INTRODUCTION

The French-Quinebaug Rivers basin is located approximately 45 miles southwest of Boston and extends from south-central Massachusetts to northeastern Connecticut and northwestern Rhode Island (fig. 1). The basin is bordered on the east by the Blackstone River basin, on the west by the Chicopee River basin, and on the southwest by the Shetucket River basin. The French and Quinebaug Rivers drain a total of 740 mi^2: 422 mi^2 in Connecticut, 58 mi^2 in Rhode Island, and 260 mi^2 in Massachusetts (Anderson, 1975). This report describes streamflow, ground-water availability, and the chemical quality of water in the portion of the basin located in Massachusetts.

The Quinebaug River heads at an unnamed pond near Mashapaug Pond in Union, Connecticut, flows north into Massachusetts and then 75 miles southeast and south to Norwich, Connecticut, where it joins the Shetucket River. The French River is the largest tributary of the Quinebaug River. It heads in the uplands near the town of Leicester, Massachusetts and flows south to its confluence with the Quinebaug River near Mechanicsville, Connecticut. Topographic relief in the basin is moderate, with altitudes ranging from 1,264 feet on Mount Pisgah in Wales, Massachusetts to 25 feet where the Quinebaug River joins the Shetucket River.

Thirteen towns occupy all or most of the study area and contain a population of approximately 80,000. Many communities are rural or suburban with populations under 8,000. Many communities formed in the Quinebaug River valley in the 19th century, when mills were established along the river and its tributaries. In the last few decades, most of the mills have been abandoned or subdivided into space for light manufacturing and retail businesses. The remaining industries produce tools, optical equipment, electronics, and textiles. The towns of Charlton and Dudley are the only two agricultural communities remaining in the basin.

Since 1952, the combined population of the municipal water districts in the basin has grown 52 percent, while the amount of water used has increased 55 percent. Water planners and managers are searching for new water sources to meet the future needs of their growing populations. In response to the growing demand for water, the U.S. Geological Survey and the Massachusetts Department of Environmental Management, Division of Water Resources have joined in a cooperative statewide program to describe the water resources of all river basins in Massachusetts and provide information for water-resource planning and water-supply development. This atlas is a product of that program and is based on field work conducted between 1981 and 1983.

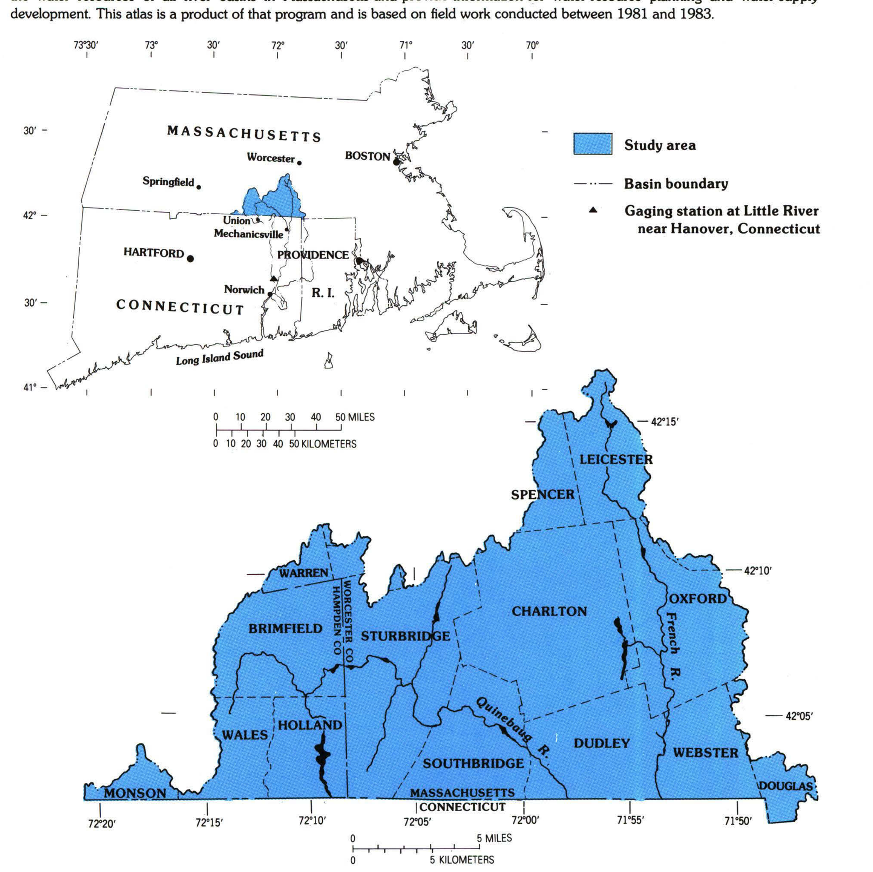


FIGURE 1.—Location of the French-Quinebaug Rivers basin.

