PREPARED IN COOPERATION WITH THE
METROPOLITAN DISTRICT COMMISSION
BOSTON, MASSACHUSETTS

INTRODUCTION

The increase in population, urbanization, and expansion of industry have augmented the need for water-resources development throughout Massachusetts. To evaluate the water resources of the Commonwealth, definition of water availability and potential is based on data being collected and analyses being made of river basins throughout Massachusetts. This report is the result of a study of the Millers River basin. The Metropolitan District Commission of Boston proposes to supplement storage in the Quabbin Reservoir by diversion of surface waters from the basin.

The basin is located in north-central Massachusetts and southwestern New Hampshire (see fig. 1). The outline, culture, topography and lines of equal median annual precipitation of the basin are shown in figure 2. The area is 392 square miles with a mean altitude of about 1,000 feet. Physiographically, the basin is located in the New England province and upland section and is described as dissected and glaciated peneplains on complex structures (Fenneman, 1938). The basin has about 78 percent forest cover, 11 percent open land, 8 percent wetland, and 3 percent urban area.

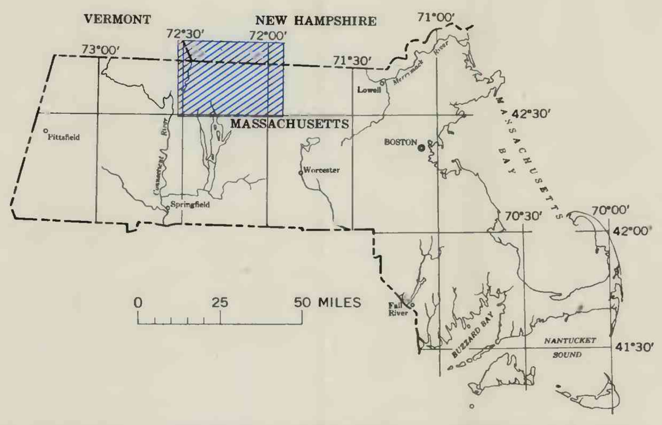


FIGURE 1.—INDEX MAP SHOWING LOCATION OF BASIN.

The industrial products of the basin are many and diverse. A few of the major products are paper, machine tools, furniture and dairy products. Farming and dairying are declining and recreation and tourism are on the rise. The area boasts several camping, hunting and fishing and other recreational areas which, in many cases, border lakes and reservoirs.

The resident population density of the area is 163 persons per square mile; however, in the warmer season of the year this number is considerably increased by tourists and vacationers. The major population centers are Gardner (20,463), Athol (11,989), Winchendon (6,689), Orange (6,206), and Templeton (6,006).

