Summary Appraisals of the Nation's Ground-Water Resources—Mid-Atlantic Region

GEOLOGICAL SURVEY PROFESSIONAL PAPER 813-I

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By ALLEN SINNOTT *and* ELLIOTT M. CUSHING

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A discussion of ground water in relation to the total water resources of the region

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Factors for converting English units to units of the International System (SI) based on the metric system are given below.

English system units	*Symbols*	*Multiplication factors for obtaining SI equivalent units*	*SI units*	*Symbols*
Length:				
inches	(in)	25.4	millimeters	(mm)
feet	(ft)	.3048	meters	(m)
miles	(mi)	1.609	kilometers	(km)
Area:				
acres		.4047	hectares	(ha)
square miles	(mi^2)	2.590	square kilometers	(km^2)
Volume:				
U.S. gallons	(gal)	3.785	liters	(L)
acre-feet	(acre-ft)	1,233.5	cubic meters	(m^3)
cubic feet	(ft^3)	.02832	cubic meters	(m^3)
Slope:				
feet per mile	(ft/mi)	.189	meters per kilometer	(m/km)
Flow:				
U.S. gallons per minute	(gal/min)	.06309	liters per second	(L/s)
cubic feet per second	(ft^3/s)	.02832	cubic meters per second	(m^3/s)
million gallons per day	(million gal/d)	3,785	cubic meters per day	(m^3/d)
billion gallons per day	(billion gal/d)	3.785	cubic hectometers per day	(hm^3/d)

SUMMARY APPRAISALS OF THE NATION'S GROUND-WATER RESOURCES— MID-ATLANTIC REGION

By ALLEN SINNOTT and ELLIOTT M. CUSHING

ABSTRACT

The Mid-Atlantic Region covers a total area of about 108,000 square miles. It includes parts of Vermont, Massachusetts, New York, Pennsylvania, Maryland, West Virginia, and Virginia, the entire States of New Jersey and Delaware, and the District of Columbia. It encompasses the entire drainage basins (within the United States) of the Hudson, Delaware, Susquehanna, Potomac, and the James River and includes Long Island and the coastal drainage of New Jersey, Delaware, Maryland, and Virginia.

Ground water in the region occurs in three broad types of geologic terrane: (1) unconsolidated deposits in the Coastal Plain seaward of the Fall Line; (2) hard, consolidated sedimentary rocks and crystalline igneous and metamorphic rocks in the remainder of the region; and (3) unconsolidated sand, gravel, and other deposits of glacial origin that overlie the older rocks extensively in the glaciated northern part of the region.

Ground water is derived primarily from precipitation; it can be intercepted for use by pumping from wells before it reaches the streams or before it drains into coastal wetlands or the ocean.

The natural discharge from the aquifers in the region is estimated to be at about 38.6 billion gallons per day; in addition, at least 140–350 trillion gallons is stored in the rocks.

About 949 billion gallons of fresh ground water was withdrawn in 1970. This quantity represents about 9 percent of the total freshwater use of 10,220 billion gallons. Available ground-water reserves indicate that a considerable part of the additional supplies needed for the anticipated increase in economic activity in the region could be developed from ground water.

INTRODUCTION

This report describes the ground-water conditions in one of the 21 Water Resources Regions designated by the U.S. Water Resources Council (1970)—the Mid-Atlantic Region in northeastern United States (fig. 1). The purposes of the report are (1) to summarize the broad facts about the overall ground-water resources of the Mid-Atlantic Region, (2) to describe current development and management problems of important ground-water reservoirs in the region, (3) to discuss options for future ground-water development, and (4) to identify the additional ground-water information needed to provide a sound basis for better management of the region's water resources.

The report is one of a series being published by the Geological Survey to document the Nation's ground-water resources, region by region, and to analyze the role of the resource in National water supply.

PHYSICAL, GEOGRAPHICAL, AND ECONOMIC SETTING

The Mid-Atlantic Region includes the entire drainage basins of five major streams in the heavily populated and industrial northeastern United States (fig. 2). These are the Hudson River, in New York, Vermont, and Massachusetts; the Delaware River, chiefly in New York, Pennsylvania, and New Jersey; the Susquehanna River, chiefly in Pennsylvania and New York; the Potomac River, in West Virginia, Pennsylvania, Maryland, and Virginia; and the James River, chiefly in Virginia. Two smaller tidewater basins, those of the Rappahannock and York Rivers, lie between the Potomac and James Rivers in Virginia. The region as a whole extends from the international boundary with Canada southward nearly to Virginia's southern boundary.

In addition to these five basins, the region includes also a small part of the St. Lawrence River drainage area in northeastern New York and northwestern Vermont, and lesser stream basins and coastal reaches from southeastern Virginia to New York, including all of Long Island.

The Mid-Atlantic Region extends inland from the coast an average of about 200 mi, and it is nearly 700 mi long. It covers an area of about 108,000 mi^2, and encompasses all or parts of nine States and the District of Columbia. One of the largest—and certainly the most economically important—of the

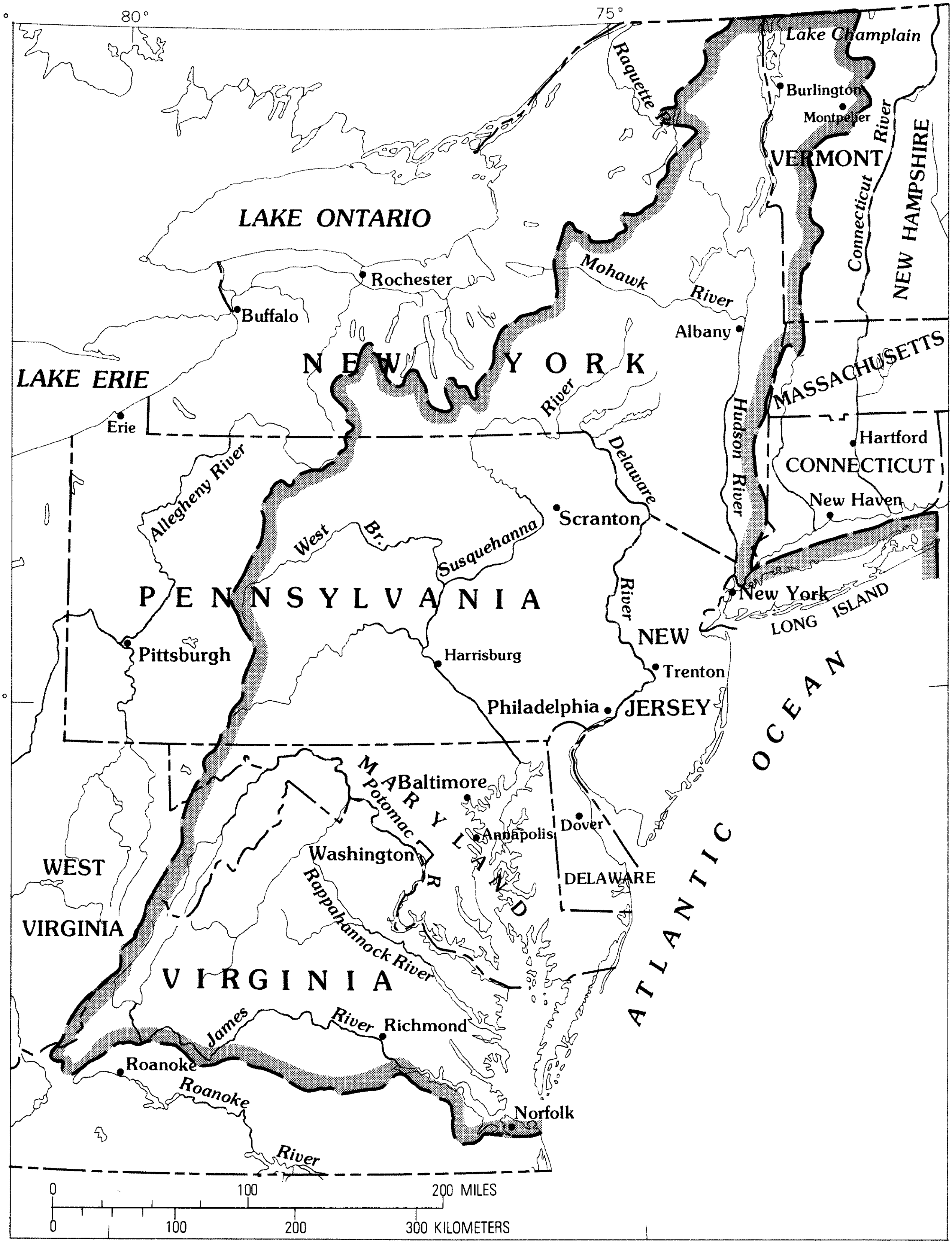


FIGURE 1.—The Mid-Atlantic Region includes much of the heavily populated and industrially developed northeastern United States.

world's estuaries, Chesapeake Bay, lies within the southeastern coastal part of the region.

The Mid-Atlantic Region is generally humid, with four distinct seasons, characterized by frequent weather changes. The climate along the coast is generally less severe than inland, because the ocean is warmed near the southern part of the region by the northeastward-flowing currents of the Gulf Stream.

Average annual temperatures range from about 44° F (6.6° C) in northern Vermont to about 60° F (15.6° C) in southern Virginia.

Precipitation is the ultimate source of virtually all the freshwater available for use in the Mid-Atlantic Region, although water stored in deep-lying rocks may have been emplaced many thousands of years ago. The annual precipitation on the region averages about 40 inches but varies somewhat, depending on location. It is about 40 inches or more along the coast and over 50 inches in upstate New York, southern Vermont, and West Virginia. It is a little less than 36 inches in northern Vermont, south-central New York, two small areas in south-central Pennsylvania, and near the Virginia-West Virginia boundary. (See fig. 3.)

Although the Mid-Atlantic Region covers only about 3 percent of the land area of the United States, it contains about 19 percent of the national population—more than 38,500,000 people. The regional average population density is about 350 people/mi ^{2}, compared to about 54 people/mi ^{2} for the entire United States. Several large population centers are within its boundaries, including three of the largest metropolitan areas of the country, New York City, Philadelphia, and Washington, D.C. (See fig. 4.)

The region generates nearly 22 percent of the national personal income, and its per-capita personal income is 15 percent above the national average. Thus, the Mid-Atlantic Region has a high level of economic development—the highest among the Water Resources Regions in the country. (See U.S. Water Resources Council, 1972, summary tables.) Despite this fact, however, there are economically depressed areas in the region with declining population, particularly the abandoned coal-mining districts in Pennsylvania and West Virginia. The present increasing demand for coal as a source of energy may reactivate many former coal-producing districts.

PHYSIOGRAPHIC DIVISIONS

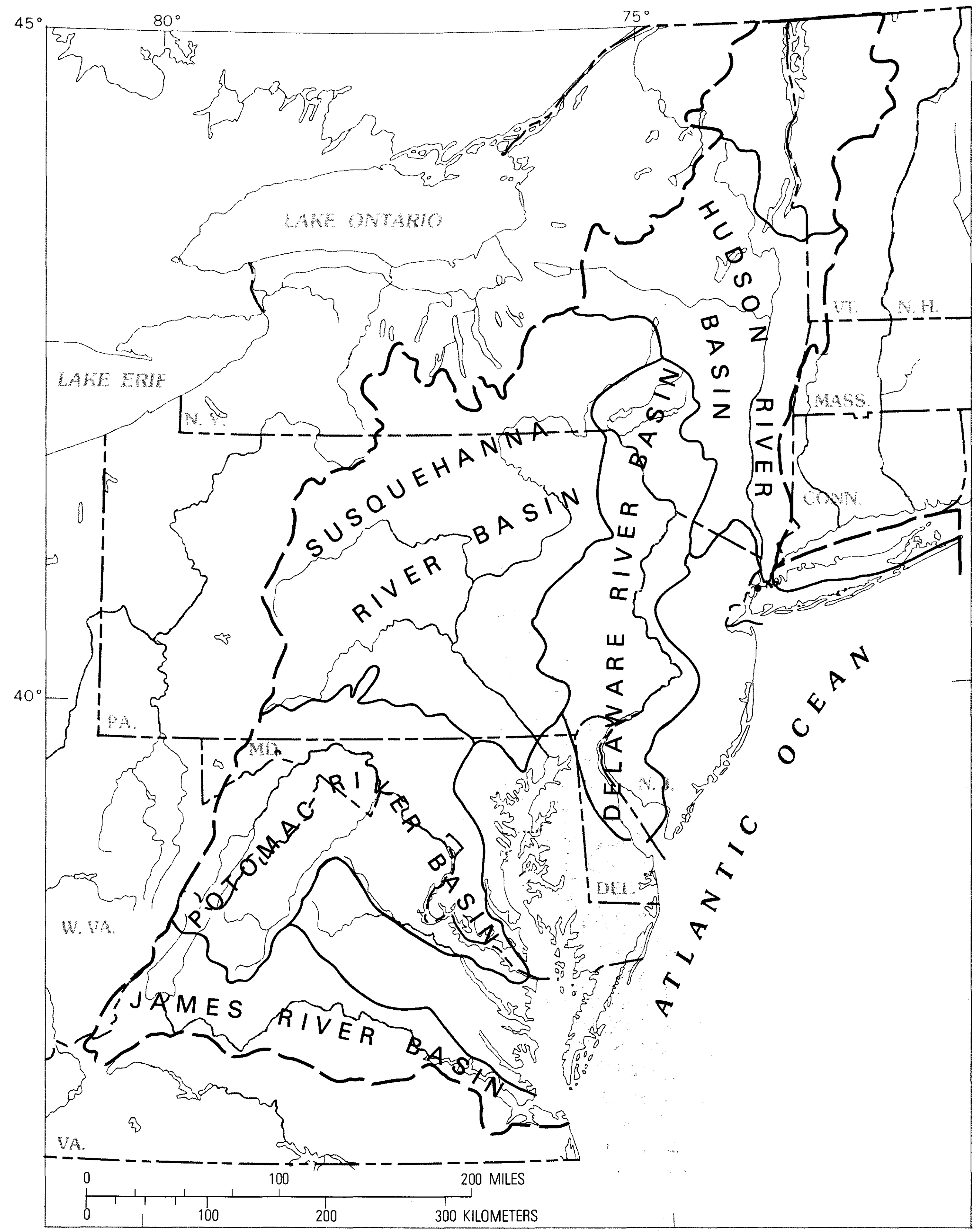
Several physiographic provinces, as defined by Fenneman and others (1946), lie within the Mid-Atlantic Region. (See fig. 5.) The most important of these, from the standpoint of ground-water supplies, is the Coastal Plain province, which flanks the entire eastern part of the region along the Atlantic Ocean. The other major physiographic divisions include the Piedmont province, immediately west of the Coastal Plain; the narrow Blue Ridge province and its northeastern correlative, the Reading Prong of the New England province; the Valley and Ridge province; and, in the west and northwest, the Appalachian Plateaus province. In addition, in the northernmost part of the region, there are the eastern part of the Adirondack province, the Champlain Valley, and the extreme western flank of the New England province.