CONVERSION FACTORS AND ABBREVIATIONS

For the convenience of readers who may prefer to use metric (International System) units rather than inch-pound units used in this report, values may be converted by using the following factors:

Multiply inch-pound unit	By	To obtain metric unit
	Length	
Inch (in.)	25.40	Millimeter (mm)
Foot (ft)	0.3048	Meter (m)
Mile (mi)	1.609	Kilometer (km)
	Area	
Square mile (mi^2)	2.590	Square kilometer (km^2)
Acre	4,047	Square meter (m^2)
	Volume	
Million gallons (Mgal)	0.003785	Cubic hectometer (hm^3)
Million gallons per square mile (Mgal/mi^2)	0.001461	Cubic hectometer per square kilometer (hm^3/km^2)
	Flow	
Cubic foot per second (ft^3/s)	0.02832	Cubic meter per second (m^3/s)
Gallon per minute (gal/min)	0.06309	Liter per second (L/s)
Gallon per day (gal/d)	3.785	Liter per day (L/d)
Million gallons per day (Mgal/d)	0.04381	Cubic meter per second (m^3/s)
	Hydraulic units	
Foot per second (ft/s)	0.3048	Meter per second (m/s)
Square foot per day (ft^2/d)	0.0929	Square meter per day (m^2/d)
	Temperature	
Degree Fahrenheit (°F)	°C = 5/9 (°F–32)	Degree Celsius (°C)
	Specific conductance	
Microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C)	1.0	Microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C)

HYDROLOGIC CYCLE AND WATER BALANCE

The endless circulation of water between the atmosphere, land, and ocean is called the hydrologic cycle. In the French-Quinebaug Rivers basin, inflow of water takes place as precipitation from rainfall and snowmelt. Outflow of water takes place as streamflow and evapotranspiration. Precipitation discharges to streams as overland flow to tributaries (runoff), and as subsurface flow following infiltration into the ground (baseflow). Evapotranspiration is a process which removes about one half of the water that falls on the basin as precipitation (fig. 2). It is a combination of evaporation from open bodies of water and moist soils, and transpiration of soil moisture by plants. Evaporation is most effective during the summer months and is controlled by temperature, windspeed, duration of sunlight, soil-moisture availability, and the amount and type of vegetative cover (Thornwaite, 1957).

The average monthly amounts of inflow and outflow for the French-Quinebaug Rivers basin is illustrated in figure 2. Precipitation delivers an average of 46 inches of water per year to the basin, as measured at the Southbridge rain gage. The measured average annual runoff of the Quinebaug River at Quinebaug, Connecticut is 23 inches. Therefore, on the average, approximately 23 inches of water are returned from the basin to the atmosphere by evapotranspiration each year.

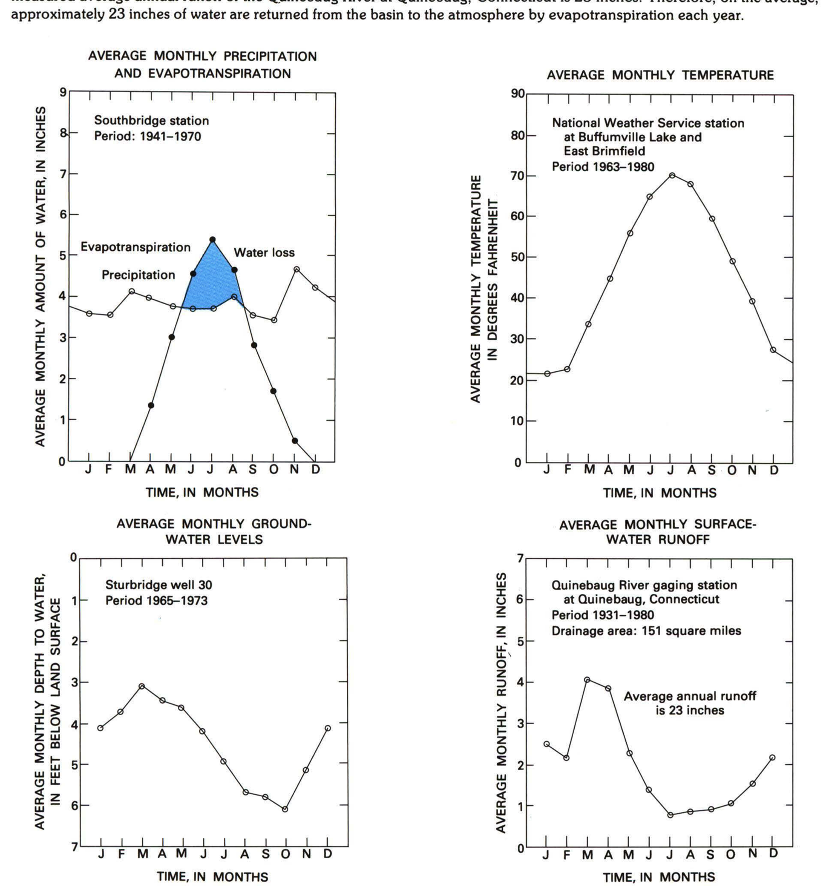


FIGURE 2.—Generalized water balance.

