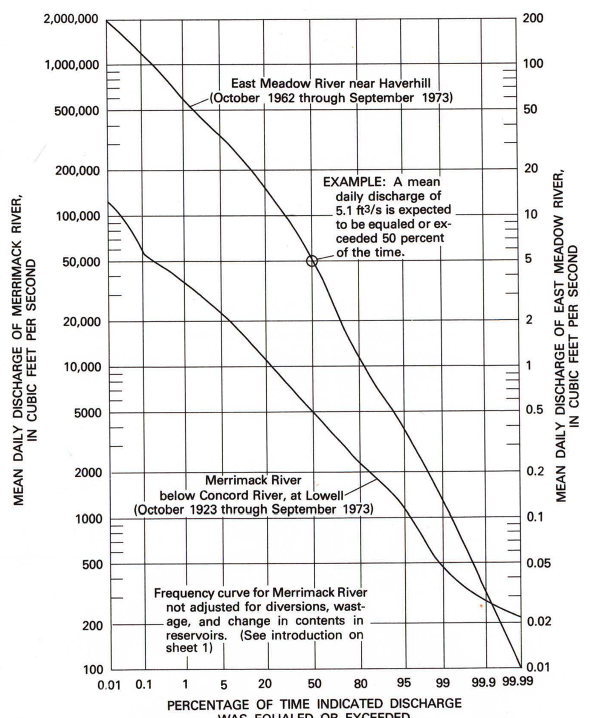
SURFACE WATER AVAILABILITY

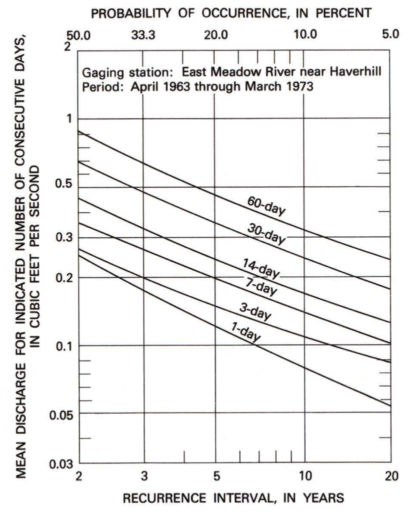
FLOW DURATION

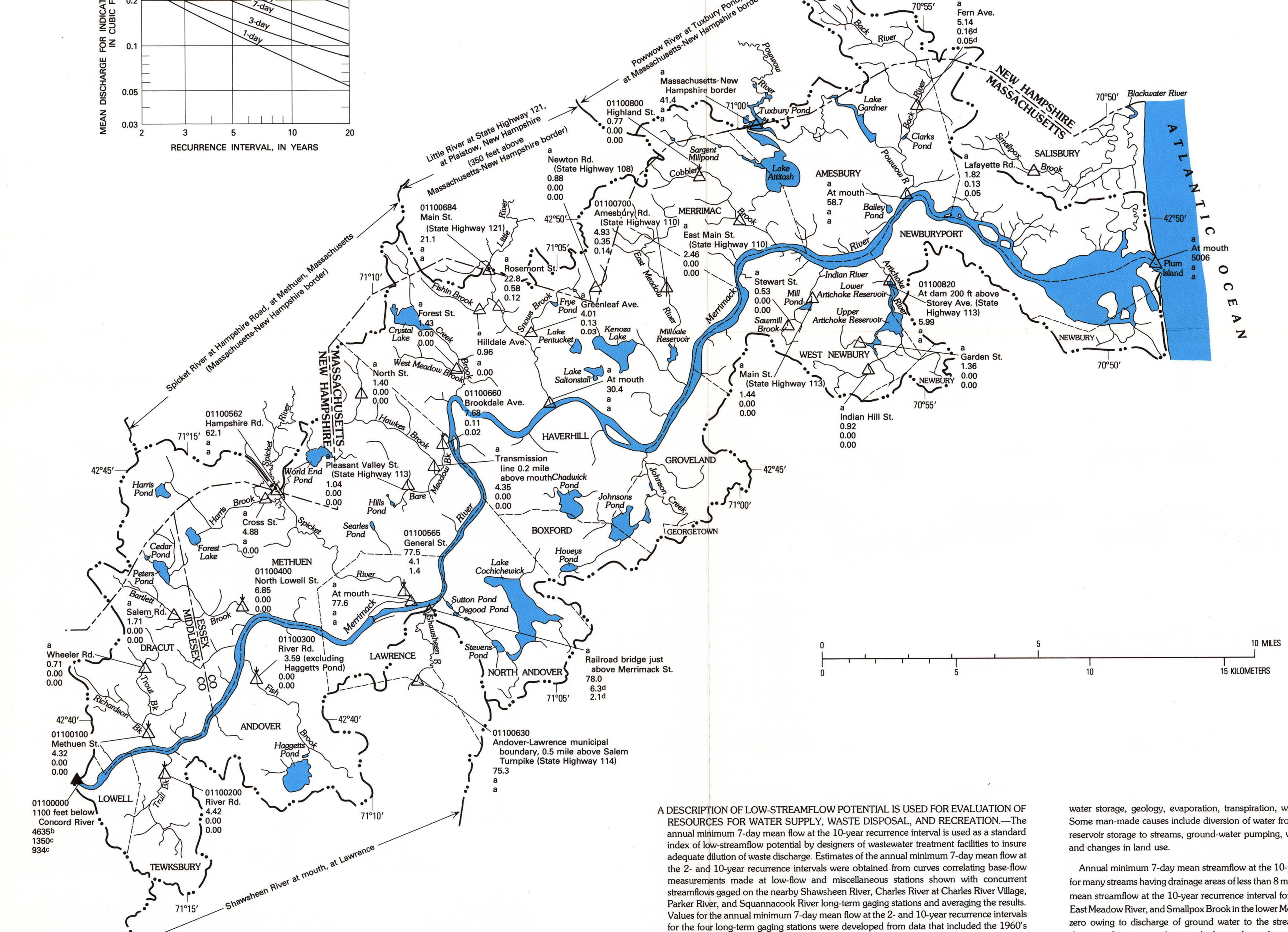


THE PERCENTAGE OF TIME FLOWS HAVE BEEN EQUALED OR EXCEEDED DURING PERIOD OF RECORD SHOWN.—The slope of the flow-duration curve for high flows in East Meadow River is moderated by swamps that provide temporary natural storage, which absorb peak flows and sustains high flows. The slope of the flow-duration curve for high and medium flows in the Merrimack River is moderated by flood-control reservoirs, water-supply reservoirs, and lakes that store peak flows as well as other flow for later diversion and gradual release during periods of lower flow. The steep part of this curve, representing flows exceeded less than 0.1 percent of the time, is due to the peak flows of the March 1936 flood and the September 1938 hurricane, which occurred before construction of the five major flood-control dams in the upper Merrimack River basin. (See table 2 on sheet 1.)

