Water Resources of the Delmarva Peninsula

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By E. M. CUSHING, I. H. KANTROWITZ, *and* K. R. TAYLOR

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GLOSSARY

Anion. A negatively charged ion.

Aquifer. A formation, group of formations, or part of a formation that is water bearing.

Artesian aquifer. An aquifer overlain by a confining bed and containing water under artesian conditions.

Artesian conditions. The occurrence of ground water under sufficient pressure to rise above the upper surface of the aquifer.

Base flow. Discharge entering stream channels from the ground-water reservoir. The fair-weather flow of streams.

Cation. A positively charged ion.

Cone of depression. A conical depression on a water table or other potentiometric surface produced by pumping.

Cubic feet per second per square mile. The average number of cubic feet of water flowing per second from each square mile of area drained, assuming that the runoff is distributed uniformly in time and area.

Cubic foot per second (cfs). The discharge of a stream of rectangular cross section 1 foot wide and 1 foot deep, whose average velocity is 1 foot per second.

Daily-record gaging station. A site on a stream where a continuous record of discharge is obtained.

Draft-storage frequency curve. A graph showing the frequency with which storage equal to or greater than selected amounts will be required to maintain selected rates of regulated flow (draft).

Effective porosity. The amount of interconnected pore space expressed as the percentage of the total volume of a sediment occupied by the interconnecting interstices.

Flow-duration curve. A graph showing the percentage of time that specified discharges are equaled or exceeded.

Frequency. The recurrence interval, in years, of an annual flow event.

Fresh water. Water containing less than 1,000 milligrams per liter dissolved solids.

Ground-water discharge. That part of streamflow that consists of water discharged into a stream channel by seepage from the ground-water reservoir; same as base flow.

Ground-water reservoir. An aquifer or group of related aquifers.

Hydraulic conductivity. The volume of water at the prevailing kinematic viscosity that is transmitted in unit time through a cross section of the aquifer of unit area, measured at right angles to the direction of flow, under a unit hydraulic gradient. It replaces the field coefficient of permeability formerly used in U.S. Geological Survey reports. Hydraulic conductivity is equivalent to the transmissivity divided by the thickness of the aquifer.

Hydrograph. A graph showing changes in stage, flow, velocity, or other aspect of water with respect to time.

Ion. An electrically charged atom or group of atoms.

Milliequivalents per liter. The concentration of a solute, in milligrams per liter, divided by the chemical combining weight of the solute. The chemical combining weight is the atomic or molecular weight of the solute divided by its valence.

Milligrams per liter. The weight, in milligrams, of a solute in 1 liter of solution.

Miscellaneous measuring site. A site on a stream where streamflow data are collected over a short period of time.

Overland flow. The water that moves over the land surface directly to streams promptly after rainfall or snowmelt.

Partial-record station. A site on a stream where some streamflow data are collected systematically over a period of years.

Permeability. A measure of the relative ease with which a porous medium can transmit a fluid. Hydraulic conductivity replaces the field coefficient of permeability formerly used in U.S. Geological Survey reports.

Potentiometric surface. The surface to which the water in an aquifer will rise under its full head.

Recurrence interval. The average interval of time within which a given hydrologic event will be equaled or exceeded in severity once.

Runoff. The water draining from an area. When expressed in inches, it is the depth to which an area would be covered if all the water draining from it in a given period were uniformily distributed on its surface. The term may be used to compare runoff with precipitation, which also is usually expressed in inches.

Saline water. Water containing 1,000 or more milligrams per liter dissolved solids.

Saturation, zone of. The zone in which interconnected interstices are saturated with water under pressure equal to or greater than atmospheric.

Specific capacity. The rate of discharge of water from a well divided by the drawdown of water level in it. Specific capacity varies slowly with duration of discharge, which should be stated when known. If the specific capacity is constant, except for the time variation, it is roughly proportional to the transmissivity of the aquifer.

Specific conductance. The conductance of a cube of a substance 1 centimeter on a side, measured as reciprocal ohms or mhos. Commonly reported as millionths of mhos, or micromhos, at 25°C.

Specific yield. The ratio of the volume of water drained from a saturated deposit by gravity to the volume of the deposit.

Storage coefficient. The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head. In an artesian aquifer the water derived from storage with decline in head comes from expansion of the water and compression of the aquifer; similarly, water added to storage with a rise in head is accommodated partly by compression of the water and partly by expansion of the aquifer. In a water-table aquifer, storage coefficient is virtually equal to the specific yield.

Transmissivity. The rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient. It replaces coefficient of transmissibility formerly used in U.S. Geological Survey reports.

Water table. The upper surface of the zone of saturation.

Water-table aquifer. An aquifer containing water under water-table conditions.

Water-table conditions. The condition under which water occurs in an aquifer that is not overlain by a confining bed and that has a water table.

Water year. A 12-month period beginning October 1 and ending the following September 30. Designated as the year ending September 30.

WATER RESOURCES OF THE DELMARVA PENINSULA

By E. M. Cushing, I. H. Kantrowitz, and K. R. Taylor

ABSTRACT

The Delmarva Peninsula comprises about 6,500 square miles on the Atlantic Coastal Plain and includes parts of Delaware, Maryland, and Virginia. The peninsula is underlain by unconsolidated sediments that range in thickness from a featheredge at the Fall Line (the northern boundary of the peninsula) to as much as 8,000 feet along parts of the Atlantic coast.

Precipitation averages 43 inches per year, and streamflow averages 15 inches per year. About 6½ inches of the average streamflow is overland flow, and the remaining 8½ inches is ground-water discharge. The streams are generally perennial; however, low flow (7-day low flow at the 2-year recurrence interval) ranges from 0 to 1.16 cubic feet per second per square mile. Some low-flow data (in cubic feet per second per square mile) from 36 daily-record gaging stations, 25 partial-record gaging stations, and 120 miscellaneous sites are summarized for ready comparison.

Drafts that may be made from specified amounts of storage with a chance of deficiency once in 5, 10, and 20 years, on a long-term average, are related to the median annual 7-day (7-day 2-year) low flow to permit preliminary estimates to be made of storage requirements to supplement natural low flows.

Streamflow is generally low in dissolved solids and chemically suitable for most uses except in the downstream reaches of those streams subject to tidal invasion of saline water.

Ten regional aquifers furnish nearly all the water used on the peninsula. Hydraulic characteristics vary from aquifer to aquifer and from place to place within each aquifer. The Quaternary aquifer, which is the most areally extensive, generally has the highest transmissivity and is the most productive water-bearing unit on the peninsula. It is also the most susceptible to pollution. Large parts of all the aquifers contain water of generally good chemical quality. In the recharge areas of the various aquifers, ground water is a calcium bicarbonate type, generally with less than 250 milligrams per liter dissolved solids. As water moves downgradient in the aquifers, the dissolved-solids content increases and the chemical character of the water changes to a sodium bicarbonate type. Farther downgradient, the water changes to a sodium chloride bicarbonate type and in places contains more than 1,000 milligrams per liter dissolved solids.

Saline water from surface-water bodies could intrude the shallow updip parts of the aquifers if ground-water withdrawals in these areas are significantly increased or if the bottom sediments of bays and estuaries near pumping centers are sufficiently disturbed, such as by dredging. Contamination of fresh water by updip movement of the saline ground water in the deeper parts of the aquifers is not considered to be a threat in the foreseeable future.

Annual use of water on the peninsula in 1970 was about 137 mgd (million gallons per day), of which about 14 mgd was withdrawn from streams for irrigation supplies, and the remainder, 123 mgd, was withdrawn from the aquifers. About 75 percent of the ground-water supply was from the Quaternary aquifer and the water-table parts of the older aquifers. It is estimated that the use of water on the peninsula by 2010 will be 260 mgd.

The amount of fresh water that can be developed perennially on the peninsula is estimated to be 1,500 mgd. This amount is about 10 times the 1970 use and about six times the estimated use by the year 2010. Large long-term water supplies will probably have to be developed from the Quaternary aquifer. The perennial yield of this aquifer is estimated to be 1,000 mgd.

INTRODUCTION

Public Law 89–618, dated October 4, 1966, and enacted by the 89th Congress, authorizes and directs the Secretary of the Interior "to make a comprehensive study and investigation of the water resources of the Delmarva Peninsula with a view to determining the availability of fresh water supplies needed to meet the anticipated future requirements of the Delmarva Peninsula area, and with a view to determining the most effective means from the standpoint of hydrologic feasibility of protecting and developing fresh water sources so as to insure, insofar as practicable, the availablility of adequate water supplies in the future." This report gives the results of the study.

The Delmarva Peninsula lies between Chesapeake Bay on the west and the Atlantic Ocean and Delaware Bay on the east. It extends from about the latitude of Norfolk, Va., to northern Maryland and Delaware (fig. 1). For the purpose of this study, the northern boundary of the peninsula is the Fall Line, which is the boundary between the Piedmont and the Coastal Plain physiographic provinces. The area included in the study comprises about 6,500 square miles of Delaware, Maryland, and Virginia.

The abundance of water-bearing sand and gravel (aquifers) in the unconsolidated sediments of the peninsula make ground water the most widely available source of fresh water. Surface water, also, is available to those who have access to streams. Al-

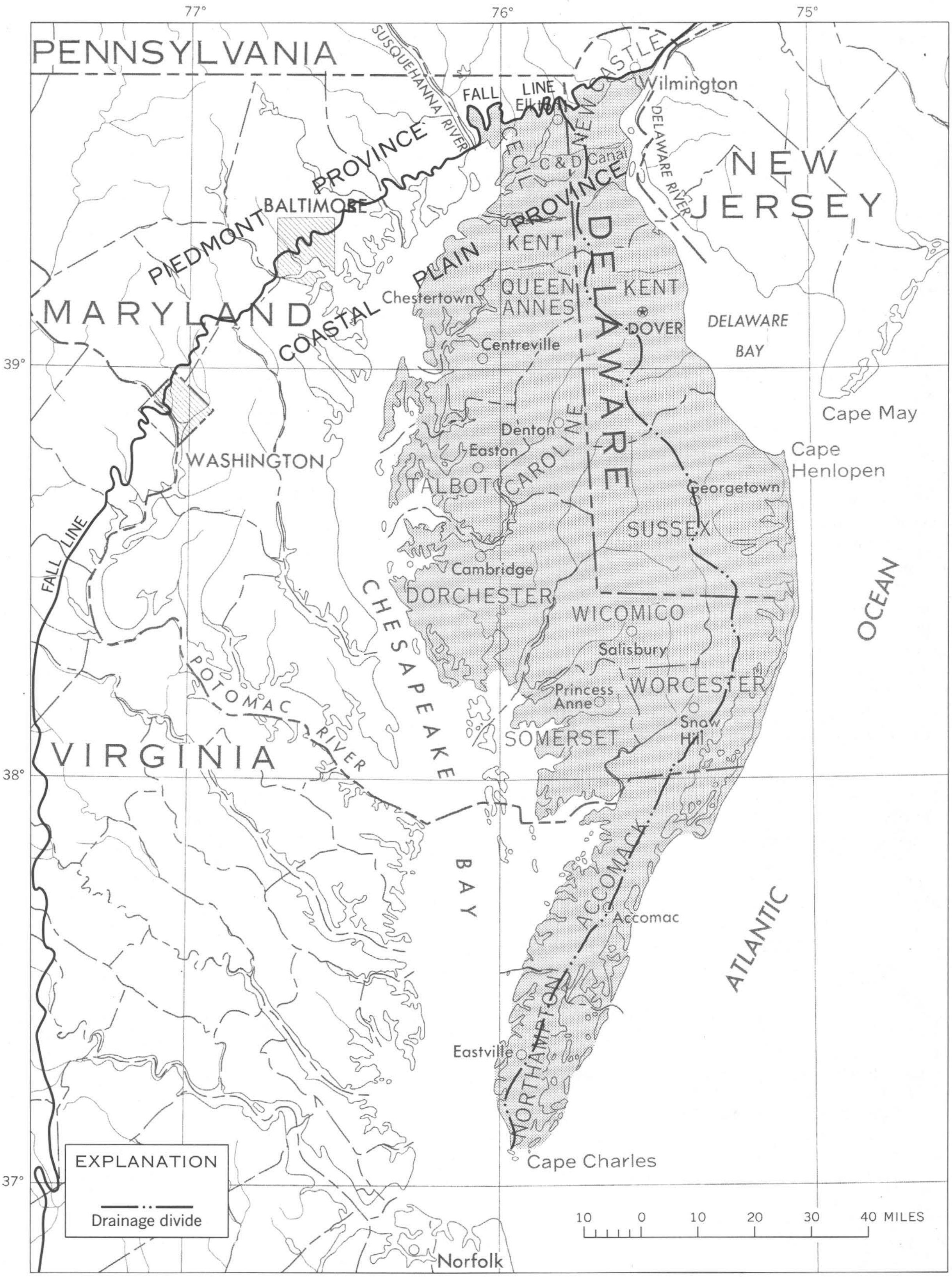

Figure 1.—Area of study (shaded).

though this report deals separately with ground water and surface water, ground water and the base flow of streams are virtually one water, and those considering the use of water from wells are reminded that such use could effectively diminish the amount of water available from streams.

Many of the previous water-resources investigations on the peninsula have been made by the U.S. Geological Survey in cooperation with State, county, and municipal agencies, and some have been made by State or other governmental agencies. Although most studies have been restricted to counties or local areas, some have covered as many as three counties. Few, however, have treated the subject of water resources on a peninsulawide basis, and the proper development, use, and conservation of the water resources cannot be achieved without a thorough understanding of the regional geologic environment and its influence on the response of the hydrologic system to climate and to water-supply development.

The cooperation of the following State officials and their staff members is gratefully appreciated: Robert R. Jordan, State Geologist, Delaware Geological Survey; Robert D. Varrin, Director, Water Resources Center, University of Delaware; Kenneth N. Weaver, Director, Maryland Geological Survey; Arnold Schiffman, Chief, Ground Water Services, Maryland Water Resources Administration; James L. Calver, State Geologist, Virginia Division of Mineral Resources; and Julian M. Alexander, Commissioner, Virginia Division of Water Resources. These officials furnished geologic and hydrologic information and geophysical logs for the study. Driller's log, well-construction, pumping, and water-level information furnished by numerous well drillers in the area is also appreciated.

GENERAL GEOLOGY

The Delmarva Peninsula is a part of the Atlantic Coastal Plain that extends from Long Island, N.Y., southward to the Gulf of Mexico. Crustal movements along the Atlantic continental margin have produced a seaward slope on the crystalline-rock basement surface (fig. 2). Areas northwest of the Fall Line were uplifted during the movements and underwent erosion, while areas southeast of the Fall Line were depressed and became centers of deposition. The sediments eroded from the uplifted areas filled the depositional basin to the southeast. These sediments, consisting of clay, silt, sand, and gravel, constitute the present unconsolidated deposits underlying the peninsula. They range in thickness from a featheredge at the Fall Line to more than 8,000 feet along the Atlantic coast in Maryland. The sediments have been mapped in the outcrop area and divided into geologic units on the basis of lithology and paleontology (table 1). Although differences exist in the nomenclature of rock-stratigraphic units between States, the time-stratigraphic relationships are fairly well understood and agreed upon.

Detailed subsurface mapping of rock- and time-stratigraphic units was not attempted during this study. Rather, an attempt was made to identify and map the major sand bodies that function as aquifers over wide areas of the peninsula. Ten such aquifers were identified; their approximate stratigraphic position is indicated in table 1 and figure 26. The aquifer names used in this report are informal and, in general, follow prior usage in the area.

Correlation of aquifers was based on the study of geophysical logs from approximately 200 wells and test holes on the peninsula and in adjacent areas. Because control points were often widely separated, many logs did not provide overlapping sections; instead, lateral equivalence was determined by picking recognizable stratigraphic horizons to establish a general geologic framework. To help verify correlations, log interpretations were supplemented by lithologic and paleontologic studies of drill cuttings and cored samples. Four principal stratigraphic horizons were identified; they divide the unconsolidated deposits into five major geologic units (table 1).

NONMARINE CRETACEOUS SEDIMENTS

A thick and geologically complex series of nonmarine sediments directly overlies the crystalline rocks. These sediments are predominantly of Cretaceous age, although Triassic units are probably present at depth (Anderson, 1948, p. 13), and Jurassic sediments may also occur (Kraft and others, 1971, p. 659). Nevertheless, for simplicity, the entire mass of nonmarine sediments is referred to as Cretaceous.

The nonmarine Cretaceous sediments consist of a series of interbedded lenses of lignitic light-gray and white quartz sand, and variegated red, light-gray, purple, brown, and yellow silt and clay. The sediments are characterized by their variable and lenticular nature and their generally bright colors, indicative of deposition in a deltaic environment of shifting river channels, flood plains, and swamps.

The nonmarine Cretaceous sediments constitute approximately three-fourths of the total volume of unconsolidated deposits. The altitude of the top ranges from more than 100 feet above sea level at the Fall Line to more than 2,000 feet below sea level along the Maryland coast. Similarly, the thickness of the unit ranges from zero to more than 6,000 feet.

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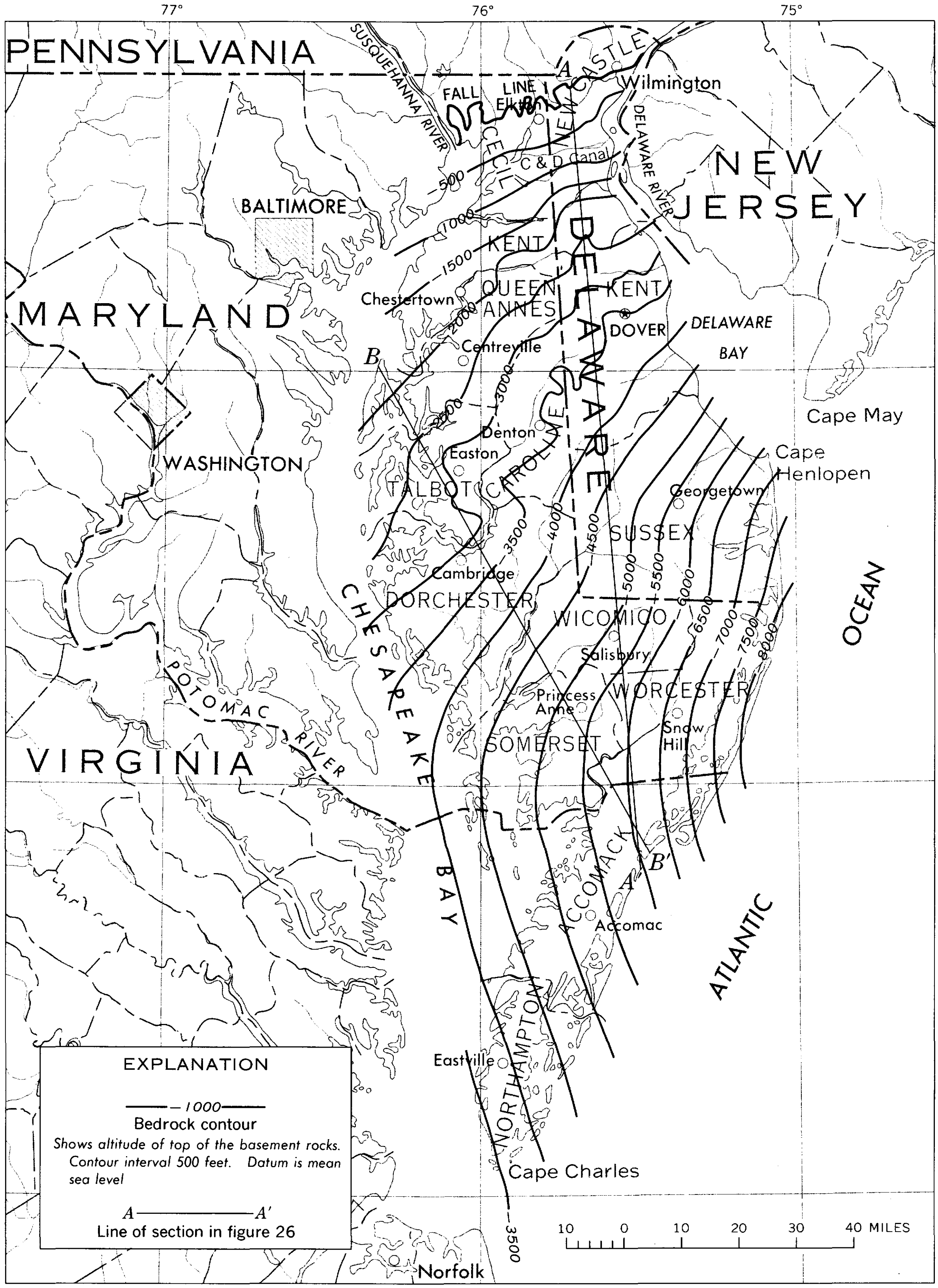


FIGURE 2.—Configuration of the top of the basement rocks.

Table 1.—*Coastal-Plain stratigraphic nomenclature and aquifers*

System	Series	Stratigraphic units: Virginia	Stratigraphic units: Maryland	Stratigraphic units: Delaware	Stratigraphic units: New Jersey	Informal units used in this report	Aquifer names used in this report
Quaternary	Holocene	--------	--------	--------	--------	Quaternary sediments	Quaternary aquifer
Quaternary	Pleistocene	Columbia Group undivided	Columbia Group undivided	Columbia Group undivided	Cape May Formation Pensauken Formation Bridgeton Formation	Quaternary sediments	Quaternary aquifer
Tertiary	Pliocene(?)	--------	Brandywine Formation	--------	Cohansey Sand	Quaternary sediments	Quaternary aquifer
Tertiary	Miocene	Chesapeake Group: Yorktown Formation St. Marys Formation Choptank Formation Calvert Formation	Chesapeake Group: Yorktown Formation St. Marys Formation Choptank Formation Calvert Formation	Chesapeake Group undivided	Cohansey Sand Kirkwood Formation	Miocene sediments	Pocomoke aquifer Manokin aquifer Frederica aquifer Federalsburg aquifer Cheswold aquifer
Tertiary	Oligocene	(Section not present)	(Section not present)	(Section not present)	(Section not present)	(Section not present)	(Section not present)
Tertiary	Eocene	Chickahominy Formation Nanjemoy Formation	Piney Point Formation Nanjemoy Formation	Piney Point Formation Nanjemoy Formation	Piney Point Formation Shark River Formation Manasquan Formation	Eocene and Paleocene sediments	Piney Point aquifer
Tertiary	Paleocene	Aquia Formation	Aquia Formation Brightseat Formation	Rancocas Group: Vincentown Formation Hornerstown Sand	Vincentown Formation Hornerstown Sand	Eocene and Paleocene sediments	Aquia and Rancocas aquifer
Cretaceous	Upper Cretaceous	Mattaponi Formation	Monmouth Formation Matawan Formation Magothy Formation Raritan Formation	Mount Laurel Sand Matawan Group: Marshalltown Formation Englishtown Formation Merchantville Formation Magothy Formation	Tinton Sand Red Bank Sand Navesink Formation Mount Laurel Sand Wenonah Formation Marshalltown Formation Englishtown Formation Woodbury Clay Merchantville Formation Magothy Formation	Marine Cretaceous sediments	Magothy aquifer
Cretaceous	Lower Cretaceous	Potomac Group: Patapsco Formation Patuxent Formation	Potomac Group: Patapsco Formation Arundel Formation Patuxent Formation	Potomac Formation	Raritan Formation and Potomac Group undifferentiated	Nonmarine Cretaceous sediments	Nonmarine Cretaceous aquifer

EXPLANATION

-------- No name assigned

(hatched) Section not present

MARINE CRETACEOUS SEDIMENTS

Marine sediments of Late Cretaceous age overlie the nonmarine Cretaceous beds. The Magothy Formation, although included as the basal marine unit (table 1), actually represents a transition between marine and nonmarine deposition. Lithologically, the Magothy resembles the light-colored lignitic quartz sand of the nonmarine Cretaceous sediments. It is distinguished from these sand beds, however, by its widespread lateral continuity. The Magothy Formation represents deposition during the lagoonal or estuarine phase of the Upper Cretaceous marine encroachment. Marine Cretaceous sediments consisting of dark-gray and greenish-gray clay, silt, and sand overlie the Magothy. Glauconite, a secondary mineral indicative of a deep-water marine environment, is commonly present and produces the greenish color in these sediments.

The contact between the Magothy Formation and the underlying nonmarine sediments is generally marked by brightly colored clay in the nonmarine sediments. Also, on gamma-ray logs the contact can generally be identified because the high level of natural radioactivity of the glauconitic marine beds distinguishes them from the underlying nonmarine sediments.

EOCENE AND PALEOCENE SEDIMENTS

Marine sediments of Eocene and Paleocene age overlie the Cretaceous deposits. The sediments consist of dark-gray and greenish-gray clay, silt, and sand. Glauconite is present in all the deposits and is commonly the principal constituent of the sandy units. The Eocene and Paleocene sediments are distinguished from the lithologically similar marine Cretaceous sediments on the basis of their generally greater concentration of glauconite.

The contact between the Eocene and Paleocene and the Cretaceous sediments is marked by a highly radioactive zone that produces a distinctive pattern on gamma-ray logs. Minard, Owens, Sohl, Gill, and Mello (1969, p. H25) noted a zone of increased radiation at the base of the Paleocene in New Jersey and believed that the more intense radiation was due to a concentration of phosphatic material. Bentonite, which has been reported by Jordan and Adams (1962) from this stratigraphic position in a well near Dover, Del., may also be the source of the radioactive elements.

MIOCENE SEDIMENTS

Marine Miocene sediments disconformably overlie the Eocene and Paleocene sequence. The Miocene sediments consist of light- to medium-gray quartz sand and medium- to dark-gray silt and clay. Shells and shell fragments are found throughout the deposits, and some beds are composed almost entirely of shell debris. Diatomaceous material is common, particularly in the basal part of the Miocene. The abundance of shell material and the absence of significant amounts of glauconite are characteristics of the Miocene sediments and are indicative of marine deposition in relatively shallow water.

On gamma-ray logs the contact between the Miocene and the underlying Eocene and Paleocene sediments is marked by a sharp change in count rate owing to the lower level of natural radioactivity of the Miocene sediments. Also, the shell beds in the Miocene are marked by extremely high resistivities on electric logs, and this response further distinguishes these sediments from the underlying deposits.

QUATERNARY SEDIMENTS

A mantle of Quaternary sediments overlies the truncated surfaces of the older unconsolidated deposits (fig. 26). The Quaternary sediments are composed of two principal lithologic types: (1) fluvial (river) sand and gravel and (2) littoral and shallow-marine clay, silt, and sand. The fluvial deposits are of Pleistocene age and are composed of beds of tan and brown iron-stained sand and gravel, which represent the coarse sediment loads of braided and coalescing streams. The fluvial deposits make up the bulk of the Quaternary sediments in the northern part of the peninsula. South of about the latitude of Easton, Md., the fluvial sediments begin to grade into the littoral and shallow-marine beds. These beds consist of tan and gray sand along with some layers of clay and silt. South of about Salisbury, Md., they are the principal Quaternary deposits present.

Holocene deposition has been significant only in coastal areas and possibly in the marsh areas along the lower part of the Chesapeake Bay. The Holocene deposits are lithologically and genetically similar to the Pleistocene littoral and shallow-marine sediments upon which they generally rest.

Where the veneer of coarse-grained Quaternary deposits overlies fine-grained or glauconitic Tertiary and Cretaceous sediments, the interbed contrasts are strong enough so that the contact can be readily identified on geophysical logs. Where the deposits overlie coarse-grained Tertiary deposits, the contact can usually be distinguished on logs because of the "cleaner" nature of the Quaternary sediments—that is the relative scarcity of interstitial clay and silt. In some places in extreme northern parts of the peninsula, where the Quaternary sediments overlie coarse-grained Cretaceous sediments, the contact is difficult to determine on geophysical logs.

HYDROLOGY

Precipitation on the peninsula is the source of most of the fresh water available for use there. Unlike many localities, the peninsula does not significantly benefit from streamflow that originates outside the area. Small additional amounts of water are available for use from the deeper aquifers that are recharged on the western shore of Chesapeake Bay and contain fresh water under the peninsula. For all practical purposes, however, the perennial amount of water available on the peninsula is local precipitation.

The average annual precipitation on the peninsula during 1949–65 was 43 inches per year. This value was determined by planimetering an isohyetal map (fig. 3) adapted from Mather (1969). The amount of precipitation, depending on location, ranged from less than 40 inches to more than 47 inches per year. The period 1949–65 was chosen for use because it is concurrent with most of the available streamflow records on the peninsula.

Precipitation not only varies with location but also with time. Figure 4 shows the variability of yearly precipitation at a selected location on the peninsula. The pattern of monthly precipitation at this same site is shown in figure 5.

Precipitation upon the peninsula is dissipated as evapotranspiration, overland flow, and infiltration into the ground. Precipitation on either impervious or water-saturated surficial deposits flows overland into streams, lakes, or ponds. Most precipitation retained by vegetal surfaces evaporates and returns directly to the atmosphere. Some precipitation on the land also evaporates, but a part infiltrates into the ground if the soil is permeable and unsaturated. The first demand for the infiltrating water is that of the soil to replace soil moisture that has been depleted, primarily by vegetation and direct-surface evaporation. After soil-moisture requirements are met, the remaining water percolates slowly downward through the pore spaces in the earth materials underlying the soil zone until it reaches the ground-water reservoir. The water then moves slowly downgradient in the reservoir and discharges into streams, lakes, bays, and the ocean, and eventually returns to the atmosphere by evaporation.

CHEMISTRY OF THE WATER

Water changes in chemical character as it moves from the atmosphere over and through the ground. The factors producing these changes may be summarized as follows: Solution of gaseous and particulate matter by atmospheric precipitation, solution of mineral matter by water flowing over and through the ground, reaction of dissolved chemical species with mineral matter, and mixing of fresh and saline water.

Although chemical analyses of precipitation were not obtained for the Delmarva Peninsula, considerable data have been collected for nearby areas (Gambell and Fisher, 1966; Fisher, 1968; and Pearson and Fisher, 1971). The principal chemical species dissolved in rainfall are sodium, sulfate, chloride, and nitrate. The sulfate concentration of precipitation on the peninsula is probably between 2 and 4 mg/l (milligrams per liter). The concentration of each of the other constituents is probably less than 1 mg/l, although sodium and chloride concentrations may be significantly higher in coastal areas because of sea spray. The pH of precipitation in equilibrium with atmospheric carbon dioxide is about 5.6 (Hem, 1970, p. 91). Solution of atmospheric sulfur dioxide reinforces the hydrogen-ion content, and, as a result of man's activities, present-day precipitation may have pH values of less than 5 (F. J. Pearson, written commun., 1972).

The chemistry of shallow ground water is controlled in large part by the chemistry of atmospheric precipitation. The similarity of precipitation and shallow ground water (analysis 1) is apparent in figure 6. On the average, about two-thirds of the precipitation returns directly to the atmosphere by evapotranspiration, so that the total solute concentration of water infiltrating the ground is about three times greater than that of precipitation. Thus, the water reaching the ground-water reservoir contains 15–20 mg/l dissolved solids.

Changes occur in the chemical character of ground water as it moves through the ground-water reservoir and reacts with mineral matter with which it comes in contact. The nature of these changes for the major anions and cations is indicated by the arrows in figure 6. For illustration, data are presented in figure 6 from four wells located approximately along a ground-water flow path in one of the aquifers in the Miocene sediments. Additional analyses from wells on other flow paths in the same aquifer were also used to help define the direction of chemical change. Similar patterns of change occur in all the aquifers underlying the peninsula.

