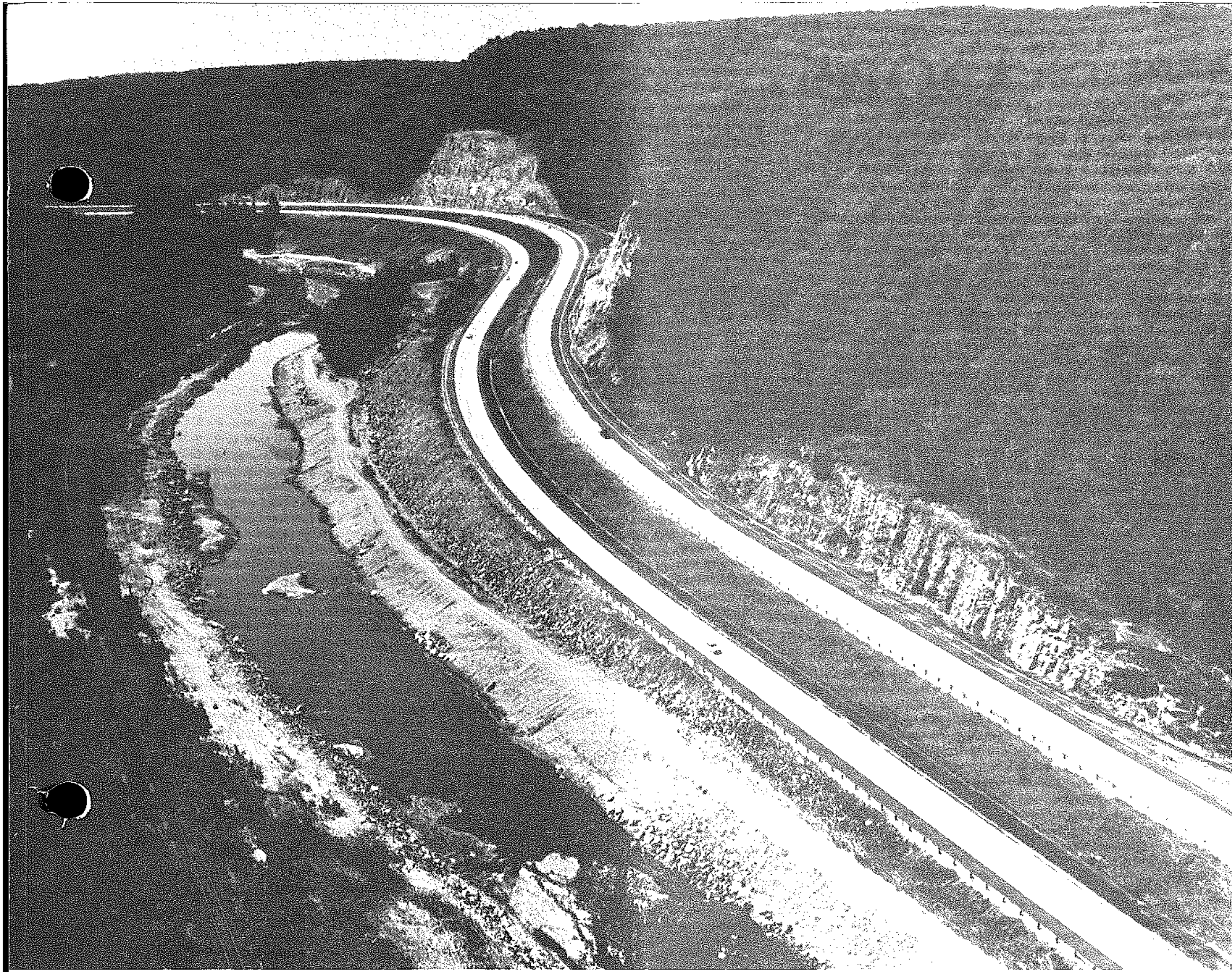


WATER RESOURCES INVENTORY OF CONNECTICUT

PART 5

LOWER HOUSATONIC RIVER BASIN

BY

WILLIAM E. WILSON, EDWARD L. BURKE, CHESTER E. THOMAS, JR.

U. S. GEOLOGICAL SURVEY

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

CONNECTICUT WATER RESOURCES BULLETIN NO. 19

1974

WATER RESOURCES INVENTORY OF CONNECTICUT
PART 5
LOWER HOUSATONIC RIVER BASIN

BY
WILLIAM E. WILSON
EDWARD L. BURKE
CHESTER E. THOMAS, JR.
U.S. GEOLOGICAL SURVEY

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

CONNECTICUT WATER RESOURCES BULLETIN NO. 19

1974

CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS–CONT.

TABLES

SUMMARY

The 557 square miles of the lower Housatonic River basin in western Connecticut include the basins of two major tributaries, the Pomperaug and Naugatuck Rivers. Nearly all water is derived from precipitation, which averaged 47 inches per year during 1931-60. In this period an additional 570 billion gallons of water per year entered the basin in the main stem of the Housatonic River at Lake Lillinonah, and some water was imported by water-supply systems from outside the basin. Almost half the precipitation--21.6 inches--was lost from the basin by evapotranspiration. Except for small amounts exported, the remainder discharged as runoff and underflow into Long Island Sound.

Variations in streamflow at 6 long-term 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 two low-flow characteristics, the 7-day annual minimum flow for 2-year and 10-year recurrence intervals, have been determined for many partial-record stations throughout the basin.

Of the 37 principal lakes, ponds, and reservoirs in the basin, 6 have usable storage of more than 1 billion gallons. The "maximum safe draft rate" (described in: "Storage of Water in Lakes and Reservoirs") of the largest of these, Thomaston Reservoir near Thomaston, is 75.6 million gallons per day for the 10-year and 20-year recurrence intervals of annual lowest mean flow.

Floods have occurred during every month, at one time or another. The two greatest floods on the Naugatuck River in historical time occurred 2 months apart in 1955. The larger, in August, had a peak of 106,000 cfs (cubic feet per second) at Beacon Falls. Since then, the likelihood of major floods has been considerably reduced by a program of flood control in the basin.

Water can be obtained from three aquifers underlying the basin--stratified drift, till, and bedrock. Stratified drift covers about 16 percent of the basin, mostly in valleys and lowlands, and its saturated part generally ranges in thickness from 10 feet in small valleys to 200 feet in the Housatonic River valley. Its transmissivity ranges from 0 to 47,000 ft^2/day (feet squared per day). Till, deposited directly by glacial ice, forms a widespread but discontinuous mantle over bedrock in most upland areas and extends beneath stratified drift in lowlands; it ranges in thickness from 0 to 200 feet. The median value of 31 published determinations of hydraulic conductivity of till in southern New England is 0.67 ft/day and ranges from 0.013 to 29 ft/day. Crystalline bedrock underlies most of the basin and is composed principally of granite, gneiss, and schist. Sedimentary-volcanic bedrock underlies only the Pomperaug River basin. Regardless of rock type, water is obtained mostly from fractures.

Streambed deposits are significant features of the hydrogeologic system because they affect the amount of water from streams and lakes that can be induced to infiltrate aquifers. Based on field tests, characteristic values of vertical hydraulic conductivity of streambed deposits are 0.40 ft/day for fine-grained deposits and 14 ft/day for gravelly deposits.

Ground-water supplies generally range in yield from several millions of gallons per day from large well fields to 1 gpm (gallon per minute) from single wells. Large supplies, with yields of 100 gpm or more from individual wells, are most commonly obtained from stratified drift. Yields to be expected from screened wells tapping this aquifer can be calculated by use of a series of graphs in conjunction with estimates of transmissivity and aquifer thickness.

The yields of 14 principal ground-water reservoirs are estimated from aquifer characteristics and also from the amount of water that can be obtained from aquifer storage, from interception of runoff, and from infiltration of streamflow at low-flow conditions, using a hypothetical well-field arrangement for each reservoir. It is assumed that induced infiltration is restricted to an amount equal to the 7-day annual minimum streamflow for a 2-year recurrence interval. Yields range from 1.4 to 15 mgd (million gallons per day) during periods of no recharge, and from 2.0 to 17 mgd during recharge periods.

Small to moderate water supplies can be obtained from any of the aquifers under suitable conditions. For example, data from 294 wells in the basin indicate that yields of a few gallons per minute can be obtained from bedrock at most sites. The likelihood of obtaining an adequate domestic supply is slightly greater in granite than in schist and also is greater where the overburden is stratified drift rather than till.

Chemical analyses of precipitation samples collected monthly from five stations in the basin during a 9-month period in 1966 show that rainfall is acidic and that sulfate is the dominant anion, probably because of industrial fumes and smoke within and near the basin.

Where unaffected by man's activities, water in the basin is generally low in dissolved-solids concentration, is of the calcium magnesium bicarbonate type, and is soft to moderately hard. In general, streamflow is less mineralized than ground water, particularly when it consists largely of direct runoff. However, streamflow becomes more highly mineralized during low-flow conditions, when most of it consists of more highly mineralized water discharged from aquifers. The median value of dissolved-solids concentration of water at 22 stream sites was 51 mg/l (milligrams per liter) during high flow, and 68 mg/l during low flow within the study period. Iron and manganese occur naturally in objectionable concentrations in parts of the basin, particularly in streams draining swamps and in water from bedrock containing iron- and manganese-bearing minerals.

Man's activities have degraded the quality of water in streams in much of the basin, except in the Pomperaug subbasin. In the Naugatuck River basin, the degradation in quality is shown by wide and erratic changes in dissolved-solids concentration, excessive amounts of certain trace elements, a low dissolved oxygen content, and abnormally high temperatures. Ground water is degraded principally by induced infiltration of stream water containing chemical wastes, by wastes stored on the ground and by effluents from septic tanks.

Below its confluence with the Naugatuck River, much of the Housatonic River and adjoining marshes, wetlands, and aquifers contain salt water. Measurements of specific conductance during low-flow conditions in 1969 indicate that the dissolved-solids concentration of water in the estuary ranged from 210 mg/l near Twomile Island to 20,000 mg/l near Long Island Sound.

The quantity and quality of water in the basin are satisfactory for a wide variety of uses, and, with suitable treatment, the water may be used for most purposes. In 1967, the total amount of water used in the basin was about 194 billion gallons. About 90 percent of this was used for industrial purposes, and 95 percent of the industrial water was obtained from surface-water sources. In the same year, 17 municipal and private water-supply systems supplied water of satisfactory quality to about three-fourths of the population.

INTRODUCTION

PURPOSE AND SCOPE

Connecticut, in common with many other States, has experienced a rapid increase in population in the past few decades, accompanied by industrial expansion, changes in agricultural technology, and a rising standard of living. These changes have contributed to a steadily rising demand for water that is expected to continue in the foreseeable future. Although the water that supplies this demand is ample, it varies in amount and in quality from place to place, from season to season, and from year to year. Therefore, as the need for water increases, so does the need for accurate information and careful planning to obtain optimum use of known water supplies and to locate new areas for development.

Accordingly, in 1959 the General Assembly, on recommendation of the State Water Resources Commission, authorized a water-resources inventory of Connecticut. Under this authorization, and under supplemental authorizations of the General Assembly, the U.S. Geological Survey, in cooperation with the Water Resources Commission and subsequently with the Connecticut Department of Environmental Protection, has undertaken a series of studies to determine the quantity and quality of water available in the State. To facilitate these investigations, the State has been subdivided into 10 study areas, each bounded by natural drainage divides. (See map inside front cover.) The resulting reports will be useful to State, regional, and town planners, town officials, water-utility personnel, consulting hydrologists, well drillers, and others concerned with the development and management of the water resources. This report covers the fifth of the 10 study areas. It is a companion report to a published basic-data report for the same area, Connecticut Water Resources Bulletin 20 (Grossman and Wilson, 1970). A list of cooperative reports dealing with water resources in Connecticut is given on the back cover.

THE LOWER HOUSATONIC RIVER BASIN

The lower Housatonic River basin is in western Connecticut, as shown on the index map inside the front cover. The area, as defined for this report, is the drainage basin of the Housatonic River downstream from Shepaug Dam at Lake Lillinonah; it includes the basins of two major tributaries, the Pomperaug River and the Naugatuck River, that flow into the Housatonic River from the north. The lower Housatonic River basin includes 557 square miles.

The basin is characterized by rugged topography; elevations range from sea level along the Housatonic River between its mouth and Derby to more than 1,600 feet in the headwaters of the Naugatuck River in Norfolk. Steep slopes and rolling uplands rise from the flatlands at the mouth of the Housatonic River estuary and the bottomlands of the Housatonic, Naugatuck, and Pomperaug Rivers. The Housatonic River is affected by ocean tides as far north as Derby, and salty water in the estuary reaches inland about 10 miles to Two-mile Island.

In a land-use classification, more than 75 percent of the basin is "vacant"; another 15 percent includes water-supply lands, recreation, State forest, or water bodies; most of the remaining land is residential. Urban and industrial development is concentrated principally in the major valleys. The rolling uplands are largely farmed or are undeveloped. Extensive areas of steep slopes and rocky upland interspersed with streams and many lakes, ponds, and reservoirs give the basin much natural beauty.

Industrial development of the bottomlands and residential development of adjacent hillsides form the pattern of land use along much of the Naugatuck River valley south of Watertown and along the Housatonic River valley south of Monroe and Oxford. Waterbury, centrally located in the Naugatuck River valley, has earned the name "Brass City" as the leading center of brass manufacture in the United States. A variety of other goods, including timing and electronic devices, recording instruments, tools, aircraft, clothing, and products made of copper, plastic, leather, and rubber are also manufactured.

Two major highways, north-south Connecticut Route 8 and east-west Interstate Route 84, join in Waterbury; two other major highways, Connecticut Route 15 and Interstate Route 95, cross the southern part of the basin.

GUIDE FOR USE OF THIS REPORT

Water supplies may be obtained from streams, lakes, and aquifers. Although the sources are closely related, the methods used for estimating the amount potentially available from each, and the techniques of development of each, are sufficiently different to merit discussion in separate sections of this report. The succeeding sections discuss the quality and use of water.

The availability of surface water in the basin is summarized on plate B, which locates lakes, ponds, and reservoirs with usable storage and indicates the amount in storage. The map also shows, for all but very small streams, mean flow and low-flow parameters. These values exclude estimated amounts of artificial augmentation of streamflow. Estimated amounts of augmentation for 1931-60 are shown along the streams. The text contains more detailed information in the section titled "Surface Water," including tables and graphs showing flow duration, low flow and high flow frequency, and draft storage relations.

The availability of ground water is summarized on plate C, which is presented in three sections corresponding to the basins of the Housatonic, Naugatuck, and Pomperaug Rivers, and which shows the areal distribution of the principal aquifers. This plate also shows the thickness and transmissivity of the stratified-drift aquifer; these parameters can be used with the graphs in the section titled "Ground Water" to estimate the potential yields of screened wells and the distribution of drawdowns around a well pumping at a constant rate. Areas favorable for the development of large ground-water supplies are also indicated on plate C. The hydrologic models used to evaluate these areas are illustrated on figure 33, and the quantities of water potentially available are given in table 19.

The natural quality of water in streams and aquifers is summarized in table 21 and is discussed in the section titled "Quality of Water." The discussion includes the natural and manmade aspects of water quality that may restrict the use of water for some purposes. Areas where these restrictive conditions are known to exist are delineated on maps (figs. 42, 43, and 49).

A discussion of man's use of water in 1967 includes a table giving the suitability of water in the basin for various industrial uses (table 27), and an illustration of the source, use, and disposal of water (fig. 60). The principal public water-supply systems and the quality of water they distribute are described in tables 28 and 29.

All data-collection points specifically referred to in this report are shown on plates A or B. Locations of these and all other sites for which data were collected for this study are shown on maps in the companion report (Grossman and Wilson, 1970). That report contains well records, logs of wells and test holes, laboratory analyses of sediment samples, and records of pumping tests. In addition, it lists sources of other published hydrologic data for the basin, including those with records of surface water and water quality.

ACKNOWLEDGMENTS

The data on which this report is based were collected and analyzed by many employees of the U.S. Geological Survey. Considerable unpublished information was obtained from State agencies, including the Water Resources Commission, Department of Transportation, Board of Fisheries and Game, Development Commission, and the Geological and Natural History Survey; and from a Federal agency, the U.S. Corps of Engineers. Appreciation is expressed for information obtained from personnel of Geraghty and Miller, Consulting Ground-Water Geologists; Leggette, Brashears and Graham, Consulting Ground-Water Geologists; Camp, Dresser, and McKee, Consulting Engineers; and Metcalf and Eddy, Engineers. William Duncan of S. B. Church Company supplied much valuable well information. The cooperation and assistance of the staff of the Central Naugatuck Valley Planning Agency are gratefully acknowledged. The personnel of many private and municipal water-utility companies and industrial firms provided access to unpublished information and to their plants and facilities. Appreciation is expressed especially to the personnel of the Bridgeport Hydraulic Company, the Naugatuck Division of the Connecticut Water Company, and the Naugatuck Chemical Division of UniRoyal, Inc.

THE WATER BUDGET

The hydrologic operation of the lower Housatonic River basin can be expressed by a water budget, which, like a fiscal budget, lists receipts, disbursements, and water on hand. The water budget is the quantitative expression of the hydrologic cycle--the continual movement of water between the oceans, the atmosphere, and the land masses of the earth. The cycle can be considered to begin with water vapor in the atmosphere, which condenses to form clouds from which rain or snow falls onto the land surface. Part of this water is dispersed across the land surface into streams and lakes, and part seeps into the ground. Much that collects on the land surface or seeps into the ground soon evaporates or is taken up by plants and transpired to the atmosphere. Some, however, moves slowly underground toward nearby streams or the ocean, into which it eventually discharges. Part of the water that reaches the streams, lakes, and the ocean also evaporates to complete the cycle.

The amounts of water stored within the basin change continuously in response to the changing rates at which they enter and leave the basin. Large amounts are stored temporarily in the atmosphere as water vapor, on the land surface in streams and other bodies of water, and beneath the land surface as ground water. None of these amounts is constant in a given locality, as the water is continually moving from place to place. Although the quantities vary from year to year, the water budget always balances--the disbursements equal the receipts, plus or minus changes in storage.

WATER SOURCES

Precipitation is the source of water for all streams in the basin. During 1931-60, annual precipitation on the lower Housatonic River basin ranged from 33 inches to 64 inches and averaged 47 inches. During the same period, mean monthly precipitation--based on records from three weather bureau stations (U.S. Weather Bureau, 1958, 1964) weighted in proportion to the area represented by each station--ranged from 3.0 to 4.6 inches. Mean monthly and minimum monthly precipitation are evenly distributed throughout the year (fig. 1). On the other hand, maximum monthly precipitation varies widely, and floods that vary widely in magnitude have occurred in nearly every month of the year.

In addition to precipitation on the area, during 1931-60 about 570 billion gallons of water per year from the upper Housatonic River basin entered the study area via the Housatonic River at Lake Lillinonah (Shepaug Dam). In comparison with average streamflow at this site, underflow was negligible. The Waterbury municipal system diverted about a billion gallons per year into the basin via the Naugatuck River, and the New Haven Water Company diverted a like amount annually into the basin in the Milford area.

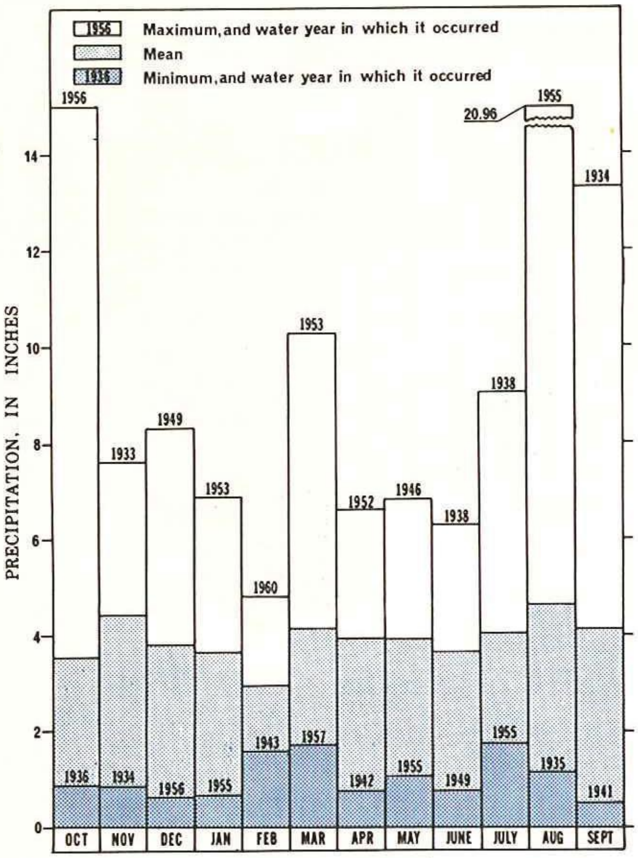


Figure 1.--Monthly precipitation, water years 1931-60.

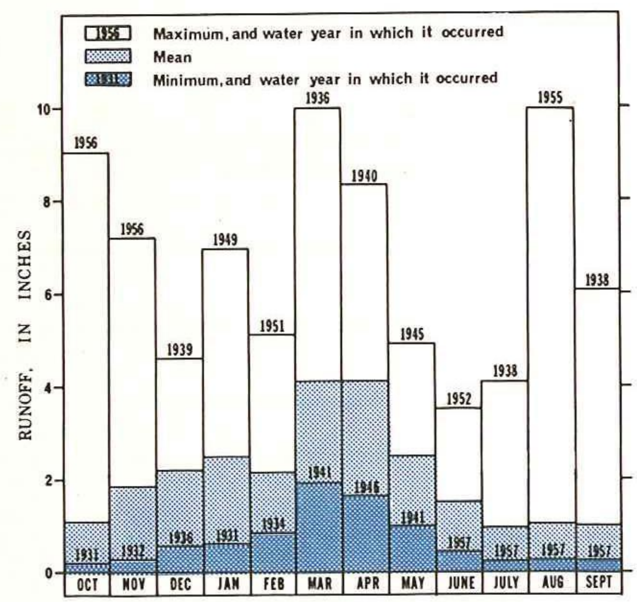


Figure 2.--Monthly runoff from basin, water years 1931-60.

WATER LOSSES

Discharge from the study area is about evenly divided between evapotranspiration and runoff. Mean annual runoff is equivalent to about 25 inches of water spread over the drainage area. Runoff has been measured since 1928 on the Housatonic River at Stevenson and since 1918 on the Naugatuck River at Beacon Falls. These stations include the runoff from 1,806 of the 1,949 square miles comprising the entire Housatonic River basin. The reported streamflow past each gaging station in the reference period, 1931-60, is adjusted in proportion to runoff contribution to represent mean monthly and mean annual runoff for the lower Housatonic River basin. The mean monthly runoff and minimum monthly runoff (fig. 2) are greater in early spring than in late summer, reflecting melting of ice and snow in March and April and greater ground-water discharge in the spring. During the summer, losses from evaporation and transpiration increase. Maximum runoff, like maximum precipitation, varies widely from month to month and has less well-defined seasonal variation; floods have occurred in nearly every month of the year. The floods of March 1936 and January 1949 resulted from a combination of heavy rains and rapid snowmelt, whereas the maximum runoffs from July to October resulted from hurricanes and other severe storms.

A part of all streamflow in the lower Housatonic River basin is derived from ground-water runoff from contiguous aquifers. During winter, when temperatures are below freezing, and during rainless periods in summer and fall, the flow of streams consists almost entirely of ground-water runoff. Swamp storage was probably minimal during the drought conditions prevailing during this study, and swamp storage is not considered separately in this report. Separation of hydrographs into principal components indicates that approximately 40 percent of total runoff or the equivalent of 10 inches or 97 billion gallons of water per year is ground-water runoff.

Nearly half or about 22 inches of the water that falls on the lower Housatonic River basin is returned to the atmosphere by evapotranspiration. This figure was computed from the difference between the mean annual precipitation (about 47 inches) and the mean annual runoff (about 25 inches).

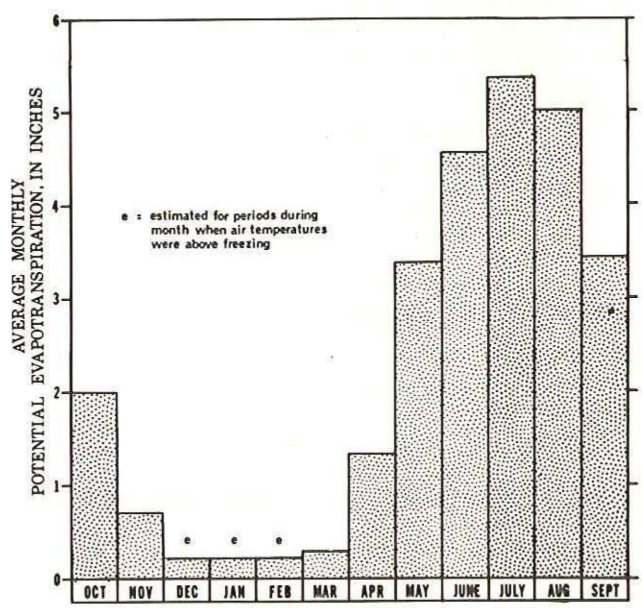


Figure 3.--Monthly potential evapotranspiration, water years 1931-60.

The rate of evapotranspiration differs from month to month largely in response to changes in air temperature and duration of daylight (Thornthwaite, 1952, p. 382). Thus, evapotranspiration is greatest during the growing season, April to October, when the temperature is above freezing and the days are longest. These major factors repeat themselves with little change year after year, and the annual evapotranspiration and its distribution are relatively constant for a given locality. The annual evapotranspiration for the report area is known from the long-term relationship of precipitation and runoff, as discussed in the preceding paragraph; accordingly, its potential mean monthly distribution in the study area for water years 1931-60 may be estimated by a method similar to that of Thornthwaite and Mather (1957). (See fig. 3.)

An average water budget for the lower Housatonic River basin, based on the factors of the budget as derived by the methods described above, is shown on figure 4. Precipitation during late autumn and winter is sufficient to cause abundant runoff and an increase in storage. Precipitation in the late spring and summer is similar in quantity, but it is inadequate to satisfy the large evapotranspiration losses. As a result, runoff is reduced and storage is decreased in lakes, swamps, streams, soils, and aquifers.

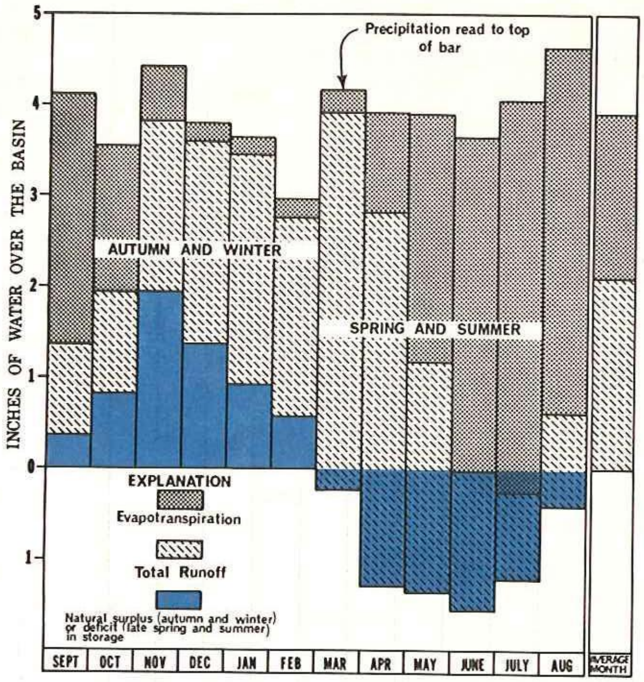


Figure 4.--Monthly water budget for the basin, water years 1931-60.

U. S. GEOLOGICAL SURVEY STATION NUMBER	STREAM AND LOCATION	DRAINAGE AREA (sq.mi)
	STREAM-GAGING STATIONS IN BASIN	
2035.1	Pootatuck River at Sandy Hook	24.2
2036	Nonewaug River at Minortown	17.2
2040	Pomperaug River at Southbury	75.3
2045	Pomperaug River at Bennetts Bridge	89.3
2048	Copper Mill Brook near Monroe	2.50
2055	Housatonic River at Stevenson	1,545
2056	West Branch Naugatuck River at Torrington	33.4
2057	East Branch Naugatuck River at Torrington	13.8
2060	Naugatuck River near Thomaston	71.9
2064	Leadmine Brook near Harwinton	18.9
2065	Leadmine Brook near Thomaston	24.0
2069	Naugatuck River at Thomaston	101
2082.7	Mad River near Waterbury	12.0
2084.5	Naugatuck River near Naugatuck	246
2085	Naugatuck River at Beacon Falls	261
	STREAM-GAGING STATION IN VICINITY OF BASIN	
1880	Burlington Brook near Burlington	4.12

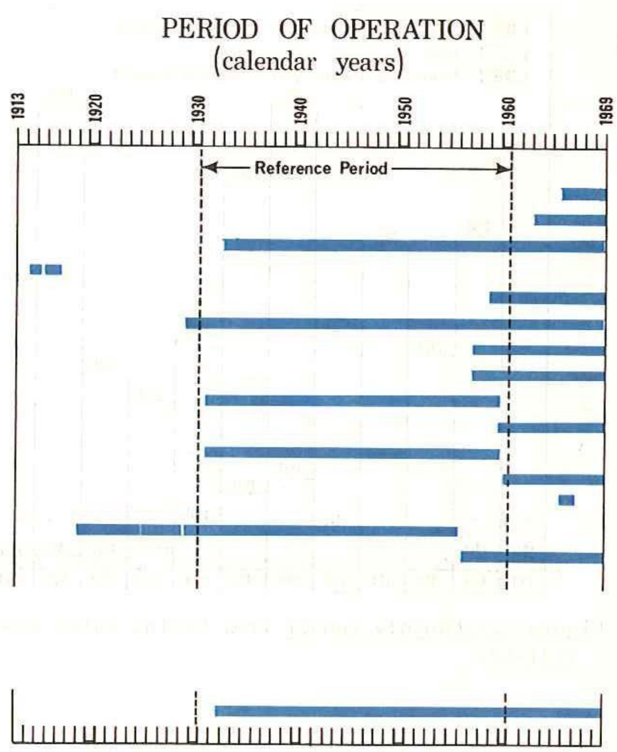


Figure 5.--Length of continuous streamflow records at gaging stations in the basin and vicinity, Connecticut.

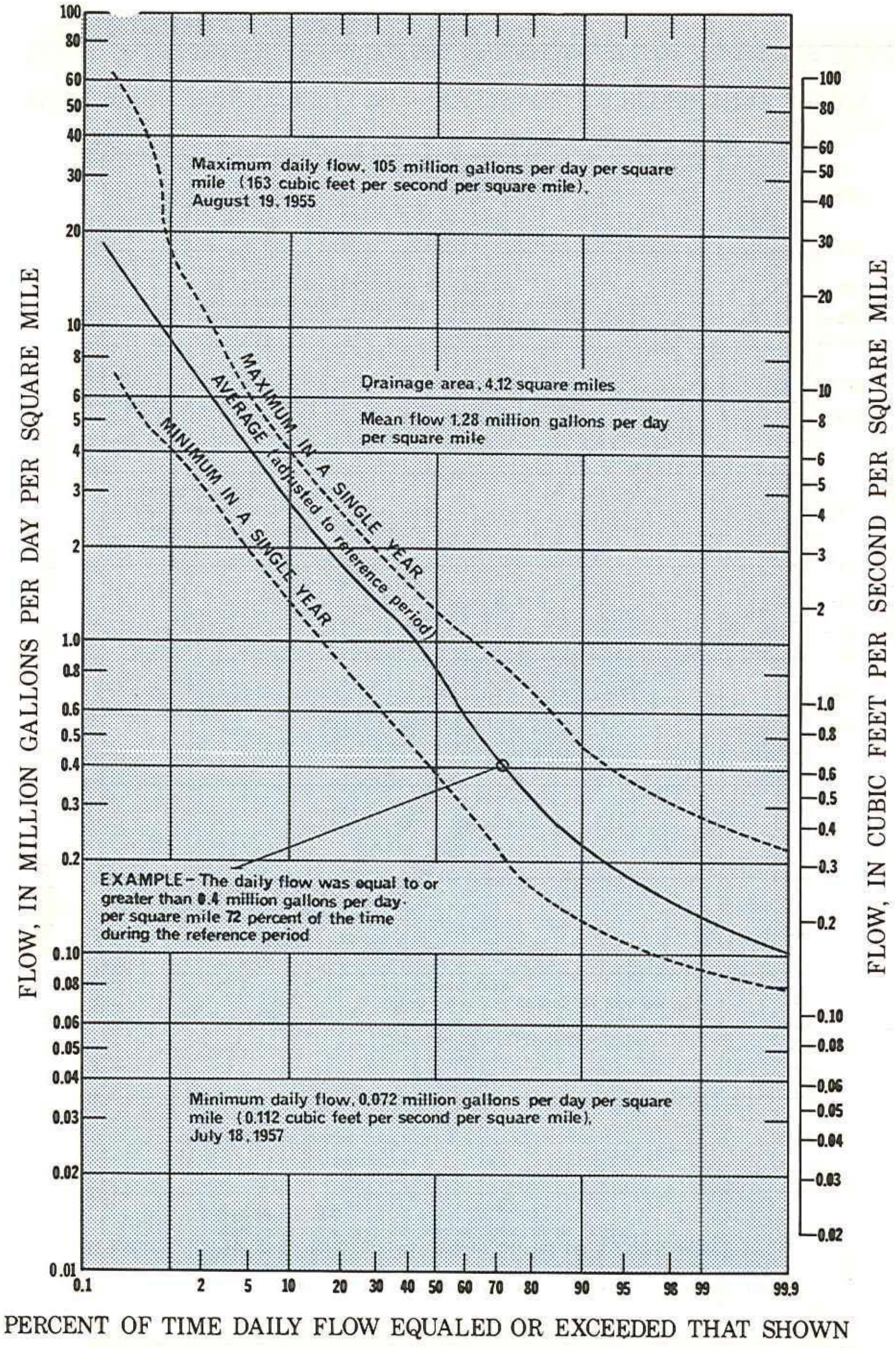


Figure 6.--Duration of daily mean streamflow of Burlington Brook near Burlington, water years 1931-60.

