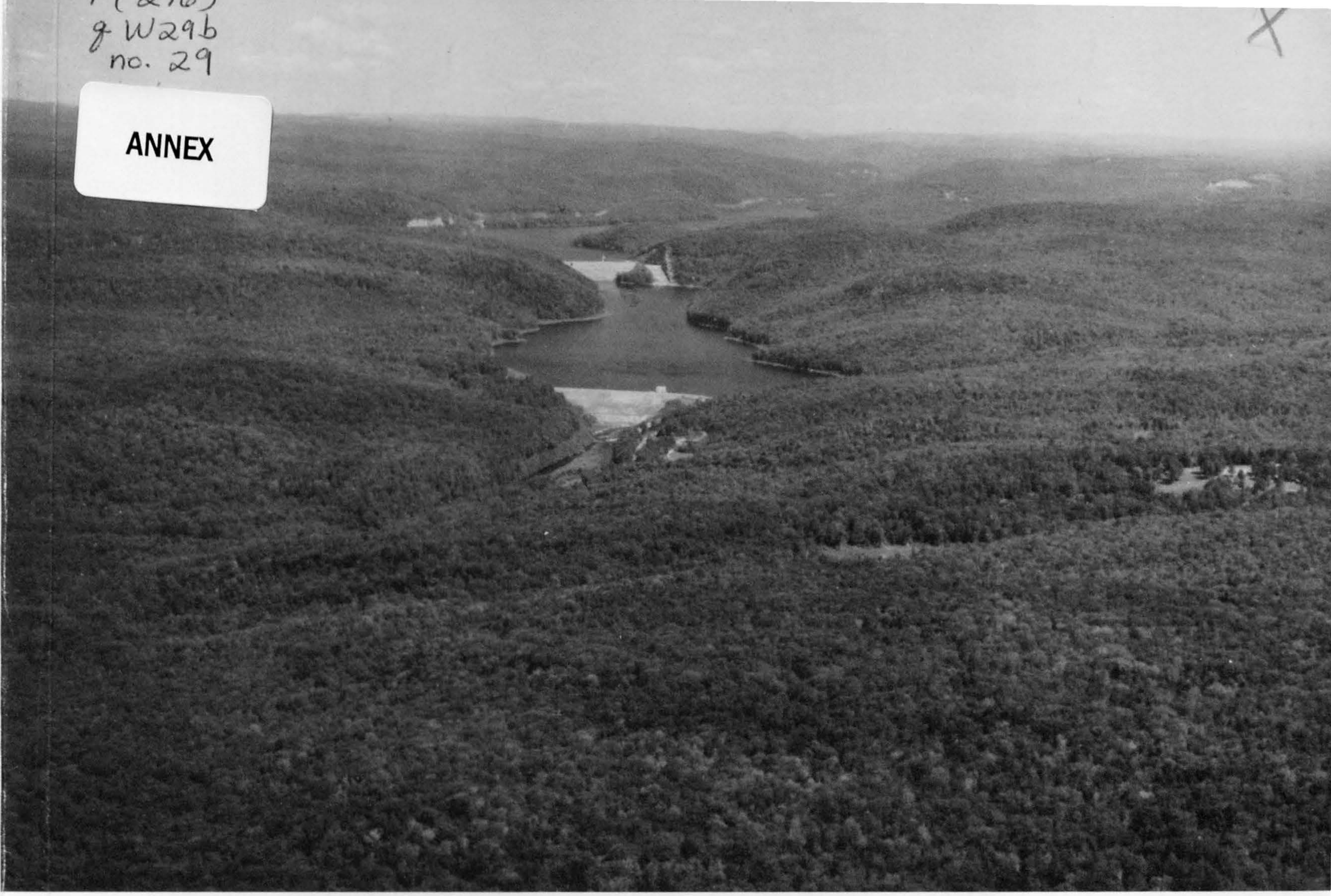


WATER RESOURCES INVENTORY OF CONNECTICUT

PART 9

FARMINGTON RIVER BASIN

BY

ELINOR H. HANDMAN, F. PETER HAENI, AND MENDALL P. THOMAS

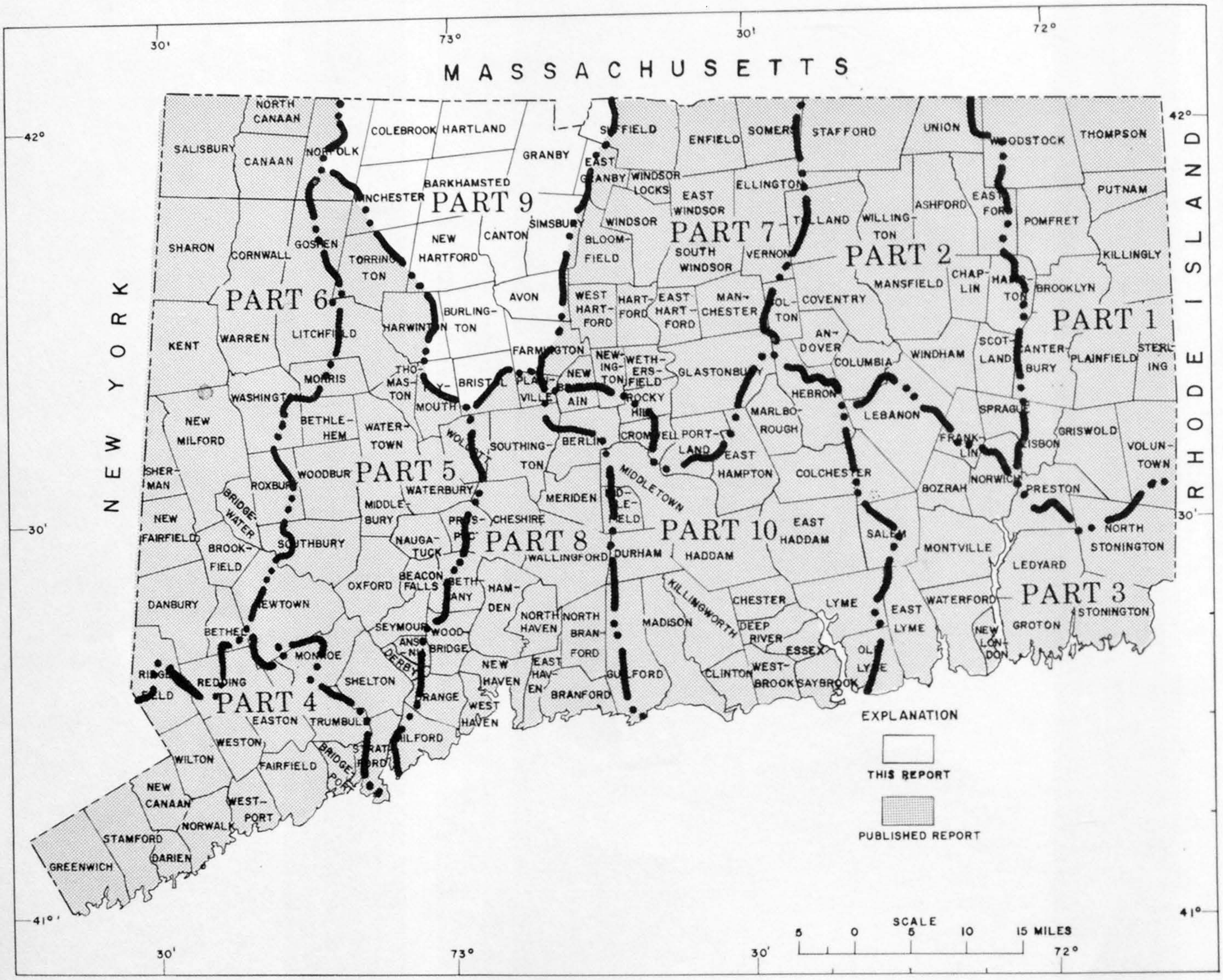
PREPARED BY THE
U. S. GEOLOGICAL SURVEY
IN COOPERATION WITH THE
CONNECTICUT DEPARTMENT OF ENVIRONMENTAL PROTECTION

CONNECTICUT WATER RESOURCES BULLETIN NO. 29

1986

COVER PHOTO--Colebrook River Lake is a valuable resource in the Farmington River Basin. Located on the West Branch of the Farmington River in the Town of Colebrook, it has a usable capacity of 31.5 billion gallons. Completed in June 1969 by the U.S. Army Corps of Engineers for multi-purpose use, it protects flood-prone areas along the Farmington River during periods of high flows and augments flows in the Farmington River during periods of low flows.

Photograph courtesy of U.S. Army Corps of Engineers, Waltham, Massachusetts.



THE WATER RESOURCES INVENTORY OF RIVER BASINS IN CONNECTICUT

PART 1-Quinebaug River Basin
PART 2-Shetucket River Basin
PART 3-Lower Thames and Southeastern Coastal River Basins
PART 4-Southwestern Coastal River Basins
PART 5-Lower Housatonic River Basin
PART 6-Upper Housatonic River Basin
PART 7-Upper Connecticut River Basin
PART 8-Quinnipiac River Basin
PART 9-Farmington River Basin
PART 10-Lower Connecticut River Basin

WATER RESOURCES INVENTORY OF CONNECTICUT
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FARMINGTON RIVER BASIN

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SUMMARY

The Farmington River basin covers 435 square miles in north-central Connecticut upstream from Tariffville and downstream of the Massachusetts state line. Most water in the basin is derived from precipitation, which averages 48 inches (366 billion gallons) per year. An additional 67 billion gallons of water per year enters the basin from Massachusetts in the West Branch of the Farmington River, Hubbard River, Valley Brook and some smaller streams. Of the total 433 billion gallons, 174 billion gallons returns to the atmosphere through evaporation and transpiration, 239 billion gallons flows out of the study area in the Farmington River at Tariffville, and 20 billion gallons is diverted for Hartford water supply.

Variations in streamflow at 23 continuous-record gaging stations are summarized in standardized graphs and tables that can be used to estimate streamflow characteristics at other sites. For example, mean flow and low-flow characteristics such as the 7-day annual minimum flow for 2-year and 10-year recurrence intervals, have been determined for many partial-record stations from the data for the 23 continuous-record stations.

Of the 31 principal lakes, ponds, and reservoirs in the basin, eight have usable storage capacities of more than 1 billion gallons. Two of the largest, Colebrook River Lake and Barkhamsted Reservoir, have more than 30 billion gallons usable storage.

Floods have occurred in the area in every month of the year. The greatest known flood on the Farmington River was in August 1955, which had a peak flow of 140,000 cubic feet per second at Collinsville. Since then, three major flood-control reservoirs have been constructed to reduce the hazards of high streamflow.

The major aquifers underlying the basin are composed of unconsolidated materials (stratified drift and till) and bedrock (sedimentary, igneous, and metamorphic). Stratified drift overlies till and bedrock in valleys and lowlands; it averages about 90 feet in thickness, and is capable of large sustained yields of water to individual wells. Based on hydrologic characteristics and available recharge, sixteen stratified-drift areas are selected as the most favorable for large-scale development. Potential yields can be estimated by several methods.

Small water supplies can be obtained from all aquifers. Wells in bedrock yield at least one to two gallons per minute at most sites. The probability of adequate yields for domestic supply is greater from sedimentary than from crystalline bedrock and is also greater from stratified-drift overburden than from till.

The quality of water from all sources in the basin is good except where adversely affected by swamp drainage, aquifer composition or human activities. The water is generally low in dissolved-solids concentration and is soft to moderately hard. Surface water is less mineralized than ground water, especially during high-flow conditions when it is primarily direct runoff. Samples of water collected from 20 streams during high flow had 34 mg/L median dissolved-solids concentration and 16 mg/L median hardness. Samples collected from the same sites at low flow had 52 mg/L median dissolved solids and 28 mg/L median hardness. In contrast, water from wells had 112 mg/L median dissolved-solids concentration and 60 mg/L median hardness.

Iron and manganese occur in objectionable concentrations in a few parts of the basin where streams drain swamps and aquifers are rich in iron- and manganese-bearing minerals. Five percent of streams at high flow, 21 percent at low flow, and 7 percent of ground-water samples contained iron in sufficient concentration to cause stains on plumbing fixtures and laundry.

Human activities have modified the quality of water in parts of the basin. The high bacterial content of the Pequabuck River, and the high nitrate and chloride concentrations in some ground-water samples, are evidence of man's influence.

The quantity and quality of water in the basin's streams and aquifers are satisfactory for a wide variety of uses, and, with suitable treatment, may be used for most purposes. The total amount of water used by 21 principal public supplies within the basin was 29 billion gallons in 1970. About 70 percent of this was used for domestic and commercial purposes, and nearly 30 percent was used by industry. Analyses of water from these systems show good quality.

INTRODUCTION

PURPOSE AND SCOPE

Connecticut has experienced a significant increase in population in the past few decades accompanied by industrial growth, changes in patterns of land use, and an improved standard of living. These factors have contributed to an increased demand for water that is expected to continue. The total amount of water reaching Connecticut is sufficient for immediate and anticipated needs, but its quantity and quality can vary in different areas and at different times. Therefore, as the need for water increases, so does the need for accurate information to plan the development of known supplies and to evaluate the water supply potential of new areas.

In 1959, the Connecticut General Assembly, on recommendation of the Water Resources Commission, authorized a statewide water-resources inventory. Under this and supplemental authorizations of the General Assembly, the U.S. Geological Survey, in cooperation with the Water Resources Commission (later incorporated into the Connecticut Department of Environmental Protection), has undertaken a series of studies to determine the quantity and quality of water available. For these investigations, Connecticut was divided into 10 study areas, each bounded by natural drainage divides, State boundaries, and Long Island Sound. (See map inside front cover.) The resulting reports are designed to be useful to planners, public officials, water-utility personnel, consulting hydrologists, well drillers, and others concerned with the development, management, use, conservation, and protection of water resources. This report describes one of the 10 study areas. A companion report (Hopkins and Handman, 1975) lists much of the data on which this report is based. A list of cooperative reports on the water resources of other areas is given on the back cover of this report.

THE FARMINGTON RIVER BASIN

The Farmington River basin is a part of the Connecticut River basin and extends north into Massachusetts. The term "Farmington River basin" as used in this report concerns the Connecticut part of the basin or 435 square miles out of the total drainage area of 577 square miles. (See figure 1.)

The Farmington River has its source in the Berkshire Hills of western Massachusetts and flows southerly through the Litchfield Hills of northwestern Connecticut to the town of Farmington. Here its course changes significantly and it flows north through a broad flat floodplain to Tariffville where a gorge defines the lower limit of the basin included in this report. Elevations range from 150 feet above sea level at Tariffville to more than 1,300 feet in the towns of Colebrook and Hartland in Connecticut and more than 1,900 feet in Massachusetts. The land surface is gently rolling within the valleys with high ridges and steep slopes dividing them.

The basin is largely rural with farms and woodlands. There is some residential and commercial development, particularly in the lower part. The upper reaches of the West Branch and East Branch are developed for water supply for the greater Hartford area by the Metropolitan District Commission.

GUIDE FOR THE USE OF THIS REPORT

Water supplies may be obtained from streams, lakes, and aquifers. Methods used to estimate the amount of water potentially available from each source and the techniques of development are sufficiently different to be treated in separate surface-water and ground-water sections of this report.

The availability of surface water is summarized on plate D, which shows the amount of available storage in selected reservoirs and low flows of major streams. Streamflow information in the text includes tables and graphs of flow duration, low-flow frequency and duration, flood peaks, frequency of floods, and draft-storage relations.

The availability of ground water is summarized on plates B and D. Plate B delineates the principal water-bearing units and the saturated thickness and composition of the stratified drift. The range in well yield from the principal water-bearing units is given. Plate D shows areas of stratified drift favorable for the development of large ground-water supplies and the estimated amount of water available under specific conditions. The text discusses the aquifers, the movement, and storage of ground water and the methods used to estimate the yields of the favorable areas. It includes data on yields for each of the main types of aquifers.

The quality of water is discussed in the section "Quality of Water." It is based primarily on interpretation of samples collected in 1971 from 41 sites on 26 streams, 7 sites on lakes and reservoirs, 108 wells and 3 precipitation-collection sites. Individual analyses are in Water Resources Data for Connecticut, 1971-75, (U.S. Geol. Survey, 1972-76). Sites are located on plate A.

Water use is shown on plate C and discussed in the text. Water quality data for the principal water-supply systems are listed in tables 22 and 29.

All data collection points referred to in this report are located on plate A which was also published in the companion basic data report (Hopkins and Handman, 1975). The basic-data report also contains well records, logs of wells and test holes, laboratory analyses of sediment samples, and lists sources of other published hydrologic and water-quality information.

A list of abbreviations, some common equivalent relations, and a glossary of technical terms are included at the end of this report.

ACKNOWLEDGEMENTS

The data on which this report is based were collected and analyzed by employees of the U.S. Geological Survey. Unpublished information was obtained from the files of several State agencies, including the Department of Environmental Protection, Water and Related Resources Unit (formerly the Water Resources Commission), the Fish and Water Life Unit (formerly the Board of Fisheries and Game), the Policy, Planning and Research Unit, the Connecticut Geological and Natural History Survey, the Department of Transportation, and the Connecticut Development Commission. Ground-water data from Geraghty & Miller, Inc., consulting ground-water geologists, and well- and test-hole data from the S. B. Church Co., and the R. E. Chapman Co., contributed significantly to the study. Other information and assistance were provided by property owners, well-drilling contractors, consultants, planning agencies, and company and public officials too numerous to name. All have helped to make this report possible; their contributions are sincerely appreciated.

THE HYDROLOGIC CYCLE

The hydrologic cycle is a term used to denote the circulation of water between oceans, land masses, and the atmosphere. When water vapor in the atmosphere condenses to form clouds, rain or snow may develop and fall onto the land surface. Part of this water flows across the land to collect in streams and lakes, and part seeps into the ground. Much of the water on the land surface or in the ground is soon evaporated or taken up by plants and returned to the atmosphere by transpiration. Some, however, moves through permeable soils and rocks and discharges into nearby streams and lakes. The part that reaches the streams, lakes, and eventually the oceans, is evaporated to complete the cycle.

As water moves through the hydrologic cycle, large amounts are stored temporarily in the atmosphere as vapor or clouds, on the land surface in streams, lakes, and oceans, and beneath the land surface as ground water. The amounts in storage change constantly as the water moves, and the physical, chemical, and biological properties also change. Quality of water in the hydrologic cycle is discussed separately.

THE WATER BUDGET

The hydrologic cycle in a drainage basin can be described by a water budget, which, like a fiscal budget, lists receipts, disbursements, and amounts on hand. The receipts of water in the Massachusetts part of the Farmington River basin consist almost entirely of precipitation on the area. Disbursements consist of surface runoff, ground-water runoff, and evapotranspiration. The receipts and disbursements of water in the report area in Connecticut are similar except for an additional disbursement, the diversion, of water from the report area to supply the needs of the Hartford Metropolitan District Commission. The amount on hand-stored within the basin is constantly changing. The amounts in each element of the budget may vary from year to year, but the budget always balances. Taking into account changes in storage, the disbursements are equal to the receipts. The approximate amounts involved in each of the major elements of the water budget in an average year are shown in figure 2.

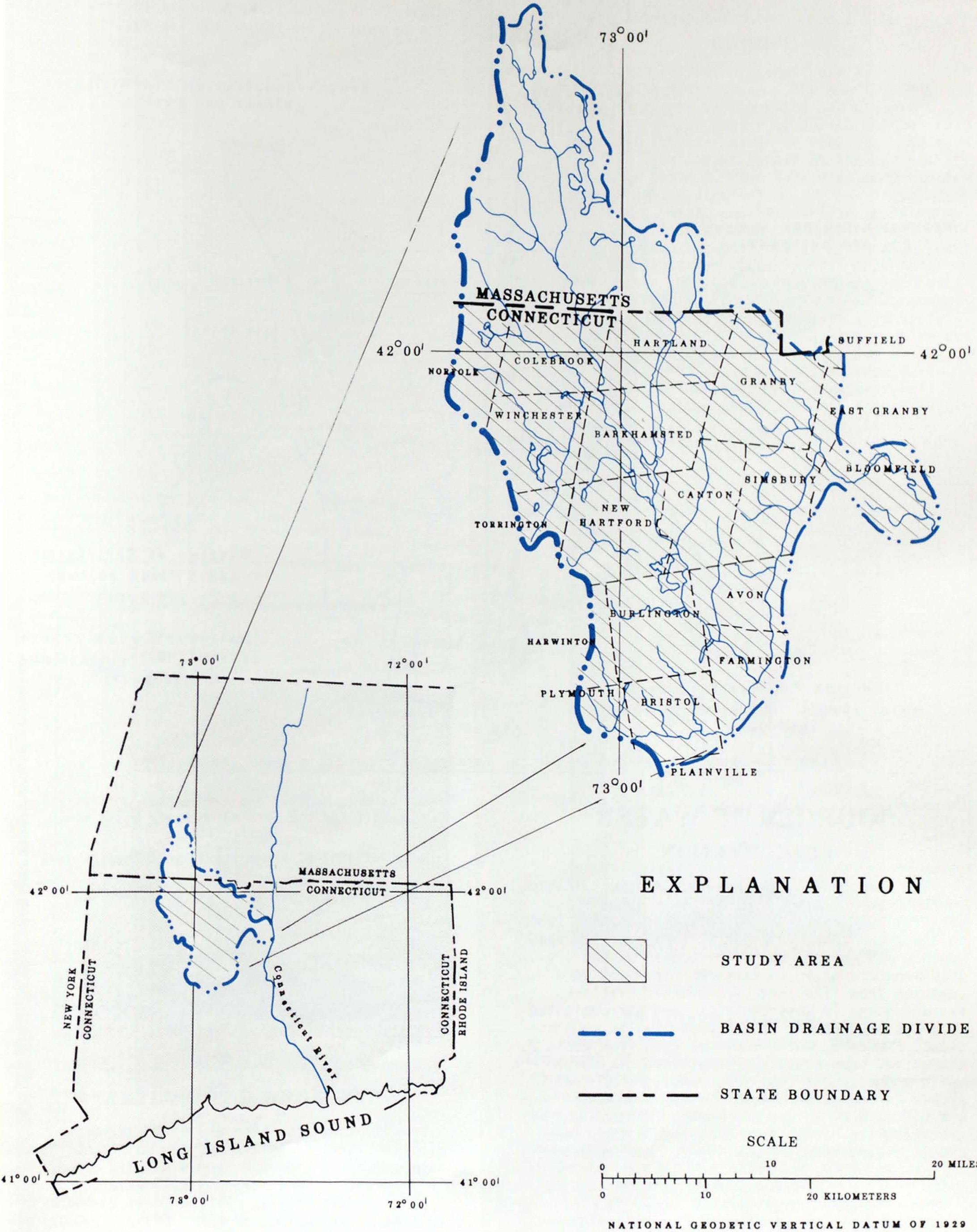


Figure 1.--The Farmington River basin and study area

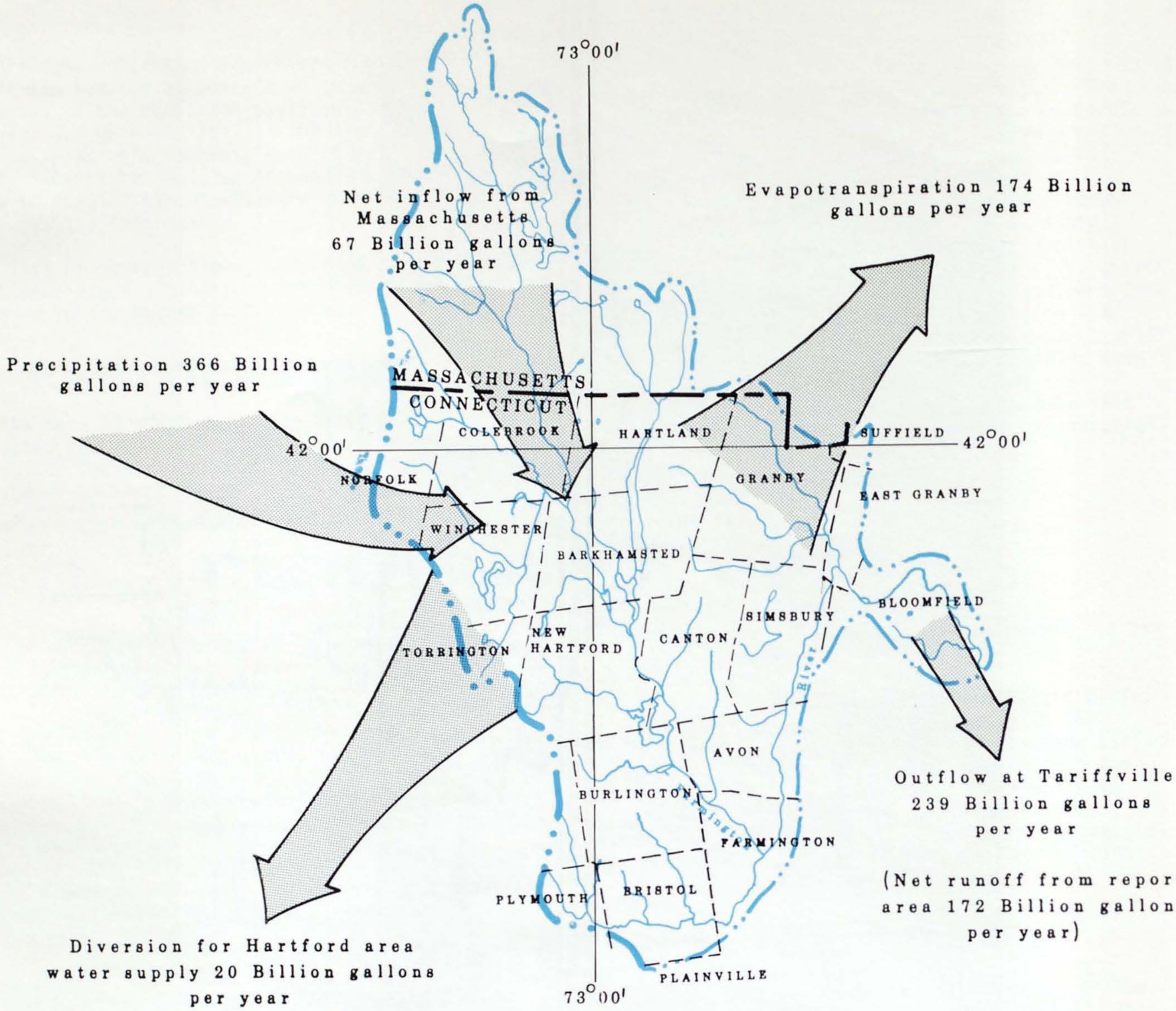


Figure 2.--Annual water budget for the Farmington River basin above Tariffville

SOURCES OF WATER

PRECIPITATION

The mean monthly and mean annual precipitation on the upper Farmington River basin above Tariffville for the reference period October 1930 to September 1960 are given in table 1. The mean monthly and mean annual water budget on the project area are given in table 2. The data were computed from five long-term weather stations, including one in Massachusetts, and were weighted in proportion to the area represented by each station. Figure 3, which includes data from table 2, shows that mean monthly precipitation is quite uniform throughout the year, ranging from 3.25 inches in February to 4.56 inches in November; the average is 4.04 inches per month. Minimum monthly precipitation ranges from 0.53 inches (September 1948) to 1.93 inches (July 1939). Maximum monthly

Table 1.--Mean monthly and mean annual precipitation and runoff for the Farmington River basin above Tariffville

(Data for 1931-60 water years, in inches of water)

Farmington River basin above Tariffville ($577\ mi^2$)		
Month	Precipitation	Runoff
October	3.71	1.21
November	4.43	1.97
December	3.85	2.09
January	3.78	2.37
February	3.09	1.99
March	4.18	4.12
April	3.94	4.68
May	3.87	2.68
June	4.20	1.64
July	4.09	.97
August	4.39	1.10
September	4.20	1.04
Annual total (water year)........	47.73	25.86

precipitation ranges from 5.42 inches (February 1951) to 25.35 inches (August 1955). The mean annual precipitation of 48.42 inches is equivalent to 366 billion gallons on the report area of 435 square miles.

Table 2.--Mean monthly and mean annual water budget calculated for the Farmington River basin project area

(Data for 1931-60 water years, in inches of water)

Month	Precipi-tation	Evapotrans-piration	Precipitation minus evapotrans-piration	Runoff	Change in storage[1]
October	3.74	1.72	2.02	1.22	0.80
November	4.56	.73	3.83	1.89	1.94
December	3.97	2/ .20	3.77	2.01	1.76
January	3.91	2/ .20	3.71	2.38	1.33
February	3.25	2/ .20	3.05	2.05	1.00
March	4.31	.38	3.93	4.10	- .17
April	4.04	1.50	2.54	4.32	- 1.78
May	3.98	2.84	1.14	2.62	- 1.48
June	4.17	3.80	.37	1.67	- 1.30
July	3.99	4.46	- .47	1.02	- 1.49
August	4.35	3.96	.39	1.15	- .76
September	4.15	2.98	1.17	1.02	.15
Mean annual	48.42	22.97	25.45	25.45	0

1 Minus sign indicates net loss in storage, no sign indicates net gain.

2 Evapotranspiration estimated for times when air temperature was above freezing. It is assumed to be zero when air temperature is at below freezing.

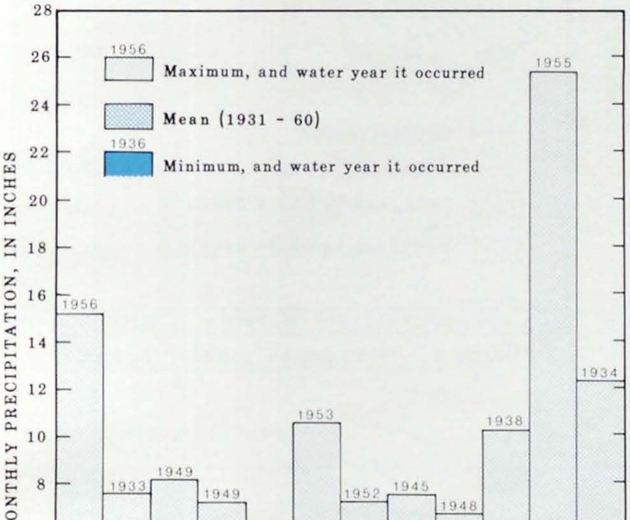


Figure 3.--Monthly precipitation

STREAMFLOW AND UNDERFLOW

Precipitation is the only natural source of water for all the stream basins that are entirely within the project area. However, a substantial source is streamflow entering from Massachusetts - estimated to be 67 billion gallons per year. Underflow into the basin is negligible. The inflow-outflow pattern of streamflow is shown in figure 2.

LOSSES OF WATER

RUNOFF

Long-term records of runoff are available for the Farmington River basin. The mean monthly and mean annual runoff on the total basin above Tariffville for the reference period October 1930 to September 1960 are given in table 1. The mean monthly and mean annual runoff on the project area are given in table 2. The data were computed from records of gaging stations on the Farmington River at New Boston, Mass. and Tariffville or Rainbow, Conn. Figure 4 shows that the mean monthly runoff follows a marked seasonal cycle, being much lower in July and September (1.02 inches) than April (4.32 inches). Minimum monthly values also vary seasonally, ranging from 0.28 inches (September 1957) to 1.84 inches (April 1946). This cycle reflects a combination of causes, among which are increased evaporation and transpiration during the summer, storage of water as ice and snow during the winter, and increased ground-water runoff in the spring. Maximum monthly runoff varies widely, ranging from 4.15 inches (July 1935) to 12.70 inches (August 1955).

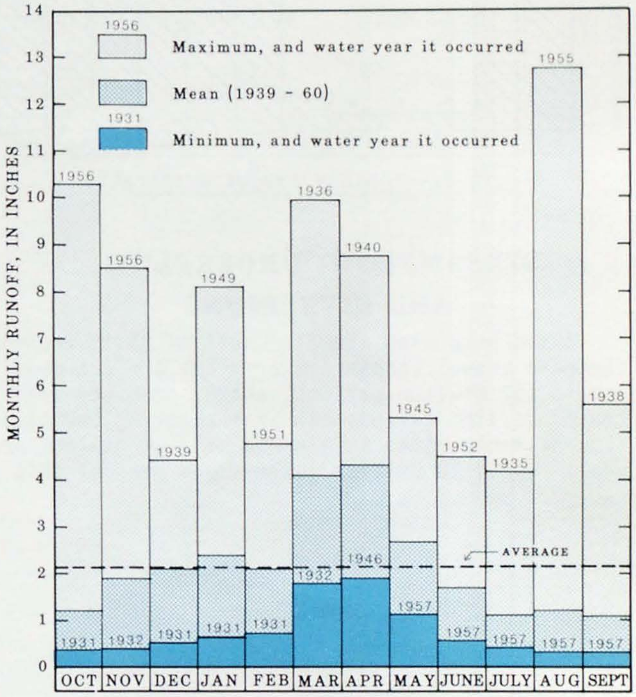


Figure 4.--Monthly runoff

EVAPOTRANSPIRATION

Much of the precipitation on the basin is returned to the atmosphere by evaporation and transpiration. The combined process, evapotranspiration, is difficult to measure directly and is commonly computed as a remainder after all other gains and losses have been accounted for. Measurements of reservoir and ground-water levels indicate that surface-water and ground-water storage have not changed substantially over long periods of time. Therefore, mean annual evapotranspiration is estimated to be equal to mean annual precipitation (48.42 inches) minus mean annual runoff (25.45 inches), or 22.97 inches.

Evapotranspiration rates change throughout the year in response to changes in air temperature and duration of daylight (Thornthwaite, 1952, p. 382). They are highest during the growing season, April through October, when the temperature is high and daylight hours are increased. The cycle repeats itself with little change year after year, and annual evapotranspiration is relatively constant for a given locality. Theoretical mean monthly evapotranspiration rates are computed by a method similar to the one described by Thornthwaite and Mather (1957) and are shown in table 2 and in figure 5.

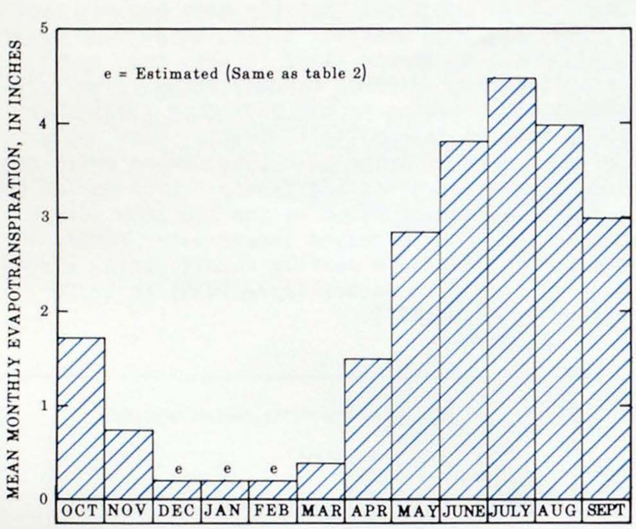


Figure 5.--Monthly evapotranspiration

STREAMFLOW, UNDERFLOW, AND DIVERSIONS

Based on a mean annual runoff of 25.45 inches, the mean annual streamflow from the project area totals 192 billion gallons, which, combined with the 67 billion gallons per year entering the basin from Massachusetts, totals 259 billion gallons per year. About 20 billion gallons per year of this total is diverted for municipal supply of the Hartford metropolitan area. Underflow out of the basin is negligible.

SUMMARY OF THE WATER BUDGET

The mean monthly water budget for the basin is shown in figure 6 and tabulated in table 2. Precipitation in late autumn and winter exceeds evapotranspiration, which results in increased storage and abundant runoff. Precipitation in late spring and summer is generally less than evapotranspiration; this results in decreased storage and sharply reduced runoff. Storage of water may thereby change in lakes, stream channels, aquifers, and soils.

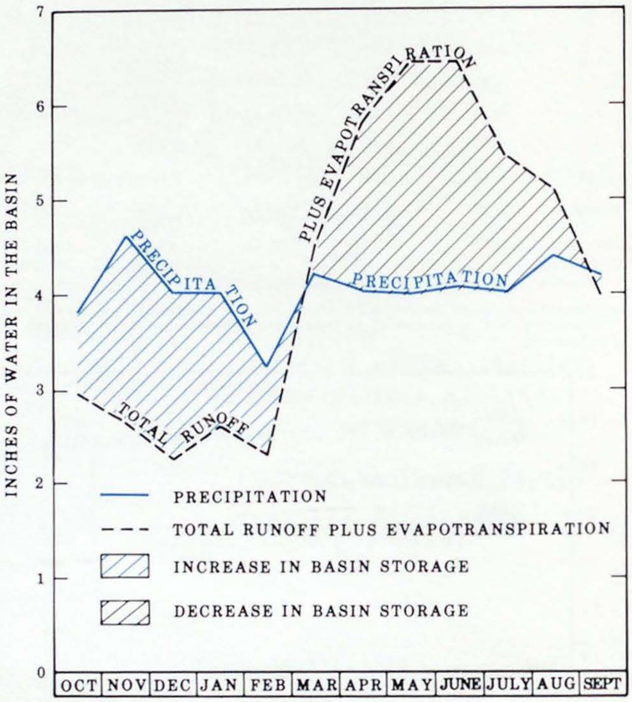


Figure 6.--Mean monthly water budget

Table 3.--Chemical and physical properties of precipitation and dry fallout

[Composite monthly samples from Colebrook, Burlington, and New Britain, April to November, 1971. Concentrations of chemical constituents in milligrams per liter. Individual analyses are in Water Resources Data for Connecticut (U.S. Geological Survey, 1971-72)]

Constituent or property	Station: Colebrook 1P Median	Range	Burlington 2P Median	Range	New Britain 3P Median	Range	All stations: Median	Range
Calcium (Ca)	0.6	0.1 - 8	1.1	0.3 - 5	0.6	0 - 3	0.6	0 - 8
Magnesium (Mg)	.10	.01- .7	.1	.01- .5	.10	.01- .38	.01	.01- .7
Sodium (Na)	.4	0 - 1.7	1	.4 - 22	.8	.3 - 3	.8	0 - 22
Potassium (K)	.3	0 - .8	.7	.2 - 3.2	.4	0 - 2.3	.4	0 - 3.2
Ammonium (NH_4)	.79	.31- 2.84	1.07	.1 - 19	.74	.27- 1.42	.93	.10- 19
Bicarbonate (HCO_3)	0	0 - 15	2	0 - 30	0	0 - 2	0	0 - 30
Sulfate (SO_4)	4.6	2 - 12	5.4	2.3 - 26	6.1	2 - 11	5.6	2 - 26
Chloride (Cl)	.38	.10- 2	.50	.2 - 3.1	.80	.3 - 6.5	.6	.10- 6.5
Nitrate (NO_3)	1.99	.66- 3.5	2.3	.88- 38	1.10	0 - 3.98	1.9	0 - 38
Dissolved solids, calculated	9	5 - 37	16	6 - 101	13	3 - 23	12	3 - 101
Hardness, as $CaCO_3$ (Ca + Mg)	2	0 - 23	3	1 - 14	2	0 - 9	2	0 - 23
Hardness, as $CaCO_3$ (Noncarbonate)	1	0 - 15	0	0 - 14	2	0 - 7	1	0 - 15
Specific conductance (micromhos at 25°C)	38	14 - 62	38	17 - 151	37	24 - 69	38	14 - 151
pH	4.5	4.3 - 6.7	5.6	4.5 - 6.8	4.5	3.8 - 5.6	4.6	3.8 - 6.8
Number of samples.......	24		24		24		24	

WATER-QUALITY CHANGES WITHIN THE HYDROLOGIC CYCLE

Water moving through the hydrologic cycle undergoes changes in chemical and physical properties. As it falls as rain or snow, it picks up or dissolves particles and gases from the atmosphere. Once on the ground, water continues to be modified by reactions with soils, rocks, and organic matter. Its chemistry depends largely on the composition and physical properties of the materials it contacts and on the length of time of contact. Thus, slow moving ground water generally is more highly mineralized than surface runoff. Lakes and streams are a mixture of surface runoff and ground-water runoff and are likely to be intermediate in mineral content. The quality of water in the diverse environments of the hydrologic cycle is shown in figure 7.

Water quality is modified by the activities of man at all stages of the hydrologic cycle. For example, soot and motor exhaust may affect the composition of precipitation; animal wastes, fertilizers, petroleum residues, and road salts may degrade the quality of surface runoff; leachate from landfills and septic tanks may contaminate ground water and industrial wastes may contaminate streams and ground water. On the other hand, water can be treated to remove particles and solutes to purify it. Figure 8 shows some man-induced changes in water quality.

QUALITY OF PRECIPITATION

Rainfall composition varies considerably from place to place, from storm to storm, and within a storm. The path of an airmass has a major influence on the composition of precipitation. Rain from storms from the ocean contains significant concentrations of chloride and sodium ions, especially near the coast. Storms that have passed over industrial areas contain impurities derived from fumes and smoke -- particularly sulfates and nitrates. High sulfate concentration is usually associated with acid rain which is common near urban areas. Dust, salt spray, industrial wastes, unburned fuel, pesticides and agricultural chemicals are dissolved and removed from the atmosphere by precipitation. Initial rainfall in a storm may contain higher concentrations of dissolved solids than are contained in later rainfall.

Precipitation samples were collected at two sites within the basin, and one site just south of the basin during April - November 1971, as shown in figure 9. For each station a composite sample containing all the precipitation and all the dry fallout for each month was analyzed. Values shown in figure 9 represent material from both sources. The monthly composite analysis was weighted to the monthly precipitation total for the calculation of each chemical parameter. The results of the analyses of samples from Colebrook, Burlington, and New Britain are summarized in table 3 and the sites are located in figure 9 and on Plate A.

Atmospheric water will adsorb carbon dioxide until equilibrium is reached at a pH of 5.7 (Barrett and Brodin, 1955, p. 252). A pH of 5.7 is, therefore, regarded as the neutral point with respect to acidity of atmospheric water (a pH of 7.0 is neutral for water solutions at the earth's surface). Table 3 shows that the median pH at each of the sites is below 5.7, which indicates acidic conditions. The general acidity is ascribed to the reaction between sulfur dioxide and water. Most of the atmospheric sulfur dioxide in the basin originates in urban areas to the south and west.

Although the amount of material carried into the basin by a single storm is small, the cumulative effect is substantial. During the 8-month sampling period, the total amount of precipitation-borne material that reached land surface in the basin was about 38,000 tons. The amounts of calcium, sodium, sulfate, and chloride that entered the basin during this period are shown in figure 9.

QUALITY OF RUNOFF

The quality of runoff under natural conditions is determined by the composition of precipitation, the type of earth materials encountered and the length of time runoff is in contact with earth materials. During periods of high flow most of the water in a stream channel is direct runoff. Its composition is close to that of precipitation with a lower concentration of dissolved solids and lower pH than stream water at low flow. During periods of low flow, most of the water in a stream channel is from ground water; its dissolved-solids concentration and pH are higher.

Water percolating into the ground dissolves more rock and soil than does water flowing over the surface. Thus ground water contains higher concentrations of dissolved solids. These relationships are shown in table 4, which summarizes dissolved-solids concentration and pH of precipitation, surface water, and ground-water samples.

More detailed information on the quality of surface water and ground water is included in the section titled "Quality of Water".

Table 4.--Dissolved-solids concentration and pH of water from different sources

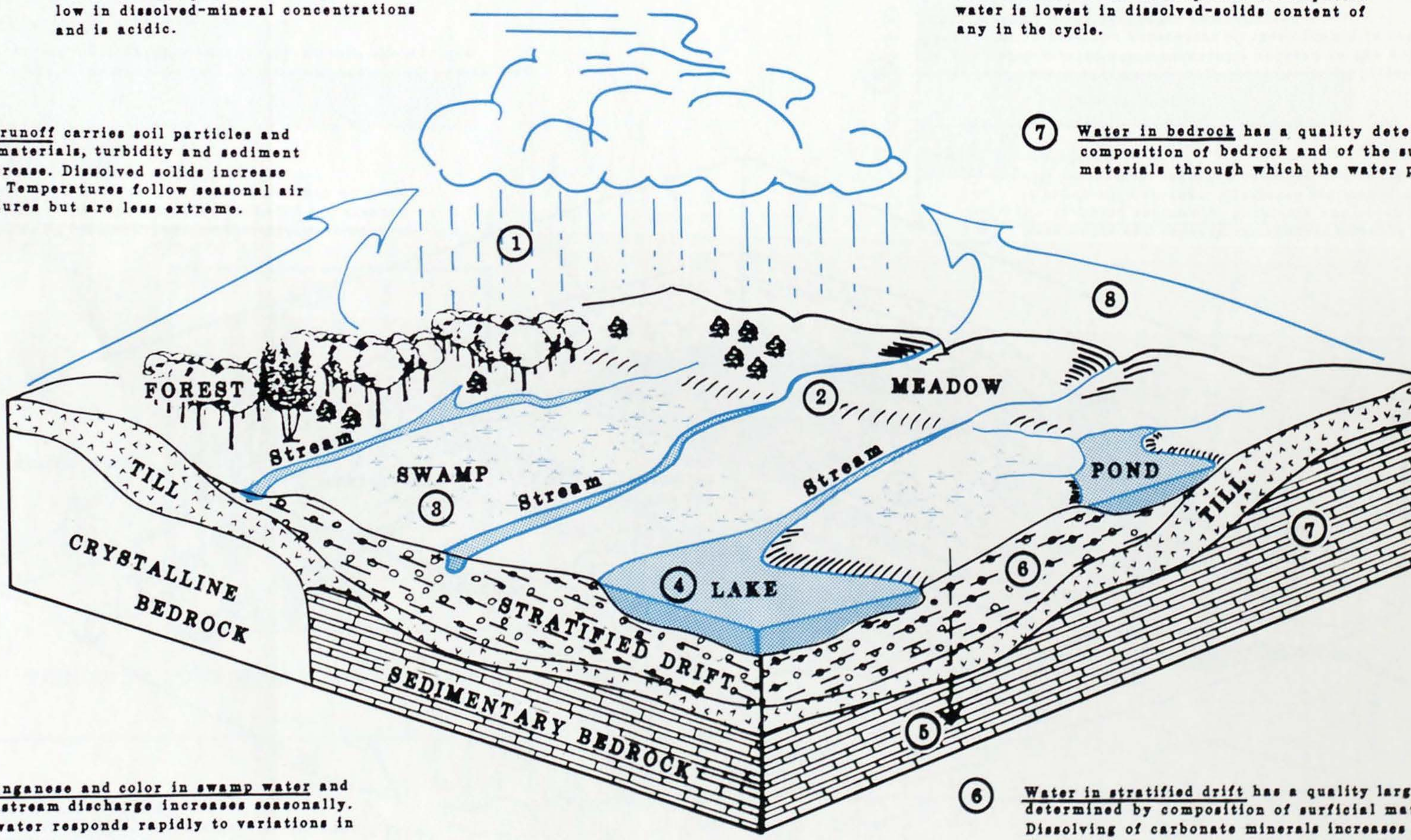
		Source of water			
		Precipitation	Reservoirs	Streams	Ground water
Dissolved solids, in milligrams per liter	Median	12	36	43	112
	Range	3 - 101	26 - 149	20 - 199	36 - 1895
pH	Median	4.6	6.7	6.8	7.8
	Range	3.8 - 6.8	6.4 - 7.2	5.2 - 7.8	6.8 - 8.4
Number of samples		24	8	40	88
Number of sites		3	8	20	88

(1) **Precipitation**-Water from the atmosphere dissolves dust particles and gasses but is low in dissolved-mineral concentrations and is acidic.

(8) **Evapotranspiration** moves in vapor form from the land surface to the atmosphere. Atmospheric water is lowest in dissolved-solids content of any in the cycle.

(2) **Surface runoff** carries soil particles and organic materials, turbidity and sediment loads increase. Dissolved solids increase slightly. Temperatures follow seasonal air temperatures but are less extreme.

(7) **Water in bedrock** has a quality determined by composition of bedrock and of the surficial materials through which the water passes.



(3) **Iron, manganese and color in swamp water** and its downstream discharge increases seasonally. Swamp water responds rapidly to variations in air temperature.

(6) **Water in stratified drift** has a quality largely determined by composition of surficial materials. Dissolving of carbonate minerals increases hardness. Ground water also moves upward from the bedrock and influences the quality of water in the surficial deposits.

(4) **Storage of water** in lakes, ponds, and reservoirs reduces turbidity and sediment load while sunlight bleaches out color. Thermal stratification in deep water depletes oxygen in the lower layers.

(5) **Infiltration** increases the mineral region of water during low-flow periods. The more highly mineralized ground-water runoff may substantially increase the mineral content of smaller streams.

Figure 7.--Quality of water in the hydrologic cycle

[Water is most pure as vapor in the atmosphere; it becomes progressively more mineralized as it moves through the cycle]

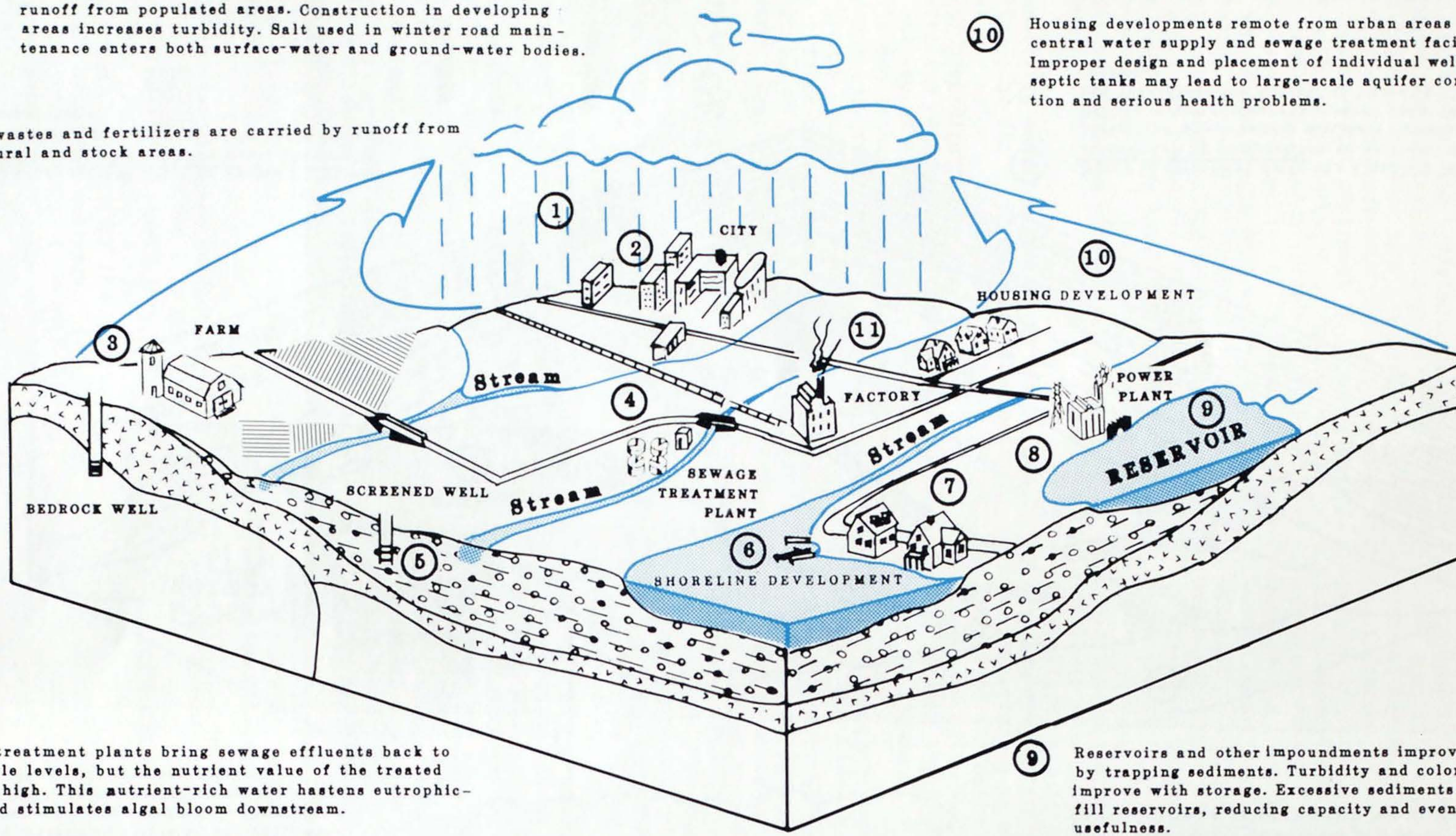
(1) Gaseous, liquid, and solid materials produced by man's activities are dissolved and absorbed by precipitation and returned to earth. Sulfur, lead, unburned hydrocarbons, soot, and fly ash all contribute to mineralization of precipitation before it reaches land surface.

