Prepared in cooperation with the
COMMONWEALTH OF MASSACHUSETTS
WATER RESOURCES COMMISSION



# INTRODUCTION

For use of those readers who may prefer to use metric units rather than English units, the conversion factors for the terms used in this report are listed below.

## CONVERSION FACTORS

Factors for converting English units to metric units are shown to four significant figures. However, in the text the metric equivalents are shown only to the number of significant figures consistent with the values for the English units.

| Multiply English unit | By | To obtain metric unit |
|---|---|---|
| inches (in.) | 25.40 | millimeters (mm) |
| feet (ft) | 0.3048 | meters (m) |
| miles (mi) | 1.609 | kilometers (km) |
| square miles ($mi^2$) | 2.590 | square kilometers ($km^2$) |
| cubic feet ($ft^3$) | $2.832 \times 10^{-2}$ | cubic meters ($m^3$) |
| million gallons (Mgal) | $3.785 \times 10^{+3}$ | cubic meters ($m^3$) |
| million gallons per day (Mgal/d) | $4.381 \times 10^{-2}$ | cubic meters per second ($m^3/s$) |
| gallons per minute (gal/min) | $6.309 \times 10^{-2}$ | liters per second (l/s) |
| cubic feet per second ($ft^3/s$) | $2.832 \times 10^{-2}$ | cubic meters per second ($m^3/s$) |
| inches per year (in./yr) | $2.54 \times 10^{+1}$ | millimeters per year (mm/yr) |
| feet squared per day ($ft^2/d$) | $9.29 \times 10^{-2}$ | meters squared per day ($m^2/d$) |

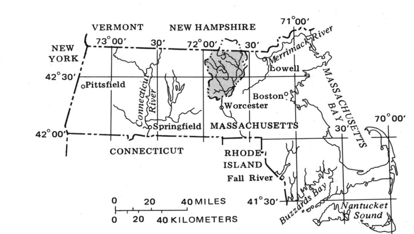


FIGURE 1.—*Map showing location of study area*

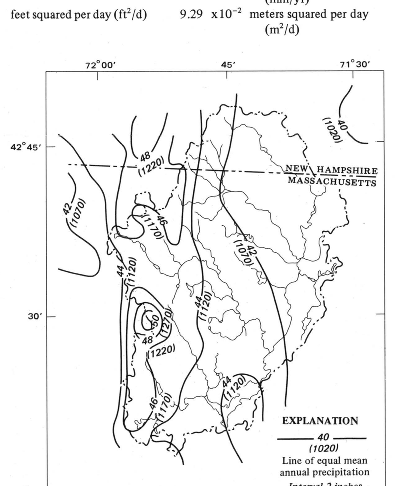


FIGURE 2.—*Map showing distribution of precipitation on basin*

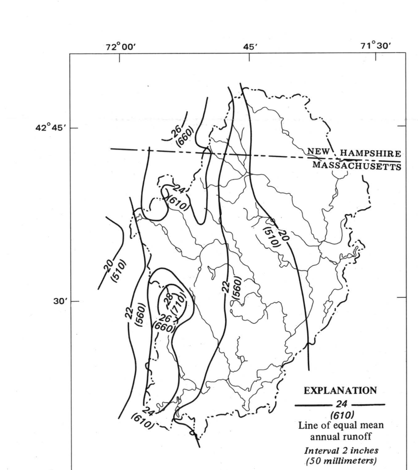


FIGURE 3.—*Map showing distribution of runoff in basin*

Because of rapidly increasing needs for water supplies and for accurate water data to plan development and management of Massachusetts' water resources, the U.S. Geological Survey, in cooperation with the Massachusetts Water Resources Commission, is preparing a series of reports describing the water resources of the Commonwealth. This report covers the parts of the Nashua River basin and the Souhegan River basin which lie in Massachusetts. The Nashua River heads in Massachusetts, flows northward into New Hampshire, and at the city of Nashua is tributary to the Merrimack River, which flows generally eastward to the ocean. The total drainage area of the Nashua River basin upstream from the Massachusetts-New Hampshire State line is 507 $mi^2$ (816 $km^2$), of which 445 $mi^2$ (716 $km^2$) is in Massachusetts. Only 9 $mi^2$ (14 $km^2$) of the Souhegan River basin, the headwaters area of the basin, lies in Massachusetts.

On the average, precipitation on the basin is 44 inches (1140 mm) per year, of which roughly half evaporates or is transpired. (See precipitation and runoff maps.) Part of the remainder travels over the land surface directly to stream channels during or immediately after storm periods and makes up a large part of the streamflow during rises. However, most of the water not evaporated or transpired percolates through the ground to the water table and then moves to streams, where it becomes the major component of annual streamflow (runoff). Ground-water runoff may be as much as two-thirds of the average annual runoff and, in unregulated streams, is frequently the sole supply for streamflow during low flow.

# MUNICIPAL WATER USE

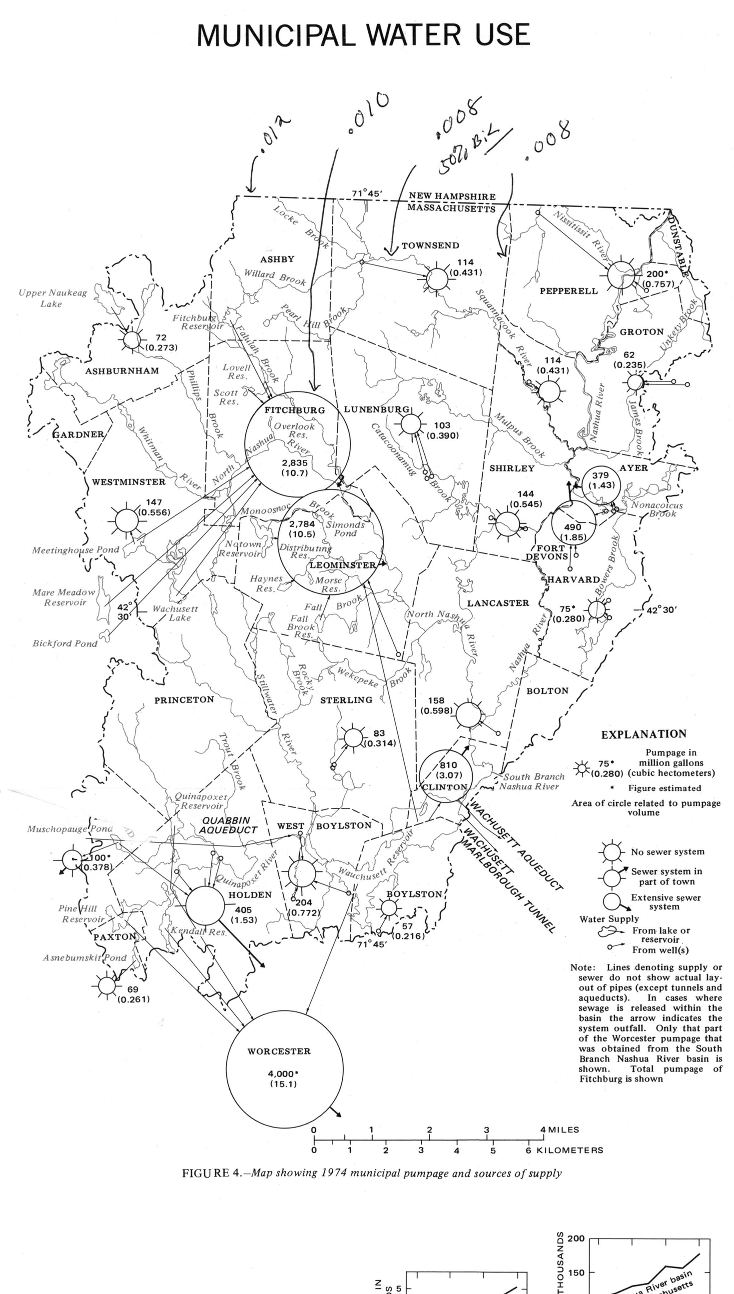


FIGURE 4.—*Map showing 1974 municipal pumpage and sources of supply*

Municipal water departments or companies in the basin distributed 9.2 billion gallons (35 $hm^3$) of water during 1974. This is equivalent to about 5 percent of the average annual runoff in the Nashua River basin in Massachusetts. An additional 112 billion gallons (424 $hm^3$) of water was exported during 1974 to municipal water systems outside the basin; 59 billion gallons (223 $hm^3$) of water was brought into the basin. The 53 billion gallons (201 $hm^3$) of water thus lost to the basin is equivalent to about 30 percent of the average annual runoff of the Nashua River basin in Massachusetts.