The steep slope of the low-flow part of the duration curve (flows exceeded 95 percent of the time) for East Meadow River is caused by high rates of evapotranspiration from swamps. However, the gentle slope of the low-flow part of the duration curve (flows exceeded 99 percent of the time) for the Merrimack River is due to discharge from lake, reservoir, and ground-water storage.

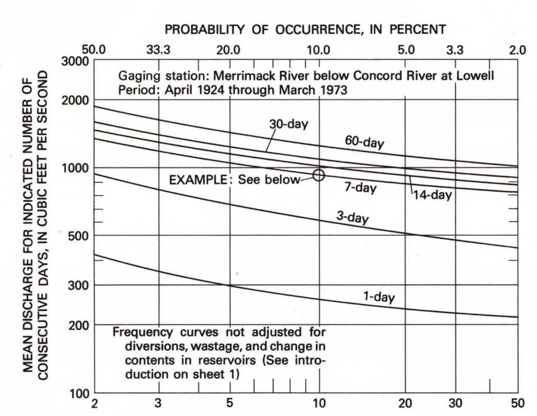
LOW STREAMFLOW





EXPLANATION

- ▲ Continuous-record gaging station
- Discontinued gaging station
- Low-flow measurement station
- △ Miscellaneous-measurement station
- Dam
- 01100660 Station number, in downstream order. Number from U.S. Geological Survey's data-collection network
- Brookdale Ave. Location on river course
- 7.68 Drainage area, in square miles
- Annual minimum 7-day mean flow, in cubic feet per second
  - 0.11 2-year recurrence interval
  - 0.02 10-year recurrence interval
  - a Not determined.
- 4635[b] Total drainage area above gaging station; not adjusted for diversion reservoirs in drainage basin.
- 1350[c] Unadjusted for diversions, wastage, and change in contents in reservoirs above gaging station.
- 2.1[d] Withdrawal of ground water from drainage basin above station for municipal supply causes annual minimum 7-day mean flows at the 2- and 10-year recurrence intervals to be lower than prewithdrawal period.
- Basin boundary



