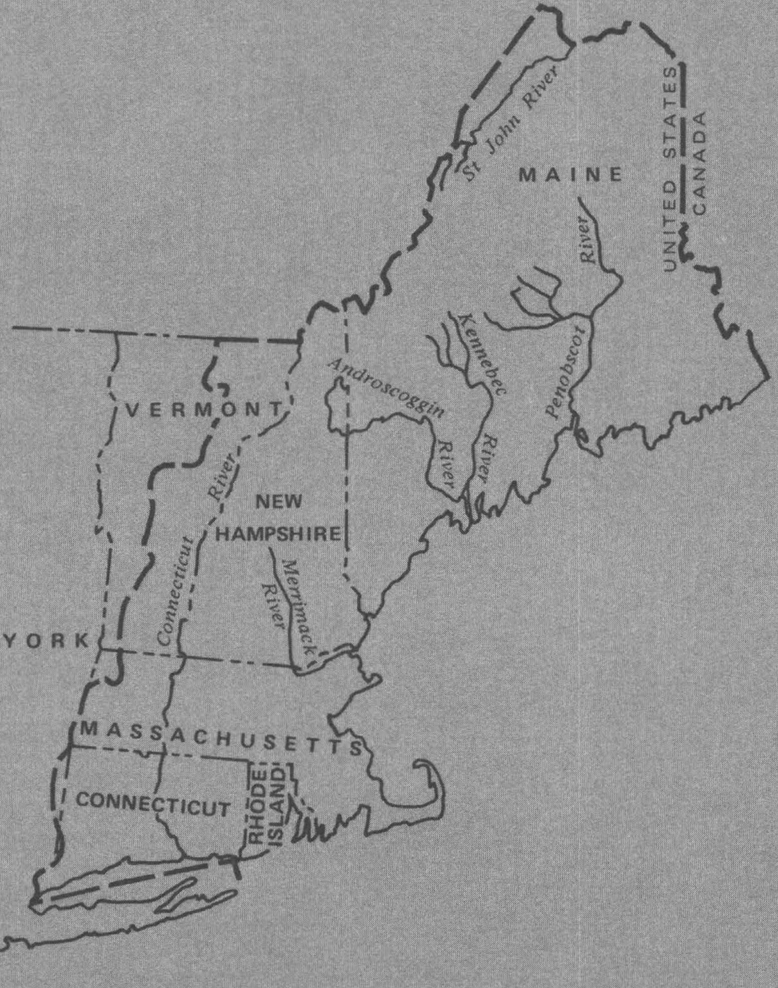
Summary Appraisals of the Nation's Ground-Water Resources— New England Region

GEOLOGICAL SURVEY PROFESSIONAL PAPER 813-T



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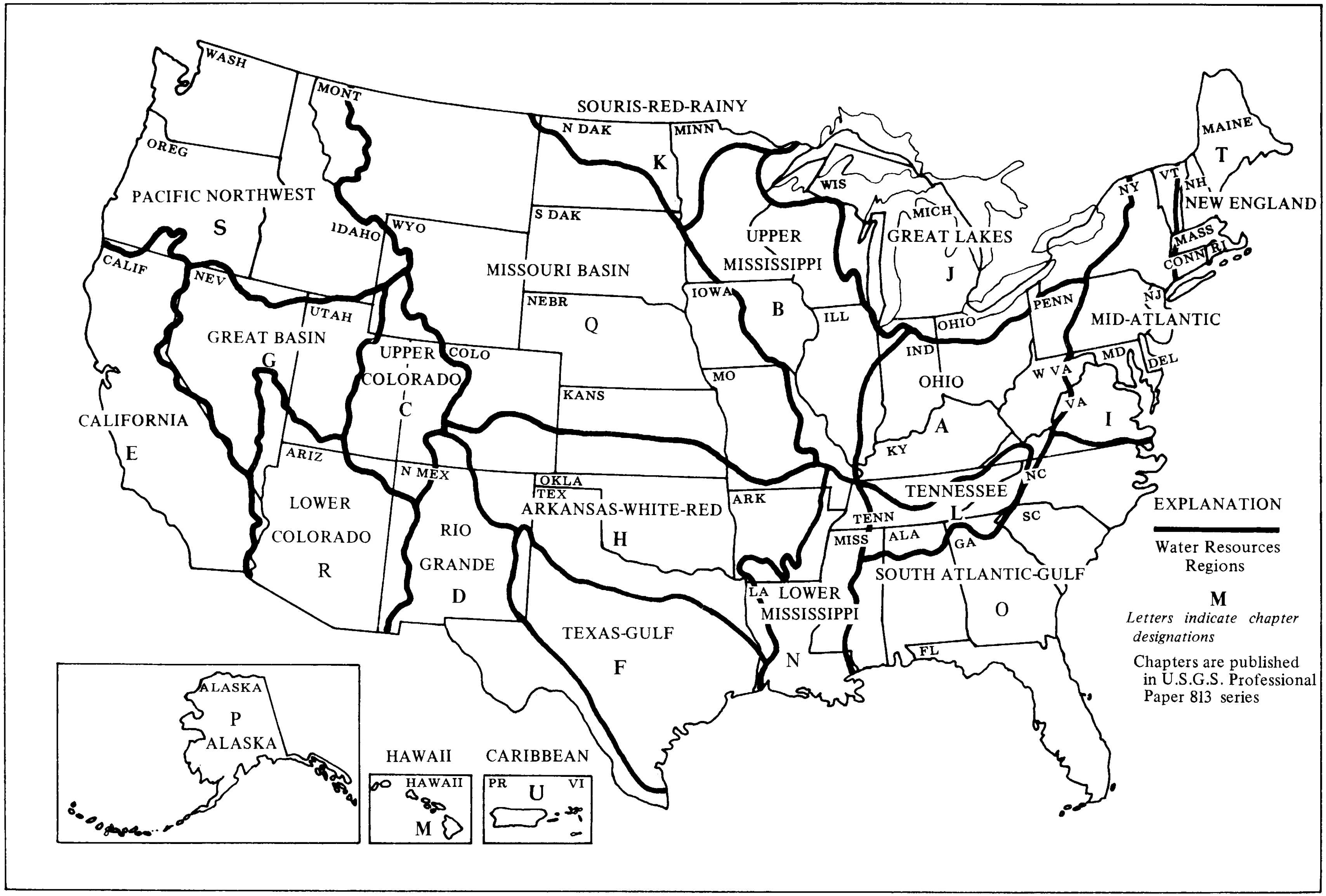

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Boundaries shown are those established by the United States Water-Resources Council for Water-Resources Regions in the United States.

Summary Appraisals of the Nation's Ground-Water Resources—New England Region

By ALLEN SINNOTT

GEOLOGICAL SURVEY PROFESSIONAL PAPER 813-T

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

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UNITS OF MEASUREMENT

[In this report, measurements are given in inch-pound units followed in parentheses by equivalent values in units of the International System (SI) based on the metric system. The table below shows the units and symbols for both systems, together with multiplication factors by which inch-pound units can be converted to SI units]

Inch-pound	*Symbols*	*Multiplication factors for obtaining SI equivalent units*	*SI units*	*Symbols*
Length:				
inch	(in.)	25.4	millimeter	(mm)
foot	(ft)	0.3048	meter	(m)
mile	(mi)	1.609	kilometer	(km)
Area:				
acre		0.4047	hectare	(ha)
square mile	(m^2)	2.590	square kilometer	(km^2)
Volume:				
gallon	(gal)	3.785	liter	(L)
acre-foot	(acre-ft)	1,233.5	cubic meter	(m^3)
cubic foot	(ft^3)	0.02832	cubic meter	(m^3)
Slope:				
foot per mile	(ft/mi)	0.189	meter per kilometer	(m/km)
Flow:				
gallon per minute	(gal/min)	0.06309	liter per second	(L/s)
cubic foot per second	(ft^3/s)	0.02832	cubic meter per second	(m^3/s)
million gallons per day	(million gal/d)	3,785.	cubic meter per day	(m^3/d)
billion gallons per day	(billion gal/d)	3.785	cubic hectometer per day	(hm^3/d)

SUMMARY APPRAISALS OF THE NATION'S GROUND-WATER RESOURCES—NEW ENGLAND REGION

By ALLEN SINNOTT

ABSTRACT

The New England Region has a total area of about 62,400 square miles (160,000 km²) and includes the States of Maine and New Hampshire, eastern Vermont, most of Massachusetts and Connecticut, all of Rhode Island, and a small part of southeastern New York. The longest stream is the Connecticut River, which extends from northern Vermont and New Hampshire, through western Massachusetts and central Connecticut, and drains into Long Island Sound. Other major streams are the Penobscot and Kennebec Rivers in Maine, the Androscoggin in Maine and New Hampshire, the Merrimack in New Hampshire and Massachusetts, and the Housatonic in western Massachusetts and Connecticut. Of the smaller streams, some, like the Charles River in the Boston area, are widely known because of their proximity to large population centers.

Ground water occurs in two types of geologic materials: consolidated rocks and unconsolidated sedimentary rocks. The consolidated rocks underlie the entire region. They include crystalline igneous and metamorphic rocks and consolidated sedimentary rocks—shale, sandstone, and limestone and other carbonate rocks. The most productive unconsolidated rocks are sand and gravel of glacial origin. These deposits occur all over Cape Cod and nearby islands in southeastern Massachusetts and in many valleys throughout the region.

Ground water is derived from precipitation. It can be intercepted for use by pumping from wells (1) before it discharges to the streams as base flow and (2) before it drains directly into coastal wetlands, bays, Long Island Sound, or the ocean.

Withdrawals of fresh ground water in 1975 aggregated about 220 billion gallons (830 hm³), or about 12 percent of the total freshwater withdrawals (from all sources) of 1,800 billion gallons (6,800 hm³). In view of the available ground-water reserves, considerable additional water, for the anticipated continuing increase in population and economic activity, could be developed.

INTRODUCTION

Early development of ground water in the United States was brought about largely by individuals seeking small domestic supplies. Later, use of ground water extended to small farms, towns, and small commercial and industrial establishments, all of which required only moderate quantities of water. Such developments rarely interfered with each other, and problems were few. However, with increasing population and with gradual urbanization and industrial growth, local overdevelopment of ground water became more common. Local concentration of withdrawals resulted in excessive pumping lifts, decline of water levels below pump intakes or even below the bottoms of wells that had been drilled when water levels stood higher. Reduction in yields resulted in increasing costs for deepening wells and increasing pump capacities with new equipment. In addition, local deterioration in water quality became troublesome. These and related problems gradually encouraged the acquisition of knowledge about ground water that has today become a major scientific discipline.

Because water is a vital element in any long-range plan for development, it should be accorded its proper place in planning. Major projects utilizing surface water have the benefit of long experience and much information on structural design and concepts to enable optimum development. On the other hand, comparatively few large-scale systems have been developed for ground-water supplies, and much less design information is available for such projects. The comparative lack of experience in such developments also has hampered consideration of conjunctive use of ground water with surface water in order to meet specific water requirements. In certain areas, ground water may be the only source available or may provide water for several years until more distant supplies can be developed. In other places, ground water may be used conjunctively with surface water in meeting peak demands, such as augmenting seasonal low streamflow, or it may serve for day-to-day supply.

