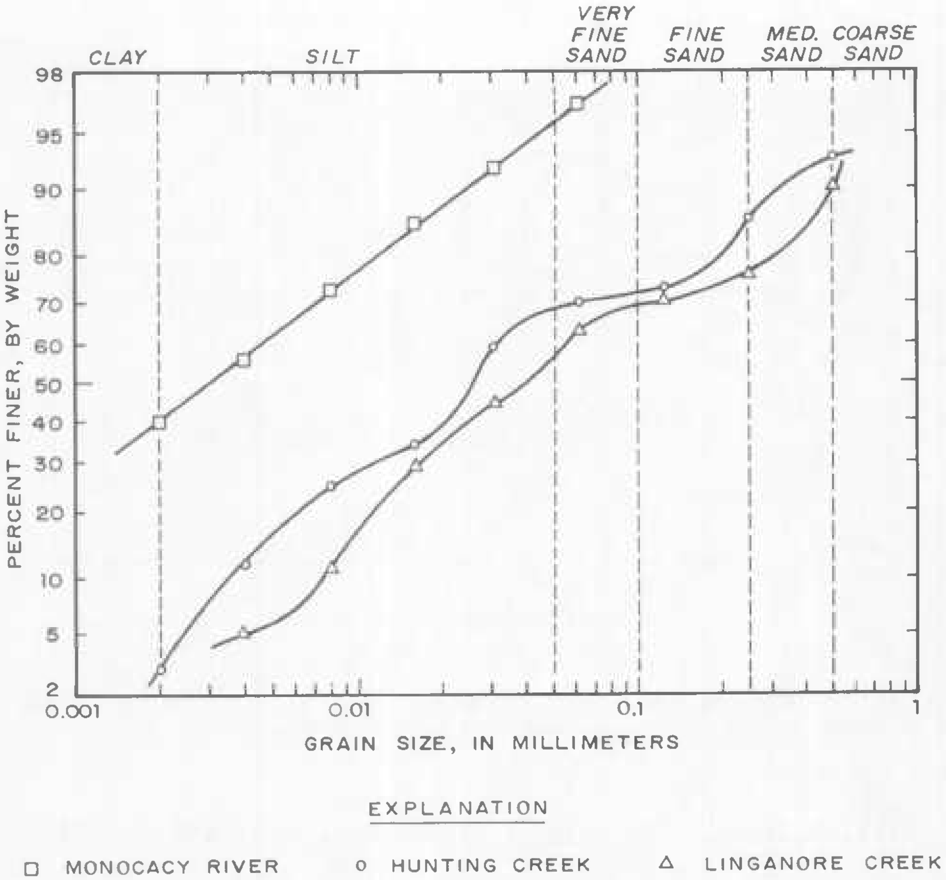

FIGURE 45. Grain-size distributions of suspended sediment in Hunting Creek at Jimtown, Linganore Creek near Frederick, and the Monocacy River at Reich's Ford Bridge near Frederick.

underflow in the vicinity of the basin outlets owing to a hydrologic-gradient component that is parallel to the stream; these quantities are considered negligible due to the low gradients, narrow widths where underflow occurs, and low transmissivities.

Evapotranspiration may be estimated using a variety of methods, but, if long-term, average conditions are being investigated, change in storage may be considered negligible and evapotranspiration estimated as the residual term in the equation.

The storage factor (ΔS) includes ground-water storage; water stored in stream channels, reservoirs, and at land surface; and soil moisture. In some situations, such as investigations of short-term conditions or seasonal variations, change in ground-water storage may be significant, either positive (gain) or negative (loss). For longer term considerations, the positive and negative changes in storage generally cancel out.

The factors of the budget may be expressed in terms of inches over the basin to allow basin-to-basin comparisons of hydrologic processes, in percent of precipitation to show relative importance of each factor, and in billions of gallons per year to use with water-use figures. Hydrologic budgets for eight of the basins in Frederick County are given in table 19.

TABLE 19

HYDROLOGIC BUDGETS OF BASINS THAT HAVE LONG-TERM, CONTINUOUS RECORDS

[All data from water years 1971-80, except Linganore Creek (1969-71) and Hunting Creek (1971-72).]

Basin	Precip-itation station	$P^{1/}$ =	R_S +	R_G +	ET +	ΔS
Catoctin Creek near Middletown	CMP	52	10	10	32	0
		100	19	19	62	0
		61	12	12	37	0
Bennett Creek at Park Mills	UNV	45	9	10	26	0
		100	20	22	58	0
		49	9	11	29	0
Monocacy River at Bridgeport	GET	45	15	5	25	0
		100	33	11	56	0
		136	44	16	76	0
Linganore Creek near Frederick	UNV	40	6	6	28	0
		100	15	15	70	0
		57	9	8	40	0
Monocacy River at Jug Bridge near Frederick	F3E	46	13	8	25	0
		100	29	17	54	0
		650	187	112	351	0
Fishing Creek near Lewistown	CMP	52	14	15	23	0
		100	27	28	45	0
		6.6	1.8	1.9	2.9	0
Owens Creek at Lantz	CMP	52	13	16	23	0
		100	25	30	45	0
		5.4	1.4	1.6	2.4	0
Hunting Creek at Jimtown	CMP	53	12	16	25	0
		100	22	30	48	0
		17	4	5	8	0

CMP: Catoctin Mountain Park
UNV: Unionville
GET: Gettysburg
F3E: Frederick 3E

1/ Upper row of figures for each basin show units in inches;
middle row of figures for each basin show units in percent of precipitation;
lower row of figures for each basin show units in billions of gallons per year.

HYDROLOGIC BUDGETS OF BASINS HAVING PARTIAL RECORDS

Rough estimates of hydrologic budgets may be made for the partial-record basins through comparison with one of the stations for which a long-term, continuous record is available and assuming that the budget components of both basins represent similar proportions of precipitation (table 20). Such estimates assume similar hydrologic behavior, but this can be affected by geologic and topographic differences between basins; a basin should be selected for comparison on the basis of similar geology, topography, size, drainage density, and other such characteristics. Expressed in inches, the budgets will be the same as for the basins used for comparisons for equal amounts of precipitation; the quantities of water will be a function of the drainage areas of the basins.

TABLE 20

HYDROLOGIC BUDGETS OF BASINS THAT HAVE PARTIAL RECORDS

[All values in billions of gallons per year. All data from water years 1971-80.]

Basin used for correlation	Basin	Precipitation station	P	= R_S	+ R_G	+ ET	+ ΔS
Catoctin Creek at Middletown	Little Catoctin Creek near Brunswick	F3E	6.9	1.3	1.3	4.3	0
	Friends Creek neer Emmitsburg	EMG	10.6	2.0	2.0	6.6	0
	Cetoctin Creek et Olive	CMP	102	19	19	64	0
Monocacy River at Bridgeport	Toms Creek near Keysville	EMG	76	25	8	43	0
Owens Creek at Lantz	Owens Creek near Rocky Ridge	EC	34	9	10	15	0
Monocecy River at Jug Bridge near Frederick	Potomac River Tributary et Point of Rocks	F3E	2.4	0.7	0.4	1.3	0
	Tuscarora Creek at Tuscarora	F3E	16.3	4.7	2.8	8.8	0
	Monocacy River near Walkersville	AVG	530	154	90	286	0
	Ballenger Creek near Lime Kiln	F3E	16.1	4.6	2.8	8.7	0
	Monocacy River at Dickerson	AVG	805	233	137	435	0
Bennett Creek at Park Mills	Little Pipe Creek at Keymar	UNV	63	13	14	36	0
	Bush Creek at Reels Mill	UNV	23	5	5	13	0

F3E: Frederick 3E
EMG: Emmitsburg 2SE
CMP: Catoctin Mountain Park
UNV: Unionville
AVG: Average of ell of the above
EC: Average of EMG and CMP.

HYDROLOGIC BUDGET FOR FREDERICK COUNTY

The hydrologic budget for Frederick County as a whole must include a term, I, for water imported into the county, because the county's boundaries do not entirely coincide with hydrologic boundaries. The imported water consists of streamflow plus underflow into the county. For basins lying partly within Frederick County, the imported streamflow is assumed to be proportional to the area lying outside. Underflow was estimated using Darcy's law and the water-level contours of plate 2; less than 1 billion gallons per year enters the county. Underflow leaving the county, U, may be estimated in a similar fashion; the quantity is negligible. The hydrologic budget for the county then, in inches and in billions of gallons per annum (BGA), may be estimated as

$$P + I = R_S + R_G + U + ET + \Delta S$$

$$48 \text{ in.} + 13 \text{ in.} = 25 \text{ in.} + 11 \text{ in.} + 0 \text{ in.} + 25 \text{ in.} + 0 \text{ in.}$$

or

$$555 \text{ BGA} + 153 \text{ BGA} = 288 \text{ BGA} + 131 \text{ BGA} + 0 \text{ BGA} + 289 \text{ BGA} + 0 \text{ BGA}.$$

This budget does not include water flowing in the Potomac River, which drains several thousand square miles before flowing along the southwestern edge of the county. It also does not include relatively small amounts of water that originate within the county but drain to the Potomac River by way of numerous small, ungaged tributaries.