OCCURRENCE AND AVAILABILITY OF GROUND WATER

The Mid-Atlantic Region is underlain by a wide variety of geologic formations that together control the storage, movement, and chemical quality of the ground water. The rocks range from the unconsolidated clays, sands, and gravels of the Coastal Plain and watercourses to much older rocks west and northwest of the Fall Line (fig. 6). These older rocks include consolidated sedimentary rocks and some ancient intrusive and volcanic rocks in the Piedmont Lowland; limestones, dolomites, sandstones, and shales of the Valley and Ridge province; crystalline igneous and metamorphic rocks of the Piedmont Upland; and those of the Blue Ridge and the Adirondack provinces. Most of these older rocks are relatively impermeable, but yield small to moderate supplies of ground water from fractures or joints to depths of about 200 to 300 feet below the surface.

The rocks of the region can be grouped into three general classes. These are (1) the unconsolidated deposits that underlie the Coastal Plain, (2) the crystalline igneous and metamorphic rocks and consolidated sedimentary rocks found in the remainder of the region, and (3), surficial deposits of glacial origin, occurring widely in the northern part of the region. The glacial deposit of greatest importance with respect to ground water is stratified drift, much of which consists of sand and gravel that commonly occur in stream valleys forming what are called watercourse aquifers.

The general hydrogeologic characteristics of the rocks in each of the principal physiographic prov-


45°
80°
75°
40°
LAKE ONTARIO
LAKE ERIE
N.Y.
PA.
MD.
W. VA.
VA.
DEL.
N.J.
VT.
N.H.
MASS.
CONN.
HUDSON RIVER BASIN
DELAWARE RIVER BASIN
SUSQUEHANNA RIVER BASIN
POTOMAC RIVER BASIN
JAMES RIVER BASIN
ATLANTIC OCEAN
0
100
200 MILES
0
100
200
300 KILOMETERS

inces of the Mid-Atlantic Region are described in the following pages.

COASTAL PLAIN

The Coastal Plain lies east of the Fall Line, and forms the southeastern part of the Mid-Atlantic Region. It extends from southern Virginia northeastward through Maryland, Delaware, Pennsylvania, New Jersey, and Long Island. (See fig. 6.) Topographically its surface is nearly flat or gently undulating, and altitudes range from sea level along the Atlantic coast to roughly 250 ft at the Fall Line.

The Coastal Plain is underlain by unconsolidated deposits. The formations consist mostly of sand and clay with minor amounts of gravel, and locally some beds of "marl" or shell rock. These deposits begin as a featheredge along the Fall Line and dip gently southeastward in a thickening wedge that rests directly on the underlying crystalline igneous and metamorphic rocks and other hard rocks that make up the basement complex—the seaward extension of the hard rocks of the adjacent Piedmont province. Configuration of the buried surface of the basement complex is shown in figure 7, from which it can be seen that the overlying deposits reach a maximum total thickness of more than 8,000 ft.

Overall, the general geology of the Coastal Plain deposits appears to be simple. There is, however, considerable complexity in many of its details. (See Brown and others, 1972, for a description of the structural and stratigraphic framework of the Atlantic Coastal Plain, and the relation of the tectonic and geologic history to present distribution of permeability.) The formations are areally extensive. In general, the shallow formations dip more gently than the deeper ones, and the seaward (southeastward) dip is on the order of 10 to 20 ft/mi.

Surficial deposits of the Coastal Plain are largely permeable unconsolidated sand and gravel that is thickest on Long Island and in New Jersey, Delaware, and eastern Maryland (fig. 8). Large quantities of water can be obtained from these deposits by wells generally less than 300 ft deep. Yields of individual wells may be as much as 2,000 gal/min where the greatest thicknesses of coarse material are present. Elsewhere in eastern Maryland, and in eastern Virginia, the surficial deposits of the Coastal Plain are thin and the yield of individual wells is small.

Deeper artesian aquifers of the Coastal Plain are among the most productive in the Mid-Atlantic Region. The depth of wells may be as much as 1,300 ft, and yields of more than 2 million gal/d may be available from some wells.

Beneath the ocean shoreline, and seaward at various distances, the downdip reaches of the artesian aquifers contain brackish water. (See Back, 1966.) Large quantities of ground water withdrawn from wells close to an interface between freshwater and brackish water may cause encroachment of brackish water into the freshwater part of the aquifer and eventually into wells.

Near the Fall Line, where the Coastal Plain sediments thin out against the basement rocks that are exposed in the Piedmont Province, only small to moderate supplies generally are available. Most wells there will not yield more than a few hundred gallons per minute. Locally, as in the Philadelphia-Camden area, somewhat larger yields have been obtained.

A number of distinct stratigraphic units have been delineated in the Coastal Plain, ranging from about 10 in Virginia to more than 20 in New Jersey. Many of these formations are permeable and have been defined as aquifers. Most are of wide areal extent and those that are of particular economic importance as major sources of ground water have been investigated and described. Large rates of withdrawal from one aquifer commonly are reflected in others proximate to it because of vertical leakage through intervening less-permeable beds. Hydraulic continuity through the complex interbedding is characteristic of Coastal Plain sediments. Most of the aquifers are not separate and independent hydrologic units; rather, each is part of a complex hydrologic system, and this system may even include streams and lakes where the aquifers are at or near the land surface.

Because the leaky nature of this complex system allows water to flow from one formation to another, it is generally not relevant to estimate quantities of ground water that are available from the individual aquifers. Rather, it is more meaningful to estimate the quantity available from the entire system. As will be shown later, for the Coastal Plain part of the region the minimum quantity of ground water that is being discharged under present hydrologic conditions is estimated to be a little more than 9 billion gal/d.

FIGURE 2.—The Mid-Atlantic Region comprises the entire drainage basins of five major rivers in the northeastern United States, including also smaller coastal river basins, and the United States part of the upper St. Lawrence River basin. It covers all of New Jersey and Delaware, parts of several other States, and the District of Columbia.

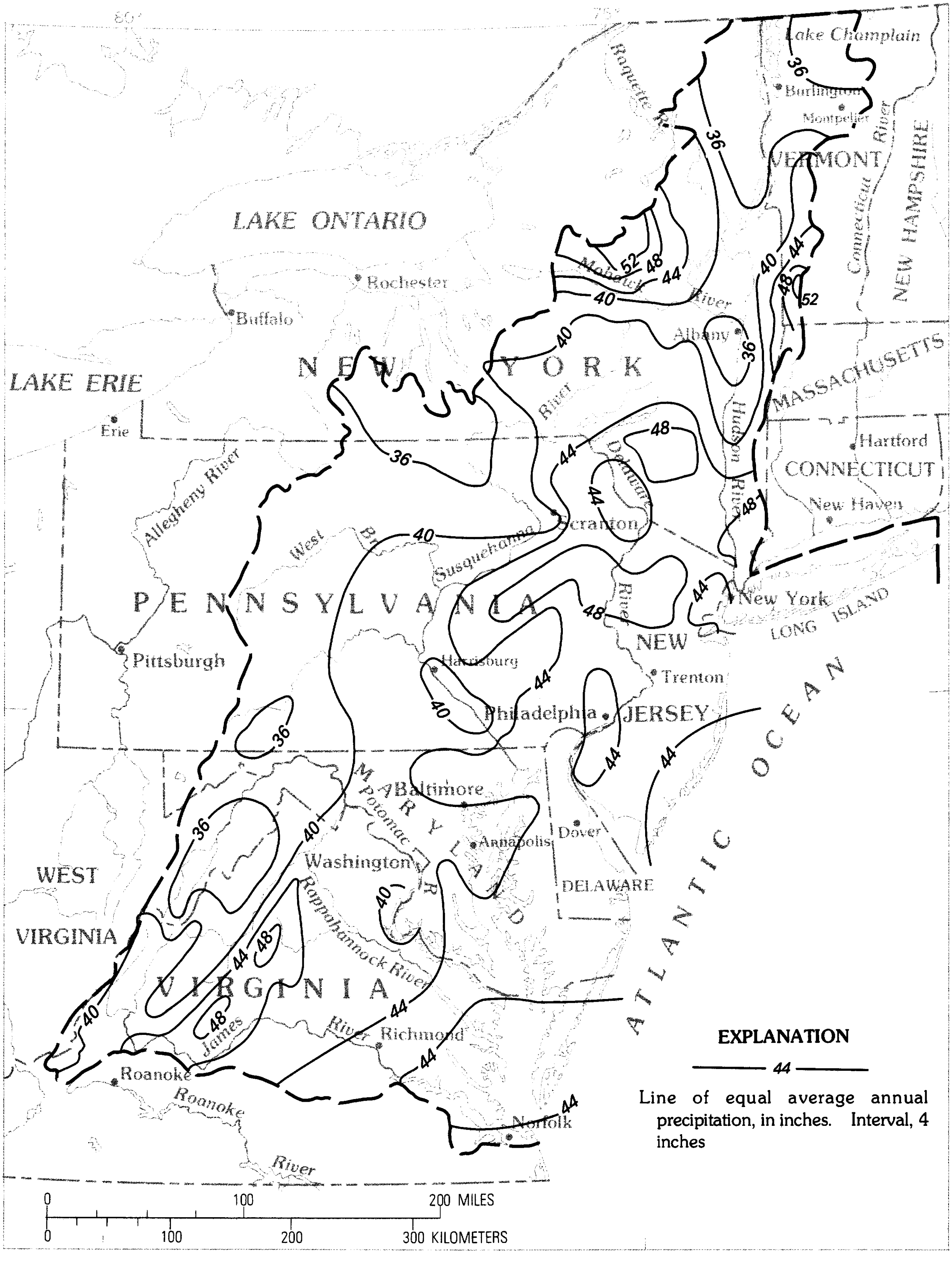


FIGURE 3.—Precipitation in the Mid-Atlantic Region averages about 40 inches and is the ultimate source of virtually all recharge of the aquifers in the region. (Based on period 1931–60. Source: National Weather Service.)

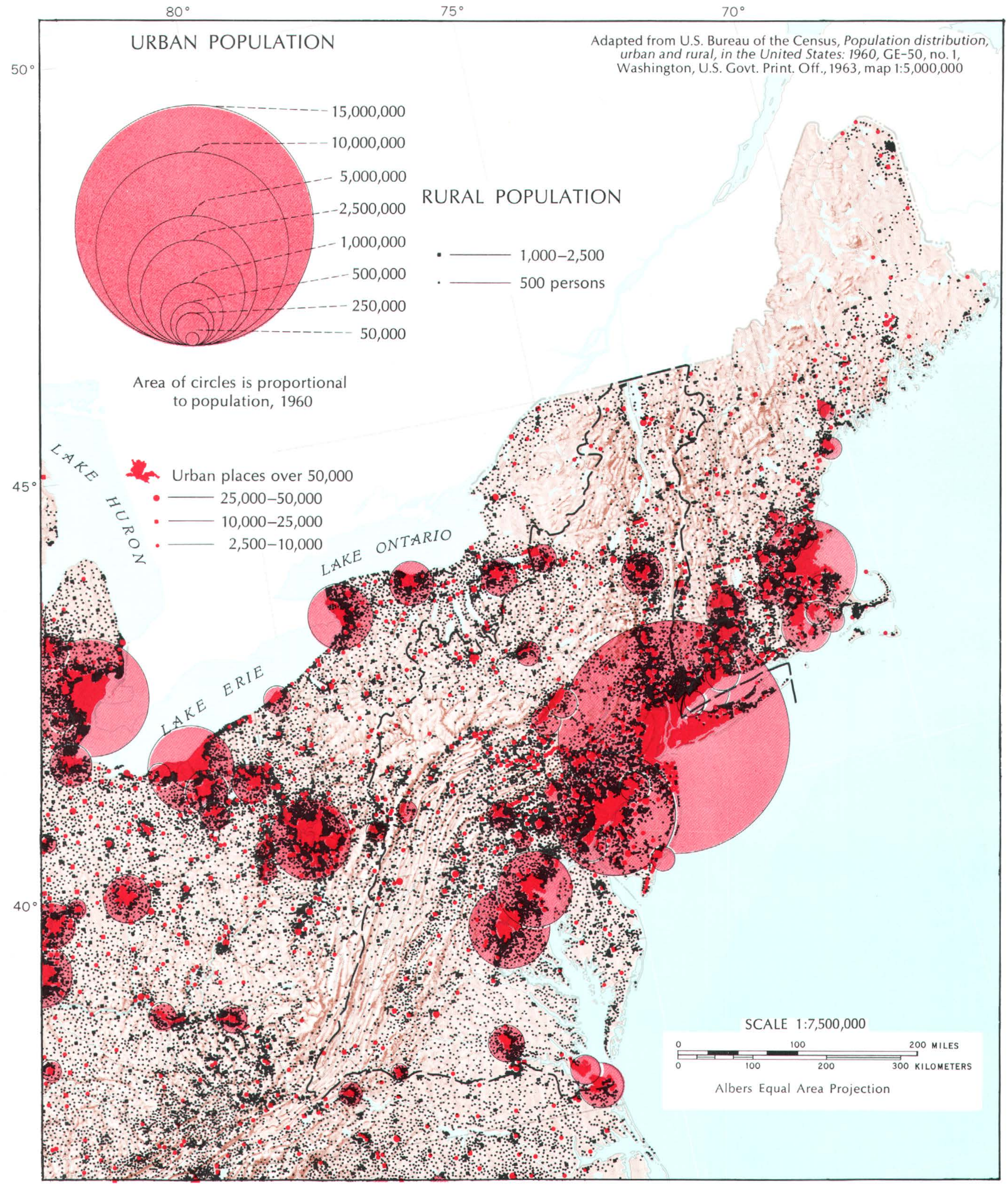


FIGURE 4.—The Mid-Atlantic Region includes large urban centers of population. (Map, from U.S. Geological Survey, 1970, National Atlas of the United States: p. 243.)