This report is concerned with one of the 21 Water Resources Regions designated by the U.S. Water Resources Council (1970)—the New England Region in northeastern United States. The chief purposes of this study are (1) to present the current overall situation with respect to ground-water resources, (2) to discuss important problems, (3) to point out areas that have good potential for additional development, and (4) to identify those areas where additional information is needed on ground water and its occurrence and availability, so as to provide an improved basis for present and future management of all water resources.

PHYSICAL AND ECONOMIC SETTING

GEOGRAPHY AND CLIMATE

Almost the entire New England Region (fig.1), as defined by the U.S. Water Resources Council (1970),

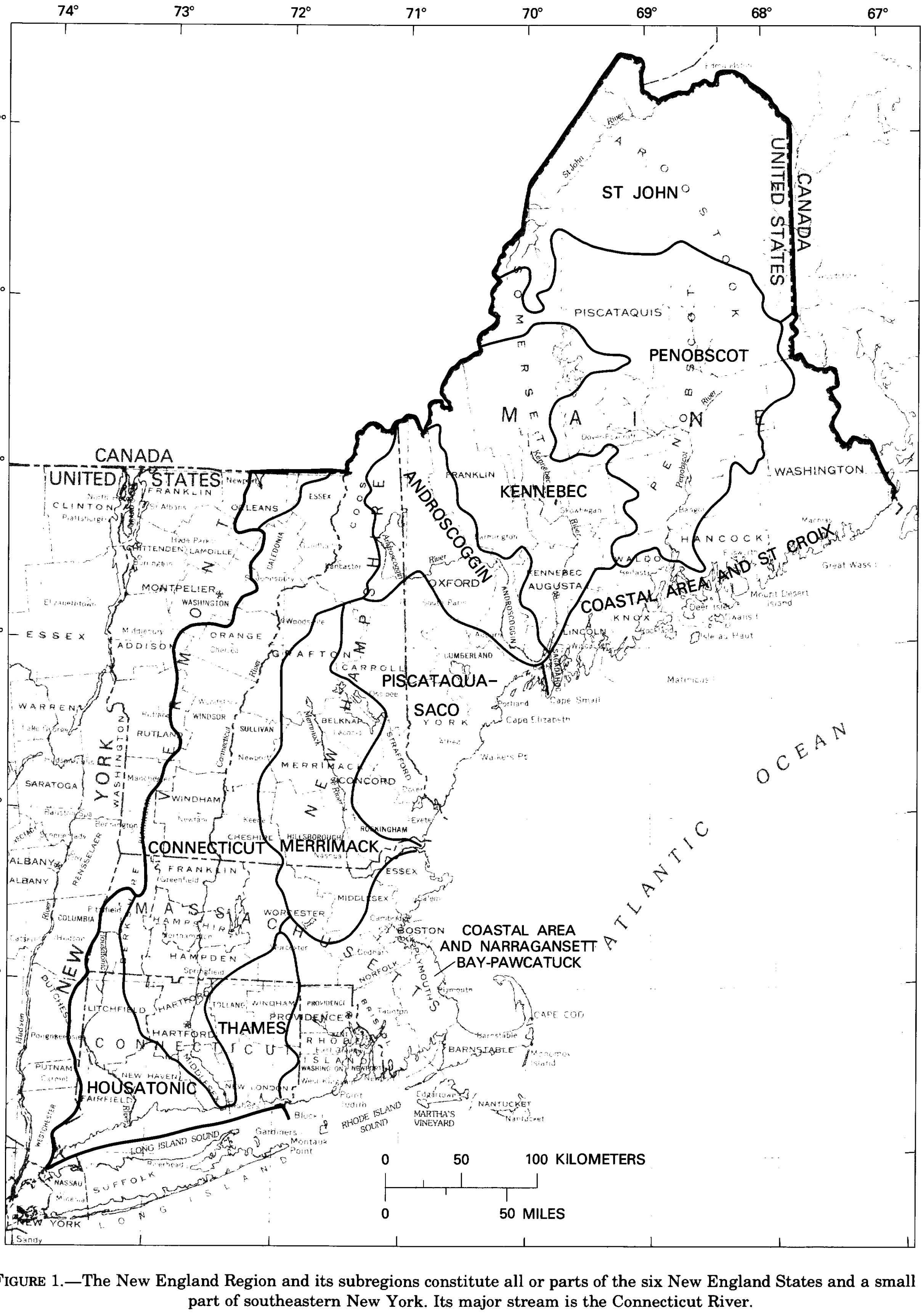

FIGURE 1.—The New England Region and its subregions constitute all or parts of the six New England States and a small part of southeastern New York. Its major stream is the Connecticut River.

lies within the Glaciated Appalachians ground-water region (Thomas, 1952, p. 63). Cape Cod and the nearby islands, Martha's Vineyard and Nantucket, lie in the Coastal Plain ground-water region. Within the New England Region, these two ground-water regions correspond to the New England and Coastal Plain physiographic provinces, respectively, as defined by Fenneman and others (1946).

The New England Region includes all of Maine and New Hampshire, eastern Vermont, most of Massachusetts, virtually all of Connecticut, and all of Rhode Island. In addition, it includes a strip as wide as 10 mi (16 kilometers) in southeastern New York.

The longest stream is the Connecticut River, which extends from the Canadian border through eastern Vermont and western New Hampshire to the coast of Connecticut. Other major streams include the Housatonic River, extending from northwestern Massachusetts to coastal Connecticut; the Merrimack, from New Hampshire to northeastern Massachusetts; the Androscoggin, from northern New Hampshire to south-central Maine; and the Kennebec and Penobscot Rivers, in central and eastern Maine, respectively.

The New England Region extends 125 mi (200 km) inland from the coastline for most of its southern two-thirds; in Maine, it reaches about 200 mi (320 km) in width. The distance from northernmost Maine to the southwest corner of Connecticut is 528 mi (850 km); the total area of the region is about 62,400 mi^2 (160,000 km^2).

As elsewhere in the northeastern United States, the New England Region is generally humid and has four distinct seasons, with frequent changes of weather. The climate along the coast is generally less severe than it is inland, because of the moderating influence of the ocean and Long Island Sound.

Average annual temperature ranges from 38°F (3.3°C) in northern Maine to about 50°F (10°C) in Connecticut, Rhode Island, and southeastern Massachusetts. Average annual precipitation ranges from about 40 in. (1,000 mm) in Maine to 45 in. (1,140 mm) in the three southernmost States.

POPULATION AND ECONOMIC DEVELOPMENT

The New England Region covers only 2 percent of the land area of the United States but contains about 6 percent of its population—11,803,000 in 1975. Compared with the national average of 54 people/mi^2 (21/km^2) for the United States, the region averages about 190 people/mi^2 (75/km^2). The largest population center is Boston, but the region includes 24 other Standard Metropolitan Statistical Areas. (See fig. 2.)

The New England Region generates about 6 percent of the national personal income, and its per capita personal income is 7 percent above the national average. Thus, economic development is generally high—among the six highest of the 21 Water Resources Regions. (See U.S. Water Resources Council, 1972, summary tables.)

GROUND WATER

Nationally, ground water has developed from a minor but important source of domestic supply during the early years to a source of 23 percent of the nation's total freshwater withdrawals in 1975 (Murray and Reeves, 1977, table 17). Withdrawals of ground water in the New England Region totaled about 600 million gal/d (2.3 million m^3/d; fresh ground-water withdrawals amounted to 12 percent of the total freshwater withdrawals.

During the protracted northeast drought of 1962–1965, many municipal water supplies were greatly reduced as levels in major surface reservoirs became dangerously low (Barksdale and others, 1966). This was the largest, longest, and most severe drought in the history of the Northeast United States. The effect was cumulative from year to year as reserves were depleted and streamflow and ground-water levels dropped to record lows (Schneider and Spieker, 1969, p. 4, 5). Many local water shortages and problems developed by 1965. For example, in Maine 21 supply systems restricted water use, and more than 50 municipalities in Massachusetts imposed similar restrictions.

CONSOLIDATED ROCKS

Crystalline igneous and metamorphic rocks and sedimentary rocks, including carbonates, occur in extensive areas.

Among the rocks of igneous origin are granite, rhyolite, diabase, pegmatite and basalt; those of metamorphic origin include gneiss, schist, phyllite, slate, marble, quartzite, and argillite. These mostly hard rocks are the most widespread and are commonly tapped for small domestic or livestock supplies. They lie at the surface in belts throughout Maine, in much of New Hampshire and eastern Vermont, in the broad uplands flanking the Connecticut Valley lowland in Massachusetts and Connecticut, and in most of Rhode Island except the Narragansett Bay area.

Among the sedimentary rocks, carbonate rocks occur notably in the Aroostook Valley in northern Maine and in the Housatonic River valley in western Massachusetts and western Connecticut. They include limestone, dolomite, and calcareous shale. Wells drilled in these rocks or in marble, their metamorphic equivalent, can obtain substantial supplies if large solution openings in the saturated zone are reached. Dry

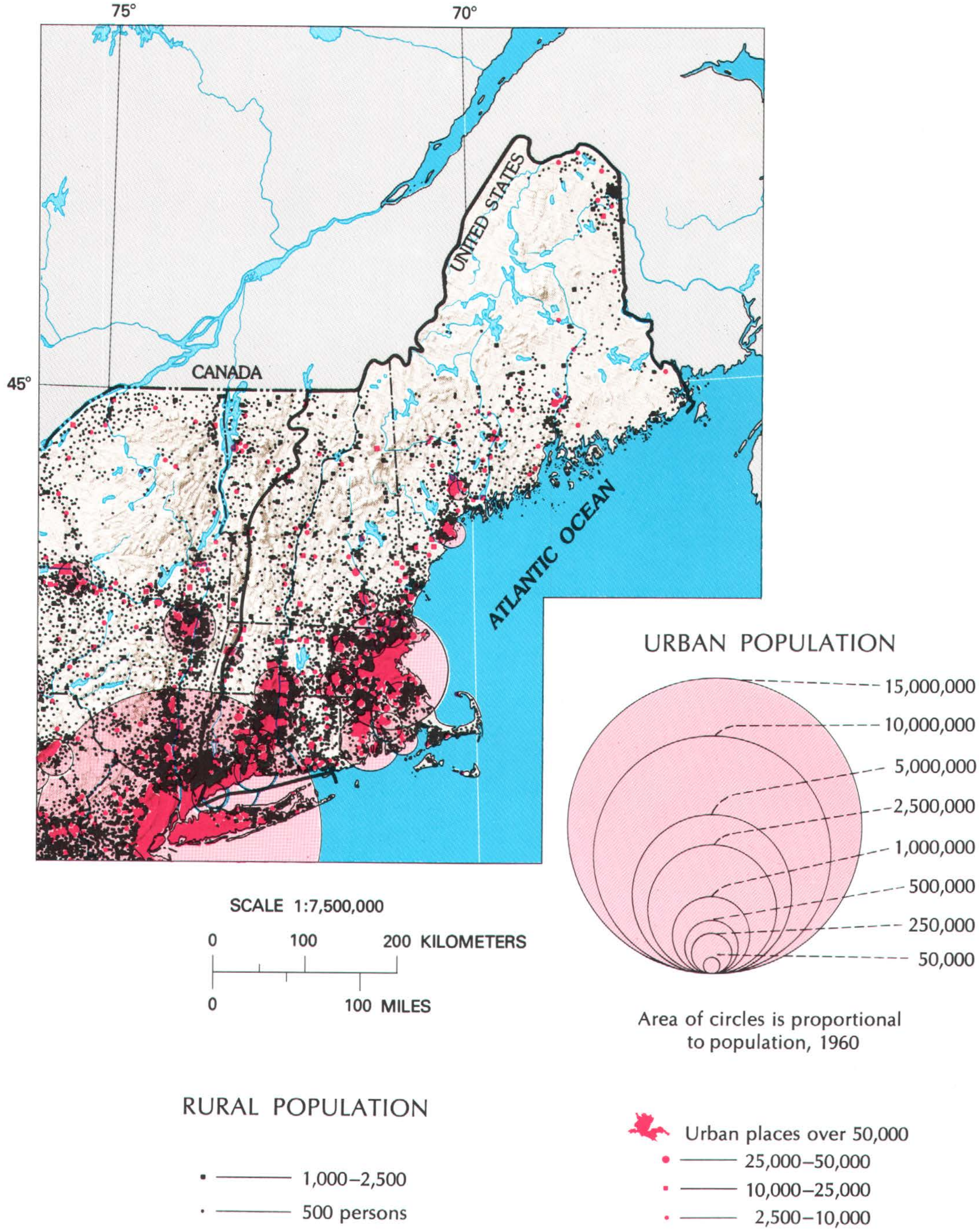

FIGURE 2.—Boston, which has an important place in the Nation's history, is by far the largest population center in the New England Region.

holes, however, are common, and so test drilling is usually required.

