MARYLAND
GEOLOGICAL SURVEY

SL 6046-1-78

CONVERSION FACTORS AND ABBREVIATIONS

The following factors may be used by those readers who wish to convert the inch-pound units in this report to International System (SI) units.

Multiply Inch-Pound Unit	By	To obtain International System Unit
inch (in.)	2.540	centimeter (cm)
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)
gallon (gal)	3.785	liter (L)
inch per year (in/yr)	25.40	millimeter per year (mm/yr)
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)	0.00004381	liter per second (L/s)
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]
ounce (oz)	28.35	gram (g)
ton per day (ton/d)	907.2	kilogram (kg/d)

Chemical concentration and water temperature are given in SI units. Chemical concentration is expressed in milligrams per liter (mg/L), micrograms per liter (μg/L), or micrograms per kilogram (μg/L). Specific conductance of water is expressed in microsiemens per centimeter at 25°C (μS/cm). 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 36

WATER RESOURCES OF WASHINGTON COUNTY, MARYLAND

by

Mark T. Duigon
Maryland Geological Survey

and

James R. Dine
U.S. Geological Survey

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

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WATER RESOURCES OF WASHINGTON COUNTY, MARYLAND

by

Mark T. Duigon and James R. Dine

ABSTRACT

The western part of Washington County, underlain by strongly folded clastic sedimentary rocks, is steeper and more forested than most of the eastern part, where limestone and dolomite predominate. The eastern edge of the county is underlain by metamorphic rocks.

Ground water occurs predominantly under unconfined, secondary-permeability conditions. Unconsolidated sediments and overburden generally are not sufficiently permeable or are of insufficient saturated thickness to be used directly for water supplies. Ground-water levels range from near land surface to more than 150 feet below and they fluctuate from a few feet to tens of feet. Highest water levels occur during February through April, and lowest levels occur in October. Long-term trends are of lesser magnitude than seasonal variations. Reported well yields range from 0 to 385 gallons per minute, and specific capacities range from 0.00 to 86 gallons per minute per foot. Variability of well yields within geologic units is about as great as variability among units. Ground water is generally hard to very hard; total dissolved-solids concentrations range from about 20 to more than 2,000 milligrams per liter. Concentrations of trace elements, pesticides, and organic compounds generally were less than detection limits in the wells and springs sampled.

Streamflow characteristics are presented for 35 stations on 30 streams. Mean monthly flows at nine stations having long-term, continuous records range from about 2 to greater than 10,000 cubic feet per second. The highest streamflows generally occur in March or April, whereas the lowest occur in August through October. Mean annual flows range from approximately 13 to nearly 6,000 cubic feet per second. One-hundred-year peak flows at 33 stations range from 147 to 39,950 cubic feet per second. Seven-day, 10-year low flows at 28 stations (excluding the two stations on the Potomac River) range from 0.0 to 66 cubic feet per second, and, areally, from 0.000 to 0.425 cubic feet per second per square mile. Areally, annual high flows tend to be lower in the eastern drainage basins than in the western basins but low flows are generally greater, and flow-duration curves for the eastern basins are less steep than for the western basins. Most stream waters are calcium bicarbonate types. Nine trace elements were detected in stream-bottom materials from some of the 15 sites sampled. Seventeen pesticides and related compounds were detected and 11 were not detected in samples of stream-bottom materials obtained from 18 sites.

Hydrologic budgets were estimated for 28 drainage basins. An average annual budget is precipitation (39.6 inches) = subsurface runoff (9.6 inches) + surface runoff (5.5 inches) + evapotranspiration (24.5 inches) + change in storage (0.0 inches). Basins underlain by large proportions of carbonate rock are characterized by higher proportions of subsurface runoff compared to noncarbonate basins.

INTRODUCTION

LOCATION

Washington County is located in the west-central part of Maryland and includes the narrowest part of the State's panhandle (fig. 1). The north boundary with Pennsylvania is the Mason and Dixon Line. The Potomac River is the boundary with West Virginia along most of the southern edge of Washington County, and with Virginia for about 2 mi at the southeastern edge. Sideling Hill Creek forms the western boundary with Allegany County, and the crest of South Mountain forms the eastern boundary with Frederick County.

Washington County is about 47 mi wide along the Mason and Dixon Line, but less than 2 mi wide near Hancock, where the Potomac River makes its northernmost bend. The area of the county is 467.07 mi^2, of which 454.97 mi^2 is land (Frese, 1987, p. 623). Hagerstown, the county seat and commercial center, is located in the northeastern part of the county and is equidistant (approximately 65 mi) from Baltimore and Washington, D.C.

PURPOSE AND SCOPE

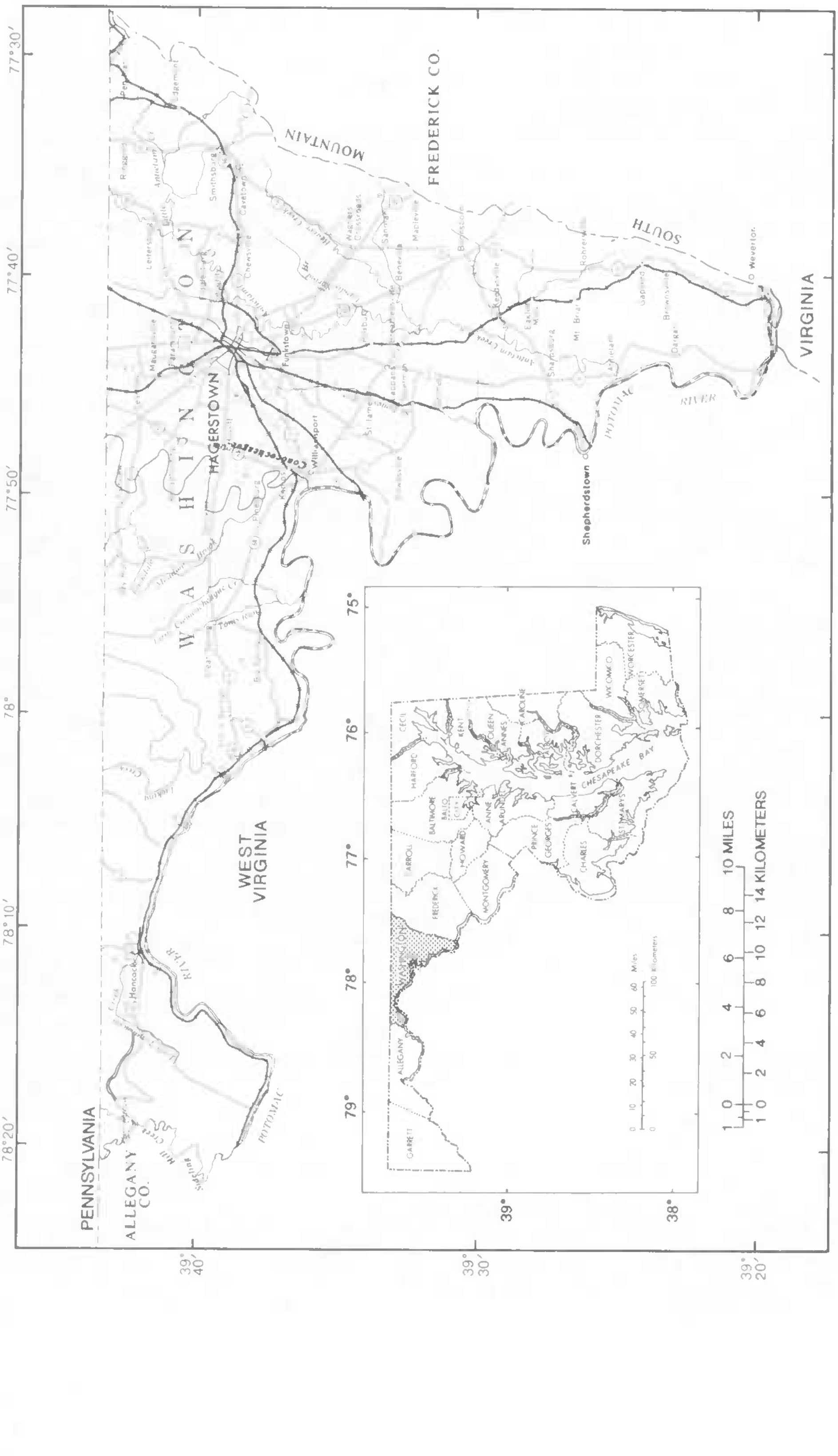
Rational decisions on matters concerning water availability and protection need to be based on accurate hydrologic data coupled with sound interpretation. This report provides an updated assessment of the availability and quality of ground- and surface-water resources in Washington County and presents an evaluation of the spatial and temporal variations in the properties of these resources.

This report is based on a compilation of data collected over many years; the basic data are published separately (Duigon and others, 1989). Much of the well-yield information is based on drillers' completion reports for more than 2,000 wells inventoried throughout the county. Streamflow characteristics are based on discharge measurements made by the U.S. Geological Survey and drainage-basin physical characteristics. Areal water-quality assessment is based primarily on analyses of physical properties and major ions determined by State and Federal laboratories. The hydrologic budgets are based chiefly on interpretation of hydrographs for seven streamflow-gaging stations for which long-term records are available.

GEOGRAPHIC SETTING

The physical geography of Washington County is well described by Cloos (1951). Two streams and a drainage divide form three of the four county boundaries. All major streams (Sideling Hill Creek, Tonoloway Creek, Licking Creek, Conococheague Creek, and Antietam Creek), as well as smaller ones, drain into the Potomac River. A large part of the streamflow passing through Washington County originates in Pennsylvania and a smaller amount originates in Allegany County. Altogether, 993 mi^2 of tributary drainage is in Pennsylvania and Allegany County.

Since the publication of Cloos' 1951 report, industry and population have increased (population data from Maryland Office of Planning); the 1990 population of Washington County was 121,393. Six of the nine incorporated localities have populations exceeding 1,000, and five unincorporated localities have populations exceeding 1,000. The population of the county as a whole increased about 7.3 percent during 1980–90, and the city of Hagerstown increased in population by about 3.8 percent to 35,445 during this period. Many suburban



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

Figure 1.—Location of Washington County.

residents commute to nearby industrial-commercial centers, but some commute to more distant destinations beyond the county boundaries.

Most of the land is agricultural or forested (fig. 2). Forests generally cover hillsides and ridges, whereas agricultural land is located in valleys, particularly the Hagerstown Valley. Urban or built-up land is concentrated in the vicinity of Hagerstown-Williamsport. Small areas of other land uses, such as quarries, are scattered throughout the county. As the population shifts from urban to suburban areas, much of the change in land use will be at the expense of agricultural land.

GEOLOGIC SETTING

Washington County includes parts of two physiographic provinces—the Blue Ridge and the Valley and Ridge (fig. 3). The Blue Ridge province is mostly underlain by metamorphosed igneous and sedimentary rocks that are the eroded remnants of an overturned anticlinorium. The sedimentary strata of the Valley and Ridge province have not been altered to as great an extent as the rocks of the Blue Ridge, but have been strongly folded and faulted. Attitudes of these beds range from horizontal to vertical. Lithologies in the Valley and Ridge include shale, mudstone, siltstone, sandstone, and limestone and various combinations of these.

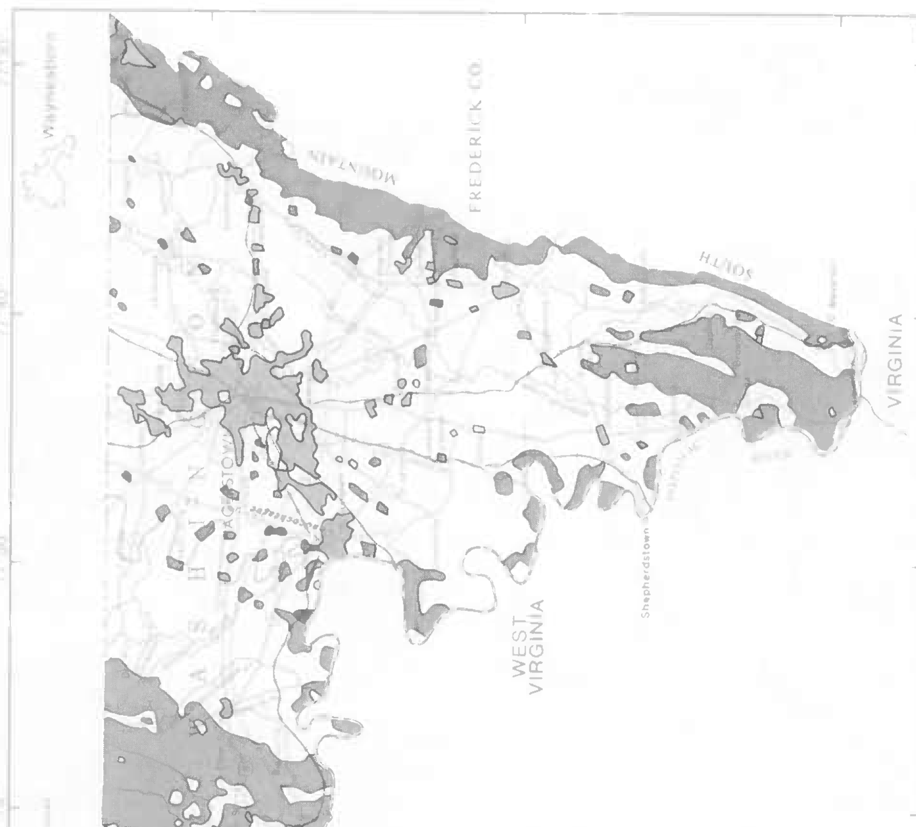
The general trend of the ridges and intervening valleys is approximately northeast-southwest. The Hagerstown Valley (the Maryland part of the Great Valley) occupies the area from the western base of South Mountain to the Bear Pond Mountains west of Clear Spring. The Hagerstown Valley is underlain predominantly by relatively soluble carbonate rocks, and shows karstic development. The karst of the Valley and Ridge province is fluviokarst—that is, nonkarstic fluvial erosion and sedimentation processes are important in producing the geomorphic features of the area. The other, more narrow valleys are underlain by soft, less resistant lithologic types, mostly shales, and the ridges are formed by resistant sandstones (or quartzite as at South Mountain and Elk Ridge).

Nearly all of the geologic units exposed in Washington County range in age from Precambrian through Mississippian; Triassic diabase dikes intrude some of the units, and Quaternary sediments are present in places along streams and mountain flanks. Geologic interpretations of the region are constantly evolving as ongoing field work and mapping on a 7½-minute quadrangle basis reveal new details. The stratigraphic nomenclature of this report follows that shown on the geologic map of the county compiled by Edwards (1978) from his own observations and from the earlier mapping of Stose and Swartz (1912), Jonas and Stose (1938), Cloos (1941), Sando (1957), and Geiser (1970). This map is included as plate 1.

PREVIOUS INVESTIGATIONS

An investigation of the ground-water resources of Washington County by Slaughter and the surface-water resources by Darling was published by the Maryland Geological Survey in 1962. Numerous additional data have been collected since then, and studies of various aspects of the geology and water resources also have been conducted.

A report on the soils of Washington County (Matthews, 1962) describes their agricultural and engineering properties and shows their locations. Depositional environments of the lower part of the New Market Limestone near Clear Spring were discussed by Matter (1967).



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

Figure 2.—General land use in Washington County (from USGS Land-Use Series, Baltimore, Md., and Cumberland, Md., sheets; scale 1:250,000).

Figure 3.—Physiographic features of Washington County.

Geiser (1974) analyzed cleavage in the Bloomsburg Formation in the area west of Hancock. Reinhardt and Wall (1975) measured and described the Tomstown Formation at three localities in the eastern part of the county and discussed environments of deposition of that unit. Fauth mapped the geology of the Catoctin Furnace and Blue Ridge Summit quadrangles (1977) which include the northeastern corner of Washington County, and the Myersville quadrangle (1981), which includes a part of the west flank of South Mountain. Bjerstedt (1986) described the stratigraphy and environments of deposition of the rocks exposed at the road cut where U.S. Highway 40 crosses Sideling Hill near Hancock. Edwards (1978) compiled the geologic map of Washington County on which the stratigraphic nomenclature of this report is based.

Traveltimes in Antietam and Conococheague Creeks were studied by Taylor and Solley (1971) and in the Potomac River by Searcy and Davis (1961) and by Taylor and others (1985). The U.S. Army Corps of Engineers provide flood-plain information for Antietam Creek (1972) and for a 26-mi reach of the Potomac River (1977). Flow characteristics of Washington County streams are described by Walker (1971) and Carpenter (1983).

Nutter (1973, 1974) described the hydrology of carbonate terrane in the county. The relation of photolineaments to well yields in the Hagerstown Valley is described by Rauch and Plitnik (1984). Otton and Hilleary (1985) described a number of Washington County springs in their discussion of physical, thermal, and chemical characteristics of Maryland springs. Trainer and Watkins (1975) evaluated differences in hydrology between basins underlain by carbonate rock and by other fractured rock for the upper Potomac River basin of which Washington County is a part. Comprehensive well-yield, water-level, streamflow, and water-quality data for Washington County were compiled as part of the present study and are presented separately (Duigon and others, 1989).

ACKNOWLEDGMENTS

This investigation was undertaken in cooperation with the U.S. Geological Survey. Well drillers and local residents provided much helpful information about wells and well locations; special gratitude is expressed to those property owners who allowed field personnel to make hydrologic measurements and collect water samples. Michael Tompkins, Maryland Geological Survey, assisted with much of the data processing.

THE HYDROLOGIC CYCLE

The circulation of water in the environment is termed the hydrologic cycle. Not all of the complexities of the global hydrologic cycle are represented in Washington County, but the important features that are present are shown in figure 4. Some elements of the hydrologic cycle are readily observed and well understood. Other elements are not "seen" and are often misunderstood by nonspecialists. For example, precipitation has been measured at numerous sites for many years and compilations of records are readily available and interpreted; on the other hand, large, unmeasured quantities of water are transferred back to the atmosphere by direct evaporation plus uptake from soil and release to the atmosphere by plants (transpiration). Odum (1971, p. 20) reports that, for every gram of carbon dioxide fixed in a grassland or forest ecosystem, as much as 100 grams of water are transpired. Hydrologic boundaries may or may not be readily observed—surface water can be seen to

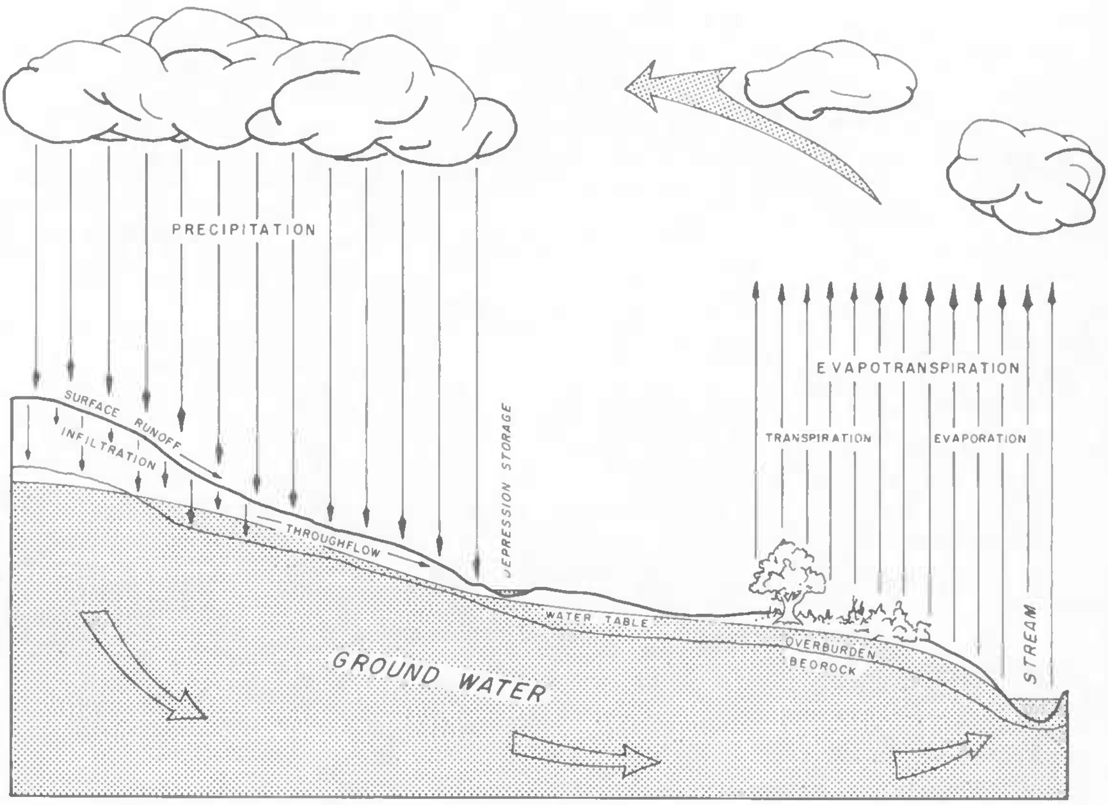


Figure 4.—The hydrologic cycle.

lie within channels or banks, but the boundaries of ground-water flow systems are usually inferred by indirect evidence.

The hydrologic cycle is an open system at the scale of a county. Much of the water in Washington County is derived from local precipitation, but additional quantities flow into the county in streams or through the ground. Of the precipitation that falls, some water flows over the land surface and leaves the county by streams, and some infiltrates into the ground. Only a fraction of this infiltrating water actually recharges ground water—some evaporates directly or is transpired by plants, and some may move laterally through unsaturated soil and into streams. The remainder percolates downward until it reaches the water table and begins to flow in response to hydraulic gradients in the saturated zone.

Ground water that discharges onto the land surface may do so at a spring and flow away within a channel. There are hundreds of springs in Washington County, the largest of which discharge from carbonate rocks (limestone and dolomite). Joints and fractures in carbonate rocks have been enlarged by dissolution by circulating ground water to form small caves in some areas of the county. Some small streams that enter caves reappear at the surface as a rise, or resurgence. Most flow of water between the surface and subsurface, however, is diffuse.

Water moving through the hydrologic cycle picks up, transports, and deposits a variety of chemicals and contaminants. Precipitation can contain significant quantities of material from atmospheric sources; Katz and others (1985) found that dissolved constituents in precipitation accounted for 12 to 19 percent of the total dissolved load in stream water in the Catoctin Mountains, which are located a few miles east of Washington County. Quality of the water changes as the chemical environment through which it moves varies—differences in mineralogy, atmospheric pressure, and mixing with other water are some factors affecting water quality. Washington County water quality is discussed further in the "Ground-Water Quality" and "Surface-Water Quality" sections of this report.

GROUND WATER

Ground water may occur under confined or unconfined conditions (fig. 5). Confined conditions exist where a fully saturated, permeable zone is bounded above and below by relatively impermeable material. In this situation, hydrostatic pressure can build up and the water level in a well drilled into the aquifer will rise above the top of the aquifer; such a well is an artesian well. If the water rises above land surface, the well is a flowing well. A fracture zone or bedding-plane partings can function as permeable stratum. Well WA Ac 44 is located at the break in slope on the west side of Tonoloway Ridge in the western part of Washington County. The reason this well flows may be because ground water is confined to bedding-plane partings (dip in the vicinity of the well is approximately 60°, from the ridgetop toward the well).

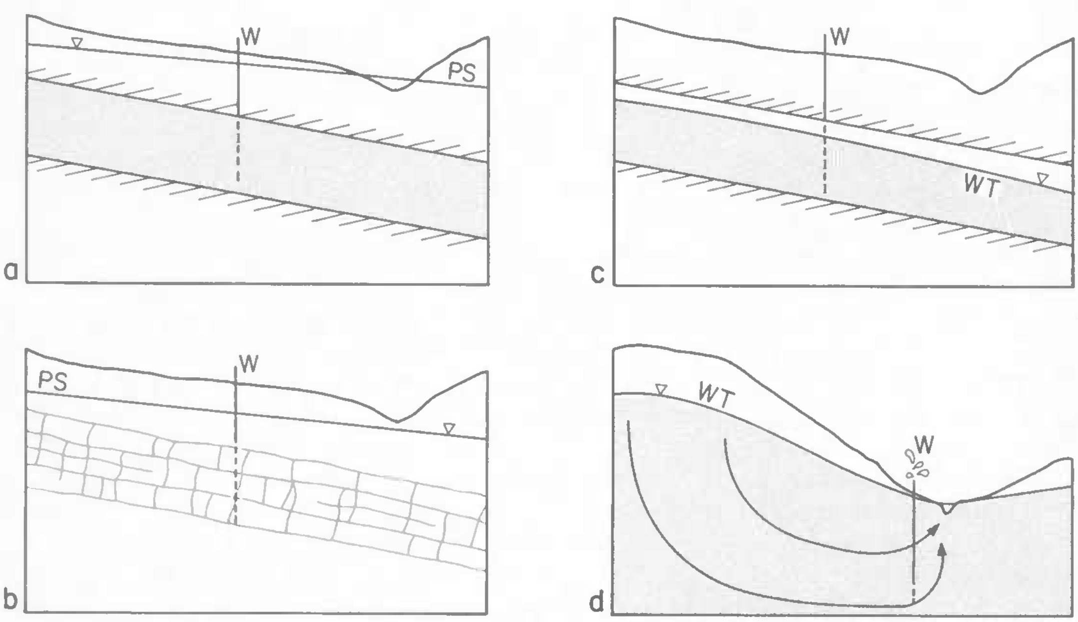


Figure 5.—Confined and unconfined conditions. W, well (dashed part of well represents open interval); PS, potentiometric surface of confined aquifers; WT, water table of unconfined aquifers. a) Low-permeability confining beds form upper and lower boundaries of confined aquifer. b) Ground water is confined under pressure to a zone of rock fractures. c) Permeable zone is not fully saturated; upper boundary of unconfined aquifer is water table. d) Flowing artesian well in unconfined aquifer due to ground-water flow paths that develop in an area of high relief.

Unconfined, or water-table, conditions exist where there is no upper confining zone or where the top of the saturated zone of the permeable material is lower than an overlying confining zone. In an unconfined aquifer, the surface of the zone of saturation, the water table, is itself the upper boundary of the aquifer, and aquifer thickness can vary over time as the water table fluctuates. Under some circumstances, an artesian well drilled into an unconfined aquifer can flow (fig. 5d); in this case topography, rather than permeability, provides the control. Well WA Di 86, located near the Potomac River, is an example of a flowing well in an unconfined aquifer. Conditions intermediate between confined and unconfined are termed semiconfined.

GROUND-WATER LEVELS

Water levels reported by drillers in well-completion reports are listed in Duigon and others (1989). Water-level data from 50 wells measured periodically and 8 wells having recorders also are tabulated in that report. Locations of wells and springs cited in this report are shown on plate 2.

Short-term water-level fluctuations correspond somewhat, but not exactly, to precipitation (fig. 6). During the spring-summer growing period, much of the rain that infiltrates the soil is taken up by plants and never reaches the water table. Frozen ground and snow accumulation also affect the timing of recharge by precipitation. These factors produce notice-

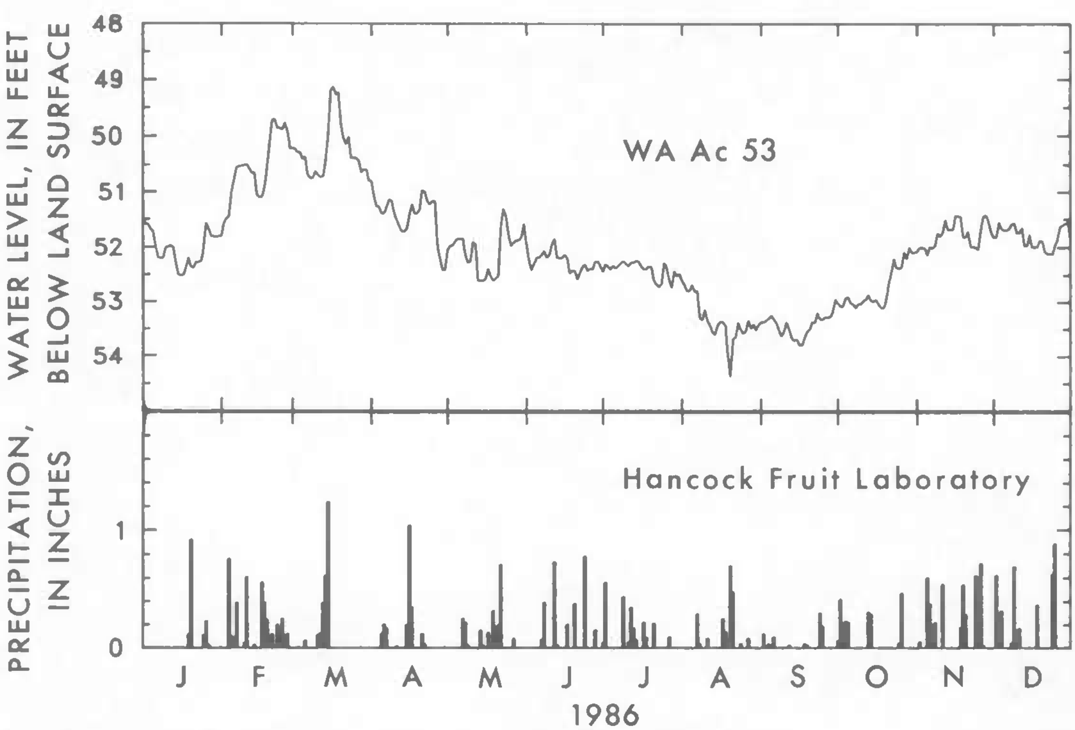


Figure 6.—Seasonal fluctuations in ground-water levels in well WA Ac 53 and precipitation during 1986. The well and the precipitation station are located in Hancock (precipitation data from National Oceanic and Atmospheric Administration, 1987).

able seasonal fluctuations in water levels, although precipitation normally does not vary much seasonally. The lowest water level in a well can occur any time of the year, but minimum water levels measured in Washington County are most frequent in October (fig. 7). Maximum water levels occur with approximately equal frequency in February, March, and April.

Long-term fluctuations generally are smaller than seasonal fluctuations (fig. 8). Long-term water-level fluctuations are indicated by the trend lines in figure 8, which are smoothing curves computed using robust locally weighted regression (Cleveland, 1979, 1985). The longest period of record of water-level observations is for well WA Ac 1, located in Hancock near the Potomac River. Water levels measured in this well over the period October 1946 to April 1987 are shown in figure 8. The highest water level was 35.7 ft below land surface, measured January 2, 1976. The lowest level was 55.8 ft below land surface, measured November 19, 1953. Water levels also are shown for well WA Dj 2, located along the crest of South Mountain, for the period December 1956 to April 1987. The extremes for this well are

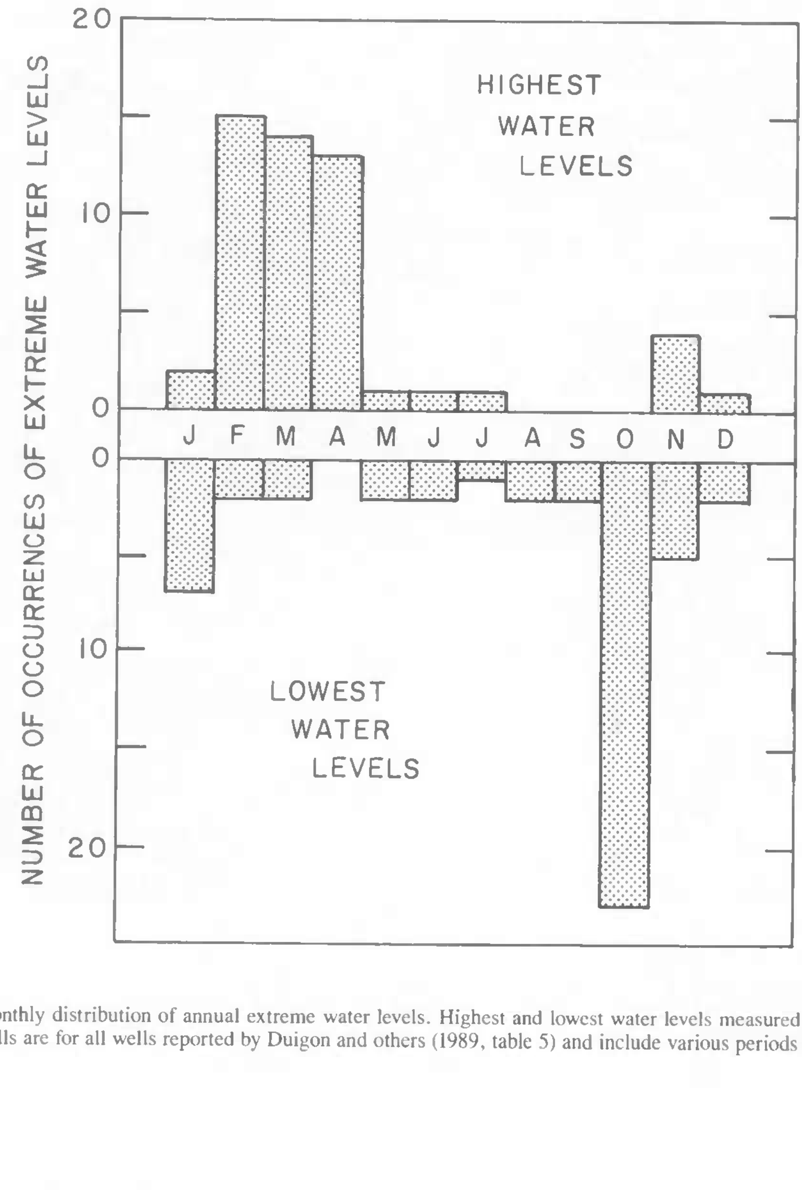


Figure 7.—Monthly distribution of annual extreme water levels. Highest and lowest water levels measured in observation wells are for all wells reported by Duigon and others (1989, table 5) and include various periods of record.

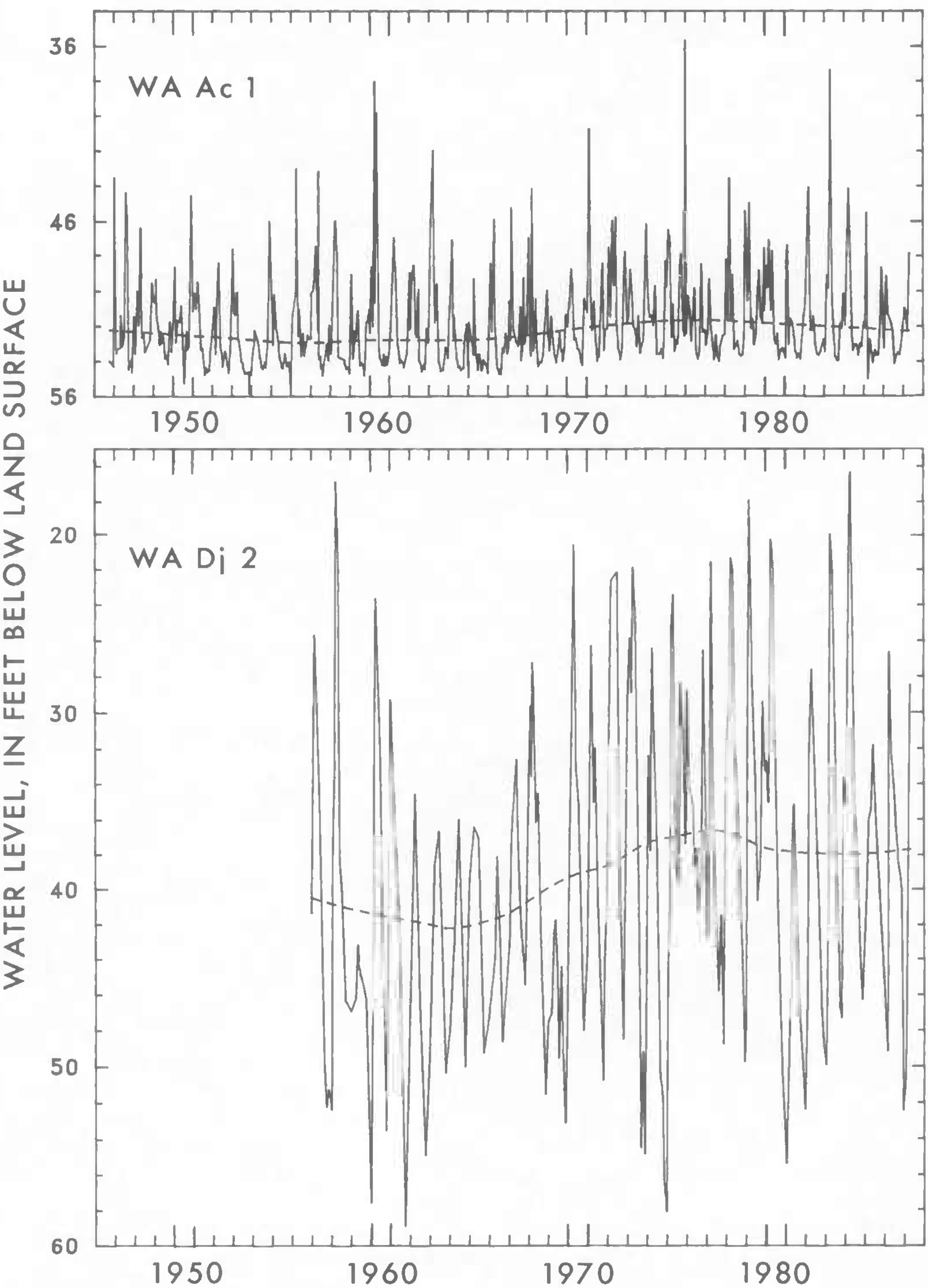


Figure 8.—Long-term fluctuations in ground-water levels. Trend line (dashed) is robust locally weighted regression curve.

16.4 ft below land surface, measured April 23, 1984, and 58.9 ft, measured October 5, 1961. The low water levels shown in figure 8 correspond to the drought of the 1960's and are followed by higher water levels of the wet 1970's and the moderate 1980's. The effect of topography may be seen in the greater range of water-level fluctuation in the mountaintop well, WA Dj 2, compared with fluctuations in WA Ac 1, which is near a major river.

Water-level fluctuations also can result from other causes (fig. 9). Well WA Bk 25, in Smithsburg, is a test well drilled in 1970. It is cased to a depth of 128 ft, which is approximately the position of the contact of the Tomstown Formation (dolomite) with the overlying colluvium. Water level in the well has been monitored with an analog recorder and fluctuates about a level above the contact. The center panel of figure 9 shows hourly values digitized from the recorder chart for the period 0100 hours on August 31, 1985, through 2400 hours on October 1, 1985. A small-amplitude periodic fluctuation is superimposed on a general downward trend. The general trend was removed by subtracting a 25-hour running mean from the hourly values; the residuals are plotted in the upper panel. These semidiurnal fluctuations are the result of tidal forces acting on the solid aquifer matrix and, to a lesser extent, are the result of changes in barometric pressure. Tidal dilatation of jointed aquifers of low primary permeability such as the Tomstown Formation can add to the driving force of the hydraulic gradient that moves water through low-permeability zones (Davis, 1966). The particularly high rise on September 27 is probably the result of the passage of a low-pressure storm system.

The lower panel in figure 9, showing part of the analog recorder chart, displays two events not seen in the discrete hourly values of the other two panels—fluctuations caused by the Mexico City earthquake of September 19, 1985 (magnitude 8.1) and an aftershock (magnitude 7.3) that occurred on September 20th (also shown by Smigaj and Davis, 1987, fig. 7). Short-period oscillations of water level occurred in the well in response to Rayleigh waves (a type of seismic surface wave), which cause greater water-level fluctuations in wells than do other wave types (Cooper and others, 1965, p. 3922). No other wells in Washington County were equipped with analog water-level recorders at the time, so comparisons of water-level responses in wells in the county cannot be made. Elsewhere, water-level responses were observed in 12 wells in Pennsylvania (Pennsylvania Geology, 1985, p. 15), and in wells in Idaho (Earthquake Information Bulletin, 1985, p. 191), Texas, New Mexico, Missouri, and Florida (Finley, 1985, p. 7). The tidal fluctuations also are evident in the lower panel of figure 9.

The occurrence of tidal- and earthquake-induced fluctuations in the water level of well WA Bk 25 is evidence that this well is completed in a confined aquifer (Cooper and others, 1965; Bredehoeft, 1967; Robinson and Bell, 1971). The overlying colluvium (or a zone within the colluvium) can act as the confining zone.

The downward percolation of ground water can be impeded in some localities by a low-permeability horizon, which allows a saturated zone to build up, or be perched, at a level above the main ground-water body. The impeding zone can be a low-permeability soil horizon, such as a fragipan only a few feet deep, or it could be a low-permeability bedrock zone. Soils characterized by seasonally high water perched on fragipans are identified in the Washington County soil survey (Matthews, 1962).

Ground-water levels are shown on plate 2. This map was prepared using water-level data from the basic-data report (Duigon and others, 1989); however, to eliminate seasonal extremes, water levels reported for February, March, April, and October were not included. Altitudes of springs and the stream network also were used in making this map, which represents average conditions.

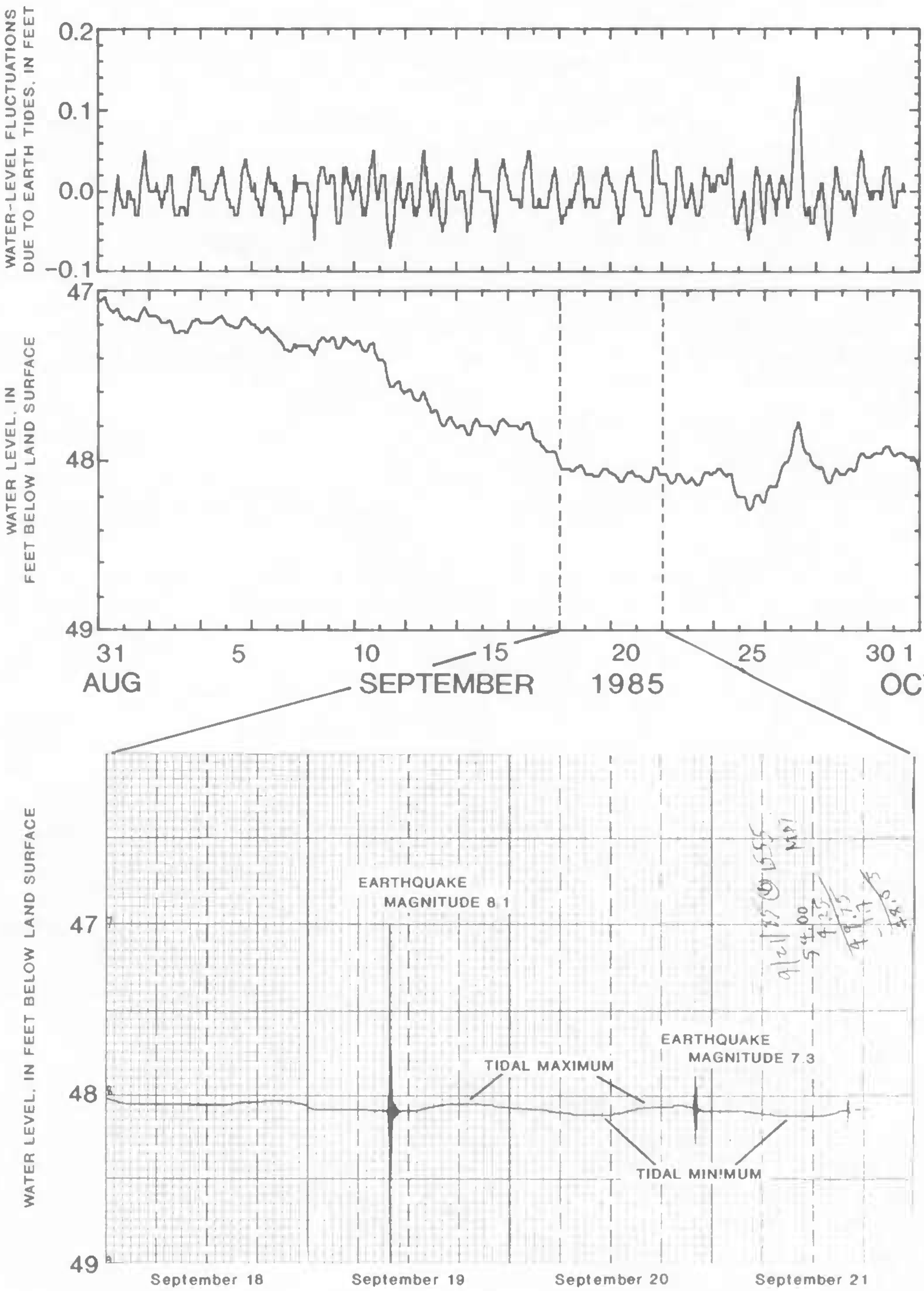


Figure 9.—Response of water levels in well WA Bk 25 to earth tides and to Mexico City earthquake of September 1985. Center panel was plotted using hourly water levels for September. Top panel shows these values with long-term variability filtered out; residuals are due chiefly to earth-tide effects. Bottom panel is reproduction of original analog record showing earthquake and aftershock, as well as earth-tide, effects.

The configuration of the water-level surface resembles that of the land surface. Hydraulic gradients are steepest along the flanks of ridges and gentlest in the broad Hagerstown Valley. Ground water generally flows downgradient toward the streams, which flow to the Potomac River.

Plate 2 is a generalized map, derived from measurements collected over a long period of time and drawn at a relatively coarse scale. At a more local scale, most ground-water flow is through fractures, bedding-plane partings, or solution channels, and the direction of flow can deviate from the direction of the hydraulic gradient. Variations in water level of several feet may occur over short horizontal distances because of the heterogeneous, anisotropic nature of the water-bearing formations, and such variations can affect interpretations of localized ground-water flow. This is most likely to occur in areas underlain by carbonate rocks where circulating ground water has enlarged joints and fractures by solution; in such situations, the configuration of the ground-water-level surface may bear little resemblance to land-surface topography. Nevertheless, plate 2 is useful for understanding general ground-water flow patterns in Washington County.

AQUIFER PROPERTIES

The hydrogeologic properties of the rocks of Washington County are highly variable. The crystalline rocks and the well-indurated sedimentary rocks generally have little primary, or intergranular, permeability; joints and fractures provide secondary permeability, which permits ground-water flow. The joints and fractures are generally tight but, in some carbonate rocks, can be considerably enlarged by the solvent action of circulating ground water.

Relations of joints with lithology and structure in the Great Valley of Maryland and West Virginia were discussed by Davies (1968). He described three joint sets in the Weverton Formation and the Tuscarora Sandstone and three to six sets in the carbonate rocks and in the Martinsburg Formation. Geiser (1974) described the occurrence of, and some controls on, cleavage in the Bloomsburg Formation. The rocks are mostly covered by unconsolidated material (scattered alluvial and colluvial deposits of Quaternary age, or thoroughly weathered rock, or both) that can have significant primary porosity and storage capability. These unconsolidated deposits are generally not sufficiently permeable or do not have sufficient saturated thickness to be useful aquifers.