(11) Industry contributes waste to the air, water, and ground. Many industrial wastes are difficult and expensive to treat. Often direct discharge to streams is the disposal method employed and miles of downstream reach are contaminated as a result. Burial of solid waste merely delays the eventual discharge of the noxious material into nearby waterways or the ground-water reservoir.

(2) Petroleum residue from paved areas, leachate from wastes, fertilizers from lawns and gardens, are all carried by runoff from populated areas. Construction in developing areas increases turbidity. Salt used in winter road maintenance enters both surface-water and ground-water bodies.

(10) Housing developments remote from urban areas lack central water supply and sewage treatment facilities. Improper design and placement of individual wells and septic tanks may lead to large-scale aquifer contamination and serious health problems.

(3) Animal wastes and fertilizers are carried by runoff from agricultural and stock areas.



(4) Sewage treatment plants bring sewage effluents back to acceptable levels, but the nutrient value of the treated water is high. This nutrient-rich water hastens eutrophication and stimulates algal bloom downstream.

(9) Reservoirs and other impoundments improve water quality by trapping sediments. Turbidity and color of the water improve with storage. Excessive sediments will gradually fill reservoirs, reducing capacity and eventually end their usefulness.

(5) Heavily pumped wells near streams receiving wastes may induce poor quality surface water into the aquifer.

(8) Fossil fuel plants contribute large amounts of materials to the air which precipitation eventually returns to the earth. Water used to cool the generators of these plants is returned to the streams at an increased temperature.

(6) Lakes and ponds which receive nutrients (nitrate and phosphate ions) and sediments are prematurely aged. Continuation results in unsightly algal blooms in summer.

(7) Intensive development can cause contamination of ground water and pollution of the lake because of waste disposal problems.

Figure 8.--Effects of human activities on water quality
[Chemical and physical properties are modified, usually resulting in deterioration in quality]

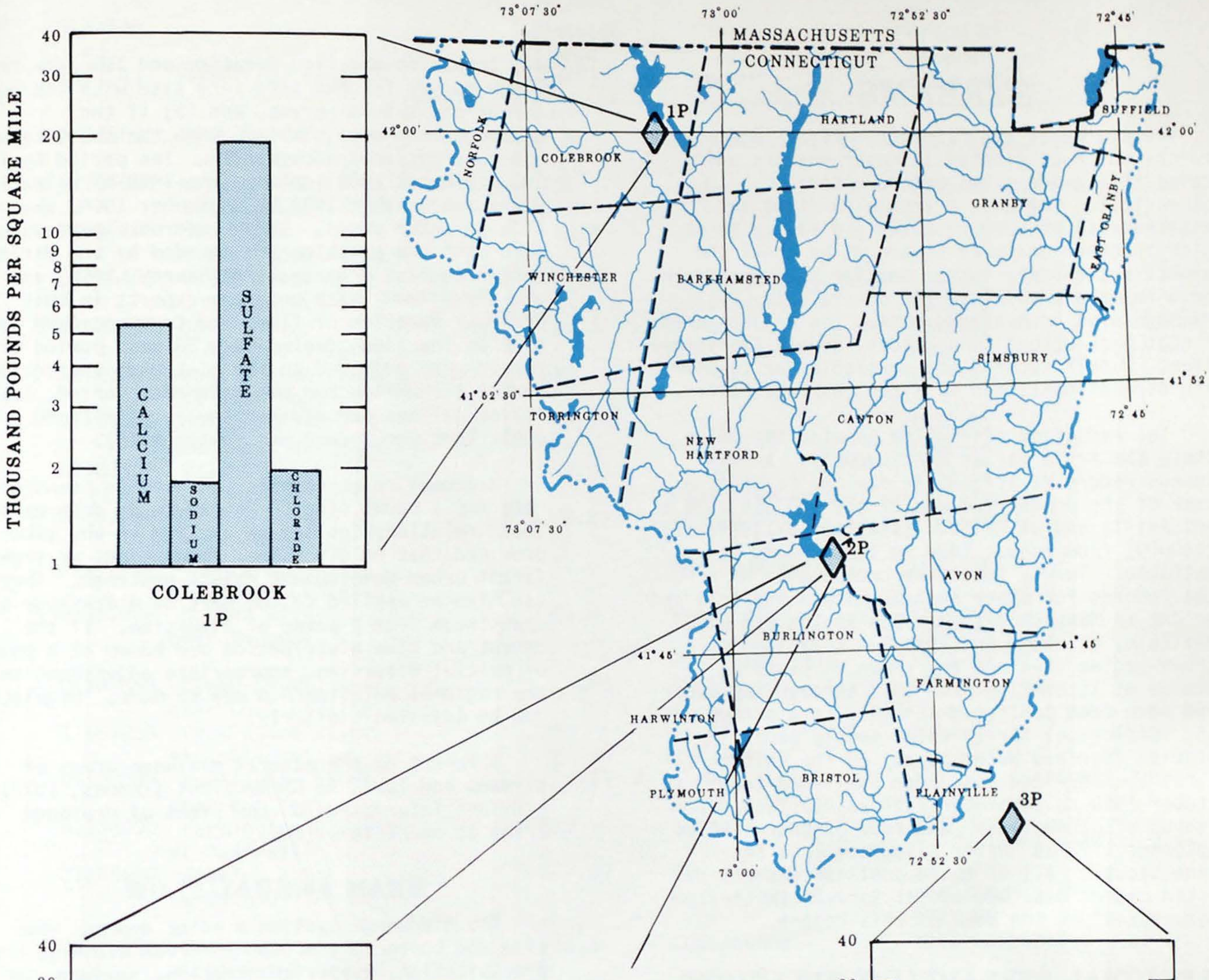


Figure 9.--Chemical quality of precipitation and dry fallout at Colebrook, Burlington and New Britain

[Accumulation of calcium, sodium, sulfate and chloride, April to November, 1971]

SURFACE WATER

STREAMS

The source of the Farmington River is its West Branch, which originates in Massachusetts and drains 104 square miles before entering Connecticut. The East Branch also rises in Massachusetts as Hubbard River and Valley Brook, which together drain 28 square miles above the Connecticut border. Other smaller streams add to these to make a total of 142 square miles of drainage area in Massachusetts. The project area, or that part within Connecticut, covers 435 square miles. Runoff records are available for the three main streams mentioned at sites near the border.

The amount of streamflow passing any point within the basin varies continuously. A continuous record of streamflow for the Farmington River at the downstream end of the project area at Tariffville and at Rainbow (stations 01189995 and 01190000) from August 1928 to the present is available. Twenty four other continuous or partial records for other streams within the area and for one in Massachusetts at New Boston are also available, as shown in table 5. Locations of stream-gaging stations are shown on plate A. Records of streamflow from 1913 through September 1960 have been published annually in a series of U.S. Geological Survey water supply papers entitled "Surface Water Supply of the United States". They have also been published from October 1960 to September 1964 as "Surface Water Records of Connecticut" and from October 1964 to September 1982 as "Water Resources Data for Connecticut." All of these publications are listed under "U.S. Geological Survey" in the "References" at the back of this report.

REGIONAL STREAMFLOW RELATIONS

Streamflow records are the basis for determination of water-supply potential and are used to estimate mean annual flows, duration of flows, frequency and duration of low and high flows, and magnitude and frequency of floods. For the purpose of this study, all records were extended or shortened to 30-year reference periods, beginning in April or October 1930 and ending in March or September 1960, so that comparable estimates could be made for any selected location. Short-term records were adjusted by (1) selecting a long-term site nearby with similar geologic characteristics, (2) comparing the flow-duration and low-flow frequency curves for the long-term site with its concurrent short-term curves, and (3) if the distributions were similar, then the short-term site was adjusted accordingly. The period April 1930 to March 1960 includes the 1930-59 climatic years and October 1930 to September 1960, the 1931-60 water years. These reference periods conform with the practice recommended by the World Meteorological Organization (Searcy, 1959) and are consistent with previous reports in this series. Duration of flows and frequency and duration of low flows during this 30-year period of record were adjusted to the statewide average mean annual streamflow for the reference period, 1.16 million gallons per day per square mile (1.80 cubic feet per second per square mile).

Regional relationships are used to transfer data for a known site to one where no data exists. These relationships may be applied to any site provided that no diversion, regulation, or significant urban development exists upstream. They can also be applied to the part of a drainage area downstream from a point of diversion. If the amount and time distribution are known at a point of partial diversion, appropriate adjustment to the regional relationship may be made. Regulation can be adjusted similarly.

A report on the natural drainage areas of streams and lakes in Connecticut (Thomas, 1972) provides information on the sizes of drainage areas at specific sites.

MEAN ANNUAL FLOW

The discharge passing a point depends upon size and topography of the upstream drainage area, precipitation, evapotranspiration, surface- and ground-water storage, and the influence of man on the system. The areal variation in the mean annual runoff of unregulated streams-streams with discharges not affected by upstream controls is shown by lines of equal streamflow ratio (figure 10). These lines represent the ratio of local mean annual runoff to the average statewide value of 1.16 million gallons per day per square mile (1.80 cubic feet per second per square mile) for the reference period water years 1931-60. To determine the amount of streamflow at a specific site, use a weighted average ratio representative of the entire upstream drainage area.

Table 5.--Periods and types of streamflow records at gaging stations

Station no. (pl. A)	Station name	Drainage area (mi^2)	Type of record	Period of record (water years)
01185500	West Branch Farmington River at New Boston, Mass.	92	Continuous	1913 to current year
01186000	West Branch Farmington River at Riverton.	131	Do.	1955 to current year
01186100	Mad River at Winsted.	18.5	Do.	1957-69
01186400	Sandy Brook at Robertsville.	34.9	Low flow only	1961-67
			Continuous	1968-76
01186500	Still River at Robertsville.	84.7	Do.	1948-67
				1969 to current year
01187000	West Branch Farmington River at Riverton.	217	Do.	1929-55
01187300	Hubbard River near West Hartland.	20.7	Do.	1938-55
				1956-78
01187400	Valley Brook near West Hartland.	7.03	Do.	1940-72
			Peak flow only	1973-74
01187680	Cherry Brook near Canton Center.	8.23	Continuous	1967-71
01187700	Cherry Brook at Canton Center.	12.6	Low flow only	1961-66
01187800	Nepaug River near Nepaug.	23.5	Continuous	1918-55, 1958-72
			Peak flow only	1973-84
01187850	Clear Brook near Collinsville.	.59	Continuous	1917-73
01187980	Farmington River at Collinsville	360	Do.	1963-77
01188000	Burlington Brook. near Burlington	4.13	Do.	1931 to current year
01188090	Farmington River. at Unionville	378	Do.	1977 to current year
01188100	Roaring Brook at Unionville.	7.60	Low flow only	1961-78
			Peak flow only	1962-68, 1971-84
01189000	Pequabuck River at Forestville.	45.4	Continuous	1941 to current year
01189180	Hop Brook at West Simsbury.	1.52	Do.	1967-71
01189190	Stratton Brook at West Simsbury.	1.41	Do.	1967-71
01189200	Stratton Brook near Simsbury.	5.13	Low flow only	1961-71
			Peak flow only	1964-66, 1972-84
			Continuous	1966-71
01189210	Hop Brook near Simsbury	10.8	Do.	1966-71
01189300	East Branch Salmon Brook at North Granby.	12.4	Low flow only	1961-65, 1967, 1969-73
01189390	East Branch Salmon Brook at Granby.	39.5	Continuous	1964-76
01189400	West Branch Salmon Brook at West Granby.	15.7	Low flow only	1961-65, 1967-73
01189500	Salmon Brook at Granby.	67.4	Continuous	1946-63
01189995	Farmington River at Tariffville.	577	Peak flow only	1913-28
			Continuous	1928-39, 1971 to current year
01190000	Farmington River at Rainbow.	589	Continuous	1940 to current year

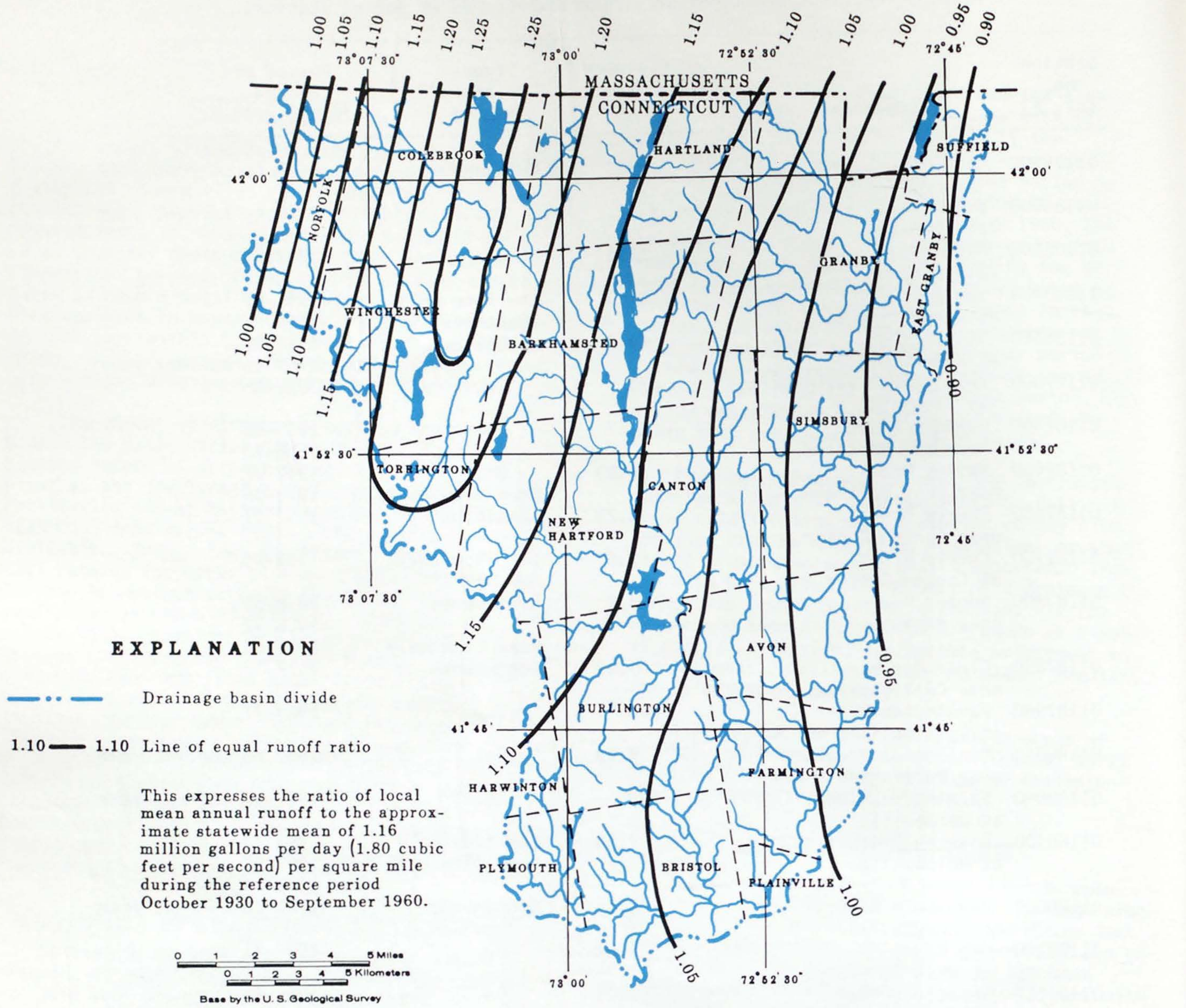


Figure 10.--Areal variations in mean annual runoff

FLOW-DURATION CURVES

Cumulative frequency curves, called flow-duration curves, show the average percentage of time the specific daily flows are equaled or exceeded at sites for which continuous records of daily flow are available. Flow-duration curves based on continuous records from stream-gaging stations in the Farmington River basin for the reference period 1930-60 are shown in figures 11-16. Also shown are the minimum and maximum limits of duration in a single year.

A family of regional flow-duration curves developed by Thomas (1966) for ungaged sites, shows the effect of basin surficial geology on the shape of the curves. Regional flow-duration curves based upon gaging-station records in the physiographic region known as the "Litchfield Hills" apply to this basin and are shown in figure 17.

In general, the curves show that streamflow from areas having a large proportion of coarse-grained stratified drift is more evenly distributed in time than streamflow from areas mantled largely by till. This reflects the generally large infiltration rate and storage capacity of coarse-grained stratified drift and the resultant high proportion of ground-water runoff from these deposits. In contrast, the uneven time distribution of streamflow from till areas reflects the low infiltration rate and low storage capacity of these deposits and the resultant large proportion of surface runoff.

The flow-duration curves shown in the figure apply only to unregulated streams if their mean annual streamflow is 1.16 Mgal/d/mi^2 (1.80 ft^3/s/mi^2), the statewide average for the reference period 1930-60. They may be used with figure 10 and the diagram in figure 18 to estimate flow-duration curves for ungaged sites on unregulated streams in the basin.

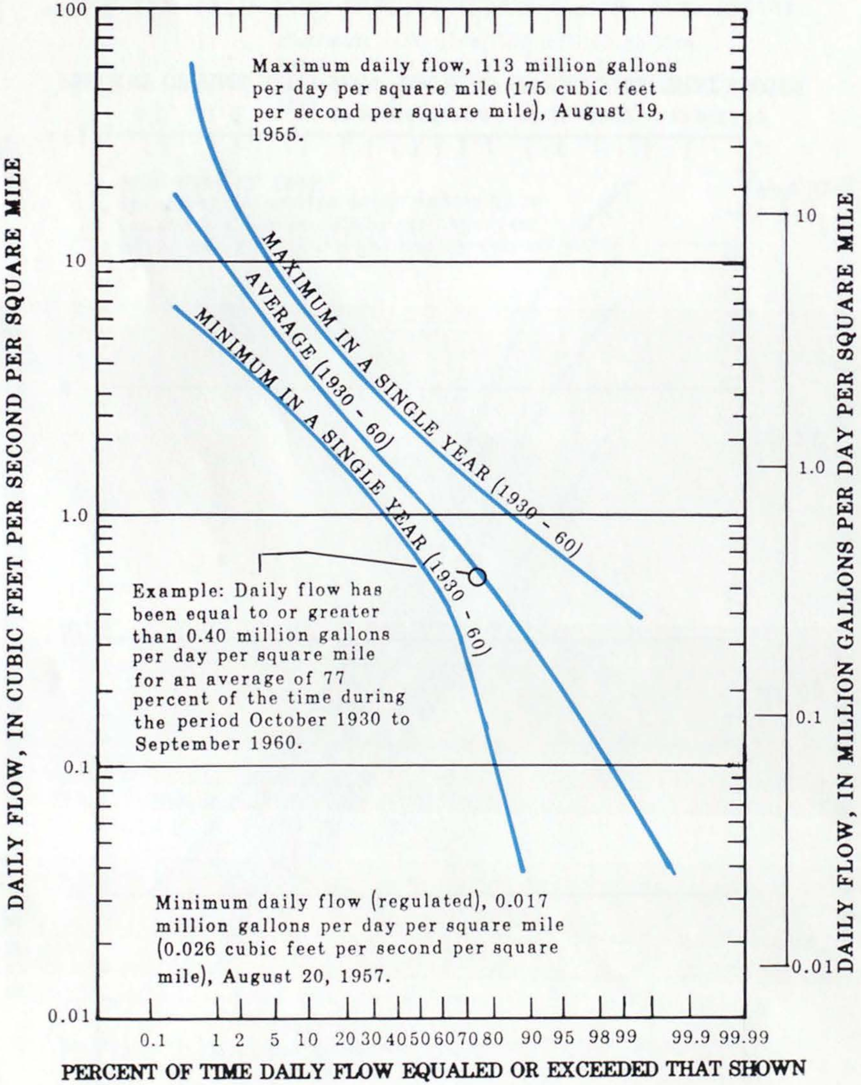


Figure 11.--Daily flow duration at West Branch Farmington River at New Boston, Massachusetts

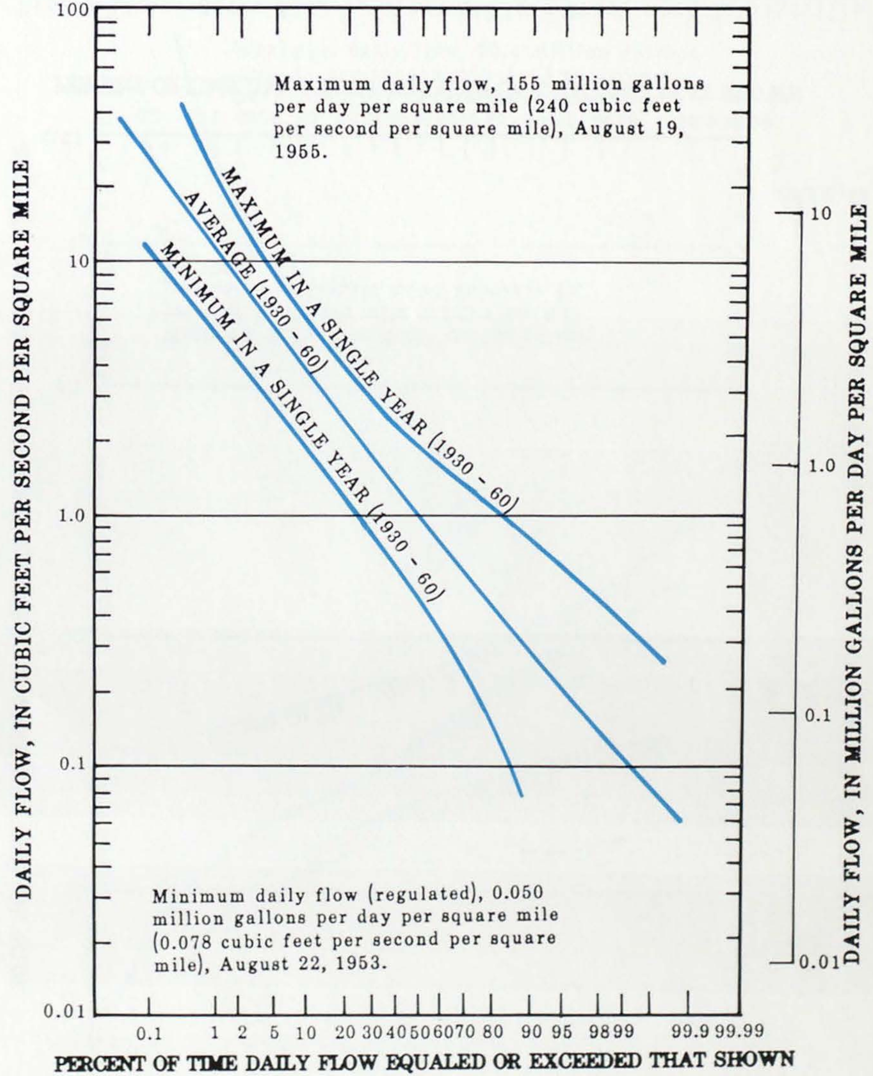


Figure 12.--Daily flow duration of West Branch Farmington River at Riverton

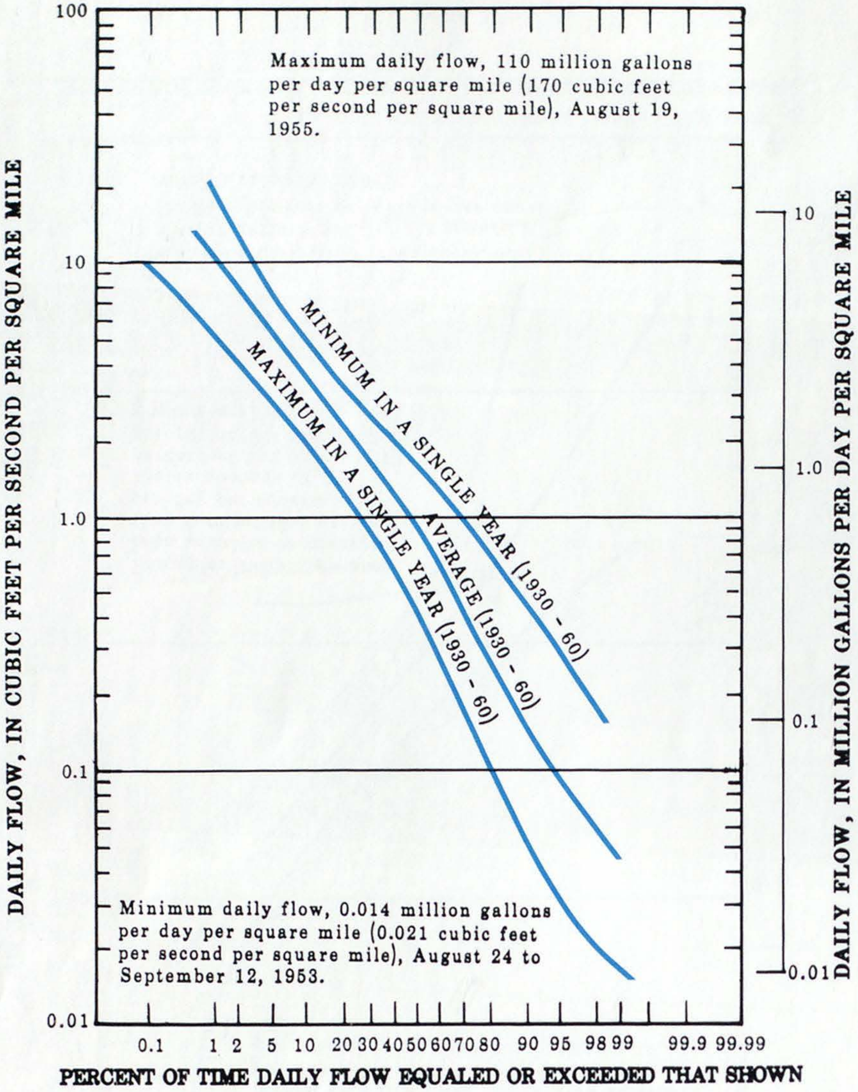


Figure 13.--Daily flow duration of Nepaug River near Nepaug

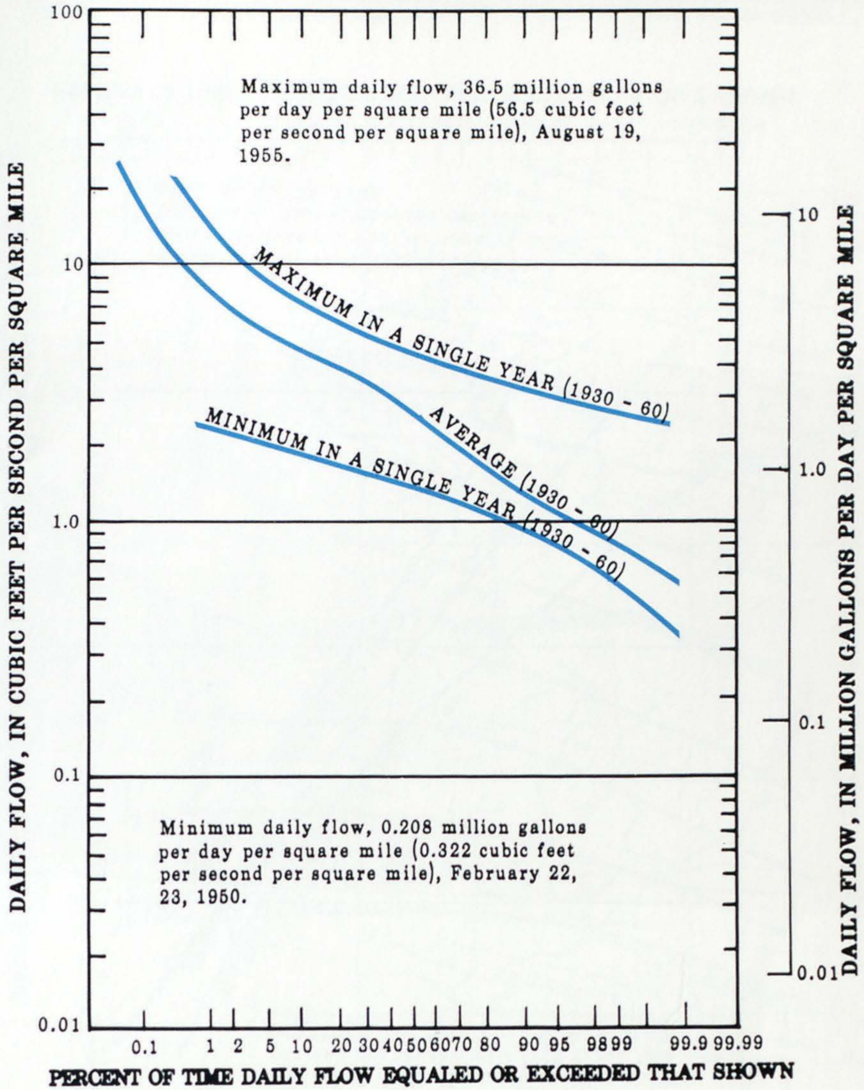


Figure 14.----Daily flow duration of Clear Brook near Collinsville

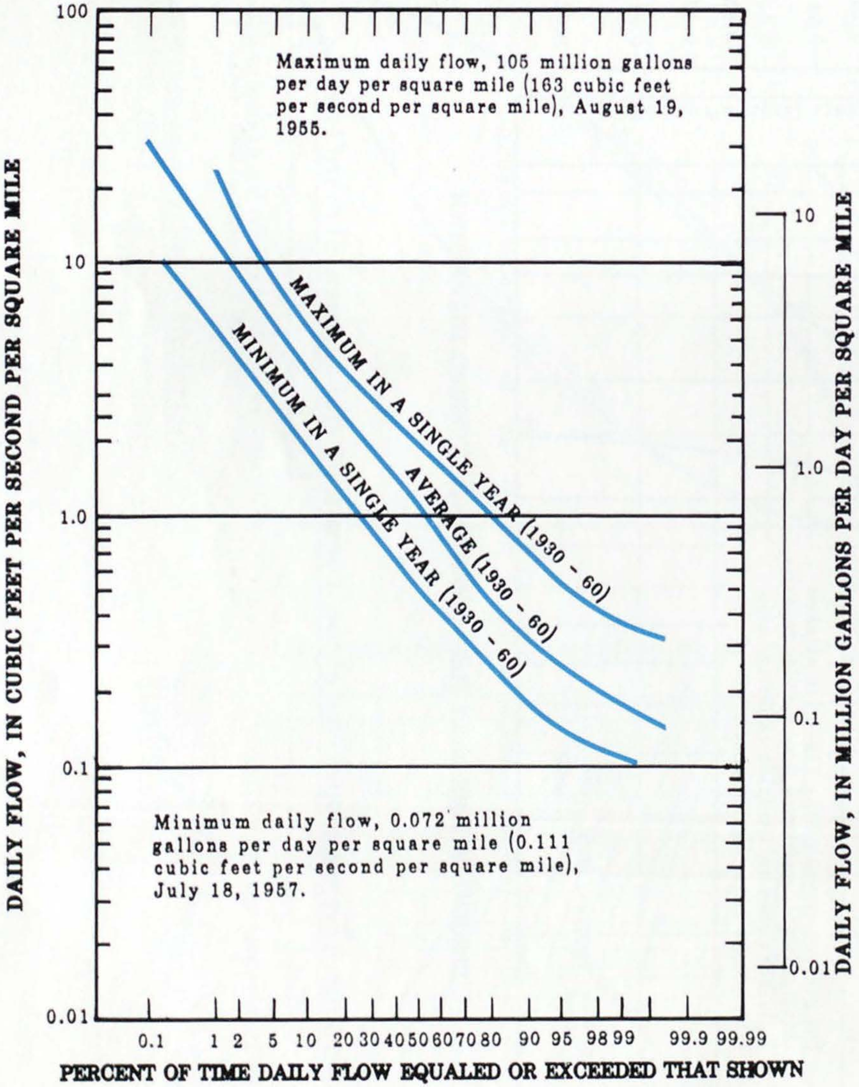


Figure 15.--Daily flow duration of Burlington Brook near Burlington

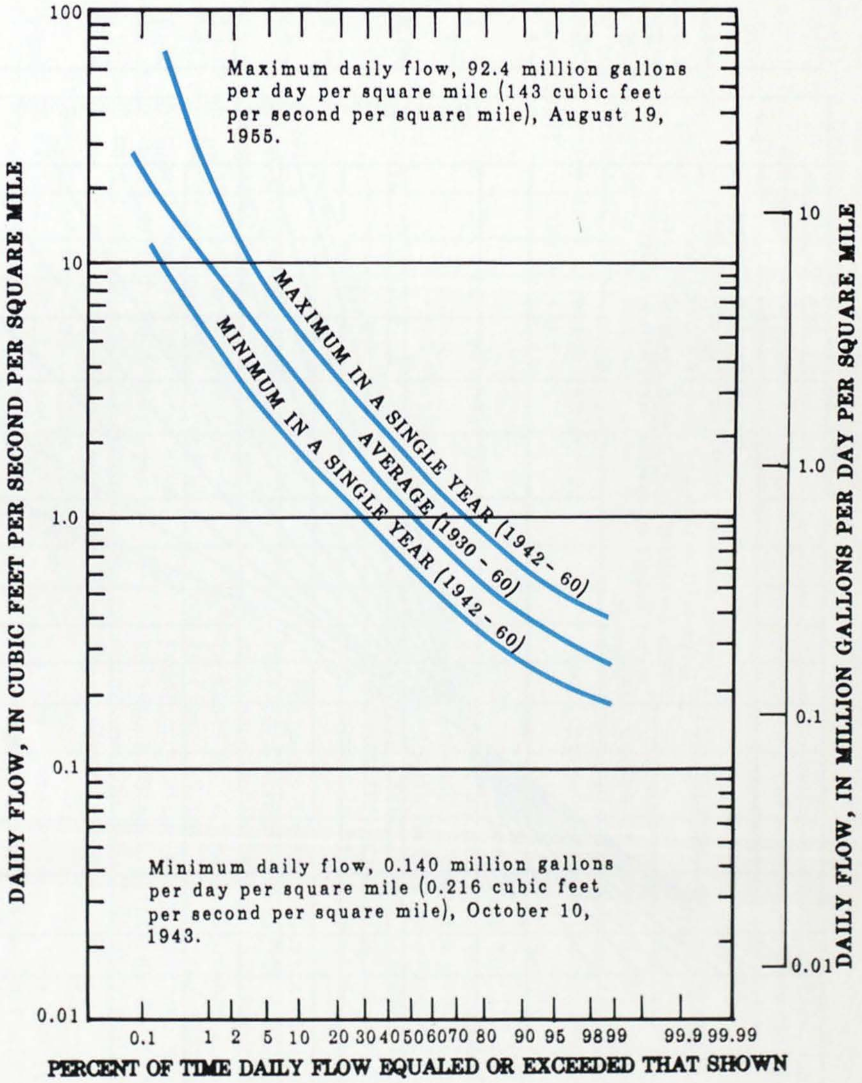


Figure 16.--Daily flow duration of Pequabuck River at Forestville

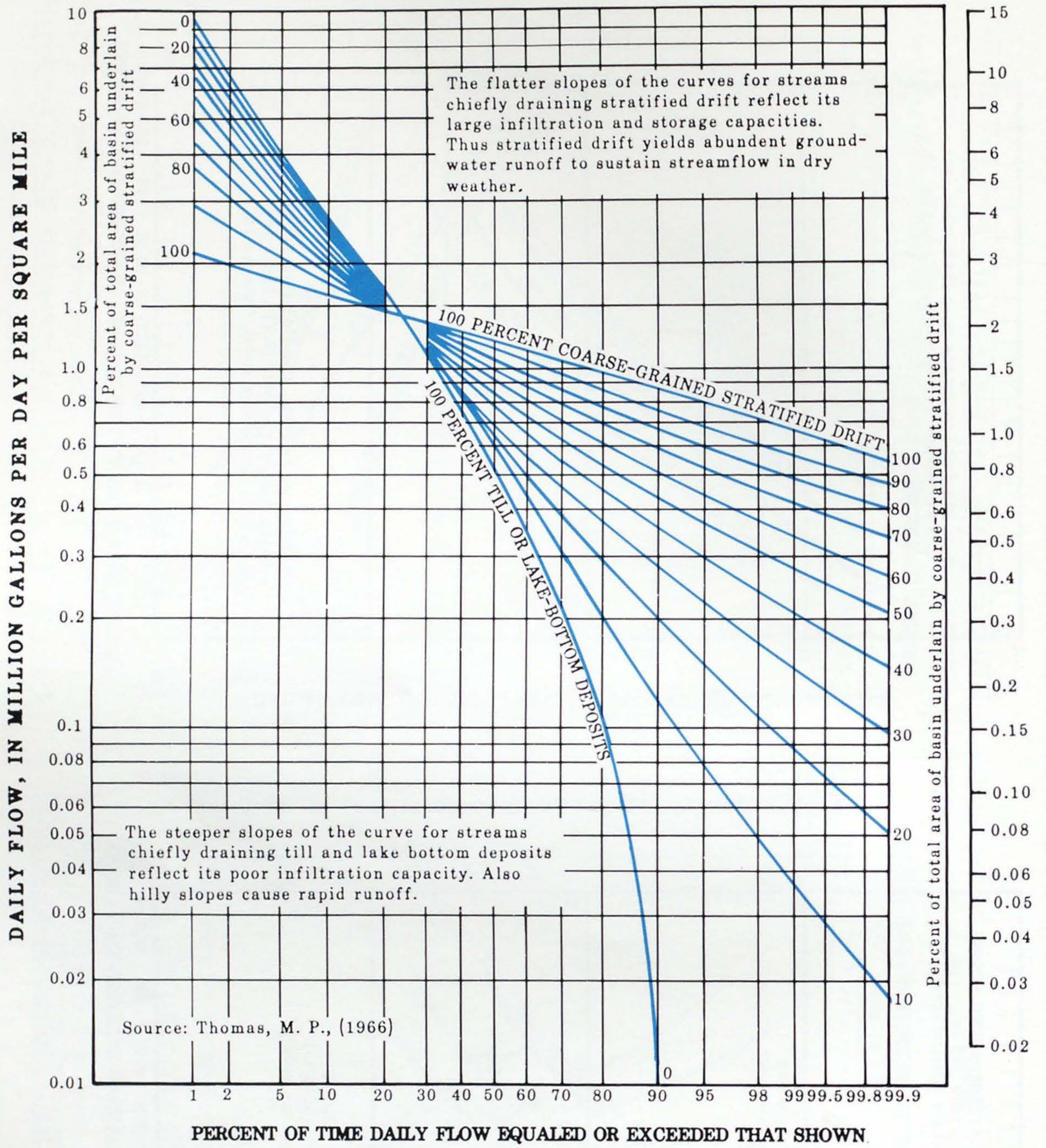


Figure 17.--Regional duration curves of daily mean streamflow

For example, assume that an average flow-duration curve is needed for the period 1930-60 for a site with a drainage area of 8.0 mi^2, of which 1.6 mi^2, or 20 percent of the total, consists of stratified drift. The site is located where the mean annual streamflow for the upstream drainage area (from fig. 10) is 1.06 times the statewide average. The flow-duration curve for this site is that shown in figure 17 for 20 percent stratified drift. Values of flow from this curve must be multiplied by the drainage area, 8.0 mi^2, and by the ratio 1.06 to give the average flow-duration curve for this site for the period 1930-60. The result in tabular form is:

Percentage of time	1	5	10	30	50	70	90	95	99
Average flow equaled or exceeded, in Mgal/d	68	32	23	11	5.5	3.3	1.7	1.4	0.75

Maximum and minimum flow-duration curves for single years may be estimated by relationships shown in figure 18. For example, if the flow of 3.3 Mgal/d was equaled or exceeded 70 percent of the time on the average flow-duration curve shown in the table above, then during the driest year of the period 1930-60 this flow was probably equaled or exceeded 44 percent of the time, and during the wettest year, 91 percent of the time. These curves can be used to estimate water availability during wet- and dry-year extremes for reservoir design and for induced recharge to aquifers adjacent to streams.

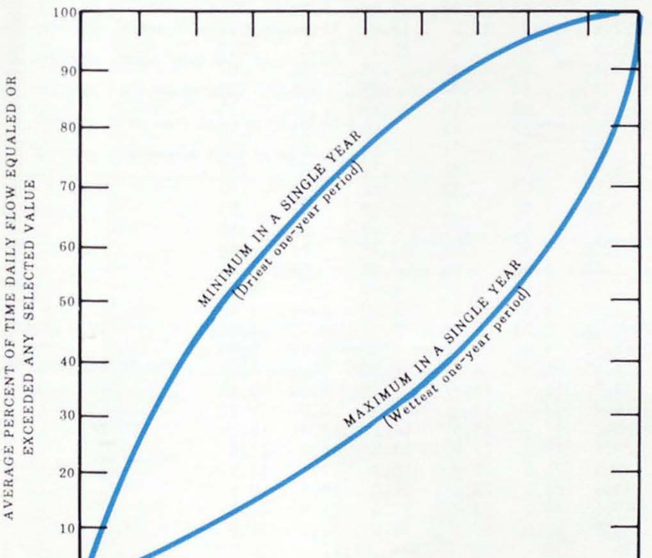


Figure 18.--Range in duration of streamflow, 1931-60 water years

Any diversion or regulation upstream from a selected site would require adjustments to the natural flow-duration curve.

LOW-FLOW FREQUENCY CURVES

Occurrences of low flow are best shown by frequency curves of annual lowest mean flows for various periods of consecutive days as derived from long-term streamflow-gaging stations.

Commonly used indices of low flow are the lowest annual mean flow for (1) 30 consecutive days having an average recurrence interval of 2 years (30-day, 2-year low flow), and (2) 7 consecutive days having an average recurrence interval of 10 years (7-day, 10-year low flow). Techniques for describing low-flow frequency have been presented by Riggs (1968).

Frequency characteristics of low flows at long-term streamflow-gaging stations, for the reference period April 1930-March 1960, are given in table 6. A graphical representation is shown in figure 19 for the stream-gaging station on the Farmington River at New Boston, Massachusetts. Relations between points on duration curves and points on low-flow frequency curves for this area are given in table 7.

The State of Connecticut and its Department of Environmental Protection, in their report on criteria for water-quality standards (Connecticut General Assembly, 1967, Public Act No. 57), recommend that the streamflow to which these standards apply be the 7-day, 10-year low flow.

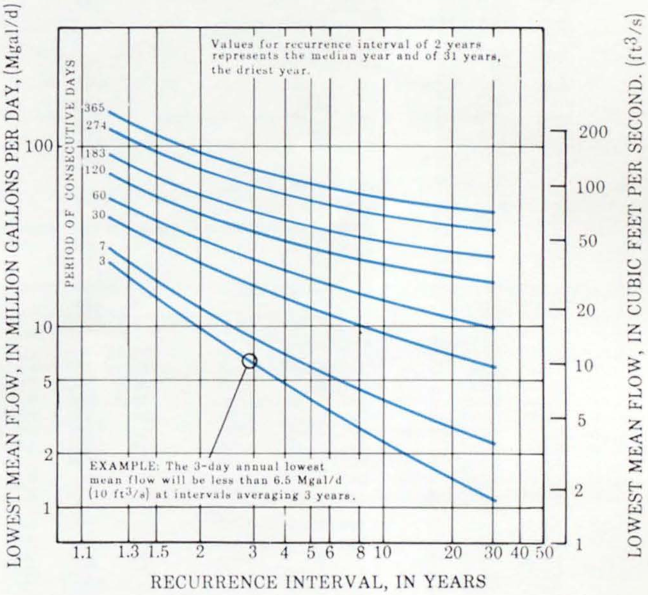


Figure 19.--Low-flow frequency curves of West Branch Farmington River at New Boston, Massachusetts

Table 6.--Annual lowest mean flows for indicated periods of consecutive days and indicated recurrence intervals at long-term stream-gaging stations

[Flows are adjusted to the reference period April 1930 to March 1960.]

Station no. (pl. A)	Station name	Period consecutive days	Annual lowest mean flows (ft^3/s) for indicated recurrence intervals in years						
			1.2	2	3	5	10	20	31
01185500	West Branch Farmington	3	37	17	11	6.20	3.60	2.60	1.80
	River at New Boston, Mass.	7	44	21	15	9.50	6.10	4.50	3.30
		30	65	36	28	21	15	12	9.50
		60	83	48	39	30	24	19	16
		120	113	68	55	47	39	32	28
		183	143	86	72	62	52	45	39
		274	192	117	95	83	72	62	54
		365	244	147	118	104	90	79	70
01187000	West Branch Farmington	3	69	45	37	31	23	17	15
	River at Riverton.	7	84	53	45	36	28	23	19
		30	129	76	64	50	40	32	26
		60	168	93	78	63	50	40	36
		120	238	127	104	86	71	60	54
		183	320	166	132	113	97	84	79
		274	449	240	192	168	147	130	121
		365	594	367	320	281	229	212	186
01187300	Hubbard River near	3	2.25	1.27	.90	.62	.40	.26	.20
	West Hartland.	7	2.50	1.40	1.01	.70	.44	.28	.22
		30	3.95	2.32	1.73	1.23	.81	.55	.43
		60	6.25	3.60	2.60	1.83	1.18	.77	.60
		120	11.6	6.60	4.70	3.30	2.11	1.38	1.07
		183	20.9	12.5	9.40	6.80	4.55	3.10	2.45
		274	34.0	23.0	18.3	14.4	10.5	7.80	6.50
		365	53.0	36.8	32.4	25.5	19.9	15.1	13.1
01187400	Valley Brook near	3	.79	.44	.35	.29	.22	.19	.17
	West Hartland.	7	.90	.48	.38	.33	.26	.22	.20
		30	1.50	.71	.57	.48	.40	.32	.30
		60	2.35	1.13	.89	.71	.59	.45	.40
		120	4.55	2.20	1.75	1.35	1.06	.81	.71
		183	8.00	4.00	3.05	2.30	1.75	1.35	1.18
		274	16.5	8.20	6.30	4.60	3.45	2.75	2.30
		365	30.5	15.0	11.5	8.50	6.70	5.50	4.60
01187800	Nepaug River near	3	3.56	1.57	.95	.56	.31	.17	.12
	Nepaug	7	3.90	1.69	1.17	.78	.47	.30	.23
		30	5.22	2.66	2.00	1.50	1.04	.78	.64
		60	7.83	4.09	3.02	2.25	1.66	1.25	1.01
		120	15.2	7.70	5.65	4.29	3.25	2.41	2.02
		183	23.6	12.7	9.53	7.38	6.02	4.84	4.06
		274	36.8	22.5	17.7	15.0	12.9	11.6	10.0
		365	49.9	35.2	30.2	28.4	25.7	23.8	22.7
01187850	Clear Brook near	3	1.10	.60	.48	.40	.34	.30	.27
	Collinsville	7	1.16	.65	.52	.44	.38	.35	.32
		30	1.28	.76	.63	.54	.49	.45	.43
		60	1.38	.85	.72	.62	.55	.52	.50
		120	1.52	.97	.82	.71	.64	.61	.58
		183	1.68	1.08	.93	.81	.72	.67	.64
		274	1.89	1.26	1.07	.93	.81	.74	.70
		365	2.25	1.55	1.32	1.15	.99	.88	.83
01188000	Burlington Brook	3	1.28	.93	.82	.73	.66	.62	.60
	near Burlington.	7	1.42	1.08	.95	.85	.76	.71	.68
		30	2.20	1.40	1.20	1.08	.97	.88	.84
		60	3.00	1.70	1.45	1.27	1.14	1.07	1.02
		120	4.60	2.35	1.99	1.63	1.52	1.49	1.40
		183	6.60	3.25	2.63	2.19	2.01	1.95	1.88
		274	11.0	5.25	4.00	3.25	2.97	2.89	2.80
		365	16.4	7.90	5.80	4.75	4.40	4.20	4.07
01189000	Pequabuck River	3	19.0	14.0	12.0	10.7	9.50	8.60	8.15
	at Forestville.	7	22.5	16.7	14.7	12.8	11.3	10.0	9.50
		30	27.0	20.3	17.9	16.0	14.2	12.8	12.2
		60	32.5	22.5	19.6	17.4	15.5	14.3	13.8
		120	47.5	29.0	24.2	21.2	18.8	17.4	17.0
		183	58.0	33.5	27.5	23.8	21.0	19.2	18.5
		274	84.0	49.5	40.0	33.8	29.0	25.9	24.5
		365	120	76.0	58.0	51.0	42.5	37.0	34.0
01189995	Farmington River	3	320	225	195	168	144	127	110
	at Tariffville.	7	343	240	205	178	155	138	125
	(1940-60 at Rainbow)	30	422	286	238	208	186	168	157
		60	490	330	275	235	210	188	176
		120	605	405	340	290	250	215	200
		183	720	485	410	350	295	255	236
		274	970	640	530	450	380	335	307
		365	1,400	860	690	570	480	440	400
01190000	Farmington River	3	210	117	91.0	72.0	56.0	45.0	40.0
	at Rainbow.	7	310	218	193	175	155	138	130
	(1930-39 at Tariffville)	30	405	280	250	225	200	180	170
		60	455	308	270	242	217	197	188
		120	595	385	337	298	258	228	213
		183	770	470	400	348	303	272	258
		274	1,002	630	525	455	403	372	358
		365	1,240	810	670	590	535	495	475

Table 7.--Relation of duration curves to low-flow frequency curves

[The example shows that the 30-day, 2-year low flow is equivalent to the flow at 90 percent on the flow-duration curve.]