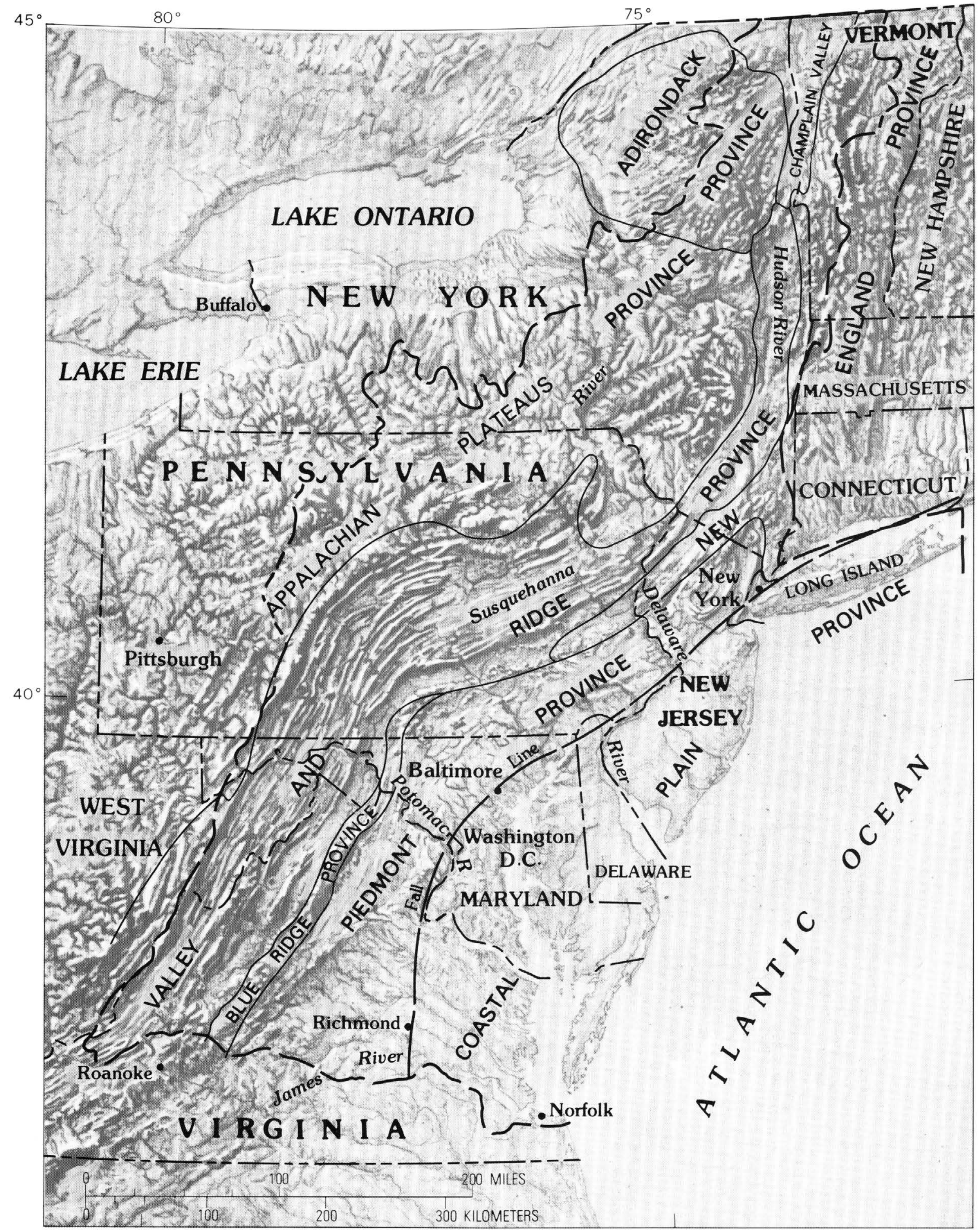


FIGURE 5.—The major physiographic divisions of the Mid-Atlantic Region also define, in a general way, the principal geologic terranes. (After Fenneman and others, 1946.)

The surficial deposits of sand and gravel that underlie the southeastern part of the Region probably constitute the most potentially productive aquifer in the Coastal Plain (fig. 6). These surficial deposits, together with the updip parts of deeper aquifers, constitute a water-table aquifer that blankets about 20,000 mi^2 on Long Island, N.Y., New Jersey, Delaware, eastern Maryland, and eastern Virginia. Large supplies of more than about 5 million gal/d are obtainable from this water-table aquifer. Withdrawals of this magnitude from the deeper artesian aquifers would entail large drawdowns and pumping lifts, and possible dewatering of these aquifers.

Large ground-water withdrawals from the surficial deposits should be located as far as possible from the ocean, consistent with other requirements, in order to minimize the threat of saline encroachment. The water-table aquifer in the surficial deposits also is vulnerable to surface pollutants.

PIEDMONT PROVINCE

The basement complex that lies beneath the wedge of Coastal Plain deposits crops out at the surface along the Fall Line, an imaginary line marking the western limit of the Coastal Plain. (See fig. 6.) The Piedmont province is a plateau of gently undulating hills and locally extensive lowlands lying between the Fall Line and the foot of the Blue Ridge in Virginia and Maryland and the Reading Prong of the New England province farther to the northeast. It averages about 50 mi in width, being narrowest in the northeast and widest southward in southern Virginia.

The province is underlain by weathered crystalline metamorphic and igneous rocks, by consolidated sedimentary rocks and some intrusive and volcanic rocks, and by carbonate rocks. The Piedmont contains two subprovinces, the Piedmont Upland and the Triassic Lowland. The upland consists mostly of crystalline rocks, and the lowland consists of relatively soft shale and sandstone and hills or ridges of harder rocks, such as diabase, basalt, and argillite.

Adequate quantities of ground water are available in the Piedmont province for domestic supply, light industry, and small municipalities. In the crystalline rock areas, the most dependable supplies of water are obtained by wells of moderate yield drilled into the lower part of the weathered zone and the upper part of the underlying fractured rock. Wells commonly yield up to about 15 gal/min per well, and some wells produce as much as 400 gal/min. Yields from wells in the consolidated sedimentary rocks commonly are somewhat greater than those in the crystalline rocks.

The quality of the ground water in the Piedmont is generally excellent, although in places it is high in iron or is hard where withdrawn from limestone aquifers or other sedimentary rocks containing calcareous materials.

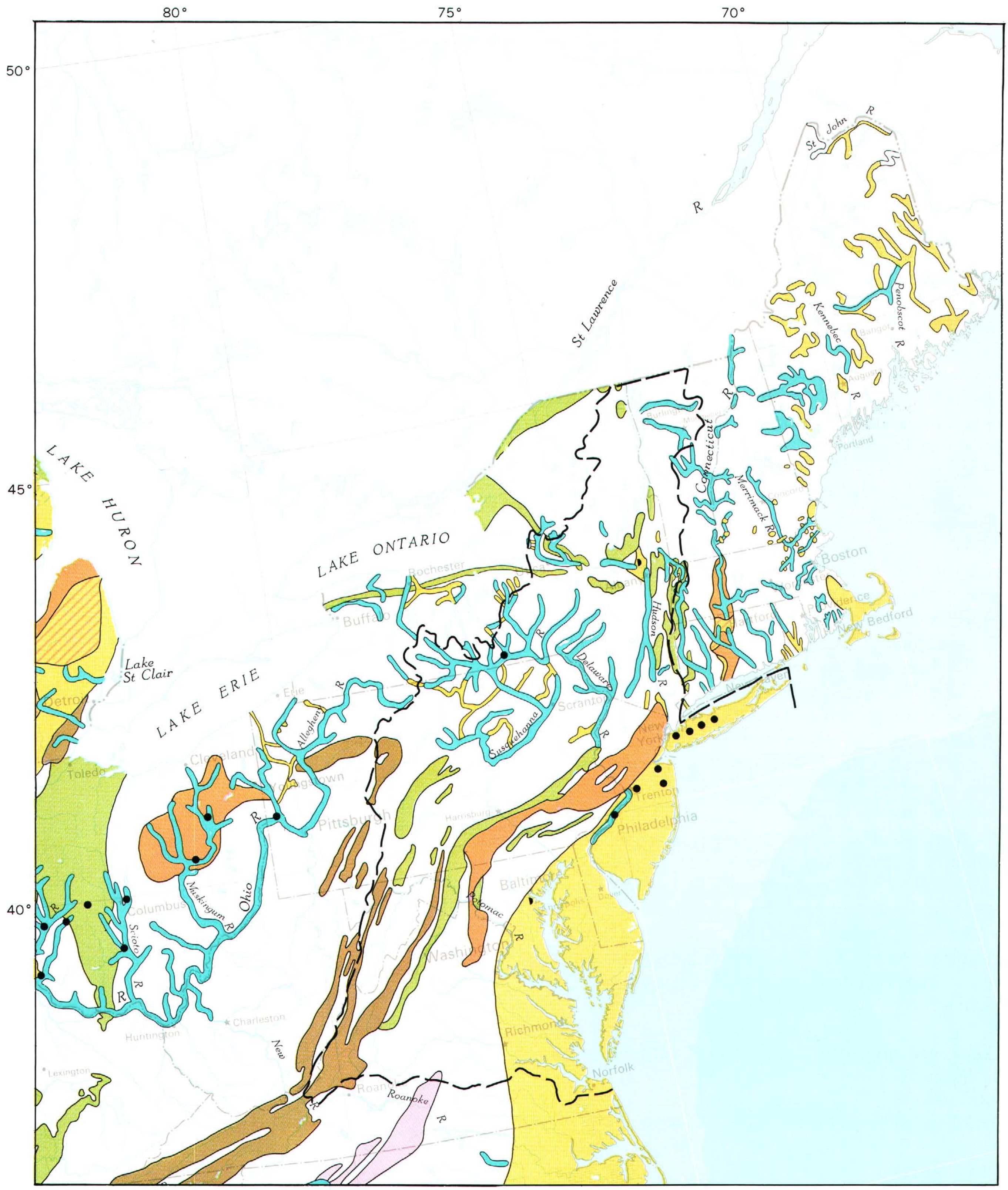
BLUE RIDGE PROVINCE

Along the western flank of the Piedmont province in Virginia, Maryland, and southern Pennsylvania lies the narrow northeast-trending Blue Ridge province (fig. 5). Within the Mid-Atlantic Region the average width of this province is less than 10 mi.

The rocks that underlie the Blue Ridge are metamorphosed sedimentary and igneous rocks very much like the crystalline rocks of the Piedmont. The Blue Ridge rocks, however, are more resistant to erosion and stand higher than the carbonate rocks to the northwest and the Piedmont rocks to the southeast. Because of their elevated position, they tend to be stripped of surficial weathered material and fractured rock, and drained of ground water (McGuinness, 1963). Expected well yields are less than 50 gal/min. Very little is known about the maximum water-yielding potential of the Blue Ridge rocks. Four wells drilled at Catoctin Mountain Park, Md., have yields that range up to 74 gal/min and average 36 gal/min. Possibly 150 to 200 gal/min could be pumped from the highest yielding well. These wells were drilled in metarhyolite and Catoctin Metabasalt and their depths range from 120 to 247 feet. They were located in topographic depressions believed to represent fracture zones in the underlying bedrock (Nutter, 1973). The average yield of these wells is about four times better than the average yield of the domestic wells in the vicinity. Water from the Blue Ridge rocks generally is of good quality, containing low concentrations of dissolved solids.

VALLEY AND RIDGE PROVINCE

The Valley and Ridge province lies just west of the Blue Ridge and its northeastern counterparts from Virginia to southern New York. In addition, it extends northward as the Hudson-Champlain section to the Canadian boundary; in this northward extension it lies west of the New England province (fig. 5). The province is bounded on the west by the Appalachian Plateaus and Adirondack provinces. In its southern half it is 50 to 100 mi wide; in eastern Pennsylvania and New York it narrows to about 25 mi.



SCALE 1:7,500,000

0 100 200 300 MILES

0 100 200 300 400 KILOMETERS

Map from U.S. Geological Survey
United States National Atlas, 1970

EXPLANATION

Colored patterns indicate areas underlain by one or more aquifers generally capable of yielding to a well at least 50 gallons per minute (or 3 liters per second) of fresh water (generally less than 1000 milligrams per liter of dissolved solids)

UNCONSOLIDATED AQUIFERS

Watercourse: alluvial valley traversed by stream from which recharge can be induced

Sand and gravel: in intermontane valleys; abandoned or buried alluvial valleys; alluvial terraces; sand dunes; Coastal Plain; glacial outwash and ice-contact deposits of glaciated regions

CONSOLIDATED ROCK AQUIFERS

Sandstone: includes some unconsolidated sand

Carbonate rock: limestone and dolomite

Sandstone and carbonate rocks

Crystalline rocks, igneous and metamorphic

Ruled pattern of any of these colors indicates that the corresponding aquifer underlies a productive sand and gravel aquifer as explained above

WITHDRAWALS FROM WELLS

- Represents withdrawal of 81,000 acre-feet or 100 million cubic meters annually, equivalent to 72 million gallons a day

- Represents half of the quantity described for preceding symbol

FIGURE 6.—Many areas in the Mid-Atlantic Region are underlain by at least one aquifer capable of yielding supplies of at least 50 gallons per minute of ground water to most wells. (Map, from U.S. Geological Survey, 1970, National Atlas of the United States: p. 123.)