WATER USE AND WATER AVAILABILITY

Water use in Frederick County totaled approximately 7.7 billion gallons in 1984 (based on pumpages reported to the Maryland Water Resources Administration and estimates for domestic-well pumpage), which was 1.8 percent of total runoff and 1.4 percent of average annual precipitation. Ground-water sources provided approximately 37 percent of the water used in Frederick County during 1980 (Wheeler, 1983). Ground-water appropriations for which permits were required, and 1982–83 totals and daily averages are listed in the Frederick County basic-data report (Dine and others, 1985). Appropriations of quantities less than an average of 10,000 gal/d are not required to be reported to the Maryland Water Resources Administration.

Dine and others (1985, table 5) list 17 surface-water appropriation permits issued by the State for average daily quantities exceeding 10,000 gal/d. Some of these were for multiple sources, including wells, springs, and quarries. Water is presently withdrawn from the Potomac River near Tuscarora, treated in the New Design plant, and delivered to an aluminum-producing facility near Adamstown (permit number 68-SAP-005). The permitted quantity (average per day) is 8,000,000 gal/d. The daily average reported for 1982–83 is 1,090,282 gal/d, for a yearly total of 397,953,000 gal. The town of Brunswick also includes the Potomac River as a source of its permitted allotment of 1,000,000 gal/d, although it withdraws water from the river only during emergencies, relying on springs under normal conditions. In water year 1966, a year of severe drought, annual flow in the Potomac River (measured at Point of Rocks) amounted to 1.15 trillion gallons. This is still a vast quantity, apparently sufficient to supply the needs of the entire county. However, downstream users, including the city of Rockville in Montgomery County, the U.S. Army Corps of Engineers (supplying the Washington, D.C. area), the Washington Suburban Sanitary Commission, and the Fairfax County Water Authority, withdraw an average of 10.21 billion gallons per month (based on the period October 1981–September 1985; unpublished data from U.S. Geological Survey files). These users already place a large demand on Potomac River water.

About half of the residents of Frederick County rely on individual wells or springs for their water supply and on septic-tank systems for disposal of their waste waters. All municipal and private water-supply systems, except the city of Frederick and the town of Brunswick, use only ground-water sources. Water-supply and sewerage facilities for the county's utilities regions (fig. 46) are described in table 21.

In order to preserve aquatic habitats and provide aeration and dilution of wastes discharged into streams, minimum flows must be maintained. Tsai and Wiley (1983) concluded that approximately 3 ft^3/s was a minimum flow required for certain fish in Maryland Piedmont streams. Langbein and Durum (1967) reported on the aeration capacity of streams and the relation of velocity and depth to a stream's reaeration ability. Systems withdrawing water from streams and reservoirs need to allow provision of minimum flows and may use the information developed in the section "Low-Flow Characteristics" to determine quantities of water that are available or need to be stored.

The hydrologic budget serves as a guide to the availability of water in a basin. Unless water is imported from outside the basin (e.g., via pipeline), the maximum quantity of water available on an annual basis is the annual precipitation. The budget may vary with seasonal consumption or distribution of precipitation, but these variations are averaged for consideration on an annual basis. Water may be "borrowed" from ground-water storage, but cannot be withdrawn continuously or the stored water will eventually be depleted. "Borrowing" commonly occurs in summer months, and replenishment occurs in winter and spring. As the budget figures show, a considerable amount of water is consumed by evapotranspiration; over half of the mean annual precipitation in some basins is lost in this manner.

Annual base flow exhibits a narrower range of variation than does annual overland flow or annual total runoff (fig. 47). The percentage of base flow making up total annual runoff varies from basin to basin. Furthermore, the percentage varies somewhat from year to year within a single basin. The relation of annual base flow to annual total runoff for Catoctin

TABLE 21

PUBLIC WATER-SUPPLY AND SEWAGE FACILITIES IN FREDERICK COUNTY

		Public water-supply facilities			Public sewage-treatment fecilities	
Region	Name	Source	Aquifer/stream	Amount (Mgal/d)	Capacity (Mgal/d)	Effluent discharged to
C-1	Wolfsville	-	-	-	-	-
C-2	Myersville	8 springs stream	Catoctin Metabasalt Catoctin Creek	0.003	0.3	Catoctin Creek
	Interstate 70 Rest Area	4 wells	Catoctin Metabasalt	.02	.028	Grindstone Run
C-3	Middletown	10 wells 4 springs	Catoctin Metabaselt do.	.3	.25	Catoctin Creek
	Fountaindale Services, Inc.	8 wells	do.	.17	.1	Hollow Road Creek
	Braddock Water Compeny, Inc.	3 wells	Harpers Formetion Cetoctin Metebasalt Antietam Formation	.07	-	-
C-4	Jefferson	-	-	-	.12	Cetoctin Creek
	Briercrest Apertments	3 wells	Catoctin Metabaselt	.045	(served by Jefferson)	-
C-5	Lander	-	-	-	-	-
C-6	Brunswick/Rosemont/ Knoxville area	1 spring	Washington Co. MD Catoctin Metabasalt	.32	.5	Potomac River
		3 springs	Loudoun Co., VA Granodiorite end biotite granite gneiss	.06	(new fecility planned)	
		stream	Potomac River	1		
M-1	Bridgeport area	-	-	-	-	-
M-2	Double Pipe Creek area	-	-	-	-	-
M-3	Creagerstown area	-	-	-	-	-
M-4	Fort Detrick	stream	Monocacy River	4.25	1.	Monocacy River
M-5.1	Frederick/ Carroll Creek aree	stream	Monocacy River Fishing Creek Tuscarora Creek Linganore Creek	.8 1.8 .35 1.3	7.	Monocacy River
M-5.2	Amelano Manor Water Company	1 well	New Oxford Formation	.0015	-	-
	White Rock-Lake Spring Water Company, Inc.	1 well	Herpers Formation	.022	.05	Tuscarora Creek
	Crestview Estates	-	-	-	.024	Muddy Run
M-5.3	Walkersville	3 wells	Grove Limestone	.530	(sewage piped to Frederick)	-
		stream	Grape Creek	.175		
	Woodsboro	2 wells	Grove Limestone Frederick Limestone	.046	.1	Israel Creek
	Fountain Rock	1 spring	Grove Limestone	.0015	-	-
M-5.4	Phoenix Properties, Inc.	3 wells	Urbana Formation	.042 (increase plenned)	-	-
	Lake Linganore County System	reservoir	Lake Linganore	1.2	.3	Lingenore Creek
M-6	Rocky Fountain Water Company	1 spring	Frederick Limestone	-	-	-
M-7	-	-	-	-	-	-

Creek near Middletown is shown in figure 48. Base flow also varies seasonally, as seen in the figures for monthly means computed for Catoctin Creek near Middletown using data for the period 1961–80 (table 22). The lowest monthly base flows in this basin occur from August through October, with more than half occurring in September.

The amount of ground-water runoff (expressed in inches in the hydrologic budget) varies from basin to basin. Owens Creek at Lantz, Hunting Creek at Jimtown, and Fishing Creek near Lewistown have the most inches of annual base flow, but owing to their small drainage

TABLE 21—*Continued*

		Public water-supply facilities			Public sewage-treatment facilities	
Region	Name	Source	Aquifer/stream	Amount (Mgal/d)	Capacity (Mgal/d)	Effluent discharged to
M-8	Victor Cullen Center	1 spring 3 wells	Catoctin Metabasalt do.	.05	.125	Friends Creek
M-9	Friends Creek area	-	-	-	-	-
M-10	Emmitsburg	5 wells 2 springs stream	do. do. Turkey Creek	.015 .25	.25 (0.9 Mgal/d facility planned)	Flat Run
	Mount St. Mary's College	2 wells	Gettysburg Shale	.07	.114	Toms Creek
M-11	Beaver Dam Creek area	-	-	-	-	-
M-12	Camp Airy	2 wells	Harpers Formation	.0045		Owens Creek
	Foxville Naval Quarters	4 wells	Catoctin Metabasalt	(not available)	(not available)	Do.
	U.S. National Park Service	3 wells	do.	.022	-	Do.
M-13	Thurmont	1 spring 6 wells streams	Weverton Formation Gettysburg Shale Harpers Formation High Run	.2 .3	.5 1	Hunting Creek Do.
	Cunningham Falls State Park	streams	Hunting Creek	-	-	Hunting Creek
M-14	Upper Fishing Creek area	-	-	-	-	-
M-15	Tanner Branch area	-	-	-	-	-
M-16	Mt. Airy	4 wells	Marburg Schist	.2	.25 (Carroll Co.)	South Br. Patapsco River
M-17	Upper Linganore Creek area	-	-	-	(Liberty facility planned)	
M-18	New Market	wells	-	-	.12 (planned) .01	Linganore Creek
M-19	Pinecliff	3 wells	Antietam Formation	.001	.01	Monocacy River
	Peter Pan Inn	6 wells	Urbana Formation	.009	.03	Bush Creek
M-20	Ballenger Creek Water System	6 wells	Grove Limestone	.5	2	Ballenger Creek
	Concord Mobile Homes	3 wells	Harpers Formation	.012	.013	Ballenger Creek
	Valley View Mobile Home Park	1 well	New Oxford Formation	.0105	.007	Butterfly Branch
M-21	Kempton School	1 well	Marburg Schist	.01	.025	Fahrney Branch
M-22	New Design Road Water Treatment Plant	stream	Potomac River	8	-	-
M-23	Point of Rocks	2 wells	Tomstown Dolomite	.02	.15	Potomac River

