Water Resources of Massachusetts

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 90-4144

Prepared in cooperation with the
COMMONWEALTH OF MASSACHUSETTS
DEPARTMENT OF ENVIRONMENTAL MANAGEMENT,
DIVISION OF WATER RESOURCES

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By Alison C. Simcox

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U.S. GEOLOGICAL SURVEY

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ILLUSTRATIONS

ILLUSTRATIONS (Continued)

CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
feet per mile (ft/mi)	5.283	meter per kilometer
	Area	
square mile (mi^2)	2.590	square kilometer
acre	4,047	square meter
	Volume	
million gallons (Mgal)	3.785×10^{-3}	cubic hectometer
	Flow	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
cubic feet per second per square mile [$(ft^3/s)/mi^2$]	0.01093	cubic meter per second per square kilometer
gallon per minute (gal/min)	6.309×10^{-5}	cubic meter per second
	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

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

Water Resources of Massachusetts

By Alison C. Simcox

ABSTRACT

This report describes the water resources of Massachusetts. It contains sections describing the location, use, quality, and management of water resources in Massachusetts, followed by a summary of the surface-water and ground-water resources of all 27 river basins designated by the State for planning purposes. The data for each basin include information about selected continuous record streamflow-gaging stations, the distribution and size of major lakes and streams, and the character of the principal aquifers. Each basin summary is accompanied by a map that shows basin and political boundaries, hydrography, locations of continuous-record streamflow-gaging stations, and aquifer areas. The aquifer areas were derived from the Hydrologic Investigations Atlases and generally show areas that are likely to yield 100 gallons per minute or more to individual wells. The report was compiled from many reports, including 30 U.S. Geological Survey Hydrologic Investigations Atlases that inventory water resources of the State.

INTRODUCTION

This summary of the water resources of Massachusetts is based on an inventory of the State's water resources described in a series of Hydrologic Investigation Atlases by the U.S. Geological Survey (USGS) in cooperation with the Massachusetts Department of Environmental Management's Division of Water Resources. It is also based on annual hydrologic data reports that are the product of a long-term program, to collect stream and well data, that is cooperatively supported by the Massachusetts Divisions of Water Resources and Water Pollution Control, the Metropolitan District Commission, the U.S. Army Corps of Engineers, and the USGS, and on a statewide series of gazetteers of hydrological characteristics of streams.

Purpose and Scope

This report compiles water-resources information that is available in many separate reports, especially the USGS Hydrologic Investigations Atlas series, into a single volume. The report contains streamflow and aquifer-yield data as well as a general description of all 27 basins designated for water-resources planning by the Massachusetts Water Resources Commission. Planning basin descriptions are accompanied by maps that show river-basin drainage divides, political boundaries, hydrography, continuous-record streamflow-gaging stations, and areas of stratified drift favorable for ground-water development.

The report is intended for use by the public and by water-resources professionals needing a brief description of the State's water resources. However, not all information that is available for each river basin could be included; for more detailed information the reader may refer to the references at the end of the report.

Physiographic Setting

Massachusetts is included in two physiographic provinces, or regions of similar geologic structure and climate (fig. 1). Most of the state is in the New England Province, which is characterized by hills and valleys that are predominantly oriented from north to south. Altitude increases from a few feet above sea level near the coast to more than 3,900 ft at Mount Greylock in the northwestern corner of the State. Southeastern Massachusetts, including Cape Cod and the islands of Martha's Vineyard and Nantucket, is in the Coastal Plain Province. This area is characterized by plains and low hills underlain by a blanket of unconsolidated sediments ranging from 80 to 1,500 ft in thickness.

Glacial History

Glaciation modified the topography and drainage patterns in Massachusetts and left much of the land covered by glacial deposits. These deposits are the primary source of ground water for public supply in the State and discharge from these aquifers sustains streamflow during dry periods.

The last glacial stage, the Weichselian/Wisconsinan, began as early as 110,000 years ago and ended as recently as 10,000 years ago (Sugden and John, 1976, p. 131). In North America, an ice sheet from the region of Labrador and Hudson Bay reached into the northern United States; in Massachusetts, the ice reached its southernmost position at Martha's Vineyard and Nantucket between 16,000 and 22,000 years ago (Sirkin, 1982, p. 45; Larson, 1982, p. 102). The vast quantity of water held in ice in North America, Europe, and Siberia caused a world-wide drop in sea level so that much of the continental shelf was above water.

As the ice sheet advanced southward, it moved weathered bedrock and soil. Hills were formed or reshaped, valleys were deepened, lowlands were buried, and some streams were diverted. Much of the displaced rock material was deposited from the glacial ice as till--an unsorted mixture of clay- to boulder-sized material.

About 15,500 years ago, the ice started to melt rapidly and recede northward. In Massachusetts, the ice front had retreated north of Boston within about 1,000 years after its farthest southward migration (U.S. Geological Survey, 1976, p. 7). As the glaciers melted, soil and rock fragments from within the ice were transported, sorted, and deposited by meltwater as stratified drift along stream channels, in lakes and in the ocean. Stream-channel deposits, also known as fluvial deposits, consist largely of sand and gravel deposited by meltwater at the sides, terminus, or further downstream of the melting glacier. Lake-bottom deposits, called lacustrine deposits, consist of gravel, sand, silt, and clay that settled on the bottom of former lakes. The coarser material is generally contained within the deltas of streams that entered the lakes; the finer material settled in the deeper parts of the lakes. The marine deposits also contain a variety of grain sizes: coarser materials deposited in deltas along the sea coast, and silt and clay in deeper water. During this deglaciation period, the sea level rose and inundated coastal areas, which had been depressed by the weight of the ice. As the process continued, the land rebounded, exposing the marine deposits. In Massachusetts, marine deposits are found along parts of the Coastal Plain Province north of Boston (Lyford and others, 1984, p. 10).

GEOHYDROLOGIC SETTING

If a surface-water or ground-water resource is to be developed as a renewable long-term source, there must be a dependable and adequate quantity of water to replenish or recharge that source. In the glaciated northeast, surface water is mainly replenished by precipitation, ground-water discharge, surface-water diversions, and return flows to streams. Ground water is mostly replenished by precipitation, natural and induced infiltration from streams, and inflow of ground water from adjacent and underlying till and bedrock. The amount of recharge available to a sur-

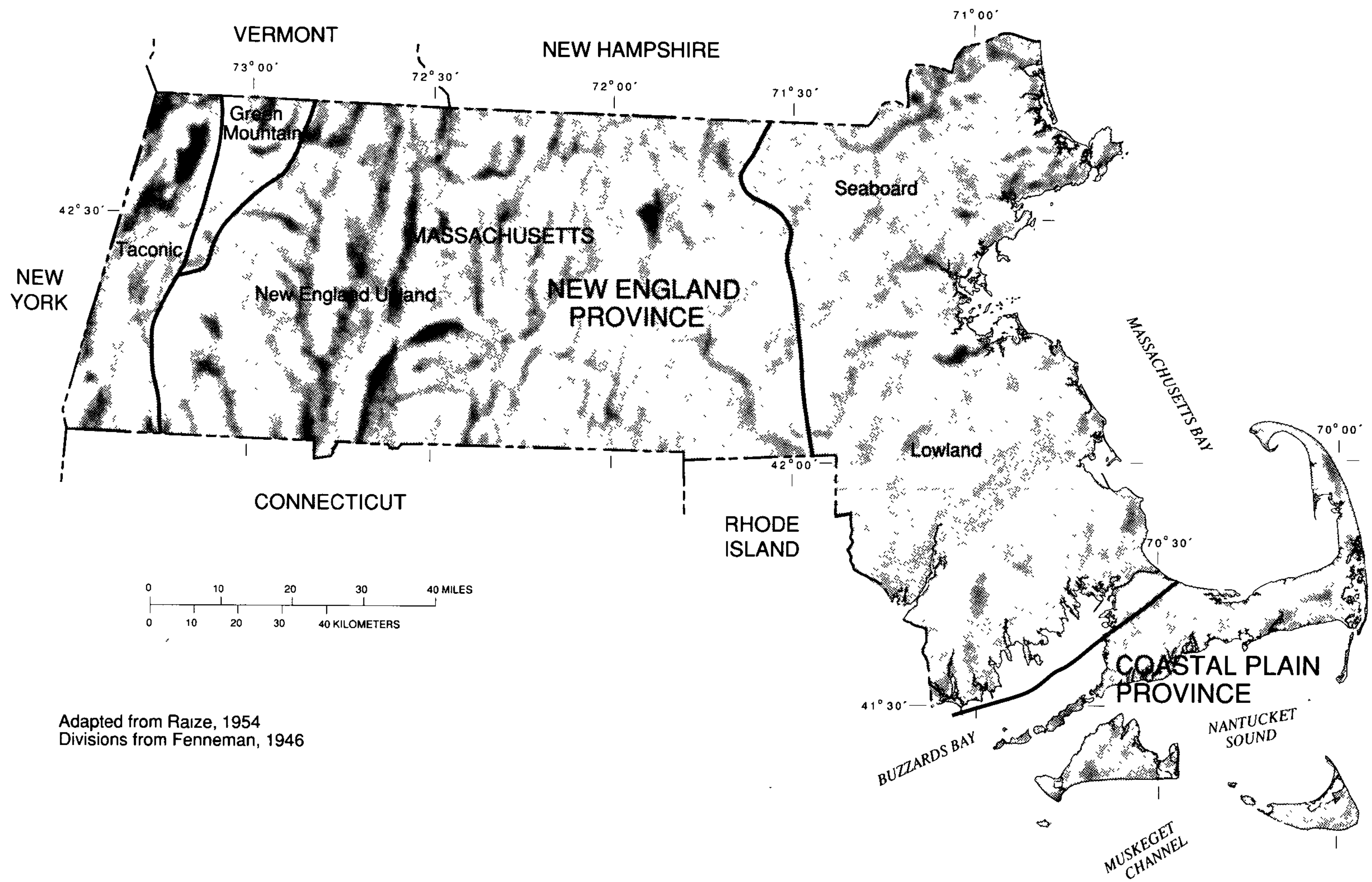


Figure 1.--Physiographic provinces and subdivisions in Massachusetts.

face-water or ground-water resource generally increases with increasing drainage area, except where large amounts of water are diverted from upgradient streams or wells.

Although it is convenient to discuss surface water and ground water separately, they are actually part of a continuous, complex hydrologic cycle. Except during storms, streamflow in Massachusetts largely consists of ground-water discharge from glacial aquifers adjacent to the stream. Most municipal wells in the State are located near streams so that water from the streams can be induced by pumping to flow into an aquifer and contribute to well yield. The amount of streamflow contribution to a well depends on such factors as hydraulic conductivity (permeability) and thickness of the streambed materials, the area of the streambed through which infiltration occurs, and the depth of water in the stream. Although it may be possible to divert the entire flow of a stream to a well, there are commonly minimum streamflow requirements for uses such as navigation, hydroelectric power generation, recreation, fisheries, and downstream withdrawals.

The interaction of surface and ground water affects not only the quantity of water that can be used from each source, but also the quality of water in each source. If contaminated surface water infiltrates an aquifer, the quality of water in the aquifer may decline. Similarly, contaminated ground water that discharges into surface water may lower its quality.

HYDROLOGIC CYCLE

Virtually all surface water and ground water in Massachusetts originated as precipitation and is part of the hydrologic cycle. Driven largely by radiant energy from the sun and the Earth's gravity, water in this cycle constantly moves through the air, land, and sea. Precipitation in Massachusetts averages 44 in. per year (fig. 2).

Some precipitation flows quickly over the land surface and through upper soil layers and enters streams and lakes as direct runoff. The greatest direct runoff values, 32 in. or more, are in the mountainous areas of Massachusetts where precipitation is relatively high (fig. 3). Elsewhere in the State, annual runoff generally ranges from 20 to 26 in. Precipitation, that is neither returned to the atmosphere as evapotranspiration nor becomes direct runoff, penetrates farther into the ground and becomes ground water. Ground water moves slowly downward and laterally through pores between grains of sand and gravel and through fractures and joints in rocks. Although some ground water near the coast flows directly into the ocean, most ground water discharges into streams, lakes, ponds, and wetlands before flowing into the ocean.

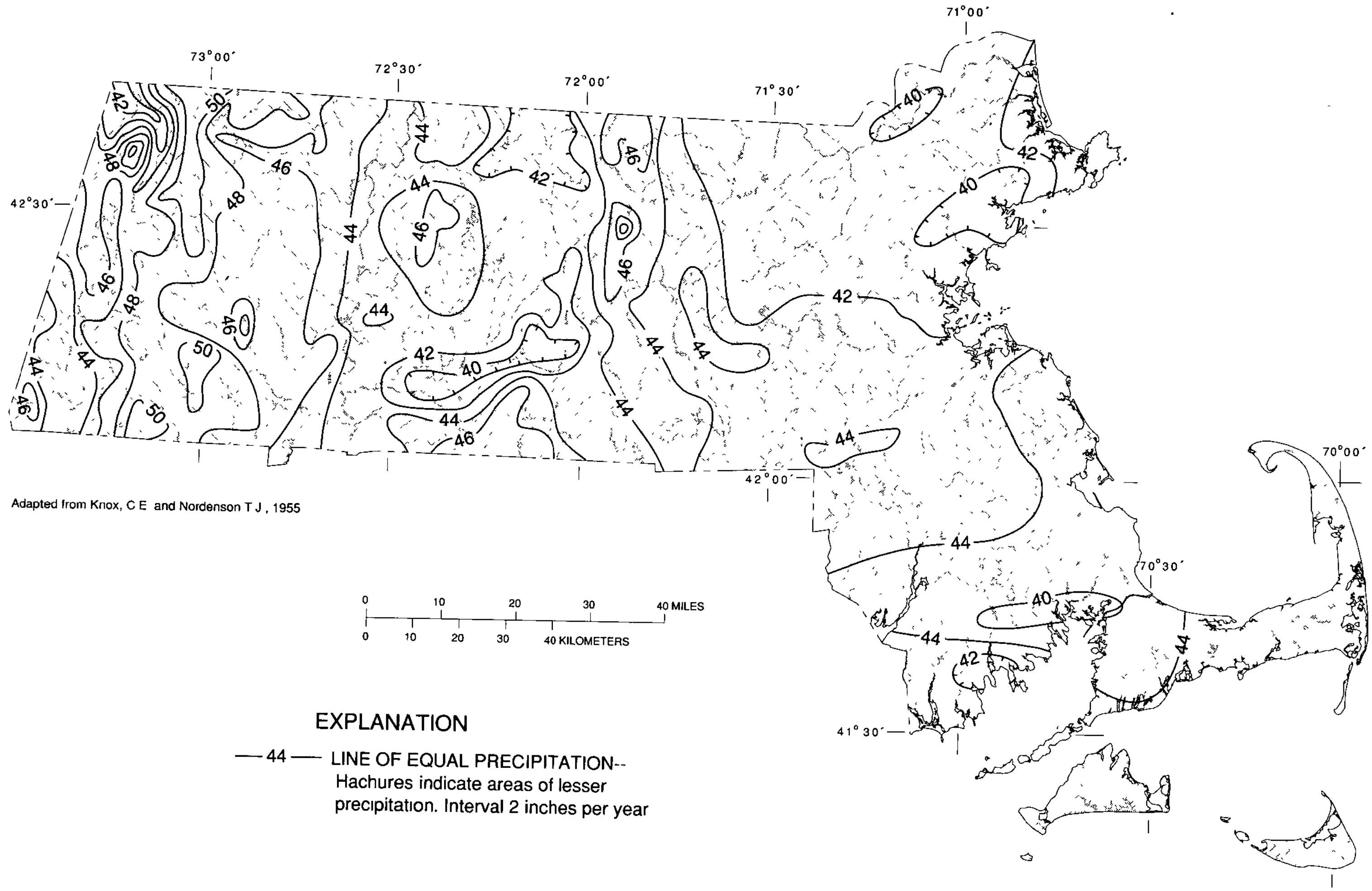
Changes in the volume of water stored in the ground are largely the result of seasonal changes in evapotranspiration. During the growing season in the summer, evapotranspiration intercepts and returns water to the atmosphere, causing a decrease in ground-water recharge.

The result of this variation of evapotranspiration causes water levels to decline in summer and rise in late fall, winter, and early spring. Water levels in stratified drift generally fluctuate less than 6 ft annually, but in till and bedrock beneath till, water levels fluctuate as much as 15 to 20 ft annually (Frimpter, 1981).

Surface Water

All surface water in Massachusetts can be assigned to a river basin, which is an area of land drained by a river and its tributaries. The boundaries of a river basin generally follow the crests of hills. Six river basins in the State are federally designated as hydrologic units (U.S. Geological Survey, 1974): (1) the Merrimack River basin, (2) the Coastal basins, (3) the Thames River basin, (4) the Connecticut River basin, (5) the Housatonic River basin, and (6) the Hudson River basin. The Division of Water Resources (MDWR) of the Massachusetts Department of Environmental Management (MDEM) has subdivided these six hydrologic units into 27 subunits known as planning basins (fig. 4). The Atlantic Ocean has been designated basin number 28. Except in the southeastern part of the State, the basins can be used for ground-water as well as surface-water planning because, in general, ground-water divides closely correspond with surface-water divides. In southeastern Massachusetts, because glacial deposits commonly form a continuous layer over bedrock, surface-water and ground-water divides generally do not coincide.

To describe the surface-water hydrology of an area, information is needed about rates and volumes of flow, and changes in these values resulting from human activities. Long-term and short-term flow measurements are made at carefully selected locations along



Adapted from Knox, C E and Nordenson T J , 1955

EXPLANATION

—44— LINE OF EQUAL PRECIPITATION--
Hachures indicate areas of lesser precipitation. Interval 2 inches per year

Figure 2.--Average annual precipitation in Massachusetts.

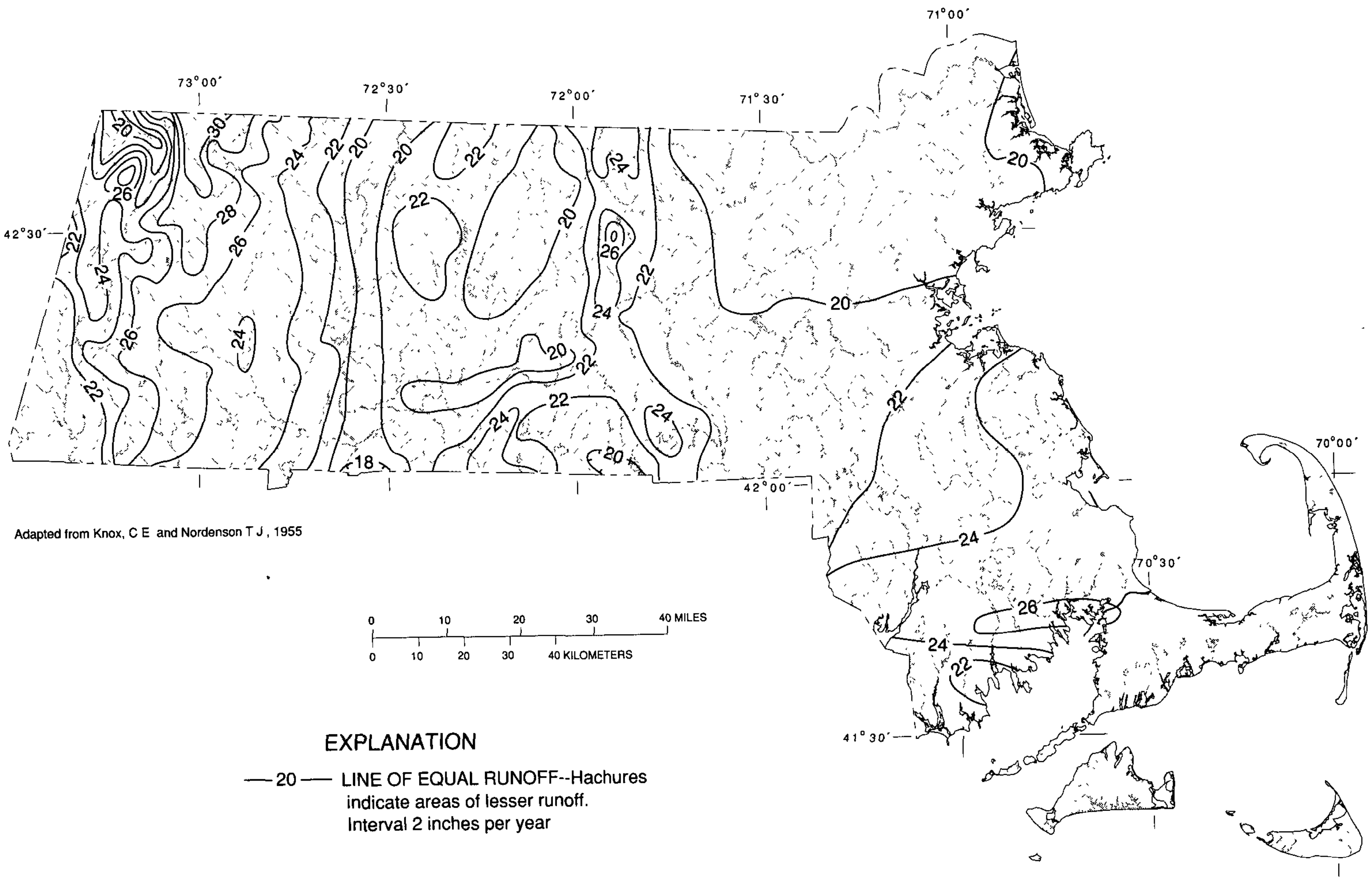


Figure 3.--Average annual runoff in Massachusetts.

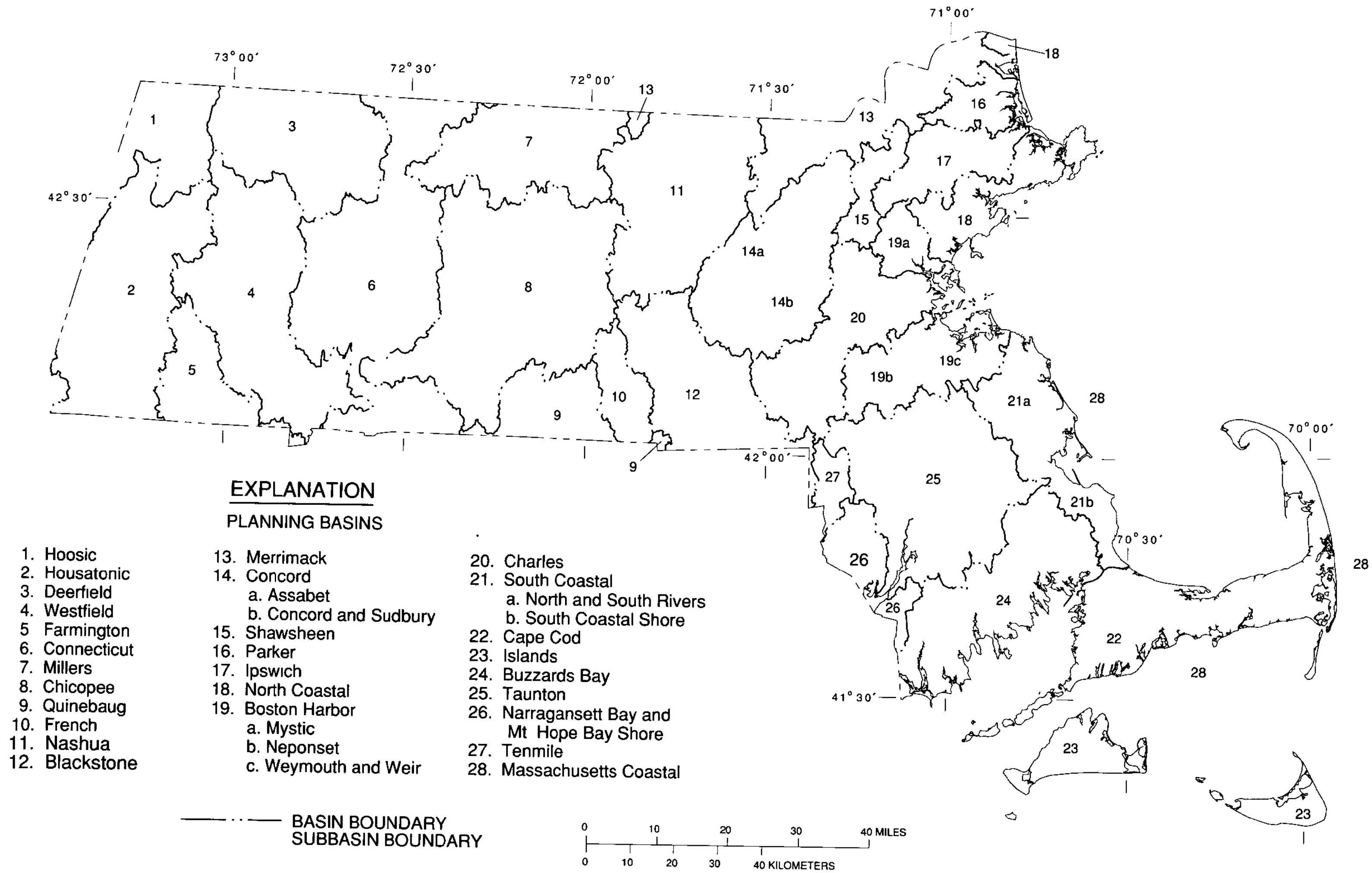


Figure 4.--Location of planning basins in Massachusetts.

streams and at dams and other control structures for streamflow forecasting, project operation, water allocation, research, and basic-data needs. From these data, average values of discharge and the yearly, seasonal, and daily variations in discharge values may be estimated for a drainage area. The USGS, in cooperation with various State and Federal agencies, currently (1989) maintains a network of 72 continuous-record streamflow-gaging stations in Massachusetts.

Streamflow records from stations in Massachusetts indicate that average discharge is primarily related to drainage area (fig. 5). Factors that cause some variation in this relationship include basin shape, geology, and climate. The highest average discharge in Massachusetts historically has been measured in the lower parts of the Connecticut (about 16,500 ft^3/s) and Merrimack (about 7,600 ft^3/s), rivers with the largest drainage areas. The State planning basins for the Connecticut and Merrimack Rivers are much smaller than the rivers' total drainage basins; they drain large areas of New Hampshire and Vermont. Planning basins with discharge rates of less than 100 ft^3/s are mostly in the Coastal River basin where drainage areas are less than 40 mi^2.

Throughout Massachusetts, average streamflow ranges from about 1.1 to 2.5 $(ft^3/s)/mi^2$ of drainage area. The higher values, 2 $(ft^3/s)/mi^2$ or more, are generally for river basins in the mountainous, western parts of the State: the Hudson, Deerfield, and Farmington River basins, where precipitation and runoff are relatively high. The lower values, 1.5 $(ft^3/s)/mi^2$ or less, are in the eastern coastal river basins, which generally have lower annual precipitation and runoff. Cape Cod, which has the lowest value, 1.1 $(ft^3/s)/mi^2$, has little runoff because of the high permeability of the surficial aquifers.

Statewide, the lowest runoff generally occurs during July, August, and September because of high rates of evaporation and transpiration, and low soil moisture. Runoff increases from October to early spring, a period when evaporation and transpiration rates are generally low and soil moisture is high. Annual peak discharges are most likely to occur in March or April when snowmelt is supplemented by rain, but unusually large streamflows may also occur at other times of the year during intense thunderstorms, storms of unusual duration, or hurricanes.

Ground Water

The principal water-bearing geologic units in Massachusetts can be separated according to rock type and ability to yield water. Stratified glacial drift of well-sorted sand and gravel deposits, stratified drift of clay and silt, and poorly sorted glacial till form the State's unconsolidated deposits. Of these, the clay, silt and till are not considered water sources for new supplies. Until the early 20th century, shallow wells dug in till were the most important water source for farms and other rural domestic uses in New England. However, because till wells are susceptible to drought and to contamination from the land surface, and since modern deep-well drilling equipment is available, wells drilled in bedrock are preferred for rural supplies. Fractured bedrock occurs everywhere in the State and is a water source for rural domestic supplies everywhere except where it is deeply buried and contains sea water such as beneath Cape Cod, the Islands, and near the coast.

Stratified-drift Aquifers

The most important sources of ground water in Massachusetts are unconfined stratified-drift aquifers. The upper boundary of these aquifers is the water table, and the lower boundary is a layer composed of much less permeable material such as clay, glacial till, or bedrock.

In most of Massachusetts, stratified-drift deposits form thin and narrow, but very productive aquifers along valleys, separated from one another by bedrock ridges. However, in the southeastern corner of the State, including Plymouth County, Cape Cod, Martha's Vineyard and Nantucket, no bedrock ridges separate the aquifers, and the stratified drift commonly forms a continuous layer over the bedrock. The highest yields from stratified-drift aquifers are derived from wells in thick, saturated, medium-sand to cobble-gravel deposits. The most dependable yields are derived from wells near streams, because seepage from streams can contribute to well yield.

Bedrock Aquifers

Although generally less productive than stratified drift, bedrock is more widely used for residential water supplies and provides large yields in some parts

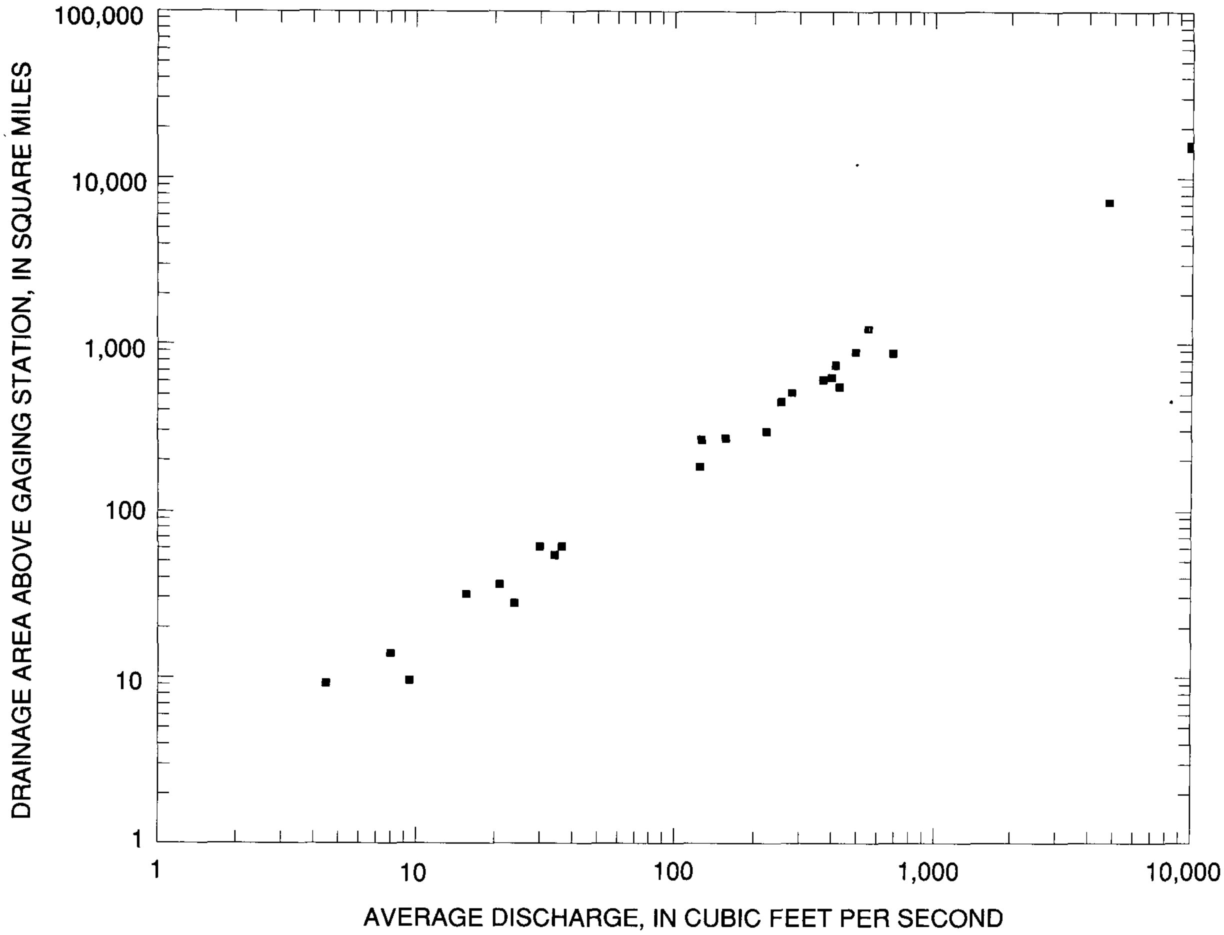


Figure 5.--Average instantaneous discharge as a function of drainage area for selected streamflow-gaging stations in Massachusetts with 20 or more years of continuous record.

of Massachusetts. The three principal types of bedrock aquifers in the State are crystalline (igneous and noncarbonate metamorphic), sedimentary, and carbonate (U.S. Geological Survey, 1985, p. 249-252). The crystalline-bedrock aquifer underlies much of the State and is composed mainly of granite, gneiss, and schist. The major sedimentary-bedrock aquifer is located along the Connecticut River valley of west-central Massachusetts and consists of sandstone, shale, and conglomerate, with interbedded lava flows (traprock). Sedimentary rocks also occur in the Boston basin in eastern Massachusetts and the Narragansett basin the southwestern part of the State. Major rock types in the Boston basin include shale, conglomerate, and volcanics. Sedimentary rocks in the Narragansett basin, commonly folded and faulted, have been partly metamorphosed. Rock types in this basin include conglomerate, sandstone, siltstone and traces of coal. The carbonate-bedrock aquifer is located in Berkshire County in western Massachusetts and is composed of limestone, dolomite, and marble interbedded with schist and quartzite.

The yield of a well in bedrock depends on the presence of open joints, fractures, and fault and shear zones. Porosity in sedimentary rocks and solution cavities in carbonate rocks are also important to yield. However, the openings in the bedrock must be continually replenished with water to sustain well yield. Yields in bedrock are usually dependable where saturated sand and gravel overlie the aquifer. Less dependable yields occur where till or other poorly permeable sediments overlie bedrock, or where there is no overlying saturated material.

WATER USE

In 1985, about 6,250 Mgal/d of freshwater was withdrawn from rivers, streams, lakes, and aquifers in Massachusetts. Most (81 percent) of this water was used to generate thermoelectric power and was returned to surface water where it could be reused. The remainder of the water was used for domestic and commercial purposes (15 percent), by industry and mining (3 percent), and by agriculture (less than 1 percent).

The total freshwater withdrawals included about 95 percent surface water and about 5 percent ground water. Surface water is the main source of water for thermoelectric, public supply, and industry in all major urban areas of the State. Ground water comprises about one-fourth of the water used for public supplies, and supplies large quantities of water to some industries, especially in the west-central and western part of the State.

The total amount of water withdrawn for public supplies in 1985 was about 767 Mgal/d. Surface water supplied 586 Mgal/d, while ground water supplied 181 Mgal/d. The proportion of surface water to ground water in public supplies varies across the State. Surface water, mostly from reservoirs, has historically been the main source of public-water supply to all major urban areas of the State. In 1985, there were 22 major reservoirs (capacity greater than 5,000 acre-ft), 13 of which were built for water supply. The Quabbin Reservoir, located about 65 mi west of Boston, is the largest reservoir in the State and the principal public-water supply for most cities and towns within 15 mi of Boston. This reservoir, which has a surface area of 39 mi^2 and a capacity of about 1.3 million acre-ft (412 billion gallons), is possibly the world's largest reservoir built expressly for water supply (Knowlton and Coogan, 1974).

In 1985, withdrawals for commercial enterprises, such as hospitals, hotels, and computer firms, totaled about 514 Mgal/d, about one-half of which was provided by public systems. In the same year, about 220 Mgal/d of water was withdrawn for industrial use, of which about 90 percent was fresh and 10 percent was saline. Public-water systems supplied about 69 Mgal/d for industrial use. The amount of water used in industry in 1985 was only about one-fourth of that used in 1970 (Murray and Reeves, 1972, p. 24; Solley and others, 1987). Between 1970 and 1985, manufacturing industries, such as textile, shoe, paper, and shipbuilding industries declined in size, while the number of service, computer, electronics, and research businesses, which generally use less water, increased. Withdrawals for mining operations in 1985 were small (about 2 Mgal/d).

Agriculture in Massachusetts used about three times more surface water than ground water in 1985 and accounted for less than one percent of all water used in the State. Most water used for agricultural purposes is used to irrigate crops and golf courses. All irrigation is done by spraying, except in southeastern Massachusetts where about 1,800 acres of cranberries are flooded annually. From 1970 to 1985, withdrawals of water in Massachusetts for irrigation decreased almost four-fold, from 58 to 16 Mgal/d, and withdrawals of water for other agricultural uses decreased by about 38 percent (Murray and Reeves, 1972, p. 22; Solley and others, 1987). These decreases reflect the decline of tobacco as an important cash crop and the loss of farmland to commercial, industrial, and residential development.

Instream use of water also is significant in Massachusetts and has affected the location of many of the State's industries. Instream uses include navigation, hydroelectric-power generation, waste assimilation, recreation, and aquatic habitat. Currently, the largest instream use of water is hydroelectric-power generation, which supplies about 5 percent of the State's electricity. In 1985, more than 98,000 Mgal/d of water were used by hydroelectric power plants to generate almost 2,000 gwh (gigawatt-hours) of electricity. A small amount of water used in this process is lost during cooling; the remainder is discharged downstream of the plant.