WATER USE

In 1980, municipalities in the basin used a total of 2,523 Mgal of water, of which 66 percent was ground water and 34 percent was surface water. Domestic consumption of water ranged from 70 to 90 percent of the total used by each town, and the remainder was used by industry.

Domestic water use in the basin has increased over the past 30 years, while industrial water use has remained essentially constant. For example, the population in Oxford almost doubled from 1952 to 1980, and its water use increased approximately 60 percent. Over the same period, Webster's population grew by 9 percent while its water use increased by 23 percent (fig. 3). Despite increasing population, industrial water use has remained low due to the replacement of "wet" industries, such as mills, by "dry" industries such as electronics. In the last 5 years (1980–84), there has been a modest increase in the basin-wide rate of the average daily water use from 6.19 Mgal/d to 6.61 Mgal/d (Massachusetts Department of Environmental Management, Division of Water Resources, 1985, p. 10).

Towns in the French-Quinebaug Rivers basin are supplied with water from various sources. Dudley, Webster, Oxford, and Sturbridge are supplied solely by ground water (table 1). Their municipal wells are located in small, sand and gravel aquifers beneath the tributary valleys of the basin. Southbridge, the only town in the basin that is served solely by surface-water, is supplied with water from the Quinebaug River and from reservoirs on both Cohasse and Hatchet Brooks (see fig. 5). Spencer and Leicester both have a combination of ground- and surface-water supplies for their municipal needs. Spencer imports water from a well in the Chicopee River basin and surface water from Shaw Pond in Leicester. Leicester, which obtains ground water from wells in the town and surface water from Henshaw Pond, also imports ground water and spring water (65 Mgal in 1980) from Paxton, in the Nashua River basin. Brimfield, Wales, Holland, and Charlton do not have municipal water supplies; industrial and private users in these towns rely on private wells.

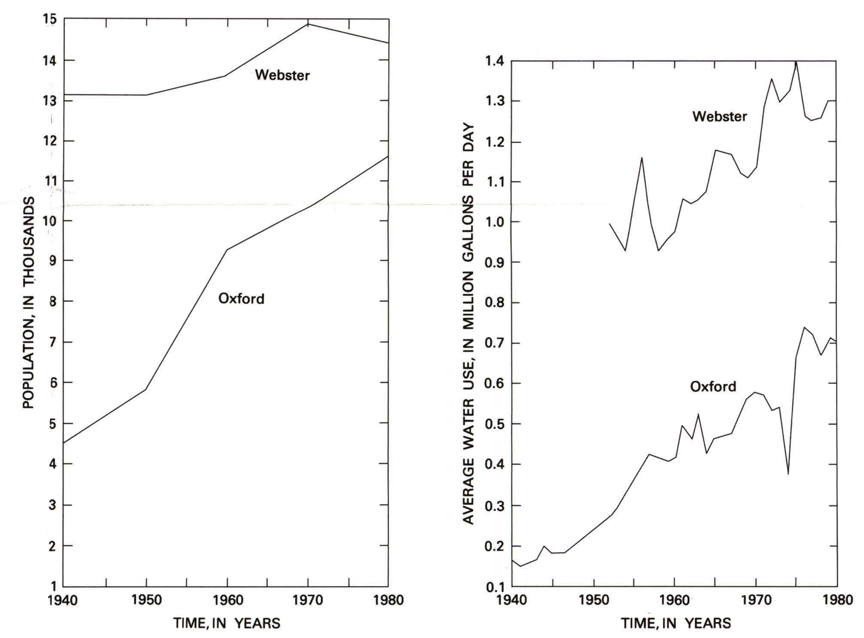


FIGURE 3.—Trends in population and municipal water use.

TABLE 1.—Municipal water use in 1980
[gal/min, gallons per minute; Mgal, million gallons]