Municipal pumpage commonly differs sharply from year to year, but a general trend is evident for increasing pumpage resulting from increases of population served and increasing per capita use.

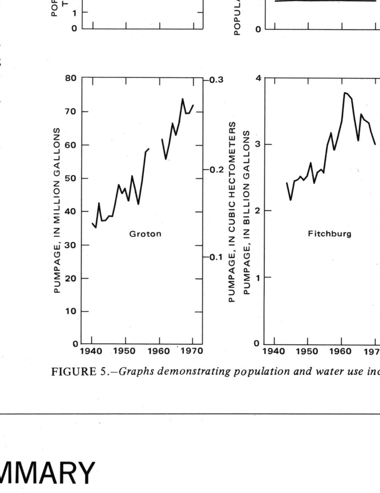


FIGURE 5.—*Graphs demonstrating population and water use increases*

# SUMMARY

Demand for water has been increasing during the last several decades, and, during 1974, use of basin waters for municipal supplies in Massachusetts was equivalent to about 30 percent of the average runoff in the study area.

Flow in many of the streams in the basin is, or can be, affected by diversions and regulation. For example, during 1961-70, 97 percent of the flow in the South Branch Nashua River basin upstream from Wachusett Dam was diverted out of the basin. Average runoff in the basin is about 22 in. (56 mm) per year. Flooding has not normally been a problem. However, with increasing building on the flood plains, flood damage could increase in the future. Low-flow intensity differs greatly between streams because of the variability of the unconsolidated glacial deposits within the basin and because of pond and reservoir regulation.

Available data indicate that water in most of the streams is soft and mildly acid and, except for some excessive iron and(or) manganese, meets the U.S. Public Health Service (1962) recommended chemical limits for drinking water. However, the data indicate that the North Nashua and Nashua Rivers are very strongly enriched, both chemically and biologically.

# SURFACE WATER

## STREAMFLOW

The flow of streams changes from day to day, year to year, and place to place. The potential usefulness (or destructiveness) of the streams is determined by the duration and(or) frequency of their rates of flow. In order to obtain streamflow information in the basin, four continuous-record stream-gaging stations are or have been operated, and measurements of streamflow were made during low-flow periods at many other stream sites. Flow in most of the major rivers and many of the tributaries is affected by regulation and(or) diversions. The South Branch Nashua River is the most affected stream in the basin; nearly all of the runoff from the South Branch is diverted out of the basin for municipal supplies in Greater Boston and Worcester. Flow in the North Nashua River is influenced by regulation of reservoirs in the headwater streams and diversions into the basin. The diversions average about 5 $ft^3/s$ (0.1 $m^3/s$), or about 3 percent of the average flow past the gage near Leominster. Flow in the Squannacook River is occasionally influenced by reservoir regulation during low flow periods. Many outlets of lakes and ponds on the tributary streams are dammed, and outflow is or may be regulated by manipulation of stoplogs or gates. In many of the streams, day to day variations in streamflow are markedly affected by regulation and diversion.

The locations of the stream-gaging stations are shown on the map in the low-flow section. A summary of a few important facts concerning them is shown in the Surface-Water Data section.

### DAILY FLOW VARIATION

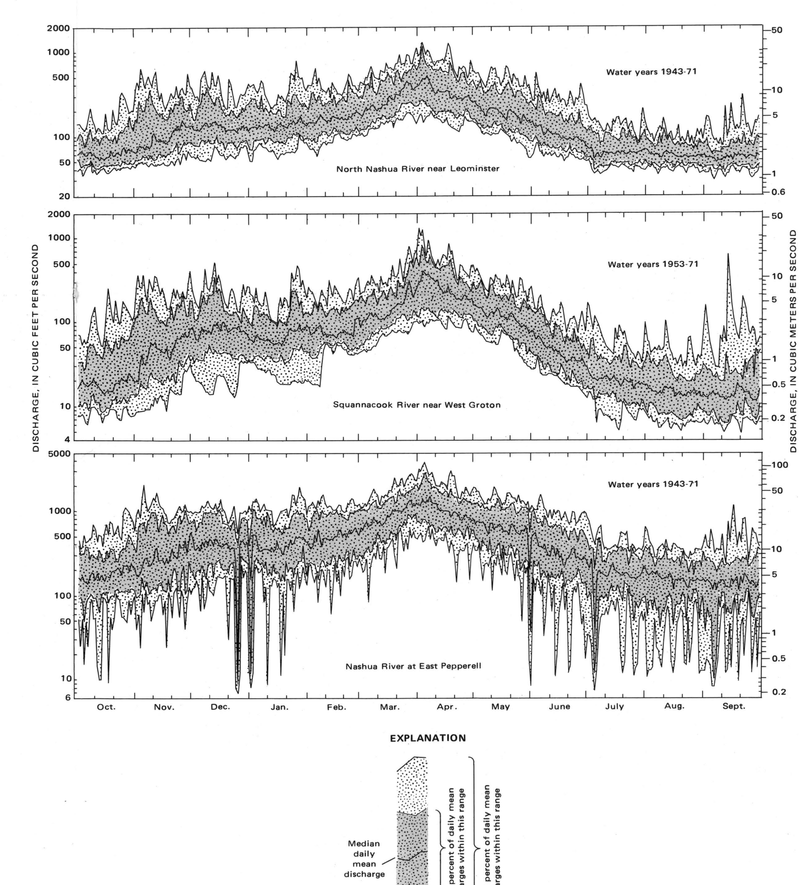


FIGURE 6.—*Graphs showing variation of daily mean flow at gaging stations on major steams in basin*