The Connecticut Valley lowland in west-central Massachusetts and central Connecticut (fig. 3) is underlain by sandstone, conglomerate, shale, and interbedded trap rock. The last is a poor aquifer, but the sedimentary rocks yield small to moderate supplies—more than 300 gal/min (about 19 L/s) to individual wells.

Elsewhere, the partly metamorphosed sedimentary rocks include quartzitic conglomerate, slate, phyllite, argillite, and marble. These rocks occur widely in Maine and in several areas in New Hampshire, in western Massachusetts and western Connecticut, northwest of Boston, and in the Boston and Narragansett basins in eastern and southeastern Massachusetts and southeastern Rhode Island. They yield small to moderate supplies of water. In some places large

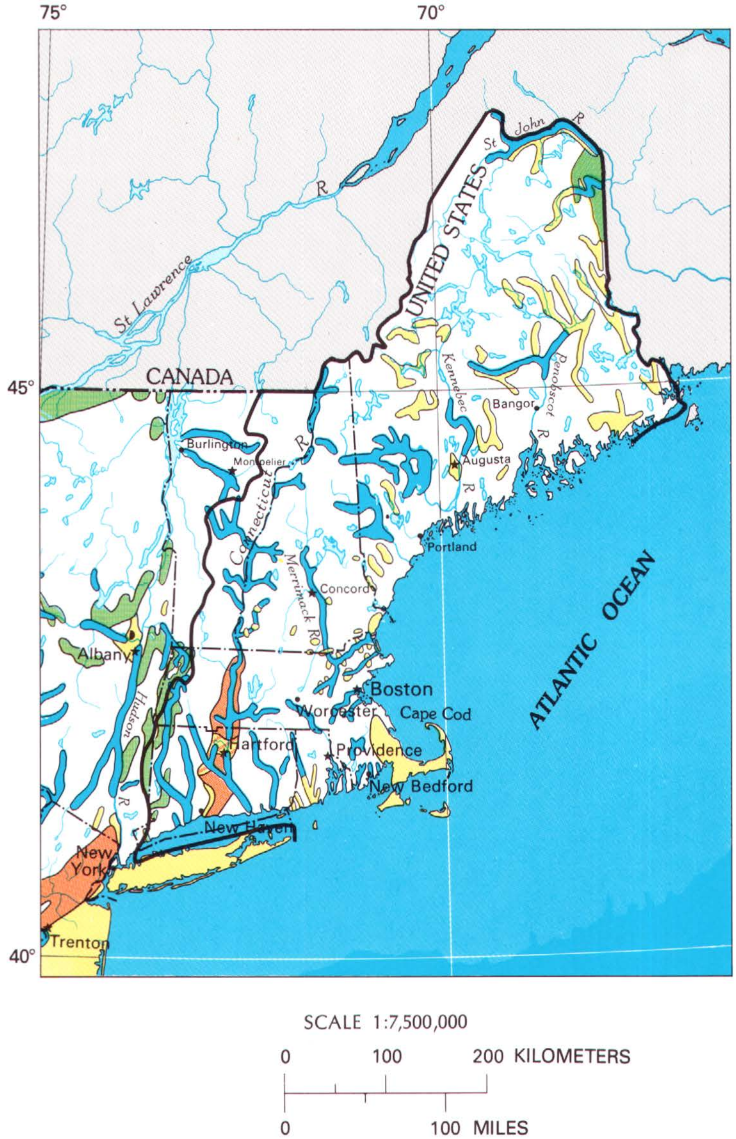

FIGURE 3.—Cape Cod, the lower Connecticut Valley, and many smaller areas in the New England Region are underlain by at least one aquifer capable of yielding at least 50 gal/min (3L/s) of water to individual wells.

supplies, up to perhaps 500 gal/min (32 L/s), can be obtained where these rocks are strongly fractured, as in the shear zones of faults.

Preglacial sedimentary rocks have been reached at depth in wells drilled near Provincetown on Cape Cod and near Duxbury, in southeastern Massachusetts; they also crop out on Martha's Vineyard, south of the Cape. These sediments evidently are related to the extensive Coastal Plain deposits outside the region in New Jersey and farther south; they have not been tapped for water because ample supplies are available from the more accessible overlying drift.

UNCONSOLIDATED ROCKS

The geologically younger rocks in the New England Region are commonly the more productive sources of ground water. These include the unconsolidated sedimentary rocks that were deposited during the glacial epoch, or Ice Age. As the continental glaciers, which covered all of New England, retreated, their meltwaters deposited bodies of so-called stratified drift. Except for lake deposits, the stratified drift contains little clay, and the sand and gravel beds are moderately to highly permeable.

Where meltwater streams flowed in contact with glacier ice, the deposits of stratified drift thus formed are called ice-contact deposits. Bradley (1964) found that in southeastern New Hampshire they are generally coarser and more permeable than outwash deposits formed beyond the glacier terminus.

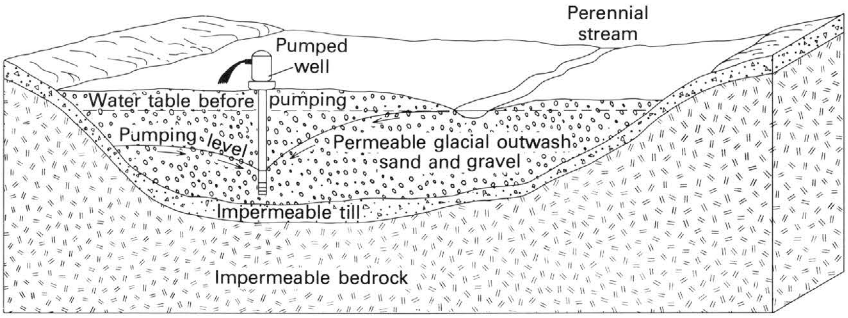

FIGURE 4.—Diagram of a watercourse aquifer showing a pumped well obtaining part of its water from a perennial stream. Situations like this are common in many valleys in the New England Region.

The unstratified drift, or till, consists of poorly sorted clay, sand, gravel, and boulders, deposited directly by the ice, and yields only very small supplies of water to dug wells, chiefly for domestic use.

WATERCOURSE AQUIFERS

Gravel and sand beds in river valleys are among the best sources of large quantities of ground water. These so-called watercourses are of particular importance to ground-water development in the entire region (fig. 3).

Thomas (1952, p. 10) defines watercourses as hydrologic units that include both surface water and ground water; that is, the water in a stream channel plus the ground water in the alluvium that underlies the channel and forms the bordering flood plains. The pervious beds in the stream valley are commonly in hydraulic continuity with the stream, and pumping water from them induces recharge from the stream. (See fig. 4.) In many places, this results in exceptionally large yields, provided that the permeability of the aquifer between the river and the well field is high. Where the alluvial deposits (or, in the New England Region, commonly glacial outwash deposits) are of fine texture, yields are proportionately lower; indeed, they may be very low.

In recent usage, the water-bearing sediments in the watercourses have come to be referred to commonly as watercourse aquifers; this term serves to suggest their elongated shape as well as the potential or recharge from streams. Well yields adequate for municipal water supplies are obtained from sand and gravel in stratified drift and alluvium in watercourses. Individual wells may yield from a few hundred gallons per minute to as much as 2,000 gallons per minute (125 L/s).

Genetically related to watercourse aquifers are buried valleys, which are valleys no longer occupied by the streams that formed them. As noted by Thomas (1952, p. 10–11), some alluvial channel deposits have an extent, thickness, and permeability far greater than the present streams could possibly produce, and some valley deposits have been buried so that they no longer form any part of the present drainage system. Thus, although the materials may be of equal or greater permeability than a comparable watercourse aquifer, the opportunity for recharge may be limited to direct infiltration from precipitation, and if so, the perennial yield is likely to be much less.

As of mid-century, many of the principal watercourses of New England had not been explored for their ground-water potential (Thomas, 1952, p. 64). However, substantial progress has since been made to determine the watercourse aquifer distribution in many parts of the New England Region. Among the larger river systems where permeable sands and gravels have been identified and described are the St. John, Penobscot, Kennebec, Androscoggin, Connecticut, and Housatonic systems. (See Prescott, 1966, 1968, 1969, 1973a; Cederstrom and Hodges, 1967; Norvitch, 1966; and Norvitch and others, 1968.)

QUANTITY OF GROUND WATER

The component of streamflow that is base flow, or ground-water discharge, has been determined for various geologic terranes by many investigators, generally by inspection of stream hydrographs. The peaks in such hydrographs represent increased runoff caused by precipitation; the lower parts of the curves of the hydrographs represent the component of discharge from the aquifers that are in hydraulic continuity with the stream.

Bue (1970) shows that the mean streamflow from the New England Region during 1931–60 was 91,240 ft^3/s (2,580 m^3/s). Adding to this rate the estimated streamflow from the region into Canada, 14,030 ft^3/s (397 m^3/s) (Lois A. Swallow, U.S. Geol. Survey, unpub. data), the mean streamflow from the region is about 105,300 ft^3/s (3,000 m^3/s), or about 68 billion gal/d (258 hm^3/d).

Assuming, conservatively, that base flow is only 40 percent of the mean streamflow in the region, the average total yield of water from the rocks in the entire region, under present hydrologic conditions, is about

27 billion gal/d (102 hm^3/d). This estimate of ground-water yield compares favorably with the result from an alternative method wherein an average recharge rate of 0.2 million gal/d/mi^2 (290 $m^3/d/km^2$) was assumed for areas of till and bedrock and 1 million gal/d/mi^2 (1,460 $m^3/d/km^2$) for the areas of stratified drift and alluvial aquifers.

It is of course impractical, nor would it be desirable, to intercept all of this ground water before it is discharged into streams, for they would be dry or nearly so during times of minimal precipitation. In addition, a part of this water is flowing through low-permeability earth materials that would yield water only slowly to wells. However, a substantial part of this estimated total is nevertheless a potentially valuable resource.

