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.

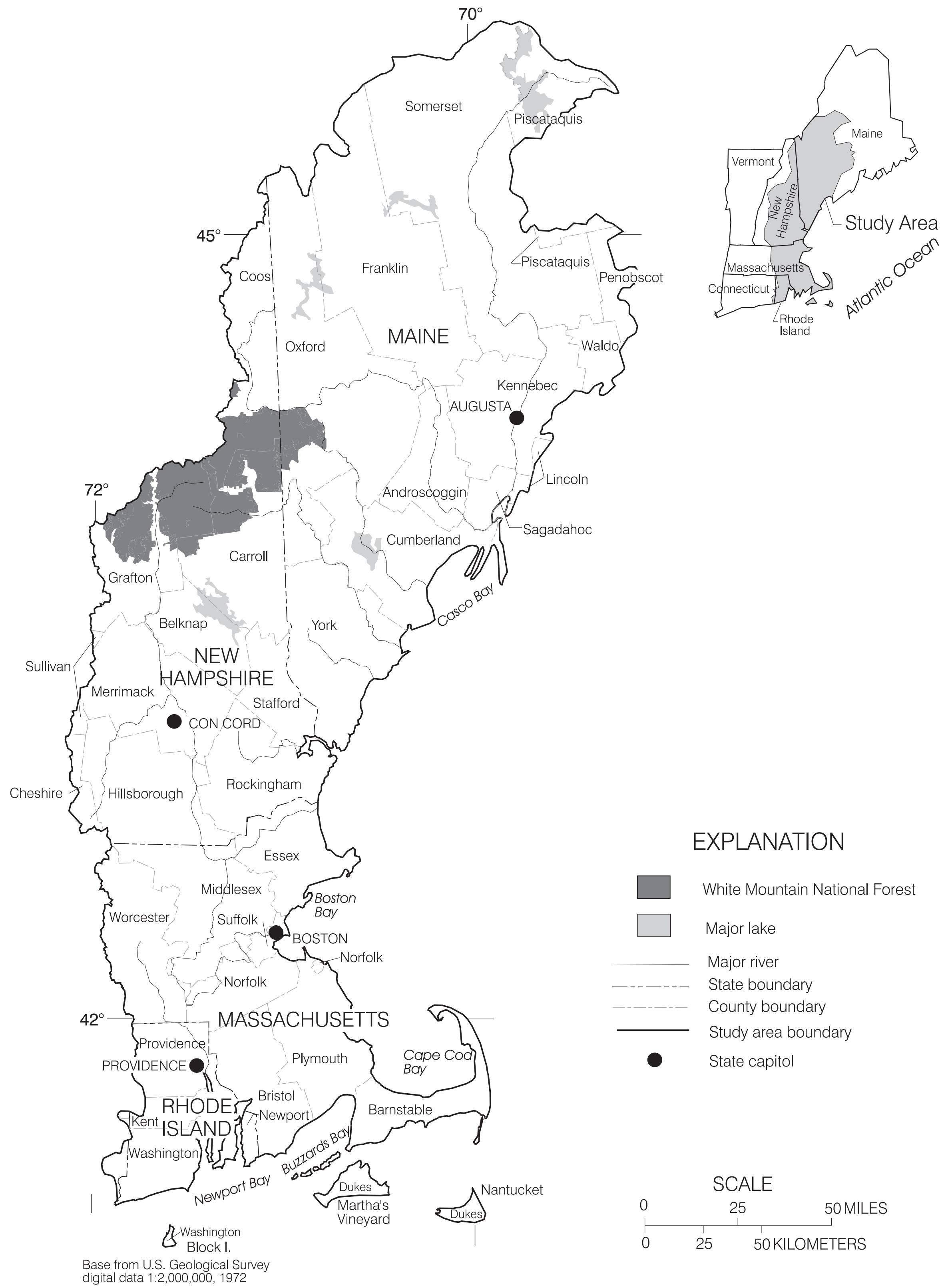

Figure 1. Location of the New England Coastal Basins study area in Maine, Massachusetts, New Hampshire, and Rhode Island.