WATER QUALITY

The suitability of water for different uses is largely dependent on the water's chemical and physical quality. Generally, in Massachusetts both surface and ground water are suitable for most uses, including drinking water if limited treatment is provided. Where influenced by human activity however, water quality can be seriously degraded.

Surface Water

Chemical data on the surface water of Massachusetts is necessary to determine its domestic, agricultural, and industrial usefulness. The major inorganic chemicals dissolved in water, commonly termed 'common constituents', include constituents such as calcium, magnesium, sodium, potassium chloride, sulfate, nitrogen, and bicarbonate. Common measurements include physical measurements such as specific conductance and temperature, biological measurements, and measurements of streamflow and concentration of suspended sediments. Some trace elements commonly are present in natural water. Trace elements present in natural water include aluminum, arsenic, copper, iron, lead, manganese, phosphorus, radon, and zinc. Some of these are toxic to people, aquatic plants and animals, and crops. Organic compounds also can be present. Many of these are organochlorine compounds, such as DDT and other pesticides, which persist in the environment, and phenols (Briggs and Feiffer, 1986, p. 27). Samples of bottom materials are commonly distributed unevenly so that obtaining a 'representative' sample or even a duplicate sample can be difficult. Data on water quality of selected streams in Massachusetts are published on a water-year (October through September) basis in a series of publications: "Water resources data, Massachusetts and Rhode Island, water year (year)".

In Massachusetts, the quality of surface water varies depending largely on adjacent land use and on instream water use. During periods of high streamflow the quantity and quality of natural runoff is a major influence on surface-water quality. During periods of low streamflow, sewage-treatment plant effluent and ground-water discharge can control the quality. Effluent discharged into rivers and streams commonly causes a reduction of oxygen and increases in nutrients, turbidity, and bacteria. Water quality of rivers and streams also can be degraded from industrial discharges. Pollution can be associated with an activity at a known location, such as the operation of a landfill, or the site of an underground storage tank or salt-storage area; other sources of pollution can be associated with activities that take place over a wider area, such as pesticide and fertilizer application or highway salting.

Some water-quality trends in New England were noted in a study of water-quality records collecting during 1974-81 at more than 300 locations on major U.S. rivers (Smith and others, 1987). Increases in dissolved-oxygen concentrations were commonly observed in New England and can probably be attributed to point-source pollution-control measures taken after passage of the Clean Water Act in 1972. In general, fecal coliform and fecal streptococcal bacteria counts declined along the Atlantic coast. These decreases may be due to improved municipal waste treatment. An increase in nitrate levels in many streams in the eastern U.S. over the same period is associated with increased fertilizer use. An increase in the use of deicing salts on highways has caused sodium and chloride levels to increase in surface water in many parts of New England. Trends in trace-element concentration are largely unknown. However, data from the study indicate that levels of dissolved lead in streams near the East Coast have declined, probably as a result of decreased consumption of leaded gasoline.

The quality of surface water in Massachusetts also is affected by the acidity of precipitation. Areas most affected by decreases in pH in surface water are those in eastern and central Massachusetts that contain granitic and other noncalcareous bedrock with low buffering and cation-exchange capacities. In Berkshire County, however, acidic precipitation is largely buffered by rocks and soil that contain carbonate minerals. Crushed limestone is added to buffer some ponds that stock fish. Acidic public water supplies commonly are treated with sodium hydroxide to decrease corrosion and leaching of lead and copper from water pipes, and decrease corrosion and release of asbestos from cement-asbestos pipes. In 1986, plumbing codes in Massachusetts were changed to limit the lead in solder to less than 0.02 percent to decrease dissolution of lead from plumbing.

Surface-water quality also can be degraded by natural causes. For example, water derived from wetlands can be highly colored and acidic because of contact with decomposing plants. In addition, the long retention time of water in wetlands during dry periods can cause depletion of oxygen.

Ground Water

Ground-water quality reflects the chemical makeup of the aquifer and the soil and rock material through which the aquifers were recharged. Although virtually all ground water in Massachusetts comes from precipitation, generally the longer the contact between rock and water, the greater will be the concentrations of dissolved materials in the water. Therefore, because deep ground water flows more slowly and has been in contact with rock longer than shallow ground water, it is generally more mineralized than shallow ground water.

Stratified drift

Stratified-drift aquifers consist of layers of unconsolidated sand and gravel that commonly are composed almost exclusively of quartz and feldspar, which are relatively stable minerals with low solubility in water. Analyses of 697 samples collected from public-supply wells in stratified-drift aquifers throughout

Massachusetts in 1984 by the Massachusetts Department of Environmental Protection (MDEP) had a median dissolved-solids concentration of 88 mg/L (milligrams per liter) and a median hardness (as calcium carbonate) of 32 mg/L. In 85 percent of the 697 analyses, pH was less than 7; the median pH was 6.3 (Frimpter, 1988). Because of its acidity and low concentration of dissolved solids, water from stratified-drift aquifers is commonly corrosive to metal and cement pipes. As with surface water, sodium hydroxide or other chemicals are added to some ground water in public-water supplies to increase the pH and decrease corrosivity.

Water from stratified-drift aquifers may have concentrations of iron and manganese that require treatment before distribution in public supplies. These elements, which are the products of weathering of minerals and dissolution of oxide coatings on aquifer materials, are easily dissolved in acidic water in the absence of oxygen. Although water in stratified-drift aquifers commonly contains dissolved oxygen near saturation levels, oxygen may become depleted when ground water passes through organic deposits, such as peat or river-bottom sediments. As a consequence, water from a well screened below a layer of peat may become progressively enriched in iron and manganese as pumping draws ground water through the peat layer.

Organic deposits can cause other problems as well. Decomposition of organic material in wetland deposits may add dissolved ammonia, hydrogen sulfide, and iron to ground water. This process has been observed, for example, in Provincetown on Cape Cod, where marsh deposits have been buried by postglacial sand dunes (Frimpter and Gay, 1979, p. 7-9).

Wells in some coastal areas are vulnerable to contamination by salt water. Under natural conditions, a steady flow of fresh ground water towards the sea prevents encroachment of seawater into the aquifer, but large withdrawals of ground water by wells can cause the boundary between saline and fresh water to move landward. Although no public-supply wells or wellfields have been closed, sodium concentrations in some wells in Truro on Cape Cod, which supplies water to Provincetown, reached levels that exceeded the State guideline of 20 mg/L (milligrams per liter) in public drinking water. The problem was controlled by decreasing pumping rates at the wells and distributing withdrawals from the aquifer.

Bedrock

Crystalline bedrock

The crystalline-bedrock aquifer, which underlies most of the State, is primarily composed of granite, gneiss, and schist. Ground water from this aquifer is generally low in dissolved solids (median of 120 mg/L), moderately hard (median of 90 mg/L as calcium carbonate), and slightly alkaline (median pH of 7.8). Some wells yield water containing elevated concentrations of iron, which can be removed by treatment before use. This condition is most common in bedrock, such as schist or gneiss, that contains large amounts of ferromagnesian minerals or small amounts of iron sulfides. Other local variations in bedrock mineralogy, such as the presence of carbonate lenses and sulfide-bearing zones, can affect ground-water quality. In addition, radon has been detected in water from crystalline-bedrock aquifers in New York, Pennsylvania, and other parts of New England, and in water from Triassic sediments in Connecticut and New Jersey, and is likely to be present at some locations in Massachusetts.

Sedimentary bedrock

The sedimentary-bedrock aquifer in the Connecticut River valley of west-central Massachusetts consists of sandstone, shale, and conglomerate, with interbedded lava flows. These rocks were deposited in a continental-basin environment and contain traces of gypsum, a mineral characteristic of evaporite deposits. Localized ore deposits contain copper, lead and zinc sulfides, fluoride, and secondary uranium-bearing minerals. Ground water from this bedrock aquifer is slightly alkaline and has a median pH of about 7.9. Water from the upper 200 ft of the aquifer commonly contains moderate amounts of dissolved solids and is moderately to very hard, but water from deeper parts generally contains larger amounts of dissolved solids and is much harder. For example, a 510-ft-deep well yielded water with 1,600 mg/L dissolved solids, but 15 samples from shallower depths had a median dissolved-solids concentration of 360 mg/L. The sedimentary-bedrock aquifer generally yields water that contains higher median concentrations of sulfate (120 mg/L), sodium (21 mg/L), and fluoride (0.2 mg/L) than any other aquifer in Massachusetts.

Carbonate bedrock

The carbonate-bedrock aquifer in the valleys of Berkshire County in western Massachusetts is composed of limestone, dolomite, and marble interbedded with schist and quartzite. Like the sedimentary-bedrock aquifer, water from the carbonate-bedrock aquifer tends to be slightly alkaline (median pH of 7.8), and very hard (median of 210 mg/L as calcium carbonate), with moderately high concentrations of dissolved solids (median of 220 mg/L). But, unlike the sedimentary-bedrock aquifer, it commonly contains little sodium (median of 3.7 mg/L), sulfate (median of 17 mg/L), and fluoride (median of less than 0.1 mg/L).

Sources of Contamination

The unconfined, shallow stratified-drift aquifers that supply almost all of the State's public-supply wells are extremely susceptible to contamination from activities at the land surface. Most water-quality problems occur in the eastern third of Massachusetts, which contains most of the State's population. Many of these problems can be attributed to waste disposal, urbanization, and agricultural activities. Since 1978, 74 of the approximately 1,400 public-supply wells and wellfields in the State have been closed because of contamination. Over 600 private wells in 120 communities are also known to have been contaminated (Executive Office of Environmental Affairs, 1990).

Organic compounds widely used by industry, especially solvents such as trichloroethylene, methyl chloride, and tetrachloroethylene, are the major ground-water contaminants in the State--56 public-supply wells have been closed because of contamination with organics. Organic compounds commonly reach ground water from waste lagoons, pits, landfills, transfer stations, and leaking sewage lines, or from improper storage and illegal discharge.

In Massachusetts, there are 17 facilities that store and treat hazardous waste, 10 facilities that store hazardous waste at the site of generation, and over 13,000 facilities that generate hazardous waste. Of the 13,000 generators, over 1,500 produce more than 1,000 kilograms (about 2,200 pounds) a month (Executive Office of Environmental Affairs, 1990).

Treatment, storage, and disposal of hazardous waste occurred at many more sites in the past than at present; many of these sites have been abandoned or now only generate hazardous waste. Spills and releases have occurred at many of the operating and abandoned sites and facilities. To date, remediation has been completed at only a small percentage of sites.

Septic systems, which service about one-third of the houses in Massachusetts, can contribute to ground-water pollution and threaten private and public water supplies. The MDEP requires that water suppliers withdrawing over 100,000 gal/d own or control land use within 400 ft of a well, for protection against biological contamination. Smaller public-supply wells can have smaller protection areas whose sizes vary according to yield or demand. However, these protection areas do not protect wells from contamination by nitrates and organic compounds. Some public-supply wells and many private wells have been contaminated by nitrates or organics or both. To provide further protection, the areas within one-half mi of each public-supply well have been designated by MDEP as "interim wellhead protection areas".

Leachate from landfills has caused the closing of at least six public-supply wellfields and an unknown number of private wells. Landfill leachates commonly contain high concentrations of iron, dissolved solids, nitrogen (as ammonia or nitrate) and waste organic compounds. Most well closures have resulted from contamination by waste organics. Landfills that have closed since 1971 must be capped with relatively impermeable material. For new landfills, and additions to existing landfills, the MDEP now requires that additional measures, such as installation of liners, leachate-collection systems, and monitoring wells, be taken to protect ground water.

Other sources of ground-water contamination include road salt, oils, fuels, chemicals stored in underground tanks, and agricultural fertilizers and pesticides. In 1967, the Massachusetts Department of Public Works (MDPW) began covering all of its stored salt to prevent leaching, and in 1978 the Department began providing funds to towns and municipalities to cover salt stockpiles. Fuel oil or gasoline has contaminated private and public wells in several locations. For example, a public-supply wellfield in the stratified-drift aquifer in Truro, on Cape Cod, was closed because of a gasoline leak from a nearby underground-storage tank. This closing required the use of temporary emergency wells and increased the demands on other wellfields. Agricultural pesticides have been detected in water from public and private wells in the farming areas of the Connecticut River valley in west-central Massachusetts, and in water from private wells near potato fields in southern Bristol County in southeastern Massachusetts. In the 1980s, the pesticides ethylene dibromide (EDB) and aldicarb were found to have contaminated over 50 private wells and were responsible for the closing of the wells of the West Springfield municipal water supply (Executive Office of Environmental Affairs, 1990). Massachusetts now requires pesticide and fertilizer products to be registered and restricts the use of many pesticides.

WATER-RESOURCES MANAGEMENT

In Massachusetts, cities and towns have the primary responsibility to regulate land use and to manage their water resources. However, communities must follow guidelines specified in State laws. Policies pertaining to water-resources planning and management are made primarily by the Massachusetts Water Resources Commission (MWRC) within the Executive Office of Environmental Affairs (MEOEA), and by the Massachusetts Water Resources Authority (MWRA). MWRC, which includes representatives from MEOEA, the Executive Office of Communities and Development, and the public, sets criteria and priorities for cooperative programs between Federal and State government agencies that relate to water issues. Most of the water-resources planning and regulation functions are divided between two MEOEA departments: MDEM (Department of Environmental Management) and MDEP (Department of Environmental Protection--formerly the Department of Environmental Quality Engineering).

Most of the water-resources responsibilities of MDEM are met by the Division of Water Resources. These responsibilities include regulation of interbasin transfer, flood control, and water-resources planning and development and hydrologic data collection for State programs. The Division also licenses well drillers and maintains files of well-completion reports. The Division has cooperative programs with USGS and other Federal agencies to collect and interpret water resources data (for example, precipitation, streamflows, ground-water levels, water chemistry, water use) and to assess ground- and surface-water resources.

MDEP has several divisions that are responsible for water quality: Water Supply, Water Pollution Control, Environmental Analysis, Hazardous Waste, Solid Waste, and Wetlands and Waterways Regulation. The Division of Water Supply issues permits for all water withdrawals in excess of 100,000 gal/d, permits for public supply wells, collects information on ground-water quality, and allocates funds to communities for water treatment and for acquisition of land to protect aquifers. The Division of Water Pollution Control develops and implements programs to prevent or clean up the pollution of ground water and surface water. This is partly accomplished by the issuance of surface- and ground-water discharge permits. The Division also administers MDEP's programs to improve and update the maintenance and operation of waste water facilities. The Division researches new technologies for the control of water pollution and abatement. The Division cooperates with USGS to maintain a streamflow monitoring network, resource inventory, and to research solutions for operational problems. The Division of Environmental Monitoring is the analytical laboratory for MDEP. It regularly collects and analyzes samples of raw and treated public drinking water and is responsible for the analysis of samples of ground water that may be contaminated. The Division of Hazardous Waste responds to chemical spills and other emergencies involving oil and hazardous materials, investigates illegal disposal, and supervises the cleanup of hazardous-waste. It also approves programs to monitor ground-water movement and quality, supervises hydrogeologic studies, and evaluates proposals to clean contaminated water. The Division of Solid Waste oversees the operation of landfills and other solid-waste facilities and ensures that environmental safeguards protect surface water and ground water from leachate contamination. The Division also helps communities to develop long-term plans to dispose of solid waste. The Division of Wetlands and Waterways Regulation works with local conservation commissions to administer the Wetlands Protection Act, which regulates activities in or near wetlands.

A third MEOEA department, the Metropolitan District Commission (MDC), manages watersheds of the Boston metropolitan water system, and manages flood-control projects, especially in eastern Massachusetts.

Water-resources planning and management responsibilities of MWRA, which became operational in July 1985, include supplying water and sewerage services to about 60 municipalities, and leading the effort to clean Boston Harbor.

The USGS helps inventory the State's water resources. As part of this effort, USGS currently (1989) maintains a network of 72 continuous-record streamflow-gaging stations in Massachusetts (45 in cooperation with MDEM's Division of Water Resources or MDEP's Division of Water Pollution Control or both, 11 in cooperation with MDC, 12 for the U.S. Army Corps of Engineers (includes two that also receive MDEM and MDEP funding), three for the Federal Energy Regulatory Commission, and two as part of a Federal water-resources network.

Several recent State and Federal acts affect the management of water resources of Massachusetts. In 1983, the Massachusetts State legislature passed the Interbasin Transfer Act (Chapter 658) authorizing MWRC to approve any significant interbasin transfer of surface or ground water, including wastewater. Before an interbasin transfer is approved, MWRC must be certain that all reasonable efforts have been made to identify and develop water sources in the receiving area of a transfer, that all practical measures have been taken to conserve water in the receiving area, and that reasonable streamflows will be maintained in the river from which water is diverted. In addition, evaluation of the diversion's effects is required.

In 1985, the Massachusetts State legislature passed the Water Management Act (Chapter 21G). That act requires the registration and permitting of all water withdrawals greater than 100,000 gal/d and gives MDEP additional authority to respond to water emergencies.

Figure 6.--Connecticut River, Deerfield, Massachusetts.

RIVER BASINS IN MASSACHUSETTS

The following pages describe each of the 27 river basins designated by MDEM for planning purposes (fig. 4). The planning basins are discussed in downstream order within the six larger drainage areas: the Merrimack, Coastal, Thames, Connecticut (fig. 6), Housatonic, and Hudson River basins. Data are given for selected streamflow-gaging stations in each planning basin. Drainage areas, given in mi^2 above the gaging station, and average, minimum, and maximum discharges, given in ft^3/s, are from the USGS Water-Resources Data report for the 1985 water year (October 1984 to September 1985) (U.S. Geological Survey, 1987). Data on the 7-day 2-year and 7-day 10-year low flows (commonly cited streamflow statistics) and stream gradients are from the USGS gazetteers of hydrologic characteristics of streams in Massachusetts (Wandle, 1984a, 1984b, 1984c; Wandle and Fontaine, 1984; Wandle and Keezer, 1984; Wandle and LeBlanc, 1984; Wandle and Lippert, 1984; Wandle and Morgan, 1984; and Wandle and Phipps, 1984). Descriptions of the surface-water and ground-water resources of the planning basins are summarized from the USGS Hydrologic Investigations Atlases. Each basin summary is accompanied by a map showing principal streams, areas of stratified glacial drift favorable for ground-water development, and location of continuous-record gaging stations.

Merrimack River basin

(State planning basins: Merrimack, Nashua, Concord (Assabet and Sudbury), and Shawsheen River basins)

The Merrimack River begins in New Hampshire and flows southward about 78 mi through central New Hampshire and into Massachusetts. Near the city of Lowell, Mass., the river turns to the northeast and flows about 38 mi parallel to the State border before emptying into the Atlantic Ocean at the town of Newburyport, Mass. The Merrimack River drains an area of more than 5,000 mi^2 and is the fourth largest river basin in New England. About one-fourth of this area is located in Massachusetts and includes the Nashua, Concord, Shawsheen, and Merrimack River planning basins (figs. 4 and 7).

Nashua River basin

North Nashua River near Leominster, Mass.

Drainage area: 110 mi^2 (includes 2.16 mi^2 above outlet of Ashby (Fitchburg) Reservoir)

Average discharge: 195 ft^3/s (Oct. 1935 to Sept. 1985)

Extremes for period of record:
Maximum discharge: 16,300 ft^3/s (Mar. 1936)
Minimum discharge: 11 ft^3/s (Aug. 1948)
Minimum daily discharge: 22 ft^3/s (Sept. of 1936 and 1957)

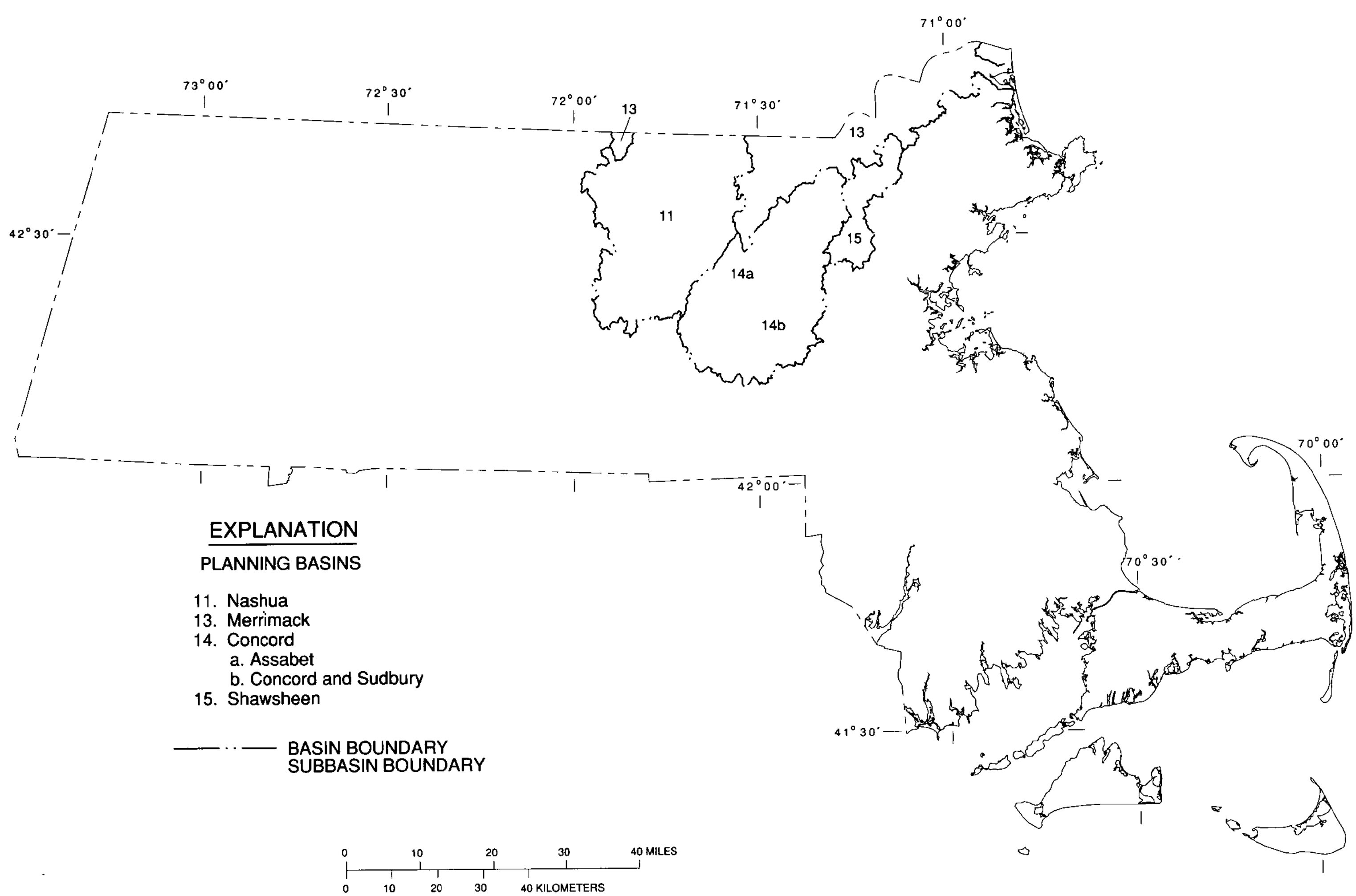


Figure 7.--Location of Massachusetts planning basins within the Merrimack River basin.

Low flow (45 years of record):
7-day 2-year low flow: 45.4 ft^3/s
7-day 10-year low flow: 35.3 ft^3/s

Remarks: Regulation at low flow by mills upstream. Flow includes diversion into basin for municipal supply.

Squannacook River near West Groton, Mass.

Drainage area: 63.7 mi^2 (excludes 2.16 mi^2 above outlet of Ashby Reservoir)

Average discharge: 111 ft^3/s (Oct. 1949 to Sept. 1985)

Extremes for period of record:
Maximum discharge: 4,010 ft^3/s (Oct. 1955)
Minimum daily discharge: 2.0 ft^3/s (Sept. 1965)

Low flow (31 years of record):
7-day 2-year low flow: 12.9 ft^3/s
7-day 10-year low flow: 5.5 ft^3/s

Remarks: Occasional regulation at low flow by mill upstream. Flow from 2.16 mi^2 above outlet of Ashby Reservoir diverted for municipal supply.

Nashua River at East Pepperell, Mass.

Total drainage area: 435 mi^2 (includes 119 mi^2 above Wachusett Reservoir from which flow is diverted for use in Greater Boston area and Worcester)

Average discharge: 570 ft^3/s (Oct. 1935 to Sept. 1985)

Extremes of period of record:
Maximum discharge: 20,900 ft^3/s (Mar. 1936)
Minimum daily discharge: 1.1 ft^3/s (Aug. 1939)

Low flow (45 years of record):
7-day 2-year low flow: 93.3 ft^3/s
7-day 10-year low flow: 46.0 ft^3/s

Remarks: Discharge includes water released into the Nashua River while diverting some flow for use by metropolitan Boston, and includes water diverted into basin from Ware River basin for municipal use. Flow regulated by power plant upstream.

In Massachusetts, the Nashua River basin is located in Middlesex and Worcester Counties and includes all or part of 27 cities and towns, including Fitchburg, Leominster, and Worcester (fig. 8). Altitudes range from 2,006 ft at Wachusett Mountain to about 155 ft above sea level where the Nashua River crosses into New Hampshire. Unless otherwise noted, the following description of the water resources of the Nashua River basin is based on Hydrologic Investigations Atlas 276 (Brackley and Hansen, 1977).

Surface water

The Nashua River basin covers about 443 mi^2 of north-central Massachusetts. About 75 percent of the

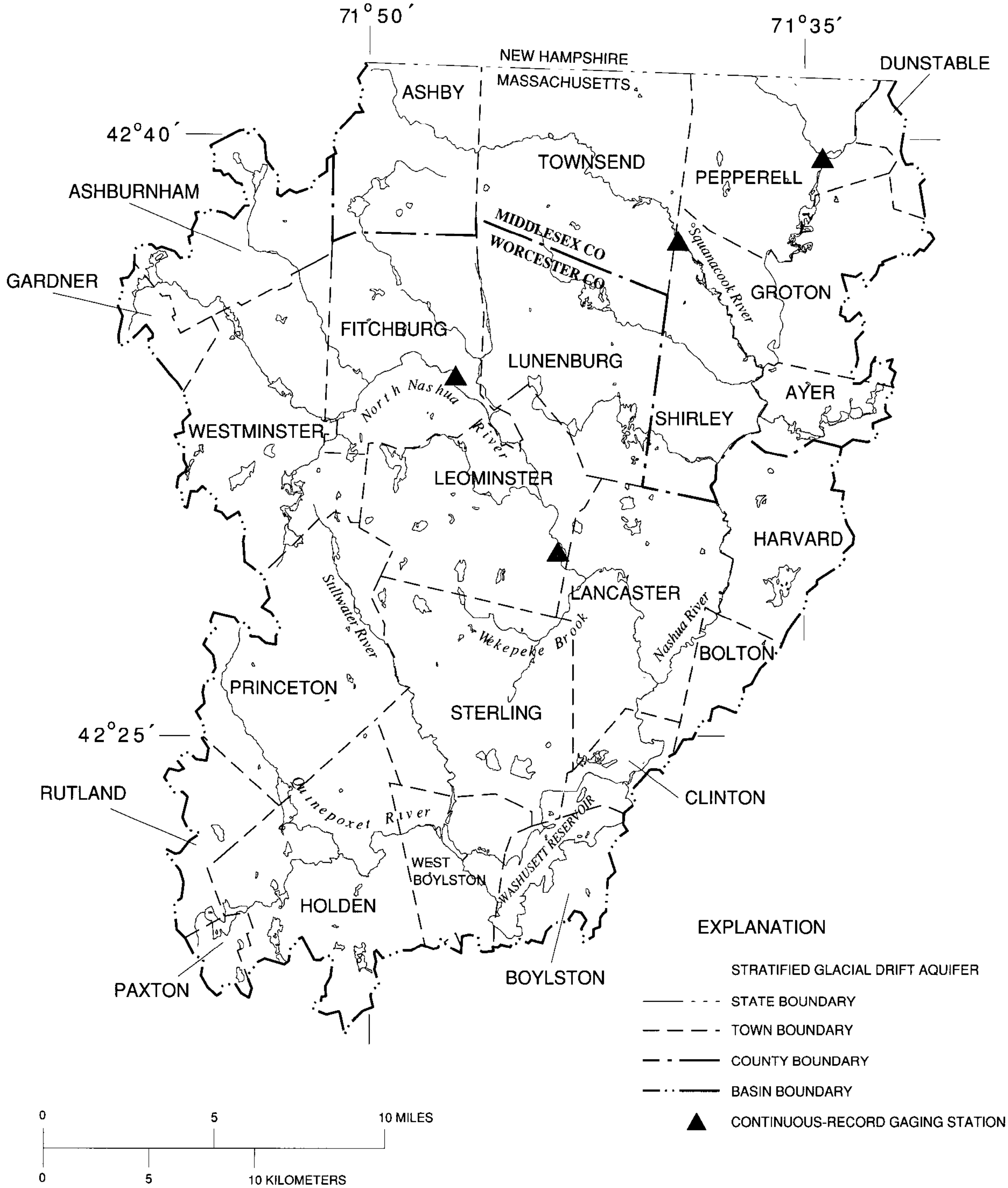


Figure 8.--Principal streams and areas of stratified drift in the Nashua River basin. (Modified from U.S. Geological Survey Hydrologic Investigations Atlas 276.)

basin is forested and about 4 percent contains lakes (Wandle and Fontaine, 1984, p. 31). There are a total of 161 lakes and ponds in the basin, of which 94 have an area of 10 acres or more. Only one lake, the Wachusett Reservoir in Boylston, Clinton, and West Boylston is larger than 500 acres (Massachusetts Department of Environmental Quality Engineering, Division of Water Pollution Control, 1976a, p. 7, 41-44). This reservoir, which covers about 4,135 acres, is an important part of the MWRA's water-supply system.

The Nashua River begins at the junction of the North Nashua and the South Nashua Rivers in Lancaster, in the southeastern part of the basin, and flows in a northeasterly direction into New Hampshire, where it joins the Merrimack River at the city of Nashua. The main channel of the river is located along the eastern side of the basin, and western tributaries are much longer than those that enter the river from the east (fig. 4). The length of the main channel from the drainage divide to the USGS streamflow-gaging station in East Pepperell, several miles south of the State border with New Hampshire, is about 50 mi, with an average channel slope of about 10 ft/mi (Wandle and Fontaine, 1984, p. 31).

The North Nashua River begins in Fitchburg and flows about 23 mi in a southeasterly direction over about a dozen dams and through Fitchburg and Leominster before joining the South Branch Nashua River in Lancaster. The North Nashua River has a gradient of about 41 ft/mi (Wandle and Fontaine, 1984, p. 30). The South Nashua River begins at the outlet of Wachusett Reservoir and flows northward about 5 mi, with an average channel slope of about 12 ft/mi, before joining the North Nashua River.

The flow of the Nashua River and its many tributaries is affected by regulation or diversions or both. Some of the runoff in the headwaters of the Nashua River basin is diverted into reservoirs for use by the city of Worcester, and most of the flow in the South Nashua River basin upstream from Wachusett Dam is diverted out of the basin for municipal supplies in the Greater Boston area and the Worcester area.

Ground water

The most productive aquifers in the Nashua River basin are sand and gravel deposits in low-lying areas near surface-water bodies. Some deposits along the main valleys of the Nashua River basin can yield several hundred gallons per minute to single wells. Areas of high potential well yield lie along the Squannacook River in Townsend, the Nashua River at Fort Devens, and the Still River in Bolton. Much of the main valleys of the North Nashua and Nashua Rivers below Fitchburg contained glacial lakes, and are underlain by fine-grained lake deposits up to 100 ft thick. The best known of these lakes was Lake Nashua, which extended broadly over the drainage area of the Nashua River from Boylston to East Pepperell (Massachusetts Department of Environmental Quality Engineering, Division of Water Pollution Control, 1976b, p. 15). Lake deposits generally yield less than 100 gal/min to wells, but, if interspersed with coarser deposits, can yield 100 to 300 gal/min.

The basin is underlain by several types of crystalline bedrock. Wells drilled in bedrock for domestic use are commonly 100 to 200 ft deep and generally yield 2 to 10 gal/min. Some wells drilled in bedrock for industrial use, mostly in Leominster, yield 20 to 150 gal/min.

Concord River basin

Assabet River at Maynard, Mass.

Drainage area: 116 mi^2

Average discharge: 186 ft^3/s (Oct. 1941 to Sept. 1985)

Extremes for period of record:
Maximum discharge: 4,250 ft^3/s (Aug. 1955)
Minimum daily discharge: 0.20 ft^3/s (Feb. 1965)

Low flow (10 years of record):
7-day 2-year low flow: 20.1 ft^3/s
7-day 10-year low flow: 15.1 ft^3/s

Remarks: Occasional diurnal fluctuation at low flow by mills upstream. Flow affected by reservoirs and by occasional release of water from these reservoirs at low flow.

Sudbury River at Framingham, Mass.

Drainage area: 75.2 mi^2

Average discharge: 117 ft^3/s (Oct. 1875 to Sept. 1985)

Concord River below River Meadow Brook at Lowell, Mass.

Drainage area: 400 mi^2 (diversion as needed from 92.6 mi^2 for use by Greater Boston area)

Average discharge: 635 ft^3/s (Oct. 1936 to Sept. 1985)

Extremes for period of record:
Maximum discharge: 5,410 ft^3/s (Jan. 1979)
Minimum daily discharge: 4.0 ft^3/s (Sept. 1957)

Low flow (44 years of record):
7-day 2-year low flow: 71.9 ft^3/s
7-day 10-year low flow: 32.2 ft^3/s

Remarks: Low flow regulated by mills upstream. Discharge includes undiverted water from 92.6 mi^2 in Sudbury River basin and Lake Cochituate.

The Concord River basin is situated in Worcester and Middlesex Counties of Massachusetts, and includes the Assabet and Sudbury River basins (fig. 9). The Concord River basin includes all or part of 36 cities and towns, including the city of Lowell and the town of Framingham, the most populous town in the State. Topography is generally low, with altitudes ranging from about 480 ft in the headwaters area of the Sudbury River and about 420 ft in the headwaters area of the Assabet River to about 50 ft above sea level at the confluence of the Concord and Merrimack Rivers. Unless otherwise noted, the following description of the water resources of the Concord River basin is based on Hydrologic Investigations Atlases 312 (Pollock and others, 1969) and 662 (Brackley and Hansen, 1985).

Surface water

The Concord River basin covers about 398 mi^2 of northeastern Massachusetts. The basin is heavily forested (about 71 percent of the land area), and contains many wetlands, lakes, and ponds (Wandle and Fontaine, 1984, p. 32). There are a total of 121 lakes and ponds, 75 of which have an area of 10 acres or more. Three lakes, all in the tributary Sudbury River basin, are over 500 acres in size. They include Whitehall Reservoir in Hopkinton (601 acres), Lake Cochituate in Framingham, Natick, and Wayland (594 acres), and Sudbury Reservoir in Marlborough and Southborough (1,292 acres) (Massachusetts Department of Environmental Quality Engineering, Division of Water Pollution Control, 1976a, p. 7, 54-58).

The Concord River begins at the junction of the Assabet and Sudbury Rivers in Concord, and flows about 16 mi northward to the city of Lowell, where it joins

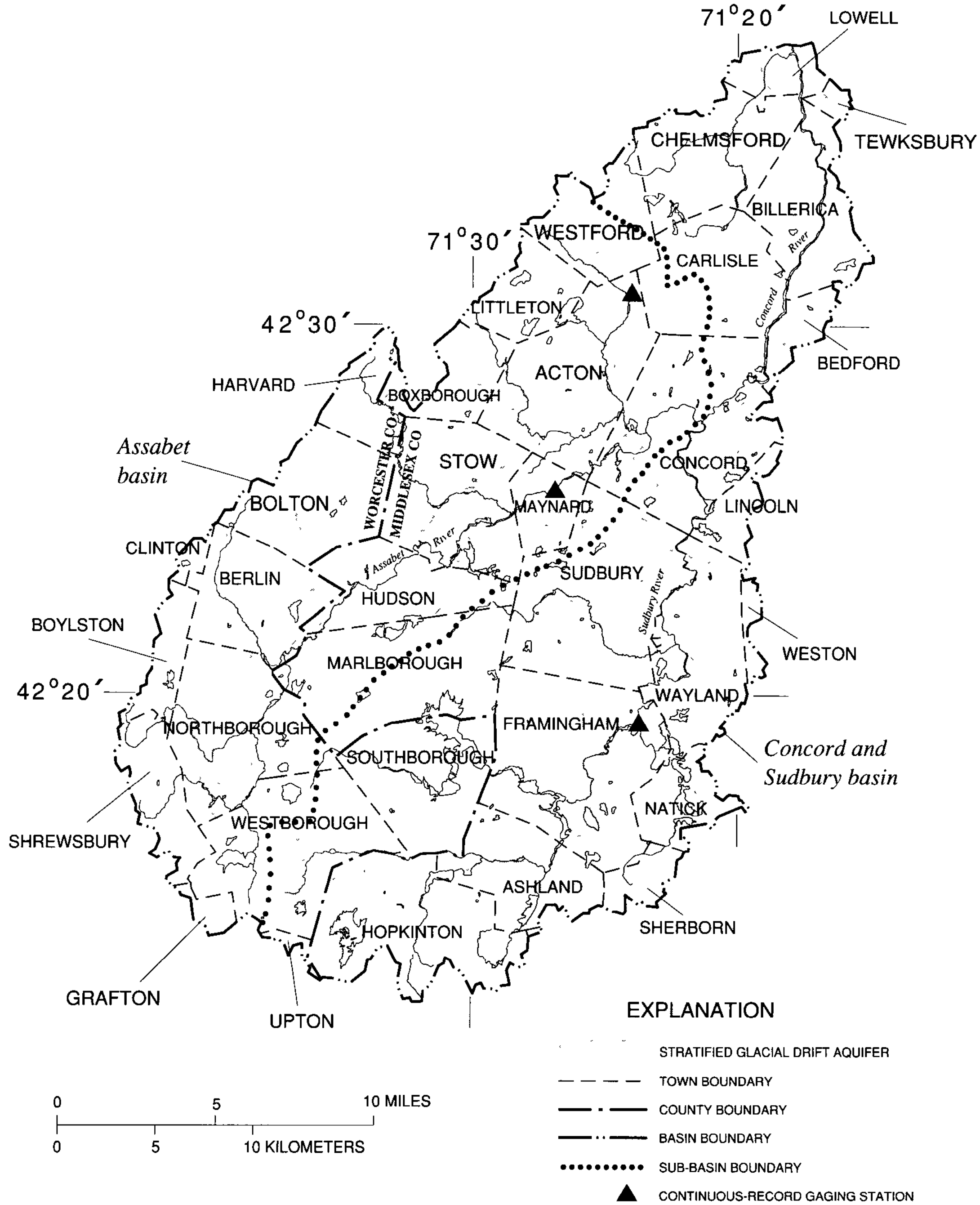


Figure 9.--Principal streams and areas of stratified drift in the Concord River basin. (Modified from U.S. Geological Survey Hydrologic Investigations Atlas 662.)

the Merrimack River. The main channel is about 47 mi long from the drainage divide in Westborough to its confluence with the Merrimack River in Lowell. The relatively low stream gradient of the river, about 5 ft/mi, causes it to be generally slow moving (Wandle and Fontaine, 1984, p. 32).