Period of low flow in consecutive days	Average percent of time on the duration curve for indicated recurrence interval, in years, on the frequency curve						
	1.2	2 (median year)	3	5	10	20	31 (driest year)
3	92	97	98	99.2	99.7	99.8	99.9
7	88	95	97	98	99.2	99.6	99.7
30	81	90	94	96	98	99	99.3
60	74	85	90	94	96	98	98
120	61	75	81	87	92	95	96
183	49	65	72	77	84	88	91
274	35	50	57	63	70	75	78
365	25	37	44	50	56	62	65

The lowest mean flows for 7, 15, 30, 60, and 120 consecutive days at long-term gaging stations in the basin for the period April 1930 to March 1960, and the climatic year in which they occurred, are given in table 8.

ANNUAL HIGH-FLOW FREQUENCY CURVES

Annual high-flow frequency curves are used to calculate storage for flood control. The recurrence intervals of highest annual mean flows for various periods of consecutive days at long-term gaging stations are given in table 9. This table shows, for example, that the annual highest mean flow for 30 consecutive days at the 10-year recurrence interval on West Branch Farmington River at New Boston, Massachusetts is 900 ft^3/s. Thus, there is a 10-percent chance that a 30-day highest mean flow of 900 ft^3/s will be exceeded in

Table 8.--Annual lowest mean flows for indicated consecutive days at long-term stream-gaging stations

[Flows in the years indicated were the lowest during the period April 1930 to March 1960]

Station No. (pl. A)	Station name	Drainage area (mi^2)	Natural (N) or Regulated (R)	Lowest mean flow (ft^3/s) for indicated periods of consecutive days and climatic year in which it occurred									
				7-day	Year	15-day	Year	30-day	Year	60-day	Year	120-day	Year
01185500	West Branch Farmington River at New Boston, Mass.	92.0	R	3.6	1957	5.5	1957	8.8	1957	23	1957	86	1957
01187000	West Branch Farmington River at Riverton	217	R	38	1953	55	1953	74	1953	107	1953	199	1930
01187300	Hubbard River near West Hartland	19.9	N	3.0	1957	4.5	1953	13	1957	20	1957	82	1957
01187400	Valley Brook near West Hartland	7.03	N	.2	1953	.3	1953	.5	1953	.8	1953	2.0	1957
01187800	Nepaug River near Nepaug	23.5	N	.3	1935	.5	1953	1.2	1953	3.9	1953	11	1949
01187850	Clear Brook near Collinsville	.63	N	3.8	1940	4.5	1939	5.3	1940	7.9	1941	12	1941
01188000	Burlington Brook near Burlington	4.13	N	.67	1941	.72	1941	1.2	1941	1.8	1941	2.8	1957
01189000	Pequabuck River at Forestville	45.4	R	13	1950	14	1950	18	1948	24	1957	44	1949
01190000	Farmington River at Rainbow	583	R	102	1957	113	1957	172	1957	240	1957	411	1931

Table 9.--Annual highest mean flows and corresponding elevations for indicated periods and recurrence intervals

[Shown for long-term gaging stations, based on data for the reference period October 1930 to September 1960]

Station No. (pl. A)	Station name	Drainage area (mi^2)	Datum (ft above sea level)	Period of consecutive days	Annual highest mean flow (ft^3/s) for indicated recurrence interval (years)							Annual highest average elevation (ft above sea level) for indicated recurrence interval (years)						
					1.05	2	5	10	25	50	100	1.05	2	5	10	25	50	100
01185500	West Branch	92.0	758.21	0	1,300	2,700	5,000	8,000	15,000	20,000	32,000	763.8	765.2	766.5	767.5	769.7	770.3	772.0
	Farmington			1	960	1,800	3,300	5,200	9,200	14,000	21,000	763.4	764.4	765.6	766.5	767.9	769.1	770.4
	River			3	680	1,300	2,200	3,200	5,000	7,000	9,500	762.9	763.8	764.8	765.6	766.5	767.2	768.0
	near			7	450	930	1,500	2,000	2,800	3,500	4,300	762.4	763.3	764.1	764.6	765.3	765.7	766.1
	New Boston,			15	370	730	1,100	1,300	1,700	2,000	2,300	762.2	763.0	763.6	763.8	764.3	764.6	764.9
	Mass.			30	290	540	750	900	1,100	1,200	1,400	762.0	762.6	765.7	763.3	763.6	763.7	764.0
				60	230	400	520	580	660	710	750	761.8	762.3	762.6	762.7	762.8	762.9	763.0
				120	190	300	360	400	440	460	490	761.7	762.0	762.2	762.3	762.4	762.4	762.5
				183	170	260	310	340	370	400	420	761.6	761.9	762.0	762.1	762.2	762.3	762.3
				365	110	180	220	250	270	290	310	761.3	761.6	761.8	761.9	761.9	762.0	762.1
01188000	Burlington	4.13	714.00	0	100	290	450	600	800	1,100	1,400	718.5	720.2	721.0	721.6	722.2	723.0	723.7
	Brook			1	60	100	170	250	390	530	730	717.9	718.5	719.3	719.9	720.7	721.3	722.0
	near			3	34	57	94	130	190	260	340	717.3	717.8	718.4	718.9	719.4	720.0	720.5
	Burlington.			7	21	38	59	78	110	130	170	716.9	717.4	717.9	718.2	718.6	718.9	719.3
				15	15	28	41	51	65	78	91	716.7	717.2	717.5	717.7	718.0	718.2	718.4
				30	13	22	30	37	45	52	60	716.6	717.0	717.2	717.4	717.6	717.7	717.9
				60	10	17	22	26	30	32	35	716.5	716.8	717.0	717.1	717.2	717.3	717.4
				120	9	14	17	19	21	22	24	716.4	716.6	716.8	716.9	716.9	717.0	717.0
				183	7	12	15	16	18	19	20	716.3	716.6	716.7	716.7	716.8	716.9	716.9
				365	5	8	10	11	12	13	14	716.1	716.3	716.4	716.5	716.6	716.6	716.7
01190000	Farmington	589	35.36	0	4,400	7,600	14,000	22,000	37,000	55,000	80,000	40.3	42.3	45.1	47.9	52.3	56.3	60.9
	River			1	3,800	7,000	13,000	20,000	33,000	49,000	71,000	39.9	41.9	44.8	47.2	51.3	55.1	59.2
	at			3	3,200	5,800	10,000	15,000	25,000	35,000	50,000	39.5	41.3	43.5	45.5	48.9	51.8	55.3
	Rainbow.			7	2,400	4,500	7,400	10,000	15,000	20,000	26,000	38.9	40.4	42.2	43.5	45.5	47.2	49.2
	(Regulated)			15	1,800	3,500	5,400	6,900	9,200	11,000	13,000	38.5	39.7	41.0	41.9	43.1	43.9	44.8
				30	1,500	2,800	4,000	4,900	6,300	7,300	8,500	38.3	39.2	40.0	40.7	41.6	42.1	42.8
				60	1,300	2,100	2,900	3,400	4,100	4,700	5,200	38.1	38.7	39.3	39.6	40.1	40.5	40.9
				120	1,000	1,700	2,200	2,500	2,800	3,000	3,200	37.9	38.4	38.8	39.0	39.2	39.3	39.5
				183	900	1,500	1,900	2,100	2,400	2,500	2,700	37.8	38.3	38.5	38.7	38.9	39.0	39.1
				365	610	1,000	1,300	1,500	1,700	1,800	1,900	37.5	37.9	38.1	38.3	38.4	38.5	38.5

any one year. The instantaneous peak discharge (0 consecutive days) at 10-year recurrence interval is 8,000 ft^3/s.

STORAGE OF WATER

EXISTING LAKES, PONDS, AND RESERVOIRS

Storage information for selected surface-water bodies in the area is presented in table 10. The volume of usable water in storage is defined as that which may be withdrawn by gravity through a valve or gate. Water-quality information on the public water-supply reservoirs is given in table 28.

DRAFT-STORAGE RELATIONS

If the minimum flow of a stream is inadequate for a projected rate of use, a dam and reservoir may be constructed to store water for subsequent release to maintain the desired flow. Table 11 shows the frequency with which various amounts of storage are required to maintain selected rates of regulated flow at long-term stream-gaging stations based on records for the reference period. Values of storage required for a recurrence interval of 2 years apply for the condition of median annual streamflow, and values for a recurrence interval of 31 years apply for the condition of lowest annual streamflow. The underlined values in table 11 are greater than the total volume of streamflow in some years and would not be replaced every year. The figures are based on frequency-mass curves that in turn are based on low-flow frequency relationships.

Table 10.--Available data for selected lakes, ponds, and reservoirs

[n.d. No data was available]

Station no. (pl. A)	Name and location	Natural(N) or artificial(A)	Drainage area (mi^2)	Surface area (acres)	Surface elevation 1/ (ft above sea level)	Maximum depth (ft)	Average depth (ft)	Storage: Total (Mgal)	Storage: Usable (Mgal)	Present use	Source of data
01185000	Otis Reservoir at Cold Spring, Mass.2/	A	15.9	1,100	1,419	34.5	16.3	5,840	5,840	Conservation, recreation	Massachusetts Water Resources.
01185700	Abbey Lake near Montville, Mass.	A	1.75	54	1,479	34	17.47	306	218	Multipurpose reservoir	U.S. Department of Agriculture.
01185710	West Lake near Montville, Mass.	A	1.46	83	1,575	23	13.6	368	212	Do.	Do.
01185850	Colebrook River Lake near Colebrook.	A	119	1,210	790	194	80.74	44,746	44,746	Do.	U.S. Army Corps of Engineers.
01185860	Howells Pond near West Hartland.	A	1.50	17	1,132	11	6.4	34.8	n.d.	Recreation	Connecticut State Board of Fisheries and Game.
01185880	Hartland Pond near West Hartland.	N&A	.26	49	1,155	24	9.9	156	n.d.	Do.	Do.
01185900	West Branch Reservoir near Riverton.	A	127	190	641	100	47.0	2,800	2,800	Compensation	Metropolitan District Commission, Hartford, Conn.
01186005	Burr Pond at Burrville.	A	1.32	85	988	13	5.1	147	n.d.	Recreation	Connecticut State Board of Fisheries and Game.
01186080	Rugg Brook Reservoir near Winsted.	A	2.39	45	1,032	n.d.	n.d.	225	n.d.	Water supply	Winsted Water Department.
01186090	Mad River Reservoir near Winsted.	A	18.3	188	983	151	51.6	3,160	3,140	Multipurpose reservoir	U.S. Army Corps of Engineers.
01186140	Crystal Lake Reservoir near Winsted.	N&A	1.10	176	1,019	44	18.9	1,065	450	Water supply	Winsted Water Department.
01186150	Sucker Brook Reservoir near Winsted.	A	3.15	54	935	63.2	32.4	650	480	Flood control	U.S. Army Corps of Engineers.
01186160	Highland Lake at Winsted.	N&A	7.05	447	881	62	19.7	2,845	1,070	Recreation and industry	Conn. State Board of Fisheries and Game.
01186248	Gaylord Pond near Robertsville.	A	1.42	43	954	9+	4.4	61	0	Recreation	Do.
01186300	Doolittle Pond near North Colebrook.	N&A	.90	190	1,390	60	29.8	1,930	n.d.	Industrial	Do.
01186320	Lake Triangle at North Colebrook.	A	3.42	50	1,035	10	4.4	71.4	64.7	Recreation	Do.
01187030	West Hill Pond near Winsted.	N&A	1.32	238	938	61	24.6	1,160	n.d.	Recreation and industry	Do.
01187500	Barkhamsted Reservoir near Barkhamsted.	A	52.5	2,276	530	115	42.9	31,800	30,300	Water supply	Metropolitan District Commission, Hartford, Conn.
01187600	East Branch Reservoir at New Hartford.	A	61.2	437	420	58	21.0	2,990	2,940	Do.	Do.
01187900	Nepaug Reservoir near Collinsville.	A	31.6	850	482	100	34.6	9,665	9,490	Do.	Do.
01188150	Terryville Reservoir no. 3 near Terryville.	A	.09	5.6	829	12	9.0	16.5	n.d.	Do.	Terryville Water Co.
01188200	Bristol Reservoir no. 4 near Harwinton.	A	1.77	42	852	32	18.0	249	n.d.	Do.	Bristol Water Department
01188250	Bristol Reservoir no. 5 near Terryville.	A	1.14	40	880	44	15.7	200	n.d.	Do.	Do.
01188300	Bristol Reservoir no. 2 near Terryville.	A	.31	19	877	25	15.8	98	n.d.	Do.	Do.
01188350	Bristol Reservoir no. 3 near Terryville.	A	5.78	4.3	670	-	5.35	7.5	n.d.	Do.	Do.
01188400	Old Marsh Pond near Terryville	N&A	2.24	135	688	-	13.4	589	n.d.	Do.	Do.
01188450	Bristol Reservoir no. 1 at Terryville.	A	.43	33	599	-	7.3	74.7	n.d.	Do.	Do.
01188492	Dunham Mill Pond near Bristol.	A	.19	27	921	8.5	4.8	42.3	22.9	Recreation	Connecticut State Board of Fisheries and Game.
01188500	Whigville Reservoir at Whigville.	A	4.10	11	570	28	17.8	64.8	37.8	Water supply	New Britain Water Department.
01189170	Simsbury Reservoir at West Simsbury.	A	.87	9.9	450	31	17.6	56.9	n.d.	Do.	Village Water Company, Simsbury.
01189360	Manitook Lake near Granby.	N&A	1.55	54	194	20	8.0	145	n.d.	Recreation	Connecticut State Board of Fisheries and Game.

1/ Taken from U.S. Geological Survey 7½-minute quandrangle. Elevations are those from date of surveys.

2/ North of area shown on plate A.

Table 11.--Storage required to maintain indicated regulated flows at long-term stream-gaging stations

[Data are adjusted to the reference period April 1930 to March 1960. Storage required would refill during a year, except for figures underlined; these would take longer. Storage is uncorrected for reservoir seepage, evaporation, and for computational bias, all of which would increase the amount of storage required.]

Station No. (pl. A)	Station name	Drainage area (mi²)	Recurrence interval of annual lowest mean flow (years)	Maximum storage needed for refilling during the year of lowest mean flow (Mgal/mi²)	Storage required (Mgal/mi²) to maintain indicated regulated flow [(Mgal/d)/mi²]																
					0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.65	0.70	0.75	0.80	0.90	1.00
01185500	West Branch Farmington River at New Boston, Mass.	92.0	1.2	130	--	--	--	--	--	--	--	--	--	2.0	4.0	6.0	8.0	10	14	20	28
			2	78	--	--	--	0.5	1.0	2.5	3.0	6.0	8.0	12.5	15.5	20	27	33	40	57	73
			5	54	--	1.0	2.0	3.0	5.0	8.5	12	16	21	27	34	40	49	57	67	89	116
			10	48	1.0	2.0	3.0	6.0	8.0	12	16	21	27	34	43	52	62	74	84	109	136
			31	40	1.0	3.0	5.0	9.0	14	19	26	34	42	53	64	75	88	101	116	150	200
01187000	West Branch Farmington River at Riverton.	217	1.2	150	--	--	--	--	1.0	1.5	2.0	2.5	3.0	5.5	7.0	9.0	12	16	20	28	37
			2	112	--	--	--	2.0	4.0	6.0	8.0	11	16	22	28	36	43	50	59	76	93
			5	100	--	--	1.5	4.0	7.5	12	17	23	30	40	50	60	70	82	92	116	140
			10	76	--	1.0	3.0	6.5	11	16	22	30	39	49	59	70	81	92	104	129	154
			31	60	--	2.0	6.0	11	17	23	31	39	49	60	70	82	94	106	120	148	177
01187300	Hubbard River near West Hartland.	20.7	1.2	192	--	--	--	3.0	5.0	10	15	18	22	28	34	38	42	46	52	64	77
			2	147	1.0	3.0	6.0	10	15	19	24	29	35	40	46	53	61	67	75	91	109
			5	113	2.0	7.0	12	18	24	31	38	46	54	62	70	79	89	99	109	130	152
			10	93	5.5	10	16	23	30	38	47	56	65	74	84	94	105	117	128	154	180
			31	66	8.0	15	23	31	41	51	61	72	83	95	108	121	134	147	161	191	221
01187400	Valley Brook near West Hartland.	7.03	1.2	406	--	--	2.0	4.0	6.0	9.0	12	16	20	26	31	36	41	47	53	66	76
			2	189	--	2.0	4.0	8.0	13	18	25	31	38	45	52	59	68	76	84	101	120
			5	109	2.0	6.0	11	16	24	31	39	46	55	65	74	84	95	106	117	141	167
			10	87	3.0	7.0	13	20	29	37	46	55	66	76	87	99	112	125	138	168	197
			31	60	5.0	11	18	28	37	46	57	70	83	97	112	126	139	156	172	215	238
01187800	Nepaug River near Nepaug.	23.5	1.2	198	--	--	1.0	2.0	4.0	7.0	10	12	15	19	23	28	33	37	42	53	66
			2	113	1.0	3.0	6.0	10	13	17	23	29	34	41	47	54	62	71	79	99	118
			5	67	3.0	6.0	10	15	22	30	38	46	55	64	73	84	95	104	117	143	171
			10	53	3.0	8.0	14	21	29	37	45	48	65	75	85	98	109	122	135	166	199
			31	44	5.0	10	17	26	36	45	56	68	79	93	104	118	133	149	164	201	247
01187850	Clear Brook near Collinsville.	0.59	1.2	85	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
			2	66	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	4.0
			5	41	--	--	--	--	--	--	--	--	--	--	--	.90	3.0	5.0	6.0	11	21
			10	32	--	--	--	--	--	--	--	--	--	.90	1.8	3.0	5.0	7.0	11	18	30
			31	27	--	--	--	--	--	--	--	.90	1.4	2.3	3.7	6.0	7.0	10	14	25	46
01188000	Burlington Brook near Burlington.	4.13	1.2	153	--	--	--	--	--	2.0	3.0	4.0	5.0	7.0	10	14	18	22	27	37	47
			2	125	--	--	1.0	3.0	5.0	7.0	9.0	13	20	24	30	36	42	48	57	72	88
			5	78	--	--	2.0	4.0	8.0	12	18	24	31	38	46	54	62	72	80	100	123
			10	63	--	1.0	3.0	6.0	11	16	23	30	37	46	55	64	73	83	94	118	145
			31	52	--	2.0	4.0	8.0	14	21	30	37	47	56	67	78	89	101	114	142	173
01189000	Pequabuck River at Forestville.	45.4	1.2	168	--	--	--	--	--	1.0	2.0	4.0	6.0	8.0	11	13	16	19	23	32	44
			2	117	--	--	--	--	2.0	3.0	6.0	9.0	14	19	26	34	42	50	60	79	98
			5	74	--	--	--	--	4.0	8.0	15	22	30	39	48	58	68	79	91	115	142
			10	60	--	--	--	3.0	6.0	11	19	28	37	48	58	70	82	94	107	134	163
			31	45	--	--	2.0	5.0	9.0	18	27	36	48	59	71	84	96	109	124	155	189
01189995	Farmington River at Tariffville.	577	1.2	135	--	--	--	--	--	--	--	2.0	4.0	6.0	8.0	11	15	20	25	33	46
			2	69	--	--	--	--	1.0	3.0	5.0	8.0	12	18	24	31	38	47	55	75	95
			5	57	--	--	--	--	2.0	5.0	10	17	24	32	43	53	64	77	89	115	143
			10	55	--	--	--	2.0	4.0	8.0	17	24	33	43	54	64	77	88	102	130	159
			31	48	--	--	--	3.0	8.0	14	23	32	41	52	64	76	88	101	116	147	180

By relating unit runoff for various flow frequencies to percentage of drainage basin underlain by coarse-grained stratified drift, frequency-mass curves can be generated for ungaged sites.

The amounts of storage required to maintain various draft rates in previously unregulated streams are presented in table 12. These data are shown for indicated percentages of drainage area underlain by coarse-grained stratified drift. Interpolations between percentages given may be made if necessary. Storage used to provide regulated flow would be replaced within one year. Table 12 is based upon an average streamflow of 1.16 Mgal/d/mi² for the reference period. Before table 12 can be applied to a particular site, the rate of regulated flow and the amount of storage required must be adjusted to the average streamflow at that site by using the appropriate ratio determined from figure 10.

The amounts of storage required according to table 12 are smaller than the true values because they include a bias of about 10 percent, which results from the use of the frequency-mass curve. Moreover, losses due to evaporation and seepage from the reservoir are not included. The amounts shown in the table are sufficiently accurate for preliminary planning and for tentative site selection. Furthermore, regulated flow rates assume continuous use and may be increased proportionately if use is intermittent.

Following is an example for a site with a drainage area of 6.0 mi², 30 percent of which is covered by stratified drift, and located where the mean annual streamflow is 1.06 times the statewide average. To determine the amount of storage required to maintain a regulated flow of 2.3 Mgal/d at this site, 1) divide 2.3 Mgal/d by the drainage area of 6.0 mi², which results in a unit-

Table 12.--Storage required to maintain indicated regulated flows at sites on unregulated streams related to surficial geology

[Data are adjusted to the reference period April 1930 - March 1960 and to an average streamflow of 1.16 (Mgal/d)/mi^2. Storage required would be replenished within a year. Storage is uncorrected for reservoir seepage, evaporation, and for bias in computation, all of which increase the amount of storage required.]

Percent of area covered by coarse-grained stratified drift	Recurrence interval of annual lowest mean flow (years)1/	Maximum amount of storage which would be replenished during the year of annual lowest mean flow (Mgal/mi^2)	Storage required (Mgal/mi^2) to maintain indicated regulated flow (Mgal/d)/mi^2																
			0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.65	0.70	0.75	0.80	0.90	1.00
0																			
	2	102	3	6	9	13	18	24	31	38	46	54	63	72	82	92	102	--	--
	5	66	9	14	20	27	34	42	50	59	69	80	92	104	117	130	144	--	--
	10	61	11	18	26	35	45	56	--	--	--	--	--	--	--	--	--	--	--
	31	48	18	27	37	47	--	--	--	--	--	--	--	--	--	--	--	--	--
10																			
	2	95	--	1	3	7	11	16	22	28	35	43	51	60	69	79	89	109	131
	5	67	1	5	9	14	20	28	37	46	56	67	--	--	--	--	--	--	--
	10	59	3	7	13	20	29	39	49	--	--	--	--	--	--	--	--	--	--
	31	44	5	11	19	29	39	--	--	--	--	--	--	--	--	--	--	--	--
20																			
	2	90	--	--	--	1	4	8	12	18	24	31	39	47	55	64	73	--	--
	5	61	--	--	3	6	11	18	25	32	40	48	58	--	--	--	--	--	--
	10	55	--	2	6	11	17	24	32	41	51	--	--	--	--	--	--	--	--
	31	44	--	4	10	16	24	33	43	--	--	--	--	--	--	--	--	--	--
30																			
	2	82	--	--	--	--	1	3	6	10	15	20	27	34	42	50	59	77	--
	5	57	--	--	--	2	6	10	15	21	28	35	44	53	--	--	--	--	--
	10	52	--	--	1	4	8	14	21	29	37	46	--	--	--	--	--	--	--
	31	44	--	--	3	8	15	22	30	38	--	--	--	--	--	--	--	--	--
40																			
	2	78	--	--	--	--	--	--	2	5	8	12	18	24	31	39	47	65	--
	5	53	--	--	--	--	2	4	8	13	18	24	31	39	47	--	--	--	--
	10	48	--	--	--	1	3	7	12	18	24	31	40	--	--	--	--	--	--
	31	43	--	--	--	2	6	12	19	26	35	--	--	--	--	--	--	--	--
50																			
	2	--	--	--	--	--	--	--	--	1	3	5	9	13	18	24	32	48	67
	5	50	--	--	--	--	--	--	3	6	10	15	21	27	34	42	--	--	--
	10	49	--	--	--	--	--	1	5	10	15	22	29	37	45	--	--	--	--
	31	45	--	--	--	--	2	5	9	15	22	30	39	--	--	--	--	--	--
60																			
	2	--	--	--	--	--	--	--	--	--	--	1	4	7	11	16	22	36	54
	5	48	--	--	--	--	--	--	--	2	5	8	12	17	23	30	38	--	--
	10	47	--	--	--	--	--	--	1	4	7	12	17	23	30	39	--	--	--
	31	43	--	--	--	--	--	--	3	7	13	19	26	34	42	--	--	--	--
80																			
	2	--	--	--	--	--	--	--	--	--	--	--	--	--	1	4	7	16	29
	5	44	--	--	--	--	--	--	--	--	--	--	2	4	8	12	17	29	--
	10	43	--	--	--	--	--	--	--	--	--	1	3	7	12	17	23	38	--
	31	42	--	--	--	--	--	--	--	--	--	3	8	13	18	25	33	--	--
100																			
	2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	3	11
	5	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	3	11	21
	10	--	--	--	--	--	--	--	--	--	--	--	--	--	1	2	6	15	29
	31	--	--	--	--	--	--	--	--	--	--	--	--	1	3	7	12	25	40

1/ Values for recurrence interval of 2 years represent the median year of the reference period, and values for recurrence intervals of 31 years represent the driest year of the reference period.

Table 13.--Notable floods of record

Station No. (pl. A)	Stream and location	Mar. 19, 1936 Elevation (ft above sea level)	Mar. 19, 1936 Flow (ft^3/s)	Sept. 21, 1938 Elevation (ft above sea level)	Sept. 21, 1938 Flow (ft^3/s)	Dec. 31, 1948 Elevation (ft above sea level)	Dec. 31, 1948 Flow (ft^3/s)	Aug. 19, 1955 Elevation (ft above sea level)	Aug. 19, 1955 Flow (ft^3/s)	Oct. 16, 1955 Elevation (ft above sea level)	Oct. 16, 1955 Flow (ft^3/s)
01185500	West Branch Farmington River at New Boston, Mass.	768.86	9,080	771.15	18,500	768.71	11,700	772.27	34,300	767.56	7,910
01186000	West Branch Farmington River at Riverton	-	-	-	-	-	-	506.70 *495	57,200 * 4,700	498.07	10,600
01186230	Still River at Winsted	-	30,600	-	37,000	-	-	-	-	-	-
01186500	Still River at Robertsville	-	-	-	-	520.36	9,550	526.72 *525.9	44,000 *31,700	520.26	9,270
01187000	West Branch Farmington River at Riverton	485.64	19,900	490.17	37,100	486.17	22,000	492.52 -	101,000 *31,900	-	20,000
01187980	Farmington River at Collinsville	266.5	34,000	270.9	54,000	265.9	32,000	280.8 *274	140,000 *61,300	-	-
01188000	Burlington Brook near Burlington	720.58	533	721.24	676	720.87	591	723.22	1,690	720.24	475
01189000	Pequabuck River at Forestville	-	-	205.0	3,800	204.42	3,260	210.94	11,700	205.39	4,170
01189500	Salmon Brook near Granby	-	-	-	-	162.54	3,440	172.57	40,000	161.17	10,800
01189995	Farmington River at Tariffville	143.61	26,900	144.2	29,900	-	-	-	-	-	-
01190000	Farmington River at Rainbow	-	26,600	-	29,900	49.19	26,500	58.86 *55.8	69,200 *52,500	51.71	34,700

* Modified peaks showing effect of regulation of Mad River, Sucker Brook, Colebrook River flood-control reservoirs constructed after 1955, from Master Manual of Reservoir Regulation, Farmington River watershed (U.S. Department of the Army, Corps of Engineers, 1970).

regulated flow of 0.383 Mgal/d/mi^2; 2) for a drainage area 30 percent of which is covered by stratified drift, a recurrence interval of 31 years (driest year), and a regulated flow of 0.383 Mgal/d/mi^2, by interpolation in table 12, the required storage is 27.3 Mgal/mi^2; 3) adjusting for the statewide average mean annual flow (27.3 x 1.06 = 25.8 Mgal/mi^2) or at total of 155 million gallons for 6.0 square miles (25.8 x 6.0); and 4) adjusting for bias, evaporation, and seepage raises this to about 170 million gallons.

FLOODS

HISTORY

Floods have occurred in the Farmington River basin in every month of the year. Spring flooding is the most common and usually results from the combined effects of rapid snowmelt and rain, whereas summer and fall flooding are commonly the result of hurricanes.

Since the first settlement of the region in 1633, there have been many severe floods. Notable historic floods that have occurred include:

January 1770	December 1878	September 21, 1938
March 1801	March 1896	December 31, 1948
November 1853	November 4, 1927	August 19, 1955
May 1854	March 19, 1936	October 16, 1955
October 1869		

The flood of August 19, 1955, was the most severe of record and was probably the largest of any since at least the "Jefferson Flood" of March 1801. Elevations of observed flood peaks at long-term stream-gaging stations in the basin from March 19, 1936 to October 16, 1955 are given in table 13.

Following the flood of August 1955, many flood protection reservoirs and stream improvements were completed within the basin. The Corps of Engineers, U.S. Army, now has three large storage reservoirs, Colebrook River Lake, Mad River, and Sucker Brook, located in the basin (see Plate A). The Soil Conservation Service of the U.S. Department of Agriculture also has floodwater retarding structures on the Clam River in Massachusetts. The effect of the storage in these reservoirs upon the flood peaks of August 1955 has been estimated by the Corps of Engineers and these modified peaks are also shown in table 13. The capacities and other technical data for some of the reservoirs are listed in table 10.

Descriptive information on the major floods in New England through 1955 is given by Thomson and others (1964). More detailed records of the major floods of 1936, 1938, and 1955, based primarily on gaging-station records, are given in Grover (1937), Paulsen and others (1940), U.S. Geological Survey (1947), and Bogart (1960). Partial-duration series of flood peaks above selected bases for 7 long-term stream-gaging stations in the Farmington River basin were compiled by Green (1964).

MAGNITUDE AND FREQUENCY

Knowledge of the magnitude and frequency of flood-peak stages and discharges is essential for land-use planning, design of flood-control structures, highways and bridges, and for delineation of flood-prone areas. The maximum flood of record and median annual flood at gaging stations in The Farmington River basin are given in table 14. For preliminary planning, estimates of the flood flow for any recurrence interval at all the sites listed in the table and for all ungaged sites within the basin where the drainage area is 2 square miles or more can be made from figures 20 and 21. More detailed methods of estimating flood flows for Connecticut are available (Weiss, 1975; Weiss, 1983). The median annual flood at a site has a 50 percent chance of occurring in any year and may be estimated from figure 20 if the drainage area is known. Peak flows for other recurrence intervals up to 100 years (1-percent chance of occurring in any year) are obtained by multiplying the median annual flood by the appropriate ratio for any selected recurrence interval determined from figure 21. The total area of swamps, ponds, lakes, and overflow areas within the basin, expressed as a percentage of the total drainage area, indicates the effect basin storage has upon the shape of these curves.

It must be emphasized that the curves in figures 20 and 21 apply only to unregulated streams draining rural areas; flood peak discharges in urban areas are significantly higher because pavement and storm sewers shorten the concentration time of the runoff.

The terms "recurrence interval" or "return period", commonly used in comparing the severity of floods, are based upon a continuous series of annual flood events. The reciprocal of the recurrence interval is the probability; it is the percent chance of a flood of a given magnitude or greater occurring within any one year. In the design of structures such as bridges or culverts, it is necessary to consider the probability that a flood peak discharge with a selected annual recurrence interval will be exceeded within the design lifetime of the structure. Table 15 presents this relationship and is based upon the binomial distribution $P = 1-(1-p)^n$, where P is the probability that an annual flood with a selected recurrence interval, or its reciprocal "p", will be equaled or exceeded within "n" number of years. This relationship has been discussed in detail by Markowitz (1971).

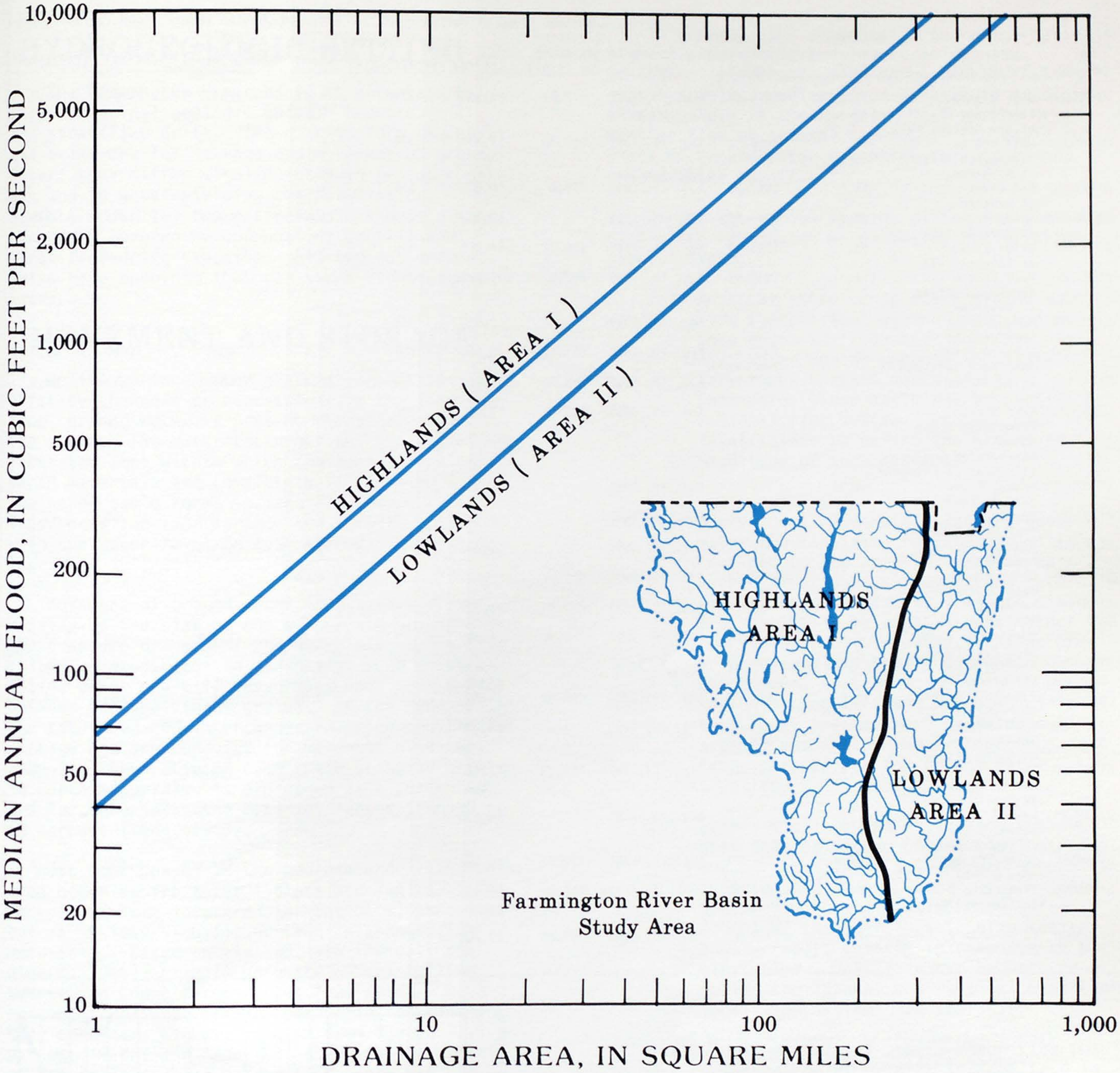


Figure 20.--Median annual flood related to drainage area.

Table 14.--Maximum flood of record and median annual flood at stream-gaging stations through 1982

Station No. (pl. A)	Station name	Drainage area (mi^2)	Period of continuous record	Maximum flood of record: Date	Maximum flood of record: Elevation (ft above sea level)	Maximum flood of record: Flow (ft^3/s)	Maximum flood of record: Flow [$(ft^3/s)/mi^2$]	Ratio to median annual flood	Median annual flood (unregulated): Elevation (ft above sea level)	Median annual flood (unregulated): Flow (ft^3/s)	Median annual flood (unregulated): Flow [$(ft^3/s)/mi^2$]
01185500	West Branch Farmington River at New Boston, Mass.	92.0	1915-82	Aug. 19, 1955	772.27	34,300	373	14.9	764.9	2,300	25.0
01186000	West Branch Farmington River at Riverton	131	1956-82	Aug. 19, 1955	506.70	57,200	378	-	-	-	-
01186100	Mad River at Winsted	18.5	1957-69	Aug. 19, 1955	776.0	10,200	551	-	-	-	-
01186400	Sandy Brook at Robertsville	34.9	1961-67, 1968-76	Aug. 19, 1955	-	10,100	289	8.08	566.7	1,250	35.8
01186500	Still River at Robertsville	84.7	1949-82	Aug. 19, 1955	526.72	44,000	519	-	-	-	-
01187000	West Branch Farmington River at Riverton	217	1930-55	Aug. 19, 1955	492.52	101,000	374	-	-	-	-
01187100	Morgan Brook near Winsted	7.06	-	Aug. 19, 1955	-	2,510	356	-	-	-	-
01187300	Hubbard River near West Hartland	20.7	1938-55, 1957-82	Aug. 19, 1955	611.12	10,500	507	10.5	600.9	1,000	48.3
01187400	Valley Brook near West Hartland	7.03	1941-74	Aug. 19, 1955	565.70	5,400	768	15.4	557.2	350	49.8
01187500	East Branch Farmington River at outlet of Barkhamsted Reservoir near Barkhamsted	52.5	-	Aug. 19, 1955	536.26	11,600	220	-	-	-	-
01187550	Beaver Brook near Barkhamsted	4.96	-	Aug. 19, 1955	-	3,350	675	-	-	-	-
01187680	Cherry Brook near Canton Center	8.23	-	Aug. 4, 1969	-	720	88	2.0	-	360	43.7
01187800	Nepaug River near Nepaug	23.5	1918-55, 1958-72	Aug. 19, 1955	-	10,000	426	15.6	509.5	640	27.2
01187850	Clear Brook near Collinsville	.59	1922-73	Aug. 19, 1955	493.62	56.5	96	4.04	-	14	23.7
01187980	Farmington River at Collinsville	360	1963-77	Aug. 19, 1955	280.8	140,000	389	-	-	-	-
01188000	Burlington Brook near Burlington	4.13	1932-82	Aug. 19, 1955	723.22	1,690	409	7.04	719.8	240	58.1
01188100	Roaring Brook at Unionville	7.60	1962-82	Feb. 2, 1973	-	570	75	3.80	-	150	19.7
01189000	Pequabuck River at Forestville	45.4	1942-82	Aug. 19, 1955	210.94	11,700	258	9.00	201.4	1,300	28.6
01189300	East Branch Salmon Brook at North Granby	12.4	1961-65, 1967-73	Aug. 19, 1955	-	14,300	1,150	-	-	-	-
01189390	East Branch Salmon Brook at Granby	39.5	1964-76	Sept. 26, 1975	170.58	1,940	49	2.52	166.0	770	19.5
01189395	West Branch Salmon Brook at West Granby	11.7	-	Aug. 19, 1955	-	10,500	897	-	-	-	-
01189500	Salmon Brook near Granby	67.4	1947-63	Aug. 19, 1955	172.57	40,000	593	19.0	157.0	2,100	31.2
01189995	Farmington River at Tariffville	577	1913-28, 1929-39, 1971-82	Sept. 22, 1938	144.21	29,900	52	-	-	-	-
01190000	Farmington River at Rainbow	589	1940-82	Aug. 19, 1955	58.86	69,200	117	-	-	-	-

Table 15.--Probability of recurrence of annual flood peaks and high mean discharges

[Example shows that there is a 72 percent chance for a flood peak with a 20-year recurrence interval to be equaled or exceeded within a 25-year period]

Recurrence interval of annual flood peak (years)	Probability (percent chance) that an annual flood peak or high mean discharge with a selected annual recurrence interval will be equaled or exceeded within the indicated period, in years: 1	10	25	50	100
10	10	65	93	-	-
20	5	40	72	92	-
50	2	18	40	64	87
100	1	10	22	39	63
200	0.5	5	12	22	39
500	.2	2	5	10	18

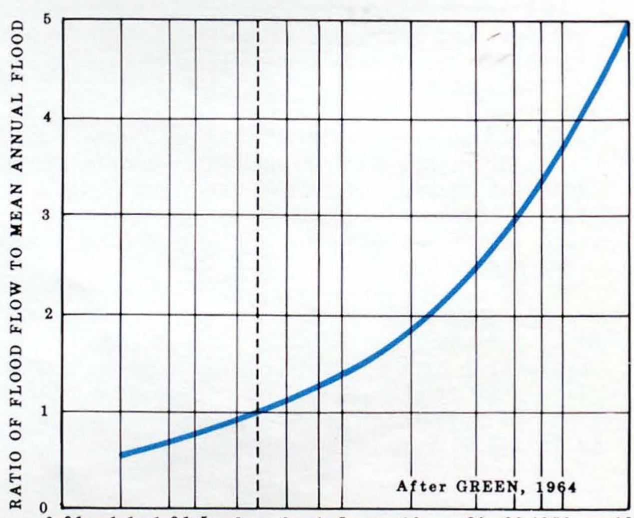


Figure 21.--Recurrence intervals of peak flows

GROUND WATER

HYDROGEOLOGIC SETTING

The Farmington River basin is underlain by three principal geologic units: bedrock, till, and stratified drift. These units form the physical framework for storage and movement of ground water; they differ significantly in geologic origin and in water-yielding characteristics. Bedrock underlies the entire basin and is discontinuously covered by unconsolidated till and stratified-drift deposits. All the subsurface units have openings that can store and transmit water.

MOVEMENT AND STORAGE

Unlike surface water that is present in discrete channels or depressions in the land surface, ground water is present everywhere beneath the basin. The water table defines the top of the saturated zone within which the open spaces in earth materials are completely filled with water. The water table forms springs and swamps where it intersects the land surface and locally coincides with the water level in most streams, ponds, and lakes.

Movement of ground water is governed principally by the size of the subsurface openings and the pressure or head of the water within the flow system. Unconsolidated materials, such as stratified drift and till, have many open pore spaces between the individual grains. If the pore spaces are saturated and interconnected, they provide for storage and are conduits for movement of water. Porosity, the ratio of open space to solid matrix in Earth materials, is expressed as a percentage and for unconsolidated material ranges from 20 to 50 percent (Todd, 1959).

Most open spaces in the bedrock underlying this area occur as fractures (joints and faults). The rocks have some intergranular (primary) porosity, but it is less significant than in unconsolidated materials. Based on limited data (Randall and others, 1966), primary porosity of crystalline bedrock in Connecticut ranges from about 1 to 3 percent. Measured primary porosities of sedimentary rocks are higher; ranging from 2.9 to 11.6 percent (Haeni and Anderson, 1980, p. 43). Many of the intergranular spaces in bedrock are not interconnected, however, and are of little consequence to ground-water movement.

The head in a ground-water flow system is a measure of the potential energy of the fluid; ground water flows in the direction of decreasing head. Differences in the altitude of the water table in an unconfined flow system, one in which the water table is at atmospheric pressure and is free to rise and fall, indicate the direction of horizontal ground-water flow.

In general, the altitude of the water table is highest under hills and lowest at streams. Consequently, ground water moves downward along this hydraulic gradient from uplands to adjacent streams where it discharges. Most of the dry-weather flow of natural streams in the basin consists of ground-water discharge that is termed ground-water runoff.

Ground-water flow systems differ in size and, within the Farmington River basin, are of three general types:

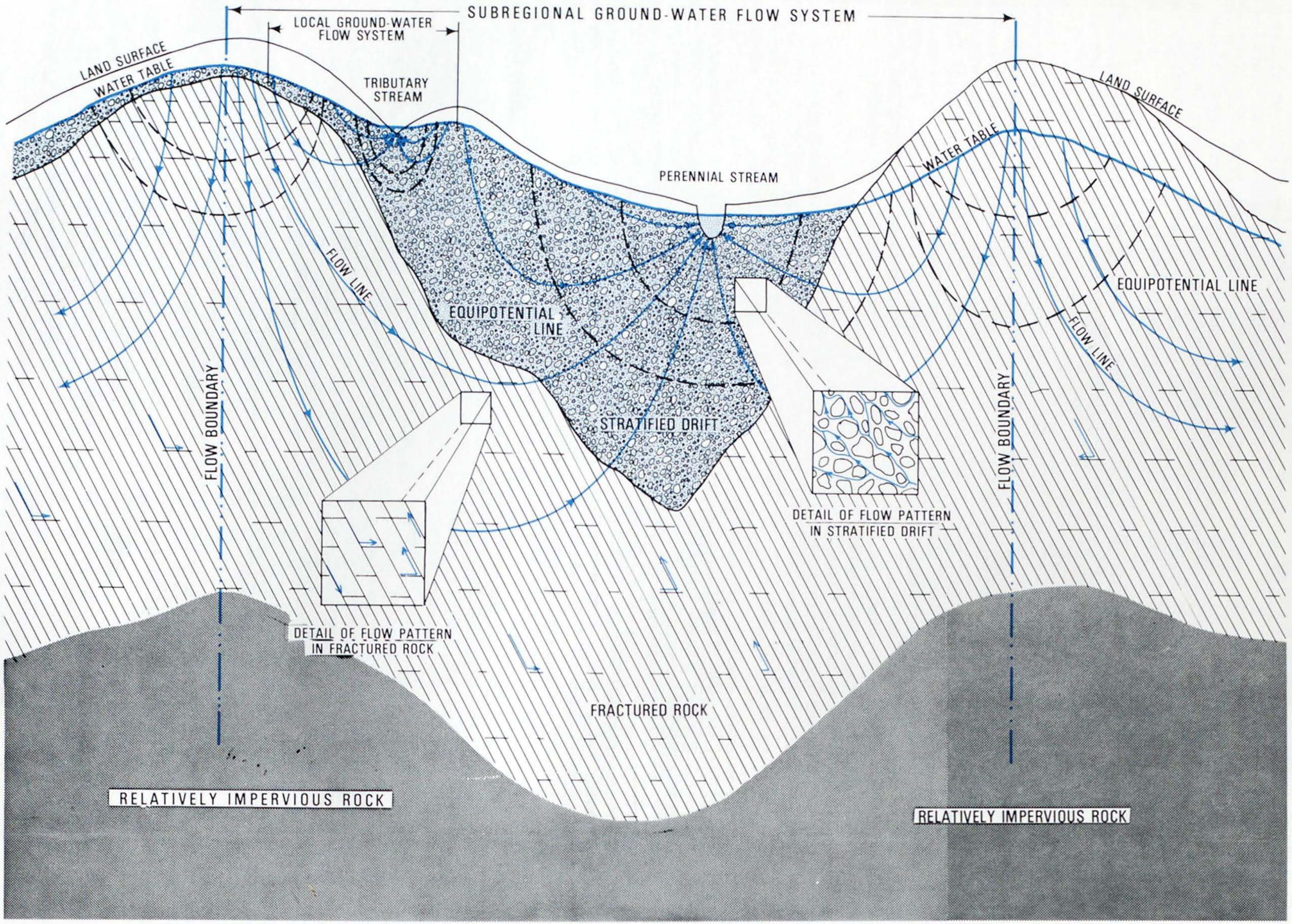
(1) Regional--very large scale ground-water flow systems that extend under one or more major surface-water drainage divides. Water moving through the sedimentary rocks beneath parts of the Farmington River basin may be part of a regional flow system. Present data are insufficient to define the extent or magnitude of such systems.

(2) Subregional--moderately large ground-water flow systems that are generally confined to the areas drained by major perennial streams. They extend laterally from drainage divide to drainage divide and vertically to depths where either the bedrock has no interconnected fractures or a regional system is present. Subregional systems occur in both unconsolidated deposits and bedrock. In this area, they are the most hydrologically significant system and are the ones most frequently tapped for ground-water supplies.

(3) Local--small ground-water flow systems that develop around ponds, small streams, and swamps. These systems are generally superimposed upon a larger, subregional system and commonly exist only a few months of the year. Their size varies considerably, chiefly in response to precipitation. Data that can be used to define the lateral and vertical extent of local flow systems are sparse.

The general pattern of ground-water flow that is most common in the study area is idealized in figure 22. At a given site, all three types of flow systems may exist; several local systems may be incorporated within a subregional system, which, in turn, is part of a regional one.

Ground-water flow systems are dynamic, with water continually entering and leaving. Under conditions of equilibrium, the systems are in dynamic balance and water entering or leaving must be accounted for. In the equation that describes this balance, water entering a ground-water system



from Mazzaferro and others, 1979

Figure 22.--Idealized pattern of ground-water flow in stratified drift and bedrock

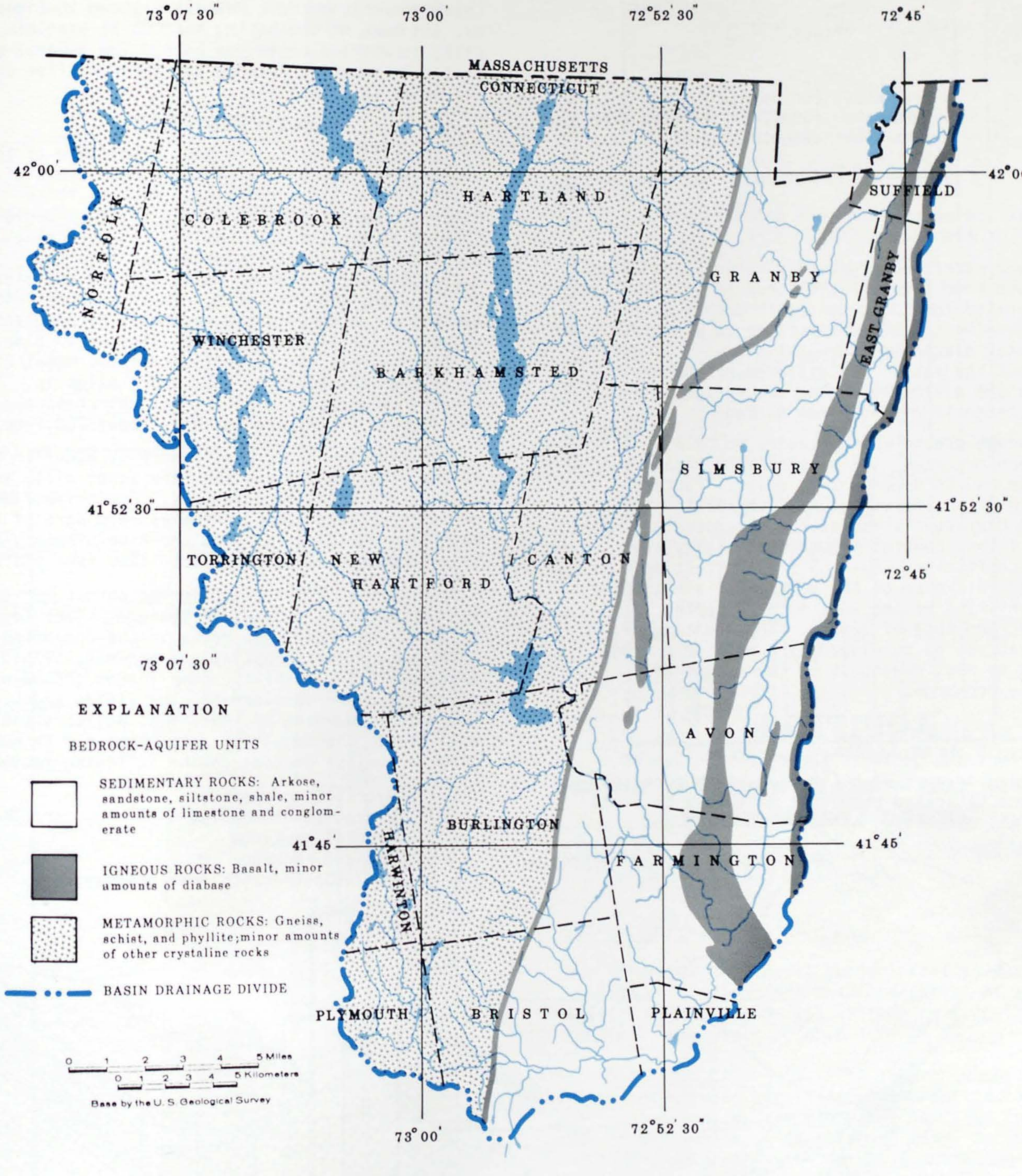


Figure 23.--Areal distribution of bedrock units

is treated as one item, ground-water recharge; water leaving the system is divided into several components. For a natural system where there is no pumping from the aquifer, the balance can be expressed as shown:

$$GW_{(r)} = GW_{(ro)} + GW_{(et)} + U \pm S,$$

where:

$GW_{(r)}$ = Ground-water recharge,
$GW_{(ro)}$ = Ground-water runoff to streams,
$GW_{(et)}$ = Ground-water evapotranspiration,
U = Underflow,
S = Changes in ground-water storage.