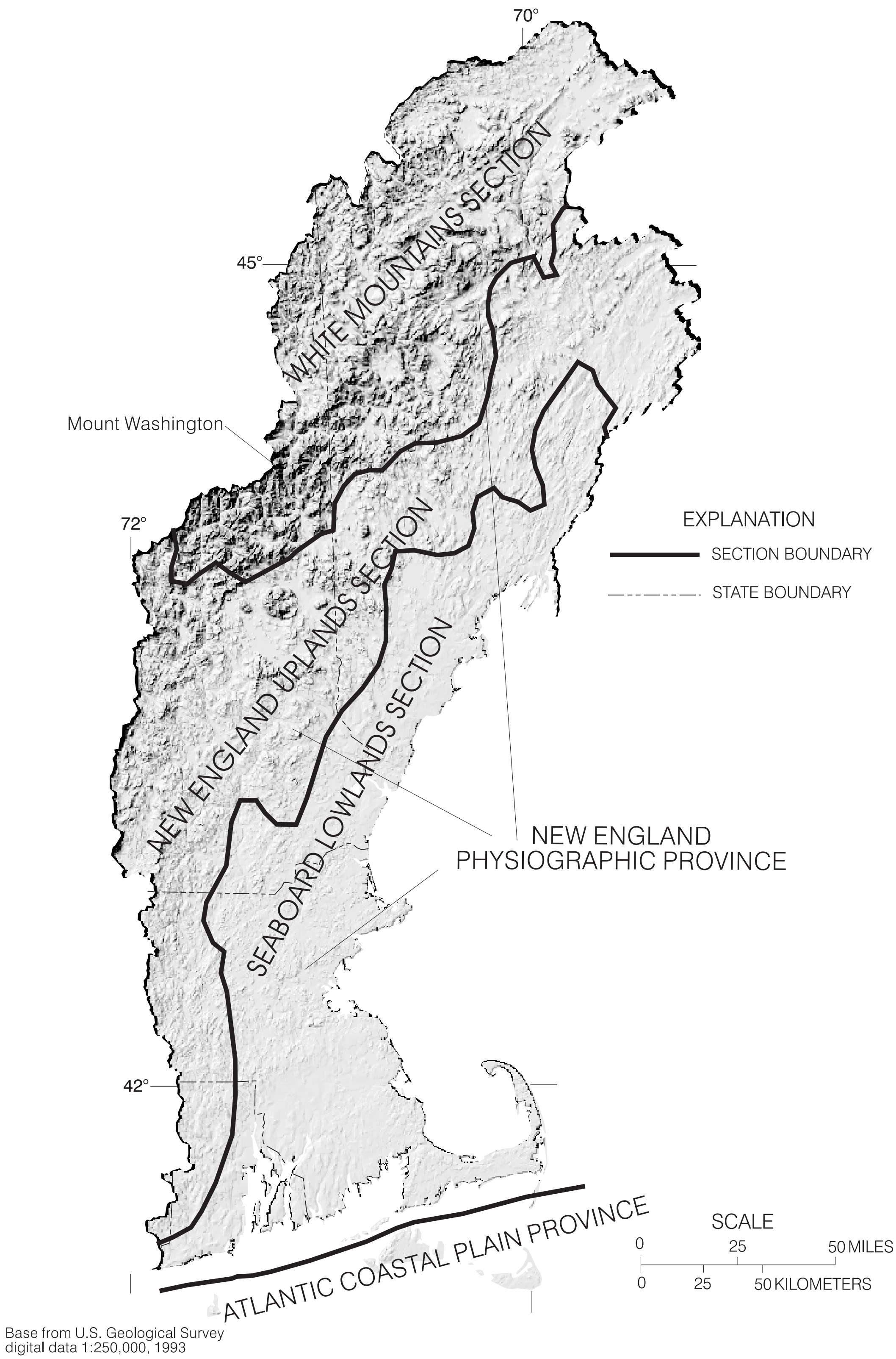

Figure 2. Physiographic regions of the New England Coastal Basins study area.