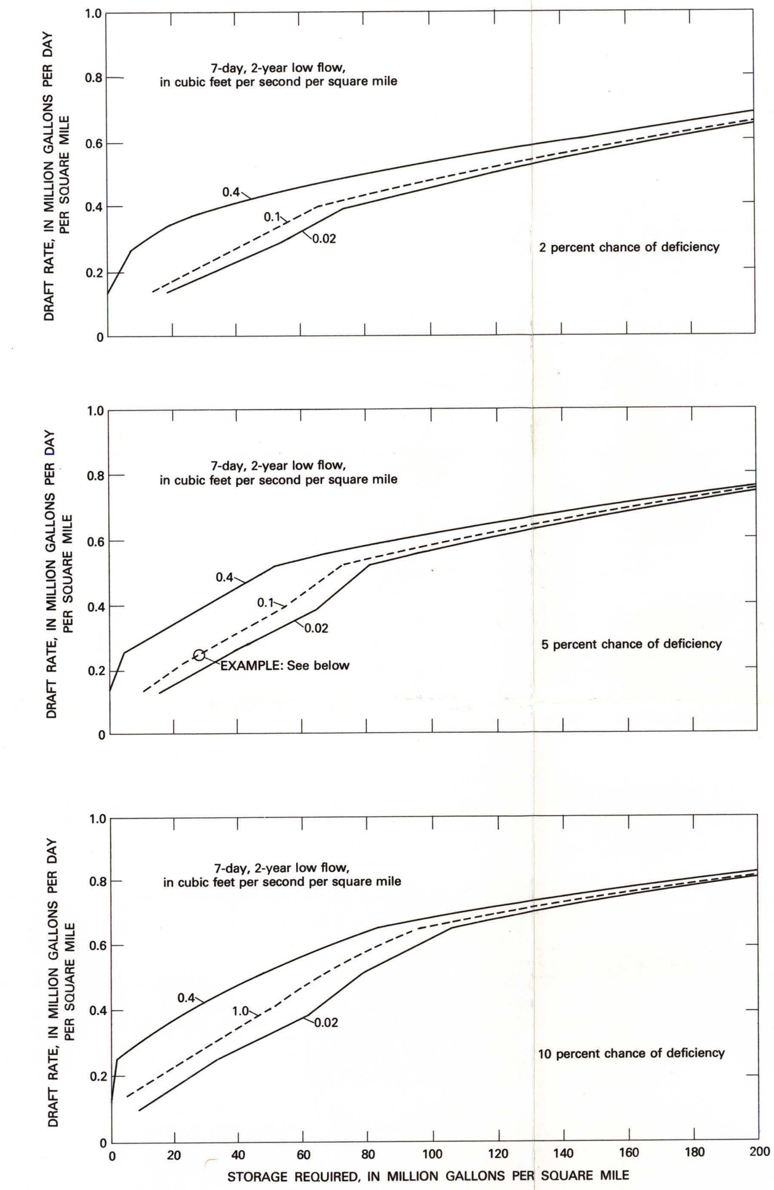
EXAMPLE: The annual minimum 7-day mean flow will be less than 934 ft³/s at intervals averaging 10 years in length, and the associated probability that the annual minimum 7-day mean flow will be less than 934 ft³/s in any 1 year is 10 percent.

A DESCRIPTION OF LOW-STREAMFLOW POTENTIAL IS USED FOR EVALUATION OF RESOURCES FOR WATER SUPPLY, WASTE DISPOSAL, AND RECREATION.—The annual minimum 7-day mean flow at the 10-year recurrence interval is used as a standard index of low-streamflow potential by designers of wastewater treatment facilities to insure adequate dilution of waste discharge. Estimates of the annual minimum 7-day mean flow at the 2- and 10-year recurrence intervals were obtained from curves correlating base-flow measurements made at low-flow and miscellaneous stations shown with concurrent streamflows gaged on the nearby Shawsheen River, Charles River at Charles River Village, Parker River, and Squannacook River long-term gaging stations and averaging the results. Values for the annual minimum 7-day mean flow at the 2- and 10-year recurrence intervals for the four long-term gaging stations were developed from data that included the 1960's drought.