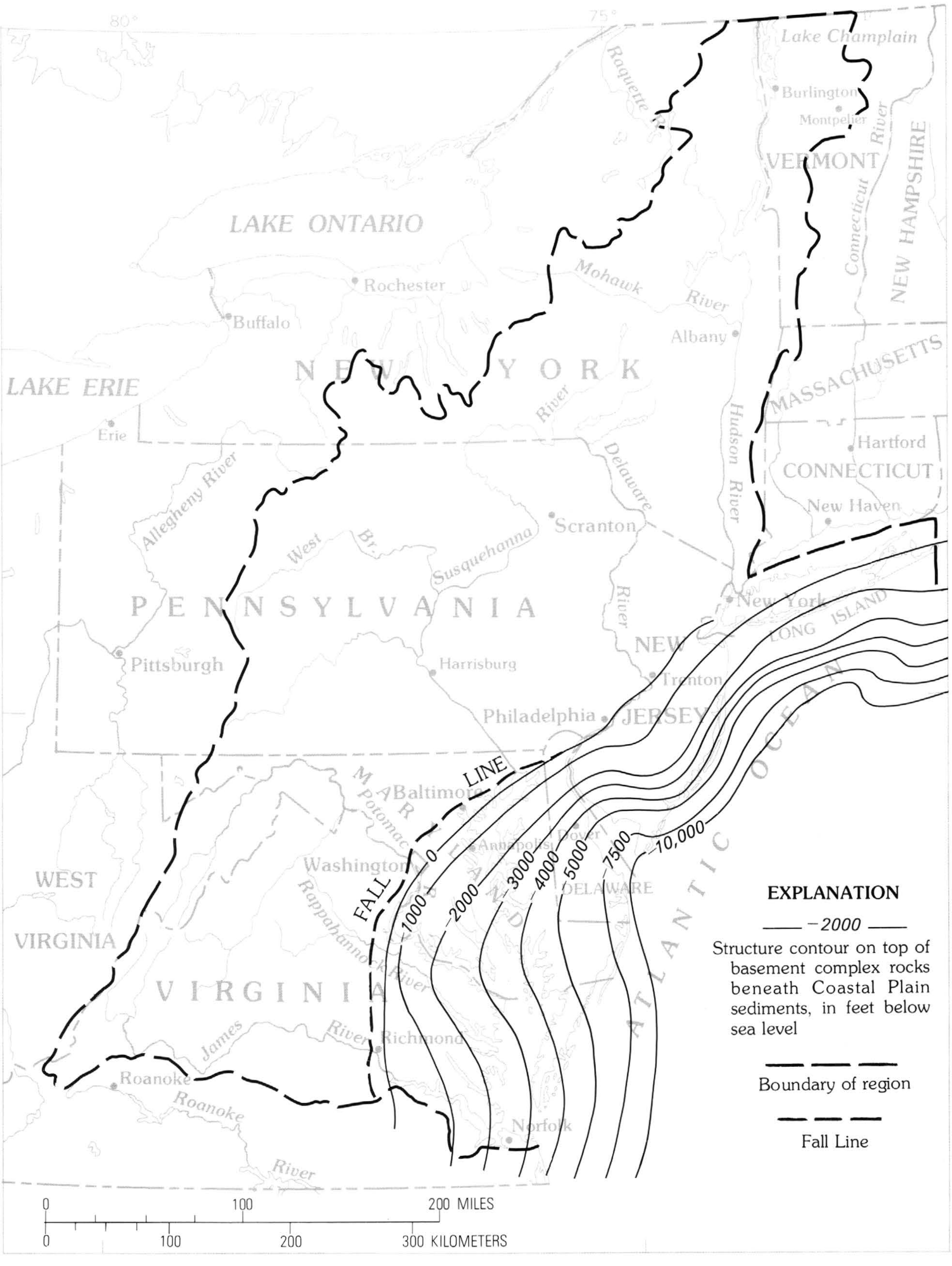


FIGURE 7.—The buried surface of the basement complex slopes seaward from the Fall Line to depths greater than 8,000 ft below sea level. (Adapted from Maher, 1971, pl. 4.)

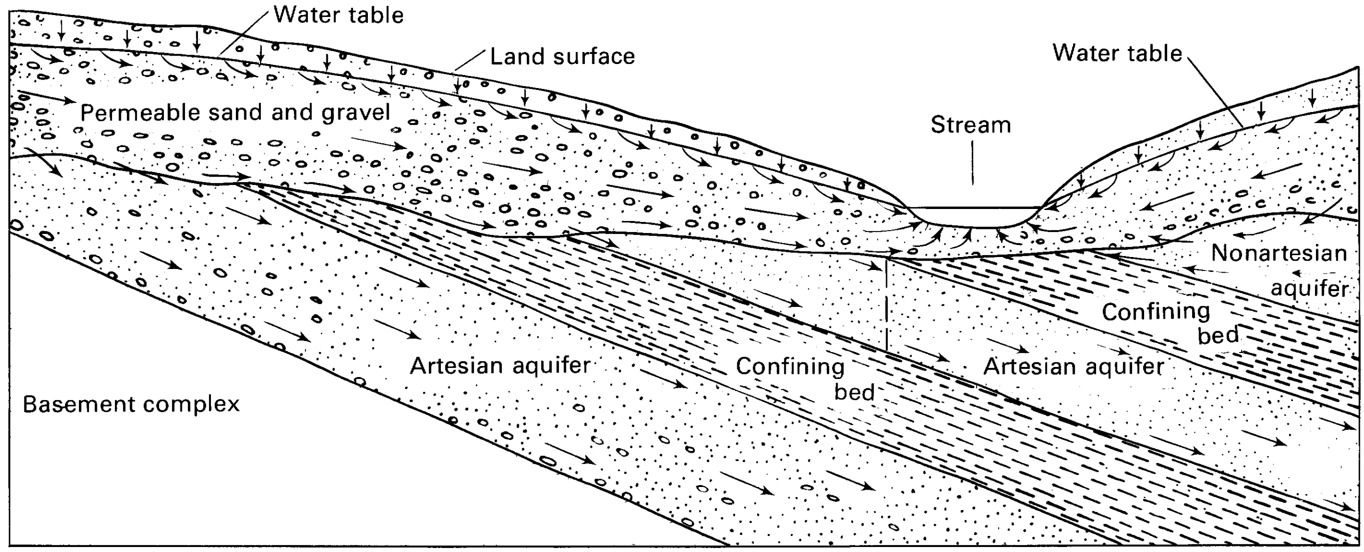


FIGURE 8.—Seaward-dipping artesian aquifers of the Coastal Plain are covered by surficial deposits of water-bearing sand and gravel on Long Island, N.Y., and in New Jersey, Delaware, eastern Maryland, and eastern Virginia. (Adapted from Parker and others, 1964, fig. 13.)

The province is underlain by folded and faulted sandstones, limestones, dolomites, shales, and quartzites. The structural trend in its southern part is generally northeastward, changing to northward up the Hudson Valley. Differential erosion has resulted in resistant beds standing as ridges, with intervening alluvium-filled valleys.

The chief sources of ground water in the Valley and Ridge province are permeable fractured sandstones and cavernous limestones. These are readily recharged from precipitation and stream infiltration. Much smaller quantities of ground water are available from the less permeable shales and siltstones. In all these rocks, secondary openings and fractures tighten with depth; hence, the shallow rocks, to depths of several hundred feet, are the most productive to wells.

Dry wells are common in the areas underlain by limestone. Some of these may be attributed to the fact that the water table is extremely deep because of underground drainage through interconnecting solution cavities. Water can usually be obtained by deepening the well to reach the water table. Many dry wells in limestone are caused simply by failure of the wells to penetrate any water-bearing solution cavities or fractures. A copious supply might be found in another well—perhaps only a few feet away— that taps such openings. Thus, exploratory drilling is commonly required.

In the Susquehanna River basin, well yields in the more mountainous part of the basin area average about 125 gal/min and may reach 700 to 1,000 gal/min (Seaber and Hollyday, 1965; Seaber, 1968). In the Great Valley section of the same basin, the predominant rocks, limestone and dolomite, are even more productive, and yields of wells may exceed 1,000 gal/min.

In the Hudson-Champlain section, the valley-fill deposit in the Glens Falls, N.Y., area is a productive aquifer (Giese and Hobba, 1970). Well yields average 67 gal/min but reach 400 gal/min. The bedrock, near Plattsburgh, N.Y., consists of sandstone and carbonate rocks. It is overlain by relatively impermeable glacial deposits and is in an artesian system. Well yields average about 15 gal/min from sandstone and 35 gal/min from carbonate bedrock. Some wells in the carbonate rocks produce as much as 200 gal/min.

The chemical quality of the ground water in the Valley and Ridge province is closely related to the lithology. Water from sandstone is usually soft and generally low in dissolved solids. Water from carbonate rocks generally is hard and is contaminated locally by nitrate. Shales in the eastern panhandle of West Virginia (Hobba and others, 1973) are reported to yield hard water containing excessive iron. In the broad, major downfolded (synclinal) basins, high chloride or sulfate content is common. Where coal beds occur, many wells yield acid water that may also contain high iron and sulfate.

Many wells constructed in permeable weathered zones in carbonate-rock aquifers yield turbid water from the residual clay in solution channels and caverns. Hobba and others (1973) note that in the West Virginia panhandle, "lowering the water table removes support of clay plugs in the roofs of water-filled caverns in the bedrock, and the plugs may collapse to cause sink holes at the land surface."

The chemical quality of ground water in the Hudson-Champlain section is generally excellent or good, although hardness and alkalinity are problems locally.

APPALACHIAN PLATEAUS PROVINCE

In the western part of the Mid-Atlantic Region, the Appalachian Plateaus province extends from north-central Pennsylvania into southern New York (fig. 5). A small area in the extreme northwestern part of the Potomac River basin in West Virginia and Maryland also lies in the province.

The underlying bedrock consists of nearly horizontal beds of alternating sandstone, shale, some limestone, and seams of coal.

In the Pennsylvania part of the province, the average yield per well may be about 200 gal/min. In New York, yields are significantly lower, averaging about 60 gal/min. The quality of water from the bedrock at depths of less than about 250 feet is generally good except near coal mines, where iron is locally troublesome. Saline water commonly occurs at depths of only 300 to 500 feet (Becher, 1970).

The parts of the Appalachian Plateaus province that lie in the Mid-Atlantic Region in northern Pennsylvania and New York are glaciated. Outwash deposits from the meltwaters of Pleistocene continental glaciers are found in the lowlands. In addition, postglacial alluvial sands and gravels in the stream valleys form watercourse aquifers (Thomas, 1952, p. 10). The glacial outwash deposits and the watercourse aquifers are the chief sources of dependable ground-water supplies in the glaciated part of the province. (See fig. 6.) Many wells in sand and gravel deposits yield moderate to large supplies of water—some more than 1,000 gal/min. Recharge from the streams can be induced by pumping wells drilled in the watercourse aquifers, but induced infiltration of stream water reduces streamflow.

The quality of the ground water from the glacial deposits is generally good. However, it may be hard where the drift contains limestone pebbles, and iron is troublesome locally, particularly in New York.

ADIRONDACK PROVINCE

The eastern part of the Adirondack province lies within the Mid-Atlantic Region in northern upstate New York (See fig. 5.) It is just north of the Appalachian Plateaus province and west of the Hudson-Champlain section of the Valley and Ridge province. The province is a nearly circular uplift of ancient granite, gneiss, and other crystalline rocks surrounded by shale, sandstone, limestone, and dolomite. Valleys contain glacial outwash and alluvium. Many peaks exceed 4,000 ft in altitude; Mount Marcy, the highest mountain in New York, has an altitude of 5,344 ft.

The population of the province is sparse, and the demand for water, accordingly, is small. Yields of wells are generally moderate, 15 to 35 gal/min; the water occurs mostly in fractures in both the crystalline rocks and the consolidated sedimentary rocks. Larger yields are obtained locally from solution openings developed along fractures in the carbonate rocks. Locally, substantial yields are available also in glacial outwash deposits in valleys.

The quality of ground water is generally good, and that from the crystalline rocks is excellent—less than 100 mg/L of dissolved solids.

NEW ENGLAND PROVINCE

In the Mid-Atlantic Region, the New England province is represented by the western part of Vermont, the extreme northwestern part of Massachusetts, and a narrow area extending southwestward across southern New York and northern New Jersey into eastern Pennsylvania as far as Reading. (See fig. 5.) This extension is known as the Reading Prong; in New Jersey it is called the Highlands.

The bedrock consists of ancient crystalline, igneous, and metamorphic rocks, some of which are carbonate rocks. Locally the carbonate rocks are faulted and contain solution openings, forming aquifers that may yield a few hundred gallons per minute. Similar yields may be obtained from deposits of stratified glacial drift in stream valleys (watercourse aquifers).

Ground water of generally good quality can be developed from the various kinds of bedrock and from the stratified drift. The carbonate bedrock, however, yields water that is moderately hard.

AVAILABILITY OF GROUND WATER TO MEET FUTURE NEEDS

C. L. McGuinness, in his comprehensive treatise on the "Role of ground water in the National water situation" (1963, p. 110–111) recounted the circumstances leading to the gradual increase in demand for ground water as a source of water supply during the early development of the country. Ground water in the Mid-Atlantic Region has assumed increasing importance through the years, following much the same pattern as that described by McGuinness for the country as a whole.