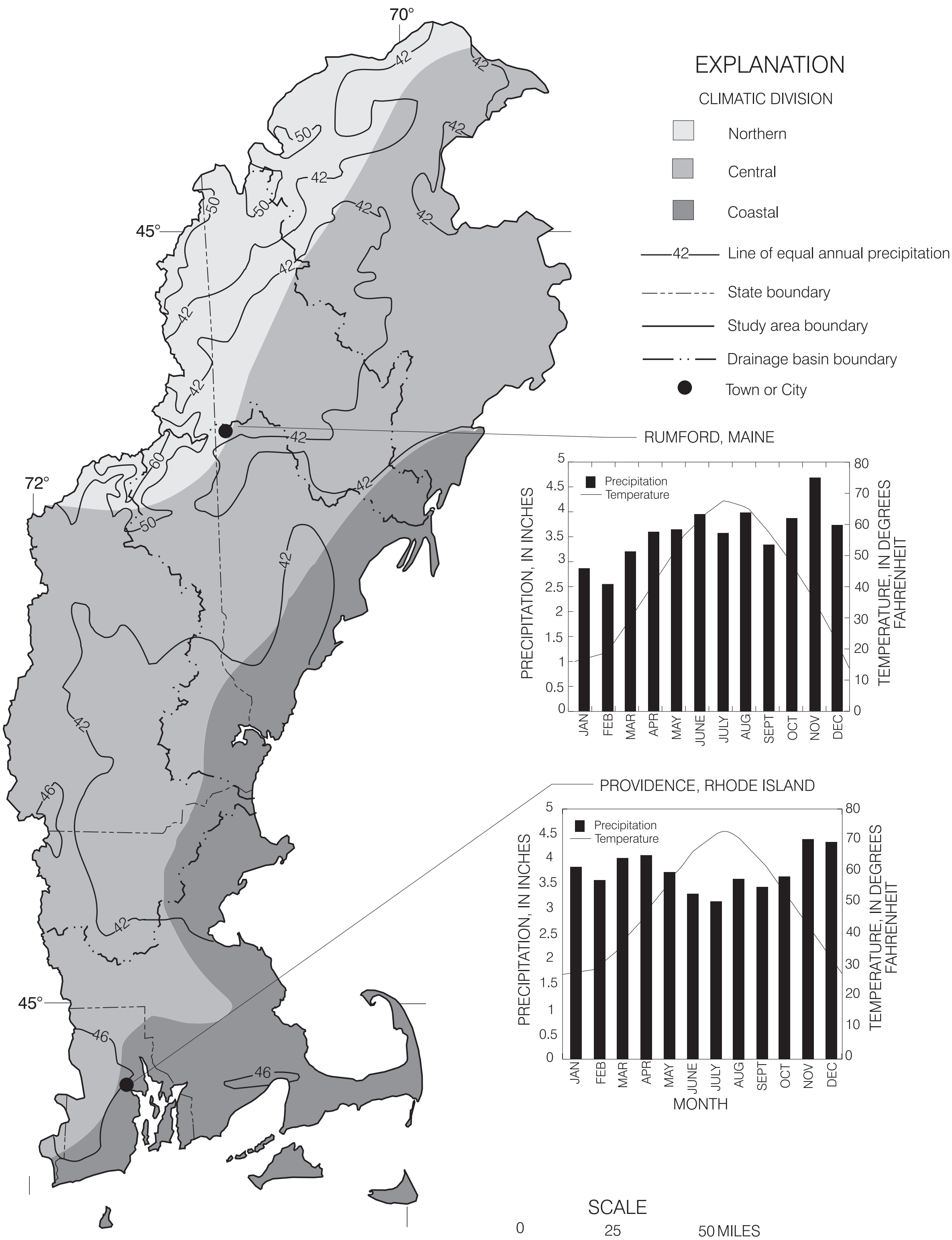

Figure 3. Mean monthly precipitation and air temperature at selected stations, annual precipitation, and climatic divisions in the New England Coastal Basins study area, 1961-1990.