Total water system	Source of supply (see fig. 12)	Location	Pump capacity (gal/min)	Total ground-water pumpage (Mgal)	Total surface-water pumpage (Mgal)	Estimated population	Population[1] served	Average gallons used per day per capita[2]	Remarks
Auburn	No municipal wells in basin	—	—	—	—	—	—	—	
Brookfield	No municipal wells in basin	—	—	—	—	—	—	—	
Brimfield	No municipal supply	—	—	[3]63.	—	[4]2,318.	—	[5]75.	
Charlton	No municipal supply	—	—	[3]184.	—	[4]6,719.	—	[5]75.	
Douglas	No municipal wells in basin	—	—	—	—	—	—	—	
Dudley	D2W 3, driven	Off West Main St.	[6]630.	—	—	—	—	—	
	D2W 4, gravel packed	Off Schofield Ave.	200.	—	—	—	—	—	Shut down.
	D2W 5, gravel packed	do.	365.	[7]321.	—	8,717.	[7]8,600.	102.	
	D2W 6, gravel packed	Off New Boston Rd.	336.	—	—	—	—	—	Not approved.
	D2W 7, gravel packed	Off Schofield Ave.	400.	—	—	—	—	—	Not approved.
East Brookfield	No municipal wells in basin	—	—	—	—	—	—	—	
Holland	No municipal supply	—	—	[3]44.	—	[4]1,589.	—	[5]75.	
Leicester									
Cherry Valley	—	—	—	—	[7]108.	9,446.	[7]4,500.	66.	Source is
Rochdale	—	—	—	—	—	—	—	—	Henshaw
Water District	—	—	—	—	—	—	—	—	Pond.
Hillcrest	LPW 16, bedrock	Off Pleasant St.	100.	[7]56.	—	—	[7]400.	—	
Water District	LPW 18, bedrock	do.	60.	—	—	—	—	—	
Leicester Water	LPW 1, bedrock	Off Whittemore St.	50.	[7]2.	—	—	[7]2,176.	84.	Paxton wells are
Supply District	PBW	Off Grove St. in Paxton	72.	—	—	—	—	—	in the Nashua River basin.
	PBW	do.	100.	—	—	—	—	—	Leicester also
	PBW	do.	50.	—	—	—	—	—	gets water
	PBW	do.	80.	—	—	—	—	—	from a spring.
	LPW 35, bedrock	Off Pine St. in Leicester	210.	—	—	—	—	—	Not in use.
Millbury	No municipal wells in basin	—	—	—	—	—	—	—	
Monson	No municipal wells in basin	—	—	—	—	—	—	—	
Oxford	OXW 13, gravel packed	Off Route 12	[8]500.	—	—	—	—	—	
	OXW 57, gravel packed	do.	[9]580.	—	—	—	—	—	
	OXW 14, gravel packed	Off Nelson St.	[9]320.	[10]256.	—	11,680.	[10]6,070.	116.	
Southbridge	Supplied by Quinebaug River	—	—	—	[10]741.	16,665.	[10]17,600.	115.	Impounding reservoirs on Cohasse and Hatchet Brooks.
Spencer	SWW 11, gravel packed	Off South Spencer Rd. in Chicopee Basin.	800.	—	—	[4]5,000.	—	—	Surface-water source is Shaw pond in Leicester.
Sturbridge	S4W 43, gravel packed	All wells are located west of Quinebaug River by Sturbridge Village.	500.	[7]246.	—	5,976.	[7]5,000.	135.	
	S4W 44, gravel packed		500.	—	—	—	—	—	
	S4W 109, gravel packed	—	[11]515.	—	—	—	—	—	
Sutton	No municipal wells in basin	—	—	—	—	—	—	—	
Wales	No municipal supply	—	—	[3]32.	—	[4]1,177.	—	[5]75.	
Warren	No municipal wells in basin	—	—	—	—	—	—	—	
Webster	WLW 2, well field	Off route 193 Thompson Rd.	1,620.	—	—	—	—	—	
	WLW 4, gravel packed	Off Memorial Beach Drive	950.	470.	—	14,480.	[7,12]14,200.	78.	
	WLW 5, gravel packed	Off Bigelow Rd.	1,442.	—	—	—	—	—	
West Brookfield	No municipal wells in basin	—	—	—	—	—	—	—	

Total ground-water pumped from municipal wells 1,674
Total surface-water pumped by town + 849
Total ground/surface water pumped in 1980 2,523 Mgal

[1]Dr. Robert Dannely, Massachusetts Department of Public Health, Division of Health and Statistics Research, oral commun., 1983.
[2]Unadjusted for fire hydrant use.
[3]Estimated population multiplied by 75 gallons per day X 365 days.
[4]Assume that the estimated population is equivalent to the population served by the municipal supply.
[5]The average gallons used per day per capita is estimated to be 75 gallons per day per person.
[6]Edward Fournier, Superintendent, Dudley Water Department, oral commun., 1982.
[7]MDEQE water-supply statistics, 1980 (winter population).
[8]Leggette, Brashears, and Graham, Inc., written commun., 1981.
[9]Massachusetts-American Water Company, Millbury, Mass.
[10]MDEQE water-supply statistics, 1980 (year round).
[11]Tighe and Bond, 1982.
[12]Webster Water Department, written commun., 1980.

STREAMFLOW

Low Streamflow

Streamflow is sustained by both overland flow and ground-water discharge. During long periods of no precipitation, or when evapotranspiration exceeds precipitation, flow in unregulated streams is supplied mainly by ground-water discharge. These periods, characterized by the lowest annual streamflows, usually occur between July and September (fig. 4).