The principal reactive mineral dissolved by ground water in the sediments underlying the Delmarva Peninsula is calcite (calcium carbonate often with minor amounts of associated magnesium). Calcite occurs as shell material in the marine sediments and also as secondary mineralization in the marine and,

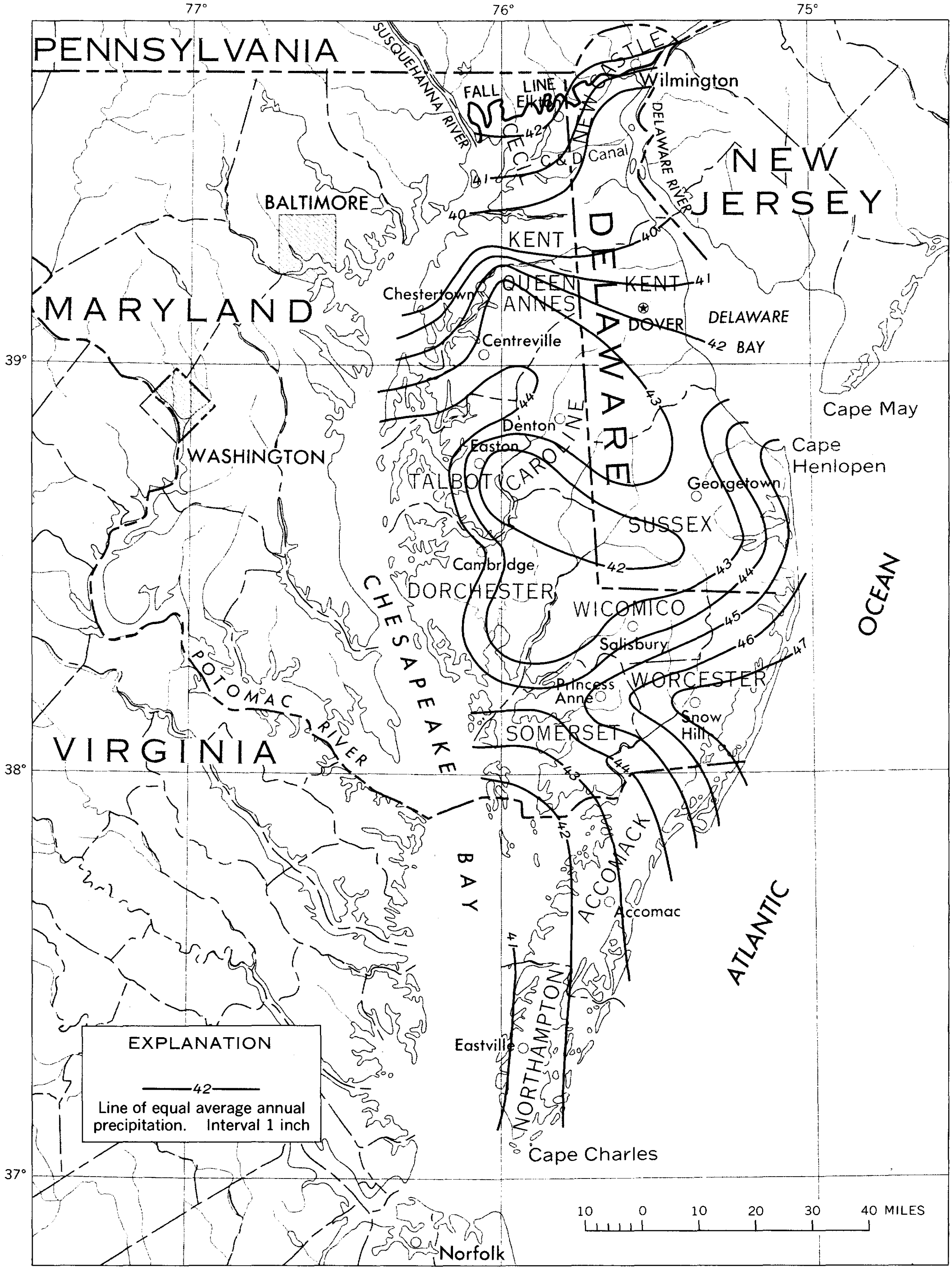


FIGURE 3.—Average annual precipitation, 1949–65 (after Mather, 1969).

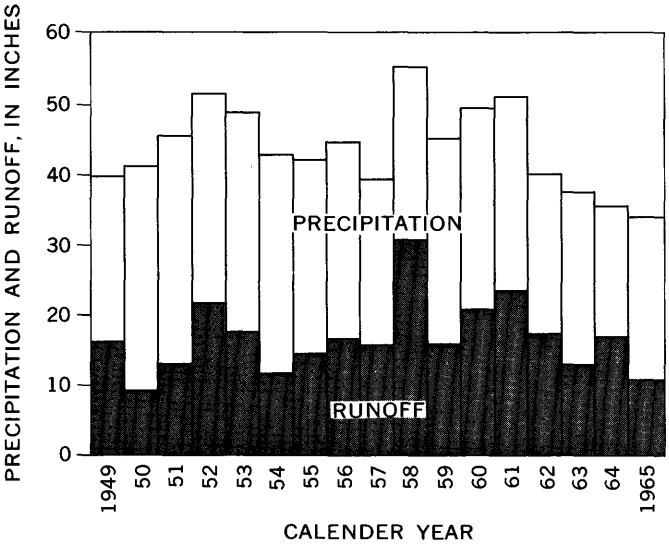


FIGURE 4.—Annual precipitation at Bridgeville, Del., and runoff for Nanticoke River near Bridgeville, Del. (site 86).

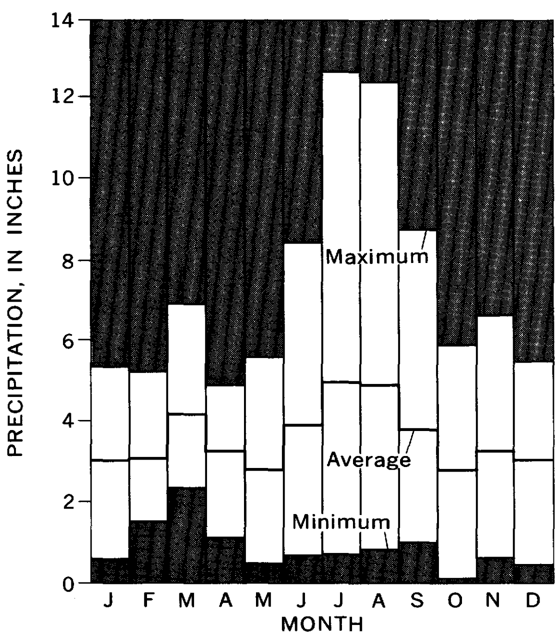


FIGURE 5.—Monthly precipitation at Bridgeville, Del., 1949–65.

to a far lesser extent, in the nonmarine sediments. Solution of calcite causes ground water to become enriched with calcium and bicarbonate, and the chemical evolution of the water trends toward the calcite end point (fig. 6). The dissociation of calcite to calcium and bicarbonate ions raises the pH of the water by using up hydrogen ions. At some point, generally when calcium constitutes about 90 percent of the total cations in the water, calcium ions in solution are exchanged for sodium ions held on some mineral surfaces in the sediments. It is known that the ion-exchange capacity of sediments increases with increasing pH (Robinson, 1962, p. 79). Therefore, the downgradient increase in the pH of the ground water may possibly initiate the ion-exchange process.

Because of the removal of calcium by the exchange reaction, ground water is generally not in equilibrium with the available calcite (Back, 1966, p. 40), and calcite solution continues to occur. Bicarbonate remains the dominant anion, but, as the exchange reaction continues, sodium gradually replaces calcium as the dominant cation (analyses 2 and 3, fig. 6).

Saline sodium chloride water exists in the deeper downgradient part of all the aquifers. As the circulating fresh ground water mixes with this water, it becomes enriched with sodium and chloride (analysis 4, fig. 6). Sodium becomes increasingly dominant, and the addition of chloride ions decreases the relative percentage of bicarbonate. Magnesium, potassium, and sulfate may also be added to ground water as a result of mixing with the deep saline water. According to Back (1966, p. 9), the origin of the saline water may be due to one or more of the following processes: Retention of ions from sea water trapped in the sediments at the time of deposition, intrusion of sea water after deposition, concentration of ions by solution of minerals, and concentration of ions by filtration through clay membranes.

The concentration of dissolved iron in ground water is controlled by the Eh (oxidation-reduction potential) and pH of the solution (Hem, 1970, fig. 15). On the Delmarva Peninsula iron concentrations are generally higher in recharge areas and tend to decrease downgradient. The pH of ground water in recharge areas is almost always between 5 and 7. Within this range, ferric iron is insoluble, and the solubility of ferrous iron increases with decreasing Eh. The highest concentrations of dissolved iron occur in the recharge areas of aquifers composed of nonmarine sediments (or in the recharge areas of marine aquifers overlain by saturated nonmarine sediments). Apparently, Eh values are low owing to the oxidation of lignite or peat commonly contained in the nonmarine sediments.

As ground water with dissolved ferrous iron moves downgradient, Eh decreases, bicarbonate is brought into solution, and pH increases. When reducing conditions are established in the aquifer and pH values reach about 8 or more, the iron precipitates as ferrous carbonate (siderite). The concentration of dissolved iron in downgradient water is, therefore, generally low.

Fluoride concentrations may also be controlled by pH. Fluoride occurs in minor amounts in accessory

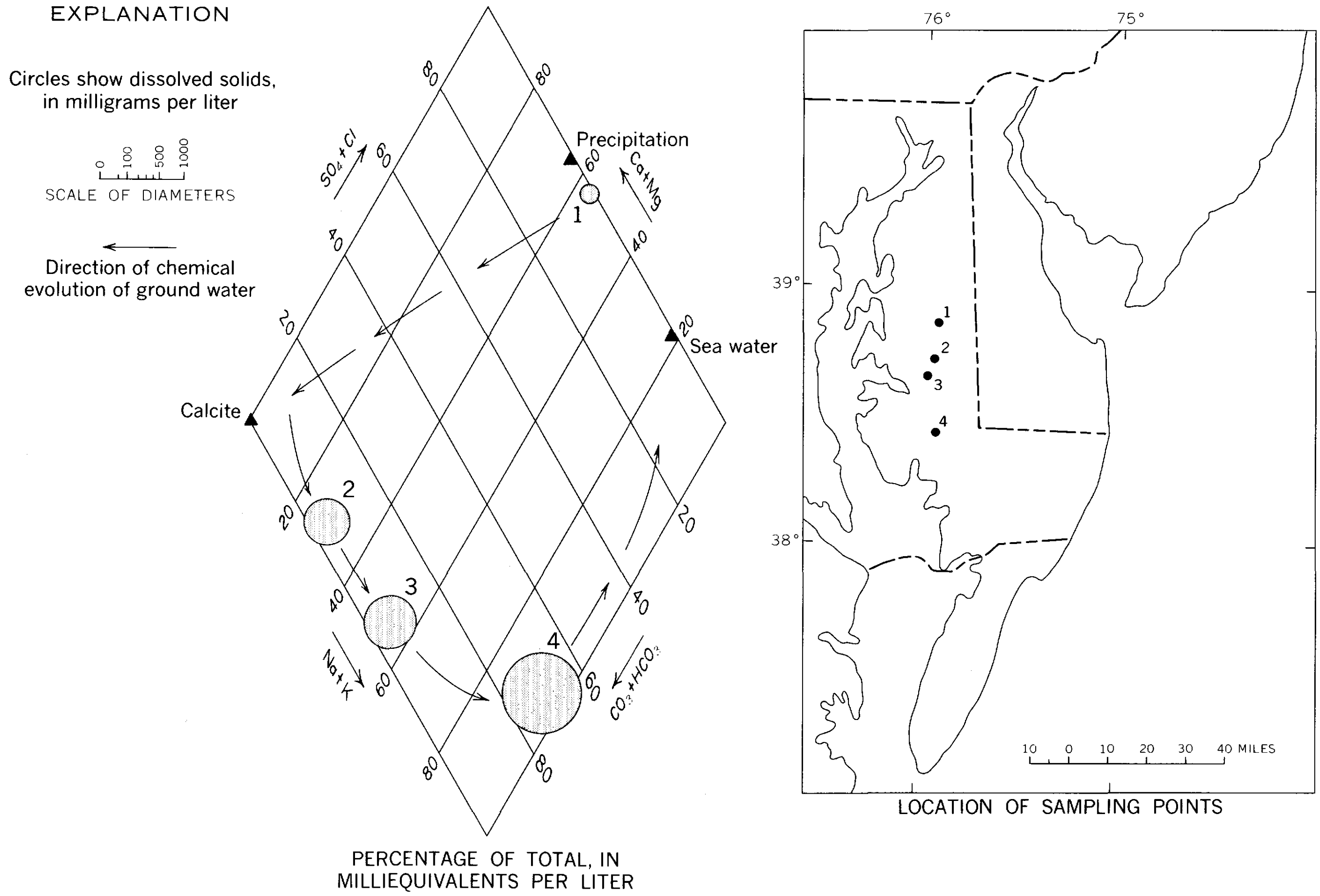


FIGURE 6.—Chemical evolution of water in a typical aquifer.

minerals in most sediments. The minerals have a low solubility, and fluoride concentrations in ground water are generally less than 1 mg/l. In water that has a high pH, hydroxide ions may be exchanged for fluoride on some mineral surfaces (Hem, 1970, p. 178). This exchange reaction may explain the relatively high concentrations of fluoride (1–5 mg/l) in the downgradient part of several aquifers where the pH of ground water is greater than 8. The downgradient increase in fluoride concentration may also be related to changes in the mineralogy of the sediments.

Silicate minerals constitute the bulk of the sediments underlying the peninsula. The concentration of dissolved silica in ground water may be controlled by the structure of the minerals that are available for solution although the exact nature of the control is not understood (Hem, 1970, p. 108). Of the silicate minerals in the sediments underlying the peninsula, quartz is the least soluble silicate mineral, clay minerals are intermediate in solubility, and amorphous silica (such as diatomaceous material) is the most soluble. Maximum concentrations of dissolved silica range from 20 mg/l in clay-poor quartz aquifers to 60 mg/l in clayey sand associated with diatomaceous sediments. Silica concentrations decrease in the downgradient parts of several aquifers, but the controlling factors are not apparent.

Nitrogen does not occur naturally in any of the sediments on the peninsula. It is, however, a common constituent of organic compounds. Nitrate (NO_3) is the end product of the decomposition of organic nitrogen. Nitrate is introduced into the ground by nitrogen-fixing plants and bacteria, plant debris, animal wastes, and organic and most inorganic fertilizers. Thus, the source of nitrate is shallow, either from the soil or from shallow waste-disposal systems, and significant concentrations of nitrate are limited to the shallow parts of the aquifers.

Relatively low concentrations of nitrate, perhaps 5–10 mg/l, may result from the natural decomposition of plant tissue or from the activity of certain bacteria. Higher concentrations of nitrate are usually indicative of manmade pollution, either from fertilizers or from waste disposal. The association of nitrate with high sulfate concentrations in the recharge areas of several aquifers suggests that much of the nitrate may be derived from fertilizers.

The temperature of ground water is primarily related to the internal heat of the earth, air temperature, and depth below land surface. Ground water in the upper 40–50 feet of the saturated zone is strongly influenced by seasonal change in air temperature. The annual fluctuation of ground-water temperature may be as much as 10° Celsius (centigrade) in the upper 10 or 20 feet and about 1°C at 50 feet. Water at depths between about 50 and 120 feet below land surface has a fairly constant temperature, which is generally 1½°–3°C higher than the mean annual air temperature. On the Delmarva Peninsula the mean annual air temperature ranges from about 12½° to 15½°C. At depths below about 120 feet, ground-water temperatures begin to increase. Temperature gradients measured at three wells on the peninsula are shown in figure 7.

The relative proportions of ground water (base flow) and overland flow largely determine the chemical character of water in streams. The chemical character of base flow and overland flow for two streams are shown in figure 8. For both streams the data

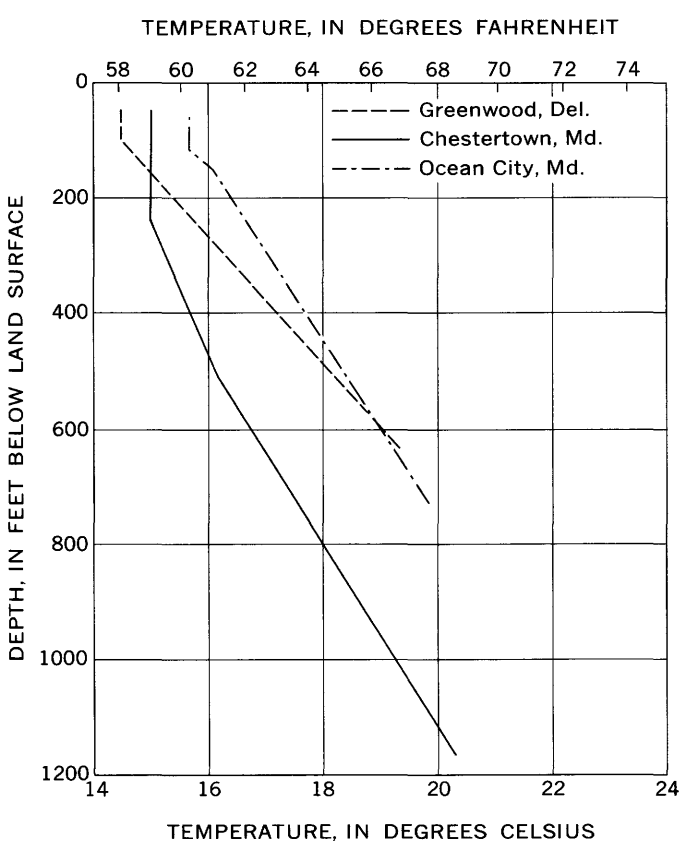


FIGURE 7.—Relation between ground-water temperature and depth.

shown are for the highest (overland flow) and lowest (base flow) rates of discharge at which samples were collected. Base flow at site 119 is essentially the product of the solution of calcite by a water having an initial composition similar to that of precipitation. The base flow at this site resembles ground water that has moved along relatively short flow paths (fig. 6). In contrast, base flow at site 86 is a mixture of a shallow ground water and a deeper more mineralized sodium bicarbonate or sodium chloride water; the fairly low dissolved-solids content, however, indicates that the bulk of the base flow is shallow dilute ground-water discharge. Except for a higher bicarbonate content, overland flow at both sites is similar in chemical composition to precipitation. The added bicarbonate may come from the solution by storm runoff of calcite in the upper part of the soil zone or from the presence of small amounts of ground-water discharge in the streams during high-flow periods.

Because it is in contact with the atmosphere, surface water is affected by short-term fluctuations of air temperature. In general, surface-water temperatures are equivalent to air temperatures, except that ground-water inflow tends to increase streamflow temperatures in the winter and decrease them in the summer.

SURFACE WATER

The Delmarva Peninsula is flat in the coastal and nearshore areas, gently rolling in some inland areas, and fairly rugged in parts of Cecil County, Md. Surface elevations range from sea level to about 310 feet above sea level. Most of the land area, however, is less than 80 feet above mean sea level.

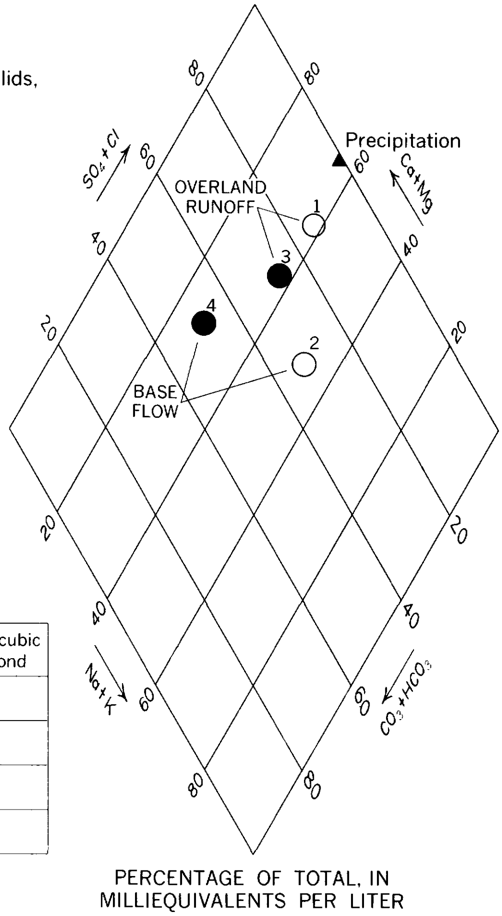
Surface water in the western and central parts of the peninsula drains to the Chesapeake Bay, whereas that in the eastern part drains to the Delaware River and Bay and to the ocean (fig. 1). None of the rivers entirely within the project area drain more than 200 square miles at the point where they become tidal; most of the eastward-flowing streams do not drain more than 25 square miles above tide effect. The westward-flowing streams in the northern part of the peninsula have tidal flow almost to the headwaters and for this reason have cross-sectional areas much larger than would be expected in such small basins. In affect, these channels are landward extensions of Chesapeake Bay.

Numerous manmade changes have altered the natural drainage. Extensive ditching has been done in many parts of the peninsula to make the land suitable for farming. In low-lying areas, interbasin connections in the headwaters of streams are not un-

EXPLANATION

Circles show dissolved solids, in milligrams per liter

0 100 500 1000
SCALE OF DIAMETERS



Analysis	Site	Discharge, in cubic feet per second
1	86	869
2	86	6
3	119	433
4	119	10

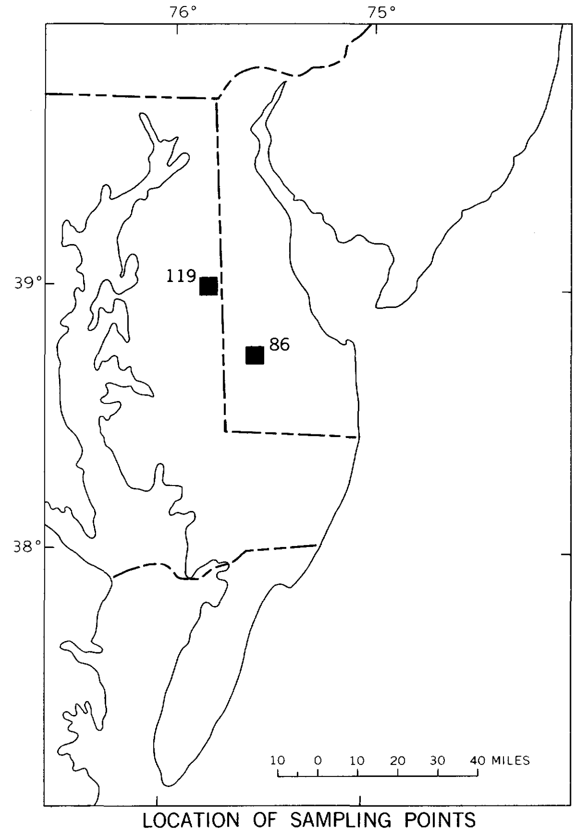


FIGURE 8.—Chemical character of surface water.

usual. Many stream channels have been straightened and deepened, causing them to discharge runoff more rapidly.

Streams have not been appreciably utilized for water supply on the peninsula but are, nevertheless, potential sources of fresh water. Collection and analysis of streamflow records are necessary to determine the capability of streams to provide adequate quantities of water during low flow, the quantity of water perennially available, and the rate and volume of runoff during high flow.

AVAILABILITY OF DATA

An important characteristic of streamflow is its variability with time and location. Many years ago, the recognition of this fact was the basis for a program to measure and record on a systematic and continuous basis the flow of selected streams and rivers.

The streamflow-measurement program on the Delmarva Peninsula began late compared with those of other parts of the country because the peninsula depends almost entirely on ground water for supply. In 1929 the collection of streamflow records was started on Beaverdam Creek near Salisbury, Md., and, except for a few periods between 1933 and 1936, the record has been collected continuously up to the present time (1972). Beginning in 1943, other stations were added to and some were dropped from the streamflow-measurement network. At present, daily records of streamflow for a period of at least 5 consecutive years are available at 36 locations. Nine of these daily-record gaging stations are along the Fall Line in Maryland and Delaware and record the flow of streams that originate outside the study area. These streams flow into the Delaware River and Chesapeake Bay just below the Fall Line. Streamflow records from these nine stations were used, however, in developing some of the relations shown in this report.

To obtain a broad geographic coverage for the low-flow frequency characteristics of streams on the peninsula, the data from the daily-record gaging stations were supplemented by measurements made at 25 partial-record stations and 120 miscellaneous sites.

Table 2 lists the streamflow sites on the peninsula for which streamflow characteristics are given in this report. The station numbers in the first column are permanent nationwide numbers assigned by the Geological Survey to stations at which streamflow data are collected on a recurrent basis. The numbers in the second column are index numbers for locating sites on plate 1. Both numbering systems are based on a downstream-order sequence.

TABLE 2.—*Streamflow-measuring sites and selected low-flow frequency characteristics of streams*

Class of station: D, daily-record gaging station; P, partial-record gaging station; M, miscellaneous measuring site.

Drainage area: [a], approximately.

Period of record: *, no data for 1 or more years during period; **, operated as daily-record station.

Type of data: L, low-flow frequency; H, high-flow frequency; D, flow duration; S, draft storage.

Annual low flow: [b], minimum flow observed in cubic feet per second per square mile (no usable relation found with daily-record station); [R], affected by regulation.

Daily-record station used for correlations: [c], partial-record station; [d], miscellaneous measuring site.

Station No.	Index No. (pl. 1)	Station name	Class of station	Latitude	Longitude	Drainage area (sq mi)	Average discharge period of record (cfs)	Type of data included in report	Period of record (water years)	Annual low flow, in cubic feet per second per square mile, for 7 consecutive days and for indicated recurrence interval, in years: 2-year	10-year	20-year	Daily-record station used for correlation
Delaware River basin													
01477400	1	South Branch Naaman Creek near Claymont, Del.	P	39°49'00"	75°29'40"	3.83	-----	L	*1955–69	0.10	0.03	---	01480000
01477800	2	Shellpot Creek at Wilmington, Del.	D	39°45'39"	75°31'10"	7.46	9.07	L H D	1945–67	.07	.03	0.03	--------
	3	West Branch near Newark, Del.	M	39°39'20"	75°47'00"	[a]4.1	-----	L	1968–70	[b](.12)	---	---	--------
01478000	4	Christina River at Coochs Bridge, Del.	D	39°38'16"	75°43'46"	20.5	25.3	L H D S	1943–67	.18	.06	.04	--------
	5	Muddy Run at Glasgow, Del	M	39°36'36"	75°44'48"	[a]5.3	-----	L	1968–70	[b](.05)	---	---	--------
01478500	6	White Clay Creek above Newark, Del.	D	39°42'50"	75°45'35"	66.7	72.1	L H D S	1952–59, 1962–67	.25	.11	.09	--------
	7	Pike Creek near Roseville Park, Del.	M	39°42'24"	75°41'43"	[a]5.9	-----	L	1968–70	.41	.19	---	01478000
01479000	8	White Clay Creek near Newark, Del.	D	39°42'00"	75°41'10"	87.8	104	L H D S	1932–36, 1944–57, 1960–67	.36	.14	.10	--------
01479500	9	Mill Creek at Stanton, Del	P	39°42'50"	75°40'00"	12.4	-----	L	*1955–69	.19	.06	---	01478500
01480000	10	Red Clay Creek at Wooddale, Del.	D	39°45'52"	75°38'08"	47.0	60.3	L H D S	1943–67	.34	.17	.13	--------
01480100	11	Little Mill Creek at Elsmere, Del.	D	39°44'05"	75°35'14"	6.70	8.99	L	1963–69	.25	.09	---	01480000
01481500	12	Brandywine Creek at Wilmington, Del.	D	39°46'10"	75°34'20"	314	436	L H D S	1946–67	.33	.21	.18	--------
01482300	13	Red LionCreek at Red Lion, Del.	P	39°36'20"	75°39'55"	3.20	-----	L	*1955–69	.09	.03	---	01477800
	14	Drawyer Creek tributary near Odessa, Del.	M	39°27'45"	75°41'17"	[a]4.7	-----	L	1968–70	.45	.26	---	01493500
01483150	15	Wiggins Millpond Outlet near Townsend, Del.	P	39°24'12"	75°42'16"	3.82	-----	L	*1957–69	.60	.31	---	01493500
01483200	16	Blackbird Creek at Blackbird, Del.	D	39°21'58"	75°40'10"	3.85	4.25	L H D	1957–67	.10	0	---	--------
	17	Sawmill Branch near Blackbird, Del.	M	39°21'38"	75°37'19"	[a]3.4	-----	L	1968–70	.06	0	---	01489000
Smyrna River basin													
01483300	18	Providence Creek near Clayton, Del.	P	39°18'05"	75°38'28"	11.8	-----	L	*1955–69	0.25	0.14	---	01493000
01483350	19	Mill Creek at Smyrna, Del	P	39°17'09"	75°36'45"	4.77	-----	L	*1955–69	.29	.19	---	01493000
Leipsic River basin													
01483500	20	Leipsic River near Cheswold, Del.	D	39°13'58"	75°37'57"	9.35	10.7	L H D S	1932–33, 1943–67	0.32	0.20	0.18	--------
St. Jones River basin													
01483650	21	Fork Branch at Dupont, Del	P	39°11'56"	75°34'40"	7.50	-----	L	*1955–69	0.01	0	---	01483200
01483680	22	Maidstone Branch at Dupont, Del.	P	39°11'18"	75°34'04"	17.3	-----	L	*1955–69	.05	.01	---	01483700
01483700	23	St. Jones River at Dover, Del	D	39°09'49"	75°31'10"	31.9	30.0	L D	**1958–67	.04	.01	---	--------
	24	Tidbury Creek at Rising Sun, Del.	M	39°05'53"	75°31'43"	[a]8.6	-----	L	1968–71	[b](.05)	---	---	--------
Murderkill River basin													
01484000	25	Murderkill River near Felton, Del.	D	38°58'33"	75°34'03"	13.6	16.8	L D	**1960–67	0.20	0.10	---	--------
01484020	26	Browns Branch near Houston, Del.	P	38°57'31"	75°30'33"	12.4	-----	L	1955–69	.37	.21	---	01484000
01484040	27	Hudson Branch near Canterbury, Del.	P	39°01'56"	75°31'30"	8.40	-----	L	*1955–60	.52	.39	---	01488500
01484050	28	Pratt Branch near Felton, Del.	P	39°00'37"	75°31'46"	3.29	-----	L	*1955–69	.21	.12	---	01484100
01484060	29	Double Run near Magnolia, Del.	P	39°03'16"	75°29'43"	5.68	-----	L	*1955–69	.32	.19	---	01484000
Mispillion River basin													
01484100	30	Beaverdam Branch at Houston, Del.	D	38°54'20"	75°30'49"	2.83	3.47	L D	**1958–67	0.21	0.11	---	--------
	31	Tantrough Branch near Milford, Del.	M	38°53'22"	74°29'27"	[a]4.2	-----	L	1968–71	.33	.12	---	01484500

TABLE 2.—*Streamflow-measuring sites and selected low-flow frequency characteristics of streams*—Continued

Station No.	Index No. (pl. 1)	Station name	Class of station	Latitude	Longitude	Drainage area (sq mi)	Average discharge period of record (cfs)	Type of data included in report	Period of record (water years)	Annual low flow, in cubic feet per second per square mile, for 7 consecutive days and for indicated recurrence interval, in years: 2-year	10-year	20-year	Daily-record station used for correlation
		Cedar Creek basin											
01484200	32	Cedar Creek near Lincoln, Del.	P	38°51'03''	75°25'05''	7.21	-----	L	*1955–69	0.85	0.47	---	01484500
		Broadkill River basin											
01484300	33	Sowbridge Branch near Milton, Del.	D	38°48'51''	75°19'39''	7.08	9.76	L H D S	1956–67	0.52	0.27	---	--------
01484240	34	Pemberton Branch near Milton, Del.	P	38°46'26''	75°20'29''	6.68	-----	L	*1955–69	.45	.18	---	01484300
01484270	35	Beaverdam Creek near Milton, Del.	P	38°45'41''	75°16'03''	6.10	-----	L	1955–69	1.16	.77	---	01484300
		Love Creek basin											
	36	Bundicks Branch near Jimtown, Del.	M	38°43'17''	75°12'23''	[a]5.5	-----	L	1968–71	0.25	0.15	---	[c]01484270
		Herring Creek basin											
	37	Unity Branch at Fairmount, Del.	M	38°39'45''	75°13'21''	[a]3.3	-----	L	1968–71	0.06	0	---	01484500
		Indian River basin											
	38	Deep Branch near Mt. Joy, Del.	M	38°39'45''	75°17'58''	[a]6.4	-----	L	1968–71	0.06	0.02	---	01484500
01484500	39	Stockley Branch at Stockley, Del.	D	38°38'19''	75°20'31''	5.24	6.95	L H D S	1943–67	.31	.11	0.08	--------
	40	Shoals Branch near Millsboro, Del.	M	38°34'37''	75°20'38''	[a]7.2	-----	L	1968–71	.19	.06	---	01484500
	41	Phillips Ditch near Millsboro, Del.	M	38°34'03''	75°20'24''	[a]3.8	-----	L	*1968–71	0	---	---	--------
	42	Wartons Branch near Millsboro, Del.	M	38°33'42''	75°16'30''	[a]5.9	-----	L	*1968–71	0	---	---	--------
01484550	43	Pepper Creek at Dagsboro, Del.	P	38°32'50''	75°14'40''	8.78	-----	L	1955–69	.14	.05	---	01484500
	44	Blackwater Creek near Clarksville, Del.	M	38°32'43''	75°09'49''	[a]4.5	-----	L	1968–69	0	---	---	--------
		Dirickson Creek basin											
	45	Bearhole Ditch at Bunting, Del.	M	38°28'17''	75°09'22''	[a]6.2	-----	L	1968–71	0.11	0.02	---	01484500
		St. Martin River basin											
	46	Middle Branch at Showell, Md	M	38°24'02''	75°12'45''	[a]3.7	-----	L	1968–71	0	---	---	01485500
	47	Birch Branch at Showell, Md	M	38°24'33''	75°12'48''	[a]6.5	-----	L	1968–71	.03	0.02	---	01485500
		Gargathy Creek basin											
	48	Assawoman Creek near Temperanceville, Va.	M	37°53'38''	75°31'45''	[a]2.8	-----	L	1969–70	0.04	0	---	01484800
	49	Whites Creek at Mutton Hunk, Va.	M	37°47'07''	75°35'27''	[a]1.8	-----	L	1968–70	.22	.06	---	01486000
		Folly Creek basin											
	50	Ross Branch near Accomac, Va.	M	37°41'50''	75°40'06''	[a]1.2	-----	L	1968–70	0.08	0	---	01486000
		Finney Creek basin											
	51	Nickawampus Creek near Oak Grove Church, Va.	M	37°38'11''	75°43'28''	[a]1.2	-----	L	1968–70	0.17	0.08	---	01484800
		Mattawoman Creek basin											
	52	Mattawoman Creek at Reedtown, Va.	M	37°22'40''	75°55'19''	[a]0.3	-----	L	1968–70	[b](0.60)	---	---	--------
		Nassawadox Creek basin											
01484800	53	Guy Creek near Nassawadox, Va.	D	37°30'08''	75°52'22''	1.72	-----	L	**1964–69	0.06	0	---	01670000
	54	Nassawadox Creek near Nassawadox, Va.	M	37°31'31''	75°52'37''	[a]4.2	-----	L	1968–70	[b](.05)	---	---	--------
		Occohannock Creek basin											
	55	Occohannock Creek near Painter, Va.	M	37°34'25''	75°48'27''	[a]2.6	-----	L	1968–70	0.19	0.04	---	01484800
		Pungoteague Creek basin											
	56	Pungoteague Creek at Locksville, Va.	M	37°40'23''	75°45'57''	[a]1.1	-----	L	1968–70	0	---	---	01486000
	57	Taylor Creek near Pungoteague, Va.	M	37°37'20''	75°48'29''	[a]2.6	-----	L	1968–70	.04	0	---	01486000