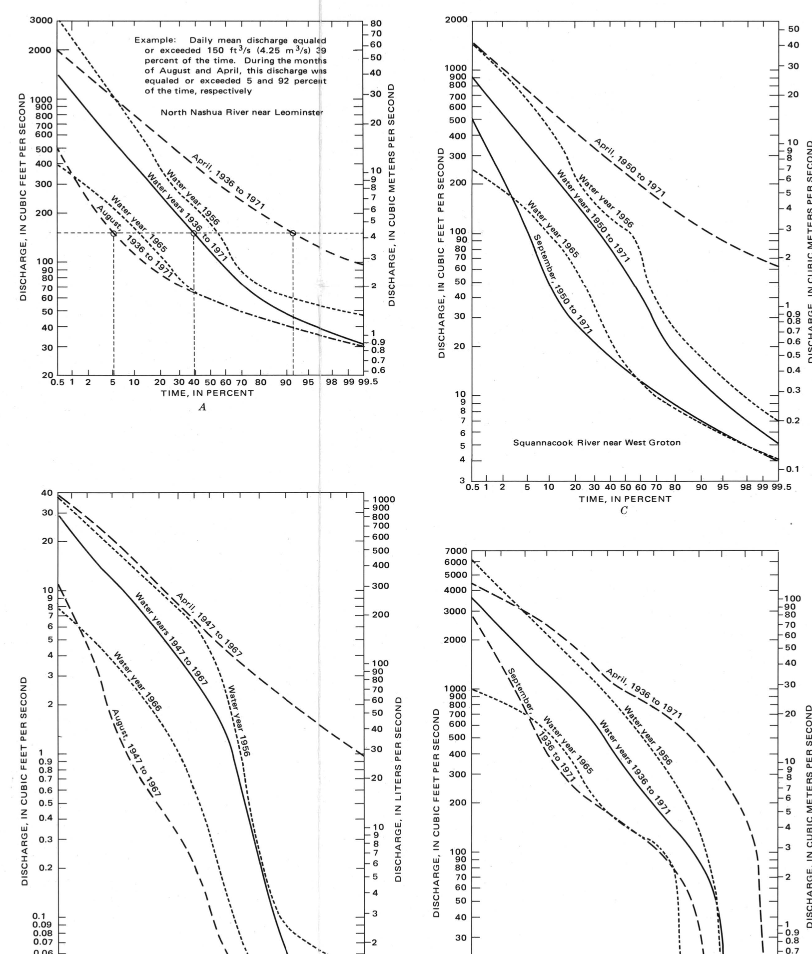


FIGURE 7.—*Graphs showing duration of flow at gaging stations*

The effects of regulation and(or) diversion on streamflow are illustrated in the graphs of daily flows of the North Nashua, Squannacook, and Nashua Rivers. The range of median discharges is much smaller at the North Nashua and Nashua River gages (regulated) than at the Squannacook River gage (flow relatively unregulated). Furthermore, except for the jagged bottom of the 80 percent envelope of the Nashua River graph caused by shutdowns of a powerplant just above the gage, there is less variation between the 60 and 80 percent envelopes for the North Nashua and Nashua Rivers than for the Squannacook River, indicating that flow of the North Nashua and Nashua Rivers is more tightly controlled than flow of the Squannacook.

The time frame used in the graphs is the water year, which is the 12-month period ending September 30 of the year designated.

The percentage of time during which daily mean discharges exceed various rates, without regard to the sequence in which the flows occur, is shown above. The curves reflect all the hydrologic factors that influence streamflow. Therefore, the differences between the overall characteristics of basins may be compared on the basis of the shape of their respective long-term curves (solid line). The high discharge end of the curve represents surface runoff primarily and the slope of this end of the curve is indicative of the volume of surface-water storage and the characteristics of the precipitation, snowmelt, and topography in the basin upstream from the gage site. The slopes of the high discharge range of the curves for North Nashua River, Rocky Brook, and Squannacook River are very similar. The moderate degree of slope reflects the rolling hills of the basin uplands, the numerous lakes and ponds that attenuate runoff intensity by temporarily storing water, and the infrequency of intense storms. The slope of the high discharge end of the Nashua River curve is slightly flatter than the others and reflects the additional influences of slower runoff from the gently rolling land in the eastern part of the basin and the larger amount of channel storage in the streams, which, in this part of the basin, have lower gradients. For streams that are not influenced by artificial storage, the low discharge end of the curve primarily represents ground-water runoff, and the slope of the curve reflects the amount of channel storage, and subsurface and swamp storage, which contribute to streamflow. For basins where there is artificial storage, the curve also reflects the release or storage of water, especially in the lower discharge ranges. For example, the flattening of the low discharge end of the North Nashua River curve reflects augmentation of low flows from reservoir storage. Conversely, the steep drop in the low discharge end of the Nashua River at East Pepperell curve reflects weekend and holiday shutdowns of industrial dams.

In addition to the curves based on long-term periods, duration curves are included for the months of highest (April) and lowest (August or September) monthly median discharge. As an example, for the North Nashua River gage, the curve labeled "April 1936 to 1971" is based on the daily mean discharges during the 36 Aprils from 1936 to 1971. Also, duration curves are shown for the individual water years of highest and lowest annual average discharge.