Low streamflow is controlled by both natural and manmade factors. Natural factors include evapotranspiration and the amount and distribution of the unconsolidated glacial sediments in the basin. Among the manmade factors that control low flow are streamflow diversion, upstream reservoir storage, urbanization, and ground-water pumpage. Pumping wells near streams can reduce streamflow by intercepting ground-water discharge and by causing infiltration of water through the streambed. Measurements of low-flow are necessary for sanitary engineers, water managers, and conservationists to determine whether streamflow is sufficient for liquid-waste disposal, water supply, power generation, irrigation, fish habitation, and recreational activities (Riggs, 1972).

Figure 5 shows the location of 5 stream-gaging stations and 22 low-flow partial-record sites where low-flow measurements were made during this study. The flow-duration curves for the two stations in figure 6 show the daily flow exceeded between 99.5 and 0.1 percent of the time.

The slope of a flow-duration curve is affected by the hydrologic and geologic characteristics of the basin. A curve with a predominantly steep slope indicates highly variable streamflow that is derived mostly from direct surface runoff. A curve with a flat slope indicates that flows are relatively uniform because runoff is temporarily stored in swamps, reservoirs or as ground water (Searcy, 1959). The texture of the glacial sediments in the basin affects the amount of water stored in the ground and thereby affects the slope of the flow-duration curves. A curve with a steep slope may indicate the presence of sediments which are fine-grained and poorly sorted, such as till, which tends to shed rather than absorb water from precipitation. On the other hand, a flow-duration curve with a flat slope may indicate the presence of coarse, well-sorted sediments, such as sandy outwash. These sediments absorb, store, and gradually discharge more water than till and bedrock, thus sustaining low streamflow for a longer time than either till or bedrock.

The flow-duration curves for the Little River near Hanover, Connecticut and the Quinebaug River at Quinebaug, Connecticut (fig. 6) have similar slopes over most of the length of the curves, as they drain similar glacial sediments. However, at high discharge, the curve for the Quinebaug River has a flatter slope because the river flows through swamps, several small impoundments, and two major reservoirs.

Low-flow frequency curves for the Little River near Hanover, Connecticut (fig. 7) and the Quinebaug River at Quinebaug, Connecticut (fig. 8), show the probability that the average daily discharges for the time span indicated will be less than a specified value. The curves relate the average discharge for a consecutive number of days to the recurrence interval of that discharge. The recurrence interval, RI, is defined as:

$$RI = (n + 1)/m$$

in which n is the number of years that discharge measurements were made, and m is the numerical rank of the measurements when ordered by magnitude. In general, the slope of the low-flow frequency curve becomes flatter as regulation increases. However, the effect of some types of regulation, for example hydropower, will tend to steepen parts of the frequency curve.

A determination of low-streamflow potential is needed for the evaluation of river-basin resources for water supply, waste disposal, and recreation. For example, the annual minimum 7-day mean flow at the 10-year recurrence interval is used by designers of waste-treatment facilities as an index of the dilution capacity of streams. Calculated annual minimum 7-day mean flows with a 10-percent (7-day, 10-year) and a 50-percent (7-day, 2-year) annual probability for all low-flow partial-record sites in the basin are shown in figure 5.

At least six low-flow measurements were made at each partial-record site between 1980 and 1982 and compared to concurrent flows at two long-term stream-gaging stations within the basin: Little River near Hanover, Connecticut, and Quinebaug River at Quinebaug, Connecticut. A two-step procedure was used to obtain the 7-day, 10- and 7-day, 2-year flows. First, a relation was developed between the low-flow measurements at the partial-record sites and the concurrent daily mean flows at the Little River and the Quinebaug River gaging stations. Then, the 7-day low-flow statistics for each partial-record site were determined from this relation using the appropriate low-flow statistics for the nearest gaged station.

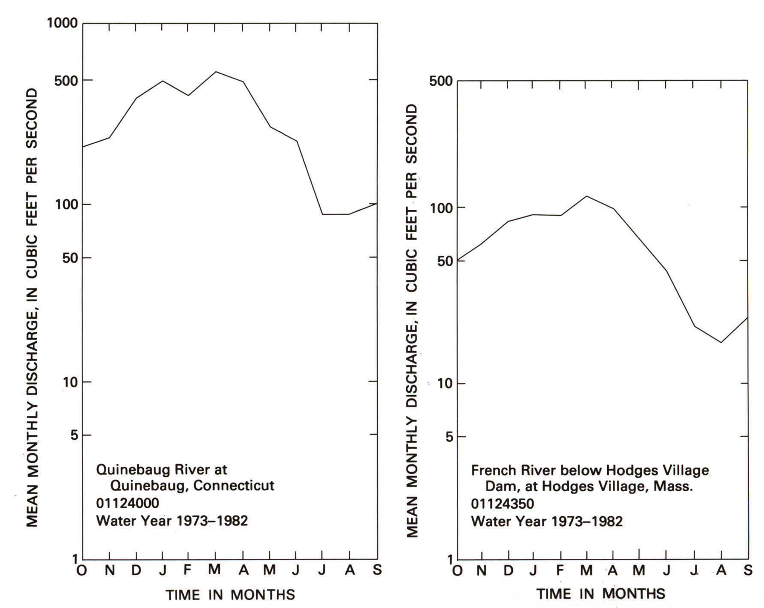


FIGURE 4.—Mean monthly discharge for two stream sites in the French-Quinebaug Rivers basin.