areas, they have the least volume of base flow in terms of billions of gallons per annum (BGA) (tables 19 and 20). The Monocacy River basin, because of its size, discharges the greatest volume of ground water annually, although its areal rate, in inches, is low. The small basins probably yield more ground water per unit area because of their higher mean altitudes, which result in somewhat lower temperatures and, consequently, lower rates of evapotranspiration. The upper reaches of these watersheds make up a larger portion of these basins and contain steeper segments of the stream profiles; the mean channel slopes of Owens Creek at Lantz and Fishing Creek near Lewistown are 198 ft/mi and 256 ft/mi, respectively, compared to 19.5 ft/mi and 5.87 ft/mi for the Monocacy River at Bridgeport and at Jug Bridge near Frederick (Dine and others, 1985, table 6). Relative to their areas, they have steeper gradients and larger volumes of rock (and thus, presumably, more water) above their outlets.

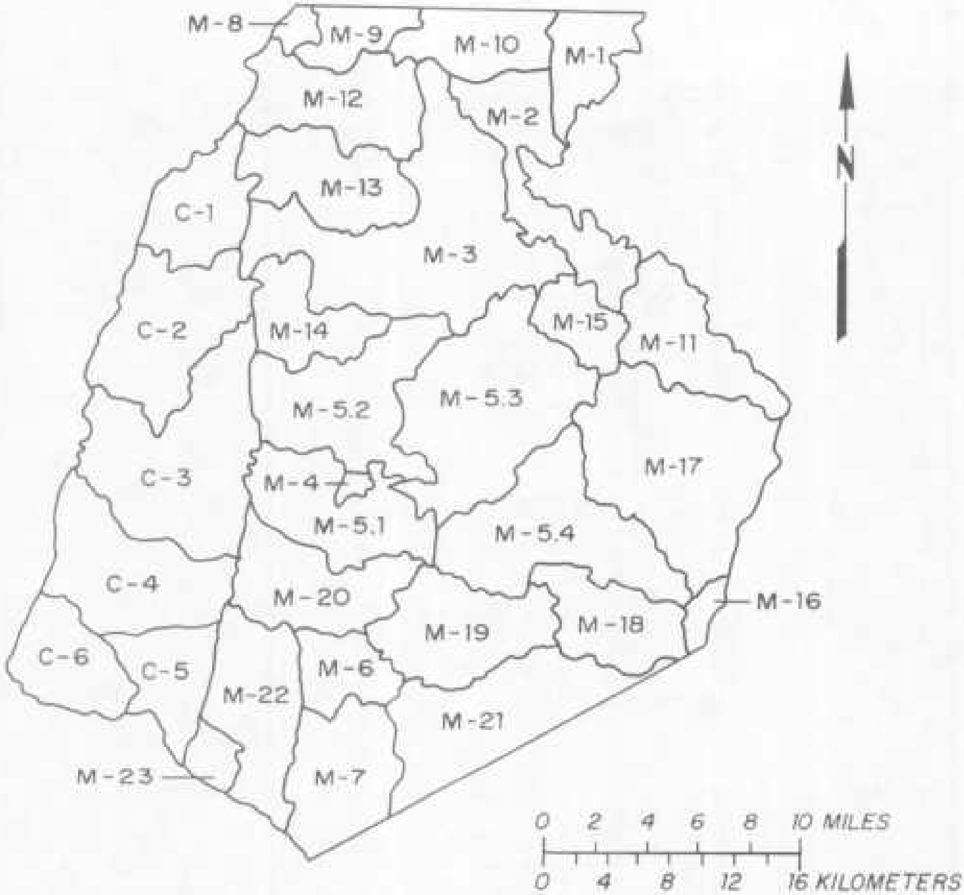

FIGURE 46. Index map of water-utility regions (regions defined by Board of County Commissioners of Frederick County, 1977).

The surface-runoff component of total streamflow responds to precipitation more quickly than does the subsurface component. The mean monthly surface-water runoff component is generally lowest in August rather than September, as is the case with base flow, because of the attenuated nature of the ground-water system's response to hydrologic events. The distribution of annual values for Catoctin Creek near Middletown for the period 1961–80 (fig. 47) illustrates the effect of infrequent high volumes of overland runoff on the distribution of runoff components.

Clearly, a vast amount of water remains available for use, but exactly how much depends on how much of the use is consumptive and how much of the used water is returned in reusable condition. Changes in patterns of water use may affect any of the components of the hydrologic budget, and thereby the amount of water available. Use of storm-water infiltration basins, replacement of individual septic systems by public sewerage, and reuse of renovated waste water are some resource-related factors that can affect the total amount of water available in different areas. The economics of distribution also play a role in the exploitation of the available resource. Despite the large quantity of ground water in circula-

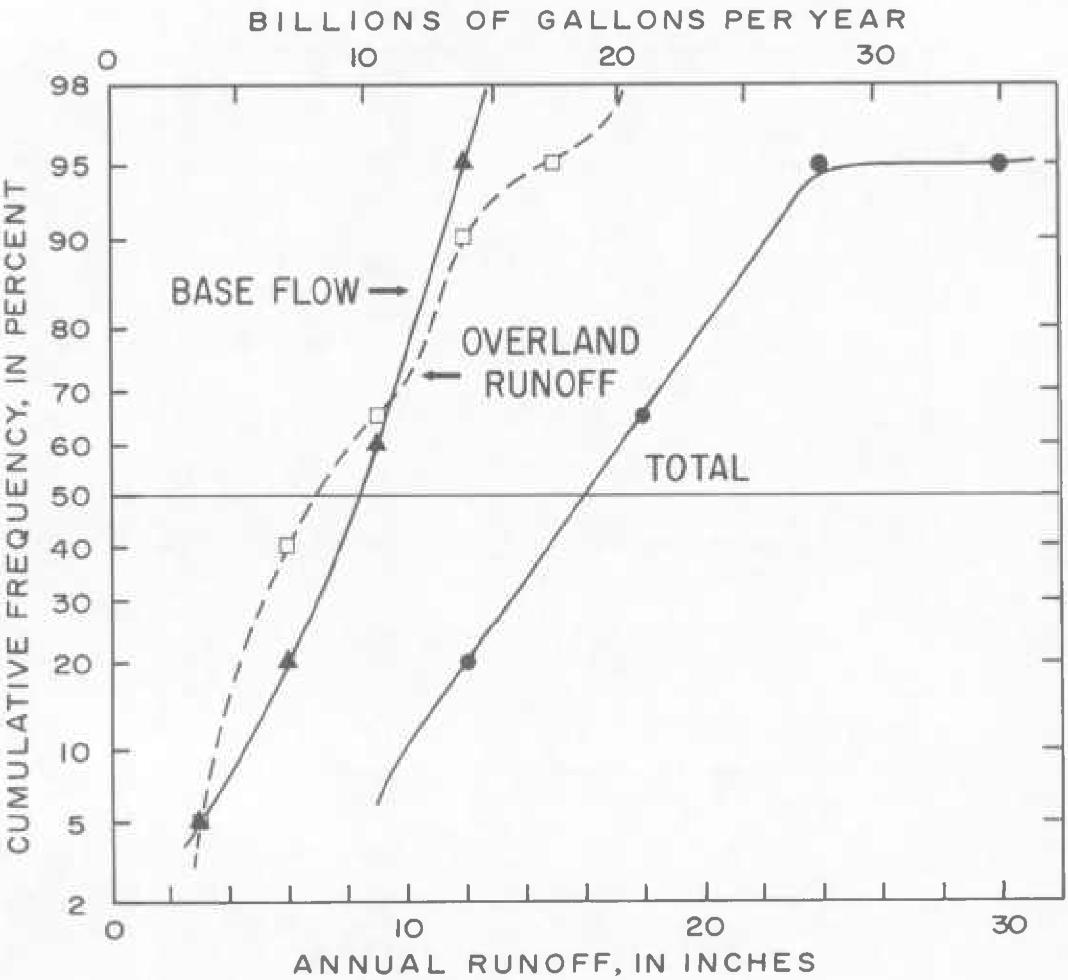

FIGURE 47. Cumulative frequencies of annual runoff components, Catoctin Creek near Middletown, 1961-80.

tion, determined by examination of the hydrologic budget, there are occasional problems in obtaining water from underground sources in Frederick County; approximately half of the wells yield less than 10 gal/min.