The Assabet River begins in wetlands in Westborough and flows generally northward and northeastward to its confluence with the Sudbury River in Concord. The river is about 30 mi long, and, except at dams, has an average channel slope of about 6 ft/mi (Wandle and Fontaine, 1984, p. 31).

The Sudbury River also begins in wetlands in Westborough before flowing eastward to Ashland, then northward and northeastward to its confluence with the Assabet River. In its lower reaches, the Sudbury River has a lower stream gradient than the Assabet River. The lowest stream gradient, about 1 ft/mi, occurs along an approximately 12-mi reach of the Sudbury River that flows through a national wildlife refuge in the towns of Sudbury, Wayland, Lincoln, and Concord. After joining the Assabet River in Concord to become the Concord River, the stream gradient continues to be very low until it reaches the Tabot Dam in Billerica (Massachusetts Department of Environmental Quality Engineering, Division of Water Pollution Control, 1980, p. 8).

The upper 75 mi^2 of the Sudbury River basin are part of the MWRA's water-supply system. The reservoirs in this area, including Sudbury Reservoir, were created to supply water during emergencies and high-demand periods. This part of the basin is also used to convey water from the Wachusett Reservoir in the adjacent Nashua River basin through aqueducts for use in the Concord River basin or in Greater Boston.

Ground water

The principal aquifers in the Concord River basin are composed of stratified sand and gravel, up to 140 ft thick, deposited in stream channels at the end of the glacial period. Some areas with high potential well yields lie along Stony Brook in Westford; adjacent to Lake Cochituate in Framingham, Natick, and Wayland; and along River Meadow Brook in Chelmsford.

Many broad lowlands in the Concord River basin mark the sites of glacial lakes, such as Lake Sudbury, which extended from South Framingham to Weston and from Concord to Wellesley, and Lake Assabet, which was located mainly in Westborough, Southborough, and Northborough (Massachusetts Department of Environmental Quality Engineering, Division of Water Pollution Control, 1976b, p. 15).

The Concord River basin is underlain by a variety of crystalline rocks. Wells drilled in bedrock for domestic-water supplies are commonly 100 to 300 ft deep and yield 2 to 10 gal/min, although yields up to 225 gal/min have been reported. Fine-grained lake deposits generally yield less than 100 gal/min to wells, but, if interspersed with coarser deposits, can yield 100 to 300 gal/min.

Shawsheen River basin

Shawsheen River near Wilmington, Mass.

Drainage area: 36.5 mi^2

Average discharge: 61.2 ft^3/s (Oct. 1964 to Sept. 1985)

Extremes for period of record:
Maximum discharge: 1,660 ft^3/s (Jan. 1979)
Minimum discharge: 0.70 ft^3/s (Aug. 1983)

Remarks: Diversion upstream at times for municipal supply.

The Shawsheen River basin is located in Essex and Middlesex Counties and includes all or part of 12 towns and the city of Lawrence (fig. 10). Topography is low, with altitudes that range from 10 ft at the mouth of the Shawsheen River to 250 to 300 ft above sea level at the top of small hills along the drainage divide. Unless otherwise noted, the following description of the water resources of the Shawsheen River basin is based on Hydrologic Investigations Atlas 614 (Gay and Delaney, 1980a).

Surface water

The Shawsheen River basin covers about 78 mi^2 of northeastern Massachusetts. The basin is characterized by low, rounded hills and many wetlands. It contains a total of 18 lakes and ponds, nine of which have an area of 10 acres or more. The largest lake is Fosters Pond in Andover and Wilmington, which is 135 acres (Massachusetts Department of Environmental Quality Engineering, Division of Water Pollution Control, 1976a, p. 7, 60).

The Shawsheen River begins in Bedford, flows northeastward for about 25 mi, and is joined by many small tributaries before entering the Merrimack River in Lawrence. In its upstream half, the river flows in a well-defined channel that meanders over a 200- to 600-ft-wide grassy flood plain. In its downstream half, the river flows through a gently curving pool and riffle channel that is crossed by several dams. The river has a low gradient and flows through wetlands for nearly one-half of its length. From the headwaters area to the USGS streamflow-gaging station near Wilmington, a distance of about 11 river mi, the channel slope of the Shawsheen River is about 5 ft/mi (Wandle and Fontaine, 1984, p. 33).

In 1974, about 85 percent of the municipalities in the Shawsheen River basin obtained all or part of their water from sources outside of the basin. The town of Burlington began diverting water from the Shawsheen River near Wilmington in 1973, and at that time was permitted to divert water from January through June at rates that varied from 3.1 to 12.5 ft^3/s, depending on streamflow available.

Ground water

The principal aquifers in the basin are composed of unconsolidated sand and gravel deposited by meltwater streams during the glacial period. The most productive of these aquifers sustain well yields of several hundred gallons per minute and lie primarily along the Shawsheen River and its major tributaries, Elm, Heath, Strong Water, and Vine Brooks. Aquifers that sustain well yields of less than 200 gal/min occur in many tributary-stream valleys and wetland areas. These aquifers are generally less than 50 ft thick and have small surface areas.

Bedrock in the basin is composed of a variety of igneous and metamorphic rocks. Wells in bedrock yield up to 100 gal/min, but generally yield much less. The median yield of 26 bedrock wells in this basin is 10 gal/min, an amount sufficient for domestic supplies.

Merrimack River basin

Merrimack River below Concord River at Lowell, Mass.

Total drainage area: 4,635 mi^2 (diversions as needed from 210 mi^2 for use in Greater Boston area and Worcester)

Average discharge: 7,562 ft^3/s (Oct. 1923 to Sept. 1985)

Extremes for period of record:
Maximum discharge: 173,000 ft^3/s (Mar. 1936)
Minimum daily discharge: 199 ft^3/s (Sept. 1923)

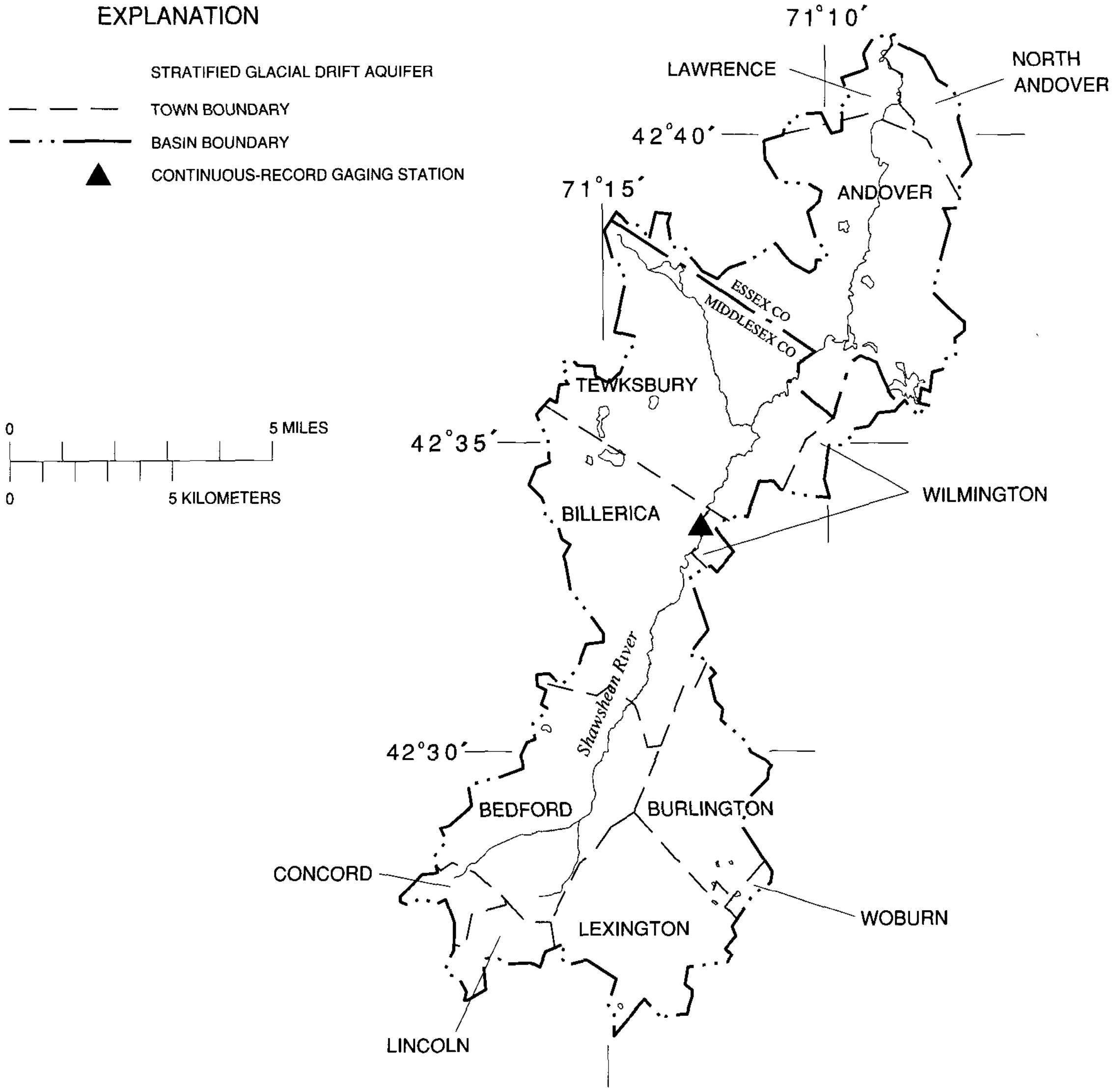


Figure 10.-Principal streams and areas of stratified drift in the Shawsheen River basin. **(Modified from U.S. Geological Survey Hydrologic Investigations Atlas 614.)**

Low flow (57 years of record):
7-day 2-year low flow: 1335 ft^3/s
7-day 10-year low flow: 930 ft^3/s

Remarks: Discharge includes water released from 210 mi^2 in Sudbury and Nashua River basins and from Lake Cochituate. Flow regulated by power plants and by upstream lakes and reservoirs.

In Massachusetts, the Merrimack River planning basin includes the Stony Brook basin, the headwaters area of the Souhegan River basin, and the drainage area of the Merrimack River below the confluence of the Merrimack and Concord Rivers, excluding the Shawsheen River basin (fig. 11). The basin, sometimes referred to as the lower Merrimack River basin, is located in Essex and Middlesex Counties and includes all or part of 28 cities and towns, including the cities of Haverhill, Lawrence, and Lowell. Altitudes in the basin range from sea level to about 300 ft above sea level at the tops of small hills. Unless otherwise noted, the following description of the water resources of the Merrimack River basin is based on Hydrologic Investigations Atlas 616 (Gay and Delaney, 1980b).

Surface water

The Merrimack River basin covers about 279 mi^2 of northeastern Massachusetts. Within this area, there are 76 lakes and ponds, 42 of which are 10 acres or larger. Only one lake, Lake Cochichewick in North Andover (592 acres), is larger than 500 acres (Massachusetts Department of Environmental Quality Engineering, Division of Water Pollution Control, 1976a, p. 7, 51-52). The Merrimack River flows in a well-defined channel that ranges in width from about 400 to 1,400 ft. About 9 mi of the river above its mouth at Newburyport are part of an estuary bordered by tidal marshes. From the State line to the Merrimack estuary, a distance of about 50 river mi, the river drops about 90 ft in altitude. This drop includes flow over dams in the cities of Lowell and Lawrence, where some streamflow is diverted through extensive canal systems.

Streamflow in the Merrimack River is affected by reservoirs, especially those used for flood control and water supply. Flood-control reservoirs store water during peak streamflow and release it during periods of lower streamflow. From 1960 through 1974, water diverted by the city of Worcester and by the MDC (now the MWRA) from the tributary Nashua and Concord River basins by way of Pine Hill, Kendall, Sudbury, and Wachusett Reservoirs reduced the mean annual streamflow in the lower Merrimack River by about 177 ft^3/s. Although the Merrimack River flows through or adjoins 15 municipalities in the basin, only Lowell, Lawrence, and Methuen use it for water supply.

Hydroelectric power production along the Merrimack River and its tributaries causes diurnal streamflow fluctuations in the lower part of the basin, especially from July to September, when streamflow contributions from tributary drainage areas are small.

Ground water

The principal aquifers in the Merrimack River basin are composed of unconsolidated sand and gravel that were deposited in meltwater streams during the glacial period. Aquifers that can sustain well yields of more than 300 gal/min lie primarily along the Merrimack River and its major tributaries. The largest area of glacial deposits capable of yielding more than 300 gal/min to single wells is located in northwestern Amesbury, near the New Hampshire border. Many small aquifers (saturated thickness less than 50 ft) in stream valleys and wetlands throughout the basin sustain wells yielding less than 100 gal/min.

Igneous and metamorphic bedrock throughout the basin provides a sufficient quantity of water for most domestic wells. Yields range from less than a gallon per minute to about 100 gal/min. The median yield of 41 bedrock wells is 10 gal/min.

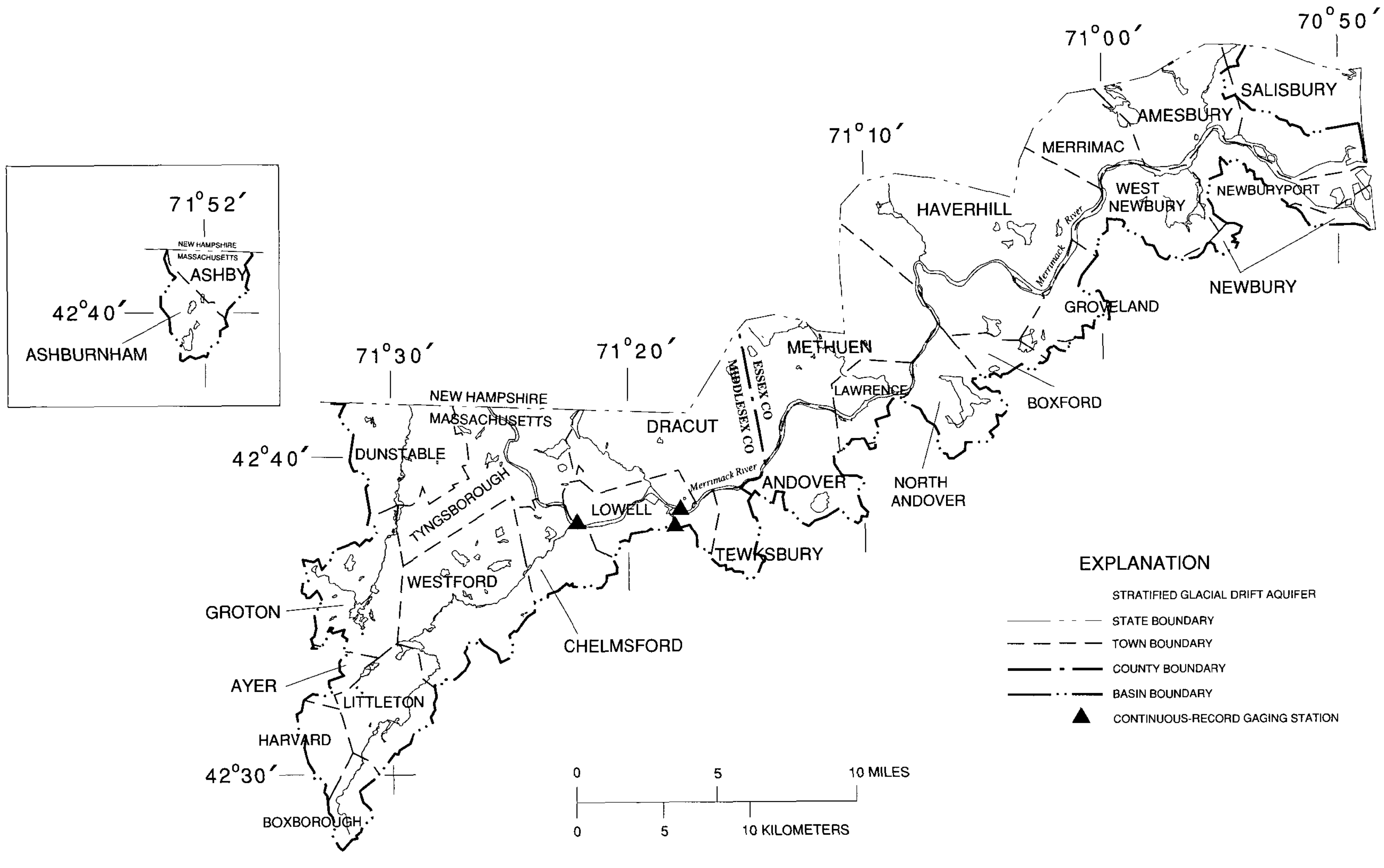


Figure 11.--Principal streams and areas of stratified drift in the Merrimack River basin. (Modified from U.S. Geological Survey Hydrologic Investigations Atlas 616.)

Coastal basins

State planning basins: the Coastal basins of the North Shore (Parker, Ipswich, and North Coastal basins); the Boston Harbor basins (Charles, Mystic, Neponset, and Weymouth and Weir River basins); the Coastal basins of the South Shore and Buzzards Bay (North and South Rivers, and the South Coastal Shore and Buzzards Bay drainage basins); Cape Cod and Islands; and the basins of Narragansett Bay (Taunton, Blackstone, Ten Mile, and the Narragansett Bay and Mount Hope Bay Shore drainage basins (fig. 12))

The Coastal basins of Massachusetts are part of a broad northeast-trending belt of lowlands that extend from Rhode Island to Augusta, Maine, and include parts of the Continental Shelf. The lowlands have a total length of about 200 km and a width of 60 to 100 m (Denny, 1982, p. 5). The Coastal basins drain into the Atlantic Ocean and numerous bays along the east coast, and are characterized by plains and low hills. Stream gradients are gentle in the coastal lowlands, but steepen rapidly along the edge of the central highlands.

Parker River basin

Parker River at Byfield, Mass.

Drainage area: 21.3 mi^2

Average discharge: 36.9 ft^3/s (Oct. 1945 to Sept. 1985)

Extremes for period of record:
Maximum discharge: 489 ft^3/s (Mar. 1968)
Minimum daily discharge: 0.09 ft^3/s (Sept. and Oct. 1957)

Low flow (35 years of record):
7-day 2-year low flow: 0.79 ft^3/s
7-day 10-year low flow: 0.21 ft^3/s

Remarks: Occasional regulation by mill and ponds upstream.

The Parker River basin, located in Essex County, contains all or part of nine towns (fig. 13). Altitudes are generally less than 200 ft above sea level, although some bedrock hills have altitudes of 300 to 400 ft. Drumlins composed of glacial till are scattered throughout the area. The following description of the water resources of the Parker River basin is based on Hydrologic Investigations Atlas 247 (Sammel, 1967).

Surface water

The Parker River basin, which has an area of about 66 mi^2 in northeastern Massachusetts, contains numerous small streams that wind through extensive wetlands. It is bordered on the south by basins of the Rowley River and a few smaller coastal streams, which together drain about 15 mi^2 and are discussed

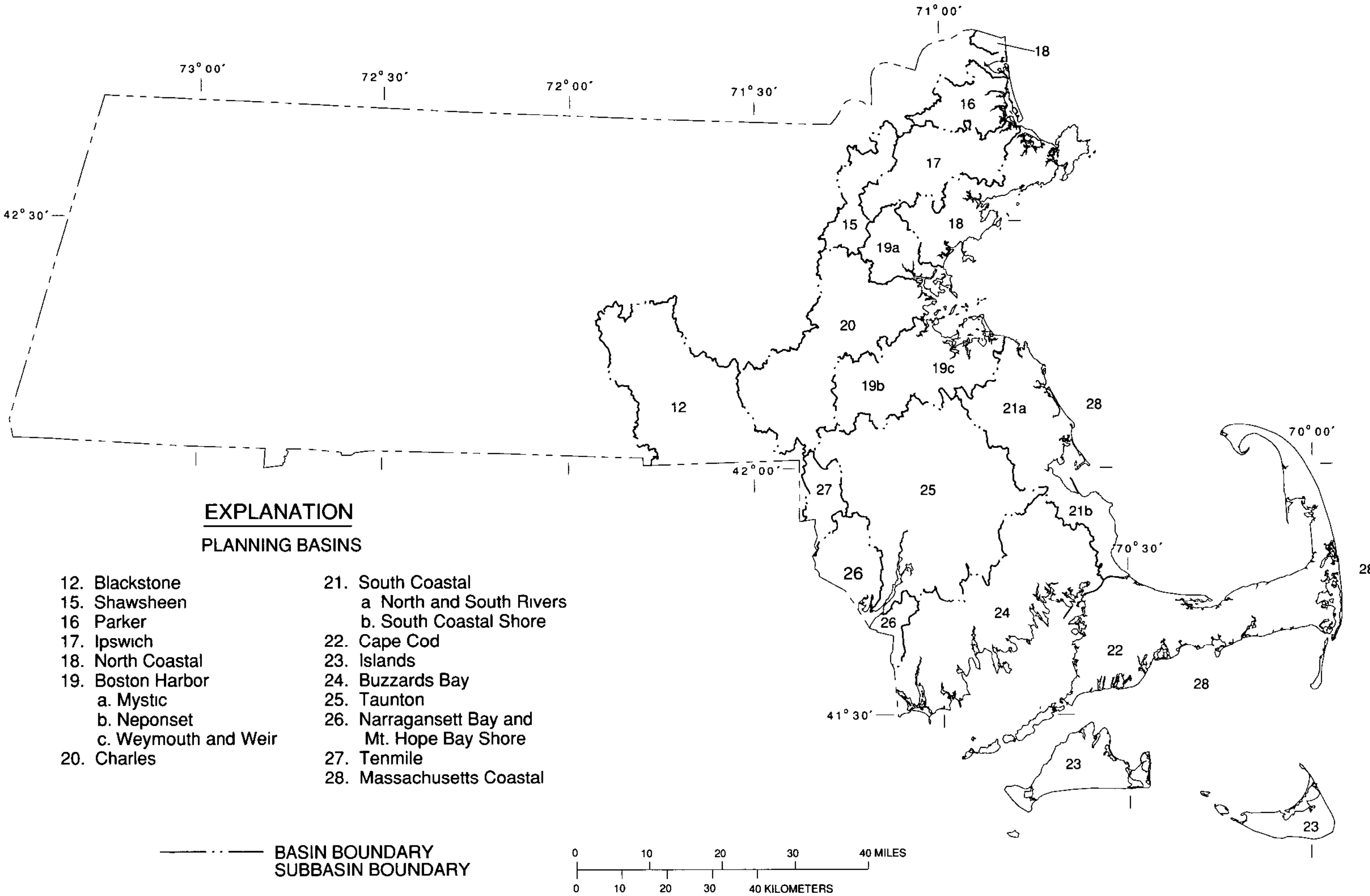


Figure 12.--Location of Massachusetts planning basins within the Coastal basin.

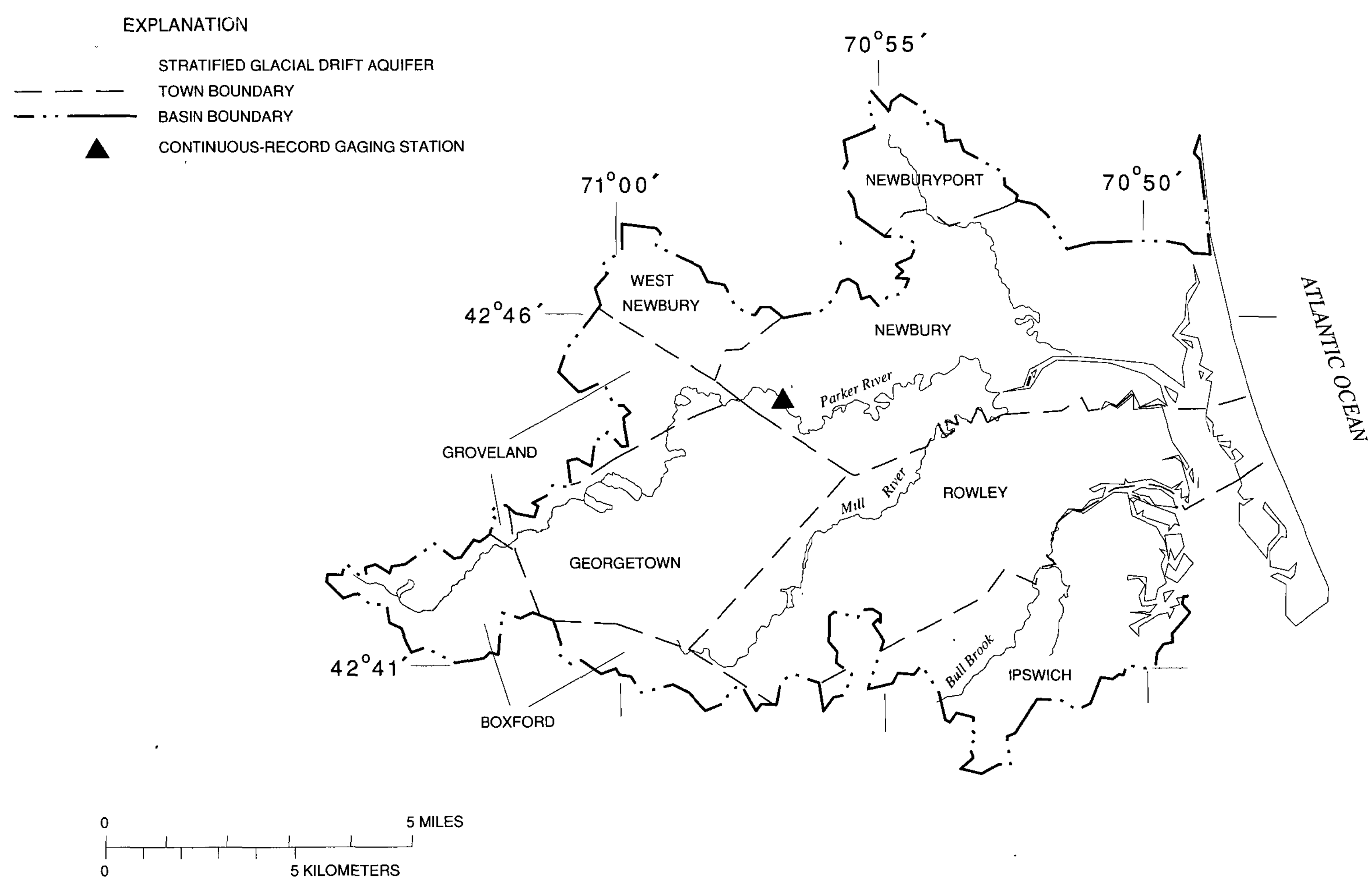


Figure 13.--Principal streams and areas of stratified drift in the Parker River basin. (Modified from U.S. Geological Survey Hydrologic Investigations Atlas 247.)

with the Parker River in this report. Upstream of coastal tidal marshes, about 70 percent of these basins is forested and about 15 percent is covered by lakes, ponds, and marshes (Wandle, 1984a, p. 32). There are a total of 18 lakes and ponds, 10 of which cover at least 10 acres. The largest lake is Pentucket Pond in Georgetown, which is 85 acres (Massachusetts Department of Environmental Quality Engineering, Division of Water Pollution Control, 1976a, p. 7, 62). Wetlands upstream from Byfield and the tidal estuary downstream from Byfield minimize flood flows caused by storms by temporarily storing surface water in low areas and in wetland sediments. However, because wetlands transpire and evaporate large amounts of water, low flows can be depressed downstream from wetlands during the late spring to early fall growing season.

As is common in areas containing many wetlands, stream gradients are low. For example, the channel slope from the headwaters area of the Parker River to the USGS streamflow-gaging station at Byfield, a distance of about 11 river mi, is about 6 ft/mi.

About one-third of the runoff from the Parker River basin is measured at the Byfield streamflow-gaging station; the remainder enters the river channel in the tidal reach below Byfield or flows directly into tidal marshes and Plum Island Sound.

Ground water

The most productive aquifers in the Parker River basin are in the western third of the basin and consist of ice-contact deposits composed of sand and gravel, which were deposited in stream channels and temporary lakes in contact with glacial ice. Most of the aquifers in the eastern two-thirds of the basin consist of sandy glacial-outwash deposits, which are generally thin and less permeable than the ice-contact deposits. These outwash deposits, however, may be productive where buried beneath younger marine or swamp deposits in the central part of the basin. The largest yields are likely where the coarser ice-contact deposits underlie or interfinger with outwash. Most aquifers in the basins, both ice-contact and outwash, are extensively overlain by organic swamp deposits, which may result in excessive iron concentrations in ground water. Yields of large-diameter, gravel-packed wells in glacial deposits are as much as 500 gal/min, and the average yields of small-diameter, driven wells are about 10 to 22 gal/min. In addition, bedrock supplies small amounts of ground water almost anywhere.

Ipswich River basin

Ipswich River at South Middleton, Mass.

Drainage area: 44.5 mi^2

Average discharge: 62.6 ft^3/s (Oct. 1938 to Sept. 1985)

Extremes for period of record:
Maximum discharge: 839 ft^3/s (Jan. 1979)
Minimum discharge: 0.1 ft^3/s (Sept. and Oct. 1957)

Low flow (42 years of record):
7-day 2-year low flow: 1.4 ft^3/s
7-day 10-year low flow: 0.41 ft^3/s

Remarks: Diversions upstream for municipal supply. Occasional regulation by mill upstream.

Ipswich River near Ipswich, Mass.

Drainage area: 125 mi^2

Average discharge: 188 ft^3/s (Oct. 1930 to Sept. 1985)

Extremes for period of record:
Maximum discharge: 2,680 ft^3/s (Mar. 1968)
Minimum discharge: 0.34 ft^3/s (Sept. 1978)

Low flow (50 years of record):
7-day 2-year low flow: 6.0 ft^3/s
7-day 10-year low flow: 2.0 ft^3/s

Remarks: Diversions upstream for municipal supply. Some regulation by reservoirs upstream.

The Ipswich River basin is located in Middlesex and Essex Counties and contains all or part of 22 cities and towns, including the cities of Peabody and Beverly (fig. 14). The river basin is a major source of water for 15 cities and towns in or near the basin. Public supplies for two cities, Lynn and Peabody, and one town, Lynnfield, in the southern part of the basin are obtained from the MWRA's water-supply system. The following description of the water resources of the Ipswich River basin is based on Hydrologic Investigations Atlas 196 (Sammel and others, 1964).

Surface water

The Ipswich River basin covers about 155 mi^2 in northeastern Massachusetts. About 74 percent of the basin is forested, and about 10 percent is covered by lakes, ponds, and marshes (Wandle, 1984a, p. 32). There are 75 lakes and ponds, 36 of which are at least 10 acres in area. The largest lake is Putnamville Reservoir in Danvers, which is 270 acres (Massachusetts Department of Environmental Quality Engineering, Division of Water Pollution Control, 1976a, p. 7, 63-65). The Ipswich River begins in wetlands in northern Burlington and follows a meandering, northeasterly course for about 35 mi to its mouth in Plum Island Sound. Much of the course of the river and its tributaries is through wetlands, and stream gradients in the basin are low. From the river's headwaters area to the USGS streamflow-gaging station near Ipswich, a distance of about 27 river mi, the channel slope of the Ipswich River averages about 2.5 ft/mi (Wandle, 1984a, p. 32).

The base flow of the Ipswich River is derived mainly from discharge of water from ground water and from wetlands. During much of late summer and early fall, when evapotranspiration rates are high, streamflow in the Ipswich River basin is severely affected by ground-water withdrawals. In addition, streamflow is significantly reduced by out-of-basin diversions of surface water and ground water.

Ground water

Aquifers in the Ipswich River basin consist mostly of relatively fine-grained glacial-outwash deposits that include some coarser-grained ice-contact deposits. In addition to these stratified-drift deposits, bedrock yields small but reliable amounts of water almost everywhere in the basin.

The stratified-drift deposits are generally less than 50 ft thick and underlie about 30 percent of the basin. Many are covered by organic swamp deposits. Most of the favorable areas for ground-water development are along the course of the Ipswich River or in nearby wetlands, especially in Wilmington, Peabody, Middleton, Wenham, and Hamilton. However, surface-water use during low-flow periods reduces the amount of water available to wells that are completed in stratified deposits near the river.

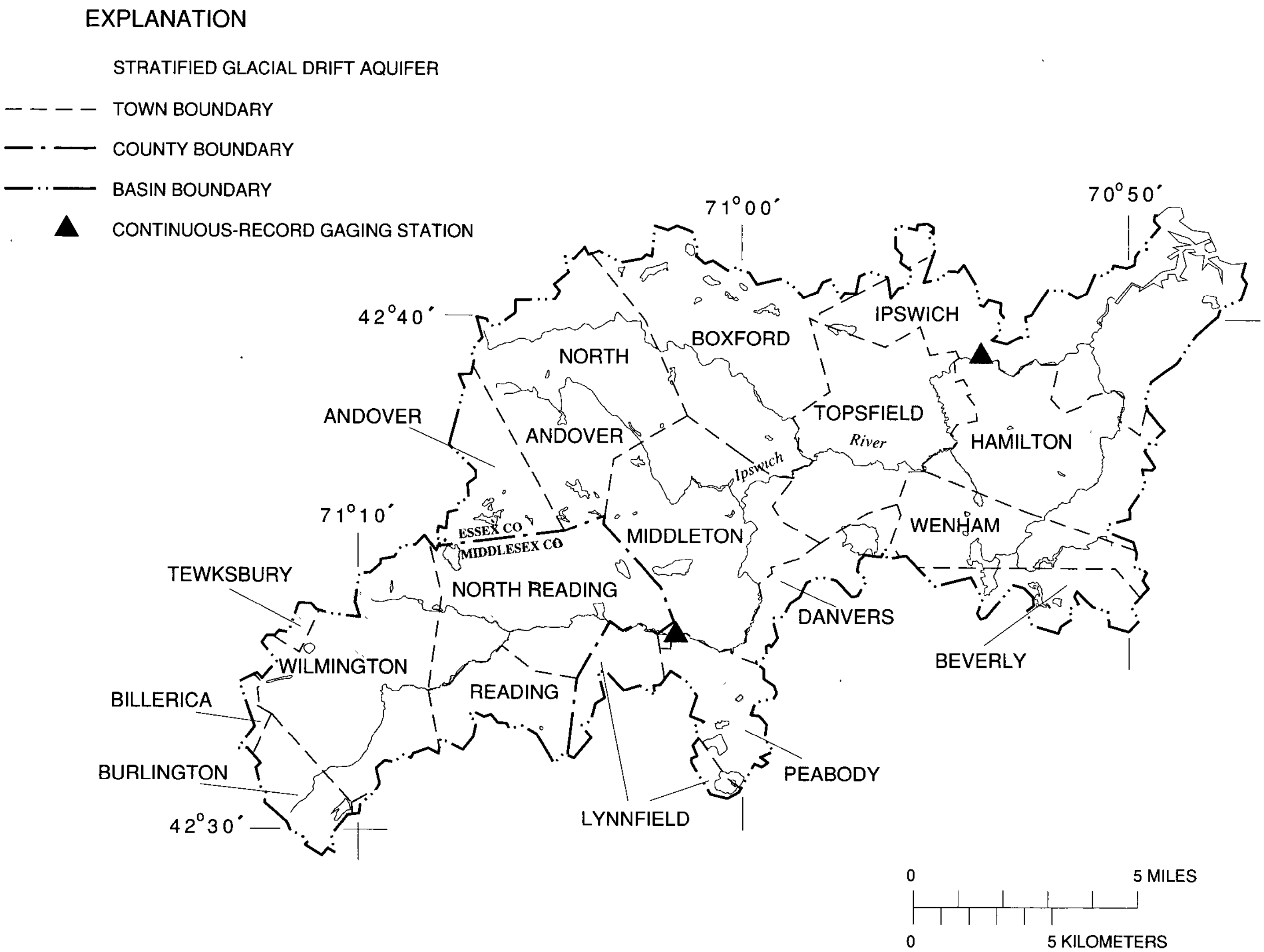


Figure 14.--Principal streams and areas of stratified drift in the Ipswich River basin. (Modified from U.S. Geological Survey Hydrologic Investigations Atlas 196.)