### LOW FLOW

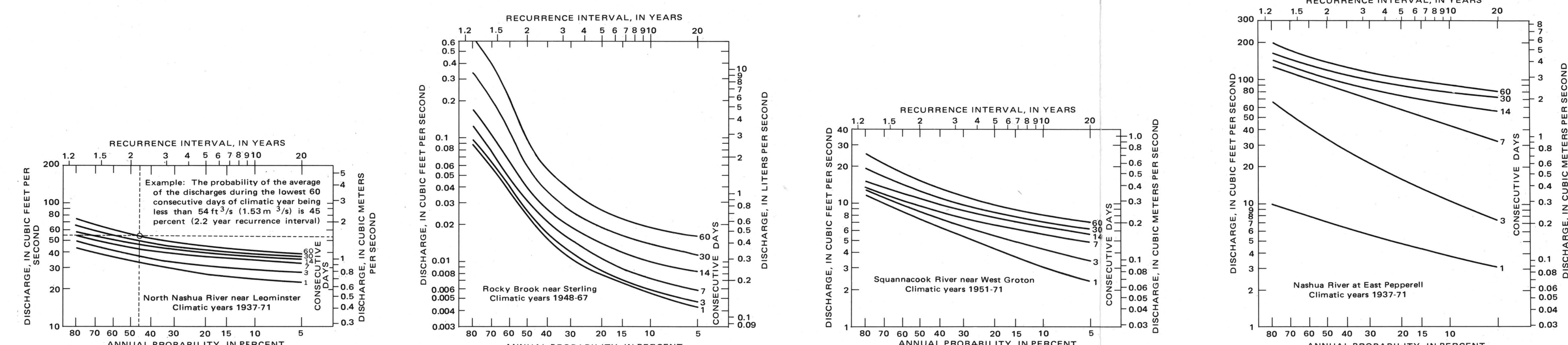


FIGURE 8.—*Graphs showing low flows at gaging stations*

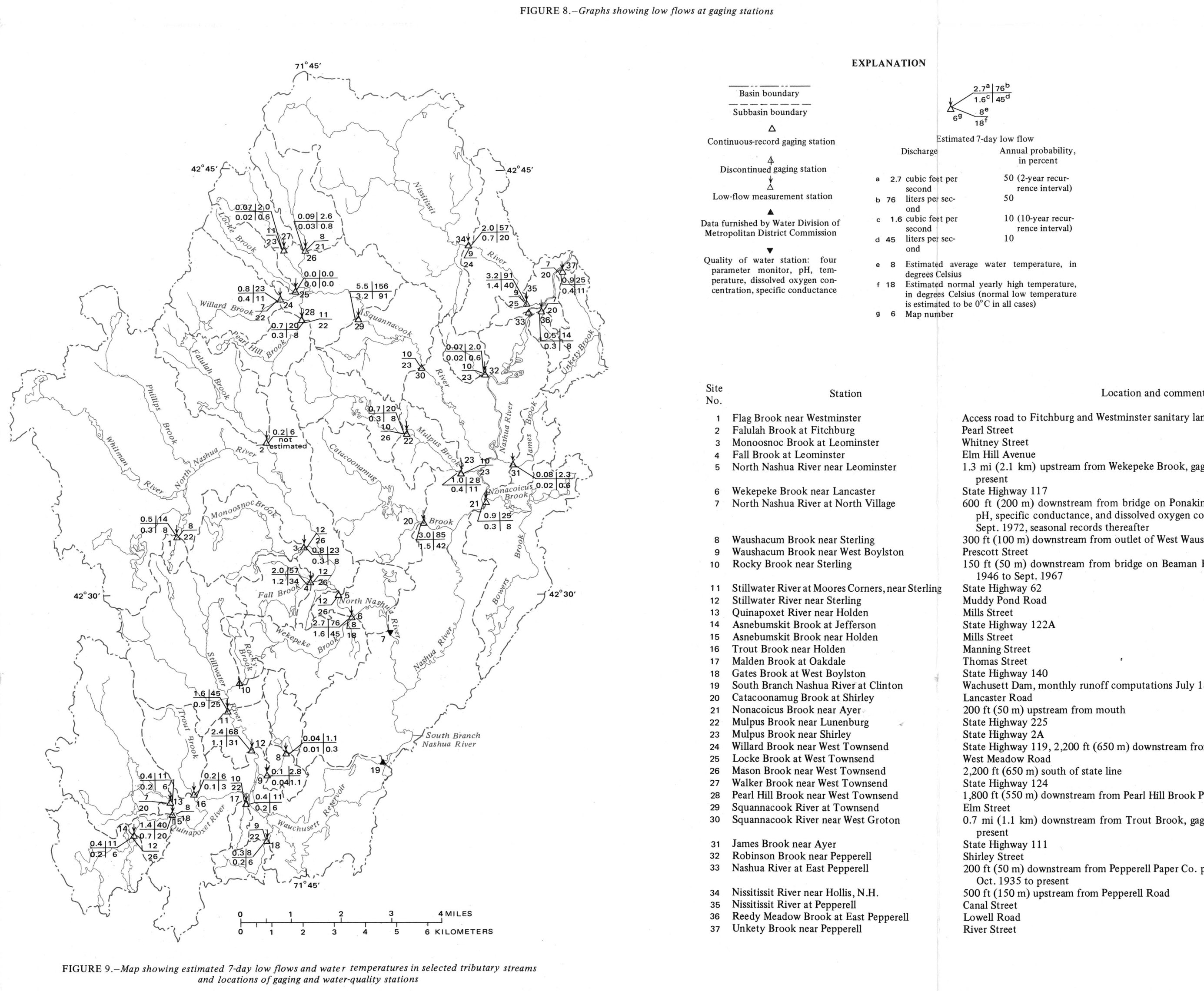


FIGURE 9.—*Map showing estimated 7-day low flows and water temperatures in selected tributary streams and locations of gaging and water-quality stations*

| Site No. | Station | Location and comments |
|---|---|---|
| 1 | Flag Brook near Westminster | Access road to Fitchburg and Westminster sanitary landfill site |
| 2 | Falulah Brook at Fitchburg | Pearl Street |
| 3 | Monoosnoc Brook at Leominster | Whitney Street |
| 4 | Fall Brook at Leominster | Elm Hill Avenue |
| 5 | North Nashua River near Leominster | 1.3 mi (2.1 km) upstream from Wekepeke Brook, gaging station records Sept. 1935 to present |
| 6 | Wekepeke Brook near Lancaster | State Highway 117 |
| 7 | North Nashua River at North Village | 600 ft (200 m) downstream from bridge on Ponakin Road; continuous temperature, pH, specific conductance, and dissolved oxygen concentration records Oct. 1968 to Sept. 1972, seasonal records thereafter |
| 8 | Waushacum Brook near Sterling | 300 ft (100 m) downstream from outlet of West Waushacum Pond |
| 9 | Waushacum Brook near West Boylston | Prescott Street |
| 10 | Rocky Brook near Sterling | 150 ft (50 m) downstream from bridge on Beaman Road, gaging station records Oct. 1946 to Sept. 1967 |
| 11 | Stillwater River at Moores Corners, near Sterling | State Highway 62 |
| 12 | Stillwater River near Sterling | Muddy Pond Road |
| 13 | Quinapoxet River near Holden | Mills Street |
| 14 | Asnebumskit Brook at Jefferson | State Highway 122A |
| 15 | Asnebumskit Brook near Holden | Mills Street |
| 16 | Trout Brook near Holden | Manning Street |
| 17 | Malden Brook at Oakdale | Thomas Street |
| 18 | Gates Brook at West Boylston | State Highway 140 |
| 19 | South Branch Nashua River at Clinton | Wachusett Dam, monthly runoff computations July 1896 to present |
| 20 | Catacoonamug Brook at Shirley | Lancaster Road |
| 21 | Nonacoicus Brook near Ayer | 200 ft (50 m) upstream from mouth |
| 22 | Mulpus Brook near Lunenburg | State Highway 225 |
| 23 | Mulpus Brook near Shirley | State Highway 2A |
| 24 | Willard Brook near West Townsend | State Highway 119, 2,200 ft (650 m) downstream from Trapfall Brook |
| 25 | Locke Brook at West Townsend | West Meadow Road |
| 26 | Mason Brook near West Townsend | 2,200 ft (650 m) south of state line |
| 27 | Walker Brook near West Townsend | State Highway 124 |
| 28 | Pearl Hill Brook near West Townsend | 1,800 ft (550 m) downstream from Pearl Hill Brook Pond |
| 29 | Squannacook River at Townsend | Elm Street |
| 30 | Squannacook River near West Groton | 0.7 mi (1.1 km) downstream from Trout Brook, gaging station records Oct. 1949 to present |
| 31 | James Brook near Ayer | State Highway 111 |
| 32 | Robinson Brook near Pepperell | Shirley Street |
| 33 | Nashua River at East Pepperell | 200 ft (50 m) downstream from Pepperell Paper Co. powerplant, gaging station records Oct. 1935 to present |
| 34 | Nissitissit River near Hollis, N.H. | 500 ft (150 m) upstream from Pepperell Road |
| 35 | Nissitissit River at Pepperell | Canal Street |
| 36 | Reedy Meadow Brook at East Pepperell | Lowell Road |
| 37 | Unkety Brook near Pepperell | River Street |

The annual (climatic year) probability that the average of the daily mean discharges during given time spans will be less than specified, at least once, is shown in the above curves. This information may be used in studies of waste dilution, availability of water for supply or cooling, reservoir storage capacity, and other fields where low flows are critical. A climatic year is the 12-month period ending March 31 of the year designated.

The 7-day low flow, which is the average of the discharges during the 7 consecutive days of lowest total volume of flow during a climatic year, is an index of the amount of storage in a basin (primarily ground water) that contributes to streamflow during low-flow periods. The discharge for which there is a 10-percent annual probability that the 7-day low flow will be less is commonly used to evaluate the dilution capabilities of streams in waste-disposal studies. Also, the Massachusetts Division of Water Pollution Control and the U.S. Environmental Protection Agency specify that this discharge will be used in the interpretation of water-quality standards. Discharge at the 50-percent probability level is the median annual 7-day low flow.

Application of discharges from the 7-day low-flow curves to the duration curves of stations in this basin and other basins in Massachusetts indicates that discharge at the 50- and 10-percent annual probability level is exceeded roughly 95 and 99 percent of the time, respectively.

The relationship between the estimated discharges and drainage area is masked by strong geologic effects. The data indicate that estimates based solely on area could be wrong by as much as a factor of 30. Therefore, it is not advisable to use data from the map to extrapolate estimates for nearby unmeasured streams. Furthermore, the estimates are based on conditions of diversion (and possible regulation) as they existed when measurements of discharge were made during the summer and fall of 1971 to 1973, and changes in the hydrologic regimen must be accounted for in updating these estimates.

