NATIONAL WATER-QUALITY ASSESSMENT PROGRAM

Water-Quality Assessment of the New England Coastal Basins in Maine, Massachusetts, New Hampshire, and Rhode Island: Environmental Settings and Implications for Water Quality and Aquatic Biota

Water-Resources Investigations Report 98-4249

U.S. Department of the Interior
U.S. Geological Survey

Cover photograph is a panoramic view of the Merrimack River and the Amoskeag Mills in Manchester, New Hampshire, looking south from the west side of the river, circa 1883. Photograph is courtesy of the Manchester (N.H.) Historic Association.

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By Sarah M. Flanagan, Martha G. Nielsen, Keith W. Robinson, and James F. Coles

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Pembroke, New Hampshire
1999

U.S. DEPARTMENT OF THE INTERIOR
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FOREWORD

The mission of the U.S. Geological Survey (USGS) is to assess the quantity and quality of the earth resources of the Nation and to provide information that will assist resource managers and policymakers at Federal, State, and local levels in making sound decisions. Assessment of water-quality conditions and trends is an important part of this overall mission.

One of the greatest challenges faced by water-resources scientists is acquiring reliable information that will guide the use and protection of the Nation's water resources. That challenge is being addressed by Federal, State, interstate, and local water-resource agencies and by many academic institutions. These organizations are collecting water-quality data for a host of purposes that include: compliance with permits and water-supply standards; development of remediation plans for specific contamination problems; operational decisions on industrial, wastewater, or water-supply facilities; and research on factors that affect water quality. An additional need for water-quality information is to provide a basis on which regional- and national-level policy decisions can be based. Wise decisions must be based on sound information. As a society we need to know whether certain types of water-quality problems are isolated or ubiquitous, whether there are significant differences in conditions among regions, whether the conditions are changing over time, and why these conditions change from place to place and over time. The information can be used to help determine the efficacy of existing water-quality policies and to help analysts determine the need for and likely consequences of new policies.

To address these needs, the U.S. Congress appropriated funds in 1986 for the USGS to begin a pilot program in seven project areas to develop and refine the National Water-Quality Assessment (NAWQA) Program. In 1991, the USGS began full implementation of the program. The NAWQA Program builds upon an existing base of water-quality studies of the USGS, as well as those of other Federal, State, and local agencies. The objectives of the NAWQA Program are to:

- Describe current water-quality conditions for a large part of the Nation's freshwater streams, rivers, and aquifers.
- Describe how water quality is changing over time.
- Improve understanding of the primary natural and human factors that affect water-quality conditions.

This information will help support the development and evaluation of management, regulatory, and monitoring decisions by other Federal, State, and local agencies to protect, use, and enhance water resources.

The goals of the NAWQA Program are being achieved through ongoing and proposed investigations of 50 of the Nation's most important river basins and aquifer systems, which are referred to as study units. These study units are distributed throughout the Nation and cover a diversity of hydrogeologic settings. More than two-thirds of the Nation's freshwater use occurs within the 60 study units and more than two-thirds of the people served by public water-supply systems live within their boundaries.

National synthesis of data analysis, based on aggregation of comparable information obtained from the study units, is a major component of the program. This effort focuses on selected water-quality topics using nationally consistent information. Comparative studies will explain differences and similarities in observed water-quality conditions among study areas and will identify changes and trends and their causes. The first topics addressed by the national synthesis are pesticides, nutrients, volatile organic compounds, and aquatic biology. Discussions on these and other water-quality topics will be published in periodic summaries of the quality of the Nation's ground and surface water as the information becomes available.

This report is an element of the comprehensive body of information developed as part of the NAWQA Program. The program depends heavily on the advice, cooperation, and information from many Federal, State, interstate, Tribal, and local agencies and the public. The assistance and suggestions of all are greatly appreciated.

Robert M. Hirsch
Chief Hydrologist

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CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATIONS

Multiply metric unit	By	To obtain inch-pound unit
	Length	
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
acre	0.4047	hectare (ha)
square mile (mi^2)	2.590	square kilometer
	Velocity and Flow	
foot per second (ft/s)	0.3048	meter per second
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
gallon per minute (gal/min)	0.06309	liter per second
million gallons per day (Mgal/d)	0.04381	cubic meter per second
	Temperature	
degree Fahrenheit (°F)	°C = 5/9 x (°F-32)	degree Celsius °C
	Hydraulic Conductivity	
foot per day (ft/d)	0.3048	meter per day
	Transmissivity	
foot squared per day (ft^2/d)	0.09290	meter squared per day

In this report, chemical concentration in water is expressed as International Systems Units, in milligrams per liter (mg/L) or micrograms per liter (µg/L). Milligrams per liter is a unit expressing the concentration of chemical constituents in solution as weight (milligrams) of solute per unit volume (liter) of water; 1,000 µg/L is equivalent to 1 mg/L.

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

Abbreviations: Abbreviated units used in this report that are not identified in the conversion table include:

lbs/ac	pounds per acre
µeq/L	microequivalents per liter
ft/mi	foot per mile
ft^3/s	cubic foot per second
in/yr	inches per year
km	kilometer
in/mo	inches per month
lbs	pounds
µS/cm	microsiemens per centimeter
kg	kilograms
$lb/d/mi^2$	pounds per day per square mile
µg/g	micrograms per gram

Water-Quality Assessment of the New England Coastal Basins in Maine, Massachusetts, New Hampshire, and Rhode Island: Environmental Settings and Implications for Water Quality and Aquatic Biota

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Abstract

The New England Coastal Basins in Maine, Massachusetts, New Hampshire, and Rhode Island constitute one of 59 study units selected for water-quality assessment as part of the U.S. Geological Survey's National Water-Quality Assessment (NAWQA) program. The New England Coastal Basins study unit encompasses the fresh surface waters and ground waters in a 23,000 square-mile area that drains to the Atlantic Ocean. Major basins include those of the Kennebec, Androscoggin, Saco, Merrimack, Charles, Blackstone, Taunton, and Pawcatuck Rivers. Defining the environmental setting of the study unit is the first step in designing and conducting a multi-disciplinary regional water-quality assessment. The report describes the natural and human factors that affect water quality in the basins and includes descriptions of the physiography, climate, geology, soils, surface- and ground-water hydrology, land use, and the aquatic ecosystem.

Although surface-water quality has greatly improved over the past 30 years as a result of improved wastewater treatment at municipal and industrial wastewater facilities, a number of water-quality problems remain. Industrial and municipal wastewater discharges, combined sewer overflows, hydrologic modifications from dams and water diversions, and runoff from urban land use are the major causes of water-quality degradation in 1998. The most frequently detected contaminants in ground water in the study area are volatile organic compounds, petroleum-related products, nitrates, and chloride and sodium. Sources of these contaminants include leaking storage tanks, accidental spills, landfills, road salting, and septic systems and lagoons. Elevated concentrations of mercury are found in fish tissue from streams and lakes throughout the study area.

INTRODUCTION

The National Water-Quality Assessment (NAWQA) program of the U.S. Geological Survey (USGS), is designed to assess the status and trends in the quality of the Nation's ground- and surface-water resources and aquatic biological communities, and to develop an understanding of the major factors that affect water-quality conditions (Hirsch and others, 1988; Leahy and others, 1990). Investigations of water quality in more than 50 major hydrologic basins and aquifer systems, referred to as NAWQA study units, form the building blocks of the program. The NAWQA study units include 60 to 70 percent of the Nation's water use and population served by public-water supplies (Leahy and Wilber, 1991). The first group of 20 study-unit investigations as part of the NAWQA program began in 1991. A second group of 16 study-unit investigations was initiated in 1994; and a third group of 12 investigations began in 1997. This last group includes the New England Coastal Basins study unit.

The New England Coastal Basins study unit (referred to as the study area in the remainder of the report) encompasses 23,000 mi^2 in western and central Maine, central and eastern New Hampshire, eastern Massachusetts, most of Rhode Island, and a very small part of Connecticut (fig. 1). The major islands of Martha's Vineyard, Nantucket Island, and Block Island are also part of the study area. The study area includes the drainage basins of the Kennebec, Androscoggin, Saco, Merrimack, Charles, Blackstone, Taunton, and Pawcatuck Rivers, as well as small coastal drainage basins between these major river basins. Almost two-thirds of New Hampshire is in the study area, as well as a third of Maine, half of Massachusetts, and 95 percent of Rhode Island (fig. 1). In addition, a very small part (1.1 percent) of Connecticut in New London and Windham Counties is in the study area. Every county in New Hampshire and Rhode Island lies either entirely or partly within the study area. In Maine, the study area includes all of five counties (Franklin, Oxford, York, Cumberland, and Androscoggin) and parts of seven more (Somerset, Piscataquis, Penobscot, Waldo, Kennebec, Lincoln, and Sagadahoc). In Massachusetts, the study area includes all of Barnstable, Bristol, Norfolk, Suffolk, Plymouth, Dukes, and Nantucket Counties and parts of Worcester, Middlesex, and Essex Counties (fig. 1).

The quality of surface and ground waters in the New England Coastal Basins study area will be assessed intensely by the USGS for 6-7 years. Assessment activities will include a review of existing water-quality information, collection and analysis of water-quality and aquatic organism samples, and preparation of reports and other summaries describing the results of work performed (Ayotte and Robinson, 1997).

Purpose and Scope

This report describes the environmental setting of the New England Coastal Basins study area, including its physical and cultural characteristics. The influence of the environmental setting on water quality will also be discussed. The description of the environmental setting will be based primarily on a review of existing reports, research, and data.

Information presented in this report will serve as the basis for the design of a water-quality monitoring and assessment program of the study area. This water-quality monitoring and assessment program will attempt to define how these environmental settings influence ground- and surface-water quality and aquatic ecology.

Acknowledgments

The authors gratefully acknowledge the assistance provided by members of the Liaison Committee of the New England Coastal Basins study area, and the organizations they represent, for the data and information provided during the preparation and review of this report. The authors would like to recognize Marc Loiselle and Thomas Weddle of the Maine Geological Survey for providing information and guidance on bedrock and surficial geology, and Amy Rolfs, a U.S. Geological Survey intern, for her contributions to the report. Robert Rourke, University of Maine at Orono, and Steve Hundley, U.S. Department of Agriculture, provided data on soil chemistry in Maine and New Hampshire, respectively. James Omernik, U.S. Environmental Protection Agency, provided data on ecoregions, total alkalinity in streams and lakes, and the 22 District Conservationists of the U.S. Department of Agriculture Natural Resources Conservation Service provided information on agricultural activities.

ENVIRONMENTAL SETTING

An understanding of the physical and cultural characteristics, termed the environmental setting, of the study area is required to develop a monitoring strategy that will effectively determine how water quality varies throughout the study area, and which natural and human factors affect water quality. The physical and cultural characteristics include a basic understanding of the climate, geology, soils, surface- and ground-water hydrography, terrestrial and aquatic ecology, and human settlement and industry.

Physiography

Physiography represents the topographic expression of the land surface. The study area is divided into two provinces, the New England Physiographic Province and the Atlantic Coastal Plain Province (Fenneman, 1938). The New England Physiographic Province is further divided into three major sections, the White Mountains, the New England Uplands, and the Seaboard Lowlands (fig. 2). These physiographic sections are divided into broad bands that roughly parallel the coast. The islands on the southern end of the study area belong to the Atlantic Coastal Plain Province, which continues primarily further south along the Atlantic seaboard.

The White Mountains section, delineated where mountains dominate the landscape, is roughly bounded by the 1,500-ft elevation contour. Topographic relief is as much as 3,500 ft locally in the White Mountains of New Hampshire, although in the bulk of the White Mountains physiographic section, elevations generally rise only 500-1,500 ft above the local landscape. Mount Washington (elevation of 6,288 ft) in the White Mountains is the highest point in the study area (fig. 2). Rivers in the section generally radiate outward from hills and mountains in a somewhat dendritic drainage pattern (Fenneman, 1938).

Fenneman (1938, p. 358) described the New England Upland section as "an upraised peneplain bearing occasional monadnocks and dissected by narrow valleys." It is an area of undulating hilly topography, ranging in elevation from below 1,000 ft to above 2,000 ft. Streams run in well-graded and rounded valleys. Local relief ranges from a few hundred feet to 1,000 ft at the larger mountains in the section.

The Seaboard Lowlands section is lower in elevation and less hilly than the New England Upland section. The boundary between these two sections is between 400 and 500 ft in elevation in most places (Fenneman, 1938). Fenneman considered the Seaboard Lowlands as the sloping margin of the uplands, although it also roughly coincides with the area inundated by the ocean and areas of large proglacial lakes during the last glacial retreat (Stone and Borns, 1986). Topographic relief is limited to less than approximately 200 ft in most places. Small streams and rivers generally flow towards the coast along the land-surface slope.

Climate

The climate in the study area is continental due to prevailing westerly winds and is characterized by changeable weather, wide ranges in diurnal and annual temperatures, distinct seasonal trends that vary from year to year, and equable distribution of precipitation throughout the year. Important local influences on the climate are terrain, elevation, and proximity to the Atlantic Ocean. These influences combine to create three climatic divisions: the Northern Division, the Central Division, and the Coastal Division (U.S. Department of Commerce, 1977, 1982a, 1982b, and 1982c) (fig. 3).

The Northern Division contains parts of New Hampshire and Maine and encompasses the highest mountains and terrains of greatest relief. The climate is mainly influenced by weather systems originating from the west and north. Local influences, such as high elevation and latitude, also have a pronounced effect on the climate. The Central Division includes over 50 percent of the study area, covering parts of Maine, New Hampshire, Massachusetts, and Rhode Island. Because it is low in elevation and latitude, the climate is more moderate than the Northern Division. The Central Division does experience slight climate modification from maritime influences. The Coastal Division comprises a narrow strip of land immediately adjacent to the coast and covers areas of Maine, New Hampshire, Massachusetts, and Rhode Island. The climate is strongly influenced by its proximity to the Atlantic Ocean and its low elevations.

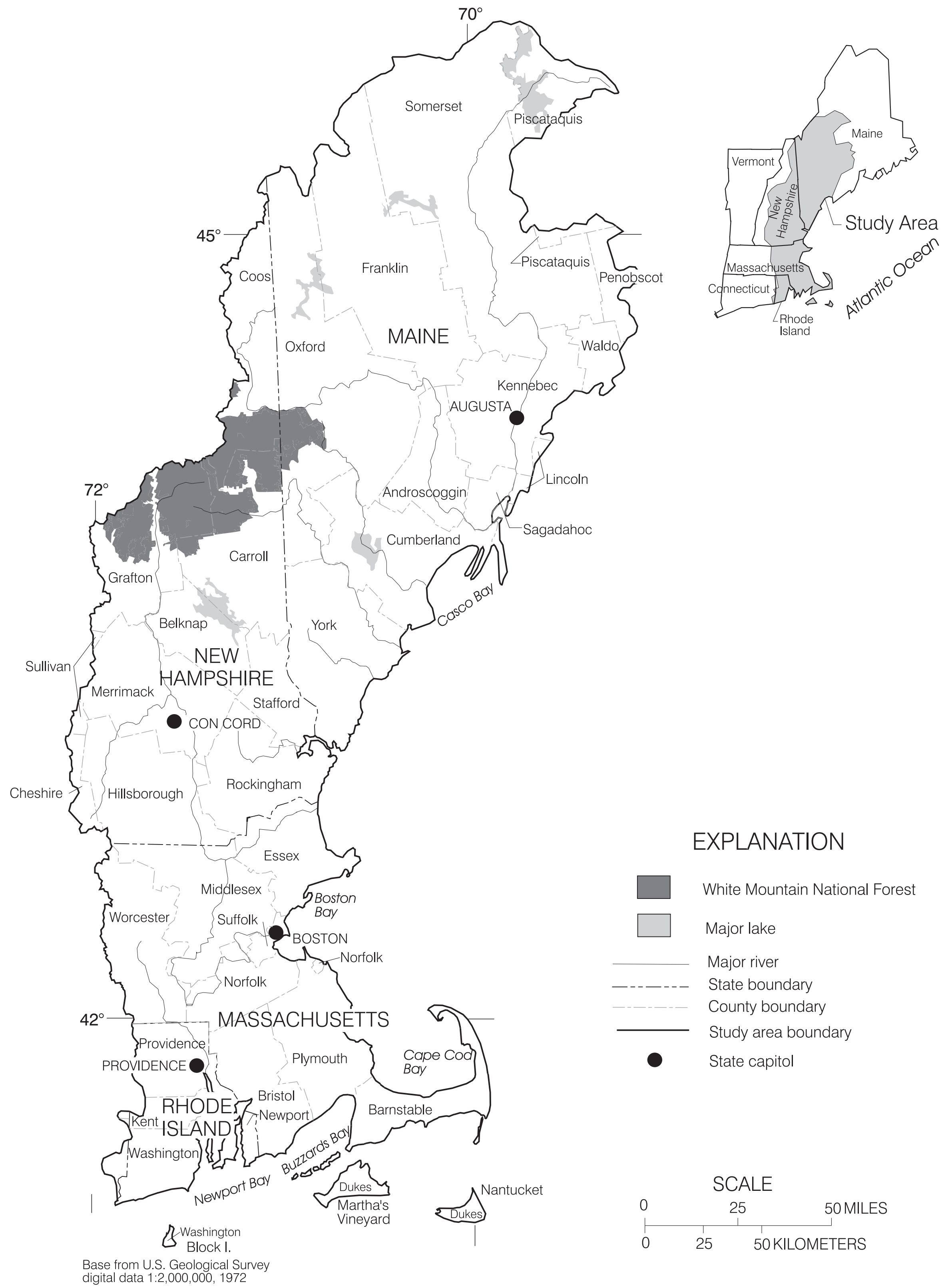


Figure 1. Location of the New England Coastal Basins study area in Maine, Massachusetts, New Hampshire, and Rhode Island.

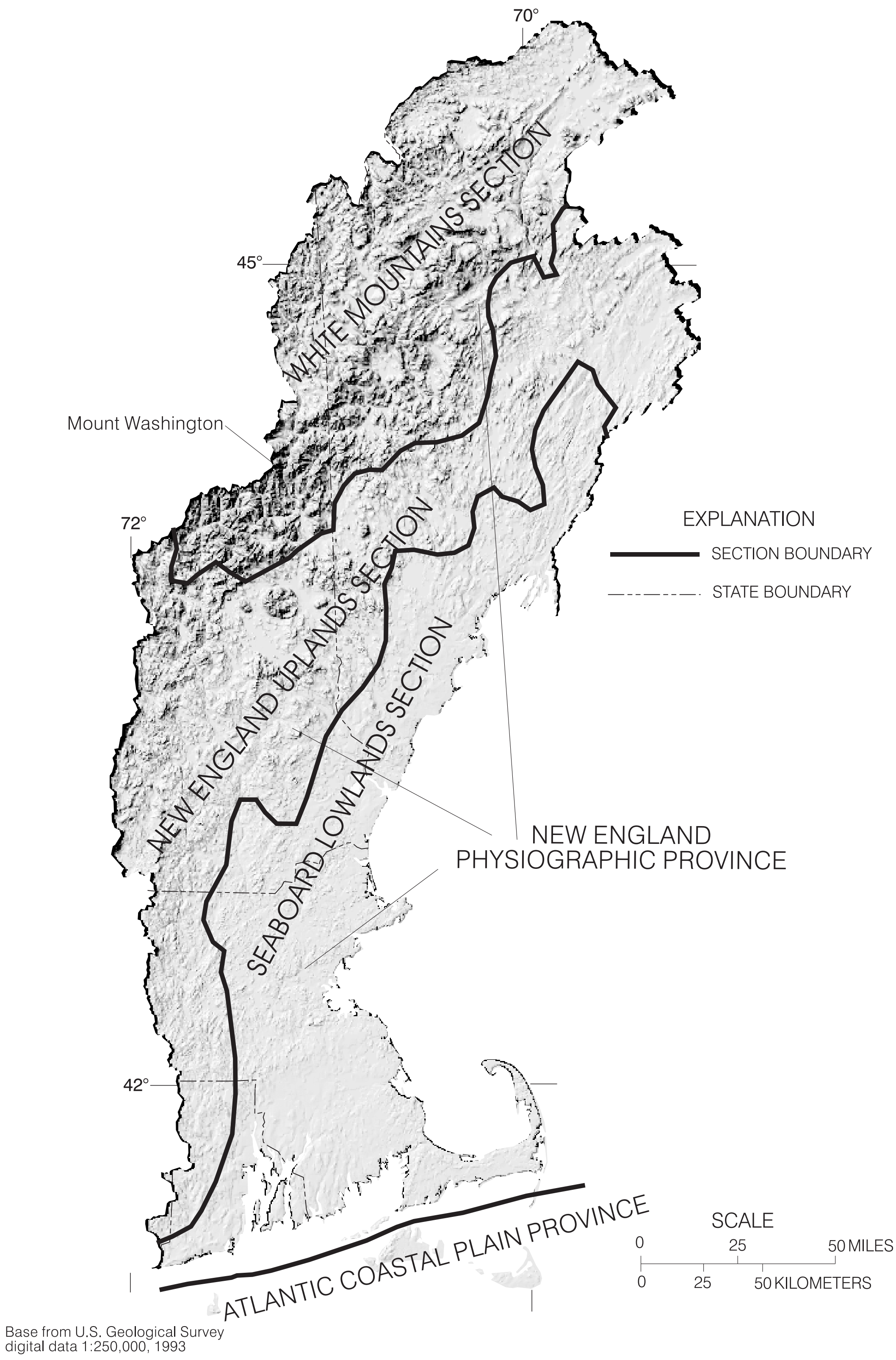


Figure 2. Physiographic regions of the New England Coastal Basins study area.

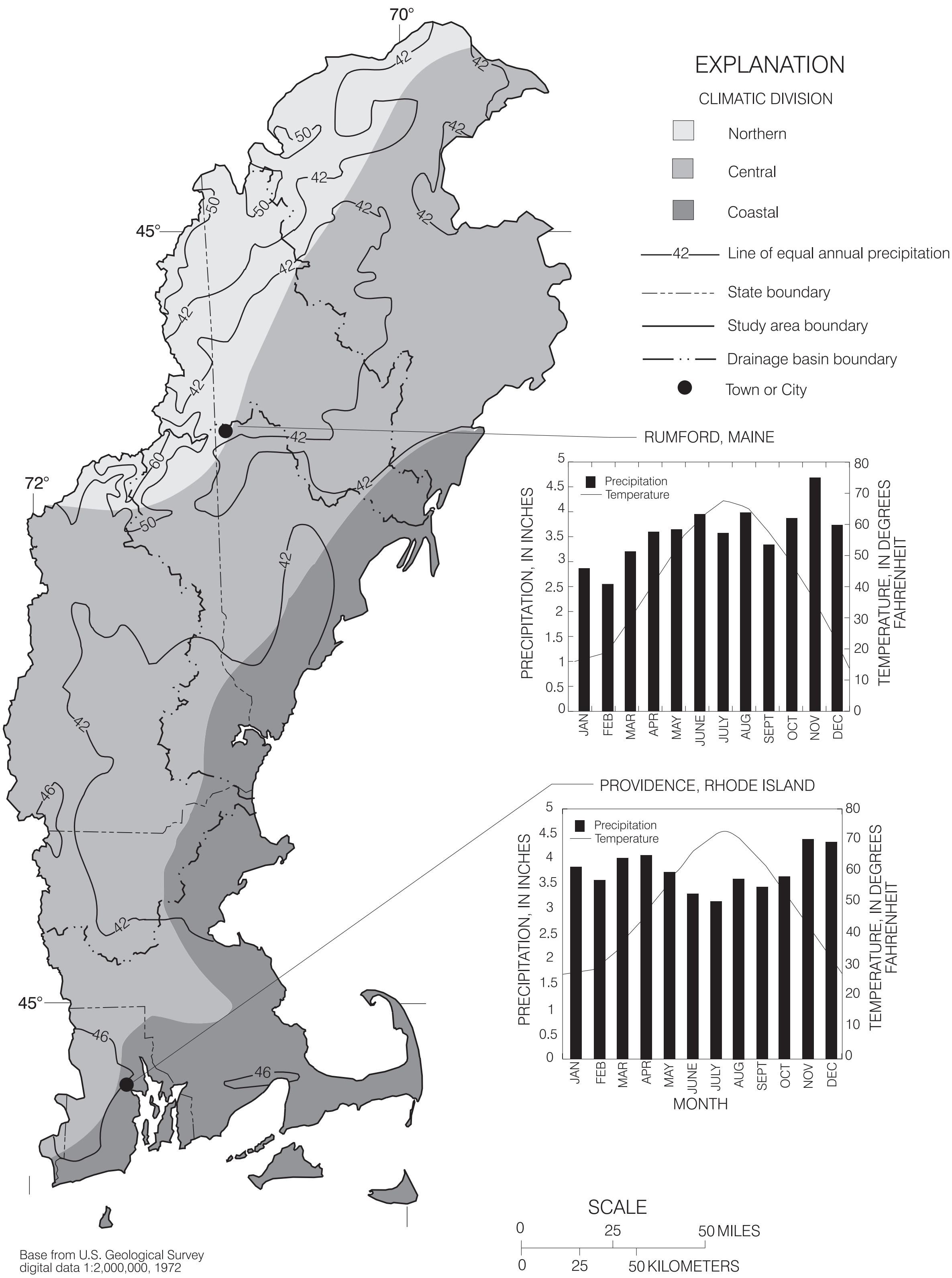


Figure 3. Mean monthly precipitation and air temperature at selected stations, annual precipitation, and climatic divisions in the New England Coastal Basins study area, 1961-1990.

Precipitation is evenly distributed throughout the year, yet there is variation in the average annual amount of precipitation that falls at locations within the study area (fig. 3). This variation is due in part to the effects of terrain, elevation, and proximity to the ocean. The average amount of precipitation the study area receives is 40-50 in/yr (U.S. Department of Commerce, 1977, 1982a, 1982b, and 1982c); however, average annual precipitation ranges from 42 in/yr in low-lying areas to greater than 60 in/yr near the summits of the White Mountains (Knox and Nordenson, 1955) (fig. 3). Frontal systems and coastal storms are additional sources of precipitation in the Coastal Division, compared to the Central and Northern Divisions, where summer showers and thunderstorms supply more of the precipitation.

The amount of frozen precipitation is dependent upon elevation, terrain, and latitude. Snowfall amounts are generally greatest in January or February. The Coastal Division typically averages 20-50 in/yr of snow or sleet compared to 30-70 in/yr in the Central Division, and 50-110 in/yr in the Northern Division. The Northern Division is typically covered with a layer of snow for approximately 3-4 months, usually melting by April. The snowmelt is a major source of water in streams during late winter and early spring. Approximately one-half to two-thirds of the precipitation becomes runoff in a river or stream.