TABLE 2.—*Streamflow-measuring sites and selected low-flow frequency characteristics of streams*—Continued

Station No.	Index No. (pl. 1)	Station name	Class of station	Latitude	Longitude	Drainage area (sq mi)	Average discharge period of record (cfs)	Type of data included in report	Period of record (water years)	Annual low flow, in cubic feet per second per square mile, for 7 consecutive days and for indicated recurrence interval, in years: 2-year	10-year	20-year	Daily-record station used for correlation
		Hunting Creek basin											
	58	Lee Mont Branch at Lee Mont, Va.	M	37°46'33"	75°40'57"	[a]2.1	-----	L	1968–70	0.05	0	---	01484800
		Bagwell Creek basin											
	59	Katy Young Branch near Parksley, Va.	M	37°47'51"	75°40'02"	[a]2.7	-----	L	1968–70	0.07	0	---	01484800
		Muddy Creek basin											
	60	Bethel Branch near Bloxom, Va.	M	37°50'53"	75°36'13"	[a]2.7	-----	L	1968–70	0.07	0.04	---	01485500
		Pocomoke River basin											
	61	North Fork Green Run near Whitesville, Del.	M	38°27'07"	75°22'41"	[a]2.6	-----	L	1968–71	0.08	0.04	---	01485000
	62	South Fork Green Run near Willards, Md.	M	38°25'50"	75°22'36"	[a]5.7	-----	L	1968–71	.02	0	---	01485000
01485000	63	Pocomoke River near Willards, Md.	D	38°23'20"	75°19'30"	60.5	65.5	L H D S	1949–67	.10	.04	0.03	--------
	64	Burnt Mill Branch near Pittsville, Md.	M	38°24'55"	75°24'25"	[a]4.2	-----	L	1968–71	0	---	---	01485000
	65	Aydylotte Branch at Pittsville, Md.	M	38°24'02"	75°24'52"	[a]4.1	-----	L	1968–70	0	---	---	--------
	66	Burnt Mill Branch at Willards, Md.	M	38°23'20"	75°20'15"	18.1	-----	L	1950–53, 1969–71	0	---	---	01485000
	67	Adkins Race at Powellville, Md.	M	38°19'53"	75°22'25"	18.7	-----	L	1950–53, 1969, 1971	.02	.01	---	01485500
	68	Tilghman Race near Powellville, Md.	M	38°16'55"	75°22'45"	[a]5.8	-----	L	1968–71	.02	0	---	01485500
01485500	69	Nassawango Creek near Snow Hill, Md.	D	38°13'45"	75°28'20"	44.9	50.0	L H D S	1949–67	.06	.03	.03	--------
	70	Pollitts Branch at West, Md	M	38°12'53"	75°35'27"	[a]2.3	-----	L	1968–71	0	---	---	01485500
	71	Wagram Swamp Branch near Pocomoke City, Md.	M	38°01'52"	75°31'55"	[a]3.3	-----	L	1968–70	0	---	---	01485500
		Manokin River basin											
01486000	72	Manokin Branch near Princess Anne, Md.	D	38°12'50"	75°40'18"	[a]5.8	3.92	L H D	1951–67	0.02	0	---	--------
	73	Loretto Branch at Princess Anne, Md.	M	38°12'57"	75°41'28"	[a]4.0	-----	L	1968–71	.07	.05	---	01486000
	74	Jones Creek near Princess Anne, Md.	M	38°10'29"	75°41'06"	[a]3.2	-----	L	1970–71	0	---	---	--------
		Wicomico River basin											
	75	Leonard Pond Run near Delmar, Md.	M	38°25'24"	75°33'53"	13.4	-----	L	1950–51, *1963–71	0.13	0.07	---	01486500
	76	Connelly Mill Branch near Delmar, Md.	M	38°25'59"	75°35'41"	3.66	-----	L	1964, 1968–71	.27	.14	---	01484500
	77	Little Burnt Branch near Salisbury, Md.	M	38°24'49"	75°36'04"	3.39	-----	L	1964, 1968–71	.26	.18	---	[d]78
	78	North Prong Wicomico River near Salisbury, Md.	M	38°24'32"	75°35'42"	24.8	-----	L	*1963–71	.60	.44	---	01487000
	79	Middle Neck Branch near Salisbury, Md.	M	38°23'18"	75°33'01"	[a]2.1	-----	L	1964, 1968–71	.29	.19	---	01486500
01486500	80	Beaverdam Creek near Salisbury, Md.	D	38°21'05"	75°34'11"	19.5	23.2	L H D S	1930–32, 1939–67	.28	[E].07	[E]0.04	--------
	81	Tonytank Creek at Fruitland, Md	M	38°19'52"	75°35'54"	4.98	-----	L	*1950–71	.52	.44	---	01486500
	82	Passerdyke Creek near Allen, Md.	M	38°17'47"	75°40'07"	[a]7.2	-----	L	1968–71	.04	.01	---	01485500
	83	Barkley Branch near Allen, Md.	M	38°16'54"	75°40'50"	[a]2.7	-----	L	1968–71	0	---	---	01486000
		Nanticoke River basin											
	84	Nanticoke River at Greenwood, Del.	M	38°48'20"	75°34'53"	[a]16	-----	L	1968–71	0.25	0.16	---	01487000
	85	Gum Branch near Bridgeville, Del.	M	38°46'07"	75°30'59"	[a]7.5	-----	L	1968–71	.24	.13	---	01487000
01487000	86	Nanticoke River near Bridgeville, Del.	D	38°43'42"	75°33'44"	75.4	90.8	L H D S	1943–67	.29	.19	0.16	--------
01487100	87	Deep Creek at Old Furnace, Del.	P	38°40'01"	75°31'02"	33.0	-----	L	*1955–63, 1968	.16	.05	---	01484500
01487120	88	Tyndall Branch near Hardscrabble, Del.	P	38°37'54"	75°29'30"	12.7	-----	L	*1955–66	.16	.05	---	01484300
01487300	89	Butler Mill Branch near Woodland, Del.	P	38°37'56"	75°39'35"	6.96	-----	L	*1955–69	.27	.07	---	01489000
	90	Gum Branch near Seaford, Del.	M	38°35'53"	75°37'49"	[a]5.8	-----	L	1968–71	.05	0	---	01485000
01487500	91	Trap Pond Outlet near Laurel, Del.	D	38°31'40"	75°29'00"	16.7	16.1	L H D S	1951–67	.02	.01	.01	--------
01487700	92	Elliott Pond Branch near Laurel, Del.	P	38°34'39"	75°31'42"	8.55	-----	L	*1955–69	.27	.09	---	01484500
	93	Little Creek near Laurel, Del.	M	38°31'19"	75°34'45"	[a]15	-----	L	1968–71	.19	.05	---	01484500

TABLE 2.—*Streamflow-measuring sites and selected low-flow frequency characteristics of streams*—Continued

Station No.	Index No. (pl. 1)	Station name	Class of station	Latitude	Longitude	Drainage area (sq mi)	Average discharge period of record (cfs)	Type of data included in report	Period of record (water years)	Annual low flow, in cubic feet per second per square mile, for 7 consecutive days and for indicated recurrence interval, in years: 2-year	10-year	20-year	Daily-record station used for correlation
		Nanticoke River basin—Continued											
	94	Tussocky Branch near Portsville, Del.	M	38°32′30″	75°38′16″	[a]8.7	-----	L	1968–71	0	---	---	--------
	95	Wright Creek near Portsville, Del.	M	38°35′06″	75°41′50″	[a]3.6	-----	L	1968–71	[b](.16)	---	---	--------
	96	Plum Creek near Sharptown, Md.	M	38°31′00″	75°42′36″	[a]2.8	-----	L	1968–71	.32	.07	---	01489000
	97	Nanticoke River tributary near Sharptown, Md.	M	38°30′43″	75°43′59″	[a]1.4	-----	L	1968–71	0	---	---	01489000
	98	Green Branch at Vernon, Del.	M	38°53′24″	75°40′00″	[a]3.9	-----	L	1968–71	[c](.05)	---	---	--------
01488500	99	Marshyhope Creek near Adamsville, Del.	D	38°51′00″	75°40′29″	44.8	51.4	L H D S	1943–67	.10	.04	.03	--------
	100	Smithville Ditch at Smithville, Md.	M	38°45′45″	75°44′14″	[a]12	-----	L	1968–71	[b](.06)	---	---	--------
	101	Brights Branch near Atlanta, Del.	M	38°43′34″	75°42′05″	[a]4.6	-----	L	1968–71	.09	.02	---	01484500
	102	Sullivan Branch near Federalsburg, Md.	M	38°44′38″	75°46′45″	[a]7.6	-----	L	1968–71	.09	0	---	01489000
01489000	103	Faulkner Branch at Federalsburg, Md.	D	38°42′45″	75°47′35″	7.10	8.74	L H D S	1950–67	.14	.01	0	--------
	104	Tanyard Branch near Federalsburg, Md.	M	38°41′44″	75°44′27″	[a]2.8	-----	L	1968–71	.07	0	---	01492000
	105	North Branch Davis Millpond Branch near Federalsburg, Md.	M	38°39′53″	75°45′17″	[a]2.8	-----	L	1968–71	.21	.11	---	01490000
	106	Skinners Run near Federalsburg, Md.	M	38°40′30″	75°49′20″	[a]3.2	-----	L	1968–71	[a](.12)	---	---	--------
	107	Marshyhope Creek tributary near Petersburg, Md.	M	38°36′18″	75°50′05″	[a]3.0	-----	L	1968–71	.20	.13	---	01490000
	108	Puckum Branch near Eldorado, Md.	M	38°36′44″	75°47′50″	[a]2.5	-----	L	1968–71	.08	.04	---	01490000
	109	Chicone Creek at Reids Grove, Md.	M	38°31′55″	75°49′06″	4.69	-----	L	1951–53, 1969–71	.06	.02	---	01490000
	110	Baron Creek at Md.-Del. State Corner, Md.	M	38°27′30″	75°42′00″	[a]8.9	-----	L	1950–53, 1969, 1970	.24	.13	---	01489500
	111	Rewastico Creek above Rewastico Pond near Hebron, Md.	M	38°25′05″	75°44′06″	[a]8.4	-----	L	1950–53, 1969, 1971	.14	.08	---	01489500
01489500	112	Rewastico Creek near Hebron, Md.	D	38°24′40″	75°45′15″	12.2	8.88	L D	**1950–56	.12	.07	.06	01485500
	113	Quantico Creek at Quantico, Md.	M	38°22′12″	75°44′23″	10.1	-----	L	1950–51	0	---	---	01489500
		Transquaking River basin											
	114	Transquaking River at Hawkeye, Md.	M	38°33′33″	75°55′29″	[a]2.2	-----	L	1968–71	0.05	0	---	01489000
01490000	115	Chicamacomico River near Salem, Md.	D	38°30′45″	75°52′50″	15.0	17.0	L H D S	1951–67	.22	.12	0.10	--------
		Choptank River basin											
	116	Harrington-Beaverdam Ditch at Marydel, Del.	M	39°06′38″	75°44′25″	[a]9.8	-----	L	1968–71	0.04	0.01	---	01491000
	117	Tappahanna Ditch at Marydel, Del.	M	39°06′36″	75°43′40″	[a]16	-----	L	1968–71	.03	.01	---	01491000
	118	Cow Marsh Creek near Petersburg, Del.	M	39°02′55″	75°41′06″	[a]20	-----	L	1968–71	.04	.01	---	01491000
01491000	119	Choptank River near Greensboro, Md.	D	38°59′50″	75°47′10″	113	122	L H D S	1968–67	.09	.04	0.03	--------
	120	Gravelly Branch near Greensboro, Md.	M	38°59′26″	75°45′50″	[a]16	-----	L	1968–71	.11	.05	---	01491000
	121	Forge Branch at Greensboro, Md.	M	38°59′05″	75°49′00″	9.84	-----	L	1952–53	.07	.03	---	01491000
	122	Forge Branch tributary near Ridgely, Md.	M	38°57′23″	75°50′27″	[a]2.6	-----	L	1968–71	[b](.06)	---	---	--------
	123	Spring Branch near Greensboro, Md.	M	38°56′37″	75°48′45″	[a]5.3	-----	L	1968–71	.26	.19	---	01491000
	124	Choptank River tributary near Ridgely, Md.	M	38°56′05″	75°51′05″	[a]4.0	-----	L	1968–71	[b](.45)	---	---	--------
01491180	125	Watts Creek near Denton, Md.	P	38°52′29″	75°47′38″	[a]11	-----	L	1964–69	.07	.04	.03	01488500
	126	Herring Run near Hobbs, Md.	M	38°51′00″	75°47′46″	[a]4.9	-----	L	1968–71	.02	0	---	01492000
	127	Mill Creek near Williston, Md.	M	38°49′12″	75°49′36″	[a]4.5	-----	L	1968–71	.16	.04	---	01493000
	128	Robins Creek at Bureau, Md.	M	38°48′42″	75°51′51″	[a]4.5	-----	L	1968–71	.04	0	---	01489000
	129	Fowling Creek at Harmony, Md.	M	38°47′02″	75°52′28″	[a]6.1	-----	L	1968–71	.26	.07	---	01489000
	130	Beaverdam Ditch at Ingleside, Md.	M	39°05′32″	75°52′37″	[a]4.5	-----	L	1968–71	[b](.15)	---	---	--------
	131	Mason Branch at Bridgetown, Md.	M	39°01′59″	75°53′00″	32.5	-----	L	1968–71	.25	.13	---	01491000
	132	German Branch near Ingleside, Md.	M	39°03′02″	75°57′04″	[a]11	-----	L	1968–71	.14	.06	---	01493000
	133	Blockston Branch near Ruthsburg, Md.	M	38°58′06″	75°56′45″	[a]8.4	-----	L	1968–71	.18	.10	---	01493000
01491500	134	Tuckahoe Creek near Ruthsburg, Md.	D	38°58′00″	75°56′35″	85.2	94.3	L D	**1951–56	.16	.08	---	01491000
	135	Piney Branch near Ridgely, Md.	M	38°57′39″	75°55′09″	[a]4.8	-----	L	1968–71	[b](.22)	---	---	--------
	136	Norwich Creek at Queen Anne, Md.	M	38°55′22″	75°58′25″	[a]9.7	-----	L	1968–71	[b](.02)	---	---	--------
	137	Knott Millpond near Hillsboro, Md.	M	38°52′55″	75°55′35″	8.45	-----	L	1952–53, 1968–71	.33	.18	---	01493000
	138	Deep Branch near Denton, Md.	M	38°51′25″	75°54′41″	[a]3.3	-----	L	1968–71	.39	.27	---	01493000

TABLE 2.—*Streamflow-measuring sites and selected low-flow frequency characteristics of streams*—Continued

Station No.	Index No. (pl. 1)	Station name	Class of station	Latitude	Longitude	Drainage area (sq mi)	Average discharge period of record (cfs)	Type of data included in report	Period of record (water years)	Annual low flow, in cubic feet per second per square mile, for 7 consecutive days and for indicated recurrence interval, in years 2-year	10-year	20-year	Daily-record station used for correlation
		Choptank River basin—Continued											
	139	Hog Creek near Bethlehem, Md.	M	38°45′50″	75°55′00″	3.64	-----	L	1952–53, 1968–71	0.22	0.06	---	01489000
	140	Kings Creek near Easton, Md.	M	38°47′20″	76°00′35″	8.67	-----	L	1952–53	.03	0	---	01489000
01492000	141	Beaverdam Branch at Matthews, Md.	D	38°48′40″	75°58′15″	5.85	6.56	L H D	1950–67	.02	0	---	--------
	142	Miles Creek near Trappe, Md.	M	38°40′15″	76°01′45″	5.70	-----	L	1952–53	.14	.09	---	01489500
	143	Gravel Run at Ellwood, Md.	M	38°40′31″	75°52′38″	[a]4.3	-----	L	1968–70	.19	.07	---	01490000
	144	Cabin Creek at Cabin Creek, Md.	M	38°37′35″	75°54′50″	6.05	-----	L	1952–53	.55	.33	---	01489000
		Wye River basin											
	145	Wye River at Queenstown, Md.	M	38°59′21″	76°08′28″	[a]3.8	-----	L	1968–71	0.21	0.13	---	01492500
	146	Wye East River at Wye Mills, Md.	M	38°56′33″	76°04′53″	[a]10	-----	L	1968–71	.26	.15	---	01493000
01492500	147	Sallie Harris Creek near Carmichael, Md.	D	38°57′55″	76°06′30″	8.09	8.22	L D	**1951–56, 1968–71	.22	.15	---	01493000
	148	Skipton Creek near Skipton, Md.	M	38°52′46″	76°03′14″	[a]4.6	-----	L	1968–71	.04	.02	---	01490000
	149	Mill Creek near Wye Mills, Md.	M	38°54′55″	76°03′50″	5.48	-----	L	1952–53	.46	.27	---	01493000
		Chester River basin											
	150	Gravelly Run near Millington, Md.	M	39°13′07″	75°45′41″	[a]12	-----	L	1968–71	0.02	0	---	01493000
	151	Sewell Branch near Blackiston, Del.	M	39°15′20″	75°44′02″	[a]6.5	-----	L	1968–71	.02	0	---	01483700
	152	Jordan Branch near Kenton, Del.	M	39°14′04″	75°43′13″	[a]4.5	-----	L	1968–71	.02	0	---	01483700
	153	Cypress Branch at McKays Corner, Del.	M	39°19′29″	75°44′06″	[a]3.6	-----	L	1968	[b](0)	---	---	--------
01492980	154	Cypress Branch at Millington, Md.	P	39°15′28″	75°50′01″	[a]38	-----	L	*1964–69	.07	.03	0.02	01493500
	155	Mills Branch near Millington, Md.	M	39°16′34″	75°52′10″	9.98	-----	L	1953–54, 1968–71	.09	.04	---	01493000
	156	Unicorn Branch near Sudlersville, Md.	M	39°11′28″	75°50′03″	[a]8.1	-----	L	1968–71	.15	.05	---	01493000
01493000	157	Unicorn Branch near Millington, Md.	D	39°15′00″	75°51′40″	22.3	23.0	L H D S	1948–67	.30	.17	[R].15	--------
	158	Red Lion Branch at Pondtown, Md.	M	39°13′11″	75°54′01″	[a]22	-----	L	1968–71	.23	.12	---	01493000
	159	Chester River tributary near Chesterville, Md.	M	39°16′28″	75°56′22″	[a]3.6	-----	L	1968–71	.47	.25	---	01493500
	160	Foreman Branch at Ewingville, Md.	M	39°12′39″	75°58′59″	5.27	-----	L	1953–54	.09	.02	---	01493500
01493500	161	Morgan Creek near Kennedyville, Md.	D	39°16′50″	76°00′55″	10.5	9.02	L H D S	1951–67	.28	.13	.10	--------
01494000	162	Southeast Creek at Church Hill, Md.	D	39°07′57″	75°58′51″	12.5	12.6	L H D	**1951–56	.20	.11	---	01493000
	163	Granny Finley Branch near Burrisville, Md.	M	39°06′55″	76°02′28″	[a]8.5	-----	L	1968–71	.11	.04	---	01494000
01494100	164	Old Mill Stream Branch at Centreville, Md.	P	39°02′23″	76°04′22″	11.2	-----	L	1953–54, 1964–69	.36	.22	.17	01493000
	165	Three Bridges Branch at Centreville, Md.	M	39°03′14″	76°03′17″	[a]8.5	-----	L	1968–71	.12	.05	---	01494000
	166	Mill Pond Outlet near Langford, Md.	M	39°11′16″	76°06′58″	5.10	-----	L	1953–54, 1968–71	.45	.26	---	01493500
		Worton Creek basin											
	167	Mill Creek at Haynesville, Md.	M	39°17′00″	76°08′06″	[a]4.5	-----	L	1953–54, 1968–71	0.15	0.08	---	01493500
		Churn Creek basin											
	168	Churn Creek at Smithville, Md.	M	39°18′22″	76°06′15″	[a]1.7	-----	L	1968–71	0.53	0.29	---	01493500
		Sassafras River basin											
	169	Duffy Creek near Cecilton, Md.	M	39°23′45″	75°49′31″	[a]1.6	-----	L	1968–71	0.38	0.19	---	01493500
01494500	170	Jacobs Creek near Sassafras, Md.	D	39°21′50″	75°49′13″	5.39	5.00	L D	**1951–56	.45	.26	---	01493000
	171	Swantown Creek near Galena, Md.	M	39°20′50″	75°50′31″	[a]3.6	-----	L	1968–69	.42	.28	---	01493500
		Elk River basin											
01495000	172	Big Elk Creek at Elk Mills, Md.	D	39°39′26″	75°49′20″	52.6	67.0	L H D S	1932–67	0.36	0.17	0.14	--------
01495500	173	Little Elk Creek at Childs, Md.	D	39°38′30″	75°52′00″	26.8	38.2	L H D	**1949–58	.33	.15	.13	01495000
	174	Mill Creek near Elkton, Md	M	39°36′03″	75°51′47″	[a]4.2	-----	L	1968–70	.12	.05	---	01496000
01495550	175	Perch Creek near Elkton, Md.	P	39°34′16″	75°48′53″	[a]6.0	-----	L	1964–69	.15	.07	.05	01496000
	176	Back Creek near Mt. Pleasant, Del.	M	39°30′36″	75°45′10″	[a]4.8	-----	L	1968–70	.17	.08	---	01493000
	177	Long Branch near Chesapeake City, Md.	M	39°33′05″	75°47′33″	[a]5.2	-----	L	1968–70	.06	.02	---	01493000
	178	Sandy Branch at Bohemia Mills, Md.	M	39°27′36″	75°56′27″	[a]2.8	-----	L	1968–71	.57	.29	---	01493500

TABLE 2.—*Streamflow-measuring sites and selected low-flow frequency characteristics of streams*—Continued

Station No.	Index No. (pl. 1)	Station name	Class of station	Latitude	Longitude	Drainage area (sq mi)	Average discharge period of record (cfs)	Type of data included in report	Period of record (water years)	Annual low flow, in cubic feet per second per square mile, for 7 consecutive days and for indicated recurrence interval, in years: 2-year	10-year	20-year	Daily-record station used for correlation
		Elk River basin—Continued											
	179	Little Bohemia Creek near Warwick, Md.	M	39°26′05″	75°48′25″	2.45	-----	L	1953–54	0.49	0.29	---	01493500
		Northeast River basin											
01496000	180	Northeast Creek at Leslie, Md.	D	39°37′40″	75°56′40″	24.3	32.1	L H D S	1949–67	0.19	0.09	0.07	--------
01496050	181	Little Northeast Creek at Mechanic Valley, Md.	P	39°38′26″	75°55′49″	[a]14	-----	L	1964–69	.20	.08	.06	01496000

STREAMFLOW CHARACTERISTICS

Because precise long-range forecasts of precipitation are not possible and because streamflow is primarily dependent on precipitation, the precise prediction of flow extremes is not possible. However, the probable frequency of flow extremes can be computed on the basis of past streamflow records. These computed frequencies can be used as predictive tools if the flow regime of a stream does not change.

The flow-duration curve has often been used to describe the time distribution of streamflow. It relates the magnitude of daily flow to the percentage of time a specified flow is equaled or exceeded. Each daily flow is treated as an independent input in the usual computation of flow-duration data; the usefulness of the resulting curve is, therefore, limited because the chronologic sequence of flows is not taken into account.

The concepts of recurrence interval and frequency are widely accepted to describe the probability of occurrence of flow extremes. The frequency of a given flow is a measure of the average number of times the given flow will be equaled or exceeded in severity during a specified period of years. The recurrence interval is the average time, in years, between occurrences of a given flow extreme. The recurrence interval is the reciprocal of probability, as shown in the following table:

Recurrence interval (years)	*Probability of occurrences (percent)*
2	50
5	20
10	10
20	5
25	4
50	2
100	1

A phrase such as "the 25-year flood is 500 cfs" means that, over a long period of time, an average of four floods per 100 years will exceed 500 cfs. In referring to low-flow extremes, a period of time is usually associated with the recurrence interval. For example, a 7-day 10-year discharge of 1 cfs means that five times during the next 50 years the annual minimum average flow for 7 consecutive days will be less than 1 cfs.

Streamflow characteristics that may be helpful to designers and planners are given in the following sections. These data are presented in tabular form, with graphical examples given as an aid in using the data.

FLOW DURATION

The flow-duration curve is a cumulative frequency curve that shows the percentage of time specified discharges were equaled or exceeded during a given period (Searcy, 1959). It is a nonsequential time distribution of the flow recorded at a gaging station and is usually based on the period of record, if no manmade changes have modified the flow regime. The flow-duration curve has often been used as a probability curve to estimate the percentage of time that a specified discharge will be equaled or exceeded in the future. The accuracy of such an estimate is dependent on how closely the period of record represents the long-term flow of the stream. It is important to remember the nonsequential nature of the flow-duration curve and its limited use in defining the yearly distribution of flow. All flows lower than those equaled or exceeded 95 percent of the time might have occurred in 1 year during a severe drought. If the curve is based on 15 years of record, it would be erroneous to say that these flows could be expected 5 percent of the time each year. The duration curve, therefore, is not a reliable method for predicting the dependability of flow.

The shape of a flow-duration curve (fig. 9) is a good indicator of the composite hydrologic and geologic characteristics of a drainage basin. A curve having a steep slope (Beaverdam Branch, fig. 9) usually indicates a basin with highly variable flow,

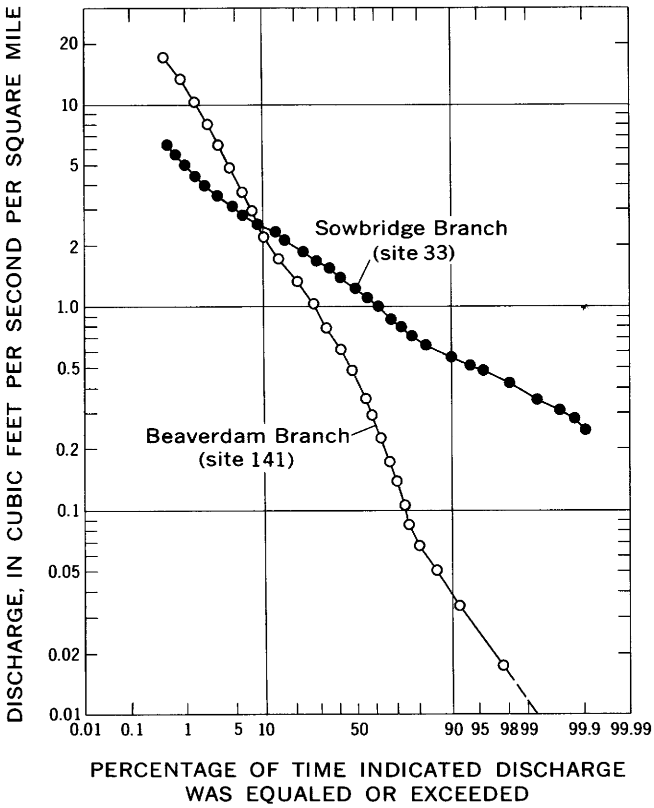


FIGURE 9.—Duration of daily flow for Sowbridge Branch near Milton, Del., and for Beaverdam Branch at Matthews, Md.

little surface- or ground-water storage, and a fairly large proportion of overland flow. A curve having a flat slope (Sowbridge Branch, fig. 9) usually indicates a basin with fairly uniform flow, large amounts of surface- or ground-water storage, and a fairly large proportion of base flow, or ground-water discharge. The two curves (fig. 9) illustrate the extreme slopes of duration curves for the daily-record gaging stations on the peninsula.

Flow data were analyzed by computer for all daily-record gaging stations on the peninsula that had at least 5 years of record at the end of the 1967 water year. Flow-duration curves were plotted from these data, and selected coordinates from the curves are given in table 3. If a graphic presentation of a curve is desired, it can be constructed on log-probability paper by plotting the given coordinates.

FLOOD FREQUENCY AT GAGED SITES

Floods on the peninsula usually result from heavy thundershowers during the summer. Because of the generally flat terrain, flood hydrographs are characterized by fairly slow rises and broad peaks. Streams in the extreme northern part of the project area have sharper peaks and higher flows per square mile of drainage than those in other areas of the peninsula. These higher flows are caused by more rugged topography and by increased and more rapid runoff from urbanized areas.

Damages to crops and property usually result from submergence by floodwaters rather than from high velocities. Road and bridge damage more often result from high velocities associated with constriction of the flood plains at embankments and bridges.

A knowledge of the magnitude and frequency of floods is necessary in the planning and economic design of bridges, culverts, dams, and other structures that are built on or near stream channels.

The computations of the flood-frequency characteristics of streams on the Delmarva Peninsula were made by computer, using the log-Pearson Type III method (U.S. Water Resources Council Hydrology Committee, 1967). The computer furnished a printout of selected flood-frequency data, a plot of the computed data, and the actual data points used in the computation. The computed theoretical curve was modified by graphically fitting the curve to the actual data when a flood during the period of record was known to be rarer than shown by mathematical analysis. Selected flood-frequency data are shown in table 4 for all daily-record gaging stations that had at least 10 years of record at the end of the 1967 water year.

Because of the demand for information on high-recurrence-interval floods for planning purposes, the peak-flow frequency data are given for floods up to the 50-year recurrence interval, if at least 25 years of peak-flow data were available for the site. A flood of magnitude and frequency other than the values shown in table 4 can be determined by plotting the tabulated values on log-probability paper and extracting the desired data from a curve drawn through the plotted points. The curves, however, should not be extrapolated to recurrence intervals higher than those given in the table.

FLOOD FREQUENCY AT UNGAGED SITES

Several methods have been used to estimate the magnitude and frequency of floods at sites where streamflow data are not available. The method presented here involves the use of peak-flow equations based on easily obtainable basin characteristics. These equations are fairly easy to apply and have the additional advantage of definable reliability associated with each recurrence interval.