North Coastal basin

The North Coastal basin is located in Essex, Middlesex, and Suffolk Counties and contains all or part of 26 cities and towns, including the cities of Beverly, Lynn, Peabody, Salem, and Revere (fig. 15).

Water demands in the basin exceed the capacity of the basin's few small aquifers and streams, and many towns and cities receive their public-water supplies from the MWRA. The Ipswich River is also a major source of imported water to the cities of Beverly, Lynn, Peabody, and Salem. The following description of the water resources of the North Coastal basin is based on Hydrologic Investigations Atlas 589 (Delaney and Gay, 1980).

Surface water

The North Coastal basin drains about 172 mi^2 of northeastern Massachusetts, and includes the drainage areas of the Annisquam, Danvers and Saugus Rivers, and several smaller river basins draining into Massachusetts and Ipswich Bays. The basin is characterized by small hills, which reach altitudes of about 350 ft above sea level, and low stream gradients. The low relief of the land has caused many wetlands to form throughout the basin, and many lakes, ponds, and swamps exist along the main river valleys. In total, the basin contains 85 lakes and ponds, 39 of which have an area of 10 acres or more. The largest lake in the basin is Lake Quannapowitt in Wakefield, which is 254 acres (Massachusetts Department of Environmental Quality Engineering, Division of Water Pollution Control, 1976a, p. 7, 66-68).

Ground water

The principal aquifers in the North Coastal basin are composed of sand and gravel deposited in stream channels during the last glacial period. Aquifers that sustain well yields of less than 200 gal/min occur in many stream valleys and swampy areas throughout the basin. These aquifers usually cover a small surface area and are less than 50 ft thick, although their size is unknown where they adjoin or underlie fine-grained marine or lake deposits. One of the largest areas of productive sand and gravel deposits in the basin is located along Goldthwait Brook in Peabody.

Bedrock is near or at the land surface in most of the basin and, in most places, can supply the few gallons per minute of water needed for domestic wells. Although bedrock wells in this area yield up to 110 gal/min, they generally yield 10 gal/min or less.

Boston Harbor (Mystic River) basin

Aberjona River (head of Mystic River) at Winchester, Mass.

Drainage area: 24.1 mi^2 (excludes 0.63 mi^2 drained by Winchester North Reservoir)

Average discharge: 28.5 ft^3/s (Oct. 1939 to Sept. 1985)

Extremes for period of record:
Maximum discharge: 1,330 ft^3/s (Jan. 1979)
Minimum daily discharge: 0.25 ft^3/s (Oct. 1950)

Low flow (41 years of record):
7-day 2-year low flow: 0.92 ft^3/s
7-day 10-year low flow: 0.46 ft^3/s

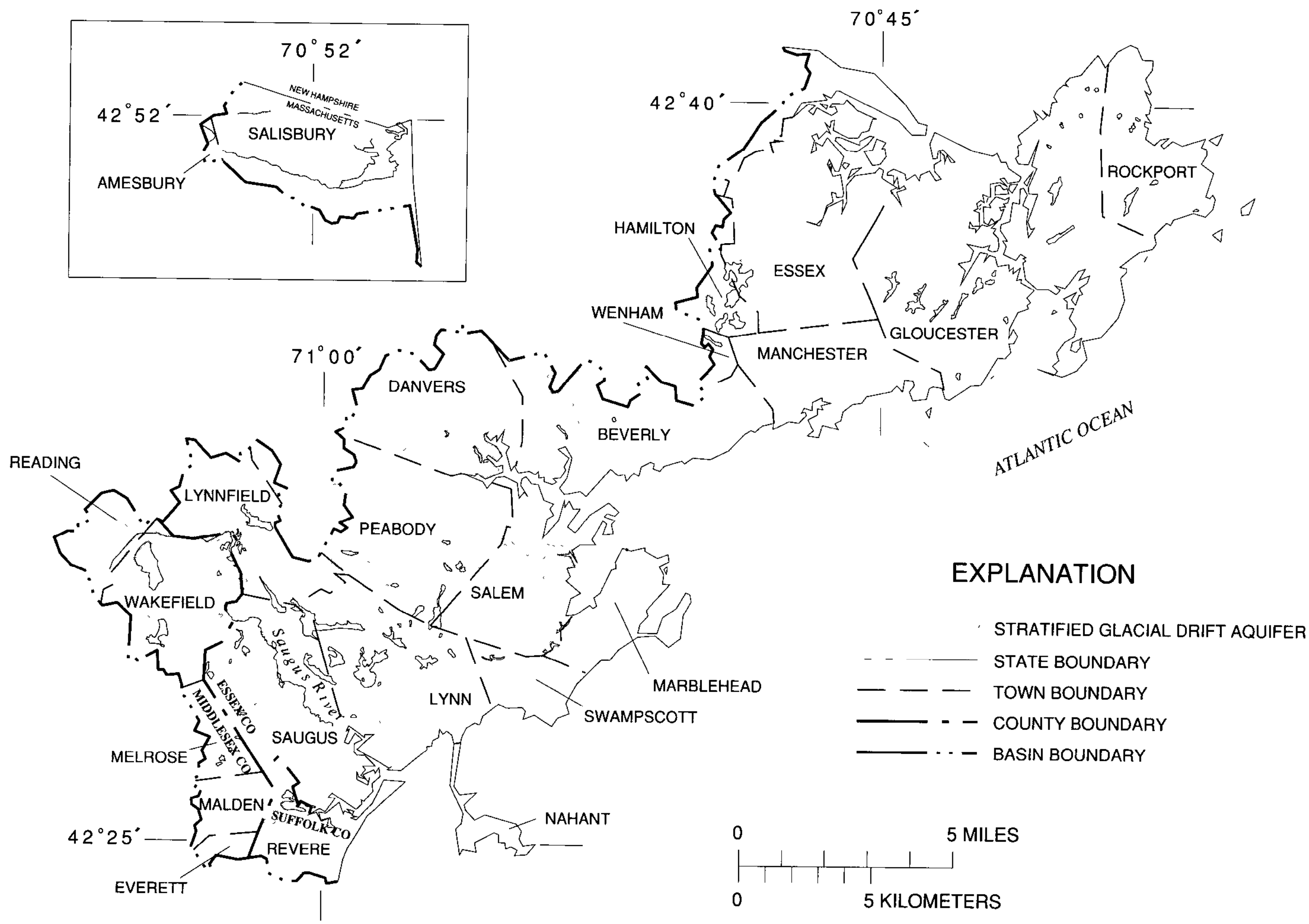


Figure 15.--Location of principal streams and areas of stratified drift in the North Coastal basin. (Modified from U.S. Geological Survey Hydrologic Investigations Atlas HA-589.)

Remarks: Flow affected by diversions for industrial use and municipal supply and by wastage and leakage from Winchester North Reservoir. Some regulation at dam upstream.

The Mystic River basin, located in Middlesex and Suffolk Counties, contains all or part of 21 towns and cities, including the cities of Boston, Cambridge, Revere, Malden, Melrose, Chelsea, Everett, Woburn, Medford, and Somerville (fig. 16). Water demands exceed the capacity of the few small aquifers and streams in this basin and many towns and cities are provided with public-water supplies by the MWRA. The Stony Brook and Hobbs Brook Reservoirs in the Charles River basin, which supply the city of Cambridge, are also major sources of imported water. The following description of the water resources of the Mystic River basin is based on Hydrologic Investigations Atlas 589 (Delaney and Gay, 1980).

Surface water

The Mystic River basin has an area of about 66 mi^2 in northeastern Massachusetts. The basin has small hills, which reach altitudes of about 350 ft above sea level, and many wetlands located in broad valleys. The low relief of the land has caused many wetlands to form throughout the basin, and many lakes, ponds, and swamps exist along the valleys of the Mystic and Aberjona Rivers. The basin contains 44 lakes and ponds, 20 of which have an area of 10 acres or more. The largest lake in the basin is Spot Pond in Stoneham, which is 307 acres in area (Massachusetts Department of Environmental Quality Engineering, Division of Water Pollution Control, 1976a, p. 7, 71-72).

The Mystic River begins at the outlet of Lower Mystic Lake and flows southeastward to Boston Harbor. Major tributaries are the Aberjona River, which begins in Reading, and Mill Brook, which begins in Lexington. The entire length of the Mystic River was originally influenced by tides. However, in 1909, Craddock Locks (now abandoned), located in Medford, prevented tides from affecting the upper part of the Mystic River, Lower Mystic Lake, and Alewife Brook. Since 1966, the Amelia Earhart Dam, located at the mouth of the Mystic River, has prevented tides from affecting the Malden River and the lower part of the Mystic River. Stream gradients in the basin are generally low. For example, the Aberjona and Mystic River system loses about 80 ft of altitude in 16 mi from the headwaters in Reading to the Amelia Earhart Dam near Boston Harbor, an average stream gradient of 5 ft/mi.

Flow in the Aberjona River commonly is reduced by ground-water withdrawals along the river and subsequent diversion out of the basin by way of the MWRA sewer system. This reduction is most noticeable during low-flow periods. For example, compared to nearby river basins such as the Assabet, Charles, and Shawsheen, the annual 7-day, 10-year low flows in the Aberjona River at Winchester are about one-half to one-third of their expected value.

Ground water

The principal aquifers in the Mystic River basin are composed of sand and gravel deposited in stream channels during the last glacial period. The most productive aquifers can sustain well yields of several hundred gallons per minute and are located in the Aberjona, Malden, and Mystic River valleys. Aquifers that sustain well yields of less than 200 gal/min occur in many stream valleys and swampy areas throughout the basins. These aquifers usually cover a small surface area and are less than 50 ft thick, although their size is unknown where they adjoin or underlie fine-grained marine or lake deposits.

Bedrock is near or at the land surface in most of the basin and, in most places, can supply the few gallons per minute of water needed for domestic wells. Although bedrock wells can yield up to 110 gal/min, they generally yield 10 gal/min or less.

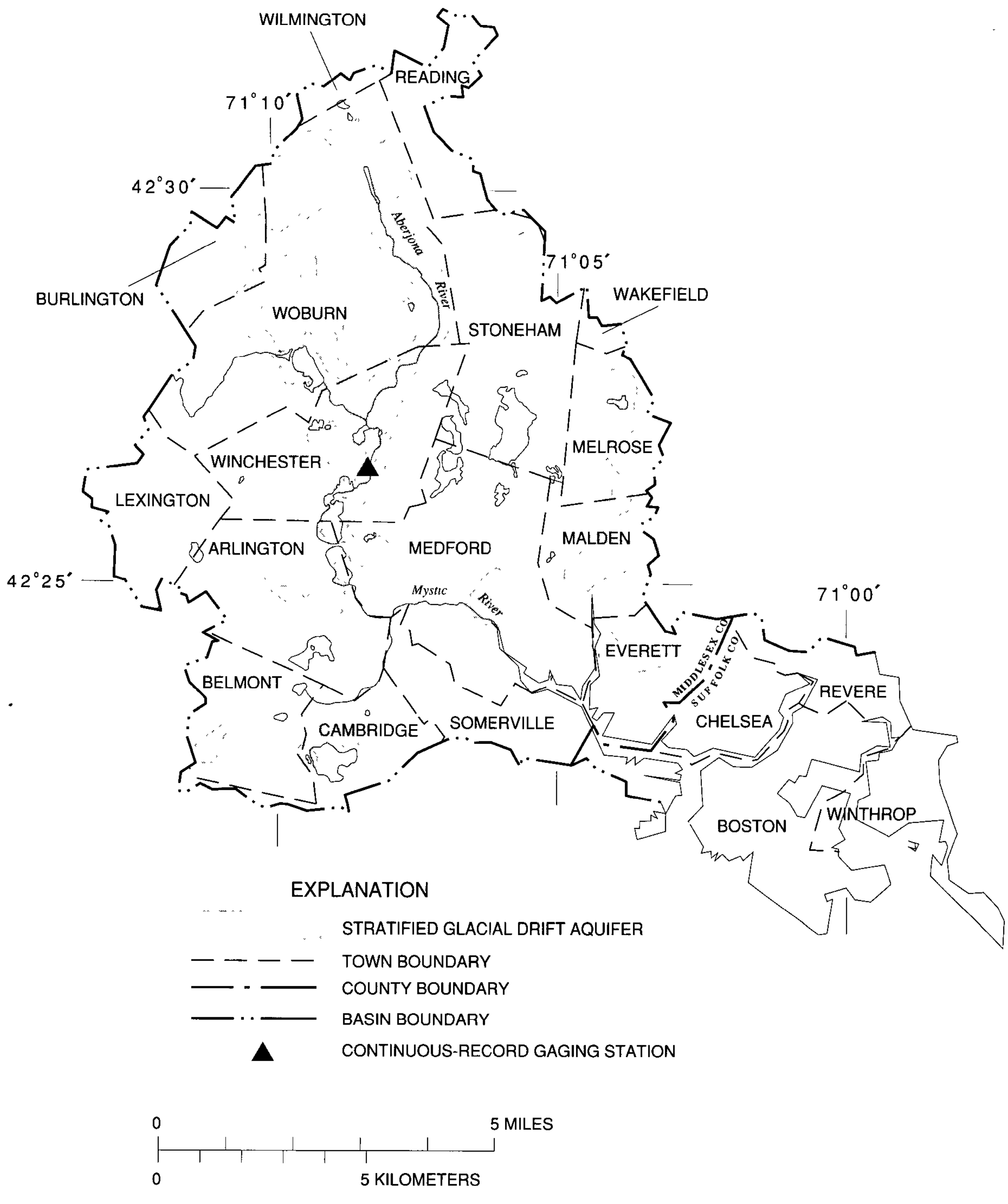


Figure 16.--Principal streams and areas of stratified drift in the Boston Harbor (Mystic River) basin. (Modified from U.S. Geological Survey Hydrologic Investigations Atlas 589.)

Charles River basin

Charles River at Dover, Mass.

Drainage area: 183 mi^2

Average discharge: 302 ft^3/s (Oct. 1937 to Sept. 1985)

Extremes for period of record:
Maximum discharge: 3,220 ft^3/s (Aug. 1955 and Mar. 1968)
Minimum discharge: 0.5 ft^3/s (Oct. 1952)
Minimum daily discharge: 0.9 ft^3/s (Oct. 1952)

Low flow (43 years of record):
7-day 2-year low flow: 32.5 ft^3/s
7-day 10-year low flow: 12.9 ft^3/s

Remarks: Flow affected by diversions to and from basin for municipal supplies.

Mother Brook at Dedham, Mass.

Average discharge: 78.4 ft^3/s (Oct. 1931 to Sept. 1985)

Extremes for period of record:
Maximum discharge: 1,040 ft^3/s (Mar. 1968)
Minimum discharge: 0 ft^3/s (at various times)

Remarks: Mother Brook is a diversion from the Charles River to the Neponset River through Dedham and Hyde Park.

Charles River at Waltham, Mass.

Drainage area: 227 mi^2 (excludes 23.6 mi^2 drained by Stony Brook, from which flow is diverted for municipal supply of Cambridge)

Average discharge: 302 ft^3/s (Oct. 1931 to Sept. 1985)

Extremes for period of record:
Maximum discharge: 4,150 ft^3/s (Feb. 1976, caused by release of water behind ice jam)
Minimum discharge: 0.1 ft^3/s (Oct 1943)
Minimum daily discharge: 0.2 ft^3/s (Oct. 1943)

Remarks: Flow affected by diversion to Mother Brook, diversions to and from basin for municipal supplies, and by water released from Stony Brook Reservoir.

The Charles River basin is located in Suffolk, Norfolk, Middlesex, and Worcester Counties, and includes all or part of 35 cities and towns, including the cities of Boston, Brookline, Cambridge, Somerville, Newton, and Waltham (fig. 17). Elevations in the basin range from about 500 ft above sea level in Hopkinton to sea level at Boston Harbor. The following description of the water resources of the Charles River basin is based

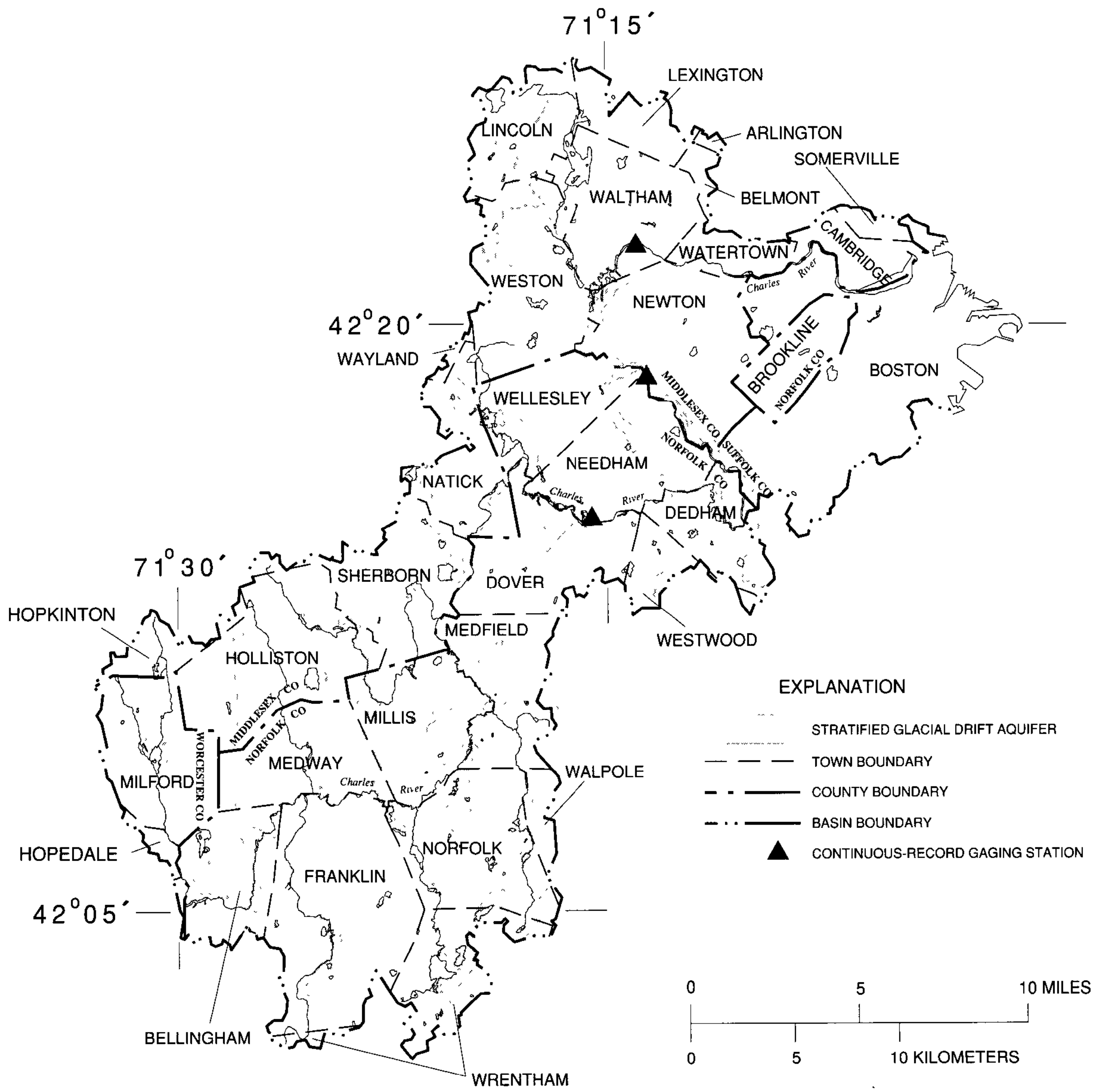


Figure 17.--Principal streams and areas of stratified drift in the Charles River basin. (Modified from U.S. Geological Survey Hydrologic Investigations Atlas 554.)

on Hydrologic Investigations Atlas 554 (Walker and others, 1975).

Surface water

The Charles River and its tributaries drain about 321 mi^2 west and southwest of Boston. Although the lower part of the basin is heavily urbanized, about 72 percent of the area above the USGS gage at Dover is covered by forests (Wandle, 1984a, p. 33). The middle and upper parts of the basin also contain many wetlands and small lakes and ponds. Above Watertown, the basin contains 139 lakes and ponds, 65 of which have an area of 10 acres or more. Only one lake, Cambridge Reservoir in Lexington, Lincoln, and Waltham (549 acres), is larger than 500 acres (Massachusetts Department of Environmental Management, Division of Water Resources, 1978, p. 67; Massachusetts Department of Environmental Quality Engineering, Division of Water Pollution Control, 1976a, p. 78-82).

The Charles River begins in Hopkinton near Echo Lake, about 30 mi southwest of Boston, and meanders about 80 mi to its mouth at Boston Harbor. The river flows through extensive wetlands in its middle reaches, and stream gradients throughout the basin are relatively low. From the headwaters area in Hopkinton to the USGS streamflow-gaging station at Dover, a distance of about 41 river mi, the channel slope of the Charles River is about 4.5 ft/mi (Wandle, 1984a, p. 33).

Below the Watertown Dam, the river was influenced by tides before the beginning of this century. In 1908, a dam was built just over a mile above the mouth of the river to prevent tidal flooding of the lowlands and to create a pool with a constant water level. This dam was replaced by the Charles River Dam at a nearby downstream site in 1978. The river contains many dams and associated ponds, many of which were mill ponds. The largest former mill pond on the Charles River is the "lakes district" in Waltham, Newton, and Weston, which was created about 1812 by increasing the height of a dam in Waltham (Fleishman, 1978).

Today, the flow is affected by releases of water from Stony Brook and Norumbega Reservoirs, diversions from the Sudbury River basin, diversions to Mother Brook, and diversions to Wellesley, Needham, and Dedham for municipal supplies. The largest diversions from the basin are through Mother Brook and to the Stony Brook Reservoir system at the town line between Waltham and Weston, which supplies water to the city of Cambridge. By law, water from the Sudbury Aqueduct can be used to augment the low flow of the Charles River.

Ground water

Stratified drift, deposited by water flowing from melting glaciers, forms the most important aquifers in the Charles River basin. Fifteen moderate- to high-yield stratified-drift aquifers have been identified in the basin above Waltham. These aquifers occur along the present river and tributary channels and are connected hydraulically to the Charles River. They cover about 75 mi^2 or about 30 percent of the basin above Waltham, and range in area from about 0.3 to 10 mi^2. The saturated thickness of the drift deposits generally increases from southwest to northeast across the upper basin. Town wells in drift deposits with an average saturated thickness of 50 ft yield from 100 to 1,500 gal/min, and average about 500 gal/min.

Most bedrock in the basin can provide a few gallons per minute of water to wells for domestic, farm, and minor industrial needs. Yields reported for such wells are usually between 1 and 5 gal/min, but may be as high as 50 gal/min.

Boston Harbor (Neponset, Weymouth and Weir Rivers) basin

Neponset River at Norwood, Mass.

Drainage area: 34.7 mi^2

Average Discharge: 54.5 ft^3/s (Oct. 1939 to Sept. 1985)

Extremes for period of record:
Maximum discharge: 1,490 ft^3/s (Aug. 1955)
Minimum daily discharge: 1.4 ft^3/s (Oct. 1963)

Low flow (41 years of record):
7-day 2-year low flow: 7.4 ft^3/s
7-day 10-year low flow: 4.5 ft^3/s

Remarks: Flow regulated by mills and reservoirs upstream. Flow affected by several diversions upstream for municipal and industrial use.

Old Swamp River near South Weymouth, Mass. (Weymouth Back River basin)

Drainage area: 4.50 mi^2

Average discharge: 9.29 ft^3/s (Oct. 1966 to Sept. 1985)

Extremes for period of record:
Maximum discharge: 590 ft^3/s (May 1984)
Minimum discharge: 0.11 ft^3/s (Sept. 1971)

Low flow (14 years of record):
7-day 2-year low flow: 0.35 ft^3/s
7-day 10-year low flow: 0.16 ft^3/s

Town Brook at Quincy, Mass. (Weymouth Fore River basin)

Drainage area: 4.22 mi^2

Average discharge: 8.93 ft^3/s (Oct. 1972 to Sept. 1985)

Extremes for period of record:
Maximum discharge: 381 ft^3/s (May 1975)
Minimum daily discharge: 0.62 ft^3/s (Sept. 1980)

Remarks: Diurnal fluctuations caused by plant upstream. Flow regulated by Old Quincy Reservoir upstream.

The Neponset and Weymouth (Fore and Back) and Weir River basins are located in Norfolk, Suffolk, and Plymouth Counties, and contain all or part of 24 cities and towns, including the cities of Boston, Brockton, and Quincy (fig. 18). The terrain is gently rolling, with altitudes that range from sea level to about 100 ft above sea level. The following description of the water resources of the Neponset and Weymouth and Weir River basins is based on Hydrologic Investigations Atlases 484 (Brackley and others, 1973) and 504 (Williams and Tasker, 1974a).

Surface water

The Neponset River basin covers about 117 mi^2, the Weymouth River basin covers about 63 mi^2, and the Weir River basin covers about 20 mi^2 of eastern Massachusetts. Although the lower parts of the basins are heavily urbanized, the upper parts are over 70 percent forested (Wandle, 1984a, p. 34). All three basins contain many small lakes and ponds, and, in their lower parts, marshes. The Neponset River basin has 65 lakes and ponds, 26 of which have an area of 10 acres or more. The Weymouth River basin has 22 lakes and

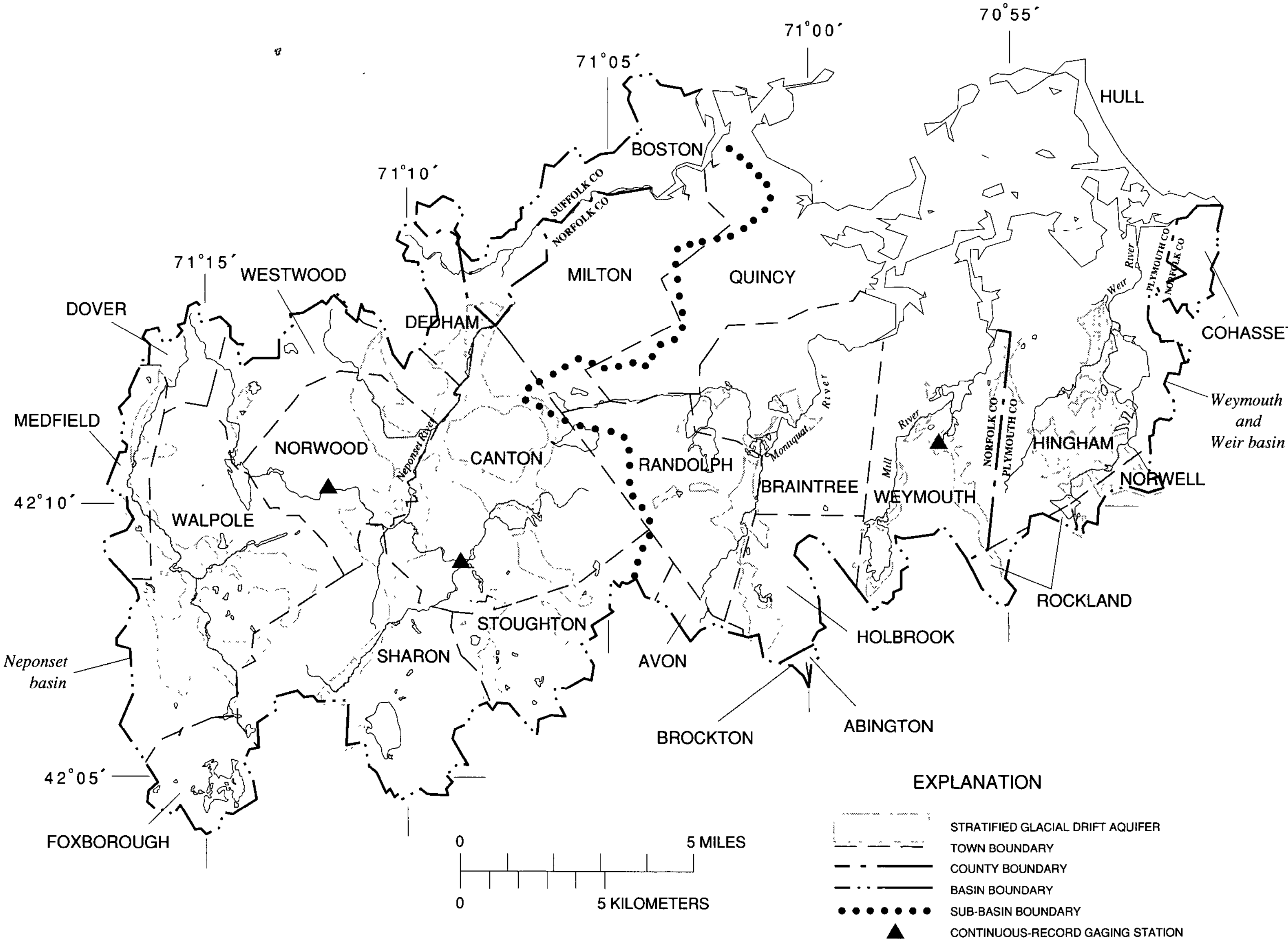


Figure 18.--Principal streams and areas of stratified drift in the Boston Harbor (Neponset, Weymouth and Weir Rivers) planning basin. (Modified from U.S. Geological Survey Hydrologic Investigations Atlas 484.)

ponds, 10 of which cover at least 10 acres, and the Weir River basin has at least 7 lakes and ponds. The largest lake in the Neponset River basin is Massapoag Lake in Sharon, which is 353 acres; the largest lake in the Weymouth River basin is Great Pond Reservoir (Great Pond) in Randolph, which is 329 acres (Massachusetts Department of Environmental Quality Engineering, Division of Water Pollution Control, 1976a, p. 7, 73-77). The largest lake in the Weir River basin is Accord Pond in Hingham, Norwell, and Rockland, which has an area of 95 acres (Massachusetts Department of Environmental Management, Division of Water Resources, 1978, p. 97).

The major rivers in the basins generally flow northeastward through an area of low hills south of Boston to Boston Harbor. Although the stream gradients in the lower parts of the basins are low, those in the upper parts are moderate. From the headwaters area in Foxborough to the USGS streamflow-gaging station at Norwood, a distance of about 11 river mi, the Neponset River drops about 24 ft/mi. Old Swamp River in the Weymouth River basin drops about 16 ft/mi from the headwaters area in Rockland to the USGS streamflow-gaging station near South Weymouth, about 4 river mi to the south.

Streamflow in many of the subbasins is affected by ground-water pumpage, and most of the major streams are affected by regulation of storage facilities. For example, the flow of the East Branch Neponset River at Canton is augmented by releases of stored water during low-flow periods. Most of the discharge from the drainage areas above Great Pond Reservoir in Braintree and Randolph and above Great Pond in Weymouth is impounded and used for municipal supplies. At times, Mill River and Mine Brook are dry near well fields and data indicate that there is probably a reduction of flow in the main stem of the Neponset River near wells.

Ground water

Unlike most of the other basins in the State, ground-water divides do not always correspond with surface-water divides in the Neponset, Weymouth, and Weir River basins. One prominent example of this occurs along parts of the southern boundary of the Neponset basin, where ground water flows north from the Taunton River basin into the East Branch Neponset River basin.

Stratified sand and gravel aquifers are the principal source of ground water in the Neponset, Weymouth, and Weir River basins. These aquifers underlie about one half of the area of the basins and, where they are thick and near surface-water bodies, can yield more than 300 gal/min to wells. Some of the thickest deposits, more than 150 ft thick, underlie parts of the Neponset River valley. The head of the Neponset has been designated a sole-source aquifer by the USEPA (U.S. Environmental Protection Agency). In addition, bedrock and glacial till throughout most of the basins can usually provide a few gallons per minute of water to wells.

South Coastal (North and South Rivers) basin

Indian Head River at Hanover, Mass. (North River basin)

Drainage area: 30.2 mi^2

Average discharge: 62.1 ft^3/s (Oct. 1966 to Sept. 1985)

Extremes for period of record:
Maximum discharge: 1,390 ft^3/s (Mar. 1968)
Minimum discharge: 0.14 ft^3/s (Sept. 1980)
Minimum daily discharge: 0.18 ft^3/s (Sept. 1980)

Low flow (15 years of record):
7-day 2-year low flow: 4.6 ft^3/s
7-day 10-year low flow: 1.3 ft^3/s

Remarks: Some regulation by mills and ponds upstream.

The North and South River basins are located in Norfolk and Plymouth Counties and include all or part of 13 towns (fig. 19). The area is largely residential, and increasingly rural southward, with business and light-industrial centers along some sections of primary roads. The following description of the water resources of the North and South River basins is based on Hydrologic Investigations Atlas 504 (Williams and Tasker, 1974a).

Surface water

The North and South River basins cover about 105 mi^2 of eastern Massachusetts (Wandle and Morgan, 1984, p. 13). Many wetlands and small lakes and ponds exist throughout the basins. Many wetland areas, especially south of the North River, are used to cultivate cranberries. There are 57 lakes and ponds, 30 of which cover at least 10 acres. The largest lake is Oldham Pond in Pembroke, which is 235 acres (Massachusetts Department of Environmental Quality Engineering, Division of Water Pollution Control, 1976a, p. 7, 83-84).

The North and South Rivers flow into an estuary, which extends about 13 mi upstream along the North River and about 8 mi upstream along the South River, and is bordered by tidal marshes for many miles above its mouth at Massachusetts Bay. The tidal reaches of streams in the basins contain a mixture of fresh and salt water. The freshwater portion of the North River in the upper part of the basin is called the Indian Head River. Stream gradients are low throughout the basins. For example, a tributary of the South River, Furnace Brook, drops about 2.5 ft/mi over a distance of almost 3 river mi (Wandle and Morgan, 1984, p. 19).

Ground water

Sandy and gravelly glacial-outwash plains and deltaic deposits can yield large supplies of water where the saturated thickness exceeds 30 ft. Some areas of high potential well yield are along Furnace Brook in Marshfield, near Herring Brook in Hanover, and in coastal deposits in Duxbury. Productive sand and gravel also occurs within or beneath unstratified glacial moraines, especially in the southern half of the area. Beach deposits provide small supplies of fresh to brackish water, but commonly have more than 500 mg/L of dissolved solids.

Granitic and altered sedimentary and volcanic rocks provide a secondary aquifer for domestic wells. In 1970, the yield of 133 bedrock wells ranged from a fraction of a gallon per minute to 128 gal/min. The yield of 81 wells was less than 15 gal/min and the yield of eight was more than 60 gal/min; five of the eight wells with higher yields were industrial wells.

South Coastal (South Coastal Shore) drainage basin

Jones River at Kingston, Mass.

Drainage area: 15.7 mi^2 (excludes 4.09 mi^2 above outlet of Silver Lake, from which flow is diverted for use in Brockton, Whitman, and Hanson)

Average discharge: 32.1 ft^3/s (Aug. 1966 to Sept. 1985)

Extremes for period of record:
Maximum discharge: 575 ft^3/s (Mar. 1968)
Minimum daily discharge: 0.59 ft^3/s (Aug. 1966)

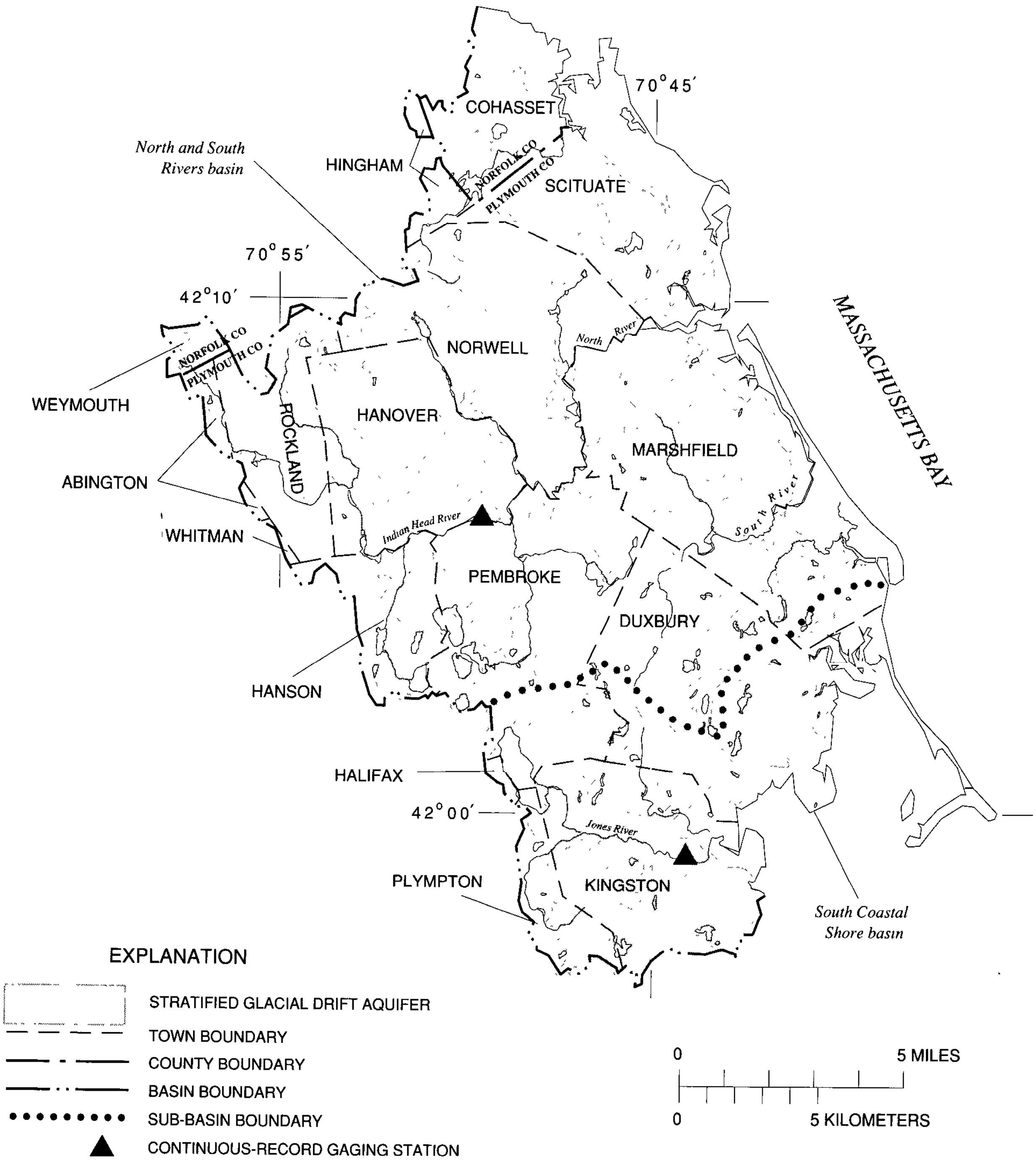


Figure 19.--Principal streams and areas of stratified drift in the South Coastal (North and South Rivers and South Coastal Shore River) drainage basin. (Modified from U.S. Geological Survey Hydrologic Investigations Atlas 504.)