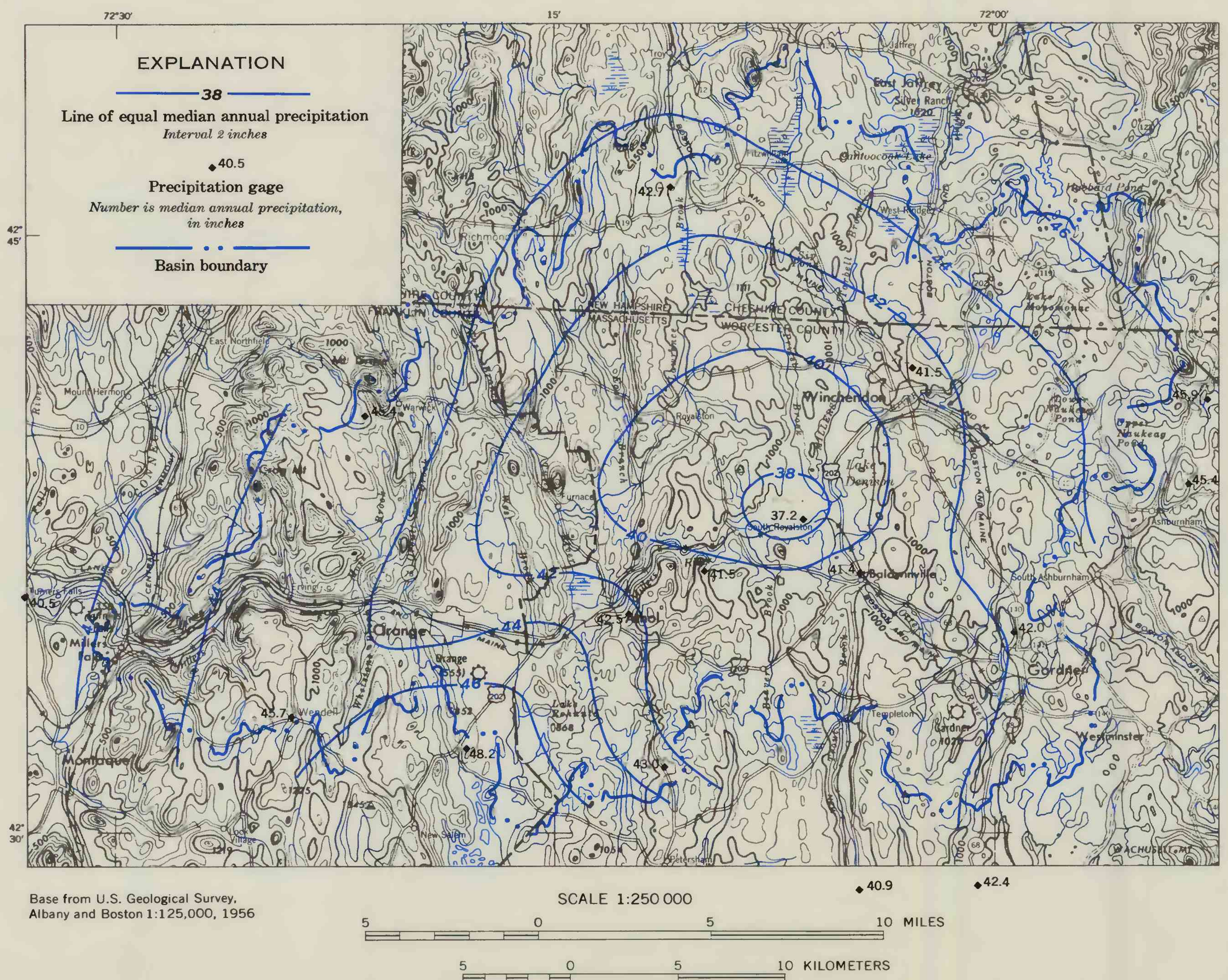


FIGURE 2.—MAP SHOWING DRAINAGE DIVIDE, CULTURE, TOPOGRAPHY AND LINES OF EQUAL MEDIAN ANNUAL (WATER YEAR) PRECIPITATION. *The median annual water year precipitation over the basin as a whole is 43.0 inches.*

A quantitative and qualitative knowledge of some of the factors involved in the hydrologic cycle (fig. 3) are necessary to analyze the water resources of the basin. These factors are: precipitation, surface-water runoff, ground water, and water storage in the basin.

FIGURE 3.—THE HYDROLOGIC CYCLE. *The movement of water is endless, from vapor to liquid to vapor——; from land and water surfaces to the atmosphere to land and water surfaces——.*

The basin is located in the mid-latitudes and is influenced by storm systems moving eastwardly across the United States. The winds generally are northwesterly in winter and southwesterly in summer. Exceptions are the prolonged pluvial periods resulting from slow moving disturbances in the north Atlantic and infrequent tropical storms in summer and fall which cause heavy intense rains. The mean monthly temperatures are shown in figure 4. The growing season averages about 120 to 140 days and occurs from the latter part of May to October.

Precipitation occurs as both rain and snow and, for long-term averages, does not vary substantially from month to month. However, individual monthly totals may vary from no measurable precipitation to over 15 inches. The median annual precipitation is about 43 inches (fig. 2). Snowfall ranges from 40 to 70 inches. Maximum snowcover usually occurs in the latter part of February and lasts into early or mid-spring.