The multiple-regression method makes use of mathematically developed formulae relating some of the physical characteristics of a gaged basin to floods

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TABLE 3.—*Duration of daily flow at daily-record gaging stations*

[*a*, approximately; *R*, affected by regulation]

Station No.	Index No. (pl. 1)	Station name	Drainage area (sq mi)	Flow, in cubic feet per second, which was equaled or exceeded for indicated percentage of time															
				0.5	1	2	5	10	20	30	50	70	80	90	95	98	99	99.5	99.9
01477800	2	Shellpot Creek at Wilmington, Del	7.46	160	110	73	36	17	8.3	5.5	3.0	1.6	1.1	0.7	0.6	0.4	0.3	0.2	0.1
01478000	4	Christina River at Coochs Bridge, Del	20.5	430	290	178	80	43	24	19	13	8.2	6.2	4.1	2.6	1.5	.9	.7	.4
01478500	6	White Clay Creek above Newark, Del	66.7	730	530	330	185	127	85	68	49	35	28	21	16	13	10	7.8	6.2
01479000	8	White Clay Creek near Newark, Del	87.8	1,100	740	450	255	176	125	100	71	52	42	31	24	17	15	13	[R]6.9
01480000	10	Red Clay Creek at Wooddale, Del	47.0	620	430	270	150	105	72	58	41	30	24	19	15	12	10	8.5	5.3
01481500	12	Brandywine Creek at Wilmington, Del	314	3,450	2,600	1,770	1,140	830	580	470	300	200	160	118	98	81	73	66	60
01483200	16	Blackbird Creek at Blackbird, Del	3.85	42	31	23	14	9.1	5.8	4.4	2.5	1.3	.9	.6	.3	.2	0	0	0
01483500	20	Leipsic River near Cheswold, Del	9.35	94	63	45	29	20	14	11	7.2	5.2	4.4	3.6	3.0	2.5	2.2	2.0	1.7
01483700	23	St. Jones River at Dover, Del	31.9	290	240	170	102	66	41	29	15	7.8	4.9	2.0	.9	.5	.5	.4	-----
01484000	25	Murderkill River near Felton, Del	13.6	160	130	87	47	31	20	15	9.0	5.1	4.2	3.1	2.6	2.1	1.8	1.5	1.3
01484100	30	Beaverdam Branch at Houston, Del	2.83	26	19	13	8.3	6.4	4.9	3.9	2.6	1.7	1.2	.8	.6	.5	.5	.4	-----
01484300	33	Sowbridge Branch near Milton, Del	7.08	----	34	28	22	18	14	12	8.6	6.0	4.8	4.1	3.5	3.1	2.8	2.4	1.8
01484500	39	Stockley Branch at Stockley, Del	5.24	44	35	28	19	15	10	7.7	5.0	3.3	2.6	1.8	1.4	1.1	1.0	.7	.1
01485000	63	Pocomoke River near Willards, Md	60.5	600	500	380	220	150	95	67	35	18	13	8.6	5.7	4.3	1 6	1.4	1.0
01485500	69	Nassawango Creek near Snow Hill, Md	44.9	470	390	300	190	120	74	52	24	10	5.9	3.6	2.5	1.8	1.6	1.4	.0
01486000	72	Manokin Branch near Princess Anne, Md	[a]5.8	50	38	26	15	8.9	5.3	3.6	1.5	.6	4	.2	.1	0	0	0	[illegible]
01486500	80	Beaverdam Creek near Salisbury, Md	19.5	170	120	93	62	45	32	25	17	11	8.7	6.6	5.4	3.9	[R]3.0	[R]1.6	[R].6
01487000	86	Nanticoke River near Bridgeville, Del	75.4	590	470	380	260	180	125	94	61	41	33	26	22	19	17	15	9.7
01487500	91	Trap Pond Outlet near Laurel, Del	16.7	140	110	83	52	36	24	18	11	4.4	2.4	1.3	.5	.3	.2	.2	0
01488500	99	Marshyhope Creek near Adamsville, Del	44.8	540	450	330	200	115	65	44	23	12	8.5	5.6	4.0	3.1	2.7	2.2	1.6
01489000	103	Faulkner Branch at Federalsburg, Md	7.10	86	58	39	25	18	13	9.4	5.8	3.1	2.2	1.4	1.1	.8	.5	.1	0
01489500	112	Rewastico Creek near Hebron, Md	12.2	61	47	36	25	18	13	9.4	6.2	4.2	3.2	2.3	2.0	1.6	1.4	1.3	1.1
01490000	115	Chicamacomico River near Salem, Md	15.0	140	100	68	44	32	23	18	12	7.8	5.9	4.5	3.8	3.0	2.6	2.1	[R].8
01491000	119	Choptank River near Greensboro, Md	113	1,270	930	720	440	270	160	110	58	30	21	14	11	8.1	6.6	5.4	[R]2.5
01491500	134	Tuckahoe Creek near Ruthsburg, Md	85.2	790	610	470	310	200	130	96	53	31	26	20	17	15	15	14	14
01492000	141	Beaverdam Branch at Matthews, Md	5.85	95	70	48	25	14	7.9	5.3	2.6	.9	.4	.2	.1	0	0	0	0
01492500	147	Sallie Harris Creek near Carmichael, Md	8.09	104	70	47	25	16	8.8	6.5	4.3	3.1	2.7	2.1	1.9	1.8	1.7	1.7	1.6
01493000	157	Unicorn Branch near Millington, Md	22.3	190	140	105	66	44	30	24	15	10	8.4	6.9	5.8	4.7	[R]3.5	[R]2.6	[R].3
01493500	161	Morgan Creek near Kennedyville, Md	10.5	115	68	46	26	16	9.7	7.8	5.5	4.3	3.7	3.0	2.4	1.9	1.2	.9	.8
01494000	162	Southeast Creek at Church Hill, Md	12.5	170	120	67	40	24	15	11	6.4	4.5	3.7	3.0	2.5	2.2	2.1	2.0	1.8
01494500	170	Jacobs Creek near Sassafras, Md	5.39	32	25	19	11	7.9	6.2	5.2	3.8	2.8	2.7	2.5	2.4	2.2	2.1	2.0	1.6
01495000	172	Big Elk Creek at Elk Mills, Md	52.6	770	480	310	170	110	78	63	45	33	27	20	16	12	9.8	8.0	5.6
01495500	173	Little Elk Creek at Childs, Md	26.8	450	350	220	110	64	42	34	23	17	14	11	8.2	6.7	5.8	5.2	4.2
01496000	180	Northeast Creek at Leslie, Md	24.3	520	350	230	110	51	31	25	16	10	7.8	5.2	4.0	3.1	2.6	2.3	1.4

TABLE 4.—*Magnitude and frequency of annual high flows at daily-record gaging stations*

[*a*, approximately]

Station No.	Index No. (pl.1)	Station name	Drainage area (sq mi)	Discharge, in cubic feet per second, for indicated recurrence intervals, in years: Annual maximum	2-year	5-year	10-year	25-year	50-year
01477800	2	Shellpot Creek at Wilmington, Del. (based on period Oct. 1, 1946, to Sept. 30, 1967).	7.46	Peak flow	1,200	2,100	3,000	4,700	-----
				Daily flow	280	408	499	623	-----
				3-day flow	113	160	195	245	-----
				7-day flow	61	83	98	119	-----
01478000	4	Christina River at Coochs Bridge, Del. (based on period Oct. 1, 1943, to Sept. 30, 1967).	20.5	Peak flow	1,400	1,740	1,970	2,270	2,510
				Daily flow	601	781	900	1,050	1,160
				3-day flow	274	338	377	425	457
				7-day flow	148	193	224	263	293
01478500	6	White Clay Creek above Newark, Del. (based on period Oct. 1, 1952, to Sept. 30, 1967).	66.7	Peak flow	2,870	3,680	4,190	4,800	-----
				Daily flow	1,050	1,410	1,630	1,900	-----
				3-day flow	533	690	783	889	-----
				7-day flow	311	430	518	640	-----
01479000	8	White Clay Creek near Newark, Del. (based on periods Oct. 1, 1931, to Sept. 30, 1936; Oct. 1, 1943, to Sept. 30, 1957; and Oct. 1, 1959, to Sept. 30, 1967).	87.8	Peak flow	3,690	4,990	5,870	7,020	7,890
				Daily flow	1,550	2,190	2,720	3,510	4,210
				3-day flow	815	1,140	1,370	1,700	1,970
				7-day flow	463	640	776	969	1,130
01480000	10	Red Clay Creek at Wooddale, Del. (based on period Oct. 1, 1943, to Sept. 30, 1967).	47.0	Peak flow	2,180	2,880	3,380	4,040	4,540
				Daily flow	872	1,230	1,490	1,860	2,170
				3-day flow	434	595	709	861	980
				7-day flow	248	350	425	531	617
01481500	12	Brandywine Creek at Wilmington, Del. (based on period Oct. 1, 1946, to Sept. 30, 1967).	314	Peak flow	7,360	10,600	13,000	16,300	-----
				Daily flow	4,680	6,420	7,390	8,430	-----
				3-day flow	2,820	3,940	4,670	5,560	-----
				7-day flow	1,710	2,390	2,890	3,580	-----
01483200	16	Blackbird Creek at Blackbird, Del. (based on period Oct. 1, 1957, to Sept. 30, 1967).	3.85	Peak flow	104	194	275	-----	-----
				Daily flow	48	91	134	-----	-----
				3-day flow	29	48	64	-----	-----
				7-day flow	19	30	39	-----	-----
01483500	20	Leipsic River near Cheswold, Del. (based on periods Oct. 1, 1931, to Sept. 30, 1933, and Oct. 1, 1943, to Sept. 30, 1957).	9.35	Peak flow	195	394	618	1,060	-----
				Daily flow	125	215	297	430	-----
				3-day flow	66	116	160	232	-----
				7-day flow	40	63	82	111	-----
01484300	33	Sowbridge Branch near Milton, Del. (based on period Oct. 1, 1956, to Sept. 30, 1967).	7.08	Peak flow	33	57	81	108	-----
				Daily flow	28	42	51	65	-----
				3-day flow	27	39	48	59	-----
				7-day flow	24	35	42	52	-----
01484500	39	Stockley Branch at Stockley, Del. (based on period Oct. 1, 1943, to Sept. 30, 1967).	5.24	Peak flow	55	80	98	122	142
				Daily flow	41	64	82	106	126
				3-day flow	32	49	62	78	92
				7-day flow	25	38	46	57	65
01485000	63	Pocomoke River near Willards, Md. (based on period Oct. 1, 1950, to Sept. 30, 1967).	60.5	Peak flow	643	776	851	933	-----
				Daily flow	623	748	808	867	-----
				3-day flow	506	636	706	779	-----
				7-day flow	340	450	516	595	-----
01485500	69	Nassawango Creek near Snow Hill, Md. (based on period Oct. 1, 1950, to Sept. 30, 1967).	44.9	Peak flow	490	727	863	1,010	-----
				Daily flow	480	704	808	906	-----
				3-day flow	422	590	665	730	-----
				7-day flow	313	436	489	535	-----
01486000	72	Manokin Branch near Princess Anne, Md. (based on period Oct. 1, 1951, to Sept. 30, 1967).	[a]5.8	Peak flow	118	192	240	299	-----
				Daily flow	67	112	143	183	-----
				3-day flow	45	67	79	93	-----
				7-day flow	28	41	48	57	-----
01486500	80	Beaverdam Creek near Salisbury, Md. (based on periods Oct. 1, 1929, to Sept. 30, 1932, and Oct. 1, 1938, to Sept. 30, 1967).	19.5	Peak flow	243	453	618	853	1,050
				Daily flow	174	301	391	509	597
				3-day flow	138	226	287	364	420
				7-day flow	94	146	180	222	253
01487000	86	Nanticoke River near Bridgeville, Del. (based on period Oct. 1, 1943, to Sept. 30, 1967).	75.4	Peak flow	561	1,000	1,400	2,040	2,650
				Daily flow	528	949	1,310	1,890	2,410
				3-day flow	460	792	1,060	1,470	1,810
				7-day flow	366	577	725	921	1,070
01487500	91	Trap Pond Outlet near Laurel. Del. (based on period Oct. 1, 1952, to Sept. 30, 1967).	16.7	Peak flow	209	334	413	506	-----
				Daily flow	150	239	296	366	-----
				3-day flow	110	167	204	250	-----
				7-day flow	77	110	130	154	-----
01488500	99	Marshyhope Creek near Adamsville, Del. (based on period Oct. 1, 1943, to Sept. 30, 1967).	44.8	Peak flow	661	1,230	1,670	2,300	2,820
				Daily flow	583	1,090	1,490	2,070	2,540
				3-day flow	460	818	1,080	1,430	1,690
				7-day flow	316	522	663	841	971
01489000	103	Faulkner Branch at Federalsburg, Md. (based on period Oct. 1, 1950, to Sept. 30, 1967).	7.10	Peak flow	177	409	616	936	-----
				Daily flow	109	214	293	396	-----
				3-day flow	65	116	153	203	-----
				7-day flow	42	68	86	108	-----
01490000	115	Chicamacomico River near Salem, Md. (based on period Oct. 1, 1951, to Sept. 30, 1967).	15.0	Peak flow	210	336	428	552	-----
				Daily flow	155	237	291	356	-----
				3-day flow	107	169	213	273	-----
				7-day flow	74	107	129	156	-----
01491000	119	Choptank River near Greensboro, Md. (based on period Oct. 1, 1948, to Sept. 30, 1967).	113	Peak flow	1,590	2,950	4,000	5,450	-----
				Daily flow	1,500	2,750	3,800	5,200	-----
				3-day flow	1,060	2,050	2,790	3,750	-----
				7-day flow	714	1,250	1,580	1,980	-----
01492000	141	Beaverdam Branch at Matthews, Md. (based on period Oct. 1, 1950, to Sept. 30, 1967).	5.85	Peak flow	272	596	968	1,730	-----
				Daily flow	140	294	465	860	-----
				3-day flow	67	132	200	325	-----
				7-day flow	43	76	100	132	-----
01493000	157	Unicorn Branch near Millington, Md. (based on period Oct. 1, 1948, to Sept. 30, 1967).	22.3	Peak flow	283	508	694	974	-----
				Daily flow	194	333	444	604	-----
				3-day flow	133	231	311	430	-----
				7-day flow	94	153	194	247	-----
01493500	161	Morgan Creek near Kennedyville, Md. (based on period Oct. 1, 1951, to Sept. 30, 1967).	10.5	Peak flow	357	673	938	1,330	-----
				Daily flow	185	320	425	572	-----
				3-day flow	91	141	178	226	-----
				7-day flow	48	71	86	103	-----

TABLE 4.—*Magnitude and frequency of annual high flows at daily-record gaging stations*—Continued

Station No.	Index No. (pl.1)	Station name	Drainage area (sq mi)	Discharge, in cubic feet per second, for indicated recurrence intervals, in years					
				Annual maximum	2-year	5-year	10-year	25-year	50-year
01494000	162	Southeast Creek at Church Hill, Md. (based on periods Oct. 1, 1951, to Sept. 30, 1959, and Oct. 1, 1960, to Sept. 30, 1965).	12.5	Peak flow	465	829	1,170	1,730	-----
01495000	172	Big Elk Creek at Elk Mills, Md. (based on period Oct. 1, 1932, to Sept. 30, 1967).	52.6	Peak flow	3,110	4,870	6,290	8,410	10,200
				Daily flow	1,080	1,560	1,900	2,370	2,750
				3-day flow	540	763	924	1,150	1,320
				7-day flow	303	420	507	630	730
01495500	173	Little Elk Creek at Childs, Md. (based on period Oct. 1, 1948, to Sept. 30, 1958).	26.8	Peak flow	1,580	2,360	3,190	-----	-----
01496000	180	Northeast Creek at Leslie, Md. (based on period Oct. 1, 1948, to Sept. 30, 1967).	24.3	Peak flow	1,480	2,310	2,960	3,900	-----
				Daily flow	677	1,020	1,290	1,680	-----
				3-day flow	334	465	562	696	-----
				7-day flow	181	258	321	414	-----

of selected recurrence interval for that basin. The resulting empirical equations for different recurrence interval can be used with basin characteristics, determined from topographic maps, to estimate floods for ungaged sites. The equations are in the form

$$P_n = K_n A^a B^b C^c \ast\ast\ast M^m \pm \text{S.E.}P_n$$

where

P is the magnitude of peak flow of recurrence interval n,

K_n is a regression constant,

A, B, C, * * * M are basin characteristics,

a, b, c, * * * m are regression exponents, and

S.E.P_n is the standard error, in percent, of the estimated flow.

A multiple-regression analysis of flood-frequency characteristics for streams in Maryland (Walker, 1971) indicates that the following basin characteristics had a significant effect on peak flow:

1. Drainage area (A);
2. Channel-slope index (S);
3. Percentage of drainage area in forest (F); and
4. Geographic factor (G).

The geographic factors (fig. 10) are a regionalized average of the ratios of peak-flow values from the gaging-station flood-frequency relations to the peak-flow values from the regression equations. The boundaries separating the geographic areas (fig. 10) were modified from those shown by Walker (1971).

The regression constants, exponents, and associated standard errors for the regression equations are shown in table 5 and are taken directly from Walker (1971). They can be used to estimate peak flow for the 2-, 5-, 10-, 25-, and 50-year recurrence interval. These values are equally applicable to Delaware because all gaging-station data in Delaware were used in the regression analysis. Because of the absence of flood-frequency data, the applicability of these formulae in estimating peak flows for the Virginia part of the peninsula could not be tested. The nontidal reaches of streams in the Virginia part of the peninsula are short and drain small areas. Any significant floods are likely to be a result of wind-driven tides, for which the multiple-regression method is not applicable.

TABLE 5.—*Summary of flood-peak regression relations*

Model: $P_n = K_n A^a S^b F^c G^d$

Recurrence interval (n), in years, for flood peaks (P)	Regression constant (K)	Regression exponents for indicated basin characteristics				Standard error (± percent)
		a (area, A)	b (slope, S)	c (forest, F)	d (geography, G)	
2	54.2	0.947	0.331	−0.394	0.809	32
5	88.9	.921	.329	−.362	.856	31
10	112	.908	.336	−.337	.956	32
25	141	.894	.350	−.302	1.11	37
50	46.0	.915	.377	0	.909	37

Three basin characteristics (A, S, and F) required in the regression equation should be determined, if possible, from the most recent Geological Survey 7½-minute quadrangle maps (scale 1:24,000). The procedure for determining the basin characteristics is as follows:

1. Drainage area (A):
   a. Locate site on map and outline basin boundary.
   b. Determine drainage area, in square miles.
2. Slope index (S):
   a. Measure stream length, in miles from site to drainage divide.
   b. Determine the difference in altitude, in feet, between a point 10 percent of stream length upstream from site and a point 85 percent of stream length upstream from site.
   c. Divide difference in altitude by 75 percent of stream length to get slope index, in feet per mile.
3. Forest cover (F):
   a. Determine the area, in square miles, in the drainage basin covered by forest (usually shown by green overprint).
   b. Divide by total drainage area and multiply by 100.
   c. If there is no forest cover in the basin,

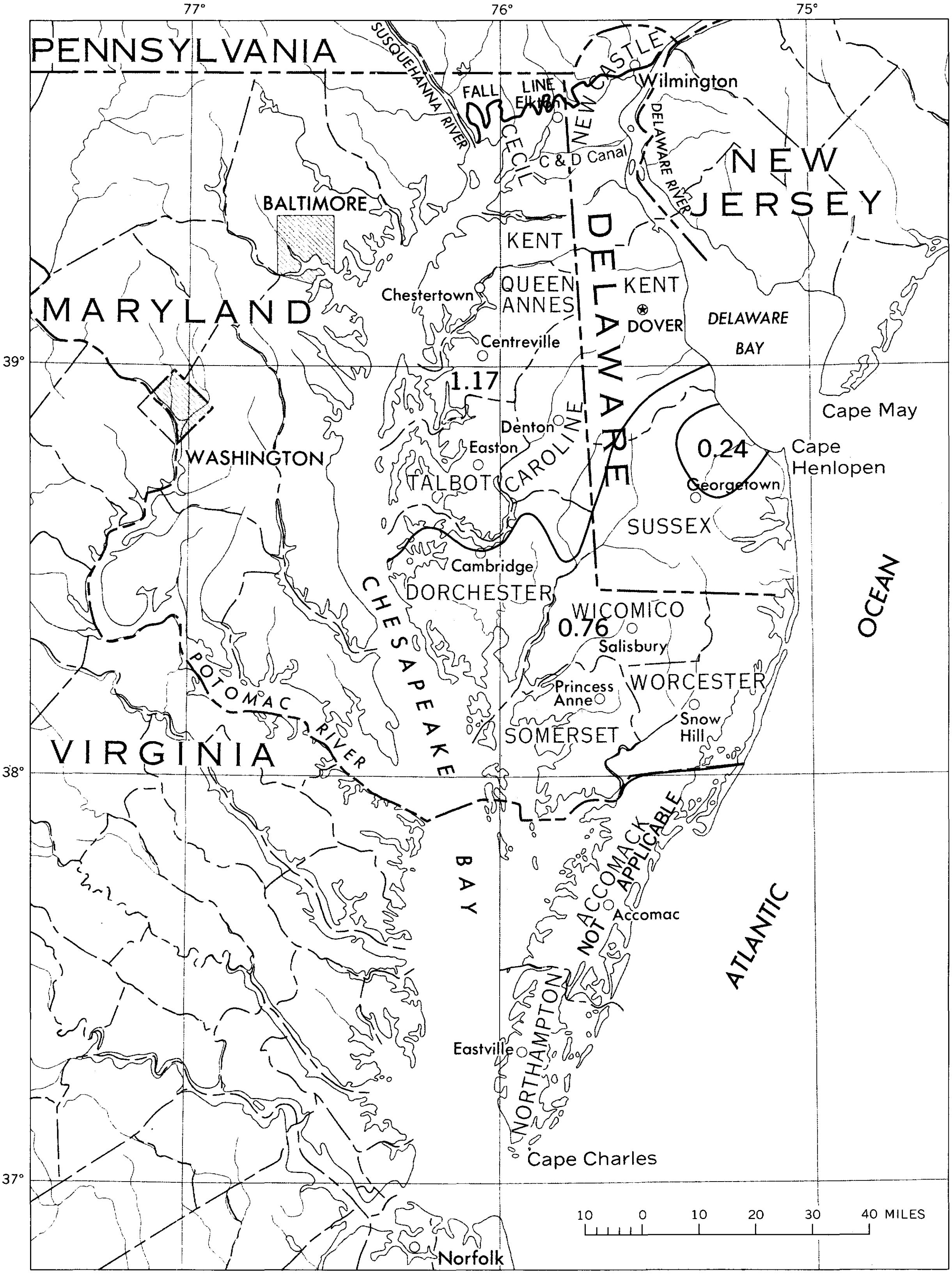

Figure 10.—Geographic factor for flood-frequency determination.

use a value of 1 percent to enable computation.

4. Geographic factor (G):
   a. Locate site in figure 10.
   b. Use geographic factor shown on map.

The standard error associated with each recurrence interval (table 5) is the same regardless of the magnitude of the computed flow. The errors associated with the multiple-regression method may seem unusually large, but it should be remembered that the method is an estimating procedure for sites where flood data are not available. Other methods may have equally high, but undefinable, errors associated with them.

The regression constants and exponents (table 5) were developed from data that represent near-natural or unregulated floods. The use of these values to estimate floods in highly urbanized or otherwise extensively changed basins may result in estimated peaks significantly different from actual peaks.

Illustrative problem.—An estimate of the peak flow that will be equaled or exceeded on the average of once every 25 years (25-year peak flow) is required at a site with the following basin characteristics:

1. Drainage area (A) = 15 square miles;
2. Channel-slope index (S) = 8 feet per mile;
3. Percent forest cover (F) = 40 percent; and
4. Geographic factor (G) = 1.17 (fig. 10).

Using the model equation, regression constants, and regression exponents from table 5, the 25-year peak will be

$$P_{25} = 141\ (15)^{0.894}(8)^{0.350}(40)^{-0.302}(1.17)^{1.11}.$$

Determining the exponential terms in the equation by slide rule, logarithms, or graph (fig. 11):

$$P_{25} = \frac{141(11.3)\ (2.07)\ (1.19)}{(3.05)}$$

$P_{25} = 1{,}290$ cfs (cubic feet per second)

The 25-year peak flow is estimated to be 1,290 cfs, with a standard error of ± 37 percent (table 5).

DEPTH-DISCHARGE FREQUENCY

Planners are often more interested in the depth of submergence at a site resulting from a specific recurrence-interval flood than they are in the rate of flow. Fairly accurate methods have been developed for determining the flood depth that will result from a given discharge at a specific site. Because of the high cost of the required field surveys and detailed computation, however, these methods are not always feasible for broad planning, zoning, and reconnaissance. Less accurate but more economical methods are often acceptable.

Leopold and Maddock (1953) found that in arid regions at less than bankful depths a regional relation exists between depth and discharge at a given frequency. Thomas (1964) found that the relation held in New Jersey even for depths greater than bankful.

Using the methods described by Thomas (1964), flood depths at 20 gaging stations on the peninsula were computed for floods with recurrence intervals of 2, 5, 10, and 25 years. These depths were plotted against the discharge for the median annual flood (P_2) for each of the stations, and regional depth-discharge frequency relations were developed (fig. 12). A sufficient number of long-term station records on the Delmarva Peninsula are not available to define the 50-year relation. However, relations developed by Thomas (1964) for the Coastal Plain of New Jersey indicate that the depth for the 50-year flood is about 10 percent greater than that for the 25-year flood.

To test these relations for estimating flood depths, the median annual flood (P_2) was computed for each gaging station from basin characteristics and the regression formula. Using the computed median annual floods, flood depths were determined for each gaging station from figure 12. A comparison of these depths with depths determined from the gaging-station records indicated a standard error of about 30 percent. About two-thirds of the estimated depths were greater than the actual depths.

The depth determined from these relations (fig. 12) is measured from the mean channel-bottom altitude. Unless the channel has vertical banks, the mean channel-bottom altitude will increase as the stage or depth of water increases. Consequently, in order for flood depths to be measured from a constant datum, the mean channel-bottom altitude should be determined under median-flow conditions (50-percent duration).

The mean channel-bottom altitude at a site should be based on the measurement of a minimum of 10 depths at equally spaced points across the stream. The cross section should be chosen to represent average channel conditions in the reach of stream. The reliability of the channel-bottom altitude can probably be improved by averaging the depths determined at several cross sections. Except during extreme high-water periods, streams in a particular area generally flow at approximately the same duration at any given time. For this reason, channel-bottom altitude can be adjusted to approximate median-flow conditions by comparison with a nearby gaging station.

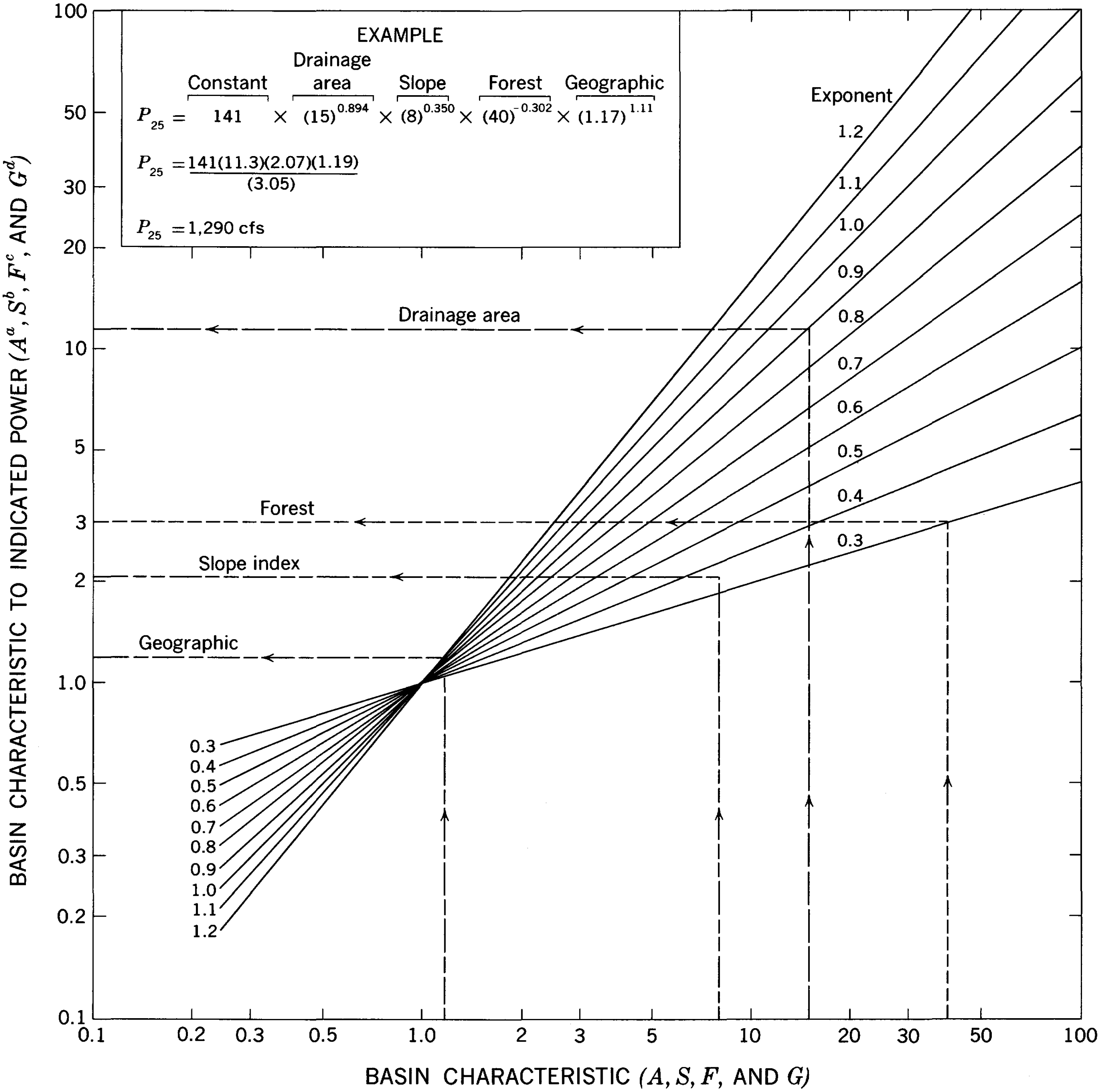

FIGURE 11.—Graph for evaluating exponential components of flood-frequency equations.

The procedure for determining the approximate flood depth at a point in the flood plain of an ungaged stream is as follows:

1. Compute the median annual peak flow (P_2) from basin characteristics.
2. From the graph (fig. 12) determine the depth for flood of the desired recurrence interval.
3. Determine the mean channel-bottom altitude under median-flow conditions.
4. Add the flood depth (step 2) to the average channel-bottom altitude (step 3) to determine the altitude of high water.
5. Determine the altitude of the point on the flood plain.
6. Subtract the altitude of the point (step 5) from the altitude of high water (step 4) to determine the approximate flood depth.

The depth-discharge frequency relations were developed from data representing natural flow conditions. The use of these relations to estimate flood

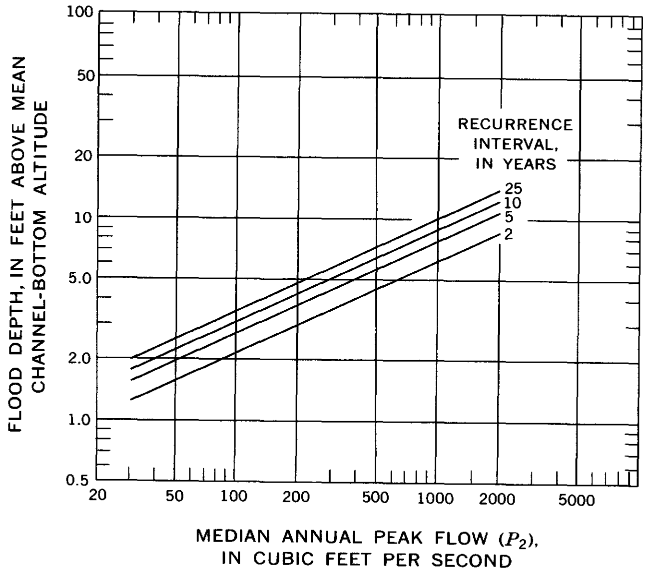

FIGURE 12.—Depth-discharge frequency relations.

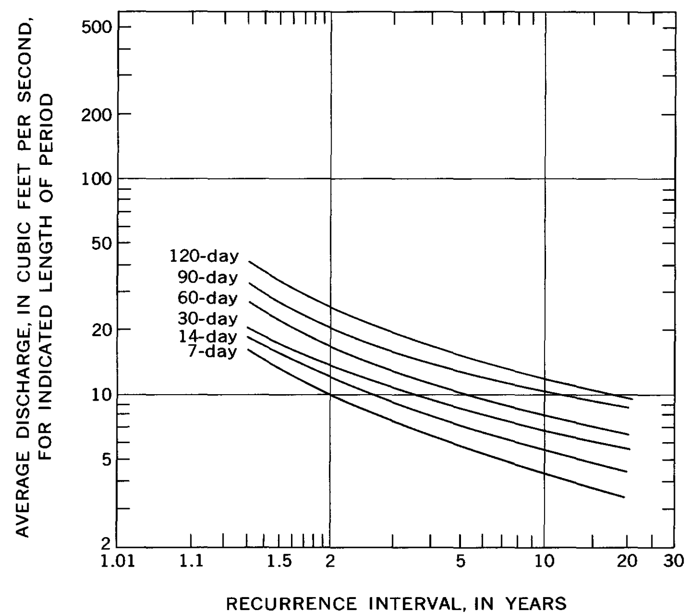

FIGURE 13.—Magnitude and frequency of annual low flow for Choptank River near Greensboro, Md. (site 119), 1948–67.

depths in channels above manmade constrictions in the flood plain or in channels that have been otherwise extensively modified by man could result in serious errors in the estimated depths. These relations should not be used in urbanized areas. More detailed and accurate methods should be used for these areas or for any area where the risk of life or large financial loss is involved.

LOW-FLOW FREQUENCY

Low-flow frequency data are used primarily in the design of water-supply and waste-treatment facilities, whose operation is critical during periods of low streamflow. For design purposes, the 7-day 10-year low flow is probably the most widely used value. It is based on annual minimum flows and can be described as the lowest average flow during any 7 consecutive days that is likely to be equaled or exceeded in severity on the average of 10 times in 100 years. It is not an extremely rare flow but neither is it a common one.

The low-flow frequency data given in this report are for four types of stations: (1) Long-term daily-record stations, (2) short-term daily-record stations, (3) low-flow partial-record stations, and (4) miscellaneous measuring sites.

The data for the long-term daily-record stations are based on a minimum of 10 years of daily record and were developed by computer, using the log-Pearson Type III method of analysis. If the computer-plotted curve did not fit the actual data, the curves were adjusted by graphical methods. Low-flow characteristics for periods of 7, 14, 30, 60, 90, and 120 consecutive days for recurrence intervals of 2, 5, 10, and where possible, 20 years were taken from these curves and are given in table 6. If a graphical presentation is desired, the data can be plotted on log-probability paper (fig. 13).

For the short-term daily-record and low-flow partial-record stations, the 7-day low-flow data for recurrence intervals of 2, 10, and, in some instances, 20 years were estimated. The data are less reliable than those for long-term daily-record stations.

Low-flow characteristics for the short-term daily-record gaging stations (less than 10 years of record) were estimated by correlating daily flows during periods of base flow with concurrent daily flows at a nearby long-term gaging station. The relation curve was used to transfer selected low-flow data from the long-term station to the short-term station. These data are given in table 2 in flow per square mile of drainage area to facilitate comparison among stations. The total flow at a site can be determined by multiplying the drainage area upstream from the site by the flow per square mile.