Low flow (16 years of record)
7-day 2-year low flow: 6.8 ft^3/s
7-day 10-year low flow: 2.2 ft^3/s

Remarks: Flow regulated by pond upstream. Flow affected at times by spillage from Silver Lake. Surface flow may be affected by ground water that enters from or moves into adjacent basins.

The South Coastal Shore basin is located in Plymouth County and a small part of Barnstable County, and includes all or part of nine towns (figs. 19 and 20a). Recreational and residential areas have been developed near the shores of the ocean and lakes. Inland, much of the land is used to cultivate cranberries; the remainder is mostly brushland and woodland. The following description of the water resources of the South Coastal Shore basin is based on Hydrologic Investigations Atlas 507 (Williams and Tasker, 1974b).

Surface water

The South Coastal Shore basin has an area of about 135 mi^2 and includes minor river basins that drain into Plymouth and Cape Cod Bays along the South Shore. The basin contains numerous wetlands, many of which are used to cultivate cranberries. There are also numerous small lakes and ponds scattered throughout the basin. In total, there are 116 lakes and ponds, 56 of which cover at least 10 acres. Only one, Silver Lake in Kingston and Pembroke (640 acres) in the northwestern corner of the basin, is larger than 500 acres (Massachusetts Department of Environmental Management, Division of Water Resources, 1978, p. 98; Massachusetts Department of Environmental Quality Engineering, Division of Water Pollution Control, 1976a, p. 7, 86-89).

Streamflows in the basin are relatively constant throughout the year compared to other basins farther inland because of a steady discharge of ground water to streams from the permeable deposits of sand and gravel.

Ground water

Most of the South Coastal Shore basin is underlain by sandy outwash plains that extend westward into the Buzzards Bay basin and comprise one of the largest aquifers in Massachusetts. The thickest deposits are in Plymouth and Bourne, and, in the adjacent Buzzards Bay basin, in South Carver and the northeastern part of Wareham. This aquifer is generally 40 to 160 ft thick, and the entire aquifer in both the South Coastal Shore and Buzzards Bay basins probably can store about 540 billion gallons of water. Yields to single wells completed in these deposits can be more than 300 gal/min.

Buzzards Bay basin

The Buzzards Bay basin is located in Bristol and Plymouth Counties and in a small part of Barnstable County, and contains all or part of 17 cities and towns, including the cities of Fall River and New Bedford (figs. 20a and 20b). Although the basin includes some urbanized areas, most inland areas are sparsely settled woodlands, wetlands, agricultural lands, and brushlands. Relief in the basin is low, with glacially rounded hills up to 384 ft above sea level. The following description of the water resources of the Buzzards Bay basin is based on Hydrologic Investigations Atlases 507 (Williams and Tasker, 1974), 560 (Williams and Tasker, 1978), and 275 (Willey and others, 1978).

Surface water

The Buzzards Bay basin has an area of about 374 mi^2 in southeastern Massachusetts. The low relief of the land has resulted in numerous wetlands, and the basin contains many small lakes and ponds. Some wetlands, especially in Rcchester and Wareham, are

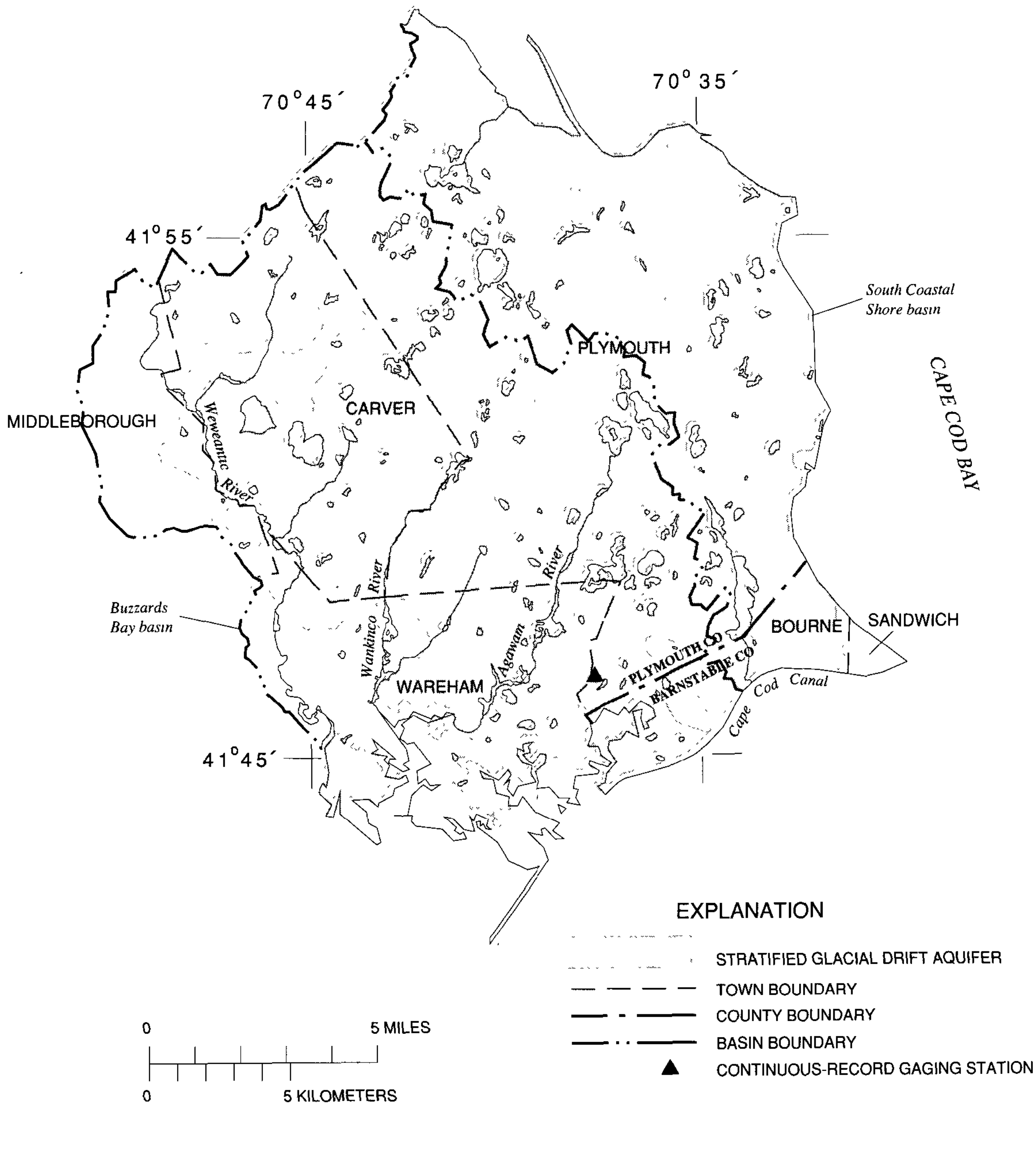


Figure 20a.--Principal streams and areas of stratified drift in the Buzzards Bay (Weweantic River) and South Coastal basins. (Modified from U.S. Geological Survey Hydrologic Investigations Atlas 507.)

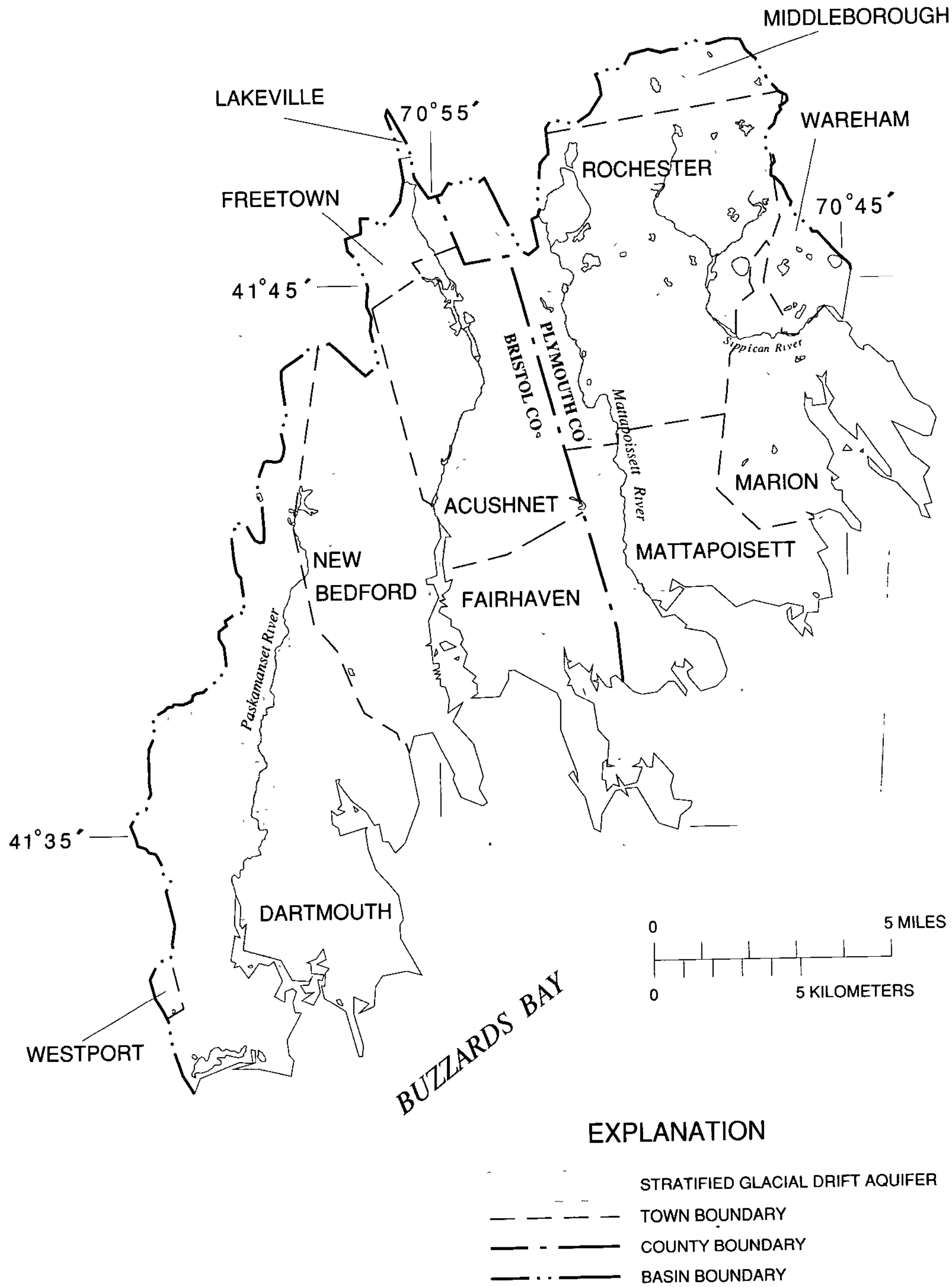


Figure 20b.--Principal streams and areas of stratified drift in the Buzzards Bay basin. (Modified from U.S. Geological Survey Hydrologic Investigations Atlas 560.)

used extensively to cultivate cranberries. There are a total of 162 lakes and ponds, of which 115 have an area of 10 acres or more. Only one lake, Snipatuit Pond in Rochester (710 acres), is larger than 500 acres (Massachusetts Department of Environmental Management, Division of Water Resources, 1978, p. 84; Massachusetts Department of Environmental Quality Engineering, Division of Water Pollution Control, 1976a, p. 7, 103-107).

The basin is composed of drainage basins of small streams that flow between north-to-south trending hills to Rhode Island Sound and Buzzards Bay. In their lower reaches, the streams are affected by tides and bordered by tidal marshes. Streamflows in the eastern part of the basin are relatively constant throughout the year compared to other basins farther inland because of a steady discharge of ground water to streams from the permeable deposits of sand and gravel. In contrast, the central and western part of the basin is underlain by thinner, less permeable sand and gravel deposits that discharge less ground water to streams. Surface runoff to streams in these areas during storms is higher than in the eastern part of the basin and, therefore, streamflows are more variable.

Ground water

The most productive sources of ground water in the Buzzards Bay basin are sand and gravel deposits in southward-sloping Rochester-Wareham-Marion outwash plain, and along the north-to-south trending valleys of the Mattapoisett, Acushnet, Paskamanset, and East Branch Westport Rivers.

The western part of the outwash plains is generally more gravelly than the eastern part, which includes the southern part of the adjacent South Coastal Shore basin. Also, outwash deposits grade to finer material to the south, especially in the Rochester-Marion area. The aquifer constituting the Rochester-Wareham-Marion outwash plain has been extensively investigated and results indicate that the aquifer can yield 100 to 300 gal/min to single wells in some areas. The Mattapoisett River valley can probably yield about 4 Mgal/d without causing the river to be dry during low-flow periods in years of average precipitation. In 1965, the town of Acushnet tested the aquifer bordering the Acushnet River near the New Bedford Reservoir and located three sites capable of yielding between 0.2 and 0.5 Mgal/d. Several industrial wells in the upper Paskamanset River basin probably could yield 0.5 to 1.0 Mgal/d; in the middle part of the basin, the town of Dartmouth has three wells that can yield a total of about 1 Mgal/d.

Where sand and gravel deposits are thinner and generally less permeable, the bedrock aquifer is commonly used. The Buzzards Bay basin is underlain mainly by granitic and metamorphic rocks, which are exposed on knolls, hills, and cliffs. Water from these rocks is obtained mostly from fractures. In general, yields range from 1 to 150 gal/min and average about 8 gal/min.

Cape Cod and the Islands

Herring River at North Harwich, Mass.

Drainage area: About 9.4 mi^2

Average discharge: 10.0 ft^3/s (Oct. 1966 to Sept. 1985)

Extremes for period of record:
Maximum discharge: 75 ft^3/s (Feb. 1983)
Minimum discharge: 0.32 ft^3/s (Sept. 1981)

Remarks: Flow regulated by many ponds upstream. Surface flow is strongly affected by ground-water discharge.

Cape Cod is a hook-shaped peninsula that extends 40 mi into the Atlantic Ocean from southeastern Massachusetts, and is separated from the mainland by a man-made canal (fig. 21a). The Cape has an area of about 395 mi^2 in Barnstable County, and includes 15 towns.

Martha's Vineyard is situated about five mi south of Cape Cod in Dukes County (fig. 21b). The island has an area of about 106 mi^2 and contains six towns. Nantucket Island, which is also Nantucket County, is situated about 25 mi south of Cape Cod and about 15 mi east of Martha's Vineyard (fig. 21b). Cape Cod, Nantucket and Martha's Vineyard have been designated sole source aquifers by the USEPA. It has an area of about 49.5 mi^2 and contains one town, Nantucket. The Elizabeth Islands are a chain of islands that extend about 15 mi off the southwestern corner of Cape Cod (fig. 21b). They cover a total of about 15 mi^2 and contain one town, Gosnold in Dukes County.

The Cape and Islands are composed of glacial end moraines, which mark the approximate locations of the ice front, and outwash plains, which were formed from sediments deposited by meltwater streams ahead of the ice front. Early glacial advances are recorded only in subsurface deposits, but later advances are recorded in two distinct areas of end moraines and outwash plains. The north sides of Martha's Vineyard and Nantucket contain end moraines related to the South Channel, Cape Cod Bay, and Buzzard's Bay glacial lobes. These moraines are bordered on the south by broad outwash plains. The Cape Cod Bay lobe retreated to the northern side of Cape Cod, where it formed the Sandwich end moraine. A similar retreat of the Buzzard's Bay lobe formed the end moraine now represented by the Elizabeth Islands. Parts of the south sides of these moraines also are bordered by outwash plains (Kohout and others, 1977, p. 375).

The following description of the water resources of Cape Cod, Martha's Vineyard, and Nantucket is based on Hydrologic Investigations Atlases 618 (Delaney, 1980), 692 (LeBlanc and others, 1986) and 615 (Walker, 1980).

Surface water

Areas of surface water on Cape Cod and the Islands include salt marshes; freshwater marshes, bogs, and ponds; and small streams. Cape Cod and the Islands have no large streams because of the high permeability of much of the unconsolidated materials. Precipitation that is not transpired by plants or evaporated largely infiltrates the ground with little or no direct surface runoff. Unlike most other basins in the State where ground water mainly discharges to bodies of fresh surface water, much ground water on the Cape Cod and the Islands discharges directly to the ocean and its bays.

Cape Cod has 353 lakes and ponds, 206 of which are at least 10 acres in area. Three lakes are larger than 500 acres: Long Pond in Brewster and Harwich (743 acres), Mashpee and Wakeby Ponds in Mashpee and Sandwich (729 acres), and Chequaquet Lake (Wequaquet Lake, Great Nine-Mile Pond) in Barnstable (654 acres). Martha's Vineyard contains 62 lakes and ponds, 38 of which cover at least 10 acres. Six of these lakes are larger than 500 acres: Edgartown Great Pond in Edgartown (1,157 acres), Tisbury Great Pond in West Tisbury (772 acres), Sengekontacket Pond in Edgartown (716 acres), Menemsha Pond in Gay Head (640 acres), Squibnocket Pond in Chilmark and Gay Head (609 acres), and Lagoon Pond in Tisbury (535 acres). Nantucket has 28 lakes and ponds, 12 of which are at least 10 acres in area, and the Elizabeth Islands have 13 lakes and ponds, five of which are 10 acres or larger. The largest lake on Nantucket is Sasachacha Pond in Nantucket (276 acres); the largest lake on the Elizabeth Islands is Cuttyhunk Pond (100 acres) (Massachusetts Department of Environmental Management, Division of Water Resources, 1978, p. 88, 89, 93, 95; Massachusetts Department of Environmental Quality Engineering, Division of Water Pollution Control, 1976a, p. 7, 90-102).

Most lakes and ponds on the Cape and Islands are located in kettle holes on outwash plains and are surface expressions of the water table. At these locations, the altitudes of the pond surfaces closely match those of the water table. Lakes and ponds on the Cape and Islands are commonly used for irrigation, recreation, and fishing, but, with one exception, are not used for public-water supplies. The exception is Long Pond in Falmouth on Cape Cod, which is a part of that town's public water supply.

Ground water

The principal aquifers on the Cape and Islands are moraines and outwash deposits, which derive their water from local precipitation. The broad outwash plains are mainly composed of sand and gravel, which, in places, is mixed with till and ice-contact deposits, silt, and clay. Yields for 24-in.-diameter wells in out-

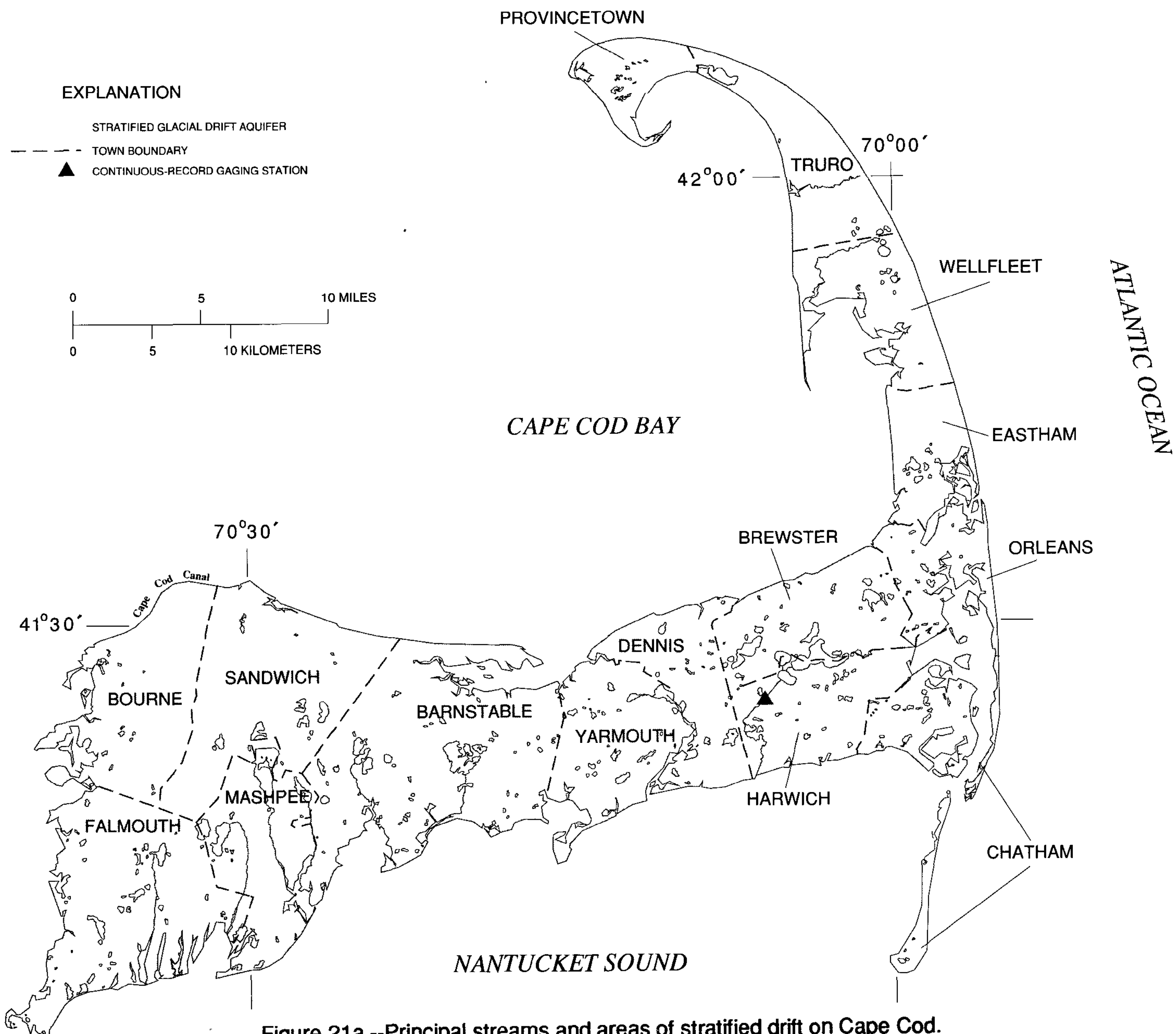


Figure 21a.--Principal streams and areas of stratified drift on Cape Cod. (Modified from U.S. Geological Survey Hydrologic Investigations Atlas 692.)

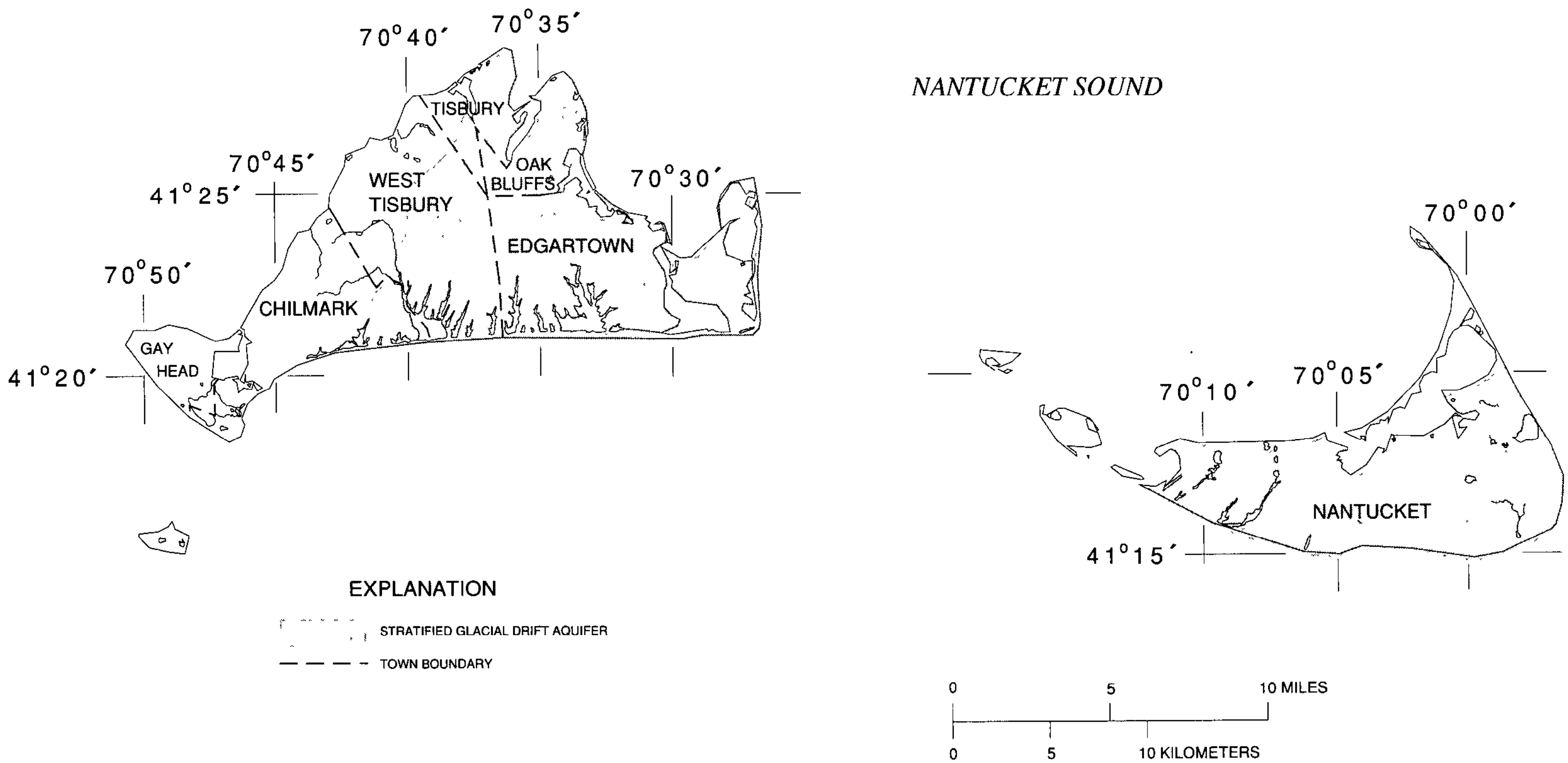


Figure 21b.--Principal stream and areas of stratified drift on the Islands (Martha's Vineyard and Nantucket). (Modified from U.S. Geological Survey Hydrologic Investigations Atlases 618 and 615.)

wash deposits generally range from about 200 to 700 gal/min. However, yields of 1,000 to 2,000 gal/min have been reported for some wells on Cape Cod, Martha's Vineyard, and Nantucket. In general, supplies of water for homes, cooling, and small businesses can be developed in most areas of outwash on the Cape and Islands from wells that are 1.5 to 2 in. in diameter with 3 ft of screen set about 10 ft below the water table.

Ground-water flow systems can be identified in areas of outwash on the Cape and Islands from the configuration of the water table. On Cape Cod, bays and streams divide the ground-water system into six areas or cells, each of which has a water-table mound (Guswa and LeBlanc, 1985). The altitude of the water table generally is highest, (about 5 to 60 ft above sea level) near the center of each cell and lowest (0 ft at sea level) near the coast. Ground water flows in the direction of the greatest hydraulic gradient, which is from the center of the mounds to the ocean. Locally, flow can be towards ponds, swamps, or streams. Under natural conditions, the six cells are hydraulically independent of one another. The steady-state flow through the total Cape Cod aquifer system, as estimated from computer-model analyses (Guswa and LeBlanc, 1985), is about 270 Mgal/d. On Martha's Vineyard, the ground water flows mainly in one cell, which has a water-table mound that reaches an altitude of 18 to 19 ft above sea level near the center of the island. Several smaller cells are located in Edgartown and on Chappaquiddick Island. On Nantucket, the water table forms several low mounds, the largest of which reaches an altitude of 12 to 14 ft above sea level halfway between Nantucket Harbor and Siasconset.

The moraines are composed of both poorly- and well-sorted sand, silt, and clay that were transported in the glacial ice and left behind when the ice retreated. The textural composition of moraines generally varies more over short distances than does the textural composition of outwash deposits. The Gay Head moraine on Martha's Vineyard consists largely of clay and silt with some sand and lignite. Because the textural variability causes permeability variability and because the unsaturated zone is greater in the moraines than the outwash plains, exploration for water supplies has been discouraged in the moraines. Yields of 2,000 gal/min are obtained from 24-in.-diameter gravel-packed wells in the most permeable zones of the moraine in Barnstable. However, wells drilled in nearby areas have penetrated thick layers of silt and clay and are reported to have been unproductive (Guswa and LeBlanc, 1985, p. 3-4).

In addition to the outwash and moraine deposits, deeper and older preglacial sand and silt are present on Martha's Vineyard and Nantucket. However, these deposits would probably yield less than 100 gal/min and could yield water with elevated iron and (or) chloride concentrations. Bedrock beneath unconsolidated deposits on Cape Cod and the Islands consists of metamorphic rocks, such as schist and gneiss, and igneous rocks, the surface of which generally slopes southeastward from about sea level on the northwestern shore of Buzzard's Bay to as much as 1,600 ft below sea level at Nantucket (Oldale, 1969). The depth to bedrock beneath glacial sediments on Cape Cod ranges from about 80 to 900 ft below sea level. Bedrock is much less permeable than the overlying sediments, commonly contains seawater, and is not considered to be part of the aquifers of Cape Cod or the Islands.

Taunton River basin

Taunton River at State Farm near Bridgewater, Mass.

Drainage area: 258 mi^2

Average discharge: 464 ft^3/s (Oct. 1929 to Sept. 1975)

Extremes for period of record:
Maximum discharge: 4,980 ft^3/s (Mar. 1968)

Minimum discharge: 8 ft^3/s (Sept. 1944)
Minimum daily discharge: 9 ft^3/s (Sept. 1944)

Low flow (26 years of record):
7-day 2-year low flow: 51.5 ft^3/s
7-day 10-year low flow: 24.6 ft^3/s

Remarks: Flow affected by diversions to and from basin for municipal supplies. Flow regulated by reservoirs and, before about 1975, by power plants upstream.

Three Mile River at North Dighton, Mass.

Drainage area: 84.3 mi^2

Average discharge: 172 ft^3/s (Oct. 1966 to Sept. 1985)

Extremes for period of record:
Maximum discharge: 2,490 ft^3/s (Mar. 1968)
Minimum discharge: 5.1 ft^3/s (Sept. 1980)

Remarks: Flow regulated by lakes and reservoirs upstream. Diversion to and from basin for municipal supplies may be compensating.

Wading River near Norton, Mass.

Drainage area: 43.3 mi^2

Average discharge: 73.4 ft^3/s (Oct. 1925 to Sept. 1985)

Extremes for period of record:
Maximum discharge: 1,460 ft^3/s (Mar. 1968)
Minimum discharge: 0.3 ft^3/s (Sept. 1926)

Low flow (26 years of record):
7-day 2-year low flow: 4.4 ft^3/s
7-day 10-year low flow: 2.2 ft^3/s

Remarks: Flow regulated to some extent by lakes and reservoirs upstream. Diversion upstream for municipal supply.

The Taunton River basin is located in Norfolk, Plymouth, and Bristol Counties (fig. 22). The basin contains all or part of 43 cities and towns, including the cities of Attleboro, Brockton, Fall River, and New Bedford. The basin is characterized by low, rolling hills with maximum elevations of about 450 ft above sea level, and by lowlands that contain swamps. The following description of the water resources of the Taunton basin is based on Hydrologic Investigations Atlases 460 (Williams and others, 1973) and 300 (Williams, 1968).

Surface water

The Taunton River and its complex network of tributaries drain about 530 mi^2 of southeastern Massachusetts. The relatively low relief of land in the basin has resulted in low stream gradients and many wetlands. The basin contains at least 50 mi^2 of wetlands and a total of 219 lakes and ponds, 135 of which have an area of 10 acres or more. Five of the lakes cover more than 500 acres: Assawompset Pond in Lakeville (2,024

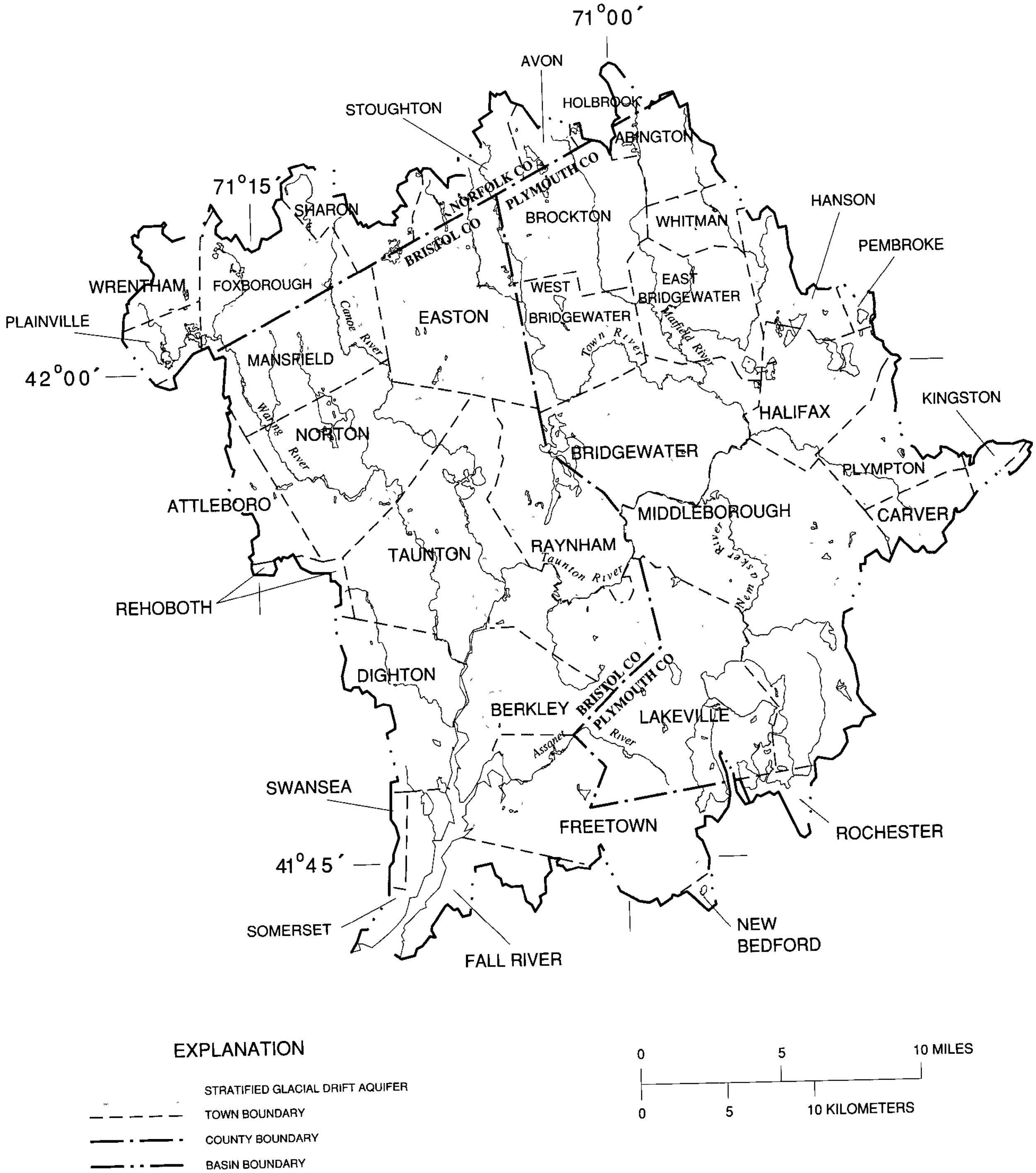


Figure 22.--Principal streams and areas of stratified drift in the Taunton River basin. (Modified from U.S. Geological Survey Hydrologic Investigations Atlas 460.)

acres), Long Pond in Lakeville and Freetown (1,721 acres), Great Quittacas Pond in Lakeville (1,185 acres), Norton Reservoir in Norton (529 acres), and Monponsett Pond in Halifax and Hanson (528 acres) (Massachusetts Department of Environmental Management, Division of Water Resources, 1978, p. 81; Massachusetts Department of Environmental Quality Engineering, Division of Water Pollution Control, 1976a, p. 7, 108-113).