Streamflow variability can be short, medium, or long term, and can be accommodated by construction of reservoirs. It is beyond the scope of this report to present an analysis of reservoir locations, capacities, and suitabilities for Frederick County. The following analysis of draft-storage relations may be useful for making preliminary estimates of storage needs for meeting water demands where water is withdrawn from streams.

The critical periods of withdrawal are during dry periods when most, or perhaps all, of a stream's flow is derived from base flow. Differences in quality between water derived from overland runoff and water derived from base flow may require consideration by some users; otherwise only the total flow quantities need be considered. Regardless of the origin (overland flow or base flow) of the water, some estimate may be made of its availability based on the streamflow characteristics described previously.

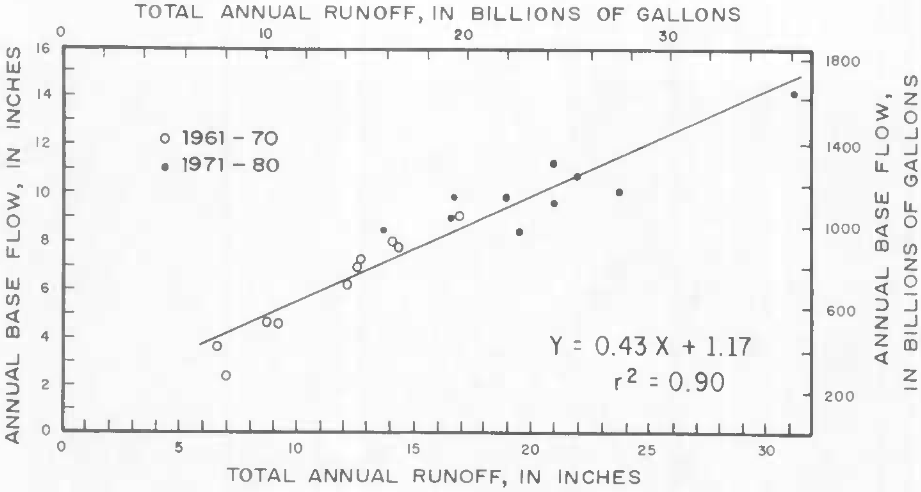

FIGURE 48. Relation of annual base flow and annual total runoff, Catoctin Creek near Middletown, 1961-80.

TABLE 22

MEAN MONTHLY BASE FLOWS, CATOCTIN CREEK NEAR MIDDLETOWN

[Values of upper row of numbers for each period are given in inches; lower row is given in billions of gallons per year.]

Water years	O	N	D	J	F	M	A	M	J	J	A	S	ANNUAL
1961-70	0.1	0.2	0.5	0.7	0.9	1.4	1.1	0.6	0.3	0.2	0.1	0.1	6.2
	.116	.232	.581	.814	1.046	1.628	1.279	.698	.349	.232	.116	.116	7.208
1971-80	.6	.6	1.1	1.5	1.1	1.5	1.5	1.0	.6	.3	.2	.2	10.2
	.698	.698	1.279	1.744	1.279	1.744	1.744	1.163	.698	.349	.232	.232	11.858
1961-80	.4	.4	.8	1.1	1.0	1.5	1.3	.8	.5	.3	.1	.1	8.3
	.465	.465	.930	1.279	1.163	1.744	1.511	.930	.581	.349	.116	.116	9.649

Mean monthly, 1961-80: 0.69 in. (0.802 billion gallons per year).

Using the low-flow frequencies for the sites already discussed, the amount of storage required to permit a given rate of water withdrawal, or draft rate, can be determined (fig. 49) for each site where suitable records are available (for this analysis, nine sites in Frederick County were used). Low flows are inherently variable; therefore, separate curves are drawn for each of several selected recurrence intervals, reflecting the need for greater volumes of storage during the drier periods that occur less frequently. The indicated amounts of storage are those required to make up the difference between the incoming streamflow and the desired draft rate.

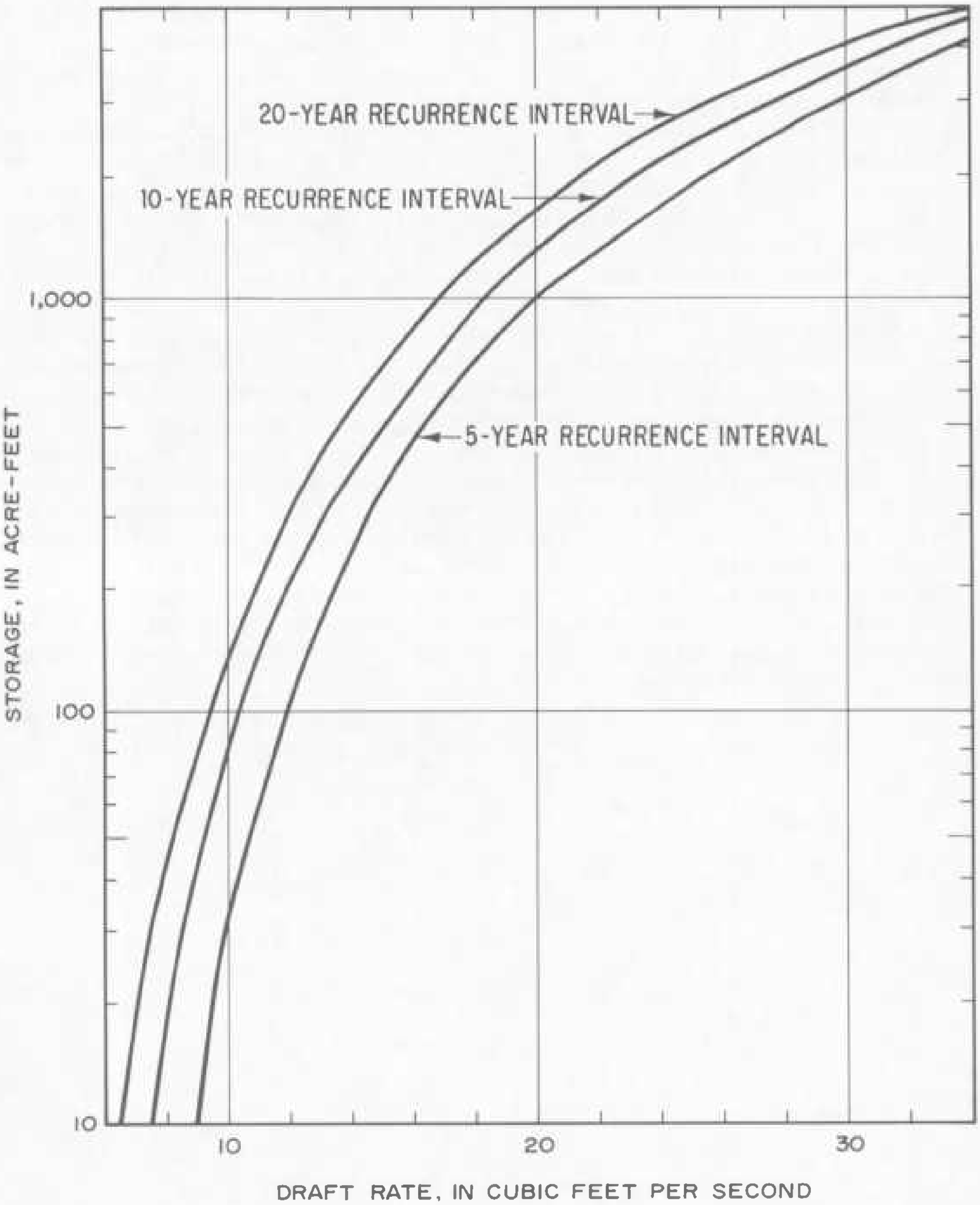

FIGURE 49. Draft-storage frequency relations, Bennett Creek at Park Mills.

Combining the draft-storage relations of all nine sites along with their 7-day, 2-year low flows (½ = 50 percent probability, or median, 7-day flow) produces a series of graphs (fig. 50) which may be used to estimate amounts of storage required for desired draft rates. These are determined for various probabilities of not meeting the demand (shown as 5-, 10-, and 20-year recurrence intervals). One can estimate the amount of storage necessary to meet demand for water withdrawn from any stream in the area if the median 7-day low flow past the site of interest can be estimated. Each line is drawn by plotting the $7Q_2$ of each station against the draft rate (expressed in $(ft^3/s)/mi^2$) that can be sustained for the indicated amount of storage. A separate line is drawn for each selected amount of storage, producing a family of lines for the indicated recurrence interval, and the procedure is repeated for each desired recurrence interval.