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

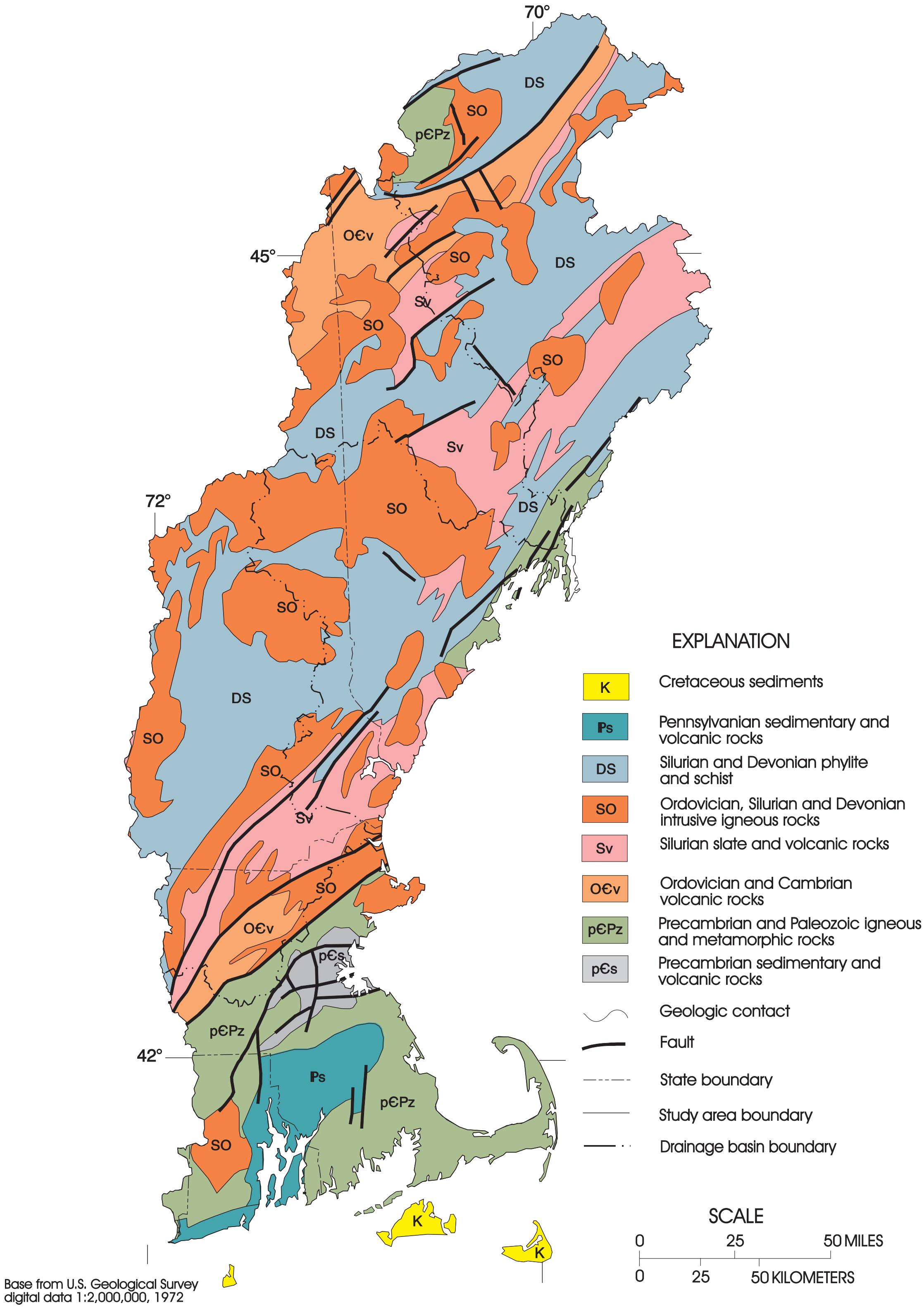

Figure 4. Generalized bedrock geology of the New England Coastal Basins study area. [Modified from King and Beikman, 1974; Lyons and others, 1997; Zen and others, 1983; Osberg and others, 1985; and Hermes and others, 1994.]