### HIGH FLOW

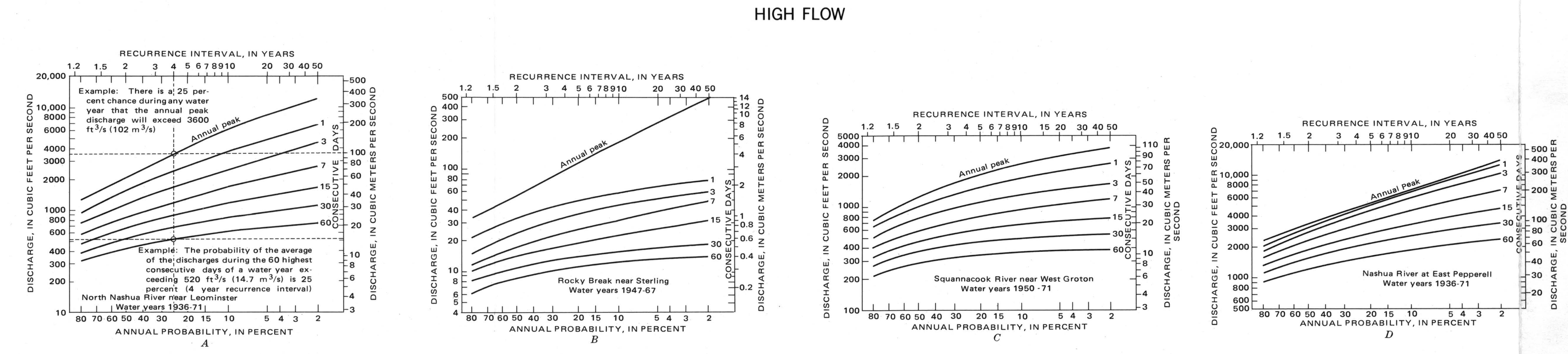


FIGURE 10.—*Graphs showing high flows at gaging stations*

Flooding has usually been a problem only during rare events, such as the 1936 flood (annual probability of exceedence less than 2 percent), and principally in urban areas where flood plains had been developed. Probability curves of the maximum peak discharge and the highest average discharges for given lengths of time exceeding various rates during a water year may be used in flood inundation, flood-control reservoir capacity, land zoning, and reservoir recharge studies.

Formulas have been developed for estimating the probability of floods in ungaged streams in Massachusetts where the drainage areas are between 0.25 and 497 $mi^2$ (0.6 and 1,290 $km^2$) and flow is not materially affected by regulation or diversions (Johnson and Tasker, 1974, p. 6-13). If a floodflow computation were to be made for a site, it would be essential to investigate the possibility of manmade alterations of flow in the basin upstream before the results could be considered reliable. This is especially true in the Nashua River basin, where reservoirs and lakes abound where storage is or can be managed. The estimating formulas that follow reference discharge to annual probability of exceedence:

$$Q_{10} = 0.102A^{0.852}S^{0.132}P^{4.59}$$

$$Q_4 = 0.144A^{0.885}S^{0.155}P^{4.43}$$

$$Q_2 = 0.193A^{0.911}S^{0.171}P^{4.27}$$

$$Q_1 = 0.260A^{0.940}S^{0.187}P^{4.08}$$

$Q_{10}$ = Annual peak discharge, in cubic feet per second, at 10 percent annual probability level.

A = Drainage area, in square miles.

S = Slope factor, in feet per mile. Determine as follows: extend main channel of stream to the basin divide drawn on the topographic map during drainage-area computation. Upstream from each stream-junction point, choose as the main channel the stream that drains the larger area. Determine the elevations at points 85 and 10 percent of the total stream length (site to divide) upstream from the site. Divide the difference in elevation of the points, in feet, by the length of the stream between them, in miles.

P = Mean annual precipitation, in feet of water. Determine by locating the basin of interest on the precipitation map (fig. 2). By interpolation, determine the mean annual precipitation for the basin to the nearest inch and convert this value to feet.

The foregoing curves could be used to forecast the occurrence of future flows if hydrologic conditions in the future are unchanged from those prevailing during the periods on which the curves are based.

### SURFACE WATER REGIMEN IN SOUTH BRANCH NASHUA RIVER BASIN

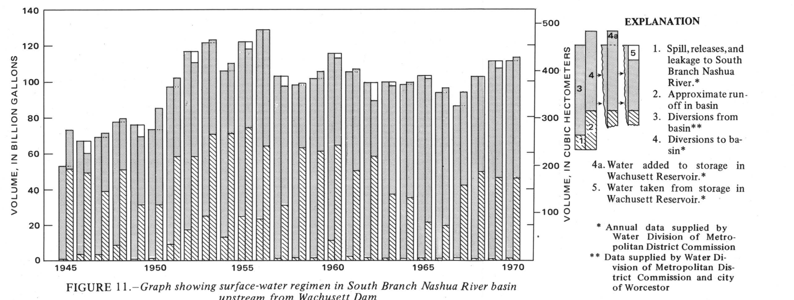


FIGURE 11.—*Graph showing surface-water regimen in South Branch Nashua River basin upstream from Wachusett Dam*

The South Branch Nashua River drainage basin upstream from Wachusett Dam is 118 $mi^2$ (306 $km^2$) in area. Worcester diverts most of the runoff from a 9 $mi^2$ (23 $km^2$) area in the Asnebumskit Brook subbasin by way of Pine Hill and Kendall Reservoirs. (See municipal supply map.) Also, flow from East Waushacum Pond is diverted around Wachusett Reservoir by piping discharge from the pond to South Meadow Brook. The brook carries the discharge to South Branch Nashua River just upstream from the Clinton-Lancaster town line. The drainage area of the pond is 1 $mi^2$ (2.6 $km^2$). Thus, the effective drainage area above Wachusett Dam is about 108 $mi^2$ (280 $km^2$). This figure is qualified "about" because flow from the 9 $mi^2$ (23 $km^2$) in the Asnebumskit Brook basin is not totally diverted during some years, and there are other diversions from the basin.

Worcester diverts much of the flow from the Quinapoxet River watershed at Quinapoxet Reservoir, and there are additional, but lesser, diversions from the basin by Holden, Rutland, Paxton, Leominster, and Clinton. In the latter two cases, the wastewater is released in and continues to be a resource of the Nashua River basin. Wachusett Aqueduct and Wachusett-Marlborough Tunnel (Metropolitan District Commission), on the average, carry about twice as much water to Greater Boston as runs off in the basin. This is accomplished by diverting water to the basin from Ware River and Quabbin Reservoir through Quabbin Aqueduct, which empties into the Quinapoxet River near its mouth.

In effect, these diversions almost eliminate the drainage basin upstream from Wachusett Dam as a source of streamflow for the Nashua River. By law, a minimum of 12 million gallons (0.05 $hm^3$) per week must be released to the South Branch Nashua River. This would amount to 0.6 billion gallons (2.3 $hm^3$) per year. Higher volumes, as occurred during the mid-1950s, are the result of spillage when the reservoir is full. On the average, during the 10-year period 1961-70, the computed basin runoff was 40 billion gallons (150 $hm^3$) per year, and the inflow from Quabbin Aqueduct was 60 billion gallons (230 $hm^3$) per year. Outflow from the basin was over 1 billion gallons (3.8 $hm^3$) per year as streamflow (including seepage through the north dike of Wachusett Reservoir) and 99 billion gallons (370 $hm^3$) per year as diversions. Thus, about 3 percent of the runoff upstream from the dam contributed to flow in the Nashua River.

During this period, there was a deficiency of precipitation that, on the average, amounted to about 3 in. (76 mm) per year. Therefore, it can be concluded that if sufficient stored water is available to carry demands over periods of low precipitation, about 17 Mgal/d (0.7 $m^3/s$) (3 in. (76 mm) per year) of additional water can be developed in the basin. This presupposes that diversions typical of the 10-year period would be maintained and that sewage from the developed water would be released outside the basin. If the waste were to be released inside the basin, development could be increased by recycling the water. If present diversions from the basin are increased (including sewer extensions where release of wastage is outside the basin) without compensating diversions into the basin, the potential for future development is less than 17 Mgal/d (0.7 $m^3/s$).