Differences in lithology and geologic structure result in large ranges of values of aquifer properties within individual geologic formations, which can cause aquifer anisotropy. Furthermore, a geologic formation can function as a confined aquifer in one area and as an unconfined aquifer in another area, or it can convert from confined to unconfined at a given location as pumping lowers the potentiometric surface below the confining bed or zone. For these reasons, representative values of aquifer coefficients T[1] and S[2] for the various geologic formations present in Washington County are of little benefit. As a generalization for the county, transmissivity (T) ranges from less than 10 to greater than 1,000 ft^2/d, and storage coefficients (S) range from approximately 10^{-4} to 10^{-1}.

[1]Transmissivity (T) is the rate of discharge of a fluid (in this case, water) through a unit width of an aquifer perpendicular to the hydraulic gradient under a hydraulic gradient of unity. It is expressed in the dimensions of $length^2/time$.

[2]Storage coefficient (S) is the volume of water released from, or taken into, an aquifer per unit surface area as a result of a unit change in hydraulic head. It is dimensionless.

Transmissivity and storage coefficient can be determined from pumping tests. During such a test, a well is pumped (preferably at a constant rate) while water levels are measured in the pumped well and, preferably, in one or more observation wells. The tests need to be of sufficient duration and enough measurements need to be made to reveal the hydrogeologic boundary conditions that exist. Such tests are infrequently conducted in Washington County; instead, short-duration tests that do not use observation wells are commonly undertaken, chiefly to evaluate well performance rather than aquifer characteristics. If such data are used to determine aquifer properties, misleading conclusions can result. In any case, a suitable analytical method must be carefully applied.

An interesting example uses data from a pumping test conducted September 30–October 2, 1958, on well WA Al 9 (located in the northeastern corner of the county), which is completed in the Catoctin Formation (metabasalt). This was a relatively long test—2,900 minutes of pumping followed by 400 minutes of recovery monitoring. Water levels were measured in two observation wells, 390 and 900 ft away from the pumped well, but they did not seem to respond to the pumping. A transmissivity of 428 ft^2/d was determined from a semilogarithmic plot of residual drawdown in the pumped well (Slaughter, 1962, p. 39).

Reexamination of the test data indicates that this value is more than one order of magnitude too high. A log-log plot of drawdown versus time (fig. 10) shows a nearly horizontal region for intermediate values of time, which is characteristic of water-table conditions.

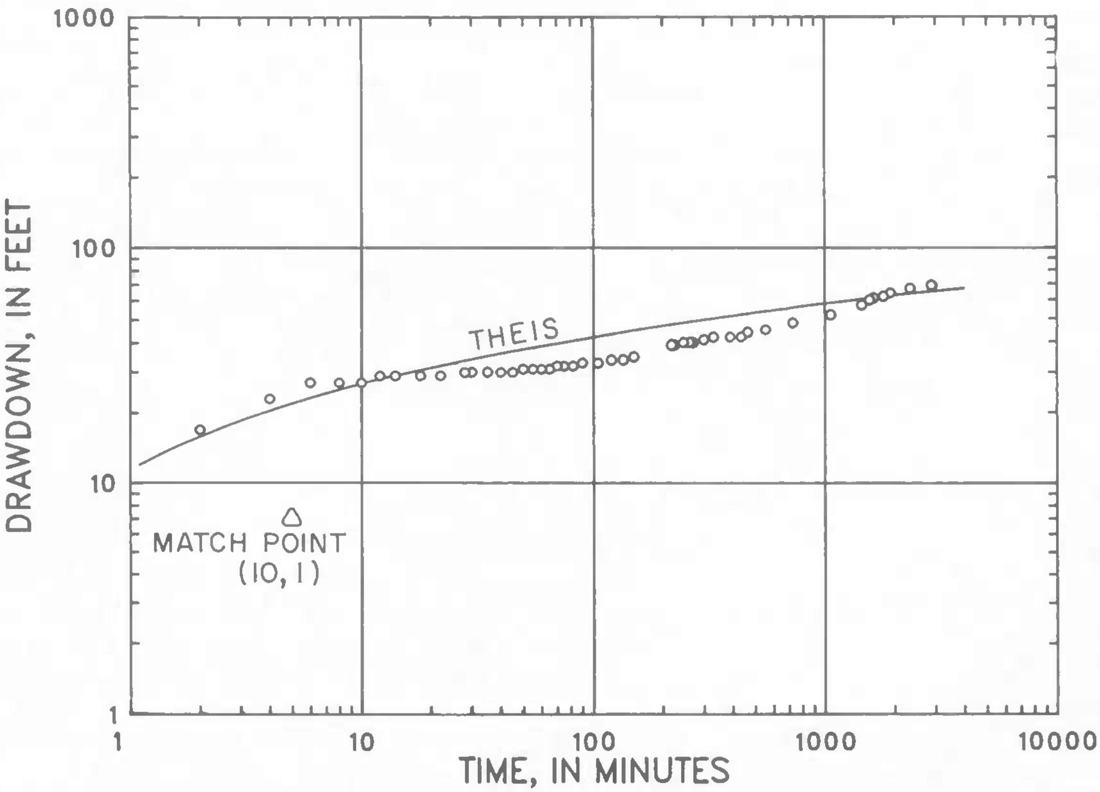


Figure 10.—Deviation of time-drawdown curve from Theis curve, well WA Al 9. Observed drawdowns for intermediate times clearly plot below the Theis solution because of delayed gravity drainage of the unconfined aquifer.

This intermediate region does not lie on the Theis curve, so a Theis-based analytical method applied to the intermediate data would overestimate transmissivity. Of the various Theis (1935, p. 521) assumptions (a well of infinitesimal diameter that fully penetrates an isotropic aquifer of infinite extent, composed of homogeneous sediments and in which transmissivity remains constant and, in the case of unconfined aquifers, ground water is released immediately from storage in the cone of depression), deviation of actual conditions from the last one probably affected water-level response to pumping the most. Nevertheless, transmissivity can be estimated by use of the Jacob (1950) semilogarithmic plotting method and the slope of the late-time drawdowns, or by curve-matching as described by Neuman (1975) and discussed in the following paragraph.

The data for well WA Al 9 are plotted logarithmically (fig. 11). Type curves were plotted at the same scales for selected values of β (a dimensionless parameter of anisotropy), and the best matches were determined for β = 0.2 (fig. 11). The drawdown values for match points (1,1) are approximately 28 ft for the Type A match and for the Type B match, so computation based on use of both types yields identical results. The drawdown value obtained from the match point is used in the equation

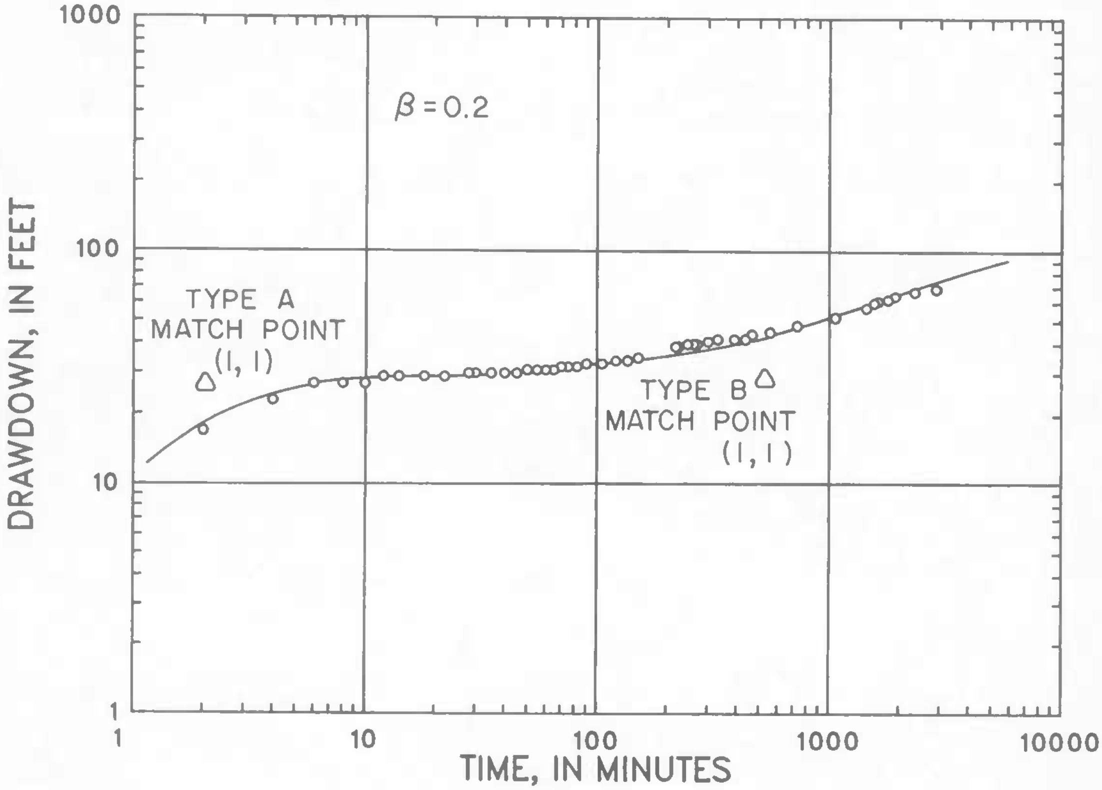


Figure 11.—Time-drawdown curve of well WA Al 9 matched to type curves for unconfined aquifers having delayed gravity response. This well was pumped at an average rate of 52.6 gallons per minute for 2,900 minutes. Type curves for β = 0.2 are used; value for drawdown at match points (1,1) is about 28 feet for both Type A and Type B curves. For explanation of method, see Neuman (1975).

$$T = c_1 (Qs_D^*/s^*),$$

where

T is transmissivity,

c_1 is a constant that depends on the units used,

Q is discharge,

s_D^* is dimensionless drawdown at the match point,

and

s^* is drawdown at the match point.

Any consistent set of units may be used; for Q expressed in gallons per minute and s* in feet and to obtain T in feet squared per day, $c_1 = 15.32$. Using the values from figure 11:

$$T = 15.32\ [52.6 \text{ gal/min } (1)/28 \text{ ft}] = 29 \text{ ft}^2/\text{d}.$$

Had the observation wells responded to pumping, then not only transmissivity, but specific yield (S_y), elastic storage coefficient (S), horizontal and vertical permeabilities, and the specific storage of the aquifer could be estimated, following the procedure outlined by Neuman (1975).

A test was conducted July 18–19, 1978, using well WA Bf 130—a supply well for the town of Clear Spring (data from files of the Maryland Water Resources Administration). This well is 305 ft deep and is cased to a depth of 55 ft. Drillers' logs describe the rocks as gray limestones, so the well is presumed to be completed in the Helderberg Formation rather than in the Oriskany Sandstone, which appears to underlie the site according to the well-location map (Duigon and others, 1989) and the geologic map (pl. 1).

Although the test was more than 25 hours in duration, only the early part is used for matching against the Theis curve (fig. 12). The deviation of the later part of the test is likely due to the decrease in pumping rate, which varied from an average of 176 gal/min near the start of the test to an average of 138 gal/min near the end of the test. Also, a second well, located approximately 200 ft away from WA Bf 130, started pumping at a rate of about 35 gal/min, 75 minutes into the test. Alternatively, the deviation of observed drawdown from the Theis solution could be caused by leakage from the unconsolidated overburden or from matrix rock of a double-porosity model (in which the aquifer is considered to consist of two components—a fissure network and permeable blocks, or matrix—each of which are characterized by different values of permeability and storage).

With the data superimposed on the Theis curve as shown in figure 12, and a match point of 1/u and W(u) selected at (1,1), the corresponding drawdown (s) is about 6.2 ft. Solving the Theis nonequilibrium formula for transmissivity (Wenzel, 1942, p. 88) yields

$$T = \frac{114.6Q}{s} W(u) = \frac{114.6\ (176 \text{ gal/min})}{6.2 \text{ ft}} (1) = 3{,}253 \text{ (gal/d)/ft or } 435 \text{ ft}^2/\text{d}.$$

FACTORS AFFECTING WELL YIELDS

Reported well yields in Washington County range from 0 (dry hole) to 385 gal/min; the median is 10 gal/min. The distribution of yields reported from 2,141 inventoried wells is not a normal distribution (Kolmogorov-Smirnov test, SPSS, Inc., 1983). A logarithmic trans-

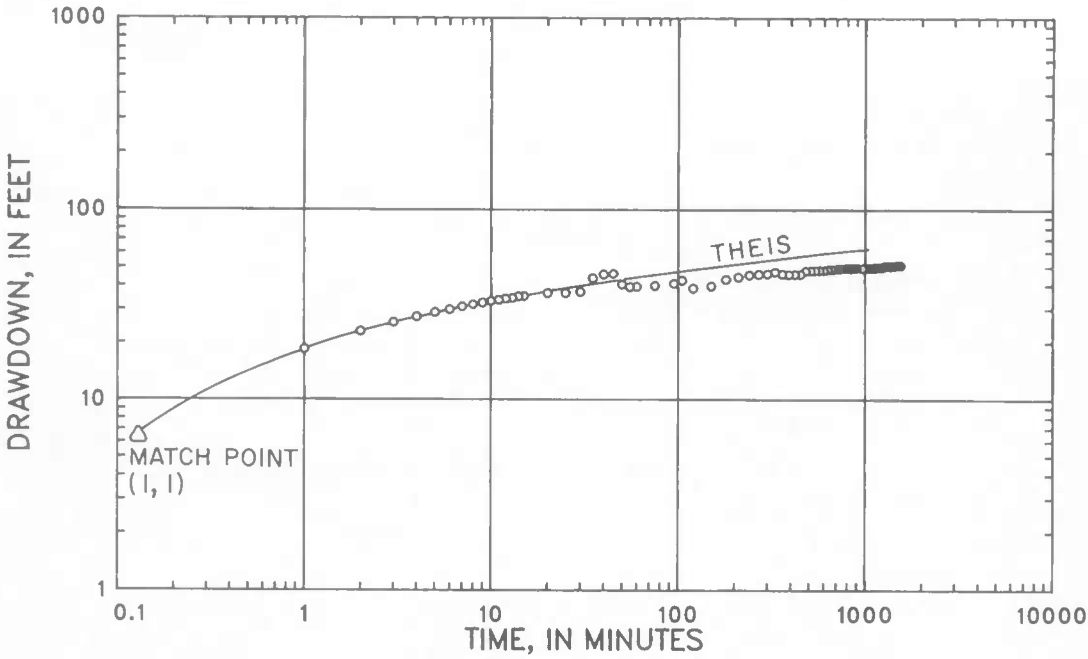


Figure 12.—Drawdown versus time for well WA Bf 130.

formation of the data does not produce a normal distribution, but does change the strong skewness to the right (yields that are greater than the mode, or most common value, extend over a broader range than do yields less than the mode) to an insignificant level, and likewise reduces the highly significant leptokurtosis (a greater frequency of yields near the mean and at the extremes than at intermediate values) to an insignificant level (fig. 13). The deviation of the distribution curve shown in figure 13 from linearity near the low-yield end is an artifact of rounding off estimated yields to a convenient 1 or 2 gal/min (convenient in part because they are easier to envision and in part because of required minimum yields).

Specific capacity (discharge divided by drawdown) provides a useful means of assessing the productivity of a well at any pumping rate. Specific capacity is constant for a given duration of pumping under ideal conditions (homogeneous, isotropic aquifer, and laminar flow). In many wells, however, increasing the pumping rate results in additional head losses caused by turbulent flow; these comprise an increasing proportion of the total drawdown. The increase in head loss due to turbulent flow results in greater total drawdown than would occur under ideal conditions. As shown in the upper panel of figure 14, drawdown for well WA Bk 25 is a nonlinear function of pumping rate (the curve is slightly concave upward). Consequently, the curve for specific capacity (lower panel) is not horizontal.

The distribution of specific capacities of 1,892 inventoried wells is shown in figure 15. As was the case with reported well yields, the distribution is approximately log-normal, but at the low-yield end, percentages are somewhat higher than might be expected based on the rest of the distribution. The log-normal distributions reflect the preponderance of low to moderate yields and the increasing rarity of higher yields. The specific capacities for which the distribution is shown in figure 15 range from 0 to 86 (gal/min)/ft; the median is 0.167 (gal/min)/ft. Most of the inventoried wells were drilled for domestic use, so in many cases low yields were considered adequate, and no efforts were made to increase yield.

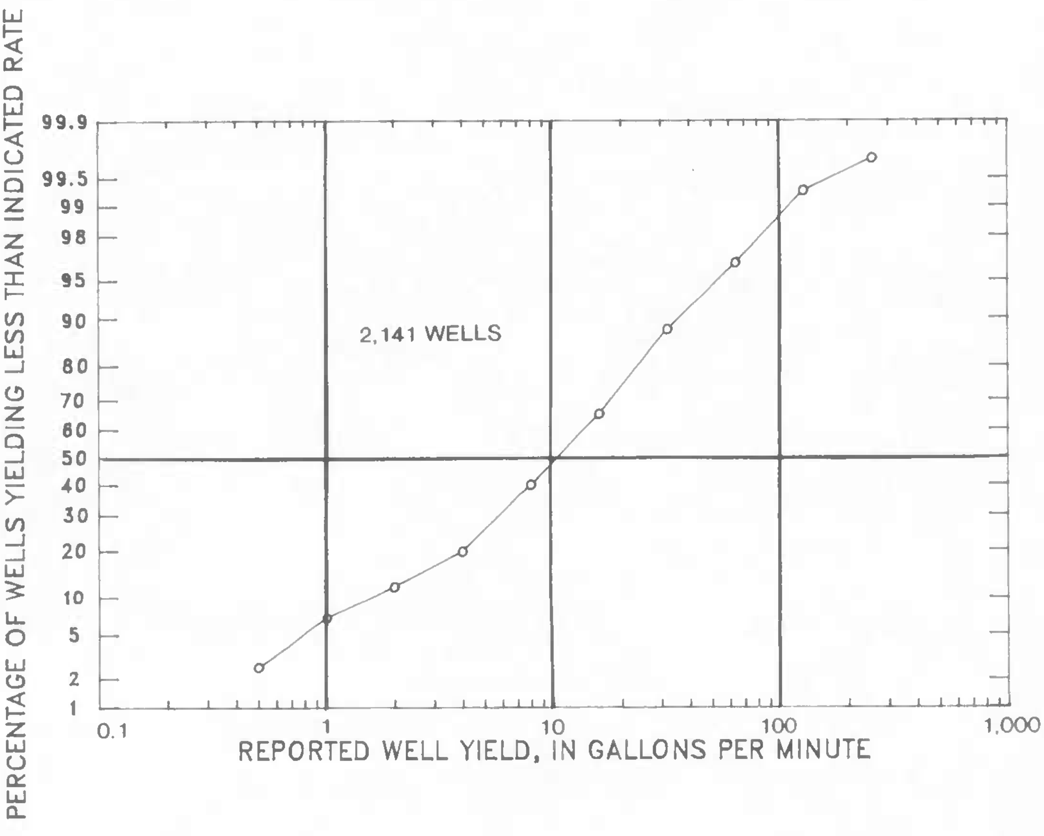


Figure 13. –Cumulative frequency distribution of yields of wells inventoried in Washington County.

The interrelations of five well-yield and well-construction characteristics are shown in figure 16 (each relation is shown both ways to facilitate comparisons). Of the 10 combinations of variables shown, only two are noticeably correlated. There is a positive correlation of specific capacity and reported yield, but that is because specific capacity is defined as yield divided by drawdown. Specific capacity and well depth are negatively correlated, because low-yielding wells are commonly drilled deeper in an effort to obtain more water, and maximum drawdown is limited by well depth. The width of the specific-capacity field in the plots with reported yield indicates a broad range of aquifer diffusivity (T/S) throughout Washington County.

There is a tendency to associate individual aquifers with individual geologic formations. In fact, ground-water flow-system boundaries in Washington County are more closely related to topography and structural features than they are to geologic-formation boundaries. The variability of hydrogeologic characteristics within a formation can be quite large, making it difficult to judge differences between formations. The well-yield and well-construction characteristics of the geologic units for which there are data are summarized in table 1. On the basis of specific capacity, no distinct groupings of geologic units can be discerned (fig. 17). Results of Kruskal-Wallis tests (SPSS, Inc., 1983) performed on specific-capacity and geologic-unit data for all rock types, for carbonate rocks, and for noncarbonate rocks indi-

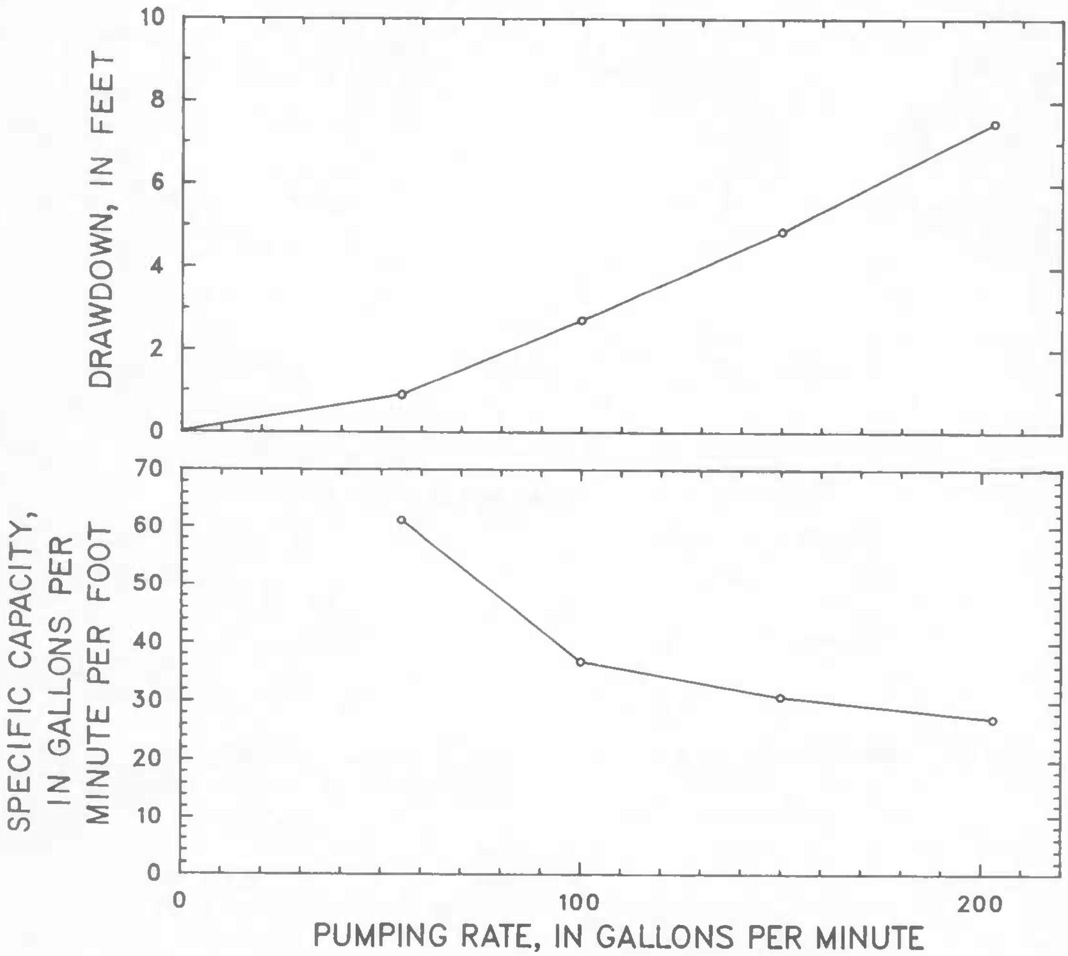


Figure 14.—Relations among pumping rate, drawdown, and specific capacity, well WA Bk 25. Drawdown for each step is the sum of the incremental drawdowns. Well is 200 feet deep; static level at the time of the test was 34.6 feet below land surface.

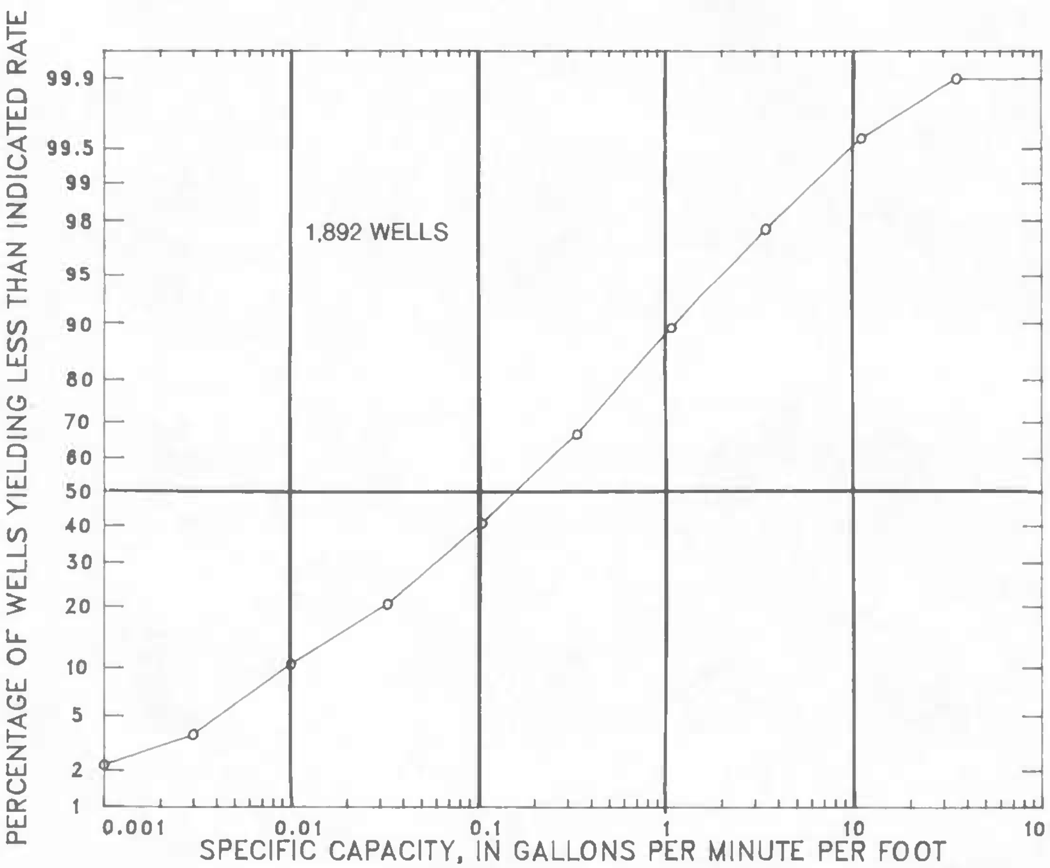


Figure 15.—Cumulative frequency distribution of specific capacities.

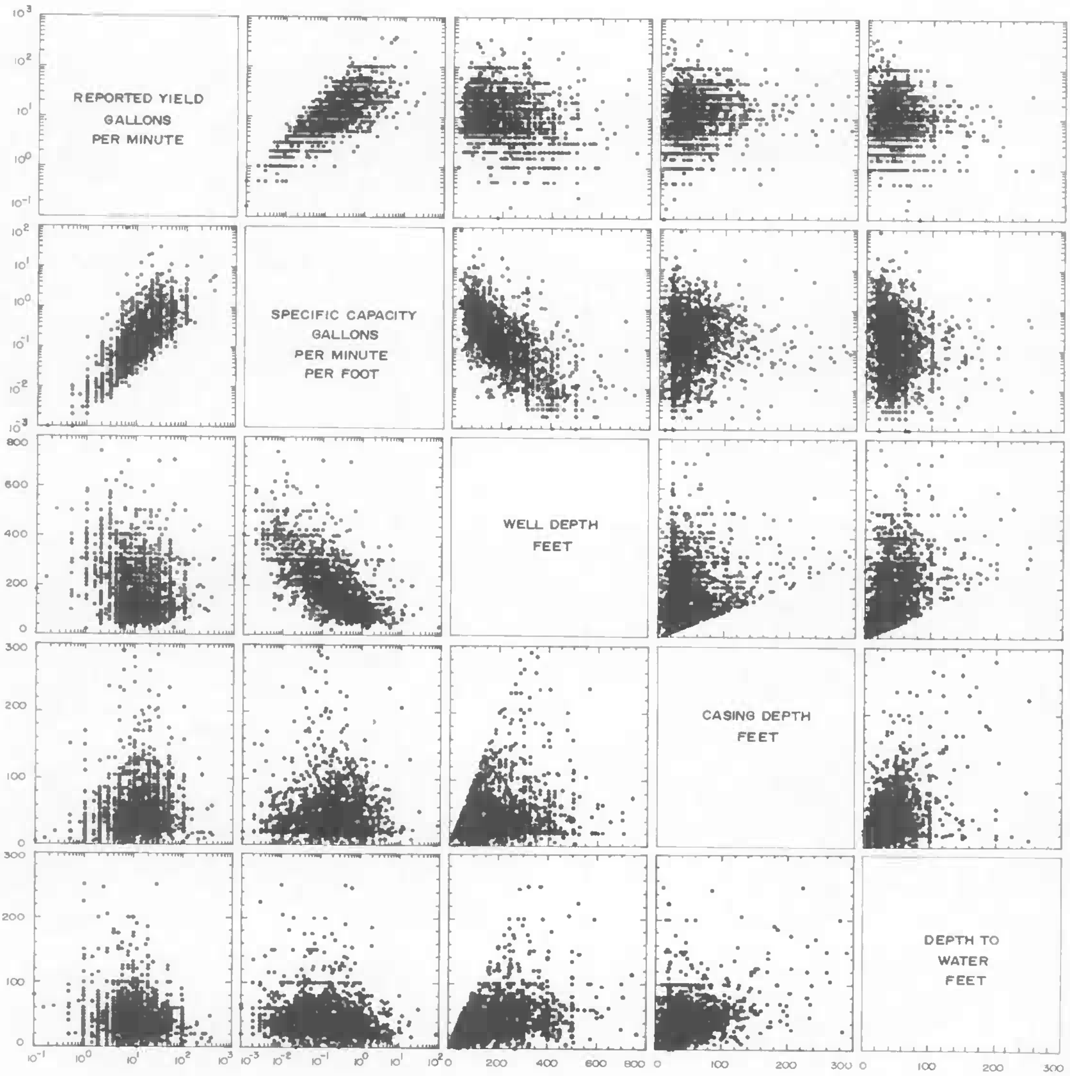


Figure 16.—Scatterplot matrix of well-yield and well-construction characteristics.

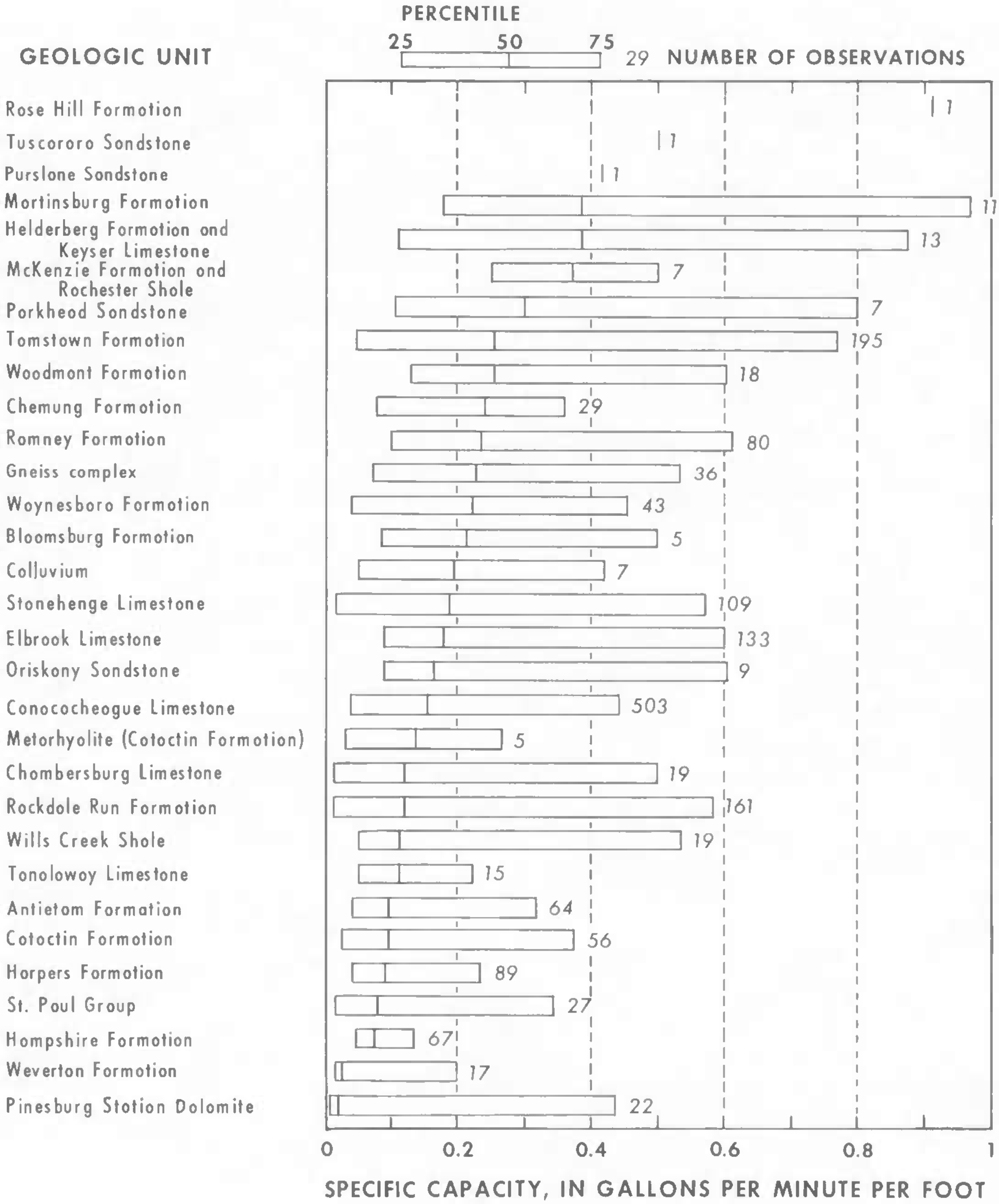


Figure 17.—Quartiles of specific capacities of wells grouped by geologic unit.

TABLE 1
WELL-YIELD AND WELL-CONSTRUCTION CHARACTERISTICS OF THE GEOLOGIC UNITS

Geologic unit[1]	Reported yield (gallons per minute)					Specific capacity (gallons per minute per foot)					Well depth (feet)				
	Number	Minimum	Maximum	Median	Mean	Number	Minimum	Maximum	Median	Mean	Number	Minimum	Maximum	Median	Mean
ALVM	0	--	--	--	--	0	--	--	--	--	3	13	27	22.4	20.8
ANTM	68	1	100	10	12.5	64	0.003	10	0.10	0.405	70	36.4	600	245	241.7
8M8G	5	2	30	10	12.0	5	.07	.50	.21	.276	8	67	330	99.5	139.1
C8BG	21	0	50	6	13.8	19	.000	2.00	.12	.324	21	65	450	175	216.0
CCCG	550	0	370	12	18.4	503	.000	30	.15	.538	641	8.2	705	150	183.6
CMNG	32	2	70	10	11.2	29	.02	6.0	.24	.443	48	12.6	400	100	117.4
CTCN	66	1	95	8	13.6	56	.002	3.33	.097	.396	78	14	500	181	193.9
ELBK	150	.5	100	15	21.4	133	.003	11	.18	.436	160	25	460	200	198.6
G8GG	37	1	53	9.4	11.9	36	.01	6.0	.228	.477	48	10	450	112.5	132.1
HDBG	14	4	150	15	44.8	13	.07	1.67	.385	.505	15	70	345	202	208.9
HMPR	70	2	90	7	12.2	67	.01	.79	.07	.127	85	38	425	180	182.9
HRPR	98	1	60	8.5	12.1	89	.003	5.00	.09	.314	109	7.8	500	200	195.4
MCKZ	8	5	25	11	13.5	7	.09	.57	.37	.359	12	11.8	250	110	105.6
MNWS	10	0	16	8	7.8	7	.000	2	.19	.434	22	23.8	434	77.5	94.7
MR8G	132	1	100	15	17.6	117	.007	4.00	.38	.654	146	15.3	400	100	115.5
MTRL	5	2	15	10	9.0	5	.008	.33	.13	.144	5	100	300	235	227.0
ORSK	11	4	50	12	15.8	9	.05	2.00	.17	.430	14	37.5	405	173	179.0
P8GS	24	1	80	6.5	12.2	22	.004	1.46	.021	.246	24	51	445	247.5	263.9
PRKD	7	6	20	10	11.4	7	.08	2.00	.30	.589	12	35	250	126	138.2
PRSL	1	30	30	30	30	1	.42	.42	.42	.42	2	128	322	225	225.0
RCKR	195	0	100	10	13.9	161	.000	12	.12	.575	225	19	760	145	180.0
RMNY	97	1	150	12	21.3	80	.002	4.00	.23	.509	121	25	500	120	145.1
RSHL	4	2	10	7.5	6.8	1	.91	.91	.91	.91	4	80	125	115	108.8
SNNG	138	0	385	12	30.4	109	.000	86	.190	1.369	138	32	910	182.5	209.4
STPL	31	.3	50	6	13.7	27	.003	2.73	.08	.292	34	49.7	508	192.5	209.6
TCRR	2	6	30	18	18.0	1	.50	.50	.50	.50	2	500	700	600	600.0
TMSN	216	0	300	15	24.6	195	.000	20	.25	.852	231	19.5	740	150	192.8
TNLY	18	3	70	10	13.5	15	.03	.45	.11	.149	20	70	320	205	190.6
TRRC	0	--	--	--	--	0	--	--	--	--	2	15.5	25	20.3	20.3
WDMN	22	.5	100	12	19.1	18	.002	1.33	.253	.390	31	40	405	109	125.3
WLCK	20	3	20	11	12.2	19	.01	2	.111	.382	26	28	565	132.5	173.6
WS8R	46	1.5	100	10	17.9	43	.012	2.00	.222	.390	52	13	475	167.5	186.6
WVRN	19	1	25	5	6.1	17	.002	5.00	.03	.384	23	22.4	500	245	229.0

cates statistically significant differences are present in each of these three categories. No significant difference was found between carbonate and noncarbonate rocks, using the Mann-Whitney U test (SPSS, Inc., 1983). Thus, the variability of specific capacity between geologic units shown in figure 17 is due partly to random variation, differences in topographic setting and degree of fracturing, presence of intergranular permeability in some parts of some units, and perhaps other factors as well.

Topography does not seem to affect reported well yield (fig. 18); however, it does seem to have some effect on well specific capacity (fig. 19). Although the differences in distributions of specific capacity among the seven topographic settings shown in figure 19 do not appear particularly great (except for wells situated on terraces), analysis by means of the Kruskal-Wallis test (SPSS, Inc., 1983, p. 692–693) indicates that topographic setting affects specific capacity differentially at a highly significant level. Based on figure 19, terraces and valley flats are the more favorable locations for productive wells, whereas hilltops and hillsides are the least favorable sites. Upland draws do not appear to be as favorable for well sites in Washington County as they are in Frederick County (Duigon and Dine, 1987, p. 38).

GROUND-WATER QUALITY

Physical Properties and Major Inorganic Ions

Duigon and others (1989) present ground-water-quality data for Washington County that have been collected over many years. Most of the physical properties and constituents vary

Depth of casing (feet)					Water level (feet below land surface)					Geologic unit[1]
Number	Minimum	Maximum	Median	Mean	Number	Minimum	Maximum	Median	Mean	
1	22.4	22.4	22.4	22.4	1	10.3	10.3	10.3	10.3	ALVM
68	10	400	72	101.6	67	6	225	60	69.0	ANTM
5	11	63.7	25	31.1	7	8	99	40	51.1	BMBG
20	18	74	29	33.4	20	20	120	47.5	48.0	CBBG
590	1.5	204	34.5	43.4	585	2.5	200	40	45.0	CCCG
34	12.6	76	34	36.8	44	4.1	90	36.5	37.6	CMNG
70	1.2	109	33.5	40.4	75	2.3	134.4	30	31.5	CTCN
147	4	190	37	48.2	151	4	165	50	50.0	ELBK
41	3	96	37	36.6	44	4	55	22	23.8	GBGG
14	20	260	54.5	66.6	15	17	150	40	68.4	HDBG
68	12	100	34	35.0	78	3	150	50	53.7	HMPR
100	7.8	160	42	50.0	105	4.3	125	38	40.1	HRPR
9	11.8	81	33	47.3	10	7.1	60	37.8	35.9	MCKZ
18	23.8	135	49	64.7	20	5	60	19	24.0	MNWS
133	10	80	31	35.0	139	3	95	30	31.4	MRBG
5	28	89	55	51.7	5	32	60	38	40.6	MTRL
12	19	185	38.8	80.4	13	20	185	65	82.7	ORSK
24	19	70	21	27.6	24	15	75	30	35.8	PBGS
7	18	42	24	29.3	11	.5	71.1	42	39.5	PRKD
1	223	223	223	223	2	61.8	250	155.9	155.9	PRSL
182	1	134	22	27.5	196	2.2	250	30	35.6	RCKR
98	7	284	36	43.0	112	0	140	35	36.8	RMNY
3	35	51	41	42.3	5	12.3	28.3	19.4	20.2	RSHL
128	1.5	125	24.5	32.4	126	3	100	30	34.8	SNNG
33	4	50	25	29.0	32	8	62.3	35	34.8	STPL
2	42	54	48	48.0	1	100	100	100	100	TCRR
222	4	290	50	60.8	223	5	246	40	48.2	TMSN
17	21	265	73	99.9	17	0	175	50	59.2	TNLY
0	--	--	--	--	0	--	--	--	--	TRRC
19	16	63.5	33	34.4	31	8	80	40	40.5	WDMN
18	13	237	34	54.2	22	5	205	50	52.1	WLCK
47	13	205	55	61.0	50	10.3	125	50	54.8	WSBR
18	18	90	37.5	45.3	21	14.9	200	60	67.3	WVRN

[1]Explanation of geologic-unit codes

ALVM	Quaternary alluvium
ANTM	Antietam Formation
BMBG	Bloomsburg Formation
CBBG	Chambersburg Limestone
CCCG	Conococheague Limestone
CMNG	Chemung Formation
CTCN	Catoctin Formation
ELBK	Elbrook Limestone
GBGG	Gneiss complex
HDBG	Helderberg Formation and Keyser Limestone
HMPR	Hampshire Formation
HRPR	Harpers Formation
MCKZ	McKenzie Formation and Rochester Shale
MNWS	Colluvium
MRBG	Martinsburg Formation
MTRL	Metarhyolite (Catoctin Formation)
ORSK	Oriskany Sandstone
PBGS	Pinesburg Station Dolomite
PRKD	Parkhead Sandstone
PRSL	Purslane Sandstone
RCKR	Rockdale Run Formation
RMNY	Romney Formation
RSHL	Rose Hill Formation
SNNG	Stonehenge Limestone
STPL	St. Paul Group
TCRR	Tuscarora Sandstone
TMSN	Tomstown Formation
TNLY	Tonoloway Limestone
TRRC	Terrace gravel
WDMN	Woodmont Formation
WLCK	Wills Creek Shale
WSBR	Waynesboro Formation
WVRN	Weverton Formation

widely throughout the county (table 2), reflecting the diversity of mineralogy, biology, and flow paths that affect the chemistry of ground water. Approximately two-thirds of the 37 geologic units (as mapped by Edwards, 1978) were sampled (table 3). Some of these units were only sampled once, whereas others are represented by several or many samples.

Concentrations of four of the constituents listed in table 2 exceed recommended limits in some samples. Dissolved nitrate concentrations in samples from three wells exceeded the national primary drinking-water regulations maximum contaminant level (MCL) of 10 mg/L as N (U.S. Environmental Protection Agency, 1987b, p. 530). Nitrate concentrations greater than this level may affect the ability of the blood of infants to carry oxygen, causing a form of anemia. Common sources of nitrate include fertilizer and animal and human wastes,

(Text continued on p. 33.)

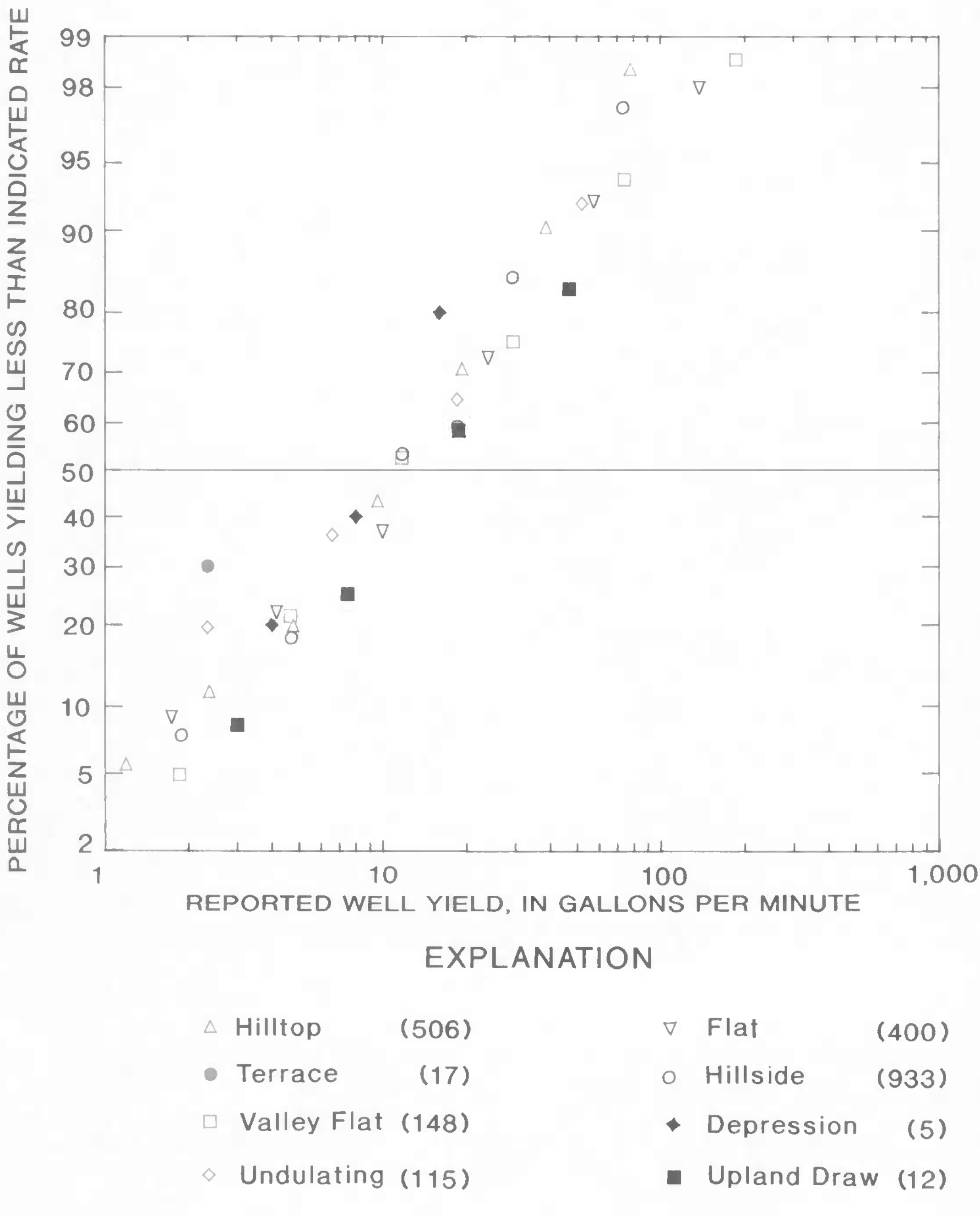


Figure 18.—Cumulative frequency distributions of yields of wells grouped by topographic setting.