Nationally, ground water has developed from a minor but important source of domestic supply to one that provides about 21 percent of the Nation's total water withdrawals from all sources in 1970 (Murray and Reeves, 1972, table 17). In the Mid-Atlantic Region, however, ground-water withdrawals in 1970 amounted to only 9.3 percent of the total water withdrawals, attesting to the relatively minor role still played by ground water in this important region in the humid East where surface water is the major source of supplies.

Many water-resources investigations and reports deal separately with ground water and surface water. Even though they are physically interrelated, ground water and surface water require different techniques of study, observation, and development. Ground water and the base flow, or dry-weather flow, of streams are two phases of a single resource. Base flow is ground water that is discharged continually from the ground-water reservoir. Overland runoff from precipitation greatly increases streamflow intermittently but flow then subsides during an ensuing period of dry weather.

WATER DISCHARGED FROM AQUIFERS

Many investigators of the water resources in areas within the Mid-Atlantic Region have made determinations of the percentage of total streamflow that is base flow, or ground-water discharge. (See, for example, Cushing and others, 1973; Nutter, 1973; Franke and McClymonds, 1972; Trainer and Watkins, 1974; Johnston, 1971; Olmsted and Hely, 1962; Rasmussen and Andreasen, 1959; Dingman and Ferguson, 1956; Dingman and others, 1954.) In the Coastal Plain province, base flow ranges from about 40 to 95 percent of streamflow, and in the part of the Mid-Atlantic Region underlain by consolidated rocks, from about 25 to 90 percent.

Bue (1970) showed that the mean streamflow from the Mid-Atlantic Region to the Atlantic Ocean during 1931–60 was 128,900 ft^3/s. Adding to this quantity the amount estimated to flow from the region into Canada, the mean streamflow from the region (area, 108,000 mi^2) is about 139,000 ft^3/s, or about 90 billion gal/d.

Assuming, conservatively, that only 55 percent of the streamflow in the Coastal Plain part of the region is base flow, then the natural discharge from unconsolidated aquifers is computed to be about 9.2 billion gal/d. Again, assuming that only 40 percent of the streamflow in the remainder of the region, underlain chiefly by hard consolidated rocks, is base flow, the discharge from the aquifers there is about 29.4 billion gal/d. Thus, the average potential yield of ground water from the entire Mid-Atlantic Region under present hydrologic conditions is at least 38.6 billion gal/d. These estimates are summarized in table 1.

TABLE 1.—*Estimates of natural discharge of ground water from aquifers in the Mid-Atlantic Region*

	Area (mi^2)	Streamflow (billion gal/d)	Portion of streamflow estimated to be base flow (percent)	Estimated discharge of ground water from aquifers (billion gal/d)
Coastal Plain part of region (mostly unconsolidated, or "soft," rocks)	20,000	16.7	55	9.2
Remaining part of region (mostly consolidated, or "hard," rocks)	88,000	73.5	40	29.4
Totals for Mid-Atlantic Region	108,000	90.2	--	38.6

It would be, of course, impractical to intercept all this water before it is discharged into streams. This estimated total, nevertheless, indicates the magnitude of the resource. For example, assuming an average daily consumption of 150 gallons of water per person, the estimated total available supply of 38.6 billion gal/d of ground water, if developed for domestic use, would provide for about 257 million people—more than six times the population of the region in 1970. For the region at large, the potential supply is sufficient to provide for anticipated population growth for the foreseeable future.

During extended periods of greater than average precipitation, more ground water would be available than the estimated 38.6 billion gal/d. Conversely, during drought conditions, substantially less would be available.

WATER IN STORAGE

In addition to the quantity of ground water estimated above, at least another 140 to 350 trillion gal-

TABLE 2.—*Estimates of ground water in storage in hydrogeologic units of the Mid-Atlantic Region*

Hydrogeologic unit	Approximate area (mi²)	Average productive thickness (ft)	Average available drawdown (ft)	Estimated average storage coefficient (dimensionless)	Estimated storage available (trillions of gallons)
Coastal Plain province (sand, clay, minor gravel)	20,000	250	150	0.1–0.2	63–125
Piedmont, New England, and Adirondack provinces (crystalline igneous and metamorphic rocks)	29,800	250	200	.001–.05	1.2–62
Blue Ridge province (crystalline rocks)	2,100	200	150	.001–.02	.07–1.3
Valley and Ridge province (sandstone and limestone)	28,700	250	200	.05–.1	60–120
Champlain Valley (sandstone and limestone)	2,700	150	100	.05–.1	2.8–5.6
Appalachian Plateaus province (sandstone and shale, coal seams)	24,700	200	150	.02–.05	15–39
Totals	108,000	---	---	-------	140–350 (rounded)

lons of water is estimated to be in storage in the major unconfined shallow aquifers of the region. As shown in table 2, this total is derived from estimates of the generally available drawdown (the difference between the static water level and maximum pumping levels) in the rocks in each of the major physiographic divisions of the region. In the manner developed by Rasmussen (1955) for Delaware, the areas of each division were multiplied by the estimated available drawdown, and by the storage coefficient (a decimal fraction representing the quantity of water per unit volume of the aquifer that can be withdrawn or replenished), and the results converted to trillions of gallons.

In addition to the estimated quantity of water in storage in the major unconfined aquifers, substantial quantities also are stored in other units in the Mid-Atlantic Region. Among these are (1) artesian aquifers, chiefly in the Coastal Plain province; (2) certain glacial deposits, roughly in the northern half of the region that was covered by continental glaciers; (3) aquifers in watercourses—stream valleys containing glacial outwash sand and gravel, or alluvial deposits, in hydraulic continuity with streams, (4) sand and gravel deposits in former river valleys that were buried beneath by later glacial deposits.

Except for the artesian aquifers beneath the Coastal Plain, it is difficult to make meaningful estimates of the quantities of ground water in these other deposits. It is particularly difficult for watercourse aquifers, which are quickly replenished by streams as ground water is withdrawn from the aquifer. However, a very conservative estimate of ground water stored in these various kinds of deposits would be at least another 20 trillion gallons, in addition to the 140 to 350 trillion gallons that are estimated to be in storage in the major unconfined aquifers.

A substantial part of the quantity that is in storage—perhaps at least 50 percent—would be potentially available as a reserve supply during emergency periods, such as the northeast drought of the middle 1960's. However, only a small part of this potential reserve supply could be developed during a drought because of the lead time required for exploratory drilling, aquifer testing, drilling of production wells, and development of suitable distribution systems by which to transport the water to municipal or industrial centers where it is needed. Thus, to cope with possible emergencies, these reserve sources of ground water ideally could be explored and water-supply systems installed well in advance of critical demand for emergency supplies.

WITHDRAWALS AND USE

In 1970, the rate of withdrawals of freshwater from all sources in the Mid-Atlantic Region was 28,000 million gal/d, of which 9.3 percent, or 2,600 million gal/d, was ground water (Murray and Reeves, 1972, table 17). This is equivalent to a total volume of 10,220 billion gal from all sources during 1970, of which 949 billion gal was from ground water. In terms of the regional population of 38,401,000 in 1970, the rate of use of freshwater was about 730 gal/d per person in the region from all sources, and the rate of use for fresh ground water was about 68 gal/d per person (Murray and Reeves, 1972, table 17). Thus, the present demand for water in the region is met primarily from surface-water sources. The quantity of ground water that is estimated to be available from the aquifers of the region indicates that substantial additional utilization of ground water is a valid management option.

Of the total freshwater withdrawn in the region from all sources in 1970, only 5 percent was consumed (lost to the atmosphere by evaporation or incorporated with manufactured products), and 95 percent was returned to the streams or aquifers (Murray and Reeves, 1972, table 17.)

Industrial use of ground water was only 1,100 million gal/d, or about 4 percent of the total freshwater withdrawals. Thus, industry, which is the principal economic activity in the region, depends largely on surface-water supplies. These supplies are vulnerable to drought and pollution and their extensive land-use requirements may not be entirely compatible with the interests of environmental protection and conservation. Accordingly, future industrial growth may depend more and more on ground-water resources, particularly small or light industries whose requirements for process water may be small and which require water of good quality.

CHEMICAL QUALITY

DESCRIPTION OF CHEMICAL QUALITY

The chemical quality of ground water in the Mid-Atlantic Region differs from place to place in accordance with the hydrologic history of the water and the nature of rock materials through which it flows. However, in most parts of the Mid-Atlantic Region freshwater of satisfactory chemical quality for virtually all uses occurs to depths of several hundred feet, and in some areas to a depth of a thousand feet or more. In overview, the Coastal Plain province contains a large, complex blanket of fresh ground water overlying a much greater volume of deep-lying brackish and saline ground water extending downdip (downslope) seaward. The boundary between the updip freshwater and the downdip saline water is mappable (Cushing and others, 1973). Freshwater, in the great mass of nonmarine formations constituting the oldest sedimentary rocks in the province, extends from several to more than 60 miles downdip from outcrop areas along the western side of the province. The quality of water in these deposits is generally soft and slightly acidic in the outcrop area, with local excessive amounts of iron, and total dissolved solids content on the order of 50 to 150 mg/L. Downdip and at greater depths below the land surface, in parts of the formation confined under younger deposits, the water is more mineralized, is commonly of the calcium bicarbonate type and slightly hard, with dissolved solids on the order of 300 to 500 mg/L. As the boundary between fresh and saline ground water is approached, dissolved solids exceed 1,000 mg/L.

A large mass of marine deposits rests on and crops out east of the nonmarine strata. These marine deposits contain fresh ground water with dissolved-solids content on the order of 100 to 250 mg/L. Water from these deposits, too, contains excessive concentrations of iron locally, and owing to the abundance of calcium carbonate shells and other calcareous material, moderate to excessive hardness is encountered in places. The relationship with downdip saline ground water in these sediments is less well defined than for the nonmarine deposits.

Water in the glacial, watercourse, and alluvial deposits is generally soft, containing less than 50 mg/L up to 150 mg/L of dissolved solids, although in places concentrations may be as much as 400 mg/L. Excessive hardness and high-iron concentrations occur in places. Saline water from tidal rivers, bays, and the Atlantic Ocean, where these waters border or contact low-lying deposits, may infiltrate the fresh ground water, either naturally or by induced landward movement owing to well pumpage. Peripheral to these saltwater bodies aquifers may contain water with dissolved-solids concentrations of 1,000 mg/L and much more. The quality of ground water in aquifers subject to freshwater recharge from rivers, lakes, or fresh reaches of estuaries may vary with the quality of the water infiltrating from these surface sources.

Owing to the great variety of rock materials in the remaining provinces, west and north of the Coastal Plain, ground-water quality varies widely. Freshwater in the silicate-type rocks (most of the metamorphic crystalline rocks and quartzose sedimentary rocks) that form highland areas, mountains, and ridge areas is different from that in the calcareous carbonate rocks (primarily limestone and dolomite) that commonly underlie major regional lowland valleys. Although there are exceptions, ground water in the silicate-type rocks is generally soft with low dissolved solids, usually less than 200 mg/L. Metamorphic crystalline rocks of the Blue Ridge province, for example, are not readily soluble to ground water, and water derived from wells or springs characteristically is very low in dissolved solids. In contrast, water in the calcareous rocks, such as in the Shenandoah Valley of Virginia, the Valley and Ridge Province, and the Taconic Province of New York and New England, is typically hard, with dissolved-solids content of 200 to 600 mg/L.

Throughout much of the area of the Appalachian provinces underlain by sedimentary belts of rocks, the fresh ground water is underlain by salty ground water at depths of several hundred to several thousand feet.

PROBLEMS ASSOCIATED WITH GROUND-WATER QUALITY

Salty ground water presents some problems and some opportunities. Many aquifers throughout the Mid-Atlantic Region are partly filled with salty water. Although unsatisfactory as a source of water supply for most uses without desalination, under favorable hydrogeologic conditions these saline reservoirs may serve as storage media for liquid wastes, petroleum, or even artificially recharged freshwater where excess surface water is available for storage.

Hard water is a problem and inconvenience, particularly in the regional valley areas of the Appalachian provinces where hardness of the water is highest. Treatment (softening) units are available for municipal, domestic, and industrial use.

Objectionable concentrations of iron are prevalent throughout the region. The problem is most pronounced in the shallow terrace and glacial deposits, and in Appalachian areas where mining of coal has affected ground-water quality.

Other natural quality problems of lesser importance include hydrogen-sulfide gas, excessive concentrations of fluoride, and contamination by oil and by organically derived natural gases such as methane.

Many quality-of-water problems are associated with man's activities. One prominent cause of ground-water quality deterioration is pumping of wells near sources of contamination and inducing water of poor quality into the aquifer. For example, salty water moved landward in one of the principal aquifers on Long Island, and in a similar situation in Atlantic City, N.J., because large quantities of ground water were pumped near the freshwater-saltwater boundary.

Pollution resulting from man's actions is a recognized source of degradation of ground-water quality. Nitrate concentrations exceeding 45 mg/L have been identified in water from wells affected by cesspools, septic tanks, and fertilized agricultural land. High concentrations of chloride have been identified in ground water affected by winter-road salting and near storage sites for road salt. Leachates from landfills and dumps have affected ground-water quality. Accidental or intentional disposal of industrial wastes may also influence ground-water quality detrimentally.

The ground-water quality problems of the Mid-Atlantic Region are many, and these are only the major ones. Miller, DeLuca, and Tessier (1974) compiled records of hundreds of cases of ground-water contamination in the northeastern States, reporting that they represent only a very small percentage of those that actually exist. Ground-water-quality management is especially important in this region of intense industry and agriculture and heavy population density.

RELATION OF GROUND-WATER TO SURFACE-WATER RESOURCES

Ground water and the base flow of streams are two different phases of a single fluid resource. It follows, then, that pumping water from wells in some areas could effectively diminish the amount of water available from streams, especially during dry periods when the base flow of streams is sustained almost wholly by ground water. Normally, the withdrawal of water from the streams under present conditions does not noticeably affect the amount of water available in the aquifers of the Mid-Atlantic Region. In the Coastal Plain, pumping from these shallow aquifers reduces the quantity of ground water that is discharged directly into bays and the ocean in addition to reducing the base flow of streams.