### DIVERSIONS FROM STREAMFLOW

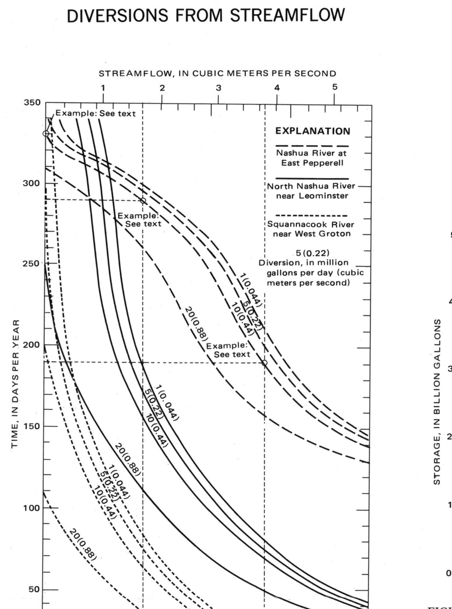


FIGURE 12.—*Graphs showing, with a 95-percent probability, the number of days per year when specified diversions can be made at the gaging stations while maintaining daily mean streamflow at not less than indicated amounts*

Two important factors in the consideration of a stream as a potential water-supply source are the number of days per year when the stream can deliver the desired diversion and the effect of the diversion on streamflow and, consequently, on downstream users.

These curves result from analyses of annual flow-duration data obtained during the periods indicated for the previous long-term duration curves. Therefore, if hydrologic conditions remain the same as during these periods, the curves can be used to plan future diversions. The examples show, with a 95-percent probability, that in any year there will be sufficient flow in the Nashua River at the East Pepperell gage during 330 days to meet a daily average diversion of 10 Mgal/d (0.44 $m^3/s$), if it is acceptable to deplete streamflow occasionally, and that, with this diversion, daily average streamflow past the point of diversion would be not less than 60 $ft^3/s$ (1.70 $m^3/s$) during 290 days and not less than 135 $ft^3/s$ (3.82 $m^3/s$) during 190 days.

### AUGMENTATION OF LOW FLOW

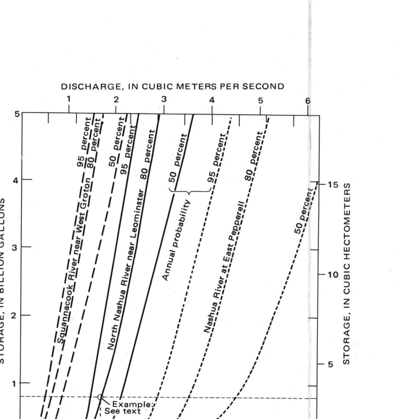


FIGURE 13.—*Graph showing storage required to maintain various flows at gaging stations*

As can be seen in the diversions illustration, there may be times when low flows, as they occur under present hydrologic conditions, would not be sufficient to meet possible requirements for diversions, power generation, or other purposes. Commonly, low flows can be supplemented to fulfill requirements by the release of water impounded during periods of abundant streamflow.

These storage-demand curves can be used to estimate the storage, unadjusted for reservoir seepage or evaporation losses, that would be needed over and above that already available to maintain the indicated flows. The curves are based on the low-flow frequency curves at the 5-, 20-, and 50-percent probability levels (95-, 80-, and 50-percent exceedence probabilities as shown in the storage-discharge curves). The example shows there is an 80-percent probability that daily mean flow past the North Nashua River gage near Leominster can be maintained at not less than 60 $ft^3/s$ (1.70 $m^3/s$) throughout any year if 0.8 billion gallons (3.0 million cubic meters) of additional storage is provided.

# DATA

## CHANCE OF OCCURRENCE

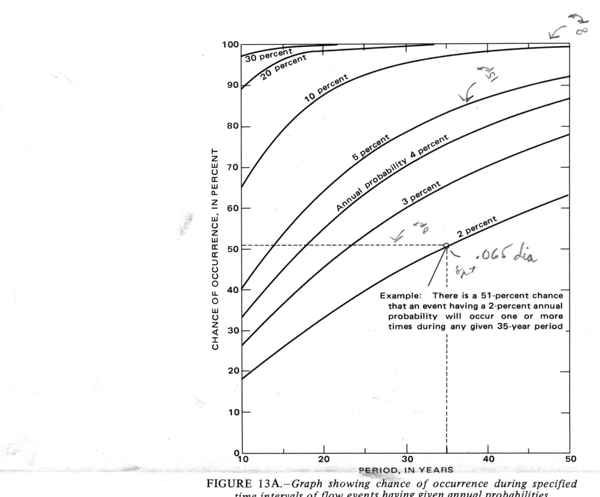


FIGURE 13A.—*Graph showing chance of occurrence during specified time intervals of flow events having given annual probabilities*

## SURFACE WATER DATA

Stream-Gaging Stations

North Nashua River near Leominster

Drainage area: 110 $mi^2$ (285 $km^2$)
Period of record: September 1935 to present
Maximum instantaneous discharge, 1936-72 water years: 16,300 $ft^3/s$ (462 $m^3/s$) Mar. 18, 1936 (highest since at least 1850)
Average flow, 1937-71 water years: 188 $ft^3/s$ (5.32 $m^3/s$)

Rocky Brook near Sterling

Drainage area: 2.28 $mi^2$ (5.91 $km^2$)
Period of record: October 1946 to Sept. 1967
Maximum instantaneous discharge, 1947-67 water years: 470 $ft^3/s$ (13.3 $m^3/s$) July 20, 1959
Average flow, 1947-67 water years: 3.45 $ft^3/s$ (0.098 $m^3/s$)

Squannacook River near West Groton

Drainage area: 62.8 $mi^2$ (163 $km^2$)
Period of record: October 1949 to present
Maximum instantaneous discharge, 1950-72 water years: 4,010 $ft^3/s$ (114 $m^3/s$) Oct. 16, 1955
Average flow, 1950-71 water years: 105 $ft^3/s$ (2.97 $m^3/s$)

Nashua River at East Pepperell

Drainage area: 433 $mi^2$ (1,120 $km^2$)
Period of record: October 1935 to present
Maximum instantaneous discharge, 1936-72 water years: 20,900 $ft^3/s$ (592 $m^3/s$) Mar. 20, 1936
Average flow, 1936-71 water years: 546 $ft^3/s$ (15.5 $m^3/s$)

## SYMBOLS

| | |
|---|---|
| °C | Degree Celsius |
| °F | Degree Fahrenheit |
| $ft^3/s$ | Cubic feet per second |
| $hm^3$ | Cubic hectometers |
| $km^2$ | Square kilometers |
| Mgal/d | Million gallons per day |
| $m^3/s$ | Cubic meters per second |
| mg/l | Milligrams per liter |
| $mi^2$ | Square miles |