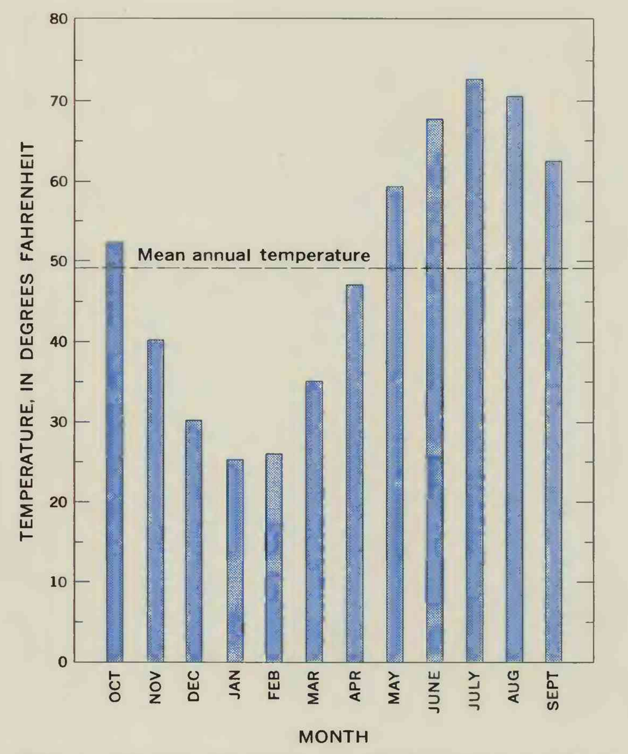


FIGURE 4.—MEAN MONTHLY TEMPERATURES, 30 YEAR NORMAL AT TURNERS FALLS. *The mean monthly temperature ranges from 24.7° F in January to 72.3° F in July and the mean annual temperature is 48.7° F.*

Table 1 lists the common conversion units for expressing rates and volumes of flow used in this report.

TABLE 1.—CONVERSION FACTORS OF SOME COMMON UNITS FOR EXPRESSING RATES AND VOLUMES OF FLOW.

To convert from	To	Multiply by
Second-foot-day (cfs-day)	Cubic feet (cu ft)	86,400
Inches	Cubic feet per second per square mile (cfs per sq mi)	26.9
Million gallons (mg)	Cubic feet (cu ft)	133,700
Million gallons per day (mgd)	Cubic feet per second (cfs)	1.547
Million gallons per square mile (mg per sq mi)	Inches	.0576

ANNUAL WATER BUDGET

An understanding and general evaluation of the hydrology and the water available in the basin may be obtained by considering the factors or items involved in the hydrologic cycle (fig. 3). The water budget or hydrologic equation is valuable in evaluating the amount of water available for use. The equation is an accounting of the inflow to, outflow from, and change in storage in a hydrologic unit, such as a drainage basin and is basically expressed as:

Inflow Items	Change in Storage Items	Outflow Items
1. Surface inflow	1. Surface storage	1. Surface outflow (runoff)
2. Subsurface inflow	2. Soil-moisture storage	2. Subsurface outflow
3. Precipitation on area	3. Ground-water storage	3. Total evapotranspiration in area

Because of conservation of matter, inflow items equal outflow items plus or minus change in storage items.

Outflow item 1, surface runoff, and change in storage items 1 and 3 may be available for man's use when developed. Inflow items 1 and 2 and outflow item 2 are insignificant compared to the basin's total budget and are not included in the discussion.

Precipitation, inflow item 3, has no well defined seasonal maximum or minimum and averages about 3.6 inches per month. The annual (Oct. 1—Sept. 30) water year magnitude and frequency of precipitation for the basin are shown in figure 5.