As an example, suppose a company requires a total of 0.6 Mgal of water per day for various purposes, and that they wish to locate in the vicinity of Harmony, approximately 2 mi east of Myersville. Little Catoctin Creek at Harmony has a drainage area of 8.83 mi^2, and the $7Q_2$ at this site is estimated to be 0.12 $(ft^3/s)/mi^2$ (table 14). If the company is willing to risk a 10-percent chance in any year that their demand cannot be met by this supply, the amount of storage required can be estimated using figure 50B. The median annual 7-day low flow ($7Q_2$) is found along the x-axis, and a line is extended upward. The desired water demand is converted to ft^3/s and the result divided by the drainage area of the basin in question. The result, 0.10 $(ft^3/s)/mi^2$, is located along the y-axis and a horizontal line is extended. The intersection of these two lines falls very close to the line representing a storage of 2 acre-ft/mi^2. The desired withdrawal rate can be met if this amount of storage is provided. This figure does not include reservoir and conveyance losses, which need to be factored in along with a factor of safety to allow for the uncertainties of the method. Once the volume of needed storage has been determined, a topographic study can be done to determine the suitability of possible reservoir sites.

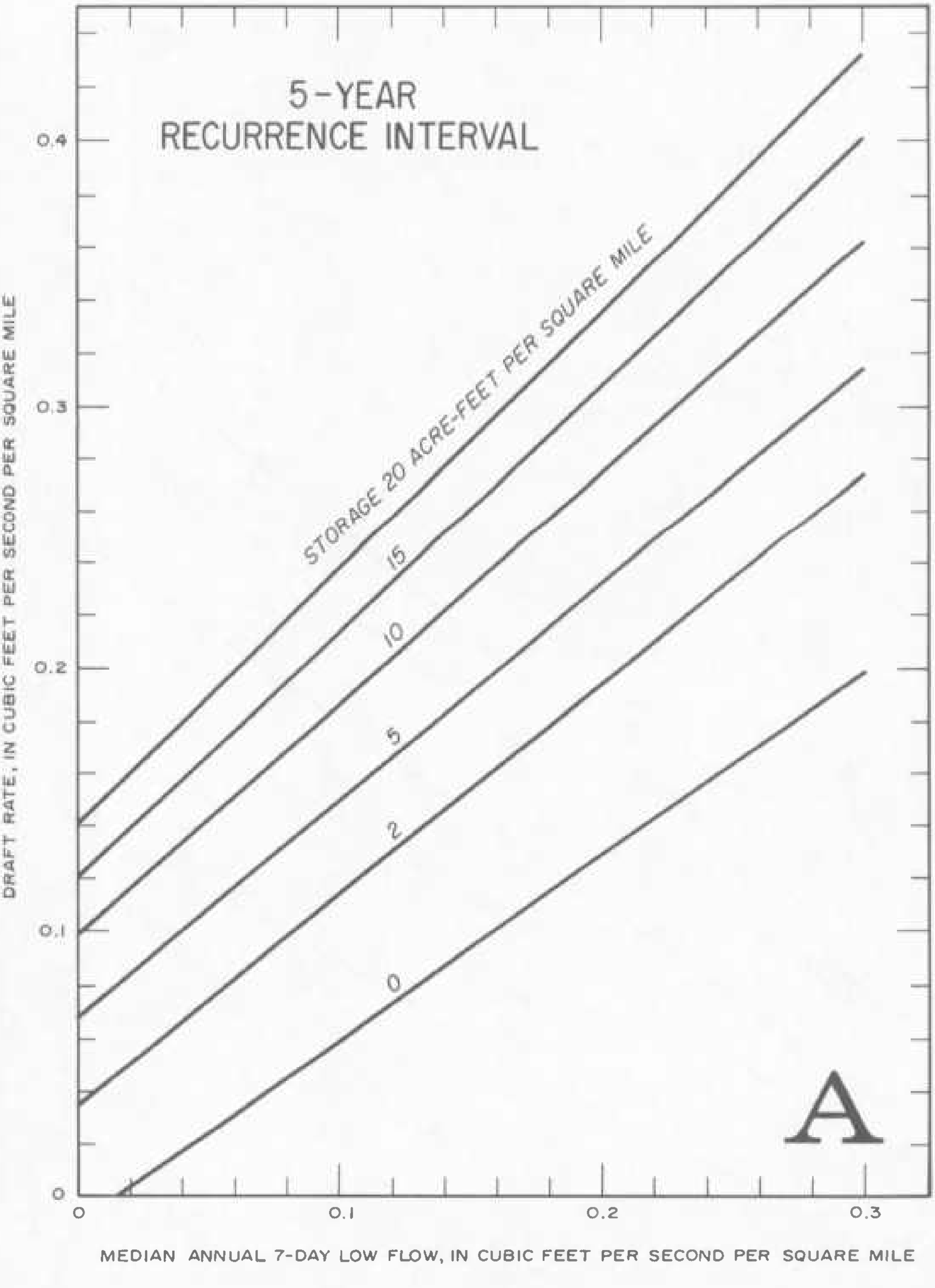

FIGURE 50. Areal draft-storage relations. A) 5-year recurrence interval; B) 10-year recurrence interval; C) 20-year recurrence interval.