All of the above terms are defined in the glossary at the end of this report.

Ground-water recharge under natural conditions is derived from precipitation that percolates to the saturated zone. It generally occurs during the nongrowing season (mid-October to mid-April). Groundwater discharge ($GW_{(ro)} + GW_{(et)} + U$) occurs throughout the year. The difference between recharge and discharge during any period is equal to the change in ground-water storage.

Although ground water appears to be a widespread resource, its availability varies over the basin and is dependent on several factors. The yield of an individual well is related to: (1) physical characteristics of the saturated earth materials that control the transmissivity and storage coefficient, (2) the areal extent and saturated thickness of the materials, and (3) the characteristics of the well such as depth, diameter, and type of finish. The quantity of water that can be developed by a well or a group of wells is also dependent on the amount of available recharge.

AQUIFERS

Aquifers are geologic formations, group of formations, or part of a formation that contains sufficient saturated permeable materials to yield significant quantities of water to wells and springs. The composition, distribution, and hydrologic characteristics of the stratified drift, till, and bedrock aquifers are discussed in the sections that follow. The areal distribution of stratified drift and till is shown on plate B (back pocket); bedrock units are shown in figure 23. In most of the basin, bedrock is overlain by till, stratified drift, or both. The general spatial relationships between the three aquifer units are shown in figure 24.

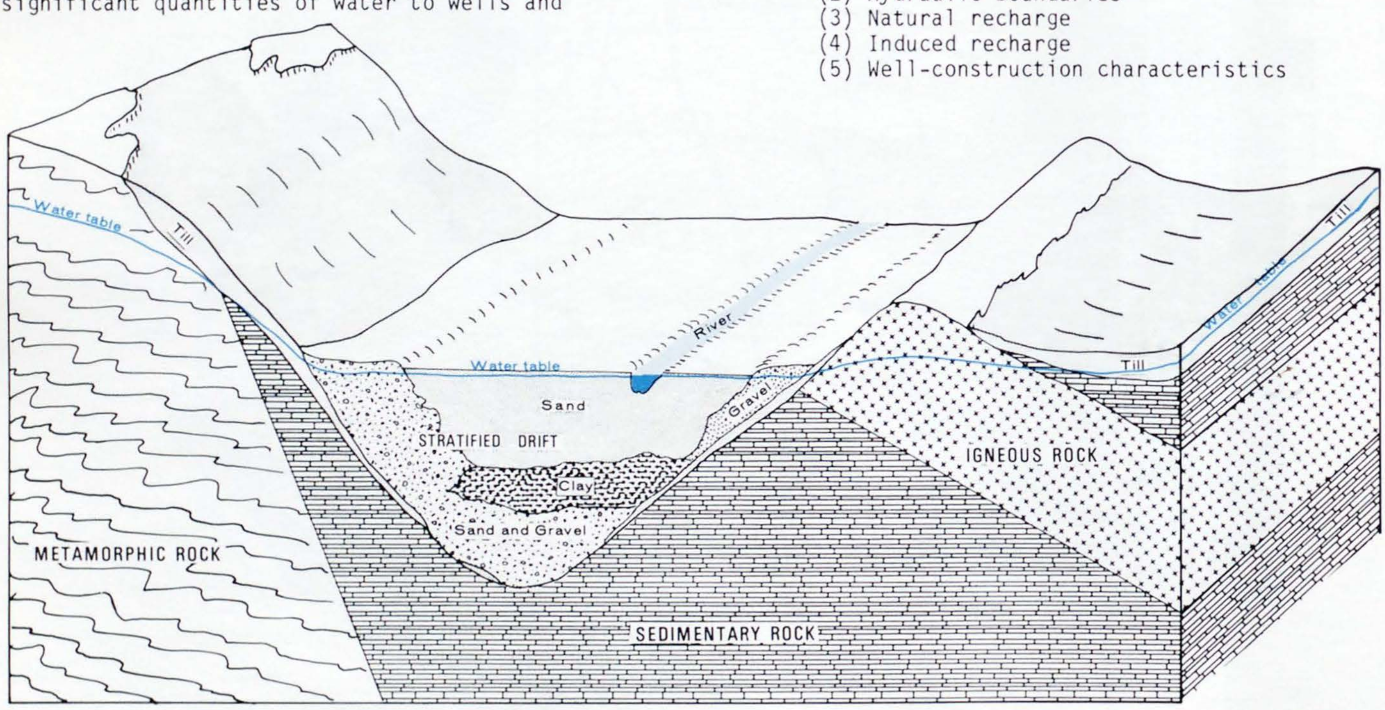
STRATIFIED DRIFT

Stratified drift, the most productive of the aquifers, is composed of interbedded layers of gravel, sand, silt, and clay. Most of these materials were deposited during the last deglaciation of southern New England and generally occur in valleys and lowlands that were the drainageways for glacial meltwaters or the sites of temporary glacial lakes. In this study, minor amounts of unconsolidated sediments of nonglacial origin -- for example, recent alluvium -- also are included within the stratified drift. About 22 percent of the basin or 125 square miles is covered by stratified drift; its thickness exceeds 400 feet in places and averages about 100 feet.

Coarse sand and gravel generally occur in the narrow, shallow valleys and fine sand, silt, and clay in the broad deep valleys. Extensive fine-grained deposits occur in the eastern part of the main Farmington valley from the Avon-Simsbury town line to the Massachusetts state line (see plate B).

Stratified drift commonly has abrupt horizontal and vertical changes in texture. (See logs of selected wells and test holes in the companion basic data report, Hopkins and Handman, 1975). Although this variability complicates ground-water exploration and development, the yields and response to pumping of individual aquifers can be evaluated. The amount of water that can be pumped from an aquifer depends on the following factors:

(1) Hydraulic properties
(2) Hydraulic boundaries
(3) Natural recharge
(4) Induced recharge
(5) Well-construction characteristics



from Mazzaferro and others, 1979

Figure 24.--Block diagram showing idealized spatial relationships between principal aquifers

Each of these factors is discussed below. Yield data from wells tapping stratified drift are included in table 16, and yield frequency is shown in figures 25 and 26. The yields of screened wells give a better indication of the productivity of stratified drift than the yields of open-end wells because the latter are less efficient.

Table 16.--Yields of wells

[Maximum, minimum, and median yields of wells tapping bedrock and stratified drift]

Aquifer	Well type (finish)	Number of wells	Yield (in gallons per minute) Maximum	Minimum	Median
Crystalline bedrock:					
Igneous (traprock)1/	Open hole	16	100	2.0	8.0
Metamorphic 1/	Do.	331	200	.1	5.0
Sedimentary bedrock2/	Do.	457	400	.2	8.0
Stratified drift1/	Do.	64	150	2.0	18
Stratified drift3/	Screened	44	1,400	4.0	141

1/ Well diameter 6 inches

2/ Well diameter 6-10 inches

3/ Screen diameter 6-100 inches. Includes wire-wound and shutter screens.

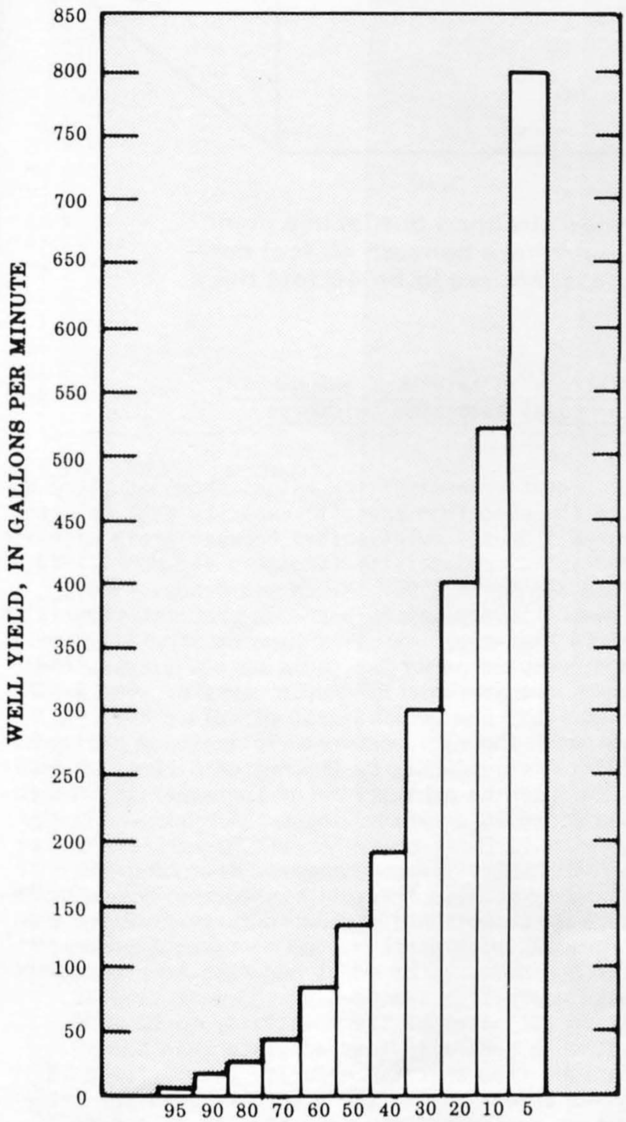


Figure 25.--Yield frequency of 44 screened wells tapping stratified drift

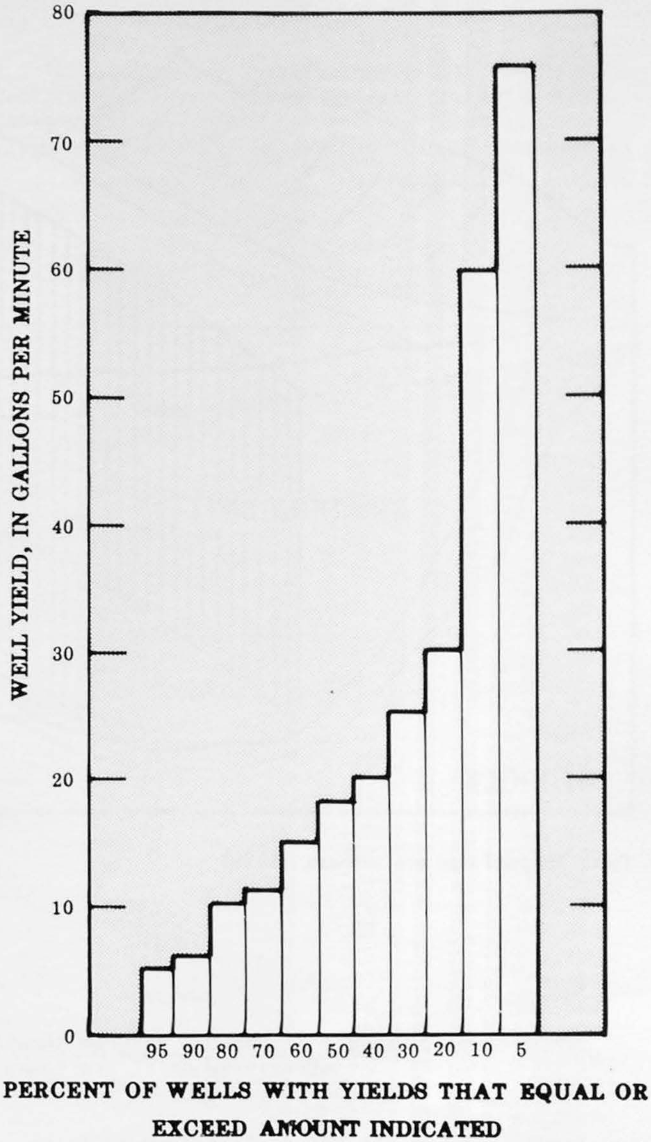


Figure 26.--Yield frequency of 64 open-end wells tapping stratified drift

Hydraulic Properties

Saturated thickness, transmissivity, and storage coefficient are characteristics of an aquifer that describe its ability to store, transmit, and yield water.

Saturated thickness.--The saturated thickness of an unconfined, stratified-drift aquifer is the vertical distance from the water table to the bottom of the aquifer. (See figure 27.) Saturated thickness determines the potential drawdown at a well site.

The total saturated thickness and general lithology of the major stratified-drift deposits in the basin are shown on plate B. It identifies the predominantly coarse-grained deposits, the fine-grained deposits, and the areas known to have coarse over fine-grained and fine over coarse-grained deposits. Areas that have little or no subsurface data are mapped as having inferred coarse- or inferred fine-grained deposits. If the entire section is composed of fine-grained material, available drawdown is unimportant, as the satisfactory installation of screened wells is

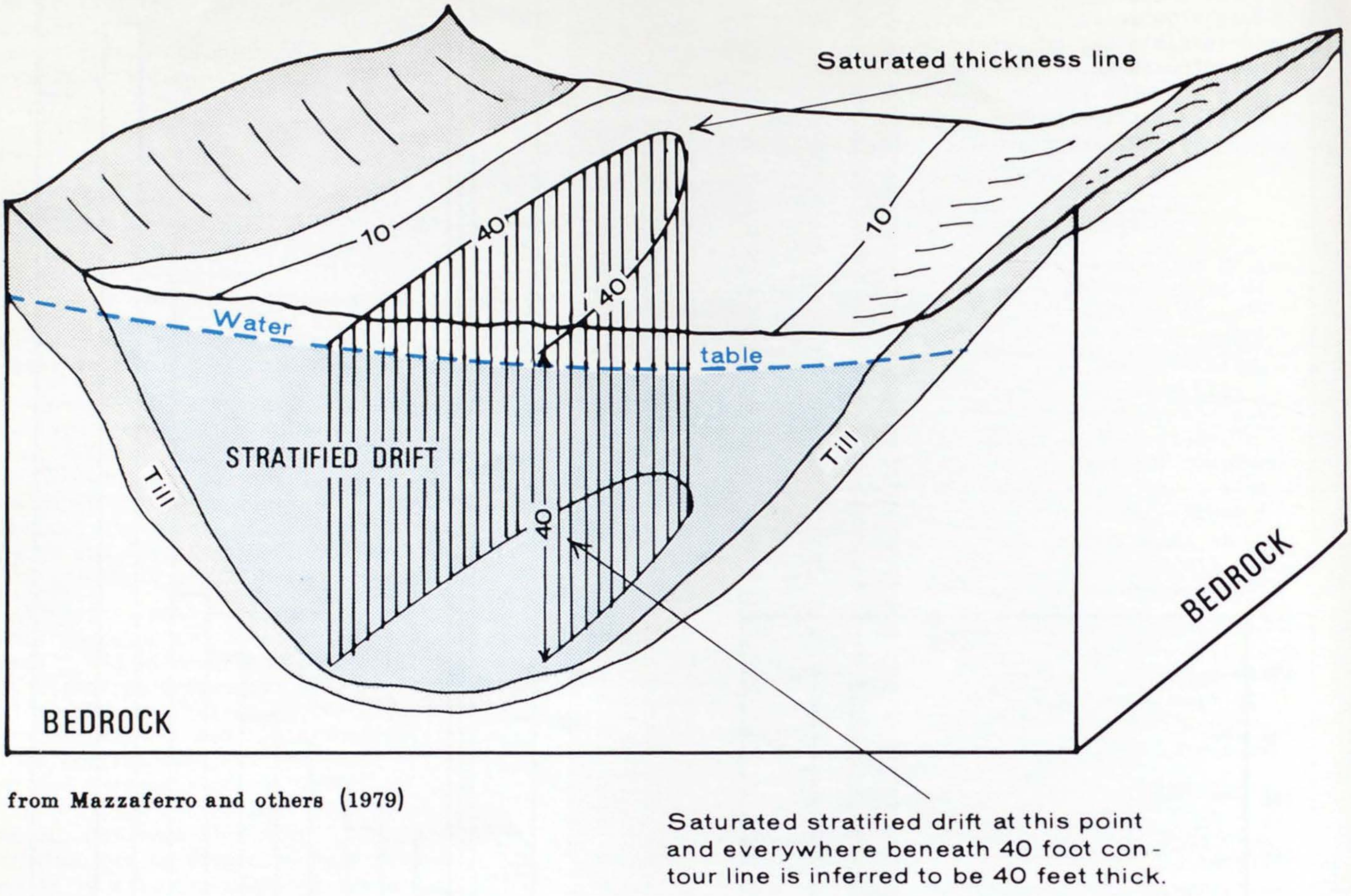


Figure 27.--Block diagram showing how variations in saturated thickness of stratified drift are shown by lines of equal saturated thickness

precluded. If the saturated stratified drift is coarse-grained throughout its vertical extent, the drawdown available for the development of wells is equal to the total saturated thickness; if it is coarse-grained at the surface and fine-grained at depth, drawdown available for development is equal to the saturated thickness of the coarse-grained, upper part of the section. Where fine-grained material overlies coarse-grained material, available drawdown is equal to total saturated thickness as in the case of sections that are coarse-grained throughout.

Saturated thicknesses range from less than 10 feet near the till-bedrock margins to more than 360 feet in parts of Plainville, Farmington, and Simsbury. Generally, saturated stratified drift more than 100 feet thick contains significant amounts of fine-grained material. Detailed studies will be needed in these areas to determine the feasibility of ground-water development.

Transmissivity.--Transmissivity describes the rate at which water moves through the aquifer. It is equal to average hydraulic conductivity (a measure of the rate at which water moves through a unit area of the aquifer) times the saturated thickness. Both transmissivity and hydraulic conductivity are more completely defined in the glossary.

Point transmissivity values shown on plate B are computed from specific-capacity data or estimated from the relationship between grain size and hydraulic conductivity (Krumbein and Monk, 1942; Rose and Smith, 1957; Masch and Denny, 1966). Transmissivity values based on specific capacities of 29 high-capacity wells tapping stratified drift and computed using the Theis method (Theis, 1963) are shown in table 17 and on plate B. The table also lists the data used to calculate the values. The ratio between vertical and horizontal hydraulic conductivity (K_v:K_h) of 0.10 is an estimate based on evaluations of the materials described in drillers' logs.

Transmissivities estimated from the relationship between hydraulic conductivity and grain-size distribution are used to further define the transmissivity distribution of stratified drift in the basin. Logs of wells and test holes, together with grain-size analyses of sediment samples, allow estimates of transmissivity to be made, although generally less accurate than those derived from specific capacity data. Table 18 gives an example of the procedure used for estimating transmissivity from the log of a test boring. Values of hydraulic conductivity are assigned to each lithologic unit of the log. These values are multiplied by the saturated thickness of the unit and totaled to obtain the transmissivity of the section.

Table 17.--Transmissivity of stratified drift

[Transmissivities are computed from specific capacities using the Theis method (Theis, 1963). Drawdowns used to calculate adjusted specific capacities are corrected for the effects of partial penetration (Butler, 1957). All K_v/K_h values assigned as vertical to horizontal hydraulic conductivity ratios equal 0.10. Specific capacity values in gallons per minute per foot of drawdown.]

Well No.1/	Pumping rate (gal/min)	Observed drawdown (ft)	Specific capacity (observed)	Specific capacity (adjusted)	Average hydraulic conductivity (ft/d)	Storage coefficient2/ (dimensionless ratio)	Transmissivity (ft^2/d)
A 290	250	11	22	36	225	0.20	4,500
BS 4	800	32	25	62	192	.20	13,500
BS 148	1,400	28	50	117	368	.20	25,700
BS 198	150	14	10	17	102	.10	3,300
BS 220	350	7	50	47	404	.20	7,300
BS 221	302	10	30	33	230	.20	4,800
BS 222	350	25	14	25	130	.20	4,300
BS 225	500	13	38	58	284	.20	9,700
BS 227	159	15	10	34	221	.20	6,600
BS 228	198	21	9	21	113	.20	3,700
F 97	190	42	4	16	78	.20	3,300
F 100	132	4	33	118	515	.10	26,300
F 204	175	8	21	43	222	.10	8,900
F 248	726	42	17	65	158	.20	13,400
F 249	870	30	29	138	315	.20	29,900
F 255	100	6	16	29	215	.10	5,600
F 268	110	4	27	43	437	.10	9,200
GR 66	510	38	13	32	93	.20	6,200
NH 132	275	50	5	17	41	.20	3,300
PV 24	265	74	3	32	40	.10	5,800
PV 33	240	29	8	29	99	.20	5,600
PV 57	500	19	26	127	323	.20	29,100
PV 63	700	33	21	87	179	.20	19,300
PM 2	488	33	14	44	151	.20	8,000
SI 37	265	11	24	36	173	.20	5,700
SI 81	400	50	8	42	127	.20	9,100
SI 84	1,200	26	46	101	269	.20	17,800
SI 230	700	13	53	153	452	.20	32,500
SI 285	710	19	37	107	292	.20	22,200

1/ See plate A for location.
2/ Assumed value; see text.

Hydraulic conductivity values are estimated for lithologic units described in each well and test-hole log by either of two methods. The first is based on materials descriptions commonly used by drillers in southern New England. (See table 19.) These values are based on an evaluation of selected well and test-hole logs from areas where hydrologic information is reliable. The second method is used for test holes where grain-size characteristics of the materials penetrated have been measured. Values are based on relationships established between median-grain size and uniformity coefficient (an index of sorting) of stratified-drift samples and laboratory determinations of horizontal hydraulic conductivity (Randall and others, 1966; Thomas, M. P., and others, 1967; Thomas, C. E. and others, 1968; Ryder and others, 1970). This relationship between grain-size characteristics and hydraulic conductivity is shown in figure 28. This method is probably more accurate than the first but neither are as accurate as values from properly conducted aquifer tests. At sites on plate B, the values of transmissivity calculated from the logs of wells and test holes are generally lower than the values calculated from specific-capacity data. This may be due to the effect of induced recharge from nearby streams on the specific-capacity data. The values estimated for logs, however, are at best only fair approximations.

Table 18.--Example of estimating transmissivity from logs of wells and test holes

[Test hole F 6th. Drilled with power auger by U.S. Geological Survey, 1971. Depth to water, 9 feet below land surface]

Materials description	Depth below land surface From To (ft)	Saturated thickness (b) (ft)	Assigned hydraulic conductivity (K) (ft/d)	Calculated transmissivity of lithologic unit (b x K) (ft²/d)
Sand, fine to very fine, and silt; few scattered pebbles; yellow-brown.	0 - 6	0	-	-
Sand, coarse, and some medium sand; little very coarse sand; little fine sand; trace fine gravel; trace fine sand; yellow-brown1/.	6 - 19	10	150	1500
Silt and some very fine sand; little fine sand; trace clay; trace medium and coarse sand2/.	19 - 25	6	2	12
Sand, medium, with little fine and little coarse sand; trace silt and very fine and very coarse sand; scattered fine gravel3/.	25 - 33	8	110	880
Sand, coarse to fine, and fine gravel; little silt.	33 - 41	8	100	800
Gravel, coarse to very fine; very coarse to very fine sand, silt and clay, red-brown; till4/.	41 - 45	4	-	-
Refusal (till)5/.	At 45	-	-	-
	Transmissivity of saturated stratified drift			3,192 ft^2/d

1/ Split-spoon sample, 12-13.5 ft depth.
Median grain size, 0.6 mm.
Uniformity coefficient 10.0.

2/ Split-spoon sample, 22-23.5 ft depth.
Median grain size, 0.05 mm.
Uniformity coefficient 4.8.

3/ Split-spoon sample, 27-28.5 ft depth.
Median grain size, .31 mm.
Uniformity coefficient 3.1.

4/ Split-spoon sample 42-43.5 ft depth.
Median grain size 0.4 mm.
Uniformity coefficient 200.

5/ Split-spoon sample, at 45 ft depth.
Median grain size, 1.0 mm.
Uniformity coefficient 420.

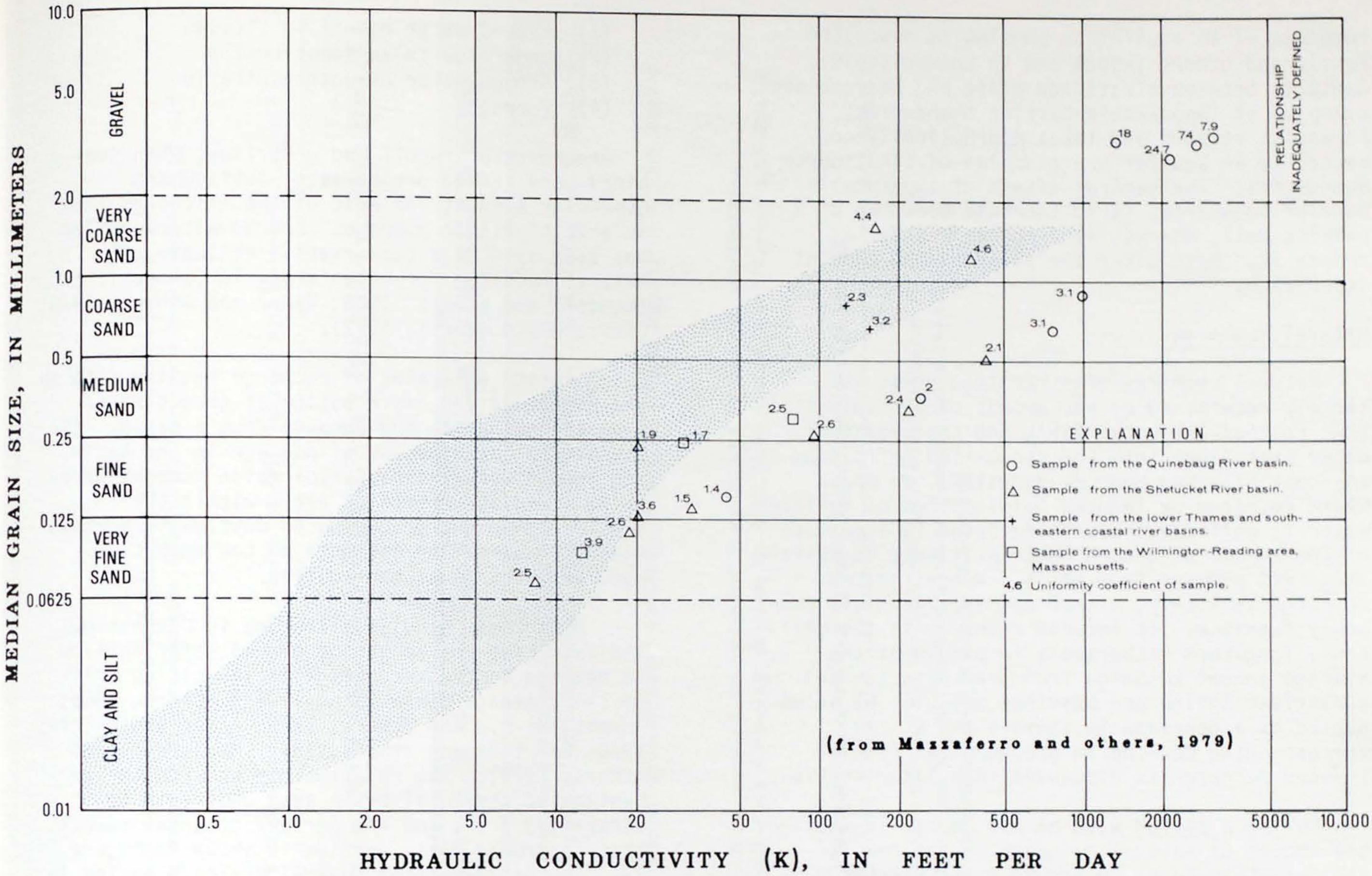


Figure 28.--Relationship between hydraulic conductivity, median grain size, and sorting in stratified-drift aquifers

Table 19.--Hydraulic conductivity values for estimating transmissivity of stratified drift

[Modified from Ryder and others, 1970, page 21]

Description (from drillers' logs)	Estimated median grain size (mm)	Estimated hydraulic conductivity (K) (ft/d)
Clay	0.02	1
Very fine sand, silt and clay.	.07	5
Very fine sand	.08	7
Fine sand	.15	20
Fine to medium sand	.20	25
Sand	.23	40
Coarse sand and clay	.45	80
Dirty gravel	.55	100
Medium to coarse sand with gravel and layers of clay.	.40	100
Medium sand	.40	125
Fine to medium sand, some medium to coarse gravel.	.25	125
Coarse sand	.70	200
Medium to coarse sand, very fine gravel.	.90	300
Medium sand and gravel	1.0	500
Coarse sand and gravel	2.0	650

Storage coefficient.--The storage coefficient of an aquifer is a measure of its ability to store or yield water. Storage coefficient under unconfined conditions is equivalent to specific yield and is determined by the drainage by gravity of available pore spaces. It is dependent upon grain-size distribution of the sediment and period of drainage (Johnson, 1967; Lohman, 1979). The storage coefficient of unconfined aquifers generally ranges from 0.1 to 0.3 and averages about 0.2 (Lohman, 1979). Storage coefficients may vary with time; data based on short drainage periods must be adjusted to compensate for the fact that gravity drainage or release from storage is not instantaneous. In this report, some analyses use adjusted storage coefficients where drainage periods are of short duration. Storage coefficients in table 17 are based on considerations of both drainage periods and materials descriptions. Storage coefficient represents a volume-to-volume ratio and is dimensionless.

Hydraulic Boundaries

One of the assumptions of the nonequilibrium equation for ground-water flow to a well (Theis, 1935) is that the aquifer is of infinite areal extent. The stratified-drift aquifers in the Farmington River basin are not infinite; they are limited by natural features that form hydraulic boundaries. Such boundaries affect the hydraulic continuity of aquifers and are of two types: Line-source boundaries and impermeable-barrier boundaries. The effect of each type on the response of an aquifer to pumping is described in Ferris and others (1962) and in Lohman (1979). Contacts between stratified drift and bedrock are examples of impermeable-barrier boundaries. Perennial streams and lakes hydraulically connected to an aquifer are examples of line-source boundaries. The general effect of impermeable-barrier boundaries is to increase drawdown at a pumping well, whereas line-source boundaries reduce it. Both alter the shape of the cone of depression.

Natural Recharge

Natural recharge of stratified drift is largely determined by the amount of precipitation that reaches the water table and the amount of water that flows into the stratified drift from adjacent till and bedrock deposits. In areas where recharge by induced infiltration of surface water is unlikely, natural recharge is a measure of the amount of ground water available to sustain long-term pumpage from wells. Where induced recharge is likely, higher pumping rates are commonly feasible. If induced recharge is insignificant, long-term withdrawals in excess of the average annual recharge from precipitation and subsurface inflow are possible but will be accompanied by a decrease in storage and a corresponding decline in ground-water levels. Induced recharge is discussed in a later section.

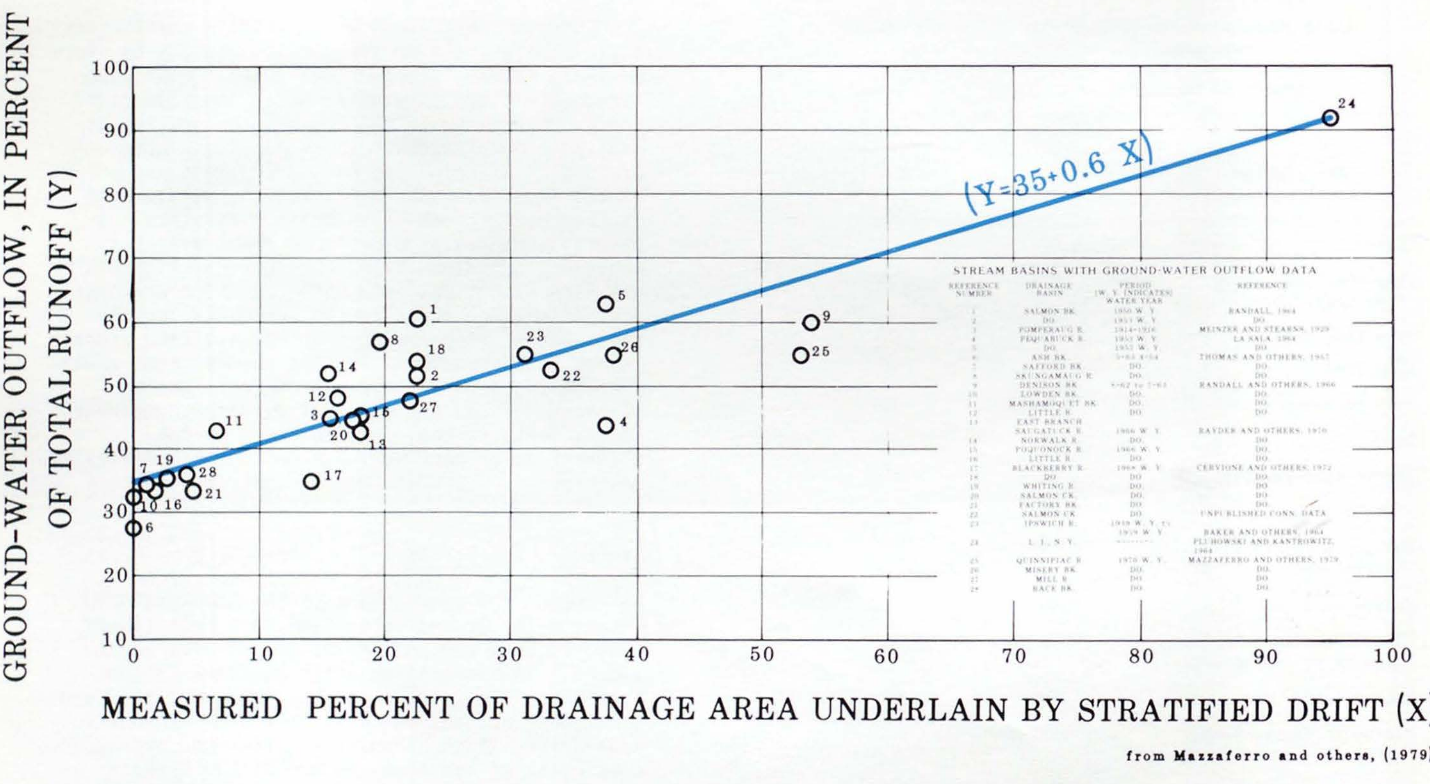
During a period with no net change in storage, the amount of natural recharge to an area is approximately equal to ground-water discharge, which includes some or all of the following components:

(1) Ground-water runoff to streams
(2) Underflow to adjacent basins
(3) Ground-water evapotranspiration
(4) Pumpage

Ground-water runoff and underflow, when combined, are termed ground-water outflow and generally account for most of the discharge from an area of little pumpage. Ground-water outflow has been used as a conservative estimate of natural recharge for other areas in Connecticut (Randall and others, 1966; Ryder and others, 1970; Cervione and others, 1972).

Accurate estimates of recharge require data on the magnitude and distribution of ground-water evapotranspiration and pumpage from a basin. If there is a small amount of pumpage in the basin, and ground-water evapotranspiration is considered to be a redistribution of water within the aquifer, then the ground-water outflow is a reasonable, conservative estimate of the amount of natural recharge to the aquifer.

Hydrologic studies elsewhere in Connecticut indicate that the amount of ground-water outflow is related to the percentage of stratified drift in the drainage basin (Randall and others, 1966; Thomas, M. P., and others, 1967; Ryder and others, 1970; Cervione and others, 1972; Mazzaferro and others, 1979). The relationship between the percentage of the total basin area underlain by stratified drift and the percent of total runoff that is ground-water outflow is shown in figure 29. The data are from several drainage basins in Connecticut, Massachusetts, and New York. The line of relation in figure 29 was developed by

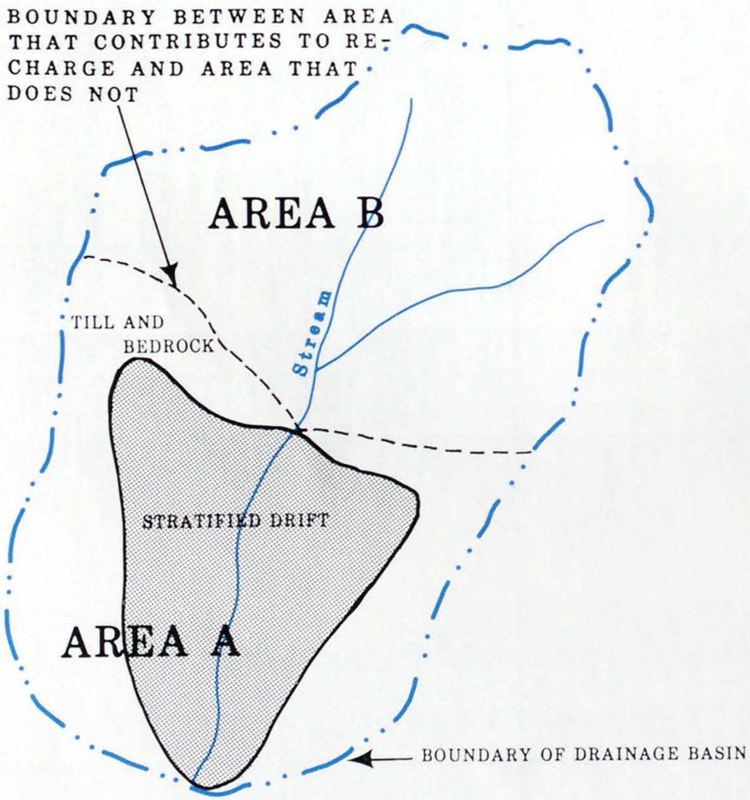


STREAM BASINS WITH GROUND-WATER OUTFLOW DATA

REFERENCE NUMBER	DRAINAGE BASIN	PERIOD (W. Y. INDICATES WATER YEAR)	REFERENCE
1	SALMON BK.	1950 W. Y.	RANDALL, 1964
2	DO.	1951 W. Y.	DO.
3	POMPERAUG R.	1914-1916	MEINZER AND STEARNS, 1929
4	PEQUABUCK R.	1953 W. Y.	LA SALA, 1964
5	DO.	1953 W. Y.	DO.
6	ASH BK.	5-63 4-64	THOMAS AND OTHERS, 1967
7	SAFFORD BK.	DO.	DO.
8	SKUNGAMAUG R.	DO.	DO.
9	DENISON BK.	8-62 to 7-63	RANDALL AND OTHERS, 1966
10	LOWDEN BK.	DO.	DO.
11	MASHAMOQUET BK.	DO.	DO.
12	LITTLE R.	DO.	DO.
13	EAST BRANCH SAUGATUCK R.	1966 W. Y.	RAYDER AND OTHERS, 1970
14	NORWALK R.	DO.	DO.
15	POQUONOCK R.	1966 W. Y.	DO.
16	LITTLE R.	DO.	DO.
17	BLACKBERRY R.	1968 W. Y.	CERVIONE AND OTHERS, 1972
18	DO.	DO.	DO.
19	WHITING R.	DO.	DO.
20	SALMON CK.	DO.	DO.
21	FACTORY BK.	DO.	DO.
22	SALMON CK.	DO.	UNPUBLISHED CONN. DATA
23	IPSWICH R.	1919 W. Y. to 1959 W. Y.	BAKER AND OTHERS, 1964
24	L. I., N. Y.	--------	PLUHOWSKI AND KANTROWITZ, 1964
25	QUINNIPIAC R.	1970 W. Y.	MAZZAFERRO AND OTHERS, 1979
26	MISERY BK.	DO.	DO.
27	MILL R.	DO.	DO.
28	BACK BK.	DO.	DO.

from Mazzaferro and others, (1979)

Figure 29.--Relationship between ground-water outflow and percentage of drainage area underlain by stratified drift



from Mazzaferro and others, 1979

(1) Measure the area of stratified drift and adjacent till and bedrock (Area A) from which ground water flows into the stratified drift. ---------------------- 2.17 mi^2

(2) Measure that part of Area A underlain by stratified drift (shaded area)-------- 1.43 mi^2

(3) Determine what percent (X) of Area A is stratified drift (X 1.43 ÷ 2.17)------ 66 percent

(4) Calculate ground-water outflow (Y) from Area A as a percent of mean annual runoff from Figure 38 -- 75 percent

(5) Calculate mean annual runoff from Area A as determined from Figure 10 (Runoff=1.05 (ratio at point of interest) x 1.16 x 2.17)------------------------ 2.64 Mgal/d

(6) Calculate average annual ground-water outflow (75 percent of 2.64 Mgal/d ---- 1.98 Mgal/d

and:

ground-water outflow equaled or exceeded 7 years out of ten by multiplying the average annual ground-water outflow by 0.80 (0.80 x 1.98 Mgal/d)---- 1.58 Mgal/d

and:

longterm minimum ground-water outflow by multiplying the average annual ground-water outflow by 0.17 (0.17 x 1.98 mgal/d) --------------------------- 0.79 Mgal/d

These coefficients (0.80 and 0.17) are the ratios of total runoff equaled or exceeded 7 years in 10 and the minimum total runoff to the mean runoff of Burlington Brook at Burlington (30 years of record).

Figure 30.--The method of estimating ground-water outflow from a stratified-drift aquifer

linear regression. It is described by Mazzaferro and others (1979), and can be expressed as:

$$Y = 35 + 0.6X$$

Where:

Y = ground-water outflow as a percentage of total runoff

X = percentage of total basin area underlain by stratified drift

The graph can be used to estimate average annual ground-water outflow, the ground-water outflow equaled or exceeded 7 years in 10, and the long-term minimum ground-water outflow from stratified-drift deposits in nonurbanized parts of the Farmington River basin. The first value represents a conservative estimate of natural recharge during average years, and the latter two values represent estimates during dry and extremely dry years. The method is based on one developed by Cervione and others (1972) and assumes that the ratio of ground-water outflow to total outflow remains nearly constant from year to year. The procedure consists of six steps, which are illustrated and described in figure 30.

The constant (0.80) used in figure 30 is the ratio of the annual runoff equaled or exceeded 7 years in 10, to the mean annual runoff of Burlington Brook at Burlington (station no. 01188000) during the 1931-60 period of record. The results of this process, shown in step 6, represent conservative estimates of natural recharge during average years, 1.98 Mgal/d, and during dry years, 1.58 Mgal/d.

Induced Recharge

Withdrawal of water from wells near streams and lakes can lower ground-water levels to the extent that water flows from the surface-water body into the aquifer. Recharge by induced infiltration is illustrated in figure 31, which shows cross sections of a stream-aquifer system under natural and pumping conditions. Most of the stratified-drift aquifers in the Farmington River basin are hydraulically connected to perennial streams, and induced recharge can increase the long-term yield of the aquifers. If the adjacent surface-water body is a major stream, induced recharge can assure a continuous water supply substantially higher than available from only natural recharge. The quantity of water that will infiltrate from a stream or lake is determined by (1) vertical hydraulic conductivity and thickness of streambed materials, (2) viscosity of the surface water, (3) average head difference between the surface-water body and the aquifer, and (4) total area of the streambed through which infiltration takes place. These factors can be used in a modified form of the Darcy equation to estimate potential induced recharge (Walton and others, 1967):

$$R_I = I_t S_r A_r$$

Where:

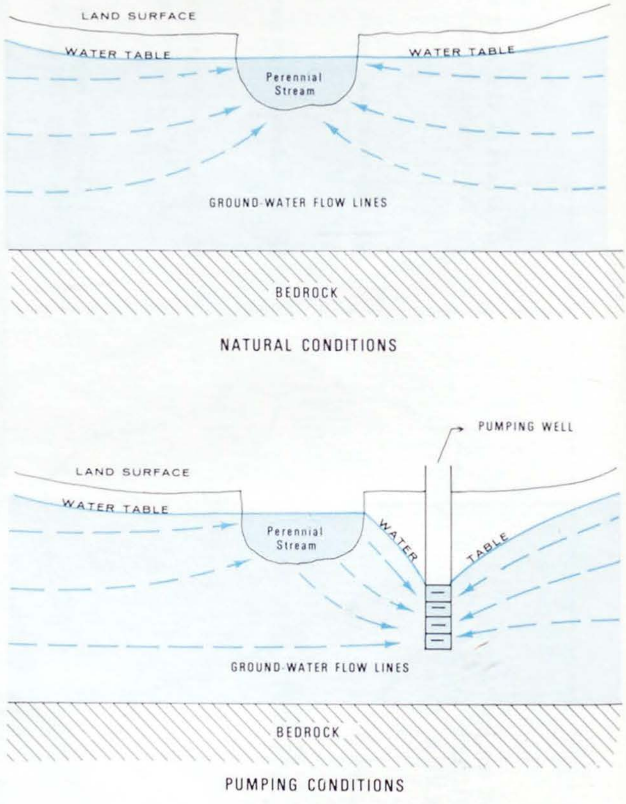
R_I = potential recharge by induced infiltration, in gallons per day (gal/d),

I_t = average infiltration rate per square foot of streambed per foot of head loss, corrected for a given surface-water temperature, in gallons per day per square foot per foot ((gal/d/ft^2)/ft,

S_r = (a) average head loss over the infiltration area or (b) average depth of water in the stream for a particular stream stage, depending upon whether the water table is above (a) or below (b) the streambed, in feet (ft),

A_r = total area of infiltration, in square feet (ft^2).

Streambed materials have a major influence on infiltration rates and on the recharge potential. Sediments in a streambed are variable because of current velocities, channel configuration, source material, aquatic vegetation, and other factors. These variations occur in three dimensions, as well as over a period of time. Streambed materials often occur as complex assemblages of organic and inorganic particles that range in size from clay to boulders. Streams alternately scour and deposit bed materials in response to runoff.



(from Mazzaferro and others 1979)

Figure 31.--Generalized diagram showing natural conditions in a stream-aquifer system contrasted with pumping conditions

Layers of decaying foliage often constitute a significant part of the bed material along sections of the major streams during fall and winter months. The changes in sediment composition with time and distance can cause variations in the vertical hydraulic conductivity of the streambed sediments and the dependent infiltration rate.

Sparse data are available on the infiltration rates of streambed materials in southern New England. A rate of 59 (gal/d/ft^2)/ft at 10^{o}C was determined for a sand and gravel streambed in southwestern Connecticut (Ryder and others, 1970). Cervione and others (1972) discuss a rate of 105 (gal/d/ft^2)/ft at 10^{o}C for a poorly sorted gravel streambed in the lower Housatonic River basin. Gonthier and others (1974) report infiltration rates ranging from 5 to 20 (gal/d/ft^2)/ft for coarse-grained sediments and a maximum rate of 525 (gal/d/ft^2)/ft, all at 15.6^{o}C, for streambed materials in the lower Pawcatuck River basin, Rhode Island.

Temperature of surface water also affects the induced recharge potential. As water temperature decreases, viscosity increases, and infiltration rates are reduced. A decrease of 1^{o}C lowers the infiltration rate 2.7 percent (Rorabaugh, 1951). During the 1976 water year, mean monthly surface-water temperatures of the Farmington River at Rainbow (station 01190000) ranged from 23.0^{o}C for July to 0.0^{o}C for January. This seasonal decrease in water temperature would result in more than a 50 percent decrease in the infiltration rate during the colder period.

Well Construction Characteristics

The construction characteristics of a well tapping a stratified-drift aquifer are important determinants of its yield. Well-construction characteristics alone may account for more than 50 percent of the drawdown in a pumping well. It is necessary to consider the type of well construction and development best suited for the aquifer at any site in order to optimize well yield. Several types of well construction are used to develop water from stratified-drift aquifers. All are basically intake structures that allow water to enter the well while preventing the entrance of aquifer materials.

Dug wells can be developed in all types of stratified-drift aquifers. They are usually lined or cased with concrete or ceramic "culvert" tile or open-jointed fieldstone, and are as much as several feet in diameter and as deep as a few tens of feet. They are generally the only type of construction that is effective in fine-grained aquifers where the upper coarse material is not saturated. A fine-grained aquifer yields water slowly, but some intermittent demands, particularly domestic uses, can be satisfied by the stored water in a large-diameter dug well. For example, a well 3 feet in diameter dug 10 feet below the water table contains about 530 gallons of water. If the pump intake is set 5 feet above the bottom of the well, about 265 gallons is available for use from storage in the well. If this amount of water is withdrawn in a short period, the well would refill to its pre-pumping level in a period of several hours, at which time another 265 gallons would be available.

Drilled open-end wells can be developed in coarse-grained aquifers to supply enough water for most domestic and some commercial uses. This type of construction consists of a blank casing, usually 6 inches in diameter, installed to the bottom of the drilled hole, which commonly ends in sand and gravel, or gravel. This construction technique is particularly suitable where a coarse-grained aquifer is overlain by a substantial thickness of fine-grained material. The yield of open-end wells is generally low because of the large drawdown within the well resulting from the vertical convergence of flow lines in the aquifer toward the bottom of the blank casing during pumping. The yields of 64 open-end wells in the basin summarized in table 16, range from 2 to 150 gal/min with a median yield of 18 gal/min. Records of these wells are given in Hopkins and Handman (1975).