Development of the aquifers to their full potential would eventually reduce the base flow of streams to zero, and it would probably allow incursion of brackish water or seawater into the lower reaches of streams and into aquifers at places where they are in direct hydraulic continuity with tidal streams, bays, or the ocean.

There are many places in the Mid-Atlantic Region where ground water and surface water could be developed conjunctively but there are as yet no large-scale conjunctive developments. Such development projects would involve balancing the use of ground-water and surface-water reservoirs according to availability and demand: surface water might, in times of surplus, be used to recharge the ground-water reservoir; conversely, ground water would be used to augment surface-reservoir supplies during low flows or during droughts.

Permeable glacial outwash deposits occur in many places in the northern part of the region, particularly in upstate New York and northern Pennsylvania and New Jersey (fig. 5). Where these deposits are watercourses (Thomas, 1952, p. 10), water can be pumped from them so as to induce recharge from the adjacent perennial stream. This might be regarded as a simple form of conjunctive use, in which water withdrawn from the ground-water body is derived from streamflow.

Artificial recharge of aquifers by pumping surplus surface water into them in the winter has been practiced by certain industries in Newark, N.J., and this practice has helped to control saltwater encroachment (Thomas, 1951, p. 127).

In southeastern Virginia, ground water from four wells drilled in Lower Cretaceous sands in the Coastal Plain is pumped directly into the Lake Prince reservoir of the City of Norfolk to augment the surface-water supplies during periods of low flow.

WATER-RELATED PROBLEMS IN THE MID-ATLANTIC REGION

IMPACT OF ECONOMIC DEVELOPMENT ON MANAGEMENT OF GROUND-WATER RESOURCES

One of the pervasive characteristics of the Mid-Atlantic Region is growth in economic activity (U.S. Water Resources Council, 1972, summary tables). Although it has attained a high average population density—more than 340/mi^2—its population is still growing. This growth is probably in response to the continuing general increase in economic development. Industrial growth expands employment opportunities, increases per capita income, and intensifies commercial agriculture, which historically has tended to concentrate in regions and areas of comparative economic advantage (U.S. Water Resources Council, 1972, p. 19). Other factors, including availability of marketing and transportation facilities and excellent harbors, contribute to industrial growth and agricultural production.

An increasing need for adequate water supplies attends the growth in economic activity. Water supplies have generally kept pace with the increasing demands through the years, but the severe northeast drought of the mid-1960's brought the realization that the margin of reserve surface-water supplies was not as comfortable as had been thought. Meetings were held in major cities, many articles and alarmist statements appeared in magazines and in the press, and the public soon became water conscious. Ground water quickly became a topic of interest, and there was much speculation as to its potential for increased development, not only as a dependable reserve supply in similar water emergencies but also as a full-fledged water source that should be accorded higher status in developmental planning.

There are ample quantities of water, particularly ground water, in the Mid-Atlantic Region. Problems relate primarily to its development, management, and distribution. Industries that require large quantities of water would be best served in the Coastal Plain part of the region. In the hard-rock areas, the best locations are along major streams, in watercourse aquifers where ground water is effectively recharged because of the hydraulic continuity between a perennial stream and the sand and gravel of the valley-fill deposits. Of course, an industry could locate some distance from the source of supply and provide water through a system of pipelines and booster pumps. The cost of such an arrangement might be advantageous when compared to the cost of locating near the source of supply.

Light industry, on the other hand, whose need for water is primarily for personnel rather than for process water, could locate almost anywhere in the Mid-Atlantic Region, consistent with other requirements.

If economic activity continues to increase, as predicted by recent studies (U.S. Water Resources Council 1972, summary tables), more consideration will undoubtedly be given to water-supply alternatives. Among these, the increased use of ground water and the conjunctive use of ground water and surface water are of greatest potential. Conjunctive use of freshwater and saline water may ultimately prove to be entirely feasible, as desalination becomes less expensive through improved technology. Indeed, certain industries, such as the dye industry, may consider locating in places where saline water is available because of the need for it in process water. Use of brackish water, with minimal cost for mixing with locally available freshwater, may result in substantial savings in certain situations.

Ground-water developments commonly entail little modification in existing land-use patterns, because the resource is obtained from beneath the surface by wells with surface pumping plants which, after construction, can be made inconspicuous by landscaping and other means. Therefore, most ground-water developments can be made with a minimum of adverse environmental impact. The coming decades may witness a greater preference for ground water than for surface water, simply because it is possible to develop ground water with less environmental damage.

Large-scale ground-water developments, even in areas of proven abundance like the Coastal Plain, may not always be possible without a considerable pipeline distribution system and booster pumping stations. During the northeast drought of the mid-1960's, when surface-water resources were strained to the limit, such large-scale ground-water transmission systems were considered. One such plan involved development of ground water from the aquifers of the New Jersey Coastal Plain, where about 20 trillion gallons of water are estimated to be in storage, and conveying it by pipeline to industrial and population centers in the metropolitan complex in Newark and vicinity. This scheme and several others were discussed in the public press, in magazine articles, and at various meetings—not, of course, with the idea of immediate solution to the drought-related water shortage then prevalent, but rather to generate positive thinking toward provision for adequate water supplies and their satisfactory distribution in preparation for the next prolonged drought, whenever it might occur. Most of the enthusiasm and discussion of these proposals quickly subsided with the end of the drought in 1967. Since then, there has been little, if any, public discussion or concern about large conjunctive or standby ground-water development projects.

Continued increase in ground-water development may be expected in the region as the modest level of development to date can be increased many times.

ACID MINE DRAINAGE

One of the difficult problems in regions where coal has been extensively mined is pollution of streams and ground water by acid mine drainage. In the Mid-Atlantic Region, there are many coal-bearing areas in Virginia, West Virginia, Maryland, and Pennsylvania. Water draining from the coal mines in these areas into streams has resulted in serious contamination. The general problem of stream and ground-water contamination by drainage of mines is well summed up by McGuinness (1963, p. 727):

> The large population and heavy industralization have combined to produce large quantities of pollutants. Mines, chiefly coal mines, are one of the main sources. Coal and certain ores contain sulfur compounds which, when exposed to the air in mines and waste piles, become oxidized to form sulfuric acid. The acid contaminates both streams and ground water, and is generated in such large quantities that the problem is far from solved in spite of the intensity with which it has been attacked.

Streams are affected more readily than ground water by drainage of water from mines, but a few good aquifers have been contaminated in the Susquehanna and Delaware River basins in Pennsylvania.

In a recent study of acid waters draining from the underground coal mines of western Maryland, Hollyday and McKenzie (1973) summarized some of the effects of acid mine drainage—the degradation of the water supply for recreational, industrial, and municipal uses; the increase in costs of treatment; more frequent replacement of treatment facilities; the staining of porcelain fixtures and of laundered clothing; endangerment of aquatic life; and detrimental effects on engineering structures and navigational equipment. They suggest pursuing the hypothesis that neutralization of acid mine waters can take place by "using the natural underground environment in place of or in conjunction with mine-mouth water treatment plants." Thus, in appropriate hydrogeologic settings, convenient natural laboratories are available in which to test the hypothesis of natural neutralization of acid mine waters.

SALINE GROUND WATER

Until recent years, saline ground water has almost everywhere been regarded as a problem. Its encroachment was to be prevented so far as possible. Its elimination, once encroachment occurred, was almost impossible to achieve. Its usefulness was limited to a very few applications, such as cooling and certain cleaning or flushing operations in some industries. More recently, however, especially in the past 10 years, saline water and particularly saline ground water and saline aquifers have come to be looked upon as a potential resource that should be included for consideration by those concerned with large-scale water management.

As mentioned previously, saline (sodium chloride) ground water occurs in the downdip reaches of all the aquifers of the Coastal Plain. (See Back, 1966, p. A2, fig. 2 and pl. 1; Cushing and others, 1973, p. 9.)

In their summary report on a comprehensive study of Long Island, Franke and McClymonds (1972, p. F 55) point out that within the next 25 to 50 years the technology for economically converting saline water to freshwater may be greatly improved. Thus, it is important to consider saline ground water in the Mid-Atlantic Region as a potentially usable component of the total ground-water resources.

Saline ground water may be considered from three points of view: (1) as a source of water, usable without treatment, by itself or in a blend with freshwater, (2) as a source of additional freshwater by employment of one of several methods of desalting, and (3) as an occupant of aquifer space usable for storage of freshwater or wastes.

Although the utility of untreated saline ground water is low, it is nevertheless an important resource in certain applications. One such application is the augmentation of freshwater supplies by mixing saline water with existing sources of supply during periods of peak demand. For example, Cederstrom (1957, p. 42) notes that during World War II a surface reservoir for the city of Newport News, on the lower York-James peninsula in Virginia, was successfully augmented with ground water containing 400 to more than 1,000 mg/L of chloride.

Saline ground water is useful also for cooling and for many industrial washing purposes. Moreover, in certain industries (as for example dye manufacturing), the chloride concentration in process water is required to be higher than that desirable for general use, and the needed concentration can be adjusted by controlled dilution.

Various methods for the conversion of saline water to suitable freshwater have been under study by the Federal Government for more than 20 years and, since 1958, on a relatively substantial scale. Desalting costs for seawater have been reduced gradually, and in 1973 were less than $1 per 1,000 U.S. gallons under favorable conditions. Further conversion cost reduction would stimulate use of saline water more widely. Many aspects of the development and feasible utilization of saline ground water have been reviewed in detail. (See Kohout, 1970.)

CONSTRAINTS ON GROUND-WATER DEVELOPMENT AND MANAGEMENT

Perhaps the most obvious constraint on the optimum development and management of ground-water resources is the lack of sufficient information upon which to base wise decisions. Needs for additional information in each of the States of the Mid-Atlantic Region are discussed in a later section of this report.

LEGAL CONSTRAINTS

Constraints imposed by law are complex and are among the various factors tending to inhibit larger scale ground-water developments. Early doctrines relating to the withdrawal and use of water are based primarily on English common law, which was gradually developed at a time when the population was widely scattered and water was far more abundant than the demand for it. Inevitably, with increasing population growth, industrialization, and urbanization, conflicts developed and some modifications were made. The need for modification is indeed genuine, as pointed out by Thomas (1951, p. 243), who stated, "many established concepts are now known to be scientifically unsound and should be revised in the light of present knowledge."

Of the States represented in the Mid-Atlantic Region, Vermont, Massachusetts, New Jersey, and Pennsylvania generally follow the "English common-law version of the riparian doctrine, which gives absolute ownership of ground water to the land owner" (Geraghty and others, 1973, pl. 34). The remaining States, New York, Maryland, Delaware, West Virginia, and Virginia, modify this doctrine, applying the American rule of reasonable use, which "restricts the land owner's rights in relation to others" (Geraghty and others, 1973, pl. 34). The present trend, however, appears to be in the direction of application of the American modification—the doctrine of reasonable use—for all the States in the Mid-Atlantic Region.

In addition to these general doctrines, some States in the Mid-Atlantic Region have established more specific controls on ground-water use. For example, Virginia and Maryland have enacted laws governing the drilling of wells. Since the late 1950's, following a long period of gradually declining artesian pressure, Virginia has required owners of flowing wells to cap them, and records for commercial and industrial wells must be furnished to the State. New Jersey and Vermont require approval of anticipated withdrawals above specified limits. On Long Island, N.Y., ground water used for cooling purposes must be returned to the ground through recharge wells, provided it has not been contaminated.

GROUND-WATER STUDIES AND NEEDS FOR ADDITIONAL INFORMATION IN THE MID-ATLANTIC REGION

There has been a general upward growth trend in the Mid-Atlantic Region, not only in population but in economic activity, manifested by industrial development, increasing urbanization, and increasing water requirements. More information will be needed regarding the occurrence and availability of additional ground-water supplies in the region, and the hydrologic effects of their developments, to facilitate efficient management of the total water resources.

Systematic programs of ground-water investigations are being carried on largely by the Geological

Survey in cooperation with State or local agencies. The discussion that follows considers the existing coverage and future needs in each of the States in the Mid-Atlantic Region.

Figure 9 shows the areas that have been studied by ground-water investigations.

Three categories of coverage are shown:

1. *Detailed quantitative* studies, in which ground water has been treated as a dynamic fluid resource. These studies include analysis of the results of aquifer-performance tests or other analyses that provide hydraulic information that serves as a guide for making predictions about the response of aquifers to changes in the pumping regimen that would result from possible additional developments.
2. *Detailed reconnaissance* studies, in which most of the available ground-water information has been collected, including quantitative data and interpretations that provide a basis for general understanding of the effects of possible future developments.
3. *General reconnaissance* studies, in which a representative sampling of readily available information has been collected and interpreted and which can provide general guidance for water developments.

Some areas in New York, New Jersey, and Virginia are not colored on figure 9. For these areas, formal reports have not been published, and no studies nearing completion are currently (1976) underway. However, Federal and State agencies have basic data on file for most of these areas. Specific inquiry may be made directly to the district office of the Geological Survey or to State agencies responsible for water studies for the appropriate State.

The following two categories of ground-water information are needed as of 1976, in the areas indicated on figure 10:

1. *Detailed quantitative* information, as previously defined. This level of ground-water information is indicated for areas where there is either an immediate need or a foreseeable need. The detailed information provided by investigations at this level allows immediate use for planning and development of major projects, such as municipal or industrial well fields, with only minimal additional study, if any.
2. *Detailed reconnaissance* information, as previously defined. This level of information is indicated for areas where only moderate future developments are likely and where a moderate amount of detailed information would suffice for small developments. Such information would provide an adequate base for additional work prior to any large-scale developments that may materialize.