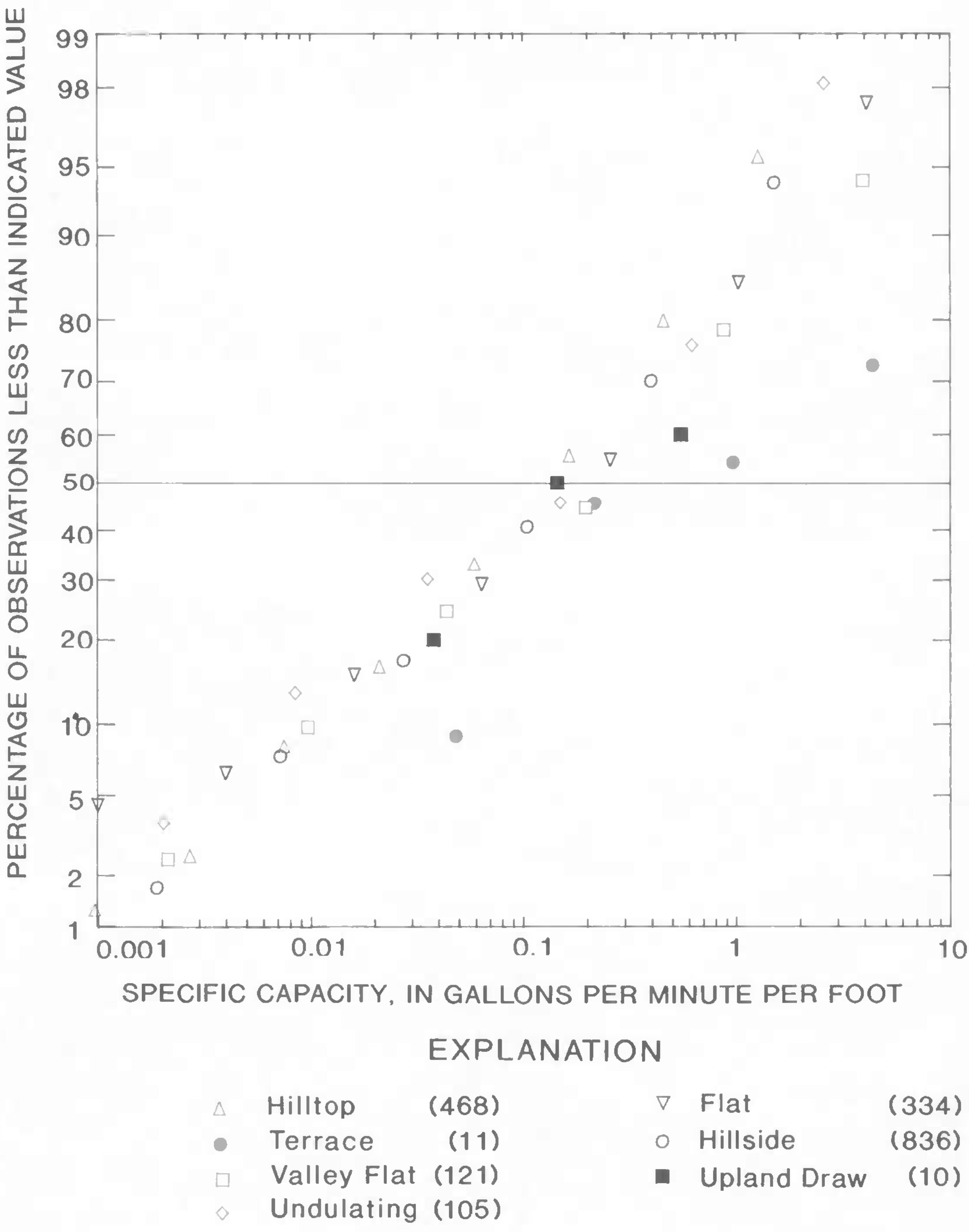


Figure 19.—Cumulative frequency distributions of specific capacities of wells grouped by topographic setting. Numbers in parentheses are numbers of observations.

TABLE 2
SUMMARY OF GROUND-WATER QUALITY
[Concentrations in milligrams per liter. For sites having multiple observations, the mean value for the site was used]

Property or constituent	Number of sites	Minimum	Maximum	Median	Mean
Specific conductance (μS/cm)	224	18	3,680	522.5	547.3
pH	226	3.0	8.4	7.5	7.34
Hardness (as $CaCO_3$)	209	.3	1,600	240	231.0
Calcium, dissolved	174	.10	550	62	64.2
Magnesium, dissolved	174	.02	90	11	15.4
Sodium, dissolved	153	.90	90	9.30	16.54
Potassium, dissolved	153	.30	83	2.30	9.33
Total alkalinity (as $CaCO_3$)	205	2.0	468	216	190.5
Sulfate, dissolved	174	<5.0	2,600	19	54
Chloride, dissolved	208	<.05	200	7	12.8
Fluoride, dissolved	164	<.05	1.6	.2	.3
Nitrate, dissolved (as NO_3)	172	.02	76	4.35	7.38
Silica, dissolved	131	.20	34	11	12.6
Total dissolved solids (sum of dissolved constituents)	120	19	2,200	290	321.6

TABLE 3
SUMMARY OF BASIC WATER CHEMISTRY OF THE GEOLOGIC UNITS
[Footnoted statistics are bracketed due to effects of observations less than detection limits]

Geologic	Specific conductance (microsiemens per cm at 25°C)					pH					Hardness (milligrams per liter as $CaCO_3$)				
unit[1]	Number	Minimum	Maximum	Median	Mean	Number	Minimum	Maximum	Median	Mean	Number	Minimum	Maximum	Median	Mean
ANTM	5	34	501	370.5	298.7	5	5.7	7.9	7.80	7.20	5	7	270	86	116.2
C88G	1	970	970	970	970	1	6.6	6.6	6.6	6.6	1	560	560	560	560
CCCG	90	301	3,680	665.5	724.9	92	3.0	8.4	7.6	7.50	86	12	1,600	290	305.5
CMNG	2	189	261	225	225	2	6.7	8.0	7.35	7.35	2	74	100	87	87.0
CTCN	13	35	537	141	172.6	13	5.2	7.7	6.65	6.59	13	25.5	260	63	91.2
ELBK	12	315	2,600	554.5	717.7	12	6.7	8.0	7.7	7.61	11	150	1,300	280	365.4
G8GG	1	280	280	280	280	1	7.9	7.9	7.9	7.9	1	120	120	120	120
HD8G	2	733	1,060	896.5	896.5	2	7.3	7.4	7.35	7.35	2	310	310	310	310
HMPR	5	40	482	225	234.4	5	6.6	8.0	7.0	7.08	5	.3	170	69	68.5
HRPR	9	18	274	105	118.4	9	5.5	7.7	6.8	6.54	9	5	120	24	40.9
MCKZ	2	279	560	419.5	419.5	2	7.2	7.5	7.35	7.35	2	130	160	145	145
MNWS	2	69	232	150.5	150.5	2	6.6	8.2	7.4	7.40	2	26	100	63	63.0
MRBG	10	115	1,380	332	438	10	5.9	8.1	7.5	7.32	10	21	730	155	195.1
ORSK	4	198	529	284	323.8	4	7.3	7.8	7.6	7.58	4	70	300	140	162.5
PBGS	1	560	560	560	560	1	7.2	7.2	7.2	7.2	1	390	390	390	390
PRKD	2	177	180	178.5	178.5	2	6.8	7.6	7.2	7.20	2	66	71	68.5	68.5
PRSL	1	250	250	250	250	1	7.0	7.0	7.0	7.0	1	40	40	40	40
RCKR	14	480	1,320	607.5	745.5	14	7.0	7.9	7.52	7.51	6	250	330	275	280
RMNY	5	110	317	271	227.8	5	6.1	8.1	7.0	7.14	5	33	170	120	102
RSHL	3	269.5	527	456	417.5	3	7.2	8.0	7.45	7.55	3	98	220	130	149.3
SNNG	10	179	890	622	580.2	10	6.6	7.7	7.45	7.40	9	2	380	270	255.8
STPL	2	430	760	595	595	2	7.2	7.5	7.35	7.35	1	250	250	250	250
TMSN	13	280	687	472	484.3	13	7.1	8.1	7.6	7.59	12	120	370	240	235.8
TNLY	2	404	418	411	411	2	7.4	7.5	7.45	7.45	2	170	220	195	195
WDMN	5	125	578	185	277.4	5	6.7	7.8	7.5	7.42	5	40	230	68	92.4
WLCK	1	450	450	450	450	1	7.3	7.3	7.3	7.3	1	270	270	270	270
WS8R	5	63	704	510	483.6	5	5.9	8.0	7.2	7.04	5	18	370	270	241.6
WVRN	2	37	71	54	54.0	2	5.3	6.8	6.05	6.05	2	13	16	14.5	14.5

[1]Explanation of geologic unit codes at end of table.

Geologic	Calcium (milligrams per liter)					Magnesium (milligrams per liter)					Sodium (milligrams per liter)				
unit	Number	Minimum	Maximum	Median	Mean	Number	Minimum	Maximum	Median	Mean	Number	Minimum	Maximum	Median	Mean
ANTM	5	1.9	53	22	27.6	5	0.52	34	7.6	11.7	3	2.3	8.6	3.3	4.73
C88G	1	170	170	170	170	1	34	34	34	34	1	3.1	3.1	3.1	3.1
CCCG	56	.90	550	85	93.4	56	2.4	60	20	21.4	75	1.0	90	18	22.5
CMNG	2	15	22	18.5	18.5	2	8.9	11	9.95	9.95	1	7.6	7.6	7.6	7.6
CTCN	13	7.5	82	13	28.6	13	.70	14	3.6	4.78	3	4.1	12	7.3	7.80
ELBK	7	37	390	81	115	7	11	90	22	33.3	10	.90	17	3.35	4.52
GBGG	1	35	35	35	35	1	8.1	8.1	8.1	8.1	1	8.5	8.5	8.5	8.5
HD8G	2	77	110	93.5	93.5	2	8.1	29	18.55	18.55	1	90	90	90	90
HMPR	5	.10	34	11	13.0	5	.02	21	10	8.84	3	6.6	60	33	33.2
HRPR	9	1.1	35	5.10	11.52	9	.10	8.7	2.0	3.02	5	2.0	19	4.5	6.73
MCKZ	2	50	57	53.5	53.5	2	2.0	3.7	2.85	2.85	2	.90	1.5	1.2	1.20
MNWS	2	9.4	25	17.2	17.2	2	.70	9.9	5.3	5.30	0	--	--	--	--
MRBG	10	4.0	220	38.5	56.5	10	2.7	45	10.55	13.18	6	4.4	20	8.55	9.42
ORSK	4	18	100	49.5	54.2	4	2.4	11	5.85	6.28	3	1.7	6.2	1.9	3.27
PBGS	1	87	87	87	87	1	42	42	42	42	1	17	17	17	17
PRKD	2	13	18	15.5	15.5	2	5.1	9.4	7.25	7.25	2	7.2	15	11.1	11.1
PRSL	1	6.6	6.6	6.6	6.6	1	5.8	5.8	5.8	5.8	1	23	23	23	23
RCKR	6	22	110	96	85.8	6	5.1	53	8.15	15.82	3	3.4	9.9	3.8	5.7
RMNY	5	6.4	50	40	30.3	5	1.4	11	5.1	6.24	3	4.8	7.3	5.8	5.97
RSHL	3	24	73	26	41.0	3	8.3	15.5	9.2	11.0	3	4.7	77	18	33.2
SNNG	9	.30	150	93	83.9	9	.30	50	7.60	11.3	8	1.6	42	8.2	13.9
STPL	1	73	73	73	73	1	17	17	17	17	1	2.5	2.5	2.5	2.5
TMSN	12	32	100	61	60.8	12	4.8	40	16.5	20.6	7	2.5	17	3.6	5.71
TNLY	2	64	68	66	66	2	2.8	13	7.9	7.9	1	1.1	1.1	1.1	1.1
WDMN	5	4.3	64	15	21.6	5	7.0	17	7.3	9.28	4	6.8	44	10	17.7
WLCK	1	80	80	80	80	1	17	17	17	17	1	1.7	1.7	1.7	1.7
WS8R	5	4.7	91	69	60.9	5	1.6	34	23	21.5	3	3.2	16	3.9	7.7
WVRN	2	2.8	4.3	3.55	3.55	2	1.3	1.5	1.4	1.4	1	1.4	1.4	1.4	1.4

TABLE 3—CONTINUED

Geologic unit	Potassium (milligrams per liter)					Total alkalinity (milligrams per liter as $CaCO_3$)					Sulfate (milligrams per liter)				
	Number	Minimum	Maximum	Median	Mean	Number	Minimum	Maximum	Median	Mean	Number	Minimum	Maximum	Median	Mean
ANTM	3	0.60	2.8	1.7	1.7	5	10	239	60	100	5	0.9	27	8.2	12.5
C88G	1	.90	.90	.90	.90	1	310	310	310	310	1	230	230	230	230
CCCG	75	.90	83	16	17.0	85	112	468	244	250.2	56	3.5	2,600	37	86.2
CMNG	1	.60	.60	.60	.60	2	85	130	107.5	107.5	2	4.6	5.5	5.05	5.05
CTCN	3	.50	2.6	.50	1.20	13	2.0	141	45	57.9	13	<5.0	110	6.0	15
EL8K	10	1.5	8.3	2.35	2.90	11	135	366	249	245.5	7	2.9	1,500	12	241.3
GBGG	1	1.1	1.1	1.1	1.1	1	142	142	142	142	1	19	19	19	19
HD8G	1	.80	.80	.80	.80	2	220	322	271	271	2	15	28	21.5	21.5
HMPR	3	.30	2.2	1.5	1.33	5	16	142	94	88.8	5	4.3	16	6.3	7.88
HRPR	5	.60	1.3	.90	.910	9	6	119	24	40.5	9	<5.0	15	2.75	(1)
MCKZ	2	.60	.80	.70	.70	2	130	160	145	145.0	2	2.3	21	11.65	11.65
MNWS	0	--	--	--	--	2	30	121	75.5	75.5	2	.6	1.0	.8	.80
MR8G	6	.50	26	1.35	5.33	10	11	214	99	99.7	10	5.0	680	27	91.0
ORSK	3	.40	1.1	1.1	.867	4	90	291	136	163.2	4	<5.0	23	(2)	(3)
PBGS	1	1.4	1.4	1.4	1.4	1	378	378	378	378	1	24	24	24	24
PRKD	2	.40	.40	.40	.40	2	87	90	88.5	88.5	2	.4	3.9	2.15	2.15
PRSL	1	2.2	2.2	2.2	2.2	1	77	77	77	77	1	22	22	22	22
RCKR	3	1.6	3.7	2.0	2.43	6	198	336	241.5	252.5	6	13	36	30	27.2
RMNY	3	.90	1.7	1.0	1.20	5	13	136	106	86.8	5	4.0	85	27	33.4
RSHL	3	.90	1.6	1.35	1.28	3	115.5	202	194	170.5	3	16	50	25.5	30.5
SNNG	8	.40	7.8	1.95	2.48	8	34	358	239.5	211.2	9	10	83	32	35.9
STPL	1	.70	.70	.70	.70	1	217	217	217	217	1	15	15	15	15
TMSN	7	.90	3.5	1.3	1.71	11	119	443	189	217.5	12	.6	110	11.7	19.6
TNLY	1	.70	.70	.70	.70	2	148	207	177.5	177.5	2	15	15	15	15
WDMN	4	.50	1.1	.55	.675	5	54	318	93	142.4	5	2.4	8.3	4.4	5.10
WLCK	1	1.0	1.0	1.0	1.0	1	242	242	242	242	1	22	22	22	22
WSBR	3	1.4	2.5	2.3	2.07	5	9	319	210	204	5	4.4	72	19	28.1
WVRN	1	1.6	1.6	1.6	1.6	2	4	11	7.5	7.5	2	8.2	11	9.6	9.60

(1) 3.4 ≤ mean ≤ 5.0
(2) 1 ≤ median ≤ 3
(3) 6.25 ≤ maan ≤ 7.50

Geologic unit	Chloride (milligrams per liter)					Fluoride (milligrams per litar)					Nitrate (milligrams per liter)				
	Number	Minimum	Maximum	Median	Mean	Number	Minimum	Maximum	Madian	Mean	Number	Minimum	Maximum	Median	Mean
ANTM	5	2.1	28	7.5	9.94	5	<0.10	0.40	0.10	(4)	3	1.7	7.1	3.2	4.00
CBBG	1	5.0	5.0	5.0	5.0	1	.30	.30	.30	.30	0	--	--	--	--
CCCG	86	1.3	200	10	16.2	55	<.05	1.0	.40	.4	86	.18	76	6.7	10.8
CMNG	2	2.0	2.3	2.15	2.15	2	<.10	.30	(5)	(6)	1	.07	.07	.07	.07
CTCN	13	1.55	27	3.95	7.75	13	<.05	.20	.10	(7)	11	.05	2.70	.45	.936
EL8K	11	<.05	14	3.6	5.12	7	.20	.90	.50	.486	10	.56	18	2.10	4.486
G8GG	1	2.3	2.3	2.3	2.3	1	.30	.30	.30	.30	0	--	--	--	--
HDBG	2	7.0	200	103.5	103.5	2	<.10	.10	<.10	<.10	0	--	--	--	--
HMPR	5	.60	89	1.6	18.9	5	<.10	.10	.10	<.10	2	1.8	4.1	2.	2.95
HRPR	9	.60	38	2.4	6.67	8	<.05	.30	.10	(8)	5	.02	.18	.05	.090
MCKZ	2	.50	1.9	1.2	1.2	2	<.10	.10	<.10	<.10	0	--	--	--	--
MNWS	2	<.05	1.2	.6	.6	2	.10	.10	.10	.10	2	.14	.45	.295	.295
MRBG	10	<.05	23	5.95	9.56	7	<.10	.80	.20	(9)	8	.59	11	2.4	3.42
ORSK	4	1.3	6.0	1.75	2.70	4	.10	.10	.10	.10	2	.18	1.1	.64	.640
PBGS	1	32	32	32	32	1	1.6	1.6	1.6	1.6	0	--	--	--	--
PRKD	2	2.1	4.2	3.15	3.15	2	.10	.20	.15	.15	0	--	--	--	--
PRSL	1	11	11	11	11	1	.10	.10	.10	.10	0	--	--	--	--
RCKR	6	4.6	30	11	13.2	6	.05	.50	.15	.192	13	1.4	30	6.1	8.89
RMNY	5	1.0	3.6	2.0	2.26	4	.10	.20	.15	.150	4	.02	.11	.05	.057
RSHL	3	3.8	36	5.85	15.2	3	.15	.20	.20	.183	1	.02	.02	.02	.02
SNNG	9	3.1	75	11.0	19.8	9	<.05	.70	.20	(10)	7	.16	23	2.95	6.84
STPL	1	5.0	5.0	5.0	5.0	1	<.10	<.10	<.10	<.10	1	6.1	6.1	6.1	6.1
TMSN	12	2.0	30	5.6	9.13	11	<.10	.50	.20	(11)	8	.34	10.2	3.7	4.34
TNLY	2	1.6	8.1	4.85	4.85	1	.10	.10	.10	.10	1	4.3	4.3	4.3	4.3
WDMN	5	1.0	5.2	2.8	3.18	4	<.05	.20	.20	(12)	2	.02	.34	.18	.18
WLCK	1	5.6	5.6	5.6	5.6	1	.30	.30	.30	.30	0	--	--	--	--
WS8R	5	3.3	43	5.0	12.8	4	<.05	.40	.25	(13)	4	.18	5.9	2.95	3.00
WVRN	2	1.5	7.0	4.25	4.25	2	.10	.20	.15	.15	1	.16	.16	.16	.16

(4) 0.160 ≤ mean ≤ 0.180
(5) 0.15 ≤ median ≤ 0.20
(6) 0.150 ≤ maan ≤ 0.200
(7) 0.090 ≤ maan ≤ 0.113
(8) 0.050 ≤ maan ≤ 0.140
(9) 0.300 ≤ mean ≤ 0.314
(10) 0.217 ≤ mean ≤ 0.228
(11) 0.191 ≤ maan ≤ 0.200
(12) 0.150 ≤ maan ≤ 0.162
(13) 0.225 ≤ maan ≤ 0.237

TABLE 3—CONTINUED

Geologic unit	Silica (milligrams per liter) Number	Minimum	Maximum	Median	Mean	Total dissolved solids (sum of ions, in milligrams per liter) Number	Minimum	Maximum	Median	Mean
ANTM	3	13	20	14	15.7	3	30	290	120	146.7
CBBG	1	6.5	6.5	6.5	6.5	1	640	640	640	640
CCCG	49	5.0	16	11	10.8	45	190	740	420	427.8
CMNG	1	21	21	21	21	1	110	110	110	110
CTCN	12	.2	34	21.3	18.7	3	65	350	100	171.7
ELBK	5	10	24	13	16	4	160	2,200	285	732.5
GBGG	1	27	27	27	27	1	170	170	170	170
HDBG	1	10	10	10	10	1	570	570	570	570
HMPR	3	13	18	16	15.7	4	100	270	145	165
HRPR	5	7.6	28	9.1	15.7	5	19	83	63	54.1
MCKZ	2	6.8	9.9	8.35	8.35	2	150	190	170	170
MNWS	0	--	--	--	--	0	--	--	--	--
MRBG	6	7.0	25	15	15.2	7	61	1,000	210	318.7
ORSK	3	5.2	12	10	9.07	2	110	330	220	220
PBGS	1	7.9	7.9	7.9	7.9	1	420	420	420	420
PRKD	2	17	19	18	18	2	110	120	115	115
PRSL	1	7.0	7.0	7.0	7.0	1	140	140	140	140
RCKR	3	9.2	11	9.5	9.90	4	290	350	310	315
RMNY	3	12	19	15	15.3	3	82	230	190	167.3
RSHL	3	8.0	10	8.0	8.67	3	160	290	280	243.3
SNNG	8	4.3	16	9.2	9.47	8	100	480	295	298.1
STPL	1	6.0	6.0	6.0	6.0	1	210	210	210	210
TMSN	7	6.1	14	11	10.5	7	140	420	270	262.8
TNLY	1	7.6	7.6	7.6	7.6	1	230	230	230	230
WDMN	4	17	21	19	19	4	83	340	110	160.8
WLCK	1	9.0	9.0	9.0	9.0	1	250	250	250	250
WSBR	3	11	20	12	14.3	3	260	420	390	356.7
WVRN	1	7.7	7.7	7.7	7.7	1	30	30	30	30

Explanation of geologic unit codes

ANTM	Antietam Formation
CBBG	Chambersburg Limestone
CCCG	Conococheague Limestone
CMNG	Chemung Formation
CTCN	Catoctin Formation
ELBK	Elbrook Limestone
GBGG	Gneiss complex
HDBG	Helderberg Formation and Keyser Limestone
HMPR	Hampshire Formation
HRPR	Harpers Formation
MCKZ	McKenzie Formation and Rochester Shale
MNWS	Colluvium
MRBG	Martinsburg Formation
ORSK	Oriskany Sandstone
PBGS	Pinesburg Station Dolomite
PRKD	Parkhead Sandstone
PRSL	Purslane Sandstone
RCKR	Rockdale Run Formation
RMNY	Romney Formation
RSHL	Rose Hill Formation
SNNG	Stonehenge Limestone
STPL	St. Paul Group
TMSN	Tomstown Formation
TNLY	Tonoloway Limestone
WDMN	Woodmont Formation
WLCK	Wills Creek Shale
WSBR	Waynesboro Formation
WVRN	Weverton Formation

which are commonly applied or disposed of at or near land surface. The three wells in which nitrate concentrations exceeded the MCL are completed in the Conococheague Limestone. Solutional features of the limestone could have facilitated the transport of contaminants by ground water, or inadequately sealed well casing could have allowed nitrate-bearing water to flow along the outside of the casing, thereby percolating downward to ground water with little opportunity for the nitrates to be removed by the soil.

Concentrations of sulfate in samples from three wells—WA Bh 22, WA Bi 19, and WA Di 185—exceed the national secondary drinking-water regulations secondary maximum contaminant level (SMCL) of 250 mg/L (U.S. Environmental Protection Agency, 1987b, p. 593). The SMCL's, which are not enforceable limits, relate to aesthetic qualities of drinking water. High concentrations of sulfate can have a laxative effect, particularly on persons unaccustomed to such levels. The source of sulfate in well WA Bh 22 (680 mg/L in a sample collected October 15, 1958) could be the industrial waste ponds located about 1,000 ft away. In well WA Bi 19, which is completed in the Conococheague Limestone, acid contamination is the likely source of sulfate (2,600 mg/L in a sample collected March 19, 1958), considering the remarkably low (3.0) pH of the sample.

The high concentration (1,500 mg/L) of sulfate in well WA Di 185, on the other hand, could be the result of natural geochemical processes. Water from this well also had elevated concentrations of calcium (390 mg/L), magnesium (90 mg/L), and iron (1.8 mg/L). The Elbrook Limestone, in which this well is completed, was deposited in a tidal-flat environment (David Brezinski, Maryland Geological Survey, personal commun., 1988). The sedimentary sequence includes evaporite deposits (mainly gypsum), which provide a source of sulfate. Heller and Rauch (1986) studied high-sulfate waters in a similar physiographic area underlain by limestones of the Greenbrier Group in West Virginia. They concluded that dissolution of gypsum was the main source of sulfate and calcium and that dissolution of pyrite could further affect the ground-water chemistry. Pyrite has not been reported in the

Elbrook Limestone. However, a residual deposit of iron ore (Geeting Ore Bank), located between Sharpsburg and Keedysville, was once worked in limestone that contained "a great deal of pyrite" (Singewald, 1911, p. 203). This deposit may have been formed in the Waynesboro or Tomstown Formation rather than in the Elbrook Limestone. Well WA Di 185 may be completed in one of these two units; more detailed mapping is necessary to verify the geologic interpretation, which was compiled from Cloos (1941).

The total dissolved-solids concentration in 18 wells exceeded the SMCL of 500 mg/L (U.S. Environmental Protection Agency, 1987b, p. 593). Such high concentrations of ions can affect taste, and, although high concentrations of total dissolved solids are not necessarily unhealthy, some individual chemical species may be present in undesirable concentrations.

Water from 10 wells and 5 springs had pH values below the SMCL range of 6.5 to 8.5 (U.S. Environmental Protection Agency, 1987b, p. 593). Values outside the range may be associated with undesirable qualities. The extreme value of 3.0 is from well WA Bi 19 and is likely due to pollution by acid—perhaps sulfuric acid, considering the high sulfate concentration. No samples had pH values greater than the recommended SMCL range.

Specific electrical conductance is easily measured in the field and is a reliable indicator of the total concentration of dissolved substances (fig. 20). For Washington County data, the relation from least-squares regression is

$$\text{TOTAL DISSOLVED SOLIDS} = 0.931\ (\text{SPECIFIC CONDUCTANCE})^{0.926},$$

and the coefficient of determination (r^2) is 0.97. The variation of specific conductance of samples grouped by geologic unit is more or less continuous (fig. 21); however, median specific conductances of ground-water samples from carbonate rocks tend to be greater than those from noncarbonate rocks—a consequence of the greater solubility of calcite and dolomite.

Disregarding the value of 3.0 for well WA Bi 19, the minimum pH is 5.2 from the Catoctin Formation (table 3). High pH is present in water from noncarbonate as well as carbonate rocks (fig. 22), but lower values of pH are more commonly associated with noncarbonate rocks. Differences in types and abundance of minerals available for weathering and buffering, and in flow velocity, result in the variability in pH.

More than 80 percent of the ground-water samples were hard (121 to 180 mg/L as $CaCO_3$). The distributions of hardness of water samples from carbonate rocks and from noncarbonate rocks (fig. 23) are distinct, but most samples from both groups are hard to very hard (>180 mg/L as $CaCO_3$). Calcite and dolomite provide calcium and magnesium ions, which are the principal hardness-causing ions, to ground water. These minerals generally are present to some extent in all of the geologic units, although they are the primary minerals in the carbonate rocks. In most of the ground water in Washington County, calcium, magnesium, and bicarbonate are the dominant ions; therefore, hardness commonly can be estimated from a simple measurement of specific conductance (fig. 24). The estimating equation, from least-squares regression, is

$$\text{HARDNESS} = 0.26\ (\text{SPECIFIC CONDUCTANCE})^{1.072},$$

and the coefficient of determination (r^2) is 0.67. Other ions, such as sodium, chloride, and sulfate, add to hardness; water samples containing significant concentrations of these ions contribute to the scatter shown in figure 24, and the regression equation yields less reliable estimates of hardness for such samples.

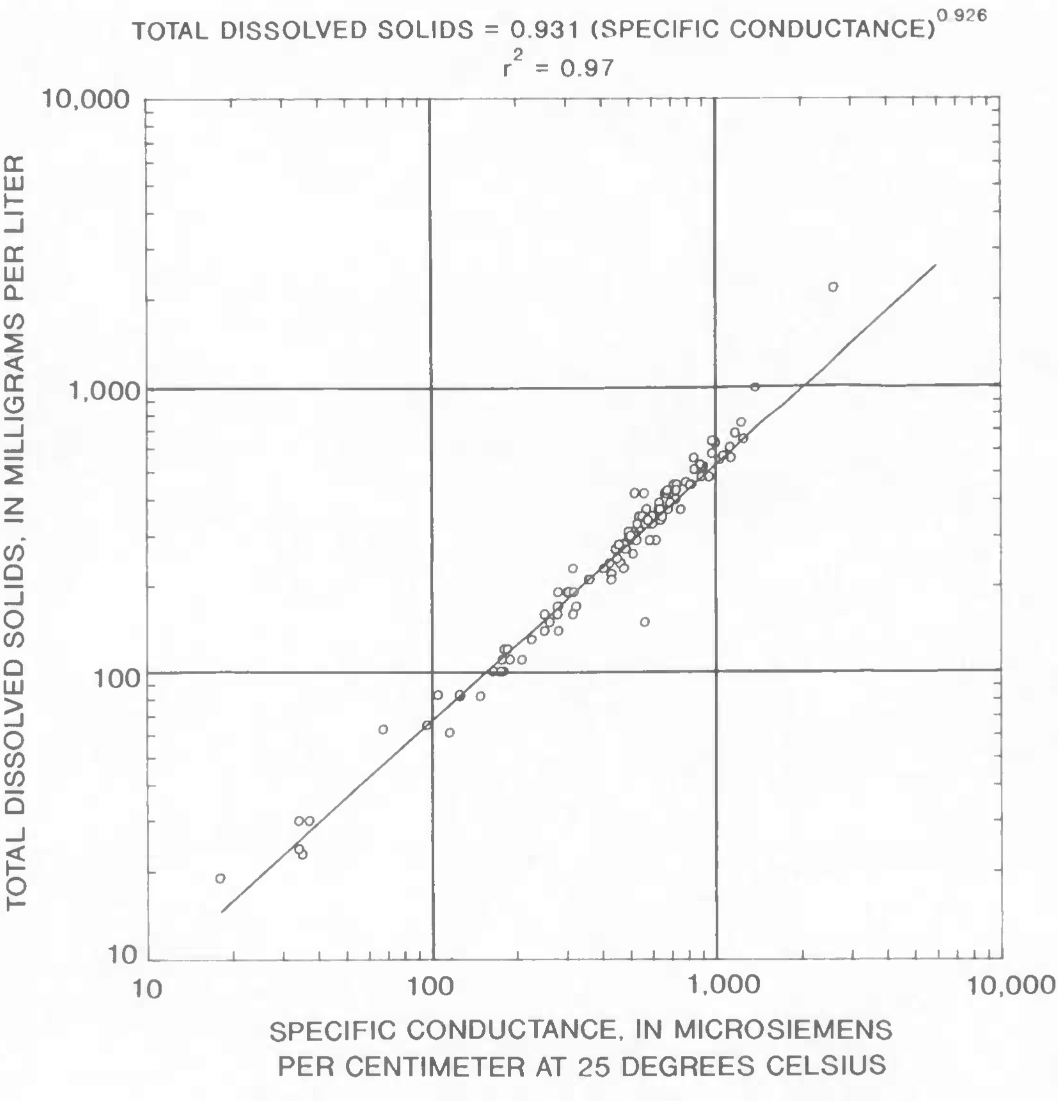


Figure 20.—Relation of total dissolved solids concentrations (sums of concentrations of major dissolved inorganic ions) to specific conductance for 121 ground-water samples.

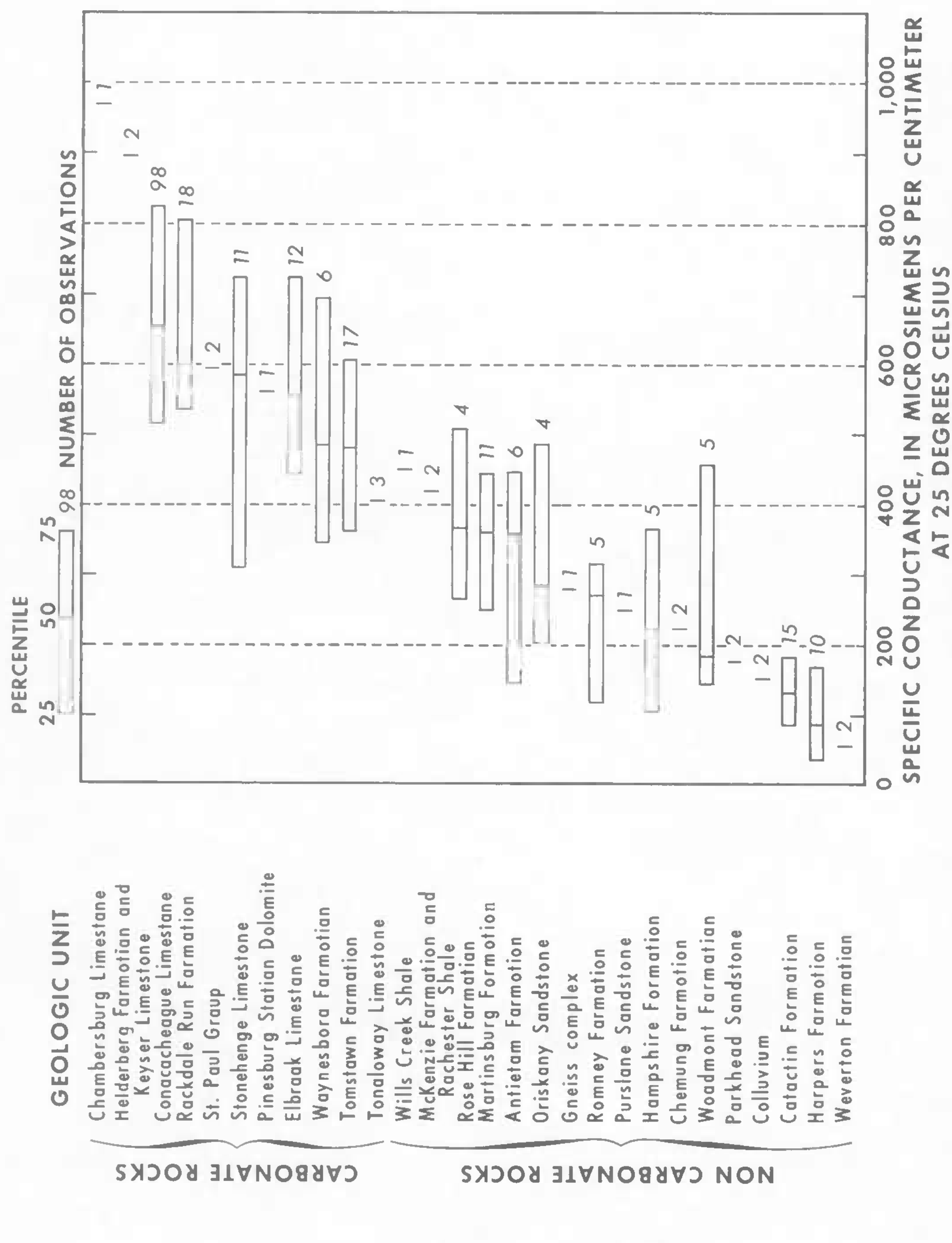


Figure 21.—Quartiles of specific conductances of ground-water samples grouped by geologic unit.

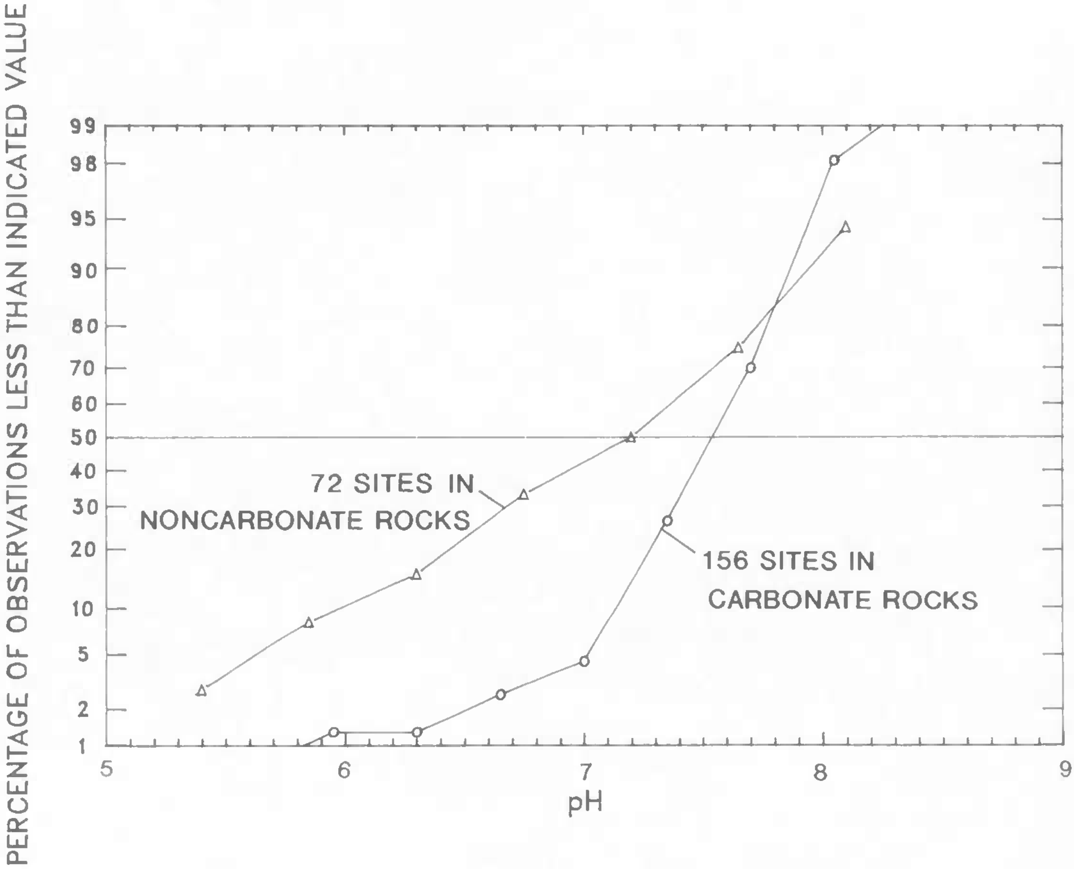


Figure 22.—Cumulative frequency distributions of pH of water samples from carbonate and noncarbonate rocks.

Ground-water-chemistry data yield information concerning ground-water flow systems, particularly in areas underlain by limestone and dolomite. Geochemical data were used for thermodynamic analysis by the computer program WATEQF (Plummer and others, 1978). Results for 24 samples from carbonate rocks are listed in table 4. A saturation index equal to zero indicates saturation with respect to the solid phase considered; negative values indicate undersaturation (solution tends to occur), and positive values indicate oversaturation (precipitation tends to occur). The degree to which ground water in carbonate terranes is saturated with respect to calcite (or dolomite) is indicative of the amount of contact between the water and the rock minerals, assuming chemical equilibrium is attained. Spring WA Ag 2, located approximately 3 mi southwest of Fairview, is undersaturated with respect to calcite and dolomite, which may indicate rapid flow through solutionally enlarged conduits. The other four spring samples were oversaturated with respect to calcite and dolomite, an indication that ground-water flow is more diffuse in those systems. Measurements at these sites over a period of time would be useful in differentiating diffuse and conduit flow to the springs.

Samples from wells are more evenly divided between undersaturation and oversaturation with respect to calcite than are those from the springs. Several of the samples are undersatu-

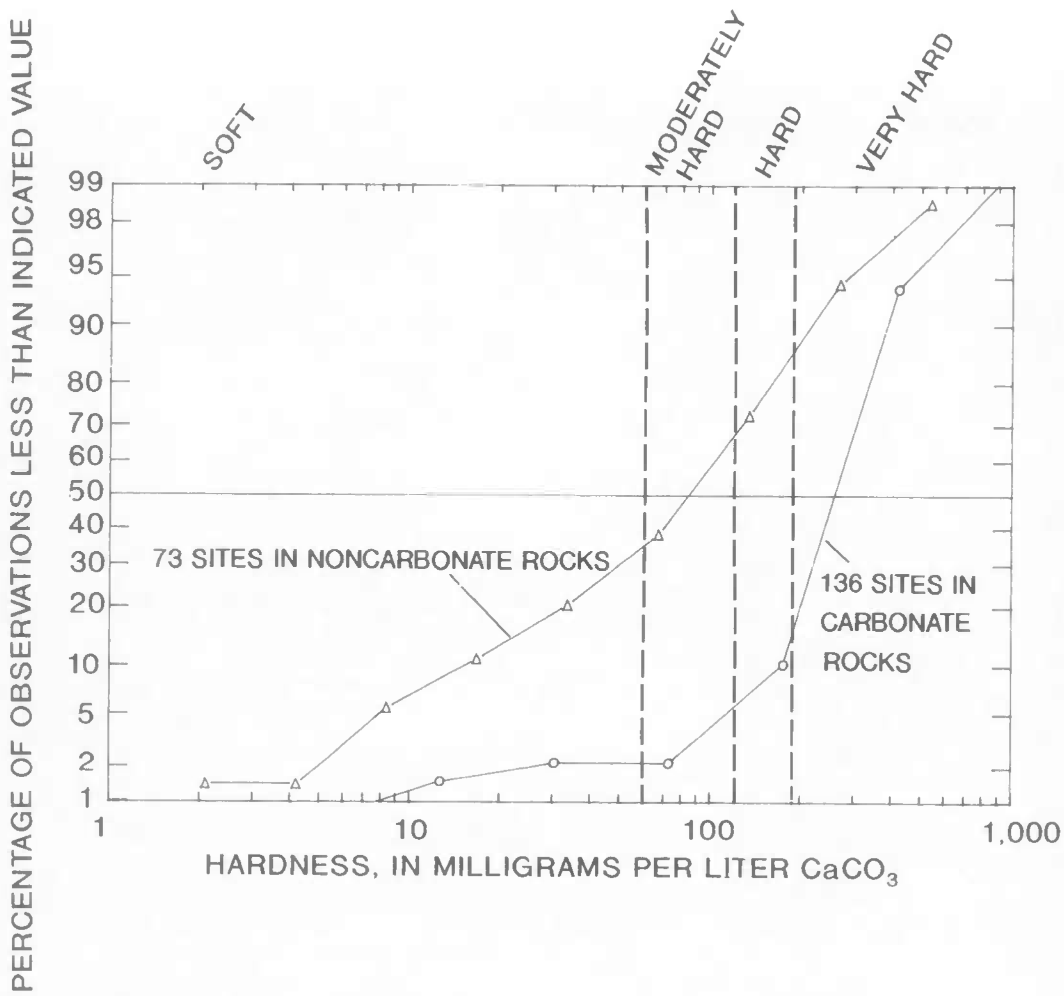


Figure 23.—Cumulative frequency distributions of hardness of water samples from carbonate and noncarbonate rocks.

rated with respect to dolomite but are oversaturated with respect to calcite; these samples are from purer limestones, as also indicated by Ca^{2+}/Mg^{2+} ratios greater than 5 (the ratios for pure dolomite are closer to 1). Whereas springs represent the terminal points of ground-water flow paths, wells can be constructed anywhere along the flow path and derive water at any stage of its evolution. In addition, a well may not be located along an optimum flow path and, thus, may derive water that moves relatively slowly, thereby increasing contact time with the rock.