Streamflow per unit drainage area varies from stream to stream during low-flow periods as the result of both natural and man-made causes. Natural causes include nonuniformity of water storage, geology, evaporation, transpiration, water-table slope, and precipitation. Some man-made causes include diversion of water from streams, managed releases from reservoir storage to streams, ground-water pumping, waste-water discharge into streams, and changes in land use.

Annual minimum 7-day mean streamflow at the 10-year recurrence interval will be zero for many streams having drainage areas of less than 8 mi²; however, annual minimum 7-day mean streamflow at the 10-year recurrence interval for Back River, Bare Meadow Brook, East Meadow River, and Smallpox Brook in the lower Merrimack River basin are greater than zero owing to discharge of ground water to the streams from porous sand and gravel deposits. Scant ground-water discharge from the upper part of the bedrock aquifer (consolidated rock) and from the extensive till layer (unconsolidated deposit) is mainly responsible for the zero values.

REGIONAL STORAGE ANALYSIS



REGIONAL DRAFT-STORAGE-FREQUENCY ANALYSIS USED IN CONJUNCTION WITH ANNUAL MINIMUM 7-DAY MEAN FLOWS AT THE 2-YEAR RECURRENCE INTERVAL CAN PROVIDE INFORMATION USEFUL TO WATER MANAGERS AND PLANNERS IN COMPARATIVE STUDIES OR IN PRELIMINARY DESIGNS FOR RESERVOIR SITES.—These regional draft-storage-analysis curves were prepared by Tasker (1977). They are based on a regional analysis of streamflow records for 12 gaging stations in eastern Massachusetts and Rhode Island, using the methods recommended by Riggs and Hardison (1973) to account for seasonal as well as year-to-year variations in streamflow.

Draft rate is gross reservoir outflow occurring at a uniform rate and is uncorrected for increased water losses resulting from enlarging the water-surface area in the basin. Storage required is the usable volume of a reservoir required to maintain the indicated draft rate. When applying these curves to the evaluation of a specific reservoir site, the user should adjust the draft rates to account for expected evaporation and seepage losses, nonuniform draft rates, and low-flow augmentation requirements. Storage requirements should be adjusted for expected losses in reservoir capacity because of sedimentation.

The Committee on Rainfall and Yield of Drainage Areas of the New England Water Works Association (1969, p. 168–169) considers it economically unsound to develop storage capabilities much beyond 200 Mgal/mi² in New England watersheds. The rationale for this decision can be seen from inspection of the draft-storage curves. Increases of draft rates require disproportionately large increases of storage for rates exceeding about 0.5 (Mgal/d)/mi².

EXAMPLE.—A stream has a 10.0 mi² drainage area and an annual minimum 7-day mean flow at the 2-year recurrence interval of 1.0 ft³/s or 0.1 (ft³/s)/mi² at a given site. To maintain a draft rate of 2.5 Mgal/d or 0.25 (Mgal/d)/mi², a storage capacity of 28 Mgal/mi² or 280 Mgal would be enough for an average of 95 out of 100 years (5 percent chance of deficiency), exclusive of losses.