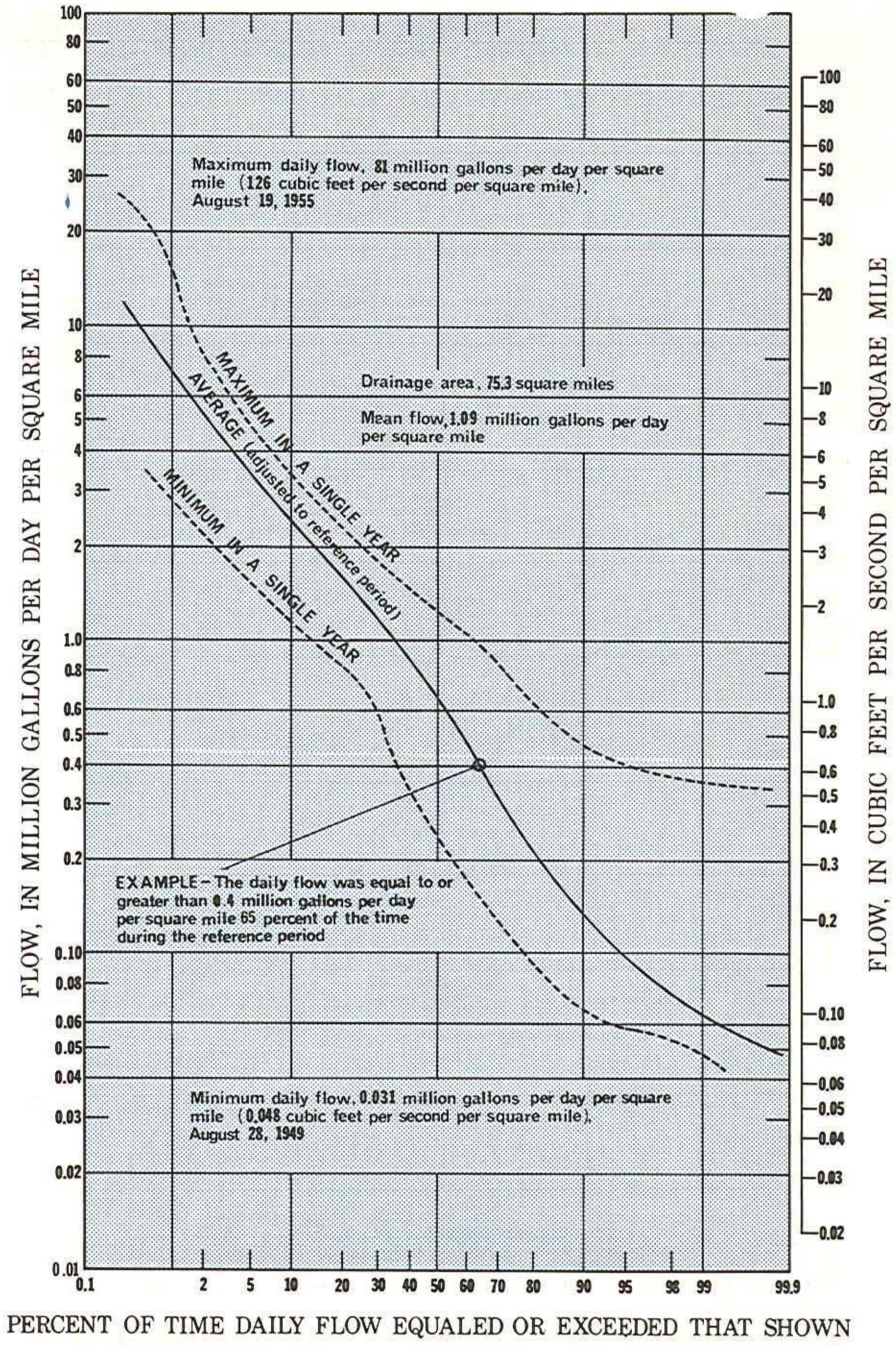


Figure 7.--Duration of daily mean streamflow of the Pomperaug River at Southbury, water years 1931-60.

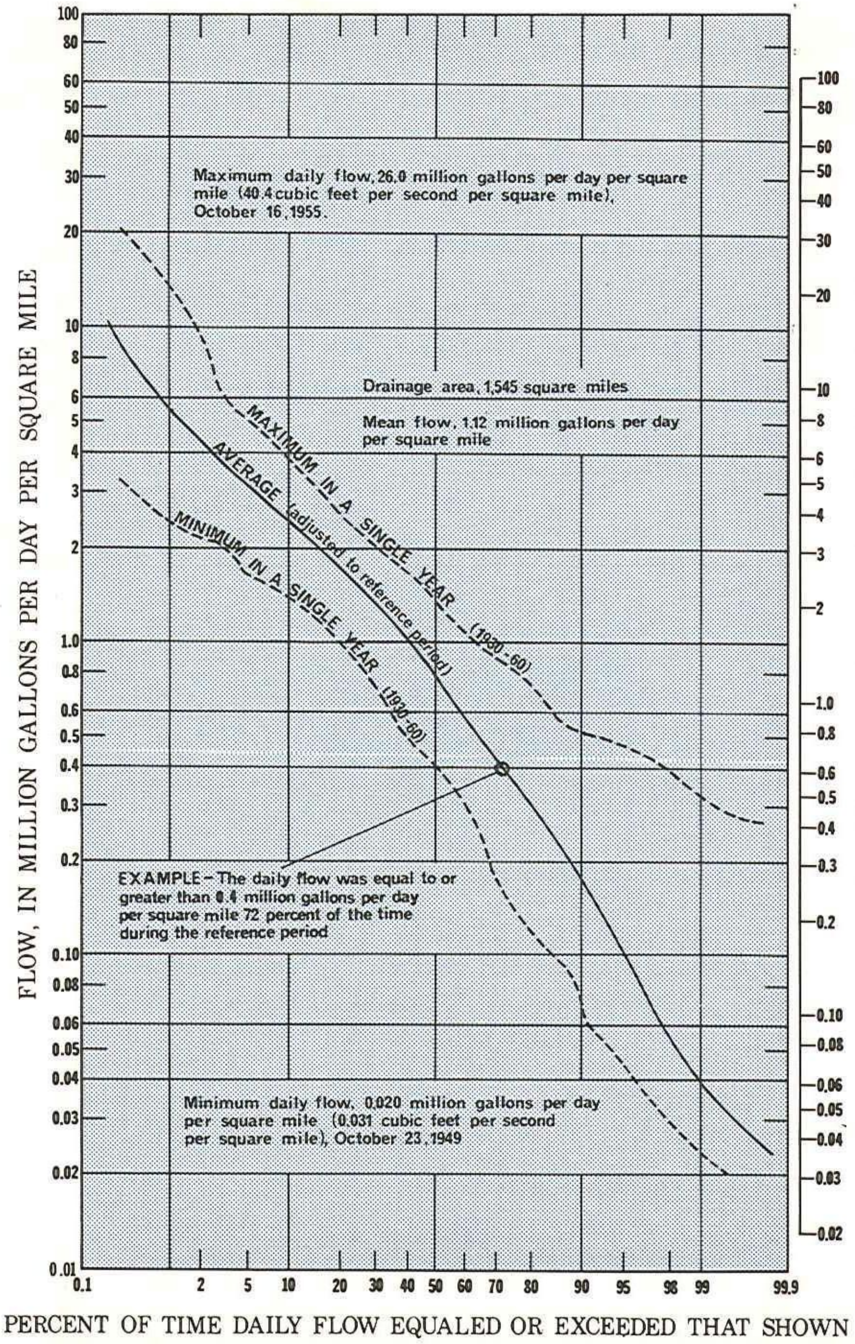


Figure 8.--Duration of daily mean streamflow of the Housatonic River at Stevenson, water years 1931-60.

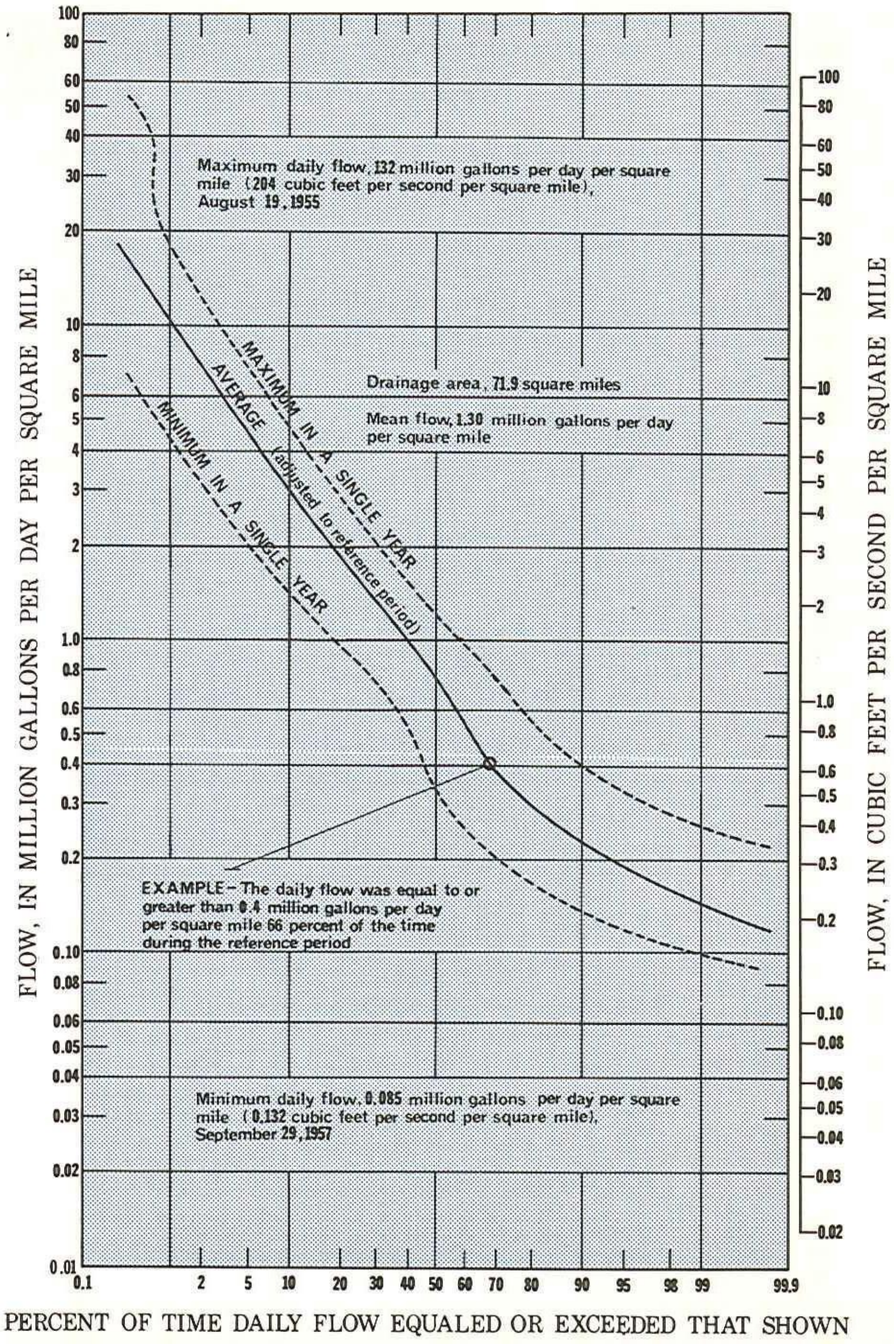


Figure 9.--Duration of daily mean streamflow of the Naugatuck River near Thomaston, water years 1931-60.

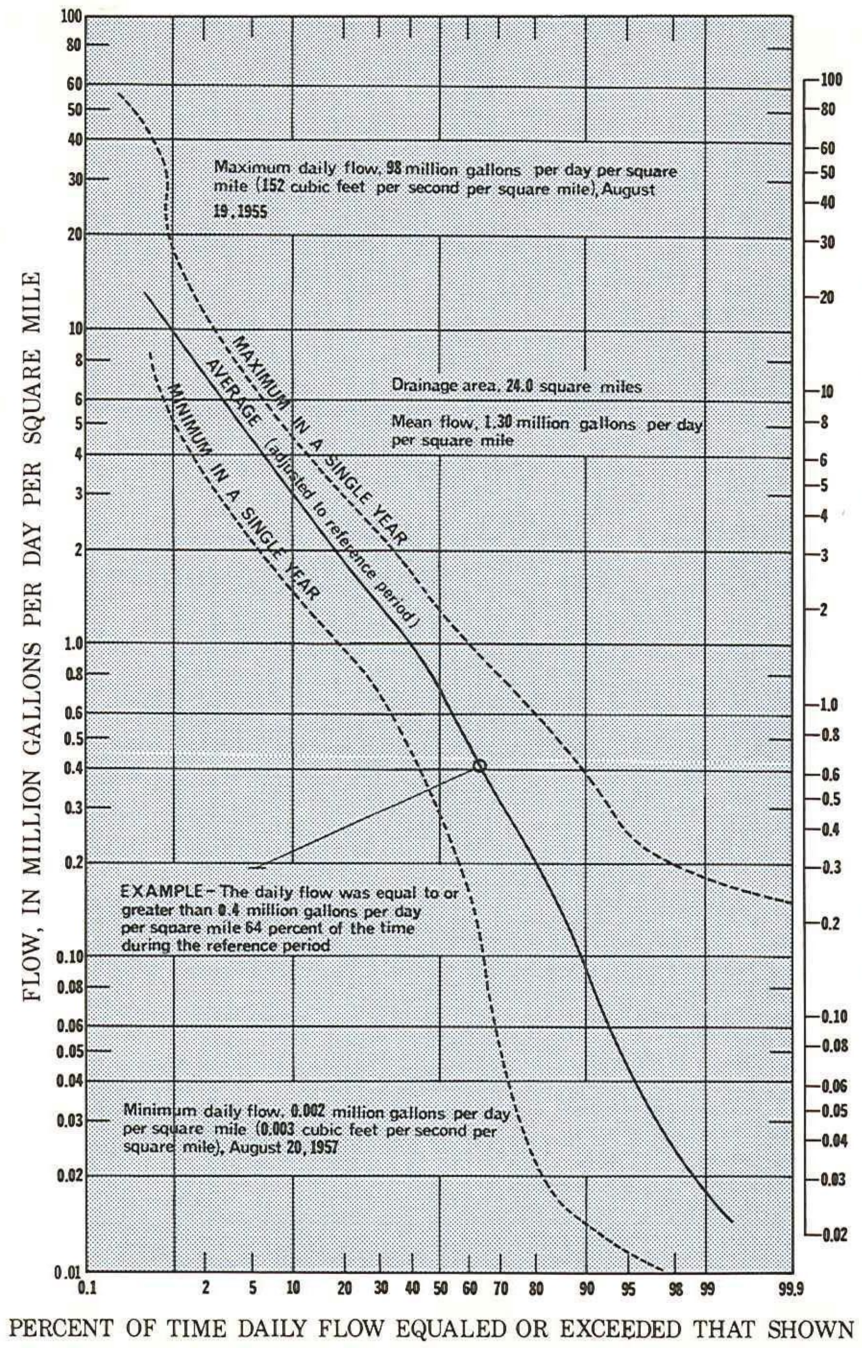


Figure 10.--Duration of daily mean streamflow of Leadmine Brook near Thomaston, water years 1931-60.

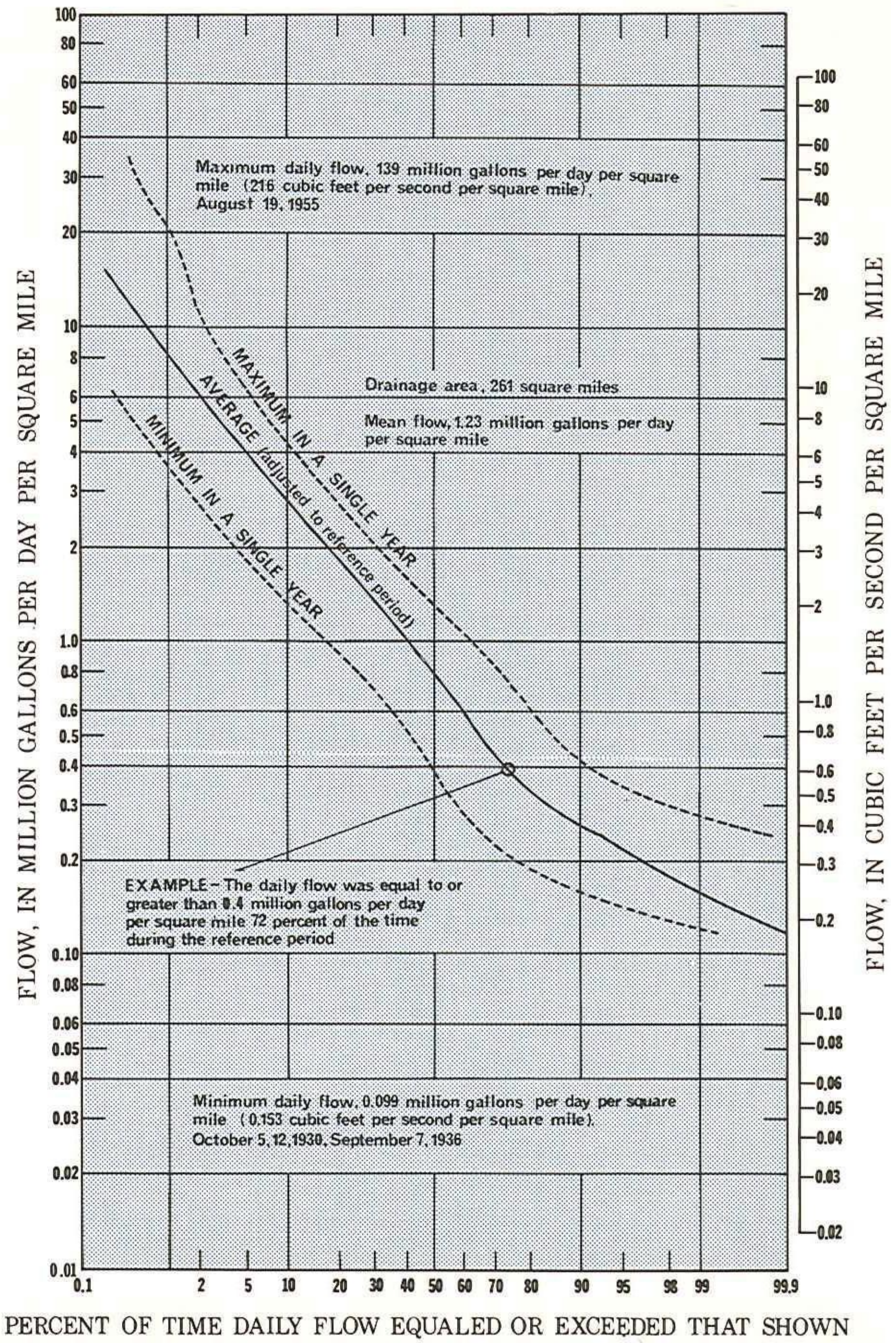


Figure 11.--Duration of daily mean streamflow of Naugatuck River at Beacon Falls, 1931-60.

Table 1.--Annual lowest mean flows for indicated number of consecutive days at designated recurrence intervals at long-term stream-gaging stations

(Flows are adjusted to the reference period April 1930 to March 1960.)

Index no. (pl. B)	Stream-gaging station	Drainage area (sq mi)	Period of low flow (consecutive days)	Annual lowest mean flow (cfs) for indicated recurrence interval (yrs)					Annual lowest mean flow (mgd per sq mi) for indicated recurrence interval (yrs)				
				2	5	10	20	31	2	5	10	20	31
1880	Burlington Brook near Burlington	4.12	7	1.03	0.74	0.62	0.54	0.49	0.161	0.116	0.097	0.085	0.077
			30	1.36	.95	.78	.70	.62	.213	.149	.122	.110	.097
			60	1.65	1.11	.91	.82	.74	.258	.174	.142	.128	.116
			120	2.35	1.48	1.24	1.03	.91	.368	.232	.194	.161	.142
			183	3.42	2.10	1.65	1.36	1.19	.536	.329	.258	.213	.186
			274	5.19	3.30	2.60	2.10	1.85	.813	.517	.407	.329	.290
2040	Pomperaug River at Southbury	75.3	7	10	6.5	5.2	4.3	3.8	.086	.056	.045	.037	.033
			30	13	8.7	7.0	5.9	5.3	.112	.075	.060	.051	.045
			60	17	11	8.6	7.2	6.5	.146	.094	.074	.062	.056
			120	27	17	13	11	10	.232	.146	.112	.094	.086
			183	43	26	20	16	15	.369	.223	.172	.137	.129
			274	75	47	37	30	26	.644	.403	.318	.257	.223
2055	Housatonic River at Stevenson	1,545	7	337	240	205	176	158	.141	.100	.086	.074	.066
			30	500	395	320	254	215	.209	.165	.134	.106	.090
			60	600	470	380	305	270	.251	.197	.159	.128	.113
			120	760	550	450	395	360	.318	.230	.188	.165	.151
			183	1,090	740	590	490	440	.456	.310	.247	.205	.184
			274	1,680	1,200	1,020	940	920	.703	.502	.427	.393	.385
2060	Naugatuck River near Thomaston	71.9	7	22	17	14	13	12	.198	.153	.126	.117	.108
			30	26	20	17	15	14	.234	.180	.153	.135	.126
			60	29	22	19	17	16	.261	.198	.171	.153	.144
			120	38	26	22	19	18	.342	.234	.198	.171	.162
			183	52	34	28	24	23	.467	.306	.252	.216	.207
			274	82	55	50	47	45	.737	.494	.449	.422	.405
2065	Leadmine Brook near Thomaston	24.0	7	1.23	.58	.39	.29	.25	.033	.016	.011	.008	.007
			30	2.25	.89	.58	.41	.35	.061	.024	.016	.011	.009
			60	3.75	1.50	1.01	.75	.64	.101	.040	.027	.020	.017
			120	8.7	3.60	2.36	1.70	1.42	.234	.097	.064	.046	.038
			183	16	7.5	4.9	3.40	2.78	.431	.202	.132	.092	.075
			274	28	16	14	13	12	.754	.431	.377	.350	.323
2085	Naugatuck River at Beacon Falls	261	7	86	68	59	50	46	.213	.168	.146	.124	.114
			30	104	81	70	60	55	.258	.201	.174	.149	.136
			60	116	90	76	66	60	.287	.223	.188	.163	.149
			120	150	110	92	79	71	.371	.272	.228	.196	.176
			183	200	137	114	98	90	.495	.339	.282	.243	.223
			274	320	220	180	152	136	.792	.545	.446	.376	.337

SURFACE WATER

STREAMFLOW DATA

Runoff is carried by many streams draining all parts of the lower Housatonic River basin. Fifteen stream-gaging stations are or have been operated in the study area. The periods of operation of these are indicated on figure 5. In addition, partial records and single measurements of streamflow were obtained at many other sites from May 1965 to September 1966. The complete drainage system and the locations of all stream-gaging stations are shown on plate B. The availability of all published records through water year 1968 for streamflow in the basin collected by the U.S. Geological Survey is shown in the companion basic-data report (Grossman and Wilson, 1970). That report also lists publications on streamflow covering the reference period, 1931-60, and the measurement period, 1965-66, in the section headed "Selected References" under U.S. Geological Survey.

Variations in streamflow at the continuous-record gaging stations are summarized in this report by means of standardized graphs and tables. To facilitate comparison between data for different streams, the records have been adjusted to a 30-year reference period beginning October 1930. This conforms with the practice of the World Meteorological Organization (Searcy, 1959). Accordingly, the analyses, interpretations, and regionalizations of streamflow are based on this 30-year reference period. The flow during this period represents the long-term flow of a stream as long as the pattern of regulation of storage or diversion of water into or out of the basin remains unchanged. The graphs or tables may then be used to estimate the amount and distribution of streamflow at the measured sites in the future. Thomas (1972) revised many of the drainage areas slightly because of the greater accuracy made possible by large-scale topographic maps (scale 1:24,000).

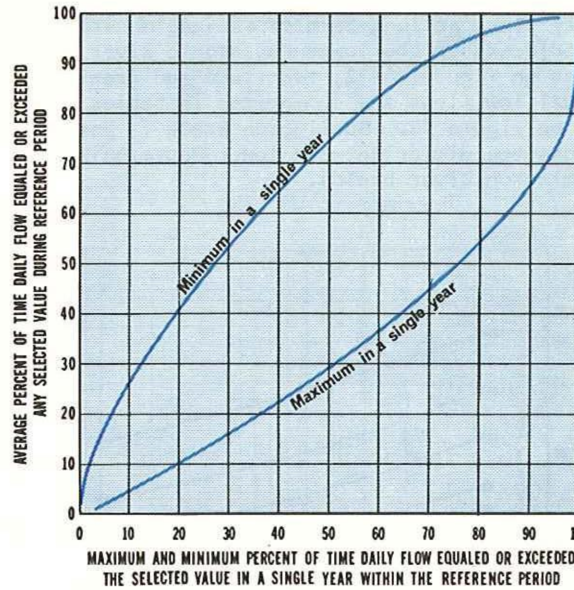


Figure 12.--Range in duration of streamflow.

Ranges are based on long-term (1931-60) streamflow records for the Pomperaug River at Southbury, Housatonic River at Stevenson, Naugatuck River near Thomaston, Leadmine Brook near Thomaston, and Naugatuck River at Beacon Falls.

Table 2.--Lowest mean flows for periods of 12 to 60 months at long-term stream-gaging stations (Flows are adjusted to the reference period April 1930 to March 1960.)

Index no. (pl. B)	Stream-gaging station	Period of consecutive months 12	18	24	36	60
		Lowest mean flow (cfs)				
1880	Burlington Brook near Burlington	3.0	4.6	5.2	6.0	6.6
2040	Pomperaug River at Southbury	60	78	85	95	105
2055	Housatonic River at Stevenson	1,340	1,580	1,740	2,000	2,220
2060	Naugatuck River near Thomaston	70	84	94	107	116
2065	Leadmine Brook near Thomaston	22	27	30	34	39
2085	Naugatuck River at Beacon Falls	200	255	290	350	400

The water-supply potential of streams is determined not only by the total amount of streamflow but also by the length of time the various flows are available (duration of daily flows) and by the frequency with which annual low flows recur (frequency distribution of annual low flows). Duration of daily flows at long-term stream-gaging stations in or adjacent to the lower Housatonic River basin is given on figures 6-12; magnitude and frequency of annual low flows are summarized in tables 1 and 2 and on figure 13. Burlington Brook is barely across the divide between lower Housatonic and Farmington River basins.

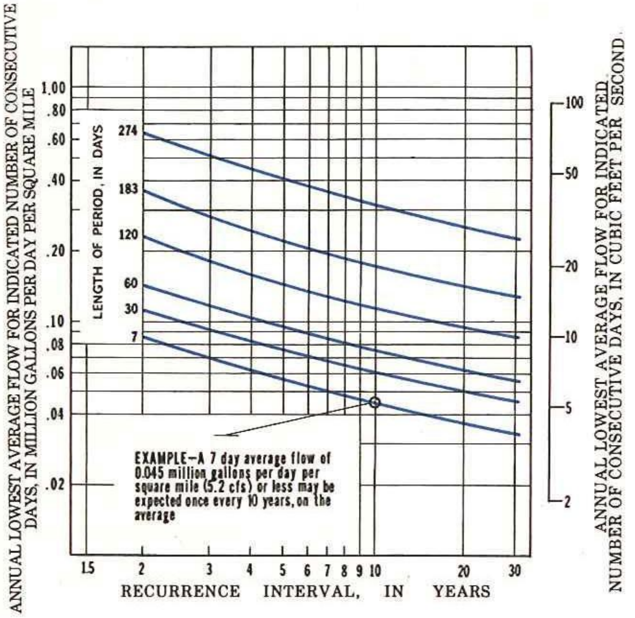


Figure 13.--Recurrence intervals of low flows of Pomperaug River at Southbury.

AREAL DIFFERENCES IN STREAMFLOW

Areal differences in annual precipitation cause large differences in amounts of annual streamflow from place to place within the basin. Average streamflow in the central and extreme northern and southern parts of the basin is 1.16 mgd per sq mi, the same as the statewide average. Streamflow is above average in the area north of Thomaston, as shown by the lines of equal runoff ratio on figure 14. The lines are based on the average streamflow at each gaging station in or near the basin; the ratios of these average streamflows to 1.16 mgd per sq mi (1.80 cfs per sq mi) were plotted near the center of the drainage basins to guide the location of the lines. Average streamflow for sites in the basin between the long-term continuous-record gaging stations may be interpolated on the figure.

DURATION OF STREAMFLOW

Whereas the amount of unregulated streamflow differs with the amount of precipitation, the timing of streamflow, except short term flow reflecting the effects of precipitation intensity, depends on the surficial geology. This relationship was shown by M. P. Thomas (1966), who presented a family of duration curves showing that runoff from areas in the State underlain by stratified drift is more evenly distributed through time than runoff from areas underlain largely by till. The relationship illustrated by the curves reflects the greater infiltration capacity and resultant high proportion of ground-water runoff from stratified drift and the poor infiltration capacity and resultant high proportion of overland runoff from till. Stratified drift absorbs a relatively large proportion of precipitation and stores it for sustained release during dry weather. The curves are based on conditions where most of the stratified drift is in the central and downstream part of a basin.

Probably because of the rugged terrain and nonuniformity of glacial till and stratified-drift deposits, the streamflow data for gaging stations in the northwestern part of the State, including part of the lower Housatonic River basin, do not fit a family of duration curves. Therefore, only duration data for the long-term gaging stations are presented in this report. The series of duration curves, figures 6-12, may be used to estimate duration curves for sites along the stream for which data are shown, allowance being made for inflow between subbasins and also for possible low-flow augmentation.

From May 1965 to September 1966, streamflow was measured at many partial-record sites in the basin during periods of base flow, when the flow was primarily from ground-water storage. These measurements were correlated with the simultaneous discharge of nearby streams, where long-term records were available, to estimate two low-flow characteristics for each partial-record site and to do the same for selected areas favorable for ground-water development. The characteristics estimated are the 7-day annual minimum flow for a 2-year recurrence interval (the median 7-day annual minimum flow) and the 7-day annual minimum flow for a 10-year recurrence interval. These characteristics, together with the mean flow for each site as interpolated from figure 14, are plotted on plate B.

To obtain the data plotted on plate B, estimated amounts of industrial releases and sewage effluent in the reference period, 1931-60, were deducted from the total low flows. Therefore, the figures shown at the sites are estimated values of natural runoff, which may be used to interpolate figures between sites shown on the plate. Expected amounts of future low-flow augmentation should be estimated for each site and added to the values interpolated from the map to obtain total flows, especially in the mainstem Naugatuck and Housatonic Rivers.