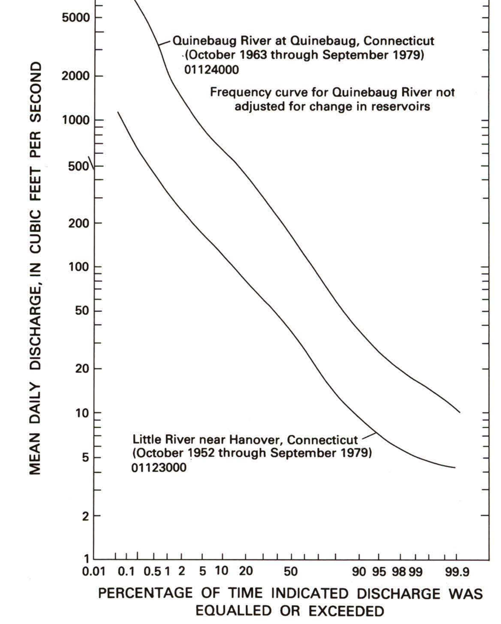


FIGURE 6.—Flow-duration curves for gaging stations.

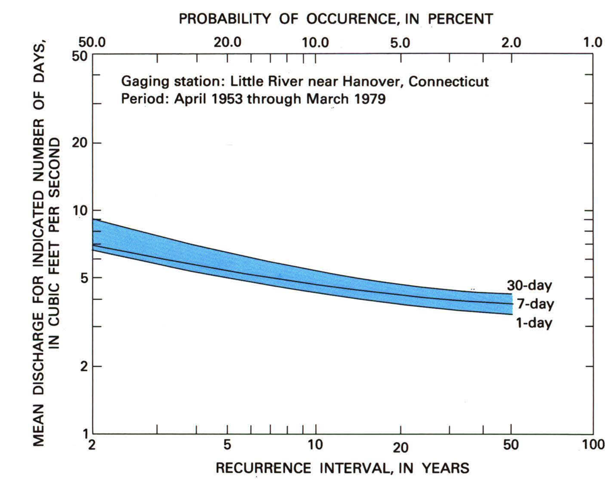
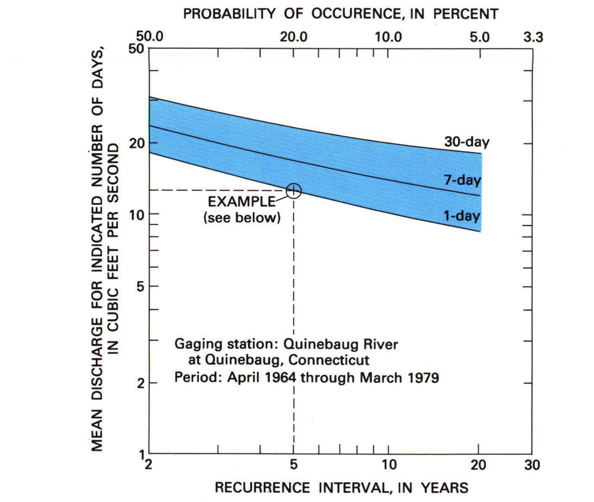


FIGURE 7.—Low-flow frequency curves for Little River near Hanover, Connecticut, gaging station.



EXAMPLE: The annual minimum 1-day mean flow will be less than 12 cubic feet per second at intervals averaging 5 years in length, and the associated probability of the annual minimum 1-day mean flow will be less than 12 cubic feet per second in any 1 year is 20 percent.

FIGURE 8.—Low-flow frequency curves for Quinebaug River at Quinebaug, Connecticut, gaging station.

High Streamflow

Regional flood-frequency formulas can be used to estimate the magnitude of a flood at ungaged sites, provided flood peaks are not significantly affected by manmade regulation. Major flooding occurred in the French-Quinebaug Rivers basin in 1886, March 1936, September 1938, and August 1955 (U.S. Geological Survey, 1982). The many lakes, ponds, and swamps, as well as flat stream gradients and topography of some of the area, provide temporary storage for overland runoff and reduce instantaneous peak discharges. To minimize property damage and loss of life, four dams were constructed impounding Buffumville Lake, Hodges Village Reservoir, East Brimfield Lake, and Westville Lake. The Buffumville Lake and Hodges Village reservoirs regulate the flow of the French River, and the East Brimfield Lake and Westville Lake reservoirs regulate the flow of the Quinebaug River (table 2).