The Taunton River begins at the confluence of the Matfield and Town Rivers just east of Bridgewater and flows about 36 mi in a generally southward direction through Taunton to Mount Hope Bay, a part of Narragansett Bay, at Fall River. The lower 8 or 9 mi of the river is a tidal estuary, above which the river is affected by tides for about 15 mi.

Ground water

The principal aquifers of the Taunton River basin are sand and gravel deposits within stratified drift. Stratified-drift deposits are exposed at land surface over about 62 percent of the basin. They are primarily ice-contact (kame), outwash, and lake-bottom sediments, which were deposited in preglacial bedrock valleys and in water-filled depressions in the till surface during retreat of the last glacier. Stratified drift is more abundant in the central and southern parts of the basin than in the northern part. In the northern one-third of the basin, stratified drift fills narrow, north-south trending valleys, which are bounded by till-bedrock uplands.

Aquifer yields for normal climatic conditions were estimated for 26 aquifers in the northern half of the basin (Lapham, 1988). The highest yields, 7.7 and 7.3 Mgal/d, were obtained for aquifers in hydraulic connection with the lower Matfield and Taunton Rivers in Bridgewater and East Bridgewater, and with the lower Canoe River in Norton and Taunton. The other 24 aquifers have potential yields of 3 Mgal/d or less.

Individual wells in the Taunton River basin can yield more than 100 gal/min if located in areas underlain by permeable sand and gravel. About 80 percent of stratified drift in the basin consists of these permeable materials; the remainder consists of poorly permeable clay, silt, and fine sand. About 25 mi^2 of the area underlain by permeable deposits can yield at least 300 gal/min of water to single wells. Many of these high-yielding deposits are in depressions in the valleys of a pre-glacial drainage system that has little similarity to the present-day drainage system.

Volcanic and granitic rocks underlie both the northern and southern margins of the Taunton River basin, and sedimentary rocks consisting of sandstone, shale, siltstone, conglomerate, and coal beds underlie the interior of the basin (Williams and Willey, 1973). Yields to single wells in bedrock in the basin range from about 0.5 to 250 gal/min. Most bedrock wells, however, yield less than 10 gal/min. The yield of bedrock wells depends partly on their intended use. Many homes, which require only 5 gal/min, have wells that are not drilled to great depth or developed to their maximum potential.

Blackstone River basin

Kettle Brook (head of Blackstone River) at Worcester, Mass

Drainage area: 31.6 mi^2

Average discharge: 53.4 ft^3/s (Oct. 1923 to Sept. 1978)

Extremes for period of record:
Maximum discharge: 3,970 ft^3/s (Aug. 1955)
Maximum discharge: 2,720 ft^3/s (Aug. 1953)
Minimum discharge: 0.2 ft^3/s (May 1940)

Low flow (40 years of record):
7-day 2-year low flow: 8.5 ft^3/s
7-day 10-year low flow: 4.9 ft^3/s

Remarks: Flow regulated by reservoirs upstream. Diversions for municipal use and through diversion tunnel.

Quinsigamond River at North Grafton, Mass.

Drainage area: 25.6 mi^2

Average discharge: 41.3 ft^3/s (Oct. 1939 to Sept. 1985)

Extremes for period of record:
Maximum discharge: 820 ft^3/s (Aug. 1955)
Minimum daily discharge: 0 ft^3/s (Aug. 1966 (caused by unusual regulation) and Sept. 1980)

Low flow (40 years of record):
7-day 2-year low flow: 2.2 ft^3/s
7-day 10-year low flow: 0.48 ft^3/s

Remarks: Some regulation by Lake Quinsigamond and ponds upstream.

Blackstone River at Woonsocket, R.I.

Drainage area: 416 mi^2

Average discharge: 765 ft^3/s (Oct. 1929 to Sept. 1985)

Extremes for period of record:
Maximum discharge: 32,900 ft^3/s (Aug. 1955, affected by failure of Horseshoe Dam on Mill River)
Minimum daily discharge: 21 ft^3/s (Aug. 1934)

Low flow (28 years of record):
7-day 2-year low flow: 134 ft^3/s
7-day 10-year low flow: 101 ft^3/s

Remarks: Flow regulated by power plants and reservoirs upstream. Discharge includes flow diverted from Nashua River basin and, at times since January 1966, from Quabbin Reservoir for supply of Worcester.

In Massachusetts, the Blackstone River basin is located in Worcester County and small sections of Middlesex, Norfolk, and Bristol Counties, and contains all or part of 30 cities and towns, including the cities of Worcester and Attleboro (fig. 23). The terrain is characterized by gently rolling hills whose altitudes increase to the west. Elevations range from almost 1,400 ft above sea level near Worcester to about 150 ft at the border with Rhode Island. The following description of the water resources of the Blackstone River basin is based on Hydrologic Investigations Atlas 682 (Walker and Krejmas, 1986).

Surface water

The Blackstone River basin drains about 335 mi^2 of south-central Massachusetts. About 67 percent of the basin is forested, and about 3 percent contains lakes

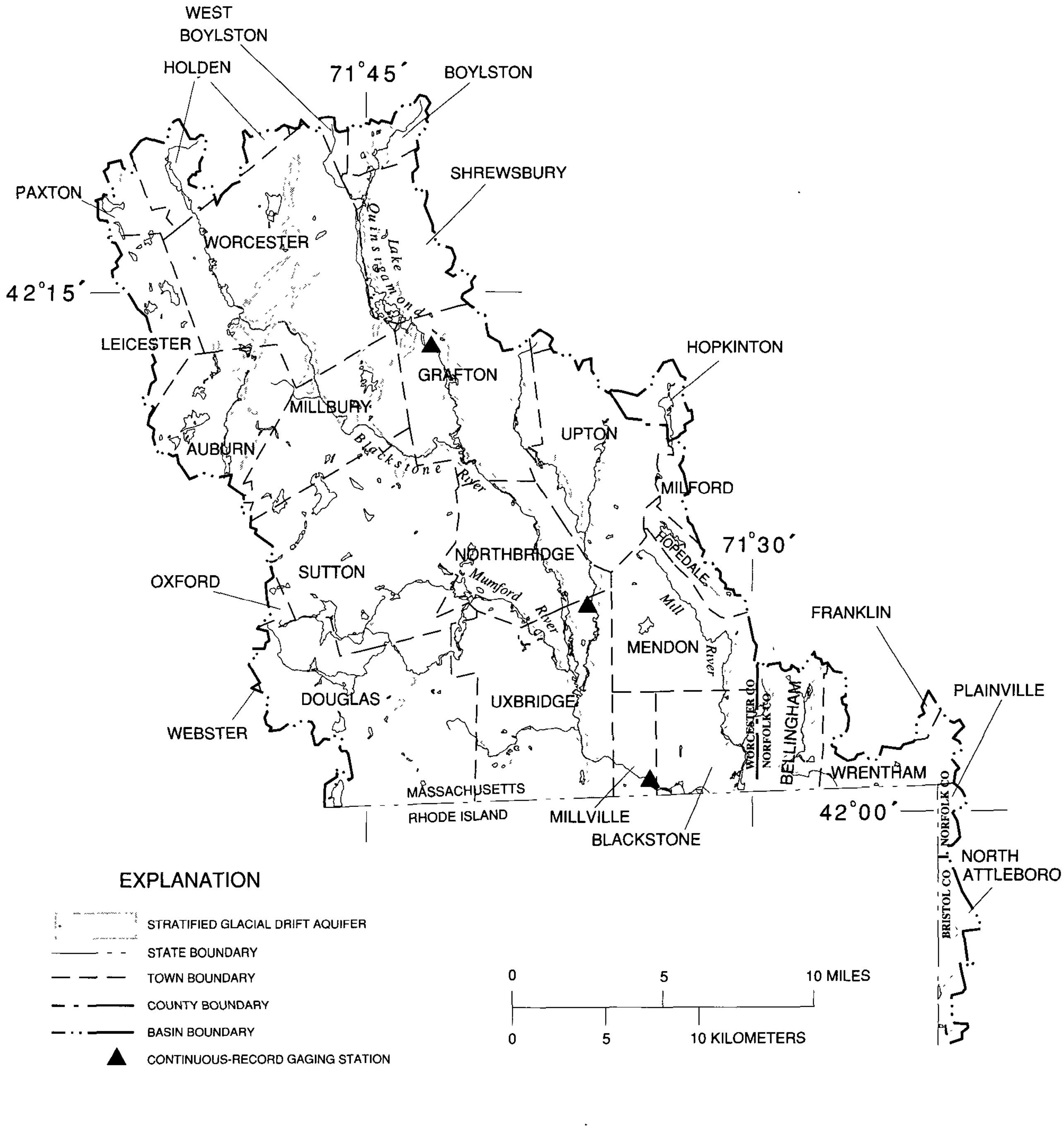


Figure 23.--Principal streams and areas of stratified drift in the Blackstone River basin. (Modified from U.S. Geological Survey Hydrologic Investigations Atlas 682.)

(Wandle and Phipps, 1984, p. 17). Many of the basin's lakes and ponds were created or enlarged by earthen dams. In total, there are 183 lakes and ponds, 107 of which have an area of at least 10 acres. The largest lake is Lake Quinsigamond in Shrewsbury and Worcester, which is 781 acres (Massachusetts Department of Environmental Management, Division of Water Resources, 1978, p. 62; Massachusetts Department of Environmental Quality Engineering, Division of Water Pollution Control, 1976a, p. 7, 45-49).

The Blackstone River begins in the southern part of Worcester at the confluence of Middle River and Weasel Brook and flows southwestward about 31 mi through a narrow valley before crossing into Rhode Island. The gradient of the river is moderate, averaging about 11.5 ft/mi from the headwaters area near Worcester to the USGS streamflow-gaging station at Woonsocket, R.I., a distance of about 43 river mi (Wandle and Phipps, 1984, p. 17). Tributary streams draining the western uplands tend to have steeper gradients than those draining the eastern uplands. Although Worcester is supplied with water from reservoirs, public supplies for most other communities in the basin are obtained from ground water.

Ground water

Sand and gravel deposited by streams from the melting continental glacier form the principal aquifers in the Blackstone River basin. The most productive sand and gravel aquifers occupy long stretches of valleys. These coarse-grained deposits generally yield from 100 to 1,000 gal/min. The most productive wells are near streams and lakes where pumping causes the surface water to move through sand and gravel to the wells. Public-supply wells in sand and gravel have yields of 45 to greater than 1,100 gal/min, and average 325 gal/min.

Fine-grained sand, silt, and clay were deposited in temporary lakes that formed in valleys as the glacier melted. Well yields of 5 to 50 gal/min have been obtained from sand layers within these fine-grained sediments.

Bedrock in the Blackstone River basin consists of granitic and metamorphic rocks which have been deformed by folding and recrystallization. These rocks can usually supply enough water for domestic wells throughout the basin. Bedrock yields average 10 gal/min, but some wells have higher yields, especially in lowlands where bedrock generally is recharged with water from overlying deposits and contains more water-yielding fractures than in upland areas.

Ten Mile River and Narragansett Bay and Mount Hope Bay Shore basins

Adamsville Brook at Adamsville, R.I.

Drainage area: 8.01 mi^2

Average discharge: 14.3 ft^3/s (Oct. 1940 to Sept. 1978)

Extremes for period of record:
Maximum discharge: 316 ft^3/s (Dec. 1969)
Minimum discharge: 0.03 ft^3/s (Sept. and Oct. 1950, Sept. 1971, and Aug. 1974)

Low flow (37 years of record):
7-day 2-year low flow: 0.15 ft^3/s
7-day 10-year low flow: 0.05 ft^3/s

The Ten Mile River and Narragansett Bay and Mount Hope Bay Shore basins are located in Norfolk and Bristol Counties in southeastern Massachusetts, and contain all or part of 16 cities and towns, including the cities of Attleboro and Fall River (fig. 24a and 24b). Although the basins include urbanized areas, most inland areas are sparsely settled woodlands, wetlands, agricultural lands, and some brushlands. Relief in the basins is low. Topography is characterized by glacially rounded hills; maximum elevations are about 450 ft above sea level. The following description of the water resources of the Ten Mile River and Narragansett Bay and Mount Hope Bay Shore basins is based on Hydrologic Investigations Atlases 300 (Williams, 1968), 560 (Williams and Tasker, 1978), and 275 (Willey and others, 1978).

Surface water

In Massachusetts, the Ten Mile River drains about 49 mi^2, and the coastal basins of Narragansett Bay and Mount Hope Bay Shore drain about 112 mi^2. These basins encompass the drainage areas of small streams that drain between north-to-south trending hills to Mount Hope Bay, Rhode Island Sound, and through Rhode Island to Narragansett Bay. The land is low-lying and contains many wetlands and small lakes and ponds. The Ten Mile River basin contains 50 lakes and ponds, many of which are located along the main channel of the Ten Mile River. Twenty-seven of the lakes in the basin have an area of 10 acres or more. The largest lake is Manchester Reservoir in Attleboro, which is 218 acres (Massachusetts Department of Environmental Quality Engineering, Division of Water Pollution Control, 1976a, p. 7, 114-116). The basins of Narragansett Bay and Mount Hope Bay Shore contain about 57 lakes and ponds. Three lakes, Copicut Reservoir in Fall River and Dartmouth (550 acres), and North Watuppa Lake (Reservoir) (1,750 acres) and South Watuppa Pond (Lake) in Fall River and Westport (1,660 acres) are larger than 500 acres (Massachusetts Department of Environmental Management, Division of Water Resources, 1978, p 84, 85).

The Ten Mile River begins in a pond in Plainville and flows about 15 mi in a southerly direction through the urbanized areas of North Attleboro, Attleboro, and Seekonk before crossing into Rhode Island. The river is crossed by many dams, and, for much of its length, flows through impoundments or is confined by concrete or masonry retaining walls (Massachusetts Department of Environmental Quality Engineering, Division of Water Pollution Control, 1985). Much of the drop in river elevation from about 230 ft above sea level in the headwaters area to about 75 ft above sea level at the Massachusetts State border occurs at dams.

Ground water

The principal aquifers are stratified-drift deposits in valleys and lowlands that are hydraulically connected to surface-water bodies. In the Ten Mile River basin, the thickest deposits of stratified drift occur along river valleys and lowlands. In the Narragansett Bay and Mount Hope Bay Shore basins, the most favorable areas for ground-water development are located in the lower Palmer River valley, along the middle and upper reaches of the East Branch Westport River, along the Runnins River, and around Central Pond. The aquifers in the towns of Seekonk and Swansea and in the Cole River valley in Dighton generally do not have the saturated thickness or permeability necessary to yield large supplies of water. Smaller deposits of sand and gravel that locally have large yields are present under some lake-bottom deposits. However, aquifers in the coastal basins have only moderate potential for ground-water development and surface water will continue to be the primary source for public-water supplies.

Bedrock west of the Taunton River is mainly composed of sedimentary rocks and some coal. The most favorable sites for obtaining water from bedrock in this area are along faults, fractures, and contacts between sedimentary and igneous rocks. Industrial wells in sedimentary rocks generally yield more than wells in igneous rocks. In general, yields from bedrock wells in the Ten Mile River and Narragansett Bay and Mount Hope Bay Shore basins range from 0.2 to 300 gal/min, and average about 8 gal/min.

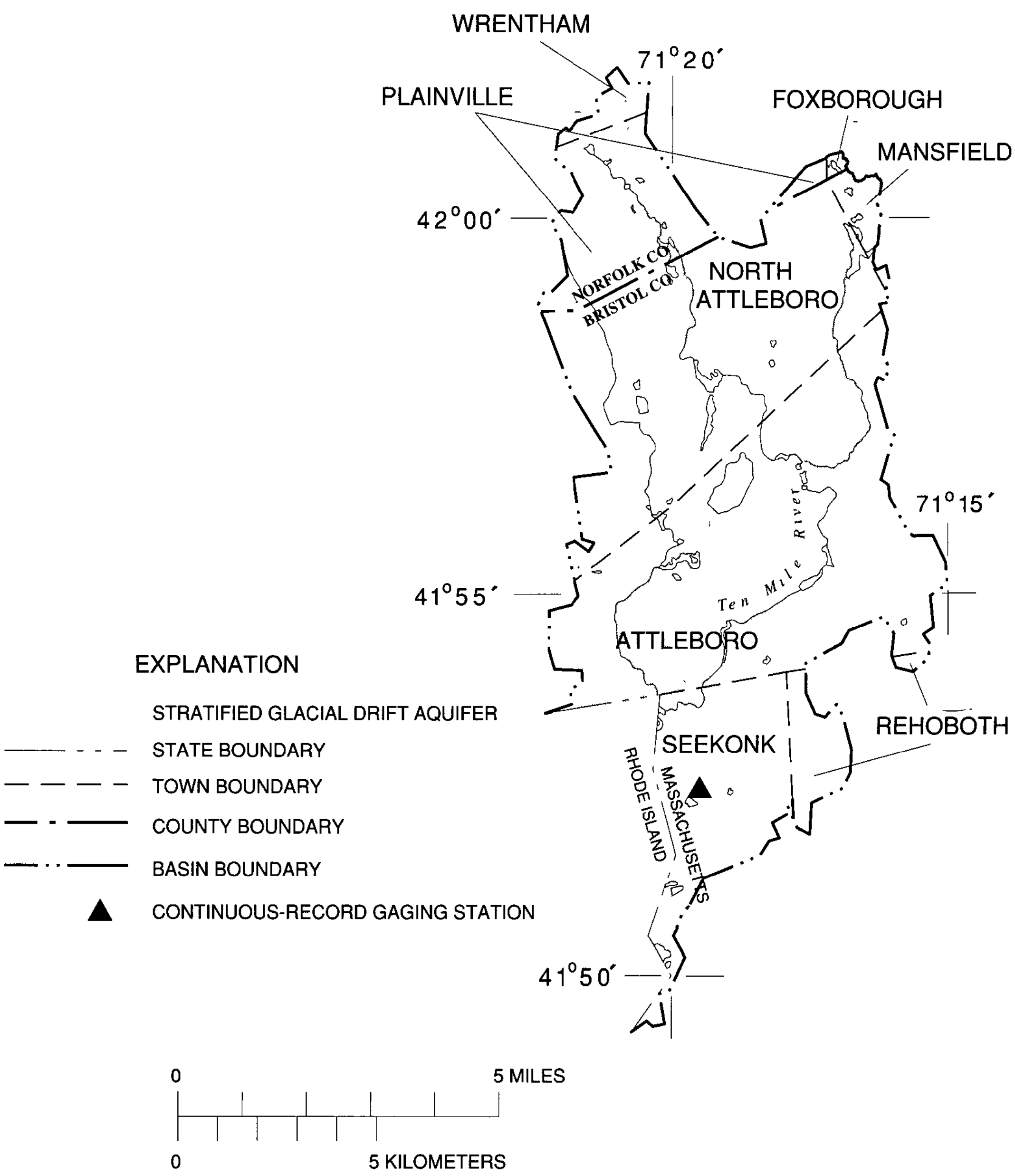


Figure 24a.--Principal streams and areas of stratified drift in the Ten Mile River basin. (Modified from U.S. Geological Survey Hydrologic Investigations Atlas 300.)

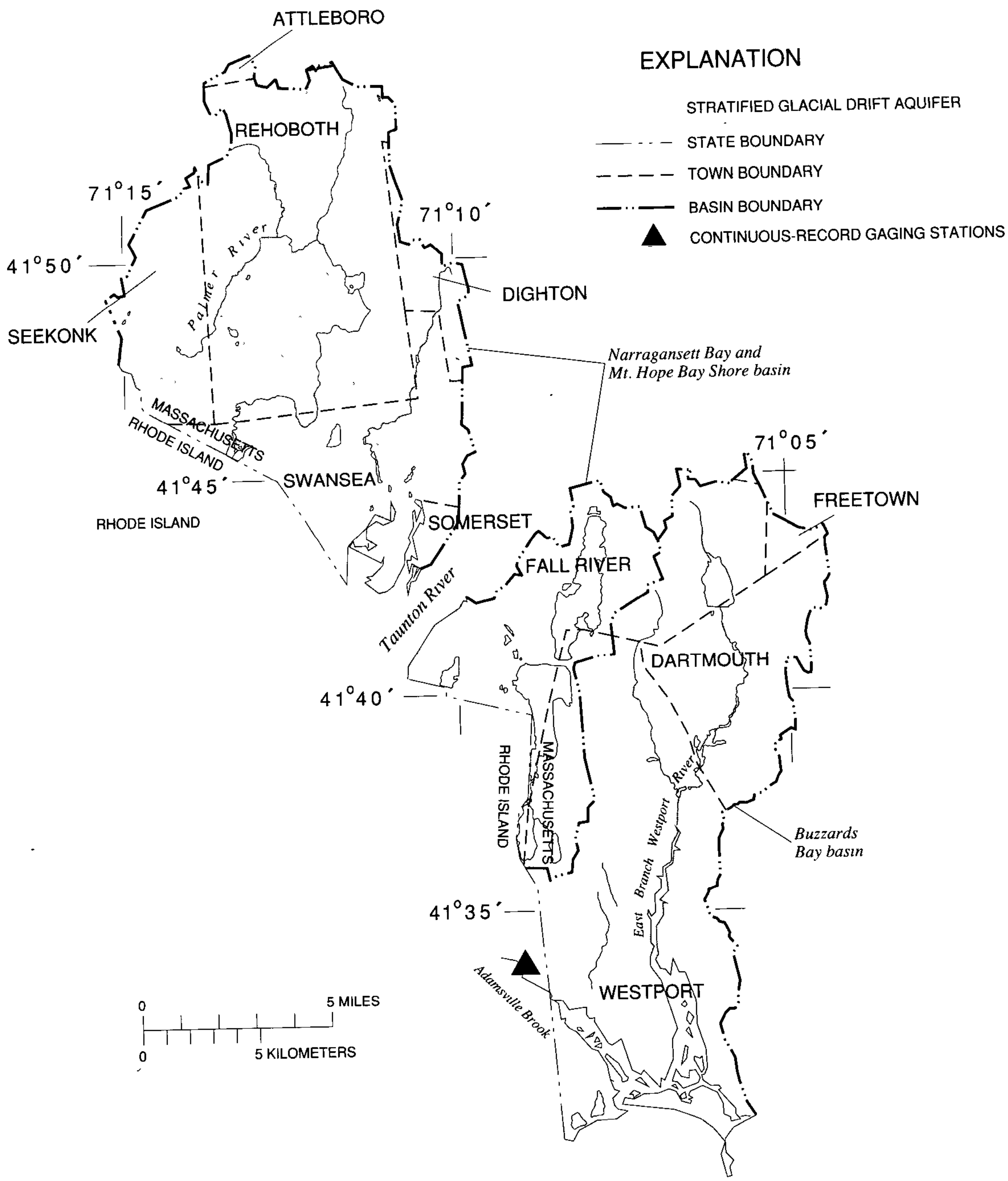


Figure 24b.--Principal streams and areas of stratified drift in the Narragansett Bay, Mount Hope Bay Shore, and Buzzards Bay basins. (Modified from U.S. Geological Survey Hydrologic Investigations Atlas 275.)

Thames River basin

(State planning basins: French and Quinebaug River basins)

The Thames River basin, which has a drainage area of about 1,480 mi^2, lies mainly in the eastern third of Connecticut, with small sections extending into south-central Massachusetts and northwestern Rhode Island. The name of the basin is derived from the Thames River, an estuary that extends about 15 mi northward from Long Island Sound at New London, Conn. The major tributaries of the Thames River are the Yantic and Shetucket Rivers. The Quinebaug is the largest tributary of the Shetucket River, and the French River is the largest tributary of the Quinebaug River.

In Massachusetts, the Thames River basin includes the French and Quinebaug River planning basins (fig. 25).

French and Quinebaug River basins

Quinebaug River at Quinebaug, Conn.

Drainage area: 156 mi^2

Average discharge: 272 ft^3/s (Oct. 1931 to Sept. 1985)

Extremes for period of record:
Maximum discharge: 49,300 ft^3/s (Aug. 1955)
Minimum discharge: about 1 ft^3/s (Sept 1943, July 1949, Sept. 1950, July 1951, Sept. and Oct. 1956, Jan. 1985 (result of freezeup))
Minimum daily discharge: about 1 ft^3/s (Sept. 1956)

Low flow (17 years of record):
7-day 2-year low flow: 24.8 ft^3/s
7-day 10-year low flow: 13.7 ft^3/s

Remarks: Flow regulated by reservoirs upstream.

French River at Webster, Mass.

Drainage area: 84.0 mi^2

Average discharge: 157 ft^3/s (Oct. 1949 to Sept. 1981)

Extremes for period of record:
Maximum discharge: 14,400 ft^3/s (Aug. 1955)
Minimum daily discharge: 2.2 ft^3/s (Aug. 1965)

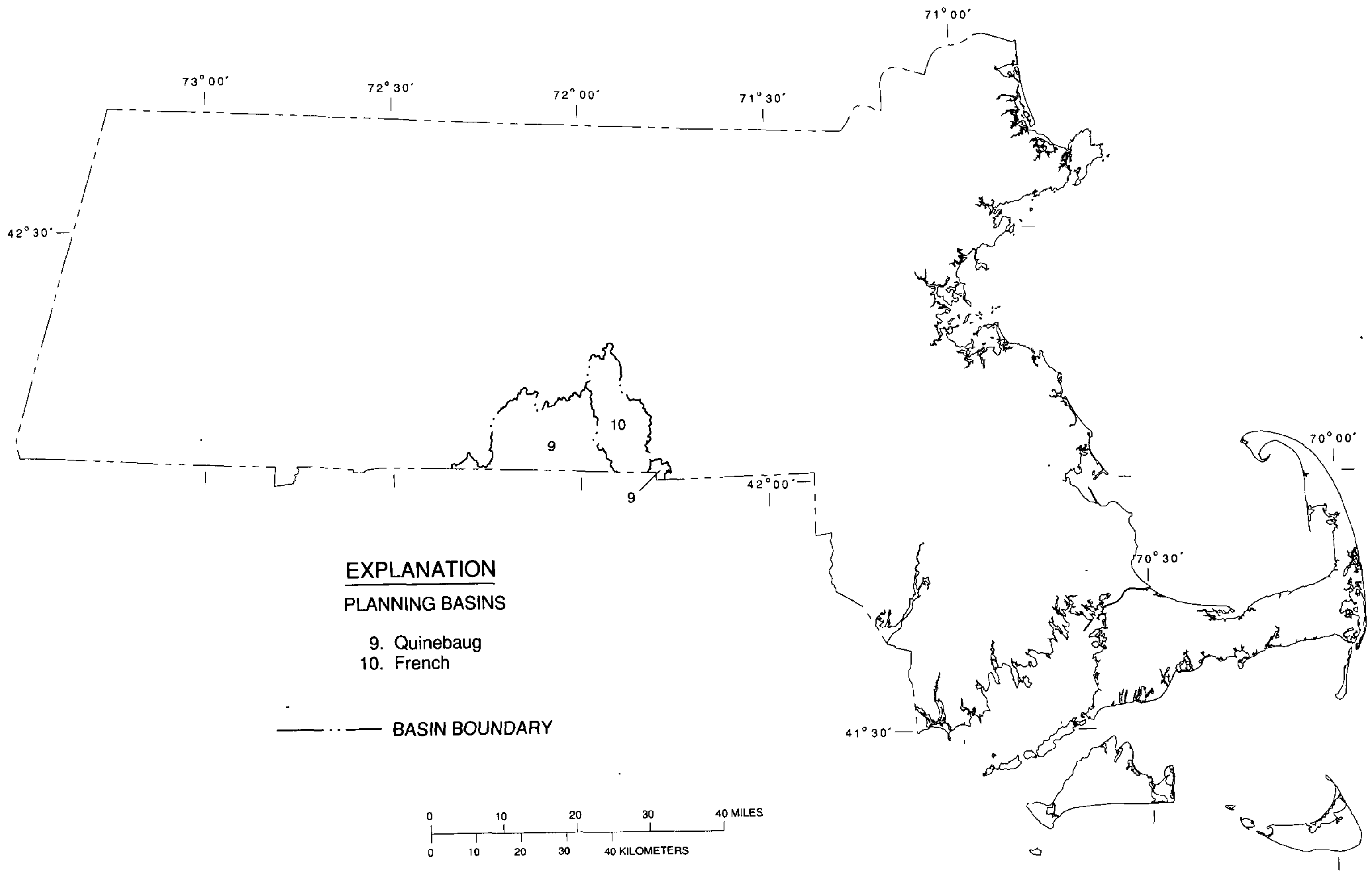


Figure 25.--Location of Massachusetts planning basins within the Thames River basin.

Low flow (20 years of record):
7-day 2-year low flow: 20.9 ft^3/s
7-day 10-year low flow: 14.8 ft^3/s

Remarks: Regulated by mills, lakes, and reservoirs.

In Massachusetts, the Quinebaug River basin is located in Hampden and Worcester Counties and contains all or part of 15 towns; the French River basin, located in Worcester County, contains all or part of 10 towns (fig. 26). The basins are heavily forested, with some areas being more than 80 percent forest (Wandle and LeBlanc, 1984, p. 17-18). Elevations in the basins range from 1,264 ft on Mount Pisgah in Wales, Mass., to about 25 ft in Norwich, Conn., where the Quinebaug River joins the Shetucket River. The following description of the French and Quinebaug River basins is based on Hydrologic Investigations Atlas 700 (Eames and Epstein, 1988).

Surface water

In Massachusetts, the drainage area of the Quinebaug River is about 154 mi^2, and that of the French River is about 95 mi^2. These areas contain the headwater streams of Shetucket River, which is one of two major tributaries of the Thames River in Connecticut. The Quinebaug River basin contains 54 lakes and ponds, 31 of which have an area of 10 acres or more. The largest lake is East Brimfield Reservoir in Brimfield and Sturbridge, which is 420 acres. The French River basin contains 67 lakes and ponds, 38 of which cover at least 10 acres. Only one lake in this basin, Webster Lake (Lake Chabunagungamaug) in Webster (1,195 acres), is larger than 500 acres (Massachusetts Department of Environmental Management, Division of Water Resources, 1978, p. 62, 64; Massachusetts Department of Environmental Quality Engineering, Division of Water Pollution Control, 1976a, p. 7, 35-39).

The Quinebaug River begins at an unnamed pond near Mashapaug Pond in Union, Conn., flows northward into Massachusetts, and then 75 mi southeastward and southward to its confluence with the Shetucket River. The Quinebaug River has a moderate slope of about 13 ft/mi from the headwaters area to the USGS streamflow-gaging station near the Massachusetts border in Quinebaug, Conn., a distance of about 29 river mi. The French River begins near Leicester, Mass., and flows southward to its confluence with the Quinebaug River in northeastern Connecticut. Together, the average daily discharge of the French and Quinebaug Rivers at the State line with Connecticut is about 300 Mgal.

Ground water

The most productive aquifers in the French and Quinebaug River basins are composed of glacial sand and gravel outwash and occur in thin, narrow, discontinuous deposits beneath valleys and lowlands in about 16 percent of the basins. Major aquifers, such as in the Quinebaug River valley, yield at least 300 gal/min to municipal wells and smaller aquifers, such as in the tributary streams of Cady, Hammett, Hachet, and Hollow Brooks, yield less than 100 gal/min to wells.

Bedrock in the French and Quinebaug River basins is used as a source of water for domestic wells. Bedrock wells in the basin yield from less than a gallon per minute to 210 gal/min, and average about 10 gal/min. Wells with the highest yields, more than 100 gal/min, are in the town of Leicester in the northern part of the French River basin. This area has some of the very few municipal wells completed in bedrock in Massachusetts.

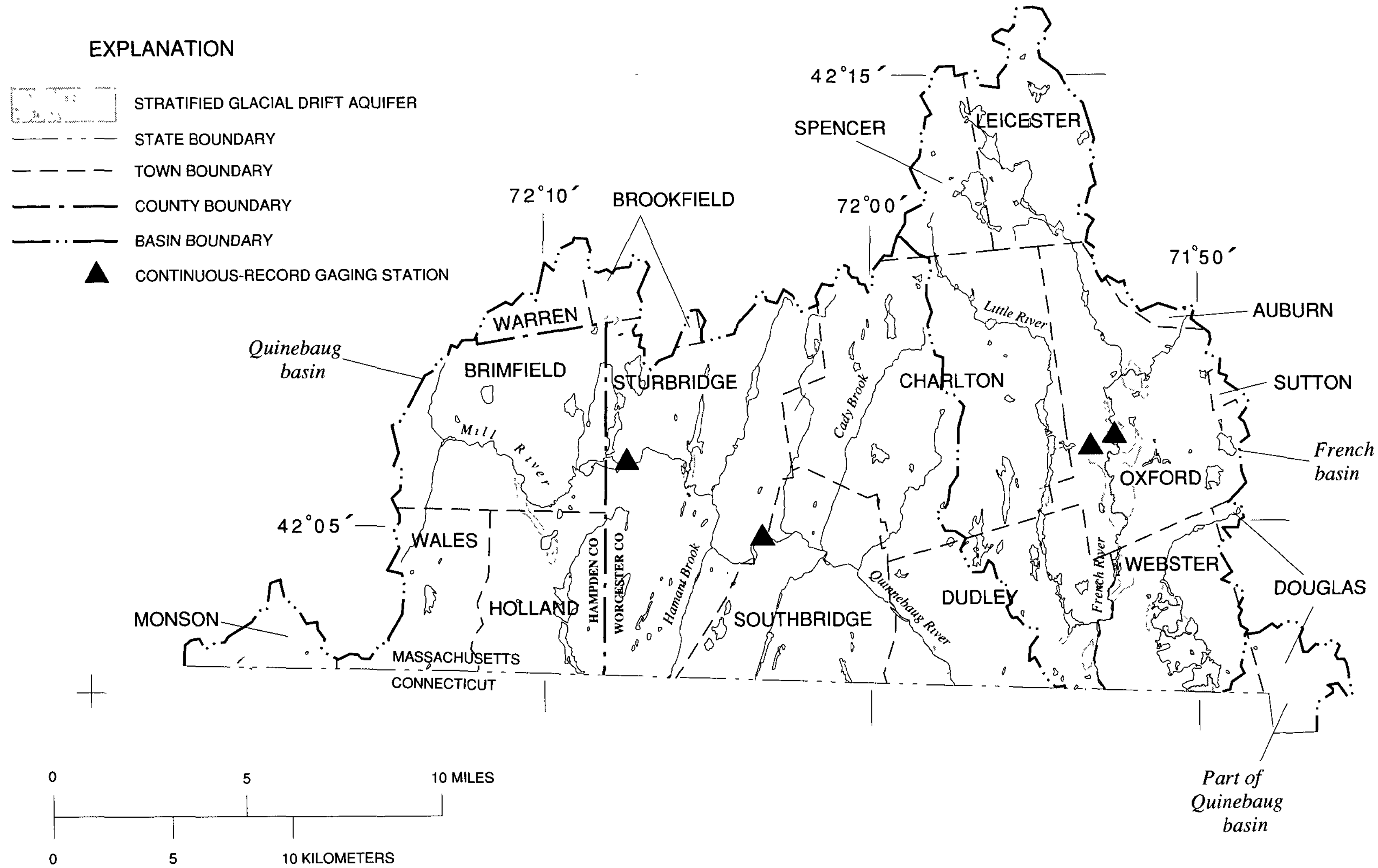


Figure 26.--Principal streams and areas of stratified drift in the French and Quinebaug River basins. (Modified from U.S. Geological Survey Hydrologic Investigations Atlas 700.)

Connecticut River basin

(State planning basins: Millers, Chicopee, Deerfield, Westfield and Farmington, and Connecticut River basins (fig. 27))

The Connecticut River basin, which covers an area of about 11,263 mi^2, is the largest drainage system in New England. The river flows south from the Boundary Mountains on the Maine-Quebec border to Long Island Sound for a total length of about 390 mi (Denny, 1982, p. 8). In Massachusetts, the Connecticut River basin has an area of about 2,728 mi^2, which occupies all of Franklin and Hampshire Counties, most of Hampden County, the eastern third of Berkshire County, and the western half of Worcester County. The tributary streams entering the Connecticut River from the west head in the Berkshire Hills and have steeper stream gradients than tributary streams from the east, which head in the Central Highlands.

The Connecticut Valley was formed by erosion of sedimentary rocks before the glacial period. These sedimentary rocks, largely sandstone, shale, and conglomerate, interspersed with volcanic rocks, were formed about 190 to 200 million years ago in the Jurassic and Triassic period. The bordering uplands are underlain by older, less erodible metamorphic and igneous rocks.

Millers River basin

Priest Brook near Winchendon, Mass.