FREQUENCY AND DURATION OF LOW FLOWS

Although flow-duration curves indicate the minimum rates of streamflow for certain percentages of time, the knowledge of how often specified low streamflows may be expected to recur and how long they may be expected to last is also useful. Annual lowest mean flows for periods as long as 274 consecutive days at various recurrence intervals for long-term gaging stations are given in table 1. The lowest mean flows for periods of up to 60 consecutive months during the reference

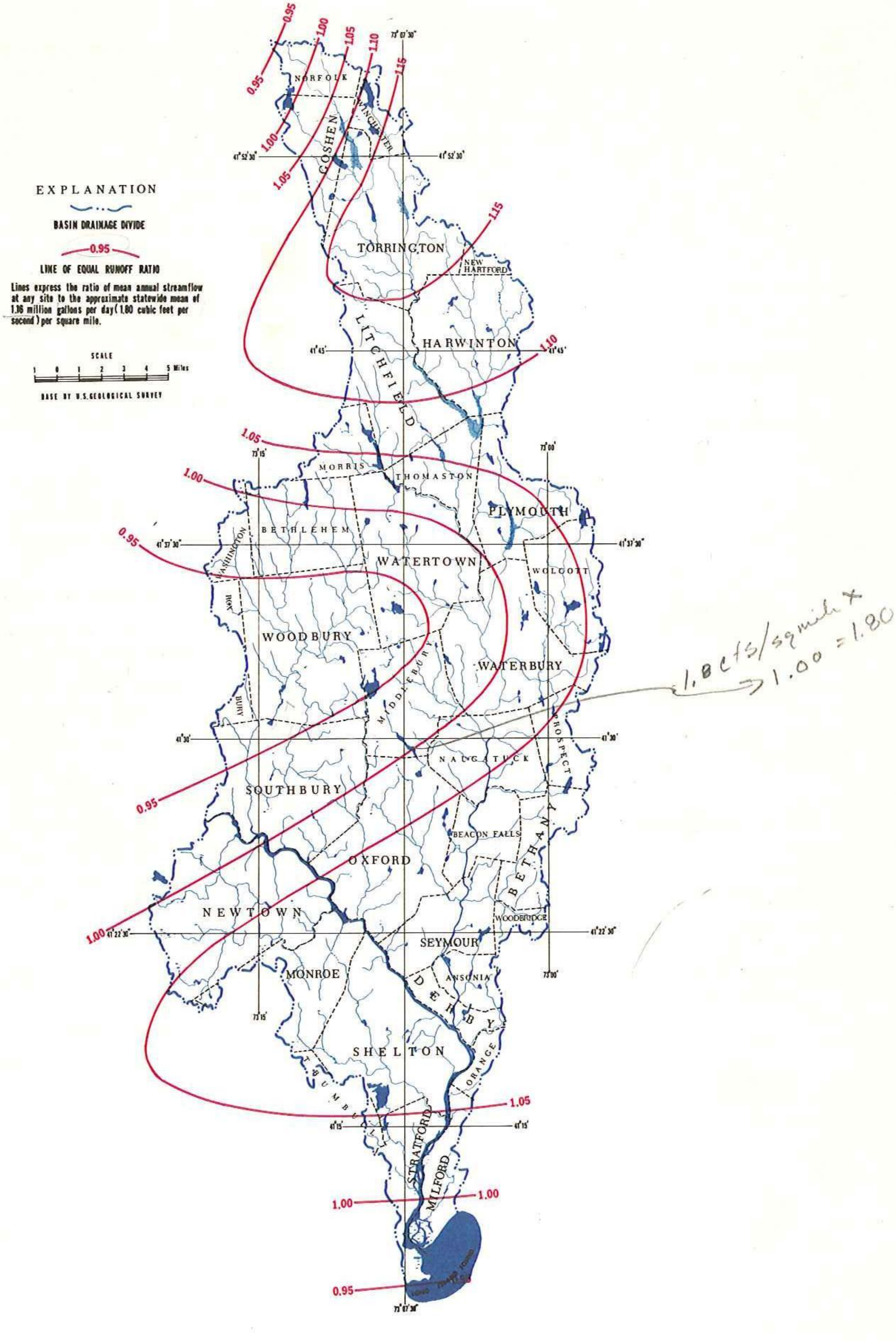


Figure 14.--Areal distribution of mean annual streamflow, water years 1931-60.

period are given in table 2. The data in table 1 can be used to construct low-flow frequency curves, such as that for Pomperaug River at Southbury, shown on figure 13. The duration curve and the low-flow frequency curve are related, and the average duration at indicated flow frequencies for long-term gaging stations in the lower Housatonic River basin is given in table 3. For example, the average duration of the 7-day annual minimum flow for the 10-year recurrence interval (plotted on plate B) is 99 percent. That is, the 10-year recurrence interval flow may be expected to be equalled or exceeded 99 percent of the time. The lowest daily discharge at 11 stream-gaging stations in the basin that was not exceeded during six different periods ranging in length from 1 to 120 consecutive days is shown in table 4.

Table 3.--Average duration of annual low flows of streams

(For reference period April 1930 to March 1960)

Period of low flow: Consecutive days	Period of low flow: Consecutive months	Average percentage of time in which streamflow equaled or exceeded the lowest mean flow for indicated number of consecutive days or months at the following recurrence intervals 1/: 2 median year	5	10	20	31 driest year
		Percent of time				
7	-	95	98	99	99.3	99.5
30	1	90	96	98	99	99
60	2	85	93	96	98	98
120	4	74	87	92	95	96
183	6	64	77	84	89	91
274	9	45	62	68	71	74
365	12	-	-	-	-	59
-	18	-	-	-	-	51
-	24	-	-	-	-	48
-	36	-	-	-	-	43
-	60	-	-	-	-	39
-	120	-	-	-	-	35
-	180	-	-	-	-	34
-	360	-	-	-	-	32

1/ Average of percentages determined from low flow frequency-duration relations at continuous-record gaging stations in or near the basin.

STORAGE OF WATER IN LAKES AND RESERVOIRS

The largest of the many lakes, ponds, and reservoirs in the lower Housatonic River basin is Thomaston Reservoir, with a surface area of 950 acres at spillway level and a usable capacity of 13,690 million gallons. Table 5 presents information on the more important surface-water bodies within the basin; additional information on the public supply reservoirs is given in table 28. About two-thirds of the lakes, ponds, and reservoirs listed in table 5 have usable storage (water that may be withdrawn by gravity through a valve or gate). Table 6 lists the maximum safe draft obtainable from some of these surface-water bodies at rates that would permit refilling within each year of the reference period. Maximum draft rates are given for years with low-flow conditions at the 10-year and 20-year recurrence intervals. The draft rates are given as annual average flow; for shorter periods of use, they may be increased correspondingly.

Low-flow frequency data for streams at the outlet of each of these reservoirs are presented on plate B. Methods of estimating draft rates and storage required are described in the following section.

Estimating the amount of storage needed

If the minimum flow of a stream is insufficient to meet needs, the stream may need to be dammed and the stored water released as needed to maintain the desired flow during low-flow periods. Table 7 lists the various amounts of storage required to maintain selected rates of flow at the listed gaging stations for 10- and 20-year recurrence intervals of annual lowest mean flow in the reference period. The figures for storage required are in percentage of mean annual volume of streamflow, and selected flows to be maintained are in percentage of mean annual flow, so that the table may be used for other sites along the same stream. The figures for the Naugatuck and Housatonic Rivers have been adjusted

Table 4.--Lowest daily discharge not exceeded during indicated number of consecutive days at selected stream-gaging stations and year of occurrence

(For years beginning April 1 and periods of record ending March 1968)

Index no. (pl. B)	Stream-gaging station	Drainage area (sq mi)	Record began	1 day (cfs)	1 day (mgd per sq mi)	Year	7 days (cfs)	7 days (mgd per sq mi)	Year	15 days (cfs)	15 days (mgd per sq mi)	Year	30 days (cfs)	30 days (mgd per sq mi)	Year	60 days (cfs)	60 days (mgd per sq mi)	Year	120 days (cfs)	120 days (mgd per sq mi)	Year
1880	Burlington Brook near Burlington a/	4.12	Sept. 1931	0.34	0.053	1965	0.56	0.088	1964 1965	0.59	0.092	1964	1.2	0.19	1931	1.47	0.23	1965	2.80	0.44	1957
2040	Pomperaug River at Southbury	75.3	June 1932	3.3	.028	1966	5.7	.049	1944 1966	6.9	.059	1944	11	.094	1964	14	.12	1953	24	.21	1964
2048	Copper Mill Brook near Monroe	2.50	June 1958	.04	.010	1964	.06	.015	1964	.09	.023	1964	.18	.046	1966	.18	.046	1966	1.6	.41	1964
2055	Housatonic River at Stevenson	1,545	Aug. 1928	b/6	0	1930	164	.068	1962	248	.10	1964	432	.18	1957	755	.32	1964	869	.36	1964
2056	West Branch Naugatuck River at Torrington	33.4	Aug. 1956	.6	c/	1965	1.1	c/	1965	1.2	c/	1965	6.4	c/	1962	8.6	c/	1966	14	c/	1964
2057	East Branch Naugatuck River at Torrington	d/11.6	Aug. 1956	.8	.044	1957	1.3	.072	1957	2.1	.12	1964	4.3	.24	1962 1963	5.6	.31	1965	13	.72	1964
2060	Naugatuck River near Thomaston	71.9	Oct. 1930	9.5	.085	1957	14	.13	1957	16	.14	1957	25	.22	e/	31	.28	1931 1935	49	.44	1948
2064	Leadmine Brook near Harwinton	18.9	Feb. 1959	.3	.010	1964	.4	.014	1964	.6	.020	1964	2.0	.068	1964	4.3	.15	1965	9.3	.32	1964
2065	Leadmine Brook near Thomaston	24.0	Sept. 1930	.7	.019	1957	1.8	.048	1959	3.5	.094	1959	7.0	.19	1959	16.0	.43	1949	68	1.83	1959
2069	Naugatuck River at Thomaston	101	Oct. 1959	8.4	.054	1964	11	.070	1964	11	.070	1964	31	.20	1965	44	.28	1964	49	.31	19
2085	Naugatuck River at Beacon Falls	246	Sept. 1928	40	.10	1930 1936	50	.13	1930	62	.16	1931	80	.21	1931	93	.24	1931	151	.40	1930

a/ Situated outside lower Housatonic River basin but close to it.

b/ Regulated.

c/ Diversion for municipal supply of city of Torrington

d/ Drainage area downstream from Lake Winchester.

e/ 1931, 1935, 1947, 1948, and 1957.

Table 5.--Lakes, ponds, and reservoirs

Index no. (pl. B)	Name and location	Source of data 1/	Artificial (A); natural, modified (N,M)	Drainage (sq mi)	Water surface (acres)	Water surface Elevation (ft)	Depth Maximum (ft)	Depth Average (ft)	Storage Total (ft)	Storage Usable (ft)	Storage Maximum amount release during water year 1966 (mg)	Use
2035.3	Lockwood Reservoir near Bethlehem	W	A	1.35	75	550	25	11	268	268	131	Public water supply
2036.49	Long Meadow Pond at Bethlehem	FG	A	1.55	110	894	7	4.2	150	150	25	Recreation
2050	Lake Zoar at Stevenson	CLP	A	1,545	1,053	93	78	27.6	9,470	2,476	640	Power, recreation
2055.09	Lake Quassapaug near Middlebury	FG	N,M	1.92	271	695	65	28.5	2,471	-	90	Recreation
2055.45	Lake Housatonic at Derby	FG	A	1,531	328	24	26	9.4	1,000	-	-	Power, Industry, recreation
2055.6	Hall Meadow Brook Reservoir near Torrington	CE	A	11.9	372	838	48	23.2	2,605	2,605	5.2	Flood control, recreation
2055.7	North Pond at North Goshen	T	A	.90	182	1,464	18	12.8	760	-	-	Public water supply
2055.8	Reuben Hart Reservoir near Goshen	T	A	5.00	126	910	47	18.3	750	750	-	Public water supply
2055.82	Hart Brook Reservoir near Goshen	T	A	.05	1	835	14	10.7	3.5	-	-	Not used
2055.86	Whist Pond near Goshen	T	N,M	.22	41.5	1,155	-	15.5	210	-	-	Public water supply
2055.9	Stillwater Pond at West Torrington	FG	A	24.2	55	735	26	11.7	365	365	14	Industry, recreation
2055.93	Allen Dam Reservoir at West Torrington	T	A	3.75	2.8	784	-	3.8	3.5	3.5	-	Public water supply
2055.94	Crystal Lake at West Torrington	T	A	4.05	6.4	723	-	8.6	18	-	-	Not used
2056.1	Lake Winchester at Winchester	FG	A	2.23	237	1,249	16	9.2	712	712	255	Industry, recreation
2056.2	Park Pond at Winchester	FG	A	.50	76.7	1,135	15	10.6	265	-	8	Recreation
2056.5	East Branch Reservoir near Torrington	CE	A	9.11	158	665	67	27.5	1,414	1,414	.8	Flood control, recreation
2066	Thomaston Reservoir near Thomaston	CE	A	93.0	950	494	114	44.2	13,690	13,690	2.2	Flood control
2068	Plymouth Reservoir at Plymouth	Tv	A	.56	37	692	-	7.7	93	-	-	Public water supply
2069.2	Northfield Pond at Northfield	FG	A	2.33	27.9	685	8	2.8	25.4	-	-	Recreation
2069.3	Nystrom Pond at Northfield	FG	A	.20	20.3	908	13	9.5	62.7	62.7	6.7	Recreation
2069.4	Northfield Brook Reservoir near Thomaston	CE	A	5.7	67	576	56	35.3	763	763	29.2	Flood control, recreation
2070	Pitch Reservoir near Thomaston	WY	A	5.39	111	727	65	39.0	1,414	1,415	210	Public water supply
2075	Morris Reservoir near Thomaston	WY	A	12.8	152	652	87	40.0	1,982	1,982	324	Public water supply
2080	Wigwam Reservoir near Thomaston	WY	A	17.3	105	560	-	21.2	737	737	12	Public water supply
2081.3	Hancock Brook Reservoir near Waterbury	CE	A	11.9	266	484	30	15.2	1,272	1,272	0	Flood control, recreation
2081.55	Lake Winnemaug near Watertown	FG	A	1.27	122	661	16	9.9	392	392	59	Industry, recreation
2081.79	Cedar Swamp Pond near Bristol	S	A	.84	139	891	13	8.2	370	370	-	Industry
2082.39	Scovill Reservoir at Woodtick	S	A	7.90	139	530	28	7.8	353	353	-	Industry
2082.49	Hitchcock Lake near Woodtick	S	A	.51	112	674	12	7.4	272	272	-	Industry
2082.79	Chestnut Hill Reservoir near Wolcott	S	A	1.44	78	637	32	17.6	447	447	-	Industry
2084.29	Long Meadow Pond near Middlebury	FG	N,M	3.42	113	599	9	4.4	179	161	37	Recreation
2084.56	New Naugatuck Reservoir near Straitsville	N	A	1.66	69.3	534	-	18.0	506	-	1	Public water supply
2084.6	Old Naugatuck Reservoir near Straitsville	N	A	2.43	33.0	630	-	31.2	335	-	-	Public water supply
2087.1	Swan Lake near Oxford	FG	A	.59	30.5	340	13	8.1	80.6	80.6	11	Recreation
2087.3	Peat Swamp Reservoir near Ansonia	A	A	.45	82.6	340	-	20.0	537	-	-	Public water supply
2088.1	Trap Falls Reservoir near Huntington	A	A	1.09	344	315	-	22.0	2,464	2,464	450	Public water supply
2088.2	Beaver Dam Lake near Nichols	FG	A	2.24	58.4	173	44	21.8	415	415	20	Recreation

1/ Chiefly from (A) Ansonia Water Co., (CE) Corps of engineers, (CLP) Connecticut Light and Power Co., (FG) State Board of Fisheries and Game, (N) Naugatuck Water Co., (S) Scovill Manufacturing Co., (T) Torrington Water Co., (Tv) Terryville Water Co., (W) Watertown Fire District, (WY) City of Waterbury.

for estimated low-flow augmentation. Table 7 includes selected flows to be maintained that are 60 percent or less of the long-term average flow (which is approximately equal to the smallest annual mean flow) to increase the likelihood that the storage withdrawn would refill during the year. The figures in this table were determined from frequency-mass curves based on low-flow frequency relationships for each gaging station (Riggs, 1964), and an example is given on the table to illustrate its use in estimating storage required.

A regional relation for storage required to maintain flows at other sites in the study area is given in table 8, and an example is given in the table to illustrate its use. The data are presented for various percentages of median 7-day annual minimum flow (2-year recurrence interval) referred to the long-term mean annual flow, so that they may be applied to sites for which these flow characteristics have been estimated. Estimates of flow characteristics for many sites in the basin are given on plate B. If plate B gives insufficient information for interpolation of the low-flow characteristics, it is necessary to make a few base-flow discharge measurements at the site, preferably during a significant drought, and correlate them with concurrent discharges at one of the long-term gaging stations, where the median 7-day annual minimum flow has been determined. A good estimate of the long-term mean annual flow at any site may be taken from the runoff ratio map, figure 14.

The storage-required values in tables 7 and 8 are slightly smaller than the true ones because they include a bias of about 10 percent that results from approximations used in the frequency-mass computation and because losses due to evaporation and seepage are not included. These values are sufficiently accurate, however, for reconnaissance planning and for the selection of a proposed site.

FLOODS

History

Floods have occurred in the basin during every month, at one time or another. Spring floods, the most common, usually result from the combined effects of snowmelt and rain; those of late summer and fall are commonly the result of hurricanes or coastal storms.

Since the late 17th century, there have been at least 17 major floods in the basin. The earliest of these, in February 1691, in Waterbury, eroded part

Table 6.--Maximum safe draft rates (regulated flows) from selected lakes, ponds, and reservoirs, reference period April 1930 to March 1960

(Lakes, ponds, and reservoirs will refill within a year.)

Index no. (pl. B)	Name and location	Drainage basin	Drainage area (sq mi)	Total usable storage (mg)	Maximum safe draft rate (mgd) during years of low-flow conditions with recurrence interval of 10 yrs	of 20 yrs	Storage used at recurrence interval of 10 yrs. (mg)	of 20 yrs. (mg)
2035.3	Lockwood Reservoir near Bethlehem	East Spring Brook	1.35	268	1/0.97	1/0.97	147	159
2036.49	Long Meadow Pond at Bethlehem	Weekeepeemee River	1.55	150	.94	.94	150	150
2050	Lake Zoar at Stevenson	Housatonic River	1,545	2,476	173	158	2,476	2,476
2055.8	Reuben Hart Reservoir near Goshen	Hart Brook	5.00	750	1/3.8	1/3.8	580	626
2055.9	Stillwater Pond at West Torrington	West Branch Naugatuck River	24.2	365	4.1	3.7	365	365
2056.1	Lake Winchester at Winchester	East Branch Naugatuck River	2.23	712	1/1.2	1/1.2	187	202
2066	Thomaston Reservoir near Thomaston	Naugatuck River	98.0	13,690	1/75.6	1/75.6	11,500	12,400
2069.3	Nystrom Pond at Northfield	Turner Brook	.20	62.7	1/.09	1/.09	14	15
2070	PitchReservoir near Thomaston	Pitch Brook	5.39	1,414	1/6.1	1/6.1	922	995
2081.55	Lake Winnemaug near Watertown	Wattles Brook	1.27	392	1/8.4	1/8.4	128	138
2082.79	Chestnut Hill Reservoir near Wolcott	Old Tannery Brook	1.44	447	1/.67	1/ .67	101	109
2084.29	Long Meadow Pond near Middlebury	Long Meadow Pond Brook	3.42	161	1.3	1.2	161	161
2087.1	Swan Lake near Oxford	Little River	.99	80.6	.55	.52	81	81
2088.1	Trap Falls Reservoir near Huntington	Pumpkin Ground Brook	1.09	2,464	1/.80	1/.80	122	132

1/ Maximum safe regulated flow limited to 60 percent of mean annual flow (the smallest annual mean flow)

Table 7.--Storage required to maintain selected regulated flows at long-term stream-gaging stations (Reference period April 1930 to March 1960)

Index no. (pl. B)	Stream-gaging station	Drainage area (sq mi)	Recurrence interval of annual low flow (years)	Indicated flow (in percent of mean annual flow) to be maintained: 10	15	20	25	30	35	40	45	50	55	60
				Storage required (in percent of mean annual volume) to maintain indicated flow										
1880	Burlington Brook near Burlington	4.12	10	0.1	0.6	1.7	3.3	5.2	7.4	9.7	12.4	14.8	17.8	20.8
			20	.1	.9	2.3	4.2	6.6	9.5	12.4	15.4	18.5	21.6	25.5
2040	Pomperaug River at Southbury	75.3	10	.5	1.7	3.2	5.0	7.2	9.7	12.3	15.1	17.8	20.9	24.0
			20	.8	2.2	4.1	6.2	8.7	11.6	14.6	17.6	20.8	24.2	27.4
2055	Housatonic River at Stevenson	1,545	10	1/.1	.7	2.1	3.8	5.8	8.0	10.5	13.0	15.7	18.2	20.5
			20	1/.3	1.1	2.6	4.6	7.1	9.6	12.5	15.0	17.6	20.0	22.4
2060	Naugatuck River near Thomaston	71.9	10	1/.6	2.2	4.3	6.4	8.7	11.0	13.6	16.1	18.5	21.3	24.4
			20	1/1.1	3.0	5.1	7.6	10.2	12.7	15.3	17.9	20.2	22.8	25.7
2065	Leadmine Brook near Thomaston	24.0	10	1.7	3.3	5.3	7.4	9.9	12.3	14.8	17.5	19.8	22.6	25.1
			20	2.1	4.1	6.4	8.9	11.6	14.3	16.8	19.3	21.4	24.1	26.5
2085	Naugatuck River at Beacon Falls	261	10	1/.6	1.8	3.6	5.7	8.3	10.8	13.4	16.0	19.0	22.1	25.4
			20	1/.8	2.4	4.2	6.5	9.2	12.0	14.9	17.8	21.0	25.0	28.6

1/ Adjusted for estimated low-flow augmentation.

Example: If at Burlington Brook the flow is equal to the 10-year recurrence interval low flow, then storage required to maintain 30 percent of the mean annual flow in cfs would be 5.2 percent of the mean annual volume in cfs-days. See plate B for low-flow characteristic values.

of the meadows. Of similar magnitude was the widespread "Jefferson flood" of March 1801, which tore out all the bridges on the Naugatuck River. Many major floods followed in the next 100 years, including those in 1841, 1853, 1854, 1869, 1874, 1878, 1896, and 1900.

General descriptive information concerning 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 by Grover (1937), Paulsen and others (1940), U.S. Geological Survey (1947), and Bogart (1960). A compilation of all flood peaks above selected magnitudes for continuous-record gaging stations within the basin is given by Green (1964).

A quantitative summary of major floods on the Naugatuck River at Beacon Falls, based on continuous streamflow records since June 1918, appears in table 9. The first flood, that of April 7, 1924, was the highest at Waterbury since 1896. The "Vermont flood" of November 4, 1927, was the biggest since the famous flash flood of June 28, 1869, when 13 inches of rain fell in 2 hours. Up to August 19, 1955, the all-time record flood in 278 years had been that of December 31, 1948. The August 1955 flood had 3.7 times the peak discharge and about twice the height of the 1948 flood. On October 16, 1955, scarcely 2 months later, occurred the second-largest flood in the 278-year period.

The likelihood of major floods has been considerably reduced by a program of flood control in the basin. The Thomaston flood-control reservoir, operated by the U.S. Corps of Engineers at the mouth of Leadmine Brook on the Naugatuck River, was completed in December 1960 and has a usable capacity of 13,690 million gallons. Smaller flood-storage reservoirs operated by the Corps and their completion dates are: Northfield Brook detention reservoir on Northfield Brook (1965), Hancock Brook detention reservoir on Hancock Brook (1965), Hop Brook detention reservoir on Hop Brook (1968), and Black Rock detention reservoir on Branch Brook (1970). The Park and Forest Commission of the Connecticut Department of Agriculture and Natural Resources operates a detention reservoir on the East Branch of the Naugatuck River (since 1964) and on Hall Meadow Brook (since 1962). Completion of the system of reservoirs in the basin would reduce a peak like that of the August 1955 flood (106,000 cfs at Naugatuck River at Beacon Falls) by approximately two thirds, to about 38,000 cfs (U.S. Corps of Engineers, written commun., 1968).

Table 8.--Storage required to maintain selected flows at sites on unregulated streams

(Data are adjusted to the reference period April 1930 to March 1960. Storage estimate uncorrected for reservoir seepage, evaporation, and for computational bias, all of which increase the amount of storage required.)

	Median 7-day annual minimum, in percent of mean annual flow	Indicated flow (in percent of mean annual flow) to be maintained										
		10	15	20	25	30	35	40	45	50	55	60
		Storage required (in percent of mean annual volume) to maintain indicated flow										
10-year recurrence interval of annual lowest mean flow	2	1.8	3.3	5.3	7.4	10	12	15	18	20	23	25
	3	1.6	3.2	5.2	7.3	9.8	12	15	18	20	23	25
	4	1.3	3.0	4.9	6.9	9.4	12	14	17	20	23	25
	5	1.0	2.6	4.4	6.4	8.8	11	14	17	19	22	25
	6	.8	2.2	3.9	5.8	8.2	11	13	16	19	22	25
	7	.6	1.9	3.5	5.3	7.6	10	13	16	18	21	24
	8	.5	1.6	3.1	4.9	7.1	9.6	12	15	18	21	24
	9	.4	1.4	2.7	4.5	6.6	9.0	12	14	17	20	23
	10	.3	1.1	2.4	4.1	6.1	8.5	11	14	16	19	22
	11	.2	.9	2.1	3.7	5.7	8.0	10	13	16	19	22
	12	.1	.7	1.8	3.4	5.4	7.6	10	13	15	18	21
	13	.1	.5	1.6	3.2	5.0	7.2	9.5	12	14	18	21
20-year recurrence interval of annual lowest mean flow	2	2.2	4.1	6.4	8.9	12	14	17	19	22	24	27
	3	2.0	4.0	6.4	8.8	12	14	17	19	22	24	27
	4	1.7	3.7	6.0	8.4	11	14	17	19	22	24	27
	5	1.4	3.3	5.5	7.8	10	13	16	19	22	24	27
	6	1.2	2.9	5.0	7.2	9.8	13	16	19	21	24	27
	7	1.0	2.5	4.5	6.6	9.2	12	15	18	21	24	27
	8	.8	2.1	4.0	6.1	8.6	12	15	18	21	24	27
	9	.6	1.8	3.6	5.6	8.1	11	14	17	20	24	27
	10	.4	1.5	3.2	5.2	7.6	11	14	16	20	23	26
	11	.3	1.3	2.8	4.8	7.2	10	13	16	19	23	26
	12	.2	1.0	2.5	4.4	6.8	9.7	13	16	19	22	26
	13	.1	.8	2.2	4.0	6.4	9.4	12	15	18	21	25

Example: If at a site on an unregulated stream the flow is equal to the 10-year recurrence interval low flow, and the median 7-day annual minimum flow at the site is 10 percent of the mean annual flow in cfs, then storage required to maintain 30 percent of the mean annual flow in cfs would be 6.1 percent of the mean annual volume in cfs-days. See plate B for low-flow characteristic values.

Table 9.--Notable floods of record
(Stage of peaks, in feet above mean sea level and corresponding flows of record)

Index no. (pl. B)	Stream-gaging station	March 12, 1936		January 25, 1938		September 21, 1938		December 31, 1948		August 19, 1955		October 16, 1955	
		Stage (ft)	Flow (cfs)	Stage (ft)	Flow (cfs)	Stage (ft)	Flow (cfs)	Stage (ft)	Flow (cfs)	Stage (ft)	Flow (cfs)	Stage (ft)	Flow (cfs)
2040	Pomperaug River at Southbury	179.73	5,990	179.72	5,980	181.60	7,420	179.22	5,600	187.40	29,400	181.35	8,860
2055	Housatonic River at Stevenson	48.48	69,500	41.78	36,000	46.48	59,500	44.95	51,800	48.41	69,400	49.48	75,800
2060	Naugatuck River near Thomaston	398.81	6,590	399.01	6,830	401.33	9,970	401.47	10,200	413.44	41,600	399.74	8,100
2065	Leadmine Brook near Thomaston	411.66	4,830	411.58	4,700	412.37	6,050	411.86	5,150	414.33	10,400	410.83	3,080
2085	Naugatuck River at Beacon Falls (near Naugatuck)1/	167.13	23,300	166.41	20,300	167.57	25,300	167.57	28,500	180.87	106,000	168.87	30,400

1/ On April 7, 1924, elevation was 167.25 ft, flow 21,900 cfs; on Nov. 4, 1927, elevation was 169 ft, flow 26,000 cfs.

Table 10.--Maximum floods of record and mean annual floods

Index no. (pl. B)	Stream-gaging station	Drainage area (sq mi)	Period of continuous record	Maximum flood of record					Mean annual flood		
				Elevation		Flow		Ratio to mean annual flood	Elevation (ft above msl)	Flow	
				Date	(ft above msl)	(cfs)	(cfs per sq mi)			(cfs)	(cfs per sq mi)
2035.1	Pootatuck River at Sandy Hook	24.2	1966-67	3- 1-66	228.25	860	36	-	-	-	-
2036	Nonewaug River at Minortown	17.2	1963-67	7-21-63	359.36	1,490	87	1.24	358.89	1,200	69.8
2037	Wood Creek near Bethlehem	3.37	1961-67	2- 8-65	-	140	42	.78	-	180	53.4
2040	Pomperaug River at Southbury	75.3	1933-67	8-19-55	187.40	29,400	390	10.89	174.83	2,700	35.9
2048	Copper Mill Brook near Monroe	2.50	1959-67	3-12-62	337.47	330	132	2.06	335.09	160	64.0
2055	Housatonic River at Stevenson	1,545	1929-67	10-16-55	49.48	75,800	49	3.61	38.37	21,000	13.6
2056	West Branch Naugatuck River at Torrington	33.4	1957-61 1/	9-12-60	551.00	3,600	108	1.64	549.79	2,200	65.9
2057	East Branch Naugatuck River at Torrington	13.8	1957-62 1/	3- 6-59	543.59	1,130	82	1.13	543.34	1,000	72.5
2060	Naugatuck River near Thomaston	71.9	1931-59 1/	8-19-55	413.44	41,600	578	11.56	396.17	3,600	50.1
2064	Leadmine Brook near Harwinton	18.9	1960-67	6- 4-60	522.71	1,520	80	1.22	522.00	1,250	66.1
2065	Leadmine Brook near Thomaston	24.0	1931-59 1/	8-19-55	414.33	10,400	433	5.78	409.07	1,800	75.0
2081	Hancock Brook near Terryville	1.20	1960-67	9-12-60	-	130	108	1.30	-	100	83.3
2084	Hop Brook near Middlebury	9.04	1961-67	3-12-62	-	800	88	1.27	-	630	69.7
2085	Naugatuck River at Beacon Falls (near Naugatuck)	261	1919-24, 1929-67 1/	8-19-55	180.87	106,000	406	11.78	162.61	9,000	34.5
2087	Little River at Oxford	4.60	1961-67	3-12-62	-	400	87	1.43	-	280	60.9

1/ Subsequently affected by flood-control reservoirs. (See "Floods" in text.)

Magnitude and frequency

Knowledge of the magnitude and frequency of floods is essential for the location and establishment of encroachment lines. The maximum flood and mean annual flood of record at gaging stations in the lower Housatonic River basin are given in table 10. Estimates of the flood flow at any other site can be made from figures 15 and 16, provided that (1) the stream is unregulated, (2) it drains a rural area,and (3) the drainage area is known. The mean annual flood can be found from figure 15, and flows for any other recurrence interval up to 100 years are obtainable by multiplying the value for the mean annual flood by the appropriate ratio from figure 16.

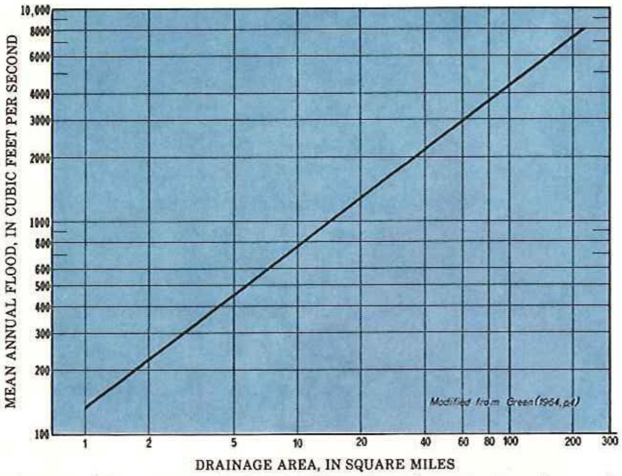


Figure 15.--Mean annual flood related to size of drainage area.

FREQUENCY AND DURATION OF HIGH FLOWS

Table 10 and figures 15 and 16 delineate the recurrence of instantaneous peak discharges. For some purposes, however, it is also useful to estimate how long periods of high flow may last and how frequently the periods may recur. Table 11 presents the recurrence intervals of annual highest average flows observed for various numbers of consecutive days in the reference period, 1931-60, at long-term gaging stations. For example, at Pomperaug River at Southbury, for a period of 30 consecutive days an average flow of 630 cfs occurred on the average once in 10 years; thus there is a 10 percent chance of a 30-day average flow of this magnitude in any one year.

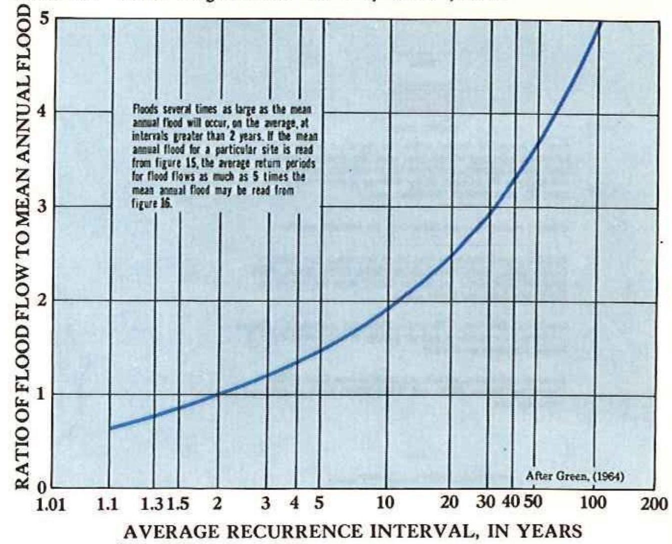


Figure 16.--Flood-magnitude frequency curve.