The chemical evolution of water in the carbonate terrane is shown by the relation of calcite-saturation indices (SI_c) to carbon dioxide partial pressure (pCO_2) (fig. 25). The envelopes of the three types of water outlined in the graph are in the same relative positions as those described by Drake and Harmon (1973, p. 956) for the Nittany and Lebanon valleys in central Pennsylvania. The saturation indices shown in figure 25 are somewhat greater than those of Drake and Harmon, indicating greater contact time between ground water and

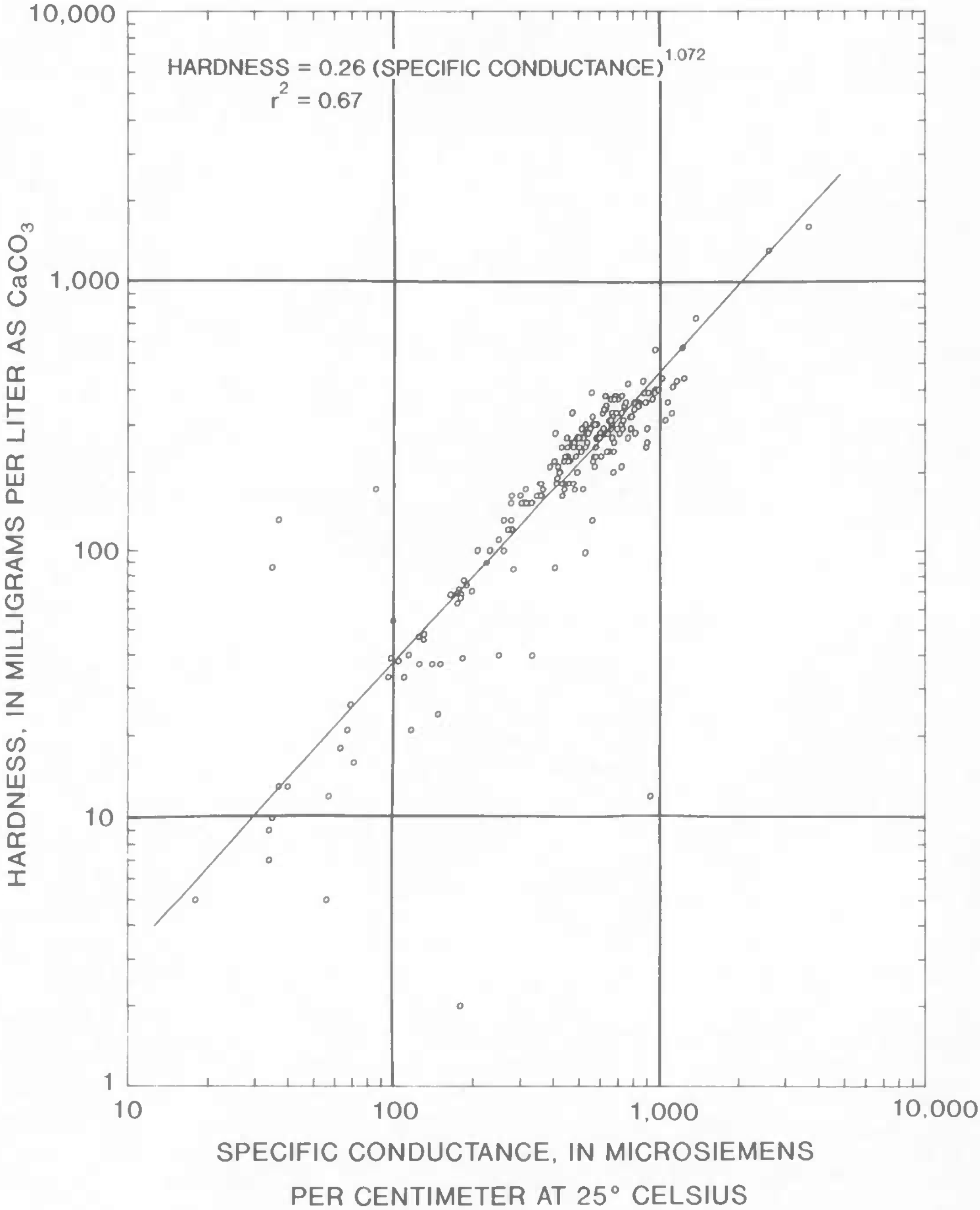


Figure 24.—Relation of hardness to specific conductance for 212 ground-water samples.

TABLE 4
GROUND-WATER GEOCHEMISTRY OF CARBONATE-ROCK UNITS

Site	Date	Geologic unit	Ca^{2+}/Mg^{2+} ratio	Saturation Index Calcite	Saturation Index Dolomite
Wells:					
WA Ag 65	05-19-87	St. Paul Group	2.605	-0.146	-0.749
WA Ag 71	05-19-87	Chambersburg Limestone	3.033	- .293	-1.107
WA Ai 1	03-07-51	Rockdale Run Formation	10.823	.358	- .401
WA Ai 74	05-21-87	Stonehenge Limestone	10.024	- .438	-1.907
WA Be 43	07-16-86	Helderberg Formation	8.238	.129	- .673
WA Bf 25	02-06-63	Conococheague Limestone	2.393	- .070	- .576
WA Bf 28	07-26-63	do.	1.403	.227	.277
WA Bg 90	04-15-87	Pinesburg Station Dolomite	1.256	.104	.060
WA Bj 105	05-19-87	Conococheague Limestone	2.029	- .110	- .557
WA Bk 25	04-09-70	Tomstown Formation	1.078	.243	.395
WA Cg 12	11-18-64	Conococheague Limestone	5.925	.494	.149
WA Ci 147	05-21-87	do.	6.066	.047	- .712
WA Dh 51	07-30-63	do.	2.926	.326	.129
WA Dh 52	05-28-64	do.	5.199	.157	- .439
WA Di 86	02-04-63	Elbrook Limestone	1.962	.219	.134
WA Di 185	05-20-87	do.	2.628	- .207	- .809
WA Di 187	05-20-87	Tomstown Formation	1.092	- .146	- .362
WA Eh 1	05-23-64	do.	2.166	- .020	- .443
WA Ei 46	05-26-64	do.	6.987	.054	- .796
Springs:					
WA Ag 2	04-24-59	Stonehenge Limestone	3.671	- .169	- .963
WA Ai 20	10-15-58	Conococheague Limestone	.910	.431	.847
WA Ak 3	08-27-81	Tomstown Formation	1.941	.312	.277
WA Ch 2	08-25-81	Conococheague Limestone	7.943	.741	.509
WA Ch 7	04-24-59	Rockdale Run Formation	6.912	.557	.190

rock—evidence that solutional development is less well developed, and diffuse flow is more important, in Washington County than in central Pennsylvania. Samples that could be identified as being from recharging waters were not available. The well waters have a broad range of pCO_2 and some are undersaturated, whereas others are supersaturated with respect to calcite. The degree of calcite saturation presumably depends on the location of the well along the flow path; as water moves along the path, carbon dioxide is depleted as calcite dissolves, assuming a closed system. (It is not to be inferred, however, that the samples represented in figure 25 were collected along a particular flow path). The spring and stream waters have low pCO_2 and greater calcite-saturation indices than well waters (the streams were sampled during base flow and, therefore, consist of ground water that discharged to the stream channels). Differences in calcite saturation do not imply differences in concentrations of calcium and magnesium among water from wells, springs, and streams; average calcium and magnesium concentrations from these three sources are about the same (fig. 26).

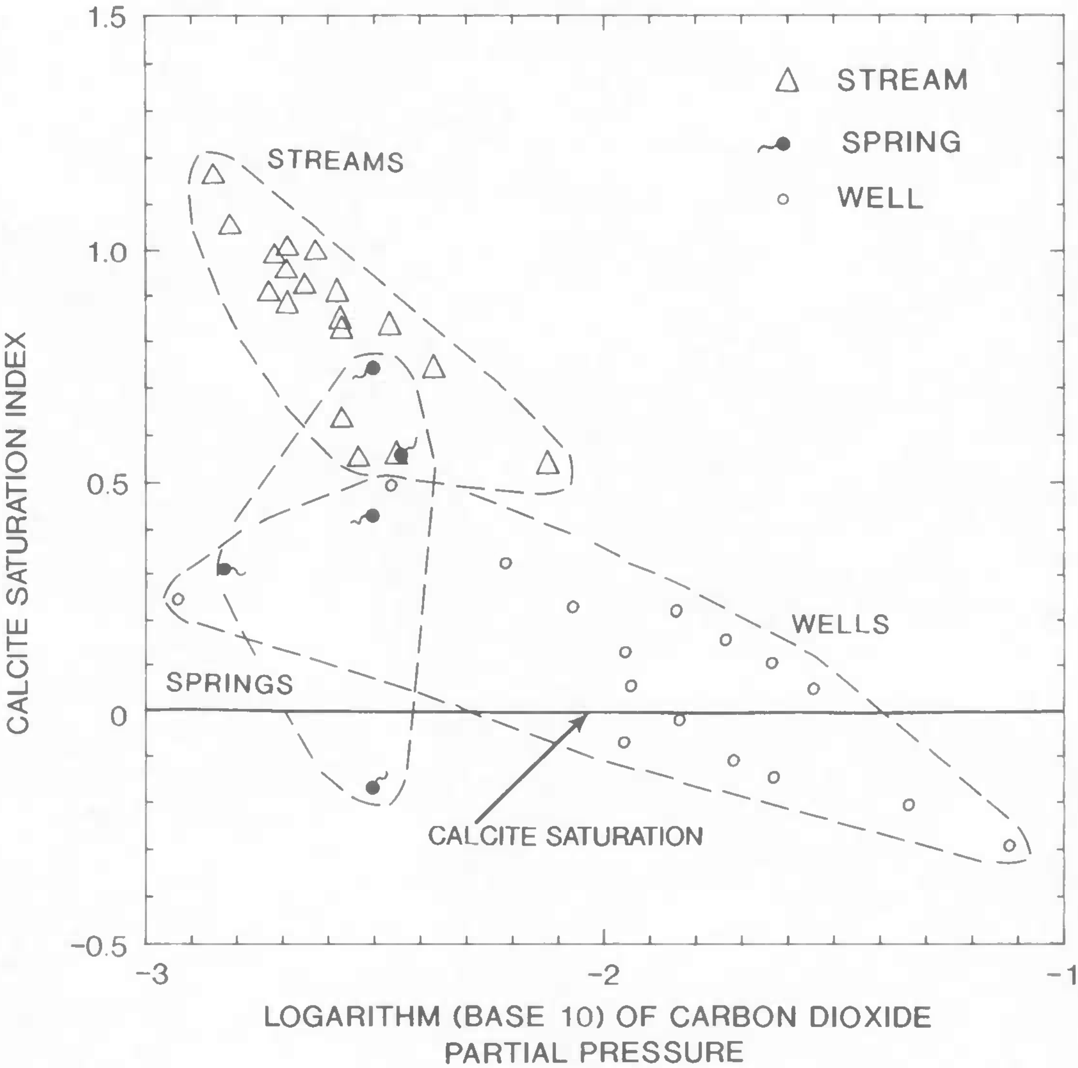


Figure 25.—Geochemical differences among well, spring, and stream waters in carbonate terrane.

Trace Elements

Selected wells and springs in a variety of geologic settings were sampled for trace elements (Duigon and others, 1989, table 13). Most values are less than detection limits, as indicated in table 5. Maximum concentrations recommended by the U.S. Environmental Protection Agency (1987b) for these elements in drinking water are listed in table 6. The concentrations of iron, manganese, and/or zinc exceeded the SMCL's in some samples.

Some analyses that are reported as total or dissolved may include contributions from sediment in unfiltered water samples (e.g., total recoverable zinc in a sample from well WA Di 10. A few rather high concentrations of dissolved iron (as much as 12,000 μg/L) and

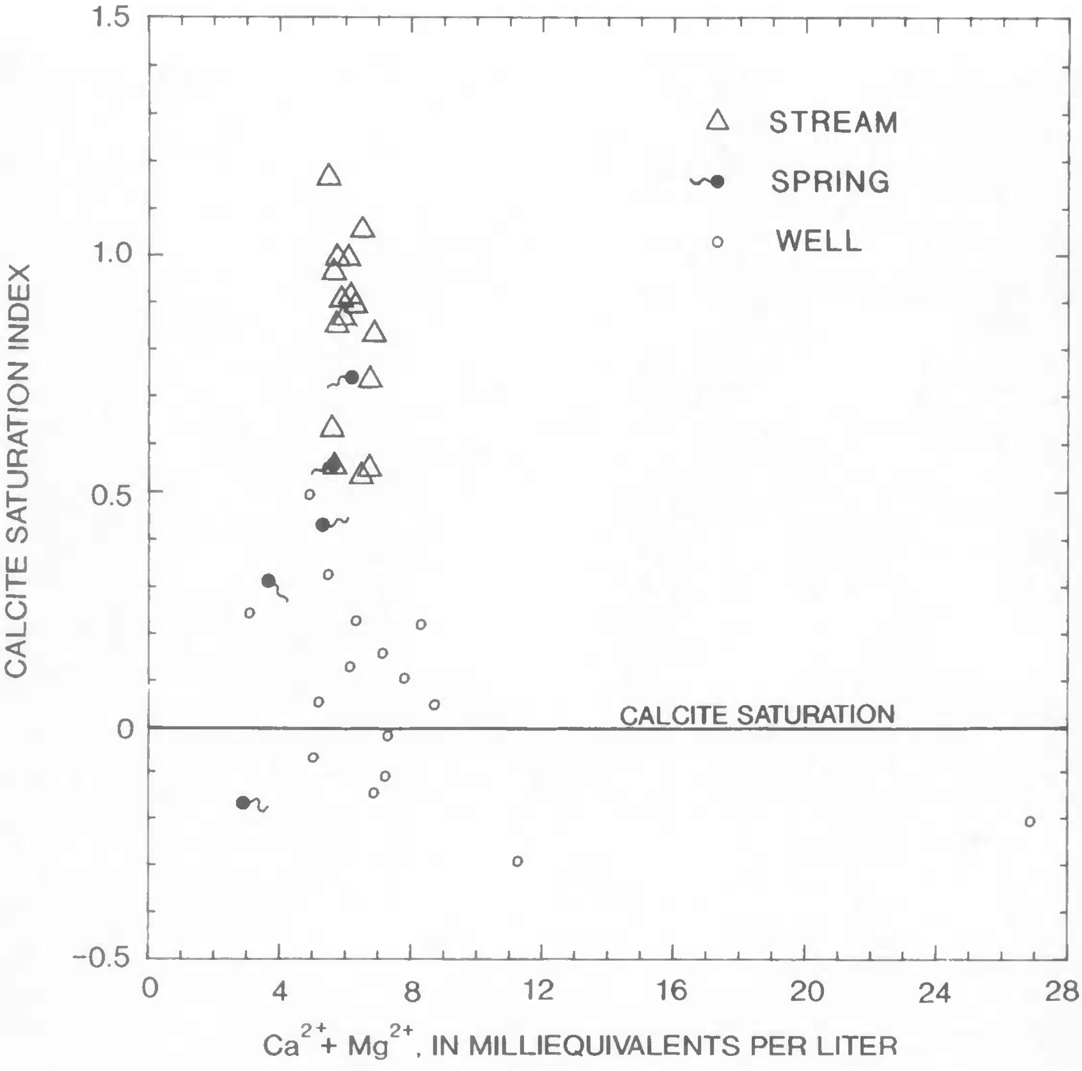


Figure 26.—Relations between calcite saturation and calcium and magnesium concentrations of well, spring, and stream waters in carbonate terrane.

dissolved manganese (as much as 1,900 μg/L) were detected in wells in the Rose Hill Formation and in the Purslane Sandstone. Although not a health risk, such concentrations can impart an objectionable taste to water and beverages, can stain laundry and fixtures, and can make the water unsuitable for some other uses. Total lithium concentration was rather high (2,900 μg/L) in water from well WA Ei 1, which is open to the Waynesboro Formation. This well, located on an artificial berm of the C & O Canal next to the Potomac River, may have received contamination from either the canal or the river. A total zinc concentration of 13,000 μg/L was reported for a sample from well WA Di 10. Possible sources of this contamination include brass, bronze, or galvanized plumbing components or white pigment.

TABLE 5
SUMMARY OF TRACE-ELEMENT ANALYSES OF GROUND WATER
[All analyses in micrograms per liter]

Constituent	Number of samples	Minimum	Maximum	Median
Aluminum, total	78	<50	3,600	<50
Aluminum, dissolved	36	<10	200	<100
Arsenic, dissolved	6	<1	<1	<1
Cadmium, total	4	<1	<1	<1
Cadmium, dissolved	6	<1	<1	<1
Chromium, total	5	5	16	10
Chromium, dissolved	6	<10	30	<10
Copper, total	111	<5	480	<5
Copper, dissolved	6	<1	17	<2
Iron, total	118	<5	5,700	20
Iron, dissolved	39	<3	12,000	10
Lead, total	4	1	9	5
Lead, dissolved	6	<5	12	<5
Lithium, total	11	<50	2,900	<50
Manganese, total	53	<5	2,000	<10
Manganese, dissolved	40	<1	1,900	<10
Mercury, total	4	< .10	.10	< .10
Nickel, total	4	1	3	1.5
Silver, total	4	<1	<1	<1
Zinc, total	111	<5	13,000	300
Zinc, dissolved	6	4	170	17

Pesticides and Organic Compounds

Water samples from six wells and one spring were tested for organonitrogen herbicides (table 7). Atrazine was detected in five wells and the spring; prometon was detected in one well; and simazine was detected in one well. MCL's and maximum contaminant level goals (MCLG's, which are nonenforceable maximum concentrations plus a factor of safety at which no adverse health effects are thought to occur) for these herbicides have not yet (1990) been promulgated, but health advisories have been issued (U.S. Environmental Protection Agency, 1988a, 1988b, 1988c, 1989, 1990). Health advisories are not enforceable limits; they are intended as guidelines to protect public health from exposures of toxic contaminants of various durations based on carcinogenicity data. Atrazine and simazine are

TABLE 6
DRINKING-WATER STANDARDS FOR TRACE ELEMENTS
[Concentrations in micrograms per liter; dashed where no level established. Source: U.S. Environmental Protection Agency, 1987b.]

Contaminant	Primary maximum contaminant level	Secondary maximum contaminant level
Aluminum	--	--
Arsenic	50	--
Cadmium	10	--
Chromium	50	--
Copper	--	1,000
Iron	--	300
Lead	50	--
Lithium	--	--
Manganese	--	50
Mercury	2	--
Nickel	--	--
Silver	50	--
Zinc	--	5,000

two of the major pesticides used in Washington County, and are applied chiefly to corn. Eight other organonitrogen herbicides were undetected. Spring WA Ak 45 was tested for 15 organochlorine insecticides, but none were detected. The detection limits of those pesticides not found in measurable quantities are well below the MCL's and MCLG's (table 8).

Fourteen wells and four springs were tested for additional organic constituents (table 9). Total organic carbon was detected in four wells and undetected in one well, and dissolved organic carbon was detected in eight wells and two springs. Methylene blue active substances (MBAS, an anionic surfactant component of synthetic detergents and an indicator of pollution by wastewater) were detected in two wells and two springs. Spring WA Ak 45, emanating from the Harpers Formation, was tested for 38 additional organic compounds, all of which were at concentrations less than detection limits. Except for vinyl chloride, the detection limits are less than the MCL's (table 8).

TABLE 7
PESTICIDE ANALYSES OF GROUND WATER
[All analyses reported in micrograms per liter]

Site number	Site type	Date	Discharge (gal/min)	Flow period prior to sampling (min)	Geologic unit	Ametryn, total	Atraton, total	Atrazine, total
WA Ag 65	well	05-19-87	--	10	St. Paul Group	<0.10	--	0.10
WA Ai 74	well	05-21-87	--	10	Stonehenge Ls.	< .10	--	.10
WA Bj 105	well	05-19-87	--	5	Conococheague Ls.	< .10	--	.50
WA Ci 113	well	08-17-83	10	15	Tomstown Fm.	< .10	<0.10	.40
WA Ci 147	well	05-21-87	--	120	Conococheague Ls.	< .10	--	.30
WA Cj 126	spring	05-21-87	--	--	Waynesboro Fm.	< .10	--	.10
WA Di 187	well	05-20-87	--	10	Tomstown Fm.	< .10	--	< .10

Site number	Cyanazine, total	Cyprazine, total	Prometon, total	Prometryn, total	Propazine, total	Simetone, total	Simetryn, total	Simazine, total
WA Ag 65	<0.10	--	<0.1	<0.1	<0.10	--	<0.1	<0.10
WA Ai 74	< .10	--	< .1	< .1	< .10	--	< .1	< .10
WA Bj 105	< .10	--	< .1	< .1	< .10	--	< .1	.10
WA Ci 113	< .10	<0.10	< .1	< .1	< .10	<0.10	< .1	< .10
WA Ci 147	< .10	--	.1	< .1	< .10	--	< .1	< .10
WA Cj 126	< .10	--	< .1	< .1	< .10	--	< .1	< .10
WA Di 187	< .10	--	< .1	< .1	< .10	--	< .1	< .10

Analyses for spring WA Ak 45

Date	Discharge (gal/min)	Geologic unit	Aldrin, dissolved	Chlordane, dissolved	DDD, dissolved	DDE, dissolved	DDT, dissolved	Dieldrin, dissolved
06-29-87	8.7	Harpers Fm.	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

Endosulfan, dissolved	Endrin, dissolved	Heptachlor, dissolved	Heptachlor epoxide, dissolved	Lindane, dissolved	Methoxychlor, dissolved	Mirex, dissolved	Perthane, dissolved	Toxaphene, dissolved
<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

TABLE 8
DRINKING-WATER STANDARDS FOR SELECTED ORGANIC CONTAMINANTS
[Concentrations in micrograms per liter; X denotes health advisory promulgated; dashed where no level promulgated. Source: U.S. Environmental Protection Agency, 1987a, 1987b, 1988a, 1988b, 1988c, 1989.]

Contaminant	Maximum contaminant level	Maximum contaminant level goal	Health advisory
Ametryn	--	--	X
Atrazine	--	--	X
Cyanazine	--	--	X
Prometon	--	--	X
Propazine	--	--	X
Simazine	--	--	X
Chlordane	--	--	X
Dieldrin	--	--	X
Endrin	0.2	--	X
Heptachlor	--	--	X
Heptachlor epoxide	--	--	X
Lindane	4	--	X
Methoxychlor	100	--	X
Toxaphene	5	--	X
Total trihalomethanes (includes bromoform, chloroform, dibromochloromethane, and bromodichloromethane)	100	--	X
1,1-Dichloroethylene	7	7	X
1,1,1-Trichloroethane	200	200	X
Benzene	5	0	X
Vinyl chloride	2	0	X
Carbon tetrachloride	5	0	X
1,2-Dichloroethane	5	0	X
Trichloroethylene	5	0	X

TABLE 9
ANALYSES OF ORGANIC CONSTITUENTS FROM SELECTED WELLS AND SPRINGS
[Concentrations in micrograms per liter, except as noted]

Site number	Site type	Date	Geologic unit	Discherge (gel/min)	Flow period prior to sampling (min)	Orgenic carbon, total (mg/L as C)	Orgenic cerbon, dissolved (mg/L es C)	Methylene blue ective substence (mg/L)
WA Af 12	well	04-24-59	Martinsburg Formetion	--	--	--	--	0.13
WA Ag 2	spring	04-24-59	Stonehenge Limestone	600	--	--	--	.09
WA Ag 65	well	05-19-87	St. Paul Group	--	10	1.3	--	--
WA Ag 71	well	05-19-87	Chambersburg Limestone	--	--	3.4	--	--
WA Ai 74	well	05-21-87	Stonehenge Limestone	--	--	--	0.8	--
WA Be 41	well	05-18-87	Oriskeny Sandstone	--	10	.7	--	--
WA Bg 27	well	05-19-87	Martinsburg Formation	--	5	<.1	--	--
WA Bj 105	well	05-19-87	Conococheague Limestone	--	5	--	.7	--
WA Cg 3	well	04-24-59	Martinsburg Formation	2.0	--	--	--	.08
WA Ch 7	spring	04-24-59	Rockdale Run Formation	300	--	--	--	.10
WA Ci 147	well	05-21-87	Conococheegue Limestone	--	--	--	1.0	--
WA Cj 126	spring	05-21-87	Waynesboro Formation	--	--	--	.5	--
WA Di 185	well	05-20-87	Elbrook Limestone	--	--	--	.3	--
WA Di 187	well	05-20-87	Tomstown Formetion	--	--	--	.6	--
WA Ei 93	well	05-20-87	Catoctin Formetion	--	10	--	.5	--
WA Ei 105	well	05-20-87	Harpers Formation	--	--	.1	.1	--
WA Ej 21	well	05-20-87	Harpers Formation	--	15	--	.3	--

Anelyses for spring WA Ak 45

Dete	Geologic unit	Discherge (gal/min)	Orgenic carbon, dissolved (mg/L as C)	Bromoform, total	Chloroform, total	Styrene, total	Toluene, totel	Xylene, total recoverable	2-Chloroethylvinylether, totel
06-29-87	Harpers Formetion	8.7	0.5	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0

Methylbromide, total	Methylchloride, totel	Methylene chloride, total	Vinyl chloride, total	Carbontetrachloride, total	Chlorodibromomethane, total	Dichlorobromomethane, total	Dichlorodifluoromethane, total	Trichlorofluoromethene, total	Chloroethane, totel	1,1-Dichloroethane, totel
<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0

1,2-Dichloroethane, total	1,1,1-Trichloroethane, total	1,1,2-Trichloroethane, total	1,1,2,2 Tetrechloroethene, total	1,1-Dichloroethylene, totel	1,2-Trans-dichloroethylene, total	Trichloroethylene, totel	Tetrechloroethylene, total	1,2-Dibromoethylene, total	1,2-Dichloropropane, total	1,3-Dichloropropane, total
<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0

Cis-1,3-dichloropropene, total	Trens-1,3-dichloropropene, totel	Benzene, total	Ethylbenzene, total	Chlorobenzene, totel	1,2-Dichlorobenzene, total	1,3-Dichlorobenzene, total	1,4-Dichlorobenzene, totel	PCB, dissolved	PCN, dissolved
<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<3.0	<0.1	<0.10

Bacteriological Quality

Coliform bacteria, specifically *Escherichia coli,* occur naturally in the gut of humans and other animals. The presence of these bacteria in ground water implies contamination by wastes from sources such as septic systems or barnyards. Ideally, contamination in wastewater from such sources is removed as the water percolates through soil and porous rock. The likelihood that a well might become contaminated is affected by the construction of the well (Jones, 1973; Jones and Murray, 1977) as well as by the nature of the rock in which the well is constructed. Bacteriological quality of ground water in Washington County was described in a report commissioned by the county (R. E. Wright Associates, Inc., 1981), which concluded that subsurface sewage-disposal practices in the county were generally adequate; most bacteriological contamination was from other sources, and affected wells tended to be old and shallow.

SURFACE WATER

COMPONENTS OF STREAMFLOW

Water flowing in a stream is derived from several sources: precipitation falling directly in the stream channel; surface (overland) runoff flowing as sheetflow and channeled flow; interflow (water moving laterally in the zone between land surface and the water table); and ground water flowing in the zone beneath the water table. A hydrograph of measured streamflow is the sum of these components. Precipitation falling directly into the channel is small compared to the other components and may be combined with surface runoff. The amount of interflow is variable, depending on permeability of the subsurface materials. Interflow generally moves more slowly than surface runoff, but more quickly than groundwater flow, which provides streamflow during prolonged rainless periods to streams whose channels intersect the water table.

Although a number of workers have reported on decomposing streamflow hydrographs into these (and other) components, there is some interchange between components and some arbitrariness in their definition; these factors, together with basin heterogeneities, make it difficult or impossible to consistently obtain unique solutions to hydrograph separations. For many purposes, it is sufficient to distinguish between overland runoff (including relatively rapid subsurface flow in the unsaturated zone—i.e., interflow) and ground-water runoff, or base flow. Computerized methods allow rapid, consistent estimates to be made. Such estimates deviate somewhat from reality owing to the simplifying and arbitrary assumptions necessary to automate the computations, but they nevertheless are useful for long-period studies.

SURFACE-WATER STATIONS AND DRAINAGE BASINS

Streamflow characteristics were estimated for 35 stations on 30 streams flowing through Washington County (pl. 3). The streamflow-data-collection program in Washington County was started in 1897 with the establishment of the recording gage on Antietam Creek near Sharpsburg, which operated for 8 years. In 1928, this station was reactivated and two other stations, Conococheague Creek at Fairview and the Potomac River at Shepherdstown, West Virginia, were established. Since the establishment of the first gage, eight instrumented stations have been operated in the county; five are presently active. In addition to instrumented stations where stream stage has been continuously recorded, miscellaneous discharge measurements have been made at 26 partial-record stations under low-flow and/or high-flow conditions. Water and stream-bottom-material samples have been collected at most of these stations for analyses of physical and chemical properties and at two additional stations where no discharge measurements were made.

The boundaries of the drainage basins upstream from the stations were delineated. Selected geomorphic characteristics of those basins are listed in table 10. Some of the factors listed in table 10 were used to estimate certain streamflow characteristics at ungaged sites, and others help to explain regional variations in streamflow characteristics.

MONTHLY AND ANNUAL MEAN FLOWS

Daily mean discharge, or daily flow, is the average streamflow for a given day. The average of daily flows that occur during a month is the monthly mean flow for that month; the average of monthly mean flows for a particular month over a period of years is the mean monthly flow for that month. Annual mean flow is the average of the daily flows for a year. Monthly mean flows and annual mean flows were calculated for eight stations in Washington County and one station just upstream from the county, in Pennsylvania, for the periods of continuous records (fig. 27). Mean monthly flows range from 2.19 to 1,173 ft^3/s (to 13,100 ft^3/s if the Potomac River is included). Areally, the mean monthly flows range from 0.130 to 2.53 $(ft^3/s)/mi^2$. Highest monthly mean flows generally occur in March or April, whereas the lowest occur in August through October when greater amounts of water are consumed by evapotranspiration. This consumption, primarily of soil moisture, diverts water that would otherwise contribute to ground-water recharge, which results in declining ground-water levels and, hence, streamflow. Mean annual flows range from 12.8 to 592 ft^3/s (to 5,990 ft^3/s if the Potomac River is included). Areally, the range is from 0.677 to 1.26 $(ft^3/s)/mi^2$.

FLOW DURATIONS

Streamflow fluctuations are more extreme in some drainage basins than in others (fig. 28). The reasons for this include differences in forest cover, basin slope, percentage of drainage area occupied by lakes and ponds, underlying geology, and climatological and other factors. The hydrographs in figure 28 are for two streams that drain approximately equal areas. Average flow in Antietam Creek is about the same as in Sideling Hill Creek for the period shown (somewhat greater during the summer); however, flow in Antietam Creek varies over less than two orders of magnitude, whereas flow in Sideling Hill Creek varies over nearly three orders of magnitude. The basin of Sideling Hill Creek, at the west end of Washington County, is about 74 percent forested (table 10), and is underlain by sandstones and shales. The basin of Antietam Creek above the gage near Waynesboro, Pa., at the east end of the county, is only about 46 percent forested. This basin is underlain not only by sandstones and shales, but also by metamorphic rocks of the Blue Ridge physiographic province as well as carbonate rocks, which underlie 47 percent of the basin.

The distribution of daily flows can be conveniently characterized by flow-duration

(Text continued on p. 57.)

TABLE 10
STREAM-STATION AND DRAINAGE-BASIN CHARACTERISTICS

Station number	Stetion name	Period of record	Type of record[1]	Drainage aree (square miles)	Main channel length (miles)
01610150	Bear Creek at Forest Park	May 1965 - Apr. 1983	K		
		June 1975 - May 1979	L		
		Mar. 1985 - Oct. 1987	L,Q	10.4	8.80
01610155	Sideling Hill Creek neer Bellegrove	July 1967 - Sept. 1977	C		
		Aug. 1985 - Aug. 1986	Q	102	34.3
01610170	Potomac River Tributery et Woodmont	Mar. 1985 - Oct. 1986	L,Q	3.29	4.60
01612500	Little Tonoloway Craek near Hancock	Oct. 1947 - Sept. 1963	C		
		Oct. 1963 - Sept. 1964	K		
		Aug. 1985 - Aug. 1986	Q	16.9	5.80
01613000	Potomac River at Hancock	Oct. 1932 - Present	C		
		Jan. 1961 - June 1980	Q	4,073	196
01613100	Tonoloway Creek et Hancock	Mar. 1985 - Oct. 1986	L,Q	113	30.0
01613150	Ditch Run near Hancock	Mar. 1965 - Feb. 1985	K		
		June 1975 - Mey 1979	L		
		Mar. 1985 - Oct. 1986	L,Q	4.80	6.50
01613160	Potomac River Tributary near Hancock	Mar. 1965 - Apr. 1975	K	1.2	2.70
01613500	Licking Creek near Sylvan, Pa.	Oct. 1930 - Sept. 1941	C		
		Mar. 1985 - Oct. 1986	Q	158	46.1
01613540	Lenes Run near Forsythe	Apr. 1980 - May 1982	L		
		Apr. 1985 - Oct. 1986	L,Q	9.98	5.95
01613545	Licking Creek near Pecktonville	Apr. 1985 - Mar. 1987	L,Q	212	55.9
01614050	Little Conococheague Creek near Charlton	Apr. 1985 - Mar. 1987	L,Q	18.1	12.4
01614500	Conococheague Creek at Fairview	June 1928 - Prasent	C		
		Oct. 1948 - Aug. 1986	Q	494	61.1
01614525	Rockdele Run at Fairview	Aug. 1976 - Sept. 1982	L		
		Apr. 1985 - Oct. 1986	L,Q	9.67	5.45
01614575	Rush Run near Huyett	Apr. 1985 - Oct. 1986	L,Q	5.20	5.93
01614577	Rush Run et Troupe Springs[2]	Aug. 1976 - Sept. 1982	L	9.49	6.13
01614625	Meadow Brook at Conococheague	Aug. 1976 - Sept. 1982	L		
		Apr. 1985 - Oct. 1986	L,Q	6.77	6.17
01614675	Conococheague Creek Tributary near Huyett	Sept. 1977 - Sept. 1982	L		
		Apr. 1985 - Oct. 1986	L,Q	7.94	6.56
01614705	Conococheague Creek et Williemsport	Aug. 1954 - Nov. 1954	L		
		Sept. 1985 - Mar. 1987	L,Q	564	85.1
01617600	Downey Branch near Downsville	Sept. 1976 - Sept. 1982	L	3.00	3.99
01617780	St. James Run at Spielman	Sept. 1977 - Sept. 1982	L		
		Apr. 1985 - Oct. 1986	L,Q	7.14	6.63
01617800	Marsh Run at Grimes	Oct. 1963 - Present	C		
		Sept. 1985 - Aug. 1986	Q	18.9	8.70
01618000	Potomac River at Shepherdstown, W. Va.	Aug. 1928 - Sept. 1953	C		
		Oct. 1953 - June 1964	K		
		July. 1964 - Present	C		
		Sept. 1960 - Jan. 1988	Q	5,936	248.5
01619000	Antietam Creek near Waynesboro, Pa.	May 1948 - Sept. 1951,			
		Oct. 1965 - Sept. 1981	C		
		Feb. 1968 - May 1973	Q		
		Aug. 1985 - Aug. 1986	Q	93.5	16.3
01619050	Little Antietam Creek at Leitersburg	Aug. 1976 - Sept. 1982	L		
		Apr. 1985 - Oct. 1986	L,Q	24.5	10.9
01619145	West Branch et Paramount	Sept. 1977 - Sept. 1982	L	5.07	3.80
01619150	Marsh Run at Fiddlesburg	Oct. 1964 - Sept. 1974	L		
		Sept. 1976 - May 1979,			
		Apr. 1985 - Oct. 1986	L,Q	31.0	12.7
01619250	Antietam Creek et Hagerstown	May 1972; Aug. 1976	Q	--	--

Altitude (feet) At 10% stream length	Altitude (feet) At 85% stream length	Mean basin altitude (feet)	Slope of main channel (percent)	Area of lakes (percent)	Forested area (percent)	Area underlain by carbonate rocks (percent)	Station number
675	980	1,060	0.86	0.126	62.4	0	01610150
500	1,060	1,120	.33	.047	73.6	0	01610155
480	930	873	2.49	.428	68.3	0	01610170
480	895	851	1.77	.236	74.1	3	01612500
--	--	1,803	.15	.060	77.0	--	01613000
425	735	939	.26	.067	68.9	3	01613100
470	705	716	.89	.317	27.8	0	01613150
450	725	677	2.58	.605	36.4	0	01613160
--	--	--	.21	.241	68.8	17	01613500
555	1,285	1,012	3.10	.056	78.9	5	01613540
415	825	998	.18	.192	66.0	17	01613545
385	1,240	745	.80	.263	42.1	54	01614050
415	805	1,054	.21	.227	37.4	42	01614500
470	1,060	667	2.73	.109	19.7	87	01614525
475	680	586	.89	.000	1.4	100	01614575
475	680	566	.89	.015	1.2	100	01614577
430	620	559	.78	.123	8.9	95	01614625
395	600	533	.79	.113	3.8	99	01614675
360	815	839	.14	.210	34.2	--	01614705
400	505	473	.66	.026	.8	100	01617600
445	585	539	.54	.024	12.2	100	01617780
385	570	509	.45	.115	11.7	100	01617800
--	--	1,524	.11	.051	68.0	--	01618000
555	1,265	1,010	1.12	.184	46.2	47	01619000
525	1,355	968	1.92	.105	30.5	49	01619050
575	730	645	1.03	.000	3.7	100	01619145
515	665	669	.30	.002	2.9	100	01619150
--	--	--	--	--	--	--	01619250

TABLE 10—CONTINUED

Station number	Station name	Period of record	Type of record[1]	Drainage area (square miles)	Main channel length (miles)
01619270	Antietam Creek below Hagerstown	May 1972	Q	--	--
01619275	Landis Spring Branch near Benevola	Sept. 1976 - Sept. 1982 Mar. 1985 - Oct. 1986	L L,Q	6.60	7.15
01619325	Beaver Creek at Benevola	Aug. 1975 - May 1979 Mar. 1985 - Oct. 1986	L L,Q	22.9	13.6
01619350	Little Beaver Creek at Benevola	Aug. 1975 - May 1979 Apr. 1985 - Oct. 1986	L L,Q	8.70	5.63
01619475	Dog Creek Tributary near Locust Grove	Aug. 1966 - July 1976	K	[3].11	.55
01619480	Little Antietam Creek at Keedysville	Sept. 1964 - May 1979 Apr. 1985 - Oct. 1986	L L,Q	24.4	7.37
01619500	Antietam Creek near Sharpsburg	June 1897 - Sept. 1905, Aug. 1928 - Present Aug. 1963 - Aug. 1986	 C Q	281	47.1
01619525	Sharmans Branch near Antietam	Sept. 1977 - Sept. 1982	L	4.62	5.02
01636730	Israel Creek at Weverton	Aug. 1975 - May 1979 Apr. 1985 - Oct. 1986	L L,Q	13.2	8.07

[1] C, continuous; K, peak flow; L, low flow; Q, water quality.
[2] Formerly published as Rush Run near Huyett with incorrect drainage area (U.S. Geological Survey, 1977-82).
[3] Drainage area remeasured from basin boundaries redrawn on U.S. Geological Survey, 1978 edition Keedysville 7-1/2-minute quadrangle map (cultural and topographic revisions).

TABLE 11
DURATIONS OF DAILY FLOWS AT CONTINUOUS-RECORD STATIONS

Station number	Station name	Drainage area (square miles)	Flow, in cubic feet per second, 0.5	1	2	5	10
01610155	Sideling Hill Creek near Bellegrove	102	1,900	1,200	860	490	290
01612500	Little Tonoloway Creek near Hancock	16.9	250	170	120	67	38
01613000	Potomac River at Hancock	4,073	42,000	31,000	23,000	14,000	9,500
01613500	Licking Creek near Sylvan, Pa.	158	2,100	1,600	1,100	620	370
01614500	Conococheague Creek at Fairview	494	5,200	4,100	3,100	1,900	1,300
01617800	Marsh Run at Grimes	18.9	65	53	43	32	25
01618000	Potomac River at Shepherdstown, W. Va.	5,936	56,000	44,000	32,000	20,000	14,000
01619000	Antietam Creek near Waynesboro, Pa.	93.5	710	520	420	290	220
01619500	Antietam Creek near Sharpsburg	281	1,600	1,200	970	700	540

Altitude (feet) At 10% stream length	Altitude (feet) At 85% stream length	Mean basin altitude (feet)	Slope of main channel (percent)	Area of lakes (percent)	Forested area (percent)	Area underlain by carbonate rocks (percent)	Station number
--	--	--	--	--	--	--	01619270
465	630	583	.59	.021	4.1	98	01619275
440	820	861	.71	.093	44.8	49	01619325
445	795	793	1.57	.563	39.5	52	01619350
500	595	571	4.28	.000	28.9	69	01619475
375	665	687	.99	.131	32.8	39	01619480
330	730	781	.20	.123	29.8	64	01619500
365	705	721	1.72	.377	77.4	--	01619525
305	615	724	.97	.112	51.6	0	01636730

which was equaled or exceeded for indicated percentage of time											Station
20	30	50	70	80	90	95	98	99	99.5	99.9	number
150	97	42	17	6.7	2.2	0.8	0.2	0.1	0	0	01610155
20	12	4.0	1.1	.5	.1	.1	0	0	0	0	01612500
5,900	4,000	2,100	1,100	740	510	410	330	300	280	230	01613000
210	140	68	33	23	14	9.7	6.1	5.4	5.0	3.6	01613500
820	590	330	180	140	100	81	63	53	45	35	01614500
18	15	9.2	5.7	4.4	3.3	2.6	1.7	1.4	1.0	.62	01617800
8,300	5,800	3,200	1,700	1,200	850	670	510	430	370	300	01618000
160	130	88	59	48	38	33	23	20	17	15	01619000
400	310	210	140	120	97	85	73	65	61	52	01619500

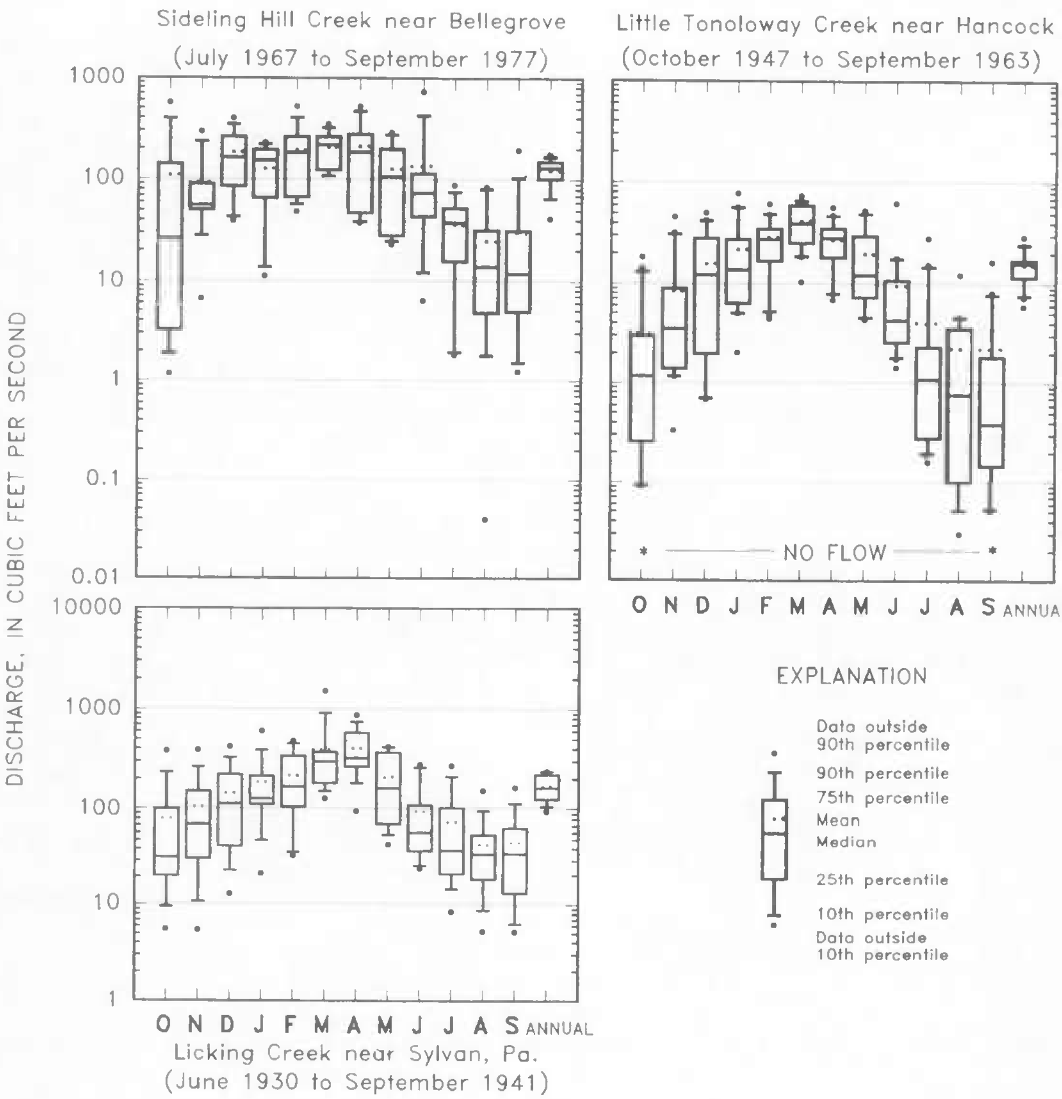


Figure 27.—Monthly and annual mean flows at nine gaging stations having continuous records.

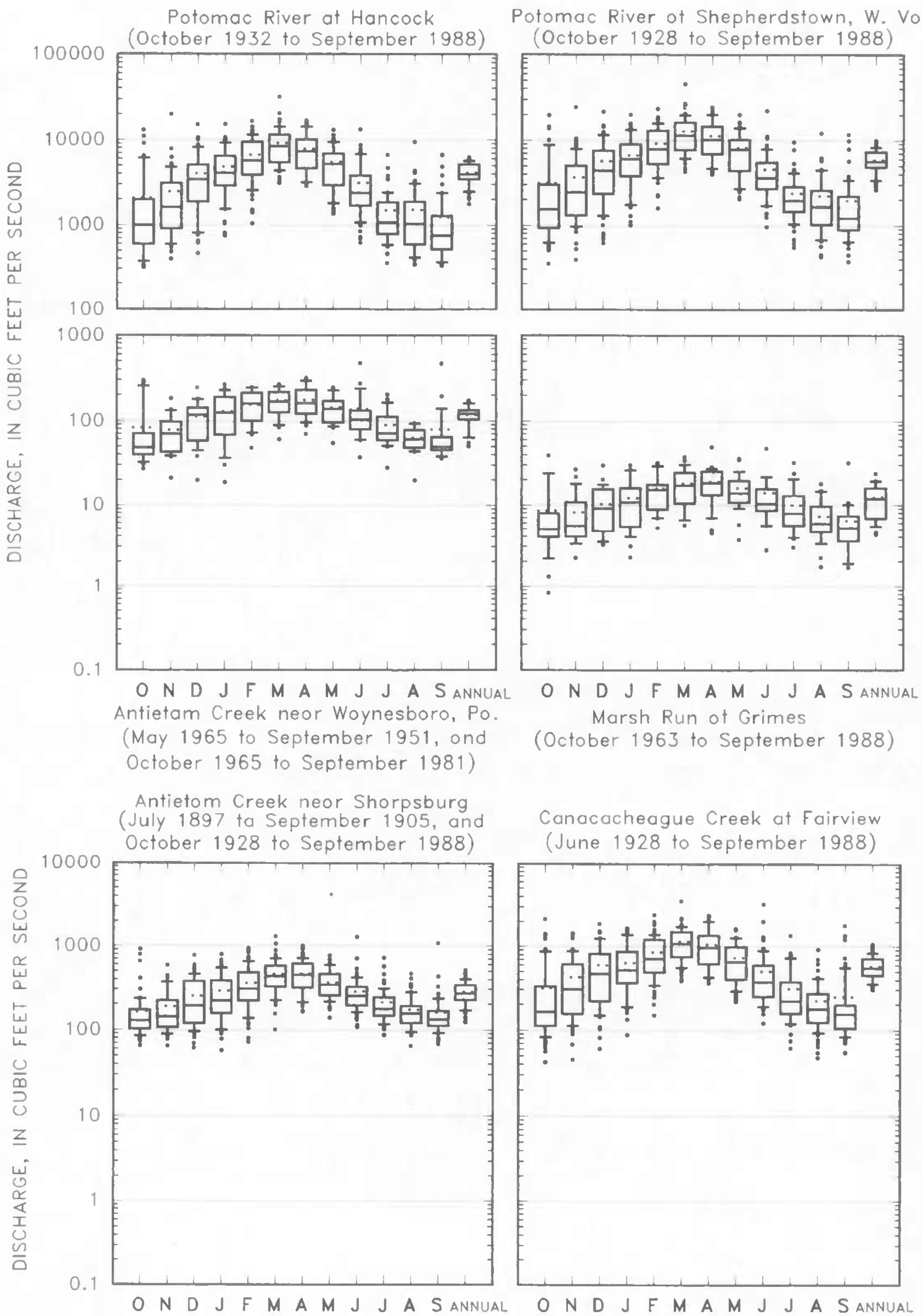


Figure 27.—Continued.