Temperatures vary widely on an annual basis. Temperature data taken from nine weather observatories in the study area, from 1961 to 1990, indicate that the warmest month in the study area is July and the coldest month January. Average temperature for July at these sites was 70.3°F and average temperature for January was 23.5°F (Northeast Regional Climate Center, written commun., 1996). Winter temperatures are more variable across the study area than summer temperatures based on monthly average temperatures. For example, average temperatures in July during 1961-90 ranged from 68.0°F at Rumford, Maine, to 72.7°F at Providence, Rhode Island, whereas the average temperature in January during the same period ranged from 16.5°F at Rumford to 27.9°F at Providence (fig. 3). The growing season ranges from 140-200 days in the Coastal Division to 90-140 days in the Northern Division (U.S. Department of Commerce, 1977, 1982a, 1982b, and 1982c).

Evapotranspiration is most pronounced in the summer and early fall period and results in a reduction of total runoff (Gay and Delaney, 1980). Evapotranspiration has a minor effect on runoff during the late fall and winter because of the loss of deciduous leaves (Likens and Bormann, 1995). On a year-to-year basis, evapotranspiration remains fairly constant (Likens and Bormann, 1995). Approximately 51 percent, or 23.2 in., of the annual inflow in the Charles River Basin at Waltham, Massachusetts, is removed by means of evapotranspiration (Myette and Simcox, 1992).

Geology

Geology has a major influence on the natural quality of surface and ground waters. The geochemistry of the various rocks and sediments is determined by the original chemical composition of the parent material and by previous geologic activity leading to their emplacement or deposition. Geochemistry of the bedrock and surficial materials plays a large role in determining concentrations of naturally-occurring substances that are dissolved in the water. In addition, the stratigraphy of the surficial sediments determines the occurrence of significant ground-water aquifers and influences the interaction between ground and surface waters.

Bedrock

Bedrock geology records a wide variety of complex geologic processes—sedimentation, deformation, metamorphism, igneous activity, and erosion. Several hundred different geologic formations have been identified in the study area, each distinguished by rock type and age. Rocks of similar age and genesis are found throughout the study area. The bedrock is generally layered and complexly deformed. Structures and contacts generally trend northeast to southwest, perpendicular to the direction of collision during the Acadian Orogeny (Marvinney and Thompson, in press). The mineralogy of the bedrock units is highly varied, from pure quartz in quartzite formations to thin layers of calc-silicate rocks, large bodies of shist with various mineral assemblages (often with high iron and manganese concentrations), and metavolcanics with high base-cation concentrations.

The oldest rocks in the study unit are of PreCambrian age. Plutonic, metaplutonic, metavolcanic, and metasedimentary rocks comprise most of the units mapped as "pC" and "pCO" on figure 4. Volcanic and sedimentary rocks of the Boston Basin (unit pCs) are of similar age. Many of these rocks were formed during an arc-margin and volcanic-arc accumulation phase, followed by sediment deposition and mafic volcanism in an extensional regime (Goldsmith, 1991a). Rocks in northwestern Maine (the northwestern most part of unit pCO), known as the Chain Lakes Massif, are highly metamorphosed sedimentary and volcanic rocks that are PreCambrian or Cambrian in age (Marvinney and Thompson, in press).

Layered volcanic and sedimentary rocks, later metamorphosed, in the northern and western part of the study unit (narrow band of unit pCO just south of the Chain Lakes Massif) were added onto the North American continent during the Taconic Orogeny of Middle Ordovician time. In Massachusetts, rocks of the same age are also mapped as unit pCO. These rocks consist of gneiss and schist with minor marble and amphibolite and were metamorphosed from sediments derived from volcanic activity interlayered with volcanic rocks and limy marine sediments (Goldsmith, 1991b).

Mudstones, sandstones, limestones, and some volcanic rocks formed during the Silurian (with some occurring later, in the Early Devonian) originally were deposited at the margins of the North American and combined European/African continents (Marvinney and Thompson, in press; Boudette, 1990). Metamorphic grade of these rocks ranges from chlorite-biotite slate to feldspar-quartz-mica migmatite. Later in the Silurian, deposition continued to occur within an oceanic basin, which separated North America from what is thought to be the combined European/African plate. The resultant rocks, mapped as unit S, consist of metamorphic rocks whose protoliths were sediments deposited during Silurian to Early Devonian time in a continental margin basin. The rocks in central New Hampshire through central Maine represent a depositional trough that was filled during Silurian time with several kilometers of carbonates, volcanic rocks, and clastic sediments derived from the North American continent to the west. These sediments were subsequently overlain by turbidite deposits and volcanics derived form the European continent to the east during early Devonian time (unit DS in Maine and New Hampshire, Marvinney and Thompson, in press). They were then repeatedly deformed and metamorphosed during the Acadian Orogeny.

Rocks mapped as unit KO are intrusive igneous rocks, many of which were repositioned during each phase of tectonic activity from the Ordovician to the Devonian. Most of these rocks in Maine and Rhode Island are granitic (Marvinney and Thompson, in press; Hermes and others, 1994). In New Hampshire and Massachusetts, the intrusive rocks consist of granites, gabbros, syenites, and granodiorites (Boudette, 1990; Zen and others, 1983).

Undeformed clastic sedimentary and minor volcanic rocks in southeastern Massachusetts and Rhode Island (unit Ps) were deposited during Pennsylvanian time in a continental basin, before rifting opened up the Atlantic Ocean during Triassic and Jurassic time (Goldsmith, 1991a). This rifting, which occurred outside the study area, is associated with extensive faulting and the formation of many igneous plutons of Jurassic, Triassic, and Cretaceous age in New Hampshire and Maine (also mapped as unit KO).

Surficial Deposits

Glaciation has shaped the landscape of eastern North America during several major glacial periods. As glaciers flowed across the landscape, they scraped and smoothed down the land surface. As glaciers retreated from the landscape during deglaciation, they created lakes and altered the course of rivers. Debris scraped off the land surface was carried by the ice and deposited as sand, gravel, and other unconsolidated sediments across the landscape. Some of the sediments were deposited by the ice directly, and the rest were carried by meltwater streams and deposited in the sea or elsewhere on land. Most of the surficial sediments found across New England are a result of glaciation.

The most recent glacial period, called the Late Wisconsin, began approximately 25,000 years ago (Stone and Borns, 1986). During this glaciation, the ice sheet advanced from Canada southward and southeastward across New England. As a result, the glacial deposits and landforms generally have northwest-southeast orientations, in contrast to the northeast-southwest grain of the underlying bedrock (Smith and Hunter, 1989). During the Late Wisconsin glaciation, the maximum extent of the ice front was at the continental shelf offshore of Maine, New Hampshire, Massachusetts, and Rhode Island. As the climate warmed, retreat of the ice margin began between 15,000 and 17,000 years ago (Smith and

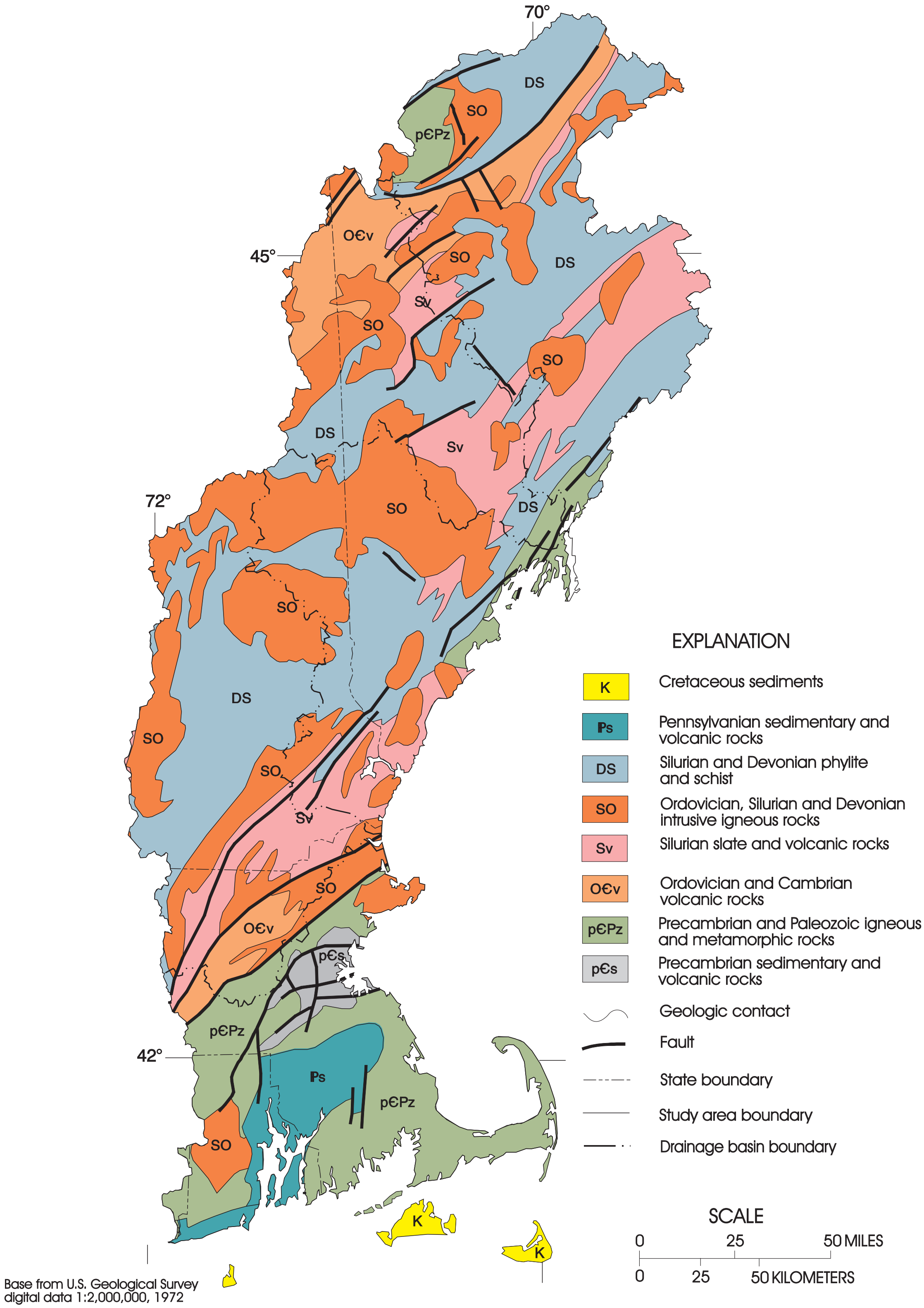


Figure 4. Generalized bedrock geology of the New England Coastal Basins study area. [Modified from King and Beikman, 1974; Lyons and others, 1997; Zen and others, 1983; Osberg and others, 1985; and Hermes and others, 1994.]

Hunter, 1989). By approximately 12,000 years ago, the land was exposed across New England (Borns, 1989; Smith and Hunter, 1989). The total loss of relief during the last glaciation was less than 200 ft according to Boudette (1990).

Glacial erosion of the land surface continued throughout the glacial period, but it is primarily during deglaciation that great quantities of glacial sediments were deposited on the land surface. The deposits found across the New England landscape record the timing and mode of deglaciation in each location, as well as depositional processes associated with deglaciation, such as the formation and filling of glacial-meltwater lakes (Koteff and Pessl, 1981). Many of these deposits form the stratified-drift aquifers that are important water sources for communities and industries throughout the study area.

Along coastal New England north of Boston, Mass., isostatic depression of the crust of the Earth (due to the weight of the glaciers) allowed the sea to transgress inland and the ice withdrew (melted) in contact with sea water. Sediments released from the melting glacier were then deposited in a marine environment. Seaward (southeast) of the maximum incursion of the sea (shown as the marine limit on fig. 5a), subglacial streams carried sediment to the ice front, and coarse-grained sediments were deposited near the retreating ice in deltas, debris flows, and by subglacial meltout directly from the ice. Fine-grained sediments that were not deposited at the ice front were carried by currents away from the ice to settle out as marine clay layers in quiet seawater (Smith and Hunter, 1989) (fig. 5a). The marine clay, also known as the Presumpscot Formation in Maine and New Hampshire (Bloom, 1960), typically fills valleys in the coastal areas and locally exceeds 100 ft in thickness (Mack and Lawlor, 1992; Williams and others, 1987). As sea level fell, sediments deposited in the marine environment were reworked by wave and current action, which left an intermittent patchwork of beach and nearshore deposits over the glacial deposits (Weddle and others, 1993).

Inland of the marine limit, the ice melted north and northwest, leaving behind a discontinuous layer of till over hills and valleys, and well-sorted coarse-grained sediments primarily in valleys and lowlands. In northwestern Maine and northern New Hampshire, Thompson and Fowler (1989) reported that eskers (long, sinuous ridges of sand and gravel deposited in tunnels and crevasses in the active glacier) were deposited in a few valleys as the glaciers melted. Other ice-contact deposits include kames, which are irregularly-shaped hills; kame terraces, which consist of flat-topped, irregularly-shaped terraces of sand and gravel deposited along a valley wall or hillside; and deltas, which are flat-topped, one-sided hills of sand and gravel deposits (Tepper and others, 1990). Thickness of these ice-contact deposits can exceed 150 ft.

Meltwater carried fine sand and gravel to many valley floors where the material was deposited as coarse-grained and (or) fine-grained lacustrine sediments. Outwash sediments can range in size from coarse-grained or gravelly sand, near the ice front, to fine-grained sands in outwash plains, and to silt and clay in lakes, estuaries, and marine embayments (Mack and Lawlor, 1992). The thickness of outwash deposits can exceed 100 ft.

Large glacial meltwater lakes formed in the study area during glacial retreat (Koteff, 1982; Koteff and others, 1984; R.B. Moore, U.S. Geological Survey, oral commun., 1995). The largest glacial lakes were in the Merrimack, Saco, Taunton, and Charles River Basins. Smaller glacial lakes formed in many of the river valleys. In most glacial-lake deposits, fine-grained lake-bottom sediments are adjacent to or interfingering with the coarse-grained sediments. Thickness of glacial-lake deposits are generally less than 100 ft in the study area, but exceed 280 ft in parts of the Saco River Basin (Moore and Medalie, 1995). In the Androscoggin River Basin in Maine, glacial-lake sediments consist primarily of fine-grained sediments (Thompson and Borns, 1985).

The prominent end moraines (or terminal moraines) along the southern parts of the study area in Rhode Island and Massachusetts formed as a ridge-like accumulation of mixed glacial deposits over a period of a few hundred years when the ice margin was at its maximum extent over southeastern New England (Stone and Borns, 1986; Kaye, 1960; Schafer, 1961). Block Island, Martha’s Vineyard, and Nantucket Island contain fragments of end moraines that mark the maximum southward position of the ice front during its final, northward retreat (Stone and Borns, 1986, fig. 5a). The environment of the glacier’s ice margin includes meltwater streams underneath and on the glacier; isolated, small ponds on the surface of the glacier; stagnant, isolated ice blocks buried beneath sediment deposits; and deep ice fractures that accumulated sediment (Trench, 1991). The resulting

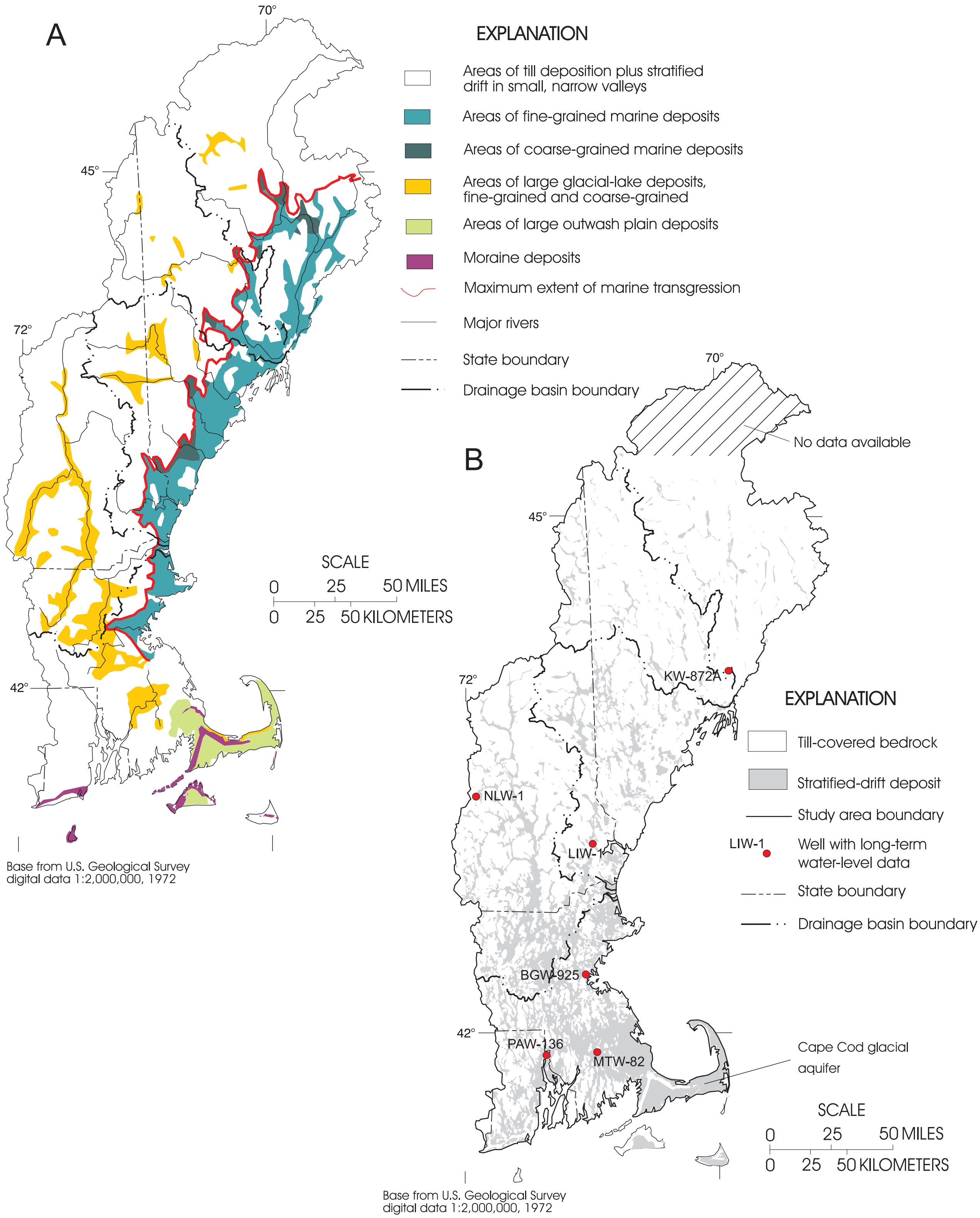


Figure 5. (A) Maximum extent of glacial lakes and the marine limit and (B) the generalized extent of stratified-drift deposits in the New England Coastal Basins study area in Maine, Massachusetts, New Hampshire, and Rhode Island.

morainal deposits have irregular, hummocky topography and are composed of distorted layers of ablation till, ice-contact stratified drift, and well-sorted outwash (Kaye, 1960).

Till is the most extensive glacial deposit in the study area (fig. 5b). It was laid down by the ice as a nearly continuous cover in the valleys and on uplands (Heath, 1983). Most of the till is either buried beneath stratified-drift deposits in valleys or lowlands or overlays the bedrock in upland areas. Till, known locally as "hardpan," is composed of boulders, gravel, sand, silt, and clay mixed in various proportions, and is usually compact, stony, and difficult to dig. Lodgement (or basal) till, deposited directly beneath active ice, is generally more compact than ablation till. Ablation till accumulated in place as stagnant ice melted. The thickness of till generally averages 20 ft but can exceed 200 ft in drumlin deposits.

Modification and redistribution of glacial deposits has been significant in the study area. Eolian deposits formed soon after deglaciation and before a vegetative cover was sufficiently developed to prevent wind erosion. Strong winds swept across the valley floors, eroding great quantities of sand and redepositing it in dunes on the east (downwind) side of the valley walls (Williams and others, 1987). Holocene alluvium formed as postglacial streams eroded glacial sediments and redeposited them as flood-plain, stream-terrace, and alluvium deposits. Moore and Medalie (1995) and Tepper and others (1990) describe large alluvium deposits in the mountainous regions of the upper Saco River Basin. Trench (1991) reports that a cap of wind-blown silt and sand 3 to 5 ft thick covers stratified-drift deposits in many parts of southeastern New England and forms the basis for much of the prime agricultural soils in this region of the study area.

Soils

The physiography and different types of glacial deposits throughout the study area cause the soils to differ. The taxonomic classification of soils found in the study area include spodosols, inceptisols, and histosols (Rourke and others, 1978). Upland areas where the water table is not near the surface are dominated by spodosols and inceptisols. Spodosols and some inceptisols are characterized by a gray to white leached horizon, where organic matter, iron, and aluminum have been leached, and a deep reddish to reddish-black zone where these materials have been redeposited. In the inceptisols, these horizons are not well developed. Spodosols and inceptisols are acidic and low in natural fertility (U.S. Soil Conservation Service, 1968). Inceptisols developed in wet areas have a gray, mottled appearance. Histosols are soils developed in wetland areas and contain large amounts of organic matter.

Soil hydrologic group classifications, obtained from the State Soil Geographic (STATSGO) soils data base, (Natural Resource and Conservation Service, 1994, accessed October 1998, at URL http://dbwww.essc.psu.edu/dbtop/doc/statsgo/statsgo_datause.html) range from A (high infiltration rates; soils are deep, well-drained to excessively well-drained sands and gravels) to D (slow infiltration rates; soils are clayey, have a high water table, or are a shallow to an impervious layer) (fig. 6). Properties represented by the soil hydrologic group affect the residence time and amount of precipitation percolating into the soil surface, where it can react with minerals and organic matter in the soil. Areas of hydrologic group D appear in the coastal and northern inland areas of Maine, primarily in areas seaward of the marine transgression (fig. 5a), or in large wetland areas. In the uplands, where glacial till is most commonly found at the surface, soils are classified as group C. Areas of stratified-drift deposits (primarily valleys in Maine and New Hampshire, but in large glacial-lake beds in Massachusetts and Rhode Island), as well as in areas of high slope, such as the White Mountains, belong to soil hydrologic group B. Sandy outwash plains and moraines of Cape Cod and the nearby offshore islands are characterized as soils hydrologic group A.

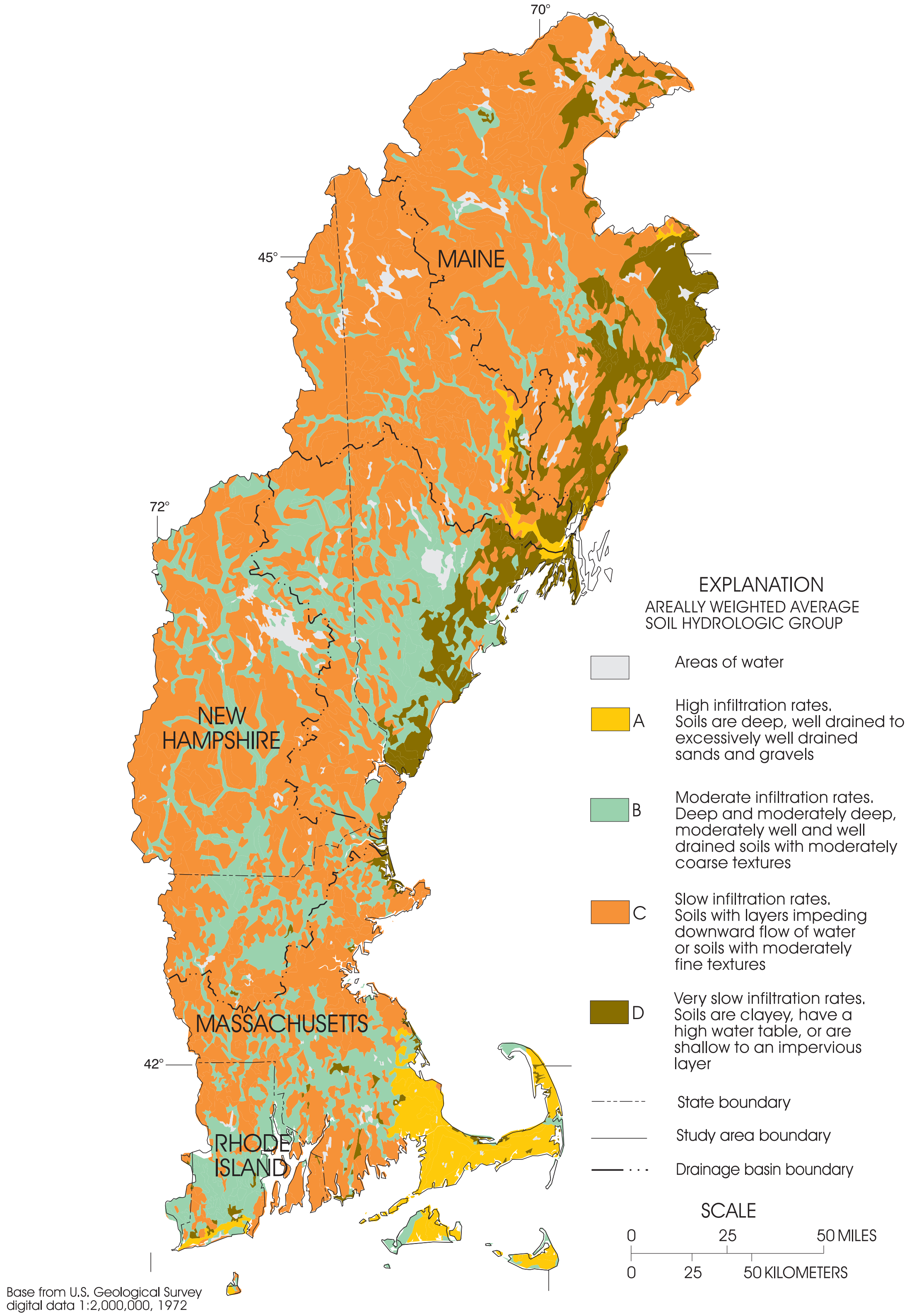


Figure 6. Generalized soil hydrologic groups of the New England Coastal Basins study area. [Data from the U.S. Department of Agriculture's State Soil Geographic (STATSGO) soils database.]

Hydrography

The NAWQA Program evaluates the quality of surface and ground waters and the aquatic biological communities found in rivers and streams. An understanding of the physical aspects of surface- and ground-water systems (the hydrography) is needed before these evaluations can be made. The following sections describe in detail the hydrography of the New England Coastal Basins study area.

Surface Water

The study are encompasses four large drainage basins and many smaller coastal drainages (fig. 7). Most of the rivers that enter the Atlantic Ocean directly are tide-affected for some distance upstream from the mouth. The large rivers are the Kennebec (5,893 mi^2), the Merrimack (5,010 mi^2), the Androscoggin (3,524 mi^2), and the Saco (1,700 mi^2) (Fontaine, 1979, 1980; New England River Basins Commission, 1978, 1980a). Small northern coastal rivers drain 2,500 mi^2 and include the Royal (143 mi^2), the Presumpscot (641 mi^2), and the Mousam (118 mi^2) Rivers in Maine (Cowing and McNelly, 1978), and the Piscataqua River (1,020 mi^2) in New Hampshire (New England River Basins Commission, 1980b); collectively these rivers form the northern coastal Basins and are grouped with the Saco River Basin in this report (fig. 7). The southern coastal rivers drain 4,243 mi^2 and include the Taunton (530 mi^2), the Charles (321 mi^2), and the Ipswich (155 mi^2) Rivers in Massachusetts, the Blackstone River (480 mi^2) in Massachusetts and Rhode Island, and the Pawcatuck River (303 mi^2) in Rhode Island, as well as many smaller coastal river basins; collectively, these rivers form the southern coastal Basins (fig. 7).