Table 11.--Annual highest average flows and corresponding average elevations for indicated recurrence intervals at long-term stream-gaging stations, reference period October 1930 to September 1960

Index no. (pl. B)	Stream-gaging station	Drainage area (sq mi)	Period (consecutive days)	Annual highest average flow (cfs) for indicated recurrence interval (years)						Annual highest elevation (ft above msl) for indicated recurrence interval (years)					
				1.03	2	5	10	25	50	1.03	2	5	10	25	50
2040	Pomperaug River at Southbury	75.3	1	800	1,200	2,200	4,000	8,200	13,400	171.3	172.1	173.9	176.9	182.6	188.4
			3	500	800	1,400	2,200	3,700	5,300	170.6	171.3	172.5	173.9	176.5	178.8
			7	380	550	970	1,360	1,890	2,300	170.2	170.7	171.6	172.4	173.4	174.1
			15	280	410	700	950	1,130	1,180	169.9	170.3	171.0	171.6	171.9	172.0
			30	210	320	480	630	830	1,000	169.6	170.0	170.5	170.9	171.3	171.7
			60	160	270	350	410	530	660	169.4	169.9	170.1	170.3	170.6	171.0
			150	110	210	260	300	320	330	169.1	169.6	169.8	170.0	170.0	170.1
			274	70	160	200	220	250	260	168.8	169.4	169.6	169.7	169.8	169.8
2055	Housatonic River at Stevenson	1,545	1	8,100	14,000	26,000	52,000	62,000	66,000	33.7	36.1	39.7	45.3	47.1	47.8
			3	7,500	12,500	21,000	39,000	42,000	44,000	33.4	35.5	38.3	42.7	43.3	43.7
			7	6,500	10,000	18,000	27,000	28,600	29,600	32.9	34.5	37.5	39.9	40.3	40.6
			15	5,000	8,500	14,000	17,500	21,400	24,000	32.1	33.9	36.1	37.3	38.4	39.2
			30	3,400	7,000	9,600	11,500	14,300	16,800	31.0	33.2	34.4	35.1	36.2	37.1
			60	2,800	5,700	7,300	8,200	9,300	10,200	30.6	32.5	33.4	33.8	34.2	34.6
			150	2,300	4,300	5,200	5,700	6,200	6,600	30.2	31.6	32.2	32.5	32.8	33.0
			274	1,800	3,000	3,900	4,300	4,800	5,000	29.7	30.7	31.4	31.6	32.0	32.1
2060	Naugatuck River near Thomaston	71.9	1	940	1,650	2,500	5,700	11,800	24,000	392.7	393.8	394.9	398.0	401.9	407.4
			3	700	1,000	1,750	3,600	5,900	7,500	392.2	392.8	394.0	396.1	398.1	399.3
			7	400	700	1,300	2,100	2,900	3,450	391.5	392.2	393.3	394.4	395.4	396.0
			15	280	530	880	1,250	1,580	1,780	391.2	391.9	392.6	393.2	393.7	394.0
			30	230	410	630	820	1,000	1,100	391.0	391.5	392.1	392.5	392.8	393.0
			60	170	320	430	510	620	700	390.8	391.3	391.6	391.8	392.1	392.2
			150	130	240	310	330	370	380	390.6	391.0	391.3	391.3	391.4	391.4
			274	90	180	220	250	280	290	390.5	390.8	390.9	391.0	391.2	391.2
2065	Leadmine Brook near Thomaston	24.0	1	320	580	1,520	2,160	3,250	4,800	406.3	407.2	409.1	409.9	410.9	412.0
			3	210	360	720	1,200	1,600	1,840	405.9	406.5	407.6	408.6	409.2	409.5
			7	140	260	420	680	840	900	405.5	406.1	406.7	407.4	407.8	408.0
			15	110	190	290	420	460	490	405.4	405.8	406.2	406.7	406.8	406.9
			30	73	142	200	250	320	375	405.1	405.6	405.8	406.1	406.3	406.5
			60	64	109	145	169	200	225	405.0	405.4	405.6	405.7	405.8	406.0
			150	48	82	98	110	124	132	404.9	405.2	405.3	405.4	405.4	405.5
			274	32	61	76	84	94	100	404.6	405.0	405.1	405.2	405.3	405.3
2085	Naugatuck River at Beacon Falls	261	1	2,600	5,000	6,600	20,000	45,000	87,000	123.4	125.4	126.4	131.5	136.8	141.6
			3	1,800	3,000	5,000	9,400	20,000	34,000	122.6	123.8	125.4	127.9	131.5	134.8
			7	1,300	2,000	3,600	5,600	9,800	14,700	122.0	122.8	124.3	125.8	128.1	129.9
			15	1,000	1,600	2,500	3,530	5,300	7,000	121.5	122.3	123.3	124.3	125.6	126.6
			30	720	1,220	1,890	2,500	3,310	4,000	121.0	121.8	122.7	123.3	124.1	124.6
			60	620	1,050	1,340	1,600	2,100	2,600	120.8	121.6	122.0	122.3	122.9	123.4
			150	430	800	1,000	1,110	1,220	1,300	120.4	121.2	121.5	121.7	121.8	122.0
			274	310	600	750	850	960	1,040	120.1	120.8	121.1	121.3	121.5	121.6

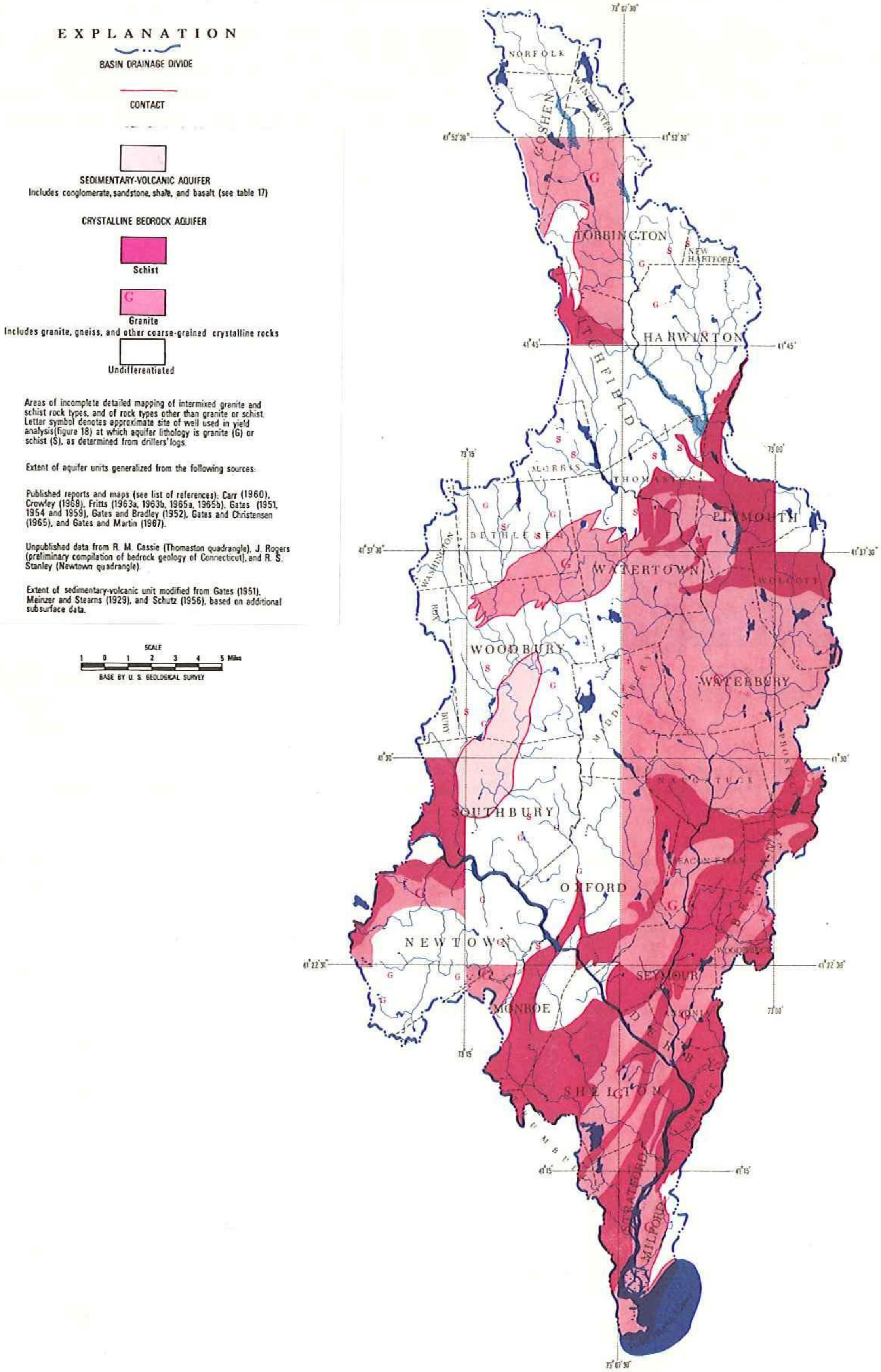


Figure 17.--Bedrock aquifers in the basin.

GROUND WATER

An unseen but important part of the hydrologic cycle occurs underground, where ground water moves through earth materials from areas of recharge to areas of discharge. These earth materials--unconsolidated sediments and the underlying bedrock--constitute the hydrogeologic framework for both the movement and storage of ground water. Optimum development and management of this resource requires an understanding of the characteristics of this framework, a knowledge of the amounts of water potentially available, and an understanding of the functioning of the ground-water system in relation to the total hydrologic system.

THE HYDROGEOLOGIC FRAMEWORK

The physical framework for the movement and storage of ground water in the lower Housatonic River basin consists of aquifers and streambed deposits. Each of the three aquifers in the basin--stratified drift, till, and bedrock--has characteristics and water-bearing properties that determine its usefulness as a source of supply. Streambed deposits are the transmitting medium between surface-water bodies and aquifers. As such, they may significantly affect the degree to which ground-water supplies can be augmented by induced infiltration of surface water.

STRATIFIED DRIFT

Occurrence and description

Stratified drift is the most productive aquifer in the lower Housatonic River basin, although it occupies only about 16 percent of the basin area. It consists of layers of sand and gravel and lesser amounts of silt and clay deposited by glacial meltwaters. It occurs almost exclusively as narrow belts in stream valleys and lowlands (plate C). Maximum width of the aquifer is generally less than 2 miles, and in much of the basin it is less than half a mile.

Much of the aquifer is heterogeneous, with many abrupt horizontal and vertical changes in texture. This heterogeneity contributes to difficulties in ground-water exploration and in aquifer analysis. Nevertheless, stratified drift in the Naugatuck River valley and in upland tributaries in the basin contains much coarse material, and in many areas it is highly productive.

Stratified drift composed of fine sand and sandy silt is commonly broader, thicker, and more uniform in texture that that composed chiefly of coarser sand and gravel. In the Pomperaug valley, the sites of old glacial lakes (Pessl, 1970) are underlain by fine-grained lacustrine and deltaic deposits that are poorly suited for development by screened wells; they adjoin coarse-grained deposits capable of yielding large quantities of water to screened wells.

Near the mouth of the Housatonic River, fine sand, organic silt, and peat were deposited as outwash and estuarine deposits. The predominance of these fine-grained deposits in the estuary greatly reduces the potential for the development of ground water--fresh or salty--in the area.

Aquifer boundaries

Most stratified drift in the basin was deposited in valleys and lowlands on bedrock or till-mantled bedrock. The stratified drift is therefore bounded laterally and at its base by these more impervious materials. Although water moves through till and bedrock into the stratified drift, its rate of movement is commonly slower in the boundary materials. Thus, the boundaries between the till-bedrock and stratified drift act as barriers that restrict well yields from the stratified-drift aquifer.

Streams traversing the valley floors may form recharge boundaries to the stratified-drift aquifer. In such places, pumping from wells will reverse the natural ground-water discharge to streams and induce water in the channels to infiltrate the stratified drift. Aquifer-stream relationships and the effectiveness of streams as recharge boundaries in the lower Housatonic River basin are discussed in the section, "Induced Infiltration."

Thickness

The thickness of the stratified-drift aquifer is an important factor in determining well yield. Where other factors, such as texture, are equal, a thick aquifer will produce more than a thin one, because of its greater capability for transmitting water, greater available drawdown, and greater amount of water in storage. Aquifer thickness generally ranges widely, from about 10 feet in many small valleys and at the sides of larger ones, to 200 feet in the Housatonic River valley. The maximum thickness at any data control point is 216 feet, at well SH 8. (See table 12.)

Saturated thickness is determined largely from descriptive logs of wells and test borings; in many logs it is difficult to distinguish stratified drift from underlying till, and thus the entire saturated section was contoured (pl. C). However, at most sites the till is probably thin (5 feet or less) or absent, and so in most valleys the saturated-thickness lines closely approximate the thickness of the stratified-drift aquifer.

The thickness of the stratified-drift aquifer is influenced by the configuration of the underlying bedrock surface. Commonly, bedrock is deeper at the center of a valley than at the sides; therefore surficial aquifers are usually thickest near valley centers. The greatest thickness seldom coincides with the course of the stream at the surface.

A longitudinal profile along the thalweg, or deepest part of the underlying bedrock valley, indicates that the bedrock surface in the area commonly forms a series of alternating shallow

Table 12.--Transmissivity of the stratified-drift aquifer from specific capacities, logs, and pumping tests of screened wells

(Well locations and explanation of well-numbering system on plate A. Additional well-construction and test data listed in companion basic-data report, Grossman and Wilson, 1970.)

Well radius: actual radius of well screen is listed throughout. However for purposes of analysis, effective well radius of gravel-packed wells is assumed to be 3 inches greater than actual radius of screen.

Aquifer thickness: assumed to be full thickness of saturated stratified drift except where it is overlain by saturated silt, muck, or peak, in which case the thickness of the fine-grained deposits is not included, and artesian conditions are assumed for the test.

Proportion of aquifer screened: screen length divided by aquifer thickness.

Duration of test: where unknown, assumed to be 1.0 day for purposes of analysis.

Drawdown, adjusted: reported drawdowns adjusted for the effects of partial penetration using a method described by Walton (1962, p. 7). A 1:10 ratio of vertical to horizontal aquifer hydraulic conductivity is assumed.

Specific capacity: pumping rate divided by drawdown.

Transmissivity, estimated from adjusted specific capacity: determined by graphic methods described by Meyer (1963, p. 338). For water-table conditions, the storage coefficient, S, assumed to be 0.10 where t = 2.0 days, and 0.20 where t = 2.0 days. For artesian conditions, S assumed to be 0.001. Transmissivity values rounded to 2 significant figures.

Transmissivity, estimated from logs: see text for discussion of method. < , greater than; > , less than.

Remarks: PL - pumping level.

Well no.	Well radius (in)	Screen only, S, gravel pack, Sg	Aquifer thickness (a, artesian conditions assumed) (ft)	Proportion of aquifer screened	Duration of test, t (days)	Pumping rate, Q (gpm)	Drawdown (ft) Reported	Drawdown (ft) Adjusted	Specific capacity (gpm/ft) From reported drawdown	Specific capacity (gpm/ft) From adjusted drawdown	Transmissivity, T (ft²/day) From adjusted specific capacity	Transmissivity, T (ft²/day) From well log	Remarks
						Town of Derby							
DE 3	8	Sg	47	0.19	2.0	575	23	7.8	25	74	13,000	28,000	Variable Q during test.
DE 4	3	Sg	87a	.09	2.0	60	28	4.2	2.1	14	4,000	4,600	Pumped simultaneously with DE 5.
DE 5	3	Sg	87a	.09	1.0	60	17	2.6	3.5	23	6,800	4,600	Pumped simultaneously with DE 4. Test no. 1, pumped 60 gpm for 1 day, then test no. 2, 92 gpm for 1 more day.
					2.0	92	27	4.0	3.4	23	6,800		
DE 6	4	S	51	.24	.4	160	19.6	6.9	8.2	23	5,200	6,800	
DE 7	6	Sg	59	.22	2.0	870	28	9.8	31	89	24,000	12,000	Initial Q = 1,000 gpm; cut back to 870 gpm after 28 hours.
						Town of Milford							
MI 1	6	Sg	49	.31	2.0	348	41	19.3	8.5	18	3,400	2,700	
MI 2	6	S	33	.24	2.0	302	21	8.6	14	35	7,000	3,500	Log indicates well is screened at 29-37 ft opposite "silt and clay."
						Town of Monroe							
MO 41	5	Sg	26a	.19	2.0	150	39	14.0	3.8	11	2,900	1,300	
MO 42	3	S	23a	.35	.4	33	16.1	8.0	2.0	4.1	1,100	2,000	
MO 43	3	S	31a	.16	.2	30	16.6	4.3	1.8	7.0	2,000	2,100	
MO 44	3	S	22a	.23	.4	55	14.6	5.2	3.7	11	2,800	2,900	
						Town of Naugatuck							
NA 16	6	Sg	73	.15	-	371	68(?)	17.0	5.4	22	4,200	4,000	Also U.S.G.S. test, 1967: Q = 235; t = 85.5; drawdowns measured in NA 9, 10, and 11: T from pumping test, 3,350ft²/day; see Grossman and Wilson (1970, table 5), for complete data.
NA 22	8	Sg	90	.22	-	1,220	11	3.7	110	330	> 27,000	11,000	
NA 23	8	Sg	100	.18	-	1,200	10.8	2.9	110	410	> 27,000	23,000	
NA 24	8	S	85	.24	-	508	63.5	22.9	8.0	22	4,200	11,000	Test no. 1, pumped 508 gpm.
					-	471	59	21.2	8.0	22	4,200	-	Test no. 2, pumped 471 gpm.
NA 29	8	Sg	86	.23	-	1,137	11.5	4.1	99	280	> 27,000	17,000	
NA 31	6	Sg	48	.31	-	270	39	18.7	6.9	14	2,500	4,200	Also U.S.G.S. test, 1967: Q = 189; t = 85; drawdowns measured in NA 9, 10, and 11; see Grossman and Wilson (1970, table 5), for complete data.
NA 35	8	Sg	105	.19	-	1,025	48	13.9	21	74	15,000	15,000	
NA 36	4	Sg	102	.10	-	200	90	14.4	2.2	14	2,800	-	
NA 37	5	S	15a	1.00	1.0	140	25	25.0	5.6	5.6	800	1,000	
NA 38	5	S	53	.28	1.0	350	25.1	9.8	13	36	7,400	5,600	NA 39 pumping during test. PL in screen.
NA 39	5	S	47	.32	1.0	175	33.5	15.4	5.2	11	2,300	2,400	NA 38 pumping during test.
NA 40	5	S	54	.19	1.0	200	22	5.9	9.1	34	7,000	6,200	NA 38 pumping during test?
						Town of Newtown							
NT 11	9	Sg	84	.26	2.0	725	50	20.0	14	36	6,400	7,400	
NT 12	9	Sg	105	.19	4.0	725	33.7	10.1	21	72	13,000	24,000	
NT 14	3	Sg	47	.21	.3	> 40	15	4.9	2.7	8.2	1,600	480	
						Town of Oxford							
OX 2	8	Sg	34	.35	-	500	30	17.1	17	29	5,400	-	PL in screen.
OX 3	6	S	21a	.67	-	300	50	45.0	6.0	6.7	1,700	11,000	Test no. 1 (1957), pumped 300 gpm. PL in screen.
					-	165	52	46.8	3.2	3.5	940	-	Test no. 2 (1963), pumped 165 gpm. PL in screen.
OX 4	6	Sg	40	.20	1.4	350	22	7.9	16	44	9,000	9,600	
OX 5	5	S	40	.25	-	60	28	10.9	2.1	5.5	1,100	3,600	
OX 6	8	S	52	.19	1.0	250	31	9.9	8.1	25	4,800	5,500	
OX 7	6	S	44	.27	1.0	150	25	12.0	6.0	12	2,100	7,100	

Table 12.--Transmissivity of the stratified-drift aquifer from specific capacities, logs, and pumping tests of screened wells--Continued

Well no.	Well radius (in)	Screen only, S, gravel pack, Sg	Aquifer thickness (a, artesian conditions assumed) (ft)	Proportion of aquifer screened	Duration of test, t (days)	Pumping rate, Q (gpm)	Drawdown (ft) Reported	Drawdown (ft) Adjusted	Specific capacity (gpm/ft) From reported drawdown	Specific capacity (gpm/ft) From adjusted drawdown	Transmissivity, T (ft²/day) From adjusted specific capacity	Transmissivity, T (ft²/day) From well log	Remarks
							Town of Seymour						
SE 5	8	S	34	.47	-	500	32	21.1	16	24	4,700	-	PL in screen.
SE 6	8	S	67	.18	-	1,000	31	9.0	32	110	24,000	-	Screened at 53-59 and 71-77 ft.
SE 7	8	S	81	.25	1.0	2,500	43	15.9	58	160	>27,000	27,000	
							Town of Shelton						
SH 1A	8	Sg	170	.12	1.0	1,100	66	13.9	17	79	16,000	-	
SH 2A	12	Sg	198	.15	.2	2,435	34.5	7.9	70	310	> 27,000	24,000	
SH 3A	12	Sg	212	.14	.3	2,343	53	11.7	44	200	> 27,000	29,000	
SH 5A	12	Sg	202	.15	1.0	2,204	57	13.1	39	170	> 27,000	23,000	
SH 6	12	Sg	203	.15	1.0	2,513	50.8	11.7	49	220	> 27,000	47,000	
SH 7	12	Sg	191	.16	1.0	2,513	55.4	13.3	45	190	> 27,000	24,000	
SH 8	12	Sg	216	.14	1.0	2,260	84	18.5	27	120	> 27,000	36,000	
SH 9	12	Sg	202	.15	.5	2,360	71	16.3	33	140	> 27,000	36,000	
SH 10	12	Sg	200	.15	1.0	2,118	122	28.1	17	75	14,000	16,000	U.S.G.S. test, 1967: drawdowns measured in SH 4 and SH 15; see Grossman and Wilson, 1970, table 5, for complete data.
SH 27	4	S	30a	.83	1.0	350	29.5	29.5	12	12	3,500	4,400	Test data apply to 8-in. test well. Screen length assumed = 25 ft.
SH 28	4	S	26a	.96	.8	295	>44	>44	< 6.7	< 6.7	<1,900	3,800	Test data apply to 8-in. test well. Screen at 29-54 ft. PL in screen.
SH 31	5	S	33	.30	1.0	350	24	11.0	14	32	6,700	1,600	PL in screen.
SH 32	5	Sg	35	.28	1.0	300	18	8.1	17	37	7,100	1,600	
							Town of Southbury						
SB 4	5	S	58	.17	4.2	220	30	7.8	7.3	28	5,200	9,100	
SB 5	5	S	63	.26	4.0	278	33.5	12.4	8.3	22	4,300	8,700	U.S.G.S. test, 1966: drawdowns measured in 9 observation wells; T from pump test, 10,400 ft²/day; see Grossman and Wilson 1970, table 5, for complete data.
SB 13	3	S	55	.09	.3	15	15	2.2	1.0	6.8	1,300	11,000	
							Town of Stratford						
ST 11	3	S	21	.19	.2	31	16.2	5.2	1.9	6.0	1,100	1,100	
ST 12	5	S	19	.53	-	300	12.4	9.0	24	33	7,000	540	PL in screen.
							Town of Thomaston						
TM 1	15	Sg	64	.19	1.0	1,300	24	8.6	54	150	27,000	13,000	
TM 13	4	S	23a	.43	-	155	14	8.4	11	18	5,100	2,800	Perforated casing.
TM 14	5	S	100	.10	2.0	650	56.5	9.0	12	72	17,000	12,000	
TM 15	5	S	26	.19	-	170	14	4.8	12	35	7,100	2,400	
TM 18	8	S	16	.31	1.0	300	13.9	8.1	22	37	7,200	4,600	
							Town of Waterbury						
WB 2B	5	S	45	.22	.1	200	6	2.0	33	100	23,000	-	Variable Q during test.
WB 3A	6	Sg	25	.20	1.0	280	19	7.4	15	38	7,800	-	
WB 10	4	Sg	60	.17	1.0	300	8	2.2	38	140	> 27,000	-	PL in screen.
WB 12A	3	Sg	83	.12	-	25	63	11.3	.40	2.2	400	-	
WB 16	5	Sg	70	.11	1.0	600	10	1.9	60	320	>27,000	-	
WB 18	5	S	70	.11	-	100	40	7.2	2.5	14	2,800	-	
WB 334	5	Sg	40	.20 est.	-	160	21	6.1	7.6	26	5,200	-	Slotted screen estimated 8 ft long.
WB 335	5	S	43	.16	.1	172	16	4.2	11	41	9,100	-	
WB 339	8	Sg	26	.31	-	400	13	5.1	31	78	16,000	-	
WB 344	4	S	32	.31	.3	115	22	9.9	5.2	12	2,400	2,700	
WB 345	4	S	39	.26	.3	150	32.7	12.4	4.6	12	2,400	4,000	
WB 346	4	S	32	.31	.3	250	21.5	9.7	12	26	5,500	2,700	
WB 368	4	S	68	.15	-	115	24	5.3	4.8	22	5,000	-	
WB 373	5	S	39	.26	1.0	178	29	11.6	6.1	15	2,800	1,300	
WB 374	5	S	68	.13	1.0	170	52	11.4	3.3	15	2,700	4,400	PL affected by nearby pumping.
							Town of Watertown						
WA 2	4	S	23	.22	1.0	50	20	5.0	2.5	10	2,000	270	PL in screen.
WA 5	5	S	47	.32	1.0	300	24.7	11.6	12	26	5,200	7,100	
WA 6	5	S	44	.27	1.0	300	8.8	3.5	34	86	24,000	12,000	
							Town of Woodbury						
WY 11	4	S	114	.08	.3	107	83.2	10.8	1.3	10	2,000	3,800	
WY 12	4	S	23	.22	1.0	80	16	5.9	5.0	14	2,700	1,600	
WY 13	4	S	21	.24	1.0	135	14	5.7	9.6	24	5,200	2,100	
WY 14	4	S	28	.36	1.0	190	18	9.5	10	20	4,300	1,900	
WY 15	4	S	29	.17	1.0	215	19	5.5	11	39	8,700	2,000	
WY 16	4	S	28	.18	1.0	130	18	5.4	7.2	24	5,200	1,900	
WY 20	3	S	80	.12	-	40	60	9.0	.67	4.4	940	-	
WY 23	5	Sg	54	.28	1.0	317	37	15.5	8.6	20	4,000	4,200	

troughs and crests, rather than a smoothly sloping profile. The thickness of the aquifer is greater in these troughs. For example, at Waterbury and Naugatuck in the Naugatuck River valley, the saturated thickness exceeds 120 feet (pl. C).

The irregularities of the bedrock floor are probably the result of differential erosion by glacial ice, resulting from differences in bedrock topography and orientation of the valleys. For example, segments of the bedrock valley trending south and southeast (pl. C), approximately parallel to the direction of glacial ice movement, are much deeper than segments trending in other directions (U.S. Geol. Survey, 1968, p. A-52). This relationship facilitated delineation of the saturated thickness in the valley segment 0.3 mile east of Stevenson Dam at Lake Zoar, for which subsurface data were unavailable, and could aid in further exploration for large ground-water supplies in the Housatonic River valley.

Transmissivity

The ease with which an aquifer transmits water, its transmissivity, determines to a large degree the potential yields of wells tapping it. Knowledge of transmissivity in conjunction with an understanding of boundary conditions and storage characteristics is used to locate areas favorable for the development of large ground-water supplies and to estimate well yields and drawdowns. The potential of the stratified-drift aquifer to yield large water supplies is due largely to its high transmissivity.

In 1970 the U.S. Geological Survey adopted the terms "transmissivity" and "hydraulic conductivity" to replace "coefficient of transmissibility" and "coefficient of permeability," respectively. The new terms express volume of water in cubic feet rather than gallons. (See Glossary.) Conversion factors for the old and new terms are given alongside the list of "Equivalents" near the end of this report.

The areal distribution of the transmissivity of the stratified-drift aquifer in the lower Housatonic River basin is shown on plate C. The map is based on 521 estimated values and shows that transmissivity generally ranges from 2,700 ft^2/day in headwater areas, smaller tributary valleys, and valley margins, to 20,000 ft^2/day in parts of the main valleys of the Naugatuck and Housatonic Rivers. The maximum value estimated was 47,000 ft^2/day at well SH 8, in the Housatonic River valley.

Transmissivity is equal to the product of aquifer thickness, b, and the hydraulic conductivity, K. Thus, the distribution of transmissivity reflects the combined effects of differences in these two factors. A thick aquifer that is fine in texture with low hydraulic conductivity may have a transmissivity equal to that of a thin aquifer that is coarse in texture with high hydraulic conductivity. For example, the aquifer in the segment of the Housatonic River valley south of Derby is more than 80 feet thick but has about the same transmissivity as the aquifer in the valley of East Branch Naugatuck River, which is less than 40 feet thick. The difference is in the texture of the deposits. In the Housatonic River valley south of Derby, the deposits are mostly organic silt, peat, and fine sand with low hydraulic conductivities, whereas in the East Branch Naugatuck River valley, they consist predominantly of coarse gravel with high hydraulic conductivity.

The distribution of transmissivity on plate C is based on estimates derived from (1) pumping tests of wells, (2) specific-capacity data from wells, and (3) descriptive logs and particle-size analyses of samples from wells and test borings.

Reliable estimates of transmissivity were obtained from two pumping tests during the investigation (table 12, wells NA 16 and 31; and SB 5). In both tests, wells were pumped at constant rates for extended periods of time, and periodic water-level measurements were made in nearby observation wells. In a third test (on SH 10 in the Shelton well field), no reliable estimate of transmissivity could be determined from the data. In all tests, the data were analyzed by applying the Theis nonequilibrium formula (Theis, 1935), as discussed in Ferris and others (1962, p. 92) and Walton (1962, p. 6). Data for the three tests are contained in the companion basic-data report (Grossman and Wilson, 1970, table 5).

Specific-capacity tests are conducted principally to determine the yield per foot of drawdown of a production well, but the data may also be utilized to estimate aquifer transmissivity. Test data and transmissivities for 84 screened wells tapping the stratified-drift aquifer are summarized in table 12; well locations are shown on plate A. These data are based mostly on drillers' records of pumping rate, drawdown in the pumping well, and test duration. As such, they are subject to the errors inherent in conducting and reporting tests under nonstandardized conditions. The estimates of transmissivity based on specific-capacity tests are, on the whole, conservative, because the larger drawdowns resulting from well inefficiency, aquifer dewatering, and barrier boundaries were not considered. Exceptions occur where a recharge boundary was intercepted during the test, thus reducing drawdowns and giving an unrealistically high value of aquifer transmissivity. Despite their limitations, the tests permit approximation of transmissivity, perhaps within ±20 percent.

Logs of wells and test holes can also be used to estimate transmissivity because the hydraulic conductivity of a deposit is directly related to differences in grain-size characteristics (Rose and Smith, 1957; Masch and Denny, 1966).. For the lower Housatonic River basin, estimates of transmissivity were made from 505 logs of wells and test holes. As shown in the example, table 13, an estimate of hydraulic conductivity is made for each lithologic unit in the log, the estimate is multiplied by the saturated thickness of the unit, and the products are totaled to give transmissivity.

Assignment of hydraulic conductivity to the units in each log is based on one method or a combination of two methods. A catalogue of hydraulic conductivities assigned to drillers' terms, summarized in table 14, is used for logs in which the descriptive terms are too general to permit a reliable estimate of specific grain-size characteristics. For this method, transmissivities determined from specific-capacity tests of 65 wells for which logs are also available are used as guides in assigning the hydraulic conductivity values to drillers' terms. (See table 12.)

A more quantitative approach is used for more detailed logs. In these, the terminology is more uniform and specific; descriptions are commonly based on examination and many involve grain-size analyses of split spoon samples. Estimates of hydraulic conductivity of lithologic units in these logs are made by comparing their descriptions with similar descriptions of 187 samples of stratified drift from eastern and western Connecticut (including 73 from the lower Housatonic River basin). These samples, collected and analyzed by the U.S. Geological Survey, are assigned hydraulic-conductivity values based on relationships between median grain size, uniformity coefficient, and hydraulic conductivity that were developed during earlier Connecticut inventory studies (Randall and others, 1966; Thomas, M. P., and others, 1967; Thomas, C. E., and others, 1968; Ryder and others, 1970). The results are summarized in table 14, in which the analyses are grouped according to differing grain-size characteristics for easier comparison with lithologic units described in logs. The grain-size analyses of samples from the lower Housatonic River basin are tabulated in the companion basic-data report (Grossman and Wilson, 1970, table 4).

Among the logs used for estimates of transmissivity are those of many test borings by the Connecticut State Department of Transportation. Estimates of hydraulic conductivity of different lithologic units of sand and gravel in these logs are listed in table 14. They are based on the same procedure described above.

Although the methods used to estimate transmissivity from logs are somewhat subjective, they are tied in with more quantitative tests and are internally consistent. Some values determined from specific-capacity tests are markedly different from those estimated from logs of the same wells (table 12). In most of these instances, transmissivity derived from specific capacity indicates the efficiency with which the well taps the aquifer and is not corrected for the net effects of boundaries, whereas the value from the log gives a better indication of the water-bearing properties of the aquifer itself.

Storage coefficient

Aquifers act not only as media for transmitting water, but also as storage reservoirs. In the lower Housatonic River basin, large volumes of water--many billions of gallons--are stored in the stratified drift. Much as in surface-water reservoirs, water is almost constantly being withdrawn from or added to aquifer storage, either by natural processes or by manipulation.

The amount of water that can be withdrawn from an aquifer is only a fraction of the total in storage. The storage coefficient of water-table aquifers commonly ranges from 0.05 to 0.30 cubic foot of water per square foot of aquifer surface per foot of head change (Ferris and others, 1962, p. 78). Nearly all this water is derived from gravity drainage, and thus the amount

Table 13.--Example of estimating transmissivity from logs of wells and test holes

Test hole WY 12th. Drilled with power auger by U.S. Geological Survey, 1966. Depth to water, 4 feet below land surface.

Material description	Depth From	(ft) To	Saturated thickness, b (ft)	Assigned hydraulic conductivity, K (ft/day)	Transmissivity of unit, Kxb (ft^2/day)
Topsoil and sand	0	5	1	67	67
Sand and gravel	5	10	5	210	1,050
Sand, very fine to fine, some silt 1/	10	32	22	6	132
Gravel	32	33	1	400	400
Sand	33	37	4	67	268
Sand, medium to very coarse, some gravel 2/	37	40	3	240	720
Sand, fine to medium, little coarse to very coarse sand, little silt, some thin gravel beds 3/	40	80	40	13	520
Sand, fine to medium, trace coarse sand	80	84	4	13	52
Till; silty, sandy, gravelly	84	85	1	-	-
Refusal	85	-	-	-	-
				Transmissivity of stratified-drift section	3,200 ft^2/day

1/ Split spoon sample, 18-19.5 ft depth.
Median grain size, 0.125 mm.
Uniformity coefficient, 6.9.
Estimated hydraulic conductivity 6 ft/day.