Wells of small diameter (generally 4 inches or less), constructed of a blank casing finished at the bottom with a short perforated section (commonly called a well point or sand point), can supply adequate amounts of water for domestic and small-scale commercial, industrial, irrigation, and public water-supply uses. This type of well construction is particularly suitable for developing water from coarse-grained aquifers and from the uppermost saturated coarse material of fine-grained aquifers. However, such wells are generally installed only where the water table is within 20 to 25 feet of land surface because of limited lifting ability of the commonly used suction-type pumps. Greater pumping lifts could be obtained in 2- to 4- inch diameter wells by use of a jet-type pump and in 3- to 4-inch diameter wells by use of a submersible pump.

Wells greater than 4 inches in diameter, finished with a screen and properly developed, can yield large supplies of water for industrial, irrigation, and public-supply uses. Such wells are generally constructed of a blank casing finished at the bottom with a continuous-slot or shutter-type well screen of selected length. The size of the open slots or shutters in the screen is commonly based on the grain-size distribution of the aquifer material adjacent to it. Some well screens may be enclosed within an artificially emplaced envelope of gravel ("gravel-packed"). Large-diameter screened wells are particularly suitable for developing water from coarse-grained aquifers and from the uppermost coarse material of fine-grained aquifers. They are most effective when the screen is set in the deepest part of these water-bearing units as is practical. The large diameter allows the installation of turbine-type pumps (including submersibles) capable of pumping several hundred or even thousands of gallons per minute. The yields of 44 large-diameter screened wells in the basin summarized in table 16 range from 4 to 1,400 gal/min, a median yield of 141 gal/min (Hopkins and Handman, 1975).

The design of large-diameter screened wells should be given careful attention. The relative length of the screened section of a well can have a significant effect on well yield and, more importantly, on specific capacity (the yield per foot of drawdown). A typical large-diameter well is screened and open to only a part of an aquifer- generally the lower part, therefore, the well only partially penetrates the aquifer. The fractional or partial penetration (screen length divided by saturated thickness of the aquifer) of 25 screened wells in the basin ranges from 0.07 to 0.66 with a median of 0.21. Pumping from a partially-penetrating well causes flow lines in an aquifer to converge vertically toward the screen. This results in greater drawdowns in and adjacent to the well than would occur if it fully penetrated the saturated thickness. This additional drawdown can be estimated from data on well diameter, pumping period, degree of partial penetration, and the ratio of vertical to horizontal hydraulic conductivity of the aquifer. The estimated additional drawdown can then be subtracted from the total drawdown to determine what the yield and specific capacity would be if the well was fully penetrating. From data in the companion basic-data report (Hopkins and Handman, 1975), the calculated specific capacity of 29 large-diameter screened wells in the basin ranged from 3.6 to 50.0 gal/min per foot with a median of 21.8 gal/min per foot. The drawdown in these wells was adjusted for the effects of partial penetration. The resulting adjusted specific--capacity values ranged from 16.1 to 153.8 gal/min/ft with a median of 43.7 gal/min/ft. If these 29 wells had been fully penetrating, their yields at the same pumping levels would have been about two times greater.

Diameter also can directly affect the yield and specific capacity of a screened well. The effects of diameter and partial penetration are illustrated in figure 32. The graphs suggest that for a screened well to be most efficient, it should have the largest diameter and longest screen possible. However, in practice, pumps generally are placed several feet above the top of the screen and, because yield is commonly considered to be directly related to drawdown, a relatively short screen is used to increase available drawdown. The net result, however, is to increase drawdown and decrease yield because of partial penetration effects. A better practice might be to determine the optimum trade-off between drawdown and screen length by using the desired well yield as a guideline. Figure 33 shows the effect that changes in partial penetration have on the yield of a well with the pumping level kept 1 foot above the screen. Yield shows initial increases, reaches a maximum at a partial penetration of about 0.4, and then decreases with increasing screen length. The graph, from Ryder and others (1981), is based on specific aquifer and well chacteristics, but the relationships shown apply to all ranges of aquifer characteristics, well diameter, and pumping period. Although a partial penetration of 0.4 appears to be the best trade-off based on hydraulic criteria, the cost of the well may also be an important consideration. The cost of a screen is directly related to its length. Note on figure 33 that well yield only increases 7 percent as partial penetration increases from 0.3 to 0.4, in contrast to a yield increase of 21 percent as partial-penetration increases from 0.2 to 0.3. Therefore, a partial penetration of about 0.3 may be economically more favorable than 0.4. The use of this trade-off results in a shorter and therefore less costly screen while sacrificing only 7 percent in well yield.

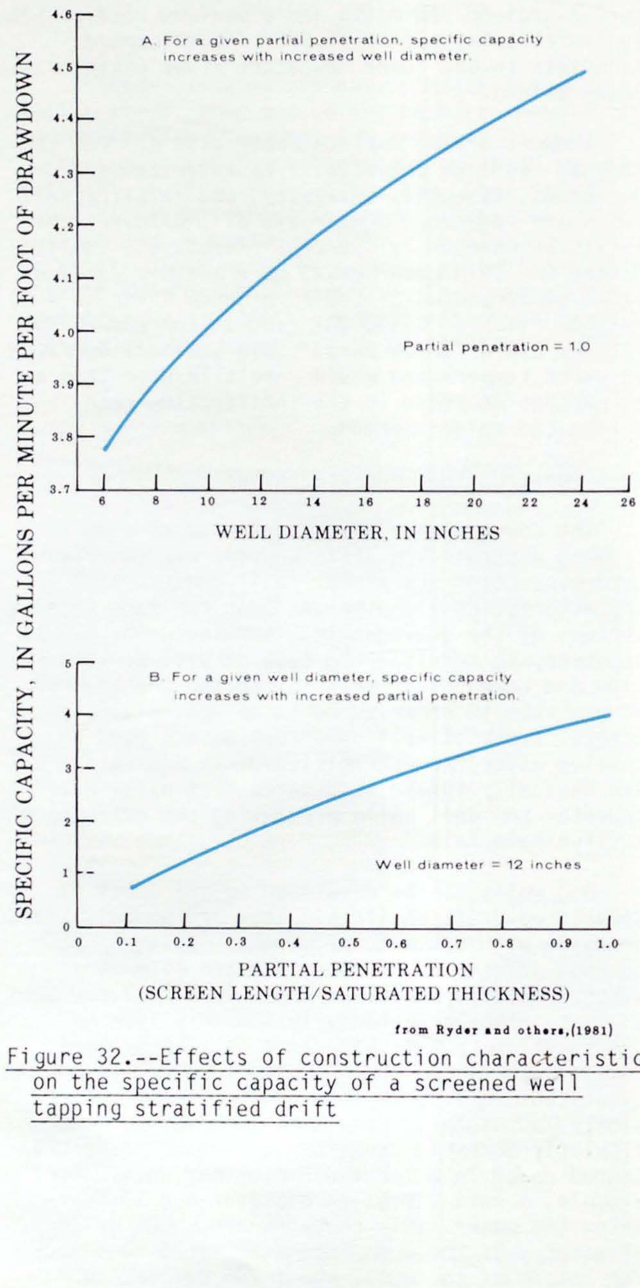


Figure 32.--Effects of construction characteristics on the specific capacity of a screened well tapping stratified drift

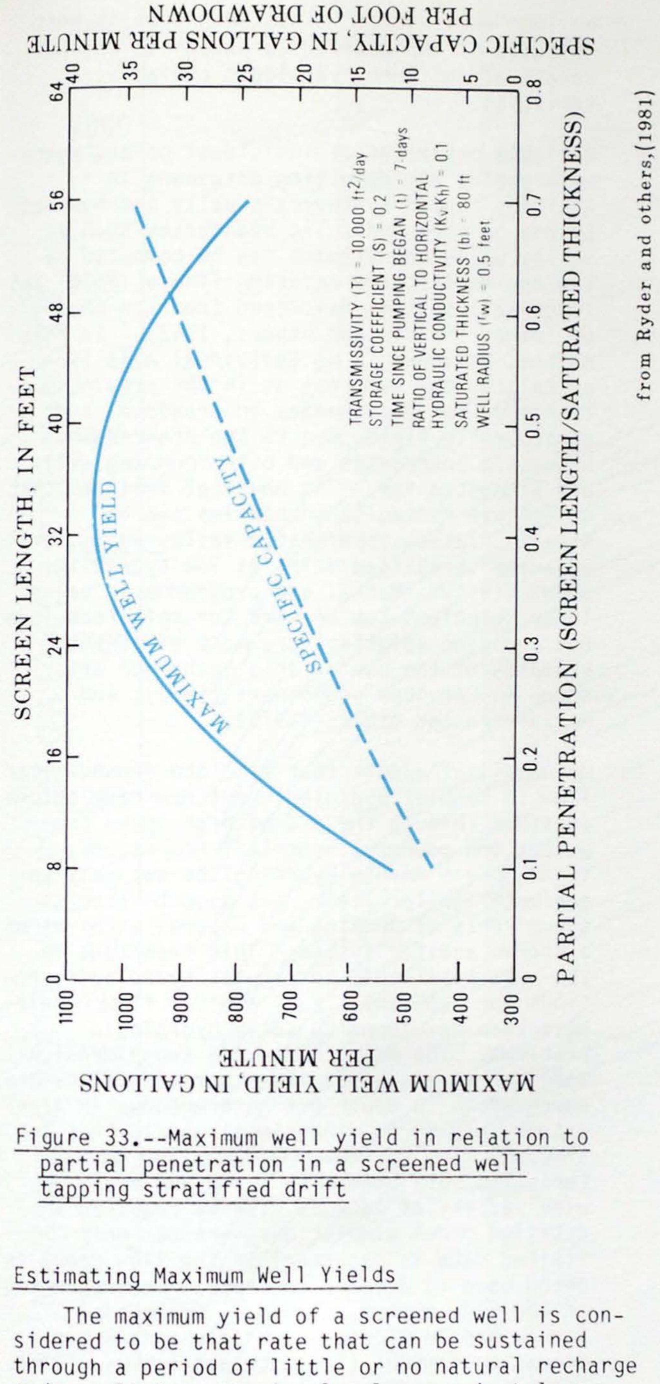


Figure 33.--Maximum well yield in relation to partial penetration in a screened well tapping stratified drift

Estimating Maximum Well Yields

The maximum yield of a screened well is considered to be that rate that can be sustained through a period of little or no natural recharge and result in a pumping level approximately one foot above the top of the screen. Carefully planned and executed pumping tests provide the most reliable information on potential yields of wells. The yield of a screened well tapping a coarse-grained aquifer can be estimated, however, by use of the curves in figure 34 that relate yield to saturated thickness for seven values of transmissivity and three values of well radius. The values used to construct the curves on figure 34 are based on the Theis nonequilibrium formula (Theis, 1935, p. 520). These curves apply only for the following conditions: (1) pumping rate is constant through the 180-day period of little or no recharge, (2) pumping level at the end of the pumping period is 1 foot above the top of the screen, (3) the screen is set in the lowest third of the aquifer (partial penetration equal to 0.3), (4) the storage coefficient of the aquifer is approximately equal to 0.2, (5) the aquifer is more or less uniform and of infinite areal extent.

The following example illustrates how the curves in figure 34 and the data on plate B can be used to estimate maximum well yield. At a hypothetical site in the basin, from plate B, the saturated thickness of a coarse-grained aquifer, which makes up the entire saturated section of stratified drift, is approximately 70 feet and the transmissivity at a nearby site is 5,000 ft^2/day. The curves in figure 34 indicate that a properly developed 8-inch well with 21 feet of screen set at the bottom of the aquifer (partial penetration equal to 0.3) can be expected to have a maximum yield of approximately 300 gal/min through the period of little or no recharge (180 days).

In practice, field conditions commonly differ from the assumed ones. Yield will be higher than indicated on figure 34 if field conditions differ from the assumed conditions in one or more of the following ways: (1) well efficiency is greater than 90 percent, (2) well radius is larger than 1.0 foot, (3) percentage of aquifer screened is greater than 30 percent, (4) time of pumping is less than 180 days, (5) recharge, including induced infiltration, occurs, (6) storage coefficient is greater than 0.2, or (7) the ratio of vertical to horizontal hydraulic conductivity is greater than 1:10 (0.10).

Yield will be lower than indicated on figure 34 if field conditions diverge from assumed ones in the opposite directions from those listed above. In addition, yield may be lower because of nearby pumping wells or of impermeable-barrier boundaries. However, either of these effects, if present, can be taken into account by using the Theis equation and the method of images.

Areas Favorable for Large-Scale Ground-Water Development

Sixteen areas in the basin that are considered the most favorable for the large-scale development of ground water for industrial, commercial, irrigation, and public-supply uses are shown on plate D. These areas are selected because of the following favorable geohydrologic conditions: (1) they are underlain by a coarse-grained aquifer that in most places makes up the entire saturated section of stratified drift, (2) the saturated thickness of the aquifers is at least 40 feet, and (3) they are traversed by a stream or streams that have a long-term 90-percent flow duration equivalent to at least 1 Mgal/d. These conditions are significant because the amount of water that can be pumped from an area depends partly on aquifer characteristics, especially transmissivity and saturated thickness, and partly on the long-term "dependable" streamflow that can be induced to infiltrate into underlying and adjacent aquifers by pumping wells. A number of low-flow statistics can be used as indices of available streamflow. The one that appears to have the most significance is the long-term 90-percent flow duration.

The long-term 90-percent flow duration of streams entering the favorable areas provides a rough index of the dependable amount of water available. Such data for large streams should, however, be used with caution, particularly if the 90-percent flow duration value is 10 Mgal/d or greater. The quantity of ground water that could actually be developed in areas traversed by such streams may be significantly less than the streamflow shown on plate D because the hydraulic characteristics and boundary conditions of the aquifer may not allow such a large quantity of water to infiltrate from the stream or to be pumped from wells. It is also important to realize that well fields placed along small streams may significantly reduce the streamflow in the vicinity of the well field. This can affect downstream users unless the water is returned to the stream near the point at which it is withdrawn.

Techniques Available for Estimating Well and Aquifer Yield

The quantity of ground water available for development from a stratified-drift aquifer can be estimated by a number of analytical techniques. Each technique requires the aquifer system be simplified to varying degrees, and each has different data requirements and computational complexities. The estimates provided by these techniques depend heavily on the specific technique and the extent to which the actual field conditions meet the simplifying assumptions.

The following examples are intended to help water-resources planners and managers choose a method of analysis that best fits their individual needs. Other studies in Connecticut have applied these techniques to aquifers that have hydrologic characteristics similar to those of stratified-drift aquifers in the Farmington River basin. For each example, a brief description of the method, the information that can be derived, the data required, the reference on the method, and a reference to a study in Connecticut that used this technique are provided. Prior to utilizing any technique, the hydrologic problem and the limiting assumptions of the method must be clearly understood.

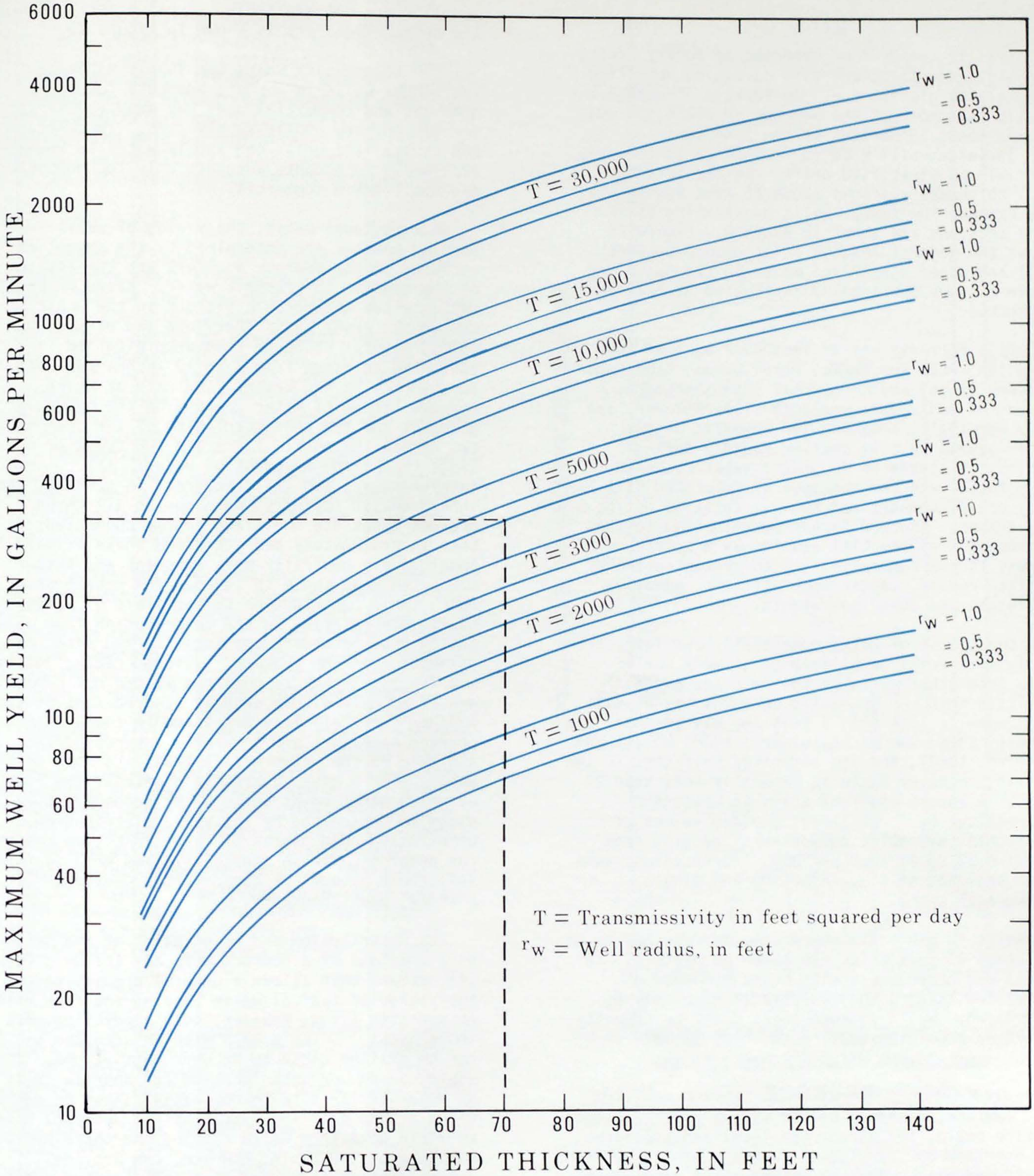
A. The long-term yield of an individual well can be approximated by a simplified form of the Theis equation (Theis, 1935). The derivation of this simplified equation, the assumptions made with respect to aquifer conditions and well characteristics, and examples of its use are given in Mazzaferro (1980, p. 17-19). The method only requires estimates of aquifer transmissivity and saturated thickness and can easily be solved manually or on a hand calculator. This method is most applicable to simple hydrogeologic settings.

B. More precise estimates of short- or long-term well yields and resulting drawdowns at points in the aquifer can be computed using the non-equilibrium equation of Theis (1935). Aquifer transmissivity, available drawdown, and specific yield (or storage coefficient) must be known or estimated. The time of pumping and well radius must also be specified. The underlying assumptions governing the use of this equation are contained in Ferris and others (1962). The analysis can be carried out by hand or by using a programmable calculator and an example of the application of this technique is presented in the previous section of this report titled "Estimating maximum well yields". This technique is most suitable if the aquifer is extensive and has relatively uniform hydrologic characteristics.

C. Reliable estimates of individual or aggregate well yields and resulting drawdowns in aquifers tapped by severals wells and bounded by one or more hydraulic boundaries such as valley walls and streams can be computed by the non-equilibrium equation (Theis, 1935) and image-well systems developed from the theory of images (Ferris and others, 1962). In this method, drawdown in an individual well is calculated the same way as in the previous technique but the changes in drawdown, and consequently yield, due to the presence of hydraulic boundaries and other pumping wells are accounted for. The physical features that constitute hydraulic boundaries can be streams, lakes, impermeable valley walls, or adjacent stratified drift of low hydraulic conductivity. Manual and programmable calculator solutions can be used for this technique but computer solutions are more efficient. Examples of the use of this technique are shown in Cervione and others (1972), and Mazzaferro and others (1979).

D. Mathematical models that simulate ground-water flow in complex hydrologic systems have become feasible through the use of high speed computers and powerful numerical techniques. These models enable hydrologists not only to evaluate aquifer yields but also to predict the effects of pumping and natural stresses on a stream-aquifer system. This technique is the most applicable to complex hydrologic settings and problems. Many aquifer flow models have been developed to solve hydrologic problems. The most common are two-dimensional models that assume aquifer characteristics are homogeneous in depth but heterogenous in areal extent, and three-dimensional models that can simulate flow systems where aquifer characteristics vary both with depth and area. A wide variety of data is usually required in detailed model simulations, whereas only limited data is necessary if the flow model is being used to develop conceptual understanding of the flow system. The U.S. Geological Survey has developed and widely uses a two-dimensional model (Trescott and others, 1976), and a three-dimensional model (Trescott, 1975, and Trescott and Larson, 1976). This technique allows a resource manager to evaluate several alternative development schemes and to predict the hydrologic impact of a stream-aquifer system. For an example of the use of this technique in Connecticut, see Haeni (1978).

Each of the techniques discussed can be applied to the 16 favorable areas shown on plate D to obtain quantitative estimates of the available ground water. The selection of a specific method should be based on the type of information needed. To use techniques C or D, additional data about the hydrologic system will be needed for each area.



from Ryder and others,(1981)

Figure 34.--Maximum well yield in relation to aquifer characteristics and radius of a screened well tapping stratified drift

TILL

Till is composed of unsorted or poorly sorted gravel, sand, silt, and clay particles deposited directly by glacial ice. It forms a discontinuous mantle over most of the bedrock in the basin and covers about 75 percent of the land surface. In the lowlands, till 5 to 10 feet thick is commonly overlain by stratified drift. In the uplands, till thickness averages about 25 feet and in places exceeds 100 feet. Wells penetrating thick till sections are shown in plate B. Figure 24 shows the general spatial relationship between till and other subsurface units in the basin and plate B shows the areal distribution of till and bedrock.

Till formerly was an important aquifer that supplied water for farms, rural homes, some suburban dwellings, and commercial establishments. Yields of individual wells in till, however, are only marginally adequate for domestic needs. Water levels in till decline rapidly during periods of little or no ground-water recharge. This factor and the thinness of saturated till in many areas commonly led to well failures during the summer. Another factor contributing to the abandonment of the till aquifer as a source of supply is the susceptibility to contamination by surface runoff, septic-tank effluent, barnyard drainage, and other pollutants.

The amount of water potentially available from individual wells in till is relatively small. Data from other parts of southern New England indicate that the hydraulic conductivity of till is generally less than 5 feet per day (Randall and others, 1966; Sammel and others, 1966; Morris and Johnson, 1967), and its saturated thickness in the Farmington River basin is generally less than 20 feet. A recent study of tills in eastern Connecticut by Torak (1979) yielded values of horizontal hydraulic conductivity ranging from about 0.13 to 47 feet per day. These values were from analyses of slug injection and slug withdrawal tests.

Wells in the basin where till is reported to be at least 40 feet thick are shown on plate B. In these and other areas with thick deposits of saturated till, 1 to 3 gal/min of water may be developed. Wells in such areas might be adequate for uses requiring small quantities of water.

BEDROCK

Bedrock, commonly called ledge, underlies the entire basin, and except for localized exposures, is overlain by varying thicknesses of stratified drift and till. Bedrock is saturated with water at some depth everywhere in the basin and forms a significant aquifer from the standpoint of number of wells supplied.

Bedrock aquifers in the Farmington River basin include sedimentary and crystalline (igneous and metamorphic) units. They are important sources of water for many homes, commercial establishments and institutions. Development of these aquifers is concentrated in areas where public water supplies are not available. Areal distribution of the bedrock aquifers is shown in figure 23.

The sedimentary units can supply water to individual wells in amounts adequate for most domestic and commercial uses and many industrial, irrigation, and public-supply uses. In contrast, the crystalline units can supply water to individual wells in amounts adequate only for domestic and small-scale commercial uses.

On a regional basis, the yields of wells tapping bedrock are determined by the amount of recharge to the bedrock aquifers and the ability of the aquifer to transmit water. Based on an estimate for metamorphic bedrock in the upper Housatonic River basin (Cervione and others, 1972), natural recharge from precipitation is estimated to range from 7 to 10 inches per year for bedrock in the basin. The rate at which bedrock transmits water depends on the hydraulic gradient and the characteristics of the open spaces within the rock. There are two types of openings that allow movement of water: (1) intergranular, and (2) fracture. In general, the intergranular (primary) openings in all three bedrock types are small and poorly connected. Even in sedimentary bedrock where these primary openings are generally more abundant and better connected than those in igneous and metamorphic rock, their contribution to the yield of wells is negligible relative to the contribution from open fractures. Secondary openings, formed after consolidation of the bedrock, include cracks, joints, and faults. Fracture openings in bedrock commonly are found only within several hundred feet of the bedrock surface. They are large in comparison to primary openings, are generally interconnected, and make up the network that transmits most of the water. For a given hydraulic gradient, the rate at which water moves through the secondary openings is determined by the size, distribution, orientation, and degree of interconnection between the openings. These characteristics are, in turn, influenced by bedrock composition, geologic history, and topography.

The distribution and orientation of the secondary openings of a bedrock unit may follow a regular pattern that allows a general prediction of the yields of typical wells tapping the rock unit. At specific sites, however, such predictions are impractical. Often a well with an adequate yield can be drilled close to an unproductive one. The yield, depth, or best location for bedrock wells at a particular site in the basin cannot be determined before drilling. Statistical analyses based on yield data from wells tapping the three bedrock aquifers of the basin, however, can provide general information regarding the expected performance of new wells. (See table 16.)

Wells that tap bedrock aquifers essentially have the same type of construction regardless of bedrock type or intended use. In general, a hole, 6 to 12 inches in diameter, is drilled through any unconsolidated material present and into underlying bedrock by either the compressed-air down-hole hammer or cable-tool method. The unconsolidated material is kept out of the hole by setting a blank casing down into the underlying hard rock. After the casing is set, drilling in rock is then generally continued until an adequate yield is obtained. The finished well consists of the blank casing extending through the unconsolidated materials and into underlying bedrock; below it, the hole extends uncased into the bedrock. Water flows through the rock fractures from the saturated bedrock to the uncased hole.

Sedimentary Bedrock

Sedimentary bedrock of Triassic and Jurassic age underlies about 114 square miles of the central part of the Farmington River basin (fig. 23) and is the chief bedrock aquifer in terms of areal extent, degree of development, and yields of wells. It consists of sandstone, siltstone, and shale, with lesser amounts of conglomerate and limestone. Basalt is interbedded with the sedimentary rocks but are part of the igneous aquifer that is discussed separately. The sedimentary rocks are extensively faulted and generally dip to the east. Although accurate estimates are not available, the average thickness of sedimentary and interbedded igneous rocks in the basin probably exceeds 4,000 feet.

The water-bearing chacteristics of these rocks are inadequately defined. Most ground water probably occurs in fractures (joints and faults), and in openings that may exist along the bedding planes that separate the individual layers. Some water, however, may occur in intergranular openings as it does in unconsolidated aquifers.

Reported yields of 457 wells tapping sedimentary bedrock range from 0.2 to 400 gallons per minute (gal/min); the median yield is 8 gal/min. The maximum and median yields are greater than those of the other bedrock aquifers in the basin. The yield frequency data in figure 35 indicates that 95 percent of the wells in sedimentary bedrock yielded 2 gal/min or more. The water needs of a typical family can be met with as little as 1 gal/min, if storage is sufficient. Therefore, the chance of drilling a successful domestic well in sedimentary bedrock is high.

Igneous Bedrock

Igneous bedrock outcrops occur over an area of about 6 square miles of the eastern and central part of the Farmington River basin (fig. 23). It consists principally of basalt and diabase units, that are interbedded with and intrude the sedimentary rocks. Three basalt flows, each from 50 to 500 feet thick (Krynine, 1950) account for the igneous rock in eastern portions of the basin. A diabase intrusive unit, 300 to 500 feet thick, forms the ridge in the center of the basin (Schnabel, 1960, Schnabel and Eric, 1965). At depth, the diabase may extend over a much larger area than its outcrops suggest. It is the same age as and is stratigraphically related to the sedimentary units, and it is not uncommon for individual wells to tap both types of rock. Only data from wells finished exclusively in igneous bedrock are used in the yield analyses of that

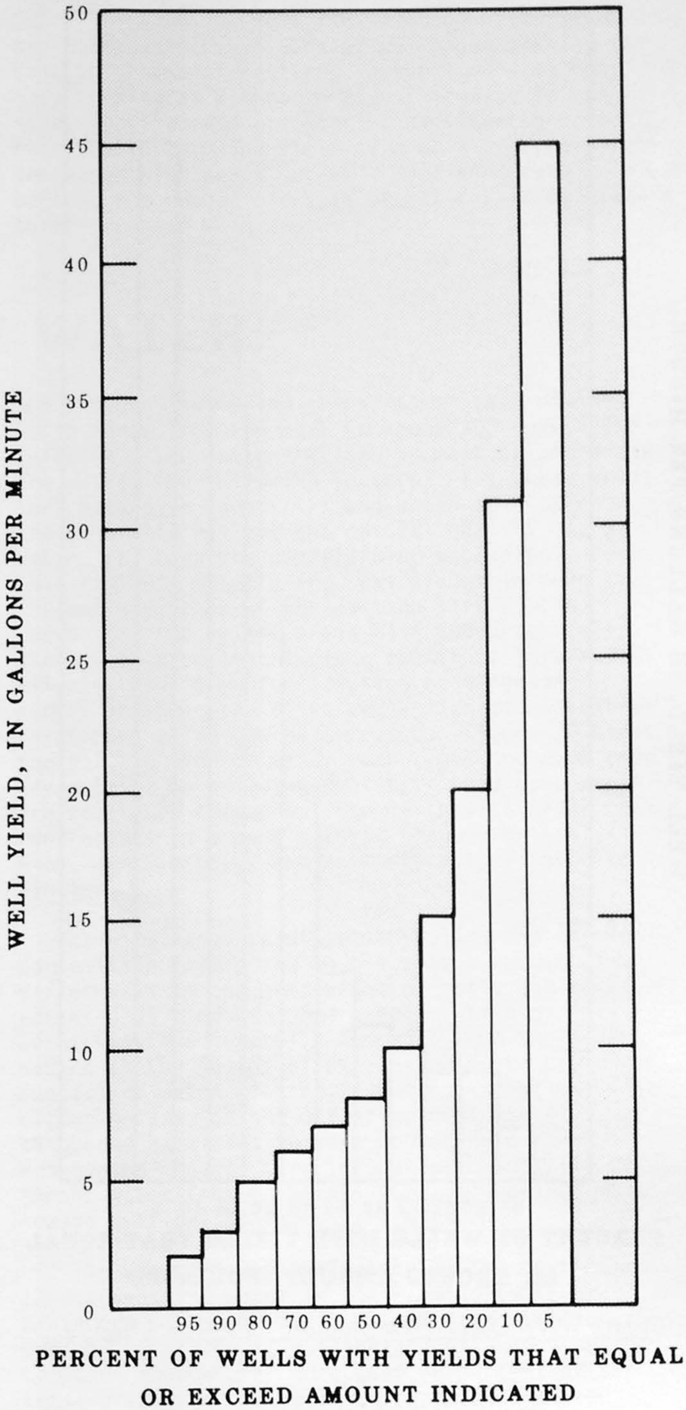


Figure 35.--Yield frequency of 457 wells tapping sedimentary bedrock

aquifer. Although it occurs close to and is interbedded with sedimentary bedrock, igneous rock is more like metamorphic rock in its water-yielding characteristics.

Yields of 16 wells tapping igneous rocks range from 2 to 100 gal/min, and the median is 8 gal/min. Most wells tapping this aquifer will yield supplies of water adequate for domestic purposes. Yield-distribution data shown in figure 36 indicate that 95 percent of the wells tapping igneous bedrock yield 2 gal/min or more. The median yield is higher than that of metamorphic rock and is the same as that of sedimentary rock.

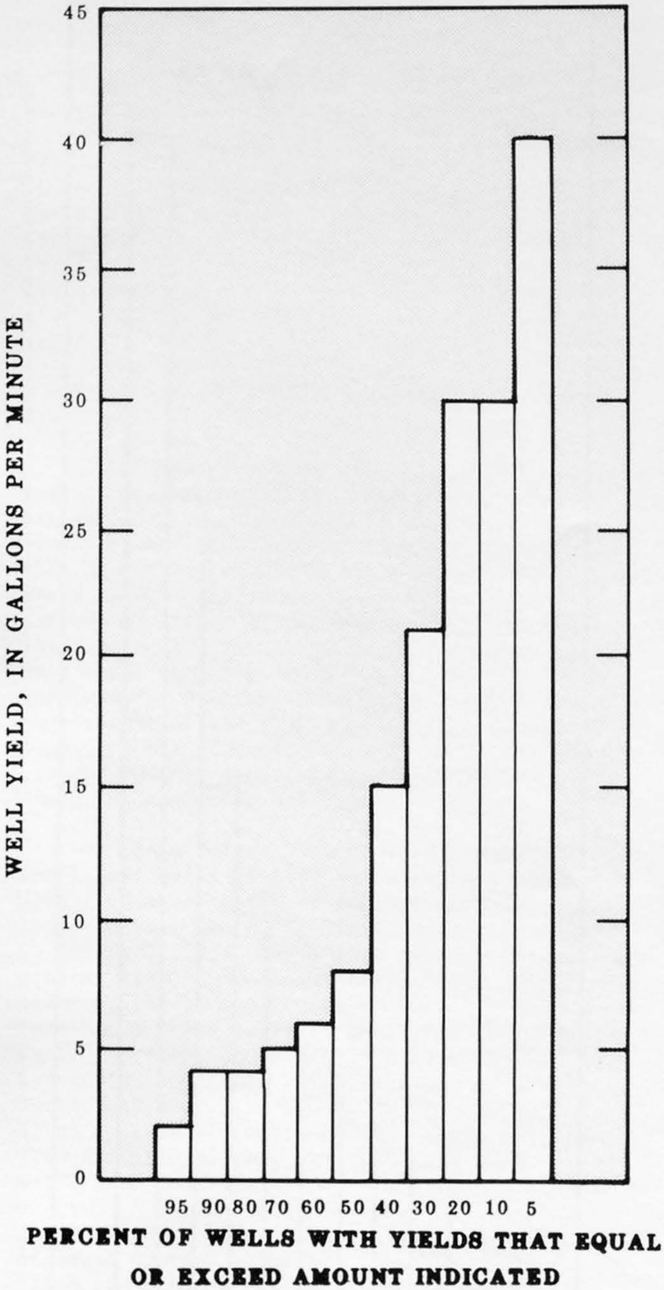


Figure 36.--Yield frequency of 16 wells tapping igneous bedrock

Metamorphic Bedrock

Metamorphic bedrock directly underlies about 300 square miles, or two-thirds of the Farmington River basin. (See fig. 23.) It extends to great depths and is the basement complex beneath the sedimentary and igneous rocks of the region. The metamorphic rock aquifer consists principally of gneiss and schist (Rodgers and others, 1956, 1959), and includes small amounts of other metamorphic and igneous rock types. Similar assemblages are collectively termed "crystalline bedrock" or "noncarbonate bedrock" in other reports of this series.

Yields of 331 wells tapping the metamorphic bedrock aquifer range from 0.1 to 200 gal/min, with a median of 5 gal/min. Figure 37 shows the well-yield frequency of this aquifer. The figure shows that 95 percent of the wells yield 0.75 gal/min or more. This is less than half the comparable figure (2 gal/min or more) for the sedimentary and igneous rocks (see figs. 35 and 36), and indicates that marginal yields may be more common in wells drilled in metamorphic rocks. Nevertheless, the chance of obtaining a yield satisfactory for domestic needs is good.

Wilson and others (1974) showed that the yield of crystalline bedrock is dependent to some degree on topographic position of the site, type of crystalline bedrock (for example, granite or schist), type of overburden (till or stratified drift), and thickness of bedrock penetrated.

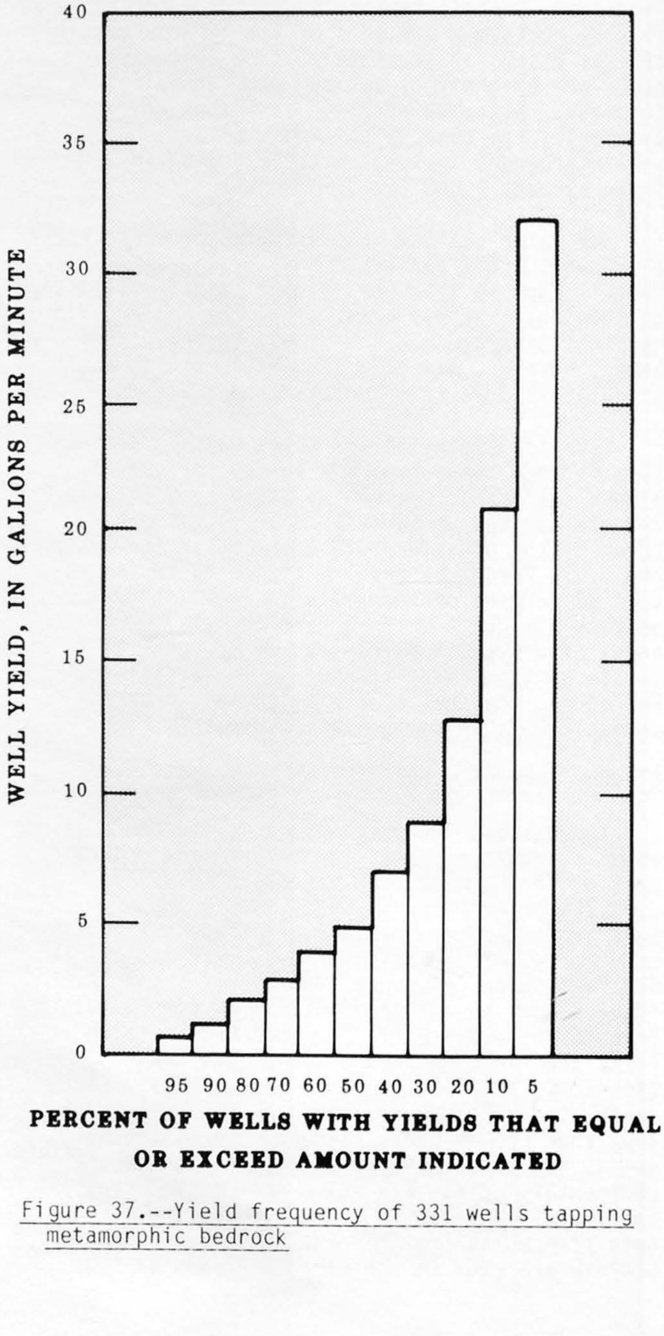


Figure 37.--Yield frequency of 331 wells tapping metamorphic bedrock

Water Supplies from Bedrock

The bedrock aquifers of the Farmington River basin can supply amounts of water adequate for domestic needs at most sites. The sedimentary bedrock aquifer is the most productive in terms of median and maximum well yields; the two crystalline bedrock aquifers are about equal. (See table 16.)

Predictions of well yields at specific sites are not possible. Yields of wells penetrating the same thickness of aquifer, in the same area, may vary considerably because of differences in the size, spacing, and orientation of interconnected rock fractures. The yield of a well generally increases with depth but at a declining rate because the number and size of water-bearing fractures decrease with depth.

QUALITY OF WATER

The water in streams is derived from ground-water and surface-water runoff, which, in turn, are derived from precipitation. Quality of stream water largely depends on the quality and proportions of these sources. When streamflow is low, practically all the flow is ground-water runoff, and its composition is similar to that of ground water. The chemical quality of ground water in areas unaffected by man depends on the minerals in the earth materials and their solubility in ground water and the length of time the minerals and water are in contact. Therefore, the areal distribution of dissolved-solid concentration of surface water during low streamflow can provide an indication of the natural chemical quality of ground water and its relation to the geology.

Water in streams at high flow is a mixture of ground-water runoff and surface-water runoff, and its chemical quality is intermediate. The physical quality of water during high flow is affected by the quality of precipitation and by suspended sediments. The suspended-sediment load is related to the erodibility and type of earth material being eroded.

Man's activities alter the chemical and physical quality of surface water. Sediment loads, for example, may be augmented by earth materials disturbed by construction or by farming. Chemical quality can be altered by crop fertilization, road salting, sewage disposal, atmospheric deposition, and refuse disposal near streams.

The quality of ground water may also be affected by fertilizers, road salts, septic-tank leaching fields, leachates from solid-waste disposal, infiltration from streams carrying waste, water-softening effluents, and by leachates from industrial-waste lagoons.

DISSOLVED SOLIDS

SURFACE WATER

Streams

The dissolved-solids concentration in streams during low flow is an indication of their chemical quality. The maximum dissolved-solids concentrations observed in the Farmington River basin during this study are shown in figure 38. Maximum concentrations in much of the basin are 100 mg/L or less although those of many streams draining the eastern valley and the southern part of the basin range from 100 mg/L to about 300 mg/L. The relatively low concentrations in most upland areas are due to the following factors: (1) these areas lack extensive industrial and urban development and generally reflect the natural quality of water, (2) they are underlain by metamorphic rocks that are less soluble and less permeable than the sedimentary rocks of the eastern part of the basin, (3) the upland areas have topographically steep slopes so that surface runoff is more rapid, allowing less time for solution of minerals. Figure 38 shows the dissolved-solids concentration in streams which can be compared. Figure 39 shows the distribution of major rock types and developed areas based on building density. Developed areas are scattered throughout the basin with major concentrations in a band passing through Bristol, Avon, and Simsbury, and another centered at Winsted.

The wide range in dissolved-solids and chemical composition from place to place is a result of differences in the properties of soils and rocks, patterns of land use, and precipitation quality. Concentrations generally increase from the headwaters to the mouths of streams owing to prolonged contact of water with soils and rocks but may also differ because of the differing capacity of suspended particles to take up and hold ions. Pronounced changes mark inflows of chemically different water from tributary streams, springs, sewage outflow, or industrial effluents.

The source and significance of the most common constituents in water in the Farmington River basin are listed in table 20. Silica, calcium, sodium, bicarbonate, sulfate and chloride, which together account for more than 90 percent of the total dissolved solids in the samples analyzed, are derived from several sources. Silica, calcium, and bicarbonate are dissolved from soil and rock; sulfate is contributed by precipitation and by organic shale layers in sedimentary rocks; sodium and chloride come mainly from sewage, industrial wastes, road salts, and precipitation.

Table 21 shows overall quality of streams in the basin by summarizing analyses of samples collected at the 20 sites shown in figure 40. The concentrations of most constituents are higher in streams draining areas underlain by sedimentary bedrock. Calcium, magnesium, sulfate, and bicarbonate show the greatest difference between areas. Concentrations of most solutes are lower during high flow than during low flow. Variations with

Table 20.--Source and significance of common constituents of natural water

Chemical constituent or physical property	Source and concentration	Significance and recommended maximum limit[1]/
Silica (SiO_2)	Dissolved from practically all rocks and soils. Most water in the basin contains amounts ranging from 1 to 20 mg/L.	High concentrations precipitate as hard scale in boilers, water heaters, and pipes. Inhibits deterioration of zeolite-type water softeners and corrosion of iron pipes.
Iron (Fe)	Dissolved from minerals that contain oxides, sulfides, and carbonates of iron. Decaying vegetation, iron objects that are in contact with water, sewage, and industrial waste are also major sources. Most water in the basin has less than 0.5 mg/L.	On exposure to air, iron in ground water oxidates to a reddish-brown preci-pitate. More than about 0.3 mg/L stains laundry and utensils, causes unpleasant odors, and favors growth of iron bacteria. Iron in water is objectionable for food and textile processing. Most iron-bearing waters, when treated by aeration and filtration, are satisfactory for domestic use.
Manganese (Mn)	Dissolved from many rocks and soils. Commonly associates with iron in natural waters but less common. Most water in the basin has less than 0.01 mg/L.	More than 0.05 mg/L oxidizes to a black precipitate. Manganese has the same undesirable characteristics as iron but is more difficult to remove.
Calcium (Ca) and magnesium (Mg)	Dissolved from rocks and soils, especially those containing calcium silicates, clay minerals, and carbonate lenses.	Hardness and scale-forming properties of water are caused principally by dissolved bicarbonate and sulfates of calcium and magnesium. (See hardness.) Hard water is objectionable for electroplating, tanning, dyeing and textile processing. It also causes scale formation in steam boilers, water heaters, and pipes.
Sodium (Na) and potassium (K)	Dissolved from practically all rocks and soils. Sewage, industrial wastes, road salt, and sea water are also major sources. Most home water softeners increase the amount of sodium in water by exchanging it for calcium and magnesium.	Because the concentration of potassium is usually low, sodium and potassium are often calculated together and reported as sodium. Quantities found in the fresh water of the report area have little effect upon the usefulness of water for most purposes; however, more than 50 mg/L may cause foaming in steam boilers. Twenty mg/L is the maximum permitted for people restricted to a low salt diet. Recommended maximum 20 mg/L for finished water.
Carbonate (CO_3) and bicarbonate (HCO_3)	Dissolved from carbonate and calcium silicate minerals by reaction with carbon dioxide in water. Decaying vegetation, sewage, and industrial wastes are also important sources.	Carbonates of calcium and magnesium cause hardness, form scale in boilers and pipes, and release corrossive carbon dioxide gas. (See hardness.) Water of low mineral content and low bicarbonate content in proportion to carbon dioxide is acidic and corrosive.
Sulfate (SO_4)	Dissolved from rocks and soils containing sulfur compounds, especially iron sulfide; also from sulfur compounds dissolved in precipitation, and sewage and industrial wastes.	Sulfates of calcium and magnesium cause permanent hardness and form hard scale in boilers and hot water pipes. Recommended maximum 250 mg/L.
Chloride (Cl)	Dissolved from rocks and soils in small amounts. Other soruces are ani-mal wastes, sewage, road salt, industrial wastes, and sea water. Chloride concentration of natural fresh water in the basin is less than 20 mg/L.	Large amounts in combination with calcium will result in a corrosive solution and in combination with sodium will give water a salty taste. Recommended maximum 250 mg/L.
Fluoride (F)	Dissolved from minerals. Natural water in the basin has up to 1.2 mg/L. Added to public water supplies by fluoridation.	About 1.0 mg/L of fluoride reduces the incidence of tooth decay in young children; larger amounts may cause mottling of tooth enamel, depending on average water intake and climate (Lohr and Love, 1954, p. 39). Recommended limits: 0.8 to 1.2 mg/L for artificially fluoridated water; maximum 2.0 mg/L for natural water.
Nitrate (NO_3	Sewage, industrial wastes, fertilizers, and decaying vegetation are major sources. Lesser amounts are derived from precipitation and solution processes.	Small amounts have no effect on usefulness of water. A concentration greater than 10 mg/L generally indicates pollution. Nitrate encourages growth of algae and other organisms which produce undesirable tastes and odors. Water containing more than 44 mg/L has reportedly caused methomoglobinemia, which is often fatal to infants (Comly, 1945). Recommended maximum 10 mg/L of nitrate expressed as N, which is equivalent to 44 mg/L nitrate expressed as NO_3.
Specific conductance	Specific conductance, or the capacity of water to conduct an electric current, is an index of total dissolved mineral content.	A specific conductance of 800 micromhos at 25°C is approximately equivalent to a dissolved-solids concentration of 500 mg/L.
Dissolved solids	Includes all dissolved mineral constituents derived from solution of rocks and soils. Locally augmented by mineral matter in sewage and industrial wastes. Measured as residue on evaporation at 180°C or	Water containing more than 1,000 mg/L dissolved solids is undesirable for public and private supplies and most industrial purposes.

	calculated as numerical sum of amounts of individual constituents. In the basin, ground water generally has a higher concentration of dissolved solids than does surface water.	
Hardness (as $CaCO_3$)	Primarily due to calcium and magnesium, and to a lesser extent to iron, manganese, aluminum, barium, and strontium. There are two classes of hardness, carbonate (temporary) and noncarbonate (permanent). Carbonate hardness refers to the hardness balanced by equivalents of carbonate and bicarbonate ions; noncarbonate refers to the remainder of the hardness. Most waters in the basin are classified as soft to moderately hard.	Hard water uses more soap to lather and deposits soap curds on bathtubs. Water having a hardness of more than 120 mg/L is commonly softened for domestic use. Hardness forms scale in boilers, water heaters, radiators and pipes, causing a decrease in rate of heat transfer and restricted flow of water. In contast, water having a very low hardness may be corrosive. A classification of hardness appears under "Hardness" in the section entitled "Quality of surface water."
Hydrogen ion (pH)	Water having concentrations of acids, acid-generating salts, and free carbon dioxide has a low pH. Where carbonates, bicarbonates, hydroxides, phosphates and silicates are dominant, the pH is high. Most natural waters range between 6 and 8.	A pH of 7.0 indicates neutrality of a solution. Values higher than 7.0 denote alkaline characteristics; values lower than 7.0 indicate acid characteristics. Acid waters and excessively alkaline waters corrode metals. Recommended limits 6.4 to 8.5 for finished water.
Color (platinum-cobalt units)	May be imparted by iron and manganese compounds, algae, weeds, and humus. May also be caused by inorganic or organic wastes from industry. True color of water is considered to be only that remaining in solution after the suspended material has been removed.	Water for domestic and some industrial uses should be free of perceptible color. Color in water is objectionable in food and beverage processing and many manufacturing processes. Usually expressed in units of color rather than in mg/L. Recommended maximum 20 standard units for raw water, 15 units for finished water.
Dissolved oxygen (D.O.)	Derived from the atmosphere and from photosynthesis by aquatic vegetation. Amount varies with temperature and pressure and decreases during breakdown of waste material. Concentration can be expressed in mg/L or as a percentage of saturation.	Dissolved oxygen in surface water is necessary for support of fish and other aquatic life. It causes precipitation or iron and magnenese in well water and can cause corrosion of metals. Standards for many streams and lakes in the basin are given in "Connecticut water quality standards" (Connecticut Department of Environmental Protection, 1977).
Detergents as MBAS	MBAS (methylene blue active substance) is a measure of the concentrations of detergents in water. Primary sources of alkyl benzene sulfonate (ABS) and linear alkyl sulfonate (LAS) are synthetic household detergent residues in sewage and waste waters.	High concentration of ABS caused undesirable ctaste, foaming, and odors. Indicates presence of sewage or industrial waste. In mid-1965, ABS gradually replaced by LAS, which is more degradable. Recommended maximum for MBAS 0.5 mg/L.
Temperature	Fluctuates seasonally in streams and shallow aquifers. At depths of 30 to 60 feet, ground-water temperature remains within 2°C or 3°C of mean annual air temperature (9°C to 11°C for the report area). Disposal of water used for cooling or industrial processing may cause local temperature anomalies.	Affects the usefulness of water for many purposes. For most uses, especially cooling, water of uniformly low temperatures is desired. A rise of a few degrees in the temperature of a stream may limit its capacity to support aquatic life. Warm water carries less oxygen in solution and is more corrosive than cold water.
Turbidity (Jackson units)	An optical property of water attibuted to suspended or colloidal matter which inhibits light penetration. May be caused by microorganisms, algae, suspended mineral substances including iron and manganese compounds, clay, silt, sawdust, fibers, or other materials. May result from natural processes of erosion or from the addition of domestic sewage, wastes from industries such as pulp and paper manufacturing, or sediment from construction activities.	Excessive concentrations are harmful or lethal to fish and other aquatic life. Turbidity is also undesirable in waters used by most industries, expecially in process water. Turbidity can modify water temperature. Expressed either in standard units or in mg/L silica. Recommended maximum 5 units for raw water, 1 unit for finished water.