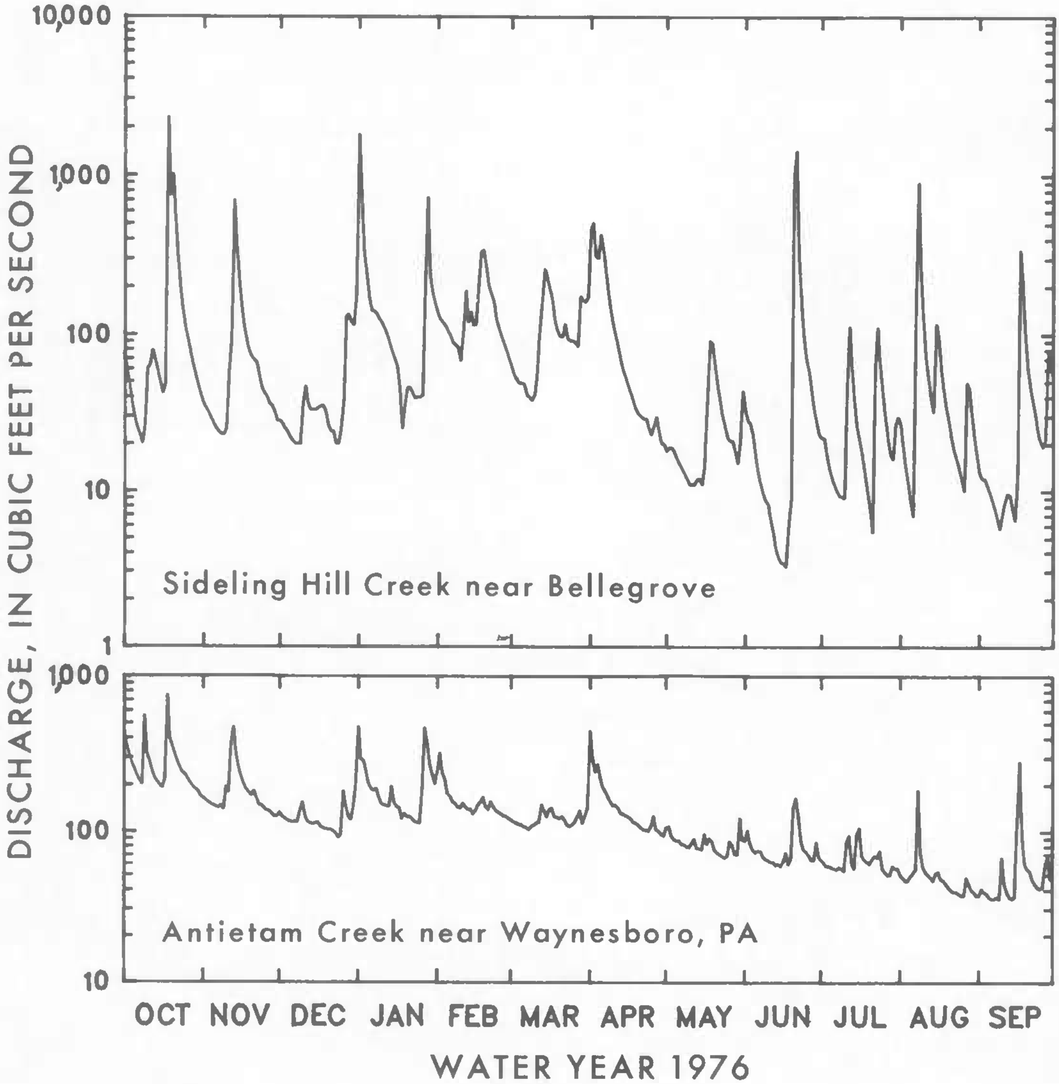


Figure 28.—Fluctuations in streamflow in a western and in an eastern drainage basin.

curves, or cumulative-frequency graphs of streamflows, which provide an approximation of the percentage of time a flow rate is equaled or exceeded (fig. 29). Selected flows and exceedance probabilities are listed for the nine gaging stations in table 11. For each station, the entire period of record was used.

The shape of the flow-duration curve is determined by the hydrogeologic characteristics of the drainage basin and is useful for comparing basins. The two opposite extremes of shape of the duration curves for Washington County streams (table 11) are shown in figure 30. The curve for Sideling Hill Creek has a steep slope, indicative of a basin with highly variable flow, little storage of ground or surface water within the basin, and a relatively large proportion of total discharge consisting of surface runoff. The flatter curve for Antie-

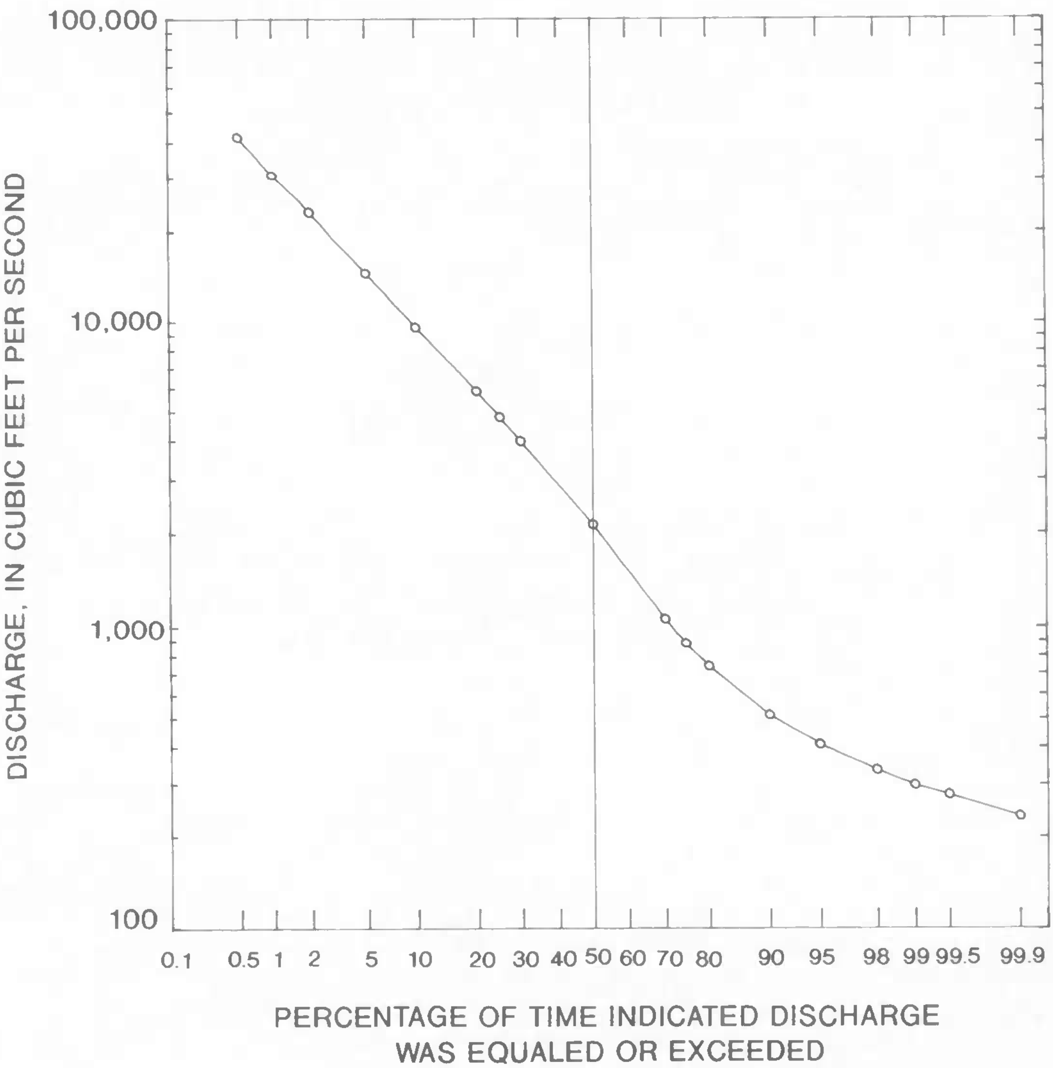


Figure 29.—Daily flow durations, Potomac River at Hancock, water years 1932–88.

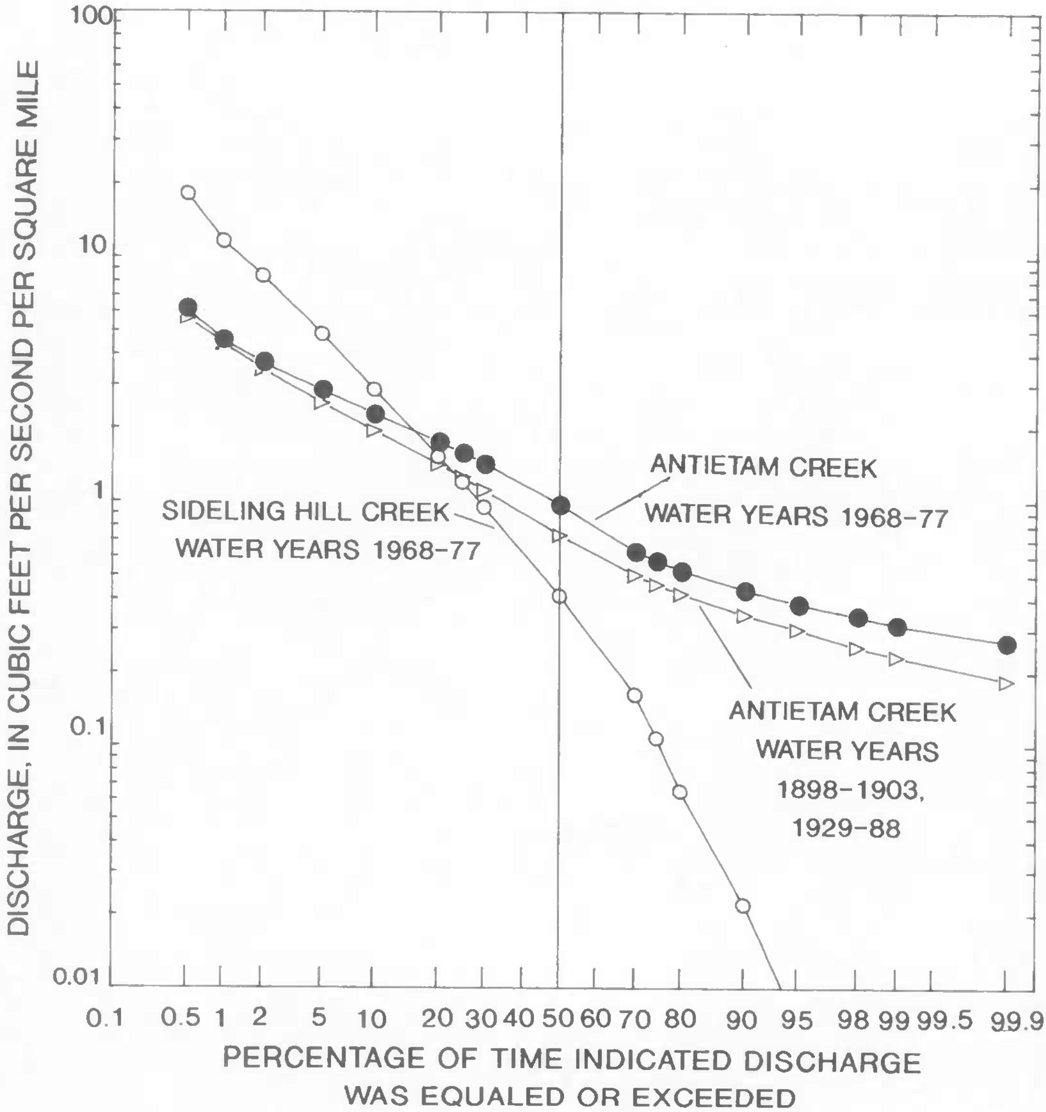


Figure 30.—Comparison of flow-duration curves, Sideling Hill Creek near Bellegrove and Antietam Creek near Sharpsburg.

tam Creek indicates that this basin has more uniform flow, greater amounts of storage, and that its total flow consists of a greater proportion of ground-water runoff compared to the Sideling Hill Creek basin.

Two curves are shown in figure 30 for Antietam Creek: one for the entire period of record and one representing the same period shown for Sideling Hill Creek. The two curves have similar shapes, but the curve representing October 1968 through September 1977 is shifted upward because that period was wetter, with no prolonged dry spells. Differences in duration curves representing different periods can be more significant. Curves for Conococheague Creek at Fairview representing a relatively wet 5-year period (1971–75), a relatively dry 5-year period (1962–66), and the 59-year period of record (1929–88) are noticeably offset (fig. 31). Median flow for the dry period is 165 ft^3/s, whereas for the wet period it is 580 ft^3/s. Higher ground-water levels or soil-moisture content during the wet period may be partly responsible for the differences in the slopes of the curves at the low discharge ends, by increasing the movement of ground water toward the streams. Longer periods of record generally are less affected by infrequent extreme flows, but caution needs to be exercised to avoid combining periods representing changes in land use or other factors that affect the physical system being considered. Two stations listed in table 11, Sideling Hill Creek near Bellegrove and Licking Creek near Sylvan, Pa., have only 10 years of record; two others, Little Tonoloway Creek near Hancock and Antietam Creek near Waynesboro, Pa., have less than 20 years of record.

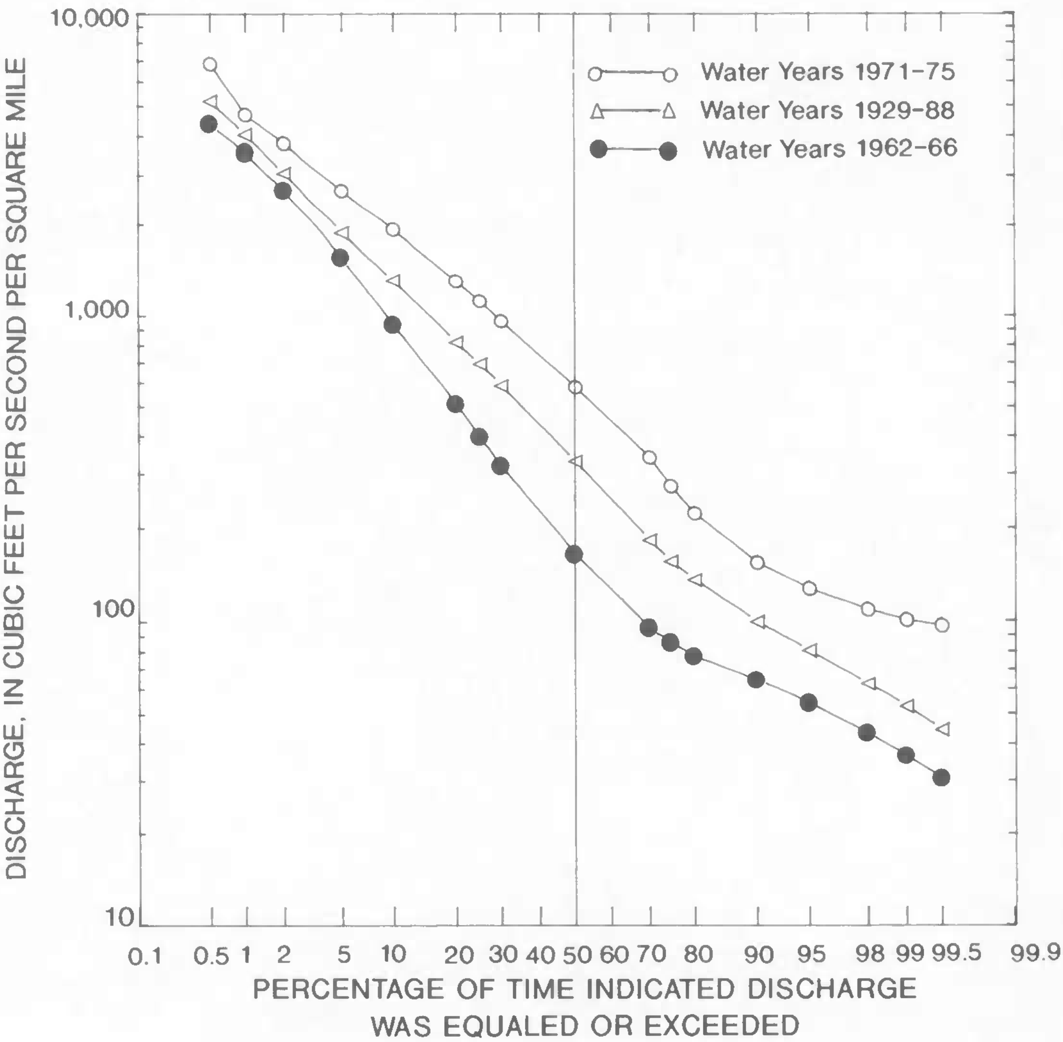


Figure 31.—Differences in shapes of flow-duration curves due to different periods of record, Conococheague Creek at Fairview.

Streamflow is not generated uniformly throughout a drainage basin, especially if the basin is large and heterogeneous. Duration curves for two stations on Antietam Creek—near Waynesboro, Pa. (drainage area 93.5 mi^2), and near Sharpsburg (drainage area 281 mi^2), illustrate differences that can occur within a basin (fig. 32). The Waynesboro station is characterized by greater variation in streamflow; both higher flows and lower flows (per unit area) occur more frequently. The greater streamflow variation may be accounted for by differences in precipitation, vegetation, basin size and slope, and other geomorphic factors, which are not uniform throughout the entire basin.

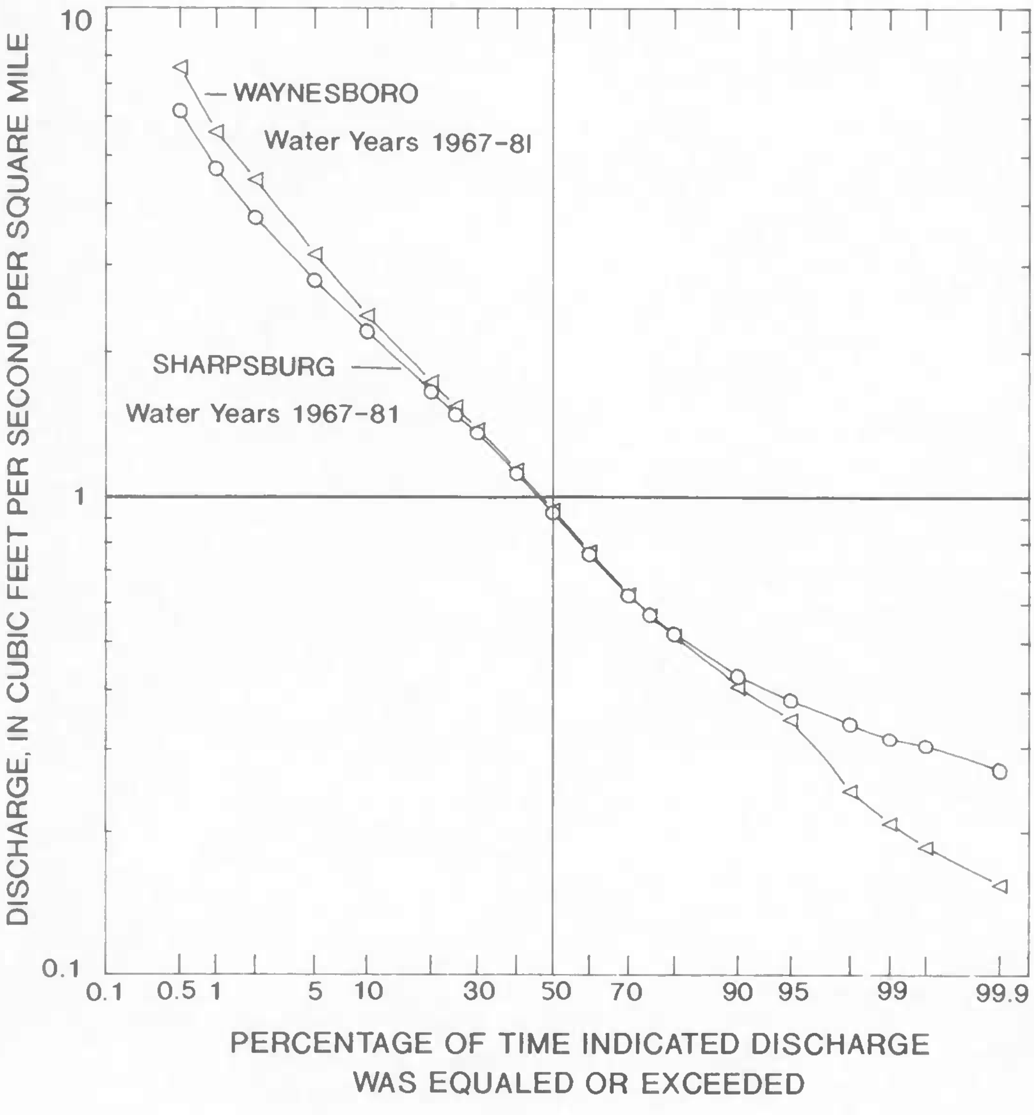


Figure 32.—Durations of daily flows at two stations on Antietam Creek—near Waynesboro, Pennsylvania (drainage area 93.5 mi^2) and downstream near Sharpsburg (drainage area 281 mi^2). Records are for water years 1967–81.

FLOOD FREQUENCIES

Most major floods in Washington County result from the passage of hurricanes. Rain associated with hurricanes caused peaks of record at five continuous-record gaging stations in the county. Peaks of record at the two Washington County gaging stations on the Potomac River occurred March 18–19, 1936, during heavy rainfall due to a northeast-moving continental low-pressure system combined with snowmelt (Thomson, 1937).

Flood magnitudes for selected recurrence intervals (the reciprocal of the probability that a given flow will be exceeded in any one year or the average period, in years, during which a given flow is exceeded once) were estimated in several ways. For stations having continuous records (table 12), floods of selected durations were estimated by fitting daily mean flow data for 1, 3, or 7 days to a log Pearson Type III frequency distribution (U.S. Water Resources Council, 1981). Estimates of high flows are less certain for stations having shorter periods of record; likewise, for a fixed record length, estimates of flows of increasing recurrence intervals become increasingly uncertain. Therefore, high flows for some recurrence intervals are omitted from table 12.

Peak flows also were estimated by fitting annual peak-flow data to the log Pearson Type III distribution. Peak-flow estimates for gaged stations also can be made based on drainage-basin characteristics, as for ungaged stations (discussed in subsequent paragraphs). Table 12 lists weighted averages of values computed by these two methods. The manner of weighting reflects the length of record and the accuracy of the regional estimating equations:

$$Q_{avg} = \frac{Q_{LP3}\,N + Q_r\,[N/\text{antilog (SE)}]}{N + [N/\text{antilog (SE)}]},$$

where Q_{avg} is the weighted average peak flow, Q_{LP3} is the peak flow estimated from the log Pearson Type III distribution, N is the number of years of record used to determine Q_{LP3}, Q_r is the peak flow estimated from the appropriate regional equations, and SE is the standard error of estimate (in logarithmic units) of the estimating equation.

Peak-flow characteristics also can be estimated at stations for which continuous records are unavailable (table 13). For peak-flow partial-record stations, annual peak-flow data were fitted to the log Pearson Type III distribution, peaks were estimated using the multiple-regression equations, and weighted averages were computed in the same manner as for stations having continuous records.

Peak-flow characteristics for Conococheague Creek at Williamsport were estimated using the multiple-regression equations, adjusted to reflect the weighting applied to obtain the estimates at the gaged station at Fairview. To make this adjustment (described more fully by Thomas and Corley, 1977), the ratio $R = Q_{avg}/Q_r$ is computed, where Q_{avg} is the weighted average peak flow in table 12 and Q_r is the estimate obtained using the multiple-regression equation. The ratio is adjusted for the difference in drainage area by using the following equation:

$$R_w = R - [2\,(\Delta A)/A_g]\,(R - 1),$$

where ΔA is the difference in drainage areas, and A_g is the drainage area of the gaged site. Multiplying the multiple-regression estimate by this adjusted ratio essentially applies the same weighting used at the gaged site to the ungaged site.

TABLE 12

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

[Upper peak-flow value derived from log Pearson Type III distribution; lower value is weighted average of upper value and value obtained using multiple-regression equations. Dashed where period of record insufficient for making reliable estimate]

Station number	Station names and period of record	Annual maximum	Discharge, in cubic feet per second, for indicated recurrence interval, in yeers					
			2	5	10	25	50	100
01610155	Sideling Hill Creek near	Peak flow	4,450	7,620	10,270	14,310	17,850	21,880
	Bellegrove (Oct. 1, 1967, to		4,390	7,270	9,690	13,370	16,610	20,250
	Sept. 30, 1977)	1-dey flow	2,460	4,270	5,930	--	--	--
		3-day flow	1,460	2,480	3,470	--	--	--
		7-dey flow	833	1,360	1,830	--	--	--
01612500	Little Tonoloway Creek near	Peak flow	520	898	1,220	1,700	2,130	2,630
	Hancock (Oct. 1, 1947, to		549	937	1,270	1,770	2,220	2,720
	Sept. 30, 1963)	1-dey flow	294	435	522	625	--	--
		3-day flow	201	281	327	376	--	--
		7-day flow	122	166	191	219	--	--
01613000	Potomac River et Hancock (Oct.	Peak flow	57,800	94,000	124,000	170,000	210,000	256,000
	1, 1932, to Sept. 30, 1988;	1-day flow	49,900	80,800	106,000	144,000	177,000	215,000
	except peak flow, water years	3-day flow	37,100	57,000	72,100	93,500	111,000	150,000
	1889, 1924, 1929, end 1933-88)	7-day flow	25,300	36,000	43,100	52,100	58,700	65,300
01613500	Licking Creek near Sylvan, Pa.	Peak flow	4,560	8,460	12,220	18,760	25,240	33,420
	(Oct. 1, 1931, to Sept. 30,		5,330	9,130	12,590	18,300	23,720	30,290
	1941)	1-day flow	2,800	5,030	7,230	--	--	--
		3-day flow	1,850	3,310	4,750	--	--	--
		7-day flow	1,160	1,920	2,620	--	--	--
01614500	Conococheague Creek at Fairview	Peak flow	7,540	11,360	14,510	19,290	23,490	28,310
	(Oct. 1, 1928, to Sept. 30,		7,080	10,870	14,090	19,080	23,500	28,500
	1988; except peak flow, water	1-day flow	6,140	9,280	11,900	15,900	19,400	23,500
	yeers 1889, 1924, end 1929-88)	3-day flow	4,490	6,840	8,750	11,600	14,100	16,900
		7-day flow	3,120	4,530	5,550	6,950	8,070	9,250
01617800	Marsh Run at Grimes (Oct. 1,	Peak flow	101	196	288	451	613	819
	1963, to Sept. 30, 1988)		113	212	304	465	621	815
		1-day flow	62.4	115	160	229	291	--
		3-day flow	48.1	82.1	108	144	173	--
		7-day flow	38.1	60.4	75.5	94.4	108	--
01618000	Potomac River et Shepherdstown,	Peak flow	74,200	115,000	147,000	192,000	231,000	273,000
	W. Va, (Oct. 1, 1928, to Sept.	1-day flow	65,200	101,000	128,000	167,000	190,000	235,000
	30, 1988)	3-day flow	50,700	76,900	96,600	124,000	147,000	171,000
		7-day flow	34,600	49,600	69,700	72,700	82,400	92,200
01619000	Antietam Creek neer Waynesboro,	Peak flow	1,460	2,590	3,600	5,240	6,770	8,600
	Pa. (Oct. 1, 1949, to Sept.		1,350	2,330	3,200	4,590	5,880	7,390
	30, 1951, and Oct 1, 1965, to	1-day flow	810	1,530	2,230	3,460	--	--
	Sept. 30, 1981)	3-day flow	573	1,070	1,560	2,450	--	--
		7-day flow	444	744	1,000	1,400	--	--
01619500	Antietam Creek near Sharpsburg	Peak flow	2,600	4,540	6,220	8,860	11,250	14,030
	(Oct. 1, 1897, to Sept. 30,		2,840	4,810	6,520	9,230	11,670	14,490
	1903, and Oct. 1, 1928, to	1-day flow	1,790	3,040	4,120	5,850	7,420	9,270
	Sept. 30, 1988)	3-day flow	1,310	2,170	2,880	3,930	4,840	5,870
		7-day flow	960	1,520	1,940	2,530	3,010	3,520

A new set of multiple-regression equations was developed for estimating peak flows in Washington County. Carpenter (1983, p. 26) excluded basins underlain by significant amounts of carbonate rock from his regression analysis, and included a caveat for using his equations in the limestone regions of Washington County. Other workers (e.g., Markova, 1967; White and Reich, 1970; White, 1976) have discussed the effects of carbonate bedrock, or, more specifically, karst development, on the behavior of flood flows. Floods are apparently damped because of ready infiltration of flood waters into bedrock that has considerable storage capacity due to solutional enlargement of joints, fractures, and bedding planes.

Basin characteristics from seven continuous-record stations and four peak-flow partial-record stations were used as independent variables in a stepwise multiple-regression procedure (SPSS, Inc., 1983). A method of weighting the peak-flow characteristics at the continuous-record stations (Tasker, 1980) was used that is related to the frequency distributions of an-

TABLE 13
ESTIMATED MAGNITUDES AND FREQUENCIES OF ANNUAL PEAK FLOWS AT PARTIAL-RECORD STATIONS

Station number	Station name (method[1])	Discharge, in cubic feet per second, for indicated recurrence interval, in years					
		2	5	10	25	50	100
01610150	Bear Creek at Forest Park (1)	378	668	907	1,270	1,580	1,920
	(2)	443	765	1,040	1,450	1,810	2,220
01610170	Potomac River Tributary at Woodmont (3)	290	487	660	927	1,170	1,440
01613100	Tonoloway Creek at Hancock (3)	3,570	5,710	7,540	10,330	12,770	15,450
01613150	Ditch Run near Hancock (1)	237	377	489	653	793	948
	(2)	199	324	429	592	736	900
01613160	Potomac River Tributary near Hancock (1)	105	149	183	230	270	313
	(2)	98	150	196	264	325	393
01613540	Lanes Run near Forsythe (3)	545	910	1,220	1,710	2,130	2,600
01613545	Licking Creek near Pecktonville (3)	8,320	12,940	16,900	22,930	28,210	34,000
01614050	Little Conococheague Creek near Charlton (3)	522	878	1,190	1,690	2,140	2,660
01614525	Rockdale Run at Fairview (3)	122	216	301	443	576	732
01614575	Rush Run near Huyett (3)	30	55	80	123	165	218
01614577	Rush Run at Troupe Springs[2] (3)	36	66	95	147	198	261
01614625	Meadow Brook at Conococheague (3)	64	116	164	247	326	422
01614675	Conococheague Creek Tributary near Huyett (3)	46	84	121	184	247	322
01614705	Conococheague Creek at Williamsport (4)	9,870	15,070	19,560	26,580	32,840	39,950
01617600	Downey Branch near Downsville (3)	20	36	53	82	111	147
01617780	St. James Run at Spielman (3)	84	150	211	315	413	531
01619050	Little Antietam Creek at Leitersburg (3)	373	639	877	1,260	1,610	2,020
01619145	West Branch at Paramount (3)	31	57	82	126	168	221
01619150	Marsh Run at Fiddlesburg (3)	100	180	257	391	521	678
01619275	Landis Spring Branch near Benevola (3)	47	86	123	187	250	326
01619325	Beaver Creek at Benevola (3)	646	1,080	1,460	2,070	2,610	3,230
01619350	Little Beaver Creek at Benevola (3)	235	404	555	796	1,020	1,270
01619475	Dog Creek Tributary near Locust Grove (1)	21	44	68	111	156	215
	(2)	23	44	66	103	140	189
01619480	Little Antietam Creek at Keedysville (3)	309	534	735	1,060	1,350	1,690
01619525	Sharmans Branch near Antietam (3)	387	647	872	1,220	1,520	1,860
01636730	Israel Creek at Weverton (3)	437	738	1,000	1,420	1,790	2,210

[1] Methods: 1, Fit of annual peak flows to log Pearson Type III distribution; 2, weighted average of value derived from log Pearson Type III distribution and value obtained from multiple-regression equations; 3, multiple-regression using basin characteristics; 4, value derived from multiple-regression equations adjusted using method of Thomas and Corley (1977) and data from station at Fairview.

[2] Formerly published as 01614575, Rush Run near Huyett with incorrect drainage area (U.S. Geological Survey, 1977-82).

nual peak flows and the periods of record at the stations. The procedure produced the following set of equations:

Estimating equation	Standard error of the estimate: Log units	Percentage: Plus	Percentage: Minus
$Q_2 = 0.015\,(L+10)^{1.408}\,(F+10)^{1.314}\,A^{0.306}$	0.13	34.9	25.9
$Q_5 = 0.037\,(L+10)^{1.341}\,(F+10)^{1.266}\,A^{0.311}$	.10	25.9	20.6
$Q_{10} = 0.062\,(L+10)^{1.319}\,(F+10)^{1.231}\,A^{0.310}$	.09	23.1	18.7
$Q_{25} = 0.115\,(L+10)^{1.295}\,(F+10)^{1.182}\,A^{0.310}$	.09	23.1	18.7
$Q_{50} = 0.175\,(L+10)^{1.285}\,(F+10)^{1.145}\,A^{0.308}$	.09	23.1	18.7
$Q_{100} = 0.258\,(L+10)^{1.279}\,(F+10)^{1.108}\,A^{0.305}$	.10	25.9	20.6

where Q_2, Q_5, . . . Q_{100} are annual peak flows of recurrence intervals of 2, 5, . . . 100 years, in cubic feet per second; L is length of the main channel, extended to the basin divide, in miles; F is the percent of the basin covered by forest; and A is the drainage area, in square miles. The standard errors of estimate are presented to provide an idea of the accuracy of the estimating equations. The percentages corresponding to the values in logarithmic units were obtained from Hardison (1969, p. D213).

Main channel length, forest cover, and drainage area are the important factors for determining peak flows for the estimating equations. Main channel length is slightly more correlated with peak flows than is drainage area. Although these two factors are themselves correlated, when used together, they also may describe basin shape, rather than merely basin size. One might expect peak flow to be inversely proportional to forest cover because surface runoff across forested land is impeded and infiltration is greater. The set of equations indicate that this is not the case—perhaps because of a correspondence of forest cover with land slope, soil infiltration capacity, or other factors having an opposite effect. The percentage of basin underlain by carbonate rock was not statistically significant, contrary to expectations. Use of two carbonate factors—percentage of basin underlain by limestone, and percentage underlain by dolomite—or use of some measure of karst development (White, 1976) may provide greater explanation of peak-flow variability, but the effort does not seem warranted for the small number of stations with which this study is concerned. On an areal basis, there do not appear to be any strong patterns in the magnitude of peak flows (table 14); the greatest peak flows tend to occur in small, steep basins.

LOW-FLOW CHARACTERISTICS

The capability of a stream to supply water, dilute and carry away wastes, and provide suitable habitat for aquatic communities may be severely diminished at very low flows, especially if extremely low flow is prolonged. Magnitudes and frequencies of low flows of specified periods are presented in this section to assist in addressing these concerns. Many water-quality standards are based on the 7-day, 10-year low-flow frequency ($Q_{7,10}$), defined as the lowest average flow for a period of 7 consecutive days which has a recurrence interval of 10 years. For analysis of low-flow characteristics, it is better not to use water years which may split the annual low-flow period. Thus, for the humid, temperate region which includes

TABLE 14
AREAL PEAK FLOWS
[Peak flows from tables 12 and 13; weighted average used where available]

Station number	Station name	Discharge, in cubic feet per second per square mile, for indicated recurrence interval, in years					
		2	5	10	25	50	100
01610150	Bear Creek at Forest Park	36.4	64.2	87.2	122.1	151.9	184.6
01610155	Sideling Hill Creek near Bellegrove	43.0	71.3	95.0	131.1	162.8	198.5
01610170	Potomac River Tributary at Woodmont	88.2	148.0	200.6	281.8	355.6	437.7
01612500	Little Tonoloway Creek near Hancock	32.5	55.4	75.1	104.7	131.4	160.9
01613000	Potomac River at Hancock	14.2	23.1	30.4	41.7	51.6	62.9
01613100	Tonoloway Creek at Hancock	31.6	50.5	66.7	91.4	113.0	136.7
01613150	Ditch Run near Hancock	49.4	78.5	101.9	136.0	165.2	197.5
01613160	Potomac River Tributary near Hancock	87.5	124.2	152.5	191.7	225.0	260.8
01613500	Licking Creek near Sylvan, Pa.	33.7	57.8	79.7	115.8	150.1	191.7
01613540	Lanes Run near Forsythe	54.6	91.2	122.2	171.3	213.4	260.5
01613545	Licking Creek near Pecktonville	39.2	61.0	79.7	108.2	133.1	160.4
01614050	Little Conococheague Creek near Charlton	28.8	48.5	65.7	93.4	118.2	147.0
01614500	Conococheague Creek at Fairview	14.3	22.0	28.5	38.6	47.6	57.7
01614525	Rockdale Run at Fairview	12.6	22.3	31.1	45.8	59.6	75.7
01614575	Rush Run near Huyett	5.8	10.6	15.4	23.7	31.7	41.9
01614577	Rush Run at Troupe Springs[1]	3.8	7.0	10.0	15.5	20.9	27.5
01614625	Meadow Brook at Conococheague	9.5	17.1	24.2	36.5	48.2	62.3
01614675	Conococheague Creek Tributary near Huyett	5.8	10.6	15.2	23.2	31.1	40.6
01614705	Conococheague Creek at Williamsport	17.5	26.7	34.7	47.1	58.2	70.8
01617600	Downey Branch near Downsville	6.7	12.0	17.7	27.3	37.0	49.0
01617780	St. James Run at Spielman	11.8	21.0	29.6	44.1	57.8	74.4
01617800	Marsh Run at Grimes	6.0	11.2	16.1	24.6	32.9	43.1
01618000	Potomac River at Shepherdstown	12.5	19.4	24.8	32.3	38.9	46.0
01619000	Antietam Creek near Waynesboro	14.4	24.9	34.2	49.1	62.9	79.0
01619050	Little Antietam Creek at Leitersburg	15.2	26.1	35.8	51.4	65.7	82.4
01619145	West Branch at Paramount	6.1	11.2	16.2	24.9	33.1	43.6
01619150	Marsh Run at Fiddlesburg	3.2	5.8	8.3	12.6	16.8	21.9
01619275	Landis Spring Branch near Benevola	7.1	13.0	18.6	28.3	37.9	49.4
01619325	Beaver Creek at Benevola	28.2	47.2	63.8	90.4	114.0	141.0
01619350	Little Beaver Creek at Benevola	27.0	46.4	63.8	91.5	117.2	146.0
01619475	Dog Creek Tributary near Locust Grove	190.9	400.0	618.2	1,009.1	1,418.2	1,954.5
01619480	Little Antietam Creek at Keedysville	12.7	21.9	30.1	43.4	55.3	69.3
01619500	Antietam Creek near Sharpsburg	10.1	17.1	23.2	32.8	41.5	51.6
01619525	Sharmans Branch near Antietam	83.8	140.0	188.7	264.1	329.0	402.6
01636730	Israel Creek at Weverton	33.1	55.9	75.8	107.6	135.6	167.4

[1] Formerly published as 01614575, Rush Run near Huyett with incorrect drainage area (U.S. Geological Survey, 1977-82).

Washington County, annual low-flow reckonings are based on the climatic year ending March 31.

Data collected at continuous-record gaging stations were fitted to the log Pearson Type III distribution. Discharges for 7, 14, 30, 60, and 120 consecutive days and for recurrence intervals of 2, 5, 10, and (for stations having sufficiently long records) 20 and 50 years were determined from this distribution (table 15). Values from table 15 are plotted for Antietam Creek near Sharpsburg (fig. 33) to illustrate the distributions of the annual low flows of the five durations. Seven-day, 10-year low flows for the stations listed in table 15 range from 0 to 66 ft^3/s (to 415 ft^3/s if the Potomac River is included). Areally, the range is from 0 to 0.257 $(ft^3/s)/mi^2$.

Streamflow at partial-record sites at which several low-flow measurements are available may be estimated using these measurements and concurrent data from a nearby station having a continuous record. A linear regression of the logarithms of discharge as shown in figure 34 may be used to estimate a low flow at the partial-record station (the value corresponding to the calculated low flow at the gaging station) (Riggs, 1972, p. 9). However, this method consistently overestimates the desired low flow (Stedinger and Thomas, 1985, p. 15). Stedinger and Thomas developed an unbiased method of estimation using the same regression relation, but deriving the desired low-flow estimate in a different manner. The desired low flow is calculated from distribution parameters of the ungaged site, which have been estimated from distribution parameters at the gaged site and the regression coefficients. This method is valid only for estimates of discharge under base-flow conditions. The 7-day low flows for recurrence intervals of 2 years ($Q_{7,2}$) and 10 years ($Q_{7,10}$) listed in table 16 were obtained using this method.

Low-flow characteristics estimated using the method of Stedinger and Thomas (1985) in this report are based on 6 to 25 measurements. The precision of the method can be improved with additional discharge measurements at the partial-record site, but the improvement becomes negligible for more than 20 measurements (Stedinger and Thomas, 1985, p. 18). The reliability of the estimate also is affected by where in the range of flows the measurements are, and the reliability is decreased if extrapolation is necessary. Low-flow conditions were moderate when data for this study were collected, requiring extrapolation to obtain the values listed in table 16.

Seven-day low flows (per square mile) tend to be lower in the western basins and higher in the eastern basins (fig. 35). Higher $Q_{7,10}$ flows, ranging from 0.048 to 0.425 $(ft^3/s)/mi^2$ (table 16), occur in those basins underlain by proportionally large areas of carbonate rock; $Q_{7,10}$ flows in basins having proportionally small areas underlain by carbonate rock range from 0 to 0.040 $(ft^3/s)/mi^2$. The importance of the hydrogeologic properties of the underlying rock was pointed out by Nutter (1973, p. 17). He noted that hydrographs of streams draining carbonate-rock terrane not only indicated less flashy conditions (lesser relative amounts of overland runoff) than those draining noncarbonate terrane, but that their recession slopes were less steep, indicating that aquifer storage coefficients in carbonate terrane are greater. Two of the basins that have high $Q_{7,10}$ flows, Beaver Creek and Little Beaver Creek, also include areas of colluvium along the western flank of South Mountain. However, low flows of Little Conococheague Creek are more moderate, even though its drainage area also includes colluvium at the western edge of the Hagerstown Valley. Therefore, other factors, such as land use, relief, and local climate probably account for some of the variability in low-flow characteristics.

TABLE 15
MAGNITUDES AND FREQUENCIES OF ANNUAL LOW FLOWS AT CONTINUOUS-RECORD STATIONS
[Dashed where period of record insufficient for reliable estimate]

Station number	Station name (period of record)	Duration (days)	Discharge, in cubic feet per second, for indicated recurrence interval, in years				
			2	5	10	20	50
01610155	Sideling Hill Creek near Bellegrove (April 1, 1968 to March 31, 1977)	7	0.4	0.3	0.0	--	--
		14	.8	.3	.0	--	--
		30	2.0	.4	.1	--	--
		60	6.3	1.5	.5	--	--
		120	15	5.1	2.6	--	--
01612500	Little Tonoloway Creek near Hancock (April 1, 1949 to March 31, 1963)	7	.1	.0	.0	--	--
		14	.1	.0	.0	--	--
		30	.2	.0	.0	--	--
		60	.3	.1	.0	--	--
		120	.9	.4	.2	--	--
01613000	Potomac River at Hancock (April 1, 1933 to March 31, 1988)	7	407	312	275	248	223
		14	434	330	290	264	239
		30	498	367	318	285	254
		60	633	442	371	323	278
		120	931	620	506	429	359
01613500	Licking Creek near Sylvan, Pa. (April 1, 1931 to March 31, 1941)	7	11	7.7	6.3	--	--
		14	13	8.6	6.8	--	--
		30	16	10	8.0	--	--
		60	22	14	10	--	--
		120	33	21	16	--	--
01614500	Conococheague Creek at Fairview (April 1, 1929 to March 31, 1988)	7	89	65	54	46	38
		14	93	67	57	49	41
		30	102	75	64	56	49
		60	122	85	71	62	53
		120	167	111	90	76	63
01617800	Marsh Run at Grimes (April 1, 1964 to March 31, 1988)	7	3.0	1.7	1.2	.9	--
		14	3.4	1.9	1.4	1.0	--
		30	3.7	2.1	1.5	1.2	--
		60	4.2	2.4	1.8	1.4	--
		120	5.0	3.1	2.4	1.9	--
01618000	Potomac River at Shepherdstown, W. Va. (April 1, 1929 to March 31, 1953, and April 1, 1965, to March 31, 1988)	7	675	489	415	363	313
		14	724	522	444	391	340
		30	829	596	507	447	391
		60	1,040	710	584	498	417
		120	1,490	980	790	660	540
01619000	Antietam Creek near Waynesboro, Pa. (April 1, 1949 to March 31, 1951, and April 1, 1966 to March 31, 1981)	7	39	29	24	20	--
		14	40	29	24	20	--
		30	43	31	26	22	--
		60	46	34	29	25	--
		120	54	41	36	34	--
01619500	Antietam Creek near Sharpsburg (April 1, 1899 to March 31, 1903, and April 1, 1929 to March 31, 1988)	7	94	75	66	60	54
		14	98	77	69	63	57
		30	104	82	73	66	60
		60	114	90	79	72	65
		120	129	99	88	80	73

SURFACE-WATER QUALITY

Water-Quality Data

Surface-water-quality data collected during this study, and data collected for various other studies in Washington County as early as 1948, are presented by Duigon and others (1989). These data were collected in accordance with U.S. Geological Survey standard pro-

(*Text continued on p. 73.*)

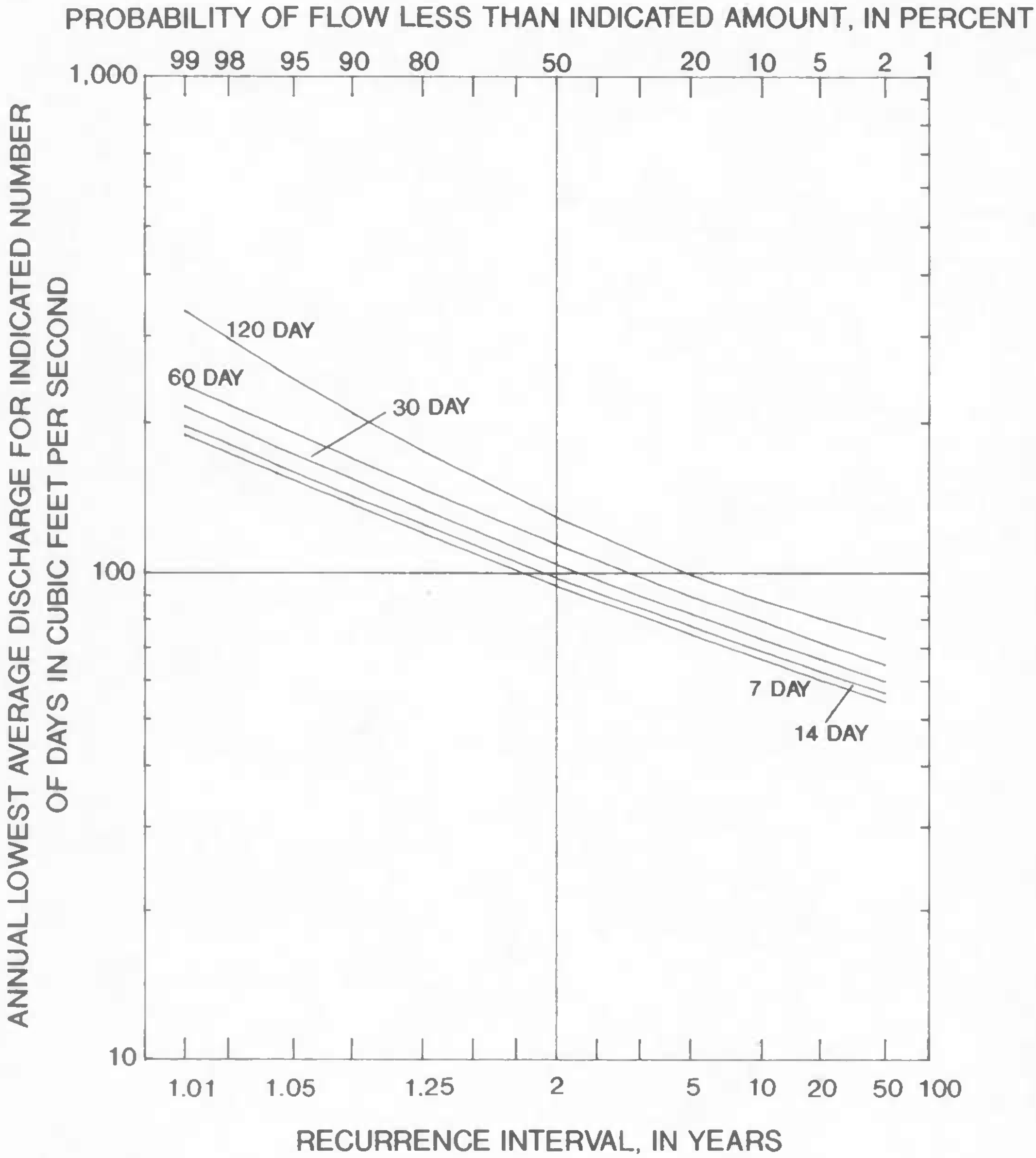


Figure 33.—Magnitudes and frequencies of annual low flows, Antietam Creek near Sharpsburg, climatic years 1900–03 and 1931–88.