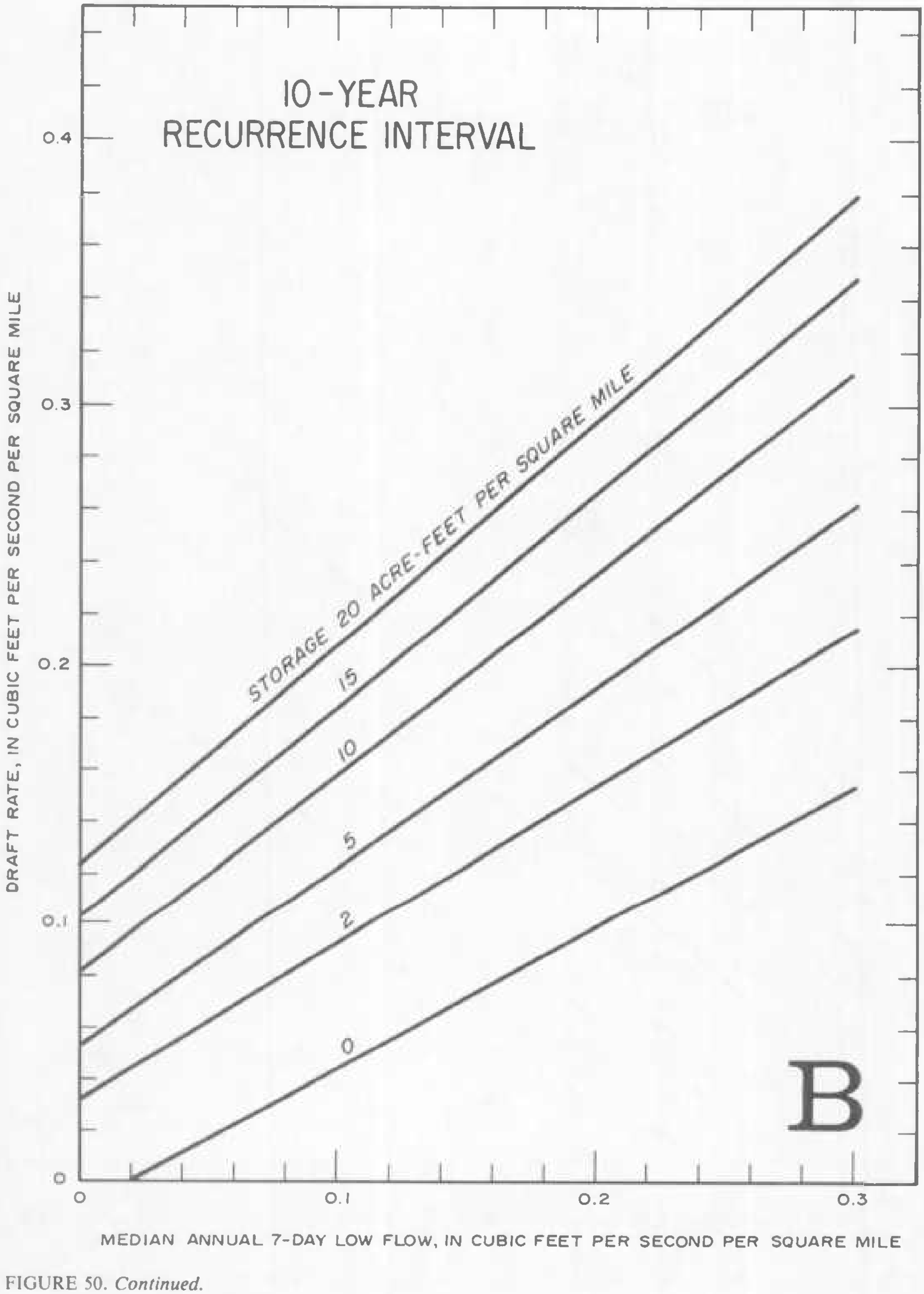

FIGURE 50. *Continued.*

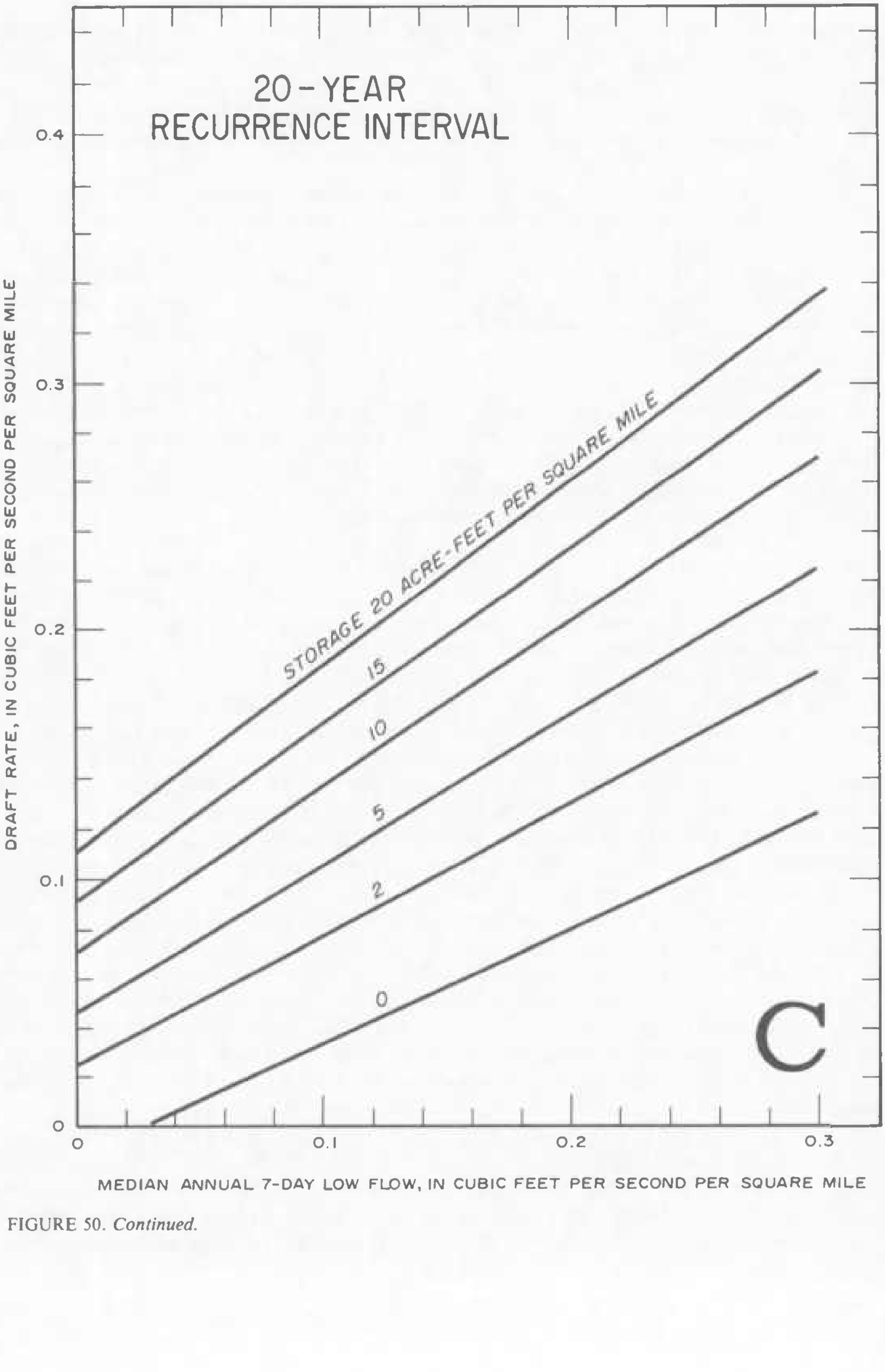

FIGURE 50. *Continued.*

SUMMARY

The population of Frederick County increased approximately 35 percent over the period 1970–80. The increasing population placed increasing demands on the county's water resources; about 7.7 billion gallons of water were used in 1984. This study provides an up-to-date assessment of the ground- and surface-water resources of the county that should be useful to planners, developers, and others dealing with water supply and water-quality protection.

Ground water occurs primarily under unconfined or semiconfined conditions in fractures in the crystalline and the well-indurated sedimentary rocks; fractures and bedding planes in the Grove and Frederick Limestones that have been enlarged by solution provide high yields to wells in many, although not all, areas where they occur. Ground-water circulation generally is controlled by local topography and most ground water flows into the Potomac River by way of the Catoctin Creek and Monocacy River drainage systems. Water levels were measured periodically at 56 wells throughout the county; four of these wells had water-level recorders installed.

Transmissivities generally are less than 1,000 ft^2/d, although some higher values occur. The storage coefficient is infrequently determined because multiple-well tests are required. Gravity yield, an approximation of the specific yield (storage coefficient of an unconfined aquifer), was determined for six basins; values range from 0.2 to 28 percent. Aquifer diffusivities (T/S) calculated from ground-water-level or streamflow recessions range from 6,400 to 74,000 ft^2/d.

Reported discharges of 1,582 wells inventoried in Frederick County range from 0 to 950 gal/min, with a median discharge of 10 gal/min. About 5 percent of the inventoried wells yield less than 1 gal/min, and about 11 percent yield less than 2 gal/min. Less than 4 percent of the wells yield more than 100 gal/min, although about 10 percent of the wells drilled for industrial, institutional, or public supplies yield at least this amount. Specific capacities of 1,177 wells range from 0 to 262.5 (gal/min)/ft, with a median value of 0.15 (gal/min)/ft.

The majority of inventoried wells were drilled to supply domestic needs and, therefore, were not sited and constructed to maximize yield. Most wells are less than 200 ft deep; water-bearing fractures are less numerous and open at greater depths. Hilltops and hillsides were the least productive settings for wells. Sites nearer to streams, particularly valley flats, were more favorable. Upland draws are likely also to be highly favorable settings, but insufficient data were available to demonstrate this conclusively. Well-yield variability is nearly as great within geologic formations as it is between formations. The Grove Limestone, the basal limestone conglomerate of the New Oxford Formation, and the Tomstown Dolomite (although this last formation was only represented by five wells; it may actually be part of the Frederick Limestone in this area) may yield more water to wells because of enlargement of joints and bedding planes by solution. It is worthy of note that the Frederick Limestone, although not a poor aquifer, is characterized by lower well yields than the other carbonate formations. This may be due to the locations of wells relative to areas of greatest solutional development of this formation. Insufficient data were available to adequately describe the water-yielding characteristics of the Wakefield Marble (two wells yielded 8 and 25 gal/min, respectively). Wells constructed in mountain wash were productive, but current State regulations require wells west of the Fall Line be cased into bedrock.

Flow measurements were obtained at 29 stations along 21 streams. Monthly and annual mean flows were determined for 12 continuous-record gaging stations. Maximum monthly flows generally occur in March or April; minimum monthly flows generally occur from August to October.

Flow durations were determined for 10 continuous-record gaging stations. The flow-duration curve for the Monocacy River at Bridgeport has the steepest slope, indicating the greatest variability in streamflow. The curve for Fishing Creek near Lewistown has the flattest slope, indicating the least variability in streamflow.

Instantaneous peak flows and average high flows for various recurrence intervals were calculated for 10 stations that had continuous records. Instantaneous peak flows and average high flows were estimated for 15 stations from multiple regression using drainage area and forest cover as independent variables. Variations in peak flows, adjusted for drainage area, may be related to the distributions of storm intensities, in addition to basin characteristics such as amount of impermeable surfaces and land slopes.

Average low flows for various recurrence intervals were calculated for the 10 continuous-record gaging stations and estimated for 15 stations based on regression with drainage area. The 7-day, 2-year low flow ($7Q_2$) ranged from 0.003 to 0.26 $(ft^3/s)/mi^2$, and the 7-day, 10-year low flow ($7Q_{10}$) ranged from 0 to 0.170 $(ft^3/s)/mi^2$. The lowest low flows per square mile generally occur in the northern part of the county; the highest $7Q_{10}$'s occur in the southern part, but the highest $7Q_2$'s occur scattered throughout the county. Low flows appear to be minimal in areas underlain by Triassic shales and sandstones.