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

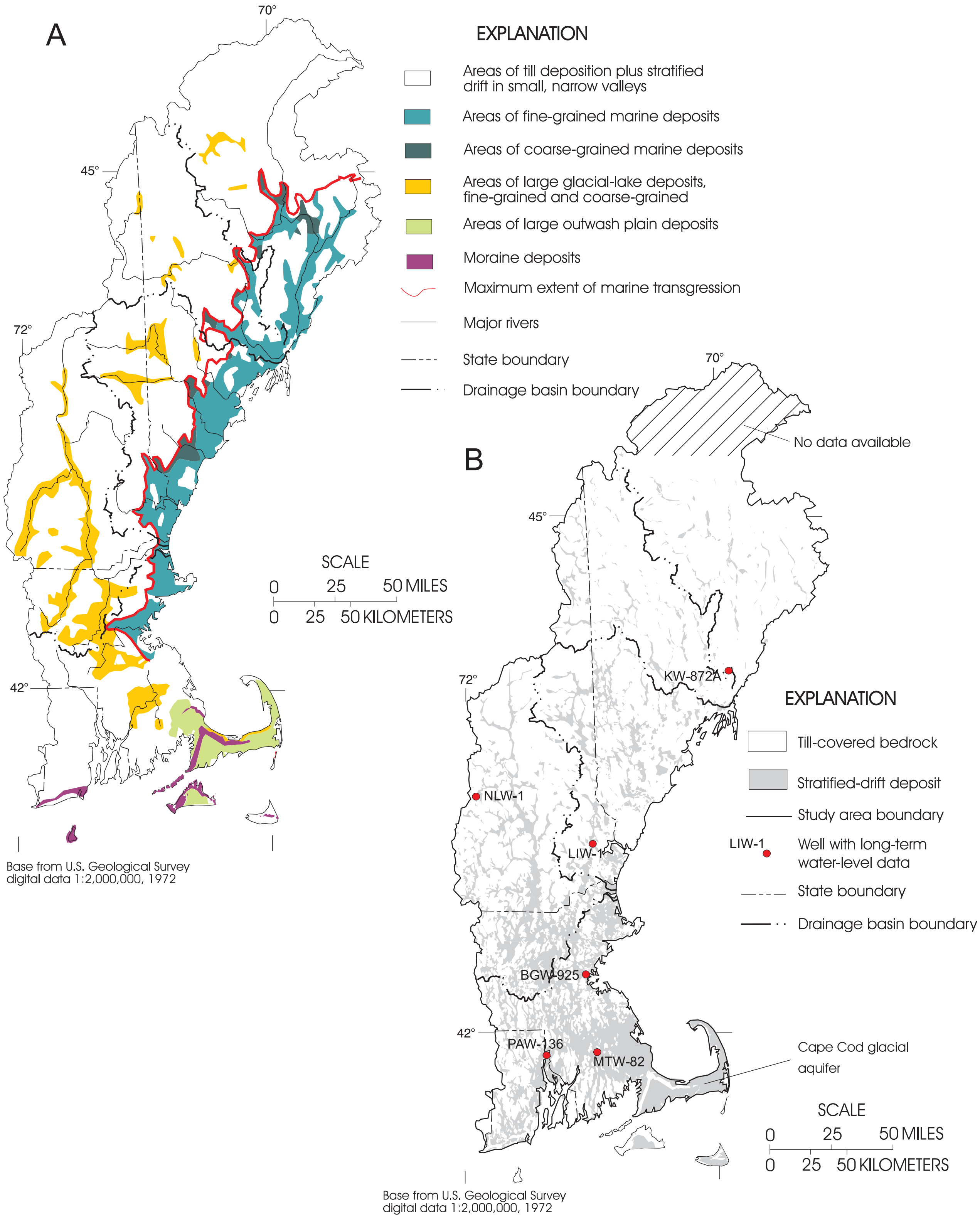

Figure 5. (A) Maximum extent of glacial lakes and the marine limit and (B) the generalized extent of stratified-drift deposits in the New England Coastal Basins study area in Maine, Massachusetts, New Hampshire, and Rhode Island.

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.