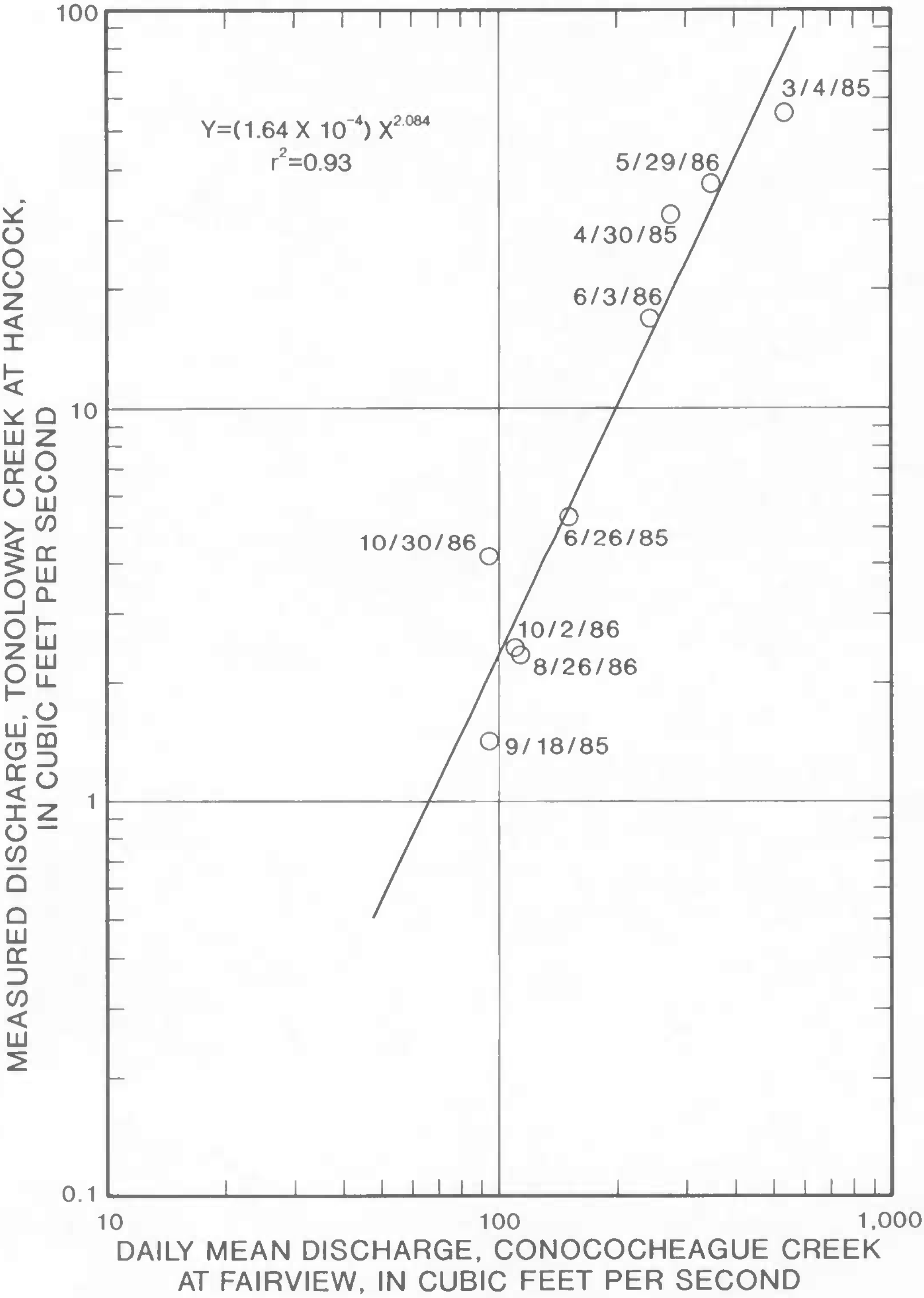


Figure 34.—Relation of low-flow measurements of Tonoloway Creek at Hancock to daily flows of Conococheague Creek at Fairview. Dates when flows occurred are shown. The relation is used to estimate the distribution of annual low flows, from which low flows of various durations and recurrence intervals are estimated.

TABLE 16
TWO-YEAR AND 10-YEAR 7-DAY LOW FLOWS

Station number	Station name	$Q_{7,2}$		$Q_{7,10}$	
		(ft^3/s)	[(ft^3/s)/mi^2]	(ft^3/s)	[(ft^3/s)/mi^2]
01610150	Bear Creek at Forest Park	0.1	0.010	0.0	0.000
01610155	Sideling Hill Creek near Bellegrove	.4	.004	.0	.000
01610170	Potomac River Tributary at Woodmont	.0	.000	.0	.000
01612500	Little Tonoloway Creek near Hancock	.1	.006	.0	.000
01613000	Potomac River at Hancock	407	.100	275	.068
01613100	Tonoloway Creek at Hancock	1.9	.017	.6	.005
01613150	Ditch Run near Hancock[1]	.1	.031	.0	.000
01613500	Licking Creek near Sylvan, Pa.	11	.070	6.3	.040
01613540	Lanes Run near Forsythe	.4	.042	.2	.019
01613545	Licking Creek near Pecktonville	12	.058	4.7	.022
01614050	Little Conococheague Creek near Charlton	1.8	.101	1.0	.056
01614500	Conococheague Creek at Fairview	89	.181	54	.109
01614525	Rockdale Run at Fairview	2.3	.241	1.4	.143
01614575	Rush Run near Huyett	.8	.157	.4	.077
01614577	Rush Run at Troupe Springs[2]	1.9	.202	1.0	.108
01614625	Meadow Brook at Conococheague	.8	.118	.3	.048
01614675	Conococheague Creek Tributary near Huyett	1.1	.142	.5	.063
01614705	Conococheague Creek at Williamsport	99	.176	55	.099
01617780	St. James Run at Spielman	2.7	.379	1.8	.259
01617800	Marsh Run at Grimes	3.0	.159	1.2	.063
01618000	Potomac River at Shepherdstown, W. Va.	675	.114	415	.070
01619000	Antietam Creek near Waynesboro, Pa.	39	.413	24	.253
01619050	Little Antietam Creek at Leitersburg	8.0	.327	4.9	.202
01619150	Marsh Run at Fiddlesburg	4.2	.137	1.5	.049
01619275	Landis Spring Branch near Benevola	1.4	.212	.7	.109
01619325	Beaver Creek at Benevola	14.9	.651	9.8	.425
01619350	Little Beaver Creek at Benevola	4.3	.494	2.6	.301
01619480	Little Antietam Creek at Keedysville	7.6	.312	4.1	.168
01619500	Antietam Creek near Sharpsburg	94	.335	66	.235
01636730	Israel Creek at Weverton	1.1	.080	.3	.024

[1]Low-flow values at Ditch Run computed by regression with data from Tonoloway Creek near Needmore, Pa.
[2]Formerly published as 01614575, Rush Run near Huyett, with incorrect drainage area (U.S. Geological Survey, 1977-82).
[3]Town Creek near Oldtown (Allegany County, Md.).
[4]Tonoloway Creek near Needmore, Pa.
[5]Catoctin Creek near Middletown (Frederick County, Md.).

Continuous-record gaging station used for regression	Coefficient of determination (r^2)	Number of measurements used	Minimum observed discharge used in the regression	Station number
[3]01609000	0.89	11	0.123	01610150
--	--	--	--	01610155
01614500	.79	9	.033	01610170
--	--	--	--	01612500
--	--	--	--	01613000
01614500	.93	9	1.41	01613100
[4]01613050	.90	14	.068	01613150
--	--	--	--	01613500
01614500	.94	10	.338	01613540
01614500	.96	9	11.8	01613545
01614500	.98	8	1.94	01614050
--	--	--	--	01614500
01614500	.93	15	2.08	01614525
01614500	.89	6	.684	01614575
01614500	.89	10	1.60	01614577
01619000	.96	8	.514	01614625
01619000	.96	6	.764	01614675
01614500	.97	10	75.5	01614705
01619000	.94	7	2.41	01617780
--	--	--	--	01617800
--	--	--	--	01618000
--	--	--	--	01619000
01619000	.96	10	6.88	01619050
01619000	.91	25	.744	01619150
01619000	.97	8	1.19	01619275
01619000	.97	10	13.2	01619325
01619000	.92	11	3.27	01619350
01619000	.89	18	2.82	01619480
--	--	--	--	01619500
[5]01637500	.96	14	.423	01636730

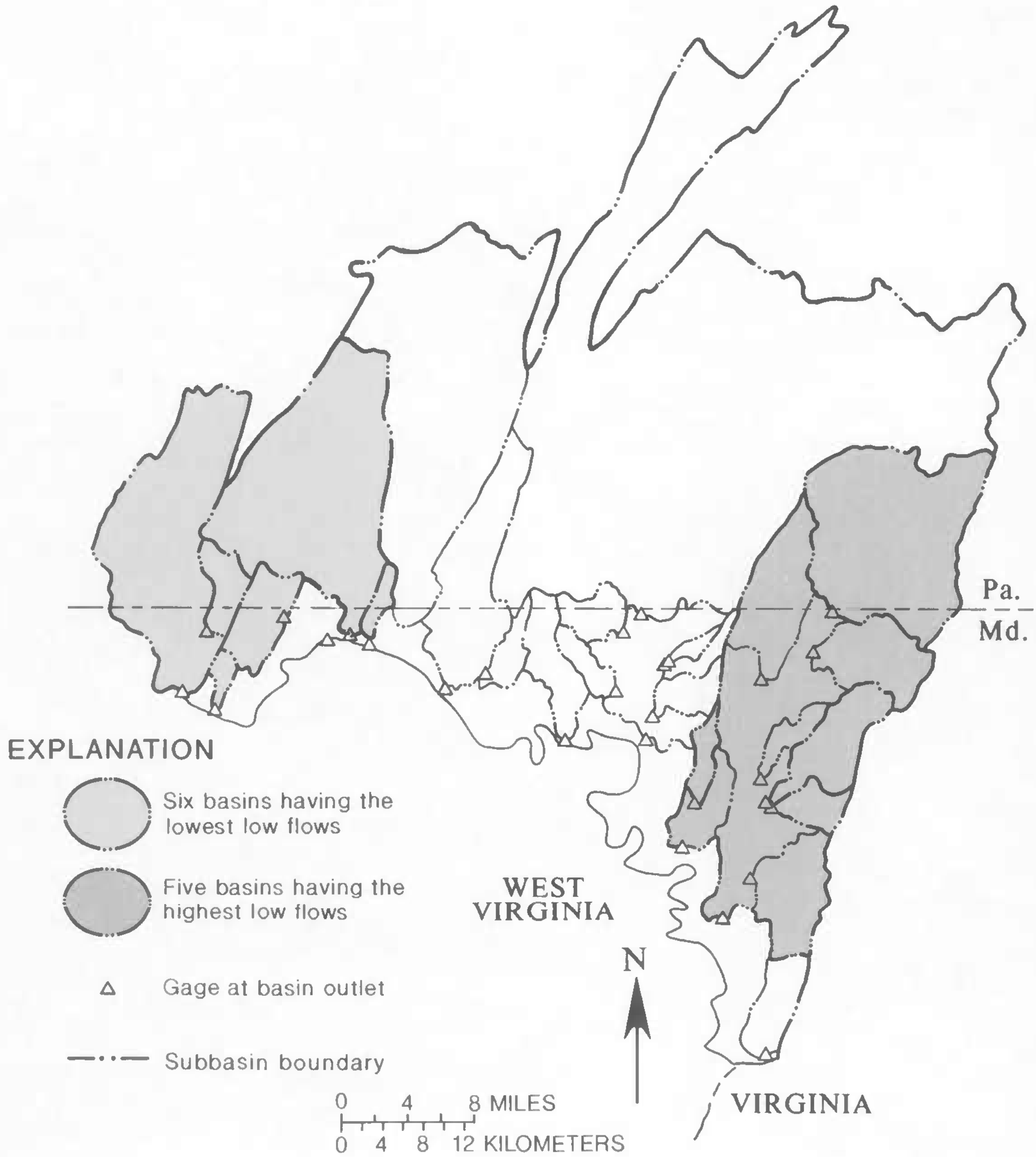


Figure 35.—Areal variation of 7-day low flows. Based on discharge per square mile (see table 16 for values for each basin). The five basins having the highest and the six basins having the lowest 2-year and 10-year 7-day low flows are highlighted. Details of the basins are shown on Plate 3.

cedures in effect at the time of sampling. Locations of sampling sites discussed in this report are shown on plate 3.

Most of the samples were obtained during base-flow periods, concurrent with streamflow measurements. The chemistry of stream water collected during base-flow conditions reflects the chemistry of the adjacent ground water, although some factors, such as aeration and reaction with bottom sediments, can alter water quality.

Physical Properties and Major Inorganic Ions

The quality of stream water in Washington County varies considerably (table 17), but most of the streams are calcium bicarbonate types (fig. 36). Three of the western streams—Bear Creek, Little Tonoloway Creek, and Ditch Run—have relatively higher concentrations of sodium and chloride (and sulfate in Little Tonoloway Creek) than the other streams have. These higher concentrations may be due to the influx of road-deicing salts and, perhaps, treated sewage effluent.

Some of these water-quality factors are related to each other (for example, hardness is calculated from concentrations of dissolved calcium and magnesium) and to streamflow.

TABLE 17
SUMMARY OF STREAM-WATER QUALITY
[Values in milligrams per liter except as noted; for sites having multiple observations, the mean value for the site was used]

Property or constituent	Number of sites	Minimum	Maximum	Median	Mean
Specific conductance (μS/cm)	28	124	714	426	412
pH	28	7.1	8.7	8.0	8.0
Dissolved oxygen	28	7.8	14.2	9.9	10.1
Hardness (as $CaCO_3$)	27	33	313	184	183
Calcium, dissolved	27	7.5	103.3	54.7	54.8
Magnesium, dissolved	27	3.4	22.0	12.3	11.7
Sodium, dissolved	27	2.5	25.0	7.1	8.8
Potassium, dissolved	27	1.4	5.2	2.6	2.9
Total alkalinity (as $CaCO_3$)	27	30	268	165	152
Sulfate, dissolved	27	8.4	79.7	22.0	25.5
Chloride, dissolved	27	3.6	60.7	15.3	18.2
Fluoride, dissolved	27	<.10	.30	.1	.13
Nitrate plus nitrite, total (as N)	28	.07	8.83	3.17	3.21
Phosphorus, total	28	.013	.530	.056	.089
Silica, dissolved	27	1.2	13.0	6.8	6.1
Total dissolved solids (residue at 180 °C)	27	60	405	244	230

SAMPLING SITES

1. Bear Creek at Forest Park
2. Sideling Hill Creek near Bellegrove
3. Potomac River Tributary at Woodmont
4. Little Tonoloway Creek near Hancock
5. Tonoloway Creek at Hancock
6. Ditch Run near Hancock
7. Licking Creek near Sylvan, Pa.
8. Lanes Run near Forsythe
9. Licking Creek near Pecktonville
10. Little Conococheague Creek near Charlton
11. Conococheague Creek at Fairview
12. Rockdale Run at Fairview
13. Rush Run near Huyett

SAMPLING SITES--continued

14. Meadow Brook at Conococheague
15. Conococheague Creek Tributary near Huyett
16. Conococheague Creek at Williamsport
17. St. James Run at Spielman
18. Marsh Run at Grimes
19. Antietam Creek near Waynesboro, Pa.
20. Little Antietam Creek at Leitersburg
21. Marsh Run at Fiddlesburg
22. Landis Spring Branch near Benevola
23. Beaver Creek at Benevola
24. Little Beaver Creek at Benevola
25. Little Antietam Creek at Keedysville
26. Antietam Creek near Sharpsburg
27. Israel Creek at Weverton

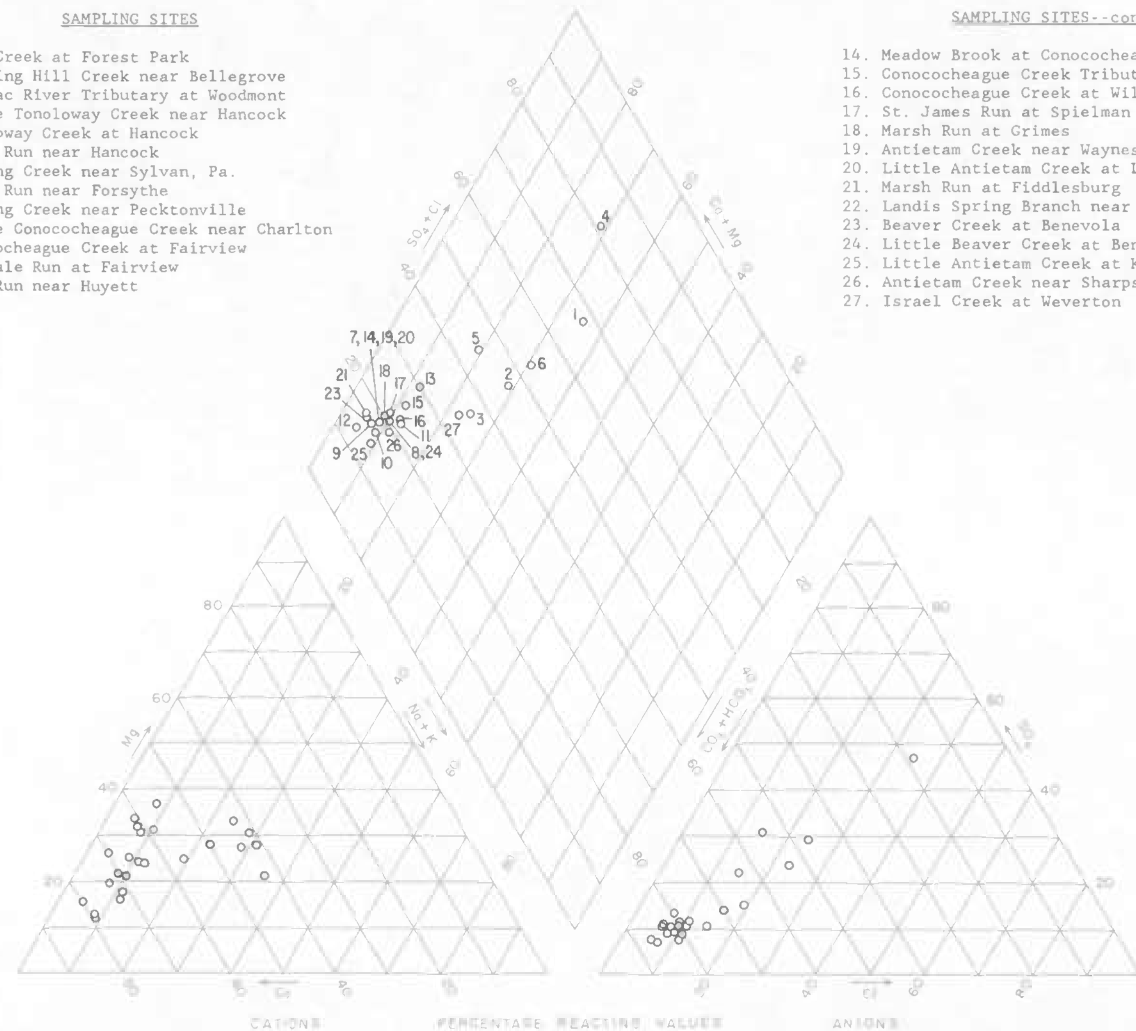


Figure 36.—Percentages of major ions in stream water. Based on samples collected during 1985–86; for sites having multiple analyses, mean values were used.

The scatterplot matrix in figure 37 shows the relations among four factors—discharge, specific conductance, total dissolved solids concentration (sum of dissolved species analyzed), and pH—based on samples from Antietam Creek near Sharpsburg collected over the period 1965–86. Of these, only pH does not correlate with any of the others. Specific conductance is a function of dissolved-solids concentration; therefore, specific conductance and total dissolved solids concentration have similar relations to discharge. The correlation is negative because of the increasing proportion of surface runoff (which contains lower concentrations of dissolved minerals than the ground-water contribution to streamflow) with increasing discharge.

Areal variation of major-ion chemistry of surface water is shown in figure 38. Major differences in stream-water quality are related to geology; 17 of the 27 stations are in drain-

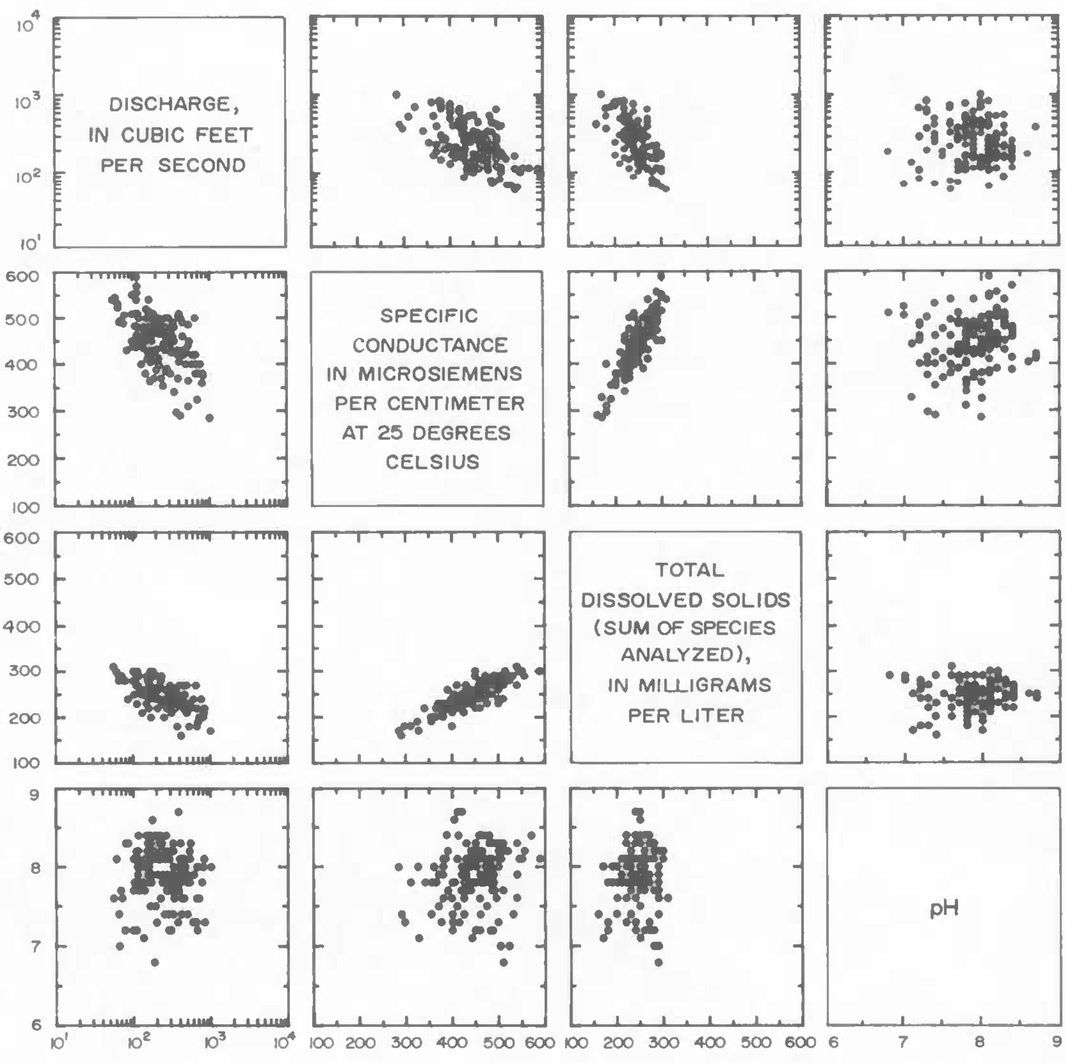


Figure 37.—Scatterplot matrix of major stream-water-quality factors. Data are for samples collected from Antietam Creek near Sharpsburg during the period 1965–86.

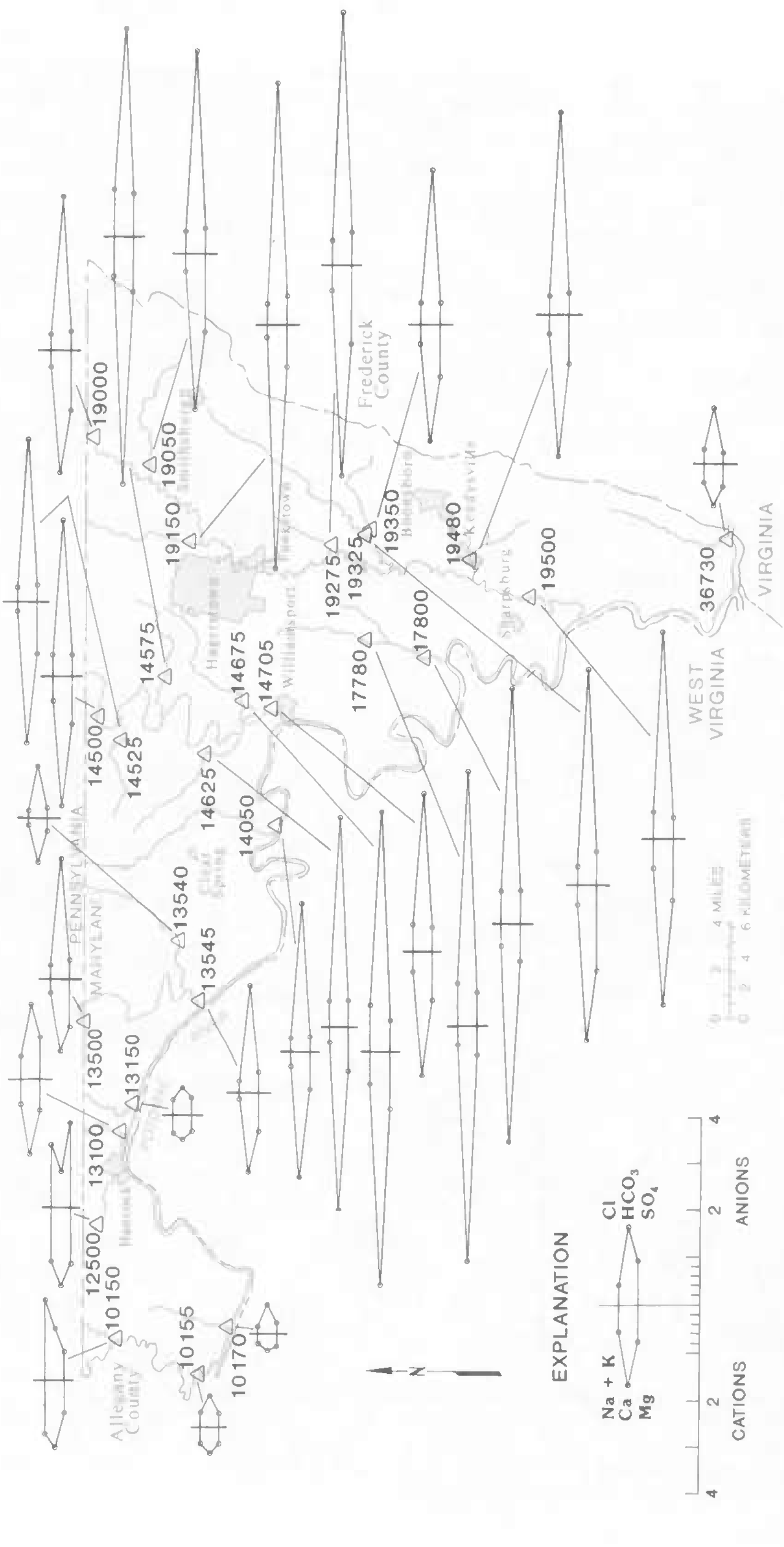


Figure 38.—Areal variation of major-ion concentrations in stream samples. Based on mean values of samples collected during base-flow conditions, 1985–86. The three leading digits, "016," of the station identifiers are not included.

age basins underlain by a high (40 percent or more) proportion of carbonate rock. Three stations in the Licking Creek basin are underlain by 10- to 25-percent carbonate rock. The major differences between carbonate and noncarbonate basins are shown in figure 39, with higher values for the indicated factors being more common in carbonate basins. Hydrogeological factors other than lithology (such as ground-water flow velocities) are also doubtless involved.

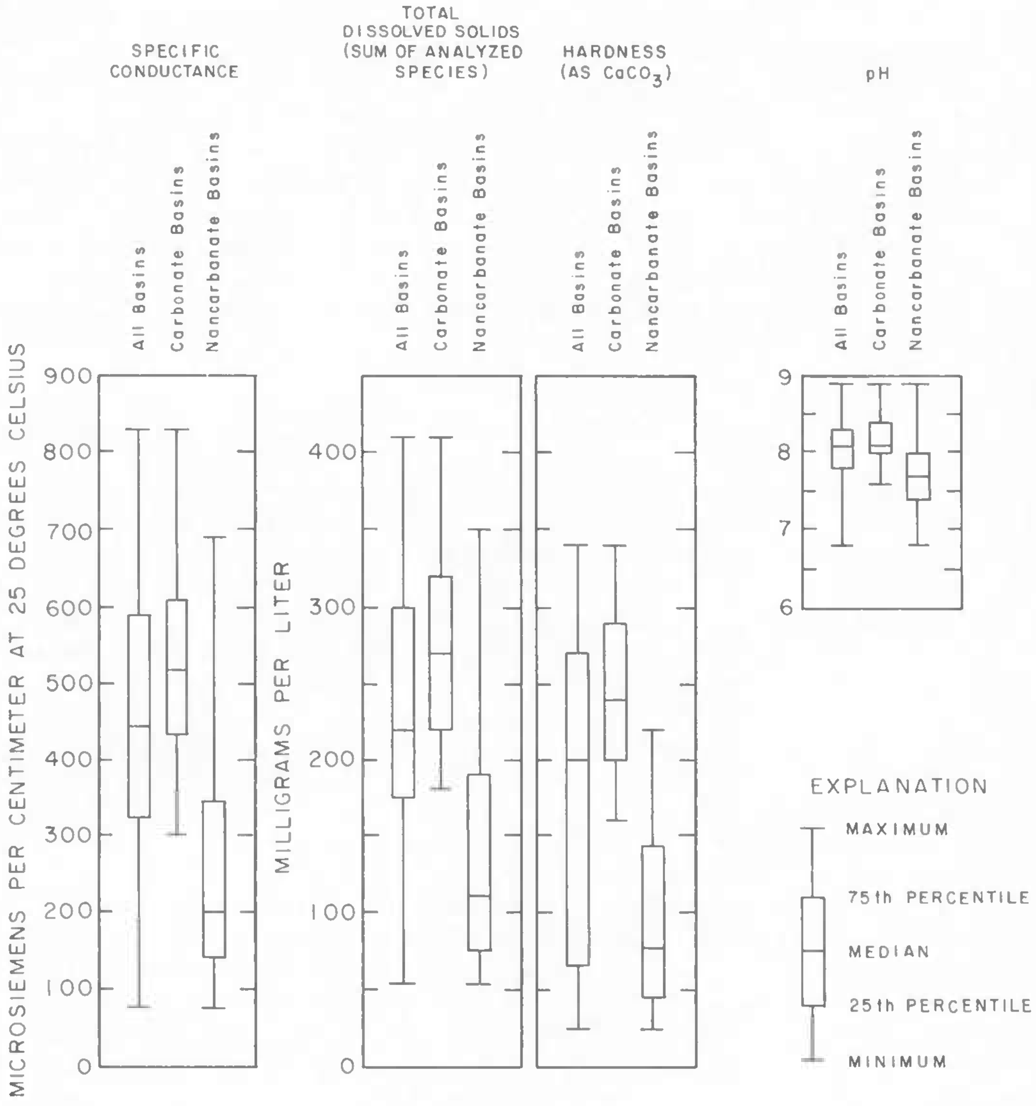


Figure 39.—Basic water chemistry of carbonate and noncarbonate drainage basins. For each parameter there are 50 observations from 17 carbonate basins and 26 observations from 10 noncarbonate basins. For this figure, drainage basins considered carbonate basins are those having a drainage area underlain by more than 38-percent carbonate rocks.

Nutrients

Nitrogen and phosphorus are commonly limiting factors for biologic growth because these elements generally occur in low concentrations naturally. Nutrient concentrations that exceed naturally occurring levels can support prolific biologic production, which can result in the depletion of dissolved oxygen. Elevated nutrient concentrations are commonly the result of fertilizer application and waste disposal. Mean concentrations of total nitrate plus nitrite for 27 stations range from less than 0.13 to 8.83 mg/L (as N); mean concentrations of total phosphorus range from less than 0.010 to 0.550 mg/L (as P) (table 18). High concentrations of phosphorus in Tonoloway Creek at Hancock probably resulted from discharges from the municipal sewage-treatment plant located one-quarter mile upstream from the sampling site; the high concentrations at the Antietam Creek stations likewise probably originated from sewage-treatment plants. Additional nutrient inputs are derived from nonpoint sources, such as fertilized fields and septic-tank disposal systems, that provide recharge to ground-water-flow systems containing solution-enlarged joints and fractures.

The highest concentrations of both nitrogen and phosphorus were measured from samples collected in carbonate drainage basins. The Hagerstown Valley includes the greatest population density in the county and also is the major agricultural region, thereby providing numerous possible sources of nutrients. Once transported to the ground-water-flow system, nutrients may be transported quickly through solutional conduits with little attenuation and then be discharged to streams.

Stream-Bottom Materials

Generally, only a fraction of the chemical load of a stream is in the dissolved state—a significant proportion may be adsorbed on and transported with sediments (Feltz, 1980, p. 271; Horowitz, 1985). In contrast, some hydrophobic constituents, such as the herbicides atrazine and linuron, may be adsorbed and transported by naturally occurring colloids (Means and Wijayaratne, 1982). Those constituents adsorbed onto colloids might be included in analyses of dissolved loads, because they will pass through the 0.45-μm filter generally used to obtain samples for analysis of dissolved material. A total concentration of a constituent in the water column is determined from analysis of a water/suspended-sediment mix that has been digested, and the concentration of the constituent associated with suspended material is generally calculated as the difference between the total and dissolved concentrations.

The concentrations of constituents associated with stream-bottom materials depend on particle size and organic content, thereby complicating comparisons of data and calculations of loads. Nevertheless, analyses of bottom materials are useful for such purposes as reconnaissance studies and identification of problem areas. Bottom sediments move sporadically downstream as streamflow hydraulics permit, so they can remain within the stream system for a long period, thereby serving as indicators of stream chemistry that might otherwise be overlooked.

Analyses for nine trace elements recovered from stream-bottom materials sampled at 15 sites are reported by Duigon and others (1989, table 18). The sediments were not analyzed for particle size, composition, ion-exchange capacity, or other factors that affect their affinity for trace elements, thus precluding direct quantitative comparisons between sites. Chromium, copper, iron, lead, manganese, mercury, and zinc were detected at all sites; arsenic and cadmium were detected at some of the sites. The higher concentrations of iron

TABLE 18
MEAN CONCENTRATIONS OF TOTAL NITRATE PLUS NITRITE AND
TOTAL PHOSPHORUS IN STREAM SAMPLES
[All values in milligrams per liter; numbers in parentheses are numbers of samples; bracketed means could not be calculated exactly because of values less than detection limits]

Station number	Station name	Nitrete plus nitrite, totel (as N)		Phosphorus, total (as P)	
01610150	Bear Creek at Forest Park	0.47	(3)	0.017≤meen<0.020	(3)
01610155	Sideling Hill Creek near Bellegrove	0.07≤mean<0.13	(3)	.020	(3)
01610170	Potomac River Tributary et Woodmont	.30	(3)	.023	(3)
01612500	Little Tonolowey Creek near Hancock	.73	(3)	0.013≤mean<0.020	(3)
01613000	Potomac River et Hancock	.52	(10)	.049	(14)
01613100	Tonolowey Creek et Hancock	.45	(2)	.550	(2)
01613150	Ditch Run near Hancock	.65	(2)	.035	(2)
01613500	Licking Creek neer Sylven, Pe.	1.00	(2)	.025	(2)
01613540	Lanes Run neer Forsythe	1.40	(2)	0.005≤meen<0.010	(2)
01613545	Licking Creek neer Pecktonville	.60	(2)	.015	(2)
01614050	Little Conococheegue Creek neer Charlton	2.17	(3)	.087	(3)
01614500	Conococheague Creek et Feirview	2.89	(42)	.184	(39)
01614525	Rockdale Run et Feirview	6.45	(2)	.040	(2)
01614575	Rush Run neer Huyett	8.83	(3)	.113	(3)
01614625	Meadow Brook et Conococheague	6.35	(2)	.065	(2)
01614675	Conococheague Creek Tributery neer Huyett	6.70	(3)	.070	(3)
01614705	Conococheegue Creek at Williamsport	3.03	(3)	.150	(3)
01617780	St. James Run at Spielman	4.23	(3)	.030	(3)
01617800	Marsh Run et Grimes	4.30	(3)	.030	(3)
01618000	Potomac River et Shepherdstown, W. Va.	1.00	(28)	.127	(61)
01619000	Antietam Creek neer Waynesboro, Pe.	4.17	(3)	.216	(9)
01619050	Little Antietam Creek et Leitersburg	4.13	(3)	.080	(3)
01619150	Marsh Run at Fiddlesburg	6.53	(3)	.057	(3)
01619250	Antietam Creek at Hagerstown	3.20	(1)	.530	(1)
01619275	Lendis Spring Brench near Benevole	5.40	(3)	.023	(3)
01619325	Beever Creek et Benevole	4.83	(3)	.033	(3)
01619350	Little Beever Creek et Benevole	3.40	(3)	.066	(3)
01619480	Little Antietam Creek at Keedysville	3.13	(3)	.110	(3)
01619500	Antietam Creek et Sharpsburg	3.63	(39)	.329	(43)
01636730	Isreel Creek at Weverton	.93	(3)	.067	(3)

and manganese compared to the other trace elements reflect their more common natural occurrence, whereas detectable levels of the other metals may indicate contamination from various sources within the drainage basins.

Stream-bottom-material samples from 18 stations were analyzed for three families of pesticides (Duigon and others, 1989, table 19) (table 19): organochlorine herbicides; organ-

TABLE 19
PESTICIDES AND RELATED COMPOUNDS FOR WHICH STREAM-BOTTOM MATERIALS WERE ANALYZED
[Number of positive analyses/number of sites sampled]

Organochlorine herbicides		Organochlorine insecticides, metabolites, and related compounds				Organophosphorus insecticides	
2,4-D	0/17	Aldrin	1/18	Heptachlor epoxide	5/17	Diazinon	1/17
2,4-DP	0/14	Chlordane	10/18	Lindane	3/18	Ethion	1/17
Silvex	0/17	DDD	15/18	Methoxychlor	0/14	Malathion	0/17
2,4,5-T	0/17	DDE	15/18	PCB	[1]10/18	Methyl parathion	1/17
		DDT	14/18	PCN	0/14	Methyl trithion	0/17
		Dieldrin	[2]17/18	Perthane	0/14	Parathion	1/17
		Endosulfan	1/14	Mirex	0/14	Trithion	0/17
		Endrin	8/18	Toxaphene	1/17		
		Heptachlor	3/18				

[1]Includes Antietam Creek near Sharpsburg, 30 μg/kg on May 17, 1972, but undetected August 31, 1976.

[2]Includes Antietam Creek near Sharpsburg, 1.3 μg/kg on May 17, 1972, but undetected August 31, 1976.

ochlorine insecticides and their metabolites (and the related compounds—polychlorinated biphenols, or PCB's, and polychlorinated napthalene, or PCN); and organophosphorus insecticides. The organochlorine insecticides are rather stable in the environment (Chau and others, 1981, p. 2) and, for this reason, have largely been replaced by less persistent carbamate and organophosphorus insecticides for insect control (Smith and others, 1987, p. 56). Pesticides, particularly the more stable forms, can be detected in stream-bottom materials even though their use had been discontinued several years before sampling. Furthermore, they may be present in stormflow samples but not in base-flow samples. For these reasons, bottom-material sampling can be a useful means of detecting pesticide contamination in streams.

Some type of pesticide was present at all but one of the 18 sites sampled (table 20); Sideling Hill Creek near Bellegrove was the only site where pesticides were undetected. Thirteen kinds of organochlorine insecticides were detected throughout the county [consistent with the findings of Truhlar and Reed (1975) for four similar watersheds in Pennsylvania]. Detectable concentrations of pesticides that are less resistant to degradation were less common, although four organophosphorus insecticides were detected. No organochlorine herbicides were detected.

Suspended Sediment

Suspended sediment is important because of its effects on aquatic habitats and engineering structures and because of its function in chemical transport. The variation in suspended-sediment load over time (over more than three orders of magnitude for Conococheague

TABLE 20
DETECTIONS OF FAMILIES OF PESTICIDES IN STREAM-BOTTOM MATERIALS
[Members of each family are listed in table 19. +, one or more members of family detected; –, none detected]

Station number	Station name	Date	Organo-chlorine herbicides	Organo-chlorine insecti-cides	Organo-phosphorus insecti-cides
01610155	Sideling Hill Creek near Bellegrove	08-26-86	-	-	-
01612500	Little Tonoloway Creek near Hancock	08-26-86	-	+	-
01613000	Potomac River at Hancock	05-18-72	-	+	-
		08-31-76	-	+	-
01613540	Lanes Run near Forsythe	05-18-87	-	+	+
01613545	Licking Creek near Pecktonville	06-30-87	-	+	-
01614050	Little Conococheague Creek near Charlton	08-22-86	-	+	-
01614500	Conococheague Creek at Fairview	08-21-86	-	+	+
01614525	Rockdale Run at Fairview	08-21-86	-	+	-
01614575	Rush Run near Huyett	08-22-86	-	+	-
01614705	Conococheague Creek at Williamsport	08-21-86	-	+	-
01617800	Marsh Run at Grimes	08-20-86	-	+	-
01619000	Antietam Creek near Waynesboro, Pa.	08-20-86	-	+	-
01619150	Marsh Run at Fiddlesburg	08-20-86	-	+	-
01619250	Antietam Creek at Hagerstown	05-17-72	-	+	-
		08-31-76	-	+	-
01619270	Antietam Creek below Hagerstown	05-17-72	-	+	-
01619350	Little Beaver Creek at Benevola	08-20-86	-	+	-
01619480	Little Antietam Creek at Keedysville	08-20-86	-	+	-
01619500	Antietam Creek near Sharpsburg	05-17-72	-	+	-
		08-31-76	-	+	-

Creek at Fairview during water years 1949–50, fig. 40) is explained, in large part, by streamflow fluctuations (fig. 41). The relation, from linear least-squares regression, is

$$\text{SUSPENDED-SEDIMENT LOAD} = [8.51\ (\text{DISCHARGE})^{2.056}] \times 10^{-5};$$

the coefficient of determination (r^2) is 0.90. The frequency distribution of suspended sediment loads in Conococheague Creek for water years 1949–79 is shown in figure 42 (data from Duigon and others, 1989).

The grain-size distribution of suspended sediment (fig. 43) depends on the source of material being eroded and on streamflow velocity. However, it is not simply a function of discharge; note in figure 43 that the distribution curves for the Conococheague Creek sample collected during the highest discharge (of 12 samples) and for the sample collected during the lowest discharge are similar. More than one-half of each sample consisted of clay-sized material, and silt made up most of the remainder. The curve for the sample collected February 20, 1961, indicates considerably less fine material comprising the sediment load than for the other two samples, although this sample was collected at a moderate discharge. A sample collected the previous day at Antietam Creek near Sharpsburg, shown in figure 43 for comparison, contained even less fine material. Knowledge of the grain-size distribution can be useful in predicting the effects of bank and channel modifications or changing land use, and in understanding certain aspects of running-water (lotic) ecology, filtration requirements for various water uses, and mechanics of chemical transport in streams.