Streamflow Characteristics

Variations in streamflow were determined on the basis of data collected at USGS streamflow-gaging stations. The USGS currently (1998) operates 90 streamflow-gaging stations in the study area. The gaged sites represent a mix of large and small rivers and their tributaries. Thirty-one of the active stations are in Massachusetts, 23 are in New Hampshire, 20 are in Maine, and 16 are in Rhode Island. Thirty-one representative streamflow-gaging stations are shown in figure 8.

The greatest amount of total streamflow is carried by the large rivers (fig. 8, table 1). Mean annual streamflow for the Kennebec River near Waterville, Maine is 7,628 ft^3/s. Mean annual flows of the other large rivers are: 6,140 ft^3/s in the Androscoggin River near Auburn, Maine; 7,632 ft^3/s in the Merrimack River near Lowell, Mass.; and 934 ft^3/s in the Saco River near Conway, Maine. The largest river in the southern coastal Basins, the Blackstone River, carries a mean annual flow of 774 ft^3/s at Woonsocket, R.I.

The highest flows in all rivers are in April as the result of spring runoff and snowmelt. Fall rains produce a secondary peak in many rivers and streams in the northern part of the study area, as shown by the monthly boxplots of streamflow for the Royal River at Yarmouth, Maine; the Saco River near Conway; N.H., the Merrimack River near Manchester, N.H.; and the Androscoggin River near Auburn, Maine (fig. 9). Low flows for the year are in July, August, and September, when high evapotranspiration rates limit the amount of precipitation that becomes available for runoff. In northern streams, winter precipitation falls as snow and is not converted to streamflow until the spring thaw, resulting in more pronounced spring streamflows as shown on the boxplots for the Royal River, the Saco River, and the Androscoggin River (fig. 9). Flow in rivers in the southern part of the study area, such as the Ipswich River near Ipswich, Mass., the Charles River at Waltham, Mass.; and the Blackstone River near Woonsocket, R.I. is more evenly distributed throughout the colder months because winter precipitation in the southern areas includes more rainfall PFPF (fig. 9). Seasonal variation of streamflow can be reduced by extreme regulation of streamflow, as shown in the boxplot for the Presumpscot River near Westbrook, Maine (fig. 9).

Runoff averages 40 in/yr in the mountainous areas of New Hampshire and averages 20 to 30 in/yr in the rest of the study area (Krug and others, 1990) (fig. 8). Most runoff in the study area is during the spring and early summer. Half of the 24.6 in. of annual runoff in the East Meadow River, a tributary to the Merrimack River in Massachusetts, occurs from March to May; the average annual runoff from August through October is less than 0.5 in/mo (Gay and Delaney, 1980).

Human activity has affected streamflow since the colonists settled New England. Some human activities, such as diverting water for municipal

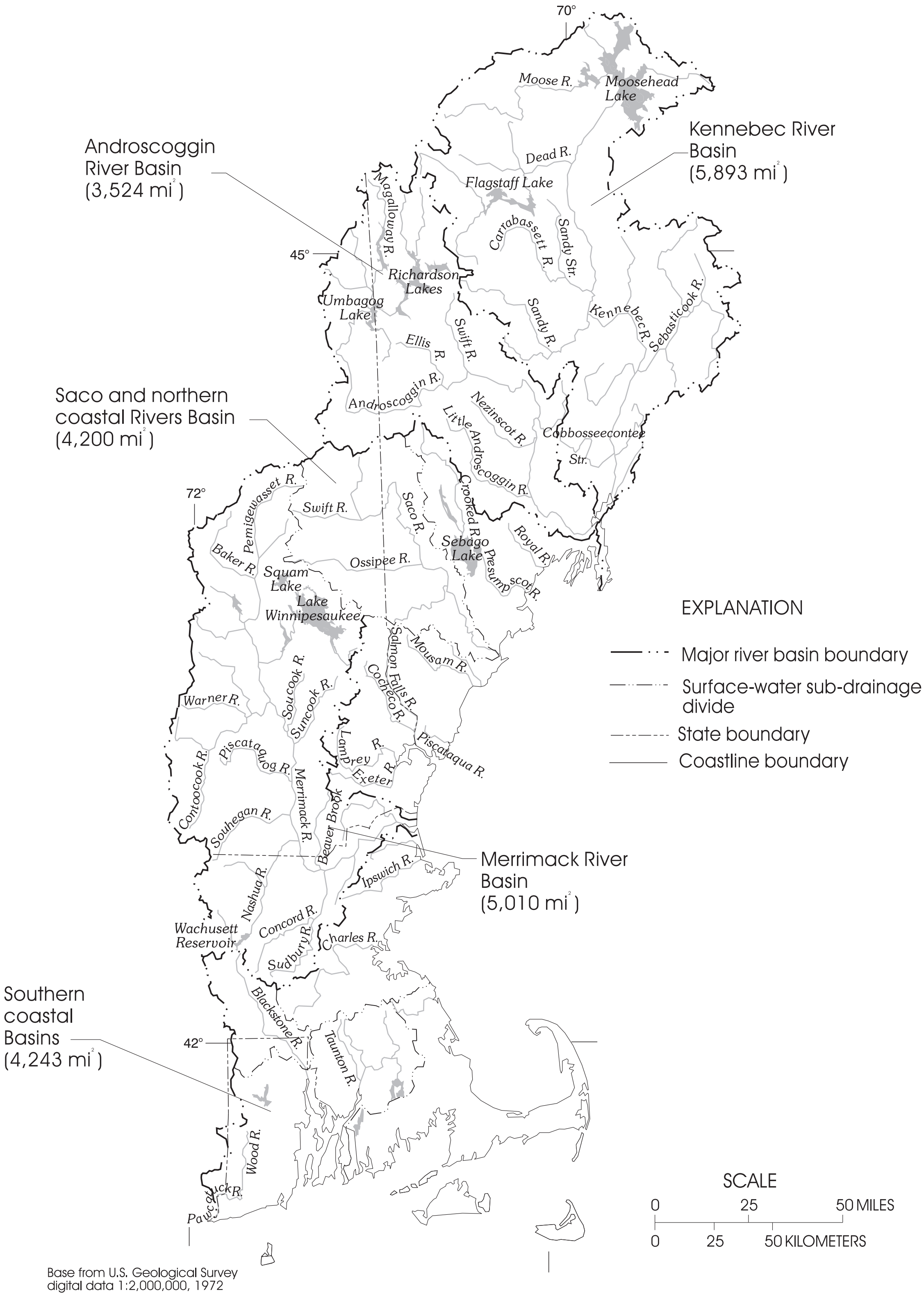


Figure 7. Generalized hydrography of the New England Coastal Basins study area.

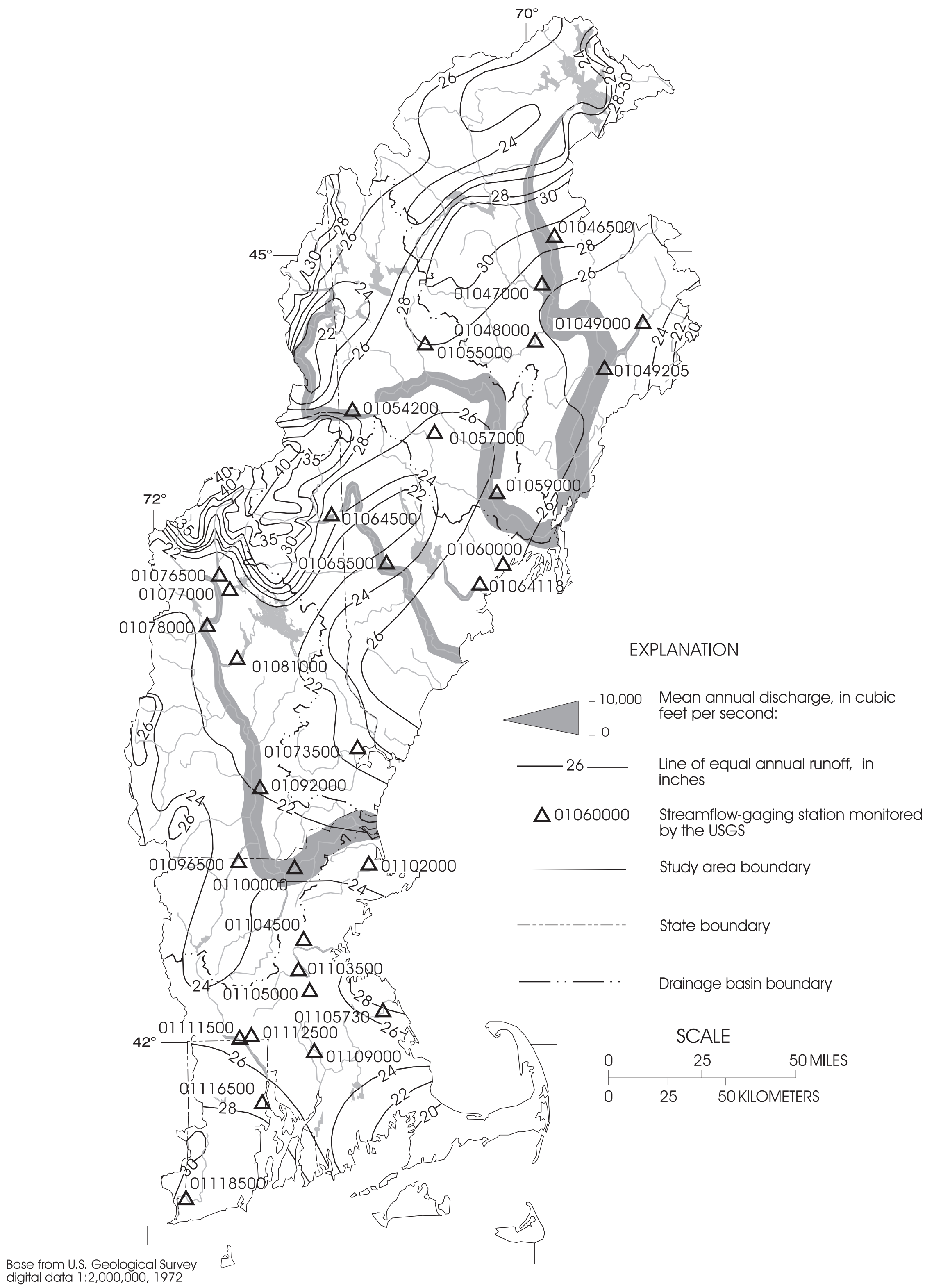


Figure 8. Mean annual discharge, mean annual runoff, and location of selected streamflow-gaging stations in the New England Coastal Basins study area.

Table 1. Streamflow characteristics for selected gaging stations in the New England Coastal Basins study area, in Maine, Massachusetts, New Hampshire, and Rhode Island

[mi^2, square miles; ft^3/s, cubic feet per second; --, no data available; Locations shown on figure 8.]

Gaging station name	Gaging station number	Drainage area, in mi^2	Period of record in water years	Mean annual stream-flow, in ft^3/s	Mean annual runoff, in inches	Flood years: Annual runoff in inches, by water year			Drought years: Annual runoff in inches, by water year		
						1984	1978	1973	1985	1965	1941
Kennebec River at Bingham, Maine	01046500	2,715	1930-96	4,445	22.2	31.6	29.3	28.5	15.7	13.5	15.2
Carrabassett River at North Anson, Maine	01047000	353	1925-96	721	27.7	42.8	39.7	36.1	17.1	14.4	12.8
Sandy River near Mercer, Maine	01048000	516	1928-79 1987-96	971	25.6	--	36.6	35.6	--	13.6	11.5
Sebasticook River near Pittsfield, Maine	01049000	572	1928-96	960	22.8	36.8	31.7	32.5	10.4	14.1	13.3
Kennebec River near Waterville, Maine	01049205	5,179	1994-96	7,628	--	--	--	--	--	--	--
Wild River at Gilead, Maine	01054200	69.6	1964-96	182	35.5	50.5	44.1	50.9	29.2	14.2	--
Androscoggin River near Auburn, Maine	01059000	3,263	1988-96	6,137	25.5	36.8	35.1	34.5	16.1	15.0	14.6
Swift River near Roxbury, Maine	01055000	96.9	1929-96	200	28.0	37.9	37.8	39.2	18.4	15.3	14.4
Little Androscoggin River near South Paris, Maine	01057000	73.5	1913-24 1931-96	138	25.5	38.7	34.3	40.4	14.0	11.6	12.2
Royal River at Yarmouth, Maine	01060000	141	1949-96	274	26.4	46.2	37.8	37.2	13.8	12.7	--
Presumpscot River near Westbrook, Maine	01064118	577	1975-95	925	22.2	40.9	31.6	--	9.5	--	--
Saco River near Conway, N.H.	01064500	385	1929-96	934	32.9	47.0	42.2	51.6	21.3	17.2	20.6
Ossippee River at Cornish, Maine	01065500	452	1916-96	879	26.4	42.8	34.9	39.0	16.7	13.4	14.9
Lamprey River near Newmarket, N.H.	01073500	183	1934-96	282	20.9	32.7	26.1	31.5	10.5	10.1	12.1
Pemigewassett River at Plymouth, N.H.	01076500	622	1903-96	1,360	29.7	42.1	37.5	43.0	20.6	16.0	20.2
Winnepesaukee River at Tilton, N.H.	01081000	471	1937-96	706	20.3	35.4	27.7	32.5	11.9	8.8	13.9
Merrimack River near Goffs Falls below Manchester, N.H.	01092000	3,092	1936-96	5,273	23.1	36.9	29.6	34.4	13.5	9.9	15.3
Nashua River at East Pepperell, Mass.	01096500	435	1935-96	576	[1]18.0	[1]29.6	[1]22.8	[1]26.6	[1]8.8	[1]6.7	[1]9.1
Merrimack River at Lowell, Mass.	01100000	4,635	1923-96	7,632	22.4	36.6	29.7	34.7	13.5	9.0	13.2
Ipswich River near Ipswich, Mass.	01102000	125	1930-96	187	[1]20.3	[1]38.1	[1]24.9	[1]29.1	[1]8.4	[1]7.6	[1]11.5
Charles River at Dover, Mass.	01103500	183	1937-96	305	[1]22.6	[1]36.8	[1]32.9	[1]29.2	[1]10.6	[1]11.0	[1]13.3
Charles River at Waltham, Mass.	01104500	251	1903-09 1931-96	306	[1]16.6	[1]30.2	[1]23.1	[1]20.3	[1]8.8	[1]9.1	[1]8.4
Neponset River at Norwood, Mass.	01105000	34.7	1939-96	55.1	[1]21.6	[1]41.6	[1]30.5	[1]27.2	[1]10.6	[1]11.3	[1]11.1
Indian Head River at Hanover, Mass.	01105730	30.3	1966-96	61.6	27.6	39.8	33.9	37.3	13.4	--	--
Wading River near Norton, Mass.	01109000	43.3	1925-96	73.3	[1]23.0	[1]38.7	[1]36.0	[1]33.5	[1]9.7	[1]11.0	[1]14.4
Branch River at Forestdale, R.I.	01111500	91.2	1912-13 1940-96	175	26.1	38.8	37.5	38.4	15.8	13.8	16.4
Blackstone River near Woonsocket, R.I.	01112500	416	1929-96	774	[1]25.3	[1]37.9	[1]34.6	[1]36.3	[1]15.4	[1]12.9	[1]15.8
Pawcatuck River at Westerly, R.I.	01118500	295	1940-96	579	26.6	39.8	36.8	40.1	17.2	16.6	--
Pawtuxet River at Cranston, R.I.	01116500	200	1939-96	349	[1]23.7	[1]35.0	[1]34.8	[1]40.4	[1]12.7	[1]12.2	[1]17.4

[1] Runoff values significantly affected by water-use activities and are not representative of natural conditions.

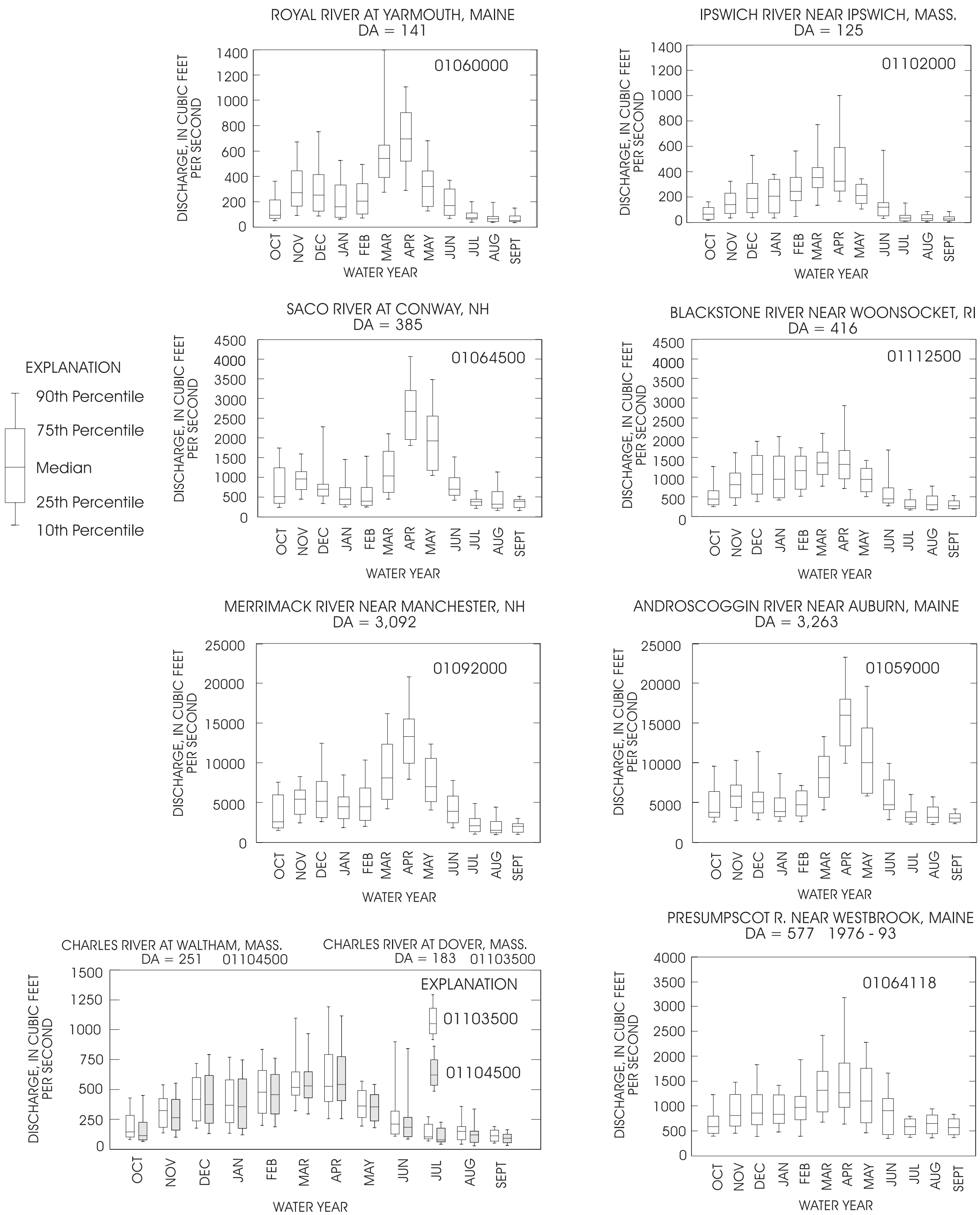


Figure 9. Distribution of monthly streamflows for selected gaging stations, for water years 1973-93 unless otherwise noted, in the New England Coastal Basins study area. Locations of stations shown on figure 8. Eight-digit number in upper corners of plot area are gaging-station numbers.

drinking-water supplies, result in reducing the amount of water flowing in a stream. Use of streamflow for hydroelectric power generation can regulate the timing and magnitude of yearly low and high flows without affecting the total flow, and often creates artificial high and low flows on a daily basis. Flood-control reservoirs diminish the magnitude of yearly high flows. Many rivers and streams in the study area are affected by more than one of these activities. Currently, most of the unregulated rivers are in the White Mountains physiographic section (fig. 2), but a few small streams in the rest of the study area remain unregulated. The largest unregulated rivers include the Sandy River (Kennebec River Basin) and the Swift River (Androscoggin River Basin) (table 1; fig. 7).

The timing and magnitude of yearly low flows (base-flow regulation) and high flows (peak-flow regulation) are regulated in most of the medium-sized rivers and all of the large rivers. Peak and baseflow is regulated by storage reservoirs and hydropower dams. There has been a shift in water-management practices in the large, northern river basins in the study area. From the mid 1800s to mid 1960s, storage was used to increase flows for driving logs downstream, but since the 1960-70's storage is used for flood control and for providing consistent flows for power generation for industrial users and commercial electricity providers. Thus, large peaks in flow are reduced, as water is held back in the spring, and normal summer to fall low flows are increased as this stored water is released throughout the year.

There were more than 1,600 dams throughout the study area in 1996 (U.S. Army Corps of Engineers, 1996). The Androscoggin River Basin had the smallest number of dams (91), whereas the southern coastal Basins had the largest number of dams (697) (table 2). Almost 36 percent of all dams were used for recreation, 18.8 percent for water supply, 17.5 percent for hydroelectric power generation, and 7.8 percent for irrigation. The rest of the dams were used for flood control (7.3 percent), as fire ponds (1.2 percent), or other uses (10.3 percent) (table 2). Location of dams from the top three categories are shown in figure 10. In general, most of the hydroelectric power dams are in the northern part of the study area, and recreational and water-supply dams are primarily in the southern and central parts (fig. 10).

The effects of reservoirs, impoundments, and lakes on streamflows can be seen in data collected during April 1987, when widespread flooding caused record or near-record flows, including those in the Saco River near Conway, N.H. and the Pemigewassett River at Plymouth, N.H. (fig. 11). While streamflow in these and other unregulated basins increased and decreased swiftly during this flood, flows in nearby rivers of similar sizes that had significant storage (the Ossipee River at Cornish, Maine and the Winnipesaukee River at Tilton, N.H.) were relatively unaffected by the flood (fig. 11).

Large and small hydroelectric power dams also produce large shifts in streamflows on a daily basis as water is released to provide power during peak electricity-use hours and held back later in the day during low electricity use (fig. 12). The degree of daily-streamflow regulation at a location depends on its proximity to upstream hydropower dams and whether those dams are managed in such a way as to cause large shifts in flow throughout the day. Daily-streamflow regulation generally has a negative impact on aquatic habitats.

Table 2. Summary of dams, by major river basin, in the New England Coastal Basins study area, in 1995-96

[Data from U.S. Army Corps of Engineers

River basin	Number of dams by major category or purpose								
	Water supply	Fish and wildlife	Flood control	Hydro-electric	Recreation	Fire pond	Irrigation	Other	Total
Kennebec	3	5	5	54	12	9	0	9	97
Androscoggin	9	3	7	53	11	1	0	7	91
Saco and northern coastal	18	7	7	73	71	6	0	23	205
Merrimack	100	1	53	93	232	1	5	52	537
Southern coastal	176	6	48	12	255	2	122	76	697
Study area total	306	22	120	285	581	19	127	167	1,627

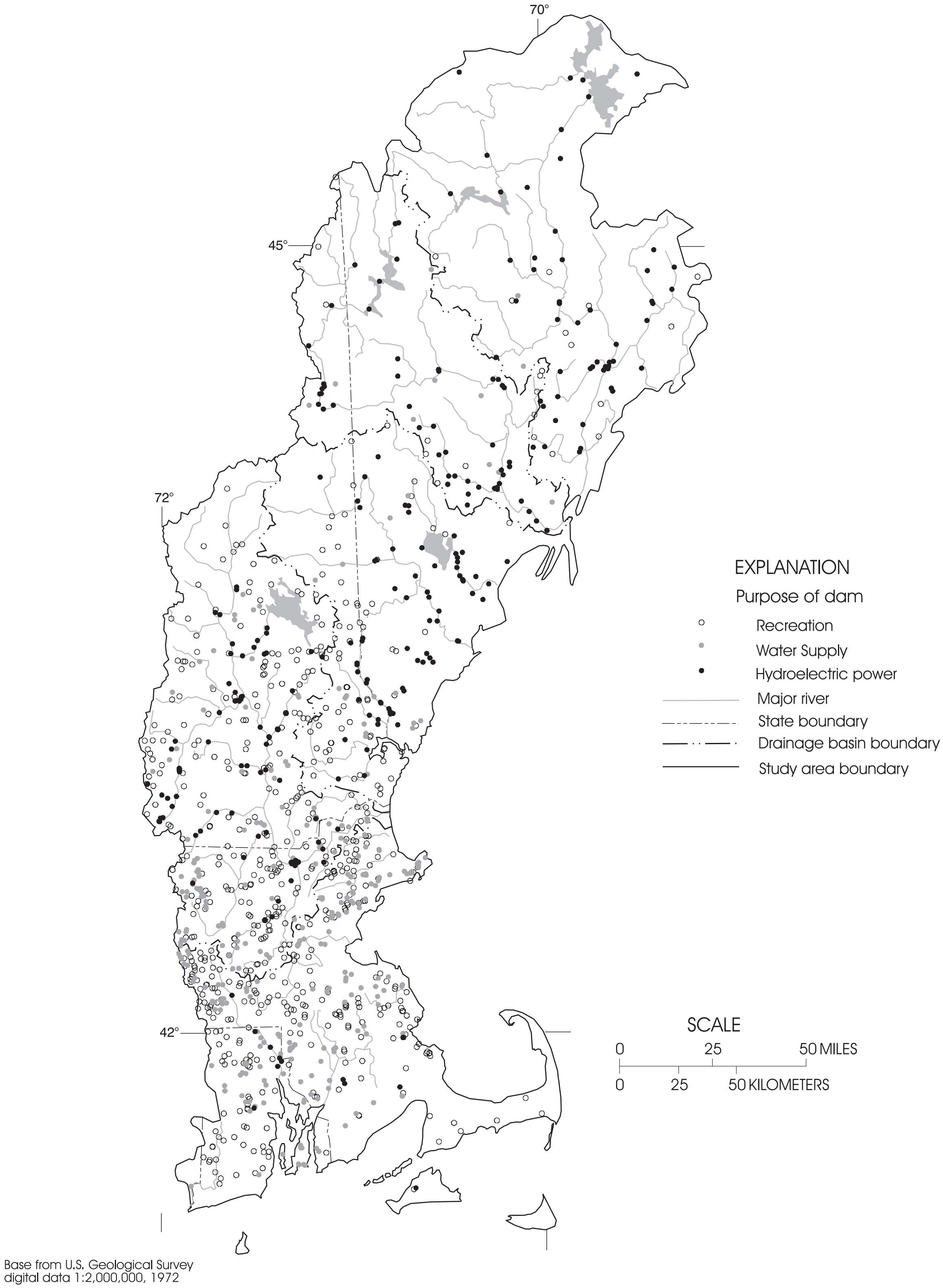


Figure 10. Location of dams used for recreation, water supply, and hydroelectric power generation in the study area. Data from the U.S. Army Corps of Engineers.