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Lowell (1969) — Salem Depot (1974)
Haverhill (1974) — South Groveland (1974)
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1968, 305 p. (1969) — 1972, 394 p. (1974)
1969, 347 p. (1970) — 1973, 433 p. (1975)
1970, 373 p. (1971) — 1974, 429 p. (1975)
1971, 401 p. (1973)
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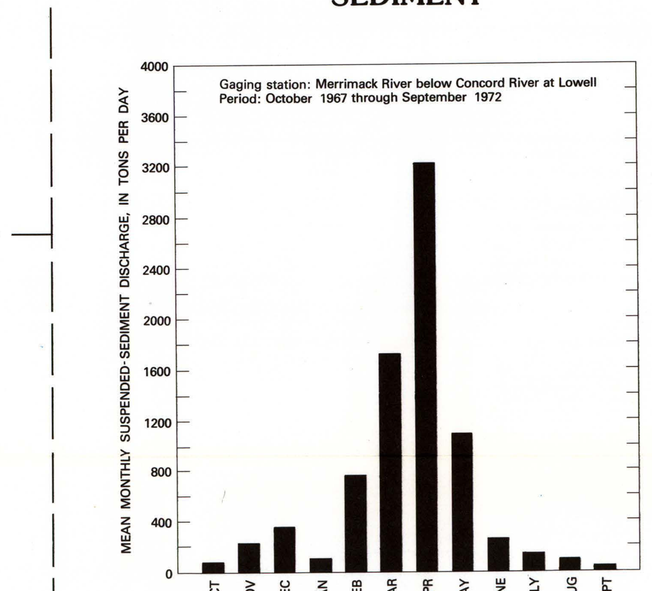
SEDIMENT



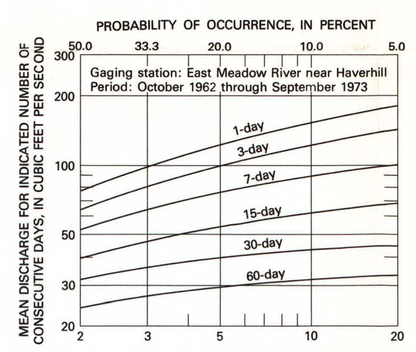
THE MERRIMACK RIVER TRANSPORTS APPROXIMATELY 75 PERCENT OF ITS YEARLY SUSPENDED-SEDIMENT LOAD DURING SPRING RUNOFF, MARCH THROUGH MAY.—Suspended sediment in streamwater is composed of clay-, silt-, and sand-size particles derived from the erosion of soils and unconsolidated deposits and maintained in suspension by the velocity of streamwater. The amount and particle size of suspended sediment varies with the stream's discharge and velocity as well as the amount and particle size of erodable material available.

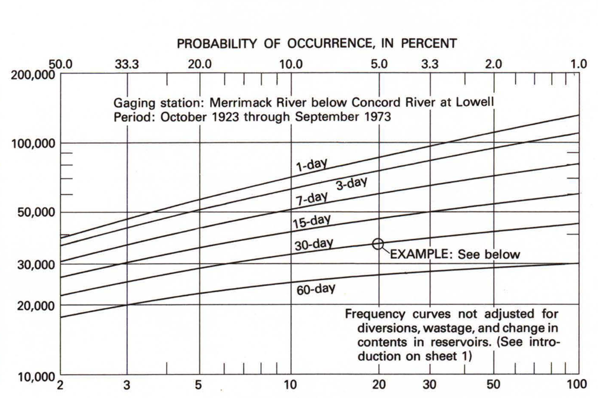
In the lower Merrimack River, high suspended-sediment concentrations occur from snowmelt and intense runoff in the upper part of the basin. Suspended-sediment concentration is highly variable but usually varies directly with streamflow. Generally, greater suspended-sediment concentrations occur during increasing streamflow than during decreasing streamflow of the same magnitude.

This occurrence of greater concentrations during increasing flow than during decreasing flow, the season of the year, amount and type of vegetative cover, land use, agricultural practices, intensity of rainfall, and construction are some of the factors explaining why a daily average streamflow of 10,100 ft³/s yielded 518 tons/d of suspended-sediment load on March 8, 1972, whereas the same streamflow yielded only 164 tons/d on July 26, 1972 at the Merrimack River below the Concord River at Lowell gaging station.