The data collected at low-flow partial-record stations consisted of two or three base-flow discharge measurements per year made over a period of several years. These measurements of instantaneous discharge were correlated with concurrent daily discharge from long-term daily-record stations, relation curves were prepared, and selected low-flow characteristics were determined for the partial-

TABLE 6.—*Magnitude and frequency of annual low flow at daily-record gaging stations*

[*a*, approximately; *R*, affected by regulation]

Station No.	Index No. (pl. 1)	Station name	Drainage area (sq mi)	Period (consecutive days)	Annual low flow, in cubic feet per second, for indicated recurrence interval, in years: 2	5	10	20
01477800	2	Shellpot Creek at Wilmington, Del. (based on period Apr. 1, 1946, to Mar. 31, 1967).	7.46	7	0.5	0.3	0.2	0.2
				14	.7	.4	.3	.2
				30	1.0	.5	.3	.2
				60	1.4	.9	.7	.6
				90	1.9	1.3	1.0	.9
				120	2.5	1.7	1.5	1.3
01478000	4	Christina River at Coochs Bridge, Del. (based on period Apr. 1, 1943, to Mar. 31, 1967).	20.5	7	3.6	1.9	1.3	.9
				14	4.2	2.3	1.5	1.0
				30	4.9	2.7	2.0	1.5
				60	6.3	3.8	2.9	2.3
				90	7.0	4.0	3.1	2.4
				120	8.3	5.1	4.0	3.3
01478500	6	White Clay Creek above Newark, Del. (based on period Apr. 1, 1952, to Mar. 31, 1967).	66.7	7	17	9.8	7.6	6.0
				14	18	11	8.6	6.8
				30	19	12	9.8	8.2
				60	25	15	12	10
				90	26	18	15	13
				120	31	22	18	16
01479000	8	White Clay Creek near Newark, Del. (based on periods Apr. 1, 1932, to Mar. 31, 1936; Apr. 1, 1944, to Mar. 31, 1957; and Apr. 1, 1960, to Mar. 31, 1967).	87.8	7	32	17	12	9.1
				14	34	19	13	10
				30	37	21	14	11
				60	40	26	21	17
				90	44	28	23	19
				120	50	33	27	23
01480000	10	Red Clay Creek at Wooddale, Del. (based on period Apr. 1, 1943, to Mar. 31, 1967).	47.0	7	16	10	8.0	6.2
				14	17	11	9.2	7.4
				30	20	13	10	8.5
				60	22	16	13	11
				90	26	19	16	14
				120	28	21	18	16
01481500	12	Brandywine Creek at Wilmington, Del. (based on period Apr. 1, 1947, to Mar. 31, 1967).	314	7	105	76	65	58
				14	110	82	70	62
				30	130	90	77	69
				60	150	100	90	81
				90	170	120	100	90
				120	180	130	110	96
01483200	16	Blackbird Creek at Blackbird, Del. (based on period Apr. 1, 1957, to Mar. 31, 1967).	3.85	7	.4	.1	0	----
				14	.5	.1	0	----
				30	.7	.2	.1	----
				60	.8	.3	.1	----
				90	1.0	.4	.2	----
				120	1.1	.5	.3	----
01483500	20	Leipsic River near Cheswold, Del. (based on periods Apr. 1, 1932, to Mar. 31, 1933, and Apr. 1, 1943, to Mar. 31, 1967).	9.35	7	3.0	2.2	1.9	1.7
				14	3.2	2.5	2.2	1.9
				30	3.6	2.8	2.4	2.2
				60	4.3	3.4	3.0	2.7
				90	5.0	3.6	3.2	2.8
				120	5.4	4.3	3.8	3.4
01484300	33	Sowbridge Branch near Milton, Del. (based on period Apr. 1, 1957, to Mar. 31, 1967).	7.08	7	3.7	2.4	1.9	----
				14	4.1	2.5	2.0	----
				30	4.3	3.0	2.6	----
				60	4.8	3.2	2.8	----
				90	5.2	3.7	3.2	----
				120	5.4	3.9	3.4	----
01484500	39	Stockley Branch at Stockley, Del. (based on period Apr. 1, 1943, to Mar. 31, 1967).	5.24	7	1.6	.9	.6	.4
				14	1.8	1.0	.7	.5
				30	1.9	1.1	.8	.6
				60	2.2	1.3	1.0	.8
				90	2.3	1.4	1.1	.9
				120	2.6	1.7	1.4	1.1
01485000	63	Pocomoke River near Willards, Md. (based on period Apr. 1, 1950, to Mar. 31, 1967).	60.5	7	5.8	3.4	2.6	2.0
				14	6.6	4.3	3.4	2.7
				30	8.0	5.0	4.0	3.3
				60	9.0	5.5	4.4	3.7
				90	11	6.0	4.7	4.0
				120	15	8.5	6.4	5.2
01485500	69	Nassawango Creek near Snow Hill, Md. (based on period Apr. 1, 1950, to Mar. 31, 1967).	44.9	7	2.7	1.8	1.4	1.2
				14	3.1	1.9	1.5	1.2
				30	4.0	2.3	1.7	1.3
				60	5.2	2.5	1.9	1.5
				90	7.0	3.4	2.5	2.0
				120	8.4	4.4	3.2	2.5
01486000	72	Manokin Branch near Princess Anne, Md. (based on period Apr. 1, 1952, to Mar. 31, 1967).	[a]5.8	7	.1	0	0	0
				14	.2	0	0	0
				30	.2	.1	0	0
				60	.3	.1	0	0
				90	.4	.2	.1	0
				120	.5	.2	.2	.1
01486500	80	Beaverdam Creek near Salisbury, Md. (based on periods Apr. 1, 1930, to Mar. 31, 1932, and Apr. 1, 1939, to Mar. 31, 1967).	19.5	7	5.4	[R]2.8	[R]1.4	[R].7
				14	6.4	4.4	3.5	[R]2.5
				30	7.6	5.2	4.3	3.5
				60	8.6	6.4	5.4	4.7
				90	9.6	7.0	6.0	5.2
				120	10	7.2	6.3	5.6
01487000	86	Nanticoke River near Bridgeville, Del. (based on period Apr. 1, 1943, to Mar. 31, 1967).	75.4	7	22	16	14	12
				14	23	18	15	13
				30	25	19	15	13
				60	28	20	17	14
				90	33	23	19	16
				120	36	26	21	18

TABLE 6.—*Magnitude and frequency of annual low flow at daily-record gaging stations*—Continued

Station No.	Index No. (pl. 1)	Station name	Drainage area (sq mi)	Period (consecutive days)	Annual low flow, in cubic feet per second, for indicated recurrence interval, in years: 2	5	10	20
01487500	91	Trap Pond Outlet near Laurel, Del. (based on period Apr. 1, 1952, to Mar. 31, 1967).	16.7	7	0.3	0.2	0.1	0.1
				14	.6	.2	.1	.1
				30	.8	.4	.3	.2
				60	1.4	.5	.3	.2
				90	2.3	.7	.4	.3
				120	3.0	1.3	.8	.6
01488500	99	Marshyhope Creek near Adamsville, Del. (based on period Apr. 1, 1943, to Mar. 31, 1967).	44.8	7	4.6	2.6	2.0	1.5
				14	4.8	2.8	2.2	1.8
				30	5.6	3.6	2.8	2.4
				60	7.5	4.4	3.4	2.7
				90	9.0	5.3	3.9	3.1
				120	11	6.3	4.7	3.7
01489000	103	Faulkner Branch at Federalsburg, Md. (based on period Apr. 1, 1951, to Mar. 31, 1967).	7.10	7	1.0	.3	.1	0
				14	1.0	.5	.4	.3
				30	1.3	.8	.7	.6
				60	1.7	1.1	.8	.7
				90	2.1	1.2	.9	.7
				120	2.6	1.5	1.1	.9
01490000	115	Chicamacomico River near Salem, Md. (based on period Apr. 1, 1952, to Mar. 31, 1967).	15.0	7	3.3	2.2	1.8	1.5
				14	3.6	2.8	2.5	2.2
				30	4.4	3.2	3.0	2.8
				60	4.6	4.0	3.6	3.4
				90	5.5	4.6	4.2	3.8
				120	6.3	5.0	4.5	4.2
01491000	119	Choptank River near Greensboro, Md. (based on period Apr. 1, 1948, to Mar. 31, 1967).	113	7	10	6.0	4.5	3.4
				14	12	7.3	5.7	4.5
				30	14	8.8	7.0	5.8
				60	17	10	8.3	6.8
				90	20	13	11	9.0
				120	26	15	12	9.9
01492000	141	Beaverdam Branch at Matthews, Md. (based on period Apr. 1, 1951, to Mar. 31, 1967).	5.85	7	.1	0	0	0
				14	.1	0	0	0
				30	.2	.1	0	0
				60	.4	.1	.1	0
				90	.5	.2	.2	.1
				120	.9	.3	.2	.2
01493000	157	Unicorn Branch near Millington, Md. (based on period Apr. 1, 1948, to Mar. 31, 1967).	22.3	7	6.6	4.8	3.9	[R]3.3
				14	7.2	5.4	4.3	3.6
				30	7.6	5.6	4.6	3.9
				60	8.8	6.4	5.2	4.4
				90	9.5	6.8	5.8	5.0
				120	10	7.2	6.0	5.2
01493500	161	Morgan Creek near Kennedyville, Md. (based on period Apr. 1, 1952, to Mar. 31, 1967).	10.5	7	2.9	1.8	1.4	1.0
				14	3.2	2.0	1.5	1.1
				30	3.7	2.2	1.6	1.2
				60	4.3	2.7	2.1	1.6
				90	4.9	3.0	2.2	1.7
				120	5.4	3.4	2.6	2.0
01495000	172	Big Elk Creek at Elk Mills, Md. (based on period Apr. 1, 1932, to Mar. 31, 1967).	52.6	7	19	12	8.9	7.2
				14	20	13	9.6	7.7
				30	22	14	11	8.7
				60	26	17	13	11
				90	30	19	15	12
				120	33	22	18	15
01496000	180	Northeast Creek at Leslie, Md. (based on period Apr. 1, 1949, to Mar. 31, 1967).	24.3	7	4.7	2.8	2.1	1.6
				14	5.0	3.0	2.3	1.8
				30	5.7	3.4	2.6	2.1
				60	7.2	4.4	3.5	2.9
				90	8.9	5.2	4.0	3.2
				120	10	6.3	4.8	3.8

record stations. These characteristics are given in table 2.

Five to eight discharge measurements, made over a period of three low-flow seasons, were available to define the flow relation between the miscellaneous measuring sites and the long-term daily-record stations. Where a usable relation could be defined (fig. 14), the 7-day low flow values for 2- and 10-year recurrence intervals are given in table 2. The extrapolation of the relation curves to estimate the 7-day 20-year low flow did not seem warranted. Low-flow data for the miscellaneous sites are somewhat less reliable than those for the partial-record and short-term daily-record stations. A usable relation for some sites could not be found, and for these sites the minimum discharge measured, converted to cubic feet per second per square mile, is shown in parentheses in table 2.

Thomas and Benson (1970) found that the low-flow characteristics of ungaged streams cannot be adequately estimated from basin characteristics determined from presently available maps. The inability to predict this part of streamflow behavior can probably be attributed to the fact that no convenient method has been found to describe, quantitatively, the composite effect of basin geology (lithology) on low flow.

The 7-day 2-year minimum annual low flows on

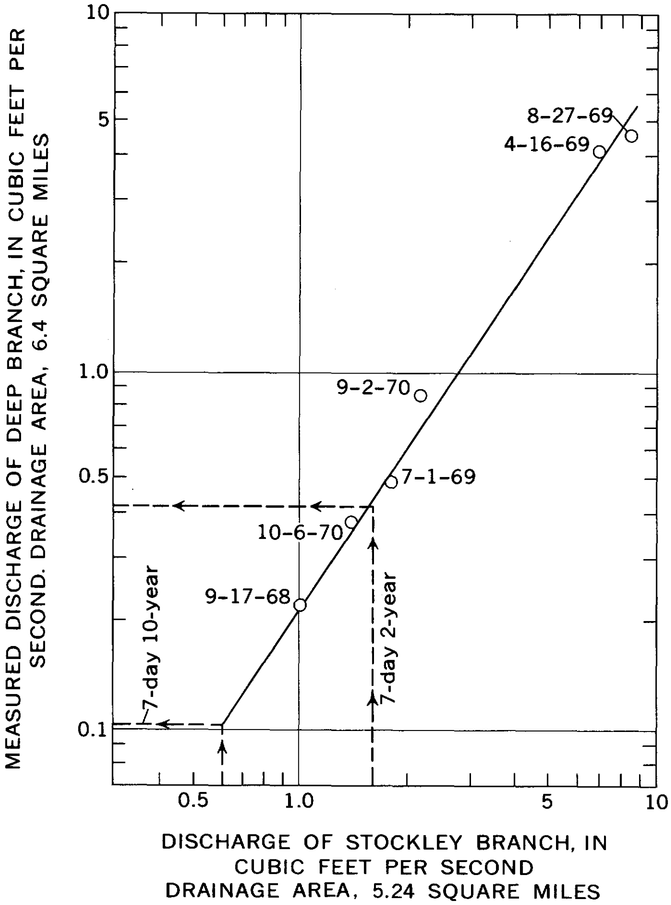

FIGURE 14.—Relation between low-flow measurements of Deep Branch near Mt. Joy, Del. (site 38), and concurrent daily flows of Stockley Branch at Stockley, Del. (site 39).

the peninsula range from 0 to 1.16 cfs per sq mi (cubic feet per second per square mile), and the 7-day 10-year minimum annual low flows range from 0 to 0.77 cfs per sq mi (table 2). The highest values are for Beaverdam Creek near Milton, Del. (site 35).

The low-flow data were plotted on maps (pl. 1), and three ranges of flow per square mile were used to show the general areal patterns. Although the pattern boundaries are extended to include the marshy areas along the bays, ocean, and tidal reaches of streams, little is known about streamflow in these areas. These maps are useful as a reconnaissance tool in finding streams with high sustained yields. The determination of specific flow characteristics at an ungaged site, however, will require the collection of some flow data.

DRAFT-STORAGE RELATIONS

If the minimum natural flow of a stream (tables 2 and 6) is not sufficient to supply a desired draft

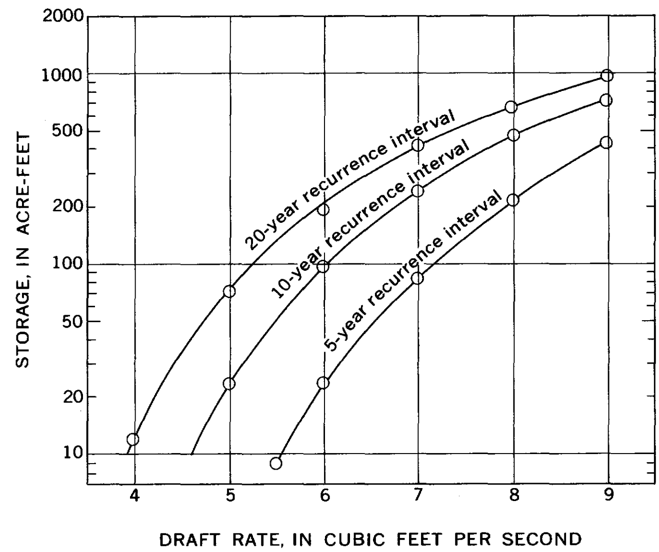

FIGURE 15.—Draft-storage frequency relations for Unicorn Branch near Millington, Md. (site 157).

rate, storage will be needed to compensate for the deficiency in flow. Draft-storage frequency data will assist the user in weighing the benefits of increased draft rates against the cost of providing the required storage.

Low-flow frequency data (table 6) for 21 daily-record gaging stations were used to compute the storage required to maintain selected draft rates during periods of low flow ranging in length from 7 to 120 days. The discharge values for a specific recurrence interval (table 6) were multiplied by the number of consecutive days to determine the volume of water available under natural flow conditions. A selected draft rate was multiplied by the same number of days to determine the volume of water required to maintain that draft rate. The maximum difference between volume required and volume available is used as the storage required to maintain the draft rate. Repetitive computations based on gradually increased draft rates at a specific recurrence interval were used to define draft-storage frequency relations (fig. 15) for each daily-record station for the 5-, 10-, and 20-year recurrence intervals. Data extracted from each station relation are given in table 7 on a unit-area basis to facilitate comparison among sites.

Draft-storage frequency data are based on an assumed uniform draft rate. Moreover, the data imply a risk that the storage will be depleted at average intervals equal to the recurrence interval of the low-flow data used in the computation. For example, storage amounts based on the 20-year recurrence interval would be inadequate on the average of five

TABLE 7.—*Draft-storage frequency for daily-record gaging stations*

Station No.	Index No. (pl. 1)	Station name	Drainage area (sq mi)	Available draft, in cubic feet per second per square mile, for indicated storage, in acre-feet per square mile: 5-year recurrence interval					10-year recurrence interval					20-year recurrence interval				
				2	5	10	15	20	2	5	10	15	20	2	5	10	15	20
01478000	4	Christina River at Coochs Bridge, Del	20.5	0.17	0.21	0.25	0.28	0.31	0.13	0 17	0.21	0.24	0.26	0.11	0.14	0 17	0.20	0.23
01478500	6	White Clay Creek above Newark, Del	66.7	.21	.26	.31	.35	.38	.18	.22	.27	.30	.33	.16	.20	.24	.28	.31
01479000	8	White Clay Creek near Newark, Del	87.8	.28	.32	.36	.40	.43	.19	.24	.30	.35	.38	.16	.21	.27	.30	.33
01480000	10	Red Clay Creek at Wooddale, Del	47.0	.30	.36	.42	.47	.51	.25	.30	.36	.41	.45	.21	.26	.32	.36	.40
01481500	12	Brandywine Creek at Wilmington, Del	314	.32	.36	.40	.45	.49	.28	.32	.37	.40	.43	.25	.30	.34	.37	.39
01483500	20	Leipsic River near Cheswold, Del	9.35	.32	.39	.44	.47	.49	.29	.34	.40	.43	.46	.27	.32	.35	.38	.41
01484300	33	Sowbridge Branch near Milton, Del	7.08	.42	.49	.54	.58	.62	.37	.44	.47	.52	.56	.30	.37	.44	.47	.51
01484500	39	Stockley Branch at Stockley, Del	5.24	.23	.28	.32	.35	.38	.19	.23	.26	.30	.32	.15	.20	.23	.26	.28
01485000	63	Pocomoke River near Willards, Md	60.5	.11	.13	.15	.18	.21	.09	.11	.14	.17	.19	.07	.09	.12	.15	.17
01485500	69	Nassawango Creek near Snow Hill, Md	44.9	.07	.10	.13	.16	.18	.06	.08	.11	.13	.15	.05	.07	.10	.12	.14
01486500	80	Beaverdam Creek near Salisbury, Md	19.5	.30	.36	.41	.45	.46	.24	.31	.36	.39	.41	.19	.27	32	.35	.37
01487000	86	Nanticoke River near Bridgeville, Del	75.4	.28	.31	.35	.38	.42	.24	.27	.31	.34	.36	.20	.23	.26	.29	.32
01487500	91	Trap Pond Outlet near Laurel, Del	16.7	.05	.07	.10	.13	.15	.04	.06	.08	.11	.13	.03	.05	.07	.10	.12
01488500	99	Marshyhope Creek near Adamsville, Del	44.8	.11	.14	.17	.20	.22	.09	.12	.14	.17	.19	.08	.10	.12	.14	.16
01489000	103	Faulkner Branch at Federalsburg, Md	7 10	.14	.18	.23	.26	.28	.13	.15	.18	.21	.23	.11	.13	.16	.18	.21
01490000	115	Chicamacomico River near Salem, Md	15.0	.24	.30	.35	.39	.42	.23	.28	.32	.36	.39	.21	.27	.31	.34	.37
01491000	119	Choptank River near Greensboro, Md	113	.10	.13	.17	.19	.22	.09	.12	.15	.17	.19	.08	.10	.13	.15	17
01493000	157	Unicorn Branch near Millington, Md	22 3	.29	.33	.36	.39	.41	.24	.28	.31	.33	.36	.21	.24	.27	.30	.32
01493500	161	Morgan Creek near Kennedyville, Md	10.5	.21	.29	.33	.38	.40	.17	.23	.27	.30	.32	.14	.20	22	.25	.27
01495000	172	Big Elk Creek at Elk Mills, Md	52.6	.30	.35	.40	.44	.47	.24	.29	.33	.36	.40	.20	.24	.28	.31	.34
01496000	180	Northeast Creek at Leslie, Md	24.3	.17	.21	.26	.30	.33	.14	.18	.22	.25	.28	.12	.15	.19	.22	.24

times in a 100-year period. The draft-storage frequency data do not indicate the magnitude of the deficiency or the length of time it will persist.

Storage data greater than 20 acre-feet per square mile of drainage area have not been shown. The number of sites for which more than this amount of storage can be provided will be limited because of the flat terrain of the peninsula. At the 20-year recurrence interval, storage of 20 acre-feet per square mile will usually increase the dependable draft from two to five times the amount available under natural flow conditions. This amount of storage is generally less than 5 percent of the average yearly flow of streams on the peninsula.

Ideally, the computation of the storage required to maintain a selected draft rate should be based on a long record of streamflow at the site. This ideal situation, however, seldom exists. In order to provide a means for evaluating the reservoir potential of many sites on the peninsula, the draft-storage frequency data were related to the median annual 7-day (7-day 2-year) low flows (figs. 16–18). This index of low flow is given in table 2 for 152 sites on the peninsula. It can be estimated for other sites by making a few discharge measurements of low flow and relating these discharges to concurrent discharges at a nearby daily-record gaging station. The draft-storage relations should not be used at sites having a low-flow index of zero.

Storage requirements based on low-flow frequency data may be biased by as much as 10 percent on the low side. No adjustment has been made for this bias in the computed data in table 7 or in the regional relations. Furthermore, the tabulated data and the regional relations do not take into account reservoir losses, such as seepage and evaporation, or losses re-

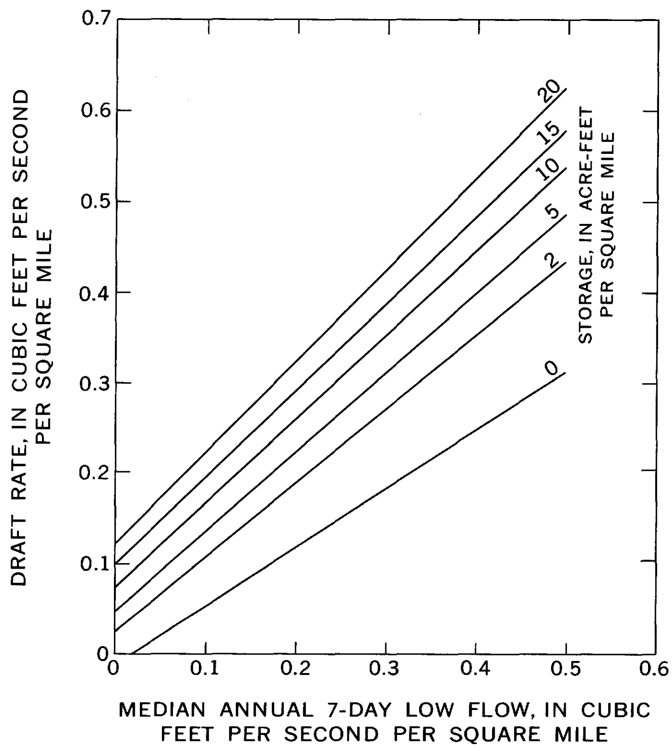

FIGURE 16.—Areal draft-storage relations for a 5-year recurrence interval.

sulting from transporting the water from the reservoir to the point of use.

The regional draft-storage frequency relations presented here are intended for use as a reconnaissance tool. A more detailed study of the geologic and hydrologic conditions at a specific site should be made for design purposes.

Illustrative problem.—Assume that a manufacturing company is investigating a plant site in northern

Kent County, Md., near site 170 (pl. 1). The water requirements for the proposed plant are 1.5 mgd

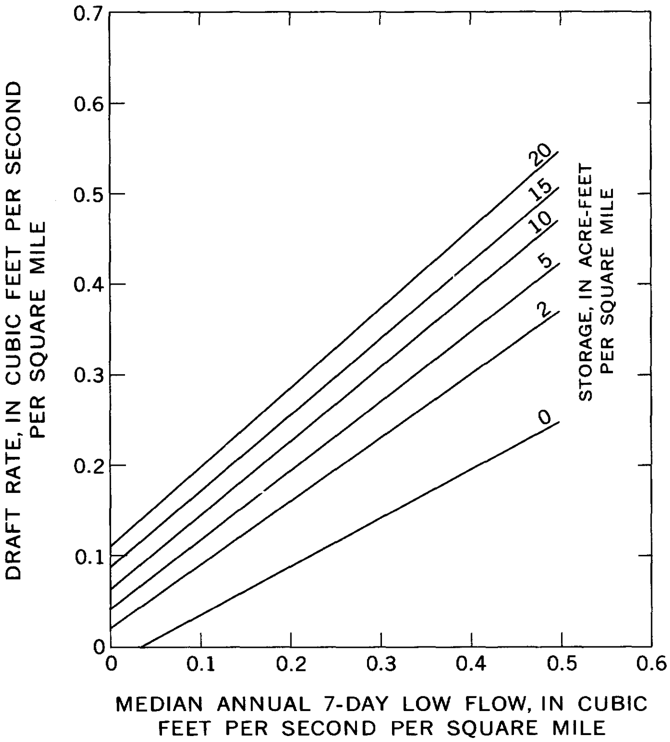

FIGURE 17.—Areal draft-storage relations for a 10-year recurrence interval.

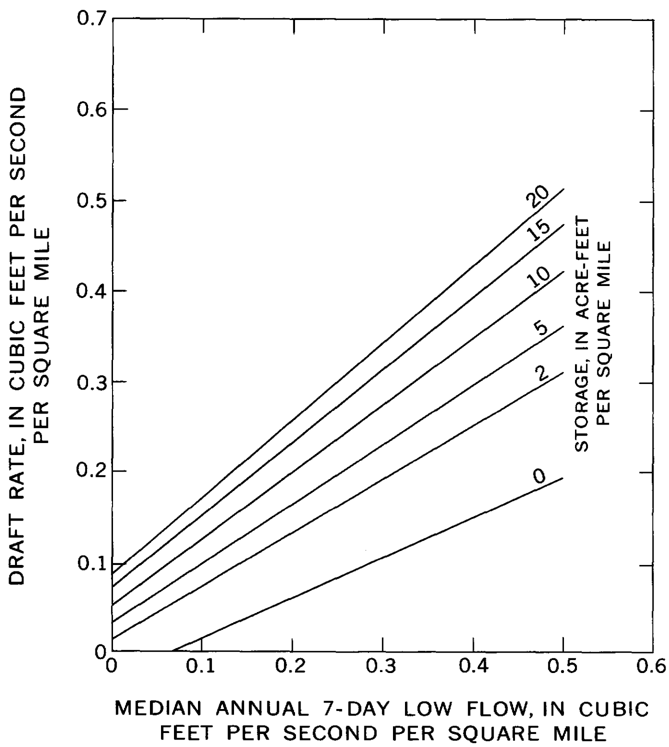

FIGURE 18.—Areal draft-storage relations for a 20-year recurrence interval.

(million gallons per day) and for economic reasons the available draft rate should not drop below this value more than once every 20 years on a long-term average. How much storage will be required to develop this water supply from Jacobs Creek at State Highway 290?

1. From table 2, the drainage area of Jacobs Creek near Sassafras, Md., (site 170) is 5.39 square miles, and the 7-day 2-year low flow is 0.45 cfs per sq mi.
2. Convert 1.5 mgd to cubic feet per second per square mile.

$$\frac{1.5\text{ mgd}\times\frac{1.55\text{ cfs}}{1\text{ mgd}}}{5.39\text{ sq mi}}=0.43\text{ cfs per sq mi.}$$

3. Use figure 18 for a 20-year recurrence interval. The abscissa is 0.45 cfs per sq mi and the ordinate is 0.43 cfs per sq mi. The required storage is 15 acre-feet per sq mi, or a total of 81 acre-feet. This storage should be increased by 10 percent for bias. If the reservoir and conveyance losses are assumed to be 15 percent, the total storage required is 125 percent of 81 acre-feet (101 acre-feet). A topographic survey of the site would be required to determine if a reservoir containing this volume of storage could be developed. It should be emphasized that a reservoir-site study has not been made on Jacobs Creek.

AVERAGE RUNOFF

Runoff on the peninsula varies from year to year (fig. 4), seasonally within each year (fig. 19), and

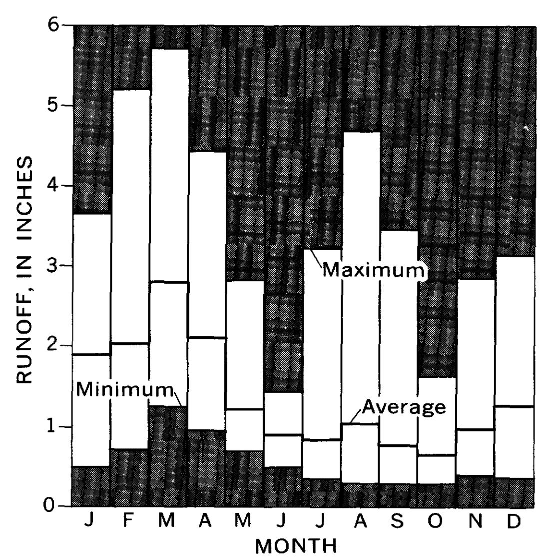

FIGURE 19.—Monthly runoff for Nanticoke River near Bridgeville, Del., 1949–65.

from day to day (fig. 20). This streamflow variability with time and location is graphically illustrated by the two hydrographs shown in figure 20 for streams that have approximately the same size drainage basins. The maximum daily flow of Sowbridge Branch is seven times the minimum daily flow for the 1960 water year, whereas, the maximum daily flow of Beaverdam Branch is 3,500 times the minimum daily flow.

To estimate the average runoff for the peninsula, it was desirable to have comparable runoff data for as many basins as possible. The fact that the daily-record gaging stations on the peninsula have been operated for periods ranging from 5 to 32 years

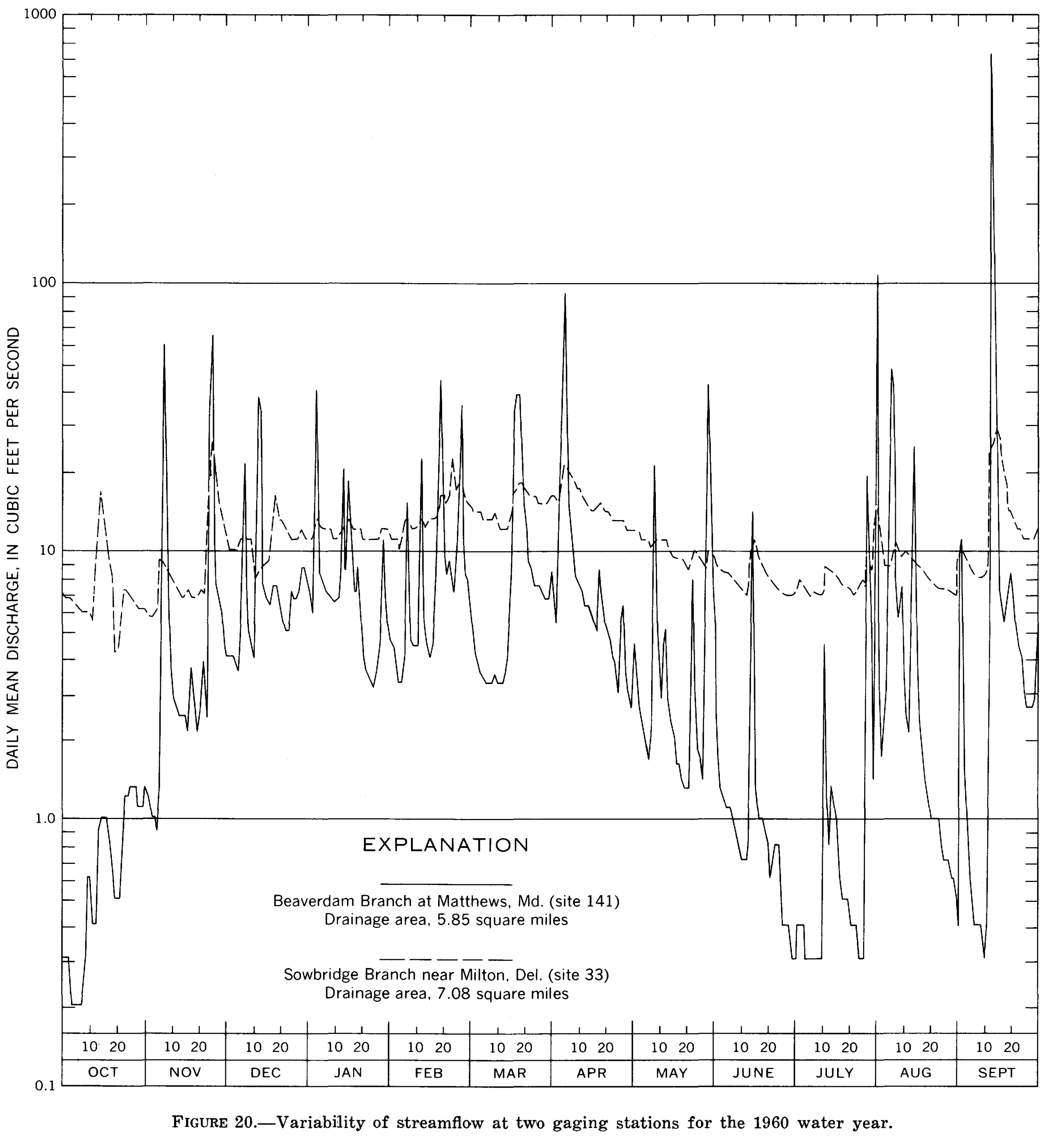

FIGURE 20.—Variability of streamflow at two gaging stations for the 1960 water year.

would indicate a need for adjusting these records to a common reference period. Records for short periods do not usually include the variations in flow typical of longer periods and may be significantly affected by a series of wet or dry years. As a test for a possible time bias in the flow data, the records at 15 long-term gaging stations were divided into three shorter periods. The average discharge determined from each of the shorter periods was compared to the average discharge from the total period. The beginning of the three periods chosen for comparison coincides with dates when new gaging stations were established. The comparisons (fig. 21) indicate little would be gained by adjusting the records to a common reference period.