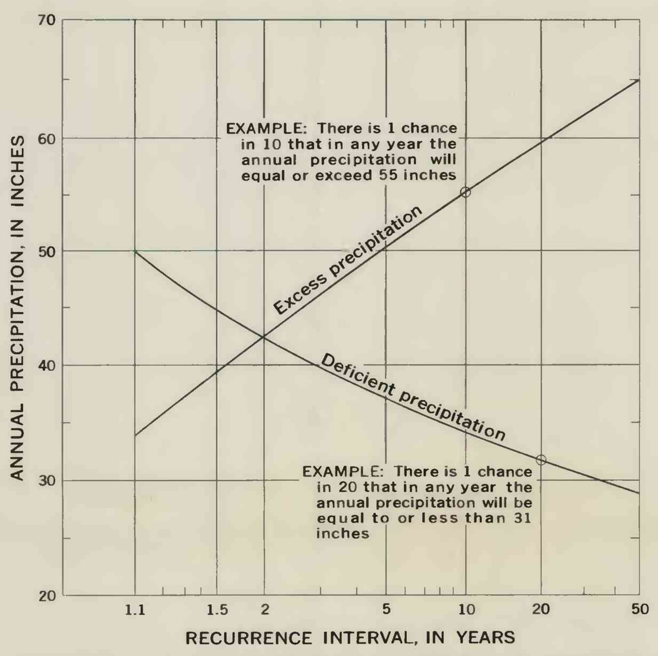


FIGURE 5.—GRAPH SHOWING MAGNITUDE AND FREQUENCY OF ANNUAL (WATER YEAR) EXCESS AND DEFICIENT PRECIPITATION. *The median annual precipitation (43 inches) is shown by the 2-year recurrence interval.*

The average precipitation frequency (fig. 5) was determined by drawing lines of equal precipitation for selected recurrence intervals from each station frequency and compiling the weighted planimeter results into an average frequency distribution for the basin.

The magnitude and frequency of the annual water year runoff, outflow item 1 of the budget, are shown in figure 6. The range about the mean runoff curves (fig. 6) for the frequencies of the 7 long-term surface water gaging sites is about ±2 percent at the 2-year recurrence interval and ±9 percent at the 50-year recurrence interval.

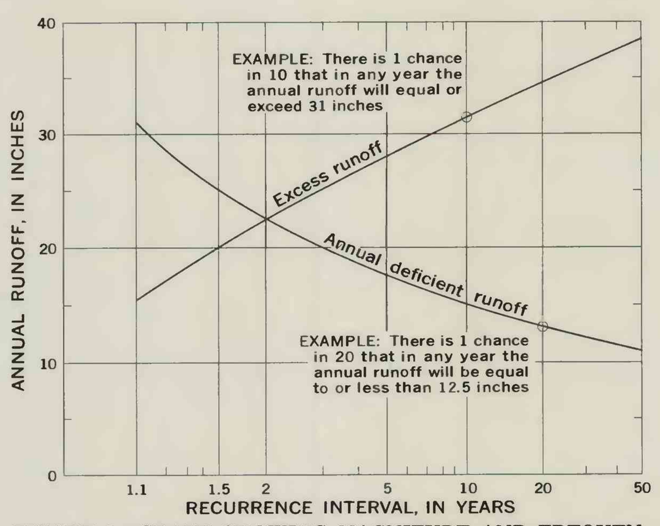


FIGURE 6.—GRAPH SHOWING MAGNITUDE AND FREQUENCY OF ANNUAL (WATER YEAR) EXCESS AND DEFICIENT RUNOFF. *The median annual runoff (2-year recurrence interval) is 22 inches.*

The 2-year recurrence interval for the curves in figures 5 and 6 is the median year or interval of time within which the magnitude of runoff and precipitation will be equaled or exceeded once (50 percent probability).

A graph for a well in Winchendon (fig. 7) shows mean monthly ground-water levels. The change in ground-water storage, item 3, for long-term annual averages is essentially zero.