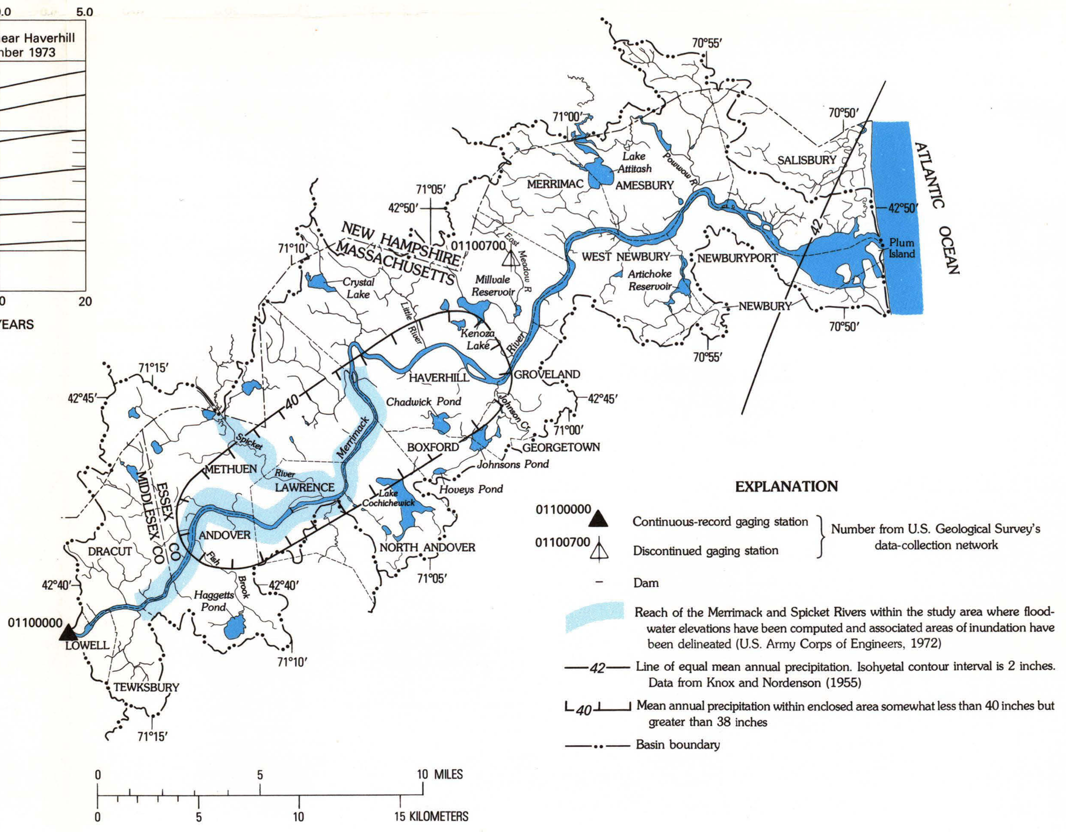
At the Lowell gaging station, annual suspended-sediment loads during October 1967 through September 1972 ranged from 119,530 to 306,463 tons/yr and had an average annual suspended-sediment load of 244,231 tons/yr or 668 tons/d. Suspended-sediment data for the Lowell gaging station are published in the annual streamflow data reports (U.S. Geological Survey, 1969, 1970, 1971, 1973, and 1974).

HIGH STREAMFLOW





EXAMPLE: The annual maximum 30-day mean flow will exceed 36,500 ft³/s at intervals averaging 20 years in length, and the associated probability of the annual maximum 30-day mean flow exceeding 36,500 ft³/s in any 1 year is 5 percent.



EXPLANATION

- ▲ 01100000 Continuous-record gaging station
- △ 01100700 Discontinued gaging station
- Number from U.S. Geological Survey's data-collection network
- Dam
- Reach of the Merrimack and Spicket Rivers within the study area where flood-water elevations have been computed and associated areas of inundation have been delineated (U.S. Army Corps of Engineers, 1972)
- —42— Line of equal mean annual precipitation. Isohyetal contour interval is 2 inches. Data from Knox and Nordenson (1955)
- Mean annual precipitation within enclosed area somewhat less than 40 inches but greater than 38 inches
- Basin boundary

KNOWLEDGE OF THE EXTENT OF PAST FLOODING AND A MEANS OF ESTIMATING FLOOD POTENTIAL ARE VITAL TO THE MANAGEMENT OF STREAMSIDE DEVELOPMENT.—Major floods in the lower Merrimack River basin occurred in April 1852, March 1936, September 1938, and April 1960; the March 1936 flood having the highest discharge since 1735 according to historical flood information documented in the annual streamflow data reports (U.S. Geological Survey, 1975). High-water marks and flood profiles for the entire Merrimack and Spicket Rivers and high-water marks for Powwow and Artichoke Rivers within Massachusetts have been published for the March 1936 flood (Massachusetts Department of Public Works, Geodetic Survey, 1936). A detailed flood-information study (U.S. Army Corps of Engineers, 1972) is available for parts of the Merrimack and Spicket Rivers in the study area as shown in the illustration. These studies have determined flood-water elevations and associated areas of inundation for the 100-year recurrence interval flood and one flood of greater magnitude. Recurrence interval is the average length of time between the exceedance of a flood of given magnitude.