WITHDRAWALS AND USE OF GROUND WATER

The rate of withdrawal of freshwater from all sources during 1975, in the New England Region, was 5,000 million gal/d (18.9 million m^3/d). Of this, 12 percent, or 600 million gal/d (2.3 million m^3/d) was from ground-water sources (Murray and Reeves, 1977, table 17). This is equivalent to a total volume of freshwater from all sources for 1975 of 1,800 billion gal (6,800 hm^3) and from ground-water sources 220 billion gal (830 hm^3). For the regional population of 11,803,000 in 1975, the rate of use of freshwater was about 420 gal/d (1.6 m^3/d) per person from all sources (Murray and Reeves, 1977, table 17). The rate of use of ground water by industry in 1975 (Murray and Reeves, 1977, table 15) was 200 million gal/d (760 thousand m^3/d)—that is, only 4 percent of the total rate of withdrawal of freshwater from all sources. Although the larger demands for water are met from surface-water sources, there is a growing awareness of the development potential of the region's ground-water resources. Considerable additional use of ground water may be expected in the future as economic activity continues to increase.

CONJUNCTIVE USE OF GROUND WATER AND SURFACE WATER

Withdrawal of water from the streams under present conditions has not noticeably affected the amount of water available in the aquifers. However, substantial steady withdrawals of water from a shallow water-table aquifer near a stream will in time reduce base flow in the stream, especially during dry periods when flow is sustained almost wholly by ground water.

Ground water and surface water might be developed conjunctively in many places. Permeable glacial outwash deposits are widespread in valleys. Where these deposits are in watercourses (Thomas, 1952, p. 10), thus forming what have been termed watercourse aquifers, water can be pumped from them so as to induce recharge from the adjacent perennial stream. This is a simple form of conjunctive use.

Large-scale conjunctive management of both ground water and surface water is not yet being practiced in the New England Region so far as is known. Such programs would involve balancing the use of ground-water and surface-water reservoirs according to the availability of water and to the demand for it. Surface water might, in times of surplus, be used to replenish the ground-water reservoir, and ground water might be used to augment surface reservoirs during periods of low flow or drought.

WATER-RELATED PROBLEMS

Despite abundant precipitation, the region has its share of water-related problems. These arise in part from natural hydrogeologic conditions and partly from growing urbanization, increasing population, and industrial activity.

Several problems relate primarily to the natural occurrence of ground water. For example, the development potential for some aquifers is limited because they are narrow, thin, and discontinuous. Other problems involve inferior quality and the susceptibility of ground water to saltwater encroachment in coastal reaches, if substantial amounts are pumped.

In addition, many problems arise from man's activities. Ground-water contamination from landfills is a major problem in some areas; others include contamination from applying deicing salts on highways and contamination from suburban septic tanks and cesspools.

RESTRICTED SIZE AND SHAPE OF AQUIFERS

The most productive aquifers in the New England Region are largely confined to stream valleys. Thus, they are long, thin, and narrow compared with the thick blanket-type deposits of the Coastal Plain in States farther south. This distribution imposes constraints on the location of larger municipal or industrial well fields. Moreover, apparently desirable sites in these valleys require test drilling to make sure that the aquifers are suitable for development. Some aquifers that occupy stream valleys contain only marginally permeable materials. Alternatively, they may not be in hydraulic continuity with the streams and so are restricted as to recharge.

The interstream upland areas are occupied by generally dense and not very permeable crystalline igneous and metamorphic rocks, largely overlain by relatively impermeable till. Such interstream areas yield only small supplies of ground water to wells.

GROUND WATER OF INFERIOR QUALITY

The chemical character of the ground water varies widely, but its overall quality is generally good to excellent. Most ground water in the region is suitable for most purposes with little or no treatment (Miller and others, 1974, p. 78). However, in some localities the water is undesirable for various uses.

Because the chemical quality of ground water is influenced by the mineral character of the rocks through which it flows, troublesome concentrations of certain dissolved constituents are found locally in some parts of the region.

Most of the common dissolved solids in ground water are undesirable in excessive concentrations. Thus, for example, fluoride, desirable in small concentrations as a factor in reducing dental caries, occurs locally in greater amounts in east-central New Hampshire north and south of Lake Winnepesaukee. Water from at least one well reportedly had a concentration of more than 10 mg/L of fluoride (Miller and others, 1974, p. 97).

Iron, usually also associated with manganese, is widespread, and has been found in ground water from several different kinds of rock. Above concentrations of about 0.3 mg/L, iron is troublesome because it stains plumbing fixtures, glassware, and laundered clothing, and impairs the taste of beverages. Manganese causes similar effects at even lower concentrations.

Radioactivity higher than usual is found in ground water in Carroll County in eastern New Hampshire and from the Rangely Lakes area in the uplands of western Maine southward to Cumberland County in the southern part of the State. It is attributed to radon gas from natural decay of radioactive minerals in granite.

In a few places, certain wells tap strongly mineralized natural water. For example, samples of water from two wells near the crest of Talcott Mountain, a trap ridge in north-central Connecticut, contained more than 3,100 mg/L of dissolved solids (Randall, 1964, p. 97). However, as pointed out by Feth and others (1965, p. 2 and sheet 1), in the entire New England Region no mineralized ground water—water containing more than 1,000 mg/L of dissolved solids—is known to occur naturally in producible quantities. It is likely that such water would be found wherever permeable rocks extend to depths of a few thousand feet, but in view of the generally dense nature of bedrock in the region, yields from deep sources are likely to be small. The general abundance—and scant development to date—of fresh ground water would seem to preclude deep drilling for supplementary water supplies.

Where mineralized water, converted to fresh water, may be required to augment other supplies, the most readily available sources are the ocean, Long Island Sound, and brackish water bodies, such as Narragansett Bay.

SALINE GROUND WATER

Saline ground water has long been a problem in many parts of the country, and the New England Region is no exception. It may be found in place during exploratory drilling, or it may be drawn into the ground-water reservoir by continued pumping of wells or well fields in places subject to salt-water encroachment.

The region has a long embayed coastline, with many estuaries that contain brackish water. The lowered water level caused by pumping from wells may reverse the normal seaward gradient, and draw saline water from brackish-water bodies or from the ocean into the shallow freshwater aquifers. Encroachment of saline and brackish water along coastal reaches and estuaries is a growing problem. Some typical instances of encroachment are listed in table 1.

TABLE 1.—*Locations of saltwater encroachment in coastal areas of the New England Region*

[Modified from Miller and others, 1974, table 44]

Location	Nature of problem	Action taken
Maine:		
Town of Bowdoinham, Sagadahoc County.	Salty water from bedrock of Kennebec River estuary contaminated a well 300 ft deep.	Well abandoned.
New Hampshire:		
Portsmouth.	Minor lateral intrusion from tidal water in Piscataqua River.	Unknown.
Massachusetts:		
Provincetown, Scituate, and Somerset.	Minor lateral intrusion from ocean and saltwater marshes affected water from wells tapping shallow aquifers.	New wells drilled farther inland; pumping from old wells reduced.
Connecticut:		
Long Island Sound coastal area including the cities of New Haven and Bridgeport.	Lateral intrusion of salty water from harbors and tidal river estuaries contaminated water from several dozen industrial and municipal wells tapping glacial sand and gravel, older sandstone and shale, and crystalline rock aquifers in areas of heavy pumping.	Wells relocated inland or pumping reduced; some wells abandoned, and at least one scavenger well installed to intercept salty water.
Rhode Island:		
City of Providence; Town of Barrington.	Salty water from estuaries and bays contaminated water from some municipal wells tapping the glacial outwash aquifer because of heavy pumping.	Pumping reduced; replacement of ground-water supply by surface water considered.

Saltwater encroachment in coastal areas near brackish-water bodies is, thus, both a current and a potential problem. However, where encroachment has already occurred, it may still be possible to utilize the ground water in one of two ways: (1) without treatment, in applications where salinity can be tolerated—for cooling or washing or flushing in certain industries or (2) by converting it to freshwater, rendering it suitable for a wide range of uses, including drinking.

GROUND-WATER CONTAMINATION

Contamination is used here to mean any appreciable deterioration of ground-water quality by man's activities. The southernmost three States of the New England Region have a rapidly growing population, advancing urbanization, and heavy industrial growth, and it is inevitable that the environment will be affected to some degree.

INDIVIDUAL SEWAGE-DISPOSAL SYSTEMS

Nearly all homes beyond the reach of central sewage facilities have individual sewage-disposal systems—septic tanks and cesspools. The spread of housing developments in expanding suburban communities has resulted in many local concentrations of individual sewage-disposal systems in the New England Region.

A study in Massachusetts (Morrill and Toler, 1973) is an example of the approach being made to assess the effects of individual onsite sewage-disposal systems. The Ipswich and Shawsheen River basins north of Boston were studied with tracers to develop a correlation between unsewered-housing density and increase in dissolved solids in the base flow of streams. Making a correction for the effect of application of highway deicing salts, the authors found that the discharge of degraded ground water from individual septic tanks was the cause of the increase in the dissolved-solids concentration in the rivers. The increase is roughly proportional to the unsewered-housing density. For example, a density of about 400 houses per square mile (150 houses per square kilometer) caused an increase in dissolved-solids concentration of about 60 mg/L in the base flow of streams; for a density of 900 houses per square mile (350 houses per square kilometer), the increase was found to be about 130 mg/L.

INDUSTRIAL AND MUNICIPAL LANDFILLS

Among the major contributors to localized deterioration of ground-water quality in the New England Region are industrial and municipal landfills. Of these, the industrial landfills are the more abundant. As noted by Miller and others (1974, p. 213),

> the location and even the existence of industrial landfills rarely are recorded with any public agency. Thus, they are not inspected on a routine basis, and problems do not become evident unless ground-water contamination is obviously taking place. In the case of the municipal landfills, although their locations are generally known to regulatory agencies, few are monitored and, again, contamination of ground water normally takes place unobserved.

Ground water contaminated by leachates (solutions that drain by gravity through landfills) ultimately discharges to streams. Although many streams are routinely monitored for water quality, deterioration of stream quality by discharge of contaminated ground water is not detected until it is too late. The aquifer beneath the landfill or other contaminating source will itself have become contaminated before detection and therefore before remedial measures can be put into effect. Installation of water-quality monitoring wells around a landfill together with a frequent or continuous sampling program would allow time for an early judgment to be made in each situation, so that appropriate management decisions could be rendered with sufficient facts and with some degree of confidence. Moreover, careful selection of landfill sites according to criteria that include local hydrogeology might result in anticipation of the adverse effects of contamination, allowing it to take place in such a manner that it could be successfully managed.

WINTER HIGHWAY DEICING PROGRAMS

Another significant source of contamination in the New England Region is the general use of highway deicing salts in the winter. The compounds used are sodium chloride and calcium chloride. Inevitably, this use has resulted in increasing chloride concentrations in ground-water supplies near the highways—some of which have received more than 20 tons of chemicals per lane-mile (11,300 kilograms per lane-kilometer) in a typical winter. The magnitude of the problem is well shown by table 2, which gives the quantities of deicing chemicals applied to highways by State highway departments during a single winter in four of the New England States. In addition, towns and cities add to the chloride burden with their own deicing programs.

The immediate advantage of the use of ice-removing salts is offset to a considerable degree, however, by the delayed cost to other public agencies forced to replace unusable water sources. As an example, New Hampshire spent about $140,000 annually to replace wells contaminated from this source. It is conceivable that desalination plants might ultimately be required to manage this problem (Terry, 1974, p. 65).