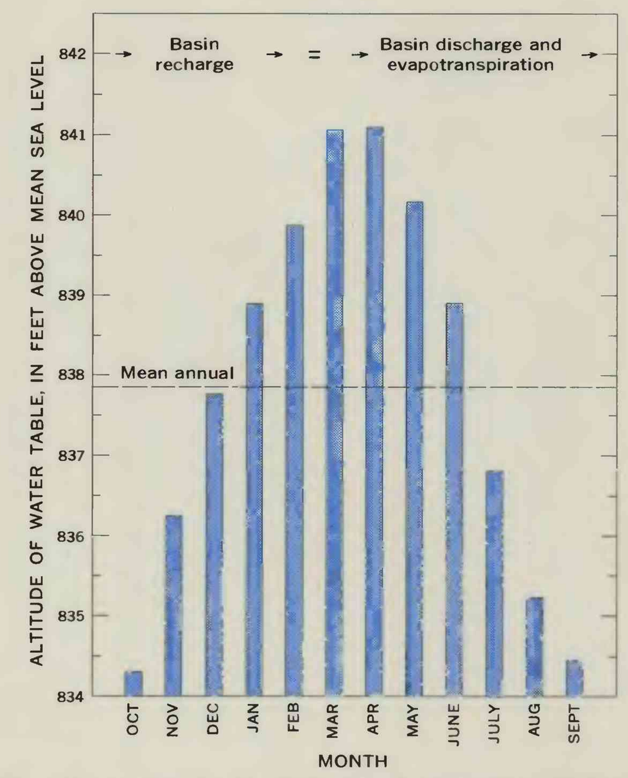


FIGURE 7.—GRAPH SHOWING MEAN MONTHLY GROUND-WATER LEVELS AT WINCHENDON, BASED ON 27 YEARS OF RECORD. *The long-term monthly averages of ground-water stage reflect the low streamflow.*

Evapotranspiration, outflow item 3 in the budget, is, in essence, part of and the reverse of precipitation. Actual evapotranspiration is limited by the availability of water and subsequently the density of vegetation and the length of the growing season. Potential evapotranspiration is the amount of water that would be returned to the atmosphere if the water were available. Therefore the potential evapotranspiration is governed by the temperature of the region and is not dependent on precipitation.

Thornthwaite (1948) devised a method of computing potential evapotranspiration from temperature. The monthly diagram of precipitation and potential evapotranspiration at a site near the west end of the basin, Turners Falls, is shown in figure 8. Computations indicate that potential evapotranspiration exceeds precipitation by about 4.5 inches in the normal year during the growing season. The actual amount of deficient moisture is probably less than 4.5 inches because of soil moisture utilization. Soil moisture will build up during the winter seasons and deplete during the growing season.