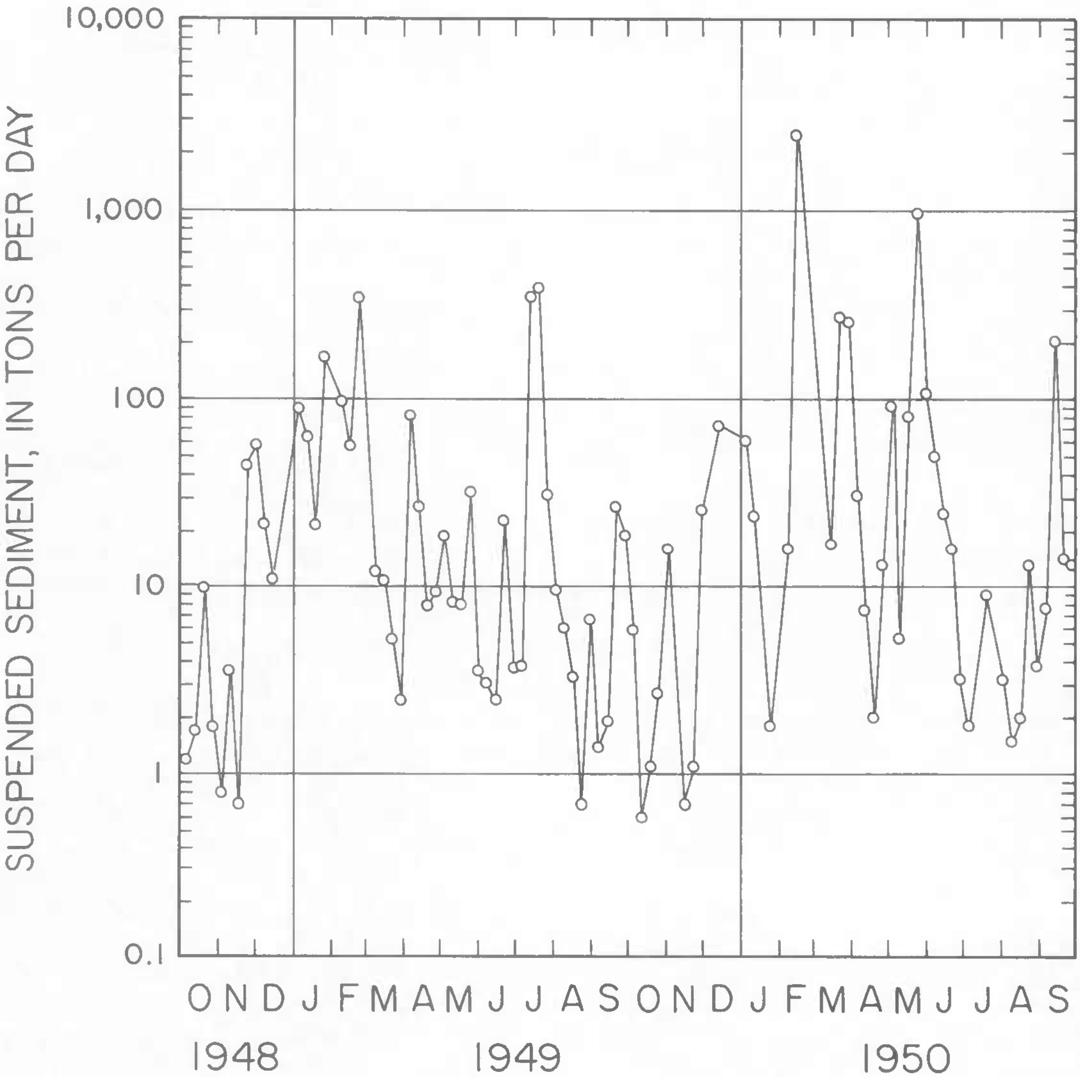


Figure 40.—Variation in suspended-sediment load, Conococheague Creek at Fairview, October 1948 to September 1950.

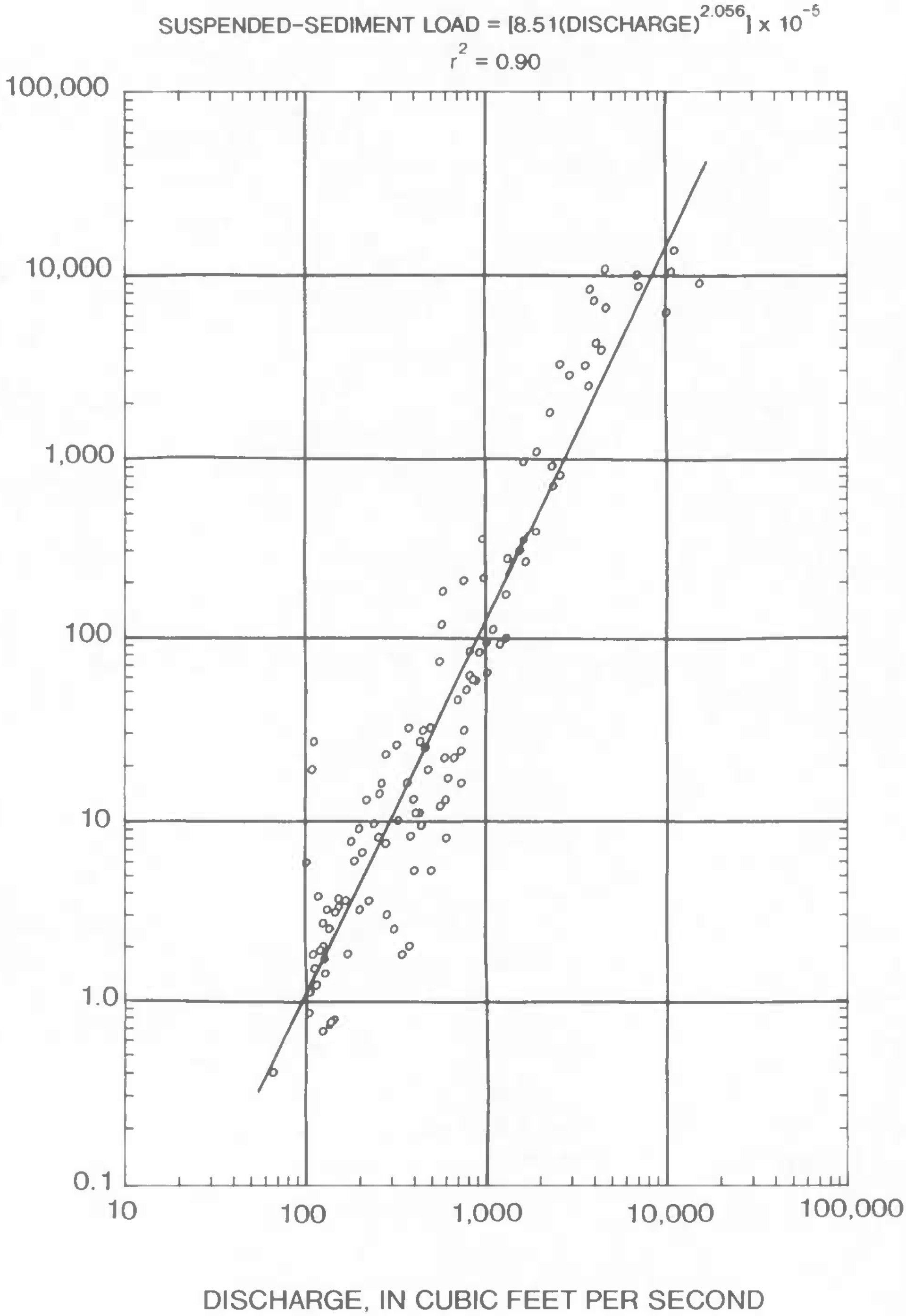


Figure 41.—Relation of suspended-sediment load to streamflow, Conococheague Creek at Fairview, October 1948 to September 1979.

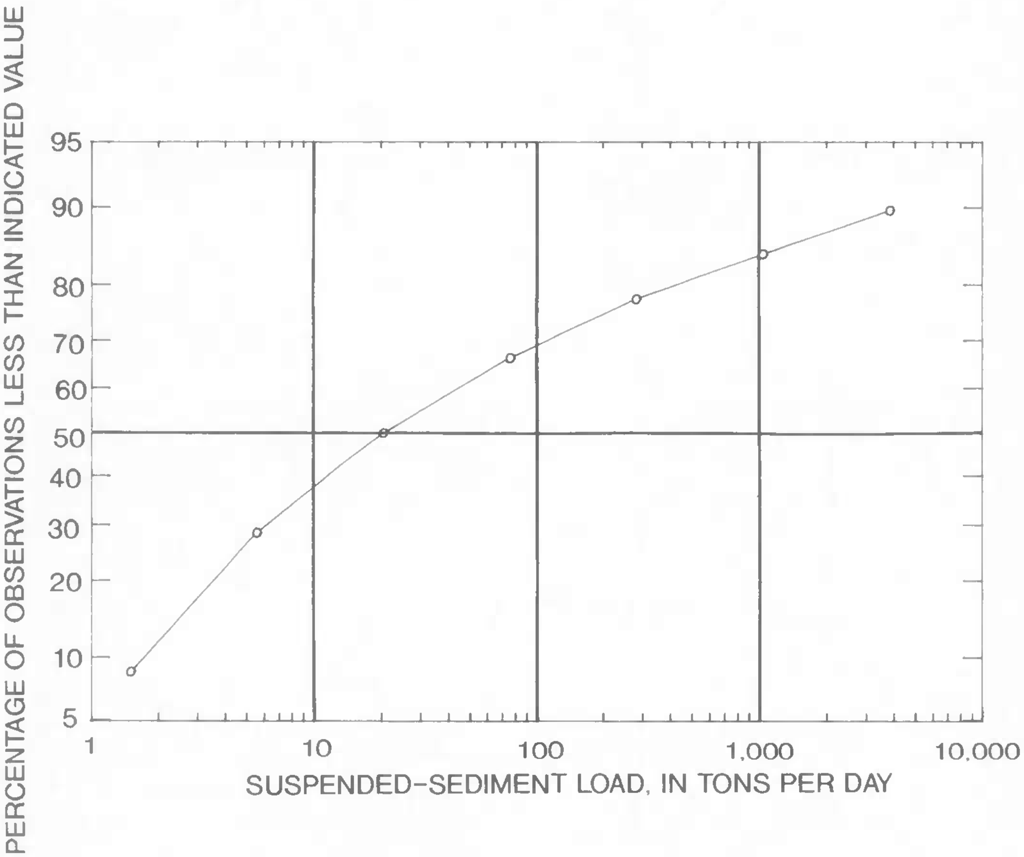


Figure 42.—Cumulative frequency distribution of suspended-sediment loads, Conococheague Creek at Fairview, October 1948 to September 1979 (116 samples).

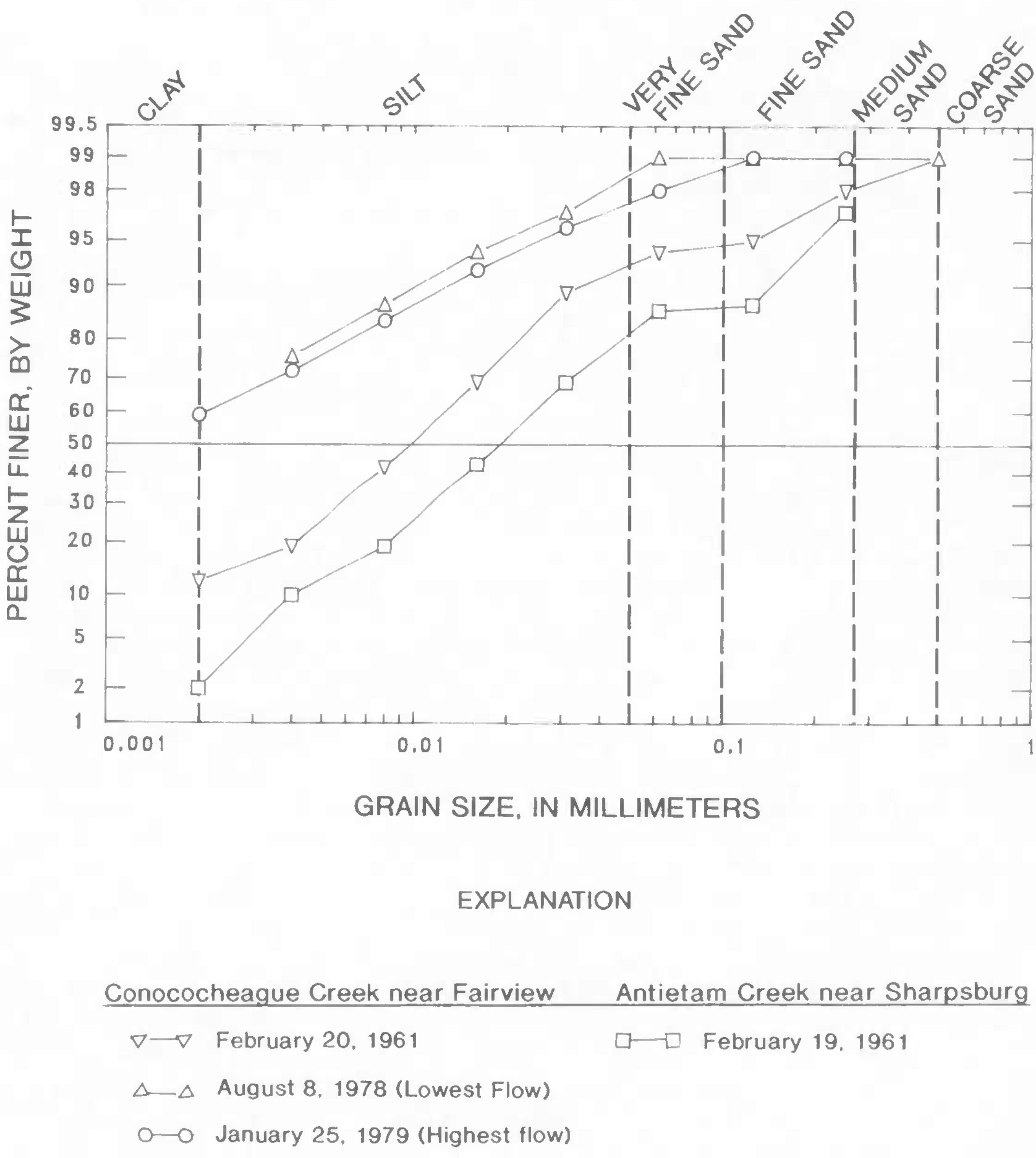


Figure 43.—Grain-size distribution of suspended sediment, Conococheague Creek at Fairview and Antietam Creek near Sharpsburg. For Conococheague Creek, grain-size distribution curves are shown for the highest (15,200 cubic feet per second) and lowest (1,560 cubic feet per second) flows for which grain size was analyzed; the sample of February 20, 1961 (4,640 cubic feet per second) is shown for comparison with the sample from Antietam Creek collected 1 day later.

HYDROLOGIC BUDGETS AND WATER AVAILABILITY

A hydrologic budget is a quantitative mass-balance statement of the hydrologic cycle (fig. 4) for a particular area. It may be expressed as

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

where P = precipitation;
I = inflow to the area by underflow, pipeline, or other means;
R_G = subsurface runoff;
R_S = surface runoff;
ET = evapotranspiration; and
ΔS = change in storage (including soil moisture, surface detention, and ground-water storage).

These components may be expressed in units such as inches per year or billion gallons per year.

HYDROLOGIC BUDGETS OF THE DRAINAGE BASINS

Hydrologic budgets were estimated for seven drainage basins for which continuous discharge data at the outlets are available (table 21). Precipitation records were obtained for 30 weather stations in and near Washington County (fig. 44; U.S. Weather Bureau, 1928–39; U.S. Weather Bureau, 1940–64; U.S. Environmental Science Service Administration, 1965–69; National Oceanic and Atmospheric Administration, 1970–88). Average basin precipitation was estimated for each year by the two-axis method described by Bethlahmy (1976). Quantities of imported and exported water are negligible for these basin analyses and are not considered further here; however, they would be significant in a budget for the entire county (for example, water flowing across the Pennsylvania border). Surface and subsurface runoff were estimated by separation of total runoff (streamflow) hydrographs into surface and subsurface components [using a modified version of the computerized separation technique of Pettyjohn and Henning (1979)]. The computerized hydrograph separations are, to some degree, arbitrary, but the method is rapid and yields consistent results. Interflow and direct channel-precipitation components of total runoff were included with the surface component in the hydrograph separations. Underflow out of the basins across the downstream boundaries of the basins also was assumed to be negligible (in some carbonate basins, this assumption is not strictly true). The amount of water in storage varies significantly seasonally, but the net change for the annual cycle is small (sometimes positive, sometimes negative) and may be considered negligible for long-term analyses. Evapotranspiration was estimated as the residual term.

The magnitudes of the streamflow/budget components are related to low-flow characteristics; the basins with the highest values of subsurface runoff are those with the greatest 2-year and 10-year 7-day low flows (table 16). The relatively high values of evapotranspiration and relatively low values of total runoff for Antietam Creek and, especially, Marsh Run indicate that some underflow out of the basins is included in the calculations of evapotranspiration. These two basins are underlain by carbonate rocks in which some solutional development has occurred, and the correspondence of ground-water and surface-water boundaries may be weaker than is generally the case in basins chiefly underlain by noncar-

TABLE 21
AVERAGE ANNUAL WATER BUDGETS OF DRAINAGE BASINS
HAVING CONTINUOUS STREAMFLOW RECORDS
[Components in first line expressed in inches; in second line expressed in percent of precipitation; in third line expressed in billions of gallons. Some totals do not balance because of rounding]

Drainage basin	Period of record (water years)	Precipitation	Surface runoff	Subsurface runoff	Evapotranspiration
Sideling Hill Creek near Bellegrove	1968-77	38.4	8.7	7.4	22.3
		100	22.1	19.0	58.8
		68.06	15.46	13.19	39.53
Little Tonoloway Creek near Hancock	1948-63	37.0	4.7	7.6	24.8
		100	12.2	20.2	67.6
		10.86	1.37	2.23	7.28
Licking Creek near Sylvan, Pa.	1931-41	37.3	6.5	7.7	23.0
		100	17.1	20.6	62.2
		102.41	17.96	21.20	63.15
Conococheague Creek at Fairview	1929-87	40.1	6.2	10.0	23.9
		100	15.0	24.7	60.2
		344.24	53.05	85.84	205.17
Marsh Run at Grimes	1964-87	39.3	1.0	8.0	30.3
		100	2.5	19.8	77.7
		12.91	.34	2.61	9.95
Antietam Creek near Waynesboro, Pa.	1949-51; 1966-81	44.2	3.7	13.4	27.1
		100	8.1	30.0	61.9
		71.82	6.01	21.77	44.03
Antietam Creek near Sharpsburg	1929-87	39.3	2.7	10.7	25.9
		100	6.6	27.0	66.3
		191.90	13.14	52.25	126.47

bonate rocks. Data are insufficient to quantify the amount of underflow or to verify ground-water-flow-system boundaries for these basins.

Hydrologic budgets for 21 additional, ungaged basins were estimated on the basis of the budgets for the gaged basins (table 22). The budget components were estimated by setting the proportion of each component, relative to average basin precipitation (in inches), equal to that of a similar, gaged, basin. The similar basins are the same as those used for estimating 7-day low flows (table 16) except for Bear Creek and Ditch Run, for which the proportions at Conococheague Creek at Fairview were used, and for Israel Creek, for which the proportions at Catoctin Creek near Middletown, located about 8 mi northeast, (Duigon and

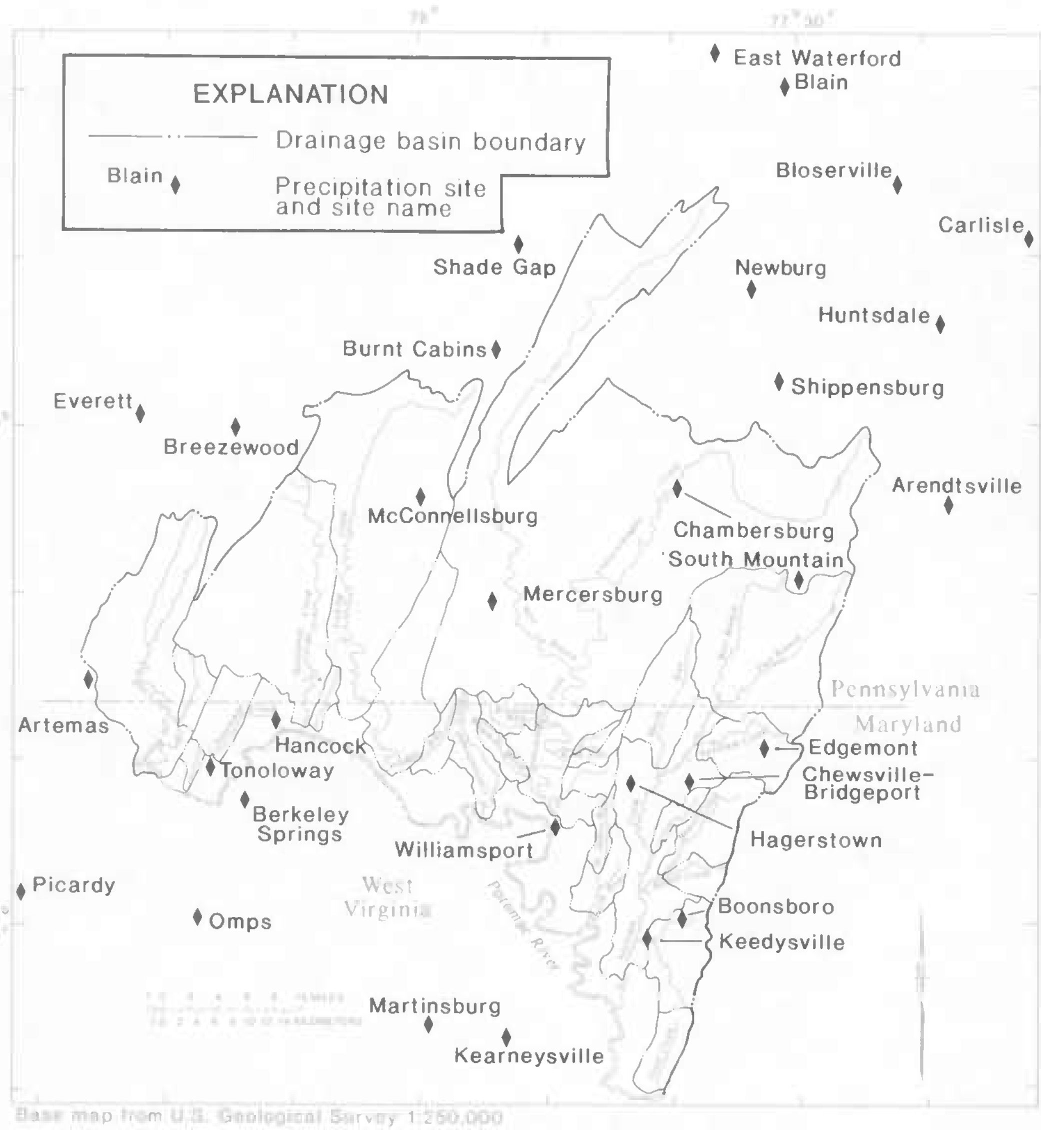


Figure 44.—Locations of precipitation stations used to estimate hydrologic budgets.

Dine, 1987, table 19) were used. These figures are also expressed in billions of gallons (by conversion, using drainage area). The total quantity of water in balance in 11 nontributary basins is approximately 915 billion gallons annually.

The interrelations of the significant components of the hydrologic budgets are shown in figure 45 for Sideling Hill Creek and for Antietam Creek. The former is a steep, forested, western basin underlain by noncarbonate rock, and was gaged near Bellegrove during water years 1968–77. Antietam Creek drains an agricultural basin of gentle relief developed over carbonate rock, and was gaged near Sharpsburg during water years 1929–87. The most notable contrast between the two basins is the lack of correlation between evapotranspira-

TABLE 22
ESTIMATED ANNUAL WATER BUDGETS OF UNGAGED DRAINAGE BASINS
[Components in first line expressed in inches; in second line expressed in billions of gallons. Some totals do not balance because of rounding]

Drainage basin	Precipi-tation	Surface runoff	Subsurface runoff	Evapo-trans-piration
Bear Creek at Forest Park	38 6.9	6 1.1	9 1.6	23 4.2
Potomac River Tributary at Woodmont	37 2.1	6 .3	9 .5	22 1.3
Tonoloway Creek at Hancock	37 72.7	6 11.8	9 17.7	22 43.2
Ditch Run near Hancock	37 3.1	6 .5	9 .8	22 1.8
Lanes Run near Forsythe	38 6.6	6 1.0	9 1.6	23 4.0
Licking Creek near Pecktonville	38 140.0	6 22.1	9 33.2	23 84.7
Little Conococheague Creek near Charlton	38 12.0	6 1.9	9 2.8	23 7.2
Rockdale Run at Fairview	38 6.4	6 1.0	9 1.5	23 3.9
Rush Run near Huyett	39 3.5	6 .5	10 .9	23 2.1
Rush Run at Troupe Springs[1]	39 6.4	6 1.0	10 1.6	23 3.9
Meadow Brook at Conococheague	39 4.6	3 .3	10 1.2	26 3.1
Conococheague Creek Tributary near Huyett	39 5.4	3 .4	10 1.4	26 3.6
Conococheague Creek at Williamsport	40 392.0	6 58.9	10 98.0	24 235.2
St. James Run at Spielman	39 4.8	3 .3	10 1.3	26 3.2
Little Antietam Creek at Leitersburg	41 17.5	3 1.3	11 4.7	27 11.5
Marsh Run at Fiddlesburg	39 21.0	3 1.4	10 5.6	26 14.0
Landis Spring Branch near Benevola	39 4.5	3 .3	10 1.2	26 3.0
Beaver Creek at Benevola	39 15.5	3 1.2	12 4.8	24 9.6
Little Beaver Creek at Benevola	39 5.9	3 .4	10 1.6	26 3.9
Little Antietam Creek at Keedysville	39 16.3	3 1.1	10 4.4	26 10.8
Israel Creek at Weverton	39 9.0	7 1.6	7 1.6	25 5.7

[1]This station formerly published as 01614575, Rush Run near Huyett, with incorrect drainage area (U.S. Geological Survey, 1977-82).

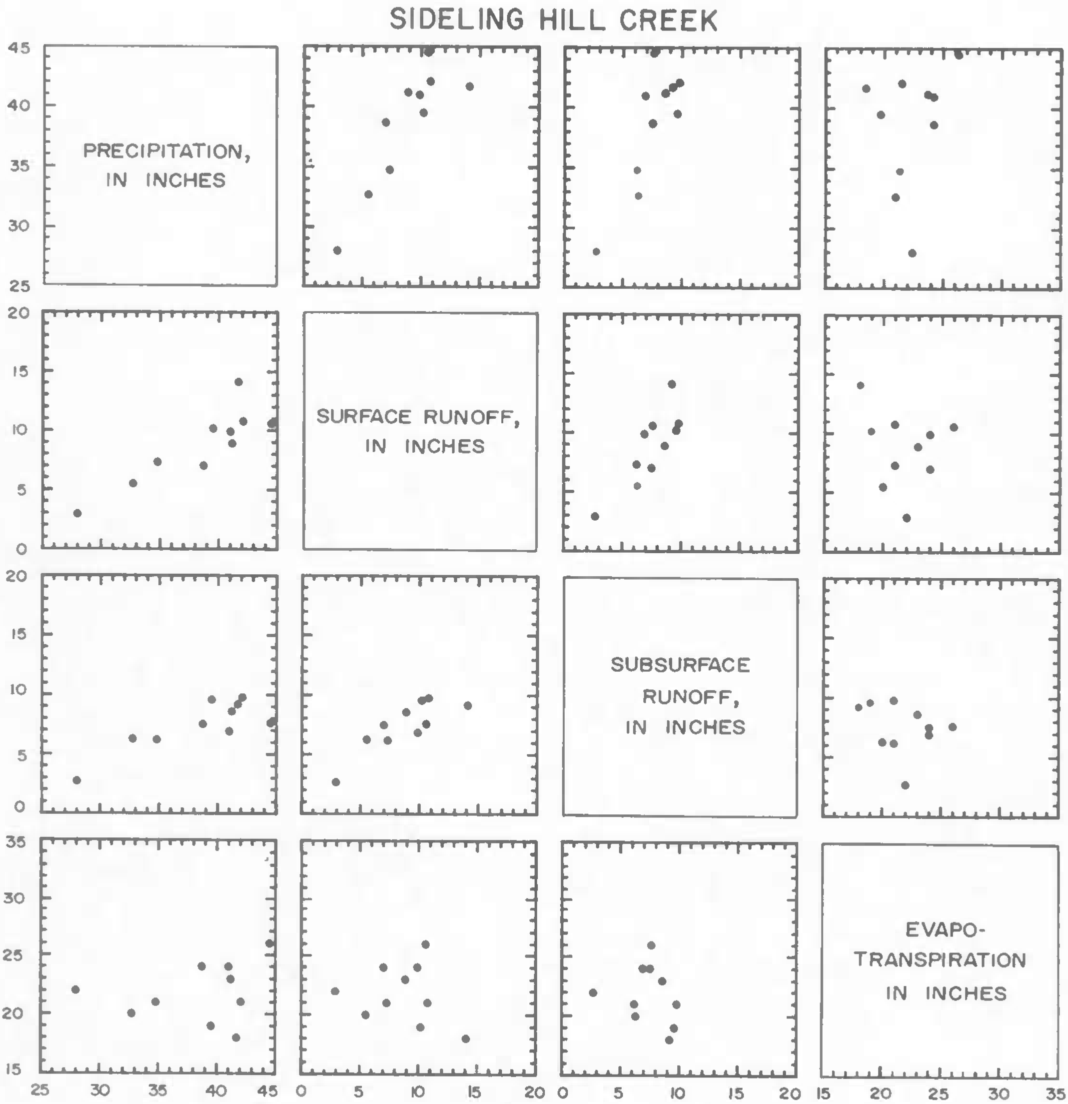


Figure 45.—Scatterplot matrices of water-budget components, Sideling Hill Creek and Antietam Creek basins. Plots for the Sideling Hill Creek basin are based on records at the gage near Bellegrove, water years 1968–77; those for the Antietam Creek basin are based on records at the gage near Sharpsburg, water years 1929–87.

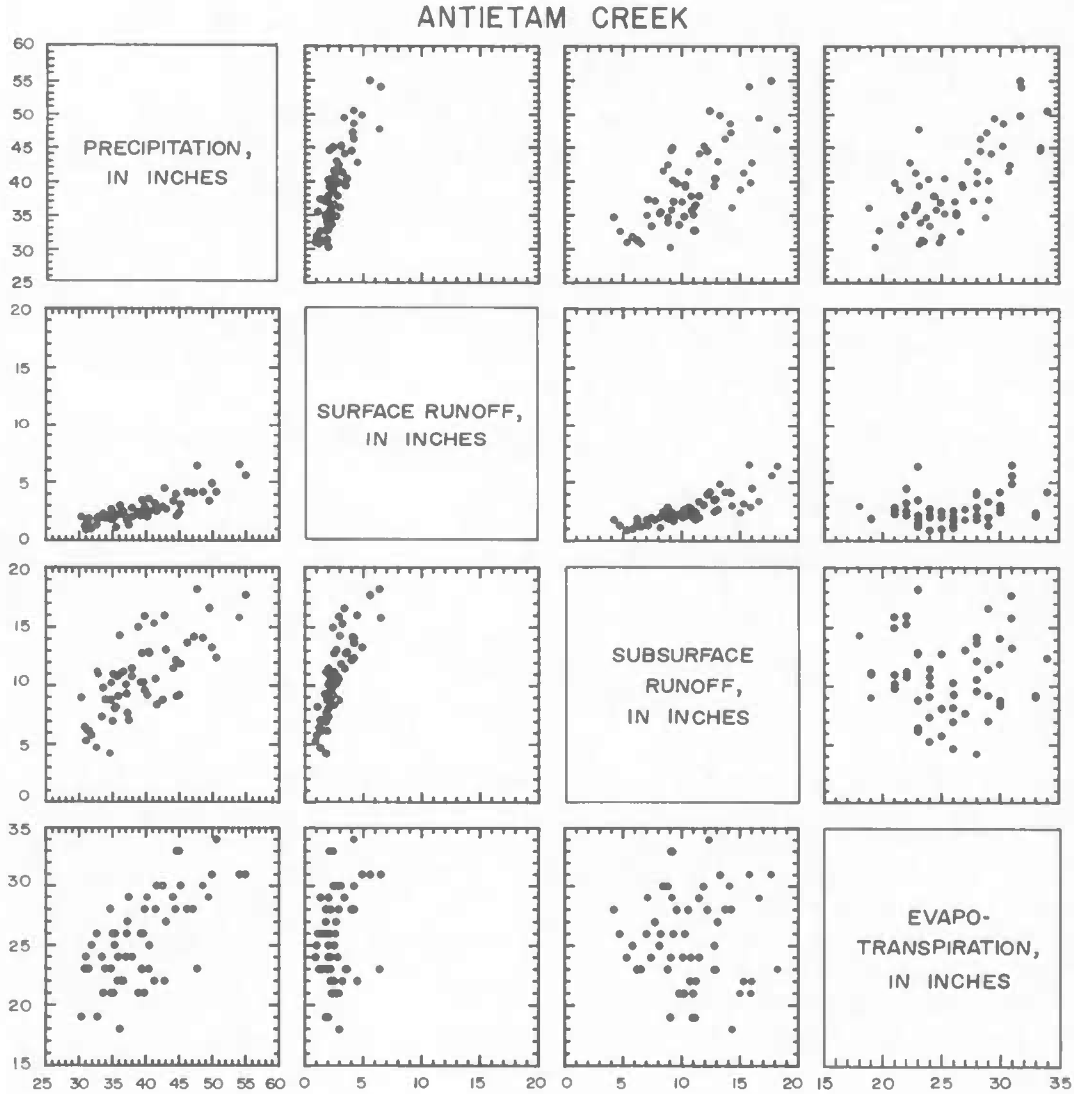


Figure 45.—Continued.

tion and any other component in the case of Sideling Hill Creek, but a strong correlation of evapotranspiration with precipitation in the case of Antietam Creek. The correlation for Antietam Creek may be due to underflow past the gage being included in the calculation of evapotranspiration. Also, total runoff in Antietam Creek is dominated by base flow (subsurface runoff). This contrast also is evident if base flow is plotted against total runoff (fig. 46); the trend slopes are steeper for the eastern basins that are underlain by carbonate rocks. The lesser variability of streamflow in Antietam Creek compared to Sideling Hill Crcek (fig. 32) results from the greater proportion of precipitation that recharges ground water, which then slowly discharges to the stream.

An average annual budget for a typical drainage basin in Washington County may be estimated by weighting the budgets for each gaged basin by drainage area:

$$P\ (39.6\text{ in.}) = R_G\ (9.6\text{ in.}) + R_S\ (5.5\text{ in.}) + ET\ (24.5\text{ in.}) + \Delta S\ (0.0\text{ in.}).$$

The periods of record are not the same for all of the gaged basins, thus adding to the uncertainty of the estimate. The hydrologic budget for Washington County can be roughly estimated in a similar fashion, giving consideration to the proportions of drainage areas outside of the county boundaries:

$$P\ (40\text{ in.}) + I\ (31\text{ in.}) = R_G\ (11\text{ in.}) + R_S\ (36\text{ in.}) + ET\ (24\text{ in.}) + \Delta S\ (0\text{ in.}),$$

or, in billions of gallons per year,

$$P\ (321) + I\ (252) = R_G\ (90) + R_S\ (293) + ET\ (190) + \Delta S\ (0).$$

WATER USE AND AVAILABILITY

All water withdrawal and use in Maryland except domestic use is regulated by the Maryland Water Resources Administration, which issues appropriation and use permits; prior to July 1, 1989 farm use was also unregulated. Permittees using more than 10,000 gal/d are required to submit semiannual reports of monthly withdrawals. Ground-water and surface-water appropriations in Washington County greater than 10,000 gal/d are listed in table 23. Additional information concerning well and spring locations, well construction, and well yields is included in Duigon and others (1989).

Water use in Washington County for 1986, based on appropriation-permit data and estimates for nonmeasured quantities (Judith Wheeler, U.S. Geological Survey, written commun., 1988) is listed in table 24. Approximately three-quarters of the inventoried wells are used for domestic supply (fig. 47). Ground-water withdrawals for 1986 totaled approximately 3.2 billion gallons; surface-water withdrawals for the year totaled about 464.4 billion gallons, which includes 448.4 billion gallons for hydroelectric power generation. Most of the water is returned and may be used by downstream users; hence, the total consumptive use (water not returned for reuse) for 1986 was approximately 1.3 billion gallons, a small fraction of the total quantity of water used.

The quantities of water available vary from year to year. Cumulative-frequency curves of the annual runoff components for the seven gaged basins are shown in figure 48. As may happen with flow-duration curves, short periods of record are more subject to shifting be-

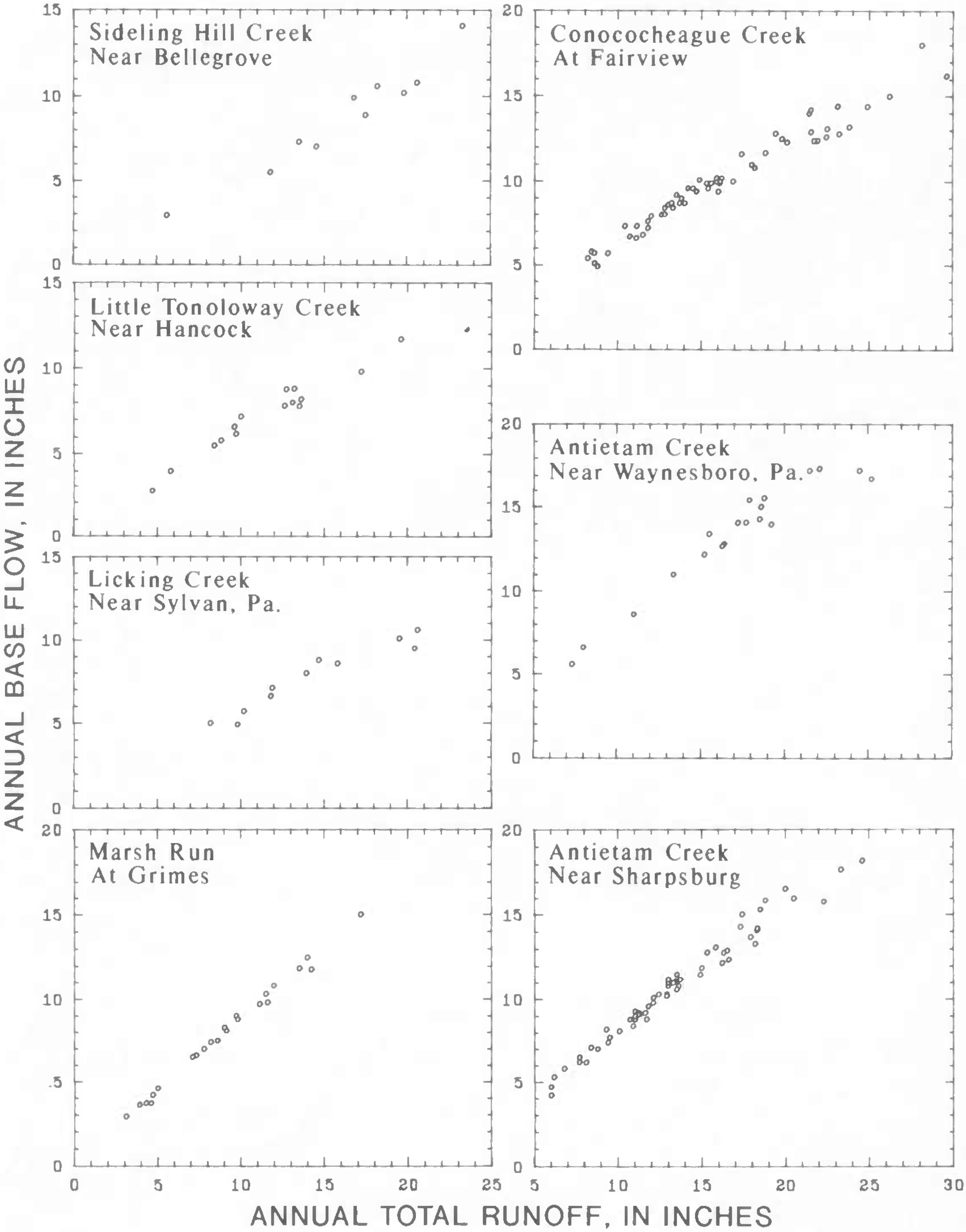


Figure 46.—Relations of base flow to total runoff for seven drainage basins.

TABLE 23
WATER APPROPRIATIONS
[Only appropriations greater than an average of 10,000 gallons per day are included; yearly totals are from all sources of water]

User	Appropriation permit number	Appropriation (gallons per day) Average	High month[1]	Source	Geologic unit or drainage basin	1986 reported pumpage (gallons) Daily average	High month daily average[1]	Yearly total
				Ground-water appropriations				
Boonsboro, Town of	WA79G013	130,000	150,000	springs	Tomstown Formation Harpers Formation	116,170	138,546	42,403,000
Brunswick, Town of	WA83G012	350,000	500,000	springs	Contact, Harpers and Catoctin Formations	229,480	282,119	83,761,000
Clear Spring, Town of	WA67G001	100,000	144,000	spring wells	Oriskany Sandstone Helderberg Formation	141,463	189,043	51,634,200
Deer Lodge Mobile Home Park	WA63G010	12,000	18,000	well	Martinsburg Formation	4,210	6,416	1,536,600
Keedysville, Town of	WA79G012	210,000	215,000	spring	Tomstown Formation	190,000	203,302	69,425,000
U.S. Army Ft. Ritchie	WA82G200	250,000	340,000	springs wells	Catoctin Formation Catoctin Formation	271,298	315,515	[2]49,105,200
Jefferson Cheese Mfg.	WA50G003	80,000	100,000	well	Stonehenge Limestone or Conococheague Limestone	230	230	[3]84,000
Doubleday and Co., Inc.	WA58G008	45,000	50,000	wells	Tomstown Formation	25,964	31,602	9,477,200
A. M. Powell Fish Hatchery	WA74G110	4,560,000	4,600,000	springs	Elbrook Limestone colluvium	12,500	10,000	4,560,000
Fountain Head Country Club	WA54G013	15,000	28,000	well	Conococheague Limestone	8,400	24,772	[4]3,067,000
H. B. Mellott Estate, Inc.	WA77G120	168,000	500,000	quarry	Waynesboro Formation	128,496	196,534	46,901,000
H. B. Mellott Estate, Inc.	WA82G101	1,500,000	1,600,000	well	Tonoloway Limestone	10,192	59,161	[5]3,719,700
Martin Marietta Aggregates	WA80G008	114,000	912,100	well	Tomstown Formation	41,590	49,873	15,180,000

TABLE 23—CONTINUED

User	Appropriation permit number	Appropriation (million gallons per day) Average	High month[1]	Source	Geologic unit or drainage basin	1986 reported pumpage (million gallons) Daily average	High month daily average[1]	Yearly total
				Surface-water appropriations				
Hagerstown, City of	WA28S001	10	13.0	stream	Potomac River	7.949	10.441	2,904
Hancock, Town of	WA75S007	.30	.500	stream	Little Tonoloway Creek	.211	.304	[6]77.132
Hancock, Town of	WA83S011	.10	.216	stream	Potomac River	.078	.328	[7]28.310
Mt. Aetna Water Assoc.	WA75S001	.05	.100	springs	Harpers Formation Harpers and Weverton Formations	.068	.076	24.750
Shepherdstown Water Works	WA73S006	.50	1.000	stream	Potomac River	.331	.399	120.888
Smithsburg, Town of	WA76S043	.175	.255	spring	Harpers Formation	.143	.172	53.056
Washington County Sanitary District	WA67S002	.10	.200	stream	Potomac River	.071	.078	25.910
Maryland Environmental Service	WA76S009	.012	.114	stream Park Lake	Little Beaver Creek	.005	.012	[8]1.833
Marquette Co.	WA19S050	1.25	4.320	stream	Antietam Creek	2.158	2.200	[3]788.4
Martin Marietta Aggregates	WA69S014	1.75	3.500	quarry	St. Paul Group	.051	.163	[9]18.585
W. D. Byron and Sons, Inc.	WA78S015	.36	.400	stream	Conococheague Creek	.381	.656	139.237

TABLE 23—CONTINUED

User	Appropriation permit number	Appropriation (million gallons per day) Average	High month[1]	Source	Geologic unit or drainage basin	1986 reported pumpage (million gallons) Daily average	High month daily average[1]	Yearly total
Hepburn Orchards, Inc.	WA76S045	0.15	0.720	stream	Tonoloway Creek	0.069	0.473	[10]25.200
Beaver Creek Country Club	WA76S099	.40	.950	stream	Black Rock Creek	.021	.061	8.468
Camp Louise	WA76S035	.02	.075	Lake Royer	Falls Creek	.008	.032	[11]3.003
Hagerstown Raceway, Inc.	WA82S004	.014	.100	stream	Conococheague Creek	.012	.023	[12]4.360
Potomac Edison Co.	WA70S006	60	85.0	stream	Potomac River	31.670	61.612	11,567
Potomac Edison Co. (Instream use--power generation)	WA83S013	932	1,205	stream	Potomac River	[13]509.6	[13]686.5	[13]186,013

[1]Daily average during month of highest use.
[2]Pumpage for July-December not reported.
[3]Estimated pumpage.
[4]Pumped April-September only.
[5]Pumped October-December only.
[6]Pumped January-August and December.
[7]Pumped September-November only.
[8]No pumpage for January.
[9]Pumped March-September and November-December.
[10]Pumped July and August only.
[11]Pumped April-October only.
[12]Pumped March-November only.
[13]July 1986-June 1987.

TABLE 24
ESTIMATED WATER USE DURING 1986
[All quantities in billions of gallons per year]

	Water supply	Domestic	Commercial	Industrial	Mining	Electric power Fossil fuel	Electric power Hydroelectric	Agricultural	Irrigation	Total
Withdrawals										
Ground water	0.263	[1]0.774	0.128	0.007	0.088	0	0	[2]1.902	0.007	3.168
Surface water	3.245	0	.011	1.011	0	11.567	448.413	.124	.022	464.393
Total	3.508	.774	.139	1.018	.088	11.567	448.413	2.026	.029	467.561
Delivered from water supply[3]	--	1.551	.350	1.401	0	0	0	0	0	3.302
Consumptive use	--	.252	.047	.606	.018	0	0	.358	.029	1.310

[1]Includes 0.007 for ground-water-source heat pumps.

[2]Includes 1.664 for A. M. Powell Fish Hatchery.

[3]Does not include 0.204 exported to Town of Brunswick, Frederick County.

Source: Maryland Water Resources Administration (Judith Wheeler, U.S. Geological Survey, written commun., 1988).