TABLE 2.—*Use of ice-removal chemicals in four New England States during the winter of 1965–1966*

[From Hanes and others, 1970]

State	Calcium chloride (tons)	Sodium chloride (tons)	Rate[1] (in tons per single-lane mile)
Connecticut	8,000	74,600	8.9
Massachusetts	5,855	120,304	20.7
New Hampshire	540	82,737	11.9
Vermont	500	83,122	18.2

[1] Rounded.

Conversions:
Tons to kilograms, multiply by 907.
Tons per mile to kilograms per kilometer, multiply by 563.

OTHER SOURCES OF CONTAMINATION

In their report on ground-water contamination in the northeastern States, Miller and others (1974) discuss several other significant sources of contaminated ground water. Among these may be mentioned (1) surface impoundments, (2) buried pipelines and storage tanks, (3) accidental spills, and (4) surface discharge of toxic materials.

Controls designed to reduce or prevent contamination from these various sources are being formulated by regulatory agencies. In reference to surface impoundments of industrial discharges, Miller and others (1974, p. 229) point out that most of the existing sites are difficult to inventory because, like industrial landfills, they are on private property. In much of New England, particularly in industrialized Massachusetts, Connecticut, and Rhode Island, these sources of contamination are common. Ongoing investigations and planned additional studies should locate most of these sources, so that they can be avoided when planning municipal water developments.

LEGAL CONSTRAINTS ON GROUND-WATER DEVELOPMENT

All the States represented in the New England Region except New Hampshire and New York follow the English rule of the riparian doctrine, which provides for unrestricted use of ground water by each landowner. Ordinarily, this does not pose serious legal problems because of the abundance of ground water in this humid region. However, in areas of increasing population and heavy and competing demands, the effects of pumping wells will probably be felt more and more, and some modification is perhaps inevitable.

As among the States in the adjacent Mid-Atlantic Region (Sinnott and Cushing, 1978, p. 2), wherever specific legal tests have been made, the present trend in the New England Region seems to be toward the American modification of the English rule—the so-called doctrine of reasonable use. This doctrine restricts the water-use rights of the landowner in relation to the needs of other landowners. By carefully planning new ground-water developments so that they are realistically scaled for actual need, much litigation may be avoided. Moreover, if use is challenged, realistic defense may be made.

As pointed out by McGuinness (1951, p. 3, 24), the American doctrine of reasonable use was first formulated in New Hampshire in 1862.

GROUND-WATER STUDIES AND NEEDS FOR ADDITIONAL INFORMATION

The general trend in growth in the New England Region is likely to continue, both in population and in economic activity. Increasing urbanization in the less populated northern States is expected. In order to meet the inevitable increased demand for additional water, more information about potential ground-water supplies is necessary. In addition, it will be necessary to control the contamination of water supplies that results from various land-use practices and municipal and industrial waste disposal.

Present programs of ground-water investigations in the region are being carried on largely by the U.S. Geological Survey, in cooperation with State and local agencies. Many of the cooperating agencies are themselves making ground-water studies.

Studies thus far in the New England Region have been based primarily on political boundaries, such as counties or designated areas around key cities. In recent years, however, many studies have been oriented toward hydrologic units—drainage basins, individual aquifers, or aquifer systems. A comparison of figure 5 (work done or nearing completion) and figure 6 (areas where additional work is indicated) suggests a trend toward hydrologic units, rather than political boundaries.

However, funding and program authorization have remained, as would be expected, with the sources of cooperative funds—namely, the State and smaller political entities. Thus, programs are primarily State-oriented, and the discussion that follows considers present coverage and anticipated needs in each of the States involved.

The map (fig. 5) shows the areas covered by recent ground-water investigations. The nature of the coverage is shown by three categories:

1. Detailed quantitative studies in which ground water has been treated as a dynamic fluid resource. These studies include analyses of aquifer tests and provide guidance in predicting response of aquifers to changes in pumping regimen.
2. Detailed reconnaissances in which most of the available ground-water information has been collected, including quantitative data and interpretations that provide a basis for determining, at least in a general way, effects of possible future developments.
3. General reconnaissances in which a representative sampling of readily available information has been collected and interpreted and which can provide guidance for planning either small ground-water developments or more detailed investigations before major developments.

Some areas in Massachusetts are not colored in figure 5. For these areas, formal reports have not been published, nor are studies currently underway. However, basic data are on file for most localities in these

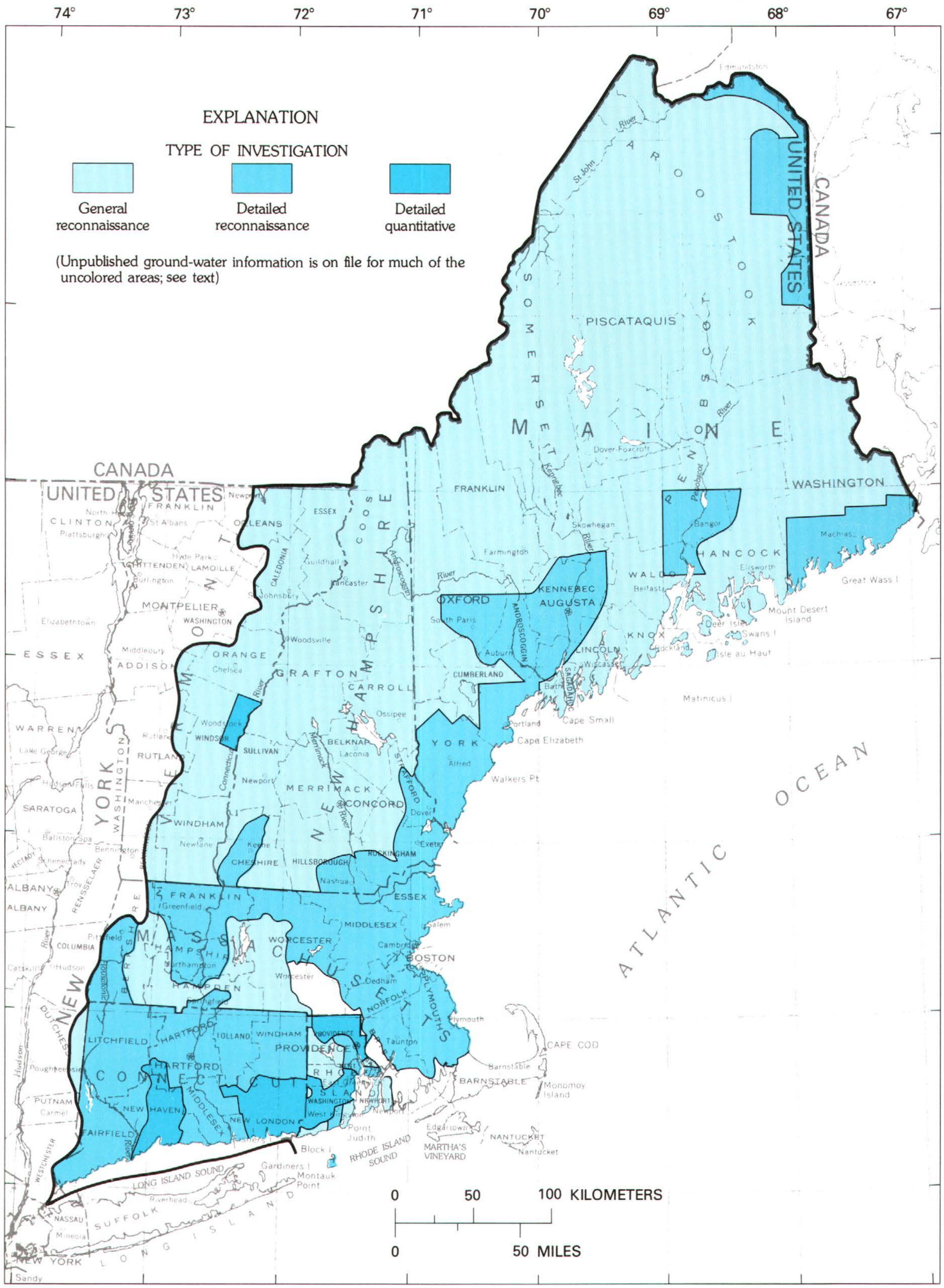

FIGURE 5.—Status of ground-water investigations in the New England Region.

areas and are available for inspection in the New England District Office of the U.S. Geological Survey in Boston. Inquiries may also be made to the Survey offices in other States for basic data and other unpublished information in the open files.[1]

Two categories of necessary ground-water information are indicated in figure 6:

1. Detailed quantitative information, as defined above. This level of ground-water information is desirable for areas where the need is immediate or foreseeable. The detailed information provided by investigations at this level allows immediate use for planning and developing major projects, such as municipal or industrial well fields, with only minimal additional site investigation.

2. Detailed reconnaissance information, also as previously defined. This level of information is indicated for areas where only moderate future developments are likely and where substantial detailed information would suffice for small developments. Such information would provide an adequate base for additional work prior to large-scale developments.

MAINE

Maine, the largest State in the region, has an area of about 33,200 mi^2 (86,000 km^2)—more than half the area of the region. Its entire area was glaciated during the Ice Age, and it is largely mantled by drift. The bedrock consists mainly of crystalline igneous and metamorphic rocks. Of the sedimentary rocks, most are consolidated. Ground water occurs in fractures and, in the calcareous sedimentary rocks, in solution cavities—many of which are fractures enlarged by solution.

Early ground-water studies in Maine were mostly reconnaissances, with information on a few selected drilled wells and lists of data on the principal springs. (See for example, Bayley, 1905.) The most comprehensive early report is that of Clapp (1909) describing ground-water conditions in southern Maine.

The report by Prescott (1963a), a reconnaissance of ground water in Maine, is the first that covers the entire State. After that reconnaissance, Prescott prepared maps of ground-water favorability where needs were most urgent. These maps are chiefly of the more populated and industrialized coastal areas and also include eastern Aroostook County in northern Maine, where ground water is used for irrigation. (See Prescott, 1963b, 1966, 1968, 1969, 1972, 1974a, b, 1977a, b, 1980.) The maps and their accompanying texts are all at the detailed reconnaissance level. (See fig. 5.) In general, the detailed reconnaissance has been directed toward those areas where population and industry are greatest.

As development expands, adjoining areas may expect an increase in economic activity and will need ground-water information for anticipated demands. Areas close to large population centers may eventually share in future industrial developments. These include the coastal reaches southeast and east of Augusta and south of Bangor—in Lincoln, Knox, Waldo and Hancock Counties in eastern coastal Maine. Also included are the upper reaches of the Saco, Presumpscot, and Royal River basins in southwestern Maine and the upper reaches of the Penobscot, Kennebec, and Androscoggin River basins in central and western Maine. These areas are gradually growing in population amid other manifestations of increasing economic activity. (See fig. 6.)

At the present time, detailed reconnaissance information is the priority need throughout the State. When, however, the need for detailed quantitative information becomes urgent as a result of pressing water-supply demands, the Portland area—encompassing the lower reaches of the Royal River draining into Casco Bay at Yarmouth—would have high priority. Integrated ground-water and surface-water information would be most useful in this area.

General baseline information on ground-water quality in Maine is necessary for defining water-quality problems. Salt used in highway deicing is probably the most widespread contaminant. In places, the salt is stored uncovered allowing contamination even when the salt is not being used. Of a more local nature are other problems such as contamination by effluent from septic tanks in rural areas.

Among the local problems in natural ground water are high radioactivity, excessive iron or manganese, and the presence of saline water in coastal areas.