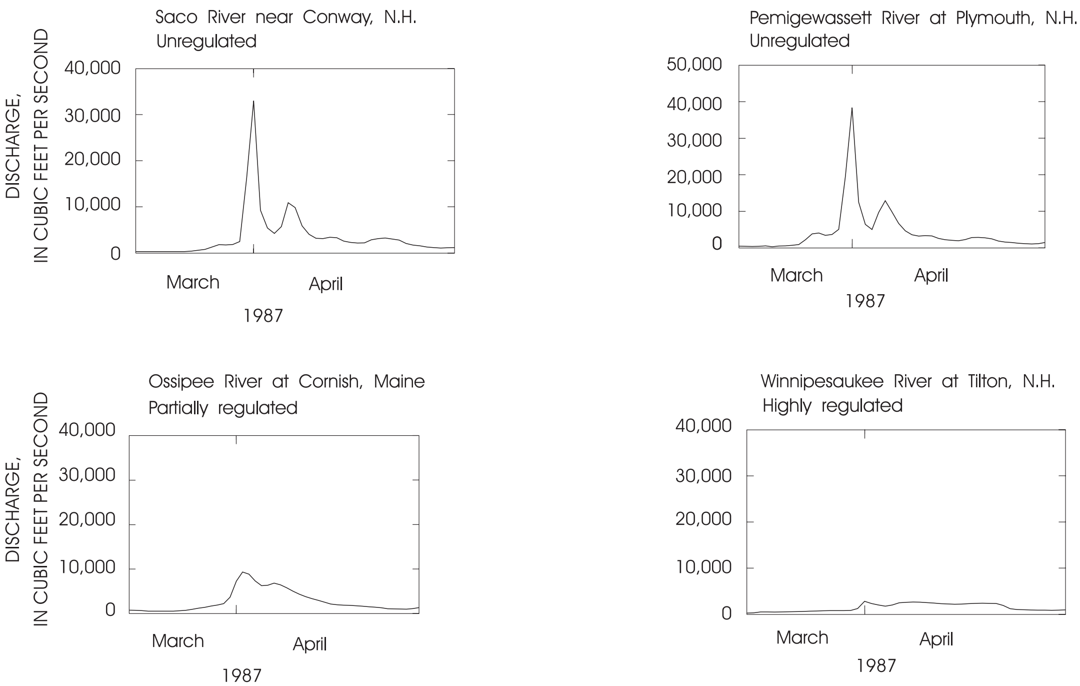


Figure 11. Selected storm hydrographs from unregulated and regulated streams and lakes for a large runoff event (March-April 1987) in the New England Coastal Basins study area in Maine, Massachusetts, Rhode Island, and New Hampshire, 1987.

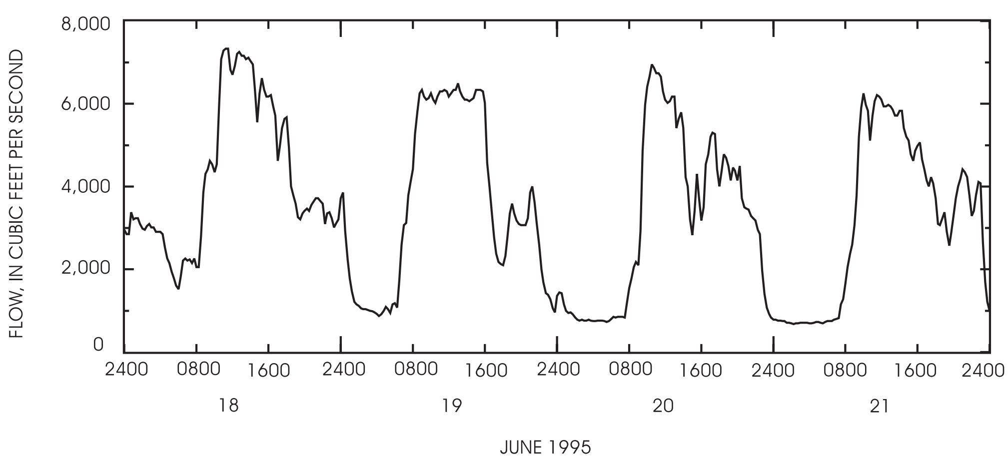


Figure 12. Daily streamflow regulation on the Kennebec River at Bingham, Maine, June 18-21, 1995.

Urbanization, which creates increased demands on water resources, has resulted in base-flow depletion in a number of rivers in eastern Massachusetts and Rhode Island. Two examples of base-flow depletion in eastern Massachusetts are in the Charles River Basin and in the Ipswich River Basin. In the Charles River Basin, withdrawals and diversions for drinking water have reduced the average runoff in the basin above Waltham, Mass., to just 16.6 in/yr (table 1). The nearby Indian Head River basin, which has fewer demands on the surface-water system, has an average annual runoff of 27.6 in/yr at Harvard, Mass. A comparison of the monthly flows in the Charles River upstream (at Dover drainage area) and downstream (at Waltham drainage area) (fig. 9) shows that the flow in the river does not increase downstream as expected because of these diversions.

A combination of surface-water withdrawals and ground-water pumping lowered baseflow in the Ipswich River Basin. Towns in the headwaters of the basin rely on wells for drinking-water supplies. The wells are completed in coarse-grained sand and gravel aquifers that are in direct hydraulic connection with the river. During the summer of 1996, 15 to 20 mi of the river ran dry because ground-water pumping had induced so much water from the river into the aquifer (D. LeVangie, Massachusetts Department of Environmental Management, Water Supply Division, oral commun., 1996). Farther downstream in the Ipswich River basin, towns rely on surface water for their drinking water. From November to May, water is diverted out of the river into reservoirs for drinking water. Also, none of the wastewater generated in the basin is returned to the Ipswich River.

Floods and Droughts

Although annual peak flows generally are in the spring, major flooding can occur at any time during the year. Typically, spring floods are caused by intense rainfall and by the melting of snow. The flood of spring 1936 was caused by intense rains and unseasonably warm weather that melted the snowpack. The severity of the flood was increased by ice jam break-ups in the rivers and a surge in runoff because the soil was frozen and impermeable. This flood resulted in a peak discharge of 161,000 ft^3/s for the Merrimack River near Lowell, Mass. (Station 01100000, fig. 8; Gadoury and others, 1994). Floods in the summer and fall are caused primarily by thunderstorms or hurricanes. The "Great Hurricane of 1938" resulted in the worst natural disaster in New England (Paulsen and others, 1940). The flood was caused by heavy rainfall followed by a hurricane and an ocean storm wave. Another major flood occurred in April 1987, primarily across the northern part of the study area. This flood caused the peak flow record of 186,000 ft^3/s for the Kennebec River at Sidney, Maine (Nielsen and others, 1994). Years with the highest amounts of total runoff (1984, 1978, and 1973) had approximately 25 to 35 percent higher runoff than the mean annual runoff for most basins (table 1).

Droughts are more difficult to define than floods because they have no distinct beginning or end. Yet they can be quantified by examining the frequency of less-than-average precipitation. A major prolonged drought in 1961-69 resulted in the drought of record in New England. This drought had a serious effect on agriculture and water supply in the region. Ground-water storage, the primary source of streamflow between rainfall events (Barksdale and others, 1966), was also severely depleted. Ordinarily in New England, ground-water storage is replenished during each non-growing season. This depletion was observed over the winter of 1964-65 and resulted in record-low streamflows during 1965, the driest year ever recorded in the study area. Other periods of drought were from 1939-44, 1947-50 (Hammond, 1991; Maloney and Bartlett, 1991; and Wandle, 1991), and from 1980-81 (Walker and Lautzenheiser, 1991). In the northern part of the study area, years with the lowest total runoff (1985, 1965, and 1941) have 50 to 65 percent of the average annual runoff (table 1). This compares to only 40 to 55 percent of the average annual runoff in the southern part of the study area, where diversions of water out of the basins leaves less of the total water budget for instream flow.

Lakes, Reservoirs, and Wetlands

There are hundreds of lakes, ponds, reservoirs, and wetland areas of various sizes throughout the study area (table 3, Anderson and others, 1976). The two largest natural lakes are Moosehead Lake (124 mi^2) in Maine and Lake Winnipesaukee (78 mi^2) in New Hampshire (fig. 7). The greater the number and total area of lakes, reservoirs, and wetlands in a basin, the greater the natural potential for storage of runoff during storms (Benson, 1962). Additional storage potential may be provided by flood-control

Table 3. Numbers and total areas of lakes and wetlands greater than 0.1 square miles in the major river basins of the New England Coastal Basins study area in Maine, Massachusetts, New Hampshire, and Rhode Island

[mi^2, square miles; data from Geographic Information and Retrieval System land cover data base (Anderson and others, 1976)]

River basin	Lakes (and reservoirs)			Wetlands	
	Number of lakes greater than 0.1 mi^2	Total area of lakes, in mi^2	Percent of basin area in lakes	Total area of wetlands, in mi^2	Percent of basin area in wetlands
Kennebec	221	335	5.6	241	4.1
Androscoggin	97	133	3.8	68	1.9
Saco and northern coastal	156	137	3.3	109	2.6
Merrimack	251	174	3.5	55	1.1
Southern coastal	269	95	2.3	151	3.6
Study area total	994	874	3.8	624	2.7

reservoirs and other reservoirs that increase the natural potential by drawing water down below the uncontrolled outlet. Based on the area of lakes, reservoirs, and wetlands, the Kennebec River Basin has almost twice the amount of natural storage potential as the other basins. The Southern coastal Basins have the smallest area of lakes and, therefore, the smallest amount of natural potential for storage of surface-water runoff during storms (table 3).

Lakes support extensive recreational activities. Lake Winnipesaukee in New Hampshire (fig. 7) and Sebago Lake in Maine (fig. 7) have evolved over the past century into popular recreational centers that support a large seasonal population and contain extensive shoreline residential developments. Moosehead Lake (fig. 7), and other large, remote lakes in Maine and New Hampshire are still relatively undeveloped. Recently, the U.S. Fish and Wildlife Service (1991) established the Lake Umbagog National Wildlife Refuge in the headwater region of the Androscoggin River Basin in Coos County, N.H. and Oxford County, Maine. The Refuge was established primarily to protect the pristine lake from future shoreline development and to protect endangered wildlife and plant species and their habitats.

Ground Water

Ground water is an important source of water for streams and lakes and is used for domestic, public, commercial, and industrial water supplies. It is available in highly variable quantities in all the geologic units of the study area (table 4).

Aquifers

There are three main types of aquifers in the study area—stratified drift, till, and bedrock. The highly permeable, relatively shallow (less than 100 ft), discontinuous stratified-drift aquifers that occupy most river valleys in New England are the principal source of drinking water for many communities that use ground water. Glacial-till aquifers are characterized by low permeability but can supply sufficient water to shallow wells for households and farm use. Fractured-bedrock aquifers are the primary source of drinking water to rural households and are an important source of water to a few public-supplied, commercial and industrial users.

A digital compilation of the sand and gravel resources for the States of Maine, New Hampshire, Massachusetts, and Rhode Island (Marvinney and Walters, 1993; Koteff, 1993; and Stone and Beinikis, 1993; Cain and Hamidzada, 1993) was used to determine the extent of stratified-drift deposits (fig. 5b). Stratified-drift deposits cover 21 percent of the study area and range from 3.7 percent of the Kennebec River Basin to 53 percent of the southern coastal Basins (fig. 5b).

Stratified-drift aquifers consist mainly of sand and gravel deposited in layers by meltwater streams flowing from the retreating glacial ice. The areal distribution, thickness, and hydraulic properties of stratified-drift aquifers are directly related to their mode of deposition. Most stratified-drift aquifers in the study area formed in a glacial-lake environment in inland and upland areas, in a marine environment near coastal areas north of Boston, Mass., and as large outwash plains in the Cape Cod region. Stratified-drift aquifers that contain significant amounts of saturated, coarse-grained ice-contact and outwash deposits can yield high quantities of water (table 4).

Table 4. Geologic units, hydraulic properties, and general water-bearing characteristics in the New England Coastal Basins study area, in Maine, Massachusetts, New Hampshire, and Rhode Island

[ft/d, foot per day; gal/min, gallons per minute; ft^2/d, feet squared per day]

Geologic unit and occurrence	Range in thickness, in feet	Hydraulic properties	General water-bearing characteristics
Outwash deposits--Stratified deposits of sand and gravel in outwash plains and valley trains. Below 400 feet altitude in Maine and New Hampshire, outwash can overlie marine or lacustrine deposits.	0 - 200	Hydraulic conductivity (k) ranges from 35 - 1,000 ft/d for outwash and ice-contact deposits. A detailed study of stratified-drift aquifers in New Hampshire showed that the calculated hydraulic conductivity for well sorted, very-fine to fine sand is about 12 ft/d; well sorted medium sand is about 51 ft/d; well sorted coarse to very-coarse sand is about 970 ft/d; and granules (or gravel) can exceed 1,000 ft/d.[1] Specific yield is approximately 0.2. Porosity of coarse gravel ranges from 24 to 36 percent.	Yields small to moderate amounts of water to dug, drilled, or driven wells and to springs. Largest yields are from wells in areas where the saturated thickness is large, the deposits are coarse grained, and in hydraulic contact with a nearby surface-water body as a source of induced recharge.
Ice-contact deposits--Well to poorly sorted, stratified deposits of sand, gravel, and cobbles, with some silt and boulders. Land forms include eskers, kames, kame deltas, and kame terraces. Not an extensive deposit in the study area.	0 - 150		These deposits are the best potential source of large supplies of ground water in the study area, especially in areas where the saturated thickness is large, the deposits are coarse grained, well sorted, and in hydraulic contact with a nearby surface-water body as a source of induced recharge. Under the most favorable conditions, from 500 to more than 1,500 gal/min of water can be obtained from individual, gravel-packed wells screened in these deposits.
Glacial-lake (lacustrine) deposits--Deposits consist of blue-gray silt, clay, and fine sand; may contain lenses of medium sand. These deposits are similar in composition to marine deposits (see fig. 5a for general locations).	0 - 280	Hydraulic conductivities of silt and clay are generally less than 1 ft/d; very fine sand is about 4 ft/d. Hydraulic conductivity is as low as 2.3×10^{-7} ft/d in marine clays.[2] Specific yield is negligible. Porosity of fine sand ranges from 24 to 36 percent. In general, porosity increases and hydraulic conductivity decreases with decreasing particle size for glacial sediments.	These deposits are too fine grained to yield significant water to wells, but can contain lenses of sand and gravel from which wells of moderate yield could be developed. Glacial-lake deposits, where found, act as a confining unit to more permeable deposits buried beneath or overlying them.
Marine clays deposits--Dark-blue to gray silt, clay and fine sand; tan where weathered. Contain layers of sand and gravel. Underlie outwash deposits and may crop out in stream valleys up to about 400 feet above sea level (see fig. 5a for general locations).	0 - 100		Marine clays have low permeability and release water slowly. Marine clays are not a significant aquifer and can act as a confining unit to more permeable deposits buried beneath or overlying them.
End moraine deposits--Composed of complex, glacially deformed sediments of sand, gravel, silt, clay, and till which locally overlie sand and gravel deposits at the heads of large promorainal outwash plains.[3] These deposits are in the southernmost part of the study area (see fig. 5a).	0 - 1,000	A study of morainal aquifers on Block Island, R.I., reported hydraulic conductivity values ranging from 3 - 2,100 ft/d, with a median of 27 ft/d.[4]	Yields depend greatly on the lithologic unit within the moraine deposit that a well is screened in. Transmissivity from 114 wells screened in differing morainal units on Block Island, R.I., ranged from 15 - 17,5000 ft^2/d, with a median of only 200 ft^2/d.[4] Wells are commonly used to supply domestic drinking water.

Table 4. Geologic units, hydraulic properties, and general water-bearing characteristics in the New England Coastal Basins study area, in Maine, Massachusetts, New Hampshire, and Rhode Island—Continued

[ft/d, foot per day; gal/min, gallons per minute; ft^2/d, feet squared per day]

Geologic unit and occurrence	Range in thickness, in feet	Hydraulic properties	General water-bearing characteristics
Till deposits--Till, the most extensive glacial deposit in the study area, is an unsorted, unstratified mixture of clay, silt, sand, gravel, angular cobbles, and boulders. Below the first few feet, particularly where thick, till is commonly clay-rich and very dense. Till covers the bedrock in upland areas in varying thicknesses and commonly underlies stratified-drift deposits in valleys and other lowland areas.	0 - 325	A study of till in southern New England showed that the horizontal hydraulic conductivity of tills derived from metamorphic and igneous (crystalline) rocks ranged from 0.004 - 65 ft/d.[5] The porosities and specific yields of these tills ranged from 22.1 to 40.6 percent and from 3.9 to 31.2 percent, respectively.[5]	Till can be a source of water to dug wells. Till transmits water slowly and the yield of dug wells is small once water stored in the well casing is pumped out. Dug wells in till are likely to go dry during periods of little or no precipitation. Yields of wells in till typically range from 1 to 5 gal/min.
Crystalline Bedrock--Bedrock formations consist of a variety of igneous and metamorphic rocks. Igneous rocks include granite, pegmatite, and granodiorite with smaller amounts of basic volcanic or intrusive rocks. Metamorphic rocks consist largely of metamorphosed sedimentary rocks and include schist, gneiss, phyllite, quartzite, and slate. Bedrock formations outcrop on hills, ridges, and steep valley walls.	Average depth of drilled wells is 309 feet, with greater than 75 percent of wells less than 400 feet in depth.[6]	Single-hole hydraulic testing done by Hsieh and others (1993) indicated that the hydraulic conductivity in fractured crystalline bedrock range from 2.8×10^{-4} to 2.8 ft/d. Cross-sectional models over a scale of several miles in fractured crystalline bedrock of moderate to high relief in the White Mountain section of the New England physiographic province indicate that the hydraulic conductivity is less than 0.086 ft/d.[7] Numeric modelling of ground-water flow near Mirror Lake, N.H., indicates that hydraulic conductivities are about 0.09 ft/d for bedrock aquifers beneath upper hillsides and hilltops.[8] Many crystalline rocks have a high number of fractures but few are connected. Therefore, the effective porosity, which is defined as the percentage of interconnected pore space, is generally much less than the total porosity of crystalline rocks and ranges from 5.0×10^{-5} to 0.01 percent.[2]	Bedrock formations are dense, relatively impermeable, and have low porosity. They contain recoverable water in secondary openings such as joints, fractures, and bedding or cleavage planes. The water in fractured bedrock aquifers is generally confined. Yields in bedrock wells depend on the number, size, and degree of interconnection of water-bearing fractures. The average yield of inventoried drilled wells (over 13,700) is 14.3 gal/min.[6] High-yielding wells in fractured bedrock are relatively rare; only 2 percent have yields greater than 100 gal/min. Yields of wells that tap bedrock aquifers in Rhode Island commonly range from 1 to 20 gal/min.[9] In Massachusetts, sedimentary-rock aquifers have higher median yields (12 gal/min) than crystalline-rock aquifers (6 gal/min) and commercial or industrial wells have median yields of 30 gal/min.[10]

[1]Moore and others, 1994.
[2]Domenico and Schwartz, 1990.
[3]Stone and Sirkin, *in* Veeger and Johnston, 1996.
[4]Veeger and Johnston, 1996.
[5]Melvin and others, 1992.
[6]Data from the U.S. Geological Survey's Ground-Water Site Inventory data base.
[7]Harte, 1992.
[8]Tiedeman and others, 1997.
[9]Johnston, 1985, p. 374.
[10]Hansen and Simcox, 1994.

The largest sole-source aquifer in the study area is the Cape Cod glacial aquifer, which covers 440 mi^2 in southeastern Massachusetts (fig. 5b). The aquifer is composed of extensive outwash deposits overlying and interbedded with layers of lacustrine clay, silt, very fine sand and till. Combined, the glacial deposits range in thickness from 100 ft at the western end of the peninsula near the Cape Cod Canal to about 1,000 ft at the northern end near the town of Truro (Leblanc and others, 1986). The water table of the aquifer is dominated by six hydraulically independent flow cells or mounds. Ground water flows radially from the center of the flow cells towards the Atlantic Ocean or ocean inlets. Analysis of the aquifer system shows that approximately 270 million gallons of water flows through the six cells on a daily basis (Olcott, 1995). In 1985, the aquifer provided water to 128 municipal wells and more than 20,000 private wells (Persky, 1986).

The USGS and the State of New Hampshire conducted a cooperative program from 1983 to 1995 to assess the State’s stratified-drift aquifers, which included a description of the areal extent, geohydrology, potential yield, and quality of water in these aquifers (Medalie and Moore, 1995). The largest stratified-drift aquifer in the State is the Ossipee Lake aquifer in the upper Saco River Basin in east-central New Hampshire (Moore and Medalie, 1995) and west-central Maine (Tepper and others, 1990). This aquifer is an example of a valley-fill system formed in a glacial-lake environment. Stratified-drift landforms in the Ossipee Lake aquifer include eskers, kames, outwash, fine-grained lacustrine, and alluvial deposits.

The USGS, in cooperation with the Maine Department of Conservation, Maine Geological Survey, and the Maine Department of Environmental Protection, has been mapping Maine’s “significant” sand and gravel aquifers since 1981. One well-studied aquifer, the Little Androscoggin aquifer in southeastern Oxford County, Maine, is an example of a valley-fill aquifer system that formed in a lowland bedrock valley near the coast and was either partly or completely inundated by the ocean during the last glaciation (Morrissey, 1983). The surficial deposits consist of highly permeable sand and gravel that were deposited in contact with glacial ice at the northern part of the valley and outwash sand deposited in front of the ice that overlies a thick layer of impermeable marine silt, clay, and fine sand at the southern part of the valley.

The Rhode Island Water Resources Board has identified 21 high-yielding stratified-drift aquifers, termed ground-water reservoirs, with transmissivity equal to or exceeding 4,000 ft^2/day and saturated thicknesses equal to or exceeding 40 ft (Trench, 1991). These ground-water reservoirs represent only a small fraction of the total area underlain by stratified drift in Rhode Island. High-yielding public-supply wells tap many of these ground-water reservoirs. A typical public-supply well may yield 700 gal/min in the deeply saturated, permeable areas (Johnston, 1985).

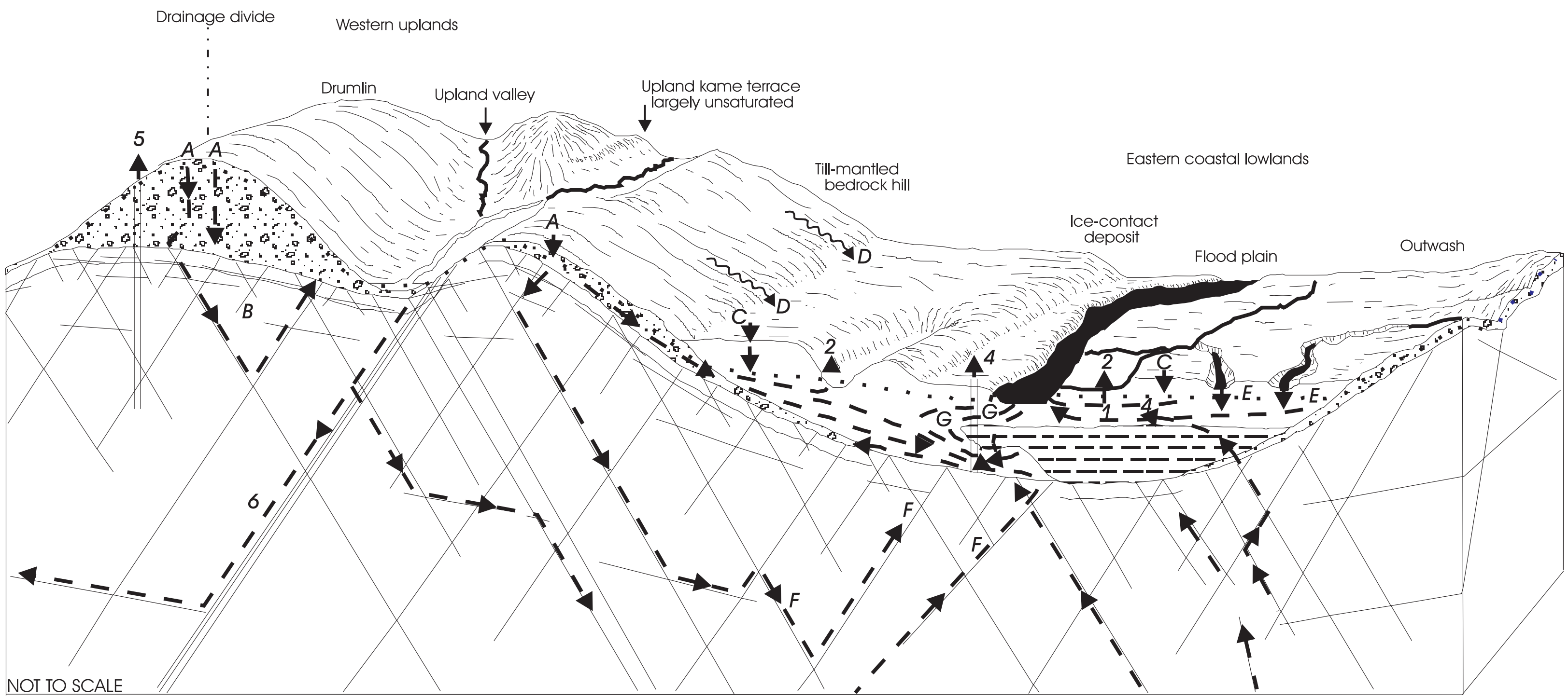
Fractured-bedrock aquifers primarily store and transmit water through intersecting fractures (table 4; fig. 13). These fractures were formed as a result of cooling stresses in magma, tectonic activity, erosion of overlying rock, and the freeze-thaw activities of glacial ice sheets that once covered New England (Hansen and Simcox, 1994). Brittle and coarser-grained rocks, such as granite and basalt, generally have wider and more continuous fractures than those of finer-grained rocks such as schist and gneiss. Most bedrock ground-water supply wells in the study area are less than 700 ft deep. Generalized hydraulic properties and aquifer characteristics of fractured-bedrock aquifers are summarized in table 4.

Recharge, Discharge, and Ground-Water Levels

Ground water is recharged by precipitation that infiltrates the land surface and percolates through the soil layer to the water table, which is the upper surface of the saturated layer (or saturated zone). The water contained in the saturated zone moves in the direction of decreasing head from recharge areas to areas of ground-water discharge. This usually corresponds to areas of topographic uplands to areas of topographic lowlands (fig. 13). The rate of ground-water flow is dependent on the hydraulic conductivity of aquifer materials and the hydraulic gradient.

Most of the recharge in New England is in late autumn and early spring, when precipitation is greatest and evapotranspiration is lowest. Vegetation, soil permeability, climatic conditions, and impervious urban areas can affect the rate of recharge to aquifers.