1/ Standards for drinking water recommended by the Connecticut Department of Health (Conn. General Assembly, 1975).

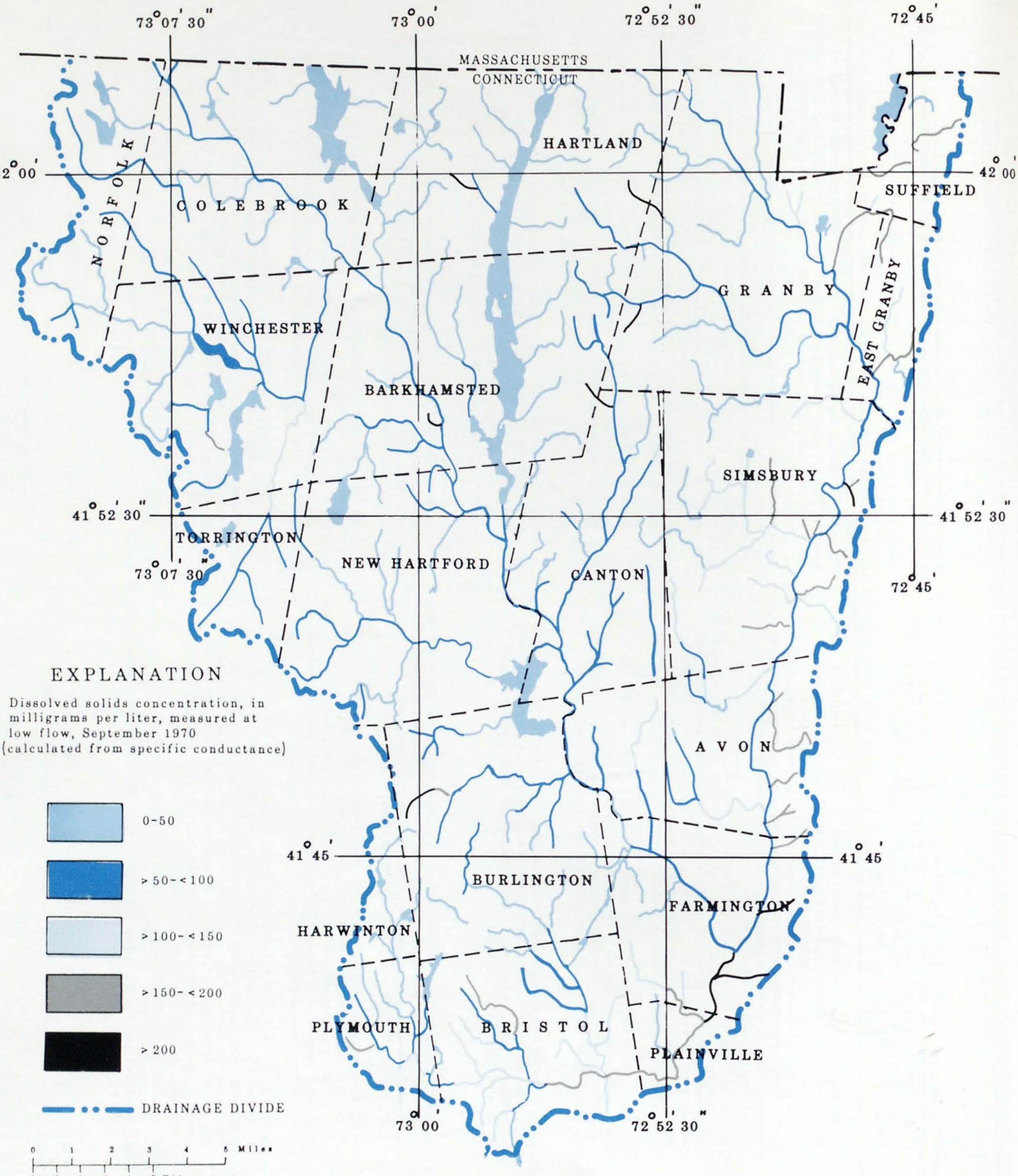


Figure 38.--Maximum concentrations of dissolved solids in surface water

Table 21.--Chemical and physical properties of water from representative streams

[Concentrations of chemical constituents in milligrams per liter]

Constituent or property	Streams draining areas underlain by: Sedimentary rock				Crystalline rock			
	At high flow 1/		At low flow 2/		At high flow 1/		At low flow 2/	
	Median	Range	Median	Range	Median	Range	Median	Range
Silica (SiO_2)	9.3	5.0 - 12	12	8.6 - 17	5.6	2.8 - 9.1	9.8	4.6 - 15
Iron (Fe)	.06	.04 - .12	.08	.03 - .54	.08	0.4 - .52	.18	.03 - .65
Manganese (Mn)	0	0 - 0	.02	0 - .03	0	0 - .05	.02	0 - .35
Calcium (Ca)	9.0	7.0 - 25	22	10 - 43	4	2 - 8	6	2 - 21
Magnesium (Mg)	1.8	.8 - 6.6	4.0	1.4 - 11	9	.6 - 2.9	1.5	.5 - 7.3
Sodium (Na)	3.6	2.0 - 5.9	4.5	2.4 - 7.5	2.2	1.1 - 2.7	3.3	1.7 - 37
Potassium (K)	.2	.1 - .8	.5	.3 - .8	.4	.2 - 2	.8	.4 - 2.8
Bicarbonate (HCO_3)	22	12 - 74	66	22 - 150	6	2 - 11	18	4 - 56
Sulfate (SO_4)	18	12 - 25	14	9.7 - 41	9.3	6.5 - 14	7.4	5 - 18
Chloride (Cl)	4.3	2.3 - 15	5.2	1.7 - 11	3.0	1.1 - 51	2.7	.5 - 76
Fluoride (F)	-	-	.1	0 - .1	-	-	.1	0 - .1
Phosphate (PO_4)	.03	.02 - .10	.03	0 - .06	.01	0 - .07	.02	0 - 1.2
Nitrate (NO_3)	.10	0 - 1.6	.60	0 - 4.0	0	0 - 2.4	.40	0 - 9.7
Dissolved solids (sum of constituents)	52	44 - 113	100	51 - 182	28	20 - 118	42	25 - 199
Hardness, as $CaCO_3$	28	23 - 90	70	31 - 138	12	7 - 32	20	7 - 82
Hardness, as $CaCO_3$ (noncarbonate)	14	7 - 34	14	8 - 36	8	3 - 25	6	0 - 58
Alkalinity, as $CaCO_3$	18	10 - 61	54	18 - 123	4	2 - 9	15	3 - 46
Specific conductance (micromhos at 25°C)	78	67 - 200	164	81 - 288	42	26 - 224	64	29 - 375
pH	7.0	6.7 - 7.5	7.3	6.9 - 7.8	6.4	5.2 - 6.8	6.9	5.9 - 7.4
Turbidity, in Jackson units	0	0 - 2	0	0 - 1	0	0 - 0	1	0 - 2
Color in platinum-cobalt units	18	4 - 35	2	1 - 8	14	3 - 30	4	2 - 30
No. of sites sampled		6		6		14		14

1/ Five-percent duration flow, May 10, 1971
2/ Ninety-five percent duration flow, August 26, 1971

flow result primarily from changes in the relative contributions of ground-water and surface runoff. The ground-water contribution to streamflow is relatively stable when compared to the surface runoff which varies with rainfall and with the seasons. During low flow much of the water in a stream channel is ground-water runoff (base flow) which, under natural conditions, is more highly mineralized than surface runoff. Furthermore, wastes are more diluted during high flow. The concentration of dissolved material in most streams is, thus, inversely related to streamflow.

The inverse relationship between streamflow and solute concentration is complicated by variations in the chemistry of precipitation, concentration by evaporation from the basin, biological processes, temperature, and human activities, all of which cause variations in stream quality with time. Time and space differences in dissolved-solids concentrations of several streams in the Farmington River basin are illustrated in figure 40.

Urban development affects the dissolved-solids concentration of surface water in a variety of ways. Runoff from rural areas may contain animal wastes and fertilizers but generally its composition is similar to that from natural areas. In the suburbs there is a higher density of septic tanks and disposal basins that release wastes to the saturated zone from which ground water is discharged into streams and lakes.

Cities rely less on septic tanks, yet the dissolved-solids load is high even in completely sewered areas. (Plate C shows sewered areas in the basin.) Wastes from industries and from sewage-treatment plants may be discharged directly into streams. Runoff from streets and highways contains roadside litter, salts used to melt snow and ice, chemicals used to control vegetation and insects, or it may be contaminated by accidental spills from vehicles, tanks, or pipelines. Storm sewers located below the water table may intercept ground water and discharge it to streams.

The inverse relationship between streamflow and dissolved-solids concentration becomes more complex after development. Man-made changes in topography, vegetation, and percentage of impervious area in a basin affect the flow characteristics of its streams. Stream quality generally deteriorates during low flow because sewage and other effluents are not sufficiently diluted. If surface runoff is significantly contaminated, however, it will degrade, rather than improve stream quality. Urban storm water may contain more dissolved solids than average domestic waste water. Sartor and Boyd (1972) determined that urban runoff contributes more pollution load during the first hour of a moderate to heavy storm than would be contributed by raw sanitary sewage from the same area during an equal period of time.

Selective discharge of industrial effluent during high flow, regulation of flow by reservoirs, diversion of water into and out of the basin, and overflow from combined storm and sanitary sewer lines also alter the natural relationship between quality and streamflow.

Figure 41 shows specific conductance and daily mean discharge for the Pequabuck River at Forestville (station 01189000) and the Farmington River at Tariffville (station 01189995) for 1971. A comparison of the two graphs shows more variation in discharge and a higher average specific conductance in the Pequabuck River. These differences result primarily from the different type and degree of urban and industrial development in the drainage areas of the two streams.

The quality of the Mad-Still-West Branch Farmington and the Pequabuck-Farmington Rivers is shown in graphic stream profiles (figs. 42 and 43). These profiles are based on data collected during low-flow conditions in August 1971. Both streams drain areas which are centers of population and industrial development. (See fig. 39.)

The concentrations of individual ions in each sample are illustrated by a modified Stiff method (Stiff, 1951). Cations are plotted to the left, anions to the right, and the resulting points connected to give an irregular polygonal pattern. The shape of the patterns emphasizes similarities and differences in water composition; the width of the pattern gives an approximate indication of the total ionic content. The Stiff patterns in figures 42 and 43 show the progressive effects of effluent discharge and urban runoff. The most upstream diagram in each figure (stations 01186095 and 01188145) represents natural quality. Calcium and bicarbonate are the predominant ions. The patterns are wider and the shapes are different at each successive downstream site. Sodium and chloride proportions are greater. The increase in specific conductance (upper graph) indicates effects of human activities. The conductance is greatly reduced, and Stiff patterns are narrower, indicating lower concentrations below the confluence with the West Branch Farmington and Farmington Rivers, owing to dilution by the greater volume of water in these streams. However, there is some degradation of the larger streams by inflow from the Still and Pequabuck Rivers. This can be seen by comparing the diagrams at station 01186450 (above the confluence) with that at station 01186800 (below the confluence) on the West Branch Farmington River. Similarly, compare the diagrams at stations 01188090 and 01189035 on the Farmington River.

Lakes and reservoirs

Compared to streams, lake water has a more constant composition. Impoundment decreases turbidity, sediment load and bacterial concentrations, and sunlight has a bleaching effect, reducing the color. Fluctuations in quality follow annual and daily cycles and are related to the biological productivity of lakes. Reducing conditions at the bottoms of stratified lakes lead to the production of nitrite, ammonia, hydrogen sulfide and ferrous iron. Stratification of lakes is discussed in the section titled "Temperature."

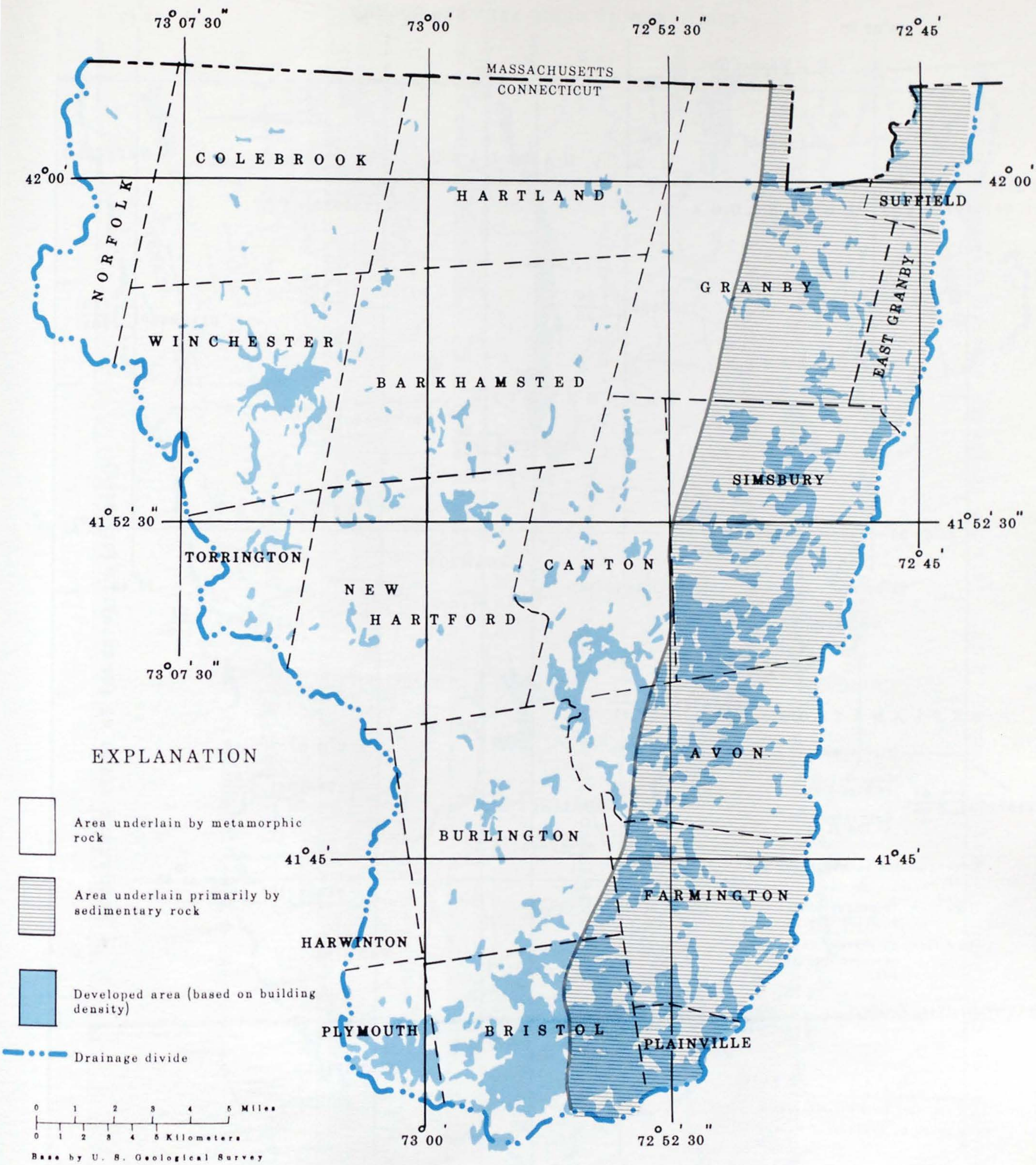


Figure 39.--Developed areas and major bedrock types

Figure 40.--Dissolved-solids concentrations in streams at high and low flow

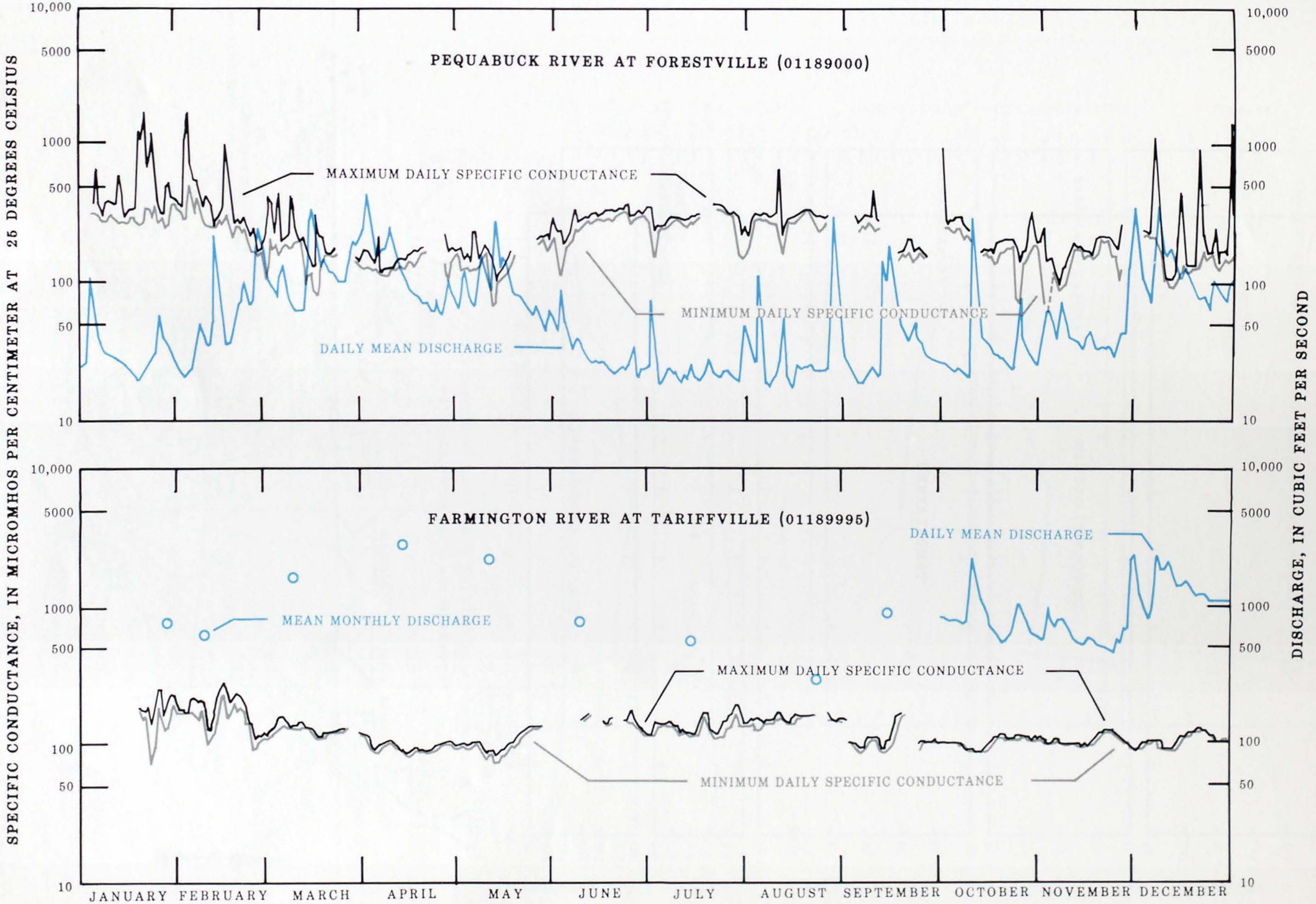


Figure 41.--Specific conductance and daily mean discharge, Pequabuck and Farmington Rivers, 1971

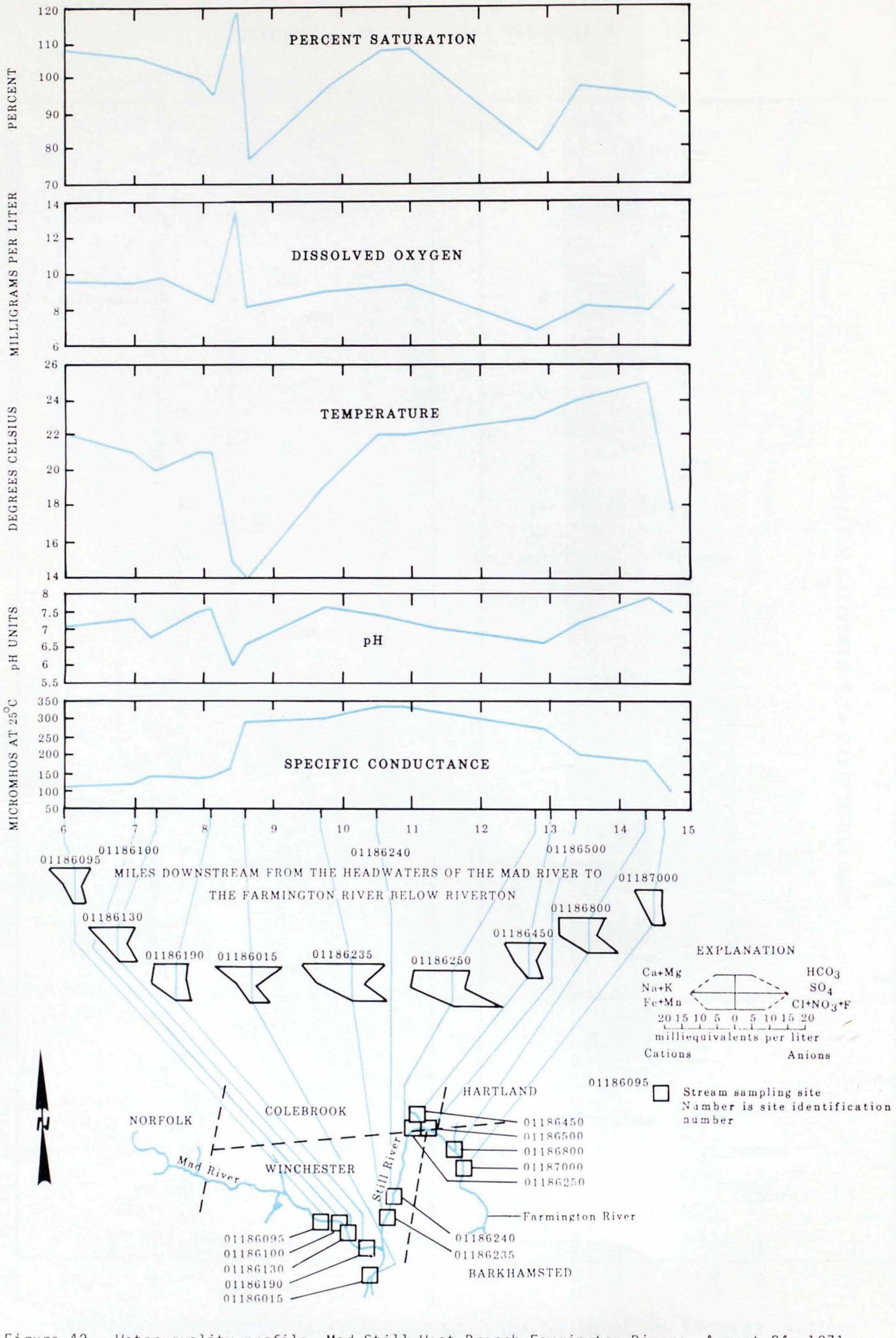


Figure 42.--Water-quality profile, Mad-Still-West Branch Farmington Rivers, August 24, 1971

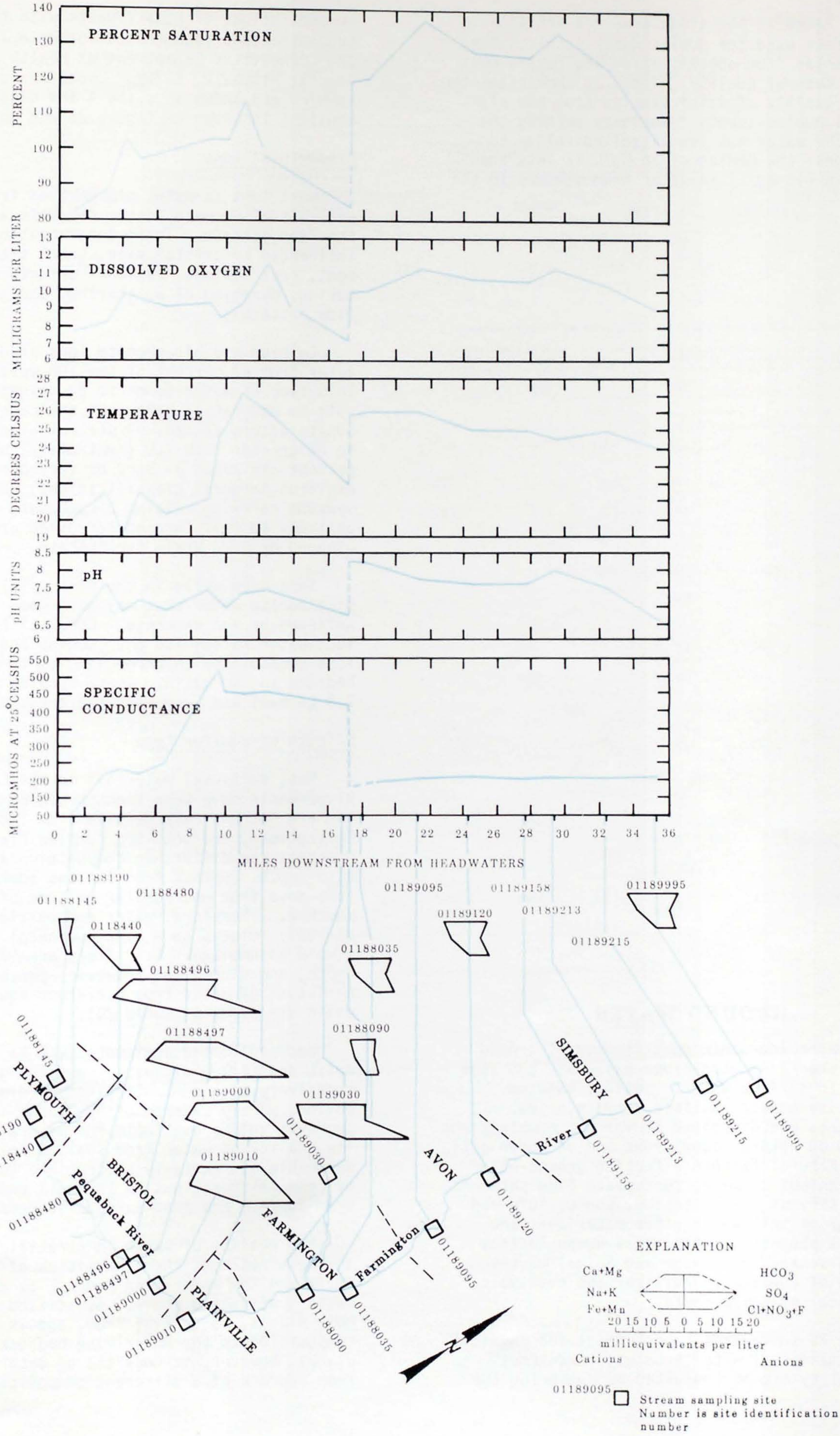


Figure 43.--Water-quality profile, Pequabuck-Farmington Rivers, August 23, 1971

Many lakes in the study area are artificial impoundments used for public water supply. They are protected from contamination and retain much of their natural quality. Table 22 summarizes the chemical quality of water samples from the eight principal public-supply reservoirs serving the basin. The water has low dissolved-solids concentrations; the median of 36 mg/L is less than the median (43 mg/L) in water from streams in the basin.

Table 22.--Chemical and physical properties of water from public water-supply reservoirs

[Concentrations of chemical constituents in milligrams per liter. Based on single samples collected in November and December, 1971, from eight reservoirs. Complete analysis for each site is in Water Resources Data for Connecticut, 1972 (U.S. Geological Survey,1973)].

Constituent or property	Median	Range
Silica (SiO_2)	5.8	3.2 - 12
Iron (Fe)	.21	.10 - .94
Manganese (Mn)	.04	.00 - .16
Calcium (Ca)	3.8	3.0 - 32
Magnesium (Mg)	1.6	.9 - 6.6
Sodium (Na)	3.5	2.2 - 8.8
Potassium (K)	.8	.6 - 1.0
Bicarbonate (HCO_3)	10	6 - 71
Sulfate (SO_4)	10	9.2 - 26
Chloride (Cl)	6.2	3.8 - 32
Fluoride (F)	.1	0 - .1
Phosphate (PO_4)	.05	.01 - .10
Nitrate (NO_3)	.2	0 - 2.2
Dissolved solids (sum of constituents)	36	26 - 149
Hardness, as $CaCO_3$	16	11 - 110
Hardness, as $CaCO_3$	6	5 - 49
Alkalinity, as $CaCO_3$	8	5 - 58
Specific conductance (micromhos per centimeter at 25°C)	54	41 - 271
pH	6.7	6.4 - 7.2
MBAS	.03	.02 - .04
Color, in platinum-cobalt units	8	0 - 200

GROUND WATER

The major inorganic constituents of ground water in the Farmington River basin are the same as those in surface water: silica, calcium, sodium, bicarbonate, sulfate, and chloride. Constituents are dissolved in various combinations depending on natural conditions and on human activities. Natural factors affecting ground-water quality include climate; subsurface flow patterns; the chemistry of precipitation, the texture and mineralogy of soil and aquifer materials; and biological processes. Principal human factors include discharge of sewage and animal wastes, spreading of chemical fertilizer and road salt, and disposal of solid waste.

Table 23 summarizes the chemical and physical characteristics of water from major aquifers. Water quality can be evaluated by comparing the concentrations of constituents with the maximum concentrations recommended for drinking water by the Connecticut Department of Health (Connecticut General Assembly, 1975). Locations of wells sampled are shown on plate A and distribution of aquifers is shown in figure 23 and on plate B.

Predominant ions

Most ions in water are derived from the minerals of unconsolidated deposits and rocks near the land surface. Their concentrations are influenced by crystal size, grain size of sediment, rock texture, regional structure, fracturing, duration of weathering, and ground-water flow patterns.

Calcium and bicarbonate ions predominate in water from 67 percent of the 108 wells sampled. This type of water tends to be slightly basic and soft to moderately hard. Of the calcium bicarbonate waters tested, 99 percent have a pH equal to or greater than 7.0 (neutrality) and only 13 percent are rated as hard or very hard. (Table 25 explains hardness classification.) Distribution systems carrying calcium bicarbonate water are unlikely to fail through corrosion or to be plugged by hard scale precipitate.

Some deep wells in the basin yield sodium bicarbonate water that may have been naturally softened by ion exchange. Chemical reactions in such water raises its pH. Sodium and bicarbonate ions predominate in three samples from sedimentary bedrock in the basin. These samples are basic (pH 7.8 to 8.1) and very soft (hardness 0 to 20 mg/L).

Effects of aquifer type

Most surficial materials in the Farmington River basin have been transported by glaciation and are not entirely derived from local bedrock. Furthermore, bedrock is a complex mixture of minerals and differs in composition areally and with depth. Waters from various sources mix as they move from one aquifer or type of rock to another. Therefore, water composition is not directly related to a single mineral species or simple assemblage. It differs areally, with depth, and with time. However, certain characteristics of water from different aquifers in the basin are evident (table 23).

Unconsolidated sediments such as stratified drift and till yield water containing comparatively high concentrations of dissolved solids, partly because of the large surface area per unit volume available for mineral dissolution. The quality of water from shallow wells in highly permeable sediments is susceptible to modification by chemical reactions in the soil and to pollution from surface and near-surface sources.

The quality of water in stratified-drift aquifers reflects the composition of both the drift and the underlying bedrock as well as other factors discussed above. Stratified drift, in most places, is derived from, and is similar in composition to the underlying bedrock. In a few places, however, it consists of materials derived from bedrock of a different composition. Its

Table 23.--Chemical and physical properties of ground water

[Concentrations of chemical constituents in milligrams per liter. Based on analyses of single samples from each well, collected in 1971-72. Complete analyses for each sample is in Water Resources Data for Connecticut 1972 (U.S. Geological Survey, 1973.]

Constituent or Property	TYPE OF AQUIFER: Stratified drift underlain by Sedimentary bedrock		Stratified drift underlain by Crystalline bedrock		Sedimentary bedrock		Crystalline bedrock	
	Median	Range	Median	Range	Median	Range	Median	Range
Silica (SiO_2)	14	6.9 - 24	12	9.2 - 17	15	8.5 - 30	14	7.8 - 22
Iron (Fe)	0.06	.01 - .65	0.08	.03 - .43	0.05	.02 - .33	0.08	.03 - 2.2
Manganese (Mn)	0	0 - .28	0	0 - .46	0	0 - 1.2	0	0 - .31
Calcium (Ca)	25	14 - 58	6.4	3 - 27	22	.1 - 419	15	1.9 - 65
Magnesium (Mg)	2.9	.8 - 11	2.2	1 - 3.8	2.1	0 - 50	2.8	.4 - 13
Sodium (Na) 1/	7.2	3.1 - 34	5.8	2.6 - 37	8.9	3 - 64	6.6	3.2 - 34
Potassium (K)	1.0	.3 - 16	1.1	.6 - 1.9	.5	.1 - 2.2	1.6	.5 - 3.5
Bicarbonate (HCO_3)	58	8 - 105	18	8 - 60	70	20 - 168	39	8 - 155
Sulfate (SO_4) 1/	17	4.5 - 140	8.2	4.1 - 110	17	4.5 - 1,300	14	3.4 - 140
Chloride (Cl) 1/	9.0	2.5 - 54	3.7	1 - 69	8.9	1.5 - 94	9.2	1 - 45
Fluoride (F)	.1	0 - .2	.1	0 - .3	.1	0 - 1.2	.1	0 - 1
Nitrate (NO_3) 1/	8.0	2.2 - 106	2.2	0 - 9.5	4.4	0 - 22	3.5	0 - 31
Dissolved solids (sum of constituents)	122	76 - 284	60	36 - 174	119	47 - 1,895	94	45 - 328
Hardness, as $CaCO_3$	73	44 - 190	24	12 - 83	68	0 - 1,252	48	6 - 181
Hardness, as $CaCO_3$ (noncarbonate)	27	1 - 135	8	0 - 50	19	0 - 1,200	18	0 -105
Alkalinity, as $CaCO_3$	46	7 - 86	15	7 - 49	57	16 - 138	32	7 - 127
Carbon dioxide (CO_2)	1.4	.8 - 8.7	1.6	1.2 - 2.6	1.1	.8 - 4.9	1.3	.8 - 2.6
Specific conductance (micromhos per centimeter, at 25°C)	188	117 - 467	87	46 - 293	178	74 - 2,060	138	55 - 516
pH	7.6	6.9 - 8.3	7.4	6.8 - 7.8	8.0	7.2 - 8.4	7.7	7 - 8.3
Depth of wells in feet	69	20 - 288	68	8 - 125	206	79 - 610	240	45 - 525
No. of wells sampled	20		8		42		37	

water may differ in quality from that of the underlying bedrock. Till is of minor importance in the Farmington River basin and water from only one well in till has been sampled for this study.

Under natural conditions, the chemical composition of ground water from sedimentary bedrock is similar to that of water from streams draining areas underlain by sedimentary bedrock, and ground water from crystalline bedrock is similar to water from streams draining crystalline bedrock. This is especially true during low-flow conditions. Solute concentrations are higher in ground water than in surface water, but relative proportions of most solutes are similar. An exception is the higher proportion of bicarbonate ions in ground water. The disproportion results from reactions involving dissolved carbon dioxide in the soil and the unsaturated zone. Growing plants can produce 2 to 10 liters of carbon dioxide per square meter of surface per day in soil (White and others, 1963). Some of this dissolves in water passing through the soil and reacts with minerals to form soluble carbonates and bicarbonates.

Sedimentary bedrock, composed of sandstone, siltstone, conglomerate, and shale, is an important aquifer in the eastern part of the basin (fig. 39). The stratigraphic and areal differences in composition of these rocks account for much of the wide range of solute concentrations in the water they produce.

Crystalline-bedrock aquifers consist primarily of metamorphic rocks in the central and western part of the basin and generally northeast--southwest trending igneous units in the east. Water from these aquifers contains low concentrations of dissolved solids (table 23). Water moves through them chiefly along joints and fractures so that only a small surface area is open to chemical attack. Furthermore, the crystalline rocks to a large degree are composed of slightly soluble minerals. These factors account for the low concentrations of solutes in water from crystalline bedrock in the basin.

Changes with time

Ground-water quality changes with time, principally in response to changes in recharge from various sources, pumping, and land use, especially in shallow stratified-drift aquifers. Variations may be related to seasonal changes in recharge and vegetal growth and decay, and to the effects of human activities, such as induced recharge of surface water.

Induced recharge can improve or degrade the quality of water in an aquifer. As surface water infiltrates into an aquifer due to pumping of a nearby well, its quality is modified by filtration, chemical, and biological action. Sediments lining the stream or lake filter out bacteria and suspended solids, but most dissolved constituents pass through. Water in an area of induced recharge is a mixture of ground water and surface water. Its quality depends on relative proportions of these two components. Surface water generally is less mineralized than ground water, hence recharge by induced infiltration is likely to result in an improvement in quality. Where surface water is polluted, however, induced recharge may cause a deterioration in quality. Deterioration is most likely during periods of low streamflow when streams receiving sewage and industrial discharge may be more highly mineralized than natural ground water.

IRON AND MANGANESE

Iron and manganese constitute only a small part of the dissolved-solids concentration in water in the Farmington River basin. Although concentrations of these two ions are low, they are troublesome in some parts of the basin. Dissolved iron exceeding 0.3 mg/L and manganese exceeding 0.05 mg/L are problems for domestic and industrial users because they precipitate on exposure to air. Reddish-brown iron oxides and black or gray manganese oxides discolor fabrics and fixtures. High concentrations also impart an objectionable taste to water. Many industrial processes, such as baking, canning, laundering, tanning, and textile manufacturing, require concentrations less than 0.2 mg/L for each ion (see table 30).

Table 24 summarizes the iron and manganese content of water in the study area. Iron concentrations are higher than manganese concentrations in 95 percent of the samples tested. Only 10 percent of the samples contain objectionable amounts of either ion. Crystalline bedrock and the stratified drift overlying it contain abundant minerals rich in iron and manganese. Water from streams and wells in areas underlain by crystalline bedrock is, therefore, the more likely to contain excessive iron and manganese concentrations than water from areas underlain by sedimentary bedrock. Figure 44 shows the distribution of these ions in water in the basin.

Surface water contains as much iron and manganese as ground water. Therefore, it is unlikely that ground water is the only source of iron and manganese in streams of the basin. The highest amounts are from streams draining swamps. Median concentrations are higher at low flow than at high flow because there is less dilution of swamp discharge by surface runoff.

Iron and manganese dissolved from minerals in soils and rocks either remain in solution or are redeposited, depending largely on the oxidation potential and pH of the water. Organic materials, as well as rocks and minerals, supply iron and manganese to natural waters. Organic materials accumulate in soils, marshes, bogs, organic-rich shales, and lake sediments in the basin.

Iron and manganese are essential for the metabolism of fungi, bacteria, aquatic and land plants, and many animals. Aquatic plants take these nutrients from bottom sediments or directly from water; land plants extract them from soil. Dead plants accumulate as iron- and manganese-rich organic debris in soil and bottom mud. A reducing environment caused by decay of organic sediments, by inundation of soil, or by oxygen depletion in the bottom of deep lakes, can return iron and manganese to solution.

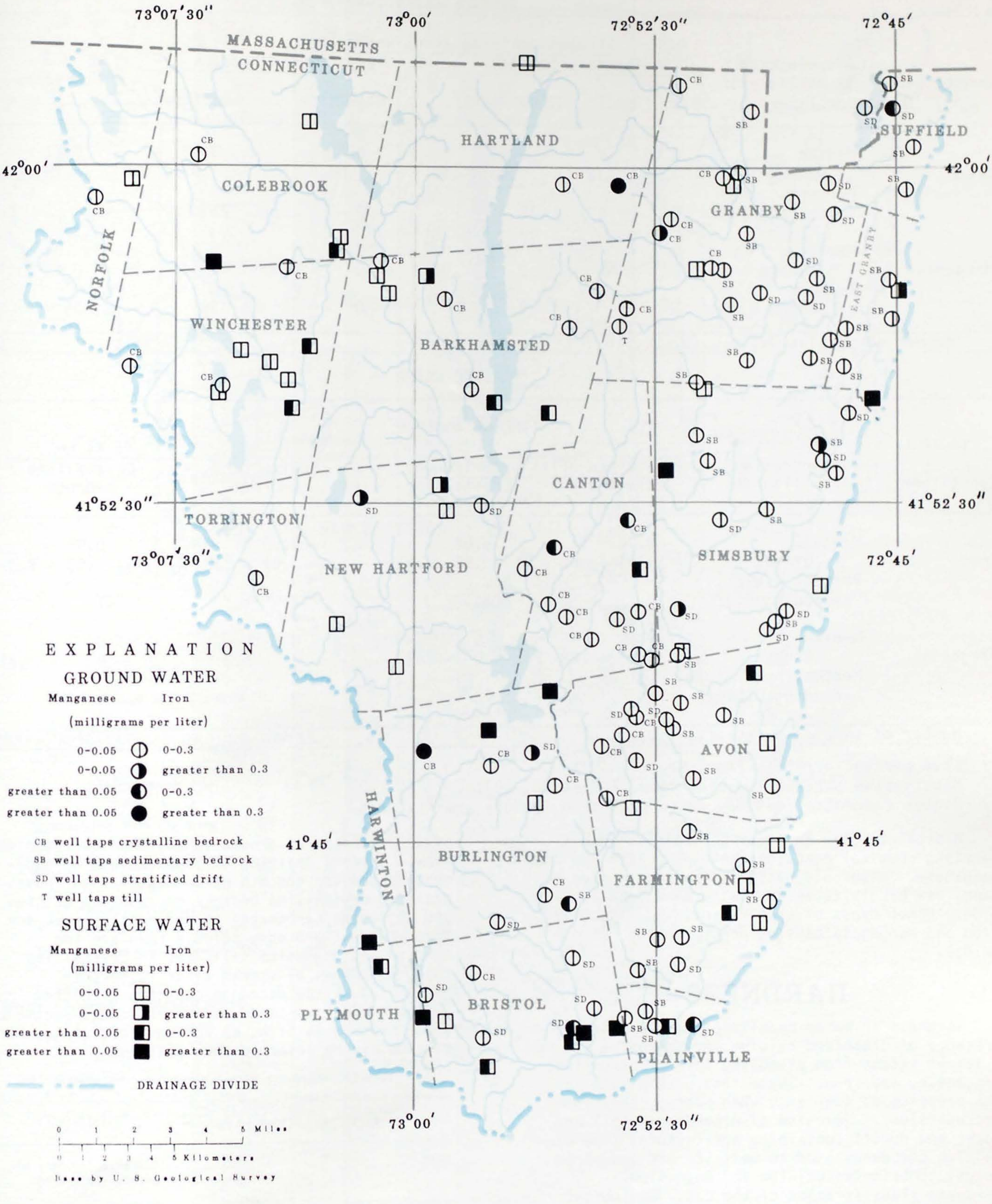


Figure 44.--Distribution of iron and manganese in water

Table 24.--Iron and manganese concentrations in surface water and ground water

SURFACE WATER

Constituent	Concentration in milligrams per liter	Streams draining areas underlain by: Sedimentary bedrock, High flow1/	Sedimentary bedrock, Low flow2/	Crystalline bedrock, High flow1/	Crystalline bedrock, Low flow2/	Reservoirs
Iron	Median	0.06	0.08	0.08	0.18	0.21
	Range	.04 - .12	.03 - .54	.04 - .52	.03 - .65	.10 - .94
	Percent exceeding 03 3/	0	16	7	23	38
Manganese	Median	0	.02	0	.02	.04
	Range	0	0 - .03	0 - .05	0 - .35	0 - .16
	Percent exceeding 0.05 3/	0	0	0	38	38
Number of samples..................		6	6	14	14	8

GROUND WATER

TYPE OF AQUIFER

Constituent	Concentration in milligrams per liter	Stratified drift underlain by: Sedimentary bedrock	Stratified drift underlain by: Crystalline bedrock	Sedimentary bedrock	Crystalline bedrock
Iron	Median	0.06	0.08	0.05	0.08
	Range	.01 - .65	.03 - .43	.02 - .33	.03 - 2.2
	Percent exceeding 0.3 3/	5	25	2	11
Manganese	Median	0	0	0	0
	Range	0 - .28	0 - .46	0 - 1.2	0 - .31
	Percent exceeding 0.05 3/	10	12	2	8
Number of samples...............		20	8	41	37

1/ Five percent duration flow, May 10, 1971
2/ Ninety-five percent duration flow, August 26, 1971
3/ Higher concentrations may cause stains on laundry and fixtures

Microbiota play an important role in accelerating chemical reactions involving iron and manganese. Anaerobic bacteria can reduce iron and manganese precipitates and bring them into solution. Other types of bacteria oxidize dissolved iron and manganese causing precipitation of oxides.

HARDNESS

Hardness in water results primarily from the presence of dissolved calcium and magnesium and to a lesser extent from dissolved barium, strontium, manganese, and iron. These ions precipitate in the presence of soap and, when heated, they form encrustations. Solution of minerals in soil and rock, and runoff containing agricultural lime or calcium compounds used to melt ice and snow from roads, contributes calcium and magnesium. Hardness classification of the U.S. Geological Survey and suitability of water of different hardness ranges for domestic and industrial use is given in table 25.

Surface water in the basin ranges from soft to hard, as shown in table 26. Streams contain harder water during low flow, when streamflow consists primarily of ground water, than during high flow. Streams draining areas underlain by sedimentary bedrock contain harder water than those draining crystalline bedrock because the calcium and magnesium carbonates in sedimentary rock are more abundant and more soluble than are the calcium and magnesium silicates in crystalline rock. Hardness of stream water is further influenced by the exchange capacity of bottom sediments and suspended sediments. When sediment concentration is high, as during flood stage, more calcium may be adsorbed than dissolved.

Table 25.--Hardness of water and resultant suitability

Descriptive rating	Hardness as $CaCO_3$, range in mg/L	Suitability
Soft	0- 60	Suitable for many uses without softening.
Moderately hard	>60 $\leq$ 120	Usable except for some industrial applications.
Hard	>120 $\leq$ 180	Softening required by laundries and for most domestic uses.
Very hard	>180	Softening required for most purposes.

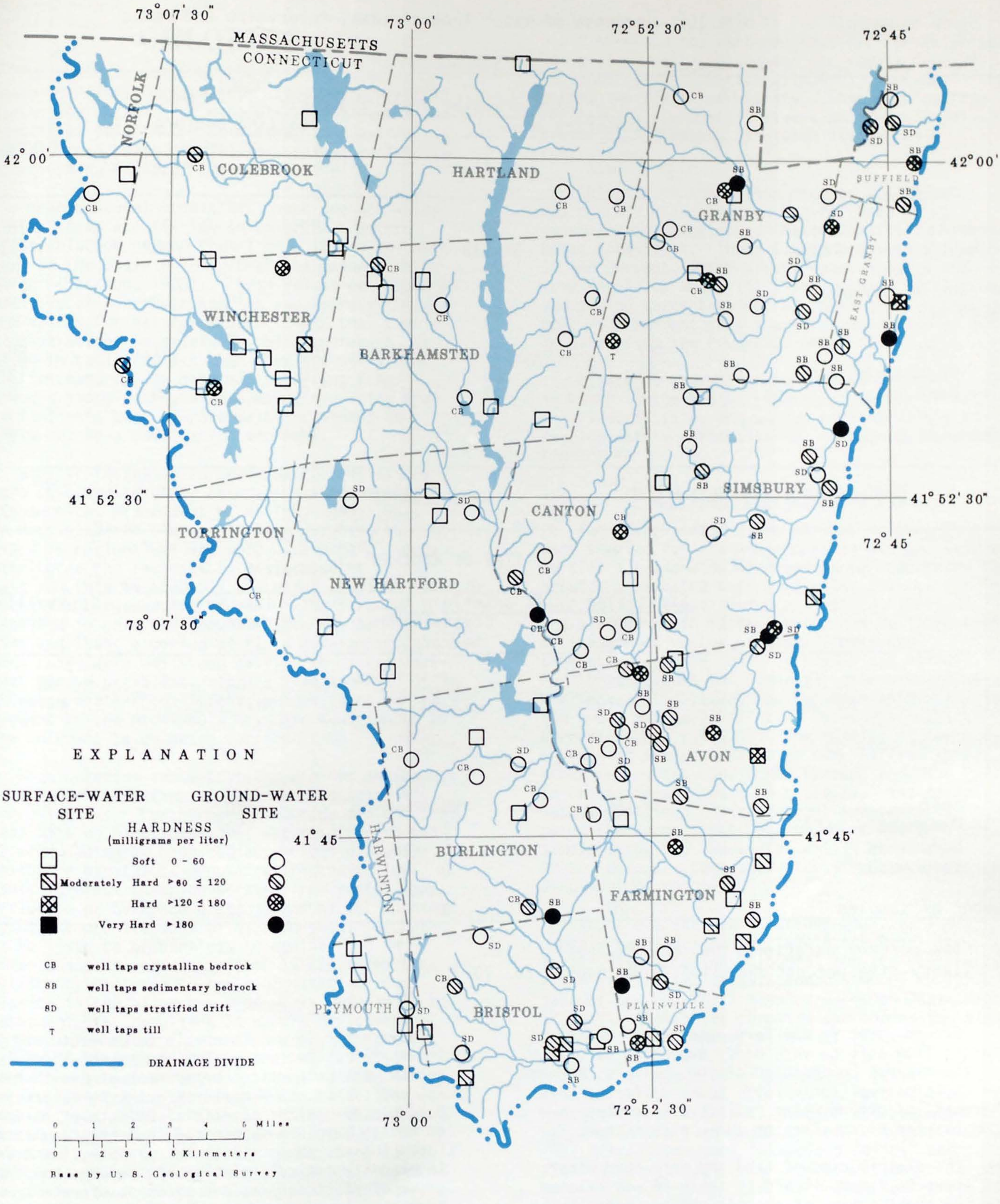


Figure 45.--Distribution of hardness in water

Table 26.--Hardness of water from streams, reservoirs and wells

SURFACE WATER

		Streams draining areas underlain by:				
		Sedimentary bedrock		Crystalline bedrock		Reservoirs
		High flow1/	Low flow2/	High flow1/	Low flow2/	
Hardness in(mg/L):	Median	28	70	12	20	16
	Range	23-90	31-138	7-32	7-82	11-110
Percent of samples rated as						
Soft		67	33	100	93	88
Moderately hard		33	33	0	7	12
Hard		0	33	0	0	0
Number of samples		6	6	14	14	8

GROUND WATER

TYPE OF AQUIFER

	per liter	Stratified drift underlain by: Sedimentary bedrock	Stratified drift underlain by: Crystalline bedrock	Sedimentary bedrock	Crystalline bedrock
Hardness in(mg/L):	Median	73	24	68	48
	Range	44-190	12-83	0-1,252	6-181
Percent of samples rated as:					
Soft		25	88	40	59
Moderately hard		60	12	38	22
Hard		10	0	10	16
Very hard		5	0	12	2
Number of samples		20	8	42	37

1/ Five percent duration flow, May 10, 1971
2/ Ninety-five percent duration flow, August 26, 1971

Ground water in the Farmington River basin ranges from soft to very hard, depending largely on the mineral composition of the aquifers through which it passes (table 26). Local differences in hardness of ground water reflect differences in composition of aquifers or zones within them.