2/ Split spoon sample, 38-39.5 ft depth.
Median grain size, 0.86 mm.
Uniformity coefficient, 18.6.
Estimated hydraulic conductivity 240 ft/day.

3/ Sample off auger flights.
Median grain size, 0.19 mm.
Uniformity coefficient, 6.6.
Estimated hydraulic conductivity 13 ft/day.
(not including gravel beds).

available is a function of time as well as of aquifer properties. In the lower Housatonic River basin a value of 0.20 is assumed to be a reasonable and probably conservative value of storage coefficient applicable to long periods of drainage of the stratified-drift aquifer.

Yields of wells

Yields of 100 gpm or more in the lower Housatonic River basin are most commonly obtained from screened wells tapping stratified drift. Yield and construction characteristics of 62 such wells are summarized on figure 27.

One of several horizontal collectors in Connecticut is located along the Naugatuck River near Naugatuck. The installation (NA 34, pl. A) was completed in 1949. Tests during the first year of operation indicated a sustained pumping capacity exceeding 2.6 mgd, with a drawdown of 68 feet in the caisson. Operational yields in the late 1960's were considerably lower and were augmented by pumpage from nearby Beacon Hill Brook. In early 1967, for example, pumpage from the collector average 1.5 mgd, including 1.0 mgd pumped from the brook into the caisson.

One of two caisson wells inventoried for this study (MO 40, pl. A) had a reported yield of 103 gpm.

Stratified drift can also be economically and efficiently tapped for small to moderate water supplies. Well types suitable for small to moderate yields include dug, open end, and screened wells,

Table 14.--Hydraulic conductivity values assigned to stratified-drift units in detailed logs of wells and test holes

Drillers' logs

Drillers' term	Assigned hydraulic conductivity, K (ft/day) 1/
Clean gravel	400
Gravel	270
Sandy gravel	210
Cobbles, hard packed	134
Hardpan gravel	80
Clean sand and gravel	400
Coarse sand, grits, gravel	270
Sand and gravel	210
Fine sand and some gravel	87
Coarse sand	134
Medium sand	80
Fine to coarse sand	54
Fine sand	27
Very fine sand	7
Dirty sand	54
Fine silty sand	13
Fine sand and clay	7
Silt and clay	0.3

Logs of wells and test holes

Predominant constituent	Proportion of-- 2/ Gravel	vf-m sand	Silt-clay	Median grain size 3/	Uniformity coefficient	Assigned hydraulic conductivity (ft/day) 4/
	-	L-Sm	Tr	vfG	<80	870
GRAVEL	-	L-Sm	Tr	vf-fG	>80	750
	-	L-Sm	Tr	c-vcSd	>10	310
	-	-	L-Sm	cSd	<80	120
Coarse to	Tr	-	Tr	cSd	< 4	640
very coarse	L-Sm-&	-	Tr	c-vcSd	<10	440
SAND	L-Sm-&	-	Tr	cSd	>10	230
		-	Tr	mSd	< 3	175
		-	Tr-L	mSd	3-6	80
Very fine		-	Tr-L	mSd	> 6	54
to medium	Tr	-	Tr-L	fSd	< 3	67
SAND		-	Tr-L	fSd	3-6	27
		-	L-Sm	fSd	> 6	13
		-	L-Sm-&	vfSd	< 3	12
		-	Sm-&	vfSd	> 3	5
		-	Tr-L	cSd	<20	190
	L-Sm	-	Tr	mSd	<10	160
		-	Tr-L	mSd	10-20	87
		-	L-Sm	mSd	<20	47
	-	&	-	St	-	1.3
SILT to CLAY	-	Sm	-	St(>.035 mm)	-	.7
	-	Sm	-	St (<.035 mm)	-	.3
	-	Tr	-	St	-	.1

Logs of Connecticut Department of Transportation, Bureau of Highways, test holes

Predominant constituent	f-c gravel	f-c sand	Silt-clay	Assigned hydraulic conductivity (ft/day) 4/
Fine to	-	&	Tr	240
coarse			L	95
GRAVEL			Tr	270
	-	Sm	L	134
	-	L	Tr	330
			L	160
	-	Tr	Tr	470
			Tr	210
	&	-	L	134
			Sm	95
Fine to			Tr	134
coarse	Sm	-	L	80
SAND			Sm	40
			Tr	108
	L	-	L	54
			Sm	13
			Tr	80
	Tr	-	L	21
			Sm	7
			Tr	67
	None	-	L	21
			Sm	7

1/ Based on transmissivities determined from specific capacity tests; modified where detailed grain-size characteristics were known.

2/ Proportional key:
&, and, 35-50 percent of unit
Sm, some, 20-35 percent of unit
L, little, 10-20 percent of unit
Tr, trace, less than 10 percent of unit

3/ Grain-size key
vc, very coarse — G, gravel
c, coarse — Sd, sand
m, medium — St, silt
f, fine
vf, very fine

4/ Based on relationships established between median grain size, uniformity coefficient, and hydraulic conductivity.

including well points. The choice depends upon a variety of factors, including geologic and hydrologic conditions in the vicinity of the well site.

Dug wells continue to supply many homes in areas underlain by stratified drift. Sites especially favorable for development of dug wells are those where the aquifer is at least 5 feet thick and the water table is shallow and does not fluctuate widely. Such conditions are common on flood plains of small streams. For example, many residents along Bronson Brook in Beacon Falls take advantage of these conditions by using dug wells as sources of domestic water supplies.

Small to moderate yields can be obtained from small-diameter screened well points driven into the aquifer. Conditions especially suitable for this type of well are similar to those for dug wells; in addition an aquifer consisting of well sorted sand contributes to the ease of construction and efficiency of development. Dug or driven wells are generally finished several feet below the annual low water table to insure against the well going dry in a drought.

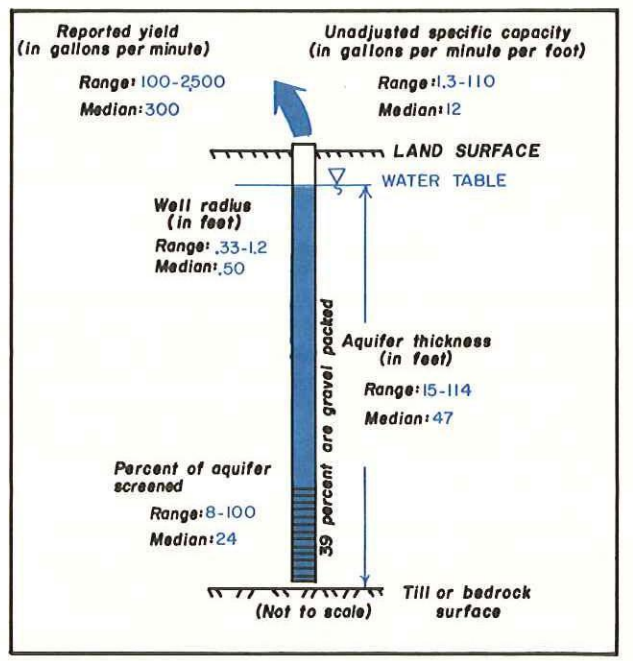


Figure 27.--Yield and construction characteristics of 62 screened wells tapping stratified drift and tested at 100 gpm or more.

TILL

The till aquifer consists of the saturated part of glacial till, a nonstratified, nonsorted deposit composed of rock particles of a wide range of sizes, from boulders to clay. Till, popularly called "hardpan," was deposited directly by glacial ice. In the lower Housatonic River basin it forms a widespread but discontinuous mantle over bedrock throughout most upland areas and extends beneath stratified drift in valleys and lowlands. It was not mapped as a separate unit but is included with the bedrock and swamp deposits in all areas not mapped as stratified drift (pl. C).

Till thickness generally ranges widely from 0 to 200 feet. In the lower Housatonic River basin the median till thickness is 30 feet at the sites of 240 bedrock wells. The average thickness is probably less than this because few of these wells were drilled in areas, common in much of the uplands, where bedrock is at or very near the land surface.

Scattered throughout the basin are areas where till is exceptionally thick, as shown on plate C. Within these areas, its thickness is known or assumed to be at least 40 feet; at many sites it exceeds 100 feet. A substantial thickness of till may increase the cost of a bedrock well because of the greater length of casing required. On the other hand, if saturated, it will contribute water to the bedrock through leakage, and it may also provide better protection from pollution by septic tank effluents. (See discussion, "Ground-water Contamination.")

The general absence of stratification and sorting in till results in a low hydraulic conductivity. Published results of 31 hydraulic-conductivity determinations of till in southern New England show that hydraulic conductivity ranges from 0.013 to 29 ft/day, with a median value of 0.67 ft/day (Allen and others, 1963; Allen and others, 1966; Baker and others, 1964; Randall and others, 1966; Sammel and others, 1966; Thomas, M.P., and others, 1967). Such low values greatly limit the potential of this aquifer as a source of large water supplies, even where its thickness is substantial.

At favorable locations, dug wells in till can provide small supplies of water for domestic and stock uses, although their number is declining. Seasonal fluctuations of the water table in till areas are commonly large, and, because of the low hydraulic conductivity, drawdowns due to pumping are also large. Thus, optimum conditions for the installation of a dug well require several tens of feet of saturated section and a shallow water table. Digging the well several feet below the annual low water level helps to sustain the supply during dry seasons.

Storage in the well is an important supplement to the yield of a dug well tapping this aquifer. Each foot of water in a well 3 feet in diameter represents 53 gallons. The water withdrawn from well storage is replaced by slow seepage from the aquifer. Tests of dug wells in eastern Connecticut have indicated that the hydraulic conductivity of till will commonly permit replenishment seepage of 200 gpd, enough for the average needs of a family of three (Randall and others, 1966); conditions in the lower Housatonic River basin are probably similar.

Increasing the diameter of a dug well increases both the amount of water that can be stored and the area of contact with the aquifer. Three large-diameter dug wells (MD 1, 2, 3) are used by the Westover Water Company to provide part of the supply of a school and small community. These wells are 18 feet in diameter and 16 to 20 feet deep. During the winter season the three are pumped together 16 hours a day, but no determination of their yields has been made.

Open-end drilled wells also tap till, especially where it is thick. The depth of 12 such open-end wells in the basin ranges from 70 to 166 feet; the median is 98 feet. Median yield is 12 gpm, slightly higher than that from open-end wells tapping stratified drift, perhaps reflecting the greater available drawdown in the till wells. However, open-end wells in till may actually tap interbedded or underlying beds of gravel. If gravel layers are penetrated during the drilling of a well through thick till to bedrock, consideration can be given to completing an open-end well in the overburden.

BEDROCK

Bedrock underlies the entire lower Housatonic River basin and is an important source of water for several thousand homes, schools, shops, and other establishments requiring small to moderate amounts of water. Bedrock forms two principal aquifers, based on differences in geologic and hydrologic characteristics: (1) crystalline bedrock, which underlies most of the area (fig. 17), and (2) sedimentary-volcanic bedrock, which underlies only about 11 square miles in the Pomperaug River basin.

Several thousand bedrock wells in the lower Housatonic River basin provide water for homes and shops, and probably several hundred new ones are drilled each year. Most of them provide trouble-free supplies that are satisfactory in quantity and quality. The yield of a bedrock well cannot be determined before drilling; nonetheless, a knowledge of factors influencing aquifer productivity can sometimes be utilized in selecting the site most likely to supply the desired yield.

Data from 294 wells in the basin indicate that yields of a few gallons per minute can be obtained from bedrock at most sites. The maximum yield of a bedrock well can be determined by pumping or by bailing the water down as close to the well bottom as possible and measuring the early rate of recovery. The effective yield of a bedrock well is supplemented by the amount of water stored in the casing and rock hole. Each foot of water stored in a 6-inch-diameter well represents about $1\frac{1}{2}$ gallons. Thus, if the water level prior to pumping is 30 feet below land surface in a well

200 feet deep, the 170 ft of storage equals 255 gallons that can augment the yield of the aquifer.

Crystalline bedrock

The crystalline bedrock aquifer underlies nearly all the lower Housatonic River basin. Most of this aquifer is composed of a hard, dense rock consisting of tightly interlocked mineral grains. Common rock types include granite, gneiss, and schist. In some areas the upper part of the bedrock has weathered into a crumbly mass; in other areas mica schist is described by drillers as "soft." The thickness and areal extent of these weathered zones are unknown; they are commonly cased off and thus are not a significant part of the aquifer.

The solid part of crystalline bedrock is essentially impervious, and water in such rock moves largely in cracks or joints, which are most common in the upper few hundred feet of bedrock. Parallel joints, forming a set, may intersect other sets, forming enlarged openings along which water moves more readily. Many joints are vertical or steeply dipping; others are roughly parallel to the bedrock surface. Although the orientation and spacing of joints are generally systematic, in detail their size and distribution are irregular, and the productivity of the aquifer differs widely from site to site.

The heterogeneity of the crystalline bedrock and the steep dip of its fractures make possible the drilling of a satisfactory well close to an unproductive one. Moving to another site in a direction perpendicular to the general trend, or "across the strike", of the bedrock or joints increases the probability of intersecting different and thus perhaps higher yielding sets of fractures.

From drillers' records of about 1,350 wells in the basin, a sample of 294 domestic wells tapping crystalline bedrock was selected to evaluate various factors probably influencing aquifer productivity. These factors include aquifer lithology, topographic situation, type of overburden, and aquifer thickness. The sample was selected so that each of these factors is well represented basinwide. Reported yields rather than specific capacities are used in all analyses of wells tapping crystalline bedrock. Specific capacities of such wells have uncertain value because yield is not necessarily proportional to drawdown (Thomas, M. P., and others, 1967, p. 57). The yields were determined by drillers by a variety of methods and for various test durations. They do not necessarily represent the full potential of the aquifer at the well site, but they do represent practical short-term yield useful for comparative purposes. Figure 18 shows the distribution of yields in the sample of 294 wells. The median yield is 5-6 gpm; about 75 percent of the wells yield at least 3 gpm, and less than 10 percent yield 20 gpm or more.

Lithology

The crystalline bedrock aquifer in the lower Housatonic River basin may be subdivided into two broad lithologic types, granite and schist. Granite is used in a broad sense to include gneiss and other similar coarse-grained, generally hard, crystalline rock types. Schist is characterized by the predominance of the mica minerals and by foliation. The response of these two types of rocks to stresses within the earth's crust differs. Granite is more competent, and it responds to crustal stresses by producing distinct and open joints. Schist is less competent, and it responds more by slipping and folding along foliation planes. Although joints develop in schist, they are likely to be nearly closed and discontinuous and therefore poor conduits for water.

Granite is tapped by more high-yielding wells and fewer low-yielding ones than schist, (fig. 19). Median well yields are 7 gpm for granite and 4 3/4 gpm for schist. These comparisons are based on 221 wells in the 294-well sample; aquifer lithology for 73 remaining wells was indeterminable.

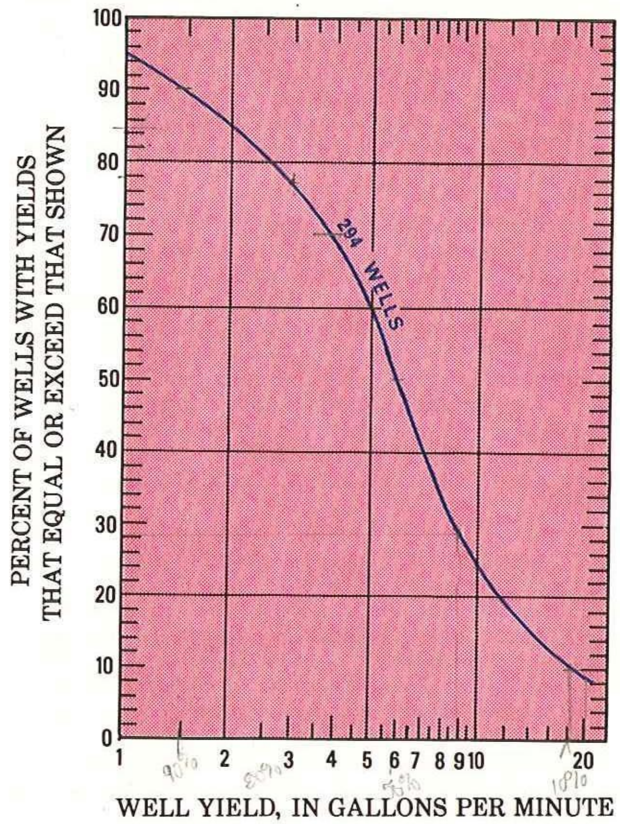


Figure 18.--Yield distribution of selected wells tapping crystalline bedrock.

The approximate extent of the principal granite and schist units in the basin is shown on figure 17. Other crystalline bedrock is undifferentiated on the map where detailed mapping is incomplete, where the rocks are too mixed to differentiate on the scale used, or where other crystalline rocks occur that do not clearly fit into the two principal types. Wells drilled in areas of undifferentiated rock, but whose type is nevertheless identifiable from the drillers' logs, are shown on the figure by a letter symbol.

An area of complex geology is broadly generalized on figure 17. In most areas mapped as granite or schist, the unit shown predominates but is not the only one; at individual sites it is possible to drill through granite, schist, some other crystalline rock, or a combination of these. Published quadrangle maps of bedrock geology provide more details and descriptions. They are listed at the end of this report in the section "Selected References."

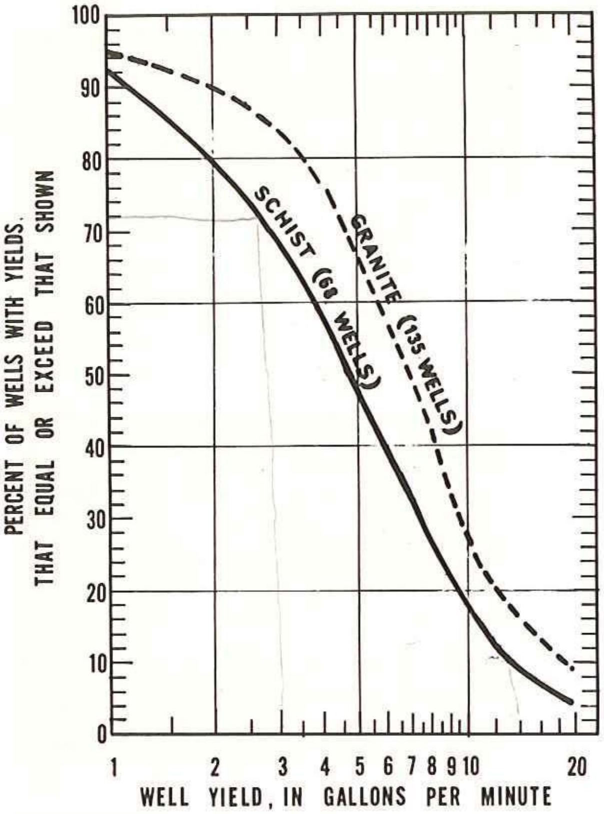


Figure 19.--Yield distribution of wells tapping granite and schist.

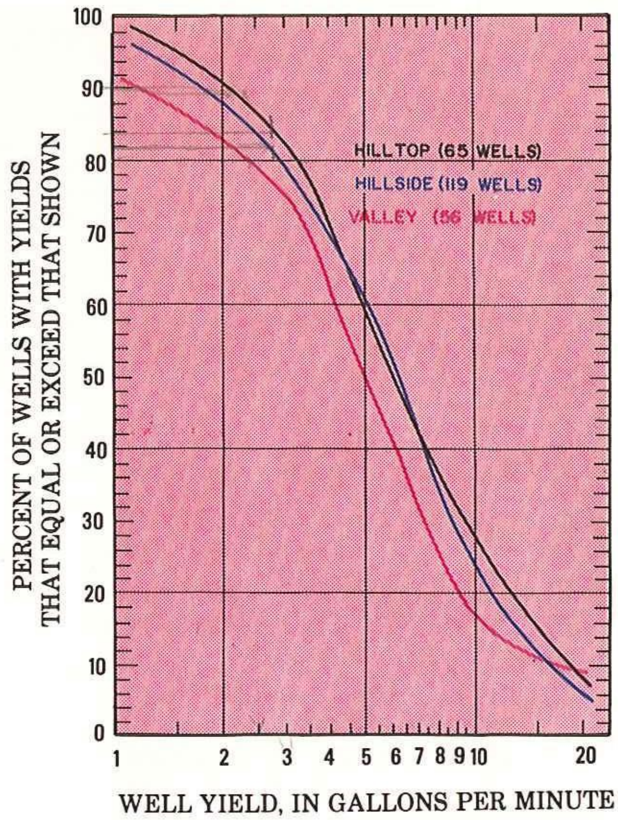


Figure 20.--Yield distribution of wells tapping crystalline bedrock overlain by till in different topographic situations.

Topographic position

The topographic position of wells drilled in crystalline bedrock has been considered to influence their yields (Cushman and others, 1953; Ellis, 1909). However, data from 240 wells in the lower Housatonic River basin suggest that topography alone has little influence on well yield. The curves of yield distribution (fig. 20) are very similar for three principal topographic positions. A slightly smaller percentage of valley wells is low yielding compared to hilltop wells, but a higher percentage of valley wells yield at least 20 gpm. Median yield values are 5 gpm for hilltop, $5\frac{1}{2}$ gpm for hillside, and $4\frac{1}{2}$ gpm for valley wells. The factor of overburden type was eliminated by using data only from wells with till overburden in this analysis.

Overburden type

Differences in hydraulic conductivity between stratified-drift overburden and till overburden may indirectly influence the water-bearing characteristics of the underlying crystalline bedrock aquifer. Because of its higher hydraulic conductivity, stratified drift in direct contact with the bedrock surface may transmit water downward to fractures more readily than till. Figure 21 shows that wells at sites where stratified drift is the overburden ("stratified drift/bedrock" wells) have a substantially greater proportion of high yields than wells at sites where till is the overburden ("till/bedrock" wells). In both groups about 76 percent of the wells yield at least 3 gpm, but the median yield is 7 gpm for the stratified drift/bedrock wells compared with $5\frac{1}{2}$ gpm for the till/bedrock wells; moreover, the proportion of wells yielding at least 20 gpm is twice as great for the stratified drift/bedrock wells as for the till/bedrock wells. Conversely, where bedrock openings are small, few, or discontinuous, yields are low regardless of the type of overburden.

All the stratified drift/bedrock wells are in valleys, whereas the till/bedrock wells are distributed in all topographic situations. The differences in yield due to overburden type are even more striking if yields of 54 stratified drift/bedrock wells (fig. 21) are compared with yields of the 56 till/bedrock wells at valley sites (fig. 20). The results further indicate that type of overburden is a more significant factor than topographic situation in influencing yields from bedrock.

Thickness of bedrock penetrated

Yield data from the lower Housatonic River basin support the conclusion of other studies in New England that the most productive zone of the crystalline bedrock is the upper 200 feet and that the probability of obtaining a substantial increase in yield at aquifer penetrations greater than 300 feet is slight (Ellis, 1909; Cushman and others, 1953; Thomas, M. P., and others, 1967; Thomas, C. E. and others, 1968). Figure 22 shows the frequency distribution of yields obtained in the uppermost 100 feet of bedrock in a sample of 114 wells in the basin that were tested at two or more depths during

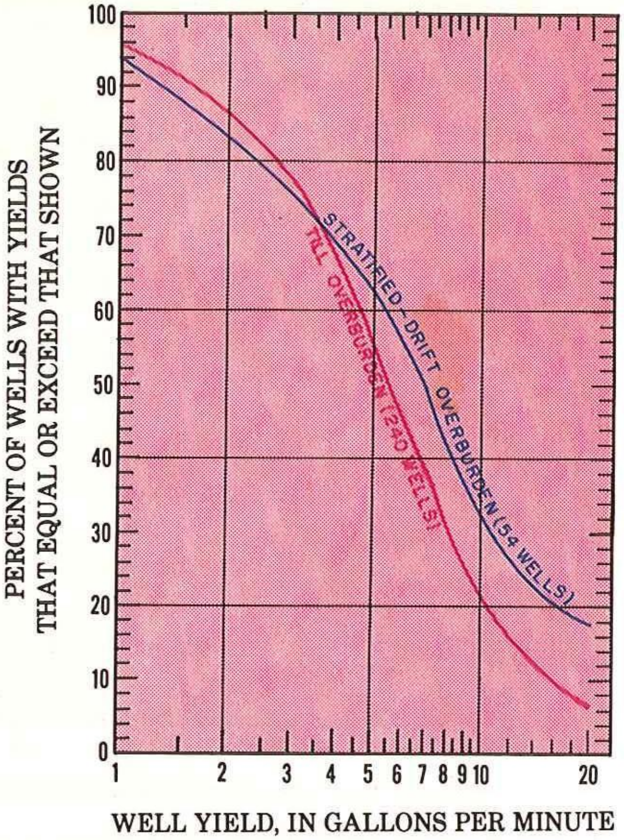


Figure 21.--Yield distribution of wells in crystalline bedrock overlain by stratified drift and by till.

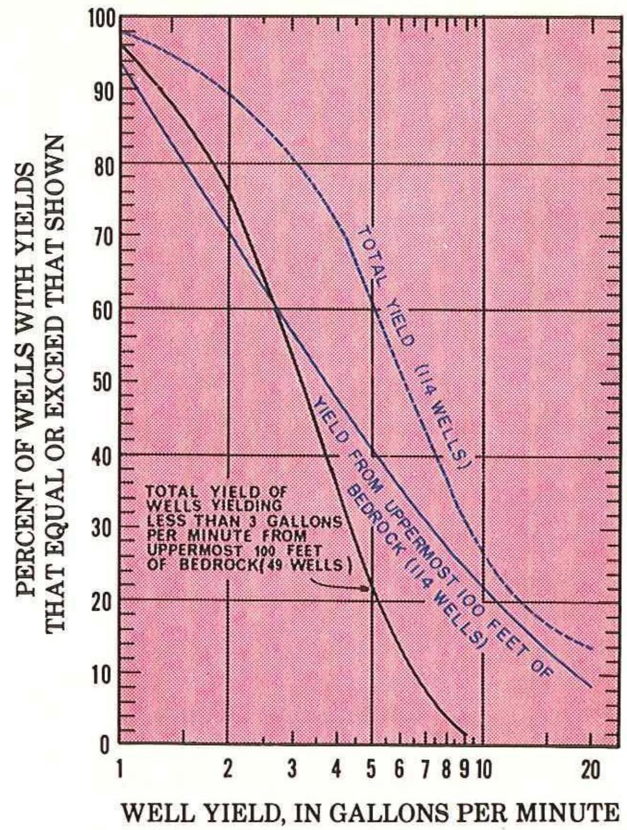


Figure 22.--Yield distribution of wells tapping crystalline bedrock tested at more than one depth during drilling.

drilling. More than 90 percent of the wells obtained at least 1 gpm, 50 percent obtained 3-4 gpm, and 20 percent obtained at least 10 gpm in the uppermost 100 feet of bedrock. The distribution of total yield, also shown on figure 22, is similar to that of the larger sample of 294 wells used in the preceding analyses. (See fig. 17.) Among the 114 wells, 47 did not penetrate more than 100 feet of bedrock, evidently obtaining sufficient yield within that range. Table 15 shows that, after well deepening, yield increase of most wells became smaller with each additional 100 feet of bedrock penetrated. Ten percent of the wells yielded at least 10 gpm more after penetrating 100-199 feet of rock, and 51 percent yielded at least 2 gpm more. But in the next 100-foot interval, none of the wells yielded as much as 10 gpm more, and 65 percent yielded an additional 1 gpm or less. And at rock penetrations of 300 feet or more, no wells yielded as much as 5 gpm additional, and the yield of only 14 percent increased at least 2 gpm.

Table 15.--Effects of deeper penetration of crystalline bedrock on yields of wells

Initial amount of bedrock penetration (ft)	Amount of bedrock penetration after deepening (ft)	Percentage of wells showing a given yield increase after deepening — Amount of yield increase: 1 gpm or less	At least 2 gpm	At least 5 gpm	At least 10 gpm	Median yield increase (gpm)	No. of wells
0 - 99	100-199	37	51	16	10	2	67
	200-299	65	21	4	0	0	23
	300 or more	43	14	0	0	1	7

Yield data also suggest that where the bedrock is unproductive in the uppermost 100 feet, it is also likely to be unproductive at greater depths. As shown on figure 22, none of 49 wells whose yields in the uppermost 100 feet of bedrock were less than 3 gpm had a total yield exceeding 10 gpm after deepening, and the median total yield of this group was only about 3 gpm. Figure 23 shows that the median yield of the bedrock wells is inversely related to thickness of bedrock penetrated. Evidently, the deeply penetrating wells were drilled at sites where the bedrock is unproductive throughout. The median yield of the total sample is $5\frac{1}{2}$ gpm, about the same as for the larger sample of 294 wells. Similar conditions are suggested by data from 17 domestic wells that penetrate more than 400 feet of bedrock (table 16). None of these wells yielded more than 1 gpm, despite a median rock penetration of 527 feet and a maximum penetration of 895 feet.

In contrast, unusually high yields are obtained from wells in the uppermost 100 feet of crystalline bedrock at some sites in the basin. Even at these sites, the above-average yield probably does not extend to greater rock depths, although the data are less definitive than those for unproductive bedrock. Data for 24 domestic bedrock wells with yields of at least 30 gpm indicate that the median rock penetration was only 70 feet. Drilling was soon halted in most of these wells because such large yields are more than enough for household needs. Where larger supplies are needed for shops, schools, and factories, the tendency is to drill to greater depths

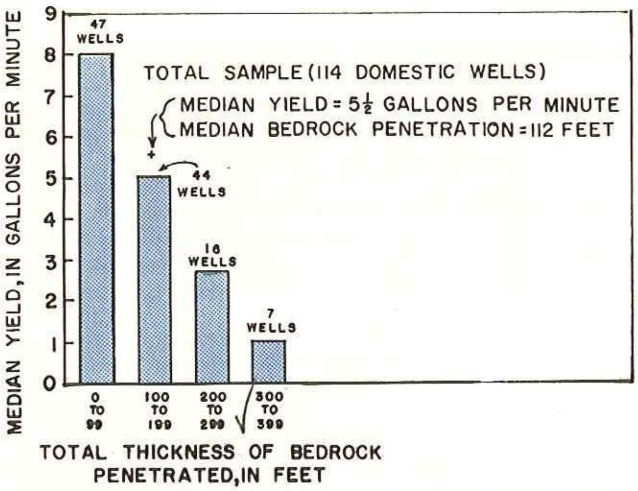


Figure 23.--Median yields of domestic wells tapping different thicknesses of crystalline bedrock.

Wells penetrating small thicknesses of bedrock have higher median yields than those penetrating large thicknesses.

in an effort to obtain the maximum supply available. In 16 such wells with yields of at least 30 gpm, median thickness of bedrock penetrated was 206 feet, with a median yield of 41 gpm. The relation of yield to bedrock penetration in these wells is unknown, but the fact that the median yield of the deeper wells is only slightly larger than that of the domestic wells suggests that the additional depth did not result in substantially greater yield.

Sedimentary-volcanic bedrock

Sedimentary and volcanic rocks underlie 11.2 square miles of the Pomperaug River basin in Southbury and Woodbury (fig. 17). The aquifer consists of a sequence of three volcanic units (lava flows) composed of basalt, interbedded with four sedimentary units, principally red and gray conglomerate, shale, and sandstone (all the sedimentary units are popularly termed "red rock") (table 17). The rocks are similar in age, type, and sequence to the bedrock underlying much of the Connecticut River valley north of Middletown but are probably thinner. Schutz (1956) indicates that the total section of the lower Housatonic River basin exceeds 1,000 feet in thickness. Near Southbury Village in 1888 a 1,525-foot well penetrated 1,235 feet of sedimentary and volcanic rocks underlain by crystalline rocks (Hovey, 1890).

The sedimentary-volcanic aquifer is broken by numerous sets of joints and by a complex network of faults (Schutz, 1956, p. 26). Most water in this aquifer is probably stored in and transmitted by the joints, and most faults are too tight to yield significant quantities of water, (Meinzer and Stearns, 1929, p. 80). Bedding planes separating layers of sedimentary rock probably also store and transmit water as reported in north-central Connecticut (Cushman, 1964, p. 31). In north-central Connecticut, drillers report that water supplies are commonly obtained at contacts between the volcanic and underlying sedimentary units (Cushman, 1964, p. 39); presumably similar conditions exist in the lower Housatonic River basin. The sedimentary rocks are porous,

Table 16.--Hydrogeologic characteristics of 17 deep wells penetrating more than 400 feet of crystalline bedrock

Characteristic	Median	Range
Yield	½ gpm	0 - 1 gpm
Static water level below land surface	46 ft	8 - 200 ft
Thickness of overburden	21 ft	2 - 50 ft
Thickness of bedrock penetrated	527 ft	428 - 895 ft
Total depth	535 ft	444 - 900 ft

but their pore spaces are so small that they yield little or no water to wells (Meinzer and Stearns, 1929, p. 79).