Ground water with a high degree of radioactivity has been found locally in the granite of western Maine, extending from the Rangely Lakes to the coastal area of Cumberland and Sagadahoc Counties (Chandler and others, 1959, p. 21). The highest radioactivity was found to be more than 290 times the allowable maximum concentration defined by the U.S. National Bureau of Standards (1953). Detailed study of this problem is warranted soon. So far as known, however, no public supplies from ground-water sources contain excessive concentrations of radioactivity.

Ground water in Maine is generally of good chemical quality, and the problems are localized.

[1]Inquiries may be addressed to the following officials:

District Chief, New England District, U.S. Geological Survey, 150 Causeway Street, Suite 1001, Boston, Mass. 02114 (for Massachusetts, Maine, New Hampshire, Vermont, and Rhode Island).

District Chief, U.S. Geological Survey, 135 High Street, Room 235, Hartford, Conn. 06103 (for Connecticut).

District Chief, U.S. Geological Survey, Post Office Box 1350, 236 U.S. Post Office & Court House, Albany, N.Y., 12201 (for New York).

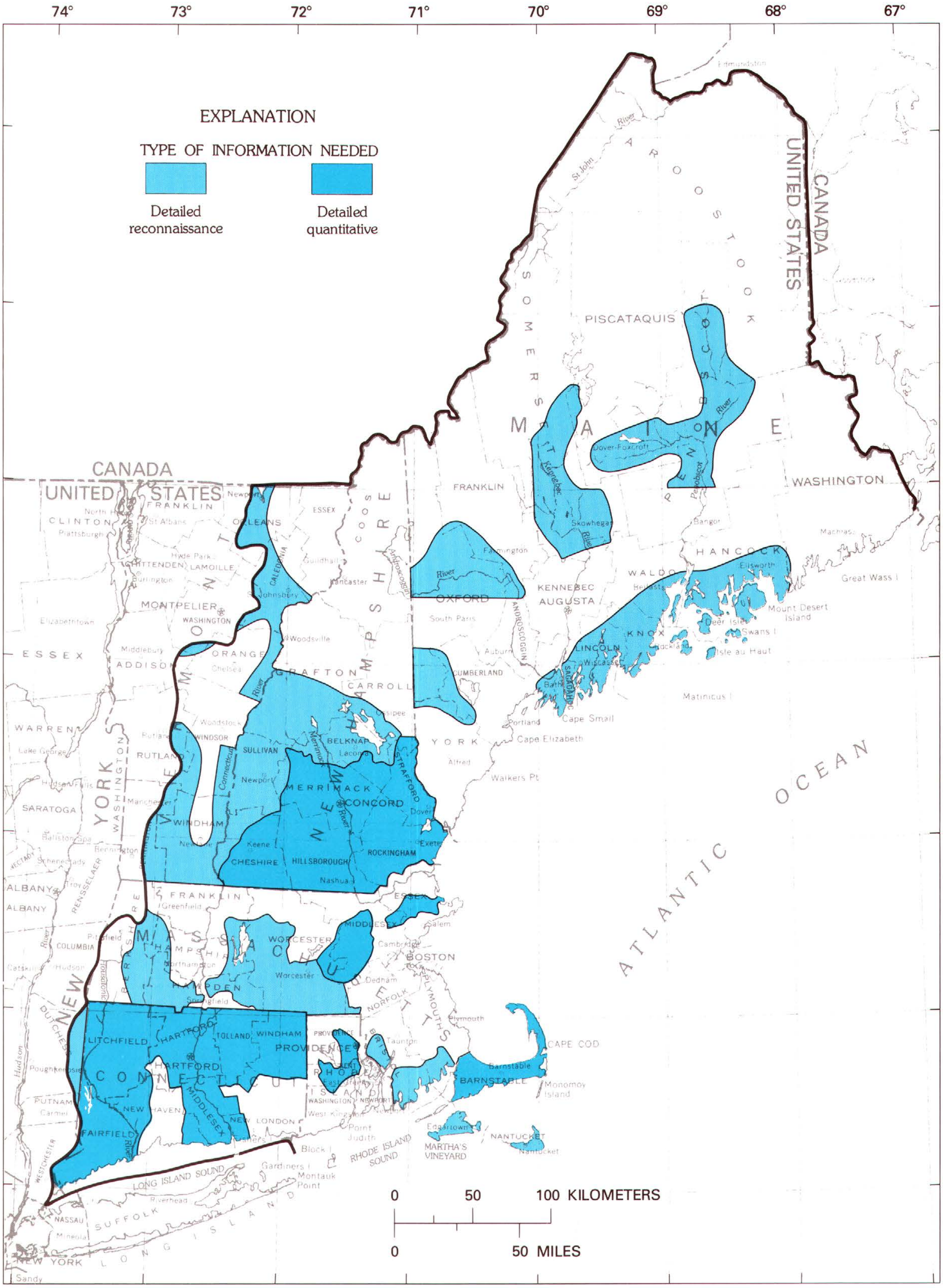

FIGURE 6.—In parts of the New England Region, additional ground-water information is necessary to assist water-resources development and management.

NEW HAMPSHIRE

New Hampshire has an area of about 9,300 mi² (24,000 km²) and has a predominantly rugged topography, culminating in the White Mountains in the north-central part of the State. Mount Washington has an altitude of 6,288 ft (1,917 m) and is the highest mountain in New England.

The precipitation is highest on these mountains, more than 70 in. (1,780 mm) compared with the general average in the State of 43 in. (1,090 mm).

Much of the bedrock consists of ancient sedimentary rocks, which are partially metamorphosed; about a third of the State is underlain by intrusive igneous rocks. Yields from wells in the bedrock are generally small because of its low permeability.

Mantling the bedrock are till and stratified drift deposited during the Ice Age. Till is generally thin in the uplands, and in places the bedrock is exposed. The unsorted till is of low permeability and yields only small supplies of water to many domestic dug wells. These are gradually being replaced by wells drilled and cased into the bedrock, affording greater sanitary protection.

Stratified drift consists of water-sorted materials deposited by the meltwaters of the waning ice sheet and commonly contains permeable sand and gravel with some clay and silt. Sand and gravel were deposited by streams, clay and silt accumulated in glacial lakes, and coastal deposits were of marine origin. Stratified drift is widespread in the lowlands; it is particularly important where it occurs in watercourse aquifers that are in hydraulic continuity with perennial streams. These aquifers are the best in the State.

Reconnaissance ground-water field work has been completed for the entire State, and the results were published in nine reports (Cotton, 1975 a–d; 1975 a, b; 1977 a–c).

An interstate general reconnaissance of the Connecticut River basin along the western boundary of the State by Cederstrom and Hodges (1967), published as a hydrologic atlas, provides additional coverage in the western part of New Hampshire.

Three detailed reconnaissances have been completed. Bradley (1964) described the ground-water resources of southeastern New Hampshire, and Weigle (1968) completed a hydrologic atlas for the area immediately adjacent to the west—the lower Merrimack River basin. Farther west, Whitcomb (1973) studied the ground-water resources of the Ashuelot River basin, also published as a hydrologic atlas.

On the basis of estimates of population and public water-supply demands through the year 2020 (Anderson-Nichols & Co., Inc., 1969), detailed quantitative studies are necessary for the southern part of New Hampshire, as indicated in figure 6. The population there is expected to quadruple, from half a million in 1966 to over 2 million in 2020. In this area, public water-supply use is expected to increase from about 50 million gal/d (190 thousand m³/d) to about 400 million gal/d (1½ million m³/d).

A detailed reconnaissance of central and west-central New Hampshire (fig. 6) may be somewhat less urgent. Here the population is expected to increase from about 106,000 in 1966 to about 250,000 by the year 2020. The use of water for public supplies is expected to increase from 7.6 million gal/d (29,000 m³/d) to 43 million gal/d (163,000 m³/d); a substantial part of the total would be ground water. The capacities of present systems would be exceeded by 26 million gal/d (98,000 m³/d) (Anderson-Nichols & Co., Inc., 1969). More information on ground-water quality in New Hampshire would be helpful, especially analyses of representative samples from all parts of the State. Of particular interest are hardness, iron and manganese, fluoride, pH, and radioactivity. Among practices likely to have a major effect on chemical quality of ground water, two are widespread: (1) the construction and operation of landfills and (2) application of deicing salts to roads. Both result in contamination problems, at least locally. Extensive sampling of ground water for chemical analyses would pinpoint areas where problems are likely to need attention and would provide a measure of the nature and scope of the water-quality information required.

In recent years, ground water has provided at least a part of the supply in 60 percent of the municipal water systems, and a major role for ground water in meeting future demands is nearly assured.

The foregoing estimates of future ground-water investigational needs are based on anticipated public-supply demands. However, such investigations may serve other needs, in areas not designated in figure 6. Land-use planning will undoubtedly proceed at an accelerated rate throughout New Hampshire during the next 40 years. Adequate water-resources information, based on systematic hydrogeologic studies, is necessary for long-range planning. Thus, additional ground-water investigations will be needed.

VERMONT

Vermont is primarily rural, with few industries and a relatively small population. A little less than half of its total area of 9,600 mi² (25,000 km²) lies within the New England Region.

Withdrawals of water from all sources are small (Murray and Reeves, 1977, table 10), but its use of ground water is proportionately high—largely because of its rural economy.

All of eastern Vermont that lies within the New

England Region is covered by general reconnaissances (fig. 5) published as ground-water favorability maps. (See Hodges, 1967, 1968a, b, c, and d.) As McGuinness (1963, p. 891) points out, the paucity of information on ground water reflects the general abundance of water and the small population and water demand.

Besides the maps, a quantitative study of the developing White River Junction area was made by Hodges and Butterfield (1972b).

Ground-water information at the detailed reconnaissance level will be necessary for the Interstate Highway corridor in the northern part of Vermont and along the Connecticut River from about the latitude of St. Johnsbury southward to the Massachusetts boundary. Much of southern Vermont would also require study because of increasing economic activity. (See fig. 6.)

The growing communities clustered around St. Johnsbury in the north and Brattleboro in the south might eventually require detailed quantitative studies.

Ground water in Vermont is ample for current needs. There is no heavy industry; tourism, skiing, and other outdoor recreation are the major attractions. Consequently, the principal need is for drinking water and water for other domestic purposes.

The quality of the water is typically good to excellent and environmental concerns are not now serious.

MASSACHUSETTS

About 8,090 mi^2 (21,000 km^2) of Massachusetts lies within the New England Region. This area constitutes the entire State except the small area (164 mi^2) (425 km^2) in the extreme northwest corner along the Hoosic River, which lies in the Hudson River Basin in the Mid-Atlantic Region.

Most of Massachusetts is in the New England physiographic province. Cape Cod, and the islands of Martha's Vineyard and Nantucket, all in the extreme eastern part of the State, are in the Coastal Plain province. The entire area was glaciated during the Ice Age.

The Connecticut Valley lowland extends through the west-central part of the State, from New Hampshire and Vermont southward to central Connecticut. It is underlain by readily eroded sandstone and shale, interbedded with volcanic rocks and mantled by drift. The lowland is flanked on the west by uplands, rising westward to the Berkshire Hills—ridges of schist, slate, and other rocks that have been strongly folded and faulted. East of the Connecticut Valley are uplands of folded sedimentary and metamorphic rocks, and still farther eastward is a broad belt of igneous rocks and hard sedimentary rocks, extending to the glacial deposits of Cape Cod.