Floods in the Merrimack River below its confluence with the Concord River have occurred mainly during the spring when snowmelt runoff from the upper Merrimack River basin has been accompanied by heavy rain. Historically, floods on tributaries to the Merrimack River in Massachusetts have peaked well before the lower Merrimack River. Although the possibility exists, it is considered highly unlikely that peak flows on tributaries to the Merrimack River will coincide with peak flows in the lower Merrimack River.

Flow data from the long-term continuous-record gaging stations provided information for the flood-frequency curves shown. These curves can be 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 lower Merrimack River basin can be estimated from instantaneous peak discharge equations developed from long-term streamflow data collected in Massachusetts (Johnson and Tasker, 1974).

In the equations listed below, instantaneous peak discharges at selected frequencies are related to drainage area, mean annual precipitation, and main-channel slope. These equations are valid if the drainage area is between 0.25 mi² and 500 mi², not affected by backwater flooding, largely rural, and not significantly affected by manmade regulation such as along the Merrimack River.

A part of the study area is urbanized, and care should be exercised when applying instantaneous peak-discharge values determined from these formulas. Flow estimates based on these formulas are likely to be too low if a large part of the stream's drainage area is urbanized.

Regional flood-frequency formulas (Johnson and Tasker, 1974):

$$P_2 = 0.0645\, A^{0.816}\, S^{0.091}\, P^{4.59}$$
$$P_5 = 0.0795\, A^{0.831}\, S^{0.116}\, P^{4.67}$$
$$P_{10} = 0.102\, A^{0.852}\, S^{0.132}\, P^{4.60}$$
$$P_{25} = 0.144\, A^{0.885}\, S^{0.155}\, P^{4.43}$$
$$P_{50} = 0.193\, A^{0.911}\, S^{0.171}\, P^{4.27}$$
$$P_{100} = 0.260\, A^{0.940}\, S^{0.187}\, P^{4.08}$$

in which,

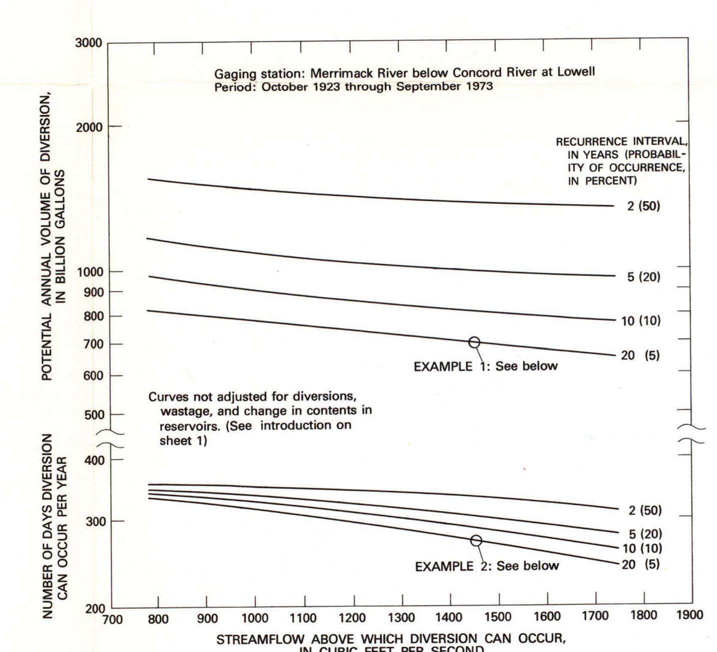
P_2, P_5, P_{10}, P_{25}, P_{50}, P_{100}=peak discharge for the 2-, 5-, 10-, 25-, 50-, and 100-year recurrence intervals.