Average annual recharge to stratified-drift aquifers from precipitation is approximately half of the annual precipitation. This equals about 20 to 24 in/yr in glaciated areas of eastern Massachusetts (Knott and Olimpio, 1986; Leblanc and others, 1986; Bent, 1995; and Hansen and Lapham, 1992), in



EXPLANATION

RECHARGE TO BEDROCK

A Infiltration of precipitation through till in uplands

B Inflow to the basin from circulation through bedrock

RECHARGE TO STRATIFIED DRIFT

C Precipitation on valley floor, which infiltrates to water table, unless diverted as evapotranspiration or storm runoff from pavement or saturated soil

D Runoff from adjacent hillsides at shallow depth Through sandy till, through soil horizons and (or) as surface rivulets

E Natural seepage losses from small tributaries not incised to the water table

F Lateral and upward flow from bedrock

G Induced infiltration from rivers near large-capacity wells where the water table is lowered by pumping

DISCHARGE FROM STRATIFIED DRIFT

1 Seepage to river

2 Ground-water evapotranspiration where the water table is shallow

3 Underflow downvalley through stratified drift (not shown)

4 Pumpage from well screened in stratified drift

DISCHARGE FROM BEDROCK

5 Pumpage from well that intersects fractures

LITHOLOGIC UNIT

Till

Stratified drift

Silt and clay

River and streams

Fractured bedrock

Water table

Direction of ground-water flow

Fault

Figure 13. Idealized geohydrologic section in the glaciated Northeast (modified from Randall and others, 1988).

southern Maine (Morrissey, 1983), in east-central New Hampshire (Tepper and others, 1990), and in southeastern New Hampshire (Stekl and Flanagan, 1992; Mack and Lawlor, 1992; Harte and Mack, 1992). In southern Rhode Island, the recharge rate is estimated to be 25 to 31 in/yr (Dickerman and Ozbilgin, 1985; Dickerman and others, 1990; Dickerman and Bell, 1993; Barlow, 1997), 14 in/yr in south-central New Hampshire (Harte and Johnson, 1995), and about 9 in/yr in areas underlain by till (Trench, 1991).

Runoff from till uplands (fig. 13) also provides large amounts of recharge to adjacent stratified-drift aquifers. A study of seepage losses to surface water along a 4-mi reach of the Saco River near North Conway, N.H., in a region of high topographic relief, indicates that adjacent upland areas account for nearly 60 percent of the recharge to stratified drift in this valley (Morrissey and others, 1988).

Factors that affect recharge to crystalline bedrock aquifers in a mountainous setting are described by Harte and Winter (1996). Bedrock recharge is controlled by relief of land and bedrock surface above ground-water sinks (such as lakes) and glacial-drift stratigraphy. Recharge to crystalline bedrock aquifers is estimated to be about 3 to 5 in/yr (Harte and Winter, 1995).

Recharge to an aquifer from surface-water bodies is induced when withdrawal wells reverse natural flow directions and induce flow into the aquifer (fig. 13). Induced infiltration is an important source of water for many high-yielding municipal wells in the study area, especially for those wells within a few hundred feet of lakes, rivers, and wetlands.

Artificial recharge of aquifers is a minor component of total recharge, but does occur in areas where farmland is irrigated, from municipal leach fields in urban areas, and from domestic leach fields in rural areas. Tepper and others (1990) reported that approximately 80 percent of the water pumped from municipal wells in the Saco River Valley aquifer between Bartlett, N.H., and Fryeburg, Maine, is returned to the aquifer through septic systems.

Ground water discharges from aquifers through seepage into streams, lakes, and wetlands; evapotranspiration; and withdrawal from wells (fig. 13). Ground-water discharge, primarily from stratified-drift aquifers, sustains streamflow during dry periods, usually during late summer or early autumn and during droughts. The rate of discharge per square mile of drainage area from coarse-grained stratified drift is greater than that from till (Wandle and Randall, 1994). Ground-water evapotranspiration is another source of discharge from aquifers and is greatest during the April to October growing season (Stekl and Flanagan, 1992). Ground-water evapotranspiration has been estimated to range from 1 to 9 in/yr in the northeastern United States (Lyford and others, 1984).

Ground-water-level monitoring shows that water-level fluctuations are usually greater in till and bedrock uplands than in stratified-drift deposits because of differences in their specific yields, which are a function of lithology (fig. 14). Median water levels for six wells show recharge occurring from approximately January through April as rainfall and snowmelt infiltrate the ground (fig. 14). Little recharge occurs during the summer growing season, however, and ground-water levels decline from April through October. Recharge begins again in the late fall after the growing season, continues into December, and ends when the ground freezes. After the ground thaws, the annual recharge cycle begins again.

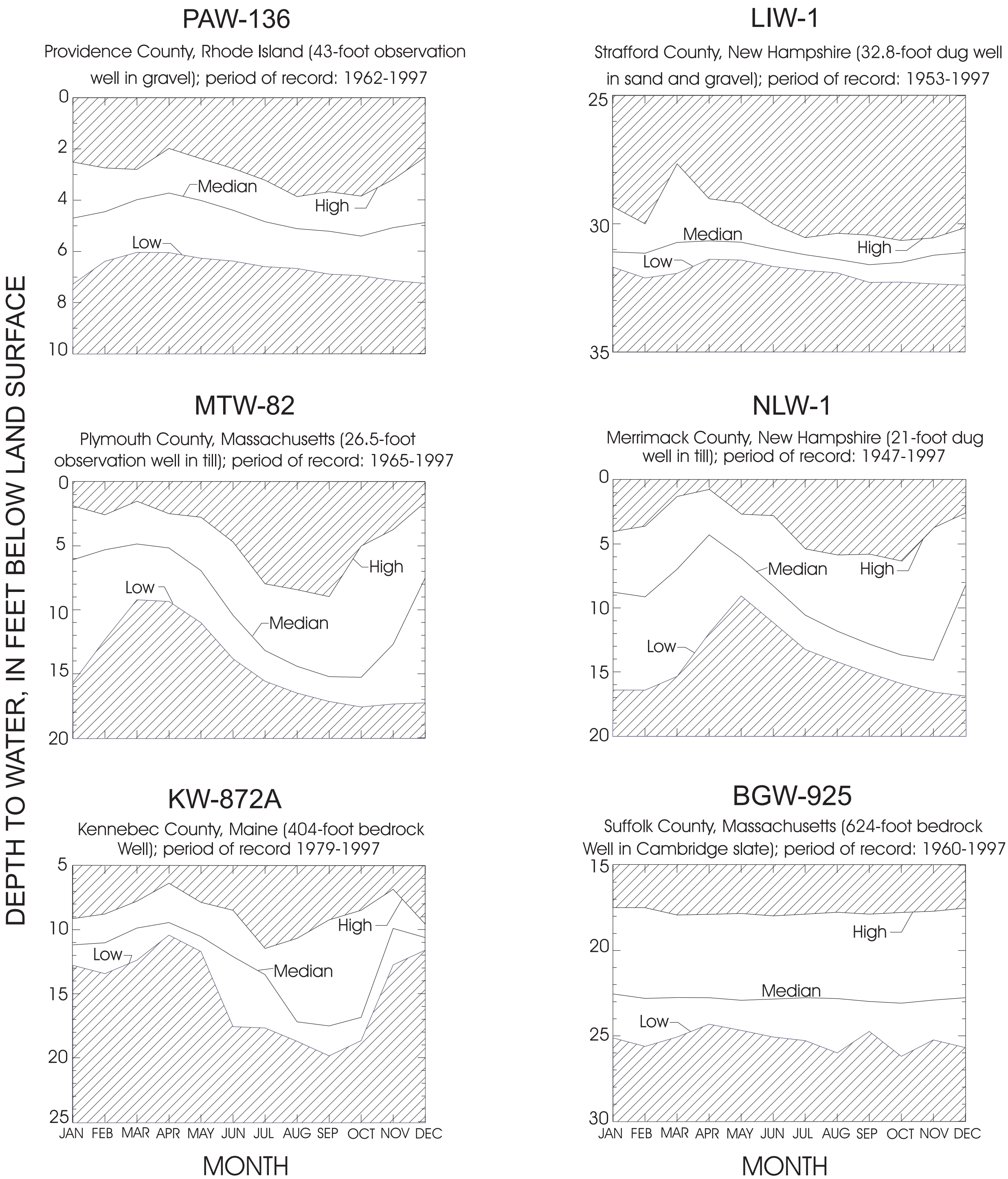


Figure 14. Comparison of monthly median and ranges of water levels in selected observation wells during the 1994 water year in the New England Coastal Basins study area. Unshaded area shows the range between highest and lowest monthly water level for periods of record. (Locations of wells shown on figure 5b).

Ecological Regions and Fisheries

The dominant ecological systems and regions in the study area are described in this section. The biological and physical components of these ecological systems have been grouped into relatively homogeneous ecological regions and systems and into site-specific aquatic habitat types by previous investigators.

Ecoregions

General patterns of vegetation and aquatic habitat can be broadly defined by ecoregions (Omernik, 1987; U.S. Environmental Protection Agency, 1997). These ecoregions were developed for the conterminous United States to divide the landscape into areas having relatively similar characteristics of landform, land use, soil, and "potential natural vegetation" (considered to be the type of climax forest that would develop upon removal of humans and their activities).

The study area includes parts of three national ecoregions (U.S. Environmental Protection Agency, 1997; fig. 15 and table 5). Two of these, Northeastern Highlands and Northeastern Coastal Zone, make up more than 95 percent of the area. These ecoregions generally separate the inland mountainous forested regions from the coastal lowland hills and plains. A small area in the extreme southeastern part of the study area is within the Middle Atlantic Coastal Plain ecosystem. This area is the northernmost section of a coastal area extending through Long Island, New York, and from New Jersey south to Georgia and emphasizes the unique ecological characteristics of the Cape Cod area and the islands of Massachusetts and Rhode Island.

Fisheries

Surface waters have been classified according to whether they contain predominantly warm-water fish species, cold-water fish species, or a mixture of both (fig. 15). Streams and lakes considered to have cold-water fisheries can be loosely defined as waters that support, on a year-round basis, wild and stocked brook trout (*Salvelinus fontinalis*) or other species requiring similar conditions. Generally, a cold-water designation is determined from a fish survey of the stream in question. For example, when a viable population of brook trout is found in a stream it is considered a cold-water fisheries. Massachusetts is the only state in the study area that has a formal definition of cold-water fisheries—waters in which the maximum mean monthly temperature generally does not exceed 20^{o} C and, when other ecological factors are favorable (such as habitat), are capable of supporting a year-round populations of cold water stenothermal aquatic life such as trout (Massachusetts Department of Environmental Protection, 1995a). Warm-water fish streams and lakes support fish species such as smallmouth bass (*Micropterus dolomieui*), largemouth bass (*Micropterus salmoides*), and chain pickerel (*Esox niger*). Warm-water streams and lakes can also contain stocked trout or salmon but these fish may not survive year-round. Streams and lakes considered to be a mixture of cold- and warm-water fisheries contain species and habitat that are suitable for both types of fisheries. Furthermore, a stream may be considered a mixed fishery when there is a transition from a cold to a warm-water fishery along its stream reaches.

Streams and lakes in Maine were classified in the Inland Fisheries River Management Plan (Maine Department of Inland Fisheries and Wildlife, 1982). Streams and lakes in New Hampshire were classified using information provided by State fisheries biologists (Jonathan Greenwood and Charles Thoit, New Hampshire Department of Fish and Game, oral commun., 1994). Information regarding fisheries in Rhode Island was provided by a State fisheries biologist (Dennis Erkan, Rhode Island Department of Environmental Management, Division of Fish and Wildlife, oral commun., 1997).

In the study area, the geographical distinction between cold- and warm-water fisheries closely follows the distinction between the Northeastern Highlands and Northeastern Coastal Zone ecoregions (fig. 15). The landform surface also is important in determining the temperature of a stream because of differences in elevation. The landform surface of the Northeastern Highlands is low mountains and typically have lower water temperatures than the valleys in the Northeastern Coastal Zone. Kimball (1986) showed that for Massachusetts the location of cold-water streams was closely dependant on elevation. Cold-water fisheries generally were limited to streams throughout the state that had a minimum mean basin elevation of 190 ft; the maximum mean monthly temperature of streams at this elevation typically did not exceed 20^{o} C. Elevation, however, can not be used exclusively to determine which

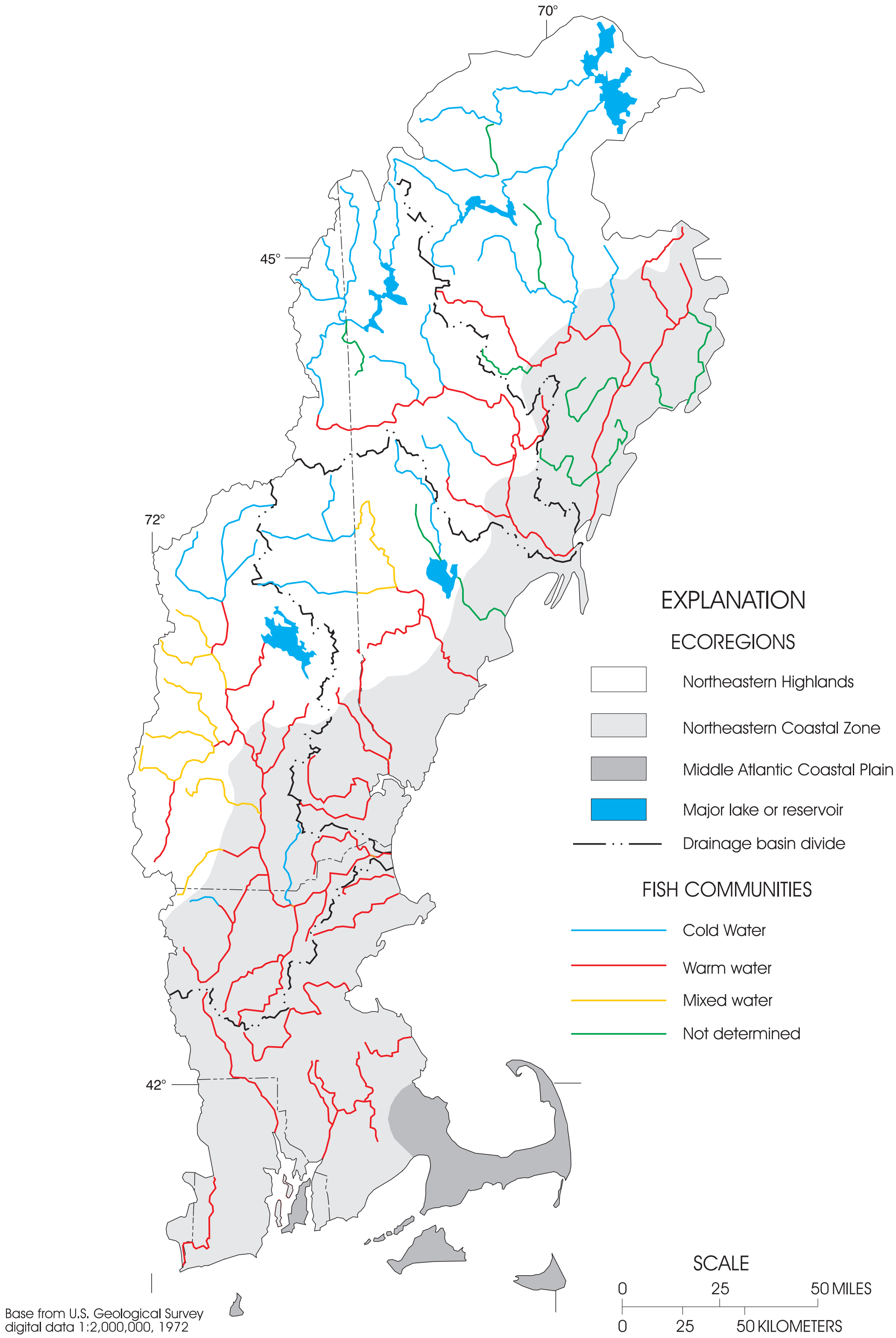


Figure 15. Ecoregions and fish communities in the New England Coastal Basins, in Maine, Massachusetts, New Hampshire, and Rhode Island.

Table 5. Descriptions of ecoregions in the New England Coastal Basins study area in Maine, Massachusetts, New Hampshire, and Rhode Island

[mi^2, square miles; --, no data; from Omerik, 1987]

Ecoregion name	Area, in mi^2 (percent of study area)	Landforms	Potential natural vegetation	Land cover	General soils
Northeastern Highlands	12,500 (54)	Low mountains, open low mountains	Northern hardwoods/spruce, northeastern spruce/fir, northern hardwoods	Forest and woodland (mostly ungrazed)	Spodosols (frigid and cryic)
Northeastern Coastal Zone	9,850 (42.5)	Irregular plains, plains with low hills, open hills (no extremes)	Appalachian oak forest	Woodland and forest with some cropland and pasture, urban	Inceptisols
Middle Atlantic Coastal Plain	860 (3.5)	Flat plains	Oak/hickory/pine	Woodland and forest with some cropland and pasture, swamp	--

streams are cold-water fisheries. Anthropogenic changes can alter streams from cold- to warm-water fisheries. Conversely, cold-water fisheries can be found at low elevations in protected headwater streams. These streams are able to support cold-water species because they are primarily fed by ground water, have dense vegetative cover, and have high gradient slopes—all of which contribute to cool water with high dissolved oxygen. For these reasons, state biologists prefer to determine the status of a stream, with regard to the fish it can support, by sampling the fish community along a designated segment rather than by elevation only.

Despite the widespread modification of aquatic habitat that has taken place over the 200 years as a result of dams, water pollution, shoreline development, and the introduction of exotic species, the rivers and lakes of the study area continue to support varied fisheries. Efforts to restore Atlantic salmon, American shad, and alewive to many rivers and streams began in the early 1970's. These efforts have included providing upstream passages in streams that were formerly blocked, the release of juvenile fish, and assessing potential habitat (Technical Committee for Anadromous Fish Restoration in the Merrimack River, 1990; and U.S. Fish and Wildlife Service, 1987). Maine, New Hampshire, Massachusetts, and Rhode Island have routine fish stocking programs that focus on important freshwater-game fishes. These stocking programs help to support fish populations that are often depleted by recreational fishing.

Population

The population of the study area in 1990 was about 7.78 million, an increase of about 14 percent between 1970 and 1990 (U.S. Bureau of the Census 1990 decennial census files). The study area is characterized by a population density that ranges from sparsely populated mountainous areas (less than 5 persons per mi^2) in parts of the headwater regions of northern New Hampshire and north-central Maine to the densely populated Boston, Mass. metropolitan area (more than 13,000 persons per mi^2). The study area contains six major metropolitan areas (table 6, fig. 16a). The Kennebec River Basin has about 0.21 million people (or less than 3 percent of the total in the study area), the Androscoggin River Basin about 0.20 million (also less than 3 percent), the Saco and northern coastal River Basins about 0.65 million (about 8 percent), the Merrimack River Basin about 1.76 million (about 23 percent), and the Southern coastal Basins about 4.96 million (about 64 percent).

Table 6. Population of the major metropolitan areas in the New England Coastal Basins study area in Maine, Massachusetts, New Hampshire, and Rhode Island

[Location of the metropolitan areas are shown in figure 16a]

Major metropolitan area	Population in 1992
Lewiston-Auburn, Maine	103,844
Portland, Maine	244,378
Boston, Mass.-N.H.	5,669,802
Providence-Fall River-Warwick, R.I.-Mass.	914,627
Barnstable-Yarmouth, Mass.	189,006
New London-Norwich, CT.-R.I.	248,246

Change in population density from 1970 to 1990 ranged from a loss of 114 persons per square mile in the Nashua River Subbasin to a gain of 250 persons per square mile in the Blackstone River Subbasin (fig. 16b). Plymouth County, Mass., Hillsborough County, N.H., and Rockingham County, N.H. were the fastest growing counties in the study area from 1970 to 1990 (fig. 1, U.S. Bureau of the Census, 1991). Suffolk County, which contains the city of Boston, decreased in population by nearly 8 percent from 1970 to 1990 (fig. 1). The expansion of the interstate highway system has allowed people to move further away from the old, densely populated metropolitan areas like Boston, Mass. and Providence, R.I. into the expanding suburban areas of east-central Massachusetts, southern New Hampshire, south-coastal Maine, and southern Rhode Island.

Land Use and Land Cover

Historically, rivers have played a major role in the development of the region's economy and land-use patterns. When European settlers first arrived in New England during the early seventeenth century, they found as much as 95 percent of the land covered with forests (Beattie and others, 1983). By 1870, more than half of the land in central and southern New England was cleared for crops, hay, pasture, and livestock. The agrarian base of the region's early economy resulted in small farms and small, closely spaced town centers. During the same period, the northern forests were extensively harvested for lumber. The Androscoggin and Kennebec Rivers (fig. 7) and their tributaries served as major transportation routes for harvested timber. These rivers also supplied hydropower and water for the many saw, pulp, and paper mills built to process wood products.

Regeneration of the forests in central and southern New England started with the westward expansion of the railroad and the beginning of the industrial revolution in the mid-1800's. As railroads began to provide transportation of food and other goods to the west, textile, leather, shoe, and other industries that required water power became established along the major rivers of New England. Many New England families abandoned their farms to work in these factories and mills or moved west in search of better opportunities. As a result, much farm land reverted back to forests and woodland. It was not until 1960 that the amount of agricultural land reverting to forest land leveled off (Frieswyk and Malley, 1985). Currently (1998), many of the large cities that are adjacent to rivers in the region, such as Manchester and Nashua, N.H., and Lawrence, Lowell, Haverhill, Methuen, Fall River, and New Bedford, Mass., began as factory or mill towns.

Land-use and land-cover information for the study area is derived from data compiled for the entire United States from topographic maps and high altitude aerial photographs at a scale of 1:250,000 and computerized at that scale (fig. 17) (Anderson and others, 1976). These data layers are a compilation of land use and land cover dating from about 1973 to 1981, and are available as Geographic Information and Retrieval System (GIRAS) files (U.S. Geological Survey, 1990). The urban part of this land-use data was updated with the U.S. Bureau of the Census 1990 population density data to reflect more accurately the current extent of residential and urban areas (Hitt, 1994). The land-use and land-cover information is classified as a

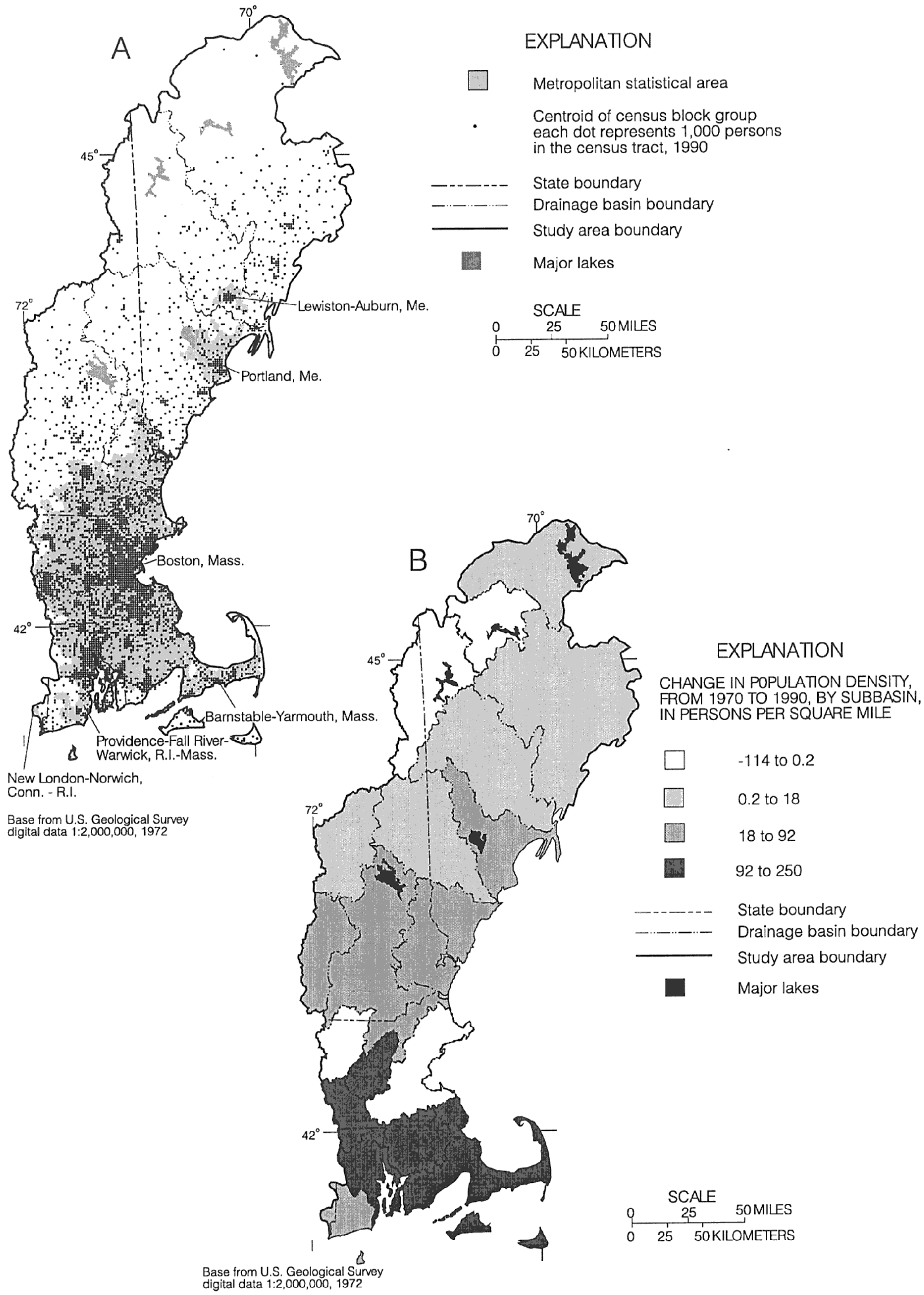


Figure 16. (A) Population distributions and metropolitan statistical areas in the New England Coastal Basins area in Maine, Massachusetts, New Hampshire, and Rhode Island (data from U.S. Census decennial files). (B) Changes in population density from 1970 to 1990, by subbasin.