Ground-water samples collected from 142 wells and 25 springs were analyzed for common ions and trace elements or pesticides. Additional data were obtained from U.S. Geological Survey files. Countywide, ground water varies from soft to very hard and is moderately hard on the average; the dominant ions are calcium, magnesium, and bicarbonate. Trace elements and pesticides were not found in significant concentrations in ground water, but contamination has occurred locally. Contamination of ground water by nitrate from fertilizer and livestock sources, and by occasional leakage of gasoline from underground storage tanks was noted. A comparison of water-quality data collected after 1980 with data collected prior to 1973 (involving seven sites) showed an increase in sodium, calcium, and chloride at two of the sites, probably reflecting contamination by road-deicing salt, or perhaps by septic-tank effluent.

Because streams generally were sampled during base-flow conditions, water quality of streams reflected the quality of ground water in the adjacent area. Samples of stream-bottom materials collected concurrently with samples from the water column were analyzed for trace elements or pesticides.

The hydrologic budget for Frederick County is: Precipitation (48 in.) + Imported Streamflow and Underflow (13 in.) = Surface Runoff (25 in.) + Subsurface Runoff (11 in.) + Underflow Leaving the County (0 in.) + Evapotranspiration (25 in.) + Change in Storage (0 in.). The total amount of water entering the county amounts to about 708 billion gallons per year; total annual runoff is about 419 billion gallons. Budgets were also constructed for individual drainage basins.

Very large amounts of ground water cannot be withdrawn efficiently from many areas of the county because of localization of ground-water flow, aquifer heterogeneities, and the transmissive properties of the aquifers. A sizeable portion of streamflow, however, is composed of ground-water runoff and may be stored in reservoirs, allowing indirect exploitation of the ground-water resource. Areal draft-storage relations determined from streamflow characteristics permit the determination of amounts of reservoir capacity required to meet desired water demands. This procedure makes use of a set of graphs and requires an estimate of the 7-day, 2-year low flow for the area of interest. Local water availability and water-distribution networks will be one of the factors influencing growth and land-use development in Frederick County.

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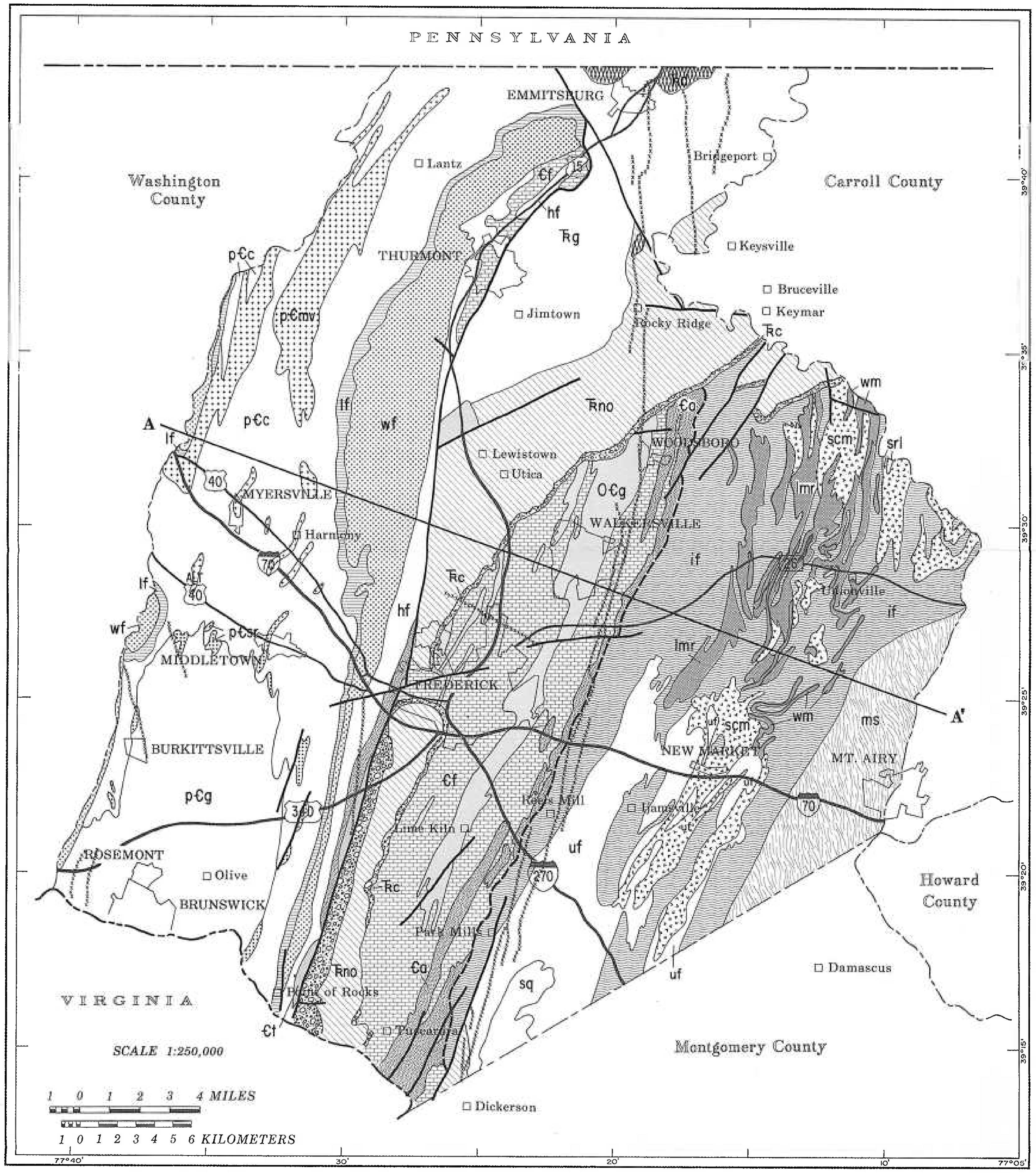
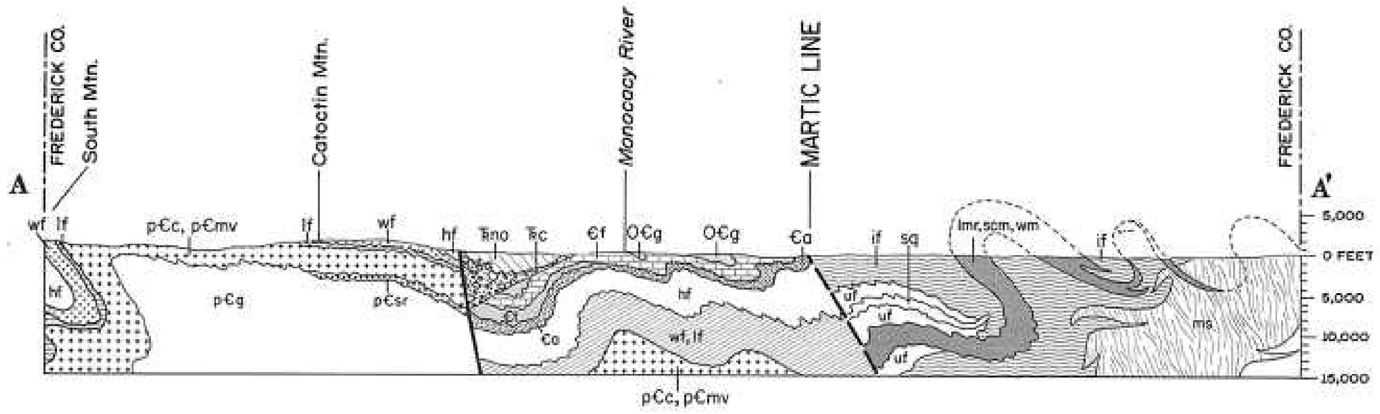


Base from Maryland State Highway Administration, 1:100,000, and Maryland Geological Survey, 1:62,500

Geology from Cleaves, Edwards, and Glaser, 1968.



SOUTH MOUNTAIN ANTICLINORIUM AND FREDERICK VALLEY

TRIASSIC

Diabase Sills and Dikes
Sills: Greenish-gray to black, medium-grained; dikes: Greenish-gray to black, medium- to fine-grained; local contact metamorphic aureoles.

Newark Group

Gettysburg Shale
Red shale and soft red sandstone and siltstone; estimated thickness less than 5,000 feet.

New Oxford Formation
Red, maroon, and gray sandstone, siltstone, and shale; basal conglomerate member: From vicinity of Maryland Rte. 73 and southward, limestone conglomerate with red and gray calcareous matrix; northward, quartz conglomerate with red sandy matrix; estimated total thickness 4,500 feet.