The western half of Massachusetts is covered by several ground-water studies (fig. 5), published as hydrologic atlases or as ground-water-favorability maps. (See Cederstrom and Hodges, 1967; Norvitch and others, 1968; Collings and others, 1969; and Gay and others, 1974.) Several areas in the central and eastern parts are covered by detailed reconnaissances.

The Assabet River basin, a tributary of the Merrimack River in central Massachusetts, has been studied (Pollock and others, 1969).

In the eastern part of the State, parts of the coastal drainage basins studied include the area between Hingham, southeast of Boston, and Wareham, at the head of Buzzard's Bay (Williams and Tasker, 1974a, b). The Taunton and Tenmile River basins in the southeastern part, west of the coastal area, were studied by Williams (1968) and Williams and others (1973). The Neponset and Weymouth River basins south of Boston have also been studied (Brackley and others, 1973), as well as the Charles River basin west of Boston (Walker and others, 1975).

In northeastern Massachusetts, Sammel and others (1964) made a detailed reconnaissance of the Ipswich River basin, and immediately to the north, Sammel (1967) made a similar study of the Parker and Rowley River basins. Baker and others (1964) wrote a water-supply paper on the Wilmington-Reading area.

In western Massachusetts, flanking the west side of the Connecticut Valley, a detailed reconnaissance may be necessary in the Westfield River basin and in the upstream Massachusetts part of the Farmington River basin that extends into Connecticut. East of the Connecticut Valley, similar information may be necessary in the Chicopee River basin and in the French and Quinebaug basins adjacent on the south; also, in the Blackstone River Basin adjacent to the latter basins on the east. No systematic work has been done in the Blackstone River basin, and studies only at the general reconnaissance level have been made for the others. Economic activity is increasing in all these basins, which may require more ground-water information for anticipated new developments.

Other areas in Massachusetts, where detailed reconnaissances may be required, include the Shawsheen and Mystic River basins north of Boston and the North Shore coastal region between Boston and Gloucester. In addition, comprehensive ground-water information is lacking in southeastern Massachusetts, including the coastal area south of the Taunton River basin, and on Martha's Vineyard and Nantucket south of Cape Cod. Coverage in these areas, together with those in the western and central parts of the State, would help to implement the systematic long-range basin-by-basin program to provide an adequate base of ground-water information.

Detailed hydrologic information in the upper Charles River basin is a prerequisite for planned treatment and disposal of sewage from several towns and for discharge of treated sewage into and out of the basin.

In the Ipswich River basin, growing needs for public water supplies require detailed quantitative information for guidance in dealing with problems of expansion and water management. A proposal to build a 10 billion gal (38 million m^3) reservoir in the basin also requires detailed ground-water facts for construction and management. Conjunctive use of ground water and surface water also is a possible management alternative.

Cape Cod is one of the most scenic parts of Massachusetts, and has some of the best beaches in New England. In 1961, the Atlantic shore of the northern part of the Cape was designated a National Seashore Park, and the influx of tourists into this vacationland has since increased considerably. Detailed quantitative ground-water information has been collected, and a model analysis for the entire Cape has been completed.

NEW YORK

The boundary of the New England Region extends only about 10 mi (16 km) into southeastern New York, mostly in Dutchess County west of Connecticut but also much smaller areas in Putnam, Westchester, and Columbia Counties. These areas aggregate about 230 mi^2 (nearly 600 km^2). Ground-water coverage is at the general reconnaissance level. A detailed reconnaissance will probably be necessary, as development increases.

CONNECTICUT

Connecticut has an areas of 5,009 mi^2 (12,973 km^2), of which about 20 mi^2 (50 km^2), along the western boundary, lies in the adjacent Mid-Atlantic Region.

Most of the State is underlain by crystalline rocks, chiefly metamorphic. Along the western boundary, in the upper Housatonic River basin, there are areas of limestone, dolomite, and some marble. Extending from north to south, in the central part, lies the broad Connecticut Valley lowland, which is underlain by sandstone, shale, and interbedded basalt. The entire State was glaciated during the Ice Age, and glacial deposits overlie the bedrock nearly everywhere.

The sand and gravel deposits laid down during the waning phases of glaciation are the most productive aquifers. They consist of valley-train and other outwash deposits and ice-contact deposits, commonly in lowlands and valleys. Where they are near perennial streams, from which water can be induced by pumping wells, they are excellent aquifers.

Quantitative work in the State—and indeed in the United States as a whole—was pioneered by the classic study by Meinzer and Stearns (1929) in the Pomperaug basin, a tributary of the Housatonic River in western Connecticut. Another major early paper is that by Brown (1925) on coastal ground water, with special reference to Connecticut. Most of the other early reports covered the Connecticut Valley lowland and adjacent areas; they were based to a large extent on records of dug wells and springs.

As shown in figure 5, the entire State has been covered by detailed reconnaissance ground-water investigations; in addition, two areas, southeastern Connecticut and the Quinnipiac River basin (New Haven-Meriden area), are covered by detailed quantitative studies. These studies are products of the Federal-State cooperative program. Detailed quantitative studies of the entire State is the present goal.

More than two-thirds of Connecticut has not been studied quantitatively (fig. 6). The need for studying the northwestern and northeastern parts of the State in the immediate future is somewhat less urgent than it is elsewhere.

The Farmington River basin, tributary to the Connecticut River basin in northwest-central Connecticut, may warrant detailed quantitative ground-water study because its rapid urbanization has resulted in conflicting land-use practices. Also, anticipating continuing population growth and economic activity, quantitative information will probably be needed on the productive glacial sand and gravel deposits in the Connecticut River Valley. The valley of the Naugatuck River, a major tributary of the Housatonic River in west-central Connecticut, is becoming more and more industrialized and urbanized, and like the Farmington River basin, problems resulting from land use are becoming widespread. Quantitative ground-water information can help to assign realistic and potentially beneficial priorities toward specific developments.

Information is necessary also on topical problems not necessarily closely related to particular areas. Among these are (1) general statewide coverage of the chemical quality of ground water, (2) urban area pilot studies where ground water would be likely to play a major role, and (3) studies relating to land-use planning.

Comprehensive information may also be needed on the sedimentary bedrock in the Connecticut Valley. Although the bedrock is not as productive as the overlying glacial aquifers, it is a potentially valuable additional source of ground water about which not much is yet known. Detailed studies would determine its suitability for storage of gas or wastes—a use heretofore unexplored. Model studies of the relation between ground water and surface water in promising areas would be a valuable prerequisite to local conjunctive management of water.

RHODE ISLAND

Rhode Island covers an area of 1,214 mi² (3,144 km²), including Narragansett Bay. It is one of the most densely populated and highly industrialized States.

Most of Rhode Island is underlain by crystalline rocks of granitic composition. However, Narragansett Bay and surrounding land areas are underlain by consolidated sedimentary rocks, which grade from essentially unmetamorphosed in the north to highly metamorphosed in the south.

The bedrock is covered nearly everywhere by glacial deposits; these may be subdivided into till and stratified drift. Till covers the uplands and averages about 20 ft (6 m) thick; it is generally of low permeability. Stratified drift occupies the lowlands; it is commonly 50 to 100 ft (15 to 30 m) thick and is moderately to highly permeable.

Wells tapping till and crystalline bedrock typically yield 10 gal/min (⅔ L/s) or less and are generally adequate to supply individual homes. Yields of wells tapping unmetamorphosed sedimentary rocks in northern Rhode Island, in areas where the glacial deposits are thick, are somewhat greater; a small percentage of these yield 100 gal/min (6 L/s) or more, or enough to supply small commercial and industrial needs. The major aquifers consist of coarse-grained stratified drift, which is locally present in most of the major stream valleys; they are the source of all large industrial and municipal ground-water supplies. Yields of large-diameter wells in these deposits are commonly 500 gal/min (30 L/s) or more, and many will yield more than 1,000 gal/min (60 L/s).

The chemical quality of the ground water is generally good (Allen, 1953, p. 44–50). The dissolved-solids content is commonly less than 150 mg/L, and with the exception of iron and manganese, concentrations of individual mineral constituents are invariably well within the limits considered acceptable for drinking water by the U.S. Public Health Service. Undesirably high concentrations of manganese and, in a few instances, iron occur in water from a significant percentage of heavily pumped wells in stratified drift. The initial concentration of manganese in water from new wells is generally very low. In some wells concentration has increased gradually—generally over a period of years. It is suspected that local manganese enrichment of ground water is related to physiochemical changes in sand and gravel aquifers as a result of infiltration induced from nearby streams, especially where streamflow is heavily laden with organic waste matter (H. E. Johnston, oral commun., 1976).

Few other widespread problems of ground-water quality have been reported. Locally, however, the quality of ground water is being degraded by landfills, deicing salts applied to highways, agricultural fertilizers, and land deposition of sewage sludge.

Ground-water studies at the reconnaissance level were completed for the entire State between 1944 and 1964, and detailed quantitative investigations, begun in 1958, have been completed for most of the principal ground-water reservoirs. Results of these studies are described in more than 50 State and Federal publications. A list of publications through 1973 is available in pamphlet form from the U.S. Geological Survey offices in Boston, Mass., and Providence, R.I. Since 1973, results of a quantitative study of the Branch River basin in northern Rhode Island (Johnston and Dickerman, 1974b) have been published. In addition, a quantitative study and a basic-data report for the Blackstone River area, also in the northern part of the State, have been published (Johnston and Dickerman, 1974a and 1974c, respectively). (See fig. 7.)

A general reconnaissance of the entire State was made by Allen (1953), and 21 quadrangle studies have been published in a State Ground-Water Map series. The ground-water maps show, on 7½-minute quadrangle sheets, the distribution of outwash deposits (stratified drift) and till, geologic sections, contours on the water-table and bedrock surfaces, and locations of wells for which data are available. They include a brief description of the availability and quality of ground water.

Detailed reconnaissances have been completed for the Providence, Woonsocket, and Wallum Lake areas, in the northern part of the State; for Block Island, off the southern shore; and for 6 of 27 quadrangle study areas. Results of these studies are published in a State Geological Bulletin series. These reports include detailed description of ground-water conditions, as well as basic data and maps; the latter provide information similar to that given in the State Ground-Water Map series.