VERMONT

Largely because Vermont is a rural State with no large cities and only minimal industrial development, the total use of water from all sources is the smallest among the northeastern States, amounting to only 110 million gal/d in 1970 (Murray and Reeves, 1972, table 10). However, use of ground water (42 million gal/d) is proportionately the highest among these same States—38 percent of the total water used (Geraghty and others, 1973). Despite this fact, the need for additional ground-water information in Vermont is only moderately urgent, the chief demand being related primarily to tourism and recreation.

In the part of western Vermont that lies within the Mid-Atlantic Region (fig. 9), ground-water favorability maps have been published for the several basins draining into Lake Champlain and the Hudson River valley (Hodges, 1966; 1967a, b, c, and d). These maps and accompanying texts are classified as general reconnaissance studies.

In addition, Hodges and Butterfield (1972) have published a detailed study that defines the quantity and quality of the ground water in the sand and gravel aquifers of the Barre-Montpelier area, in the western upstream reaches of the Winooski River basin, which drains into Lake Champlain. This study appraises the potential ground-water sources to meet expanded needs of many of the towns in Washington County. A detailed reconnaissance study is nearing completion immediately north and northeast of the Barre-Montpelier area, also in the Winooski basin.

Detailed reconnaissance ground-water information will be needed soon in the eastern parts of three basins—the Missisquoi, Lamoille, and Winooski—as a sequel to that which was provided by the work in the Barre-Montpelier area. The burgeoning recreation industry in those areas in recent years, associated mainly with the excellent skiing country, justifies such information (A. L. Hodges, Jr., written commun., 1975). Likewise, ground-water information is generally inadequate for anticipated development in southwestern Vermont, from Rutland to the Massachusetts boundary.

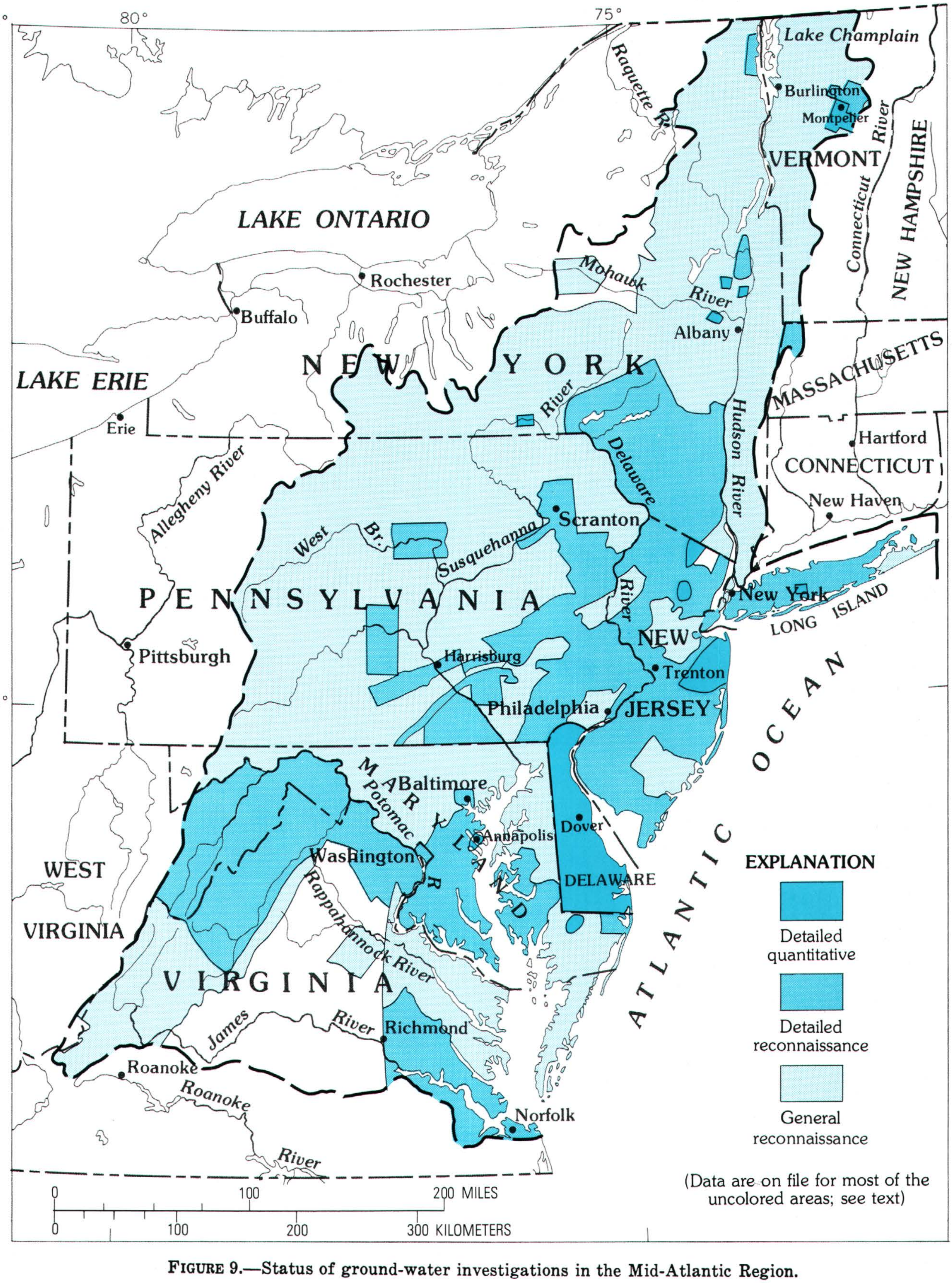


FIGURE 9.—Status of ground-water investigations in the Mid-Atlantic Region.

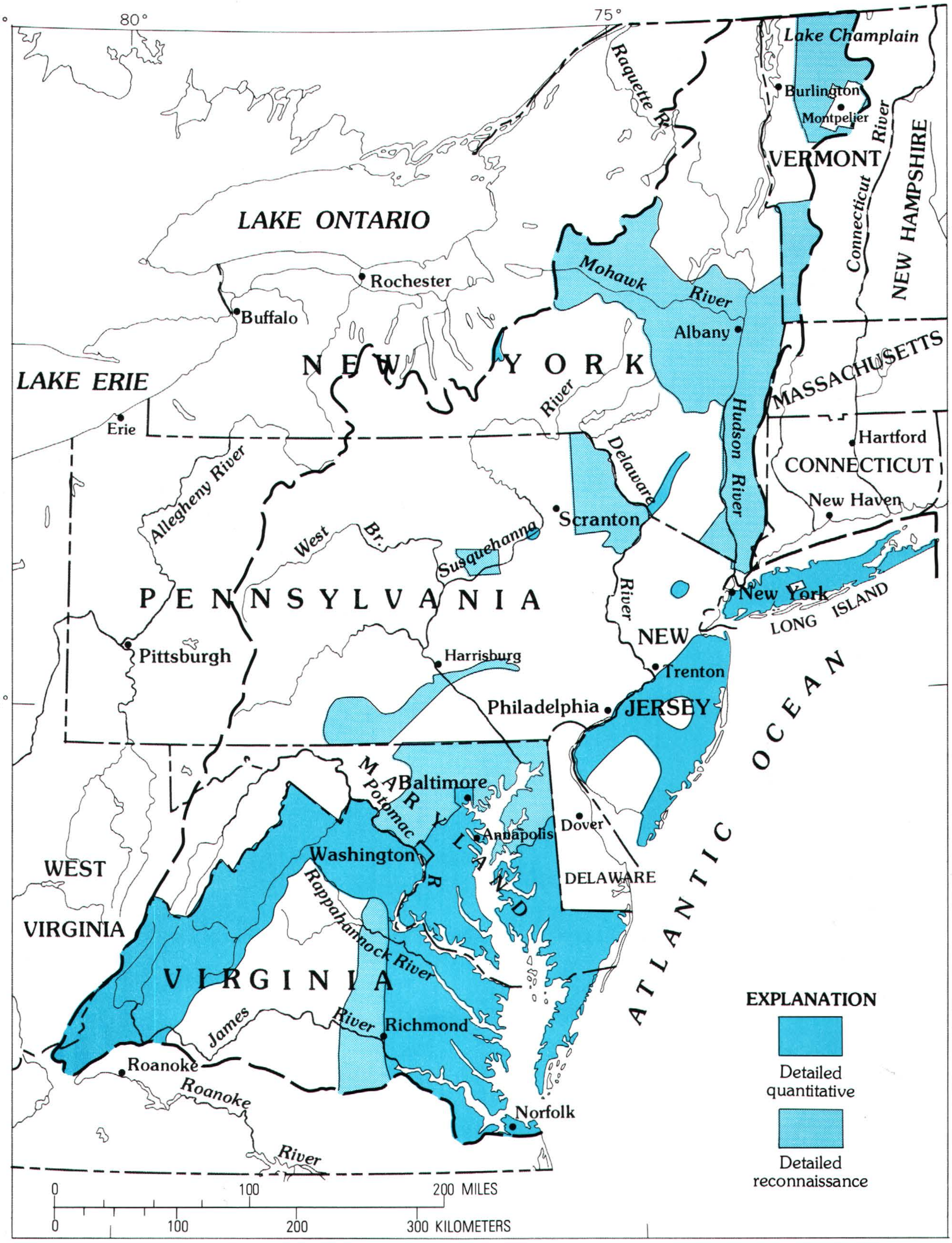


FIGURE 10.—In certain areas in the Mid-Atlantic Region, additional ground-water information is needed in order to assist water-resources development and management.

In the intervening region between Montpelier and Rutland, the need for water is believed now to be relatively stable. Adequate surface-water supplies have been developed from Lake Champlain, and additional supplies from this source should be adequate for the foreseeable future without recourse to ground-water sources, assuming that trends in economic activity continue at present rates.

MASSACHUSETTS

Only a small part of northwestern Massachusetts lies within the Mid-Atlantic Region. The Hoosic River, whose basin contains 205 mi^2 upstream from the Massachusetts-Vermont State boundary, drains 164 mi^2 in Massachusetts, 39 mi^2 in Vermont, and 2 mi^2 in New York. A tributary of the Hudson River, it flows through southwestern Vermont into New York.

A detailed reconnaissance study of the Hoosic River basin was published recently as a hydrologic atlas (Hansen, Toler, and Gay, 1973). It is sufficiently detailed to provide adequate information on the hydrogeology of the principal ground-water reservoirs in the basin. These are glacial outwash deposits forming watercourse aquifers in deep bedrock valleys along the main stem of the river. In places these deposits are 300 ft thick. Test drilling is needed to determine the best locations for additional development along the favorable river reaches described in the atlas.

The Hoosic River basin in northwestern Massachusetts is mostly rural in character and is likely to remain so for the near future. There are three principal communities—Adams, North Adams, and Williamstown. The study by Hansen, Toler, and Gay (1973) is believed adequate for needs of the near-term future, as it provides sufficient information to furnish a guide for exploratory drilling for additional ground-water developments.

NEW YORK

More than 17,000 mi^2 of New York lies within the Mid-Atlantic Region: part of the St. Lawrence Valley, nearly the entire Hudson River basin, and the northern parts of the Delaware and Susquehanna River basins. This area was glaciated during the ice age, and extensive outwash deposits occur in many of the larger valleys. The sand and gravel deposits in these valleys are the most widely used and promising sources of ground water in upstate New York. They are generally highly permeable and their hydraulic continuity with the perennial streams in the valleys allows ample replenishment for ground-water withdrawals from these deposits.

Except for parts of the upper Hudson River basin, the entire area of New York within the region has been adequately reviewed in reports prepared under the Federal-State cooperative program—largely reconnaissance studies (fig. 9). Also, a few quantitative studies of small areas have been completed. The most recent studies were made near Binghampton (A. R. Randall, oral commun., 1975), and on Long Island (Kimmel and Braids, 1974). In addition, an important series of reports covering many aspects of the hydrology of Long Island has been published; these reports contain much quantitative information. (See especially McClymonds and Franke, 1972; Franke and McClymonds, 1972.)

Many short reports have been prepared on small areas in New York by private consultants. For the most part, however, these are unpublished. Consultants also have prepared water-resources reports for all of the counties under a program with the New York Department of Health. Some of these reports describe reconnaissance ground-water investigations.

Although much information on the ground-water resources of New York has been developed in several decades of cooperative study by the U.S. Geological Survey and State and County agencies, additional quantitative information on the hydrologic systems is needed as the economy and population of the State grow. The need exists for continued detailed ground-water studies on Long Island, because most of Long Island depends almost entirely on ground water to support a large and expanding population. Additional studies now under way and others proposed for the future include (1) a continuation and refinement of the present hydrologic data-collection activities, in particular more intensive water-quality study and monitoring in parts of Long Island; (2) more complete definition of the shape and areal extent of the several aquifers, particularly in eastern Suffolk County, which is rapidly being developed and where deep public-supply wells are being drilled; and (3) predictive modeling studies to aid management decisions. These and other needs are discussed in the summary report by Franke and McClymonds (1972, p. F55–56).

In a ground-water investigation of Orange and Ulster Counties in lower upstate New York, Frimpter (1972, p. 74) suggests additional information may soon be needed for two important segments of a watercourse aquifer. One segment, northeast of Port Jervis, is in the valleys of the lower Neversink River and Basher Kill; the other segment is in the

Sandburg Creek valley near Ellenville. These segments are believed to be parts of a continuous sand and gravel body that lies beneath the present divide between the two drainages in intervening Sullivan County (M. H. Frimpter, oral commun., 1975). (See fig. 10.) More industry and housing developments are anticipated in these areas, and therefore increasing development of ground-water supplies is foreseen. Frimpter suggests that artificial recharge of ground water with excess surface-water supplies might aid optimum utilization of the water resources.

Other small aquifers probably will need study within the next few years if present trends in economic activity continue. For example, aquifers in Westchester and Cortland Counties (fig. 10) are being considered for quantitative study. Cortland County has an extensive shallow watercouse aquifer system that is highly susceptible to pollution from suburban and agricultural wastes.

Additional general ground-water investigations have been proposed in recent years for the lower Hudson River basin. Reconnaissance, in sufficient detail to provide adequate preliminary information for possible later detailed studies in local critical areas, is under consideration.