ORDOVICIAN

Grove Limestone
Dark gray to light dove, thick-bedded limestone; dolomite beds in lower part; highly quartzose limestone at base; Upper Cambrian to Lower Ordovician in age; thickness approximately 590 feet.

CAMBRIAN

Frederick Limestone
Blue, slabby, thin-bedded limestone and minor shale; contains Upper Cambrian (Trempealeauian) faunule; thickness approximately 480 feet.

Tomstown Dolomite
Interbedded light gray to yellowish-gray, thin- ta thick-bedded dolomite and limestone; some shale layers; gradational contact with Antietam; thickness 200 to 1,000 feet.

Chilhowee Group

Antietam Formation
White to dark gray and brown, thick-bedded, fine- to coarse-grained quartzite with thin argillaceous partings; first occurrence of Lower Cambrian fossils; cleavage generally obscures bedding; increasingly metamorphosed and phyllitic toward east; estimated thickness 300 to 800 feet.

Harpers Formation
Brown to dark bluish-gray banded shale, ta light bluish-gray, finely laminated phyllite; distinctively pale purple in basal part; bedding obscured by cleavage; increasingly metamorphosed toward east from shale ta slate and phyllite; estimated thickness 2,000 feet.

Weverton Formation
Interbedded white to dark gray, thin-bedded, micaceous, ferruginous, and sericitic quartzites, phyllites, and white, thick-bedded, ledge-making quartzites; some gray to brown ferruginous quartz conglomerate and purple-banded phyllite; thickness approximately 100 feet in south, increases to 425 feet in north.

Loudoun Formation
Upper conglomerate member: Quartz and granitic pebbles in pale purple phyllitic matrix; basal phyllite member: Pale purple, discontinuous, lenticular; members are in gradational contact; total thickness 0 to 200 feet.

LATE PRECAMBRIAN

Metarhyolite and Associated Pyroclastic Sediments
Metarhyolite: Dense, blue, cryptacrystalline, with white feldspar phenocrysts and glassy quartz; red porphyritic metarhyolite at contact with Catoctin Metabasalt; Pyroclastic sediments: Tuff breccia, blue slaty tuff, white tuffaceous sericitic schist, and banded green slate.

Catoctin Metabasalt
Thick-bedded metabasalt with amygdaloidal layers and secondary veins of quartz, calcite, and epidote; interbedded green tuffaceous phyllite and blue amygdaloidal metaandesite.

Swift Run Formation
Sericitic quartzite and phyllite; blue and green tuffaceous slate with sericitic blebs; some white marble with interbedded phyllite.

PRECAMBRIAN

Granodiorite and Biotite Granite Gneiss
Light gray to pale green, fine-grained, granodiorite gneiss, and dark gray biotite granite gneiss with some augen gneiss; in places a sheared muscovite-biotite gneiss; local biotite schist bands; intruded by metadiabase feeder dikes of Catoctin Metabasalt.

WESTERN PIEDMONT METASEDIMENTARY ROCKS

LATE PRECAMBRIAN (?)

Urbana Formation
Dark gray to green sericite-chlorite phyllite, metasiltstone, and quartzite; thin lenses of impure marble and calcareous phyllite occur locally.

Sugarloaf Mountain Quartzite
Massive white quartzite interbedded with softer sericitic quartzite, slate, and phyllite.

Libertytown Metarhyolite
Purple, bluish-black, and red, dense, fine-grained metarhyolite with feldspar phenocrysts; interbedded with blue and purple amygdaloidal metaandesite; both rhyolite and andesite interbedded with blue, purple, and green phyllitic slates.

Sams Creek Metabasalt
Grayish-green, massive to schistose, amygdaloidal metabasalt.

Wakefield Marble
White, fine-grained marble; subordinate white, green, and pink variegated marble; and blue marble.

Silver Run Limestone
Blue, thin-bedded, finely crystalline schistose limestone and calcareous slate.

Ijamsville Formation
Blue, green, or purple phyllite and phyllitic slate, with interbedded metasiltstone and metagraywacke; flattened pumiceous blebs occur locally.

Marburg Schist
Bluish-gray to silvery-green, fine-grained, muscovite-chlorite-albite-quartz schist; intensely cleaved and closely folded; contains interbedded quartzites.

NOT SHOWN

QUATERNARY

Alluvium:
Along streams.

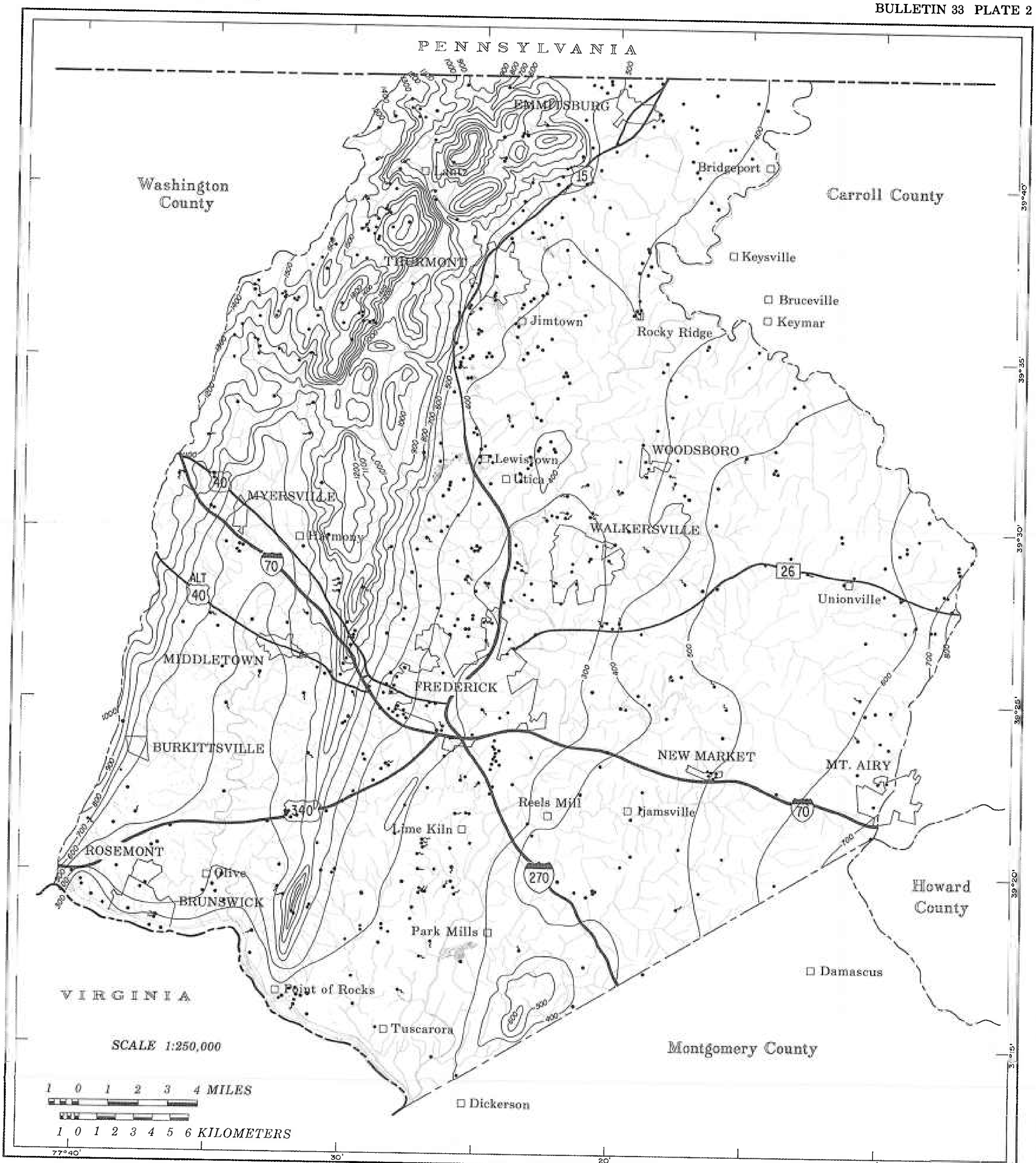
Terrace gravels:
Remnants bordering the Potomac River and the larger streams.

Mountain wash:
Alluvial cones along eastern foot of Catoctin Mountain.

Fault

Probable fault

PLATE 1. GEOLOGIC MAP OF FREDERICK COUNTY, MARYLAND.



Base from Maryland State Highway Administration, 1:100,000.

EXPLANATION

Potentiometric contour — shows oltitude ot which woter level would hove stood in tightly cosed wells. Contour intervol is 100 feet. Dotum is seo level.

Well used for control.

Spring used for control.

PLATE 2. MAP SHOWING THE ALTITUDE OF THE POTENTIOMETRIC SURFACE, FREDERICK COUNTY, MARYLAND.