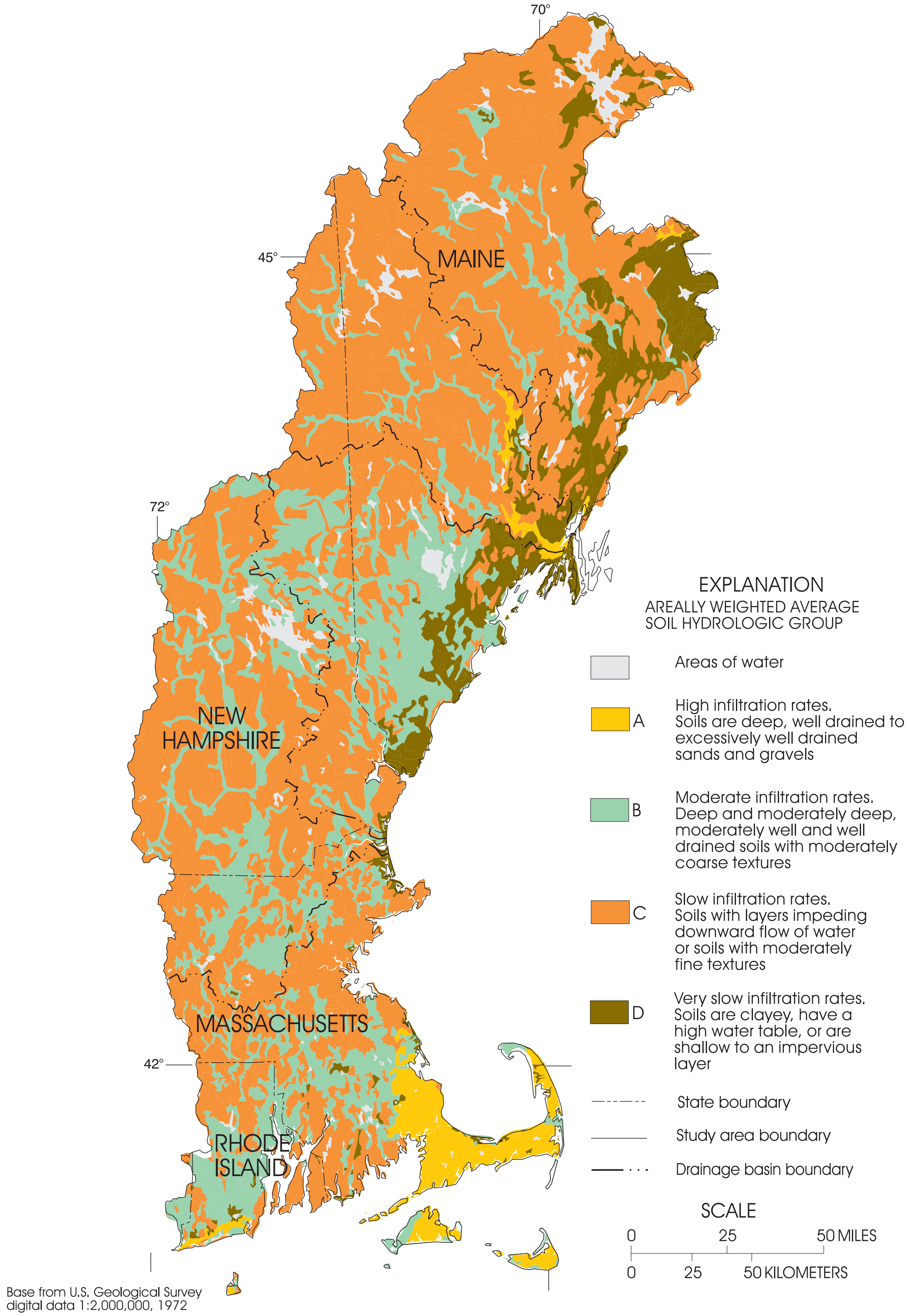

Figure 6. Generalized soil hydrologic groups of the New England Coastal Basins study area. [Data from the U.S. Department of Agriculture's State Soil Geographic (STATSGO) soils database.]