The average annual runoff for the daily-record gaging stations was determined for the period of operation (fig. 22). The records available at site 53, Guy Creek near Nassawadox, Va., are for the period 1963–67 and include a severe drought. The average runoff shown for this station (fig. 22) is an estimate determined by adjusting the runoff to that at a nearby longer-term station. Average runoff for the gaged basins on the peninsula ranges from 9 to 19 inches per year. Runoff observed for extreme years has ranged from 4 to 33 inches.

Average runoff at each station was weighted by the drainage area upstream from the gaging station, and the sum of these products was divided by the total gaged area to give an average runoff for the peninsula of 15 inches per year. The method used to determine average runoff is based on the assumption that the gaged area is a representative sample of the entire peninsula. This assumption may not be valid, because the gaged areas are necessarily confined to upland areas, and the runoff characteristics of the many square miles of lowland are not known. Although the extremes of runoff on the peninsula cover a fairly wide range (fig. 22), 20 of the 26 gaged basins that lie entirely within the study area have an average annual runoff that is within 2 inches of the peninsula average of 15 inches.

An average annual runoff of 15 inches is equivalent to a discharge rate of about 4,500 mgd from the peninsula. This quantity is the approximate total annual fresh-water yield of the peninsula under the existing climatic and hydrologic conditions.

BASE FLOW

The base flow of the streams is ground-water discharge from the underlying aquifers. Therefore, base flow is a measure of the perennial ground-water yield of the peninsula.

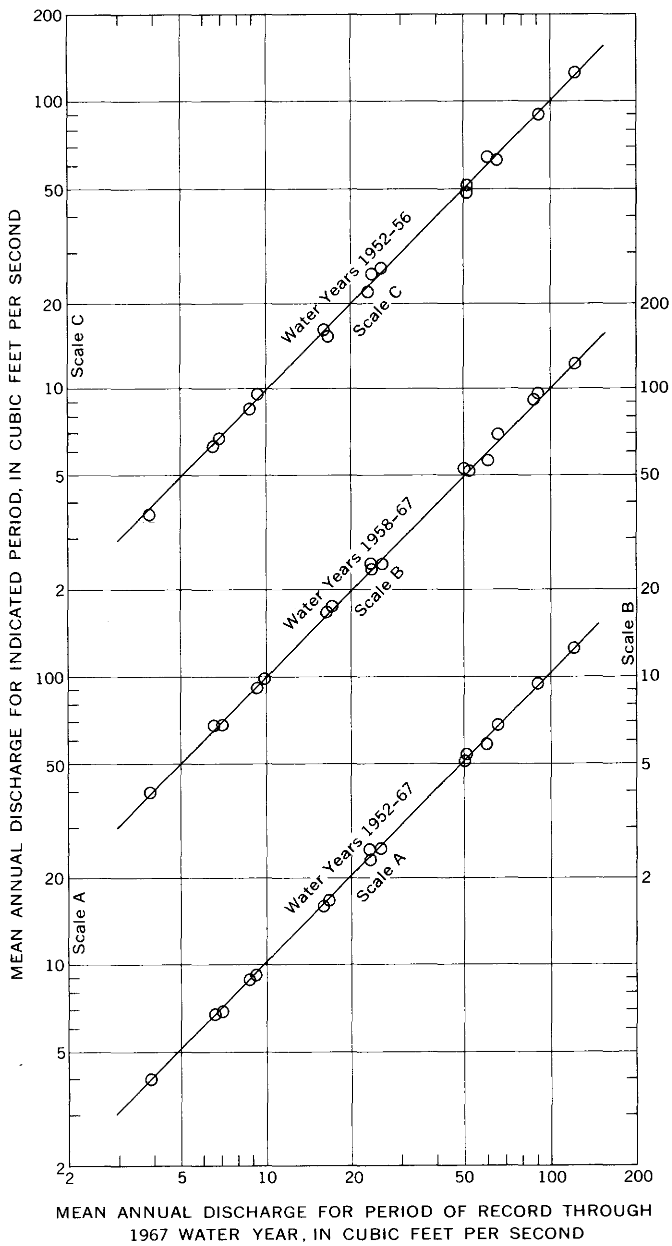

FIGURE 21.—Comparison of average discharge for varying periods of record.

The base flow of a stream can be determined by separating the overland flow from the total discharge on a streamflow hydrograph. Johnston (1971), using the hydrograph-separation techniques described by Riggs (1963), determined the amount of ground water released to streams above four gaging stations in southern Delaware and found that for a 10-year period base flow ranged from 76 to 81 percent of the total streamflow.

To determine the ground-water discharge to streams in other areas of the peninsula and to in-

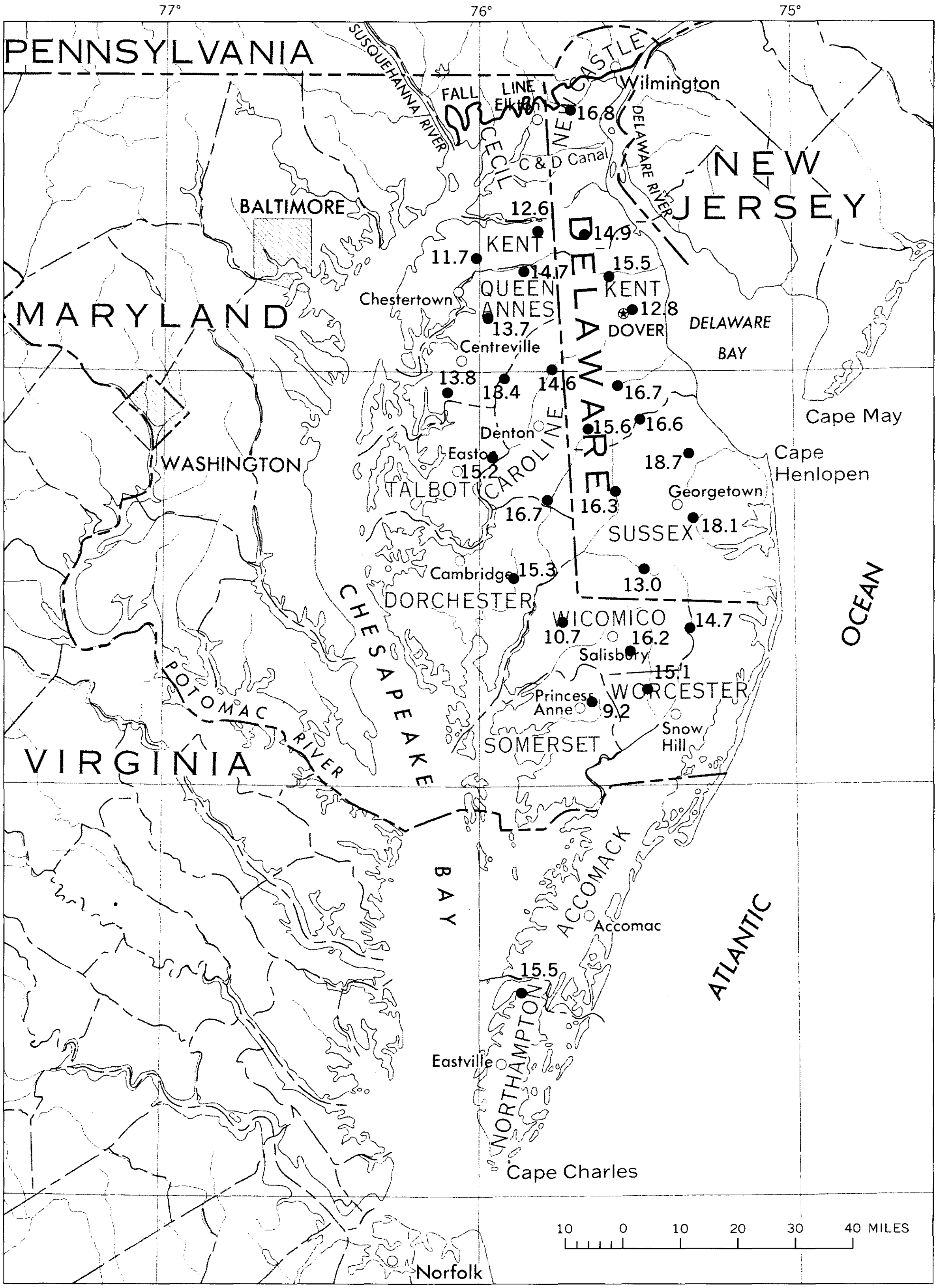

FIGURE 22.—Average annual runoff, in inches, at daily-record gaging stations.

clude a broader range in basin size and streamflow variability, hydrographs for 10 years of record were prepared for six other gaging stations. Overland flow on these hydrographs was separated from total discharge by inspection, and the base flow ranged from 37 to 64 percent of the total streamflow.

The base flow for the 10 years of record at the 10 stations was related to the discharge at the 50-percent flow-duration point (median flow). The relation shown (fig. 23) is empirical. The individual points are the base flow for a year of record plotted against the median flow for that particular year. For comparison, all values are plotted in discharge per unit area to remove the effect of basin size. The circled points are the average base flow for the 10-year period. The relation line is one of equality, and points plotting on the line indicate there is no difference between base flow determined from hydrograph separation and base flow determined from median flow. Three data points from other studies of base flow on or near the peninsula are also shown (fig. 23). These three values are not for a period equal in length or concurrent with the other data but do, however, tend to strengthen confidence in the relation.

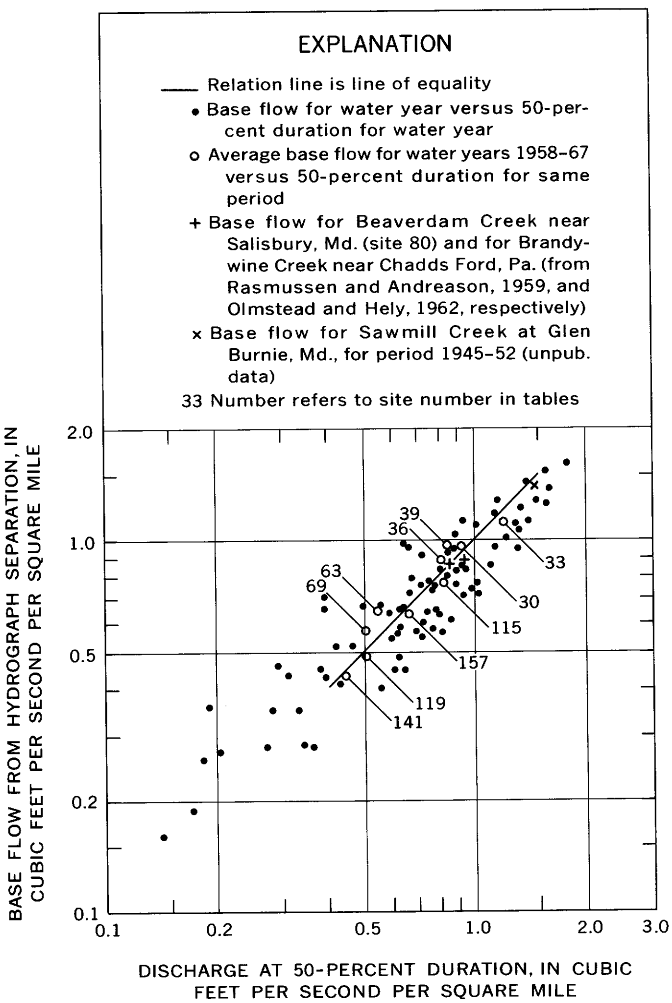

FIGURE 23.—Relation between base flow and flow at 50-percent duration.

The validity of the relation between base flow and median flow (fig. 23) facilitates estimating base flow for reconnaissance purposes without using time-consuming hydrograph-separation techniques. Median flow at gaging stations can be determined quickly by processing daily flows through a simple computer program. Median flows (50-percent duration) for all daily-record gaging stations on the peninsula are shown in table 3.

The relation between base flow and median flow was assumed to be valid for all gaging stations on the peninsula. By using the median flow for each gaging station (table 3), and weighting the data on the basis of drainage area, the base flow of streams on the peninsula was computed as 8½ inches per year (about 2,500 mgd from the 6,500 square miles of the peninsula). Average base flow for the individual gaged basins ranges from 3½ to 16½ inches per year (fig. 24). Base-flow values for extreme years have ranged from 2½ to 22 inches.

OVERLAND FLOW

Overland flow is precipitation that falls directly on a surface-water body or that reaches it by flowing over the land surface. Most of the water in streams during and shortly after storms is overland flow.

The amount of overland flow from the peninsula is about 6½ inches per year (15 inches of average runoff less 8½ inches of base flow). This is about 43 percent of the total streamflow, or an average of about 2,000 mgd. For gaged basins on the peninsula, average annual overland flow ranges from 2 to 9 inches per year, and individual annual values range from 1 to 22 inches per year.

In general, the flat terrain on the peninsula does not lend itself to the retention of overland flow for use at a later time. Within a short time after precipitation ends, overland flow has entered the bays or ocean and is no longer available as a fresh-water supply.

WATER QUALITY

The chemical quality of the surface water on the Delmarva Peninsula varies with time and location. Variations of quality with time are influenced by the

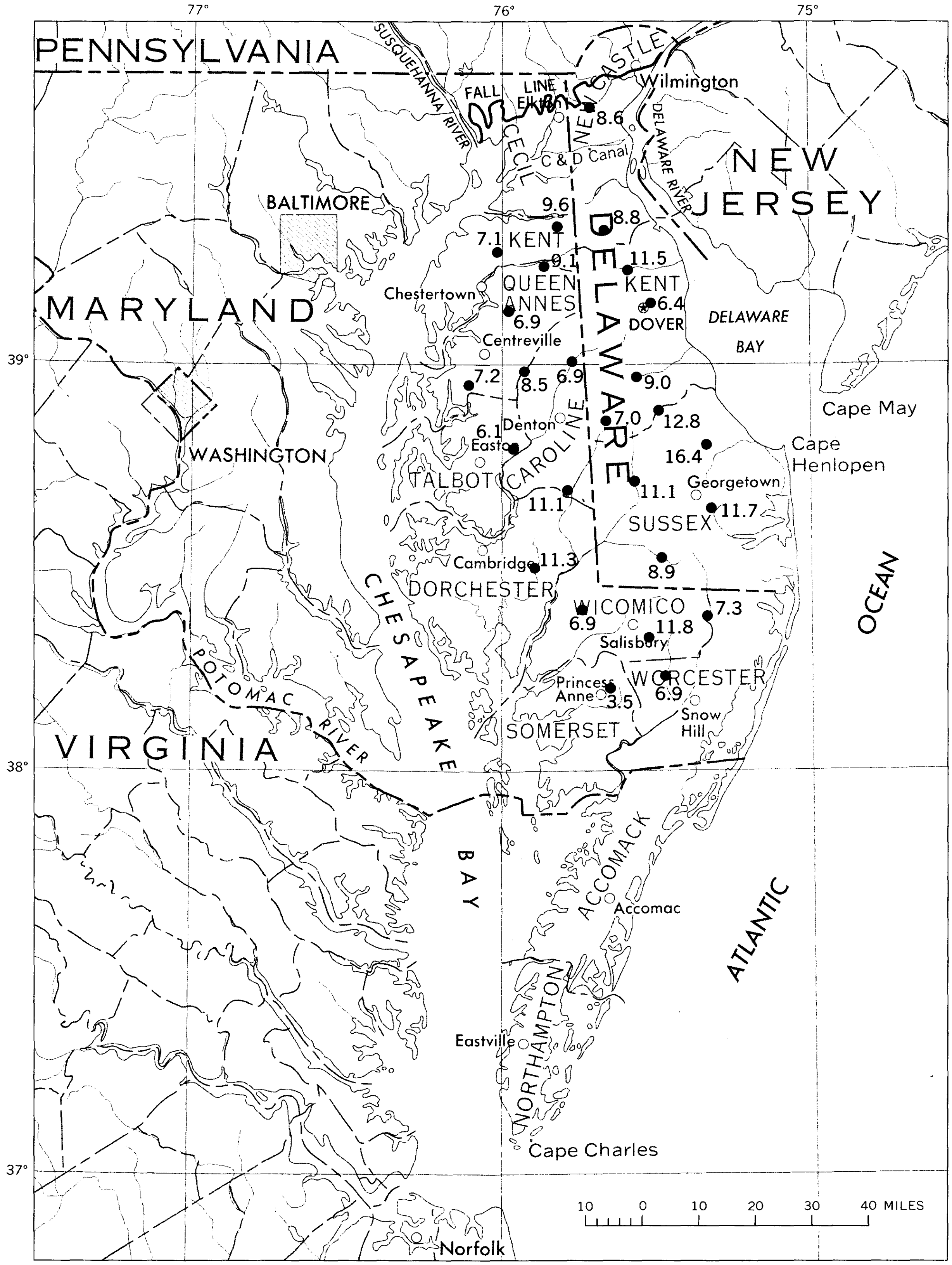

FIGURE 24.—Average annual base flow, in inches, at daily-record gaging stations, as determined from median flow.

relative proportions of the two principal components of streamflow—base flow (ground-water discharge) and overland flow (storm runoff). Variations of quality with location are related to geology and the ground-water flow pattern. Streamflow is generally low in dissolved solids and suitable for most uses except in the downstream reaches of those streams subject to tidal invasion of saline water.

The generally low dissolved-solids content of base flow (pl. 1) indicates that most discharging ground water moves through the ground only a short distance and is in contact with earth material a short time. Water in areas 1 represents precipitation concentrated by evapotranspiration with little further chemical modification. The moderate increases of hardness and bicarbonate concentrations in areas 2 and 3 are the result of the solution of calcareous material by ground water moving toward the streams along longer flow paths or through less permeable material. The relatively high concentrations of hardness and bicarbonate in areas 4 are probably related to local geology. In area 4 near Dover, Del., the Quaternary deposits are thin or absent, and most ground water discharging into the streams has moved through the calcareous Miocene sediments. The chemical nature of base flow in area 4 in northern Delaware is strongly influenced by the weathering products of the crystalline rocks north of the Fall Line. High concentrations of chloride and sodium may reflect man's activities in the Newark-Wilmington metropolitan area. Base flow in area 5 is of the calcium magnesium sulfate type. Sulfate is the dominant anion in precipitation in areas close to the Delmarva Peninsula (Fisher, 1968; Pearson and Fisher, 1971), and atmospheric sulfate probably accounts for the bulk of the sulfate load in the streams of areas 1 through 4. The high concentrations (greater than 50 mg/l) of sulfate in base flow in area 5 may result from (1) abnormally high concentrations of atmospheric sulfate, perhaps resulting from fertilizer dust, (2) contamination of shallow ground water by fertilizer leachate, or (3) generation of sulfate by anaerobic decay of organic material in the geologically young shallow sediments underlying area 5.

To show the variation of chemical concentrations with streamflow, the principal chemical constituents of water were plotted for various rates of flow at site 119, Choptank River near Greensboro, Md. (fig. 25). The site is in water-quality area 3 (pl. 1). As expected, dissolved solids and most of the principal chemical species are less concentrated at higher rates of streamflow. The exceptions are silica, sulfate, and nitrate. Increased silica concentration with increasing discharge may be caused by the chemical breakdown of clay minerals in the suspended sediment load. Increasing sulfate and nitrate concentrations may result from the inflow of fertilizer residue with storm runoff or from the decay of organic material transported in the stream during storms.

The relation between chemical concentration and rate of streamflow (fig. 25) is probably typical of streams in areas 3, 4, and 5 (pl. 1). In areas 1 and 2, the chemical quality of base flow is closer to that of precipitation, so that storm runoff has less of a modifying effect.

GROUND WATER

Ten regional water-bearing units (aquifers) are used as sources of water supply on the Delmarva Peninsula. In ascending order, these aquifers are: Nonmarine Cretaceous, Magothy, Aquia and Rancocas, Piney Point, Cheswold, Federalsburg, Frederica, Manokin, Pocomoke, and Quaternary (fig. 26 and table 1). In addition, between the Magothy aquifer and the Aquia and Rancocas aquifer is a minor water-bearing unit in the Upper Cretaceous sediments (table 1) that is used as a source of domestic water supplies in the northern part of the peninsula. Because its areal extent is not large and the quantities from it seem to be limited to small domestic water supplies, this unit is not discussed further in this report.

In the following sections, each of the 10 regional aquifers is described. For each aquifer, four maps have been prepared: (1) The configuration of the top (configuration of the base for the Quaternary), (2) thickness, (3) potentiometric surface (top of the water table for the Quaternary), and (4) chemical quality of the water.

If the altitude of the land surface is known, the approximate depth to the top of an aquifer can be determined at any site by use of the map showing the configuration of the top of the aquifer. This map also delineates the areal extent of the aquifer, the area where the aquifer contains fresh water, and the areas of use and potential use. The area of use was delineated from existing water-supply wells. The area of potential use is that area where the aquifer apparently contains water having a dissolved-solids content of less than 1,000 mg/l, but where water wells have not been drilled into the aquifer. The fact that some aquifers may have large areas of use does not indicate that the aquifer is developed to its full potential for supplying water.

The relative potential of an aquifer can be inferred from the thickness map; generally the thicker parts of an aquifer are more favorable areas for water-

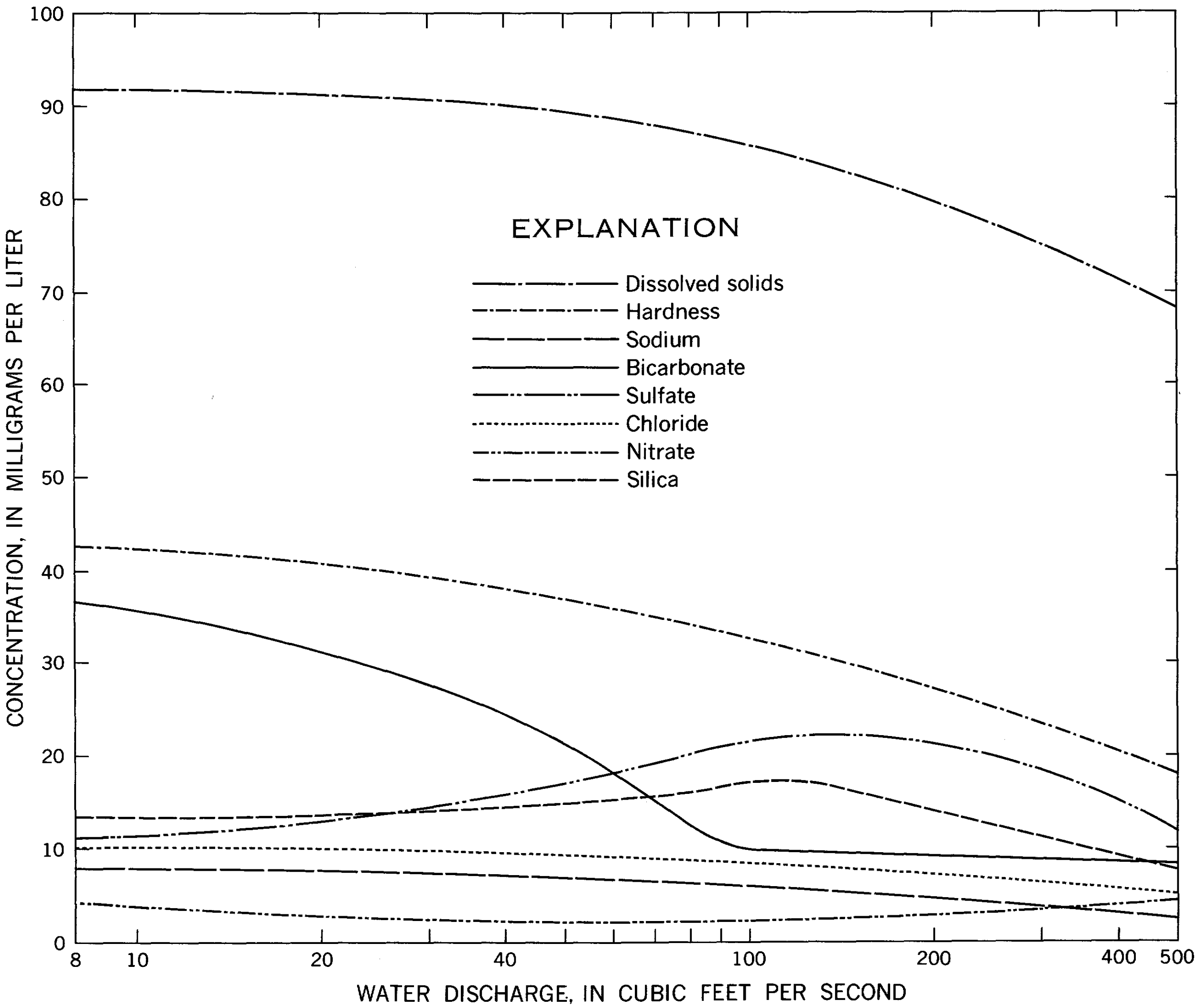

FIGURE 25.—Relation between chemical constituents of the water and streamflow for Choptank River near Greensboro, Md. (site 119).

supply development. Maps showing lines of equal transmissivities would be more useful, but sufficient data are not available to prepare them. However, the range in transmissivity of each aquifer, together with the range in the storage coefficient, is given in the aquifer discussions. These hydraulic characteristics are measures of an aquifer's capacity to transmit and store water.

The potentiometric-surface maps (water-table map for the Quaternary aquifer) can be used to determine: (1) Areas where withdrawals have lowered the water level in an aquifer, (2) the approximate direction of natural movement of water in an aquifer, and (3) the approximate depth to the water level in an aquifer if altitude of the land surface is known.

The chemical-quality map has been zoned on the basis of the dissolved-solids content of the water. For any site, the approximate concentration of the principal chemical constituents of water in an aquifer can be determined from the table on the map. Also, areas are delineated where saline water from surface-water bodies may move into the aquifer if ground-water levels are substantially lowered below sea level.

NONMARINE CRETACEOUS AQUIFER

The nonmarine Cretaceous aquifer is one of the more extensive aquifers in the Atlantic Coastal Plain. It consists of a series of interbedded sand, silt, and clay. The individual sand units seem to have some degree of continuity, but, in places, this continuity may be so circuitous that the water contained in them has a significant difference in head (Sundstrom and others, 1967).

On the peninsula the aquifer overlies the basement rocks and is overlain by the Magothy aquifer, other Upper Cretaceous sediments, or Paleocene sediments (P. M. Brown, written commun., 1970). The fresh-water section of the aquifer underlies an area of about 2,500 square miles (pl. 2) and has a maximum thickness of about 700 feet.

The aggregate sand thickness in the fresh-water section is about 150 feet; in places, an individual sand unit may be slightly more than 100 feet thick. The thickness map (pl. 2) shows the thickness of only the uppermost sand unit. From this map and the one showing the configuration of the top of the aquifer (pl. 2), the approximate drilling depth required to construct a well in the uppermost sand can be determined. Except in areas near the downdip limit of fresh water in this aquifer, lower sand units also contain fresh water, but available data are insufficient to define the thickness of the lower units.

RECHARGE, WITHDRAWAL, AND MOVEMENT OF GROUND WATER

The nonmarine Cretaceous aquifer receives most of its recharge near its updip limit, where the permeable individual sand beds are at or near the land surface. The aquifer also receives recharge on the western shore of Chesapeake Bay. About 18½ mgd of water is pumped from wells tapping the aquifer on the peninsula. Although most of the water in the aquifer moves toward local discharge points in the updip part of the aquifer, some water moves downgradient toward the ocean and Delaware Bay (pl. 2).

AQUIFER CHARACTERISTICS

Results of aquifer tests of the nonmarine Cretaceous aquifer show that transmissivity ranges from 550 to 3,000 ft^2 per day and that the storage coefficient ranges from 0.0001 to 0.0005. The storage coefficient may be as much as 0.15 in the water-table part of the aquifer. Reported specific capacities of wells in the aquifer range from less than 1 to 13 gpm (gallons per minute) per foot of drawdown. Reported yields of wells range from 3 to 300 gpm.

WATER QUALITY

Water in the nonmarine Cretaceous aquifer ranges in chemical character from calcium bicarbonate, containing less than 100 mg/l dissolved solids, to sodium chloride bicarbonate, containing more than 1,000 mg/l dissolved solids. The areas of similar water quality (pl. 2) are oriented at right angles to the direction of ground-water movement in the aquifer because the chemical character of ground water changes as the water moves downgradient from recharge to discharge areas.

Area 1 (pl. 2) is characterized by a downgradient increase in hardness. Hardness, a measure of the calcium and magnesium content of water, reaches a maximum in this area. The concentrations, however, are fairly low because only a small quantity of calcareous material is present in the aquifer. Areas 2 and 3 are characterized by a downgradient increase in sodium and bicarbonate and a decrease in hardness. Water in areas 4 and 5 show the effect of a progressive mixing with saline water.

The downdip limit of fresh water in the nonmarine Cretaceous aquifer is the boundary between areas 4 and 5 (pl. 2). The position of this interface is based on chemical analyses and interpretations of multiple-point electric logs of wells at Chestertown and Cambridge, Md., Atlantic, Va., and wells 14 miles southwest and 15 miles north of Dover, Del.

AREA OF POTENTIAL USE

The nonmarine Cretaceous aquifer is used extensively in northern New Castle County, Del., and to a lesser degree elsewhere (pl. 2). The area of potential use is about 1,750 square miles, mostly in Maryland. The aquifer has not been tapped in this area primarily because of the availability of shallower ground water. Substantial amounts of water seem to be available, but the quantity and quality of the water at a site can be determined accurately only by test drilling, pumping, and analysis.

The base of fresh water in this aquifer in the central part of the peninsula may be at a greater depth than indicated on plate 12. An electric log of a test well drilled to a depth of 1,600 feet at Cambridge, Md., shows that the aquifer contains fresh water at this depth. If the base of fresh water is significantly deeper, the downdip limit of fresh water could also be farther east (pl. 2), and the nonmarine Cretaceous aquifer could contain fresh water as far east as Vienna, Md., or, possibly, Salisbury, Md. An electric log of the Ohio Oil Co. L. G. Hammond 1, a test hole about 6 miles east of Salisbury, shows that the water in the aquifer is saline; the dissolved-solids content of the water in the upper sand unit is estimated to be 5,000 mg/l.