Flow data from the long-term continuous-record gaging stations on the Little River and Quinebaug River provided information for the flood-frequency curves shown in figures 9 and 10. Flood-frequency curves for other than instantaneous peak values are used to determine volume requirements of flood-control dams but are site specific and should not be transferred to other stream sites. Instantaneous peak discharges at ungaged sites in the French-Quinebaug Rivers basin may be estimated from instantaneous peak discharge equations developed from a series of flood-frequency formulas derived by Wandle (1982) for small, rural streams in Massachusetts:

	Average standard error (percent)
$Q_{0.5} = 41.11A^{0.745}St^{-0.097}$	25
$Q_{0.2} = 65.17A^{0.757}St^{-0.139}$	28
$Q_{0.1} = 84.98A^{0.764}St^{-0.166}$	30
$Q_{0.04} = 114.9A^{0.773}St^{-0.195}$	34
$Q_{0.02} = 141.9A^{0.780}St^{-0.217}$	38
$Q_{0.01} = 172.7A^{0.787}St^{-0.237}$	41

in which,

$Q_{0.5}$, $Q_{0.2}$, $Q_{0.1}$, $Q_{0.04}$, $Q_{0.02}$, $Q_{0.01}$ are the peak discharges, in cubic feet per second, for the specified exceedance probability. Exceedance probability is the percentage of time a specific discharge is either equaled or exceeded;

A is the drainage area, in square miles; and

St is the storage index which is the area of lakes, ponds, and swamps expressed as a percentage plus 0.5.

In the equations listed above, instantaneous peak discharges at selected exceedance probabilities are related to drainage area and mean channel slope. These equations are valid if the stream site is unregulated, manmade storage upstream is less than 4.5 Mft^3/mi^2, and the stream is unaffected by diversion or urbanization. For examples illustrating the step-by-step procedure of obtaining peak discharge estimates on natural-flow streams in the basin, the reader is referred to the text and reference tables for "Central Massachusetts" given in Wandle's (1982) report.

TABLE 2.—Major reservoirs used for flood control and recreation in the French-Quinebaug Rivers basin.
[mi^2, square miles; ft^3, cubic feet]

Reservoir	Location	Stream reservoir flows into	Drainage area (mi^2)	Storage capacity (ft^3)	Date completed	Agency controlling reservoir[1]
Hodges Village Dam	5 miles north of Webster, Mass.	French River	31.1	577,000	1959	MDFW, OXF
Buffumville Lake	2 miles west of Oxford, Mass.	Little River	26.5	555,000	1958	MDEM
Westville Lake	1.5 miles west of Southbridge, Mass.	Quinebaug River	99.5	484,000	1962	COE, MDFW
East Brimfield Lake	1 mile south-west of Fiskdale, Mass.	Quinebaug River	67.5	1,400,000	1960	MDEM

[1]Agency controlling reservoir: MDFW (Massachusetts Division of Fisheries and Wildlife); OXF, Town of Oxford; MDEM (Massachusetts Department of Environmental Management); COE, U.S. Army Corps of Engineers.

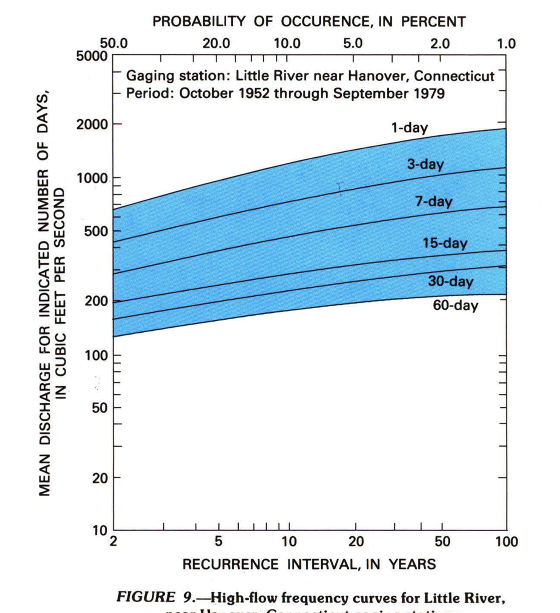


FIGURE 9.—High-flow frequency curves for Little River, near Hanover, Connecticut gaging station.