Few wells tap sedimentary-volcanic rocks in the lower Housatonic River basin, but available yield data suggest that the aquifer is more productive than crystalline bedrock. The median yield for 42 domestic wells reported by drillers is 10 gpm (fig. 24), about twice that of wells in crystalline bedrock. All the wells in sedimentary-volcanic rock are in valleys, where stratified drift is the overburden; 90 percent of them yield at least 3 gpm, and 24 percent yield 20 gpm or more (fig. 24). The yields of four wells in similar bedrock in north-central Connecticut drilled for large supplies are reported as 40, 97, 100, and 150 gpm, suggesting that the sedimentary-volcanic aquifer has a potential for high yield.

Table 17.--Geologic units of the sedimentary-volcanic bedrock aquifer (after Schutz, 1956, p. 6-19)

(Youngest at top, oldest at bottom)

Rock type	Lithology	Thickness (ft)	Remarks
Sedimentary	Sandstone and shale	?	No outcrops. Inferred from topography and analogy with rock sequence in Connecticut River valley.
Volcanic	Basalt	50-60	All basalts popularly called traprock or trap.
Sedimentary	Sandstone and shale	?	
Volcanic	Basalt	> 150	Hard, massive; forms prominent ridges.
Sedimentary	Predominantly red shale	?	Also sandstone and, reportedly, a limestone unit.
Volcanic	Basalt	30	Highly porous; in outcrops it is highly weathered and disentegrated.
Sedimentary	Conglomerate, sandstone, and shale	650	

Unlike that of a well tapping the crystalline rocks, the specific capacity of a well tapping the sedimentary-volcanic rocks provides a guide to aquifer productivity, because abundant closely

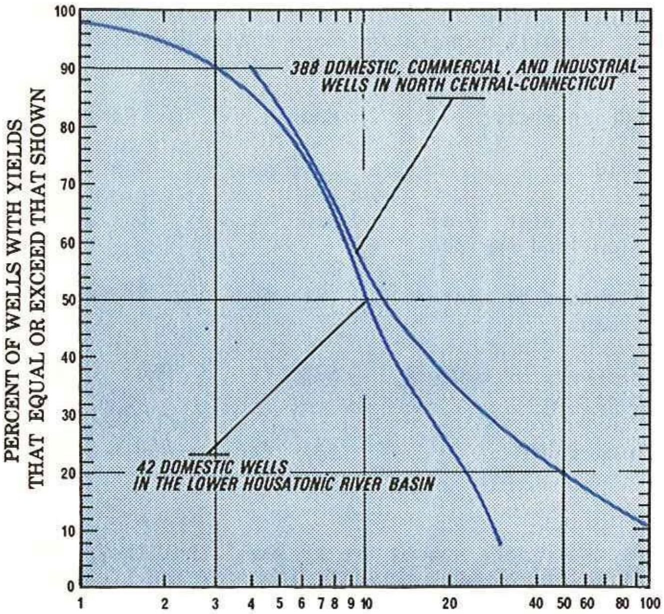


Figure 24.--Yield distribution of wells tapping sedimentary-volcanic rocks in the lower Housatonic River basin and in north-central Connecticut.

spaced openings relate yield to drawdown directly. The specific capacity of 32 domestic wells, based on drillers' data, ranges from 0.017 gpm/ft to 12.0 gpm/ft, with a median of 0.20 gpm/ft. Note that the specific capacity of a well also depends on its efficiency and effective diameter, so that specific-capacity values unadjusted for these factors provide only approximations of aquifer productivity.

Cushman (1964, p. 35) noted that in north-central Connecticut, water-bearing openings extend to greater depths in sedimentary rocks than in crystalline rocks and may reach depths as great as 450 feet. Conditions may be similar in the lower Housatonic River basin, although no supporting data are available. In the 42 domestic wells sampled, the maximum bedrock penetration was 365 feet; the median was 92 feet.

STREAMBED DEPOSITS

Stream or lakebed deposits may significantly affect the rate of induced infiltration of surface water into an aquifer. Infiltration is induced when pumping wells lower the water table beneath streambed deposits. Where streambed deposits have high hydraulic conductivity, there is a potential for a high rate of infiltration, but, where they have low hydraulic conductivity, the potential is less. Some streambed deposits in the basin are known to have lower hydraulic conductivity than the stratified drift.

Description

The beds of most free-flowing reaches of streams traversing stratified drift in the lower Housatonic River basin are gravelly. Commonly cobbles and boulders line channel floors. Logs of test borings indicate that along the Naugatuck River the streambed deposits consist of 5-15 feet of compact silty gravel, cobbles, and boulders. Along much of this river, the deposits practically form a cobblestone pavement. Beneath the Pomperaug River channel, about 5 feet of gravel, or sand and gravel, overlies the stratified-drift aquifer. These streambed deposits contain less silt and are less compact than those in the Naugatuck River valley, and in many places it is difficult to distinguish them from the underlying aquifer. Conditions along smaller tributaries are more variable, but the streambed deposits probably average 3-5 feet in thickness.

Ponded reaches of streams and much of the lower Housatonic River are underlain by fine-grained deposits, commonly including organic matter. Test holes indicate 1-5 feet of mud, silt, and muck at Stevenson Dam on the Housatonic River, and presumably similar deposits lie beneath Lake Housatonic upstream from Derby. Borings at several bridges that cross the Housatonic River downstream from Derby indicate that the river is underlain by 10-30 feet of fine to medium sand and silt, commonly with layers of peat and muck. Probably the ponded reaches of most smaller streams in the basin are underlain by several feet of fine-grained deposits.

In detail, streambed deposits of a particular stream vary greatly--areally, in vertical section, and seasonally. In free-flowing stream reaches, riffles commonly alternate with slightly ponded sections, and the bottom is composed of a complex network of channel deposits, including sand bars, gravel bars, and mud flats. The units that are most effective in retarding infiltration may be thin layers of mud or vegetation on the stream bottoms, or one or more layers of silt or organic matter within the gravelly streambed deposits or even within the aquifer. Accumulations of mud or leaves that may retard infiltration during part of the year may be swept away by later high flows. Detailed site studies over an extended period of time would be required to assess the significance of all these features, and only the gross aspects are considered in this study.

Vertical hydraulic conductivity

Streams in the basin are characteristically broad and shallow, and most infiltration is induced vertically through the stream bottom rather than horizontally through the sides. At the stream gaging sites on the Naugatuck and Pomperaug Rivers, for example (pl. B), at low-flow conditions stream widths are commonly 50-60 feet and mean depths are $\frac{1}{2}$ to 2 feet. Thus, the most significant water-bearing characteristic of streambed deposits is vertical hydraulic conductivity, which is expressed in feet per day for a water temperature of 16°C. Field determinations of this parameter at Beacon Hill Brook are based on measured streamflow losses; others at the Pomperaug and Housatonic Rivers are based on field permeameter tests. These determinations, which range from 0.13 ft/day to 14 ft/day, provide a general guideline for estimating vertical hydraulic conductivity elsewhere in the basin.

At Beacon Hill Brook, opposite wells NA 16 and 31 (pl. A), the hydraulic conductivity of the streambed is computed to be about 14 ft/day (table 18). The streambed deposits in this reach consist of about 15 feet of sand and gravel, cobbles, and boulders. Streamflow measurements were made at each end of a 632-foot reach of brook

Table 18.--Vertical hydraulic conductivity of streambed deposits, Beacon Hill Brook as determined from measured streamflow loss

Date	Combined pumping rate of NA 16 and 31 (gpm)	Measured streamflow (cfs) 1/			Measured gain (+) or loss (-), Q_i, of streamflow between upstream and downstream sites, excluding tributary		Stream temperature (°C)	Channel area, A 2/ (ft^2)	Average drawdown beneath stream, Δh 3/ (ft)	Computed hydraulic conductivity of stream bed K_v 4/ (ft/day)
		Upstream site	Tributary	Downstream site	(cfs)	(gpm)				
5-22-67	0	8.68	0.16	9.26	+0.42	+188	15	--	0	--
6-13-67	0	4.06	.09	3.77	- .38	-170	14	--	0	--
9-21-67	0	.79	0	.80	+ .01	+ 4.5	18	--	0	--
10-17-67	426	3.23	0	2.46	- .77	-345	15	8,965	8	14.2
11- 9-67	421	2.21	.19	2.14	- .26	-117	3	8,400	9	6.4

1/ Measurements are considered accurate to ±5 percent.
2/ Length of reach, 632 ft.
3/ Based on computed drawdown at upstream and downstream sites and middle of reach. Transmissivity, T = 3,350 ft^2/day (see table 12). Barrier boundaries assumed effective at 400 ft north and 500 ft south.
4/ Vertical hydraulic conductivity at 16°C under unit hydraulic gradient, $K_v = 192\, Q_i C_t / \frac{\Delta h}{b'} A$, where thickness of streambed deposits, b' = 15 ft, and temperature correction factor, C_t = 1.01 (10-17-67) and 1.43 (11-9-67).

that is probably a part of the longer reach losing water to the stratified-drift aquifer when NA 16 and 31 are pumped. Measurements made prior to pumping from the wells to determine the amount of streamflow pickup produced inconsistent results (table 18), and the gain in streamflow is probably too small to be accurately measured. Measurements of streamflow during pumping from the wells are subject to similar limitations, but they show significant losses even considering a possible error of ±5 percent for each measurement. The measured loss is considered the best one available and is used to compute the hydraulic conductivity of the streambed. The equation used in the computation (table 18) is a modified form of Darcy's equation and is discussed in more detail under "Infiltration capacity." The hydraulic conductivity computed for November is much lower than that for October because infiltration rates were substantially reduced by a mat of leaves that covered the streambed during the later measurements. Because leaves are swept away by later high flows, the hydraulic conductivity computed for October (14.2 ft/day) is considered to be more representative of the streambed deposits and of relatively coarse and permeable streambed deposits elsewhere in the basin.

Experiments with a field variable-head permeameter along reaches of the Pomperaug River indicate hydraulic conductivity values of several tens of feet per day at most sites. Along this stream, riffles with gravelly channel floors alternate with pools with sandy bottoms, but permeable gravel predominates. Most problems associated with using the permeameter in coarser grained sediments are related to sample disturbance, including compaction, channeling, and suspension followed by settling of the fine-grained fraction as the permeameter is driven into the deposits. In addition, only the upper foot or slightly more of the deposits could be tested, and this topmost layer may be unrepresentative. The net result of these limitations is a computed value that is mostly higher than actual hydraulic conductivity, and a value of 14 ft/day is judged to be reasonable for most streambed deposits of the Pomperaug River.

The field permeameter probably gives more reliable results in fine-grained deposits than in gravel. Three measurements of vertical hydraulic conductivity near the right bank of the Housatonic River, where it is impounded by Derby dam indicate values of 0.21, 0.38, and 0.66 ft/day (see pl. A, SH 4, 10 and 15), indicating silty and organic very fine sand, organic fine sand, and fine sand, respectively. An average value of 0.4 ft/day is estimated for the lake bottom as a whole, with the recognition that its hydraulic conductivity may range from half as much to twice as much in different places.

AMOUNT OF WATER POTENTIALLY AVAILABLE

Water from wells is derived principally from three sources: 1) ground-water runoff, 2) aquifer storage, and 3) induced infiltration. If withdrawals over an extended period of time exceed the amounts available from these sources, discounting any used well water returned to the local hydrologic system, declining water levels, and eventually, declining well yields result.

Development of a ground-water supply can reduce ground-water evapotranspiration over the area of lowered water levels, thus providing an additional potential source of water to wells. The magnitude of such reduction is difficult to ascertain, but it is probably small in this particular basin, in comparison with amounts potentially available from other sources. Therefore, reduction of ground-water evapotranspiration is not considered in the estimates of the amount of water potentially available, and therefore these estimates are conservative to this extent.

GROUND-WATER RUNOFF

Ground-water runoff varies throughout the year in much the same pattern as total runoff. Hydrographs of observation wells indicate that in most years the water table declines steadily during a 4- to 6-month period from late spring to early autumn, corresponding closely to the growing season. This seasonal decline, illustrated for the lower Housatonic River basin by the hydrograph for well WY 1 (fig. 25), indicates very little net recharge from precipitation during the growing season. The decline is accompanied by a decreasing rate of ground-water runoff and a reduction in the amount of ground water in storage. The decreased rate of ground-water runoff and reduction in storage are attributed largely to the seasonal demands of evapotranspiration. This period of declining water levels, corresponding closely to the 6-month growing season, is hereafter termed the period of no recharge.

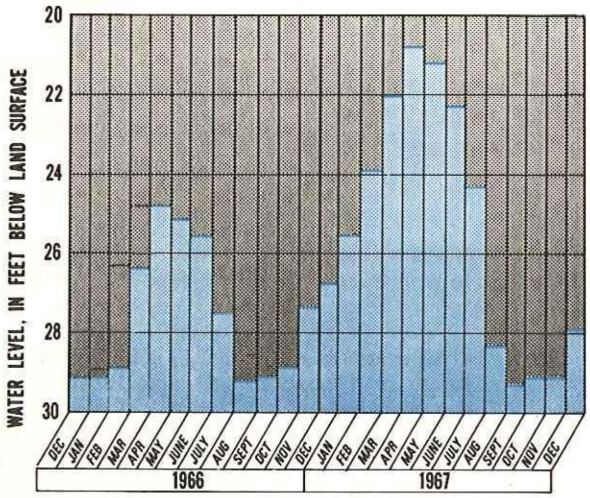


Figure 25.--Monthly changes of water level in well WY 1, December 1965-1967.

During the remaining months of the year, the water table generally rises, indicating that recharge from precipitation exceeds ground-water runoff and that net ground-water storage increases. The rate of ground-water runoff also increases because of steeper hydraulic gradients produced by the rising water table. This period of rising water levels is hereafter termed the recharge period.

Although the ground-water runoff rate changes seasonally, wells can pump at constant rates throughout the year without permanently lowering the water table as long as total pumpage (excluding pumpage of water that is recirculated and therefore used more than once) does not exceed annual ground-water runoff, assuming that adequate water is available from ground-water storage. During the period of no net recharge, all withdrawals will, in effect, be coming from ground-water storage (excluding induced infiltration). During a recharge period, recharge must be sufficient to sustain pumping rates and to replace storage water pumped during the period of no recharge. Thus, the amount of water available through the interception of ground-water runoff is determined more by the total annual ground-water runoff and the amount available from ground-water storage than it is by seasonal fluctuations in ground-water runoff and storage.

Quantitative estimates of near minimum ground-water runoff rates can be made for any streamflow site in the basin by utilizing the appropriate recurrence rate curve on figure 26 in conjunction with the Q_2, 7-day annual minimum streamflow values (that is, the lowest streamflow during a 7-day period that occurs on the average of once in 2 years) shown on plate B. Figure 26 is based on analysis of hydrographs from three unregulated streams with long-term streamflow records, the Pomperaug River and Leadmine Brook in the lower Housatonic River basin, and Burlington Brook in the adjacent Farmington River basin. For each station (locations shown on pl. B), annual streamflow hydrographs for each year of record through 1968 are used to estimate monthly ground-water runoff rates. The rates are based on templates derived from curves connecting the lowest daily discharges for the periods of record. Probably the monthly ground-water runoff rate closely approximates the long-term minimum ground-water runoff rate that can be expected on the three streams. These monthly rates are used to construct ground-water runoff frequency curves, from which the relationships between ground-water runoff recurrence rates and the Q_2, 7-day annual minimum streamflow (median 7-day annual minimum streamflow) are established (fig. 26). The assumption that the Q_2, 7-day annual minimum streamflow is a meaningful index of near minimum ground-water runoff seems reasonable because it occurs during the 6-month period (late spring to early autumn) when streamflow is largely sustained by ground-water runoff.

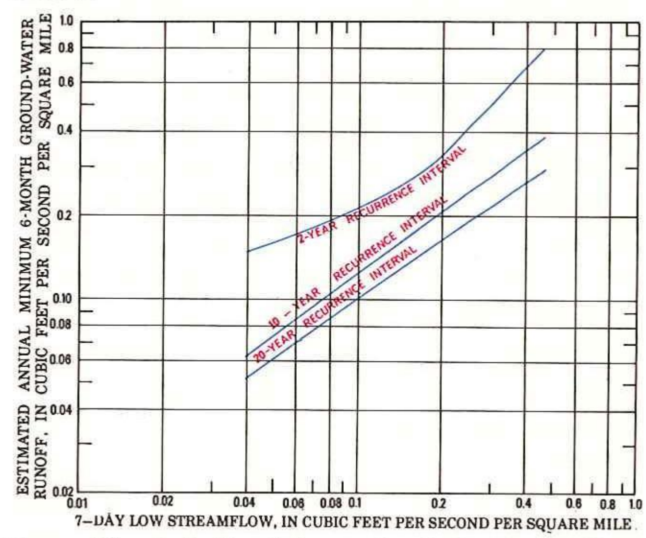


Figure 26.--Relation between Q_2, 7-day streamflow and estimated annual minimum 6-month ground-water runoff.

The Q_2, 7-day streamflow (the lowest streamflow during a 7-day period that occurs on the average of once in 2 years) is related to the estimated annual minimum 6-month ground-water runoff. The relationship shown for selected recurrence intervals is based on long-term records at Burlington Brook, Leadmine Brook, and the Pomperaug River.

WATER FROM AQUIFER STORAGE

The amount of water that can be pumped from aquifer storage is equal to the product of storage coefficient and the volume of aquifer that can be drained during the period of pumpage. To illustrate, 141.7 million gallons will be released from storage if, during 180 days of no recharge in a stratified-drift aquifer having a storage coefficient of 0.20, the water table declines 1 foot over an area of 1 square mile. In reality, pumping from wells results in coalescing cones of depression in the water table, and it is impractical to determine directly the volume of aquifer dewatered by pumping. A more useful way of determing yields from aquifer storage is to model the aquifer and its boundaries, using the Theis nonequilibrium equation (Theis, 1935), and analyzing by the image-well method. This method is utilized in evaluating the potential yield from storage of the ground-water reservoirs in the basin. (See "Potential yields of principal ground-water reservoirs.")

INDUCED INFILTRATION

Water in stream channels and lake basins can be an important source of supply to wells through induced infiltration. In the lower Housatonic River basin, wherever productive aquifers are hydraulically connected to perennial streams through permeable streambed deposits, conditions are favorable for induced infiltration, and many wells derive part of their yield by this means. In some places a special effort is made to induce infiltration. In Woodbury, for example, the Watertown Fire District derives much of its water supply (WY 12-16, 18, pl. A) indirectly from the Nonewaug River, which has been diverted into a gravel-lined canal that passes through the well field. At periods of low flow, water is released from an upstream reservoir. Similarly, in Oxford, the Seymour Water Company has placed its wells (OX 2-7) alongside the Little River and nearby artificial channels. In Naugatuck the horizontal collector of UniRoyal, Inc. (NA 34, pl. A) is designed to induce Naugatuck River water into the aquifer. The high mineralization of water from this well and others in the valley suggests that river water adversely affected by man's use moves into the aquifer. At Shelton, the Bridgeport Hydraulic Company placed its well field 40-100 feet from the Housatonic River, and its wells, which pumped a combined total of 3,100 million gallons during 1965, probably derive much of their supply from the river.

Induced infiltration and the factors controlling it are well known. However, practical quantitative means for evaluating the actual or potential rates of infiltration in environments like that of the basin are not well developed. As a result, estimates are approximate, and detailed site studies are necessary wherever more precise answers are required. Nevertheless, an understanding of the factors affecting infiltration capacity combined with a knowledge of the hydraulic conductivity and thickness of alluvial sediments (previously discussed) provide a basis for estimating optimum supplies available from infiltration.

Infiltration capacity

Factors affecting induced infiltration are conveniently expressed by a modified form of Darcy's equation:

$$Q_i = \left(\frac{K_v}{C_t}\right)\left(\frac{\Delta h}{b'}\right)(A)$$

in which

Q_i = infiltration capacity, or potential rate of induced infiltration at prevailing water temperature, in ft^3/day (multiplying by 7.48 converts ft^3/day to gpd),

K_v = vertical hydraulic conductivity of streambed deposits at 16°C, under unit vertical hydraulic gradient, in ft/day,

C_t = factor for converting vertical hydraulic conductivity at 16°C to vertical hydraulic conductivity at prevailing water temperature, dimensionless,

$\frac{\Delta h}{b'}$ = vertical hydraulic gradient, where

h = difference in hydraulic head between the surface-water level and ground-water level, in feet, and

b'= thickness of streambed deposits, in feet, and

A = area of stream channel being infiltrated, in square feet.

The equation indicates that the maximum infiltration capacity of a given reach of stream in which K_v and b' are constant in time, can be realized by establishing maximum hydraulic gradient over the full area of channel. Gradient is maximum when the ground-water head is at the bottom of the streambed deposits. The difference in head is then equal to the mean stream depth, d, plus the thickness of streambed deposits, b'. Additional ground-water drawdowns do not increase the head gradient; hydraulic gradient then varies only with stream depth. Where streams are shallow compared to streambed thickness, as in many streams in the basin at low-flow conditions, the maximum hydraulic gradient, (d + b')/b', approaches unity. Thus 1.0 is a reasonable approximation of hydraulic gradient where d, b', and the position of the ground-water level are unknown, but it is known or can be assumed that d is small compared to b' and that the ground-water level is at or below the bottom of the streambed deposits.

Under conditions of high flow, hydraulic gradient can increase manyfold, the amount depending on the amount of increase in mean stream depth. Also during high flow, infiltration rates may increase owing to the greater area covered by the stream.

Substantial variations in infiltration capacities result from seasonal changes in water temperature. The hydraulic conductivity of an aquifer is greater if the water it contains is warm water, because warm water is less viscous than cold water. The hydraulic conductivity at any point within the range of most stream temperatures can be determined by a method described by Walton and Ackroyd (1966, p. 11).

Temperature variations of the Pomperaug River at Southbury (gaging station 2040, pl. B) can be used to illustrate the resulting variations of hydraulic conductivity. During water year 1967, stream temperatures ranged from 0°C to 26°C, with a daily average of 11°C. If the hydraulic conductivity of the streambed deposits is assumed to be 13 ft/day at 16°C, the hydraulic conductivity during that year ranged from a minimum of 8.07 ft/day at 0°C to a maximum of 16.66 ft/day at 26°C, with an average of 11.40 ft/day. Thus the potential infiltration rate ranged from 71 percent of the average to 146 percent of the average, owing to temperature changes alone. The above-average infiltration rates resulting from warm temperature may be partly offset by below-average area of contact and mean stream depth during the months when temperatures are high.

Rate of flow from streams to wells

The amount of water obtained from induced infiltration obviously cannot exceed the amount of water in the stream channel. When the infiltration capacity of a reach of stream is greater than the streamflow, pumping wells near the stream might dry up sections of the stream. Estimated infiltration capacity is compared to the Q_2, 7-day annual minimum streamflows shown for most streams in the basin (pl. B, fig. 13, tables 1-4), to determine the limitations, if any, that the amount of streamflow imposes upon the amounts obtainable through induced infiltration.

The amount of water available from induced infiltration may be limited by the ability of the aquifer to transmit water to wells. Surface water that infiltrates the aquifer flows toward wells at a rate controlled by aquifer transmissivity, hydraulic gradient, and length of the flow path. Where the flow rate toward the well is less than the infiltration capacity of the streambed deposits or less than the available streamflow, the rate of induced infiltration is limited. This limitation can be reduced by placing wells near the river, thereby steepening the hydraulic gradient.

Increased infiltration resulting from warm surface water may be offset in part by the modifying effects of cool water in the aquifer. The warm water will be cooled as it mixes with the ground water, and even if it remains warmer than the ground water, it cannot move more rapidly toward the wells despite its lower viscosity until the cool water ahead of it in the aquifer is displaced.

PREDICTING YIELDS OF SCREENED WELLS

Carefully planned and executed pumping tests provide the most reliable quantitative information on both aquifer characteristics and potential yield of wells. However, some preliminary estimates of yield from wells screened in the stratified drift can be made by using the series of graphs on figures 28-32 in conjunction with estimates of transmissivity and aquifer thickness.

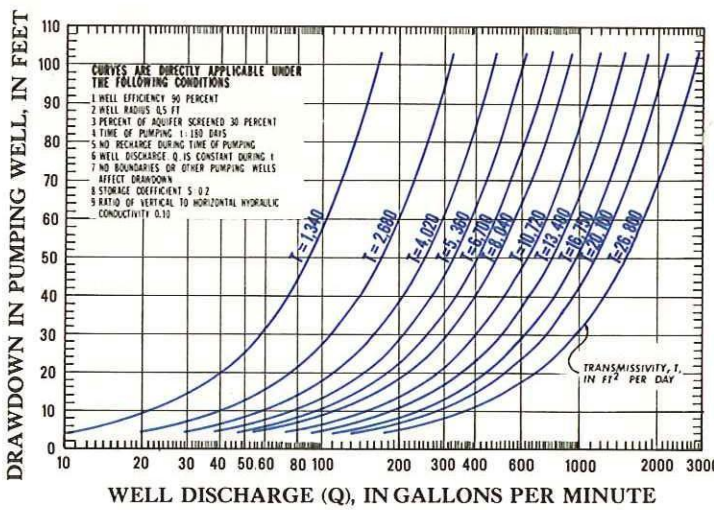


Figure 28.--Drawdown in a pumping well related to well discharge and transmissivity.

Figure 28 relates well discharge and drawdown for various aquifer transmissivities for a given set of conditions. The values used to construct the curves on figure 28 are based on the Theis nonequilibrium formula (Theis, 1935, p. 520), which incorporates several simplifying assumptions. These assumptions are seldom realized in practice, and therefore corrections are required for drawdown resulting from dewatering of the aquifer, for the effects of partial penetration (30 percent penetration is assumed), and for well efficiency (90 percent efficiency is assumed). For purposes of analysis the yield of the well is considered to be the constant rate at which it can be pumped continuously for 6 months (180 days) with no aquifer recharge (either from precipitation or induced infiltration of streamflow) and still not draw the pumping level below 1 foot above the top of the screen. The total drawdown with the pumping level at this position is considered the maximum available drawdown.

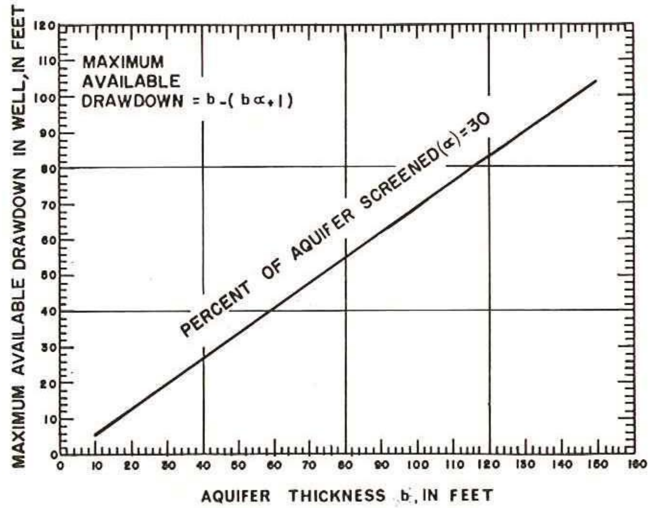


Figure 29.--Maximum available drawdown related to aquifer thickness in wells screened in lower 30 percent of the aquifer.

Maximum available drawdown is the total available drawdown with the pumping level 1 foot above the top of the screen; this value can be used in predicting maximum well yield.

Transmissivity and aquifer thickness can be estimated from plate C. Once aquifer thickness is known, maximum available drawdown for a well open to the bottom 30 percent of the aquifer can be determined from figure 29. The well yield can then be determined directly from the appropriate transmissivity curve on figure 28, provided that the conditions listed are met. Each curve on figure 28 is a smooth line drawn through segments of a closely spaced family of curves representing various values of aquifer thickness. The error resulting from this smoothing procedure may be as much as 10 percent; generally it is much less.

In practice, field conditions commonly differ from the assumed ones. Yield will be higher than indicated on figure 28 if field conditions differ from the assumed conditions in the following ways: (1) well efficiency is greater than 90 percent, (2) well radius is larger than 0.5 foot, (3) percentage of aquifer screened is greater than 30 percent, (4) time of pumping is shorter than 180 days, (5) recharge, including induced infiltration, occurs, (6) storage coefficient is greater than 0.2, and (7) the ratio of vertical to horizontal hydraulic conductivity is greater than 1/10 (0.10).

Yield will be lower than indicated on figure 28 if field conditions diverge from assumed ones in the opposite directions from those listed above. In addition, yield may be lower because of the effects of nearby pumping wells or of barrier boundaries. However, either of these effects can be taken into account by using figure 30 which gives the drawdown in a well discharging 100 gpm when a second well, also discharging at 100 gpm, is located at the indicated distance from the first well. The figure shows drawdown as a function of transmissivity and distance to the second well. When a single well is pumping 100 gpm, the drawdown resulting from the effect of a single impermeable boundary is determined by reading the distance from the pumping well to the boundary on the horizontal scale in the same figure and doubling it. In either case, the drawdown of the water table caused by a pumping rate different from 100 gpm can readily be determined from the equation shown with the curves.

The drawdown indicated on figure 30 is for an artesian aquifer. For a water-table aquifer, where the drawdown of the water table is a substantial proportion of the saturated thickness, correction for dewatering must be made, using figure 31. The actual drawdown of the water table, corrected for dewatering, is determined by subtracting the adjusted drawdown from the maximum available drawdown. The corrected value can be used on figure 28 to estimate the yield of the well.

The theoretical effects of well radius and percentage of aquifer screened on well yield are illustrated on figure 32. The common practice in the basin is to screen the lower 25 percent of the aquifer (fig. 27). Use of a longer well screen decreases the maximum permissible drawdown, if the limit used in this report (1 foot above the top of the screen) is applied, but also decreases the head losses due to partial penetration. Up to a screened ratio of about 40 percent of the aquifer, the decreased partial penetration losses are more than sufficient to offset the lower operating drawdown, resulting in a higher well yield. At greater screened ratios the decrease in available operating drawdown offsets the lower partial penetration losses, and well yield begins to decrease. On the other hand, if the operating drawdown is not restricted to the top of the screen, increasing the screen length should produce corresponding increases in yield. The assumption is made, of course, that the aquifer is homogeneous and the length of well screen can be arbitrarily increased, a situation that is uncommon. The curves on figure 32 also show that doubling the well radius from 0.5 foot to 1.0 foot increases the yield by about 10 percent. Yield values determined from figure 28, applicable

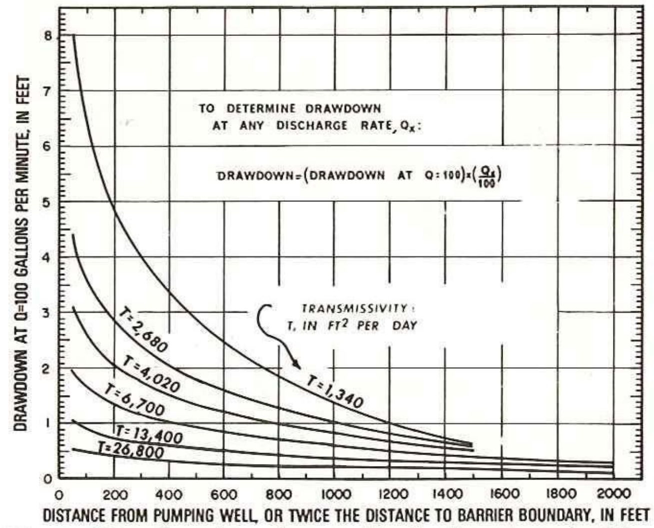


Figure 30.--Drawdown in a well discharging at 100 gpm in an artesian aquifer, at selected distances from a second well pumping at the same rate; or in a pumping well located one half the indicated distance from a single barrier boundary; for selected values of transmissivity.

The curves and equation shown can be used to estimate drawdown in an artesian aquifer resulting from pumping at any discharge rate.

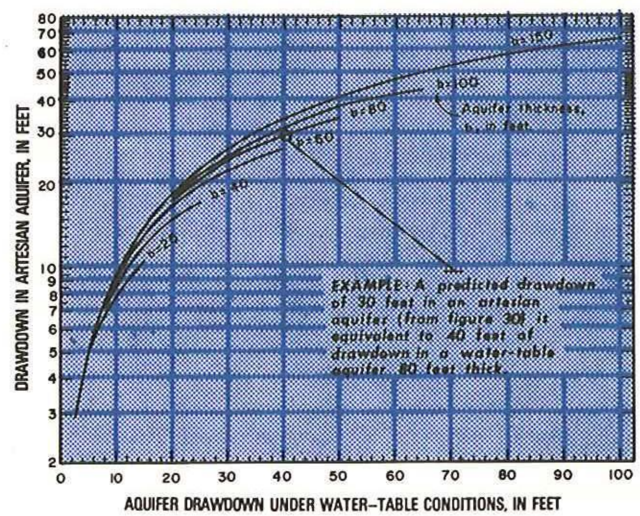


Figure 31.--Drawdown in a water-table aquifer related to drawdown in an artesian aquifer of the same thickness.

Drawdown in a water-table aquifer is larger than that in an artesian aquifer of the same thickness.

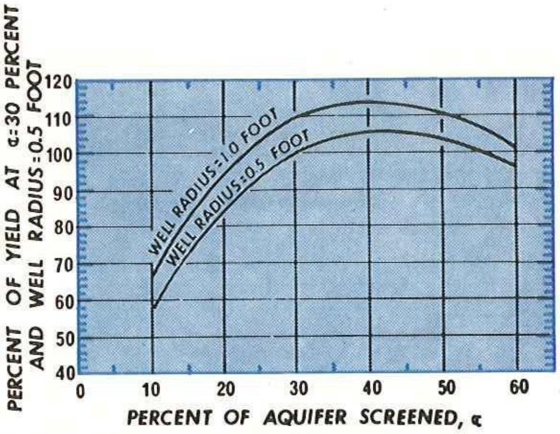


Figure 32.--Well yield related to percentage of aquifer screened and to well radius.