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# SURFACE WATER QUALITY

## DISSOLVED CONSTITUENTS

### AREAL VARIATION

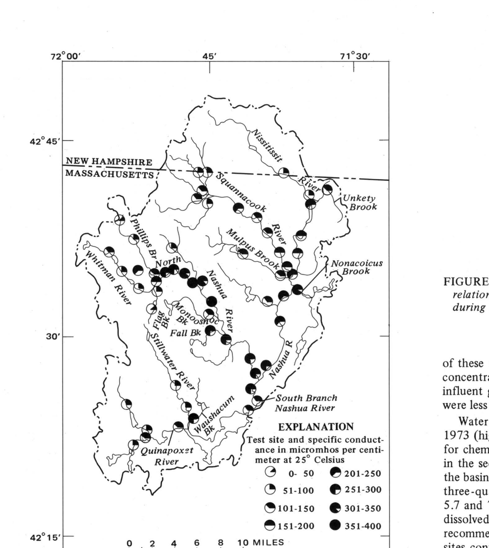


FIGURE 14.—*Map showing specific conductance measurements*

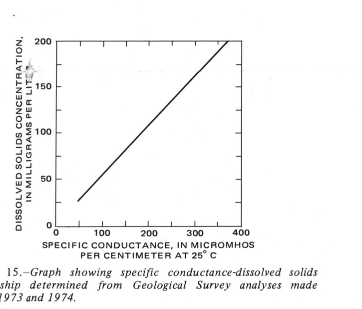


FIGURE 15.—*Graph showing specific conductance-dissolved solids relationship determined from Geological Survey analyses made during 1973 and 1974.*

To obtain an overall view of the chemical quality of surface water in the basin, specific-conductance measurements were made at 57 sites during August 31 to September 2, 1971 (fig. 14), a low-flow period. Specific conductance is an index of the concentration of dissolved solids (fig. 15). Usually, the headwaters of streams flow through sparsely populated areas and carry essentially natural chemical loads. The specific conductances measured in such reaches in the basin were generally less than 100 micromhos per centimeter at 25°C, which is typical of unadulterated surface water in eastern Massachusetts. As they flow downstream, streams receive wastes from such sources as farms, industries, towns, dumps, and highway deicing operations. In the basin, the most pronounced increases of specific conductance occurred in the North Nashua and South Branch Nashua Rivers at the industrial-population centers of Fitchburg, Leominster, and Clinton. Downstream from the confluence of these rivers to East Pepperell, a gradual reduction of dissolved-solids concentration was observed in the Nashua River because of dilution by influent ground water and inflow of water from tributary streams that were less adulterated than the main stem.

Water samples were collected at 17 sites on 15 streams during March 1973 (high streamflow) and again during January 1974 (medium flow) for chemical analyses. The locations of the sites are shown on the map in the section on phosphate. The analyses suggest that surface water in the basin is generally soft (maximum hardness 47 mg/l) and mildly acid; three-quarters of the pH values were between 6.2 and 6.7 (extremes, 5.7 and 7.0). Concentrations of chloride, nitrate, fluoride, sulfate, and dissolved solids were well below the U.S. Public Health Service (1962) recommended limits for public drinking water. However, water at some sites contained iron and (or) manganese in amounts exceeding the recommended limits of 0.3 and 0.05 mg/l, respectively. Generally, streams draining lightly populated areas had dissolved-solids concentrations in the range of 30 to 60 mg/l, whereas those receiving water from heavily populated areas had concentrations in the 60 to 100 mg/l range. Monoosnoc Brook, North Nashua River at North Leominster, Malpus Brook, and Nashua River near Ayer had sodium chloride type waters. Analyses from other sources indicated mixed type waters with none of the major ions (calcium, sodium, bicarbonate, chloride, and sulfate) predominating. The details of these analyses are available in the hydrologic-data report for the Nashua and Souhegan River basins (Brackley and Hansen).

The quality of stream water varies widely with respect to location (fig. 14). Water in different streams or water entering at various points along a particular stream may have been exposed to very different natural environments (vegetal covers, rock types, and land uses). Also, at points or zones along a stream, there may be inflow of leachates from dumps, wastes from industry, municipal wastes, and urban runoff from population centers. Also, quality varies with time (fig. 16) because of changing percentages of water from different sources. Therefore, one sample or a few samples during a short time interval should be considered as representing conditions at those times and places only.

### LONG TERM VARIATION

Specific conductance, pH, water temperature, and dissolved oxygen data have been collected on the North Nashua River at North Village in Lancaster by a monitoring station operated by the Geological Survey.

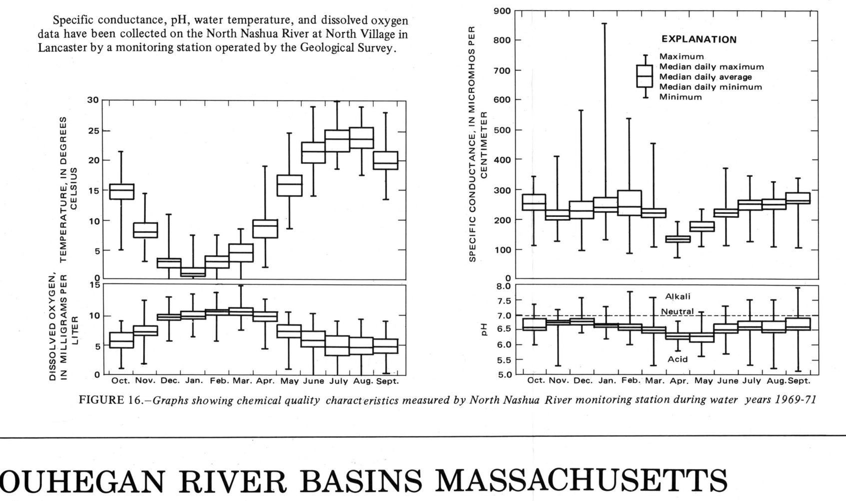


FIGURE 16.—*Graphs showing chemical quality characteristics measured by North Nashua River monitoring station during water years 1969-71*

### PHOSPHATE

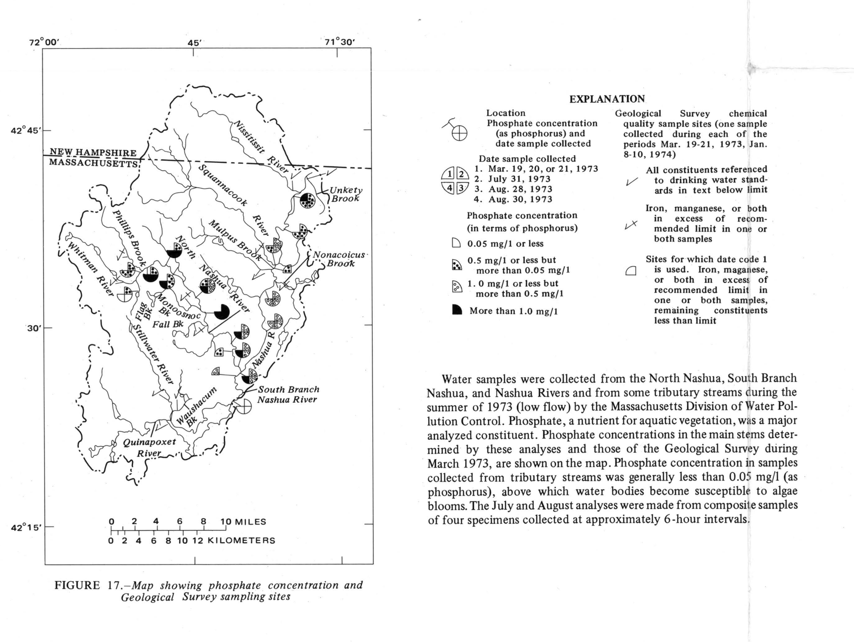


FIGURE 17.—*Map showing phosphate concentration and Geological Survey sampling sites*

Water samples were collected from the North Nashua, South Branch Nashua, and Nashua Rivers and from some tributary streams during the summer of 1973 (low flow) by the Massachusetts Division of Water Pollution Control. Phosphate, a nutrient for aquatic vegetation, was a major analyzed constituent. Phosphate concentrations in the main stems determined by these analyses and those of the Geological Survey during March 1973, are shown on the map. Phosphate concentration in samples collected from tributary streams was generally less than 0.05 mg/l (as phosphorus), above which water bodies become susceptible to algae blooms. The July and August analyses were made from composite samples of four specimens collected at approximately 6-hour intervals.