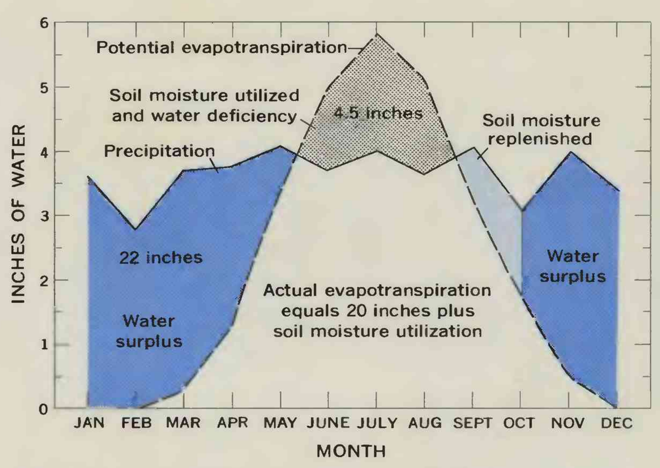
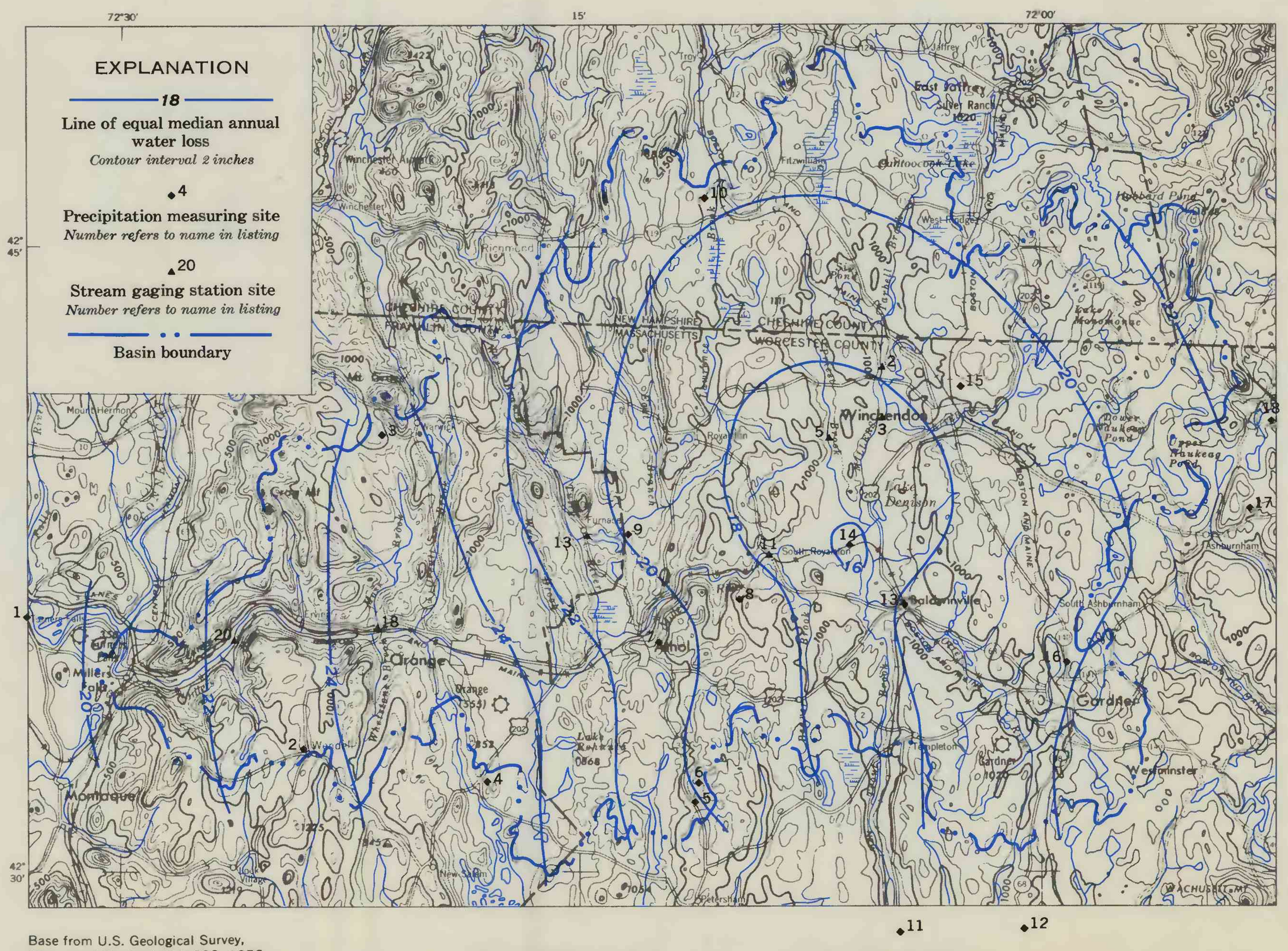


FIGURE 8.—DIAGRAM OF MONTHLY PRECIPITATION AND POTENTIAL EVAPOTRANSPIRATION AT TURNERS FALLS. *Potential evapotranspiration exceeds precipitation during the growing season.*

Lines of equal median annual water loss ± change in storage and the location and names of precipitation and stream discharge stations used to determine the lines, are shown in figure 9. Water loss is equal to evapotranspiration ± change in storage.