MAGOTHY AQUIFER

The Magothy aquifer overlies the nonmarine Cretaceous aquifer and is separated from it by a section of clay. The Magothy aquifer is overlain by the Matawan Formation in Maryland and the Merchantville Formation in Delaware (table 1). In most of the Virginia part of the peninsula, the Magothy aquifer is not present or is not a fresh-water aquifer (pl. 3). The aquifer, where it contains fresh water, under-

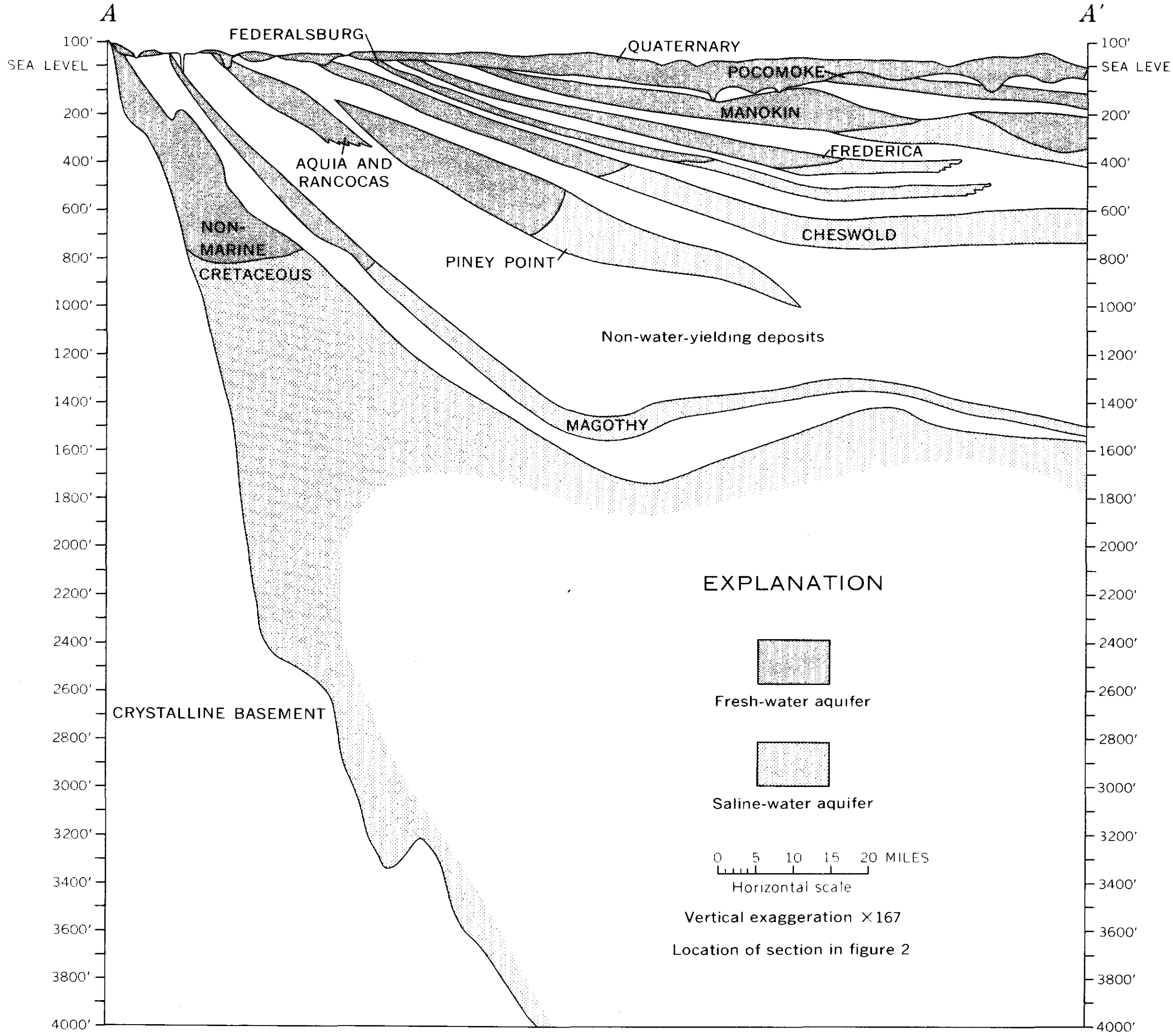

FIGURE 26.—Generalized geologic sections.

lies an area of about 2,200 square miles. The thickness of the aquifer ranges from a featheredge to more than 150 feet (pl. 3). In the areas where the thickness exceeds 50 feet, the character of the geophysical logs seems to indicate that the Magothy aquifer is resting on a sand unit in the nonmarine Cretaceous sediments—a sand-on-sand contact. If indications are correct, the entire sand section probably functions as a hydrologic unit, and it has been mapped as such (pl. 3).

RECHARGE, WITHDRAWAL, AND MOVEMENT OF GROUND WATER

The Magothy aquifer receives most of its recharge near its updip limit. The aquifer also receives recharge on the western shore of Chesapeake Bay. About 2 mgd of water is pumped from wells tapping the Magothy aquifer on the peninsula, 75 percent of which is pumped at Cambridge and Easton, Md., for public supplies. Two fairly deep cones of depression exist in the potentiometric surface in the Cambridge and Easton areas as a result of these withdrawals (pl. 3).

The regional movement of water in the Magothy aquifer is toward Chesapeake Bay, the C&D (Chesapeake and Delaware) Canal, and the Delaware River, in and near the updip part of the aquifer, and also downdip toward the cones of depression and across the peninsula toward Delaware Bay and the ocean.

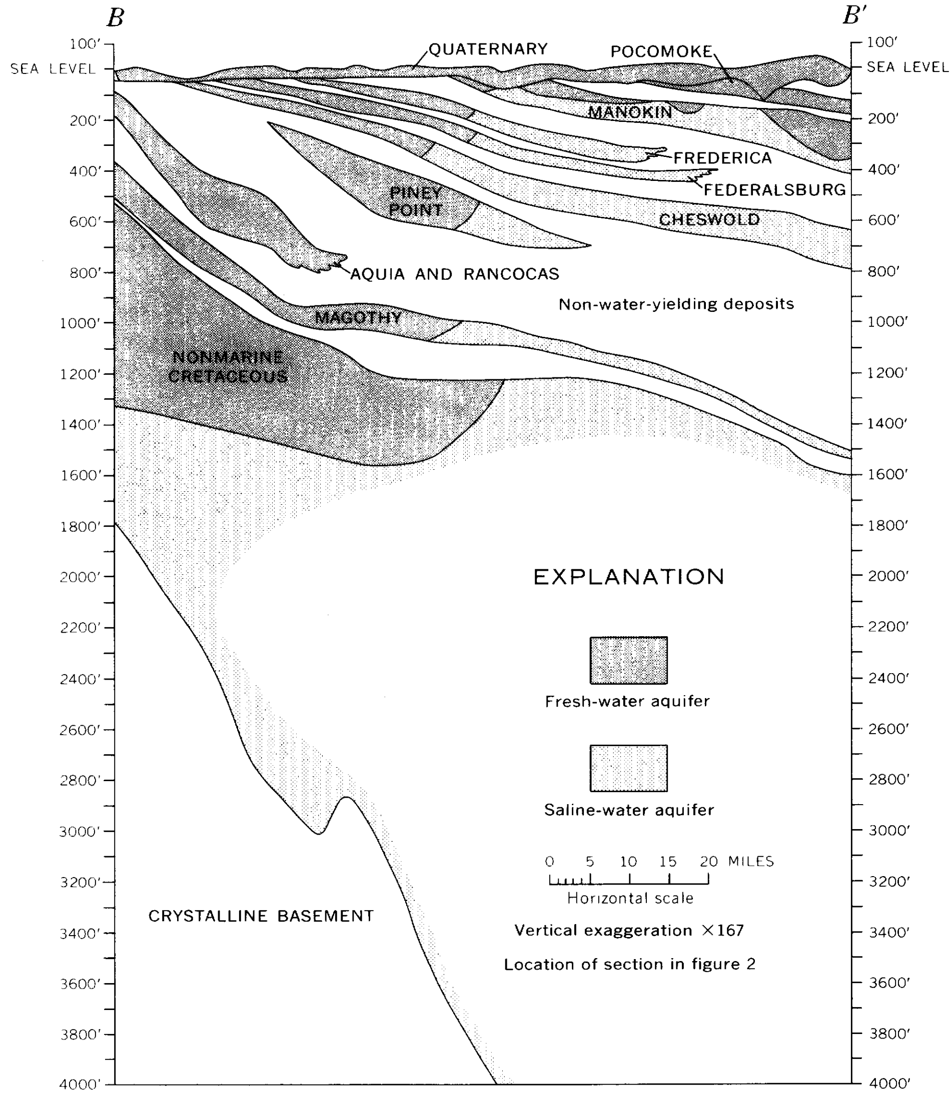

FIGURE 26.—Continued.

AQUIFER CHARACTERISTICS

Results of aquifer tests of the Magothy aquifer on the peninsula indicate that transmissivity ranges from 500 to 3,000 ft^2 per day and that the coefficient of storage is 0.0001. Reported specific capacities of wells in the aquifer range from less than 1 to 7 gpm per foot of drawdown. Reported yields of wells range from 5 to 400 gpm.

WATER QUALITY

Water in the Magothy aquifer ranges in chemical quality from calcium bicarbonate, containing less than 100 mg/l dissolved solids, to sodium bicarbonate, containing more than 1,000 mg/l dissolved solids. In area 1 (pl. 3), hardness increases downgradient and reaches its maximum in the aquifer. Because of a scarcity of calcareous material, even the maximum value (70 mg/l) is fairly low. Water in the remainder of the Magothy aquifer is characterized by increasing bicarbonate and sodium concentrations and decreasing hardness. The water mixes with saline water in area 5 as indicated by the moderately high concentrations of sulfate (65 mg/l) and chloride (100 mg/l) in water from the Magothy aquifer at Crisfield, Md.

The downdip limit of fresh water in the Magothy aquifer is shown by the boundary between areas 4 and 5 (pl. 3). The position of this interface is based largely on interpretations of multiple-point electric logs of wells at Cambridge, Md., and wells 14 miles southwest and 15 miles north of Dover, Del.

AREA OF POTENTIAL USE

The Magothy aquifer is used as a source of water supply in an area immediately downdip from its outcrop belt and at Cambridge, Easton, and Crisfield, Md. (pl. 3). The area of potential use is about 1,800 square miles. The aquifer has not been used in this area primarily because shallow aquifers are available for use as sources of water supply.

AQUIA AND RANCOCAS AQUIFER

The Aquia and Rancocas aquifer overlies lower Paleocene sediments and is overlain by the Nanjemoy Formation (table 1). Downdip it becomes silty and clayey, and the permeability decreases until the unit no longer functions as an aquifer (pl. 4). Where the unit is an aquifer on the peninsula, it contains fresh water and underlies an area of about 1,600 square miles. Its thickness in this area ranges from a featheredge to slightly more than 250 feet (pl. 4).

RECHARGE, WITHDRAWAL, AND MOVEMENT OF GROUND WATER

The Aquia and Rancocas aquifer receives most of its recharge near its updip limit, where it is at or near the surface. About 7 mgd of water is pumped from the aquifer for municipal, industrial, and domestic supplies. The regional movement of water in the aquifer is toward Chesapeake Bay and the Delaware River in and near its updip limit (pl. 4). The change in chemical quality (pl. 4) seems to indicate that water is also moving downdip in the deeper parts of the aquifer toward the facies change.

AQUIFER CHARACTERISTICS

Results of aquifer tests of the Aquia and Rancocas aquifer on the peninsula indicate that transmissivity ranges from 300 to 5,000 ft^2 per day and that the coefficient of storage ranges from 0.0001 to 0.0004. The coefficient of storage in the updip, water-table part of the aquifer is probably about 0.15. Reported specific capacities range from less than 1 to 20 gpm per foot of drawdown. Reported yields of wells in the aquifer range from 4 to 350 gpm.

WATER QUALITY

Water in the Aquia and Rancocas aquifer ranges in chemical quality from calcium bicarbonate, containing less than 100 mg/l dissolved solids, to sodium bicarbonate, containing more than 500 mg/l dissolved solids. In a general way, water-quality areas 1 (pl. 4) correspond to the principal recharge areas of the aquifer on the peninsula. The chemical characteristics of the water in areas 2 indicate that these areas are immediately downgradient from recharge areas. The existence of area 2 in the western part of Queen Annes and Talbot Counties, Md., suggests that this water has moved under Chesapeake Bay from a recharge area on the western shore.

In areas 1 and 2 (pl. 4) hardness concentrations increase downgradient to a maximum of 155 mg/l. Areas 3 and 4 are characterized by increasing bicarbonate and sodium concentrations and decreasing hardness. The moderately high chloride concentrations (as much as 55 mg/l) found in area 3 are limited to that part west of Easton in Talbot County, Md. Contamination by leakage down the annular spaces around well casings is the most likely source of the chloride. The chemical character of water in areas 2A and 3A is similar to that of water in the adjacent areas 2 and 3 in western Talbot and Dorchester Counties, Md., except for differences in hardness and sodium concentrations.

AREA OF POTENTIAL USE

The Aquia and Rancocas aquifer is used in an area of about 1,300 square miles (pl. 4). The area of potential use is about 300 square miles and lies in a belt between the area of use and the downdip limit of the aquifer at the facies change. The aquifer has not been developed in the 300 square miles because it becomes less productive in the direction of the facies change and also because shallower aquifers are available for use as sources of water supply.

PINEY POINT AQUIFER

The Piney Point aquifer overlies the Nanjemoy Formation and is overlain by the Calvert Formation (table 1). The fresh-water part of the aquifer underlies an area of about 2,000 square miles (pl. 5). Its thickness ranges from about 20 to about 270 feet (pl. 5). The upper part seems to be the most productive, as geophysical logs indicate that the aquifer becomes progressively more silty or clayey in the lower part.

RECHARGE, WITHDRAWAL, AND MOVEMENT OF GROUND WATER

The Piney Point aquifer is recharged by leakage from water-bearing sand beds overlying and underlying its updip part. The chemical constituents of water in the Piney Point in area 1 (pl. 5) indicate that in this area the aquifer may be recharged by water from the overlying Calvert Formation. About 9 mgd of water is pumped from the Piney Point, 75 percent of which is for municipal and industrial supplies in and near Dover, Del., and Cambridge, Md. The regional movement of water in the aquifer is from near the updip limit toward the two coalescing cones of depression caused by pumping in the Dover and Cambridge areas (pl. 5).

AQUIFER CHARACTERISTICS

Results of aquifer tests of the Piney Point aquifer on the peninsula indicate that transmissivity ranges from 1,200 to 6,000 ft^2 per day. The coefficient of storage ranges from 0.0002 to 0.0004. Reported specific capacities of wells range from less than 1 to 88 gpm per foot of drawdown, although the upper limit of this range may be incorrect. If the upper limit of the transmissivity range is correct, then the specific capacity of a 100-percent efficient 6-inch well, where the transmissivity is 6,000 ft^2 per day, should be about 22 gpm per foot of drawdown. Reported yields of wells in the aquifer range from 5 to 625 gpm.

WATER QUALITY

Water in the Piney Point aquifer ranges in chemical character from calcium bicarbonate, containing less than 250 mg/l dissolved solids, to sodium chloride bicarbonate, containing more than 1,000 mg/l dissolved solids. The water-quality areas (pl. 5) reflect water movement in the Piney Point under the hydraulic gradient prevailing before large-scale pumping. Although water levels in the aquifer have been greatly modified by pumping (pl. 5), water has moved but little in response to the new gradients.

High concentrations of hardness (as much as 200 mg/l) and silica (as much as 60 mg/l) in area 1 (pl. 5) are evidence of the movement of recharge water into the Piney Point aquifer from the overlying calcareous and diatomaceous Miocene sediments. Water in area 2 is characterized by increasing bicarbonate and sodium concentrations and decreasing hardness. Areas 3 and 4 are characterized by an increasing admixture of saline water.

The downdip limit of fresh water in the Piney Point aquifer is shown by the boundary between areas 3 and 4 (pl. 5). The position of this interface is fairly well defined by available chemical analyses.

AREA OF POTENTIAL USE

The Piney Point aquifer is used in slightly more than half of the area where it contains fresh water (pl. 5). In the area of potential use (about 900 square miles), shallower aquifers are generally available and are adequate to supply the present water needs.

CHESWOLD AQUIFER

The Cheswold aquifer is the basal aquifer in the Miocene sediments. In the downdip area it overlies the Piney Point aquifer and is separated from it by an interval of silt and clay. Near the updip limit of the Piney Point, this separation is small, and, in places, water from the Cheswold aquifer seems to be recharging the Piney Point. The Cheswold is overlain by a silt and clay interval, which separates it from the Federalsburg aquifer. In many of the updip areas this separation is small, and the Cheswold and Federalsburg aquifers may function as a hydrologic unit.

The Cheswold aquifer, where it contains fresh water, underlies an area of about 2,200 square miles (pl. 6). Its thickness ranges from a featheredge at its updip limit to more than 150 feet (pl. 6).

RECHARGE, WITHDRAWAL, AND MOVEMENT OF GROUND WATER

The Cheswold aquifer receives most of its recharge in the area where it is at the surface or near the surface and is overlain by thin younger Miocene or Quaternary sandy units. About 7½ mgd of water is pumped from the Cheswold, 90 percent of which is withdrawn in or near Dover, Del. The regional movement of ground water is toward Chesapeake and Delaware Bays in and near the updip part of the aquifer and also downdip toward the areas of pumping (pl. 6).

AQUIFER CHARACTERISTICS

Results of aquifer tests of the Cheswold aquifer indicate that transmissivity ranges from 200 to 4,000 ft^2 per day. The coefficient of storage ranges from 0.0001 to 0.006 in the artesian part of the aquifer and may be as much as 0.15 in the water-table part. Reported specific capacities of wells range from less than 1 to 25 gpm per foot of drawdown. Reported yields of wells range from 5 to 300 gpm.

WATER QUALITY

Water in the Cheswold aquifer ranges in chemical quality from calcium bicarbonate, containing less than 100 mg/l dissolved solids, to sodium chloride bicarbonate, containing more than 1,000 mg/l dissolved solids. Water-quality areas 1 and 2 (pl. 6) are characterized by a downgradient increase in hardness. Water in area 3 is characterized by increasing bicarbonate and sodium concentrations and decreasing hardness. Mineralization of ground water in areas 4 and 5 is largely the result of the admixture of saline water in the deeper parts of the Cheswold aquifer.

The downdip limit of fresh water in the Cheswold aquifer is shown by the boundary between areas 4 and 5 (pl. 6). The position of this interface is based on interpretations of electric logs of wells at Cambridge and Vienna, Md., and near Laurel, Del., and the position of the downdip limits of fresh water in the overlying aquifers.

AREA OF POTENTIAL USE

The Cheswold aquifer is used in an area of about 450 square miles (pl. 6). The area of potential use is about 1,750 square miles. In this area other aquifers are sufficiently productive to supply the demands for water, and drilling to the Cheswold has not been necessary.

FEDERALSBURG AQUIFER

Between the Cheswold and Frederica aquifers and generally separated from each by a silt and clay interval is a sandy unit in the Miocene sediments referred to in this report as the Federalsburg aquifer. This aquifer can be traced in the subsurface over an area of 2,200 square miles. It is composed of fine to coarse gray sand containing some silt, shells, and shell fragments.

The Federalsburg aquifer is used as a source of water supply at Federalsburg, Md. The type section for the aquifer is based on a single-point electric log of a test well, Ah 3, in Dorchester County, near Federalsburg. The interpretation made of the log places the base of the Frederica at a depth of 190 feet; a less sandy, more silty unit between 190 and 220 feet; the Federalsburg between 220 and 300 feet; and a less sandy, more silty unit between 300 and 310 feet, which separates the Federalsburg from the Cheswold, whose top is at 310 feet. In many places on the peninsula the silty or clayey sections separating the Federalsburg from the overlying and underlying aquifers are thin, so that in some places all three aquifers may function as a hydrologic unit.

Where it contains fresh water, the Federalsburg aquifer underlies an area of about 2,200 square miles. It is absent south of a line trending east and then southeast through the southern part of Maryland into northern Accomack County, Va. (pl. 7). Its thickness ranges from a featheredge at its updip limit to slightly more than 100 feet (pl. 7).

RECHARGE, WITHDRAWAL, AND MOVEMENT OF GROUND WATER

The Federalsburg aquifer receives most of its recharge where it is near the surface and is overlain by younger sandy units. Pumpage is about 3 mgd. The regional movement of water is from the updip part of the aquifer toward the bays and toward areas of pumping (pl. 7).

AQUIFER CHARACTERISTICS

Results of aquifer tests of the Federalsburg aquifer indicate that transmissivity ranges from 450 to 1,400 ft^2 per day. The storage coefficient ranges from 0.0001 to 0.003 but may be as much as 0.15 in the updip, water-table part of the aquifer. Reported specific capacities of wells in the aquifer range from less than 1 to 8 gpm per foot of drawdown. Reported yields range from 4 to 150 gpm.

WATER QUALITY

Water in the Federalsburg aquifer ranges in chemical quality from calcium bicarbonate, containing less than 100 mg/l dissolved solids, to sodium bicarbonate, containing more than 1,000 mg/l dissolved solids (pl. 7). Water-quality areas 1 and 2 represent the part of the Federalsburg aquifer characterized by a downgradient increase in hardness. In areas 3 and 4 the concentrations of bicarbonate and sodium increase and hardness decreases. In area 5, ground water mixes with saline water and becomes increasingly enriched in sodium, chloride, and sulfate.

The downdip limit of fresh water in the Federalsburg aquifer is shown by the boundary between areas 4 and 5 (pl. 7). The position of this interface is based on: Available chemical analyses; interpretation of a multiple-point electric log of a test well 3 miles south of Laurel, Del.; and comparison with the positions of the interface in the overlying and underlying aquifers.

AREA OF POTENTIAL USE

The Federalsburg aquifer is used as a source of water supply over an area of about 500 square miles (pl. 7). Its area of potential use is about 1,700 square miles.

FREDERICA AQUIFER

The Frederica aquifer overlies the Federalsburg aquifer and is separated from it by a silty and clayey interval, which in some places in the updip area is fairly thin. In these places the Frederica and the Federalsburg may function as a hydrologic unit. The Frederica is overlain by the Manokin aquifer and is separated from it by a thick silty and clayey section of Miocene sediments.

Where the Frederica aquifer contains fresh water, it underlies an area of about 2,400 square miles (pl. 8). It is absent south of a line that trends east and then southeast through Somerset and Worcester Counties, Md., into northern Accomack County, Va. Its thickness ranges from a featheredge at its updip limit to slightly more than 150 feet southeast of the limit of fresh water (pl. 8).

RECHARGE, WITHDRAWAL, AND MOVEMENT OF GROUND WATER

The Frederica aquifer receives most of its recharge where it is near the surface and is overlain by younger sandy units. Pumpage is about 3 mgd. The regional movement of water is from the updip part of the aquifer toward the bays and the areas of pumping (pl. 8).

AQUIFER CHARACTERISTICS

Little is known about the aquifer characteristics of the Frederica. A transmissivity of about 1,400 ft^2 per day was determined from one pumping test at Harrington, Del. Reported specific capacities range from 3 to 11 gpm per foot of drawdown. Reported yields of wells range from 5 to 200 gpm.

WATER QUALITY

Water in the Frederica aquifer ranges in chemical character from calcium bicarbonate, containing less than 100 mg/l dissolved solids, to sodium chloride bicarbonate, containing more than 1,000 mg/l dissolved solids. In water-quality areas 1 and 2 (pl. 8) hardness increases downgradient to a maximum of about 200 mg/l and then decreases to about 70 mg/l. Water in area 3 is characterized by increasing bicarbonate and sodium concentrations and decreasing hardness. Chloride, sulfate, and additional sodium ions are added as the water in the downgradient part of area 3 mixes with saline water. In areas 4 and 5 ground water becomes further enriched with sodium, chloride, and sulfate owing to an increasing admixture of saline water.

The boundary between areas 4 and 5 (pl. 8) is the downdip limit of fresh water in the Frederica aquifer. The position of this interface is based on: Available chemical analyses, interpretations of a multiple-point electric log of a well about 6 miles east of Salisbury, and comparison with the positions of the interface in the overlying and underlying aquifers.

AREA OF POTENTIAL USE

The Frederica aquifer is used in an area of about 800 square miles (pl. 8). The area of potential use is about 1,600 square miles. Over much of this area sufficient supplies of water can be obtained from shallower aquifers, and it has not been necessary to drill to the Frederica aquifer.

MANOKIN AQUIFER

The Manokin aquifer overlies the Frederica aquifer and is separated from it by a thick silty and clayey interval. The Manokin is overlain by the Pocomoke aquifer, or, in places, by the Quaternary aquifer, and is separated from these units by an interval of silt and clay. In the northern and eastern parts of Worcester County, Md., and in the southeastern part of Sussex County, Del., the silt and clay section between the Manokin and Pocomoke is not present, is indistinct, or is so thin that the two aquifers may function as a unit. In northern Wicomico and eastern Dorchester Counties, Md., the top of the Manokin has been eroded, and the aquifer is overlain directly by the Quaternary aquifer (pl. 9).

Where the Manokin contains fresh water, it underlies an area of about 3,500 square miles. Its thickness ranges from a featheredge at its updip limit to about 250 feet (pl. 9).

RECHARGE, WITHDRAWAL, AND MOVEMENT OF GROUND WATER

The Manokin receives most of its recharge in the updip part of the aquifer where recharge occurs by downward movement of water through the Quaternary aquifer. The chemical-quality map (pl. 9) indicates that in the Virginia part of the peninsula the Manokin is recharged by the Pocomoke aquifer along the drainage divide between the ocean and Chesapeake Bay. Pumpage is about 5½ mgd. The regional direction of water movement in the aquifer is away from the area of recharge toward the bays, the ocean, and the areas of pumping (pl. 9).

AQUIFER CHARACTERISTICS

Results of aquifer tests of the Manokin indicate that transmissivity ranges from 950 to 5,500 ft^2 per day. The coefficient of storage ranges from 0.0001 to 0.0003. Where the Manokin functions with the Quaternary as a hydrologic unit, its coefficient of storage may be as much as 0.15. Reported specific capacities of wells range from less than 1 to 35 gpm per foot of drawdown. Reported well yields range from 5 to 1,000 gpm.

WATER QUALITY

Water in the Manokin aquifer ranges in chemical quality from calcium bicarbonate, containing less than 150 mg/l dissolved solids, to sodium chloride bicarbonate, containing more than 1,000 mg/l dissolved solids. Water-quality areas 1 and 2 (pl. 9) are characterized by a downgradient increase in hardness. Water in the remainder of the aquifer shows the effect of progressive mixing with saline water.

The boundary between areas 4 and 5 (pl. 9) is the downdip limit of fresh water in the Manokin aquifer. The delineation of this interface is based on: Chemical analyses, the probable pattern of water movement within the aquifer, and the position of the interface in adjacent aquifers. The offshore position of the boundary between fresh and saline water in the Manokin is not known.

Saline water occurs beneath fresh water in parts of the Manokin. Water samples were obtained from the upper and lower parts of the aquifer at a site in Ocean City, Md., about half a mile south of the Delaware line. Water from the upper zone contained 191 mg/l dissolved solids and 35 mg/l chloride and is typical of water from area 2. Water from the lower zone, however, contained 801 mg/l dissolved solids and 296 mg/l chloride. Water high in chloride probably underlies at least the nearshore parts of area 2, and saline water (more than 1,000 mg/l dissolved solids) may underlie fresh water in areas 3 and 4.

AREA OF POTENTIAL USE

The Manokin is used as a source of water supply in an area of about 1,200 square miles (pl. 9). The area of potential use is about 2,300 square miles. In this area the aquifer has not been used primarily because of the large supplies of water available in the overlying Quaternary aquifer.

POCOMOKE AQUIFER

The Pocomoke aquifer overlies the Manokin aquifer and is generally separated from it by a silt and clay interval of Miocene sediments. In some places in the northern and eastern parts of Worcester County, Md., and in the southeastern part of Sussex County, Del., the silt and clay section between the Pocomoke and Manokin aquifers is not present, is indistinct, or is so thin that the two aquifers may function as a unit in these places. The Pocomoke is overlain by the Quaternary aquifer and is generally separated from it by an interval of silt and clay. In updip areas the Pocomoke is directly overlain by Quaternary sediments.

Where the Pocomoke contains fresh water, it underlies an area of about 2,150 square miles (pl. 10). Its thickness ranges from a featheredge at its updip limit to slightly more than 100 feet (pl. 10).

RECHARGE, WITHDRAWAL, AND MOVEMENT OF GROUND WATER

The Pocomoke receives most of its recharge in the updip part of the aquifer. Recharge occurs by downward movement of water through the Quaternary sediments. The chemical-quality map (pl. 10) indicates that in the Virginia part of the peninsula the Pocomoke is recharged by the Quaternary aquifer along the drainage divide between the ocean and Chesapeake Bay. Pumpage is about 5½ mgd. The regional movement of water is away from areas of recharge toward the ocean, the Pocomoke River, Pocomoke Sound, and Chesapeake Bay (pl. 10).

AQUIFER CHARACTERISTICS

Results of aquifer tests of the Pocomoke indicate that transmissivity ranges from 1,000 to 8,000 ft^2 per day. The coefficient of storage ranges from 0.0001 to 0.003 but may be as much as 0.15 where the aquifer is in contact with the Quaternary. Reported specific capacities of wells range from less than 1 to 30 gpm per foot of drawdown. Reported well yields range from 5 to 650 gpm.

WATER QUALITY

Water in the Pocomoke aquifer ranges in chemical quality from calcium bicarbonate, containing less than 100 mg/l dissolved solids to sodium chloride bicarbonate, containing more than 1,000 mg/l dissolved solids. Water-quality areas 1, 1A, 2, and 2A (pl. 10) are characterized by a downgradient increase in hardness. Areas 1 and 1A are the principal recharge areas for the aquifer. The differences in hardness of water in these areas reflect water-quality differences in the overlying Quaternary aquifer (pl. 11). Water in areas 3, 4, and 5 is characterized by downgradient increases in the concentrations of sodium, bicarbonate, sulfate, and chloride, owing to an admixture of saline water.

The downdip limit of fresh water in the Pocomoke aquifer is the boundary between areas 4 and 5 (pl. 10). The delineation of this interface is fairly well defined by chemical analyses, but its offshore positions (under the ocean on the east and Chesapeake Bay on the west) are not known.

AREA OF POTENTIAL USE

The Pocomoke is used as a source of water supply in an area of about 1,600 square miles (pl. 10). The area of potential use is about 550 square miles. In this area the aquifer has not been used primarily because of the large supplies of water available in the overlying Quaternary aquifer.

QUATERNARY AQUIFER

Quaternary sediments blanket most of the Delmarva Peninsula (pl. 11). These sediments are predominantly sandy and form an extensive aquifer on much of the peninsula. In the northern part of the peninsula the saturated thickness of the Quaternary generally does not exceed 20 feet (pl. 11), and the aquifer is probably not capable of supplying large quantities (100 gpm or more) of water to wells. In the southern part the saturated thickness generally ranges from 40 to slightly more than 140 feet, and large quantities of water are available. The aquifer underlies an area of 5,950 square miles.

RECHARGE, WITHDRAWAL, AND MOVEMENT OF GROUND WATER

Because the Quaternary aquifer is extensive and surficial, it is recharged by precipitation over a broad area. Pumpage is about 61 mgd. The regional movement of water in the aquifer is from areas of high water levels (generally corresponding to land-surface highs) toward the streams, bays, and ocean (pl. 11). In the areas of high water table, some water moves downward from the Quaternary and recharges underlying aquifers.

AQUIFER CHARACTERISTICS

Results of aquifer tests of the Quaternary aquifer indicate that transmissivity ranges from 100 to 50,000 ft^2 per day and that the coefficient of storage ranges from 0.0001 to 0.17. Most of these tests were of short duration and inconclusive. As the Quaternary aquifer is generally not artesian, transmissivity in the better part of the aquifer probably ranges from 2,500 to 13,000 ft^2 per day, and the storage coefficient from 0.10 to 0.15. Reported specific capacities of wells range from less than 1 to 50 gpm per foot of drawdown. Reported yields of wells range from 3 to 4,000 gpm.

WATER QUALITY

The chemical quality of water in the Quaternary aquifer is shown on plate 11. Ground water in area 1 represents precipitation concentrated by evaporation and somewhat modified by solution of calcite. This part of the Quaternary aquifer is predominantly composed of stream-laid sediments that are deficient in calcareous material. Consequently, ground water in area 1 is soft (less than 35 mg/l hardness). Recharge by infiltrating precipitation prevails throughout area 1, and the bulk of the water moves toward discharge points (streams or other surface-water bodies) along short flow paths. Therefore, the opportunities for mineral solution are limited and the dissolved-solids content of the water is low over a large area.

Area 1A functions as a recharge area for the Quaternary aquifer in much the same way as area 1. The Quaternary sediments in area 1A, however, are principally of marine origin. These sediments contain calcite in the form of calcareous shell material. Ground water in area 1A is, therefore, relatively hard (as much as 140 mg/l hardness).

Areas 2 and 3 coincide with the parts of the Quaternary aquifer in which the water table is less than 10 feet above sea level. Although the aquifer is recharged directly by infiltrating precipitation to some extent, the bulk of the water in the aquifer in these areas has moved downgradient from areas 1 and 1A. The water in areas 2 and 3 is characterized by increasing concentrations of hardness, bicarbonate, sodium, and chloride. These increases result from continued solution of calcite and mixing with the saline water, which occurs in the aquifer adjacent to and beneath saline surface-water bodies. In area 3, fresh water is restricted to about the upper 25 feet of the aquifer.

AREA OF POTENTIAL USE

The Quaternary aquifer is used over most of its outcrop. However, the amount of water pumped from it is a small percentage of the amount it is capable of yielding.

USE OF THE DATA

In planning to use ground water as a source of water supply on the peninsula, it is advantageous to know the maximum depth of fresh water and the number of fresh-water aquifers that are available. The map of the base of fresh water (pl. 12) shows the aquifer containing the deepest fresh water. Within a given boundary, contours are drawn on the base of the deepest fresh water in the aquifer shown. Beyond the boundary for a particular aquifer, either the aquifer contains no fresh water or the base of fresh water is in a deeper aquifer. Below the altitude shown on the map, only saline water will be available. Areas where saline water exists above fresh water are also shown. If this map were to be used as a guide to determine the depth at which highly mineralized water could be disposed of by injection, the following would be facts to consider: (1) Fresh water for this study is water containing less than 1,000 mg/l dissolved solids, (2) the base of fresh water is not necessarily the top of highly mineralized water, and (3) water containing more than 1,000 mg/l dissolved solids could be treated and used for water supplies.

By stacking the maps showing the areal extent of fresh water in the 10 aquifers, a map showing the number of fresh-water aquifers available at any site on the peninsula was prepared (pl. 12). This map can be used as a guide to the number of alternatives that are available for developing a ground-water supply. The irregular shapes of the areas are caused by the intersections of the limits of the various aquifers present. The number of aquifers available ranges from one to five or more. The fact that more aquifers are available in some areas than in others does not indicate that more water is available, only that the number of alternative sources is larger.