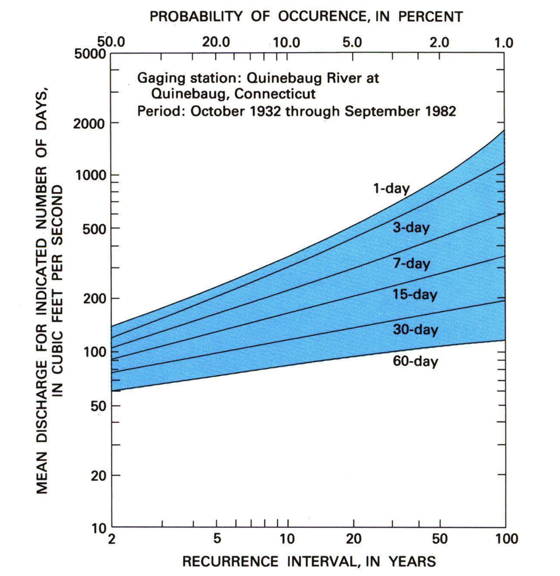
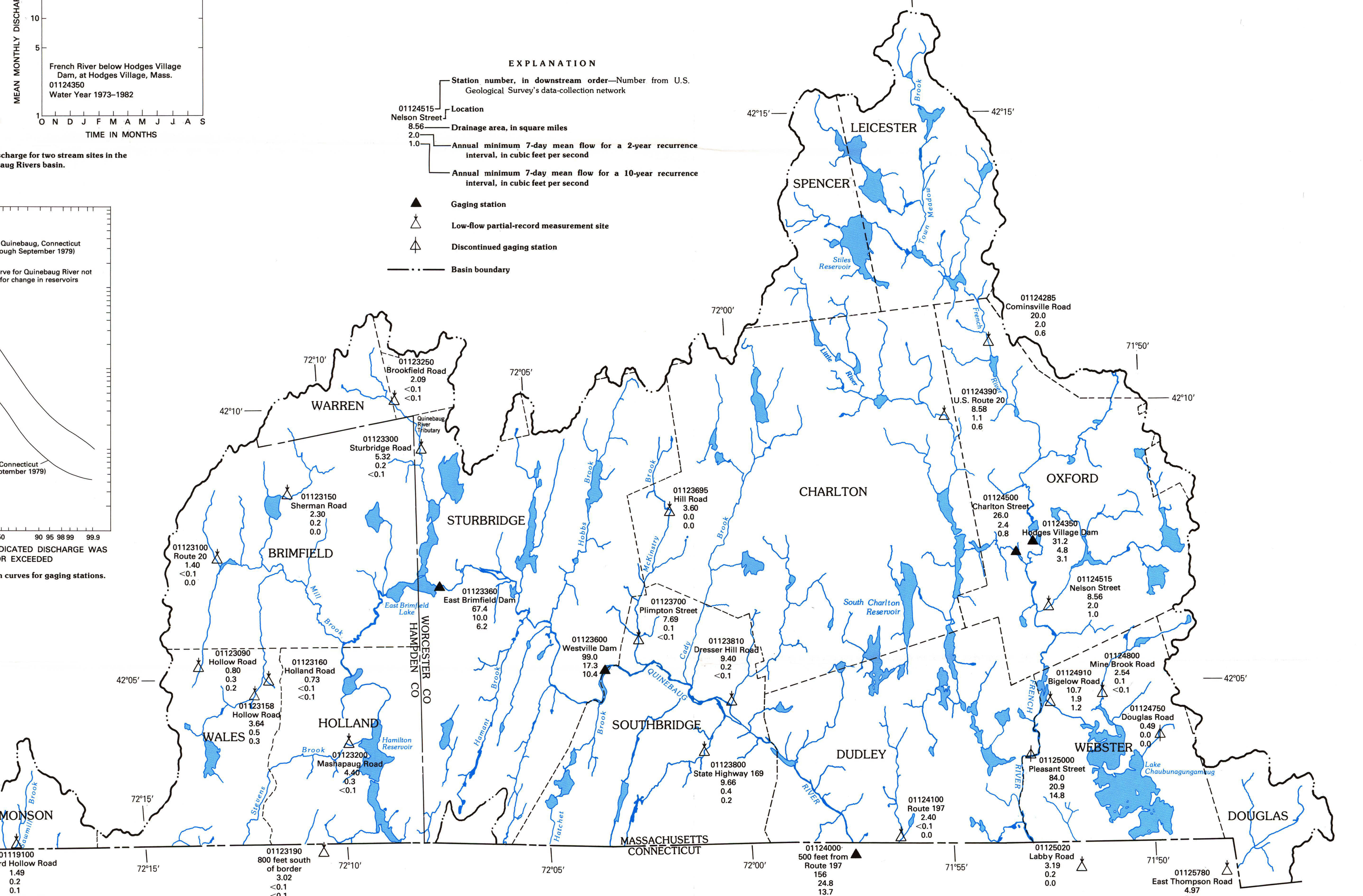


FIGURE 10.—High-flow frequency curves for Quinebaug River, at Quinebaug, Connecticut gaging station.



Base from U.S. Geological Survey 1:24,000 quadrangles

FIGURE 5.—Low-flow data at selected sites.

WATER RESOURCES IN THE FRENCH-QUINEBAUG RIVERS BASIN, MASSACHUSETTS

By
Valerie A. Eames and Victoria J. Epstein
1988

INTERIOR—GEOLOGICAL SURVEY, RESTON, VA—1988
For sale by Branch of Distribution, U.S. Geological Survey, Box 25286, Federal Center, Denver, CO 80225