Theoretical maximum yields are obtained by screening about 40 percent of the aquifer.

to a well screened in 30 percent of the aquifer and with 0.5-foot radius, can be adjusted for a different percentage of aquifer screened and (or) a well radius of 1.0 foot by multiplying the yield by the appropriate percentage on the vertical scale of figure 32.

Example of method

If aquifer thickness is 80 feet, maximum drawdown for a well screened in 30 percent of it is 56 feet (fig. 29). Assuming no interference from pumping wells or barrier boundaries, and a transmissivity of 6,700 ft^2/day, maximum yield of a proposed well 0.5 foot in radius is about 440 gpm (fig. 28).

Suppose, however, that another well situated 600 feet from the proposed well is pumping at 100 gpm. At this distance, it would theoretically cause a drawdown at the proposed well site of 0.8 foot in an artesian aquifer (from fig. 30). If the distant well is pumping at a higher rate, say 450 gpm, drawdown at the site of the proposed well is increased to 0.8 x 450/100, or 3.6 feet (from equation on fig. 30). Figure 31 shows that the adjustment for aquifer dewatering is negligible. Subtracting 3.6 ft from the available drawdown of 56 ft leaves 52.4 ft of drawdown available. With this available drawdown, a yield of about 410 gpm can be expected from the proposed well (from fig. 28).

Suppose further that a valley wall 800 feet from the proposed well site acts as a barrier boundary. The effect of this boundary would be to increase the drawdown 0.5 ft if the proposed well were pumped at 100 gpm (from fig. 30, using distance = 2 x 800 = 1,600 ft). However, the proposed pumping rate is 410 gpm, and the boundary effect thus increases drawdown by 0.5 x 410/100 = 2.0 ft (equation, fig. 30). This value is added to the drawdown caused by the nearby pumping well to obtain a combined drawdown of 5.6 ft at the proposed well site. Adjusting for water-table conditions gives a value of 6.0 ft (from fig. 31). Subtracting 6.0 ft from the maximum available drawdown of 56 ft gives 50 ft for available drawdown. A yield of about 400 gpm can be obtained with this drawdown (from fig. 28).

Assume that it is feasible to screen 35 percent of the aquifer and to use a well radius of 1.0 ft. The yield of 400 gpm is multiplied by 1.12 (from fig. 32) to get a final estimated well yield of 448 gpm.

Note that the final estimate of 448 gpm is a readjustment that attempts to offset the deeper drawdown resulting from boundary effects. The boundary effects on drawdown can be redetermined several times and the yield readjusted accordingly. In addition, the nearby pumping well may also be affected by the boundary, and, if so, its effect on the drawdown at the proposed well site would be greater than that determined from figure 30. However, the method presented is designed only for a preliminary estimate of yield, and detailed refinements are probably not justified. When hydrologic and geologic conditions are complex, such as in areas of multiple boundaries, including streams acting as recharge boundaries, and several actively pumping wells, and wide range in aquifer transmissivity and thickness, reliable estimates of yield can only be obtained from more complex model systems or from actual field testing.

POTENTIAL YIELDS OF PRINCIPAL GROUND-WATER RESERVOIRS

Stratified drift in segments of the valleys of the Pomperaug, Naugatuck, and Housatonic Rivers is particularly favorable for the development of large ground-water supplies. Fourteen favorable areas, termed principal ground-water reservoirs, are selected for analysis of the potential yields that might be developed from well fields. These are outlined on plate C and are shown as simplified models on figure 33. Details of reservoir characteristics and yield data are shown in table 19.

The 14 ground-water reservoirs are selected on the basis of the following criteria:

(1) Maximum transmissivity of the stratified-drift aquifer in the reservoir is at least 27,000 ft^2/day, and average transmissivity was determined to be at least 4,000 ft^2/day.

(2) Maximum aquifer thickness is at least 80 feet.

(3) The aquifer is suitable for the installation and use of screened wells.

(4) The area is traversed by one or more streams capable of supplying water for induced infiltration.

The analysis shows that all the ground-water reservoirs have a potential yield greater than 1 mgd. No other areas met all the above criteria and, although there may be other areas in the basin where 1 mgd can be developed, such development would probably require careful management of closely spaced wells of low yield. The potential yield of any ground-water reservoir is determined in part by restrictions on the amount of induced infiltration of streamflow permitted, and therefore the pumping capacity of the 14 reservoirs may be less than the computed yield.

In each favorable area an estimate is made of the maximum pumping rate that can be sustained without causing drawdown in excess of the maximum available drawdown in the center of the area. Estimates are made for two hydrologically signi-

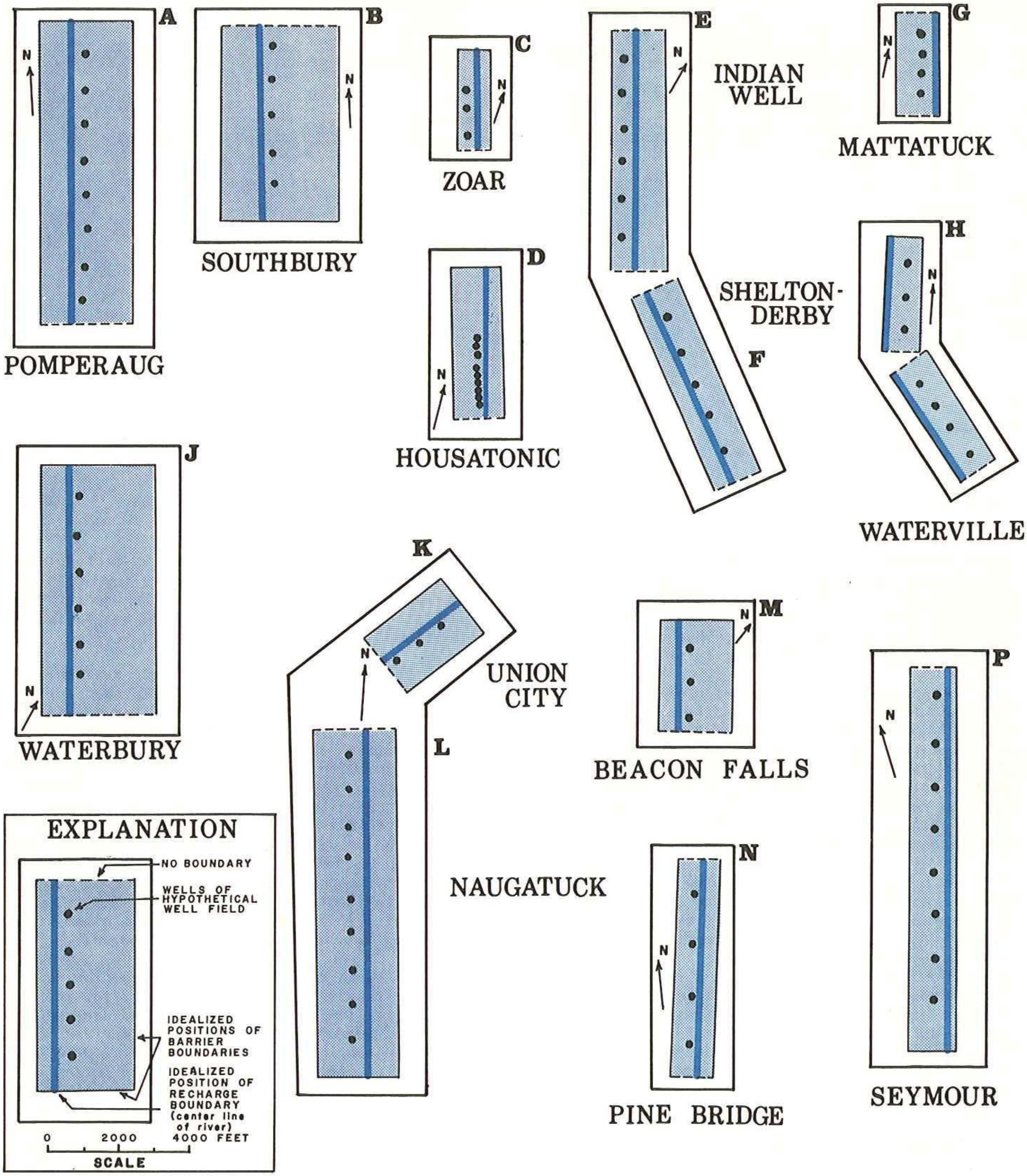


Figure 33.--Models of principal ground-water reservoirs showing location of hypothetical pumping-well array.

Principal ground-water reservoirs occur in the valleys of the Pomperaug River (areas A, B), Housatonic River (areas C-F), and the Naugatuck River (areas G-P). Estimates of yields can be determined mathematically by idealizing the distribution of trnasmissivity and positions of barrier and recharge boundaries.

Table 19.--Potential yields of principal ground-water reservoirs

Ground-water reservoir: Letter designation and name (1)	Size (sq mi) (2)	Hypothetical well field: No. of wells (3)	Well spacing (ft) (4)	Saturated thickness of aquifer at well sites (ft) (5)	Maximum available drawdown (ft) (6)	Aquifer storage: Initial average transmissivity (ft^2/day) (7)	Yield from storage during period of no recharge (mgd) (8)	Aquifer capacity: Initial average transmissivity (ft^2/day) (9)	Capacity during period of no ground-water recharge; stream acts as recharge boundary (mgd) (10)	Ground-water runoff: Annual minimum calendar year ground-water runoff. Recurrence interval 2-yr (mgd) (11)	10-yr (mgd) (12)
A. Pomperaug	0.79	8	1,000	80	55	4,000	2.3	5,100	4.0	2.6	1.8
B. Southbury	.67	5	1,000	70	48	4,700	1.6	4,800	2.2	1.6	1.2
C. Zoar	.097	3	500 1,300	80	55	8,000	.95	7,100	1.9	.82	.52
D. Housatonic (Shelton field)	.22	9	200 300	200	169	13,400	6.8	10,300	15	1.9	1.2
E. Indian Well	.39	6	1,000	120	83	4,700	2.5	5,900	4.0	1.1	.68
F. Shelton-Derby	.31	5	1,000	80	55	4,700	1.5	9,400	3.6	.52	.32
G. Hattatuck	.13	4	600	80	55	7,500	1.4	7,000	2.4	.32	.21
H. Waterville	.28	7	1,000 800	80 90	55 62	8,000	2.7	11,400	6.3	.40	.25
J. Waterbury	.82	6	1,000	80 120	55 83	6,700	3.4	7,000	4.8	1.2	.78
K. Union City	.19	3	800	80	55	6,700	1.2	12,600	3.0	.20	.13
L. Naugatuck	.81	9	1,000	100 120	69 83	6,700	4.9	6,200	7.2	1.4	.88
M. Beacon Falls	.20	3	1,000	80	55	5,500	1.1	4,900	1.4	.64	.40
N. Pine Bridge	.26	4	1,400	80	55	4,000	1.1	3,700	1.4	1.4	.85
P. Seymour	.53	8	1,200	80	55	4,700	2.2	6,200	4.6	1.2	.78

Ground-water reservoir (1)	Induced infiltration of streamflow at low-flow conditions: Principal stream entering ground-water reservoir (River) (13)	Wetted area (million sq ft) (14)	Streambed deposits: Thickness (ft) (15)	Streambed deposits: Vertical hydraulic conductivity (ft/day) (16)	Average drawdown beneath stream (ft) (17)	Average stream depth (ft) (18)	Hydraulic gradient (ft/ft) (19)	Infiltration capacity (mgd) (20)	Streamflow: Annual minimum 7-day flow Recurrence interval 2-yr (mgd) (21)	10-yr (mgd) (22)	Augmentation at low flow, in 1960's (mgd) (23)	Potential yields: During period of no ground-water recharge (mgd) (24)	During ground-water recharge period (mgd) (25)	Actual ground-water reservoir pumpage in 1960's (26)	Reservoir designation (27)
A. Pomperaug	Pomperaug	0.40	5	13.4	8	1	1.2	48	2.1	0.7	0	2.1	6.6	0.40	A
B. Southbury	do	.35	5	13.4	11	1	1.2	42	5.4	2.3	0	2.2	3.8	.90	B
C. Zoar	Housatonic	.48	15	6.8	34	1	1.1	26	154	77	64	1.9	2.7	0	C
D. Housatonic (Shelton field)	do	2.4	8	0.7	70 95	6	1.8	22	154	77	64	15	17	8.5	D
E. Indian Well	do	4.1	8	.7	21	12	2.5	51	155	77	64	4.0	5.1	0	E
F. Shelton-Derby	do	3.6	8	.7	20	10	1.8	32	155	77	64	3.6	4.1	1.9	F
G. Hattatuck	Naugatuck	.48	10	3.3	25	1	1.1	13	8.4	3.4	9.0	2.4	2.7	0	G
H. Waterville	do	.84	10	3.3	30	1	1.1	23	9.0	3.5	9.0	6.3	6.7	1.0	H
J. Waterbury	do	.75	10	3.3	20	1	1.1	20	13	5.4	14	4.8	6.0	0	J
K. Union City	do	.28	10	3.3	20	1	1.1	7.7	18	7.7	31	3.0	3.2	0	K
L. Naugatuck	do	1.0	10	3.3	25	1	1.1	28	20	8.4	33	7.2	8.6	3.0	L
M. Beacon Falls	do	.26	10	3.3	16	1	1.1	7.2	24	10	33	1.4	2.0	0	M
N. Pine Bridge	do	.90	10	3.3	17	1	1.1	25	24	10	33	1.4	2.8	0	N
P. Seymour	do	2.4	10	3.3	18	1	1.1	66	24	11	33	4.6	5.8	.40	P

ficant periods of a year: a 180-day period without ground-water recharge, and a period of approximately equal length with ground-water recharge. These estimates take into account the amounts of water available from aquifer storage, induced infiltration of streamflow, and ground-water runoff.

The procedure for determining ground-water runoff is contained in the section titled "Ground-water runoff." Annual minimum values of ground-water runoff for 2-year and 10-year recurrence intervals are given in table 19 (columns 11 and 12): the value that is selected as potentially available depends upon how restrictive are the limitations set for intercepting ground-water runoff as part of the water-management scheme.

The procedures for determining induced infiltration are contained in the sections titled "Induced infiltration" and "Rate of flow from streams to wells." In the estimates of potential yields, it is assumed desirable to restrict the quantity of induced streamflow infiltration so as to eliminate or reduce the number of times a stream will go dry. Accordingly, annual minimum values of 7-day streamflow for 2-year and 10-year recurrence intervals are given in table 19 (columns 21 and 22): the value that is selected as potentially available for induced infiltration depends upon the limitations set on depletion of streamflow.

The procedures for determining the quantities of water potentially available from aquifer storage are contained in the section titled "Water from aquifer storage."

The procedures for estimating the proportion of potentially available water that can be withdrawn on a long-term basis are the same as those discussed in the section "Predicting yields from screened wells." To simplify the analyses, the 14 favorable areas are idealized as rectangles in which the hydraulic boundaries (valley walls and streams) are straight lines and the transmissivity and storage coefficient within the boundaries are averaged.

During periods of no recharge, available ground water is considered to be derived entirely from induced infiltration and aquifer storage: the rate at which water can be withdrawn from a ground-water reservoir during periods of no recharge and with a stream assumed to act as a fully penetrating recharge boundary is herein termed aquifer capacity (table 19, col. 10). Under natural conditions, ground-water runoff is derived from storage during periods of no recharge. Water that can be induced from streams is limited either by infiltration capacity (table 19, col. 20) or streamflow (col. 21), whichever is smaller. In the analysis, the Q_2, 7-day annual minimum streamflow was used as the low-flow parameter.

In those reservoirs where streamflow is smaller than infiltration capacity (fig. 34, part A, box 1), pumpage will initially be derived from storage, but ultimately it will be derived mostly from induced infiltration. Streamflow will be reduced accordingly. In determining potential reservoir yield, Q_2, 7-day streamflow (table 19, col. 21) is compared to aquifer capacity (table 19, col. 10), and the smaller of the two is the potential yield during 180 days of no recharge. In seven of the eight reservoirs analyzed (fig. 34, part A, box 1), the potential yield is limited by the aquifer capacity; only in the Pomperaug reservoir is the potential yield limited to the low streamflow rate.

During periods of no recharge (fig. 34, part A) and where infiltration capacity is smaller than streamflow (fig. 34, part A, box 2), the potential yield of an aquifer is taken as equal to aquifer capacity or to the sum of infiltration capacity

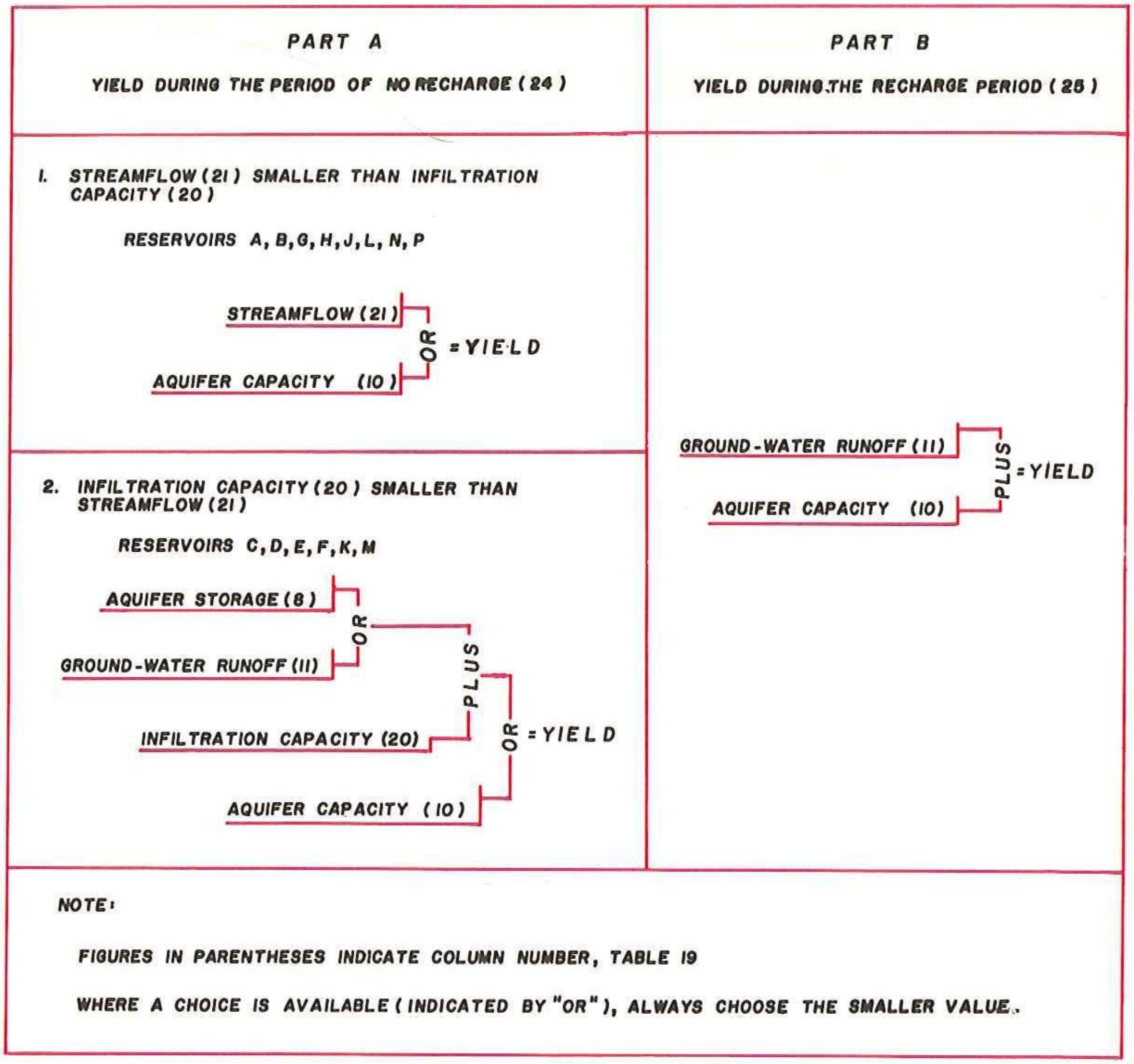


Figure 34.--Steps used to determine potential yield of ground-water reservoirs.

For most reservoirs, potential yield during periods of no recharge equals aquifer capacity, and for all reservoirs potential yield during recharge periods equals ground-water runoff plus aquifer capacity.

and yield from aquifer storage (table 19, col. 8) or to the sum of infiltration capacity and ground-water runoff (table 19, col. 11), whichever is smaller. In the six ground-water reservoirs analyzed (fig. 34, part A, box 2), available storage is equal to or greater than ground-water runoff (table 19, col. 11), and withdrawals from storage are thus limited to ground-water runoff. However, in each case, the aquifer capacity is less than the sum of the infiltration capacity (table 19, col. 20) and aquifer storage (table 19, col. 8), and the potential yield of these reservoirs during periods of no recharge is equal to the aquifer capacity (table 19, col. 10).

During the recharge period (fig. 34, part B), reservoir yield is taken arbitrarily as equal to the sum of aquifer capacity and ground-water runoff. Although the ground-water runoff during this period (table 19, col. 11) is considerably greater than the average rate for the year, some of the recharge that would have become ground-water runoff under natural conditions goes into replenishing aquifer storage depleted by pumping during the period of no recharge. Replenishment of storage during ground-water recharge periods enables pumping to continue at the aquifer-capacity rate during succeeding periods of no recharge without eventually overpumping the reservoir. In the Pomperaug ground-water reservoir, well yields during periods of no recharge are limited by the low streamflow rather than by aquifer capacity. Therefore, for the recharge period, it is assumed that streamflow increases enough to exceed the sum of aquifer capacity and ground-water runoff, and that pumping an amount equal to this sum will, therefore, not deplete the stream excessively.

Comparison of potential reservoir yields with the actual withdrawals (table 19, col. 24-26) indicates that only in the Southbury, Housatonic, Shelton-Derby, and Naugatuck Reservoirs does pumpage total even half the potential reservoir yields. The other 10 reservoirs remained practically untapped as late as 1967.

Table 20.--Source and significance of some of the chemical and physical properties of water in the basin

Chemical or physical property	Source and concentration	Significance and maximum recommended limit
Silica (SiO_2)	Dissolved from practically all rocks and soils. Usually found in the basin in small amounts ranging from 1 to 26 mg/l. Surface water usually has a lower concentration than does ground water.	Forms hard scale in boilers, water heaters, and pipes. Inhibits deterioration of zeolite-type water softeners. The USPHS (U.S. Public Health Service, 1962) has not recommended a maximum concentration for drinking water.
Iron (Fe)	Dissolved from many assorted minerals that contain oxides, sulfides, and carbonates of iron. Decaying vegetation and objects made of iron in contact with water, sewage, and industrial waste are also major sources. Surface water in the basin in its natural state usually has less than 0.5 mg/l. Ground water generally has higher concentrations than surface water.	On exposure to air, iron in ground water oxidizes to a reddish-brown precipitate. More than about 0.3 mg/l of iron 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. The USPHS recommends a maximum of 0.3 mg/l for drinking water.
Manganese (Mn)	Dissolved from many rocks and soils. Often found associated with iron in natural waters but not as common as iron. Surface water in the basin usually has less than 0.1 mg/l. Ground water generally has higher concentrations than surface water.	More than 0.2 mg/l precipitates upon oxidation. Manganese has the same undesirable characteristics as iron but is more difficult to remove. The USPHS recommends a maximum of 0.05 mg/l for drinking water.
Calcium (Ca) and magnesium (Mg)	Dissolved from practically all rocks and soils, especially calcium silicates, clay minerals, and impure limestone lenses.	Hardness and scale-forming properties of water are caused by dissolved bicarbonates and sulfates of these minerals (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. The USPHS has not recommended a maximum concentration for drinking water.
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 replace soluble hardness-producing minerals with sodium and thus increase the amount of sodium present.	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 of steam boilers. The USPHS has not recommended a maximum concentration for drinking water; however, the Connecticut State Department of Health suggests a maximum limit of 20 mg/l for municipal water supplies.
Carbonate (CO_3) and bicarbonate (HCO_3)	Results from chemical action of carbon dioxide in all natural water on calcite and calcium silicate minerals. Decaying vegetation, sewage, and industrial wastes are also important sources.	Carbonates of calcium and magnesium cause hardness and form scale in boilers and pipes, and release corrosive carbon dioxide gas (see hardness). Water of low mineral content and low bicarbonate content in proportion to carbon dioxide is acidic and can be corrosive. The USPHS has not recommended a maximum concentration for drinking water.
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 form permanent hardness and hard scale in boilers and hot water pipes. The USPHS recommends a maximum of 250 mg/l for drinking water.
Chloride (Cl)	Small amounts dissolved from metamorphosed sedimentary rocks and soils. Relatively large amounts are derived from animal wastes, sewage, road salt, industrial wastes, and sea water. Chloride concentration of natural fresh water in the basin seldom exceeds 10 mg/l.	Large amounts of chloride in combination with calcium will result in a corrosive solution and in combination with sodium will give a salty taste. The USPHS recommends a maximum of 250 mg/l for drinking water.
Fluoride (F)	Dissolved from assorted minerals, such as apatite, fluorite, mica, and scapolite. Surface water in the basin rarely has more than 0.2 mg/l. Added to some waters by fluoridation of public water supplies.	About 1.0 mg/l of fluoride is believed to be helpful in reducing the incidence of tooth decay in small children; larger amounts possibly cause mottled enamel on teeth (Lohr and Love, 1954, p. 39). Amount varies depending on average water intake and climate. The USPH recommends the following maximum concentration for drinking water: lower, 0.8 mg/l; optimum, 1.0 mg/l; upper, 1.3 mg/l.
Nitrate (NO_3)	Very small amounts in natural waters from precipitation and solution processes. Sewage, industrial waters, fertilizers, and decaying vegetation are major sources. Lesser amounts are derived from precipitation.	Small amounts of nitrate have no effect on usefulness of water. A concentration greater than 6 mg/l generally indicates pollution. Nitrate encourages growth of algae and other organisms which produce undesirable tastes and odors. The USPHS recommends a maximum of 45 mg/l for drinking water equivalent to 10 mg/l of nitrate expressed as N. Waters containing more than 45 mg/l have reportedly caused methemoglobinemia, which is often fatal to infants; therefore such water should not be used in infant feeding.
Dissolved solids and specific conductance	Includes all mineral constituents dissolved in precipitation and from rocks and soils, locally augmented by mineral matter in sewage and industrial wastes. Measured as residue of evaporation at 180°C or calculated as numerical sum of amounts of individual constituents. Specific conductance, or the capacity of water to conduct an electric current, is used as an index of total mineral content. In natural waters in the basin, ground water usually has a larger concentration of dissolved solids than does surface water. Nearly all waters sampled has a dissolved-solids concentration considerably below the limit recommended by the USPHS.	Water containing more than 1,000 mg/l of dissolved solids is undesirable for public supplies and industrial purposes. The USPHS recommends a maximum of 500 mg/l for drinking water but as much as 1,000 mg/l can be tolerated. A dissolved-solids concentration of 500 mg/l is approximately equivalent to a specific conductance of 800 micromhos at 25°C.
Hardness (as $CaCO_3$)	Hardness is primarily due to presence of calcium and magnesium, and to a lesser extent to iron, manganese, aluminum, barium, and strontium. There are two classes of hardness, carbonate (temporary) hardness and noncarbonate (permanent) hardness. Carbonate hardness refers to the hardness in equivalents with carbonate and bicarbonate; noncarbonate to the remainder of the hardness. Most waters in the basin are classified as soft, with a hardness of less than 60 mg/l.	Hard water consumes soap before lather will form 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 contrast, water having a very low hardness may be corrosive. The USPH has not recommended a maximum hardness for drinking water. The U.S. Geological Survey classification of hardness appears in the "Hardness" section of text.
Hydrogen ion concentration (pH)	Water with a dominance of acids, acid-generating salts, and free carbon dioxide has a low pH. If carbonates, bicarbonates, hydroxides, phosphates and silicates are dominant, the pH is high. The pH of most natural waters ranges 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. The USPHS has not recommended a maximum pH for drinking water.
Color	Color in water may be of natural, mineral, or vegetable origin such as iron and manganese compounds, algae, weeds, and humus material. May also be caused by inorganic or organic wastes from industry. True color of water is considered to be only that attributable to substances 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. Results are usually expressed as units of color and not as mg/l. The USPHS recommends a maximum of 15 units for drinking water.
Dissolved oxygen (D.O.)	The amount of oxygen from the atmosphere that dissolves in surface water is a function of its temperature and various physical, chemical, and biochemical characteristics. Also from oxygen given off in the process of photosynthesis by aquatic plants.	Dissolved oxygen in surface water is necessary for the support of aquatic life which in turn, is necessary for the decomposition of organic matter. As the temperature of water increases, the solubility of oxygen decreases. During the summer months when streamflow is deficient and stream temperatures are highest,less oxygen is available. The presence of dissolved oxygen can cause corrosion of metals. In ground water dissolved oxygen causes precipitation of iron and manganese. According to most authorities, a dissolved-oxygen content of not less than 5.0 mg/l is needed to support various types of healthy fish. The USPH has not recommended a maximum concentration for drinking water.
Detergents as MBAS	MBAS 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 concentrations of ABS cause undesirable taste, forming, and odors. It often indicates presence of sewage or industrial waste. In mid-1965 ABS began to be replaced by LAS. Under similar optimum conditions, LAS is more degradable than ABS. The USPHS recommends for MBAS a maximum of 0.5 mg/l for drinking water.
Temperature	Temperature fluctuates widely in streams and shallow wells following seasonal climatic changes, but wells at depths of 30 to 60 feet remain within 2 or 3 degrees of mean annual air temperature (8°C to 11°C for the report area). Disposal of water used for cooling or industrial processing may cause local temperature abnormalities.	Temperature 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 will carry less oxygen in solution than water at low temperatures, and a corrosive water will become more corrosive with increased temperatures.
Turbidity	An optical property of water attributed to suspended or colloidal matter which inhibits light penetration. May be caused by microorganisms or algae; suspended mineral substances including iron and manganese compounds, clay or silt, or sawdust, fibers, and other materials. May result from natural processes of erosion or from the addition of domestic sewage or wastes from various industries, such as pulp and paper manufacturing.	Excessive concentrations are harmful or lethal to fish and other aquatic life. Turbidity is also undesirable in waters used by most industries, especially in process water. Turbidity can modify water temperature. Results are expressed in standard units, not milligrams per liter. The USPHS recommends a maximum of 5 units for drinking water.

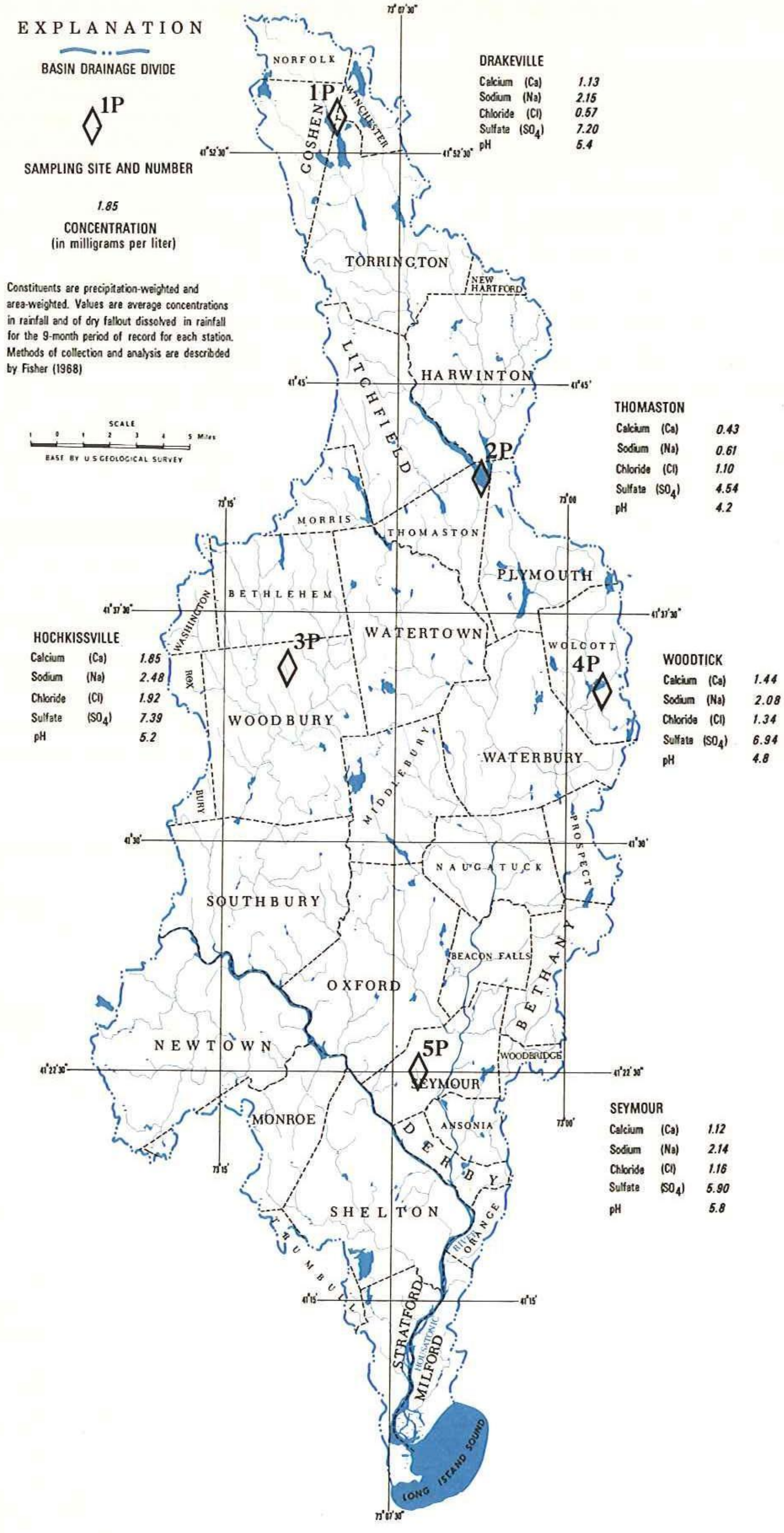


Figure 35.--Chemical quality of precipitation.