### AMMONIA AND NITRATE

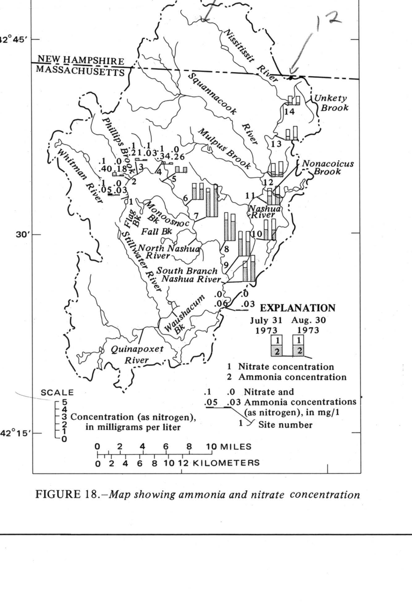


FIGURE 18.—*Map showing ammonia and nitrate concentration*

Ammonia, an indicator of recent pollution, was another important constituent determined in the analyses by the Massachusetts Water Pollution Control Division. Ammonia oxidizes ultimately into nitrate; therefore, as streams flow away from sources of pollution, initially high ratios of ammonia to nitrate diminish to lower ratios, and total concentrations decrease because of dilution from tributary and ground-water inflow. The analyses shown on the map (fig. 18) were made from composites of four samples collected at 6-hour intervals. The site numbers cross-reference sites that are shown here, on the phosphate map, and in the following graphs.

The influence of the process described above can be seen from inspection of the map (fig. 18). As the North Nashua River flows through Fitchburg, ammonia concentration increases from waste influx. Downstream from Fitchburg and Leominster, ammonia concentration increases greatly, sites 6 and 7, from releases of wastewater. Also, at these sites, nitrate formed from oxidation of the ammonia that entered the river in Fitchburg, becomes evident. Downstream from site 7, the total concentration of ammonia and nitrate progressively decreases, and the ratio of nitrate concentration to ammonia concentration increases, as the inflow of less-degraded water causes dilution and the ammonia oxidizes (through nitrite) to nitrate.

### DISSOLVED OXYGEN

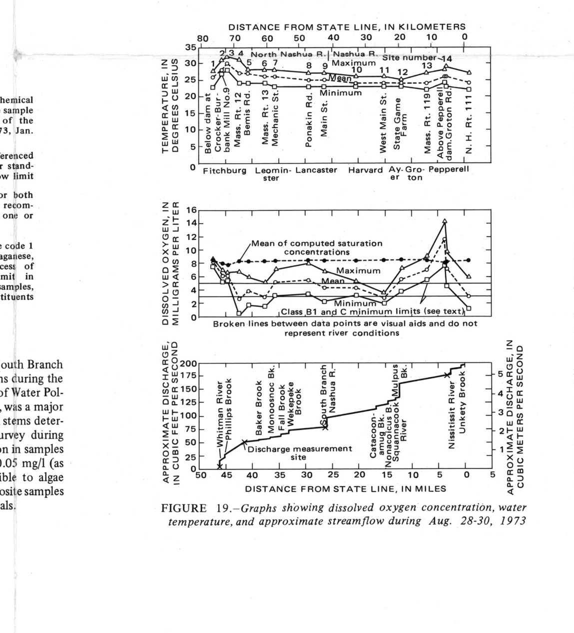


FIGURE 19.—*Graphs showing dissolved oxygen concentration, water temperature, and approximate streamflow during Aug. 28-30, 1973*

The concentrations of dissolved oxygen and water temperature (which is inversely related to oxygen solubility) shown in the graph represent 12 values per site determined from samples collected at 6-hour intervals during August 28-30, 1973. The approximation of streamflow is based on gaging station records and discharge measurements made on the main stem and many of the tributary streams during August 27-30. Because many pollutants in water reduce dissolved oxygen concentration, and low oxygen levels have injurious effects on the higher forms of aquatic life, dissolved oxygen concentration is used as an index of the biochemical quality of water. The state has established the quality requirement for water in the North Nashua River as class C and that in the Nashua River as class B1. In part, the class B1 and C requirements are that dissolved oxygen concentration will be ". . . not less than 5 mg/l during at least 16 hours of any 24-hour period nor less than 3 mg/l at any time."

A rise in water temperature of about 4°C (7°F) in the Fitchburg area presumably was caused by the release of manufacturing process water (note slight depression of mean saturation concentrations — inverse oxygen-temperature relationship). Downstream, the water temperature declined generally, because of cooler inflow.

There was a large reduction, and at times, near depletion, of the dissolved oxygen concentration in the Fitchburg area because of the oxygen needs of the organisms and oxidizing chemicals in the water. Between State Highway 13 and Ponakin Road, Lancaster, the oxygen added to the river by inflow and aeration was in excess of the biochemical oxygen demand and increased the concentration. Below Ponakin Road, however, the oxygen recharge was less than the biochemical demand, and the dissolved oxygen concentration declined to near depletion at West Main St., Ayer. Below this point, the concentration increases seem to indicate a dramatic purification of the river. However, the supersaturations indicate algal photosynthesis, which presumably caused most, if not all, of the concentration increase. The wide spread between maximum and minimum concentrations indicates there was probably a large quantity of algae present from the center of Fitchburg to the state line.

### COLIFORM BACTERIA

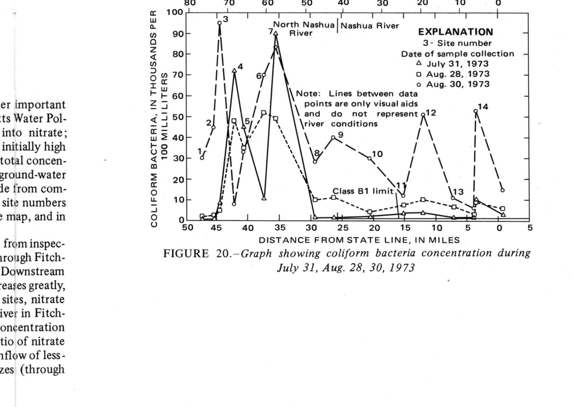


FIGURE 20.—*Graph showing coliform bacteria concentration during July 31, Aug. 28, 30, 1973*

The coliform group of bacteria is widely used as an indicator of the presence of pathogenic bacteria, even though the pathogens are not specifically identified. The coliform counts shown were obtained from daily composites of four samples collected at approximately 6-hour intervals.

The data show that there were appreciable day-to-day changes in the number of coliform bacteria per 100 ml at individual sampling sites and that the changes in bacteria concentration between sites was not consistent. For example, on July 31 and August 28, the bacteria concentration increased about tenfold in the reach between sites 3 and 4, whereas, on August 30, it decreased by about the same factor. Similarly, on July 31 and August 28, there was fairly uniform coliform bacteria concentration along the Nashua River and the lower reaches of the North Nashua River, yet, on August 30, there was clear indication of bacterial contamination in Lancaster, Ayer, and Pepperell. These variations are caused by changes of waste releases (volume and composition), volume of streamflow, and water temperature, to specify only a few of the factors that influence bacterial reproduction or concentration.

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# WATER RESOURCES OF THE NASHUA AND SOUHEGAN RIVER BASINS MASSACHUSETTS

By
R. A. Brackley and Bruce P. Hansen
1977

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