NO.	PRECIPITATION STATIONS	NO.	PRECIPITATION STATIONS
1.	Turners Falls (Montague)(b)	10.	Fitzwilliam (New Hampshire)(b)
2.	Wendell(a)	11.	Hubbardston(a)
3.	Warwick(a)	12.	Hubbardston (Williamsville)(b)
4.	New Salem (north)(c)	13.	Templeton (Baldwinville)(a)
5.	Petersham (Harvard Forest)(c)	14.	Winchendon (Birch Hill Dam)(b)
6.	Petersham (Nichewaug)(c)	15.	Winchendon(a)
7.	Athol (Waterworks)(b)	16.	Gardner(b)
8.	Phillipston(a)	17.	Ashburnham(b)
9.	Athol (Fryville)(a)	18.	Ashby(a)

NO.	GAGING STATIONS
2.	Tarbell Bk nr Winchendon
3.	Millers R nr Winchendon
5.	Priest Bk nr Winchendon
11.	Millers R at S Royalston
13.	East Br Tully R nr Athol
20.	Millers R at Erving

(a)Massachusetts Department of Public Health
(b)U.S. Weather Bureau
(c)Metropolitan District Water Supply Commission

SCALE 1:250 000
5 0 5 10 MILES
5 0 5 10 KILOMETERS
CONTOUR INTERVAL 100 FEET
DATUM IS MEAN SEA LEVEL

FIGURE 9.—MAP SHOWING MEDIAN ANNUAL (WATER YEAR) WATER LOSS FOR THE BASIN. *The median annual water loss for the basin is about 21 inches or about 49 percent of median annual weighted precipitation.*

The magnitude and frequency of water loss ± change in storage are shown in figure 10. Generally the ground water (fig. 7, basin recharge) is filled every year. Perennial supply of ground water is assured by not exceeding the capabilities of replenishment of storage. The water loss ± change in storage frequency, in figure 10, shows the probability of recurrence of years of greater than average use of storage.

The median year water loss is about 21 inches (fig. 10) and the budget equation balances, or inflow (precipitation is 43 inches) equals outflow (runoff is 22 inches plus water loss of 21 inches or 43 inches). There is 22 inches (about 382 mg per sq mi) available for use. The precipitation and runoff values are obtained from figures 5 and 6. However, for a dryer year, for instance the 10-year recurrence interval (a year similar to 1964), the runoff was 15 inches (about 260 mg per sq mi available for use, fig. 6). The budget for dryer than median years shows values of water loss plus the difference between precipitation and runoff to be near (slightly below) the median actual evapotranspiration.

However, during wetter than median years the actual evapotranspiration is satisfied and part of the precipitation aids in balancing or overbalancing the budget and the remainder may be available in storage and/or as increased streamflow within a year.