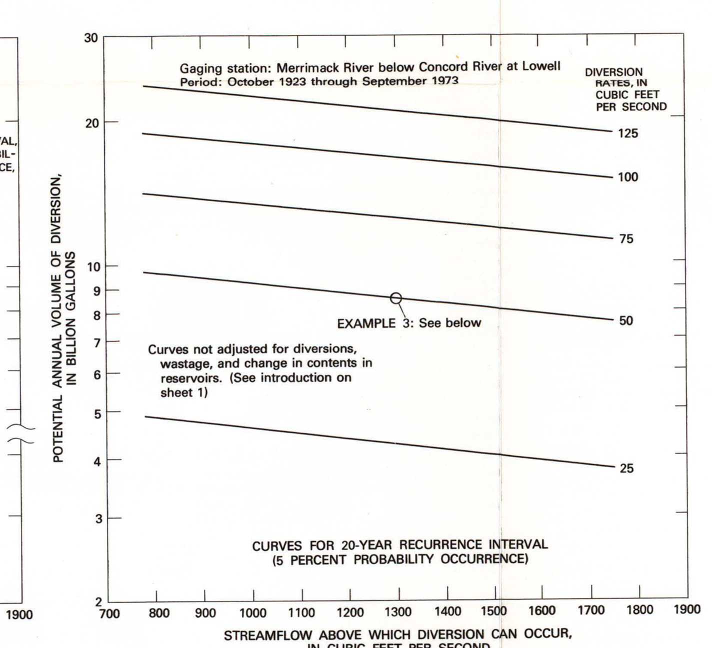
A=drainage area, in square miles,

S=main-channel slope, in feet per mile. To determine main-channel slope, choose upstream from each stream junction point on a topographic quadrangle map the stream that drains the most area. At the last junction point, continue the main channel to the surface-water drainage divide by drawing an imaginary stream channel, as indicated by contour lines. Measure the total length of the stream channel upstream from the site of interest to the drainage divide, and then locate points on the stream channel that are 85 and 10 percent upstream from the site. Determine the altitude at these points and divide the difference in altitude, in feet, by the stream length between the two points, in miles,

P=mean annual precipitation, in feet. Determine precipitation, in inches, from map and convert to feet.

VOLUME DIVERSION





DESIGNERS AND PLANNERS CAN DETERMINE THE ANNUAL VOLUME OF WATER AVAILABLE FOR DIVERSION FROM THE MERRIMACK RIVER BELOW THE CONCORD RIVER ONCE MINIMUM FLOW REQUIREMENTS DOWNSTREAM FROM THE DIVERSION STRUCTURE HAVE BEEN ESTABLISHED.—The sets of curves for the Merrimack River below its confluence with the Concord River can be used to estimate the potential annual volume of diversion available for different minimum flow requirements (example 1), and to estimate how many days a year streamflow above a given flow will occur (example 2). The potential annual volume of diversion for diversion structures of different capacities can also be estimated (example 3). These relationships were prepared by a method developed by Collings (1968).

Summation of prior claims on river water downstream from the diversion structure will yield minimum streamflow requirements, when available, to satisfy these demands. Examples of prior claims on river water are: industrial or municipal use, recreation, irrigation, fisheries resource, waste-water dilution, and limiting saltwater intrusion in an estuary.

EXAMPLE 1: If all streamflow greater than 1450 ft³/s could be diverted, the potential annual volume of diversion would be less than 700 billion gallons at intervals averaging 20 years in length, and the probability that the potential annual volume of diversion would be less than 700 billion gallons in any 1 year is 5 percent.

EXAMPLE 2: Streamflow greater than 1450 ft³/s will occur for less than 272 days a year at intervals averaging 20 years in length, and the probability that streamflow greater than 1450 ft³/s will occur for less than 272 days a year in any 1 year is 5 percent.

EXAMPLE 3: If the capacity of a diversion structure is 50 ft³/s and if the full diversion rate is made whenever streamflow is greater than 1300 ft³/s, the potential annual volume of diversion will be less than 8.5 billion gallons at intervals averaging 20 years in length, and the probability that the potential annual volume of diversion will be less than 8.5 billion gallons in any 1 year is 5 percent.

INTERIOR—GEOLOGICAL SURVEY, RESTON, VA.—1980—W79313

HYDROLOGY AND WATER RESOURCES OF THE LOWER MERRIMACK RIVER BASIN, MASSACHUSETTS, FROM CONCORD RIVER, LOWELL, TO PLUM ISLAND, NEWBURYPORT

By
Frederick B. Gay and David F. Delaney

1980