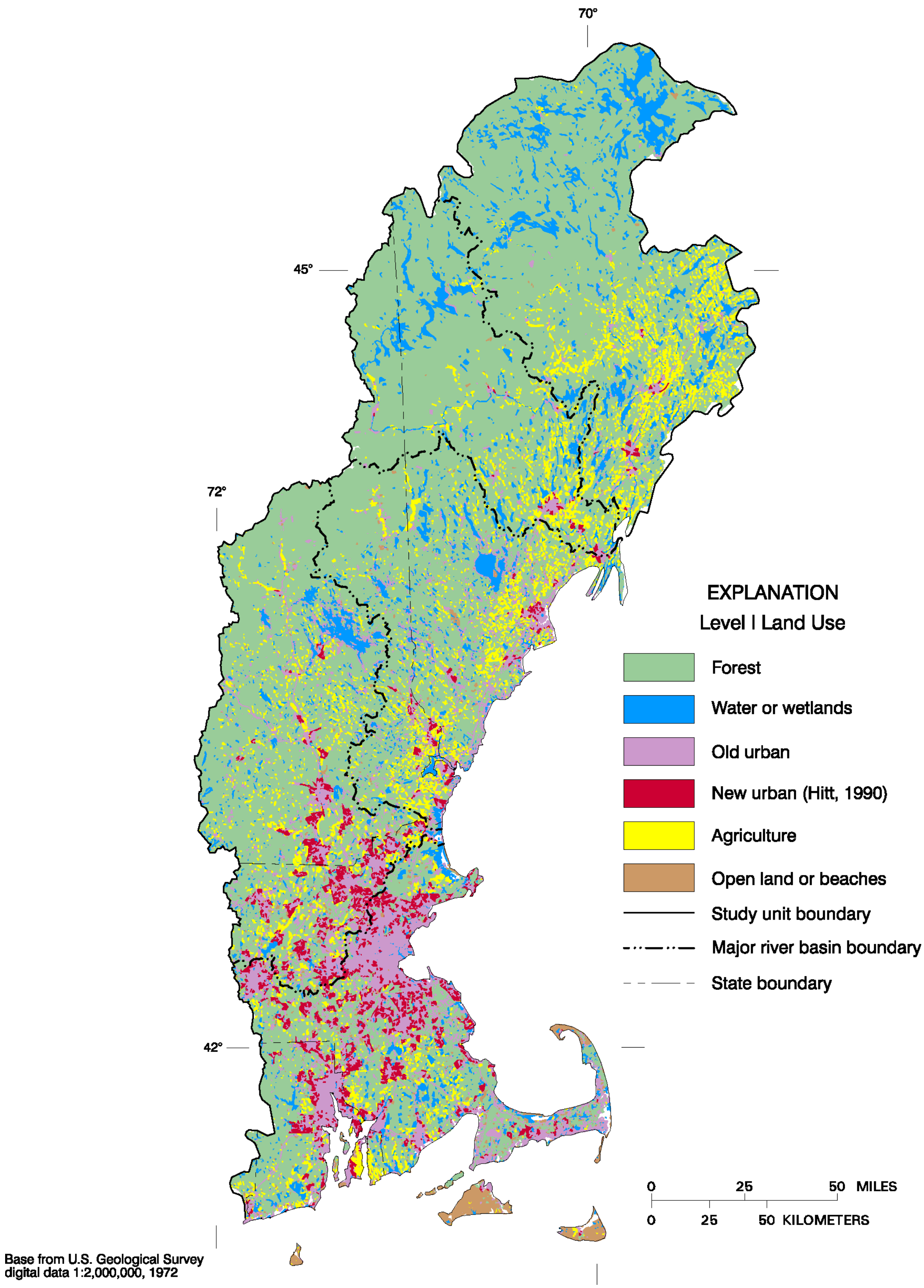


Figure 17. Generalized land use and land cover of the New England Coastal Basins, in Maine, Massachusetts, New Hampshire, and Rhode Island.

Table 7. Land use and land cover, by major river basin, in 1990, in the New England Coastal Basins study area, in Maine, Massachusetts, New Hampshire, and Rhode Island

[Surface water includes areas coded as surface water (lakes, ponds, reservoirs, rivers) and wetlands; Other includes areas coded as rangeland, barren, and beaches; Data from the U.S. Geological Survey's Geographic and Retrieval System]

Major river basin	Land use category, in square miles (percent of basin)					
	Forest	Urban	Surface water	Agriculture	Other	Total
Kennebec	4,841 (81.7)	96 (1.6)	601 (10.2)	371 (6.3)	13 (0.2)	5,922 (100)
Androscoggin	3,043 (86.6)	72 (2.0)	230 (6.6)	161 (4.6)	8 (0.2)	3,514 (100)
Saco and northern coastal	3,162 (75.6)	381 (9.1)	309 (7.4)	295 (7.1)	33 (0.8)	4,180 (100)
Merrimack	3,785 (75.3)	668 (13.3)	263 (5.2)	276 (5.5)	33 (0.7)	5,025 (100)
Southeastern coastal	2,204 (52.6)	1,386 (33.0)	312 (7.3)	219 (5.1)	205 (2.1)	4,326 (100)
Totals	17,035 (74.2)	2,603 (11.3)	1,715 (7.5)	1,322 (5.7)	292 (1.3)	22,967 (100)

hierarchical system of general (level 1) to more specific (level 2) characterization. The level 1 classification of "Forest Land", for example, is further subdivided into a level 2 classification as either deciduous, evergreen, or mixed evergreen-deciduous forest land. Although these data layers are somewhat outdated, with the exception of the urban areas, they represent the most current study-wide information available.

The updated land-use cover shows that there are four primary categories: forest land (74 percent); urbanized areas (11 percent); surface-water bodies such as rivers, lakes, wetlands, and reservoirs (8 percent); and agriculture (6 percent) (table 7). The areal pattern of land use is predominantly forest cover in the northern sections of Maine and New Hampshire; older, densely populated urban areas around the metropolitan cities of Boston and Providence; expanding suburban areas around these two cities; and small agricultural areas scattered throughout the lowland and coastal areas (fig. 17).

Forests

Forests cover 86.6 percent of the Androscoggin River Basin, 81.7 percent of the Kennebec River Basin, 76 percent of the Saco and northern coastal Basins, 75 percent of the Merrimack River Basin, and 53 percent of the Southern coastal Basins (table 7). These forests are primarily evergreen or mixed evergreen-deciduous. Recreation and timber harvesting for lumber and paper products are the primary economic activities in the forested lands in Maine and New Hampshire. The large expanse of forest cover includes most of the White Mountain National Forest (WMNF) (fig. 1). The WMNF covers 892 mi^2 (570,900 acres) in the study area and includes the headwaters of the Merrimack, Androscoggin, and Saco Rivers. Also included in the WMNF is the Hubbard Brook Experimental Forest in West Thorton, N.H., which covers 11.6 mi^2 and, since 1955, is world-renowned for its studies by the U.S. Forest Service and academia on the ecology and biogeochemistry of a northern hardwood ecosystem (Bormann and Likens, 1979).

Paper and timber companies own large tracts of commercial-grade timberland in northern New England. The U.S. Forest Service and the Governors' Task Force on Northern Forest Lands (1990) reported that as much as 95 percent of the northern forests in Maine are privately owned; forest statistics show that 86 percent of commercial forest lands in New Hampshire are privately owned (Cullen and Leak, 1988). Individuals own 90 percent of the commercial forest lands as small tracts in Massachusetts; and 88 percent in Rhode Island (Dickson and McAfee, 1988a, 1988b). Much of the wood harvested in northern New England is used for pulp and paper production industries. These industries are concentrated along the upstream reaches of the Kennebec and Androscoggin Rivers.

Since 1954, over 10 million acres in northern Maine have been treated with chemical and biological insecticides to reduce spruce-budworm (a defoliator) populations in the spruce-fir forest lands (Tom Doak, Maine Department of Conservation, Forest Service, written commun., 1994). From 1954-67, dichlorodiphenyltrichloroethane (DDT) was used to treat 21,000 to 479,000 acres of affected forest lands in northern Maine. From 1970 through 1979, chemical insecticides such as fenitrothion, mexacarbate, carbaryl, and the bacteria *bacillus thuringiensis* (Bt) were used on areas ranging from 40,000 to 3.5 million acres in northern Maine (New England River Basins Commission, 1980a).

In commercial-grade timberlands, herbicides are applied to control emergent vegetation on recently harvested areas. In 1991, chemical herbicides were aerially sprayed over 12,000 acres of recently harvested forest lands in the Maine part of the study area to control the growth of emerging hardwoods and shrubs. By 1993, over 20,000 acres (31.3 mi^2 or 68 percent more than in 1991) of recently harvested forest lands (primarily in Somerset County, Maine) were sprayed with chemical herbicides (Tom Doak, Maine Department of Conservation, Forest Service, written commun., 1994). In total, these chemically treated acres represent only 0.3 percent of the land area in the Maine part of the study area. The two most commonly used chemical herbicides to control emergent vegetation in recently harvested forest areas are triclopyr (trade name ‘Garlon’) and glyphosate (trade name ‘Rodeo’).

Agriculture

The soils and climate of the study area are generally more suitable for growing trees than for growing crops. The 6 percent of the study area classified as crop land is primarily along major rivers underlain by fine-grained stratified drift in the valley lowlands and coastal plains. From 1985 to 1994, the number of farms declined 9 percent, but the average size of the farms (140 acres per farm) has not significantly changed (U.S. Department of Agriculture, National Agricultural Statistics Service, written commun., 1995).

The primary crops produced in the five major river basins are hay, corn, potatoes, fruits and vegetables (table 8), and lesser amounts of ornamental shrubs and Christmas trees. Cranberry farming is an important agricultural activity in Barnstable County, Mass., where 40 percent of the Nation’s cranberry crop is produced.

About 107,000 head of beef and dairy are raised on farms throughout the study area (U.S. Department of Agriculture, Natural Resource Conservation Service, written commun., 1994). Dairy farming, still a principal agricultural activity, is declining as a result of rising land values, regulated milk prices, and competition with mid-western states. Poultry farming is a prominent agricultural activity in several counties, most notably Kennebec County, Maine.

Table 8. Estimated agricultural production, by major river basin, in 1994, in the New England Coastal Basins study area in Maine, Massachusetts, New Hampshire and Rhode Island, in 1994

[--, no data; data from District Conservationists, U.S. Department of Agriculture Natural Resource Conservation Service, written commun., 1994]

Significant agricultural activity	Estimated acres	Estimated production, in 1994
KENNEBEC RIVER BASIN		
Livestock	147,000	67,400 head
Poultry	730	975,000 birds
Horses	5,400	2,700 head
Vegetables	5,000	--
Fruit orchards	1,000	--
Corn (and potatoes)	9,250	18 to 20 tons per acre
Hay	12,600	3 tons per acre
ANDROSCOGGIN RIVER BASIN		
Livestock	11,000	14,500 head
Fruit orchards	3,100	14,800 tons
Horses	800	400 head
Hay	17,400	37,600 dry tons
Silage corn	5,500	75,350 green tons
Poultry	20	25,000 birds
Vegetables	730	--
SACO AND NORTHERN COASTAL RIVERS BASIN		
Hay	104,900	3 tons per acre
Vegetables	8,100	--
Fruit orchards	9,900	350 bushels per acre
Livestock	25,500	16,000 head
Corn	5,500	15 tons per acre
MERRIMACK RIVER BASIN		
Hay	34,500	2.5 dry tons per acre
Livestock	33,000	10,500 head
Fruit orchards	6,700	2.5 tons per acre
Vegetables	6,600	90 to 350 bushels per acre
Silage corn	4,800	18 tons per acre
SOUTHERN COASTAL RIVERS BASIN		
Hay	26,500	2 dry tons per acre
Livestock	--	30,300 head
Cranberries	15,000	--
Corn	9,200	116,400 green tons + 35,000 bushels
Fruit orchards	8,200	--

Estimates of nitrogen and phosphorus fertilizer use, not including manure application, for farm and non-farm applications were made for each county in the United States from 1945-91 (Richard Alexander, U.S. Geological Survey, written commun., 1995). These estimates are based on state-level fertilizer application rates compiled by the U.S. Department of Agriculture (Alexander and Smith, 1990). State data were disaggregated to the county by use of data from the U.S. Department of Agriculture Census of Agriculture survey for the number of fertilized acres in each county. The county-level data were then multiplied by the fertilizer-use rate in each state to obtain estimated fertilizer use in each county.

In 1991, nitrogen fertilizer use ranged from near zero pounds per acre in Suffolk County, Mass. (which contains the metropolitan city of Boston), to 13.5 lbs/ac in Plymouth County, Mass. (fig. 18). In 1991, phosphorus (as phosphate) fertilizer use ranged from near zero lbs/ac in Suffolk County to 6.1 lbs/ac in Newport County, R.I. (fig. 18). In general, nitrogen and phosphorus fertilizer use were lowest in the headwater regions (or mountainous areas) and heavily urbanized areas and highest in the lower regions (or coastal areas) where most of the farming occurs.

A recent study by Pait and others (1992) summarized pesticide use in cultivated agricultural lands in the Nation's estuarine drainage basins for the year 1987. The study combined the nation's major estuarine drainage basins into five major areas. The North Atlantic estuarine drainage area (NAEDA) covers all coastal basins in eastern New England from Maine to eastern Massachusetts. Most of the New England Coastal Basins study area is in the NAEDA. According to this study, herbicides are applied to harvested croplands in the NAEDA primarily in April and May, insecticides primarily in May, and fungicides primarily from June through August. Atrazine was the dominant herbicide applied in the NAEDA with almost 53,000 lbs, or 21 percent of the total agricultural pesticides used. Other major herbicides used included 2,4-D (more than 21,000 lbs) and alachlor (more than 18,000 lbs). Carbofuran was the most heavily applied insecticide in the NAEDA (almost 8,000 lbs), followed by carbaryl (more than 7,000 lbs). These two insecticides are applied primarily to crops like corn, potatoes, and apples. Metiram was the dominant inventoried fungicide applied in the NAEDA, accounting for 25 percent (65,000 lbs) of the total agricultural pesticides used. Metiram was applied primarily to apples.

Urban and Industrial Activities

About 11 percent of the study area is classified as urban (fig. 17), of which 74 percent is residential, 10 percent is commercial, 5 percent is transportation, 2 percent is industrial, and 9 percent is other urban use. The percentage of urban land use ranges from 1.6 percent in the Kennebec River Basin to 33 percent in the Southern coastal Basins (table 7). The amount of newly urban lands classified from Hitt (1994), covers 492 mi^2; this represents an increase in urban lands of almost 19 percent since the 1970s and early 1980s (fig. 17). Also, about 230 mi^2 of these newly urban lands (or nearly 47 percent) overlie stratified-drift deposits.

Textile, leather, and shoe industries were the prominent industries in the major cities in the 19th and first half of the 20th century. The cities of Fall River, Lowell, Lawrence, Haverhill, Fitchburg, and New Bedford, Mass., and Manchester and Nashua, N.H., were nationally renowned for their textile mills and apparel industries (New England River Basins Commission, 1978). By the late 1950's, these industries began to decline throughout the New England States in response to competition with other markets in the United States and abroad. For example, employment in the textile industry in Rhode Island declined from 76,000 employees in 1941 to only 8,000 employees in 1995 (Vincent K. Harrington, Rhode Island Economic Development Corporation, written commun., 1996). Currently (1998), these older industries are being replaced or augmented by a more diverse economic base that locally includes rubber, paper, and plastic products; electrical machinery; food processing; wholesale and retail trade; construction; transportation and public utilities; finance; insurance; and real estate; health services; jewelry and toy manufacturing (in Rhode Island); and high technology industries such as computers and telecommunications. Pulp and paper manufacturing continue to be important industries in the upper parts of the Kennebec, Androscoggin, and Presumpscot River Basins.

In the densely populated urban areas, water is generally supplied by public and private utilities and sanitary-sewer collection systems transport wastewater to treatment facilities that discharge into major rivers or coastal (saline or brackish) areas. In 1990, 19 municipal wastewater-treatment facilities returned an average of 28.9 Mgal/d of treated wastewater back to rivers, streams, and coastal waters in the Kennebec River Basin, 14 facilities returned 19.8 Mgal/d in the Androscoggin River Basin, 42 facilities returned 68.4 Mgal/d in the Saco and northern coastal Basins, 48 facilities returned 129.8 Mgal/d in the Merrimack River Basin, and 67

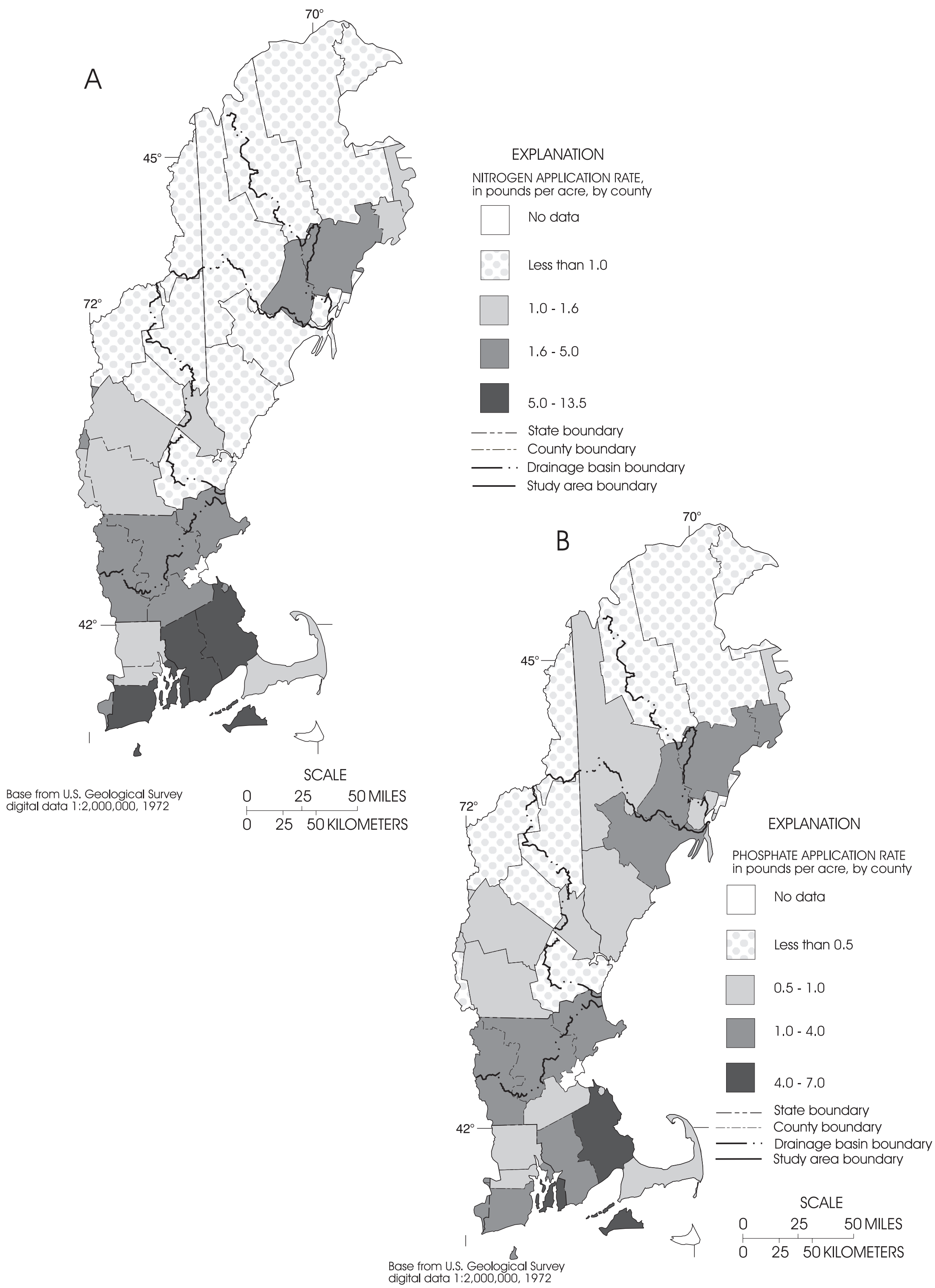


Figure 18. Nitrogen (A) and phosphate (B) fertilizer use in 1991, by county, in the New England Coastal Basins study area. [Data from Richard Alexander, U.S. Geological Survey, written commun., 1995.]

facilities returned 808.4 Mgal/d in the Southern coastal Basins (Medalie, 1996) (fig. 19). There are approximately 810 industrial waste-water dischargers in the study area (fig. 19; National Oceanic and Atmospheric Administration, written commun., 1997). The top nine industrial facilities are steam electric (non-cooling), metal finishing, water-supply treatment plant, machinery, pulp and paper, organic chemical production, electrical, electronic computer, and miscellaneous commercial-industrial.

There is also a net loss of water to a basin when a part of the total return flow from the affected basin is discharged into coastal waters. The volume of municipal waste-water return flow going directly into saline waters was 551 Mgal/d from the Southern coastal Basins and 42 Mgal/d from the Saco River Basin; this equals 56 percent of all total return flows in the study area (Medalie, 1996).

An inventory of more than 300 toxic chemicals that are released directly to the environment through the air, water, or land is maintained in the USEPA's Toxic Release Inventory (TRI) (U.S. Environmental Protection Agency, 1994). According to the TRI, about 12.3 million pounds of toxic chemicals were released to the environment in Maine, Massachusetts, New Hampshire, and Rhode Island in 1992. About 11.4 million pounds or 93 percent of the total were released to the air; the remaining 7 percent to land or water. In 1992, there were 21 industrial and chemical facilities from the TRI in the Kennebec River Basin, 23 in the Androscoggin, 54 in the Saco and northern coastal Basins, 211 in the Merrimack, and 481 in the Southern coastal Basins (fig. 20). The top 12 toxic chemicals released by industrial and commercial facilities in the four states in 1992 were toluene, 1,1,1-trichloroethane, methyl ethyl keytone, freon 113, trichloroethylene, sulfuric acid, hydrochloric acid, chlorine, chloroform, methanol, acetone, and xylene. Facilities releasing these chemicals to the air, water, and land include paper companies in Maine and northern New Hampshire and manufacturing companies in Massachusetts, southern New Hampshire, and Rhode Island (U.S. Environmental Protection Agency, 1994).

In 1997, there were 14,179 hazardous-waste sites in the study area (Amy Hoyt, U.S. Environmental Protection Agency, written commun., 1996). About 13,451 sites are managed under the USEPA's Resource Conservation and Recovery Act (RCRA) program, 638 sites are managed under the USEPA's Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA or Superfund) program, and 90 military sites are managed under the Federal Facilities program (fig. 21).

Use of Water

Surface waters and ground waters are withdrawn primarily for domestic (or household), thermoelectric, commercial, and industrial uses. This water could be withdrawn by a public supplier or withdrawn by the user directly from an aquifer or from a lake or river. In-stream use for hydropower generation far exceeds total withdrawals and therefore is not included in the overall water-withdrawal compilations in this report. Water-withdrawal data were compiled from the USGS National Water-Use Information Program for the year 1995. Total withdrawals (from ground and surface waters) were about 1,430 Mgal/d with 31 percent derived from ground-water sources and 69 percent from surface-water sources (table 9).

Total surface-water withdrawals (for domestic, thermoelectric, commercial, industrial, mining, livestock, and irrigation use) exceeded ground-water withdrawals in all basins because surface waters tend to be used more by municipalities and industries, thermoelectric power plants, and gravel-pit operators. However, about 155.5 Mgal/d of surface water is withdrawn from the Quabbin Reservoir in the Connecticut River Basin (outside of the study area) in central Massachusetts and transferred to the Southern coastal Basins (primarily for domestic use to the city of Boston and about 45 surrounding cities and towns and managed by the Massachusetts Water Resources Authority) (Joseph Whitley, U.S. Geological Survey, oral commun., 1997). If this interbasin transfer was not counted, then total ground-water withdrawals in the southern coastal Basins would have exceeded surface-water withdrawals by a 54 to 46 ratio (table 9). In addition, about 90.6 Mgal/d of surface water is withdrawn from the Wachusett Reservoir in the Nashua River Subbasin and used in the southern coastal Basins (also primarily for domestic use). These surface waters, withdrawn from the Connecticut and Merrimack River Basins and used in the southern coastal Basins, are the largest interbasin transfer of waters in New England (Medalie, 1996).

More than 99 percent of thermoelectric water use (230 Mgal/d) is at one fossil-fuel burning power

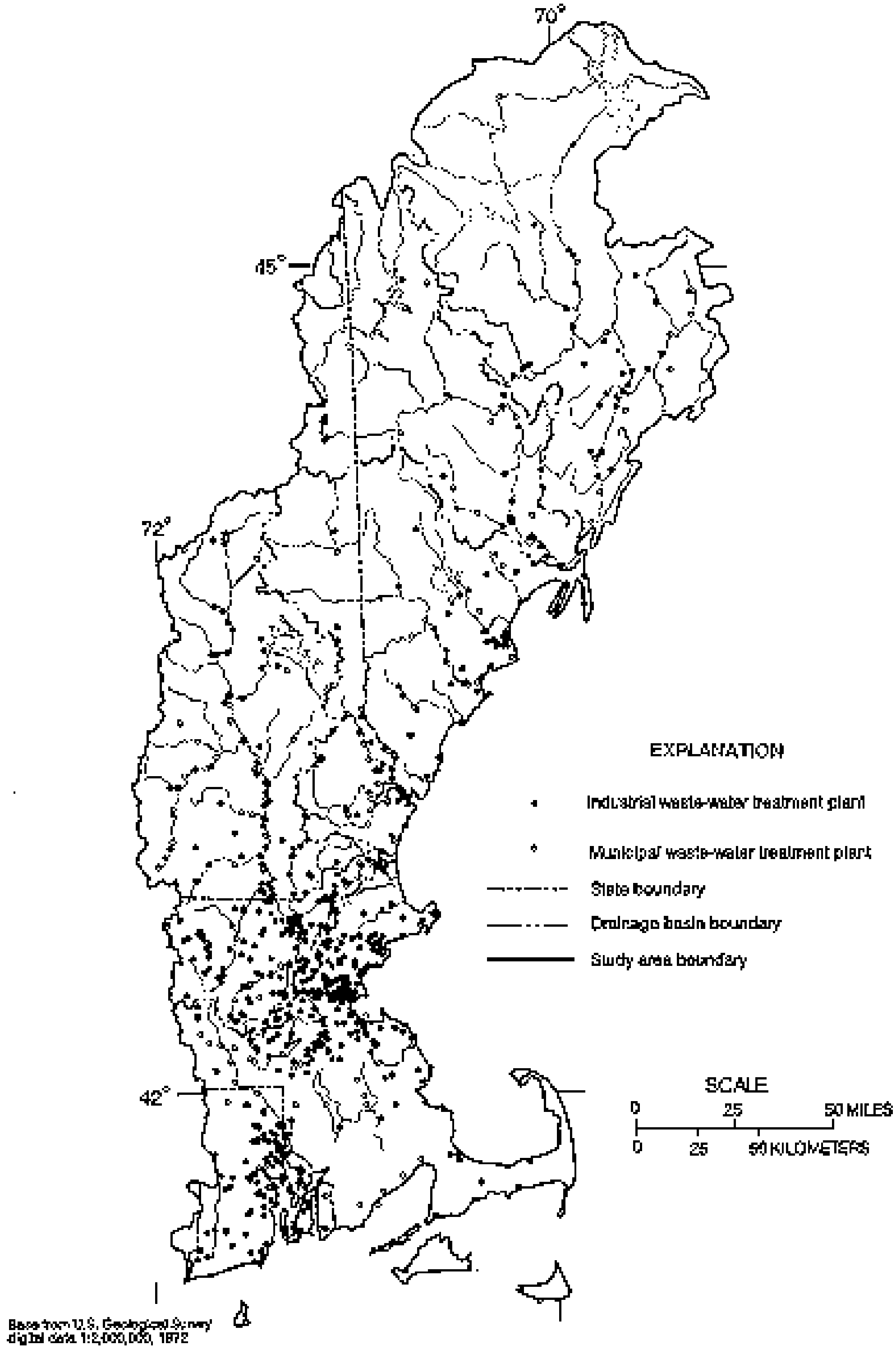


Figure 19. Location of selected industrial and municipal waste-water treatment plants in the New England Coastal Basins study area. [Data from National Oceanic and Atmospheric Administration, written commun., 1997, and Medalie, 1996.]