NEW JERSEY

New Jersey lies entirely within the Mid-Atlantic Region; its area is 7,836 mi². About three-fifths of the State is part of the Atlantic Coastal Plain, where excellent aquifers store vast quantities of ground water. The hard rocks in the northern part of the State provide sources for small to moderate ground-water supplies; where stratified glacial drift is present, larger supplies might be developed locally.

As shown in figure 9, ground-water studies have been made nearly everywhere in New Jersey, including both general and detailed reconnaissance studies. In the northern part of the State, where ground water is important but much less abundant than in the Coastal Plain, Somerset County and parts of Warren and Bergen Counties lack formal investigation. General reconnaissance coverage has been completed in Middlesex County, southwest of New York City, and in Atlantic County farther south in the Coastal Plain. Detailed reconnaissance studies have been made in the remainder of the State.

Recently, quantitative studies were completed for two areas in northern New Jersey (Vecchioli and Nichols, 1966; Vecchioli and others, 1967). Another quantitative study, of the Ramapo River, also in northern New Jersey, was made by Vecchioli and Miller (1973). A digital model is nearing completion for the Englishtown aquifer in Monmouth and Ocean Counties in the Coastal Plain (W. D. Nichols, oral commun., 1975). A comprehensive investigation of the chemical character of ground water in the Englishtown Formation has been published (Seaber, 1965).

Much of the information collected during a comprehensive study of the Wharton Tract, in southern Camden and Burlington Counties and northwestern Atlantic Coutny, has been published (Rhodehamel, 1973). In addition, detailed quantitative data from an extensive pumping test made in 1961 in the Wharton Tract are in the open files of the Geological Survey.

New Jersey ranks high among the States in volume of ground-water withdrawals, and it has probably developed its ground-water reservoirs more completely than any other State in the humid eastern part of the country (Thomas, 1951, p. 127). A number of problems include the threat of saltwater encroachment, which results because of local concentration of pumping adjacent to saltwater bodies or near the freshwater-saltwater interface in aquifers. Management of these problems would involve changing the locations of pumping centers and obtaining detailed quantitative knowledge about the ground-water reservoirs.

New Jersey lies along the axis of the Boston-Washington transportation corridor. Increasing urbanization and industrial development is taking place, following roughly along Interstate Routes 95 (the New Jersey Turnpike) and 295. There is, therefore, need for quantitative ground-water information along this corridor. For similar reasons, quantitative information is warranted in Monmouth and Ocean Counties, and in the coastal parts of Burlington, Atlantic, and Cape May Counties. Such information would augment and refine the basic preliminary work already accomplished in these areas and would assist in developing ways to minimize saltwater encroachment and other potential developmental problems.

That part of the Pine Barrens in central New Jersey, between Camden and Atlantic City, also is an area of increasing economic activity and population growth resulting from the completion, in 1964, of the expressway between the two cities. Detailed quantitative knowledge of the ground water, including model analysis to predict the impacts of ground-water development, is warranted in anticipation of the planned development of the Wharton Tract as a major source of water supply for southern New Jersey. Such a study would facilitate the conjunctive development of ground water and surface water in the Tract.

PENNSYLVANIA

Pennsylvania has the largest area of the States within the Mid-Atlantic Region—over 20,000 mi^2. About two-thirds of this area lies within the Susquehanna River basin, most of the remainder is in the Delaware River basin, and only a small part is in the Potomac River basin. (See fig. 2.)

In the glaciated northern part of the State, alluvial and outwash deposits occur in most large valleys. These deposits also extend some distance south into the unglaciated area. As watercourses, they provide an abundant source of ground water because of their hydraulic continuity with the streams that occupy the valleys. Recharge from the stream channels can be induced when these deposits are developed for ground-water supplies.

Elsewhere in the Pennsylvania part of the region, the older hard rocks yield small to moderate supplies of water. In the relatively small area of the Coastal Plain in the extreme southeastern part of the State, the unconsolidated sedimentary rocks include several productive aquifers (Greenman and others, 1961).

Pennsylvania was covered by general reconaissance ground-water studies during the 1930's (Piper, 1933; Hall, 1934; Leggette, 1936; Lohman, 1937, 1938, and 1939). Since then, the Federal-State cooperative program has carried out more detailed investigations in those parts of the State that required refined coverage for various reasons. including industrial expansion and associated population growth. This cooperative program of ground-water investigations continues to be active, and the present status of ground-water coverage in terms of published reports and active studies nearing completion is indicated on figure 9.

The general direction of effort in the continuing cooperative program is toward providing ground-water information at least at the level of detailed reconnaissance in those areas of the State where such information is required because of anticipated or potential expansion in economic activity. (See fig. 10). For the immediate future, the detailed reconnaissance level of ground-water information probably would fulfill the anticipated requirements adequately.

Ground-water investigations in Pike and Wayne Counties, which lie within the upper Delaware River basin in Pennsylvania, are scheduled in the Federal-State cooperative program. The information obtained from the proposed studies will be important in view of the anticipated acceleration of development in these areas for recreation. Recreational, tourist, industrial, and commercial activity has been enhanced by the Northeast Extension of the Pennsylvania Turnpike, completed in 1957, and by the recently completed Interstate Highway 80 across Pennsylvania to New Jersey and New York City. The planned Delaware Water Gap National Recreation Area will require water information presently only partially available.

Saline ground water occurs naturally at depths of 300 to 500 ft in the Appalachian Plateaus province in Pennsylvania (fig. 6). (Becher, 1970). More comprehensive information is needed on the occurrence of saline water in this area, and elsewhere within the region in Pennsylvania. Such information would help define the depths to which potable freshwater occurs and also provide knowledge of the chemical nature and physical extent of the underlying saline water, which, despite its quality, has potential as a possible future resource.

MARYLAND, DELAWARE, AND DISTRICT OF COLUMBIA

In view of their close proximity and current joint Federal-State cooperative programs, the District of Columbia and the States of Maryland and Delaware may conveniently be considered together. Much of their combined area lies within the Chesapeake Bay region and the eastern part of the Potomac River basin; the balance consists of coastal reaches in the Maryland Eastern Shore and southern Delaware, and minor parts of the Susquehanna and Delaware River basins.

Beginning in 1942, with a study of the Baltimore industrial area, reconnaissance studies of counties or groups of counties were made of the entire State of Maryland as part of the Federal-State cooperative ground-water program. These studies were completed in the early 1960's. Since then, detailed reconnaissance studies have been made in the five Maryland counties east of Washington, between Baltimore and Virginia on the western shore and in Talbot and Dorchester Counties on the Maryland Eastern Shore. (See fig. 9.) Detailed quantitative ground-water studies have been published for the entire State of Delaware. (See Sundstrom and Pickett, 1968, 1969, 1970, and 1971.) A comprehensive reconnaissance investigation of the water resources of the Delmarva Peninsula, which includes the Eastern Shore parts of Virginia, Maryland, and

Delaware, was completed in 1973 (Cushing and others, 1973).

Because of continued urbanization and industrial development, ground-water information is needed at the quantitative level in the area in north-central Maryland between Baltimore and the Pennsylvania boundary, which includes Howard, Carroll, Baltimore, and Harford Counties, and the city of Baltimore. It may be desirable to test the hypothesis put forth by Hollyday and McKenzie (1973) that natural neutralization of acid mine drainage waters take place in Maryland coal fields under suitable hydrogeologic conditions.

Quantitative information on ground water is needed in the remainder of Sussex County in Delaware and the Eastern Shore counties of Maryland, as a followup of the detailed reconnaissance recently completed for the Delmarva Peninsula. Economic activity in both of these areas is increasing and is expected to continue, with the usual attendant increase in demand for water.

WEST VIRGINIA

The eastern panhandle of West Virginia lies within the Mid-Atlantic Region, in the western reaches of the Potomac River basin. A hydrologic map, sections, and text have been published (Hobba and others, 1973), and a comprehensive report is in preparation. This coverage is believed adequate for this area for the near future, except for local areas where more detailed information may be needed as economic activity develops along the Interstate Highway system.

VIRGINIA

More than 17,000 mi^2 of Virginia lies within the Mid-Atlantic Region. The Coastal Plain occupies somewhat less than one-third of that area. It is underlain by unconsolidated sediments containing the State's most productive aquifers. The balance of the State is underlain by crystalline igneous and metamorphic rocks, limestones, and other carbonate rocks, sandstones, and shales.

Reconnaissance ground-water studies have been completed in the Virginia part of the region, except for most of the Piedmont province which has been investigated only in a few areas. (See fig. 9.) Virginia's paper industry is centered in the Franklin area, just south of the Mid-Atlantic Region, along the James River, in the southeastern corner of the State. It has been a major user of ground water since the early 1940's. This area has been the subject of quantitative studies (Sinnott, 1968; Brown and Cosner, 1974). The effect of the present (1975) rate of withdrawal, about 40 million gal/d, extends northward more than 25 mi to the York-James Peninsula in the southern part of the Mid-Atlantic Region.

A systematic test-drilling program in the Coastal Plain would establish a basic network of factual data for regional subsurface correlations of the water-bearing formations. Samples of water for chemical analysis, from individual aquifers, collected while drilling test wells, and at selected wells drilled for municipal or industrial supplies, would yield a better understanding of the State's ground-water quality.

Expansion of the present water-level observation-well network is desirable for determining the effects of pumping in individual aquifers near centers of major withdrawals. Also, water-quality monitoring at selected sites in the Coastal Plain should be expanded to detect changes in the position of the freshwater-saltwater interface in major aquifers.

Reconnaissance information is needed for most of the Virginia Piedmont that lies within the region, in order to determine places most favorable for light industry. Although little or no process water is required for this kind of activity, small dependable supplies of water for personnel or other limited demands are generally available in the Piedmont. Moreover, the physical environment of the Piedmont counties will continue to attract light industry, especially in established and growing municipal centers, such as the Charlottesville area.

Exploration for possible productive watercourses in the Virginia Piedmont might also be undertaken, as was done in 1950 in North Carolina (Mundorff, 1950).

CONCLUSIONS

The rocks that constitute the ground-water reservoirs in the Mid-Atlantic Region can be grouped broadly into three general classes. These are (1) the unconsolidated sedimentary rocks that underlie the Coastal Plain; (2) the igneous, metamorphic, and consolidated sedimentary rocks that underlie the Piedmont, Blue Ridge, Valley and Ridge, Appalachian Plateaus, Adirondack, and New England provinces; and (3) the unconsolidated glacial and alluvial deposits that overlie the consolidated rocks in the northern part of the region. Among these rocks, the most permeable have become the important aquifers in the region.

Large volumes of water move through and are stored in the aquifers in the Mid-Atlantic Region, and much of this water is available for use. Determinations of the base flow of streams in the region indicate that as much as 38.6 billion gal/d of ground water is being discharged into the ocean. In addition, another 140 to 350 trillion gallons of good-quality water is estimated to be in storage in the aquifers.

Current problems of ground-water development and management in the region are primarily caused by pumping large amounts of ground water from fairly small areas and by poor ground-water quality. These problems are directly or indirectly related to the large and growing population and industrialization of the region, and to natural ground-water-quality problems that occur from place to place. Ground water with naturally occurring excessive amounts of troublesome constituents, such as chloride, iron, hydrogen sulfide, calcium, and magnesium, must be dealt with throughout the region. Local contamination of aquifers in the region is being caused by substances placed on the land or put into the ground accidentally or intentionally. Activities such as deep mining of coal and coal stripping have resulted in serious contamination. Many ground-water supplies in the region have been ruined by pumping wells too near natural or manmade sources of contamination and drawing water of poor quality into the wells. This is particularly true along the coastal part of the region where salt-water encroachment is a constant threat.

If the economic activity of the Mid-Atlantic Region continues to grow as predicted, the need for water will increase also. There are several ways to meet this anticipated need in the region. Among these, greater use of ground water and the conjunctive use of ground water and surface water offer the highest potential. Ground water development can be increased many times over the modest level of development to date. Large additional quantities of ground water could best be developed in the Coastal Plain part of the region. Elsewhere the largest amounts could be obtained from areally-extensive, permeable carbonate rocks and coarse-grained glacial and alluvial deposits, particularly watercourse aquifers along major streams.

Future development should be based on the knowledge of past and present ground-water management problems in order to avoid the same pitfalls. Large-scale ground-water developments should not be restricted to small areas and the major ground-water reservoirs should be protected as much as possible from contamination. The severe water shortages experienced during the Northeast drought of the middle 1960's suggest that substantial reserve supplies should be developed to meet the needs of such emergency periods. Perhaps 50 percent of the usable ground water stored in the aquifers of the region could be developed for reserve supplies. However, only a small part of the potential reserve could be utilized during a drought because of the lead time required for exploratory drilling, aquifer testing, drilling of production wells, and construction of suitable distribution systems to transport the water to municipal or industrial centers. Thus, to cope with possible emergencies, these reserve sources of ground water ideally should be explored and water-supply systems installed well in advance of critical demand for alternate sources of supply.

To ensure the wise development and management of the water resources of the Mid-Atlantic Region more information will be required about the occurrence, availability, and quality of ground water. Additional detailed reconnaissance data are essential in north-central and southwestern Vermont; east-central and southeastern New York; northeastern, central, and south-central Pennsylvania; central and northeastern Maryland; and east-central Virginia. Moreover, supplementary detailed quantitative information is desirable for the aquifers underlying the Coastal Plain in Long Island, New Jersey, Maryland, and Virginia; for some unconsolidated glacial and alluvial aquifers in Pennsylvania, New York, and New Jersey; and for some Piedmont and Valley and Ridge aquifers—particularly the carbonate-rock aquifers—in Virginia.

Collection of the necessary knowledge about ground water, as discussed in this report, and the implementation of lines of development indicated by this knowledge, will contribute in a major way toward the full use and optimal management of ground water as an indispensable component of the total water resources of the Mid-Atlantic Region.

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