Drainage area: 19.4 mi^2

Average discharge: 32.6 ft^3/s (Oct. 1916 to Sept. 1985)

Extremes for period of record:
Maximum discharge: 3,000 ft^3/s (Sept. 1938)
Minimum discharge: 0.08 ft^3/s (Sept. 1929)

Low flow (60 years of record):
7-day 2-year low flow: 1.6 ft^3/s
7-day 10-year low flow: 0.38 ft^3/s

Remarks: Before 1962, occasional diurnal fluctuation at low flow caused by mill upstream; before 1953, regulation at low flow by mill and ponds.

Millers River at Erving, Mass.

Drainage area: 372 mi^2

Average discharge: 632 ft^3/s (Oct. 1914 to Sept. 1985)

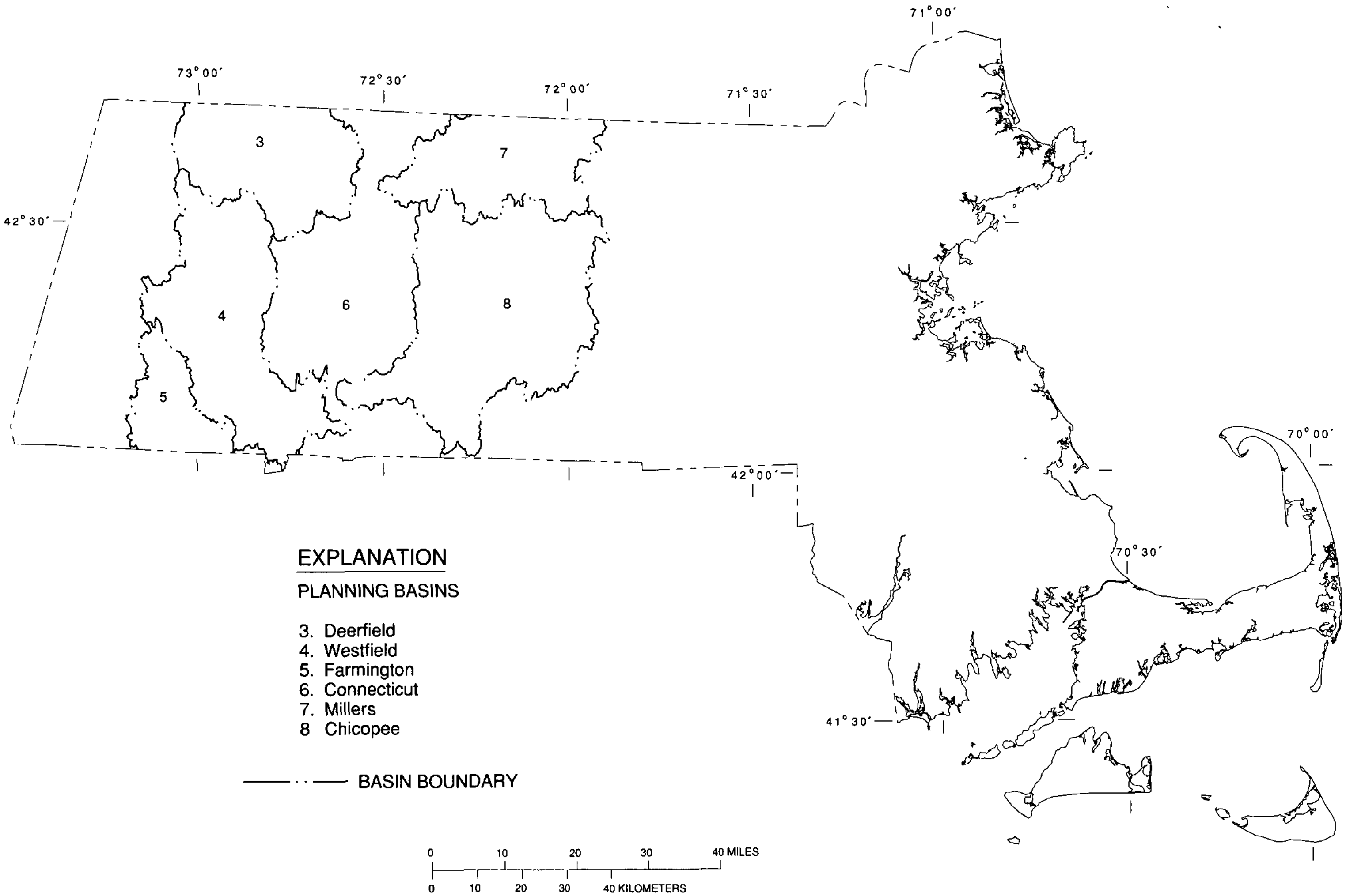


Figure 27.--Location of Massachusetts planning basins within the Connecticut River basin.

Extremes for period of record:

Maximum discharge: 29,000 ft^3/s (Sept. 1938)
Minimum discharge: about 0 ft^3/s (1915-16, because of regulation)
Minimum daily discharge: 8 ft^3/s (Sept. 1926)

Low flow (65 years of record)

7-day 2-year low flow: 80.1 ft^3/s
7-day 10-year low flow: 46.8 ft^3/s

Remarks: Flow regulated by power plants and reservoirs; high flow regulated by reservoirs.

In Massachusetts, the Millers River basin is located in Franklin and Worcester Counties, and includes all or part of 18 towns (fig. 28). The following description of the water resources of the Millers River basin is based on Hydrologic Investigations Atlas 293 (Collings and others, 1969).

Surface water

The Millers River drains a total area of about 390 mi^2, about 313 mi^2 of which are in Massachusetts. About 78 percent of the basin is forested, 11 percent is open land, 8 percent is wetland, and 3 percent contains urban areas. Many wetlands in the basin indicate areas of former shallow lakes and ponds that have gradually been filled. There are a total of 107 lakes and ponds in the basin, 72 of which have an area of 10 acres or more. Only one lake, Lake Monomonock (Lake Monomonac) in Winchendon (592 acres), is larger than 500 acres (Massachusetts Department of Environmental Management, Division of Water Resources, 1978, p. 38; Massachusetts Department of Environmental Quality Engineering, Division of Water Pollution Control, 1976a, p. 7, 26-29).

The Millers River formed at the end of the last glacial period when several glacial lakes joined and, eventually, drained into the Connecticut River. The river's headwaters are in the White Mountains of New Hampshire and in Ashburnham and Winchendon, Massachusetts. The North Branch and the main stem of the river join in Winchendon, and the river flows westward to the Connecticut River. Major tributaries of the Millers River are the Otter, which enters the Millers River in Winchendon, and the Tully River, which enters the Millers River in Athol. Both of these tributaries largely flow through wetlands.

Overall, the Millers River has a moderate gradient, averaging about 18 ft/mi from the headwaters area to the USGS streamflow-gaging station at Erving, a distance of about 43 river mi (Wandle, 1984b, p. 56). However, a 5-mi reach of the Millers River through a wooded area between South Royalston and Athol has an average gradient of about 43 ft/mi, which is about five times the average for rivers in Massachusetts (Massachusetts Department of Environmental Quality Engineering, Division of Water Pollution Control, 1974, p. 43). The gradient of the tributary Otter River averages about 18 ft/mi for a distance of about 11.5 river mi, and that of the East Branch Tully River, the major tributary of the Tully River, averages about 52 ft/mi over a distance of about 13 river mi (Wandle, 1984b, p. 55).

Ground water

Stratified glacial deposits in stream valleys form the best aquifers in the Millers River basin. The largest area of glacial outwash was deposited in a glacial lake located near Orange. Meltwater streams deposited sediments, up to 200-ft thick, into this lake. Other areas capable of yielding moderate to large amounts of ground water to wells occur near the mouth of the Millers River in Millers Falls, along the West Branch Tully River northwest of Athol, along the Otter River and Trout Brook, and in the Winchendon area.

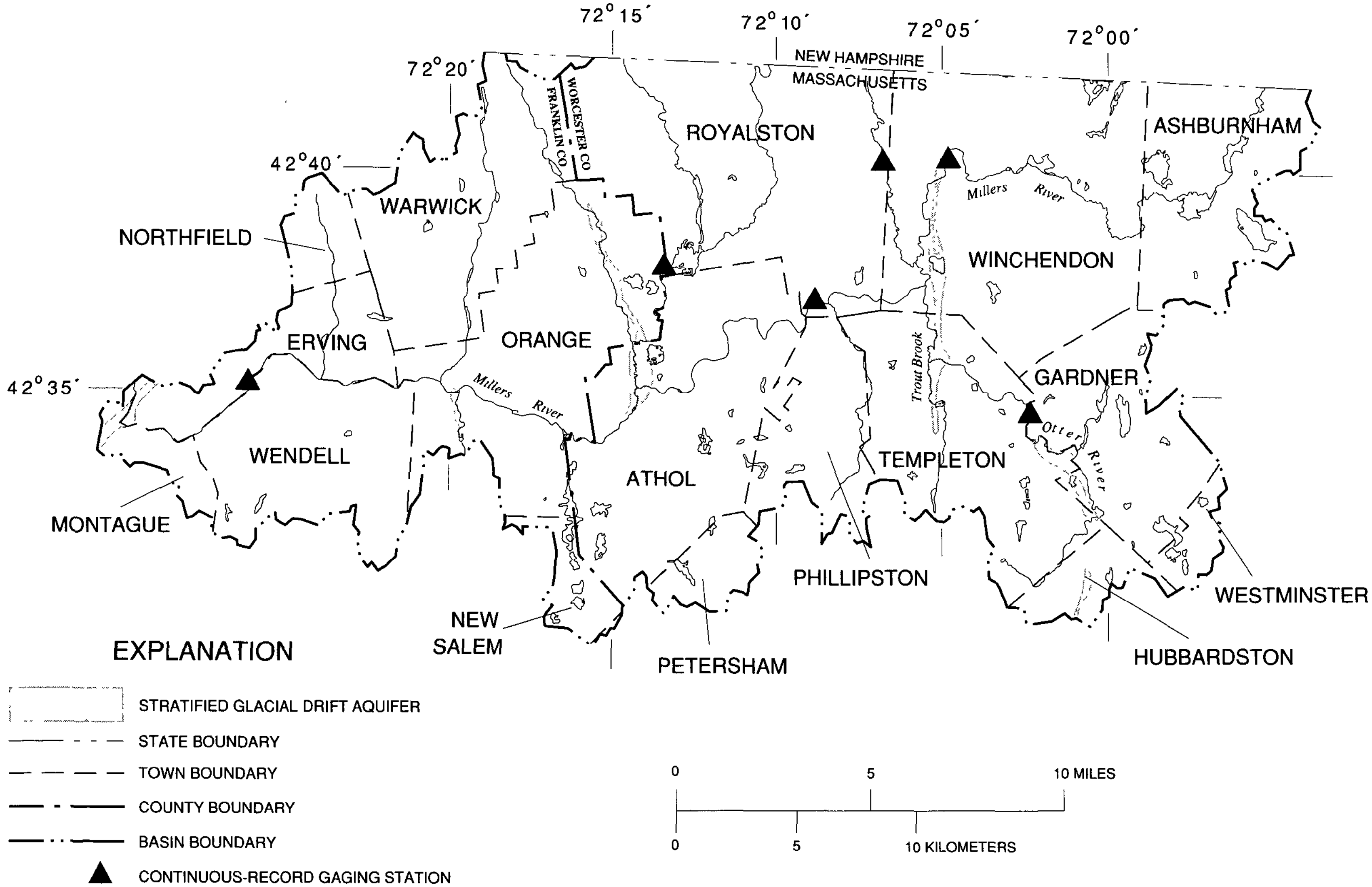


Figure 28.--Principal streams and areas of stratified drift in the Millers River basin. (Modified from U.S. Geological Survey Hydrologic Investigations Atlas 293.)

North River at Shattuckville, Mass.

Drainage area: 89.0 mi^2

Average discharge: 184 ft^3/s (Oct. 1939 to Sept. 1985)

Extremes for period of record:
Maximum discharge: 13,200 ft^3/s (Oct. 1955)
Minimum daily discharge: 5.1 ft^3/s (Oct. 1948)

Low flow (31 years of record):
7-day 2-year low flow: 13.1 ft^3/s
7-day 10-year low flow: 8.1 ft^3/s

Remarks: Diurnal fluctuation at times caused by mill upstream.

Deerfield River near West Deerfield, Mass.

Drainage area: 557 mi^2

Average discharge: 1,286 ft^3/s (Oct. 1940 to Sept. 1985)

Extremes for period of record:
Maximum discharge: 48,500 ft^3/s (Dec. 1948)
Minimum daily discharge: 28 ft^3/s (July 1962)

Low flow (40 years of record):
7-day 2-year low flow: 199 ft^3/s
7-day 10-year low flow: 95.6 ft^3/s

Remarks: Flow regulated by reservoirs and power plants upstream.

In Massachusetts, the Deerfield River basin is located in Berkshire and Franklin Counties, and includes all or part of 20 towns (fig. 29). Altitudes of the basin range from 2,841 to 120 ft above sea level.

About 78 percent of the basin is forested and only about 3 percent is urbanized. The following description of the water resources of the Deerfield River basin is based on Hydrologic Investigations Atlas 506 (Gay and others, 1974).

Surface water

The Deerfield River flows southward from its headwaters in south-central Vermont and joins the Connecticut River at Greenfield, Mass. A little over one half of its 664-square-mi drainage area, 347 mi^2, is in Massachusetts. The river flows southeastward through the Berkshire Hills of Massachusetts in a narrow valley bordered by steep slopes that rise, in places, more than 1,000 ft above the river. Near the Connecticut River, the terrain is much flatter. Overall, the gradient of the Deerfield River is quite steep, averaging 46.8 ft/mi from its headwaters to the USGS streamflow gage near West Deerfield, a distance of about 69.5 river mi (Wandle, 1984b, p. 57). The basin contains relatively few lakes and ponds, and most of these were created or enlarged by earthen dams. There are a total of 23 lakes and ponds, 16 of which cover at least 10 acres. The largest lake is Sherman

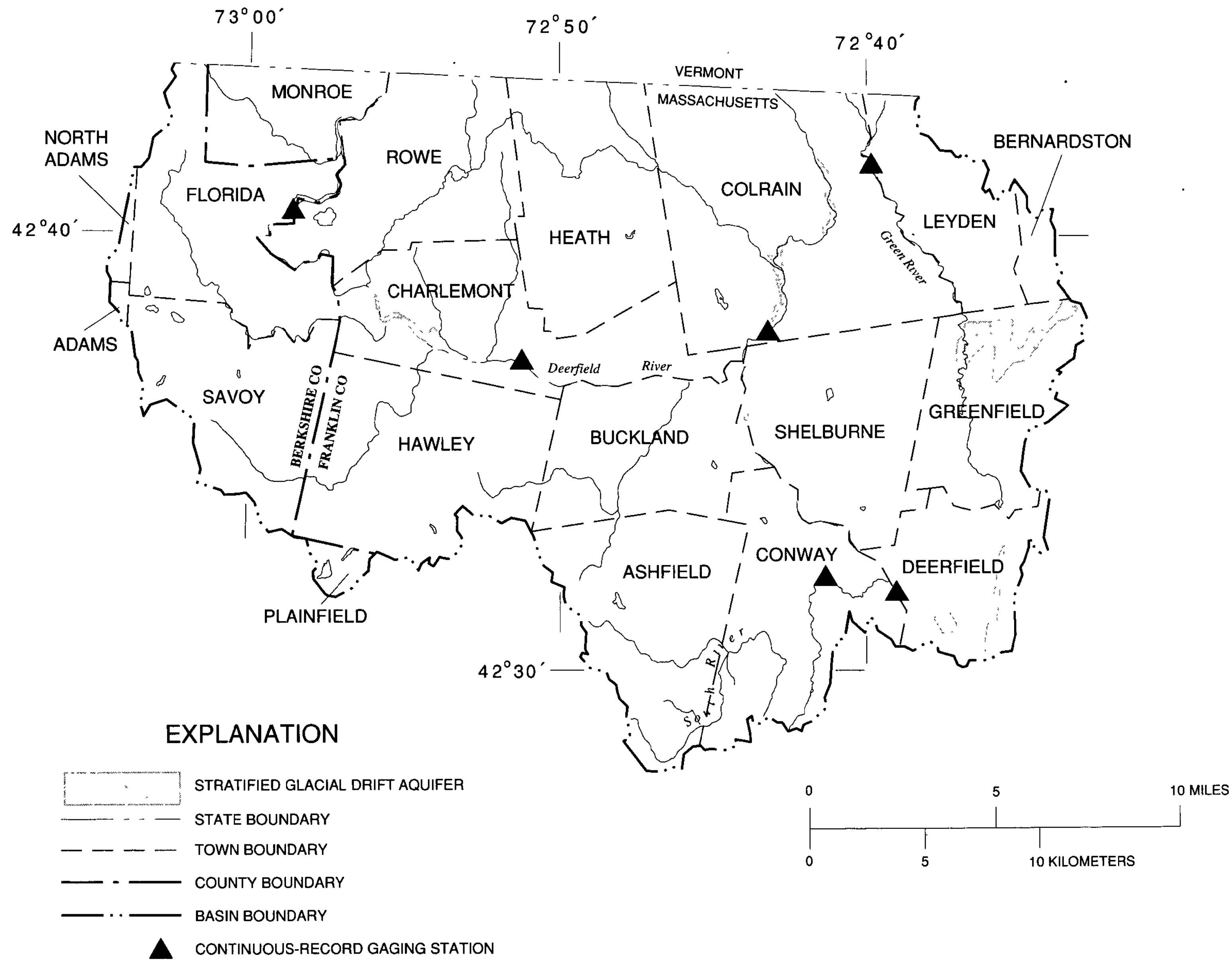


Figure 29.--Principal streams and areas of stratified drift in the Deerfield River basin. (Modified from U.S. Geological Survey Hydrologic Investigations Atlas 506.)

Reservoir in Rowe, which has an area of 162 acres (Massachusetts Department of Environmental Quality Engineering, Division of Water Pollution Control, 1976a, p. 7, 15-16).

The natural flow of the Deerfield River has been modified by the reservoirs in Vermont. More than 200 Mgal/d of water are withdrawn from the Sherman Reservoir in Massachusetts and Vermont to cool the nuclear-fuelled power plant at Rowe, Mass. The cooling water is returned to the reservoir and used downstream at hydroelectric power plants. Water released from the reservoirs during periods of power generation causes diurnal fluctuations in streamflow. The reservoirs help control floods in the basin and augment flow in the Deerfield River during low-flow periods.

Ground Water

The principal aquifers in the Deerfield River basin are alluvial sand and gravel deposits that occur along the Deerfield River and its tributaries and in the Connecticut Valley lowlands near Greenfield and Deerfield. Water from wells in these areas is largely derived from rivers and streams by induced infiltration. These aquifers can usually yield several hundred gallons per minute to single wells. However, the lowland area of Greenfield and Deerfield is also underlain by thick deposits of fine sand, silt, and clay that yields little water to wells.

Crystalline bedrock in the basin can supply about 5 gal/min of water to wells, and sedimentary rocks, which occur only in the southeastern part of the basin, can supply about 10 to 80 gal/min wells. In general, wells in both crystalline and sedimentary rocks yield more in valleys than those on slopes and hills.

Chicopee River basin

Ware River at Gibbs Crossing, Mass.

Drainage area: 197 mi^2

Average discharge: 313 ft^3/s (Oct. 1912 to Sept. 1930); 282 ft^3/s (Oct. 1930 to Sept. 1985)

Extremes for period of record:
Maximum discharge: 22,700 ft^3/s (Sept. 1938); since construction of Barre Falls Reservoir in 1958: 5,050 ft^3/s (Mar. 1979)
Minimum discharge: 5.0 ft^3/s (Oct. 1914)
Minimum daily discharge: 6.0 ft^3/s (Oct. 1914)

Low flow (23 years of record from 1931-1982 period)
7-day 2-year low flow: 43.5 ft^3/s
7-day 10-year low flow: 22.0 ft^3/s

Remarks: Flow affected by diversions for municipal supply since March 1931. Regulation by mills and reservoirs upstream.

Swift River at West Ware, Mass.

Drainage area: 189 mi^2 (includes 1.6 mi^2 drained by Beaver Brook, flow of which is diverted from the Ware River basin)

Average discharge: 314 ft^3/s (Oct. 1912 to Sept. 1939); 98.3 ft^3/s (Oct. 1939 to Sept. 1985)

Extremes for period of record:
Maximum discharge: 7,590 ft^3/s (Mar. 1936); since construction of Quabbin Reservoir in 1939: 3,070 ft^3/s (June 1984)
Minimum daily discharge: 9.1 ft^3/s (Dec. 1968)

Low flow (34 years of record from 1940-82 period)
7-day 2-year low flow: 39.0 ft^3/s
7-day 10-year low flow: 33.7 ft^3/s

Remarks: Flow regulated since 1939 by Quabbin Reservoir.

Quaboag River at West Brimfield, Mass.

Drainage area: 150 mi^2

Average discharge: 245 ft^3/s (Oct. 1912 to Sept. 1985)

Extremes for period of record:
Maximum discharge: 12,800 ft^3/s (Aug. 1955)
Minimum daily discharge: 6.6 ft^3/s (Sept. 1957)

Low flow (42 years of record):
7-day 2-year low flow: 26.6 ft^3/s
7-day 10-year low flow: 13.2 ft^3/s

Remarks: High flow slightly affected by reservoirs.

Chicopee River at Indian Orchard, Mass.

Drainage area: 689 mi^2

Average discharge: 908 ft^3/s (Oct. 1928 to Sept. 1985)

Extremes for period of record:
Maximum discharge: 45,200 ft^3/s (Sept. 1938)
Minimum daily discharge: 16 ft^3/s (several times in 1929-31)

Low flow (34 years of record):
7-day 2-year low flow: 192 ft^3/s
7-day 10-year low flow: 128 ft^3/s

Remarks: Flow affected by diversions for municipal supply. Flow regulated by power plants and reservoirs upstream.

The Chicopee River basin is located in Franklin, Hampden, Hampshire, and Worcester Counties, and encompasses all or part of 39 cities and towns, including the cities of Springfield and Chicopee (fig. 30). Most of the population is in the Chicopee and Springfield metropolitan areas in the southwestern part of the basin. The rest of the basin is largely rural woodlands. Elevations in the basin range from 1,720 ft above sea level along the basin divide in Wachusett Mountain State Reservation to 50 ft at the mouth of

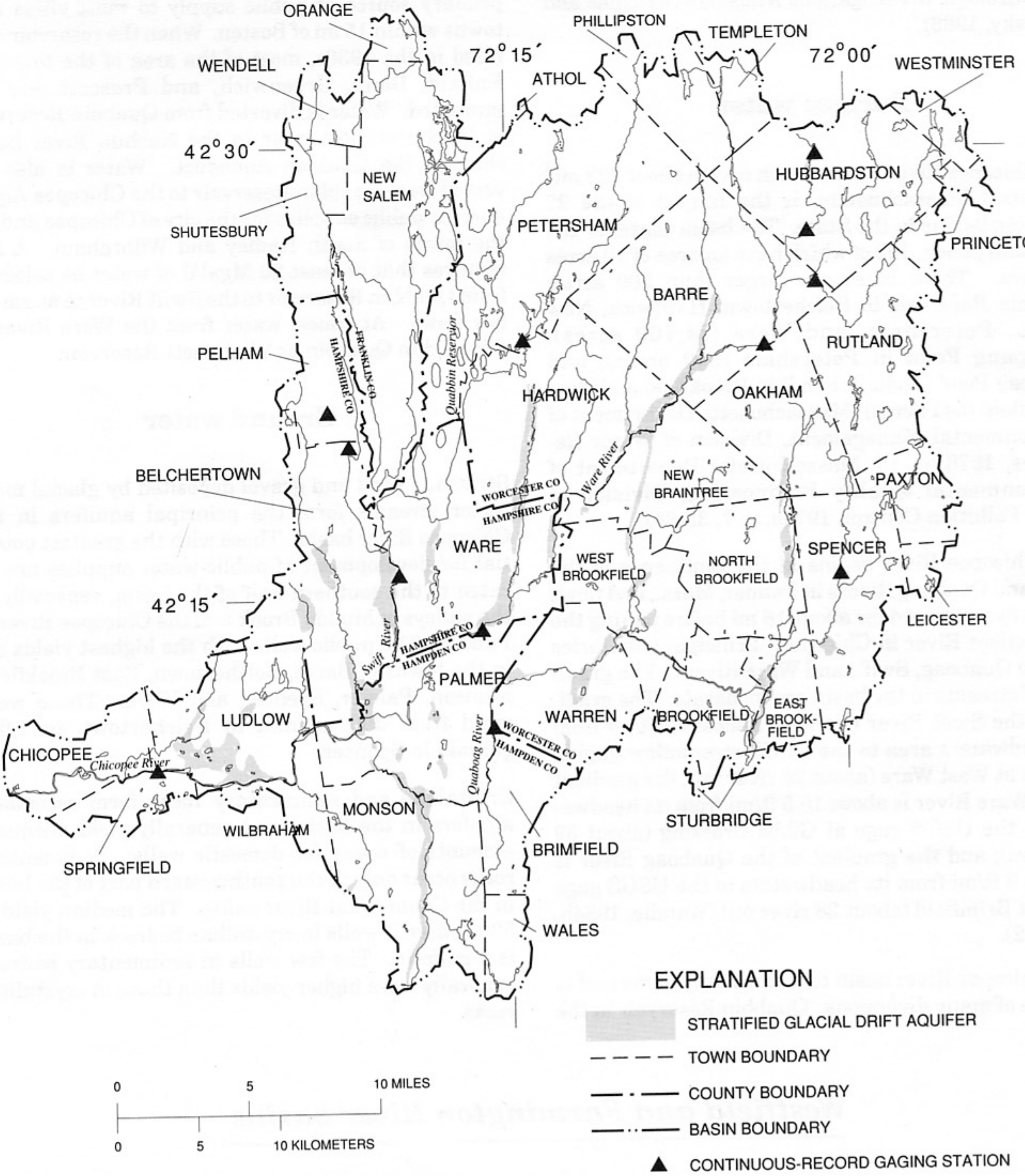


Figure 30.--Principal streams and areas of stratified drift in the Chicopee River basin. (Modified from U.S. Geological Survey Hydrologic Investigations Atlas 693.)

the Chicopee River. The following description of the water resources of the Chicopee River basin is based on Hydrologic Investigations Atlas 693 (Krejmas and Maevsky, 1986).

Surface water

The Chicopee River basin, which covers about 723 mi^2 of central Massachusetts, is the largest of the 27 planning basins in the State. The basin contains 164 lakes and ponds, 102 of which have an area of 10 acres or more. Three lakes are larger than 500 acres: Quabbin Reservoir in Belchertown, Hardwick, New Salem, Petersham, and Ware (24,700 acres); Pottapaug Pond in Petersham (549 acres); and Quaboag Pond (Podunk Pond) in Brookfield and East Brookfield (541 acres) (Massachusetts Department of Environmental Management, Division of Water Resources, 1978, p. 15; Massachusetts Department of Environmental Quality Engineering, Division of Water Pollution Control, 1976a, p. 7, 30-34).

The Chicopee River begins at the confluence of the Ware and Quaboag Rivers in Palmer, Mass., and flows generally westward for about 16 mi before joining the Connecticut River in Chicopee. Principal tributaries are the Quaboag, Swift, and Ware Rivers. The gradients of streams in the basin are moderate. The gradient of the Swift River averages almost 12 ft/mi from its headwaters area to the USGS streamflow-gaging station at West Ware (about 26 river mi); the gradient of the Ware River is about 15.5 ft/mi from its headwaters to the USGS gage at Gibbs Crossing (about 39 river mi); and the gradient of the Quaboag River is almost 9 ft/mi from its headwaters to the USGS gage at West Brimfield (about 28 river mi) (Wandle, 1984b, p. 60-62).

The Chicopee River basin contains many dams and is the site of many diversions. Quabbin Reservoir in the Swift River basin is one of the largest reservoirs constructed for public supply in the world, and is the primary source of public supply to most cities and towns within 15 mi of Boston. When the reservoir was filled in the 1930s, most of the area of the towns of Enfield, Dana, Greenwich, and Prescott was inundated. Water is diverted from Quabbin Reservoir to Wachusett Reservoir in the Nashua River basin through the Quabbin Aqueduct. Water is also diverted from Quabbin Reservoir to the Chicopee Aqueduct for public supplies for the city of Chicopee and for the towns of South Hadley and Wilbraham. A law requires that at least 20 Mgal/d of water be released from Quabbin Reservoir to the Swift River to augment low flows. At times, water from the Ware River is diverted to Quabbin or Wachusett Reservoir.

Ground water

Stratified sand and gravel deposited by glacial meltwater streams form the principal aquifers in the Chicopee River basin. Those with the greatest potential for development of public-water supplies are located in the southern half of the basin, especially in the valleys of Muddy Brook and the Chicopee River in Palmer. The public wells with the highest yields are in the towns of Barre, Belchertown, East Brookfield, Munson, Palmer, Spencer, and Ware. These wells yield from 300 gal/min in Belchertown to 1,000 gal/min in Spencer.

Crystalline and sedimentary rocks form secondary aquifers in the basin, and generally yield adequate amounts of water for domestic wells. Sedimentary rocks occur only in the southwestern part of the basin in the Connecticut River valley. The median yield of 520 domestic wells in crystalline bedrock in the basin is 6 gal/min. The few wells in sedimentary bedrock generally have higher yields than those in crystalline rocks.

Westfield and Farmington River basins

West Branch Westfield River at Huntington, Mass.

Drainage area: 94.0 mi^2

Average discharge: 190 ft^3/s (Oct. 1935 to Sept. 1985)

Extremes for period of record:
Maximum discharge: 26,100 ft^3/s (Aug. 1955)
Minimum discharge: 3.3 ft^3/s (Aug. 1955, Nov. 1957)

Low flow (45 years of record):
7-day 2-year low flow: 10.6 ft^3/s
7-day 10-year low flow: 5.6 ft^3/s

Westfield River near Westfield, Mass.

Drainage area: 497 mi^2

Average discharge: 923 ft^3/s (Oct. 1914 to Sept. 1985)

Extremes for period of record:
Maximum discharge: 70,300 ft^3/s (Aug. 1955)
Minimum discharge: 9 ft^3/s (Oct. 1921)
Minimum daily discharge: 40 ft^3/s (Dec. 1914)

Low flow (38 years of record):
7-day 2-year low flow: 116 ft^3/s
7-day 10-year low flow: 77.3 ft^3/s

Remarks: Flow regulated by reservoirs. Flow slightly affected by reservoirs and by diversion for municipal supply.

West Branch Farmington River near New Boston, Mass.

Drainage area: 91.7 mi^2

Average discharge: 182 ft^3/s (Oct. 1913 to Sept. 1985)

Extremes for period of record:
Maximum discharge: 34,300 ft^3/s (Aug. 1955)
Minimum daily discharge: 2.4 ft^3/s (Aug. 1957)

Low flow (67 years of record):
7-day 2-year low flow: 20.0 ft^3/s
7-day 10-year low flow: 5.9 ft^3/s

Remarks: Flow regulated by reservoir. High flow slightly affected by reservoirs.

The Westfield River basin is located in Berkshire, Franklin, Hampshire, and Hampden Counties of west-central Massachusetts, and includes all or part of 29 cities and towns, including the cities of Westfield and Holyoke; the Farmington River basin is located in Berkshire and Hampden Counties, and includes all or part of 10 towns (fig. 31). Together, these basins comprise about one quarter of the drainage area of the Connecticut River in the State. The basins are largely forested and sparsely populated, with most of the population concentrated in the southeastern corner of the Westfield River basin in the cities of Holyoke and Westfield. Elevations in the Westfield River basin range from 2,300 ft above sea level along the northwestern drainage divide in Windsor to 50 ft above sea level at the confluence of the Westfield and Connecticut Rivers. In the Farmington River basin, elevations range from 2,050 ft along the northwestern drainage

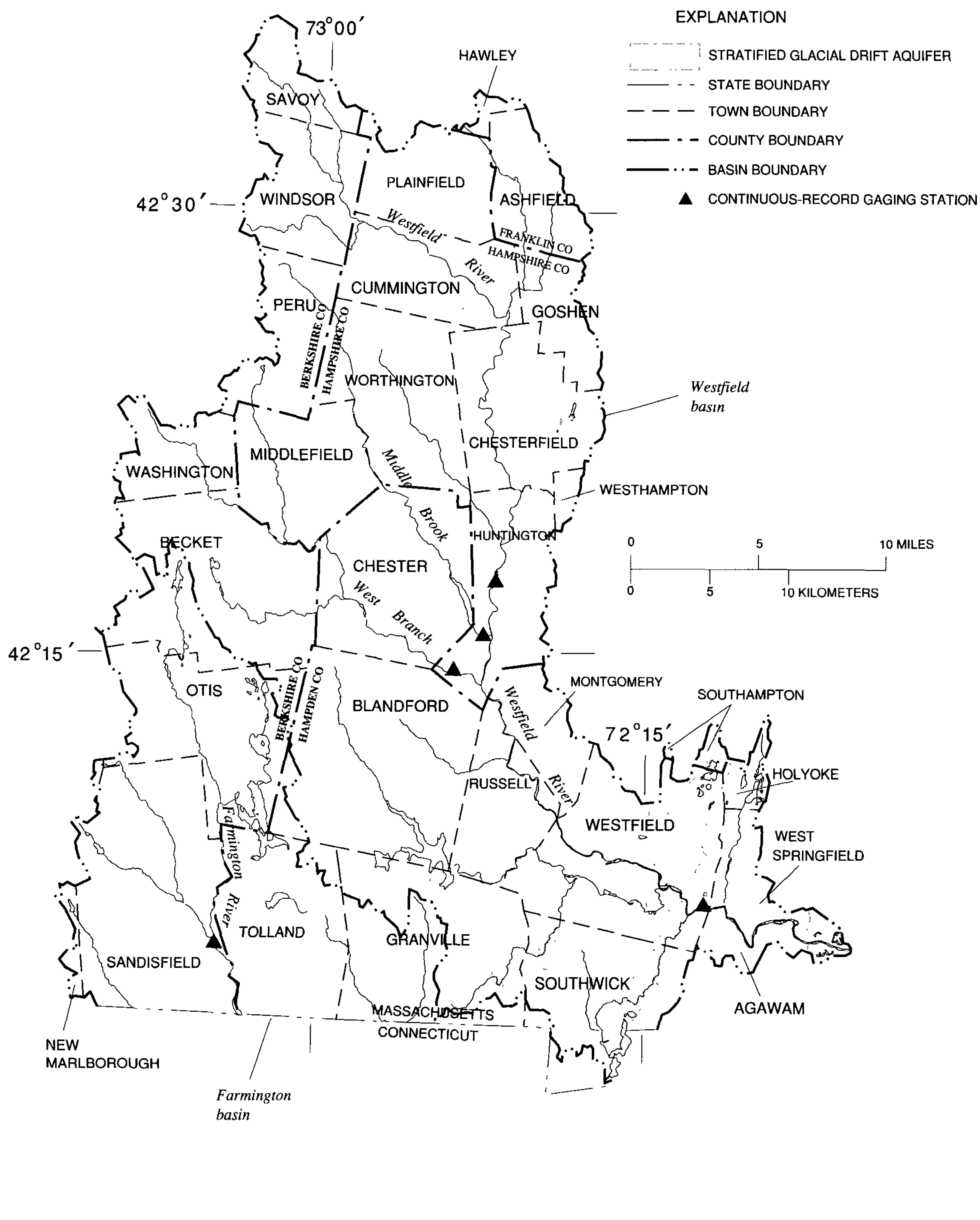


Figure 31.--Principal streams and areas of stratified drift in the Westfield and Farmington River basins. (Modified from U.S. Geological Survey Hydrologic Investigations Atlas 716.)

divide to 650 ft on the West Branch Farmington River at the Connecticut State line. The following description of the water resources of the Westfield and Farmington River basins is based on Hydrologic Investigations Atlas 716 (Maevsky and Johnson, 1988).

Surface water

The Westfield River basin drains about 517 mi^2 and the Farmington River basin drains about 156 mi^2 in Massachusetts. The Farmington River and the upper reaches of the Westfield River flow in narrow valleys bordered by steep slopes. Because of the steepness of the river banks, the low permeability of much of the surficial deposits, and large quantities of rainfall and snowmelt, the basins frequently have high runoff rates. Based on records from six long-term gaging stations, about 27 of the 47 in. of average annual precipitation become stream runoff.

Lakes and ponds in the basins were mostly created or enlarged by earthen dams, and are mostly larger than 10 acres. In the Westfield River basin, there are 78 lakes and ponds, 48 of which have an area of 10 acres or more. Only one lake, Cobble Mountain Reservoir in Blandford and Russell (1,135 acres), is larger than 500 acres. In the Farmington River basin, there are 47 lakes and ponds, 33 of which have an area of 10 acres or more. Two lakes are larger than 500 acres: Otis Reservoir (East Otis Reservoir, Clarks Pond) in Otis, which is 1,065 acres, and Colebrook River Reservoir in Sandisfield and Tolland, which is 760 acres (Massachusetts Department of Environmental Management, Division of Water Resources, 1978, p. 30-32, 44, 46; Massachusetts Department of Environmental Quality Engineering, Division of Water Pollution Control, 1976a, p. 7, 17-22).