The distribution of hard and very hard water, as shown in figure 45 and in table 26, is related to the areal extent of the sedimentary bedrock but is not restricted to any aquifer or locality. The range of values is greatest in water from sedimentary bedrock because its composition differs from place to place and changes with depth; moreover, it includes some beds of carbonate rock. Stratified drift overlying sedimentary bedrock has a high percentage of wells yielding moderately hard to very hard water chiefly because of mineralogy and the fact that it has a developed soil zone in which near-surface reactions increase calcium solubility.

Hard water is objectionable to domestic and industrial users, but because it is not harmful to health, the Connecticut Department of Health has not set limits on hardness in drinking water. Possible harmful or beneficial effects of hardness on health have been suggested, but the results are inconclusive. Muss (1962) for example, found an inverse statistical relationship between the incidence of heart attacks and hardness of water. Connecticut was rated as a low-hardness, high--heart-attack state in his study.

Hard water is commonly softened by the ion-exchange method in which sodium is exchanged for calcium. Because excessive sodium can be harmful to people who require a sodium-free diet, this method should be used advisedly. Extremely soft water is undesirable for some industrial uses as it tends to be corrosive; it is undesirable for irrigation as it "puddles" on the soil surface.

CHLORIDE

Chloride in water of the Farmington River basin is mainly derived from atmospheric precipitation and solution of minerals in soil and rocks. Additional chloride is from sewage, industrial wastes, road salts, fertilizer, animal wastes, and backflushing of water softeners.

Under natural conditions, most surface water in the study area is low in chloride. Before 1905, chloride ranged from 1 mg/L in the southern part of the basin to 2 mg/L at the Massachusetts border (Jackson, 1905). These values are based on analyses of reservoir samples and represent minimum values for natural water. Since that time concentrations in reservoirs have increased, as shown in table 22, although they are still low. The increase may be natural, resulting from changed storm paths, or man made, resulting from contaminants such as road salt and septic-tank effluent, or a combination of these.

Similar increases in chloride concentrations were observed in other reservoirs in Connecticut (Connecticut Department of Health, 1946, 1971) and in Massachusetts (Terry, 1974) indicating that the trend is regional if not more widespread. Terry attributes the increase in Massachusetts to road salt and this is probably the major cause in most Connecticut reservoirs as well. The largest increase in chloride concentration was between 1945 and 1966, a period of rapid development. Many roads were built and salting to de-ice pavement became prevalent. It was also a period of changing weather conditions, when a four-year drought in the mid-1960's may have contributed to the increase in chloride concentration.

High chloride concentrations are not toxic, but they affect the taste of water and increase its corrosiveness. Furthermore, chloride derived from road salt or backflushing of water softeners can be accompanied by high concentrations of sodium which are harmful to people restricted to low-sodium diets. Chloride derived from septic tank effluents or barnyard drainage can be accompanied by high concentrations of nitrate ions. Nitrate is believed to be harmless to adults, but in infants and in some animals it is converted to nitrite by bacteria in their digestive tracts. Nitrite in the bloodstream converts hemoglobin to methemoglobin, resulting in oxygen deficiency which can be fatal (National Academy of Sciences and National Academy of Engineering, 1973). Nitrate does not affect the industrial use of water. The Connecticut Department of Health (Connecticut General Assembly, 1975) recommends a maximum chloride concentration of 250 mg/L in drinking water, based on consideration of taste; a maximum sodium concentration of 20 mg/L, based on requirements of low-salt diets; and a maximum nitrate plus nitrite nitrogen concentration of 10 mg/L (equivalent to 44 mg/L nitrate) for prevention of methemoglobinemia.

No samples collected in the Farmington River basin exceeded the recommended limit for chloride. One shallow well (SU 57) and one sample from the Pequabuck River (station 01188497), however, exceed the limit for nitrate. Some samples from the Pequabuck and Still Rivers and from 12 wells in the basin contain excessive sodium concentrations.

Chloride concentration greater than 20 mg/L and nitrate concentration greater than 10 mg/L generally indicate contamination resulting from human activities. These limits are both exceeded in ten percent of the ground water samples and in some Pequabuck and Still River samples. Chloride and sodium concentrations are both greater than 20 mg/L in 5 percent of the ground-water samples and in water from the Pequabuck and Still Rivers.

Figure 46 shows the distribution of these ions in water in the basin. The relationship of high chloride, nitrate, and sodium concentrations to development is strong,'as can be seen by comparing figures 46 and 39.

TRACE ELEMENTS

Two reservoirs and two streams in the basin were sampled for trace elements in October 1970 as part of a nationwide reconnaissance undertaken to provide a baseline survey of water sources for metropolitan areas (Durum and others, 1971). Trace elements in surface water can be indicators of industrial wastes, and in certain concentrations can be toxic to plants and animals. For these reasons the Connecticut Department of Health has established maximum permissible levels for trace metals in drinking water (Connecticut General Assembly, 1975). The results of the survey and of analyses of water samples from three other reservoirs, one other stream, and five wells in the basin are shown in table 27. The surface waters contained concentrations substantially below the Connecticut Department of Health limits. Samples from two industrial wells, BS 95 and PV 28, however, contained excessive concentrations of dissolved chromium.

Trace elements were further analyzed in monthly samples from the Farmington River at Tariffville (station 01189995) and the Pequabuck River at Forestville (station 01189000) in 1971. Some of the Pequabuck samples exceeded Department of Health limits for chromium and copper and also contained high concentrations of zinc.

A broad spectrum of metals was tested in water samples collected at 20 sites as part of the Mad-Still-West Branch Farmington and Pequabuck--Farmington profiles investigated in August, 1971. (See discussion under "Dissolved Solids" and figures 42 and 43.) High concentrations of aluminum, chromium, and nickel were detected in the Still River at Riverton (station 01186800) and of aluminum, boron, chromium, copper, nickel, and zinc in the Pequabuck River at Forestville (stations 01188497 to 01189010). These metals are derived from industrial wastes and are not removed at sewage treatment plants.

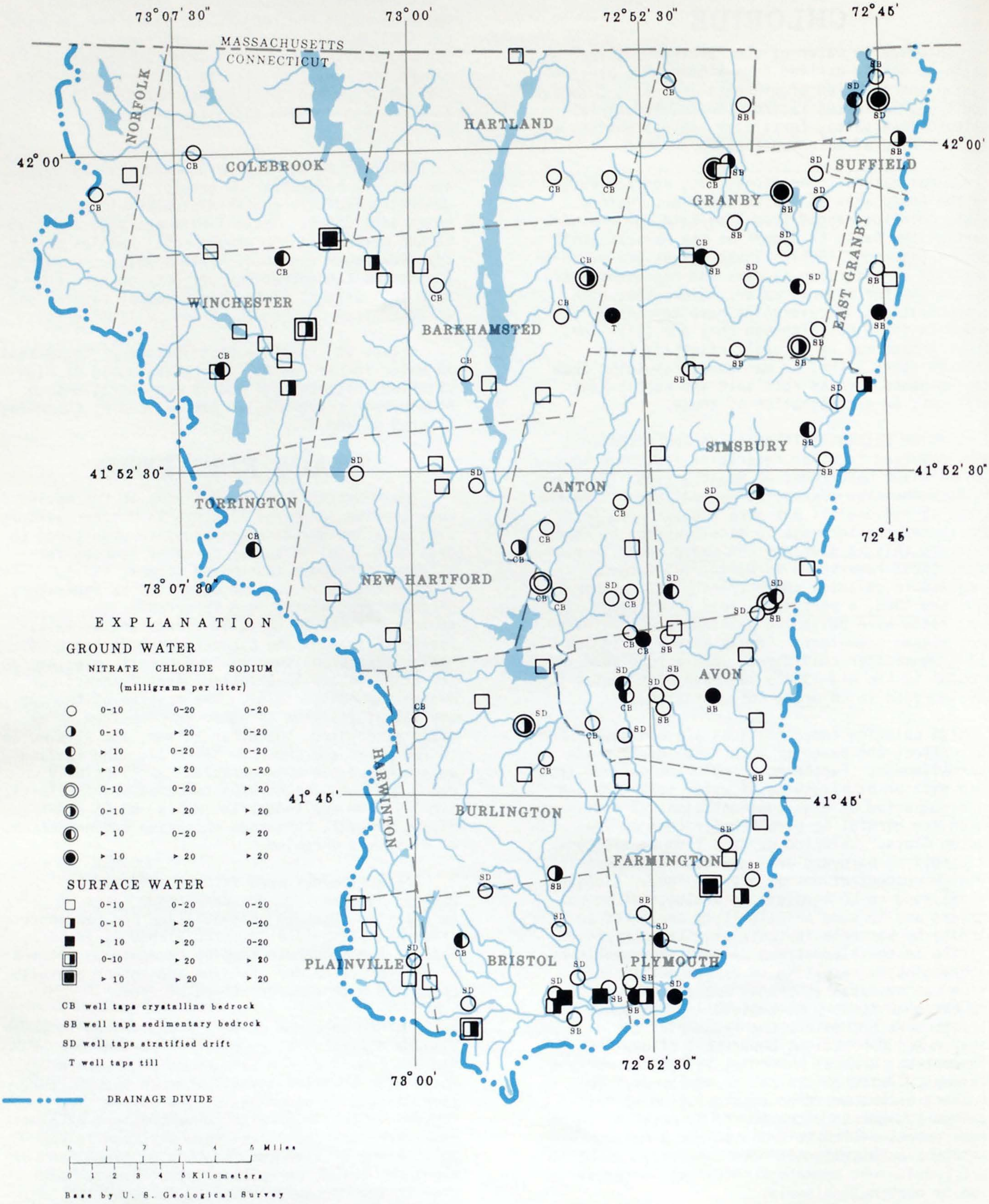


Figure 46.--Distribution of chloride, nitrate, and sodium in surface water and ground water

Table 27.--Trace elements in public water supplies, rivers, and wells

[Concentrations in micrograms per liter]

Water body and location	Station No.	Hexavalent chromium (Cr^{+6})	Lead (Pb)	Zinc (Zn)	Cobalt (Co)	Arsenic (As)	Cadmium (Cd)	Dissolved Mercury (Hg)	Copper (Cu)
Barkhamsted Reservoir near Barkhamsted	01187500	3	7	10	0	0	0	0	0
Nepaug Reservoir near Collinsville	01187870	3	2	10	1	0	0	0	-
Crystal Reservoir near Winsted	01186140	0	0	0	2	11	0	0	-
Bristol Reservoir No. 1. at Terryville	01188450	0	0	0	2	5	1	0	-
Farmington Reservoir at Farmington	01189028	0	4	30	2	2	0	-	-
Still River near Winsted.	01186240	6	6	0	0	10	0	0	-
Pequabuck River at Forestville.	01189000	0	8	0	0	10	6	0	-
Burlington Brook near Burlington.	01188000	0	0	0	-	-	-	-	0
Large North American streams.1/	Median	5.8	4.0	0	0	-	-	-	-
100 largest U.S. cities, treated water.2/	Median	.43	3.7	-	-	-	-	-	8.3
	Range	0-35	0-62	0-610	-	-	-	-	0-250
5 wells in the Farmington River basin.	Median	0	0	10	-	-	1	-	50
	Range	0-140	0	0-640	-	-	0-3	-	0-70
Permitted maximum3/		50	50	-	-	50	10	2	500

1/ Durum and Haffty (1963).
2/ Durfor and Becker (1964).
3/ Standards for drinking water, Connecticut Department of Health (Connecticut General Assembly, 1975).

BACTERIA

Coliform bacteria in water samples are used by the Connecticut Department of Health as an indication of recent pollution by human or animal wastes. The Department recommends limits of 20,000 coliform colonies per 100 mL (milliliters) in raw surface-water sources of drinking water. Concentrations up to this limit can be reduced to safe levels (1 colony/100 mL) by chlorination. Figure 47 shows the wide range of bacterial concentrations in monthly samples from different sites in the Farmington River basin. The lowest concentrations are from Burlington Brook from which all samples meet Department of Health standards. In contrast, the Pequabuck River at Farmington contains high concentrations of coliform bacteria. The high ratio of fecal coliform to streptococci shows that the pollution is partially a result of human wastes.

Figure 48 summarizes bacterial concentrations in water samples from Burlington Brook near Burlington (station 01188000) and the Farmington River at Tariffville (station 01189995) for the 9-year period ending in 1979. The median coliform concentrations, with one exception, are below the recommended limit in both streams, indicating pollution is minimal. The low ratio of fecal coliform to streptococci in the Burlington Brook samples shows that human wastes are not polluting this stream. The decrease in the fecal coliform bacteria median concentration shown in the Farmington River samples after 1973 is probably due to expanded sewage treatment in compliance with Public Act No. 57-- the "Clean Water Act" (Connecticut General Assembly, 1967).

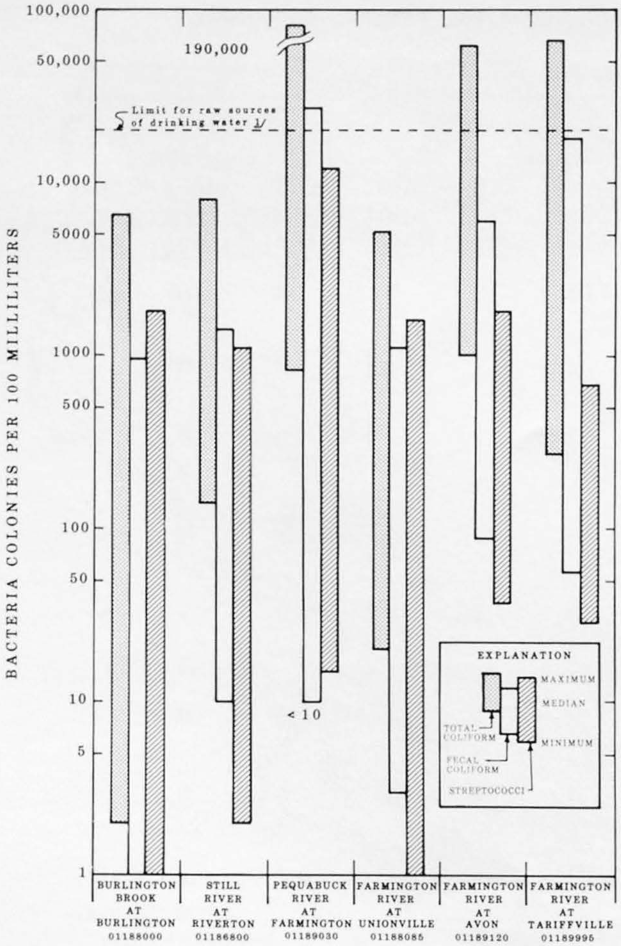


Figure 47.--Bacteria in stream-water samples, 1975 water year

SEDIMENT AND TURBIDITY

All streams carry sediments eroded from the land. The quantity carried at any time depends on erosion processes in the stream basin, that are related to climate, vegetation, and soil and rock properties. The sediment load generally increases with increased streamflow and resultant higher velocities. Clay and silt-sized sediments are suspended by turbulent flow, thus they move readily through the channel system. Coarse-grained sand and gravel have a faster settling rate and move by suspension for only short distances; more commonly they roll or bound along the stream bottom.

Turbidity, or cloudiness, of water is a result of the scattering and absorption of light by suspended particles. The particles may be organic materials; clay, silt, or sand grains eroded from the land; or organic compounds and inorganic particles derived from industrial or domestic wastes.

Human activities can greatly alter the sediment regimen of a stream. Some changes in land use result in profound changes in sediment production. Agricultural land, for example, has a greater sediment yield than has wooded land, and construction sites have an even higher yield. Urbanization increases the amount of overland flow and the frequency and magnitude of peak flows by increasing the number and size of impervious areas in a basin. This commonly results in increased sediment discharge downstream. Storm sewers, however, can increase peak flows without increasing sediment discharge.

Highway construction also increases sediment loads. Parizek (1971) reports sediment yields of 3,000 tons per mile during highway construction in Maryland. The sediment is derived from fresh road cuts, new embankments and borrow pits, and destruction of pre-construction vegetation. Divided highways require exposure and denudation of 10 to 35 acres per mile of road during construction. Even after paving and seeding have been completed, increased discharge and redirected runoff from pavements and embankments may result in further erosion.

In the Farmington River basin, as elsewhere, erosion from croplands, streambanks, and construction areas can be troublesome. An additional sediment load results from the spreading of sand on road surfaces in winter. Only 43 percent of the 930,000 tons of sand used on Connecticut roads in a typical winter is swept up. Much of the rest is washed into nearby watercourses, especially in rural areas where roads do not have catch basins.

The consequences of an increased sediment load are twofold: (1) changes in stream and reservoir morphology, and (2) changes in the properties of sediment-laden water. Sediment accumulation in reservoirs, for example, decreases storage capacity and increases the cost of water treatment.

An increase in suspended particles causes a chain of reactions by reducing penetration of solar light and heat. Warming of near-surface water reduces its density and inhibits vertical mixing. This reduces the downward transfer of oxygen which is required by plants and animals. Sediment and turbidity also affect the viscosity of water, the concentrations of minerals dissolved in it, and its adsorption of toxic materials. These factors control the aquatic life and biologic productivity of a waterway. Some sediment is beneficial in providing nutrients for plants. Excessive sediment, however, can change the flora and fauna by its abrasive effects, by reducing light transmission, and by blanketing bottom dwellers, thereby reducing the food supply for some animals. Increased sediment and turbidity thus decrease the recreational and aesthetic value of a waterway.

Excessive turbidity is objectionable for most industrial uses and is undesirable in drinking water. Coagulation, sedimentation, and filtration processes can remove particles and reduce turbidity, but such treatment increases the cost.

Excessive turbidity is objectionable for most industrial uses and is undesirable in drinking water. Coagulation, sedimentation, and filtration processes can remove particles and reduce turbidity, but such treatment increases the cost.

Sediment and turbidity of streams in the Farmington River basin are low except where affected by human activities. Samples collected monthly from Burlington Brook (station 01188000) had turbidity values ranging from 0 to 6 JTU (Jackson Turbidity Units) with a median of 1 JTU and those from the Farmington River at Tariffville (station 01189995) ranged from 1 to 10 JTU with a median of 1 JTU. Although the amounts of suspended particles in streams in the basin are not generally high enough to be objectionable, problems do occur during periods of construction. Such problems can be minimized by stabilizing

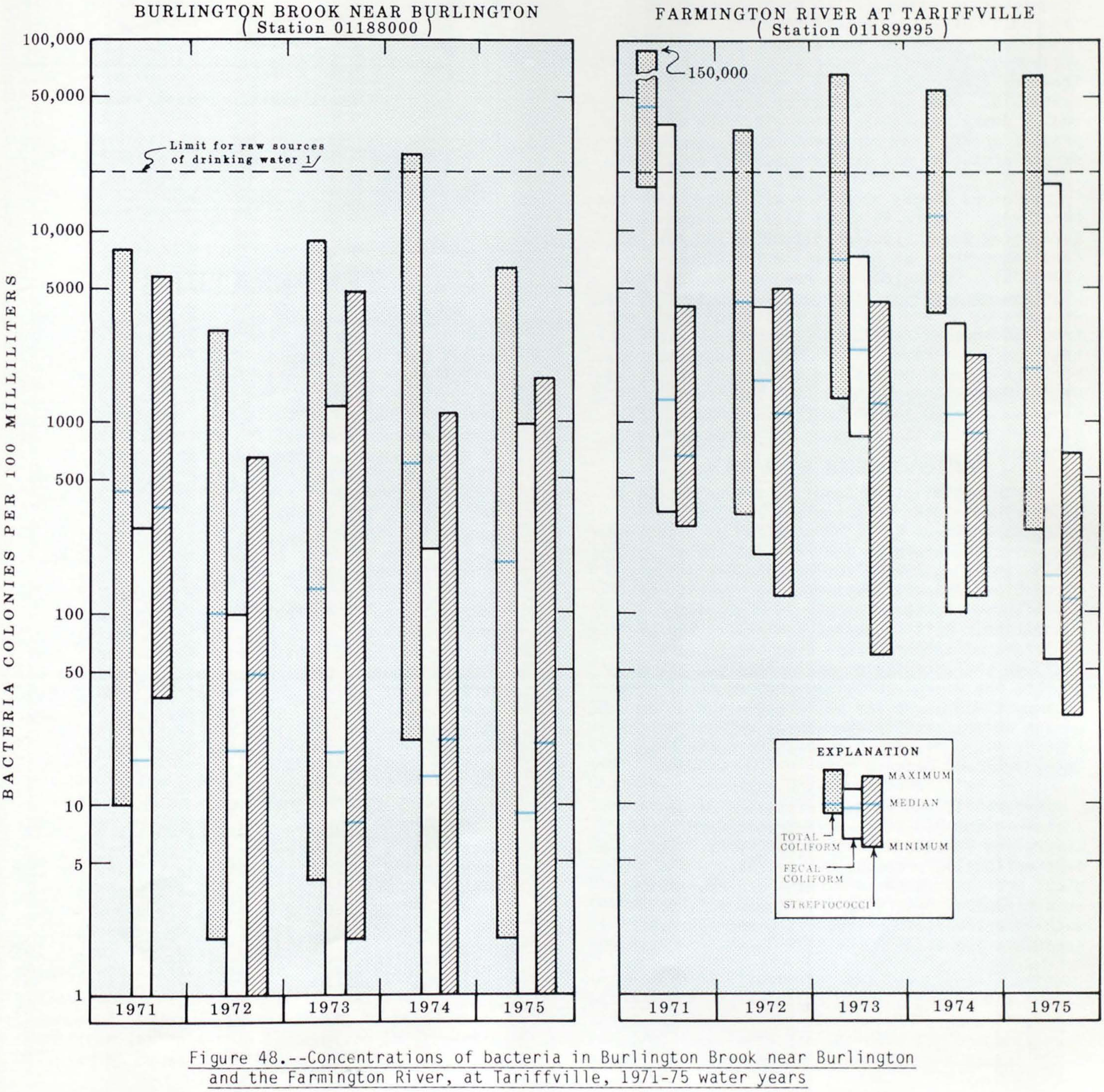


Figure 48.--Concentrations of bacteria in Burlington Brook near Burlington and the Farmington River, at Tariffville, 1971-75 water years

exposed cuts and fills, constructing temporary earth barriers to reduce the velocity of storm runoff, adjusting time schedules to reduce exposure of soil, and by building streets parallel to topographic contours. Problems caused by road sanding in winter can be reduced by using less sand per application, sweeping more frequently, and constructing sediment traps.

DISSOLVED OXYGEN

The concentration of dissolved gases, controlled by the temperature, pressure, and biochemical condition of the water, has a profound effect on aquatic life. Adequate dissolved oxygen, for example, is necessary for its survival and reproduction. Fish require concentrations above 4 mg/L to survive for long periods of time and this minimum is not met in the deep layers of some lakes in summer. (See Highland Lake in fig. 53.) Dissolved oxygen fluctuates daily in response to cycles of temperature and biological activity. In surface water it is derived directly from the atmosphere or as a byproduct of photosynthesis. Much is consumed by biologic activity and by decay of organic materials. The amount present at any time represents a balance between oxygen-producing and oxygen-consuming processes.

Dissolved oxygen decreases with increasing temperatures. Figure 49 shows this relationship for Burlington Brook (station 01188000) and for the Farmington River at Tariffville (station 01189995). Concentrations ranged from 7.0 mg/L when the water temperature was 14.0°C to 12.0 mg/L when the water was 1.0°C at Burlington Brook and from 7.0 mg/L at 20.0°C to 11.5 mg/L at 1.0°C at the Farmington River site. Monthly samples from Burlington Brook were 67 to 87 percent saturated with oxygen, whereas those from the Farmington River were 67 to 105 percent saturated. Supersaturation is caused by increased stream turbulence.

Waste assimilation involves the oxidation of biodegradable organic material, a process which consumes oxygen. The concentration of dissolved oxygen is therefore an indirect measure of stream pollution. Organic pollution consumes dissolved oxygen, and thereby increases the toxicity of pollutants. Consumed oxygen is replenished by reaeration. Both oxidation and reaeration are functions of temperature. High temperatures increase the activity of microorganisms but also deplete the dissolved oxygen they require. The optimum temperature for waste assimilation depends on the composition of the wastes and on the species of microorganisms involved in their breakdown.

Figures 42 and 43 show dissolved oxygen profiles along the Mad-Still-West Branch Farmington Rivers and Pequabuck-Farmington Rivers. Daily fluctuations in response to temperature and biological activity in these streams are overshadowed by differences resulting from human activities such as discharges by industries and sewage-treatment plants.

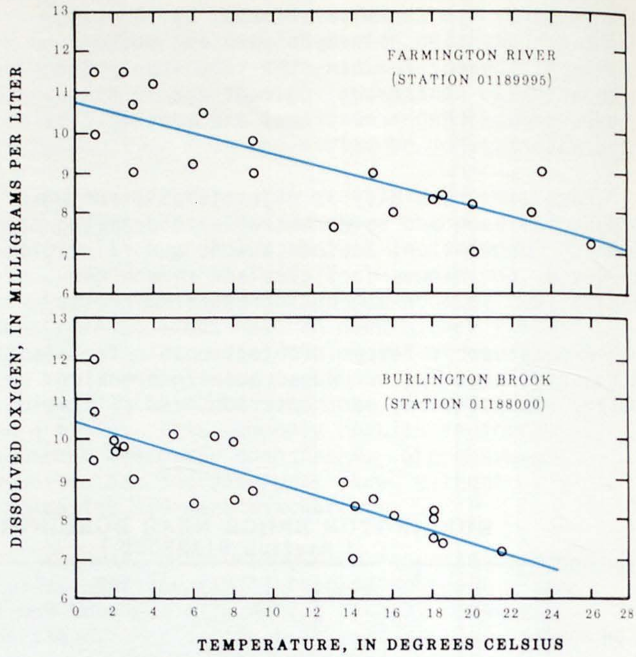


Figure 49.--Relationship between dissolved-oxygen content and water temperature, Farmington River at Tariffville and Burlington Brook near Burlington, 1971-72 water years

TEMPERATURE

Temperature affects both the physical properties of water and the chemical and biological processes that take place in it. These processes affect man's use of water for domestic supply, agriculture, industry, and waste assimilation. Cool water, up to 10°C, is best for domestic supply because chemical and biochemical reactions in warmer water produce undesirable tastes and odors. On the other hand, warmer water responds better to treatment; flocculation rates increase and chlorine has a greater effect on bacteria. Successful fish and waterlife culture requires a narrow range of water temperature. A great or sudden increase can cause rapid death and a moderate increase can cause slow death of fish by increasing their metabolic rate and oxygen requirements and by decreasing their resistance to disease and toxic substances. Agricultural uses require moderate temperatures because extreme temperatures of irrigation water affect crop growth. Some industrial uses, such as paper and pulp processing, require a uniform temperature and any increase in the temperature of water used for cooling purposes can be costly.

STREAMS

A well shaded stream, fed primarily by ground water, has a restricted range of temperature. It approximates that of the water in the aquifer that discharges into it (mean annual air temperature), except during freezing weather. Shaded streams fed by snowmelt also have a narrow temperature range. Streams fed largely by surface runoff from rainfall show greater seasonal variations than do those fed primarily by ground-water runoff.

Streams in the study area are fed by ground water and surface runoff in proportions that vary throughout the year. Their temperature follows a seasonal cycle corresponding to that of the air. This relationship is illustrated in figure 50. Maximum water temperature of Burlington Brook (station 01188000) was 23.5°C in July and August of 1971; minimum was 0°C in November, December, January, February, and March. This range is representative of streams in the basin.

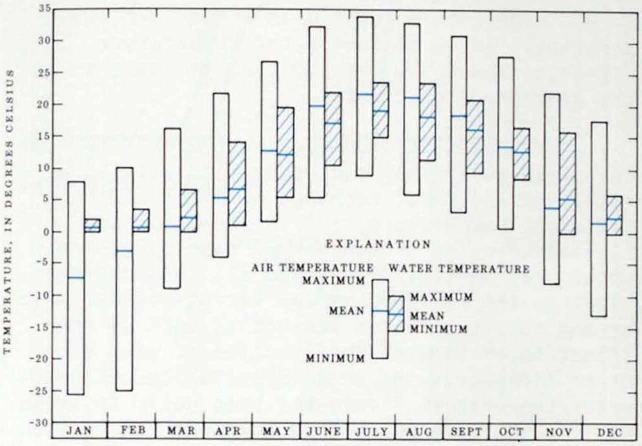


Figure 50.--Temperature of Burlington Brook and air temperature at Burlington, 1971

Figure 51 shows duration curves of maximum and minimum daily temperature for Burlington Brook at Burlington, the Pequabuck River at Forestville, and the Farmington River at Tariffville. The median water temperature at the Burlington station is 10°C, which is about 1 degree higher than mean annual air temperature at that site. The other two streams are warmer; median at the Pequabuck River station is 12°C and that at the Farmington River station is 11.5°C.

Destruction of streambank vegetation that shades the water increases radiative solar heating, resulting in mean annual water temperature that is higher than mean annual air temperature. Deforestation along some reaches and discharge of effluent into the Pequabuck and Farmington Rivers both contribute to their elevated temperature. These factors also cause temperature differences along different reaches of a stream. (See temperature profiles, figures 42 and 43.)

Use of stream water can also affect its temperature. Reservoirs, for example, alter downstream temperatures to varying degrees depending on their size, type of construction, and operating schedule. Release of bottom water from a reservoir during the summer commonly decreases the temperature of water downstream. Discharge of industrial wastes and cooling water generally increases stream temperature; discharge from power-generating plants causes the greatest increases. Other human activities that modify solar radiation, forest radiation, and groundwater inflow also affect stream temperature. Constructing new ponds, clearing streambanks of vegetation, installing sewers, and paving parts of a basin have been shown to significantly affect surface-water temperature in Long Island (Pluhowski, 1970). Figures 42 and 43 show downstream variations in temperature in streams affected by human activities.

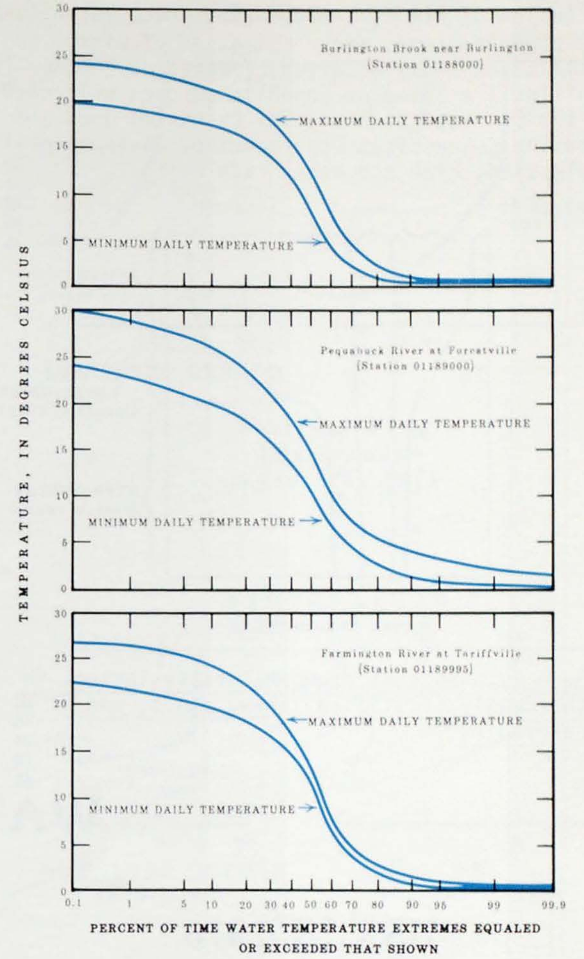


Figure 51.--Duration of maximum and minimum daily temperatures of three streams, 1971

LAKES AND RESERVOIRS

Temperature distribution in lakes is controlled by density, which can cause stratification. Thermally-stratified lakes in the Farmington basin include Barkhamsted Reservoir, Doolittle Lake, Highland Lake, and West Hill Pond (Connecticut Board of Fisheries and Game, 1959). Temperature fluctuations and stratification in lakes follow a seasonal pattern, as illustrated in figure 52. Stratification affects water quality, especially in summer and during the spring and fall overturn. In summer, warmer, less dense water (epilimnion) floats on deeper, cooler water (hypolimnion) separated by a zone of steep change (metalimnion). Circulation between the layers is minimal. Dissolved oxygen concentration is lowered in the hypolimnion, making it unsuitable for fish and other aquatic life. In spring and fall, water temperature and density are uniform throughout the lake allowing free circulation of the water. This brings iron, manganese, and decomposed organic materials to the surface, causing a seasonal increase in color and turbidity and a general deterioration of water quality.

Figure 53 illustrates the relationship between water depth and selected quality parameters in lakes and ponds in the basin. Both stratified and nonstratified lakes are included for comparison. Dissolved oxygen and pH gradients are caused by diffusion of air at the surface, photosynthesis in the upper regions, and respiration of plants and animals and decay of organic matter at depth. The profiles are based on unpublished data collected by the Connecticut Bureau of Fisheries and Game (now the Connecticut Department of Environmental Protection, Fish and Water Life Unit).

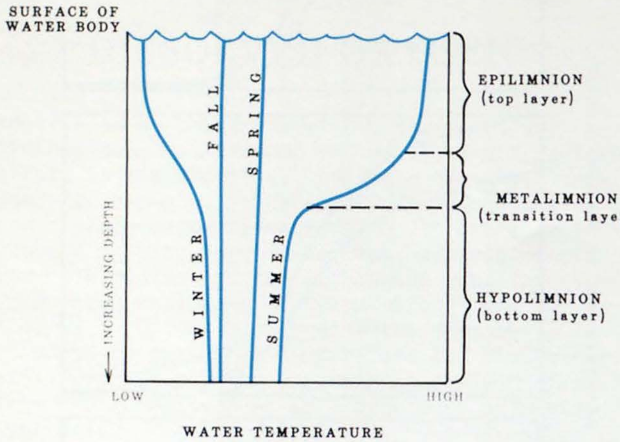


Figure 52.--Seasonal temperature variations in theramally-stratified lakes, ponds, and reservoirs

GROUND WATER

Ground-water temperature is more stable than surface-water temperature. Shallow ground water, less than 30 feet below land surface, fluctuates daily and seasonally due to conduction from the surface. The range of fluctuation decreases with depth. At about 30 feet ground-water temperature is approximately equal to mean annual air temperature and fluctuates less than 0.5°C annually. From 30 to 60 feet water temperature may be 1° to 2°C higher than local mean annual air temperature. Below 60 feet water temperature increases about 1°C per 100 feet in response to the geothermal gradient.

Differences in ground-water temperature from one place to another can occur naturally as a result of (1) local recharge of water having a different temperature, (2) interception and lateral transfer of geothermal heat by moving water, (3) vertical flow, and (4) chemical reactions in the aquifer. Areal variations can also be the result of human activities such as the injection or induced infiltration of warm water, or of radioactive or organic pollution. Ground-water temperature fluctuates seasonally in areas of induced recharge, but to a lesser degree than surface water.

WATER USE

USE IN 1970

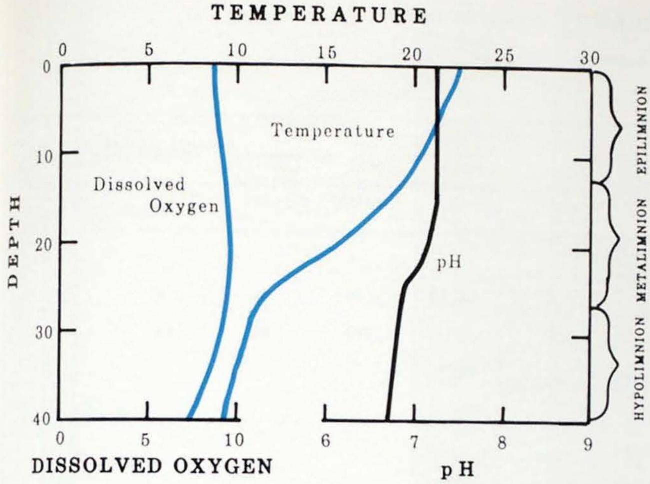
The total amount of water used by 21 principal public supplies serving the basin in 1970 is estimated at more than 29 billion gallons. Roughly half of this was used by customers within the basin. About 70 percent of the total was used for domestic and commercial purposes, an average of 136 gallons per capita per day. The source of water, capacity and type of treatment, and population supplied by these systems is shown in table 28. All surface-water supplies are chlorinated at central distribution points to meet State bacteriological standards. The areas served by principal systems and locations of water sources are shown on plate C.

Although much of the water used in the basin receives some treatment before disposal, the quality of the treated effluent depends on the type of water use and the size, age, and type of the treatment facility. The sewer-service areas and the locations of sewage-treatment facilities are shown on plate C.

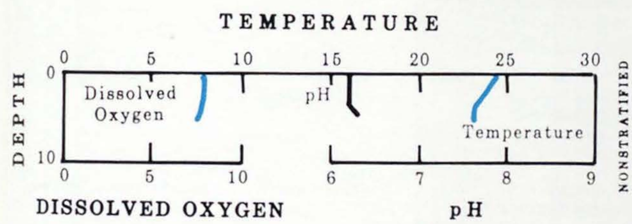
The water utilities listed in table 28 generally supply soft to moderately hard water with low dissolved-solids content. Chemical analyses of samples from 15 of these systems are shown in table 29. The water is of good chemical quality and meets the standards required by the Connecticut Department of Health (Connecticut General Assembly, 1975).

FUTURE USE

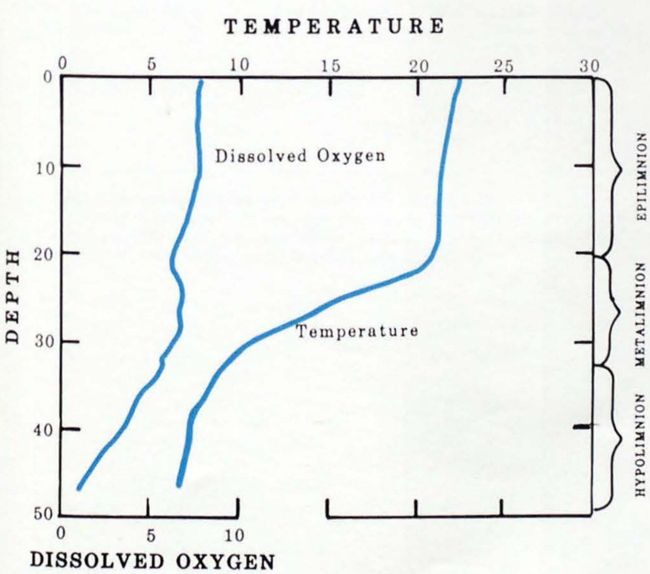
Projections of population and water consumption to the year 2000 have been prepared by the Connecticut Development Commission (1963a, 1963b). Using figures adjusted to 1970 population and water use, the projected water demand for the State for the year 2000 is about 189 billion gallons per year, a 67 percent increase over 1970. If the increase in demand in the Farmington River basin is similar, approximately 18 billion gallons per year will be needed. This projected demand represents only about 7 percent of the average annual runoff for the 1930-60 period of record. This indicates that water needs in the year 2000 can be met by sources in the basin. More ground water will probably be used in the future, and reuse of water will increase.



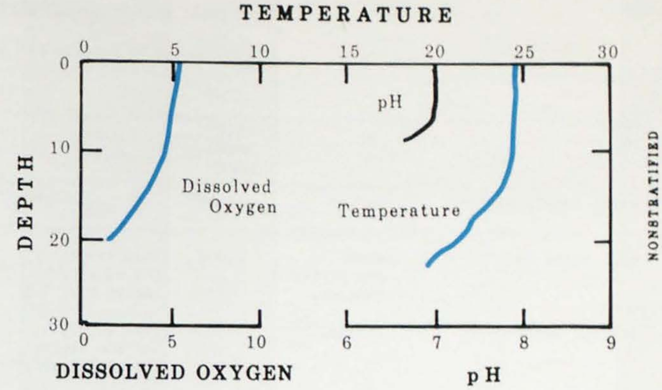
Doolittle Pond
(Norfolk)
June 24, 1953



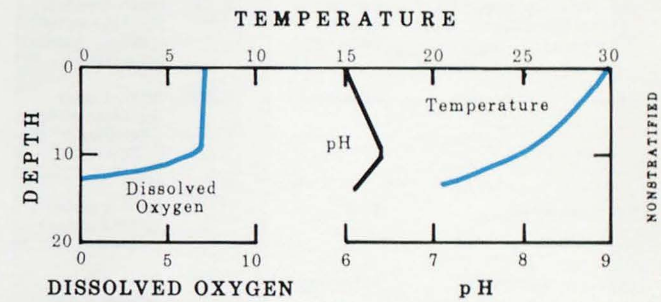
Dunham Mill Pond
(Bristol-Wolcott)
August 16, 1950



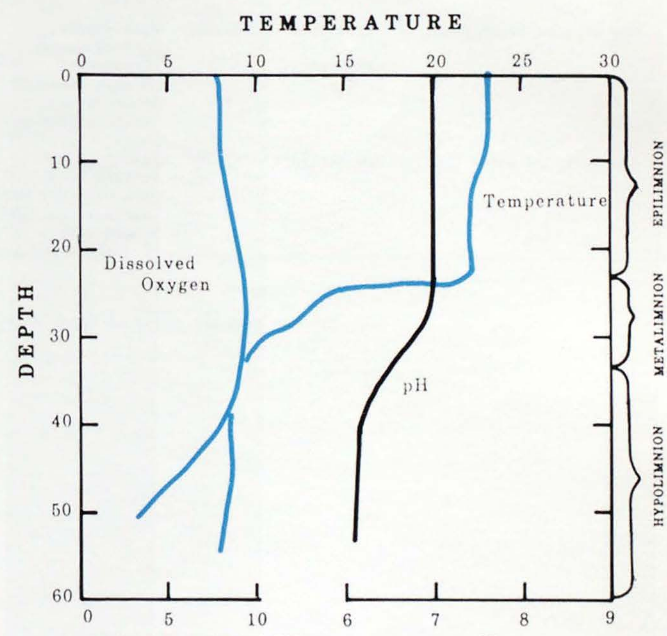
Highland Lake
(Winchester)
August 26, 1976



Hartland Pond
(Hartland)
August 23, 1971



Burr Pond
(Torrington)
August 13, 1940



West Hill Pond
(New Hartford)
August 31, 1970

Figure 53.--Water-quality profiles of lakes and ponds

Table 28.--Principal public water-supply systems serving the basin

[Based on records and estimates from water utilities for 1970]

Water supply system	Towns served	Estimated population served1/	Source2/	Treatment3/	Safe yield (Mgal/d)	Storage capacity (Mgal)	Total use (Mgal)4/	Percent of use: Domestic and commercial	Percent of use: Industrial	Percent of use: Municipal, leakage, etc.
Avon Water Co.	Avon	2,800	Total supply:							
	New Hartford		Ground water:							
	Simsbury		Wells Nos. 1-5	None	1.00	0.40	104	78	8	14
Bristol Water Dept.	Bristol	54,000	Total supply:		7.50		1,980	63	35	2
			Surface water:							
			Bristol reservoir No. 1	Cl,Cc,F, Fl,T		74.7				
			Reservoirs 2-7(Storage)	None		1,140				
			Ground water:							
			Gravel wells Nos. 1,2	Cl,Cc,Fl						
			Mix Street Wells Nos. 3-5	Cl,Cc,Fl						
Chestnut Heights Realty	Suffield	83	Total supply:		.07		1.20	100	0	0
			Ground water:							
			Well	None		.01				
Collinsville Water Co. (Suburban Water Service).	Canton	2,130	Total supply:				70.4	93	0	7
	Avon		Surface water:							
	Burlington		Nepaug Aqueduct	Cl,Cc,St		0				
			Huckleberry Hill Spring	None		0				
Farmington Water Co.	Farmington	3,000	Total supply:				90.2			
			Surface water:							
			Farmington (Wadsworth) Reservoir	Cl,F	.21					
			Nepaug Aqueduct	Cl						
Heritage Woods	Avon	50	Total supply:		0.27			100	0	0
			Ground water:							
			Caisson Well No. 1	Cl,Cc						
Lakeview Apartments	Farmington	500	Total supply:		.14		12.9	100	0	0
			Ground water:							
			Drilled well No. 1	Cl		0				
			Drilled well No. 2 (Emergency)	none		0				
Metropolitan District Commission (Hartford)	Farmington	389,000	Total supply:		82.0		20,700	64	33	3
			Surface water:							
			Nepaug Reservoir	Cl,Cc,Fl		9,665				
			Barkhamsted Reservoir	Cl,Cc,Fl		31,800				
			Reservoirs outside the basin			1,290				
New Britain Water Dept.	Plainville	100,000	Total supply:		14.3		4,510	100	0	0
	Bristol		Surface water:							
	Farmington		Reservoirs	Cl,Cc,F,Fl,T		2,360				
			Nepaug Aqueduct	Cl						
			Ground water:							
			White Bridge wells	Cl,Fl						
New Hartford Water Co.	New Hartford	1,050	Total supply:		.24		79.5	40	52	8
			Surface water:				27.0			
			New Hartford Reservoir	Cl		1.50				
			Barkhamsted Aqueduct	Cl						
			Ground water:				52.5			
			Gravel packed well	None						

Water supply system	Towns served	Estimated population served1/	Source2/	Treatment3/	Safe yield (Mgal/d)	Storage capacity (Mgal)	Total use (Mgal)4/	Percent of use: Domestic and commercial	Percent of use: Industrial	Percent of use: Municipal, leakage, etc.
Plainville Water Co.	Plainville Farmington Bristol	15,500	Total supply:		2.7		644	68	24	8
			Surface Water:				25.4			
			Plainville (Crescent Lake) Reservoir	Cl,Cc,F,T		160.				
			Ground water:			1.20				
			Woodford Wells Nos. 1, 2,4,5	Cl			423			
			Johnson	Cl			195			
			Bristol Water Dept.	Cl,Cc,Fl						
			New Britain Water Dept.	None						
Poets Corner Water Co.	Granby	70	Total Supply:		.04		4.20	100	0	0
			Ground water:							
			Drilled well No. 1	None						
Salmon Brook District	Granby	500	Total supply:		.48		12.5	100	0	0
			Ground water:							
			Gravel packed well No. 1	Cl		.10				
Tariffville Fire District (Suburban Water Service)	Simsbury	1,500	Total supply:		.35		54.8	85	0	15
			Ground water:							
			Gravel packed well No. 1	Cl		.30				
Terryville Water Co.	Plymouth	4,780	Total supply:		.92		176	69	13	18
			Surface water:							
			Reservoir Nos. 1-3	Cl		19.1				
			Ground water:							
			Gravel packed wells Nos. 1,2	Cl						
Unionville Water Co.	Farmington Avon	3,500	Total supply:				236	90	10	0
			Surface water:			1.30				
			Metropolitan District Commission (Nepaug Aqueduct)	Cl						
Village Water Co. of of New Hartford.	New Hartford	300	Total supply:		.90		8.2	100	0	0
			Surface water:							
			Village Water Co. Reservoir	Cl						
Village Water Co. of Simsbury.	Simsbury	10,410	Total supply:		2.12		341			
			Surface water:							
			Simsbury (Tuller)	Cl,Cc,F,T		56.9				
			Ground water:							
			Gravel packed wells Nos. 1-4	Cl,Cc		.86				
Wells Acres (Farmington Water Co.	Farmington	250	Total supply:		.02		5.10	100	0	0
			Ground water							
			Drilled wells	None						
West Hill Lake Water Association	New Hartford	460	Total supply:		.04			100	0	0
			Ground water:							
			Drilled well No. 2	None						
Winsted Water Dept.	Winchester	8,300	Total supply:		2.62		707			
			Surface water:							
			Crystal Lake Reservoir	Cl		1,060				
			Rugg Brook Reservoir	Cl		225				

1/ Includes some population outside the basin.
2/ Includes some sources outside the basin and emergency supplies.
3/ CL, chlorination; Cc, corrosion control; F, filtration; Fl, flouridation; St, strainers; T, taste and odor control.
4/ Includes some water used outside the basin.