The need for quantitative information was appraised by Lang (1961), who subdivided the State into 17 proposed study areas. Intensive quantitative studies of several of these areas have since been made, especially where economic development was extensive or potentially so. These studies assess the ground water available for development in areas containing thick stratified drift and show by a model the magnitude of yields theoretically obtainable from selected arrays of wells. Maps of the water table, aquifer thickness, and

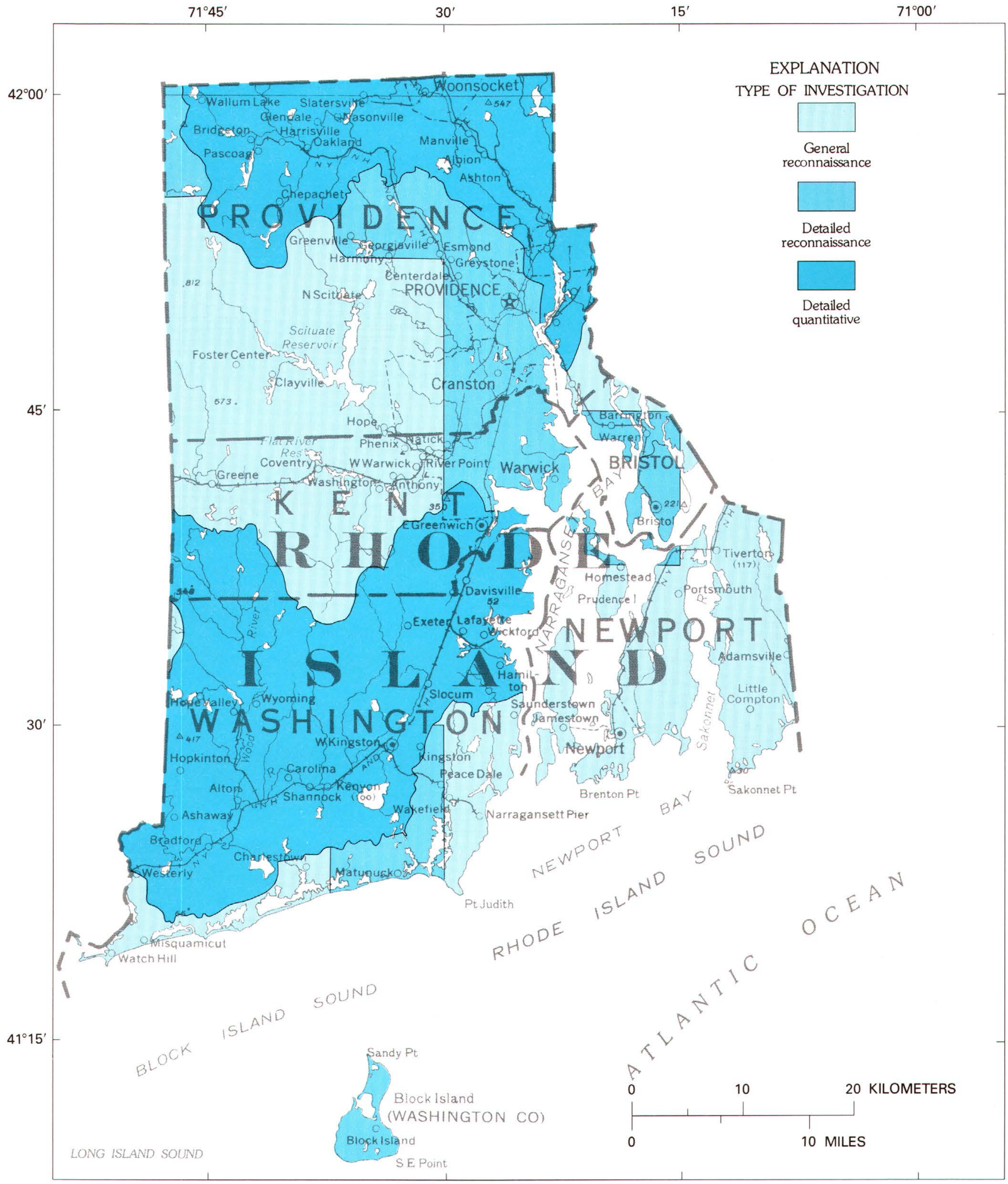

FIGURE 7.—Map showing areas of ground-water investigations in Rhode Island.

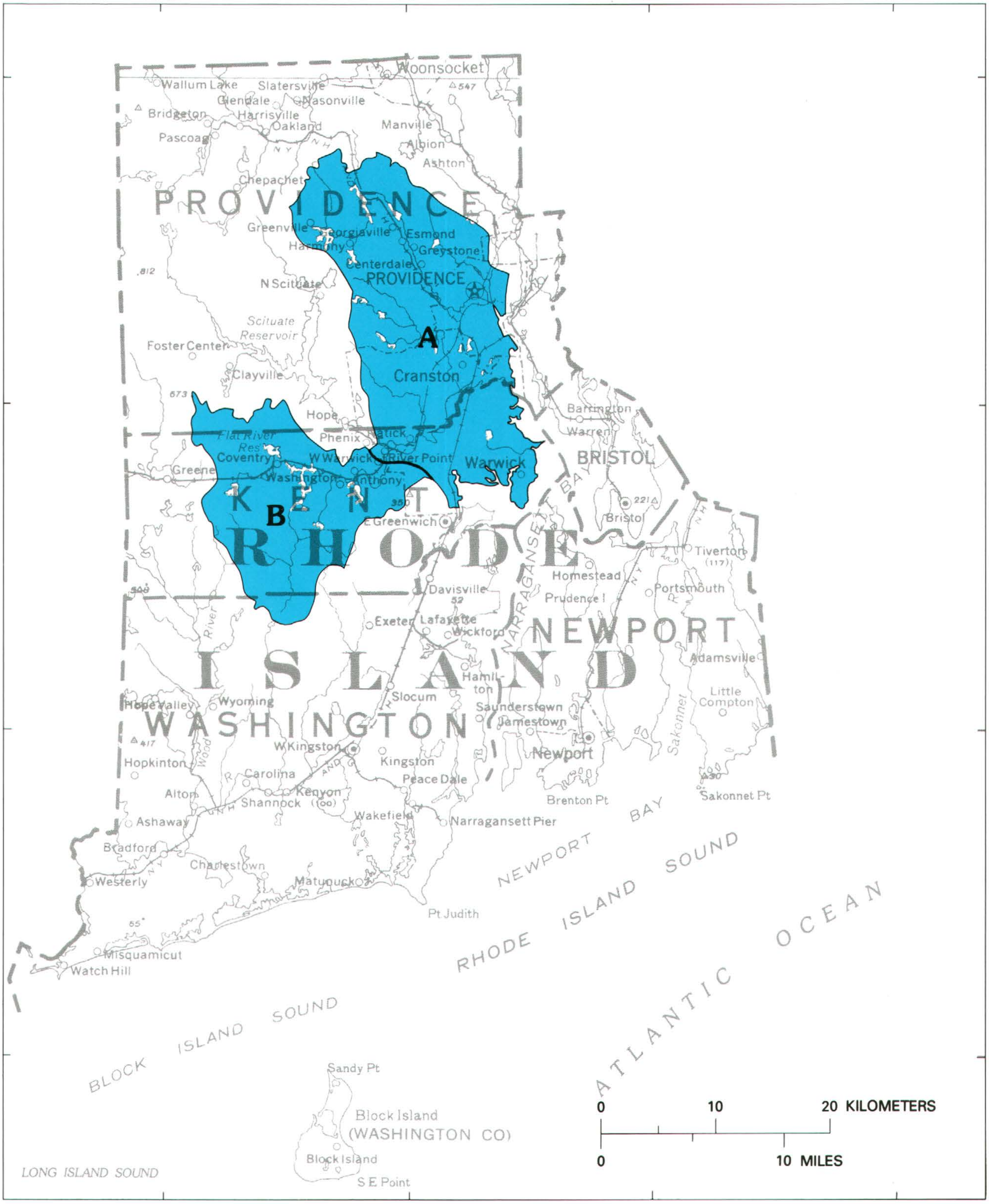

FIGURE 8.—Map showing areas in Rhode Island where quantitative ground-water information may be needed. A, Providence-Warwick area; B, South branch Pawtuxet River basin area.

aquifer permeability (or transmissivity) obtained during the studies provide information necessary for constructing digital or analog models of the ground-water system.

The Rhode Island Water Resources Board is currently (1981) engaged in an extensive exploratory drilling and aquifer-test program in the Pawcatuck River basin in southern Rhode Island. Its purpose is to locate sites favorable for developing large supplies of ground water. The most favorable will be developed as future demands dictate. The program resulted from a long-range plan to provide for orderly development and management of the State's water resources. The U.S. Geological Survey is assisting in the collection and analysis of data and will provide a management model of the stream-aquifer system in the Pawcatuck River basin. Digital and analog models of the stream-aquifer system in several subbasins are being constructed by the University of Rhode Island.

Quantitative ground-water information may be necessary in two additional areas in northern and central Rhode Island. (See fig. 8.) The Providence-Warwick area (A, fig. 8), which includes the most densely populated and highly industrialized parts of the State, is underlain by more than 50 mi^2 (130 km^2) of stratified drift. This drift, which is more than 50 ft (15 m) thick in more than half the area and locally more than 200 ft (60 m) thick, constitutes the largest ground-water reservoir in the State. The drift has yielded as much as 8 million gal/d (30,000 m^3/d) (Lang, 1961, p. 13) and may be capable of yielding more than 20 million gal/d (75,000 m^3/d). Parts of the drift deposits are in hydraulic continuity with Narragansett Bay and its brackish estuaries. Consequently, optimum development will require judicious location of pumping centers and careful management of withdrawal to prevent invasion by salt water. Development schemes and subsequent management of the reservoir can be effectively appraised by analog or digital models.

Quantitative ground-water information in the South Branch Pawtuxet River basin area would also be helpful (B, fig. 8). The northeastern part of the area is underlain by stratified drift as thick as 100 ft (30 m). Wells tapping this drift have an aggregate pumping capacity of about 3 million gal/d (11,000 m^3/d), and an additional 3 million gal/d (11,000 m^3/d) can possibly be developed (New England River Basin Commission, 1975). Excessive ground-water withdrawal may deplete low streamflows and lower pond levels. These adverse effects may be aggravated by regulation after the Big River reservoir in the headwaters of the southern part of the area is constructed. Conjunctive operation of the ground-water and surface-water reservoirs, so as to minimize stream depletion and lowering of pond levels, will require quantitative studies of the ground-water reservoir and its interaction with overlying water bodies.

CONCLUSIONS

New England is favored by an abundance of water—both surface water and ground water. It is also a region of increasing economic activity and population growth. Inevitably, additional supplies of water will be needed, not only for domestic use but also for public supplies and to meet industrial needs. Management of the water resources will require more and more ground water.

Advantages of using ground water are several: (1) In favorable areas it is available near the point of need, obviating the need for pipelines and storage reservoirs. (2) The temperature of ground water is nearly constant—roughly the same as the average air temperature. (3) Although it has higher concentrations of dissolved solids than surface water, these concentrations are relatively stable, facilitating planning and maintenance for many industrial and public supplies. (4) It is less likely to be contaminated than surface water, provided that well equipment has been properly installed; thus, it is especially desirable for personnel in industry and for public supplies. (5) Its storage volume is great—vastly more than the volume of fresh surface water and thus less likely to be affected by prolonged droughts.

These and other factors make ground water particularly attractive for various management options.

Maine, New Hampshire, and Vermont have relatively small populations. The trend, however, is growth. New Hampshire, where the population is expected to quadruple by early in the 21st century, is likely to grow most. Ground water will doubtless be important in the future development of that State.

Coastal Maine, particularly in the south, is expected also to grow considerably. Vermont, on the other hand, will probably remain more rural and much less industrialized and will continue to depend largely on tourism and recreation. Much smaller quantities of water will, therefore, be needed. The use of ground water in Vermont is high in relation to total water use; although the volume used is small, this relation is expected to continue.

Massachusetts, Connecticut, and Rhode Island are much more densely populated, urbanized, and industrialized than the northern three States. Here, the importance of ground water is already manifest. General investigations have been made to date, and more detailed ones are planned by various agencies.

The humid climate of the New England Region assures abundant supplies of water. The most pervasive problem relating to ground water, however, is the threat of local deterioration of its chemical quality. Curtailment and control of the many actual and potential sources of contamination—highway salting, landfills, and other land-use practices—are major goals for water-management programs.

Increasing awareness of environmental concerns in recent years encourages the view that generally satisfactory management of ground-water quality and contamination control will eventually be achieved. Ground water will very likely continue to play an increasingly important part in the economy of the New England Region and warrants continuing study geared to anticipated needs.

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