The Westfield River begins in Savoy in the northwestern corner of the basin and flows southward to southeastward to join the Connecticut River in West Springfield. Its major tributaries, the Middle Branch Westfield, West Branch Westfield, and Little Rivers, enter the Westfield River from the west. The West Branch Westfield River is the largest totally uncontrolled river in the State. Overall, the Westfield River has a moderate gradient, averaging almost 29 ft/mi from its headwaters to the USGS streamflow-gaging station near Westfield, a distance of about 54 river mi (Wandle, 1984b, p. 64).

Borden Brook and Cobble Mountain Reservoirs, located on the Little River in the southern part of the Westfield River basin, comprise the second largest water-supply storage system in the State. During 1985, an average of 37 Mgal/d of water was diverted from the Westfield River basin through this reservoir system to supply the Springfield water system.

The West Branch Farmington River begins in Becket in the northern part of the basin and flows southward into Connecticut, where it joins the Farmington River. The flow of the river is partially controlled by Otis Reservoir, but is more controlled just beyond the State line by Colebrook River Reservoir in Connecticut. Like the Westfield River, its major tributaries in Massachusetts, the Clam River and Sandy Brook, enter from the west. Overall, the West Branch Farmington River has a relatively steep gradient, averaging almost 68 ft/mi from its headwaters to the USGS streamflow-gaging station near New Boston, a distance of about 16 river mi (Wandle, 1984b, p. 65).

Ground water

Stratified sand and gravel in stream and river valleys form the principal aquifers in the basins. Most of these deposits are located in the southeastern half of the Westfield River basin, especially in the vicinity of Pond Brook in Westfield and Great Brook in Southwick. Pond Brook aquifer, with an area of about 8 mi^2 and a maximum saturated thickness of about 250 ft, is the larger of the two aquifers. The combined potential yield of these two aquifers is estimated to be more than 10 Mgal/d. Seismic-refraction surveys made by the USGS indicate that parts of these aquifers are located in the preglacial Connecticut River channel that extends in a north-south direction just west of East and Provin Mountains. The buried river channel is about 600 ft wide in places and ranges from sea level to more than 70 ft below sea level. Thickness of sand and gravel in the channel ranges from 35 ft near the edges to about 300 ft in the valley center.

Most of the basins are underlain by crystalline, sedimentary, and some carbonate rocks. Sedimentary rocks, such as sandstone, siltstone, and shale, occur only in valleys and lowlands of the eastern part of the Westfield River basin. Bedrock forms a secondary aquifer in the region that usually can yield adequate amounts of water for domestic needs and some small commercial and industrial needs. Drillers report an average yield of 6 gal/min from bedrock in the basins.

Connecticut River basin

Connecticut River at Montague City, Mass.

Drainage area: 7,860 mi^2

Average discharge: 13,790 ft^3/s (Oct. 1904 to Sept. 1985)

Extremes for period of record:
Maximum discharge: 236,000 ft^3/s (Mar. 1936)
Minimum daily discharge: 215 ft^3/s (Aug., Sept. 1958)

Low flow (77 years of record):
7-day 2-year low flow: 2410 ft^3/s
7-day 10-year low flow: 1690 ft^3/s

Remarks: Flow regulated by power plants and reservoirs upstream.

Mill River at Northampton, Mass.

Drainage area: 54.0 mi^2

Average discharge: 96.8 ft^3/s (Oct. 1939 to Sept. 1985)

Extremes for period of record:
Maximum discharge: 6,300 ft^3/s (Aug. 1955)
Minimum discharge: 2.2 ft^3/s (Oct. 1950)
Minimum daily discharge: 4.2 ft^3/s (Aug. 1957)

Low flow (42 years of record):
7-day 2-year low flow: 10.1 ft^3/s
7-day 10-year low flow: 6.2 ft^3/s

Remarks: Before 1956, flow regulated by mill upstream.

Fort River near Amherst, Mass.

Drainage area: 36.3 mi^2 (excludes 5.16 mi^2 around Nurse and Dean Brooks)

Average discharge: 58.1 ft^3/s (Oct. 1966 to Sept. 1985)

Extremes for period of record:
Maximum discharge: 2,100 ft^3/s (Mar. 1979)
Minimum discharge: 1.9 ft^3/s (Sept. 1966, Sept. 1981)

Remarks: Diversions upstream for municipal supply.

Connecticut River at Thompsonville, Conn.

Drainage area: 9,661 mi^2

Average discharge: 16,460 ft^3/s (Oct. 1928 to Sept. 1985)

Extremes for period of record:
Maximum discharge: 282,000 ft^3/s (Mar. 1936)
Minimum daily discharge: 968 ft^3/s (Oct. 1963)

Low flow (52 years of record):
7-day 2-year low flow: 3010 ft^3/s
7-day 10-year low flow: 2220 ft^3/s

Remarks: Flow regulated by power plants, by diversion from Chicopee River basin, and by reservoirs.

The Connecticut River basin is located in Franklin, Hampshire, and Hampden Counties of west-central Massachusetts, and contains all or part of 46 cities and towns, including the cities of Holyoke, Chicopee, Westfield, Springfield, and Northampton (fig. 32). The elevation of the valley floor ranges from about 40 ft, where the Connecticut River crosses into Connecticut, to about 330 ft, except for long ridges of volcanic rock that reach altitudes of 600 to almost 1,000 ft (Denny, 1982, p. 4). Elevations in the upland areas of the basin are as much as 1,500 ft. The following description of the water resources of the Connecticut River basin is based on Hydrologic Investigations Atlases 562 (Wandle and Caswell, 1977) and 563 (Walker and Caswell, 1977).

Surface water

The Connecticut River lowlands drain about 669 mi^2. The basin contains 97 lakes and ponds, 47 of which are larger than 10 acres. The largest lake is Tighe Carmody Reservoir in Southampton, which is 365 acres (Massachusetts Department of Environmental Management, Division of Water Resources, 1978, p. 13; Massachusetts Department of Environmental Quality Engineering, Division of Water Pollution Control, 1976a, p. 7, 23-25).

The present Connecticut River has meandered and cut into glacial lake deposits, producing wide terraces and floodplains, which are several miles wide near the State border with Connecticut and become narrower to the north. As the Connecticut River courses through Massachusetts, its annual mean flow increases from about 11,000 ft^3/s to 16,200 ft^3/s because of contributions of about 4,080 ft^3/s from the four major tributaries, the Millers, Chicopee, Deerfield, and Westfield rivers, and about 1,120 ft^3/s from smaller streams.

Ground water

Following the retreat of the last glacial ice sheet, a large lake known as Lake Hitchcock covered most of the Connecticut Valley lowlands in Massachusetts, and left deposits of silt, clay, and fine sand up to 200-ft thick in the lowlands area. Sand and gravel beneath fine-grained lake deposits, called buried outwash, is the main aquifer of the Connecticut Valley lowlands and supplies most municipal wells. These deposits may reach 50 ft or more in thickness, but are usually much thinner. Sustained yields of wells in buried outwash range from 120 to 1,200 gal/min, and about half of the wells yield more than 520 gal/min. Some deltaic deposits of sand and gravel, which are found mainly along lowland margins, also provide water for municipal supplies. Sand and gravel deposits at the surface of parts of the flood plain and lower terraces provide smaller quantities of water (5 to 50 gal/min) to shallow wells.

Pre-Triassic crystalline rocks are the only aquifers in most upland areas. These rocks generally yield about 10 gal/min to wells, but yields may be higher where recharge is available from nearby streams or overlying stratified deposits. Jurassic/Triassic sedimentary rocks generally yield 10 to 100 gal/min to wells, but more than 50 gal/min where they are overlain by stratified deposits. The highest reported yield from Jurassic/Triassic rocks (red sandstone, shale, and conglomerate) is about 700 gal/min.

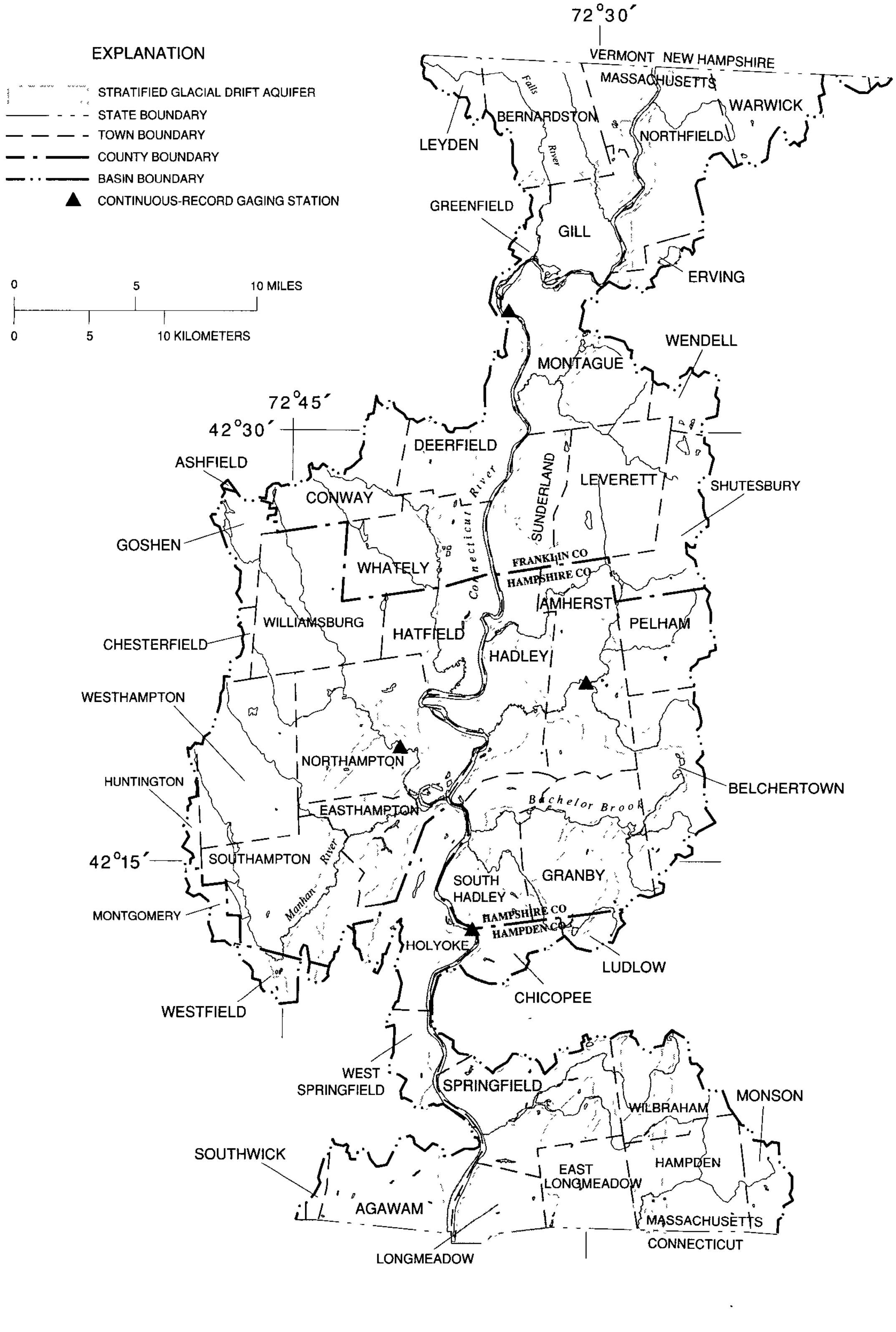


Figure 32.--Principal streams and areas of stratified drift in the Connecticut River basin. (Modified from U.S. Geological Survey Hydrologic Investigations Atlases 562 and 563.)

Housatonic River basin

(State planning basin: Housatonic River basin)

The Housatonic River basin has a drainage area of about 1,950 mi^2, about a third of which is in Massachusetts (fig. 33). The river begins in the Berkshire Hills of western Massachusetts and flows about 159 mi southward and southeastward before emptying into Long Island Sound at Stratford, Conn. Major tributaries are the Naugatuck and Shepaug Rivers in Connecticut.

Housatonic River basin

East Branch Housatonic River at Coltsville, Mass.

Drainage area: 57.6 mi^2

Average discharge: 106 ft^3/s (Oct. 1936 to Sept. 1985)

Extremes for period of record:
Maximum discharge: 6,400 ft^3/s (Sept. 1938)
Minimum daily discharge: 4.4 ft^3/s (Aug. 1936)

Low flow (24 years of record):
7-day 2-year low flow: 18.2 ft^3/s
7-day 10-year low flow: 11.4 ft^3/s

Remarks: Flow regulated by power plants upstream and by reservoir upstream. Flow affected by diversion for municipal supply.

Housatonic River near Great Barrington, Mass.

Drainage area: 282 mi^2

Average discharge: 525 ft^3/s (Oct. 1913 to Sept. 1985)

Extremes for period of record:
Maximum discharge: 12,200 ft^3/s (Jan. 1949)
Minimum daily discharge: 1.0 ft^3/s (Oct. 1914)

Low flow (67 years of record):
7-day 2-year low flow: 106 ft^3/s
7-day 10-year low flow: 69.0 ft^3/s

Remarks: Regulation at low flow by power plants upstream. High flow slightly affected by reservoirs.

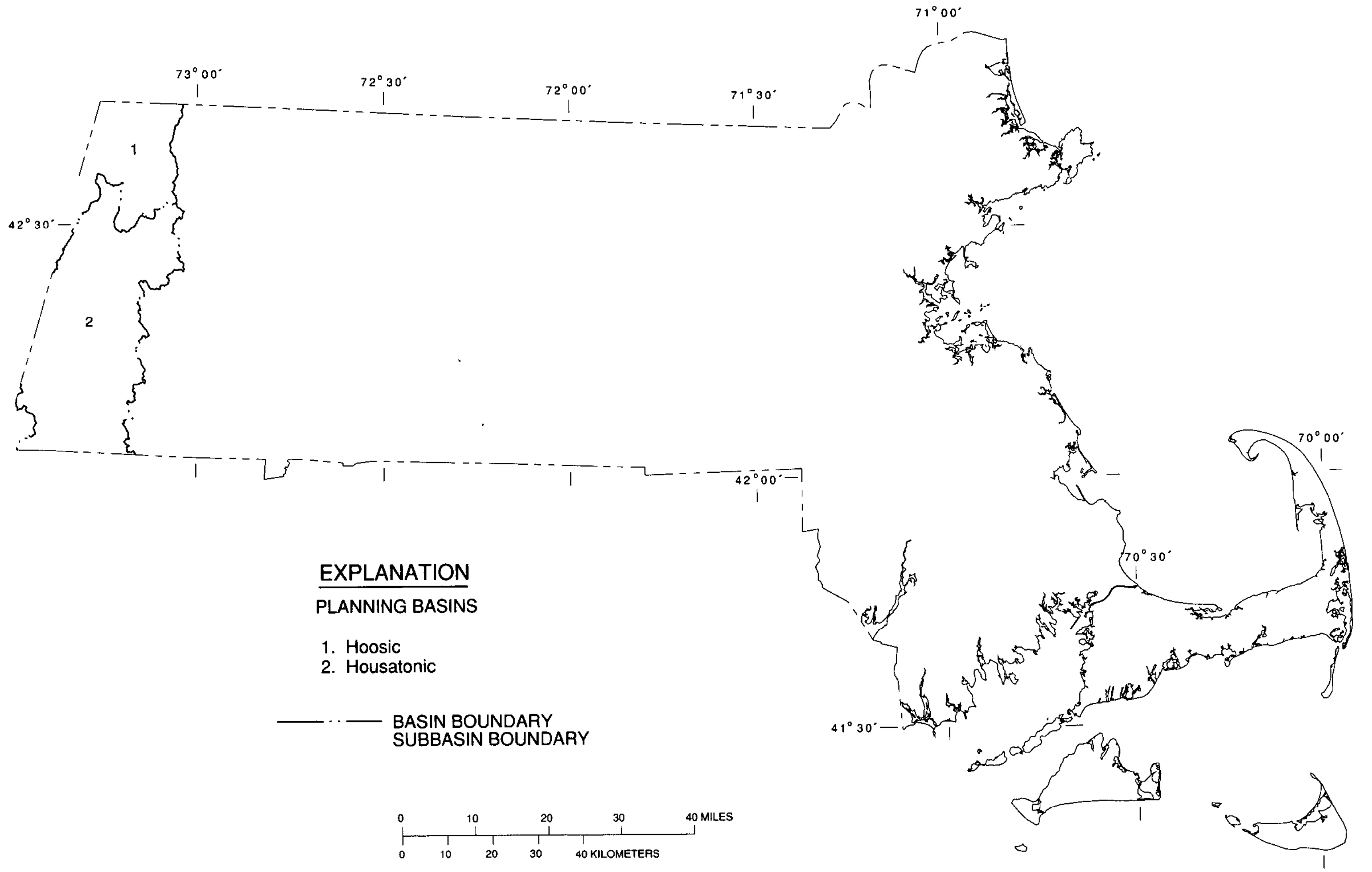


Figure 33.--Location of Massachusetts planning basins within the Hoosic and Housatonic River basins..

Green River near Great Barrington, Mass.

Drainage area: 51.0 mi^2

Average discharge: 79.4 ft^3/s (Oct. 1951 to Sept. 1971)

Extremes for period of record:
Maximum discharge: 2,120 ft^3/s (Mar. 1960)
Minimum discharge: 2.7 ft^3/s (Sept., Oct. 1964)

Low flow (20 years of record):
7-day 2-year low flow: 5.3 ft^3/s
7-day 10-year low flow: 3.3 ft^3/s

In Massachusetts, the Housatonic River basin is located in Berkshire County and contains all or part of 25 towns and the city of Pittsfield (fig. 34). The basin has deeply dissected uplands that have summits of similar altitude. Monadnocks of rock that are resistant to erosion rise above the surrounding hills. Elevations range from about 2,600 ft to about 635 ft above sea level at the border between Massachusetts and Connecticut. The following description of the water resources of the Housatonic River basin is based on Hydrologic Investigations Atlas 281 (Norvitch and others, 1968).

Surface water

The Housatonic River drains about 500 mi^2 of western Massachusetts. The basin contains a few wetlands and, compared to other basins to the west of the Connecticut River, a relatively large number of lakes and ponds. There are 113 lakes and ponds, 70 of which are larger than 10 acres. Only one lake, Onota Lake in Pittsfield (617 acres), is larger than 500 acres (Massachusetts Department of Environmental Quality Engineering, Division of Water Pollution Control, 1976a, p. 7, 11-14).

The main stem of the Housatonic River is formed by the confluence of the East Branch and West Branch Housatonic Rivers at Pittsfield. The main river flows generally southward through Massachusetts and eventually empties into Long Island Sound. In Massachusetts, the Housatonic River has a moderate gradient, averaging 16.5 ft/mi from its headwaters to the USGS streamflow-gaging station near Great Barrington, a distance of almost 50 river mi (Wandle and Lippert, 1984, p. 19).

Ground water

Water for some industries and smaller communities is obtained from wells in glacial sand and gravel deposits in lowland areas and from wells in bedrock. Springs, especially at the base of bedrock hills, are also a water source to many homes and some towns in the basin. Some of the largest sand and gravel deposits in the basin occur just east and northeast of Monument Mountain in Great Barrington and Stockbridge.

Bedrock in the basin consists of limestone, dolomite, marble, quartzite, schist, and gneiss, and is commonly highly deformed. Limestone, dolomite, and marble generally underlie valleys in this basin and form potentially high-yield aquifers. Wells that intersect openings along joints and faults in limestone, dolomite, and marble generally produce the highest bedrock yields in the State.

Circulating ground water has, in places, enlarged openings along joints and other fractures making this bedrock aquifer capable of sustaining high yields to wells. Some bedrock wells in Pittsfield have been tested at rates exceeding 1,000 gal/min (Norvitch and Lamb, 1966).

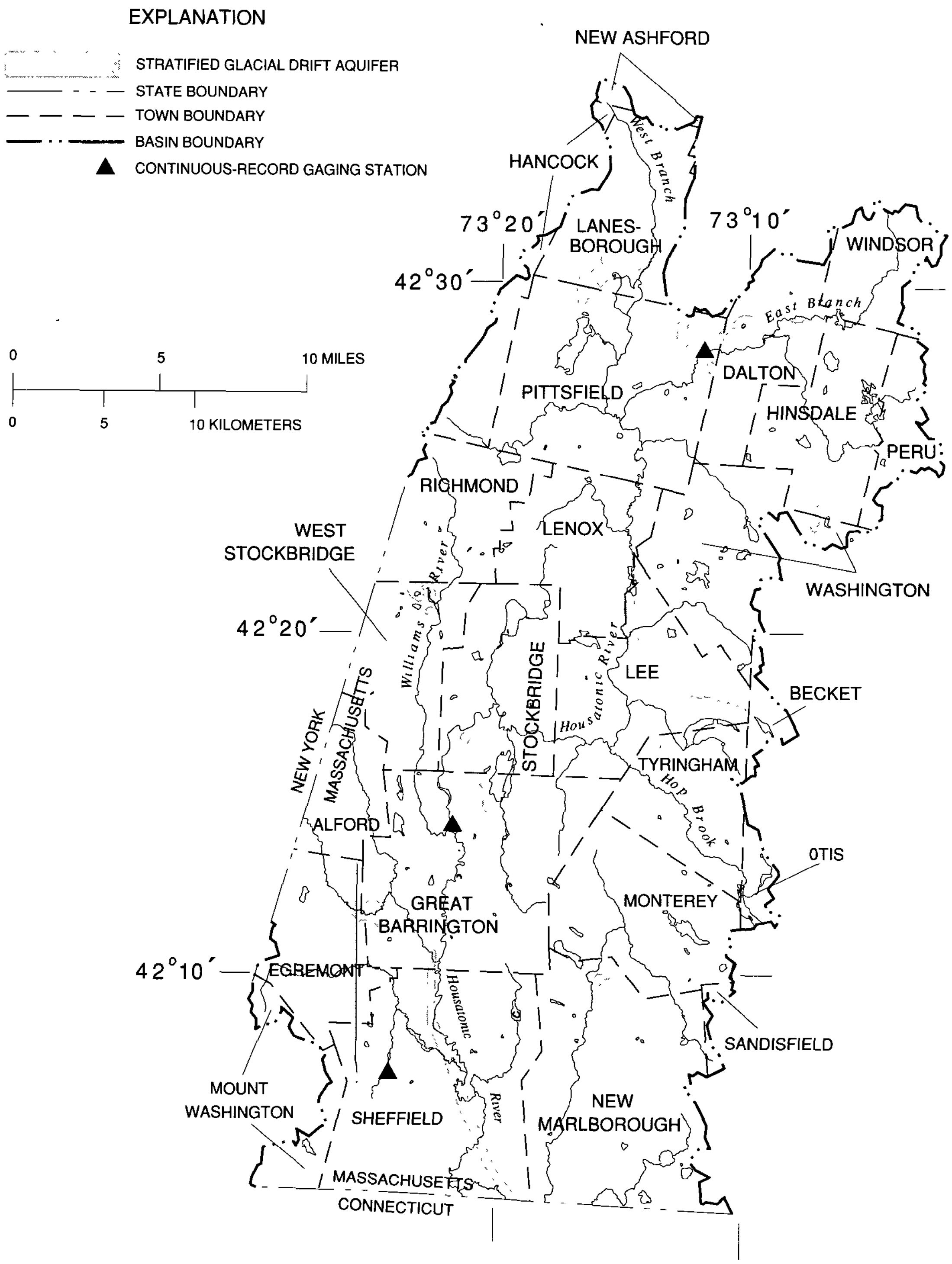


Figure 34.--Principal streams and areas of stratified drift in the Housatonic River basin. (Modified from U.S. Geological Survey Hydrologic Investigations Atlas 281.)

Hudson River basin

(State planning basins: Hoosic River, Kinderhook Creek, and Bash Bish Brook basins)

The Hudson River basin mostly lies in east-central New York, with small portions extending into southwestern Vermont, western Massachusetts, and northern New Jersey. The Hudson River, which is located almost entirely within New York, flows about 315 mi from its source in the Adirondack Mountains to its mouth at New York Harbor. The lower 161 mi is an estuary. The headwaters of one of the major tributaries of the Hudson River, the Hoosic River, and of two more minor tributaries, Kinderhook Creek and the Roeliff Jansen Kill (Bash Bish Brook), lie in western Massachusetts (fig. 35). The Hoosic River, which is about 65 mi long, is the longest of west-flowing tributaries of the Hudson River (Denny, 1982, p. 9).

Hoosic River basin

North Branch Hoosic River at Williamstown, Mass.

Drainage area: 126 mi^2

Average discharge: 272 ft^3/s (Oct. 1940 to Sept. 1985)

Extremes for period of record:
Maximum discharge: 13,000 ft^3/s (Dec. 1948)
Minimum discharge: 5.8 ft^3/s (Aug., Oct. 1940)
Minimum daily discharge: 24 ft^3/s (Sept. 1980)

Remarks: Some regulation by Cheshire Reservoir upstream.

In Massachusetts, the Hoosic River basin is located in Berkshire County and contains all or part of 12 towns and a tiny part of the city of Pittsfield (fig. 36) Elevations in the basin range from 3,487 ft above sea level on Mount Greylock, the highest point in the State, to about 560 ft at the State line. The following description of the water resources of the Hoosic River basin is based on Hydrologic Investigations Atlas 481 (Hansen and others, 1973).

Surface water

The Hoosic River drains about 164 mi^2 of northwestern Massachusetts. The relatively few lakes and ponds in the basin were mostly created or enlarged by earthen dams. There are 17 lakes and ponds, seven of which have an area of 10 acres or more. The largest lake is Cheshire Reservoir (Hoosic Reservoir) in Cheshire, which covers 418 acres (Massachusetts Department of Environmental Quality Engineering, Division of Water Pollution Control, 1976a, p. 7, 9-10).

The Hoosic River begins on the west slope of the Green Mountains in northwestern Massachusetts and flows in a northwesterly direction through southern Vermont into New York. Although the headwater streams have very steep gradients, the overall gradient of the river is moderate, averaging about 19 ft/mi from its headwaters to the USGS streamflow-gaging station near Williamstown, a distance of about 24

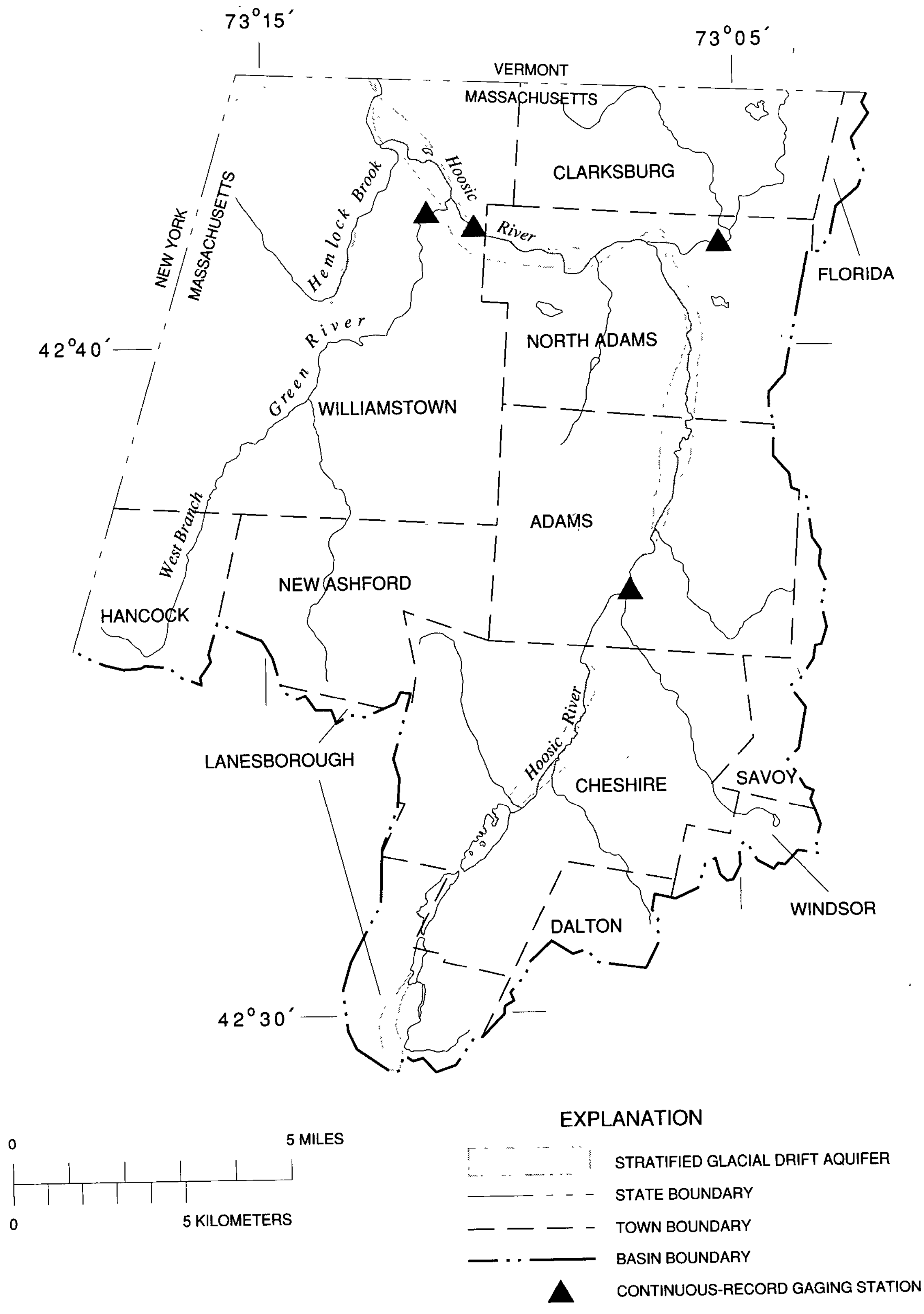


Figure 35.--Principal streams and areas of stratified drift in the Hudson and Hoosic River basins. (Modified from U.S. Geological Survey Hydrologic Investigations Atlas 481.)

river mi (Wandle, 1984c, p. 16). The natural flow regimen along the main stem of the Hoosic has been altered by Cheshire Reservoir, by flood-control structures in Adams and North Adams, by large ground-water withdrawals, by industrial use and discharge, and by discharge of wastewater from sewage-treatment plants.

Ground water

Deep bedrock valleys along the main stem of the Hoosic River have been filled, in some places, with more than 300 ft of ice-contact deposits, outwash deposits, and glacial-lake sediments. Most of this material is fine-grained and yields very little to wells, but ice-contact deposits of sand and gravel within, bordering, or underlying fine-grained material can yield large volumes of water. Well yields as high as 2,500 gal/min have been obtained from wells in sand and gravel. In general, the tributary streams are underlain by thin deposits of sand and gravel on till and bedrock.

In the uplands, bedrock crops out or is covered by various thickness of till and yields small quantities of water that are sufficient for domestic wells. In the valleys, carbonate rock (limestone and dolomite) is favorable for obtaining large quantities of water because of the presence of cavities or fractures enlarged by solution and because recharge is readily available from overlying sand and gravel.

SUMMARY

This report describes the six federally-designated drainage basins in Massachusetts, and the 27 river basins, called river planning basins, that are used by Massachusetts for water-resources planning. Maps show the principal streams and aquifers present and the location of long-term streamflow- gaging stations in each basin. General sections describe the occurrence, use, quality, and management of water resources in Massachusetts.

Hydrologic conditions in Massachusetts were significantly influenced by the last glacial stage, which mantled the land surface of the State with till and stratified-drift deposits. The stratified-drift deposits are especially important because they are the primary source of ground water for public supplies, and discharge of water from these deposits sustains streamflow during periods of little or no precipitation.

Precipitation in Massachusetts averages about 44 in/yr; the highest rates occur at high elevations in the western part of the State. Depending on the land-surface conditions, weather conditions, and season, this water evaporates, is transpired by plants, becomes runoff to streams and other surface-water bodies, or percolates downwards to become ground water. In Massachusetts, surface water and ground water interact closely, so that water pumped from wells commonly is partly derived from nearby streams and water pumped from surface-water bodies is partly derived from ground-water discharge. Because of this interconnection, the quantity and quality of one water resource commonly affects that of the other.

As a general rule, ground-water divides correspond closely with surface drainage divides of Massachusetts river basins. In these areas, State-designated planning basins are used for ground-water as well as surface-water planning. An exception to this is in the southeastern part of the State, where glacial deposits commonly form a continuous layer over bedrock. In this area there is very little surface flow and ground-water divides generally do not coincide with surface drainage divides.

Records from streamflow-gaging stations in Massachusetts indicate that average long-term discharge rates are primarily related to drainage area size. The highest average rates of discharge historically have been measured in the Connecticut and Merrimack River basins, the largest of the State's drainage basins. Streamflow-gaging stations with average discharge rates of less than 100 ft^3/s are mostly in the Coastal basin where drainage areas are less than 40 mi^2. Throughout Massachusetts, average streamflow ranges from about 1.1 to 2.5 $(ft^3/s)/mi^2$ of drainage area. The higher values, 2 $(ft^3/s)/mi^2$ or more, are typical of streams in the western parts of the State where precipitation and runoff are relatively high; the lower values, 1.5 $(ft^3/s)/mi^2$ or less, are common for streams in the Coastal basin. Statewide, the lowest runoff usually occurs during July, August, and September because of high evapotranspiration and low soil moisture; the highest rates are most likely to occur in March or April when precipitation is supplemented by snowmelt.

Volumes of surface water in storage in stream channels, wetlands, and reservoirs vary across the State. Streams in the eastern half of Massachusetts generally have more channel storage than those in the western half. Natural lakes, ponds, and wetlands generally store more water in the eastern half than in the western half of the State. However, the largest artificial reservoirs and most of the potential sites for additional reservoirs are in the central and western parts of the State.

Information is also available on the volumes and recharge rates for stratified-drift aquifers in Massachusetts. The ability of an aquifer to transmit water is expressed as its transmissivity. Coarse-grained, unconsolidated aquifers with transmissivities greater than about 1,300 ft^2/d are mapped as favorable for development of wells yielding 300 gal/min or more in the USGS Hydrologic Investigations Atlas series for Massachusetts. These aquifers mainly occur as valley fill along streams or as in large outwash plains.

The volume of water in storage in aquifers in Massachusetts generally declines during the late spring to early fall because of evapotranspiration, which is much greater during the warm summer growing season than in the winter. Water levels in glacial sand and gravel aquifers normally fluctuate less than 6 ft annually; in till and bedrock, annual fluctuations are as much as 15 to 20 ft. Specific yield, which represents the volume percent of water that a saturated aquifer will yield by gravity, generally ranges from 0.15 to 0.30 in stratified-drift aquifers composed of very fine sand to coarse gravel.

Water supplies for thermoelectric power, public supply, and industry in all major urban areas in Massachusetts are predominantly from surface-water sources. Ground water comprises about one-fourth of the water used for public supplies, and supplies large quantities of water to some industries. Ground water is a principal source of water in public supplies in southeastern Massachusetts, including Plymouth County, Cape Cod, and the Islands. Stratified-drift aquifers are becoming an increasingly important source of water for public supplies elsewhere in the State. Where no public-water supplies are available, wells completed in bedrock supply domestic and small commercial needs almost everywhere in Massachusetts, except on Cape Cod and the Islands. Instream use of water also is significant in Massachusetts and has affected the location of many industries. Currently, the largest instream use of water is for hydroelectric-power generation.

The quality of surface water varies across the State and depends largely on adjacent land use and on instream water use. During periods of high streamflow, the quality of natural runoff is a major influence on surface-water quality; during periods of low streamflow, the quality of water from sewage-treatment plants and from ground-water discharge is a major control. Surface-water quality trends in New England from 1974-81 generally indicate increases in dissolved oxygen concentrations and declines in coliform and bacteria, and in dissolved lead. During the same period, however the levels of nitrate, sodium, and chloride increased in surface water in many parts of New England.

Water from stratified-drift aquifers in Massachusetts is generally slightly acidic, and low in dissolved solids, and may contain relatively high concentrations of iron and manganese. Wells in some coastal areas are vulnerable to salt-water intrusion, although no public-supply wells have been closed for this reason.

The natural quality of water in bedrock aquifers in Massachusetts depends largely on bedrock type. Water in crystalline rocks that underlie most of the State, tends to have low dissolved-solids concentrations, is moderately hard, and is slightly alkaline. Sedimentary-bedrock aquifers in the central and southeastern parts of the State commonly contain moderate to high concentrations of dissolved solids. Water in these aquifers commonly is moderately to very hard and slightly alkaline. Water in the carbonate-bedrock aquifer in the western part of the State also tends to be slightly alkaline and contains moderate to high concentrations of dissolved solids. Water from this aquifer is commonly very hard.

Stratified drift and bedrock aquifers in Massachusetts are susceptible to contamination from human activities on the land surface, including waste-disposal, urbanization, and agriculture. Since 1978, more than 74 of a total of 1,400 public wells or well fields have been closed because of contamination. The primary cause of well closures is contamination by organic compounds. Other causes include contamination by pesticides, road salt, sewage, and landfill leachate.

In Massachusetts, policies pertaining to water-resources planning and management are made primarily by the Massachusetts Water Resources Commission within MEOEA, and by MWRA. Three MEOEA departments, the Department of Environmental Management, the Department of Environmental Protection, and the Metropolitan District Commission are responsible for most of the water-resources planning and regulation functions, and for managing watershed areas for the Boston Metropolitan area and flood-control projects. MWRA responsibilities include supplying water and sewerage services to about 60 municipalities and leading the effort to clean Boston Harbor. These State agencies cooperate with the USGS in the collection, analyses and interpretation of hydrologic information for the water resources of the State.

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