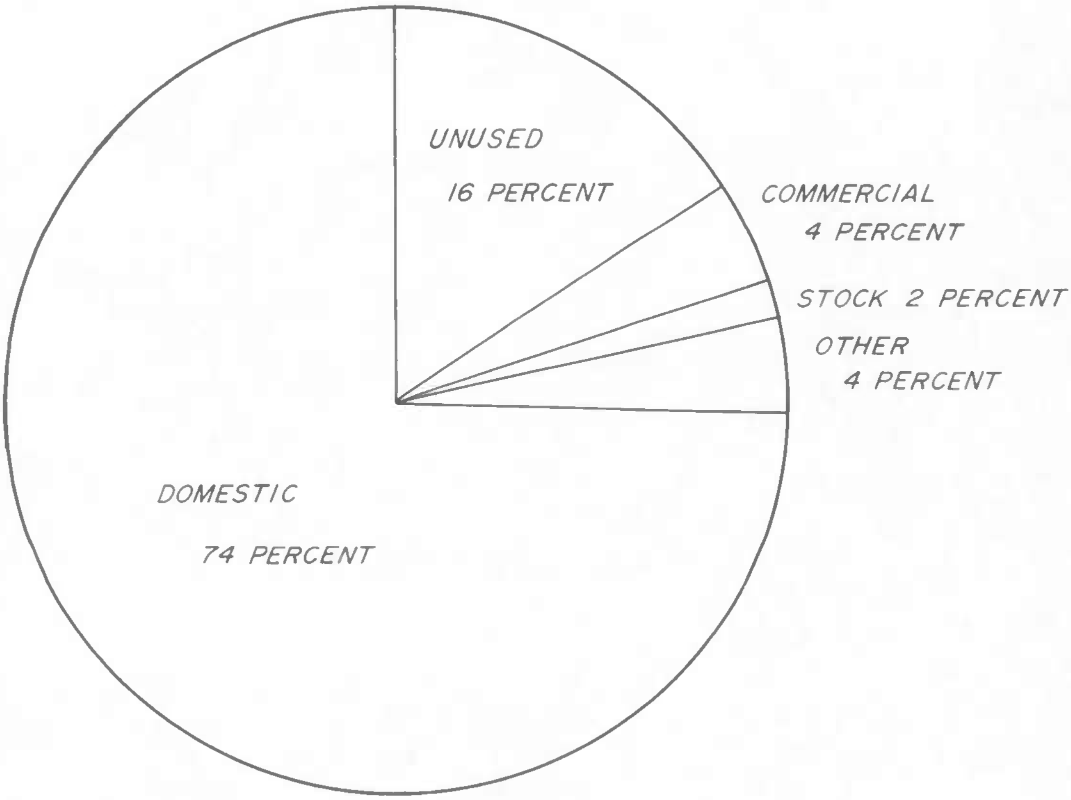


Figure 47.—Distribution of inventoried wells among water-use categories.

cause of climatic extremes than are long periods of record. Nevertheless, these curves are useful for planning purposes in which some level of risk is associated with the available water supply. For example, annual surface runoff exceeded 1.6 in. and annual ground-water runoff exceeded 5 in. for 95 percent of the years of record in the Antietam Creek basin. Volumes of water per year may be obtained by multiplying inches of runoff by drainage area and converting to consistent units (such as billions of gallons per year).

Water demands such as those listed in table 24 apparently can be easily met in Washington County, at least on an annual basis. The runoff totals of nontributary basins (a nontributary basin is one which does not drain into a larger basin, of which it is a part; tables 21 and 22, pl. 3) greatly exceed the total withdrawals (the large quantity of water used for hydroelectric generation, obtained from the Potomac River, may be considered instream use). The important practical considerations for efficient use of the water resources are location and timing of water demands and maintaining desirable water quality. These considerations include the engineering of water storage and transmission facilities as well as of suitable water-treatment and pollution-abatement techniques.

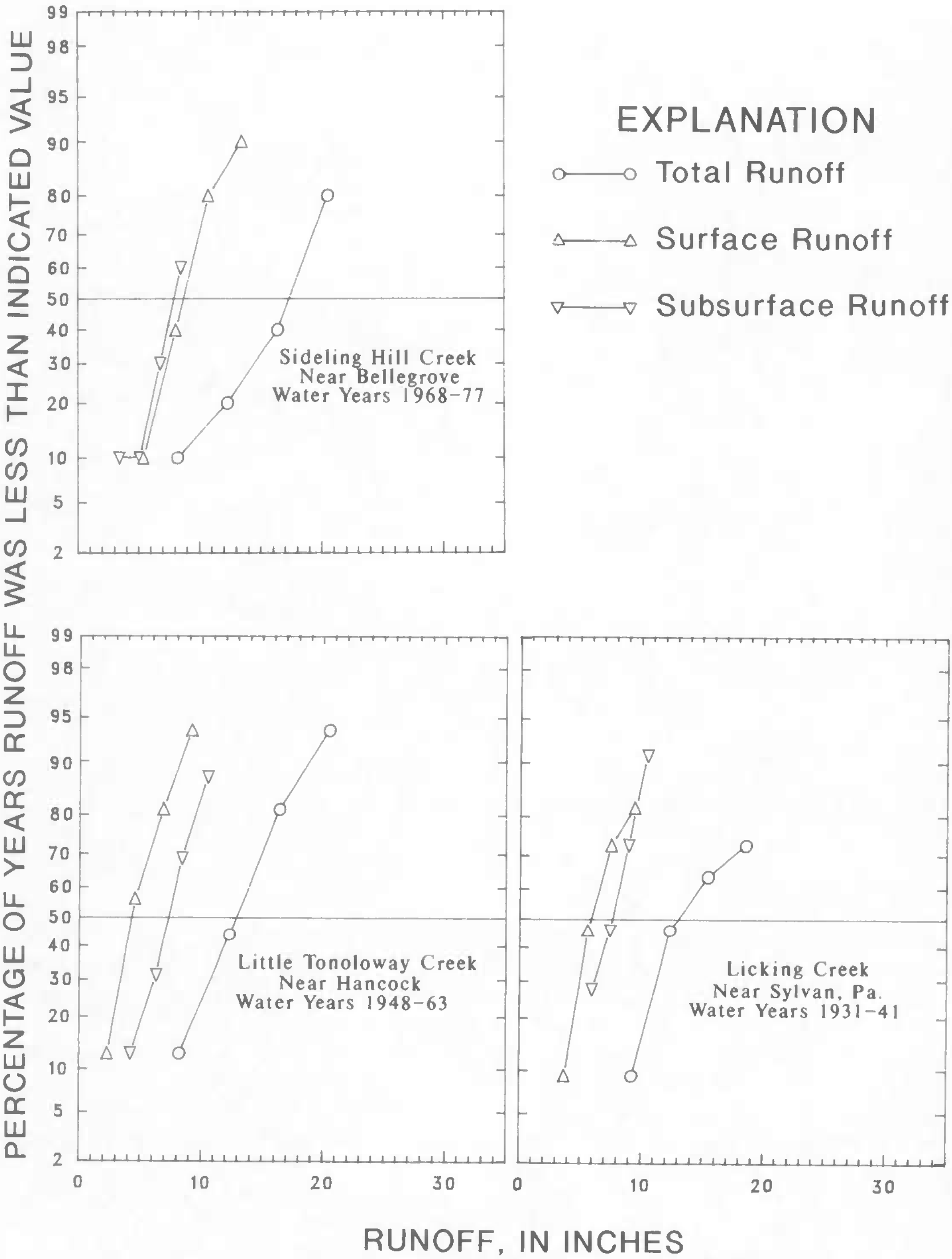


Figure 48.—Cumulative frequency distributions of annual runoff components for seven drainage basins.

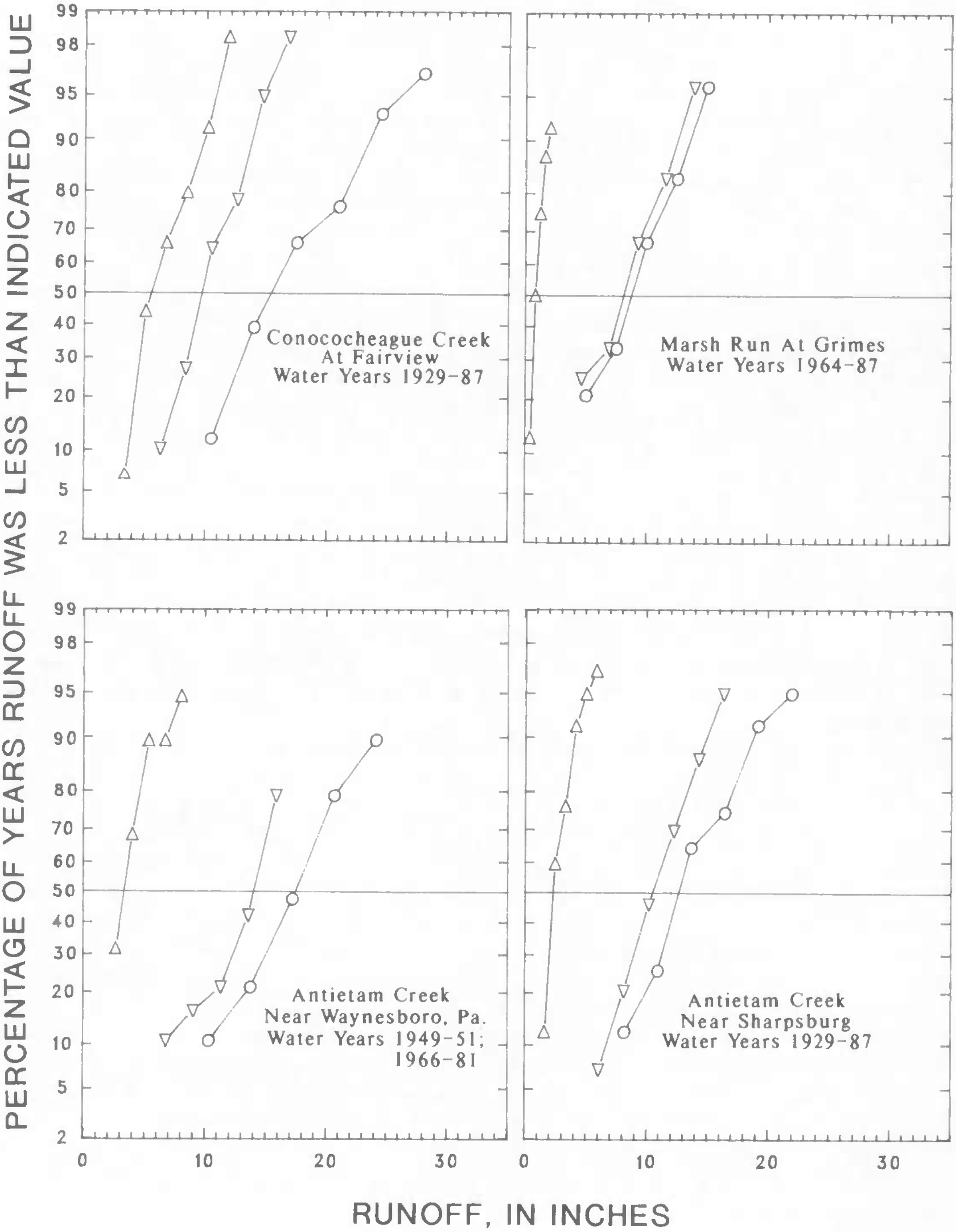


Figure 48.—Continued.

SUMMARY

Washington County, located in west-central Maryland, has a total area of 467.07 mi^2. About 993 mi^2 of additional tributary drainage area is outside the county, mostly in Pennsylvania. The county includes parts of the Blue Ridge and the Valley and Ridge physiographic provinces and possesses diverse geologic features. The western part of the county is underlain by strongly folded clastic sedimentary rocks and is steeper and more forested than most of the eastern part, where limestone and dolomite are more abundant. The extreme eastern edge of the county lies along the western flank of South Mountain and is underlain by metamorphosed sedimentary and igneous rocks. The carbonate/noncarbonate-rock dichotomy is the basis for contrasts in several hydrologic properties (such as low-flow characteristics, ground-water quality, and runoff rates) in the county.

Ground water occurs predominantly in joints, fractures, bedding planes, or other partings that are present in most of the rocks underlying Washington County. Unconsolidated sediments and overburden are common throughout the county, but generally are not used directly for water supply because of insufficient permeability or saturated thickness. Most wells obtain water from aquifers under unconfined, or water-table, conditions. Water levels in these wells range from at or above land surface to more than 150 ft below land surface. Water levels in individual wells fluctuate from a few feet to tens of feet. Highest water levels occur during late winter-early spring, and lowest levels occur most commonly in October. Magnitudes of long-term water-level trends are less than seasonal water-level variations.

The water-bearing fractures of the rocks are generally tight and restrict permeability. In some areas, however, the fractures have been enlarged by weathering or dissolution of the wall rock. The nonuniform distribution of fractures, and especially of enlarged fractures, results in highly variable aquifer transmissivity—from less than 10 to more than 1,000 ft^2/d. Well yields range from 0 gal/min (dry holes) to 385 gal/min, and the median is 10 gal/min. Specific capacities range from 0.00 to more than 85 (gal/min)/ft, and the median is 0.167 (gal/min)/ft.

Streamflow characteristics were estimated for 35 stations on 30 streams flowing through Washington County. These stations measure flow out of basins that range in size from 0.11 to 564 mi^2, excluding the two stations on the Potomac River (having drainage areas of 4,073 and 5,936 mi^2). Mean monthly flows computed for nine stations having long-term, continuous records range from 2.19 to 1,173 ft^3/s (to 13,100 ft^3/s including the Potomac River). Areally, the range is from 0.130 to 2.53 $(ft^3/s)/mi^2$. The highest monthly mean flows generally occur in March or April; the lowest occur in August through October. Mean annual flows range from 12.8 to 592 ft^3/s (to 5,990 ft^3/s including the Potomac River). Areally, the mean annual flows range from 0.677 to 1.26 $(ft^3/s)/mi^2$. One-hundred-year peak flows at 33 stations range from 147 to 39,950 ft^3/s (to 273,000 ft^3/s if the Potomac River is included), or, areally, from 22 to 1,718 $(ft^3/s)/mi^2$. Seven-day, 10-year low flows at 28 stations range from 0 to 66 ft^3/s (to 415 ft^3/s including the Potomac River); areally, they range from 0 to 0.425 $(ft^3/s)/mi^2$. On a per-square-mile basis, the eastern basins (which are gently sloped, agricultural areas underlain by large proportions of carbonate rocks) are characterized by lower annual high flows than are the western basins (which are steep, forested areas underlain predominantly by clastic rocks), but low flows are generally higher, and flow-duration curves are less steep, in the eastern basins.

Most ground water sampled in Washington County is hard to very hard. Specific conductance ranges from 18 to 3,680 µS/cm; total dissolved solids concentrations range from about 20 to 2,200 mg/L. Concentrations of trace elements, pesticides, and organic com-

pounds were generally less than detection limits in those wells and springs sampled, although the herbicide atrazine was detected in six of seven sites sampled. Most stream-water samples, collected during base-flow conditions, are calcium bicarbonate water types. The eastern carbonate-rock basins typically are characterized by higher concentrations of total dissolved solids, higher concentrations of chloride, relatively lower concentrations of sodium and potassium, and higher pH than are the western basins. Although calcium and magnesium concentrations are about equal in samples from wells, springs, and streams in carbonate terrane, calcite-saturation indices differ as ground-water chemistry evolves along flow paths from recharge to discharge areas. High concentrations of nitrate plus nitrite and of phosphate may have originated from discharge of sewage-treatment-plant effluent into some streams, but, in the carbonate basins, very high concentrations may have resulted from the recharge of water from nonpoint sources, such as septic tanks and fertilized fields, to ground-water-flow systems containing numerous solutionally enlarged joints and fractures. All nine trace elements for which analyses were made in stream-bottom materials sampled from 15 sites were detected at some of the sites. Seventeen pesticides and related compounds were detected and 11 were undetected from samples of stream-bottom materials sampled at 18 sites.

Hydrologic budgets were estimated for seven drainage basins having continuous-record gaging stations at their outlets. Budgets for 21 basins not having such records were estimated using relations determined from similar gaged basins. An average budget based on six of the gaged basins weighted by drainage area is precipitation (39.6 in.) = subsurface runoff (9.6 in.) + surface runoff (5.5 in.) + evapotranspiration (24.5 in.) + change in storage (0.0 in.). Carbonate-rock basins are characterized by relatively larger proportions of subsurface runoff compared to noncarbonate-rock basins.

Approximately 464 billion gallons of water were withdrawn from surface-water sources in Washington County in 1986, compared to only about 3 billion gallons from ground-water sources. Most water withdrawn is returned for reuse; consumptive use totaled only about 1.3 billion gallons in 1986.

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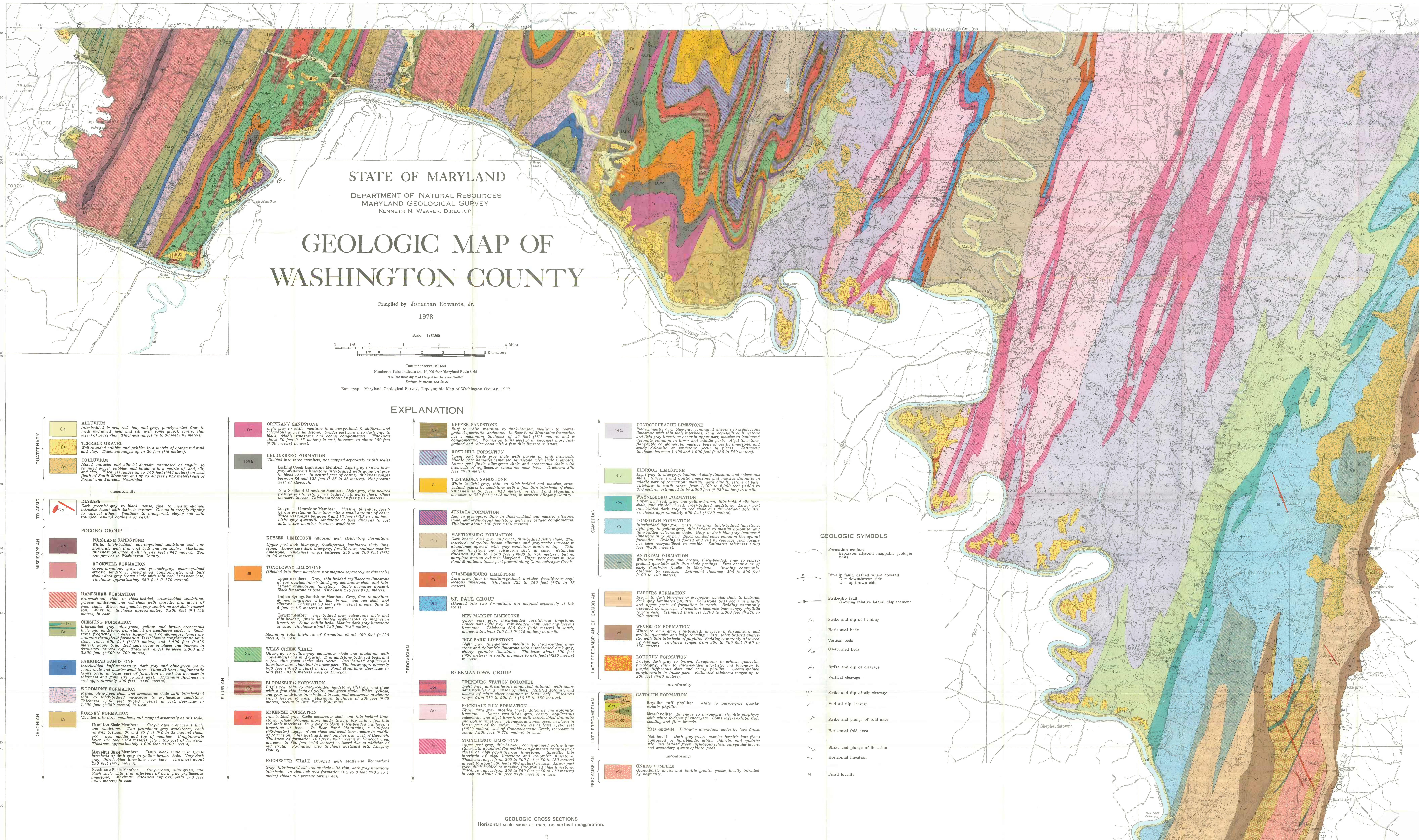


STATE OF MARYLAND

DEPARTMENT OF NATURAL RESOURCES
MARYLAND GEOLOGICAL SURVEY
KENNETH N. WEAVER, DIRECTOR

GEOLOGIC MAP OF WASHINGTON COUNTY

Compiled by Jonathan Edwards, Jr.

1978

Scale 1:62500

Contour interval 20 feet
Numbered ticks indicate the 10,000 foot Maryland State Grid
The last three digits of the grid numbers are omitted
Datum is mean sea level

Base map: Maryland Geological Survey, Topographic Map of Washington County, 1977.

EXPLANATION

QUATERNARY

ALLUVIUM
Interbedded brown, red, tan, and gray, poorly-sorted fine- to medium-grained sand and silt with some gravel; rarely, thin layers of peaty clay. Thickness ranges up to 30 feet (≈9 meters).

TERRACE GRAVEL
Well-rounded cobbles and pebbles in a matrix of orange-red sand and clay. Thickness ranges up to 20 feet (≈6 meters).

COLLUVIUM
Mixed colluvial and alluvial deposits composed of angular to rounded gravel, cobbles, and boulders in a matrix of sand, silt, and clay. Thickness ranges up to 140 feet (≈43 meters) on east flank of South Mountain and up to 40 feet (≈12 meters) east of Powell and Fairview Mountains.

unconformity

TRIASSIC

DIABASE
Dark greenish-gray to black, dense, fine- to medium-grained intrusive basalt with diabasic texture. Occurs in steeply-dipping to vertical dikes. Weathers to orange-red, clayey soil with rounded residual boulders of basalt.

MISSISSIPPIAN

POCONO GROUP

PURSLANE SANDSTONE
White, thick-bedded, coarse-grained sandstone and conglomerate with thin coal beds and red shales. Maximum thickness on Sideling Hill is 141 feet (≈43 meters). Top not present in Washington County.

ROCKWELL FORMATION
Greenish-yellow, gray, and greenish-gray, coarse-grained arkosic sandstone, fine-grained conglomerate, and buff shale; dark gray-brown shale with thin coal beds near base. Thickness approximately 550 feet (≈170 meters).

DEVONIAN

HAMPSHIRE FORMATION
Brownish-red, thin- to thick-bedded, cross-bedded sandstone, arkosic sandstone, and red shale with sporadic thin layers of green shale. Micaceous greenish-gray sandstone and shale toward top. Maximum thickness approximately 3,600 feet (≈1,100 meters) in east.

CHEMUNG FORMATION
Interbedded gray, olive-green, yellow, and brown arenaceous shale and sandstone, iron-stained on weathered surfaces. Sandstone frequency increases upward and conglomerate layers are common throughout formation. Dcs: Massive conglomeratic sandstone zones 400 feet (≈120 meters) and 1,400 feet (≈425 meters) above base. Red beds occur in places and increase in frequency toward top. Thickness ranges between 2,000 and 2,300 feet (≈600 to 700 meters).

PARKHEAD SANDSTONE
Interbedded buff-weathering, dark gray and olive-green arenaceous shale and massive sandstone. Three distinct conglomeratic layers occur in lower part of formation in east but decrease in thickness and grain size toward west. Maximum thickness in east approximately 400 feet (≈120 meters).

WOODMONT FORMATION
Fissile, olive-green shale and arenaceous shale with interbedded thin- to thick-bedded micaceous to argillaceous sandstone. Thickness 1,600 feet (≈500 meters) in east, decreases to 1,200 feet (≈360 meters) in west.

ROMNEY FORMATION
(Divided into three members, not mapped separately at this scale)

Hamilton Shale Member: *Gray-brown arenaceous shale and sandstone. Two prominent gray sandstones, each ranging between 20 and 75 feet (≈6 to 23 meters) thick, occur near middle and top of member. Conglomerate layer 175 feet (≈54 meters) below top east of Hancock. Thickness approximately 1,000 feet (≈300 meters).*

Marcellus Shale Member: *Fissile black shale with sparse interbeds of dark gray to yellow-brown shale. Very dark gray, thin-bedded limestone near base. Thickness about 250 feet (≈75 meters).*

Needmore Shale Member: *Gray-brown, olive-green, and black shale with thin interbeds of dark gray argillaceous limestone. Maximum thickness approximately 150 feet (≈46 meters) in east.*

Do **ORISKANY SANDSTONE**
Light gray to white, medium- to coarse-grained, fossiliferous and calcareous quartz sandstone. Grades eastward into dark gray to black, friable sandstone and coarse conglomerate. Thickness about 50 feet (≈15 meters) in east, increases to about 200 feet (≈60 meters) in west.

DShk **HELDERBERG FORMATION**
(Divided into three members, not mapped separately at this scale)

Licking Creek Limestone Member: *Light gray to dark blue-gray arenaceous limestone interbedded with abundant gray to black chert. In central part of county thickness ranges between 85 and 125 feet (≈26 to 38 meters). Not present west of Hancock.*

New Scotland Limestone Member: *Light gray, thin-bedded fossiliferous limestone interbedded with white chert. Chert increases to east. Thickness about 12 feet (≈3.7 meters).*

Coeymans Limestone Member: *Massive, blue-gray, fossiliferous crystalline limestone with a small amount of chert. Thickness ranges between 8 and 13 feet (≈2.5 to 4 meters). Light gray quartzitic sandstone at base thickens to east until entire member becomes sandstone.*

SILURIAN

KEYSER LIMESTONE *(Mapped with Helderberg Formation)*
Upper part dark blue-gray, fossiliferous, laminated shaly limestone. Lower part dark blue-gray, fossiliferous, nodular massive limestone. Thickness ranges between 250 and 300 feet (≈75 to 90 meters).

Stl **TONOLOWAY LIMESTONE**
(Divided into three members, not mapped separately at this scale)

Upper member: *Gray, thin-bedded argillaceous limestone at top overlies interbedded gray calcareous shale and thin-bedded argillaceous limestone. Shale decreases upward. Black limestone at base. Thickness 275 feet (≈85 meters).*

Indian Springs Sandstone Member: *Gray, fine- to medium-grained sandstone with tan, brown, and red shale and siltstone. Thickness 20 feet (≈6 meters) in east, thins to 5 feet (≈1.5 meters) in west.*

Lower member: *Interbedded gray calcareous shale and thin-bedded, finely laminated argillaceous to magnesian limestone. Some oolitic beds. Massive dark gray limestone at base. Thickness about 120 feet (≈35 meters).*

Maximum total thickness of formation about 400 feet (≈120 meters) in west.

Sw **WILLS CREEK SHALE**
Olive-gray to yellow-gray calcareous shale and mudstone with ripple-marks and mud cracks. Thin sandstone beds, red beds, and a few thin green shales also occur. Interbedded argillaceous limestone more abundant in lower part. Thickness approximately 600 feet (≈180 meters) in Bear Pond Mountains, decreases to 500 feet (≈150 meters) west of Hancock.

Sb **BLOOMSBURG FORMATION**
Bright red, thin- to thick-bedded sandstone, siltstone, and shale with a few thin beds of yellow and green shale. White, yellow, and gray sandstone interbedded in east, and calcareous mudstone enters section to west. Maximum thickness of 200 feet (≈60 meters) occurs in Bear Pond Mountains.

Smr **McKENZIE FORMATION**
Interbedded gray, fissile calcareous shale and thin-bedded limestone. Shale becomes more sandy toward top with a few thin red shale interbeds. Dark gray to black, thick-bedded argillaceous limestone at base. In Bear Pond Mountains, a 100-foot (≈30-meter) wedge of red shale and sandstone occurs in middle of formation, thins westward, and pinches out west of Hancock. Thickness of formation 160 feet (≈50 meters) in Hancock area, increases to 300 feet (≈90 meters) eastward due to addition of red strata. Formation also thickens westward into Allegany County.

ROCHESTER SHALE *(Mapped with McKenzie Formation)*
Gray, thin-bedded calcareous shale with thin, dark gray limestone interbeds. In Hancock area formation is 2 to 3 feet (≈0.5 to 1 meter) thick; not present farther east.

Sk **KEEFER SANDSTONE**
Buff to white, medium- to thick-bedded, medium- to coarse-grained quartzitic sandstone. In Bear Pond Mountains formation has a maximum thickness of 35 feet (≈11 meters) and is conglomeratic. Formation thins westward, becomes more fine-grained and calcareous with a few thin limestone lenses.

Srh **ROSE HILL FORMATION**
Upper part fissile gray shale with purple or pink interbeds. Middle part hematite-cemented sandstone with shale interbeds. Lower part fissile olive-green shale and arenaceous shale with interbeds of argillaceous sandstone near base. Thickness 300 feet (≈90 meters).

St **TUSCARORA SANDSTONE**
White to light gray, thin- to thick-bedded and massive, cross-bedded quartzitic sandstone with a few thin interbeds of shale. Thickness is 60 feet (≈18 meters) in Bear Pond Mountains, increases to 380 feet (≈115 meters) in western Allegany County.

ORDOVICIAN

Oj **JUNIATA FORMATION**
Red to green-gray, thin- to thick-bedded and massive siltstone, shale, and argillaceous sandstone with interbedded conglomerate. Thickness about 180 feet (≈55 meters).

Om **MARTINSBURG FORMATION**
Dark brown, dark gray, and black, thin-bedded fissile shale. Thin interbeds of yellow-brown siltstone and graywacke increase in abundance upward with gray sandstone strata at top. Thin-bedded limestone and calcareous shale at base. Estimated thickness 2,000 to 2,500 feet (≈600 to 750 meters), but no complete section exists in Maryland. Upper part occurs in Bear Pond Mountains, lower part present along Conococheague Creek.

Oc **CHAMBERSBURG LIMESTONE**
Dark gray, fine- to medium-grained, nodular, fossiliferous argillaceous limestone. Thickness 225 to 250 feet (≈70 to 75 meters).

Osp **ST. PAUL GROUP**
(Divided into two formations, not mapped separately at this scale)

NEW MARKET LIMESTONE
Upper part gray, thick-bedded fossiliferous limestone. Lower part light gray, thin-bedded, laminated argillaceous limestone. Thickness 280 feet (≈85 meters) in south, increases to about 700 feet (≈215 meters) in north.

ROW PARK LIMESTONE
Light gray, fine-grained, medium- to thick-bedded limestone and dolomitic limestone with interbedded dark gray, cherty, granular limestone. Thickness about 100 feet (≈30 meters) in south, increases to 680 feet (≈210 meters) in north.

BEEKMANTOWN GROUP

Ops **PINESBURG STATION DOLOMITE**
Light gray, unfossiliferous laminated dolomite with abundant nodules and masses of chert. Mottled dolomite and masses of white chert common in lower half. Thickness ranges from 375 to 500 feet (≈115 to 150 meters).

Orr **ROCKDALE RUN FORMATION**
Upper third gray, mottled cherty dolomite and dolomitic limestone. Lower two-thirds gray, cherty, argillaceous calcarenite and algal limestone with interbedded dolomite and oolitic limestone. Arenaceous zones occur in places in lower part of formation. Thickness at least 1,700 feet (≈520 meters) east of Conococheague Creek, increases to about 2,500 feet (≈770 meters) in west.

Os **STONEHENGE LIMESTONE**
Upper part gray, thin-bedded, coarse-grained oolitic limestone with abundant flat-pebble conglomerate composed of clasts of highly-fossiliferous limestone. Sporadic thin interbeds of algal limestone and dolomitic limestone. Thickness ranges from 200 to 500 feet (≈60 to 150 meters) in east to about 300 feet (≈90 meters) in west. Lower part gray, thick-bedded to massive, fine-grained algal limestone. Thickness ranges from 200 to 350 feet (≈60 to 110 meters) in east to about 300 feet (≈90 meters) in west.

OЄc **CONOCOCHEAGUE LIMESTONE**
Predominantly dark blue-gray, laminated siliceous to argillaceous limestone with thin shale interbeds. Pink recrystallized limestone and light gray limestone occur in upper part, massive to laminated dolomite common in lower and middle parts. Algal limestone, flat-pebble conglomerate, massive beds of oolitic limestone, and sandy dolomite or sandstone occur in places. Estimated thickness between 1,400 and 1,900 feet (≈430 to 580 meters).

CAMBRIAN

Єe **ELBROOK LIMESTONE**
Light gray to blue-gray, laminated shaly limestone and calcareous shale. Siliceous and oolitic limestone and massive dolomite in middle part of formation; massive, dark blue limestone at base. Thickness in south ranges from 1,400 to 2,000 feet (≈430 to 610 meters); estimated to be 3,000 feet (≈920 meters) in north.

Єw **WAYNESBORO FORMATION**
Upper part red, gray, and yellow-brown, thin-bedded siltstone, shale, and ripple-marked, cross-bedded sandstone. Lower part interbedded dark gray to red shale and thin-bedded dolomite. Thickness approximately 600 feet (≈180 meters).

Єt **TOMSTOWN FORMATION**
Interbedded light gray, white, and pink, thick-bedded limestone; light gray to yellow-gray, thin-bedded to massive dolomite; and thin-bedded calcareous shale. Gray to dark blue-gray laminated limestone in lower part. Black banded chert common throughout formation. Bedding is folded and cut by cleavage; rock locally has been recrystallized to marble. Estimated thickness 1,000 feet (≈300 meters).

Єa **ANTIETAM FORMATION**
White to dark gray and brown, thick-bedded, fine- to coarse-grained quartzite with thin shale partings. First occurrence of Early Cambrian fossils in Maryland. Bedding commonly obscured by cleavage. Estimated thickness 300 to 500 feet (≈90 to 150 meters).

LATE PRECAMBRIAN OR CAMBRIAN

hf **HARPERS FORMATION**
Brown to dark blue-gray or green-gray banded shale to lustrous, dark gray laminated phyllite. Sandstone beds occur in middle and upper parts of formation in north. Bedding commonly obscured by cleavage. Formation becomes increasingly phyllitic toward east. Estimated thickness 1,200 to 3,000 feet (≈370 to 900 meters).

wf **WEVERTON FORMATION**
White to dark gray, thin-bedded, micaceous, ferruginous, and sericitic quartzite and ledge-forming, white, thick-bedded quartzite, with thin interbeds of phyllite. Bedding commonly obscured by cleavage. Thickness ranges from 200 to 500 feet (≈60 to 150 meters).

lf **LOUDOUN FORMATION**
Friable, dark gray to brown, ferruginous to arkosic quartzite; purple-gray, thin- to thick-bedded quartzite; and blue-gray to purple tuffaceous slate and sandy phyllite. Coarse-grained conglomerate in lower part. Estimated thickness ranges up to 200 feet (≈60 meters).

unconformity

LATE PRECAMBRIAN

pЄcp pЄcr pЄca pЄcb **CATOCTIN FORMATION**

Rhyolite tuff phyllite: *White to purple-gray quartz-sericite phyllite.*

Metarhyolite: *Blue-gray to purple-gray rhyolite porphyry with white feldspar phenocrysts. Some layers exhibit flow banding and flow breccia.*

Meta-andesite: *Blue-gray amygdular andesitic lava flows.*

Metabasalt: *Dark gray-green, massive basaltic lava flows composed of hornblende, albite, chlorite, and epidote; with interbedded green tuffaceous schist, amygdular layers, and secondary quartz-epidote pods.*

unconformity

PRECAMBRIAN

pЄg **GNEISS COMPLEX**
Granodiorite gneiss and biotite granite gneiss, locally intruded by pegmatite.

GEOLOGIC SYMBOLS

Formation contact
Separates adjacent mappable geologic units

Dip-slip fault, dashed where covered
D = downthrown side
U = upthrown side

Strike-slip fault
Showing relative lateral displacement

Strike and dip of bedding

Horizontal beds

Vertical beds

Overturned beds

Strike and dip of cleavage

Vertical cleavage

Strike and dip of slip-cleavage

Vertical slip-cleavage

Strike and plunge of fold axes

Horizontal fold axes

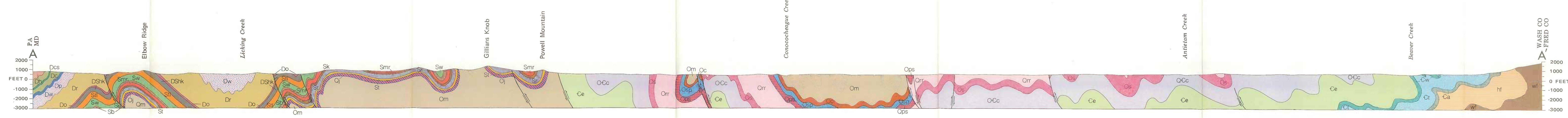
Strike and plunge of lineation

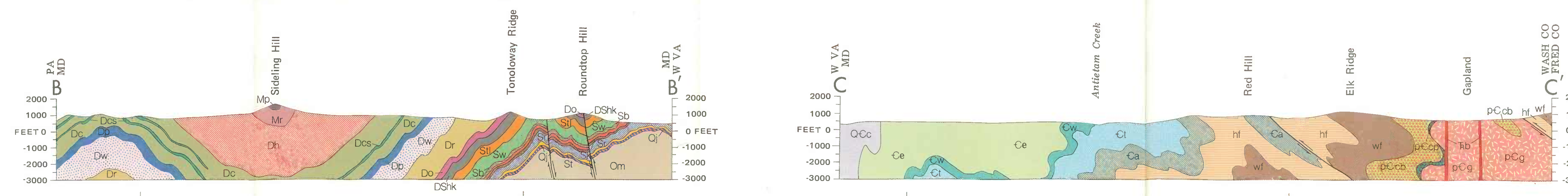
Horizontal lineation

Fossil locality

GEOLOGIC CROSS SECTIONS

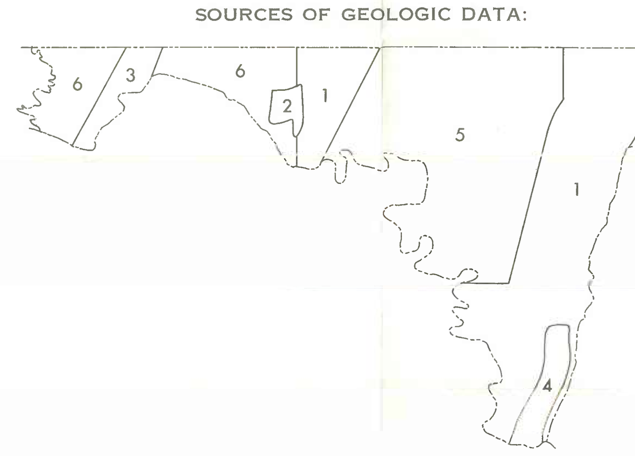
Horizontal scale same as map, no vertical exaggeration.





INDEX OF MARYLAND COUNTIES

SOURCES OF GEOLOGIC DATA:



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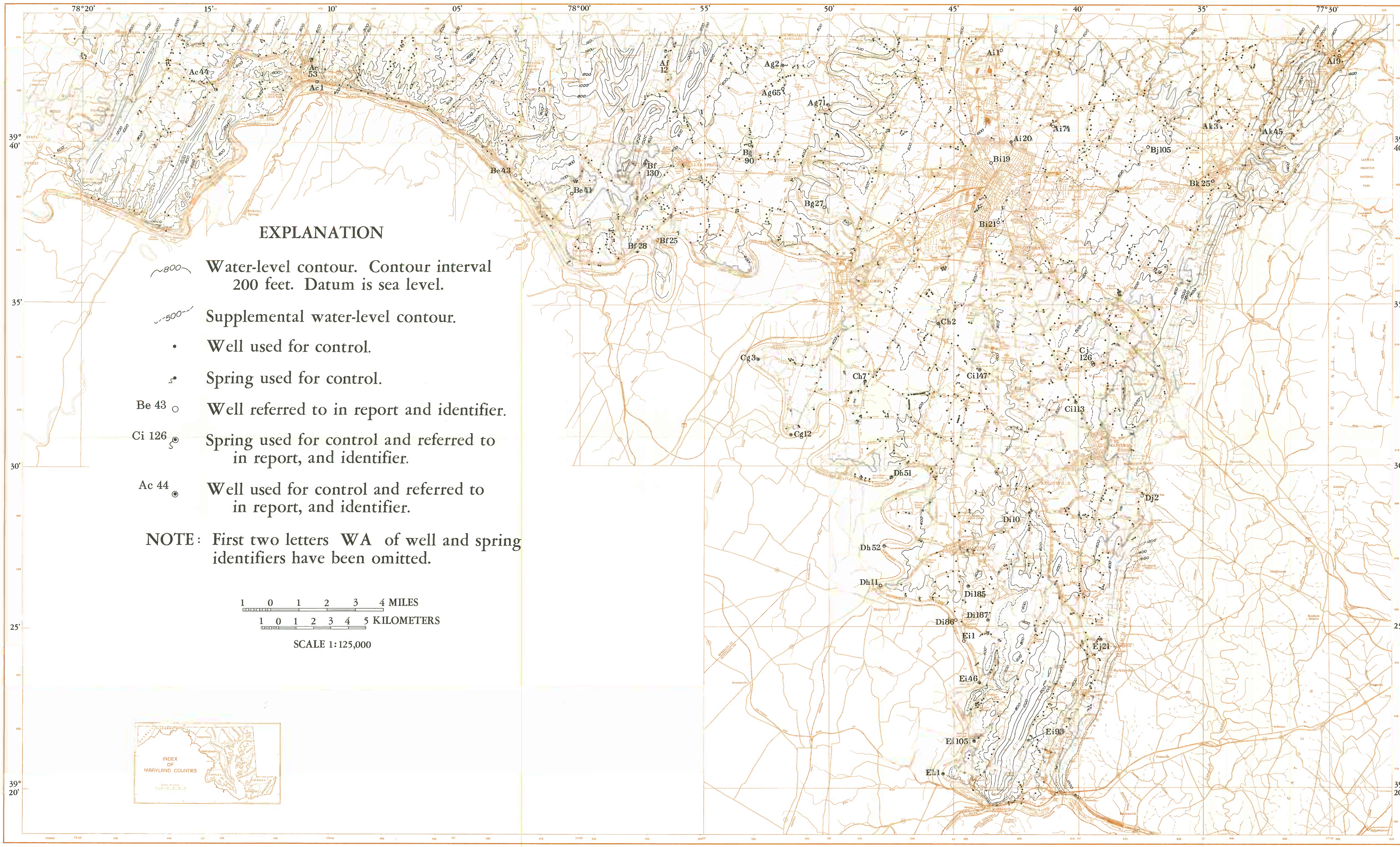
Map scribed by Margaret Ketchum McCabe

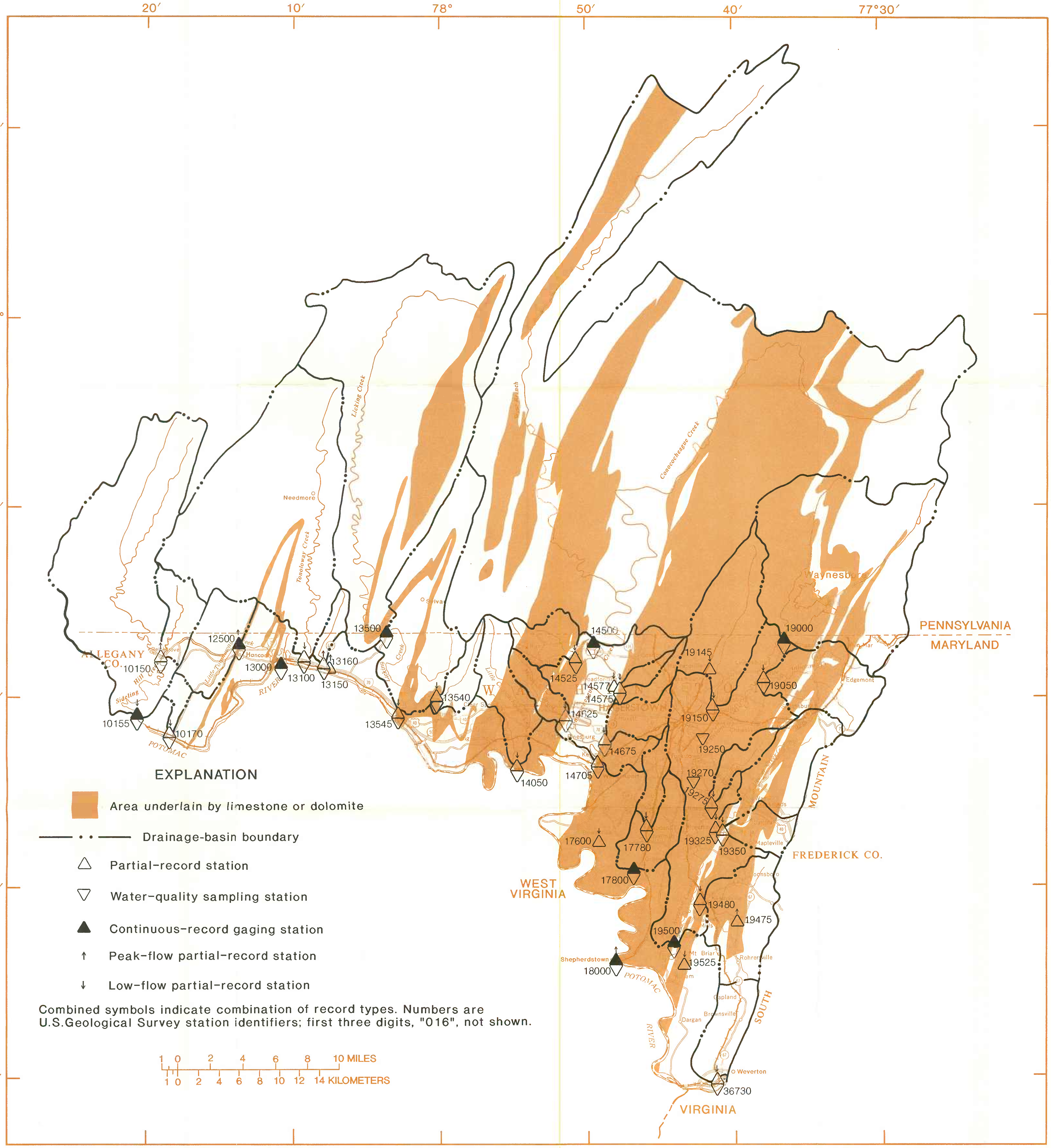
Copies of this map may be purchased from the Maryland Geological Survey, The Johns Hopkins University, Baltimore, Maryland 21218

Williams & Heintz Map Corporation, Washington, D.C. 20027



Base from Maryland Geological Survey, 1:62,500

PLATE 2. MAP SHOWING GROUND-WATER LEVELS IN WASHINGTON COUNTY, MARYLAND, AND WELLS AND SPRINGS REFERENCED IN REPORT



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

Geologic contacts from Edwards, 1978, and Berg, 1980.

Plate 3.--Map showing stream basins, locations of stream stations, and areas underlain by carbonate rocks.