Table 29.-- Chemical analyses of water from principal public-water supply systems

[Concentrations of chemical constituents in milligrams per liter. Analyses by the U.S. Geological Survey]

Water-supply system 1/	Date of collection	Source of water	Site no. 1/	Silica (SiO_2)	Iron (Fe)	Man-gan-ese (Mn)	Cal-cium (Ca)	Mag-ne-si-um (Mg)	So-dium (Na)	Po-tas-sium (K)	Bi-car-bon-ate (HCO_3)	Car-bon diox-ide (CO_2)	Sul-fate (SO_4)	Chlor-ide (Cl)
Bristol Water Dept.	11-19-71	Bristol Reservoir No. 1	01188450	5.8	0.12	0.04	3.0	1.1	3.4	0.7	8	--	9.3	5.5
	11-16-71	Well No. 1	BS 148	18	.11	.00	20	4.6	11	1.3	34	2.7	31	20
	11-16-71	Well No. 3	BS 225	13	.04	.00	20	2.9	12	1.3	53	2.1	18	19
Chestnut Heights Realty, Suffield		Well	SU 228	15	.08	.00	30	2.1	3.1	1.1	65	3.3	13	2.7
Farmington Water Co.	12-2-71	Farmington (Wadsworth) Reservoir	01189028	5.8	.14	.00	32	6.6	8.8	.6	71	--	26	32
Heritage Woods, Avon	11-19-71	Caisson Well No. 1	A 290	15	.01	.00	17	4.8	8.1	1.7	50	2.0	17	13
Lakeview Apartments, Farmington	11-29-71	Well No. 1	F 237	13	.05	.00	49	1.7	6.3	.7	122	4.9	19	16
Metropolitan District Commission, Hartford2/	12-3-71	Barkhamsted Reservoir	01187500	3.2	.10	.16	3.0	.9	2.2	.6	6	--	9.2	4.0
	12-3-71	Nepaug Reservoir	01187870	6.8	.36	.06	3.5	1.4	3.6	1.0	10	--	10	6.9
New Hartford Water Co.	11-17-71	New Hartford Reservoir3/	01187150	7.7	.28	.02	3.0	1.0	2.6	.7	8	--	9.4	3.8
	11-30-71	Well	NH 100	9.2	.06	.00	3.0	1.0	2.7	.7	8	2.2	6.3	3.5
Plainville Water Co.	4-28-70	Johnson Ave. Well	PV 63	14	.03	.00	35	3.4	6.7	.3	86	--	15	15
Salmon Brook District, Granby	12-9-71	Well	GR 66	15	.10	.02	26	2.8	5.3	.6	58	2.9	15	8.6
Tariffville Fire District, Simsbury	11-24-71	Well	SI 37	12	.06	.02	58	11	7.7	1.0	67	3.4	140	5.4
Terryville Water Co., Plymouth	11-4-71	Well	PM 1	10	.10	.00	6.5	2.0	8.5	1.5	16	2.6	12	13
Village Water Co., New Hartford	11-17-71	Village Water Co. Reservoir	01187160	12	.37	.00	6.0	2.0	5.1	.9	16	--	11	8.7
Village Water Co., Simsbury	12-8-71	Simsbury (Tuller) Reservoir	01189170	5.2	.94	.15	6.0	1.7	4.0	.8	16	--	10	9.1
	12-14-71	Well	SI 230	12	.07	.00	20	6			43	8.7	12	19
Wells Acres, (Farmington Water Co.) Farmington	12-2-71	Well	F 234	14	.05	.02	21	1.			60	2.4	13	16
Winsted Water Dept.	11-18-71	Crystal Lake Reservoir	01186140	3.2	.13	.03	4.1	1.3	2.3	.8	10	--	10	4.2
Drinking Water Standards4/				--	--	--	--	--	20	--	--	--	--	250

1/ Locations are on plate A
2/ Supplies water to New Hartford and Unionville
3/ Reservoir samples twice, mean values are listed
4/ Connecticut Department of Health (Connecticut General Assembly, 1975)

Table 29.--continued

Fluoride (F)	Phosphate (PO_4)	Nitrate (NO_3)	Dissolved solids (sum of constituents)	Hardness as $CaCO_3$ Ca + Mg	Hardness as $CaCO_3$ Non-carbonate	Specific conductance (micromhos at 25°C)	Temperature (°C)	pH	Color (platinum-cobalt units)	Detergents as MBAS	Alkalinity as $CaCO_3$
0.0	0.02	0.0	33	12	5	48	6.0	6.5	5	0.04	7
.1	--	8.0	131	69	41	200	12.0	7.3	--	--	28
.1	--	5.7	118	62	18	191	12.0	7.6	--	--	43
.1	--	25	124	84	30	186	11.0	7.5	--	--	53
.1	.06	2.2	149	110	49	271	4.0	7.2	10	.04	58
.0	--	7.5	109	62	21	167	15.0	7.6	--	--	41
.1	--	4.9	171	129	29	280	13.0	7.6	--	--	100
.1	.01	.0	26	11	6	41	--	6.6	0	.02	5
.1	.04	.2	39	15	6	57	--	7.0	5	.03	8
.0	.01	.2	32	12	5	43	--	6.6	22	.03	7
.1	--	4.9	36	12	5	46	9.0	6.8	--	--	7
.0	--	13	144	102	31	228	10.5	8.2	--	--	--
.1	--	20	122	76	29	188	10.0	7.5	--	--	48
.2	--	6.2	274	190	135	405	12.0	7.5	--	--	55
.0	--	4.9	66	24	11	103	13.5	7.0	--	--	13
.1	.02	.4	54	23	10	76	3.0	6.8	5	.04	13
.0	.07	.0	45	22	9	74	9.0	6.8	20	.02	13
0	--	4.0	99	54	18	165	9.0	6.9	--	.02	35
0	--	2.2	109	60	11	176	--	7.6	--	--	49
.1	.10	.4	33	16	7	50	7.5	6.4	200	.03	8
2.0	--	44	--	--	--	--	--	6.4-8.5	20	.5	--
--											

DEVELOPMENT OF WATER SUPPLIES

The development of a supply at a particular site should consider the quantity and quality of the water available and the requirements of its intended use. Water is generally available from streams and aquifers throughout the basin, but these sources have limitations that must be properly evaluated prior to development. The limitations commonly require that development plans consider treatment, low-flow augmentation, auxiliary storage, and reuse. The final determination of the suitability and economic practicality of water-supply development at a given site is based on the advantages and limitations of the alternative water sources potentially available.

In the study area, large supplies of water can be obtained only from the larger streams and from stratified-drift aquifers with favorable hydraulic characteristics. Smaller supplies can be obtained from a wide variety of sources and locations including smaller streams, ponds, bedrock, till, and the less favorable stratified-drift aquifers.

LARGE SUPPLIES

Areas in the basin potentially capable of providing supplies of water for industrial, public supply, and other large uses are shown on plate D. The major streams and the stratified-drift aquifers are the only sources capable of yielding large quantities of water for a sustained period. These sources are commonly adjacent and hydraulically interconnected. Major streams are bounded by stratified drift in many places and, where hydraulically continuous with the stratified-drift aquifers, sustain or augment yields from wells. During periods of little or no surface runoff, streamflow is maintained by ground-water runoff from the stratified drift. This relation between streams and stratified-drift aquifers is important because withdrawals from wells during critical dry periods may result in diminished flows in adjacent streams.

SURFACE WATER

Flows of the larger streams equaled or exceeded 90 percent of the time are shown on plate D. These values are an index of surface-water availability from unregulated streams and are approximations of the average yields available from low, run-of-the-river impoundment dams. Only small amounts of surface storage or supplemental ground water would be needed to maintain these amounts continuously during most years. Plate D also shows the storage capacities and locations of selected surface-water reservoirs. In addition to the 90-percent duration-flow figures shown on the plate, developing a particular stream for water supply or effluent dilution requires more detailed information, such as flow duration, low-flow frequency, and storage-required frequency. Methods to determine these characteristics are outlined in the section titled "Surface Water." Usable storage of selected lakes and ponds is summarized in table 10.

If the required quantity is a small fraction of low streamflow, development of a water supply may require only a small impoundment and intake structure. If the required quantity is large, a storage reservoir may be required. Although identifying and evaluating suitable dam sites involves engineering geology, economic, and environmental policy considerations beyond the scope of this report, topography, geology, and population density of the basin indicate that construction of additional large storage reservoirs is impractical in many areas. However, storage capacity of the basin's existing reservoirs (table 28) is probably more than adequate to meet the needs of the basin's population in the year 2000.

GROUND WATER

Sixteen areas underlain by stratified drift are shown on plate D. These have the most favorable characteristics for large-scale development of ground water. The methods that can be used to determine their longterm yields are described in the ground-water section of this report.

SMALL SUPPLIES

Water supplies adequate for homes and small businesses can be obtained from wells almost anywhere in the basin. Under current practices, most wells are completed in bedrock, but in many stratified-drift areas, where the water table is close to land surface, shallow dug or driven wells yield adequate supplies. Most ground water in the basin is suitable for domestic and commercial use without treatment. In some areas, high concentrations of iron and manganese or hardness may require treatment for certain uses. The problems of excessive iron, manganese, and hardness are discussed in detail in the section titled "Quality of Water."

WATER QUALITY AND DEVELOPMENT

Decisions to develop water supplies should consider the intended use of the water because the requirements differ for public, industrial, and agricultural supplies. Although water of poor quality can be treated to meet the minimum standards for any use, the expense involved can make such treatment impractical.

A further consideration is the fact that use of water generally results in deterioration in its quality. The type and degree of the deterioration depend on how the water is used and what treatment it receives before being discharged to the system. Therefore, the quality and quantity of the water that is available, its intended use, and the effect of its use on the system should be taken into account.

Water for public supply in Connecticut must meet standards established by the Connecticut Department of Health (Connecticut General Assembly, 1975). Where some constituents exceed the limits, concentrations can be reduced by dilution or by treatment. Table 29 lists the principal sources of public supply serving the basin, their physical and chemical properties, and standards for drinking water. The chemical quality of these supplies is within the recommended limits.

Requirements for some industries are more stringent than those for drinking water. Such industries may routinely treat water, whereas industries having less strict requirements omit treatment. Table 30 compares the requirements for several industries with the quality of water from various sources in the Farmington River basin.

The chemical quality of most water in the basin in its natural state is satisfactory for a wide variety of uses. In some areas, however, excessive concentrations of iron, manganese, or hardness are present. In addition, some surface waters and contiguous aquifers may at times contain sufficient industrial and municipal wastes to prohibit use of their water for public supply, recreation, and some industrial purposes. To decrease pollution, the State has adopted quality standards for streams under Public Act 57 (Connecticut General Assembly, 1967). Criteria used in the classification of streams can be obtained from the Connecticut Department of Environmental Protection (1977).

Table 30.--Limitations on water quality for industrial use and range of water quality

[Maximum limits or ranges in limits of significant properties and constituents of waters acceptable for industrial uses. Source of data: Water Quality Treatment, American Water Works Association, 1951, p. 66-67, unless otherwise noted. Chemical constituents in milligrams per liter.]

Source	Turbidity (Jackson units)	Color (platinum-cobalt units)	Hardness (as $CaCO_3$)	Alkalinity (as $CaCO_3$)	pH	Total dissolved solids	Calcium (Ca)	Iron (Fe)	Manganese (Mn)	Silica (SiO_2)	Fluoride (F)	Carbonate (CO_3)	Bicarbonate (HCO_3)
Surface Water:													
Reservoirs:	--	0-200	11- 110	5- 58	6.4-7.2	26- 149	3.0- 32	0.10-0.94	0-0.16	3.2-12	0-0.1	0	6- 71
Streams draining areas underlain by:													
Sedimentary bedrock	0-2	1- 35	23- 138	10-123	6.7-7.8	44- 182	7.0- 43	.03- .54	0- .03	5.0-17	0- .1	0	12-150
Crystalline bedrock	0-2	2- 30	7- 82	2- 46	5.2-7.4	20- 199	2.0- 21	.03- .65	0- .35	2.8-15	0- .1	0	2- 56
Ground Water:													
Aquifers:													
Stratified drift	--	--	12- 190	7- 86	6.8-8.3	36- 284	3.0- 58	.01- .65	0- .46	6.9-24	0- .3	0.8-8.7	8-105
Sedimentary bedrock	--	--	0-1252	16-138	7.2-8.4	47-1895	.1-419	.02- .33	0-1.2	8.5-30	0-1.2	.8-4.9	20-168
Crystalline bedrock	--	--	6- 181	7-127	7.0-8.3	45- 328	1.9- 65	.03-2.2	0- .31	7.8-22	0-1.0	.8-2.6	8-155

ABBREVIATIONS

°C	- degrees Celsius
°F	- degrees Fahrenheit
e.s.t.	- Eastern standard time
fig.	- figure
ft	- feet
ft^2	- square feet
ft^3/d	- cubic feet per day
ft^3/s	- cubic feet per second
$(ft^3/s)/mi^2$	- cubic feet per second per square mile
gal/d	- gallons per day
gal/min	- gallons per minute
(gal/min)/ft	- gallons per minute per foot
in	- inches
K	- hydraulic conductivity
$(lb/d)/mi^2$	- pounds per day per square mile
Mgal/d	- million gallons per day
$(Mgal/d)/mi^2$	- million gallons per day per square mile
mg/L	- milligrams per liter
mi	- miles
mi^2	- square miles
mL	- milliliters
mm	- millimeters
p.	- page
pl.	- plate
ppm	- parts per million
ug/L	- micrograms per liter
umho	- micromhos

EQUIVALENTS

°C = (°F - 32) x 0.555

1 ft^3/s - 646,317 gal/d = 0.646317 Mgal/d

1 $(ft^3/s)/mi^2$ = 13.57 inches of runoff per year

1 in of water upon 1 mi^2 = 17.4 million gallons = 2.32 million ft^3

1 Mgal/d = 694 gal/min = 1.547 ft^3/s

1 $(Mgal/d)/mi^2$ - 21.0 inches of runoff per year

1 mg/L = 1 part per million (ppm) for solutions with a density of 1,000 grams per milliliter

1 mm = 0.001 meter = 0.039 in

Hydraulic conductivity (ft/d) x 7.48 = coefficient of permeability in gallons per day per square foot

Transmissivity (ft^2/d) x 7.48 = coefficient of transmissibility in gallons per day per foot

GLOSSARY

Aquifer: A geologic formation, group of formations, or part of a formation that contains sufficient saturated permeable materials to yield significant quantities of water to wells and springs.

Basalt: A fine-grained, dark-colored, igneous rock, commonly called trap rock.

Base flow: The portion of streamflow derived from ground-water discharge.

Bedrock: Solid rock, commonly called "ledge," that forms the Earth's crust. It is locally exposed at the surface but more commonly is buried beneath a few inches to more than 300 feet of unconsolidated deposits.

Carbonate rock: A rock consisting chiefly of carbonate minerals, such as limestone or dolomite.

Casing of wells: Any construction material that keeps unconsolidated earth materials and water from entering a well.

Climatic year: A continuous 12-month period, April 1 through March 31, during which a complete annual streamflow cycle takes place from high flow to low and back to high flow. It is designated by the calendar year in which it begins, and that includes 9 of its 12 months.

Coefficient of permeability: The rate of flow of water, in gallons per day, through a cross sectional area of 1 square foot of a saturated material under a hydraulic gradient of 1 foot per foot at a temperature of 16°C. Replaced by the U.S. Geological Survey with a term--hydraulic conductivity (in this Glossary). Also, see equivalent values in preceding section.

Coliform bacteria, total: A particular group of bacteria that are used as indicators of possible sewage pollution. They are characterized as aerobic or facultative anaerobic, gram-negative, nonspore-forming rod-shaped bacteria which ferment lactose with gas formation within 48 hours at 35°C. In the laboratory, these bacteria are defined as the organisms which produce colonies within 24 hours when incubated at 35°C + 1.0°C on M-Endo medium (nutrient medium for bacterial growth). Their concentrations are expressed as numbers of colonies per 100 mL of sample.

Coefficient of transmissibility: The rate of flow of water at the prevailing water temperature, in gallons per day, through a vertical strip of an aquifer 1 foot wide extending the full thickness of the aquifer under a hydraulic gradient of 1 foot per foot. It is the product of the field coefficient of permeability and saturated thickness of an aquifer. Replaced by the U.S. Geological Survey with a new term "transmissivity" (in this Glossary). Also, see equivalent values in preceding section.

Cone of depression: A depression produced in a water table or other potentiometric surface by the withdrawal of water from an aquifer; in cross section, shaped like an inverted cone with its apex at the pumping wells.

Crystalline: Pertaining to igneous and metamorphic rocks; the most common types in the basin are basalt, diabase, granite, gneiss, schist, and phyllite.

Diabase: A medium- to coarse-grained, dark igneous rock, similar to basalt.

Direct runoff: Water that moves over the land surface directly to streams or lakes shortly after rainfall or snowmelt.

Drainage basin, drainage area: The whole area or entire land surface that gathers water and contributes it ultimately to a particular stream channel, lake, reservoir, or other body of water.

Drawdown: The lowering of the water table or potentiometric surface caused by the withdrawal of water from an aquifer by pumping; equal to the difference between the static water level and the pumping water level.

Epilimnion: The top layer of water in a thermally stratified lake, pond, or reservoir; it is between the surface and the metalimnion.

Evapotranspiration: Loss of water to the atmosphere by direct evaporation from water surfaces and moist soil combined with transpiration from living plants.

Flow duration, of a stream: The percentage of time during which specified daily discharges have been equaled or exceeded within a given time period.

Fracture: A break or opening in bedrock along which water may move.

Gaging station: A site on a stream, canal, lake, or reservoir for systematic observations of gage height or discharge.

Gneiss: A coarse-grained metamorphic rock with alternating bands of granular and micaceous minerals.

Granite: A coarse-grained, light-colored, igneous rock.

Gravel: Unconsolidated rock debris composed principally of particles larger than 2 mm in diameter.

Gravel pack: A lining or envelope of gravel placed around the outside of a well screen to increase well efficiency and yield.

Ground water: Water in the saturated zone.

Ground-water discharge: The discharge of water from the saturated zone by (1) natural processes such as ground-water runoff and ground-water evapotranspiration and (2) discharge through wells and other man-made structures.

Ground-water divide: A hypothetical line on a water table on each side of which the water table slopes downward in a direction away from the line. In the vertical dimension, a plane across which there is no ground-water flow.

Ground-water evapotranspiration: Ground-water discharge into the atmosphere in the gaseous state either by direct evaporation or by the transpiration of plants.

Ground-water outflow: The sum of ground-water runoff and underflow; it includes all natural ground-water discharge from a drainage area exclusive of ground-water evapotranspiration.

Ground-water recharge: The addition of water to the saturated zone by (1) natural processes, such as infiltration of precipitation and (2) artificial processes such as induced infiltration, recharge through basins, sumps, and other manmade structures.

Ground-water storage: The quantity of water in the saturated zone.

Ground-water runoff: Ground water that has discharged into stream channels by seepage from saturated earth materials.

Head, static: The height of the surface of a water column above a standard datum that can be supported by the static pressure at a given point.

Hydraulic boundary: A physical feature that limits the areal extent of an aquifer. The two common types of boundaries are termed impermeable-barrier boundaries and line-source boundaries.

Hydraulic conductivity (K): A measure of the ability of a porous medium to transmit a fluid. The material has a hydraulic conductivity of unit length per unit time if it will transmit, in unit time, a unit volume of water at the prevailing kinematic viscosity through a cross section of unit area, measured at right angles to the direction of flow, under a hydraulic gradient of unit change in head over unit length of flow path. In previous reports of this series, hydraulic conductivity is expressed as coefficient of permeability

$$K = \frac{\text{gallons}}{\text{day ft}^2\text{ft/ft}} = \frac{\text{ft}^3}{\text{day ft}^2\text{ft/ft}} = \text{ft/day}$$

Hydraulic gradient: The change in static head per unit of distance in a given direction. If not specified, the direction is generally understood to be that of the maximum rate of decrease in head.

Hypolimnion: The dense layer of water in a thermally stratified lake, pond, or reservoir; it is beneath the metalimnion.

Igneous: Descriptive term for rocks formed by solidification of molten or partially molten magma, such as basalt or granite.

Impermeable-barrier boundary: The contact between an aquifer and adjacent impermeable material that limits the areal extent of the aquifer. For example, the termination of permeable valley-fill deposits of sand and gravel against the bedrock valley walls. Its significant hydraulic feature is that ideally no ground water flows across it.

Inches of water: Water volume expressed as the depth, in inches, to which it would accumulate if spread evenly over a particular area.

Induced infiltration: The process by which water infiltrates an aquifer from an adjacent surface-water body in response to pumping.

Induced recharge: The amount of water entering an aquifer from an adjacent surface-water body by the process of induced infiltration.

Kinematic viscosity: The ratio of the viscosity of a fluid to its density.

MBAS (Methylene blue active substance): A measure of apparent detergents. This determination depends on the formation of a blue color when methylene blue dye reacts with synthetic detergent compounds.

Mean (arithmetic): The sum of the individual values of a set, divided by their total number. Also referred to as the "average."

Median: The middle value in a set of values arranged according to rank. It is an average of position, whereas the mean is an average of quantity.

Metamorphic: Descriptive term for rocks such as gneiss and schist which have formed, in the solid state, from other rocks.

Overburden: All the various unconsolidated materials that overlie the bedrock.

Partial penetration: A condition in which a well is not open to the full saturated thickness of an aquifer.

Phyllite: A fine-grained, metamorphic rock, similar to schist, often having a silky appearance.

Porosity: The property of a rock or unconsolidated material of containing voids or open spaces; it may be expressed quantitatively as the ratio of the volume of its open spaces to its total volume.

Precipitation: The discharge of water from the atmosphere, either in a liquid or solid state.

Recurrence interval: The average interval of time between extremes of streamflow such as floods or droughts, that will at least equal in severity a particular extreme value over a period of many years. Frequency, a related term, refers to the average number of such extremes during the same period. The date of a drought or flood of a given magnitude cannot be predicted, but the probable number of such events during a reasonably long period of time may be estimated within reasonable limits of accuracy.

Reference period: A period of time chosen so that comparable data may be collected or computed for that period. Streamflow data in this report are based on climatic years 1930 to 1959 and water years 1931 to 1960.

Sandstone: A fine to medium-grained sedimentary rock composed principally of quartz and feldspar grains.

Saturated thickness: Thickness of an aquifer below the water table.

Saturated zone: The subsurface zone in which all open spaces are filled with water. The water table is the upper limit of this zone. Water in the saturated zone is under pressure greater than atmospheric.

Schist: A metamorphic rock with subparallel orientation of the visible micaceous minerals, which dominate its composition.

Sediment: Fragmental material that originates from weathering of rocks. It can be transported by, suspended in, or deposited by water.

Sedimentary: Descriptive term for rock formed of sediment such as sandstone or shale.

Shale: A fine-grained, laminated, sedimentary rock composed principally of clay-sized particles.

Specific capacity, of a well: The rate of discharge of water divided by the corresponding drawdown of the water level in the well (gallons per minute per foot).

Specific yield: The ratio of the volume of water which a saturated rock or soil will yield by gravity, to its own volume.

Storage coefficient(s): The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head. In an unconfined aquifer, the storage coefficient is virtually equal to the specific yield.

Stratified drift: A predominantly sorted sediment laid down by or in meltwater from a glacier; includes sand, gravel, silt, and clay arranged in layers.

Thermocline, metalimnion: The middle zone in a stratified lake, pond, or reservoir, between the epilimnion and the hypolimnion, in which the change in temperature with depth exceeds 1°C per meter.

Till: A predominantly nonsorted, nonstratified sediment deposited directly by a glacier and composed of boulders, gravel, sand, silt, and clay mixed in various proportions.

Transmissivity (T): The rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of aquifer under a unit hydraulic gradient. Equal to the average hydraulic conductivity times the saturated thickness. In some previous reports of this series, transmissivity is expressed as the coefficient of transmissibility.

Transpiration: The process whereby plants release water vapor to the atmosphere.

Unconfined aquifer (water-table aquifer): One in which the upper surface of the saturated zone, the water table, is at atmospheric pressure and is free to rise and fall.

Unconsolidated: Loose, not firmly cemented or interlocked; for example, sand in contrast to sandstone.

Underflow: The downstream flow of water through the permeable deposits that underlie a stream.

Uniformity coefficient: An expression of the variability in sizes of grains that constitute a granular material. It is the ratio d_{60}/d_{10}, where d_{60} is the particle diameter corresponding to 60 percent finer on the grain-size distribution curve, and d_{10} is the particle diameter corresponding to 10 percent finer on the same curve.

Unsaturated zone: The zone between the water table and the land surface in which all the open spaces are not completely filled with water and the water is under less than atmospheric pressure.

Water table: The upper surface of the saturated zone.

Water year: A continuous 12-month period, October 1 through September 30, during which a complete streamflow cycle takes place from low to high flow and back to low flow. It is designated by the calendar year in which it ends, and that includes 9 of its 12 months.

Wentworth grade scale: A grain-size classification system based on particle diameter, the divisions of which are as follows: boulders, greater than 256 mm; cobbles, 256 to 64 mm; pebbles, 64 to 4 mm; very fine gravel, 4 to 2 mm; very coarse sand, 2 to 1 mm; coarse sand, 1 to 0.5 mm; medium sand, 0.5 to 0.25 mm; fine sand, 0.25 to 0.125 mm; very fine sand, 0.125 to 0.063 mm; silt, 0.063 to 0.004 mm; clay, smaller than 0.004 mm. This grade scale is used for sediment descriptions in this report.

SELECTED REFERENCES

American Water Works Association, 1951, Manual on water quality and treatment, 2nd edition: Lancaster, Pa., Lancaster Press, Inc., 451 p.

Baker, J. A., Healy, H. G., and Hackett, O. M., 1964, Geology and ground-water conditions in the Wilminton-Reading area, Massachusetts: U.S. Geological Survey Water-Supply Paper 1694, 80 p.

Baldwin, H. L., and McGuinness, C. L., 1963, A primer on ground water: U.S. Geological Survey, 26 p.

Barrett, Earl, and Brodin, Gunnar, 1955, The acidity of Scandinavian precipitation: Tellus, v. 7, p. 251-257.

Bentall, Ray, compiler, 1963, Methods of determining permeability, transmissibility and drawdown: U.S. Geological Survey Water-Supply Paper 1536-I, p. 243-341.

Bigwood, B. L., and Thomas, M. P., 1955, A flood-flow formula for Connecticut: U.S. Geological Survey Circular 365, 16 p.

Bingham, J. W., Paine, F. D., and Weiss, L. A., 1975, Hydrogeologic data for the lower Connecticut River basin, Connecticut: Connecticut Water Resources Bulletin 30, 59 p.

Bogart, D. B., 1960, Floods of August-October 1955, New England to North Carolina: U.S. Geological Survey Water-Supply Paper 1420, 854 p.

Brumbach, J. J., 1965, The climate of Connecticut: Connecticut Geological and Natural History Survey Bulletin 99, 215 p.

Butler, S. S., 1957, Engineering hydrology: Englewood Cliffs, N.J., Prentice-Hall, p. 157-165.

Cervione, M. A., Jr., Grossman, I. G., and Thomas, C. E., Jr., 1968, Hydrogeologic data for the lower Thames and southeastern coastal river basins, Connecticut: Connecticut Water Resources Bulletin 16, 65 p.

Cervione, M. A., Jr., Mazzaferro, D. L., and Melvin, R. L., 1972, Water resources inventory of Connecticut, part 6, upper Housatonic River basin: Connecticut Water Resources Bulletin 21, 84 p.

Colton, R. B., 1960, Surficial geology of the Windsor Locks quadrangle, Connecticut: U.S. Geological Survey Geologic Quadrangle Map GQ-137.

_____1971, Surficial geology of the Torrington quadrangle, Connecticut: U.S. Geological Survey Geologic Quadrangle Map GQ-939.

Colton, R. B., and Hartshorn, J. H., 1966, Bedrock geologic map of the West Springfield quadrangle, Massachusetts and Connecticut: U.S. Geological Survey Geologic Quadrangle Map GQ-537.

Colton, R. B., and Hartshorn, J. H., 1970, Surficial geologic map of the West Springfield quadrangle, Massachusetts and Connecticut: U.S. Geological Survey Geologic Quadrangle Map GQ-892.

Comley, H. H., 1945, Cyanosis in infants caused by nitrates in well waters: American Medical Association Journal, v. 129, p. 112-116.

Connecticut Board of Fisheries and Game, 1959, A fishery survey of the lakes and ponds of Connecticut: Connecticut Board of Fisheries and Game Report 1, 395 p.

Connecticut Department of Environmental Protection, 1977, Connecticut water-quality standards and classifications: Water Compliance Unit report dated September 26, 1977, 90 p.

_____1980, Connecticut water-quality standards and criteria: Water Compliance Unit report dated September 9, 1980, 28 p.

Connecticut Department of Finance and Control, 1970, Location of existing sanitary and water-related facilities, services and uses: Connecticut Water Resources Planning Project, 115 p.

Connecticut Department of Health, 1936, Analyses of Connecticut public water supplies.

_____1941, Analyses of Connecticut public water supplies.

_____1946, Analyses of Connecticut public water supplies.

_____1964, Public water-supply information: Connecticut Department of Health, 28. p.

_____1966, Sewage disposal in Connecticut, Connecticut Health Bulletin 80, 25 p.

_____1971, Analyses of Connecticut public water supplies.

Connecticut Development Commission, 1962, Population: Connecticut Interregional Planning Program Technical Report 131, 105 p.

_____1963a, Community services, part 1: Connecticut Interregional Planning Program Technical Report 150, 103 p.

_____1963b, Water, a resource inventory: Connecticut Interregional Planning Program Technical Report 124, 92 p.

Connecticut General Assembly, 1967, Public Act No. 57 of the 1967 session.

____1975, Standards for quality of public drinking water: Public Act No. 75-513, section 19-13-B102.

Connecticut Public Utilities Commission, 1972, Sixtieth annual report: Connecticut Public Utilities Commission, 320 p.

Cushman, R. V., 1964, Ground-water resources of north-central Connecticut: U.S. Geological Survey Water-Supply Paper 1752, 96 p.

Cushman, R. V., Allen, W. B., and Pree, H. L., Jr., 1953, Geologic factors affecting the yield of rock wells in southern New England: New England Water Works Association Journal, v. 67, no. 2, p. 77-95.

Durfor, C. N., and Becker, Edith, 1964, Public water supplies of the 100 largest cities in the United States, 1962: U.S. Geological Survey Water-Supply Paper 1812, 364 p.

Durum, W. H., and Haffty, Joesph, 1963, Implications of the minor element content of some major streams of the world: Geochimica et Cosmochimica Acta, v. 27 p. 1-11.

Durum, W. H., Hem, J. D., and Heidel, S. G., 1971, Reconnaissance of selected minor elements in surface waters of the United States, October 1970: U.S. Geological Survey Circular 643, 49 p.

Duxbury, A. C., undated, (1964?), A hydrographic survey of New Haven harbor, 1962-63: Connecticut Water Resources Bulletin 3A, 18 p. appendix, 86 p.

Ellis, E. E., 1909, A study of the occurrence of water in crystaline rocks, in Gregory, H.E., Underground water resources of Connecticut: U.S. Geological Survey Water-Supply Paper 232, p. 54-103.

Ferris, J. G., 1942, Cooperative ground-water investigations in Connecticut: New England Water Works Association Journal, v. 56, no. 2, p. 157-165.

Ferris, J. G., Knowles, D. B., Brown, R. H., and Stallman, R. W., 1962, Theory of aquifer tests: U.S. Geological Survey Water-Supply Paper 1536-E, p. 69-174.

Flint, R. F., 1930, The glacial geology of Connecticut: Connecticut Geological and Natural History Survey Bulletin 47, 294 p.

Gary, M., McAfee, R., Jr., and Wolf, C. L., editors, 1972, Glossary of geology: American Geological Institute, Washington, D.C., 805 p.

Gonthier, J. B ., Johnston, H. E., and Malmberg, G. T., 1974, Availability of ground water in the lower Pawcatuck River basin, Rhode Island: U.S. Geological Survey Water-Supply Paper 2033, 40 p.

Gray, D. M., editor, 1970, Handbook on the principles of hydrology: Port Washington, N.Y., Water Information Center, 13 sections.

Green, A. R., 1964, Magnitude and frequency of floods in the United States, part 1-A, North Atlantic slope basins, Maine to Connecticut: U.S. Geological Survey Water-Supply Paper 1671, p. 2-5, 238-254.

Grossman, I. G., and Wilson, W. E., 1970, Hydrogeologic data for the lower Housatonic River basin, Connecticut: Connecticut Water Resources Bulletin 20, 50 p.

Grover, N. C., 1937, The floods of March 1936, part 1, New England rivers: U.S. Geological Survey Water-Supply Paper 798, 466 p.

Haeni, F. P., 1978, Computer modeling of ground-water availability in the Pootatuck River valley, Newtown, Connecticut, with a section on Quality of Water by E. H. Handman: U.S. Geological Survey Water Resources Investigations Report 78-77, 64 p.

Haeni, F. P., and Anderson, H. R., 1980, Hydrogeologic data for south-central Connecticut: Connecticut Water Resources Bulletin 32, 43 p.

Harmeson, R.H., and Schnepper, V.M., 1965, Temperature of surface water in Illinois: Illinois State Water Survey Publication 49, 45 p.

Heath, R. C., and Trainer, F. W., 1968, Introduction to ground-water hydrology: New York, John Wiley, 284 p.

Hem, J. D., 1970, Study and interpretation of the chemical characteristics of natural water (2nd ed.): U.S. Geological Survey Water-Supply Paper 1473, 363 p.

Hopkins, H. T., and Handman, E. H., 1975, Hydrogeologic data of the Farmington River basin, Connecticut: Connecticut Water Resources Bulletin 28, 49 p.

Jackson, D. D., 1905, The normal distribution of chlorine in the natural waters of New York and New England: U.S. Geological Survey Water-Supply Paper 144, 31 p.

Jacob, C. E., 1944, Notes on determining permeability by pumping tests under water-table conditions: U.S. Geological Survey Open-File Report.

Johnson, A. I., 1967, Specific yield--compilation of specific yields for various materials: U.S. Geological Survey Water-Supply Paper 1662-D, 74 p.

Johnson, E. E., 1966, Ground water and wells: St. Paul, Minn., Edward E. Johnson, Inc., 440 p.

Knox, C. E., and Nordenson, T. J., 1955, Average annual runoff and precipitation in the New England-New York area: U.S. Geological Survey Hydrologic Investigation Atlas HA-7.

Krumbein, W. C., and Monk, G. D., 1942, Permeability as a function of the size parameters of unconsolidated sand: American Institute of Mining and Metallurgical Engineers Technical Publication 1492.

Krynine, P. D., 1950, Petrology, stratigraphy and origin of the Triassic sedimentary rocks of Connecticut: Connecticut Geological and Natural History Survey Bulletin 73, 248 p.

La Sala, A. M.,Jr., 1964, Geology and ground-water resources of the Bristol-Plainville-Southington area, Connecticut: U.S. Geological Survey Water-Supply Paper 1578, 70 p.

Leopold, L. B., and Langbein, W. B., 1960, A primer on water: U.S. Geological Survey, 50 p.

Lohman, S. W., 1979, Ground-water hydraulics: U.S. Geological Survey Professional Paper 708, 70 p.

Lohman, S. W., and others, 1972, Definitions of selected ground-water terms--revisions and conceptual refinements: U.S. Geological Survey Water-Supply Paper 1988, 21 p.

Lohr, E. W., and Love, S. K., 1954, The industrial utility of public water supplies in the United States, 1952, pt. 1, States east of the Mississippi River: U.S. Geological Survey Water-Supply Paper 1299, 639 p.

Markowitz, E. M., 1971, The chance a flood will be exceeded in a period of years: American Water Resources Association Bulletin, v. 7, no. 1, p. 40-53.

Martin, C. W., 1970, The bedrock geology of the Torrington quadrangle: Connecticut Geological and Natural History Survey Quadrangle Report 25, 53 p.

Masch, F. D., and Denny, K. J., 1966, Grain size distribution and its effect on the permeability of unconsolidated sands: Water Resources Research, v. 2, no. 4, p. 665-677.

Mazzaferro, D. L., 1973, Hydrogeologic data for the Quinnipiac River basin, Connecticut: Connecticut Water Resources Bulletin 26, 54 p.

_____1980, Ground-water availability and water quality in Farmington, Connecticut: U.S. Geological Survey Water-Resources Investigations Open-File Report 80-751, 57 p.

Mazzaferro, D. L., Handman, E. H., and Thomas, M. P., 1979, Water resources inventory of Connecticut, part 8, Quinnipiac River basin: Connecticut Water Resources Bulletin 27, 88 p.

McKee, J. E., and Wolf, H. W., 1963, Water quality criteria, 2nd edition: California Water Quality Control Board Publication 3-A, 548 p.

Meinzer, O. E., and Stearns, N. D., 1929, A study of ground water in the Pomperaug basin, Connecticut: U.S. Geological Survey Water-Supply Paper 597-B, 146 p.

Melvin, R. L., 1970, Hydrogeologic data for the upper Housatonic River basin, Connecticut: Connecticut Water Resources Bulletin 22, 33 p., 1 pl.

Morris, D. A., and Johnson, A. I., 1967, Summary of hydrologic and physical properties of rock and soil materials, as analyzed by the hydrologic laboratory of the U.S. Geological Survey 1948-60: U.S. Geological Survey Water-Supply Paper 1839-D, 42 p.

Murray, C. R., and Reeves, E. B., 1972, Estimated use of water in the United States in 1970: U.S. Geological Survey Circular 676, 37 p.

Muss, D. L., 1962, Relationship between water quality and deaths from cardiovascular disease: American Water Works Association Journal, v. 54, p. 1371-1378.

National Academy of Sciences and National Academy of Engineering, 1973 [1974], Water Quality Criteria, 1972, Washington, D.C., U.S. Government Printing Office, 594 p.

New England River Basins Commission, 1975, 1975 assessment of water and related land resources: Draft, August, 1975, processed report.

Norvell, W. A., and Frink, C. R., 1975, Water chemistry and fertility of twenty-three Connecticut Lakes: Connecticut Agricultural Experiment Station Bulletin 759, 45 p.

Parizek, R. R., 1971, Impact of highways on the hydrologic environment, in Coates, D. R., Environmental Geomorphology: Binghamton, N.Y., p. 151-199.

Paulsen, C. G., Bigwood, B. L., Harrington, A. W., Hartwell, O. W., and Kinnison, H. B., 1940, Hurricane floods of September 1938: U.S. Geological Survey Water-Supply Paper 867, 562 p.

Pauszek, F. H., 1961, Chemical and physical quality of water resources in Connecticut, 1955-58, progress report: Connecticut Water Resources Bulletin 1, 79 p.

Pluhowski, E. J., 1970, Urbanization and its effect on the temperature of streams on Long Island, N.Y.: U.S. Geological Survey Professional Paper 627-D, 110 p.

Pluhowski, E. J., and Kantrowitz, I. H., 1964, Hydrology of the Babylon-Islip area, Suffolk County, Long Island, New York: U.S. Geological Survey Water-Supply Paper 1768, 119 p.

Prickett, T. A., 1965, Type curve solution to aquifer tests under water-table conditions: Ground Water, v. 3, no. 3, p. 5-17.

Prill, R. C., Johnson, A. I., and Morris, D. A., 1965, Specific yield--laboratory experiments showing the effect of time on column drainage: U.S. Geological Survey Water-Supply Paper 1662-B, 55 p.

Randall, A. D., 1964, Geology and ground water in the Farmington-Granby area Connecticut: U.S. Geological Survey Water-Supply Paper 1661, 129 p.

____1970, Surficial geologic map of the Tariffville quadrangle, Connecticut-Massachusetts: U.S. Geological Survey Geologic Quadrangle Map GQ-798.

Randall, A. D., Thomas, M. P., Thomas, C. E., Jr., and Baker, J. A., 1966, Water resources inventory of Connecticut, part 1, Quinebaug River basin: Connecticut Water Resources Bulletin 8, 102 p.

Riggs, H. C., 1968, Frequency Curves: U.S. Geological Survey Techniques of Water-Rsources Investigations, Book 4, Chapter A2, p. 12.

Riggs, H. C., and Hardison, C. H., 1973, Storage analyses for water supply: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 4, Chapter B2, 20 p.

Rodgers, John, Cameron, E. N., Gates, R. M., and Reuben, J. R., Jr., 1956, Preliminary geological map of Connecticut: Connecticut Geological and Natural History Survey.

Rodgers, John, Gates, R. M., and Rosenfeld, J. L., 1959, Explanatory text for preliminary geological map of Connecticut, 1956: Connecticut Geological and Natural History Survey Bulletin 84, 64 p.

Rorabaugh, M. I., 1951, Streambed percolation in development of water supplies: International Association of Science and Hydrology, General Assembly of Brussel, vol. 2, Publication 33.

Rose, H. G., and Smith, H. F., 1957, A method for determining permeability and specific capacity from effective grain size: Water Well Journal, vol. 11, no. 3, p. 10-11.

Ryder, R. B., Cervione, M. A., Jr., and Thomas, C. E., Jr., 1970, Water resources inventory of Connecticut, part 4, southwestern coastal river basins: Connecticut Water Resources Bulletin 17, 54 p.

Ryder, R. B., and Weiss, L. A., 1971, Hydrogeologic data for the upper Connecticut River basin, Connecticut: Connecticut Water Resources Bulletin 25, 54 p.

Ryder, R. B., Thomas, M. P., and Weiss, L. A., 1981, Water resources inventory of Connecticut, part 7, upper Connecticut River basin: Connecticut Water Resources Bulletin 24, 78 p.

Sammel, E. A., Baker, J. A., and Brackley, R. A., 1966, Water resources of the Ipswich River basin, Massachusetts: U.S. Geological Survey Water-Supply Paper 1826, 83 p.

Sartor, J. D., and Boyd, G. B., 1972, Water pollution aspects of street surface contaminants: Environmental Protection Technology Series EPA-R2-72-081.

Schicht, R. J., and Walton, W. C., 1961, Hydrologic budgets for three small watersheds in Illinois: Illinois State Water Survey Report of Investigations 40, 40 p.

Schnabel, R. W., 1960, Bedrock geology of the Avon quadrangle, Connecticut: U.S. Geological Survey Geologic Quadrangle Map GQ-134.

____1962, Surficial geology of the Avon quadrangle, Connecticut: U.S. Geological Survey Geologic Quadrangle Map GQ-147.

____1970, Surficial geology of the Southwick quadrangle, Massachusetts: U.S. Geological Survey Geologic Quadrangle Map GQ-891.

____1974, Bedrock geology of the Southwick quadrangle, Massachusetts: U.S. Geological Survey Geologic Quadrangle Map GQ-117.

____1975, Geology of the New Hartford quadrangle, Connecticut: U.S. Geological Survey Geologic Quadrangle Map GQ-1257.

Schnabel, R. W., and Eric, J. H., 1965, Bedrock geology of the Tariffville quadrangle, Connecticut: U.S. Geological Survey Geologic Quadrangle Map GQ-370.

____1964, Bedrock geology of the Windsor Locks quadrangle, Connecticut: U.S. Geological Survey Geologic Quadrangle Map GQ-388.

Searcy, J. K., 1959, Flow-duration curves: Manual of Hydrology, pt. 2, low-flow techniques: U.S. Geological Survey Water-Supply Paper 1542-A, 33 p.

Simpson, H. E., 1959, Surficial geology of the New Britain quadrangle, Connecticut: U.S. Geological Survey Geologic Quadrangle Map GQ-119.

____1961, Surficial geology of the Bristol quadrangle, Connecticut: U.S. Geological Survey Geologic Quadrangle Map GQ-145.

____1966, The bedrock geology of the New Britain quadrangle, Connecticut: U.S. Geological Survey Geologic Quadrangle Map GQ-494.

Swanson, H. A., and Baldwin, H. L., 1965, A primer on water quality: U.S. Geological Survey, 27 p.

Stiff, H. A., Jr., 1951, The interpretation of chemical water analysis by means of patterns: Journal of Petroleum Technology, vol. 3, no. 10, p. 15-17.

Terry, R. C., Jr., 1974, Road salt, drinking water and public safety: Cambridge, Mass., Ballinger, 159 p.

Theis, C. V., 1935, Relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using groundwater storage: American Geophysical Union Transaction, pt. 2, p. 519-524.

Theis, C. V., 1963, Estimating the transmissibility of a water-table aquifer from the specific capcity of a well, in Bentall, Ray, compiler, Methods of determining permeability, transmissibility and drawdown: U.S. Geological Survey 1536-I, p. 332-336.

Thomas, C. E., Jr., Bednar, G. A., Thomas, M. P., and Wilson, W. E., 1967, Hydrogeologic data for the Shetucket River basin, Connecticut: Connecticut Water Resources Bulletin 12, 48 p.

Thomas, C. E., Jr., Cervione, M. A., Jr., and Grossman, I. G., 1968, Water resources inventory of Connecticut, part 3, lower Thames and southeastern coastal river basins: Connecticut Water Resources Bulletin 15, 105 p.

Thomas, C. E., Jr., Randall, A. D., and Thomas, M. P., 1966, Hydrogeologic data in the Quinebaug River basin, Connecticut: Connecticut Water Resources Bulletin 9, 84 p.

Thomas, M. P., 1966, Effect of glacial geology upon the time distribution of streamflow in eastern and southern Connecticut: U.S. Geological Survey Professional Paper 550-B, p. B209-B212.

_____1972, Gazetteer of natural drainage areas of streams and water bodies within the State of Connecticut: Connecticut Department of Environmental Protection Bulletin 1, 89 p.

Thomas, M. P., Bednar, G. A., Thomas, C. E., Jr., and Wilson, W. E., 1967, Water resources inventory of Connecticut, part 2, Shetucket River basin: Connecticut Water Resources Bulletin 11, 96 p.

Thomas, M. P., Ryder, R. B., and Thomas, C. E., Jr., 1969, Hydrogeologic data for the southwestern coastal river basins, Connecticut: Connecticut Water Resources Bulletin 18, 45 p.

Thomson, M. T., Gannon, W. B., Thomas, M. P., Hayes, G. S., and others, 1964, Historical floods in New England: U.S. Geological Survey Water-Supply Paper 1779-M, 105 p.

Thornthwaite, C. W., 1952, An approach toward a rational classification of climate: Readings in the Geography of North America, American Geographical Society Reprint Series 5, p. 374-413.

Thornthwaite, C. W., and Mather, J. R., 1957, Instructions and tables for computing potential evapotranspiration and the water balance: Drexel Institute of Technology, Publications in climatology, vol. 10, no. 3, 311 p.

Todd, D. K., 1959, Ground-water hydrology: New York, John Wiley & Sons, 336 p.

_____, ed., 1970, The water encyclopedia: Port Washington, N.Y., Water Information Center, 559 p.

Torak, L. J., 1979, Determination of hydrologic parameters for glacial tills in Connecticut: University of Connecticut, unpublished M.S. thesis, 161 p.

Trescott, Peter C., 1975, Documentation of finite-difference model for simulation of three-dimensional ground-water flow: U.S. Geological Survey Open-file Report 75-438, 32 p.

Trescott, P. C., and Larson, S. P., 1976, Supplement to Open-file Report 75-438, Documentation of finite-difference model for simulation of three-dimensional ground-water flow: U.S. Geological Survey Open-file Report 76-591.

Trescott, P. C., Pinder, G. F., and Larson, S. P., 1976, Finite-difference model for aquifer simulation in two dimensions with results of numerical experiments: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 7, Chapter C1, 116 p.

U.S. Department of the Army, Corps of Engineers, 1970, Master manual of reservoir regulation, Appendix J, Farmington River Watershed.

U.S. Geological Survey, through 1970, Surface water supply of the United States, part 1, North Atlantic slope basins, and, from 1951, part 1-A, North Atlantic slope basins, Maine to Connecticut: U.S. Geological Survey Water-Supply Papers.

U.S. Geological Survey, 1947, Minor floods of 1938 in the North Atlantic States: U.S. Geological Survey Water-Supply Paper 966, 426 p., 14 pl.

_____1954, Compilation of records of surface waters of the United States through September 1950, part 1-A, North Atlantic slope basins, Maine to Connecticut: U.S. Geological Survey Water-Supply Paper 1301, 380 p.

_____1964, Compilation of records of surface waters of the United States, October 1950 to September 1960, part 1-A, North Atlantic slope basins, Maine to Connecticut: U.S. Geological Survey Water-Supply Paper 1721, 317 p.

_____issued annually, 1961-65, Surface water records of Connecticut.

_____issued annually, 1966-82, Water resources data for Connecticut.

_____1969, Surface water supply of the United States, 1961-65, part 1, North Atlantic slope basins, vol. 1, Basins from Maine to Connecticut: U.S. Geological Survey Water-Supply Paper 1901, 1027 p., 1 pl.

U.S. Public Health Service, 1962, Drinking water standards, 1962: U.S. Public Health Service Pub. 956, 61 p.

U.S. Weather Bureau, 1958, Climatic summary of the United States--supplement for 1931 through 1952.

_____1964, Climatic summary of the United States--supplement for 1951 through 1960.

_____1960-70, Climatological data, New England.

Walton, W. C., 1962, Selected analytical methods for well and aquifer evaluation: Illinois State Water Survey Bulletin 49, 81 p.

Walton, W. C., and Ackroyd, E. A., 1966, Effects of induced streambed infiltration on water levels in wells during aquifer tests: University of Minnesota Water Resources Research Center Bulletin 2, 42 p.

Walton, W. C., Hills, D. L., and Grundeen, G. M., 1967, Recharge from induced streambed infiltration under varying ground-water level and stream-stage conditions: University of Minnesota Water Resources Research Center Bulletin 6, 42 p.

Warren, C. R., 1970, Surficial geology of the Winsted quadrangle, Connecticut: U.S. Geological Survey Geologic Quadrangle Map GQ-871.

_____1972, Surficial geology of the Norfolk quadrangle, Connecticut: U.S. Geological Survey Geologic Quadrangle Map GQ-983.

_____1972, Surficial geology of the Thomaston quadrangle, Connecticut: U.S. Geological Survey Geologic Quadrangle Map GQ-984.

Weiss, L. A., 1975, Flood flow formulas for urbanized and nonurbanized areas of Connecticut: Watershed and management symposium, Logan, Utah, Irrigation and Drainage Division, American Society of Civil Engineers, p. 658-675.

_____1983, Evaluation and design of a streamflow-data network of Connecticut: Connecticut Water Resources Bulletin 36.

Wenzel, L. K., 1942, Methods for determining permeability of water-bearing materials with special reference to discharge-well methods: U.S. Geological Survey Water-Supply Paper 887, 192 p.

White, D. E., Hem, J. D., and Waring, G. A., 1963, Chemical composition of subsurface water, in Data of geochemistry (6th ed.): U.S. Geological Survey Professional Paper 440-F, p. F1-F67.

Wilson, W. E., Burke, E. L., and Thomas, C. E., Jr., 1974, Water resources inventory of Connecticut, part 5, lower Housatonic River basin: Connecticut Water Resources Bulletin 19, 79 p.

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*22. Hydrogeologic data for the upper Housatonic River basin, Connecticut; R. L. Melvin, 1970.
*23. A proposed streamflow data program for Connecticut; M. P. Thomas and M. A. Cervione, Jr., 1970.
24. Water resources inventory of Connecticut, part 7, upper Connecticut River basin, Connecticut; R. B. Ryder, L. A. Weiss, and M. P. Thomas, 1981.
25. Hydrogeologic data for the upper Connecticut River basin, Connecticut; R. B. Ryder and L. A. Weiss, 1971.
26. Hydrogeologic data for the Quinnipiac River basin, Connecticut, D. L. Mazzaferro, 1973.
27. Water resources inventory of Connecticut, part 8, Quinnipiac River basin, Connecticut, D. L. Mazzaferro, E. H. Handman, and M. P. Thomas, 1979.
28. Hydrogeologic data for the Farmington River basin, Connecticut, H. T. Hopkins and E. H. Handman, 1975.
29. Water resources inventory of Connecticut, part 9, Farmington River basin, Connecticut, F. P. Haeni, E. H. Handman, and M. P. Thomas, 1986.
30. Hydrogeologic data for the lower Connecticut River basin, Connecticut, J. W. Bingham, L. A. Weiss, and F. D. Paine, 1975.
31. Water resources inventory of Connecticut, part 10, lower Connecticut River basin, Connecticut, L. A. Weiss, J. W. Bingham, and M. P. Thomas, 1982.
32. Hydrogeologic data for South-Central Connecticut, F. P. Haeni and H. R. Anderson, 1980.