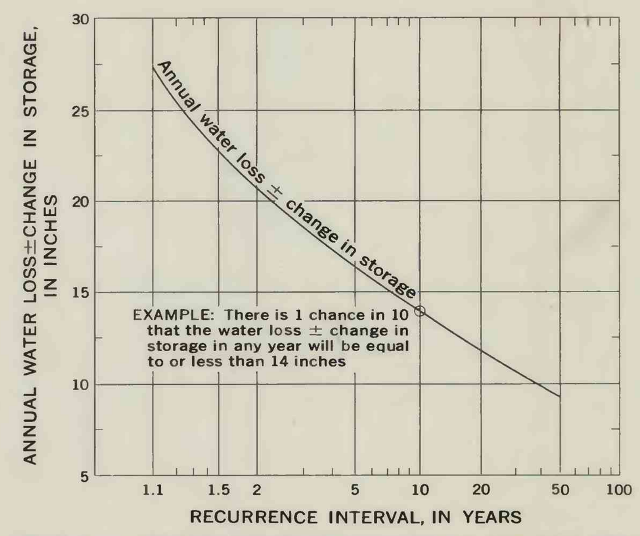


FIGURE 10.—GRAPH SHOWING MAGNITUDE AND FREQUENCY OF WATER LOSS OVER THE BASIN. *The frequency distribution was computed by subtracting equivalent years of annual precipitation from annual runoff for the period of record of each precipitation gage and averaging the resulting frequencies to obtain the average annual water loss ± change in storage frequency for the basin.*

WATER USE

The median annual precipitation, or water coming into the basin, amounts to 293 billion gallons. Of the incoming water, 150 billion gallons is available for use and 143 billion gallons is lost through evapotranspiration. Currently the domestic and industrial water use is about 5.0 billion gallons annually, 2.6 billion gallons of this is used by papermills on the Otter and Millers Rivers. Five billion gallons is about 3.5 percent of the total amount available during the median year. The amount of this water consumed is less than ⅒ of 1 percent. Figure 11 shows water used by municipalities and private industry for the major towns in the basin. The total water use, in figure 11, amounts to about 13.5 mgd, 4.0 mgd used by municipal water supplies and 9.5 mgd used by private industry.

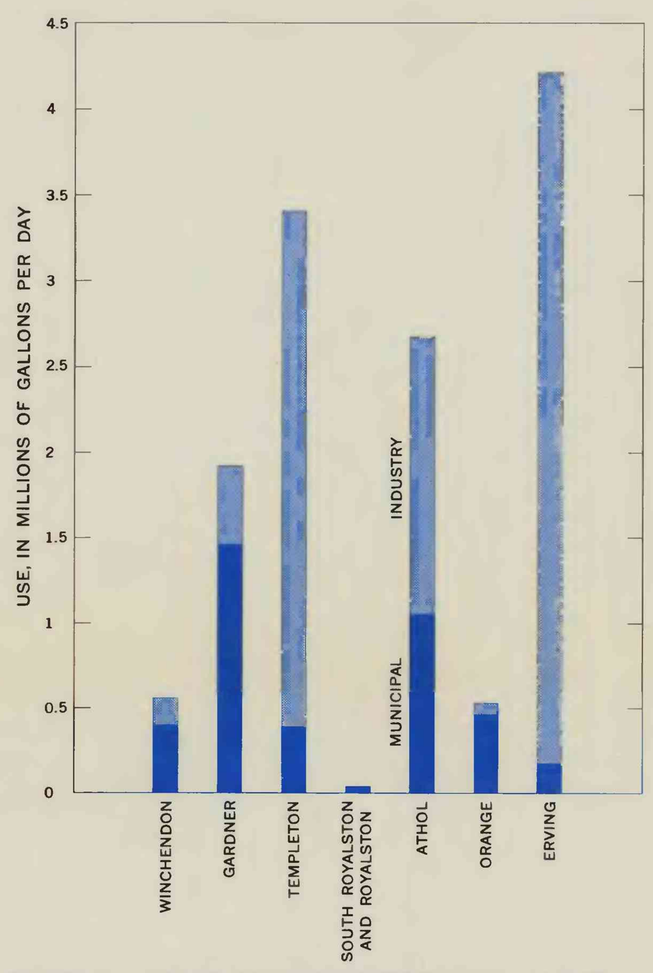


FIGURE 11.—GRAPH SHOWING CURRENT WATER USE OF SELECTED TOWNS. *For the basin as a whole, about 98 percent of the current use is from surface-water sources, the rest is from ground-water sources.*

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WATER RESOURCES OF THE MILLERS RIVER BASIN, NORTH-CENTRAL MASSACHUSETTS AND SOUTHWESTERN NEW HAMPSHIRE

By
M. R. Collings, D. R. Wiesnet, and W. B. Fleck

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