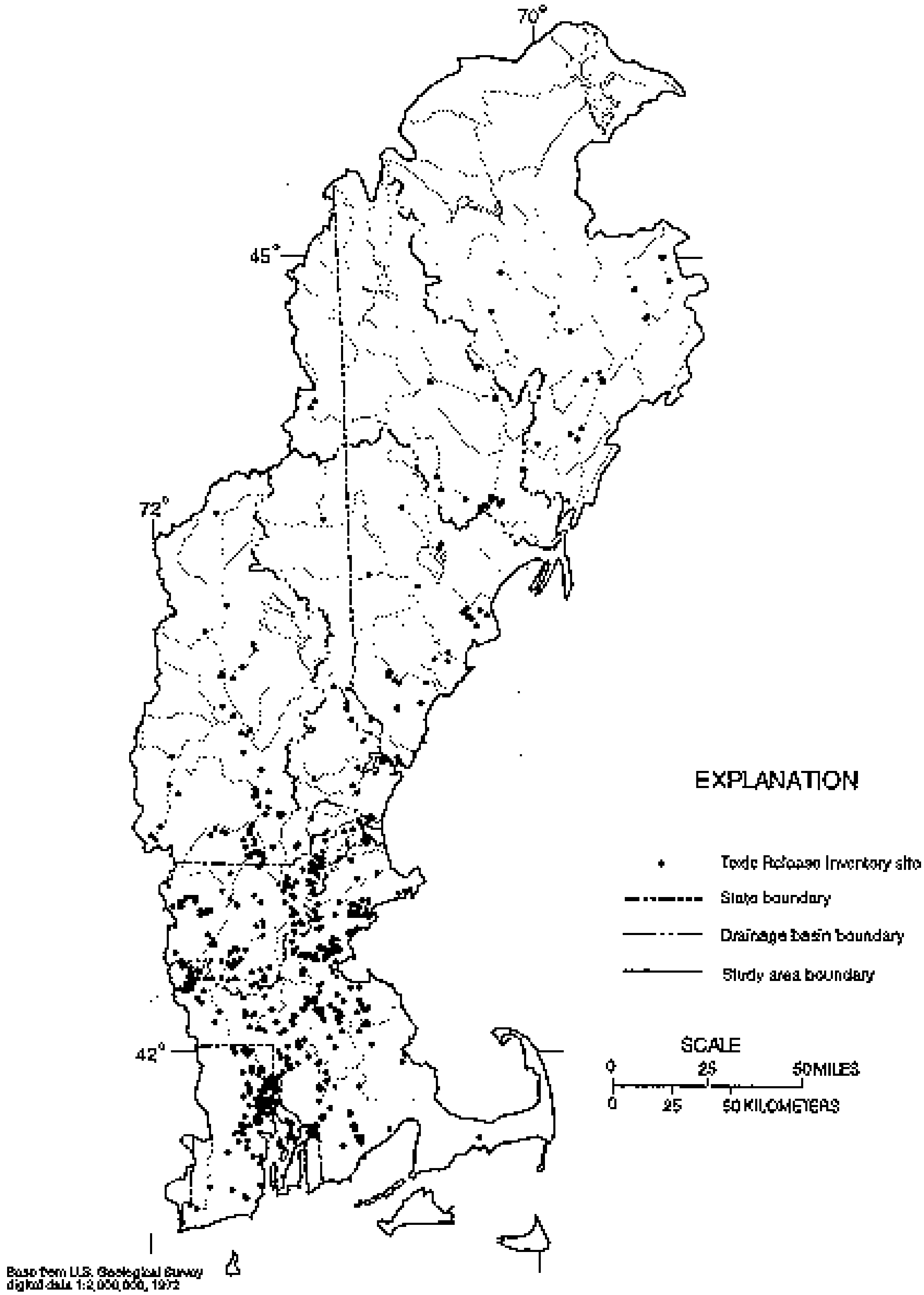


Figure 20. Location of toxic-release-inventory (TRI) sites in the New England Coastal Basins study area. [Data from the U.S. Environmental Protection Agency, 1994.]

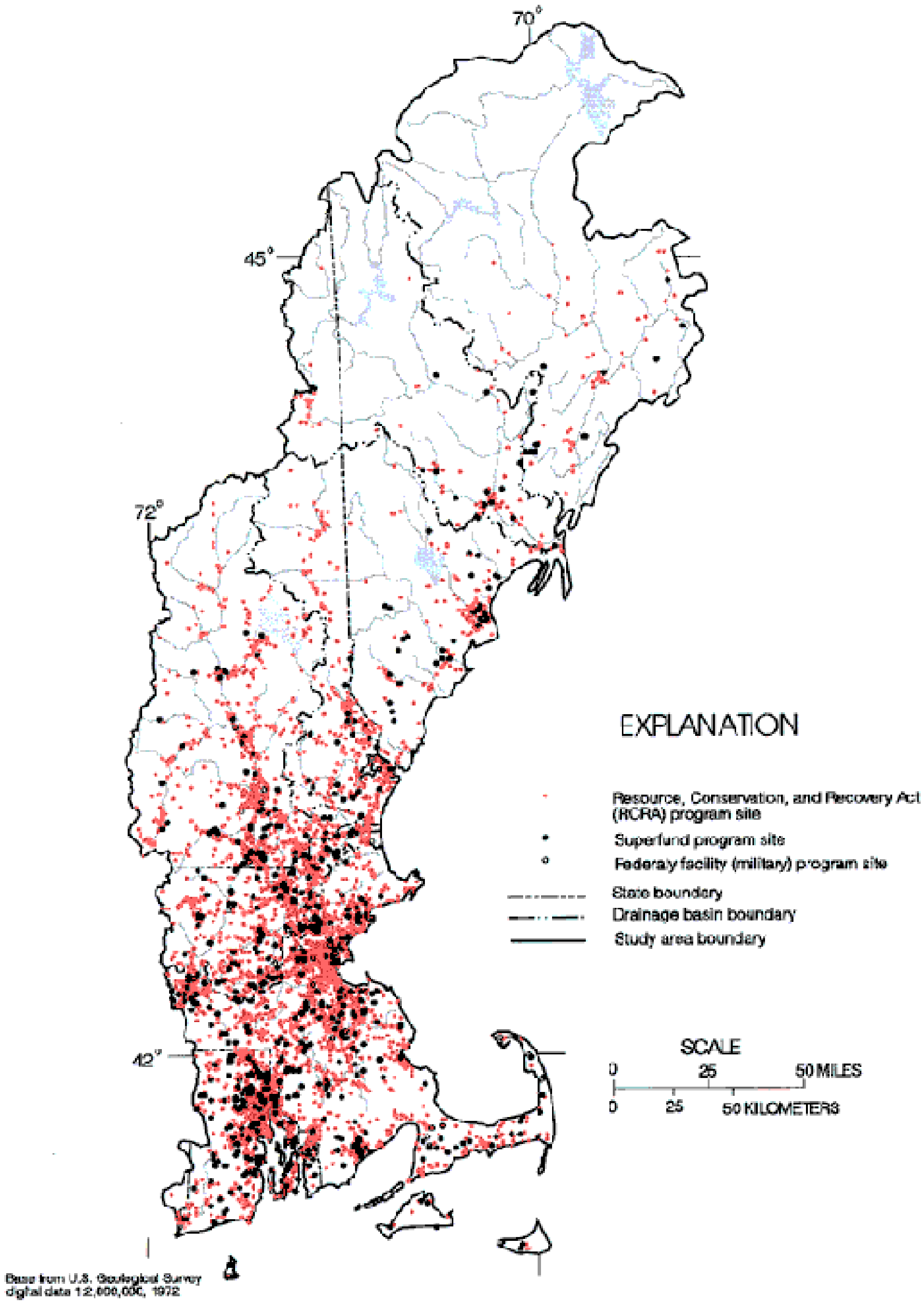


Figure 21. Location of hazardous-waste sites in the New England Coastal Basins study area. [Data from the U.S. Environmental Protection Agency, 1997.]

facility in Merrimack County, N.H. in the Merrimack River Basin (Medalie, 1997, p. 9). This facility withdraws water from the Merrimack River to use in its cooling system, and then returns the (warmer) water directly back to the river.

Total ground-water withdrawals (for domestic, thermoelectric, commercial, industrial, mining, livestock, and irrigation use) in the southern coastal Basins exceeds withdrawals from the other major basins in the study area. The proportion of total ground water withdrawn from each basin is dependent on the extent of productive stratified-drift aquifers, cost of using ground water in relation to surface water, population density at or near the water source, and the predominant use. Water withdrawn from fractured-bedrock aquifers is used primarily for domestic use and is generally available in much smaller quantities than water withdrawn from stratified-drift aquifers. For example, stratified-drift deposits cover 6.3 percent of the Androscoggin River Basin. As a result, less than 16 percent of water withdrawals from this basin were derived from ground water. In contrast, large, productive, stratified-drift aquifers are common in the southern coastal Basins; ground-water withdrawals provided 42 percent of total water withdrawals in that basin (table 9).

Table 9. Summary of total fresh-water withdrawals in 1995, by major basin and source, in the New England Coastal Basins study area in Maine, Massachusetts, New Hampshire, and Rhode Island

[Mgal/d, million gallons per day; Total fresh-water withdrawals include public-supply, self-supply, thermoelectric, commercial, industrial, mining, livestock, and irrigation, but excludes hydroelectric (or other in-stream) use. Public-supply and self-supply withdrawals for domestic use are summarized in table 10]

Major river basin	Total ground-water withdrawals, in Mgal/d (percent of total for basin)	Total surface-water withdrawals, in Mgal/d (percent of total for basin)
Kennebec	16.72 (38)	27.33 (62)
Androscoggin	9.98 (16)	52.84 (84)
Saco and northern coastal	44.58 (40)	67.9 (60)
Merrimack	96.96 (18)	[1] 446.57 (82)
Southern coastal	276.09 (42)	[2] 389.54 (58)
Study area totals	444.33 (31)	984.18 (69)

[1] Approximately 90.6 Mgal/d is withdrawn from the Merrimack River Basin, but is used in the southern coastal Basins.

[2] Approximately 155.5 Mgal/d is withdrawn from the Quabbin Reservoir in the Connecticut River Basin (outside of the study area in central Massachusetts, but is used in the southern coastal Basins.

Withdrawals from ground-water and surface-water sources for domestic use (defined as that water which is used for drinking water and other uses by households) in 1995 are further defined in table 10. Ninety percent of total (for the study area) public-supplied withdrawals from ground water sources were from the more populated Merrimack and Southern coastal Basins, as were 63 percent of total self-supplied withdrawals from ground water and 89 percent of total public-supplied withdrawals from surface water (table 10). Self-supplied withdrawals from ground-water sources exceeded public-supplied ground-water withdrawals in the sparsely populated Kennebec and Androscoggin Rivers, and the Saco and northern coastal Rivers Basins. Since self-supplied ground water comes primarily from the bedrock aquifer and public-supplied ground water comes primarily from stratified-drift aquifers, people in the rural, northern part rely more on the bedrock aquifer as a source of drinking water than people in the urban, southern part.

Table 10. Summary of public-supply and self-supply withdrawals for domestic use in 1995, by major basin and source, in the New England Coastal Basins study area in Maine, Massachusetts, New Hampshire, and Rhode Island

[PSGW, public-supplied ground water; Mgal/d, million gallons per day; SSGW, self-supplied ground water; PSSW, public-supplied surface water; SSSW, self-supplied surface water]

Major river basin	Population served by PSGW, in thousands of persons	PSGW with-drawals, in Mgal/d	Population served by SSGW, in thousands of persons	SSGW with-drawals, in Mgal/d	Population served by PSSW, in thousands of persons	PSSW with-drawals, in Mgal/d	Population served by SSSW, in thousands of persons	SSSW with-drawals, in Mgal/d
Kennebec	35	2.27	103	6.77	70	4.54	0	0
Androscoggin	35	2.29	66	4.3	77	5.15	0	0
Saco and northern coastal	174	12.91	244	16.36	286	19.72	1.7	0.12
Merrimack	695	47.28	354	24.41	657	47.81	4.9	0.34
Southeastern coastal	1,628	108.21	343	22.46	3,085	[1]198.33	0	0
Study area totals	2,567	173	1,110	74.3	4,175	275.6	6.6	0.46

[1]Approximately 155 Mgal/d originates in the Quabbin Reservoir in the Connecticut River Basin (outside of the study area).

IMPLICATIONS OF ENVIRONMENTAL SETTINGS FOR WATER QUALITY AND AQUATIC BIOTA

Surface waters and ground waters in the study area exhibit significant variations in quality; surface waters also contain a diversity of aquatic biota. In areas where human presence is minimal, the quality of waters and aquatic communities may approach natural or "pristine" conditions. Conversely, waters in areas that have been significantly altered by man could be highly degraded chemically and biologically. This section summarizes publications that provide an overview of water quality and aquatic biota in the study area and for particular environmental settings.

Surface Water

Bedrock geology controls the natural quality of surface waters in the study area. The presence of weather-resistent igneous and metamorphic rock units and thin soils results in surface waters that naturally contain low concentrations of dissolved and suspended solids. Rainwater (1962) notes that surface waters in New England contain less than 100 mg/L of dissolved solids and 275 mg/L of dissolved solids and suspended solids, respectively; these amounts are small compared to waters nationally. Calcium and magnesium ions are the prevalent cations in New England waters (Rainwater, 1962). Carbonate-bicarbonate anions are the principal anions in waters found in the high altitudes and sulfate and chloride anions are the principal anions in waters near the Atlantic Coast.

Alkalinity generally is low in the highest elevations and high in valleys having agricultural and urban lands (fig. 22). Most streams have alkalinity values less than 200 μeq/L (Griffith and Omernik, 1988). In comparison to other areas of the Eastern United States, Hendrey and others (1980) found that the New England Coastal Basins are underlain by large amounts of bedrock with low to no buffering capacity. As a result, the surface waters of the study area are highly susceptible to acidification by acidic precipitation.

Establishing the natural quality of the major rivers is difficult because the hydrology of the watersheds of all the major rivers in the study area have been significantly modified by man for nearly 3 centuries. Information from studies of small headwater streams in relatively undisturbed watersheds can be used to provide a general assessment of natural water quality in the study area. The chemistry of surface waters in the Hubbard Brook Experimental Forest (HBEF), White Mountain National Forest, New Hampshire, has been studied extensively since the early 1960s and the conclusions are summarized by Likens and Bormann (1995). Streams in the HBEF drain 30-106 acres and represent high-gradient streams draining northern hardwood forests in the Northeastern Highlands ecoregion. HBEF streams are acidic (pH of 4-5) because of the dominating presence of sulfuric and nitric acids from precipitation. Geochemical-weathering reactions neutralize the acids and bicarbonate alkalinity increases as water travels through the watersheds. Likens and Bormann (1995) found that even though there are steep slopes and high precipitation rates, erosion and transport of suspended (particulate) matter from forested watersheds is relatively low.

The Wild River at Gilead, Maine (drainage area of 70 mi^2) is monitored as part of the USGS Hydrologic Bench-Mark Network; stations in this network provide data for watersheds affected principally by natural conditions. During water years 1987-89, the median value for specific conductance was approximately 10 *u*S/cm, dissolved oxygen was 12 milligrams per liter (mg/L), fecal coliform and fecal streptococcus bacteria was 1 colony per 100 mL, alkalinity was 3 mg/L, dissolved solids was 17 mg/L, suspended solids were 2 mg/L, and dissolved nitrate plus nitrite was less than 1 mg/L (Olson and Cowing, 1993). The Wild River is mildly acidic with pH ranging between 6.0 and 6.5. On the basis of USGS water-quality monitoring in Rhode Island. Concentrations of dissolved inorganic constituents in streams in undeveloped areas are low (generally less than 100 mg/L) according to Bell (1993). Stream waters are also typically soft (hardness of less than 60 mg/L as calcium carbonate) and slightly acidic. Bedrock, glacial deposits, and soils in Maine that are composed largely of relatively insoluble silicate minerals determine these stream-quality conditions.

The influence of human activities on stream-water quality varies from the headwaters or upstream sections of the major river basins to the outlets of the rivers near their discharge to coastal waters. Human population is generally greatest near the coast and, as a result, water-quality and habitat degradation is more pronounced. In addition, human activities during the

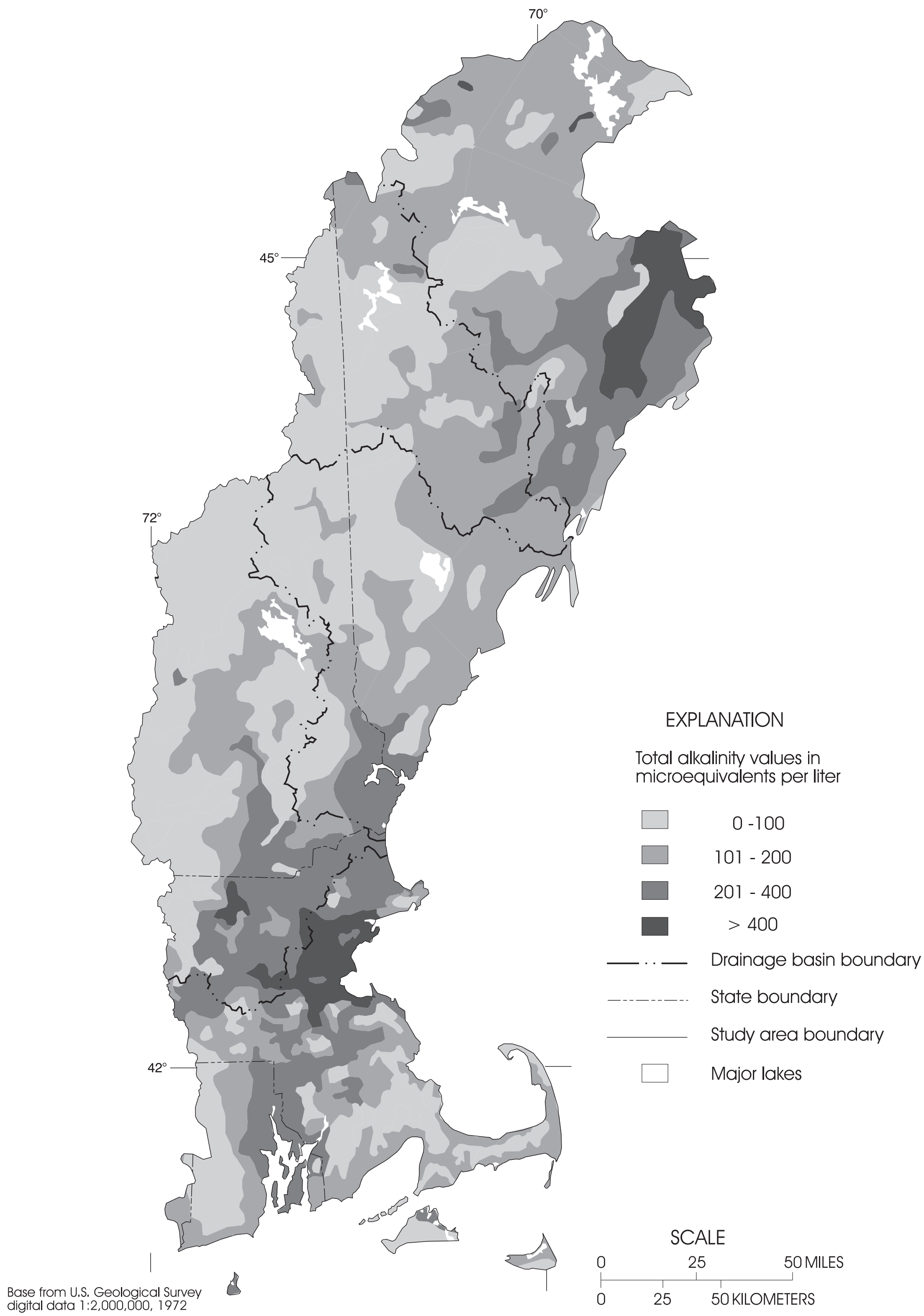


Figure 22. Total alkalinity of streams and rivers in the New England Coastal Basins study area (modified from Griffith and Omernik, 1988).

past 200 years have had significant historical effects on the waters in the study area. The discharge of raw sewage from population centers and wastes from tanneries, textile, and pulp and paper mills was pervasive earlier this century. The Androscoggin River in Maine (fig. 7) was classified as one of the Nation's 10 most polluted rivers in the 1960s and 1970s (Olson and Cowing, 1993) and typhoid and cholera outbreaks were common in cities that withdrew drinking water from rivers in the study area (Mills, 1987; and Anthony, 1969). River water quality has improved throughout New England since the passage of the Federal Water Pollution Control Act in 1972 (U.S. Environmental Protection Agency, 1995).

The quality of streams in the study area in relation to specific state water-quality criteria, and the factors that cause water-quality degradation, have been described by each state in State Water-Quality Inventory Reports (Maine Department of Environmental Protection, 1994; Rhode Island Department of Environmental Management, 1994; Massachusetts Department of Environmental Protection, 1995; New Hampshire Department of Environmental Services, 1996). According to information in these reports and summarized by the USEPA (data from http://www.epa.gov/surf/IWI/data, December 1997), approximately 82 percent of the rivers and streams assessed in the study area meet state water-quality criteria designated for each water body and 18 percent are partially or fully impaired. Typically, waters are impaired if they are of unsuitable quality for swimming, maintaining healthy aquatic biota, and (or) have a fish consumption advisory posted. Rivers and streams classified as partially or fully impaired are found throughout the study area but, overall, more waters are impaired in Massachusetts and Rhode Island than in Maine and New Hampshire. Pathogens, volatile organic compounds, organic enrichment, nutrients, and metals rank as the most common causes of impairment. Sources for these causes include industrial and municipal point sources, urban runoff, streamflow regulation, impoundments, unknown sources, natural sources, and contaminated sediments (Maine Department of Environmental Protection, 1994; Rhode Island Department of Environmental Management, 1994; Massachusetts Department of Environmental Protection, 1995; New Hampshire Department of Environmental Services, 1996).

A summary of surface-water-quality conditions and trends at selected locations and for selected properties and constituents in each of the four states can be found in Bell (1993), Olson and Cowing (1993), Strause (1993), and Toppin (1993). Greater concentrations of dissolved chloride, dissolved sulfate, dissolved solids, dissolved nitrate and nitrite, and total phosphorus were generally found in the Blackstone, Charles, Pawcatuck, and Merrimack Rivers (fig. 7) during water years 1987-89 than in the Kennebec, Androscoggin, Saco, and Presumpscot Rivers. The Blackstone, Charles, Pawcatuck, and Merrimack River Basins all have a greater population density, more urban lands, and greater numbers of wastewater discharges than the Kennebec, Androscoggin, Saco, and Presumpscot River Basins (see figs. 16, 17, 19). Upward trends of dissolved oxygen were found in the Blackstone, Kennebec, and Presumpscot Rivers; increases in dissolved oxygen concentrations are usually associated with improvements in wastewater treatment (Olson and Cowing, 1993; Strause, 1993). Increases in specific conductance were common throughout the Merrimack River Basin and are likely the result of increased usage of road deicing salt and waste discharges in this developing basin (Toppin, 1993). The impact of deicing salts on the water quality of streams can be significant; Mattson and Godfrey (1994) determined that the 223 million kilograms (kg) of road salt applied by the State of Massachusetts annually accounts for 63 percent of the variation in sodium concentrations found in Massachusetts streams.

Preliminary analysis of total phosphorus data collected by the USGS at National Stream-Quality Network sites in the study area from the 1970s to the early 1990s indicates that the greatest total loadings of phosphorus (calculated as mean daily loads) at these sites are in the Merrimack, Kennebec, and Androscoggin River Basins (fig. 23) (Marc Zimmerman, U.S. Geological Survey, written commun., 1997). The greatest yields of phosphorus, calculated in $lb/d/mi^2$, were from the Blackstone, Merrimack, and Charles River Basins. Yields of phosphorus in the Blackstone River (approximately 2.2 $lb/d/mi^2$) were about 2.5 times that found in the Merrimack River (approximately 0.9 $lb/d/mi^2$).

Contaminated sediments are an important water-quality concern in Massachusetts and Rhode Island (Rhode Island Department of Environmental Management, 1994; Massachusetts Department of Environmental Protection, 1995a). The Massachusetts Department of Environmental Protection (1995a)

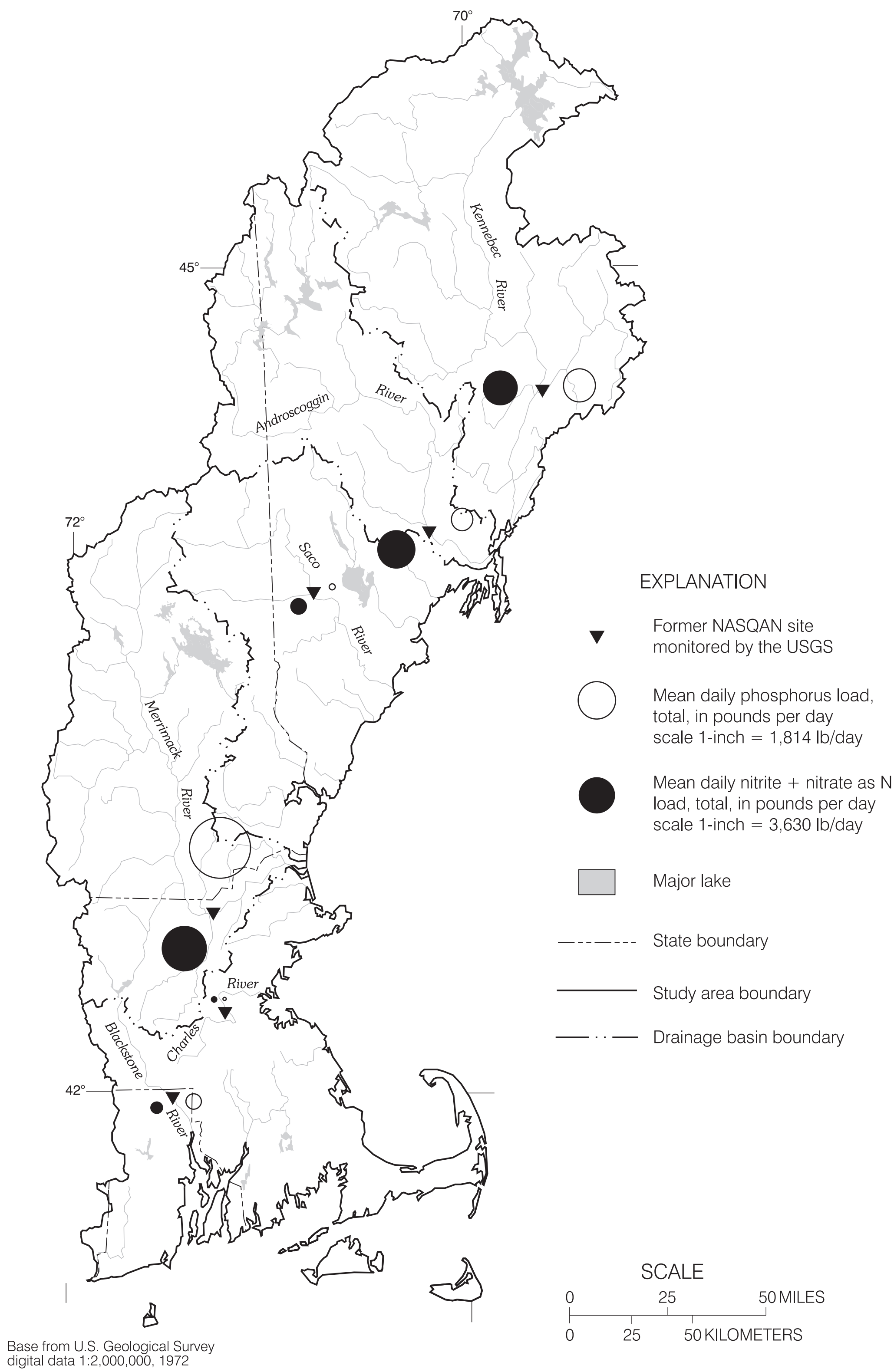


Figure 23. Mean daily total phosphorus and total nitrite plus nitrate, as N, loading at selected National Stream-Quality Accounting Network (NASQAN) sites in the New England Coastal Basins study area.

identified a number of streams in the study area that have contaminated sediments; these streams and the contaminants include Blackstone River (metals and synthetic organic compounds), Charles River (metals and oil and grease), Mill River (polychlorinated biphenyls), Sudbury River (mercury), and Ten Mile River (lead). These rivers have a history of industrial and municipal discharges that date to the industrial revolution and numerous impoundments that serve to trap pollutants. Spliethoff and Hemond (1996) assessed sediments for metals in Upper Mystic Lake in the Aberjona River Watershed near Boston. The Aberjona River Watershed historically contained a number of industries including tanneries and chemical manufacturing. They found profiles of arsenic, cadmium, chromium, copper, lead, and zinc in the lake sediments that correspond to periods of intense industrial activities in the Watershed, declines in industrial operations, sewering of the watershed, and remobilization events.