The ground-water information presented above and that presented in each aquifer discussion can be used to determine the aquifers that are available as sources of water supply anywhere on the peninsula and, in addition, the following approximations can be made: (1) The top and thickness of each aquifer (depth and maximum screened interval of a well), (2) depth to water, (3) available drawdown in a well (difference, in feet, between altitude of the potentiometric surface and altitude of the top of the aquifer), (4) temperature of water, (5) quality of water, and (6) range in specific capacities, yields, transmissivities, and storage coefficients. The following illustrates how the information can be used: what are the alternatives in developing a ground-water supply at Whiteleysburg, about 18 miles southwest of Dover, Del.?

From a topographic map, the land-surface altitude at Whiteleysburg is determined to be 65 feet above mean sea level. Plate 12 shows that the base of fresh water is in the Piney Point aquifer and that it is 500 feet below sea level, or 565 feet below land surface. Consequently, the maximum depth of a well need not exceed 565 feet.

Five or more aquifers are available at Whiteleysburg (pl. 12). As the nonmarine Cretaceous, Magothy, and the Aquia and Rancocas aquifers are below or deeper than the Piney Point (fig. 26 and table 1) and do not contain fresh water, it is necessary to look at only the maps showing the areal extent of the remaining seven aquifers (pls. 5-11). Examination of these maps reveals that Whiteleysburg is north of the limit of the Manokin and Pocomoke aquifers. Consequently, at Whiteleysburg five aquifers (Quaternary, Frederica, Federalsburg, Cheswold, and Piney Point) are available as sources of a ground-water supply.

The first or shallowest aquifer is the Quaternary. The base of the Quaternary (pl. 11) is about 20 feet above sea level, or 45 feet below land surface. The saturated thickness (pl. 11) is about 30 feet, and the water level (pl. 11) about 50 feet above sea level, or 15 feet below land surface. The pH of the water should be between 5.4 and 7.0, and the concentration of the principal chemical constituents in the water should be (area 1, pl. 11):

Constituent	*Milligrams per liter*
Dissolved solids	<100
Hardness	<35
Sodium	2–20
Bicarbonate	5–40
Chloride	5–20
Fluoride	<0.2
Silica	10–30
Iron and manganese	0.02–21

The maximum depth of a well in the Quaternary aquifer at Whiteleysburg would be 45 feet. Nitrate and, possibly, sulfate concentrations are likely to be high (pl. 11) because of the susceptibility of the shallow aquifer to pollution. The temperature of the water at such shallow depth fluctuates seasonally, and probably averages somewhat higher than the mean annual air temperature, which is about 13°C at Whiteleysburg.

The top of the second aquifer at Whiteleysburg, the Frederica (pl. 8), is about 30 feet below sea level, or 95 feet below land surface. The Frederica is about 45 feet thick (pl. 8), so that the base of the aquifer should be 140 feet below land surface. The water level (pl. 8) is about 40 feet above sea level, or 25 feet below land surface. Little is known about the chemical quality of water in the Frederica aquifer at Whiteleysburg (area 1, pl. 8), but dissolved solids should be less than 100 mg/l, hardness less than 5 mg/l, sodium less than 10 mg/l, and bicarbonate less than 50 mg/l. Temperature data from a nearby well at Greenwood, Del., indicate that the water temperature should be about 15°C (fig. 7). There should be little or no seasonal temperature change.

The top of the third aquifer, the Federalsburg (pl. 7), is about 100 feet below sea level, or 165 feet below land surface. The Federalsburg is less than 50 feet thick (pl. 7), possibly only 25 feet thick. A thickness of 25 feet would place the base of the aquifer at 190 feet below the land surface. The water level (pl. 7) is about 30 feet above sea level or 35 feet below land surface. The pH should be between 4.6 and 7.0, and the concentration of the principal chemical constituents should be (area 1, pl. 7):

Constituent	*Milligrams per liter*
Dissolved solids	<100
Hardness	<5
Sodium	<7
Bicarbonate	<55
Sulfate	10–20
Chloride	<5
Fluoride	<0.3
Nitrate	0.5–51
Silica	<15
Iron and manganese	0.05–0.8

The water temperature should be 15½°C (Greenwood curve, fig. 7).

The top of the fourth aquifer, the Cheswold (pl. 6), is about 150 feet below sea level, or 215 feet below land surface. The Cheswold is about 110 feet thick (pl. 6), and the base of the aquifer should be 325 feet below land surface. The water level (pl. 6) is about 30 feet above sea level or 35 feet below land surface. Little is known about the chemical quality of water in the Cheswold in the Whiteleysburg area (area 1, pl. 6), but dissolved solids should be less than 100 mg/l, hardness less than 75 mg/l, sodium less than 5 mg/l, and bicarbonate less than 50 mg/l. The water temperature should be 16½°C (Greenwood curve, fig. 7).

The top of the fifth and deepest aquifer available as a source of fresh ground-water supply at Whiteleysburg, the Piney Point (pl. 5), is about 320 feet below sea level, or 385 feet below land surface. The Piney Point is about 180 feet thick (pl. 5), so that the base of the aquifer should be 565 feet below land surface. As the base of fresh water and the base of the aquifer are at the same depth, the entire Piney Point aquifer at Whiteleysburg contains fresh water. The water level (pl. 5) is about 5 feet below sea level or 70 feet below land surface. Whiteleysburg is practically on the line separating water-quality areas 2 and 3 (pl. 5). Keeping in mind the changes in chemical quality of ground water in the downdip direction (fig. 6), the concentration of the principal chemical constituents will probably be:

Constituent	*Milligrams per liter*
Dissolved solids	500
Hardness	15–20
Sodium	190
Bicarbonate	400–500
Sulfate	7–20
Chloride	3–25
Fluoride	1.4–1.6
Nitrate	<2
Silica	10–30
Iron and manganese	0–0.5

The pH of the water will probably be about 8.0, and the temperature of the water 18°C (Greenwood curve, fig. 7).

If a domestic water supply is wanted at Whiteleysburg, any of the five available fresh-water aquifers will yield sufficient quantities of water. The choice of which aquifer to use will be based on the desired temperature and quality of the water and the cost of the well. At the present time, the four deeper aquifers in the Whiteleysburg area are unused (pls. 5–8).

If a larger supply, say 100 gpm, is wanted at Whiteleysburg, the reported yields of wells in the five available aquifers indicate only that each aquifer at some places in its area of use has yielded at least 100 gpm. The range in specific capacity and transmissivity for each of these aquifers is, in part, an indication of variability in texture of the aquifers. Because of this variability, testing the aquifers would be a prerequisite to developing one of them if quantity is the only requirement. If quality is a factor, the number of choices at Whiteleysburg may be reduced.

The reader should remember that the above determinations are estimates based upon the available information. By drilling and testing a particular site, more exact data can be obtained.

SALINE-WATER INTRUSION

Saline-water intrusion into the fresh-water aquifers underlying the Delmarva Peninsula is possible from two sources: (1) Saline surface water overlying or adjacent to the shallow parts of the aquifers and (2) saline ground water in the deeper parts of the aquifers.

Delaware and Chesapeake Bays, their tributary estuaries, the C&D Canal and, of course, the ocean contain saline water. Fresh ground water circulates through the aquifers and, under the natural hydraulic gradient, moves toward these saline surface-water bodies. The fresh-water gradient is generally sufficient to prevent landward movement of saline water into the aquifers.

Water levels in the shallow updip parts of several of the aquifers have been drawn down below sea level as the result of pumping. The reversal of normal hydraulic gradients in these areas could cause saline surface water to migrate landward. No evidence of saline-water intrusion has been noted at any pumping centers, however, and it seems likely that the fine-grained bottom sediments of the bays and estuaries prevent the downward movement of saline water. The only known saline-water intrusion on the peninsula was at Lewes, Del., where sea water moved into wells tapping the Quaternary aquifer after the dredging of a sea-level canal (Rasmussen and others, 1960, p. 103).

The C&D Canal, a sea-level canal between Chesapeake and Delaware Bays, crosses the central parts of Cecil County, Md., and New Castle County, Del. The canal was excavated through sediments of the nonmarine Cretaceous and Magothy aquifers in Cecil County and through generally fine-grained marine Cretaceous sediments in New Castle County. Local concern has been expressed over possible adverse hydrologic effects of deepening this canal.

The C&D Canal acts in the same way as a natural surface-water body; that is, ground water moves toward and discharges into the canal, and thus fresh-water flow acts as a hydraulic barrier to the movement of saline water into the aquifers. As long as the hydraulic gradient is from the aquifers toward the canal, saline-water intrusion into the aquifers is unlikely, even if the canal were to be deepened.

In places along the canal, the natural hydraulic gradient in the nonmarine Cretaceous and Magothy aquifers has been reversed as the result of pumping (pls. 2 and 3). Sundstrom and others (1967, p. 83 and 86) conclude that saline-water intrusion into the aquifers in the eastern part of the canal is unlikely because of the protection offered by the overlying marine Cretaceous sediments. In the western part of the canal, however, where the Magothy is exposed and there is a possibility of interconnection between the Magothy and the shallowest sand in the nonmarine Cretaceous aquifer, some saline water might intrude if shallow ground water were to be withdrawn along the canal. Present withdrawals in this area are from lower sand units in the nonmarine Cretaceous aquifer, and saline water has not intruded. Water levels in the upper part of the nonmarine Cretaceous aquifer and in the Magothy aquifer apparently are not affected by withdrawal from the lower sand units because of the intervening fine-grained sediments in the nonmarine aquifer. The protection offered by these sediments would not be affected by deepening the canal.

The water-quality maps of the aquifers on the peninsula show the areas of potential saline-water intrusion from adjacent and overlying surface-water bodies. Within these areas, the tops of the aquifers are generally less than 100 feet below the land surface. Intrusion could occur if pumpage were significantly increased or if bottom sediments of bays and estuaries near pumping centers were sufficiently disturbed, such as by dredging.

Parts of all the aquifers underlying the peninsula except the Aquia and Rancocas aquifer contain some saline water. Some of this saline water will encroach the fresh-water parts of the aquifers wherever withdrawals reduce the quantity of ground water moving downgradient toward discharge areas.

Large-scale withdrawal of water from the Piney Point aquifer at Cambridge and Dover has imposed a hydraulic gradient from the saline water toward the centers of pumping (pl. 5). Despite this change in gradient, movement of saline water has been negligible. For example, under a continuation of the present (1970) rate of withdrawal at Dover (about 1½ mgd), and assuming an aquifer thickness of 200 feet and an effective porosity of 30 percent, it would take at least 7,000 years for the nearest saline water to move to the center of pumping (a distance of about 12 miles). Similarly, for a pumping rate of 3½ mgd at Cambridge, assuming an aquifer thickness of 150 feet and an effective porosity of 30 percent, it would take at least 2,000 years for the nearest saline water in the aquifer to move to the center of pumping (a distance of about 11½ miles). Traveltime is inversely proportional to pumping rate, and doubling the pumping rate decreases the traveltime by 50 percent.

Water samples and multiple-point electric logs indicate that saline water underlies fresh water in much of the Manokin aquifer. The saline water occurs as a tongue, 30–50 feet thick, extending landward 5 miles or more from Chesapeake Bay and the ocean. It underlies the coastal areas of Delaware and Maryland, the southern parts of Worcester and Somerset Counties, and all of the Virginia part of the peninsula. The tongue thickens toward the ocean and bay until at some distance offshore the entire aquifer is occupied by saline water. Saline ground water could move into fresh-water parts of the aquifer if withdrawals from the Manokin in these areas were significantly increased.

WATER USE AND TRENDS

Average water use on the Delmarva Peninsula in 1970 was estimated to be 137 mgd. This quantity does not include saline water from the bays and estuaries used for cooling. It also does not include about 80 mgd of surface water originating outside the peninsula but used in and near Wilmington, Del., and Northeast and Elkton, Md., nor does it include the nonwithdrawal use of surface water for waste disposal and dilution.

Of the total water withdrawn on the peninsula, about 90 percent is from ground-water sources and 10 percent, used exclusively for irrigation, is from surface-water sources. Estimates of average withdrawal of ground water during 1970, by aquifer and by use, are shown in table 8. Estimates of ground-water withdrawals during 1970, by aquifer, in each county on the peninsula are shown in table 9.

The estimated population and rates of water use on the peninsula in 1950 and 1970 are shown in table 10. U.S. Census Bureau population data were adjusted to the area of the peninsula. Water use for 1950 was estimated on the basis of data by Marine and Rasmussen (1955, p. 85–89), Overbeck and Slaughter (1958, p. 123–126), and Rasmussen and Slaughter (1955, p. 132; 1957, p. 91–93).

TABLE 8.—*Estimated average withdrawal of ground water on the Delmarva Peninsula during 1970, by aquifer and by use*

Aquifer	Estimated average withdrawals (million gallons per day) by use					
	Public	Domestic	Industrial	Livestock	Irrigation	Total
Nonmarine Cretaceous	8.95	1.73	7.40	0.41	0	18.49
Magothy	1.85	.02	.15	0	0	2.02
Aquia and Rancocas	1.61	2.27	2.10	.60	0	6.58
Piney Point	5.34	.40	3.35	.03	0	9.12
Cheswold	4.84	.67	2.11	.08	.04	7.74
Federalsburg	1.12	.66	1.20	.09	.02	3.09
Frederica	1.71	.65	.83	.09	.04	3.32
Manokin	2.27	1.19	1.92	.13	.05	5.56
Pocomoke	1.12	1.71	2.45	.22	.05	5.55
Quaternary	16.37	14.59	24.57	2.94	2.60	61.07
Total	45.18	23.89	46.08	4.59	2.80	122.54

TABLE 9.—*Estimated average withdrawal of ground water on the Delmarva Peninsula during 1970, by aquifer and by county*

County and State	Estimated average withdrawals (million gallons per day) from indicated aquifer										
	Nonmarine Cretaceous	Magothy	Aquia and Rancocas	Piney Point	Cheswold	Federalsburg	Frederica	Manokin	Pocomoke	Quaternary	Total
Kent (Del.)	----	---	0.16	1.99	6.78	0.87	1.64	---	---	7.40	18.84
New Castle (Del.)	14.28	0.06	.41	---	---	---	---	0.36	---	5.88	20.99
Sussex (Del.)	----	---	---	---	---	.35	.56	---	0.98	20.04	21.93
Caroline (Md.)	----	---	---	1.35	.76	1.07	.43	---	---	4.02	7.63
Cecil (Md.)	3.27	.01	.25	---	---	---	---	---	---	----	3.53
Dorchester (Md.)	----	.75	.23	4.38	---	.25	.41	---	---	1.38	7.40
Kent (Md.)	.08	.20	2.52	---	---	---	---	---	---	.12	2.92
Queen Annes (Md.)	----	---	2.04	.60	---	---	---	---	---	.83	3.47
Somerset (Md.)	.81	.20	---	.02	---	---	---	.77	.66	.62	3.08
Talbot (Md.)	----	.80	.97	.78	.20	.55	.20	---	---	.62	4.12
Wicomico (Md.)	----	---	---	---	---	---	.08	.53	.12	13.10	13.83
Worcester (Md.)	----	---	---	---	---	---	---	2.38	1.33	4.33	8.04
Accomack (Va.)	.05	---	---	---	---	---	---	1.09	1.97	2.05	5.16
Northampton (Va.)	----	---	---	---	---	---	---	.43	.49	.68	1.60
Total	18.49	2.02	6.58	9.12	7.74	3.09	3.32	5.56	5.55	61.07	122.54

TABLE 10.—*Population and water-use data for the Delmarva Peninsula for 1950 and 1970*

	1950	1970	Annual rate of change, 1950 to 1970 (percent)
Population	418,399	566,690	+1.6
Ground-water use (mgd):			
Public supply	21	45	+4.0
Domestic supply	11	24	+4.1
Industrial supply	26	46	+3.0
Livestock supply	6	5	—0.8
Irrigation supply	0	3	----
Total	64	123	+3.4
Surface-water use (mgd):			
Irrigation supply	8	14	+2.9
Total	8	14	+2.9
Total water use	72	137	+3.3

During 1950–70, water use on the peninsula increased more than twice as fast as the population (table 10). Per capita consumption of water in the home (public and domestic supplies) has increased because of more water-using appliances and a general rise in living standards. Industrial use of water has increased in response to higher production rates and, in part, to technologic advances. Total agricultural use has increased because of the more widespread practice of supplemental irrigation.

Future water use on the peninsula is dependent largely on socioeconomic factors and, as such, can be treated only superficially in this report. Population growth and per capita consumption will control the future use of water for household purposes. Although the population of the peninsula increased at an annual rate of 1.6 percent from 1950 to 1970 (table 10), the annual growth rate from 1960 to 1970 was only about 1 percent, indicating a trend toward population stability. Public consumption of water in recent years also increased at a lower rate than indicated in table 10. For example, public-supply use in Sussex and Kent Counties, Del., in 1966 was estimated to be 14.3 mgd (Sundstrom and Pickett, 1968, p. 37; 1969, p. 43; 1970, p. 39). The comparable figure for 1970 is 15.1 mgd, representing an increase of 1.5 percent per year. In contrast, public-supply use for the entire peninsula increased about 4 percent per year during 1950–70. A compound growth rate of between 1 and 2 percent may be applicable to domestic and public supplies on the peninsula in the future.

Although industrial pumpage on the peninsula increased at an annual rate of about 3 percent between 1950 and 1970, this rate has probably decreased in recent years; in fact, the trend may have reversed. Industrial pumpage in Dorchester and Talbot Counties, Md., was estimated to be 3.1 mgd in 1960 (Mack, Webb, and Gardner, 1971, table 1). The comparable figure for 1970 is 3.8 mgd, an annual increase of 2 percent. Industrial pumpage in Sussex and Kent Counties, Del., was estimated to be 14.9 mgd in 1966 (Sundstrom and Pickett, 1968, 1969, and 1970). The comparable figure for 1970 is 13.3 mgd, an annual decrease of 3 percent. These recent trends suggest that conservation practices may be effective in stabilizing water use despite continued industrial growth. Future water use, therefore, may be little changed from present rates.

The use of water for livestock on the peninsula decreased between 1950 and 1970. Future use will probably be at about the present rate. Supplemental irrigation is beginning to play an important role in agriculture on the peninsula. In 1970 about 17 mgd was used to irrigate about 55,000 acres. According to a report prepared by the Agriculture Committee of the Delmarva Advisory Council (Miller and others, written commun., 1970), agricultural use of water is expected to more than double by 1980 and double again by 2010. According to recent trends noted on the peninsula, it seems likely that ground water will be the source of most of the anticipated increase in agricultural withdrawals.

By the year 2010, water use on the peninsula is estimated to be 260 mgd (fig. 27). This estimate is based on the following water-use assumptions: (1) Public and domestic supplies will increase at an annual rate of 1.5 percent, (2) industrial and livestock use will continue unchanged, (3) irrigation use will increase considerably, and (4) ground water will become the dominant source for irrigation.

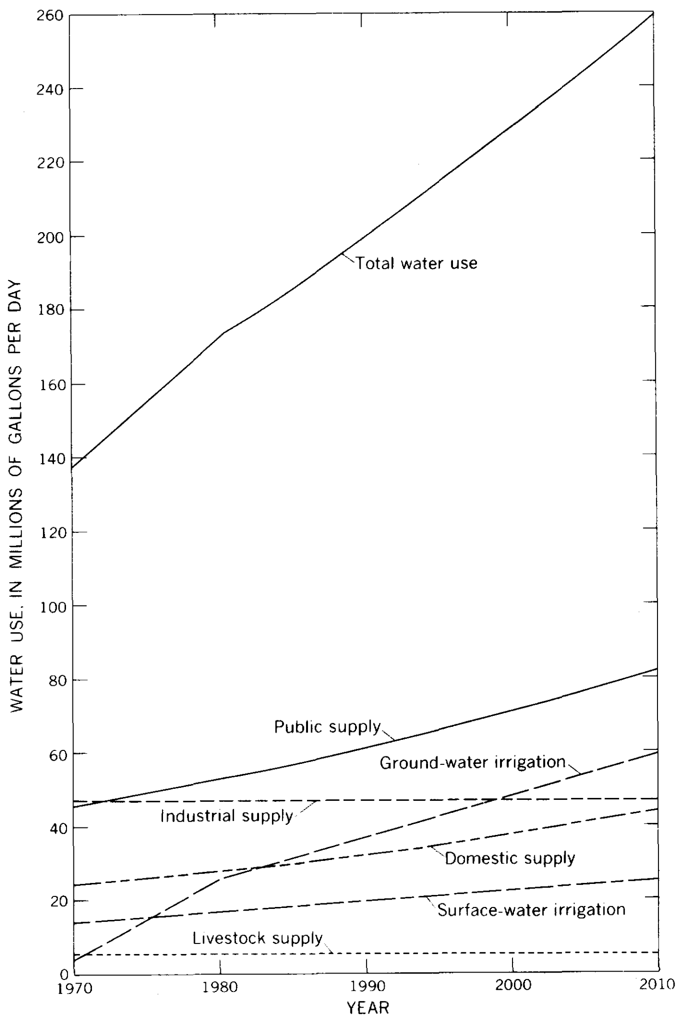

FIGURE 27.—Estimated future water use.

AVAILABILITY OF WATER

To efficiently utilize the water resources of the Delmarva Peninsula, development schemes ideally would take into account the fact that ground water and the base flow of streams are virtually one water. The average annual runoff of 15 inches is the approximate total annual fresh-water yield of the streams and aquifers on the peninsula under present climatic and hydrologic conditions. The base flow of streams (8½ in.) represents that part of the water yield available from the aquifers. Withdrawal of water from the streams under present conditions will not noticeably affect the amount of water available in the aquifers. Withdrawal of water from an aquifer, however, will, in time, change the amount of base flow in the streams and the amount of ground water discharged directly into the bays and the ocean. Development of the aquifers to their full potential will eventually reduce the base flow of streams to zero and will probably allow intrusion of saline water or sea water into the lower reaches of streams and into aquifers at places where they are in contact with or underlie tidal streams, bays, or the ocean.

Most of the streams draining more than 50 square miles can provide water supplies greater than 1 mgd during a low-flow period having a recurrence interval of 10 years. For example, the 7-day 10-year low flow of the Nanticoke River at Bridgeville, Del. (site 86, pl. 1), will provide a dependable supply of 9 mgd. Some streams draining smaller areas also have large dependable 7-day 10-year flows: North Prong Wicomico River (site 78), 24.8 sq mi and 7 mgd; Beaverdam Creek (site 35), 6.10 sq mi and 3 mgd; Cedar Creek (site 32), 7.21 sq mi and 2 mgd; and Leipsic River (site 20), 9.35 sq mi and 1¼ mgd.

Draft-storage relations indicate that, for a low-flow period having a 10-year recurrence interval, 10 acre-feet of storage per square mile of drainage area will usually increase the dependable draft rate of streams by more than 100 percent.

Surface water has generally not been developed as a source of water supply on the peninsula because (1) treatment may be required at times to control sediment content and organic color, (2) large supplies without reservoir storage are available only at a few sites, (3) few opportunities exist to store streamflow and augment low flows, and (4) ground water is generally available everywhere on the peninsula. Therefore, the aquifers, as they have in the past, will probably be used as sources of future water supplies.

The 10 aquifers on the peninsula are not separate units operating independently; each, rather, is a part of a complex system. Water in this system occurs either under water-table or artesian conditions.

The Quaternary aquifer is generally under water-table conditions, whereas the downdip parts of the older aquifers are under artesian conditions. Except for the Piney Point, the updip parts of the older aquifers are not confined. In these areas, therefore, the older aquifers are also under water-table conditions. Because the Quaternary sediments blanket most of the peninsula, the water-table parts of each of the older aquifers function, together with the Quaternary, as a single water-table aquifer. The yield of the aquifer system, including both the water-table and artesian parts, is controlled over the long term by the amount of recharge and the amount of water in storage. Under natural conditions the system is in approximate equilibrium—that is, recharge is equal to discharge and the quantity of water in storage is fairly constant. When water is withdrawn from the system by wells, either the natural discharge is diminished or the amount of water in storage is depleted, as the system attempts to remain in equilibrium. The quantity of water in storage on the peninsula, although great, is finite, so that the long-term, or perennial, yield must be based on the amount of recharge received by the aquifers.

The water-table aquifer receives all the ground-water recharge on the peninsula. A small part of the recharge is transmitted to the artesian aquifers, and the remainder is discharged from the water-table aquifer by evapotranspiration and by movement of ground water into the streams, bays, and ocean. The bulk of this discharge becomes the base flow of the streams. Base flow, then, is the approximate annual fresh-water yield of the aquifer system. Under conditions of maximum ground-water development, some evapotranspiration loss might be salvaged, but this quantity is unknown and is not considered in this report to be a part of the fresh water available for use. The base flow of streams on the peninsula is estimated to be 8½ inches per year. The annual fresh ground-water yield from the 6,500 square miles of the peninsula is, therefore, 2,500 mgd.

The quantity of water available in the aquifers is more than adequate to supply 260 mgd (estimated water use by the year 2010). Increased withdrawal of ground water at some places on the peninsula may prove that local areas do not have adequate ground-water resources to meet anticipated needs; local deficiencies can be met by importing water from other parts of the peninsula.

Generally, sufficient ground water to supply domestic needs can be obtained anywhere on the peninsula. Wells yielding more than 100 gpm can be developed in most parts of the Quaternary aquifer. If similar yields are desired from wells in an artesian aquifer, the well may have to be located in areas where the aquifer is thickest and where the depth to the top of the aquifer is sufficient to allow for a drawdown of 100 feet or more without reaching the top of the aquifer—thus preventing dewatering of the aquifer.

Although individual wells yielding more than 100 gpm may be developed in favorable parts of the artesian aquifers, large withdrawals (5 mgd or more) in a small area will probably result in excessive drawdowns. The withdrawals of about 3½ mgd at Cambridge, Md., and of about 1½ mgd at Dover, Del., from the Piney Point aquifer have caused water levels to decline about 100 feet below sea level (pl. 5). Water-level declines of at least 25 feet have occurred as far as 12 miles from Cambridge and 4 miles from Dover. In contrast, withdrawal of as much as 10 mgd from the Quaternary water-table aquifer in the Salisbury area has not caused a significant decline in the water level.

Although increased withdrawal at existing centers of pumping will probably be from the presently used aquifers, new large-scale withdrawal would probably have to come from the water-table aquifer. About 75 percent of the present (1970) withdrawal is from the Quaternary aquifer and the water-table parts of the older aquifers. Intensive development of the water-table aquifer could, theoretically, capture all the recharge and consequently eliminate all natural ground-water discharge. However, some discharge of ground water directly into the streams, bays, and ocean is necessary to prevent saline-water intrusion. To allow for the continuance of necessary natural discharge, large-scale withdrawal of water from the water-table aquifer, ideally, would be located as far from saline-water bodies as possible. If withdrawal were restricted to that part of the peninsula where the water table is 10 feet or more above sea level (pl. 11), perennial yield from this 3,600-square-mile area would be about 1,500 mgd. This estimate is conservative in that it allows for considerable natural discharge from low-lying parts of the peninsula, and it does not include the possibility of salvaged evapotranspiration or reuse of water. Also, it does not include the substantial quantities of water in storage in the water-table and artesian aquifers, although these quantities, for practical purposes, are available for use only once.

Estimates of the quantity of fresh water perennially available from the water-table part of each aquifer are shown in the following table:

Aquifer	*Estimated quantity of fresh water perennially available (mgd)*
Nonmarine Cretaceous	80
Magothy	10
Aquia and Rancocas	190
Piney Point	[1]
Cheswold	80
Federalsburg	50
Frederica	50
Manokin	[2]
Pocomoke	[2]
Quaternary	1,040
Total	1,500

[1] Included with Cheswold aquifer.
[2] Included with Quaternary aquifer.

These quantities were computed by multiplying the area of the principal water-table aquifer by the base flow of the streams. Where the Quaternary aquifer has a saturated thickness of 20 feet or more (pl. 11), it is considered to be the principal aquifer. Where the saturated thickness of the Quaternary aquifer is less than 20 feet, the water-table part of the underlying older aquifer is considered to be the principal aquifer. Quantities of fresh water perennially available are not shown for the Pocomoke and Manokin aquifers because these aquifers are everywhere overlain by at least 20 feet of saturated Quaternary sediments. Also, a quantity is not shown for the Piney Point aquifer because it does not crop out and is presumably recharged by leakage from the Cheswold aquifer.

Although large-scale water developments might be restricted to the part of the peninsula where the water table is 10 feet or more above sea level, some withdrawal from the water-table aquifer has been and will be made in areas where the water table is lower. Within these areas, large withdrawals of water might warrant aquifer monitoring to determine if saline water is moving toward the centers of pumping.

Withdrawals from an artesian part of an aquifer need not be areally restricted. The water pumped from an artesian aquifer will probably come from storage and leakage unless the withdrawal point is close enough to the water-table part of the aquifer so that additional recharge can be induced or ground water presently discharged to surface-water bodies can be salvaged. Because the artesian aquifers are generally thin and the transmissivities are small, a single artesian aquifer may not be able to supply large quantities (5 mgd or more) of water in a small area. Generally the areas where the maximum quantities of water can be developed are in the thicker parts of the aquifer. Where large quantities of water are needed, several individual wells, each developed in a separate aquifer, will yield the maximum amount of water with a minimum of drawdown and interference.

SUMMARY AND CONCLUSIONS

Large quantities of fresh water are available on the Delmarva Peninsula from streams and from 10 regional aquifers. Most streams on the peninsula are perennial because the aquifers are generally full and receive more water than they can hold. The excess water is discharged to the streams, bays, and ocean. This discharge sustains streamflow during dry periods and the movement of ground-water into the bays and ocean prevents the intrusion of saline water into the aquifers.

Average annual runoff is 15 inches. This amount is approximately the present total annual fresh-water yield of the peninsula. Although annual runoff is fairly large, 6½ inches is overland flow and is available for use only for short periods during and immediately after precipitation. The remainder, 8½ inches, is base flow and represents ground-water discharge from the aquifers. This quantity of water is available from the aquifers, or from the streams, or a part from the aquifers and the remainder from the streams, but base flow and ground water constitute virtually a single supply.

Several streams on the peninsula have sufficient natural flow to provide water supplies greater than 1 mgd during low-flow periods having a recurrence interval of 10 years. If storage of 10 acre-feet per sq mi of drainage area can be developed, the dependable draft rate for many streams can be doubled.

Fresh ground water is generally available everywhere on the peninsula and the aquifers, as they have in the past, will probably be utilized as sources of future water supplies. Ground water on the peninsula is available from 10 regional aquifers and from one or more water-bearing sand beds of local extent. The areal extent of fresh water, the areas of use and of potential use, the range of hydraulic characteristics, and the estimated amounts of perennial yield and of withdrawals for each regional aquifer are shown in table 11.

Of the 10 regional aquifers on the peninsula, the Quaternary aquifer is the most extensive, the most permeable, and the most productive. It is also the most susceptible to pollution. Together with the updip parts of the older aquifers, the Quaternary constitutes a water-table aquifer that blankets the peninsula. To avoid excessive drawdowns and possible dewatering of the artesian aquifers, future large supplies (more than 5 mgd) would have to be developed in the water-table aquifer. If the developments in the water-table aquifer are limited for the most part to the area of the peninsula where the water level is 10 feet or more above sea level, the amount of water available for use in the aquifer is about 1,500 mgd (the estimated base flow of streams in this area). If the water-table aquifer were developed to obtain this quantity of water, the present flow of the streams would be drastically decreased, and alternative methods of waste disposal and dilution would be required. Possibly a sufficient amount of ground-water discharge to the bays and ocean would still be available to prevent the intrusion of saline water into the aquifer. Additional quantities of water are available from storage in the aquifers, although this water, for practical purposes, is available for use only once.

Water in most of the Quaternary aquifer and updip water-table parts of the older aquifers generally has less than 100 mg/l dissolved solids. The water is suitable for most uses but in some areas may require iron-removal treatment. High concentrations of nitrate in much of the shallow ground water on the peninsula indicate the susceptibility of the water-table aquifer to contamination. If the peninsula's ground-water resources are developed to a maximum, some measures may have to be taken to safeguard the water quality in this aquifer.

Average use of water on the peninsula in 1970 was about 137 mgd. It is estimated that the use of water by the year 2010 will be 260 mgd. The amount of fresh water available in the streams and aquifers is more than adequate to supply the 260 mgd.

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TABLE 11.—*Summary of aquifer data*

Aquifer	Areal extent (sq mi)	Area of use (sq mi)	Area of potential use (sq mi)	Estimated perennial yield (mgd)	Estimated withdrawals 1970 (mgd)	Range in transmissivity (ft² per day)	Range in coefficient of storage
Nonmarine Cretaceous	2,500	750	1,750	80	18	550– 3,000	0.0001–0.0005
Magothy	2,200	400	1,800	10	2	500– 3,000	0.0001
Aquia and Rancocas	1,600	1,300	300	190	7	300– 5,000	.0001– .0004
Piney Point	2,000	1,100	900	(1)	9	1,200– 6,000	.0002– .0004
Cheswold	2,200	450	1,750	80	8	200– 4,000	.0001– .006
Federalsburg	2,200	500	1,700	50	3	450– 1,400	.0001– .003
Frederica	2,400	800	1,600	50	3	1,400	------------
Manokin	3,500	1,200	2,300	(2)	6	950– 5,500	.0001– .0003
Pocomoke	2,150	1,600	550	(2)	6	1,000– 8,000	.0001– .003
Quaternary	5,950	5,950	0	1,040	61	100–50,000	.0001– .17

[1] Included with Cheswold aquifer.
[2] Included with Quaternary aquifer.

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