The upstream sections of the Kennebec, Androscoggin, Saco, and Merrimack Rivers, as well as many headwater streams, are largely forested lands, have small population centers, and have mountainous to hilly terrain. Although surface waters in these areas are among the cleanest in the study area, they still suffer from a variety of anthropogenic factors. These include deposition of atmospheric contaminants, silvicultural activities, recreational and tourism-related industries (such as snow-making at ski resorts, summer homes, and associated services), and the hydrologic modification of streams and rivers.

Research performed at the HBEF since the 1960s has described the effects of both atmospheric deposition and silvicultural activities on the hydrology of small headwater basins in environmental settings that are common in the northern part of the study area (Likens and Bormann, 1995; Likens, 1985). The changing chemistry of streams in the HBEF closely mimics the change in precipitation chemistry from the combustion of fossil fuel and industrial processes (Likens and Bormann, 1995). During 1963-93, hydrogen ion and sulfate concentration in HBEF streams decreased as sulfate emissions have decreased. Even with these decreases, sulfate deposition is more than three times the amount that the watershed can neutralize (Likens and Bormann, 1995). Because of the inadequate buffering ability of HBEF streams to neutralize acids, the acidity of streams has increased. Other effects of atmospheric deposition include depletion of calcium from the watersheds, which has been linked to declines in northern forest growth (Likens and Bormann, 1995; Gregory Lawrence, U.S. Geological Survey, written commun., 1997), and nitrogen enrichment of surface waters that can lead to eutrophication of coastal waters (Jaworski and others, 1997). Jaworski and others (1997) estimated that about 64 percent of the total nitrogen exported to coastal waters from 10 basins in the Northeastern United States was due to nitrogen-oxide emissions from fossil fuel combustion. Nitrate fluxes from these basins increased 300-800 percent since the early 1900s and correlate to increases in nitrogen-oxide emissions.

Silvicultural activities include the logging of timber, road building in forests, forest regeneration, and management of forest emergent growth and pests with pesticides. Studies in HBEF found that logging and deforestation in small watersheds (approximately 100 acres or less) can increase streamflow by 30 percent and the export of nutrients 10-40 times (Likens, 1985). Effects of commercial clear cuts in large watersheds of northern New Hampshire found similar, but less extreme responses (Likens, 1985). Smith and McCormack (1988) assessed watershed losses of the herbicide triclopyr from a regenerating forest in northern Maine. They reported that total triclopyr losses from the watershed totalled 0.02 percent of the total herbicide applied. Concentrations of the herbicide in streams leaving the treated area peaked immediately after application and 6 days later as a result of a runoff event. Whereas this study indicates that there is movement of silvicultural pesticides, studies that have tested for concentrations of silvicultural pesticides in surface or ground waters throughout the northern region of the study area are unknown.

Near the major timber harvesting lands are a number of pulp and paper mills. The quality of waters near these industrial operations has been affected in the Kennebec, Androscoggin, Presumpscot, and previously, the Merrimack River Basins (Maine Department of Environmental Protection, 1994; New Hampshire Department of Environmental Services, 1996). Pollutant loadings to surface waters have been significantly reduced by the pulp and paper mills in the last 20 years. Dioxin contamination from pulp and paper mills in the Kennebec and Androscoggin Rivers continues to prevent attainment of state designated stream uses (Maine Department of Environmental Protection, 1994; New Hampshire Department of Environmental Services, 1996).

Ground Water

Natural ground-water quality is affected predominately by the types of rocks and sediments through which the water travels. Chemically, ground water is affected by four important natural processes (1) mineral dissolution and mineral precipitation, (2) oxidation-reduction reactions that can be either chemically or biologically induced, (3) ion-exchange reactions, and (4) mixing of ground waters of different chemical compositions (Johnson, 1988).

Assessments of the ground-water quality of stratified-drift aquifers for the States of Maine, Massachusetts, New Hampshire, and Rhode Island summarized existing data on dissolved solids, dissolved ions, hardness (as calcium carbonate), nutrients, and trace elements (Frimpter, 1988; Maloney, 1988; Morrissey, 1988; Trombley, 1992; and Johnston and Barlow, 1988; Medalie and Moore, 1995). These reports describe ground water from stratified-drift aquifers as containing small concentrations of dissolved solids, (generally less than 100 mg/L), with a hardness of less than 35 mg/L as calcium carbonate (and, are therefore, considered soft water), and being slightly acidic (pH often being between 5.5 and 6.5). The sand and gravel in stratified-drift aquifers are predominantly quartz and feldspar that originate from crystalline bedrock and are not easily soluble. Another reason for the small amounts of dissolved solids in stratified-drift water is the young age of the water. Because stratified-draft aquifers are generally thin (less than 100 ft) and are composed of sand and gravel, the water in the aquifers is usually recently recharged through precipitation. This results in water that generally is dilute, low in dissolved materials, and contains measurable amounts of dissolved oxygen. Ground water in stratified drift is extremely vulnerable to contamination from activities at the land surface.

Water from stratified-drift aquifers may have concentrations of iron and manganese that require treatment before distribution in public or domestic supplies (Simcox, 1992). These elements, which are the products of weathering of minerals and dissolution of oxide coatings on aquifer sediments, are easily dissolved in acidic water in the absence of oxygen. Water in stratified-drift aquifers commonly contains dissolved oxygen near saturation levels; however, oxygen can become depleted when ground water passes through organic deposits, such as peat or river-bed sediments. As a result, water from a well screened below an organic layer becomes progressively enriched in iron and manganese as pumping draws ground water through the organic layer (Simcox, 1992). A summary of ambient water-quality conditions from stratified-drift aquifers in New Hampshire showed that 51 out of 257 samples had higher dissolved iron concentrations than the USEPA secondary maximum contaminant level (SMCL) of 0.3 mg/L and 136 samples had manganese concentrations exceeding the SMCL of 0.05 mg/L (Medalie and Moore, 1995).

The quality of water from bedrock varies because the chemical composition of the bedrock varies. Water from crystalline-bedrock aquifers has greater concentrations of dissolved solids and higher specific conductance values than water from stratified-drift aquifers (Frimpter, 1988; Maloney, 1988; Morrissey, 1988; and Johnston and Barlow, 1988). Simcox (1992) reports that crystalline-bedrock aquifers in Massachusetts have median dissolved-solids concentrations of 120 mg/L, are moderately hard (median of 90 mg/L as calcium carbonate), and are slightly alkaline (median pH of 7.8). Like water from stratified-drift aquifers, crystalline-bedrock aquifers have waters that frequently contain concentrations of iron and manganese above State and Federal drinking-water standards. Sources of iron include schist and gneiss that contain an abundance of ferromagnesium minerals or appreciable amounts of pyrite and pyrrhotite (Frimpter, 1988).

Water from crystalline bedrock wells tend to contain measurable amounts of arsenic (Frimpter, 1988; Marvinney and others, 1994; and Morrissey, 1988). Approximately 10 to 15 percent of arsenic analyses from ground waters throughout Maine and New Hampshire exceeded the USEPA 50 μg/L maximum contaminant level (Morrissey, 1988; Marvinney and others, 1994). Concentrations of arsenic in Maine were statistically higher in water from bedrock wells than in water from dug wells and springs (Marvinney and others, 1994). The source of arsenic in wells is unknown. In New Hampshire, Boudette and others (1985) did not find any specific cause for the arsenic; in Maine, Marvinney and others (1994) found that the arsenic in wells could not be associated with a particular rock type.

Radon in ground water is most prevalent in the Northeastern United States and especially in New England (Zapecza and Szabo, 1988). Radon-222, a radioactive-decay product of uranium, has been found in elevated concentrations in water from crystalline-rock wells throughout the study area (Hess and others, 1979). The highest levels of radon in ground water in Maine and New Hampshire are found in water pumped from igneous plutons and granites containing the micas muscovite and biotite (Maloney, 1988, Morrissey, 1988) and in high-grade metamorphic rocks (Hall and others, 1985). The New Hampshire Department of Environmental Services estimates that up to 5 percent of the bedrock wells in the State have significant concentrations of radionuclides such as uranium, radium-222, and radium-228 (Morrissey, 1988).

The most frequently detected contaminants in ground water are volatile organic compounds (VOCs) and other petroleum-related substances (Maine Department of Environmental Protection, 1994, New Hampshire Department of Environmental Services, 1996, and Massachusetts Department of Environmental Protection, 1995a, Rhode Island Department of Environmental Management, 1994). The sources of these contaminants are primarily petroleum storage tanks (above and below ground), accidental spills of petroleum products, and the land disposal of wastes. Contamination of public-supply wells in Massachusetts is caused mostly by elevated VOCs found in the solvents of industrial wastes; many of these contaminated wells are in or near industrial parks. The most commonly detected organic compounds in ground water in Massachusetts are trichloroethylene, methyl chloride, and tetrachloroethylene. Simcox (1992) reports that from 1978 to 1990, 74 public-supply wells and wellfields in Massachusetts have been closed because of contamination and more than 600 domestic wells have been contaminated by VOC's. The Rhode Island Department of Environmental Management (1994) found that approximately 15-30 domestic wells are reported to be newly contaminated by VOC's each year.

Other sources of contamination in the study area is the introduction of chloride and sodium to wells from road-salting and elevated concentrations of nitrates from agricultural activities and on-site septic systems. Concentrations of chloride in many New Hampshire public-supply wells in urban areas have increased significantly since the 1940's when the use of salt to de-ice roads greatly increased (Hall, 1975). Contamination from road-salt storage piles and facilities and spreading of salts on roadways was the cause of 79 percent of the contaminated wells in New Hampshire (Morrissey, 1988). Sodium chloride from seawater intrusion, coastal flooding, and highwater deicing salt is the most common cause for elevated concentrations of dissolved solids in ground water on Cape Cod (Frimpter and Gay, 1979).

The Maine Department of Environmental Protection (1994) estimates that 2 percent of the private wells in Maine have concentrations of nitrate exceeding the 10 mg/L primary-drinking water regulation. The highest concentrations of nitrate were in shallow wells in agricultural areas or near septic systems. Simcox (1992) reports that leachate from landfills has resulted in the closing of at least six public-supply wells and numerable domestic wells in Massachusetts. Landfill leachate commonly contains high concentrations of iron, dissolved solids, nitrogen (as ammonia or nitrate) and waste organic compounds.

Aquatic Biota

Trace elements and synthetic organic compounds, such as organochlorine pesticides and industrial organochlorines, are present in the tissue of fish in some rivers and lakes. As a result, fish consumption advisories have been issued by the States of Maine, New Hampshire, Massachusetts and Rhode Island. Concentrations of mercury greater than or equal to 1 µg/g have been found in predatory fish in many lakes throughout Maine (Stafford, 1994). The primary source of the mercury found in fish tissue is thought to be the incineration and burning of fossil fuels (Terry Haines, U.S. Geological Survey, oral commun., 1994). Furthermore, mercury appears to be the predominant trace metal contaminant in the study area and consequently Maine and New Hampshire have issued comprehensive fish consumption advisories because of its presence in fish tissue (Terry Haines, oral commun., 1994; Dreisig and Dupee, 1994). A fish consumption advisory exists for several rivers and lakes in Massachusetts because of mercury contamination, including the Concord, Merrimack, and Sudbury Rivers, and Walden Pond (Massachusetts Department of Public Health, 1996). In addition to atmospheric deposition, mercury from industrial waste processing has contributed to contamination in Massachusetts and Rhode Island (Russell Isaacs, Massachusetts Department of Environmental Protection, oral commun., 1994). Massachusetts also has a fish consumption advisory for several rivers and lakes because of polychlorinated biphenyl (PCB) contamination, including the Blackstone, Charles, and Muddy Rivers (Massachusetts Department of Public Health, 1996). Rhode Island currently has a fish consumption advisory only for the Woonasquatucket River because of PCB, mercury, and dioxin contamination, but the Rhode Island Department of Health is in the process of assessing the need for a comprehensive statewide advisory because of mercury (Robert Vanderslice, Rhode Island Department of Health, oral commun., 1997).

During 1976-84, the U.S. Fish and Wildlife Service monitored fish tissues in the Kennebec, Androscoggin, and Merrimack Rivers as part of the National Contaminant Biomonitoring Program (NCBP) (Schmitt and Brumbaugh, 1990; and Schmitt and others, 1990). This program analyzed fish tissue for a variety of trace elements and organochlorine compounds from 117 sites nationwide. Results from the program showed that mercury concentrations in fish collected from three sites in the study area tended to be higher than the geometric mean of mercury concentrations determined from the national data set for each year samples were collected. Furthermore, concentrations of PCBs in fish tissue from the Merrimack River were among the highest detected nationally. Among the five NCBP sites in New England (which includes two sites on the Connecticut and Penobscot Rivers), the mean concentrations of lead, cadmium, chlordane, DDT, and PCBs were the highest in fish tissue from the Merrimack River (Major and Carr, 1991).

During the mid-1980s, the U.S Environmental Protection Agency administered the National Study of Chemical Residues in Fish (NSCRF), which involved one-time sampling of fish for trace elements and organochlorine compounds at 388 sites nationwide (U.S. Environmental Protection Agency, 1992). In the study area, five sites were selected on the Androscoggin River, two sites on the Sebasticook River (East and West branches), two sites on the Saco River, and one site on the Merrimack River (fish tissue analyzed for mercury only). Mercury concentrations in fish tissue collected from these rivers were substantially higher than the national median concentrations of mercury. PCB concentrations also were elevated in fish tissue from the Androscoggin River but PCBs were not detected in fish from the Saco River. Concentrations of total chlordane and DDE (primary metabolite of DDT) were generally lower at the sites than the national medians. Overall, among the four rivers containing NSCRF sites, the least contaminated fish tissue were from the Saco River.

Since 1984, the National Oceanic and Atmospheric Administration (NOAA) has coordinated the National Status and Trend Program (NSTP) to monitor spatial distributions and temporal trends of contaminant concentrations in coastal and estuarine regions of the Nation (O'Conner and Beliaeff, 1995). In 1986, the Mussel Watch Project was formed as a component of the NSTP to sample mollusks at about 300 sites nationwide. Although this project has not investigated freshwater systems, the proximity of many sampling sites to the mouths of rivers has provided some indication of the contaminants coming from those rivers. In Massachusetts and Rhode Island, four sampling sites are in Boston Harbor, six in Buzzards Bay (with one site at the mouth of New Bedford Harbor, Mass.), and three in Narragansett Bay. Sites in Boston Harbor and Buzzards Bay were among the most highly contaminated (with PCB's) nationwide. Fish-tissue samples from Boston Harbor had some of the highest concentrations of lead, mercury, and polycyclic aromatic hydrocarbons (PAHs). Overall, however, results of the NSTP have indicated that contaminant concentrations are decreasing in the mollusk tissue in Boston Harbor, Buzzards Bay, and New Bedford Harbor.

The effects of contamination on aquatic biota are reflected in the environment settings of the four States in the study area. Various riverine species of concern, most commonly associated with loss or degradation of habitat, include mollusks, fish, and insects and are inventoried by the State Natural Heritage Program offices. The dwarf wedge mussel (*Alasmidonta heterodon*) is the only biota in the study area on the Federal endangered aquatic species list (U.S. Fish and Wildlife Service, 1990). This mollusk had a historic distribution along coastal basins from New Hampshire to North Carolina, and is found in New Hampshire and Massachusetts. Smith (1995) reported that the mollusk does not live in standing water and is almost extinct in Massachusetts. Martin (1997) described a list of factors responsible for endangering freshwater mussels in Maine that also apply to the entire study area. Primary among these factors are dams, which destroy riffle habitat, create silted and anoxic streambed conditions, alter water temperatures, and interfere with the migration of host fish species. Water withdrawals from rivers, resulting in reduced streamflows, also can affect mussels by exposing or stranding them.

SUMMARY AND CONCLUSIONS

This report describes the physical, cultural, and biological features (termed the environmental settings) of the NAWQA Program's New England Coastal Basins 23,000-mi^2 study area in Maine, Massachusetts, New Hampshire, and Rhode Island. The study area includes the Kennebec, Androscoggin, Saco, Charles, Blackstone, Taunton, and Pawcatuck River Basins, as well as smaller coastal drainage basins. The information in this report will be used to design a monitoring program that will assess how environmental settings influence ground- and surface-water quality.

The study area is divided among two physiographic provinces: the New England Physiographic Province and the Atlantic Coastal Plains. Most of the study area (97 percent) is in the New England Physiographic Province. Only the offshore islands of southern Massachusetts and Rhode Island are part of the Atlantic Coastal Plain Province. The climate is continental because of prevailing westerly winds, although the climate of the coastal areas is influenced by the Atlantic Ocean. Precipitation usually is abundant throughout the year and averages 42 in/yr in some low-lying areas to greater than 60 in/yr on the higher peaks of the White Mountains. Snowfall averages from 20 to 110 in/yr from south to north, respectively. Approximately 1/2 to 2/3 percent of the precipitation that falls becomes runoff in streams. Average temperature for July was 70.3°F and average temperature for January was 23.5°F for the period 1961-90. Winter temperatures have greater variability throughout the study area than summer temperatures based on monthly average temperatures.

There are several hundred different geologic formations in the study area, each distinguished by rock type and age. These rocks consist primarily of high and low-grade metamorphic, igneous, and some sedimentary rocks and include granite, schist, gneiss, quartzite, and calc-silicate. The rocks are complexly deformed. The chemical composition of these units is highly varied. Unconsolidated glacial deposits of till and stratified drift overlie fractured crystalline bedrock in most of the study area. Stratified drift fills most major river valleys and forms almost a complete cover over southeastern Massachusetts (Cape Cod) and the offshore islands of Martha's Vineyard and Nantucket.

Stratified-drift aquifers and fractured-crystalline bedrock aquifers are the most important aquifer systems. Till is the most widely distributed glacial deposit, but is the least important aquifer system. High-yielding, stratified-drift aquifers are an important source of ground water for municipal, commercial, and industrial users. Fractured bedrock aquifers are an important source of ground water for domestic users in rural areas. Stratified-drift deposits cover 21 percent of the study area; coverage ranges from 3.7 percent in the Kennebec River Basin to 53 percent in the Southern coastal Basins. Two types of stratified-drift deposits, ice-contact and outwash, comprise the most productive aquifers in the study area. Hydraulic conductivity of stratified-drift deposits is generally many magnitudes higher than that of till or fractured bedrock.

Soils differ considerably from one another because of the physiography, complex bedrock geology, and the different types of glacial deposits. The type of soils found include spodosols, inceptisols, and histosols. Areas of poorly drained soils, where the soil type is often clayey, are in the coastal zone north of Boston, Mass., and in the northern inland areas of Maine. Moderately-well to well drained soils are present in the upland areas and in areas of stratified-drift deposits (most of the main valleys), as well as areas of high slopes, such as the White Mountains. Very well drained soils are in the sandy outwash plains and end moraines of Cape Cod, Martha's Vineyard, Nantucket, and Block Island.

The USGS currently (1998) operates 90 streamflow-gaging stations in the study area. The largest measured mean annual streamflow is 7,628 ft^3/s on the Kennebec River at Waterville, Maine. Streamflow is highest in April. Fall rains produce a secondary peak in many rivers and streams. The variability in flow from month to month decreases in rivers with a large degree of regulation.

Flows in most of the medium-sized rivers and all of the large rivers are partially to completely regulated. There are more than 1,600 dams that are used for recreation, water supply, hydroelectric power generation, irrigation, flood control, or other purposes (though some are not currently active). Natural lakes and wetlands are abundant in northern New England, providing large amounts of storage for floods and maintaining flows during the drier summer months. The Kennebec River Basin has the greatest amount of lakes, reservoirs, and wetlands compared to the other river basins.

The study area has been delineated into the Northeastern Highlands, Northeastern Coastal Zone, and the Middle Atlantic Coastal Plain ecoregions. Comprising 54 percent of the study area, the Northeastern Highlands are mountainous, contain large tracts of northern hardwood and spruce-fir forests, and have spodosol soils. The Northeastern Coastal Zone has low hills, urban and agriculture lands, inceptisol soils, and covers 42.5 percent of the study area. The Middle Atlantic Coastal Plain, covering only 3.5 percent, has flat plains, woodland and oak/hickory/pine forests with some croplands and pasture.

Most of the major rivers contain cold-water fish communities in headwaters and upstream sections of the main rivers. In downstream sections near the coast, fish communities are generally warm-water types. Habitat modifications, dams and impoundments, the introduction of non-native species, and water pollution have all modified the native fish communities.

In 1990, population was about 7.78 million, an increase of 14 percent from 1970. Population density is low (5 persons per mi^2) in the mountainous areas of northern New Hampshire and Maine and high (more than 13,000 persons per mi^2) in the Boston metropolitan area of eastern Massachusetts.

Land use and land cover is primarily forest land (74 percent), urban land (11 percent), surface-water bodies (8 percent), and agricultural land (6 percent). Land use is predominantly forest cover in the northern sections of Maine and New Hampshire, densely populated urban areas near the metropolitan cities of Boston and Providence, Rhode Island, and small agricultural areas scattered throughout the lowland and coastal areas.

The forest-products industry and recreation are the primary economic activities in the forest lands in northern New Hampshire and northern Maine. The largest public land area is the White Mountain National Forest, which covers 892 mi^2 in the headwater regions of the Merrimack, Androscoggin, and Saco Rivers. Paper and timber companies own most of the commercial forest lands as large tracts in northern New England. Individuals own the commercial forest lands as small tracts in southern New England. Major agricultural activities include growing hay, corn, potatoes, fruits and vegetables, and raising cattle and dairy cows. Cranberry farming in Barnstable County, Mass. produces 40 percent of the Nation's crop. In 1991, nitrogen fertilizer use ranged from near zero lbs/ac in Suffolk County, Mass. to 13.5 lbs/ac in Plymouth County, Mass. In 1991, phosphorus (as phosphate) fertilizer use ranged from near zero lbs/ac in Suffolk County to 6.1 lbs/ac in Newport County, R.I.

About 11 percent of the study area is classified as urban. In the densely populated urban areas, water is generally supplied by public and private utilities, and sanitary-sewer collection systems transport waste water to treatment facilities. In 1990, 190 municipal waste-water-treatment facilities returned an average of 1,055.3 Mgal/d of treated waste water back to rivers, streams, and coastal waters in the study area.

In 1992, about 12.3 million pounds of toxic chemicals were released to the environment in the States of Maine, Massachusetts, New Hampshire, and Rhode Island. In 1997, there were over 14,000 hazardous-waste sites in the study area. Almost 95 percent of these sites were managed under the USEPA's Resource Conservation and Recovery Act program.

Surface and ground waters are withdrawn primarily for domestic, thermoelectric, commercial, and industrial uses. The total amount of water withdrawals in 1995 was about 1,430 Mgal/d, with 31 percent derived from ground-water sources and 69 percent from surface-water sources.

Surface-water-quality conditions vary greatly. Surface waters naturally have low concentrations of dissolved and suspended solids, sediments, and nutrients when compared to other surface waters nationally. The presence of extensive forest cover and wetlands, thin soils in many areas, and crystalline bedrock, all contribute to low constituent concentrations.

Human activities have had a profound effect on surface-water quality. For more than 200 years, the damming of rivers, and the disposal of wastes from pulp and paper mills, lumber mills, textile and tanning factories, and untreated sewage disposal made some of the rivers among the most polluted in the United States. Improvements in wastewater treatment for industrial and municipal wastewater discharges during the past 30 years have led to major water-quality improvements in many streams. Some of the important sources of present water-quality degradation include industrial and municipal wastewater discharges, combined sewer overflows, hydrologic modifications from dams and water diversions, and runoff from agricultural and urban land uses.

The quality of water in stratified-drift aquifers is different than the quality of water from bedrock aquifers. Water in stratified drift is usually slightly acidic and has small concentrations of dissolved solids, calcium carbonate, and nutrients. Water in fractured bedrock generally is slightly basic and has greater concentrations of dissolved solids and calcium carbonate than water in stratified drift. Water in stratified drift and fractured bedrock have concentrations of iron and manganese that frequently exceed State and Federal safe-drinking-water regulations. Arsenic and radon are present in water from bedrock aquifers. The most frequently detected ground-water contaminants are volatile organic compounds, petroleum-related products, nitrates, and chloride and sodium. Causes for this contamination include leaking storage tanks, accidental spills, landfills, road salting, and septic systems.

Toxic compounds and trace elements in fish tissue, at levels dangerous for human consumption have been identified throughout the study area. Concentrations of dioxin in the tissue of fish from the Androscoggin and Kennebec Rivers have resulted in fish-consumption advisories by the States of Maine and New Hampshire. Recently, fish-consumption advisories have been issued in Maine, Massachusetts, and New Hampshire as a result of elevated concentrations of mercury in fish tissue.

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