Map shows weighted concentrations of four constituents and pH at five sites sampled monthly from April to December 1966.

QUALITY OF WATER

As water moves through different environments its chemical composition and physical character change. Precipitation dissolves and washes material from the atmosphere and carries it to the land surface. Generally the dissolved-solids content of precipitation is very low, but occasionally it may be high owing to impurities in the atmosphere. Water that falls on the basin flows over the land surface and is further modified chemically as it comes in contact with mineral, plant, and animal matter. Products of reactions resulting from these contacts are carried away to streams in solution or suspension. Reaction rates at the surface are generally slow and the dissolved-solids content of overland flow is lower than that of the average stream. A significant quantity of water also reaches streams by percolating to the saturated zone and moving laterally below the surface as ground water. This water dissolves solutes from earth materials, increasing its dissolved-solids content, as it moves slowly toward nearby streams.

Natural differences in chemical quality of water may be masked where man has substantially affected the environment. The greatest contrasts in water quality in the lower Housatonic River basin are between the rural, undeveloped areas and the urban-industrial ones. Most water in rural, undeveloped areas is under near natural conditions and is of good to excellent quality. Water in highly developed areas may be poor in quality and it is more variable, depending upon the type and degree of man's effect on the environment.

The chemical analyses forming the basis for this study have been published in reports listed in the companion basic-data report (Grossman and Wilson, 1970, p. 6). Sampling sites specifically referred to in this report are shown on plate B (surface water) and plate A (ground water); detailed locations of all sampling sites are shown in the companion basic-data report (Grossman and Wilson, 1970, pl. A). The source and significance of the chemical constituents in water are summarized in table 20 of this report. The chemical data and subsequent evaluation are limited to inorganic properties determined from water samples collected in the study area.

PRECIPITATION

Constituents derived from the atmosphere may be a substantial proportion of the dissolved solids carried by natural streams in the lower Housatonic River basin at high flow. Precipitation samples were collected monthly at five stations in the basin during a 9-month period in 1966. The analyses of calcium, sodium, chloride, sulfate, and pH in the rain water and dry fallout composites (fig. 35) are precipitation-weighted

Table 21.--Chemical and physical quality of precipitation, streams, and ground water

(Chemical constituents in milligrams per liter)

Constituent or property	Precipitation a/		Water in streams under natural conditions				Water in aquifers b/						Upper limit in drinking water c/
	Monthly composite sampled April - December 1966 at 5 stations		During high flow (4 percent flow duration) at 22 sampling sites		During low flow (99 percent flow duration) at 22 sampling sites		Stratified drift (19 wells)		Bedrock (34 wells)		Till (7 wells)		
	Median	Range	Median	Range	Median	Range	Median	Range	Median	Range	Median	Range	
Silica (SiO_2)	-	-	4.6	2.9 - 7.3	8.2	2.4 - 13	12	6.6 - 17	14	5.6 - 23	7.5	5.6 - 20	-
Iron (Fe)	-	-	.32	.03- 1.2	.12	.04 - .95	.06	.00- .71	.09	.02- .57	.02	.00- .14	0.3
Manganese (Mn)	-	-	-	-	-	-	.04	.00- 1.7	.03	.00- .34	.09	.01- .18	.05
Calcium (Ca)	1.4	0.0 - 4.3	5.5	3.4 - 7.0	9.8	4.0 - 15	12	5.1 - 25	14	2.7 - 35	6.6	2.8 - 16	-
Magnesium (Mg)	.14	.00- .58	1.6	.5 - 2.5	3.0	1.4 - 3.9	3.3	1.6 - 8.0	4.5	.5 - 16	1.8	.8 - 5.4	-
Sodium (Na)	1.2	.1 - 8.6	-	-	-	-	-	-	-	-	-	-	-
Potassium (K)	.2	.0 - 5.0	-	-	-	-	-	-	-	-	-	-	-
Sodium as sodium (Na) plus potassium (K)	-	-	5.4	2.3 - 8.3	6.4	3.2 - 10	8.3	3.5 - 15	6.2	2.8 - 47	4.8	2.8 - 8.1	-
Bicarbonate (HCO_3)	0	0 - 14	6	3 - 11	28	10 - 48	26	17 - 96	50	10 -176	18	11 - 28	-
Sulfate (SO_4)	6.4	2.1 - 24	14	11 - 17	14	7.5 - 18	16	5.0 - 23	13	2.3 - 36	13	4.4 - 37	250
Chloride (Cl)	1.1	.2 - 6.6	8.1	2.1 - 14	8.9	3.5 - 15	11	3.8 - 18	3.8	1.0 - 15	7.0	1.0 - 11	250
Nitrate (NO_3)	.2	.0 - 7.6	1.3	.1 - 8.6	.6	.0 - 5.8	2.7	.0 - 9.5	.4	.0 - 16	2.0	.1 - 6.7	45
Dissolved solids (residue on evaporation at 180°C)	15	2 - 47	51	27 - 59	68	45 - 90	91	50 -138	91	20 -192	60	29 -109	500
Hardness as $CaCO_3$	4	1 - 12	20	13 - 28	37	18 - 53	44	22 - 96	55	12 -162	24	10 - 62	-
Noncarbonate hardness as $CaCO_3$	2	0 - 12	15	10 - 23	12	4 - 24	20	3 - 32	7	0 - 39	12	1 - 39	-
Specific conductance (micromhos at 25°C)	42	14 -238	72	47 -107	106	57 -150	128	72 -236	147	38 -339	84	34 -178	-
pH (units)	5.0	3.9 - 9.7	6.1	5.3 - 6.6	7.2	6.3 - 7.4	7.0	6.4 - 7.7	7.0	6.0 - 8.6	6.9	6.2 - 7.1	-
Color (units)	-	-	14	4 - 27	5	3 -200	-	-	-	-	-	-	15

a/ Composite of 45 samples of rainfall and dry fallout collected once each month for 9 months from each of five stations.
b/ Excludes wells believed to be heavily affected by domestic or industrial wastes and by salty water from Long Island Sound.
c/ Recommended by U.S. Public Health Service (1962).

mean concentrations that have also been weighted for the area covered by each station by using the Thiessen net (Fisher, 1968, p. M4). Comparing the analyses of precipitation with those from streams under natural conditions (table 21) shows that a sizeable part of the dissolved solids in natural streams during periods of high flow has been contributed by the atmosphere.

The quality of precipitation in the lower Housatonic River basin cannot be attributed to any dominant storm during the period of record but rather reflects local conditions (fig. 35). Storms passing over the industrialized cities of Bridgeport, Danbury, Naugatuck, New Haven, Thomaston, Torrington, and Waterbury pick up significant quantities of gaseous and particulate impurities from fumes and smoke and return them to the land surface in precipitation or fallout.

Sulfate is the dominant anion in precipitation (figs. 35 and 36). Although sulfur-bearing fuels burned within the study area undoubtedly contribute major amounts of this anion, additional sulfate is derived from other industrial and metropolitan complexes encircling the basin.

Rainfall on much of the study area is distinctly acidic, probably owing to sulfur oxides and hydrogen sulfide in the atmosphere. Atmospheric water absorbs carbon dioxide until equilibrium is reached at a pH of 5.7 (Barrett and Brodin, 1955, p. 252). A pH of 5.7 is regarded as the neutral point with respect to acidity of atmospheric water solutions.

Although the amount of particulate matter carried into the basin by a single storm is small, the cumulative effect is significant. Values for the load of calcium, sodium, chloride, and sulfate that entered the basin during the 9-month sampling period are shown on figure 36. Of these, sulfate predominated in all months. September had the heaviest rainfall during the sampling period, and all constituents except calcium peaked in that month. The maximum chloride load, 0.75 ton per square mile, was in September, when storms were oceanic; lesser amounts of chloride, usually less than 0.18 ton per square mile, were deposited during each of the other summer months, when storms were continental.

SURFACE WATER AND GROUND WATER

NATURAL CONDITIONS

Despite the materials carried in precipitation, the quality of water in rural, undeveloped areas is largely unaffected by man's activities: Samples of surface water and ground water were collected at 82 sites in areas where water quality was considered to reflect near-natural conditions. The analyses, summarized in table 21, indicate by the low dissolved-solids concentration that the chemical quality of these waters for most uses is good to excellent. However, as discussed on pages 50-51, water in many parts of the basin may contain chemical constituents, such as iron and manganese, or may have properties, such as color or hardness, that adversely affect its suitability for use.

The dissolved-solids concentration of direct runoff is not much higher than that of precipitation and is generally lower than that of ground-water runoff. Therefore, the dissolved-solids concentration of streamflow at high flows, which consists chiefly of direct runoff, is lower that that of streamflow at low flows which consists largely of ground-water runoff (table 21). However, the load of dissolved solids carried by streams during high flows is greater than during periods of low flow. The quality of stream water at low flows closely resembles that of ground water.

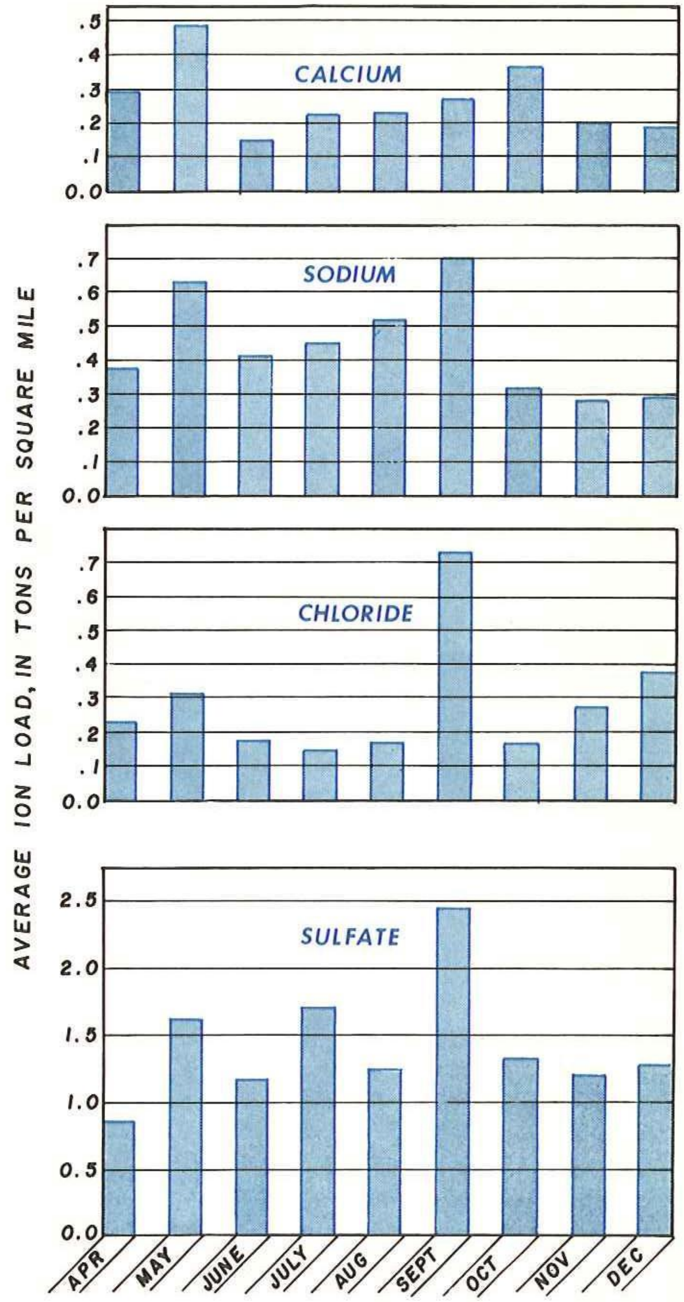


Figure 36.--Seasonal changes in four constituents of precipitation, April-December, 1966.

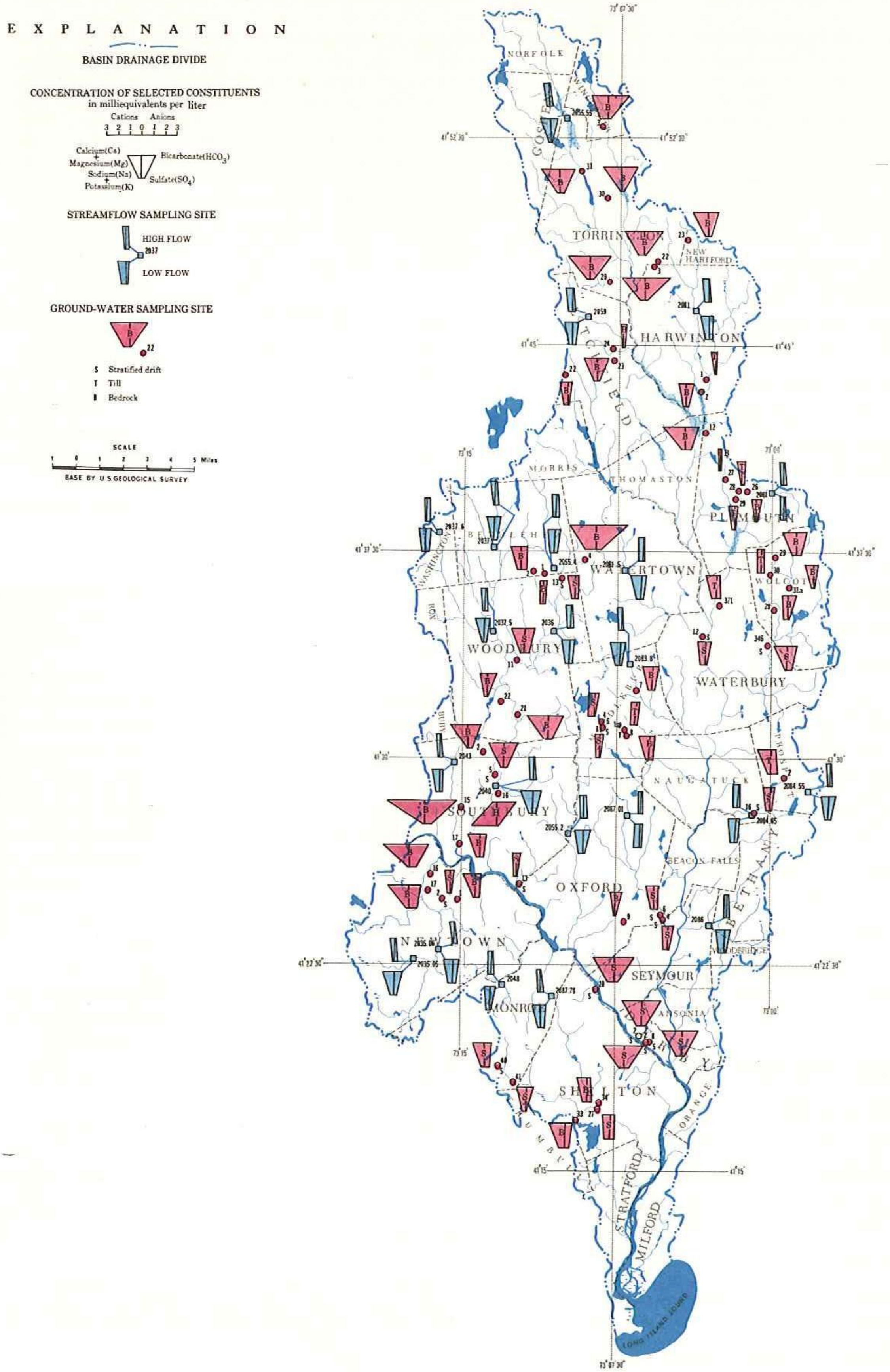


Figure 37.--Quality of naturally occurring water in streams and aquifers.

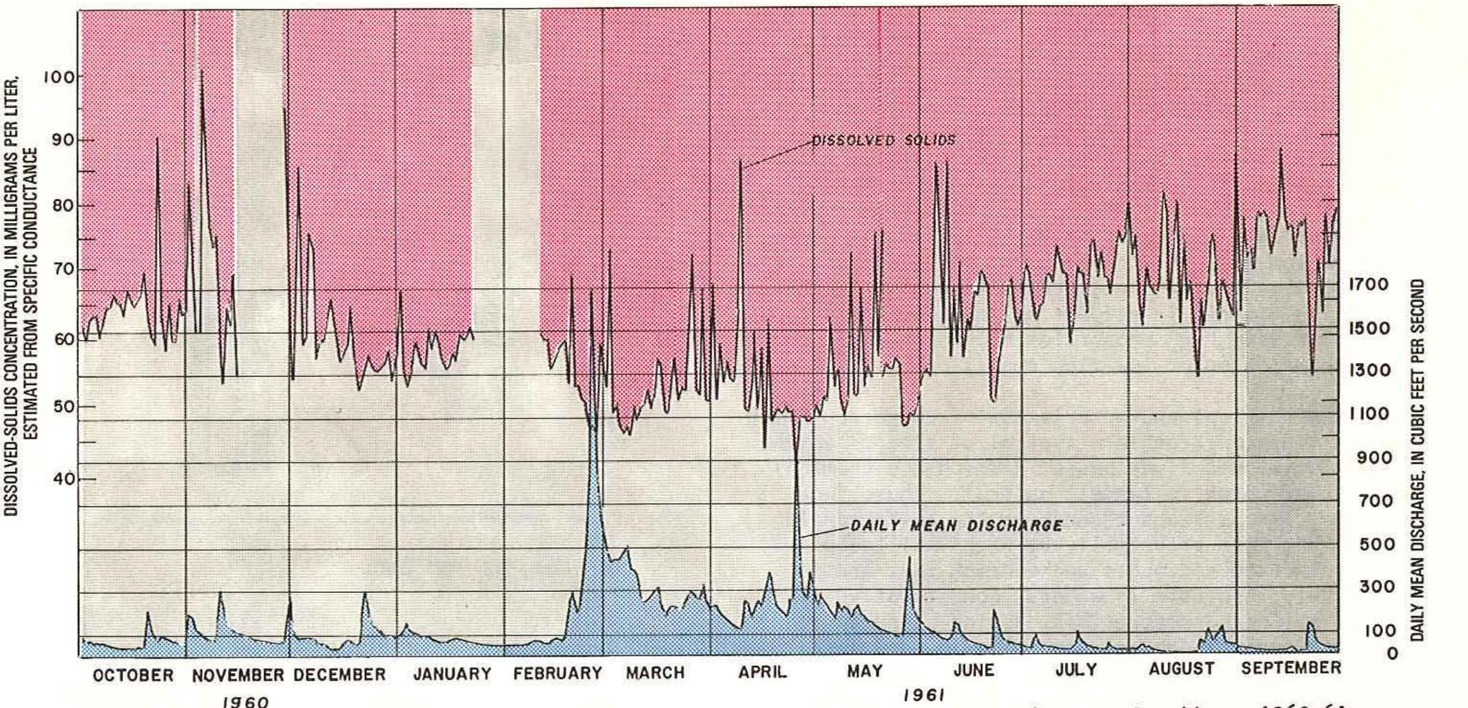


Figure 38.--Dissolved-solids concentration and discharge of Pomperaug River at Southbury 1960-61.

Specific conductance, a measure of dissolved-solids concentration, was measured once daily during period of record.

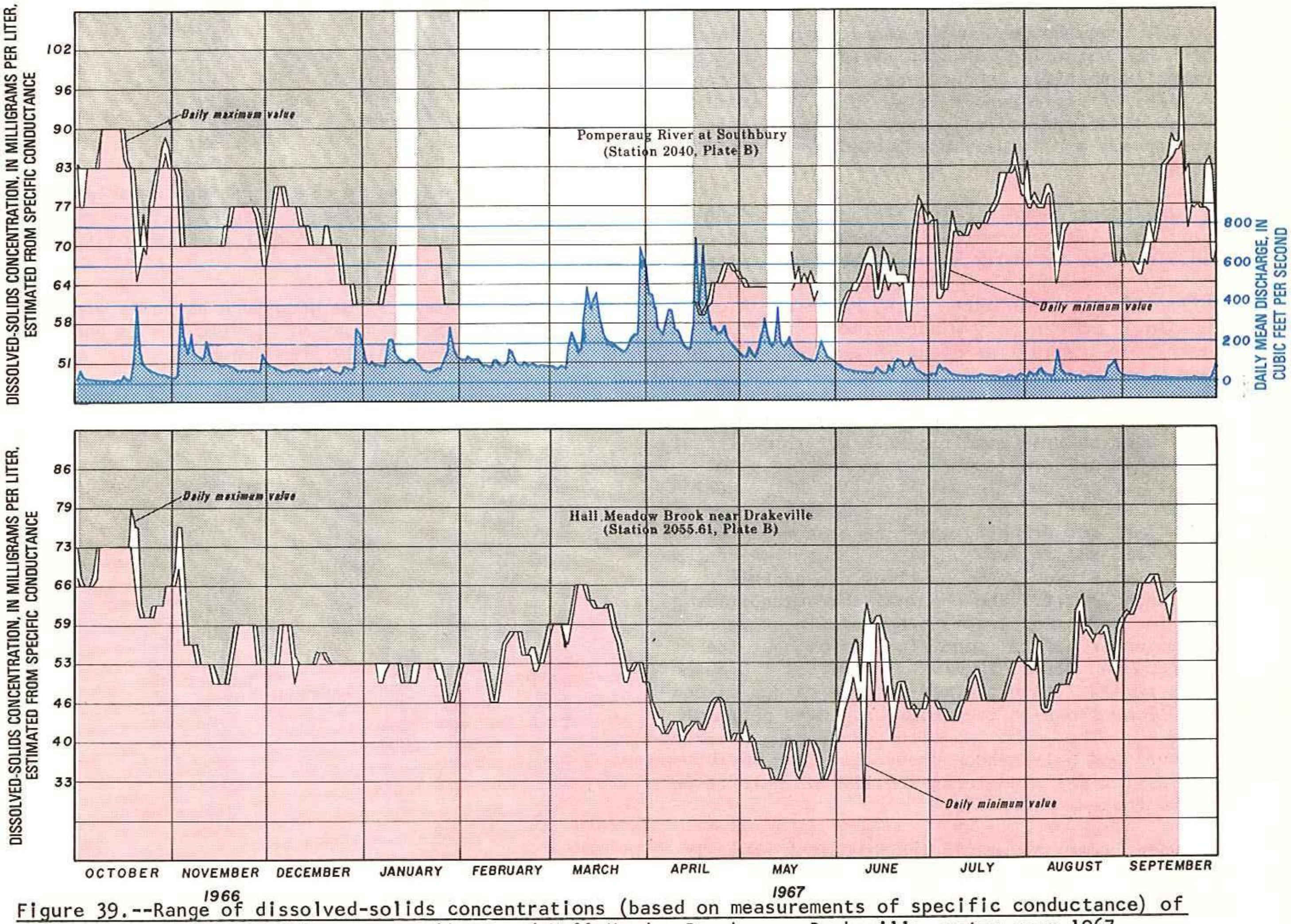


Figure 39.--Range of dissolved-solids concentrations (based on measurements of specific conductance) of Pomperaug River at Southbury and Hall Meadow Brook near Drakeville, water year 1967.

The relatively low dissolved-solids concentrations and small range of daily flow duration indicate that the quality of water in these streams was relatively unaffected by man's activities.

Two-thirds to three-fourths of the dissolved-solids concentration of water in the basin consists of calcium, magnesium, sodium, bicarbonate and sulfate. The relative proportions of these dominant constituents show that water in the basin is generally of the calcium magnesium bicarbonate type (fig. 37). Silica is about 10 percent of the dissolved solids in streams at high flow and 13 percent at low flow. It composes about 15 percent of the dissolved solids in ground water. The increase in silica content in streams at low flow reflects the relatively high proportion of ground-water runoff in streamflow under low-flow conditions.

The chemical characteristics of Pomperaug River and Hall Meadow Brook are typical of streams in the lower Housatonic River basin in which the chemical quality of water is largely natural. These two streams, like streams throughout the basin, drain areas underlain principally by highly siliceous unconsolidated sediments and bedrock that are relatively insoluble in water. Consequently, dissolved-solids concentrations, as indicated by specific conductance, are generally low and vary inversely with streamflow (fig. 38). During the spring high-flow period, the sulfate ion predominates over the bicarbonate ion (fig. 37) as a result of the flushing of the sulfur salts in precipitation and of dry fallout that has accumulated in the soil and rock openings.

The range between maximum and minimum dissolved-solids concentration for both streams, as interpreted from daily specific conductances is small, except for times of storm runoff (fig. 39). The small range and low dissolved-solids concentration indicate that both streams are largely unaffected by inorganic contaminants.

The Pomperaug River has a higher base level of dissolved-solids concentration than Hall Meadow Brook (see fig. 40), probably because the ground-water component of runoff from the sedimentary-volcanic aquifer in the lower part of the Pomperaug River subbasin is more highly mineralized than ground-water runoff from crystalline rocks in the ramainder of the lower Housatonic River basin.

Water of the Pomperaug River and Hall Meadow Brook under natural conditions is soft, low in sulfate and chloride concentrations, and close to neutral with respect to acidity (fig. 40). Median iron concentrations are below 0.3 mg/l (recommended upper limit for drinking water as prescribed by the U.S. Public Health Service, 1962), but iron concentrations vary widely and at times exceed this recommended limit. The chemical characteristics of water in these two streams are representative of streams under natural conditions throughout the Pomperaug and Naugatuck River basins, as indicated by the similarity in the medians and ranges of concentrations shown in the upper and lower parts of figure 40. Thus, the two sites, Pomperaug River at Southbury and Hall Meadow Brook near Drakeville, can serve as indices of natural quality in their respective regions.

Water from streams in the Naugatuck basin is much higher in iron concentration than water from the Pomperaug basin (fig. 40). Ground water in both basins is low in iron concentration (fig. 41), with a maximum of 0.6 mg/l in the Pomperaug system and 0.5 mg/l in the Naugatuck system. Most iron in the streams of the Naugatuck basin is probably derived from the decay of aquatic plants and leaves and is flushed mainly from swamps.

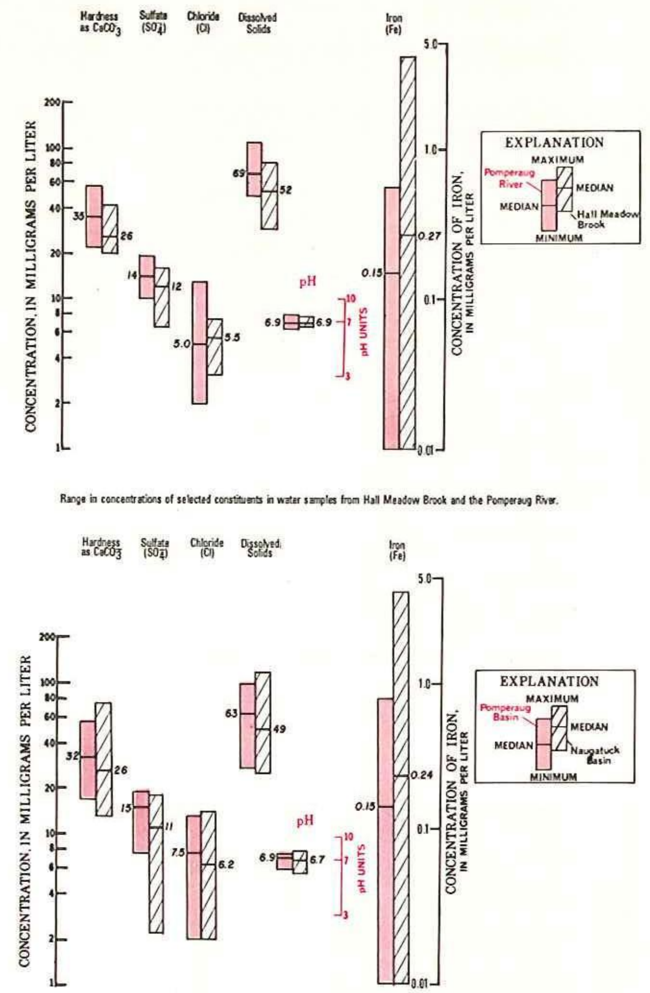


Figure 40.--Range in concentrations of selected constituents in samples of natural water from streams in the Naugatuck and Pomperaug River basins.

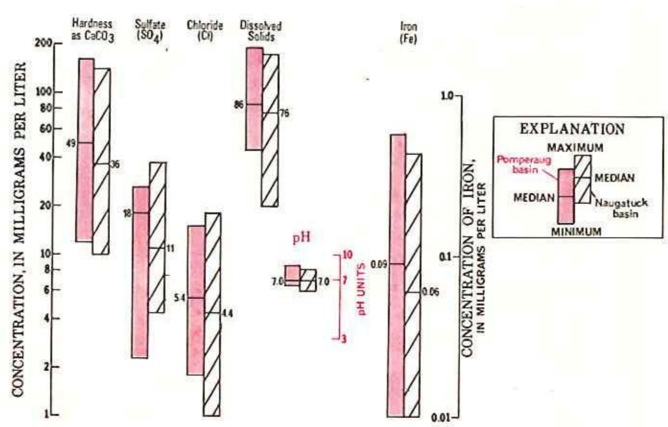


Figure 41.--Range in concentrations of selected chemical constituents in samples of natural water from wells in the Naugatuck and Pomperaug River basins.

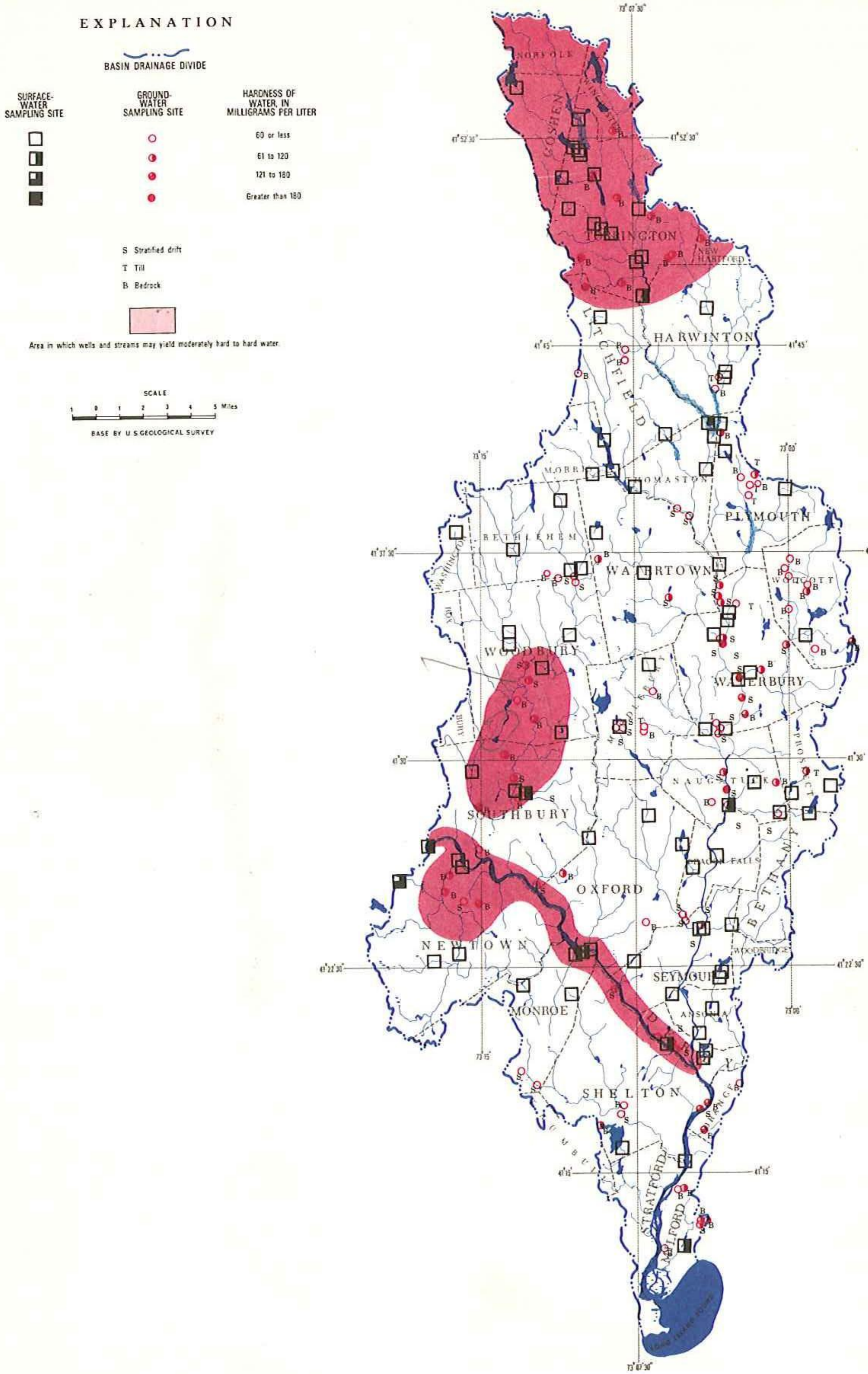


Figure 42.--Hardness of water in the basin.

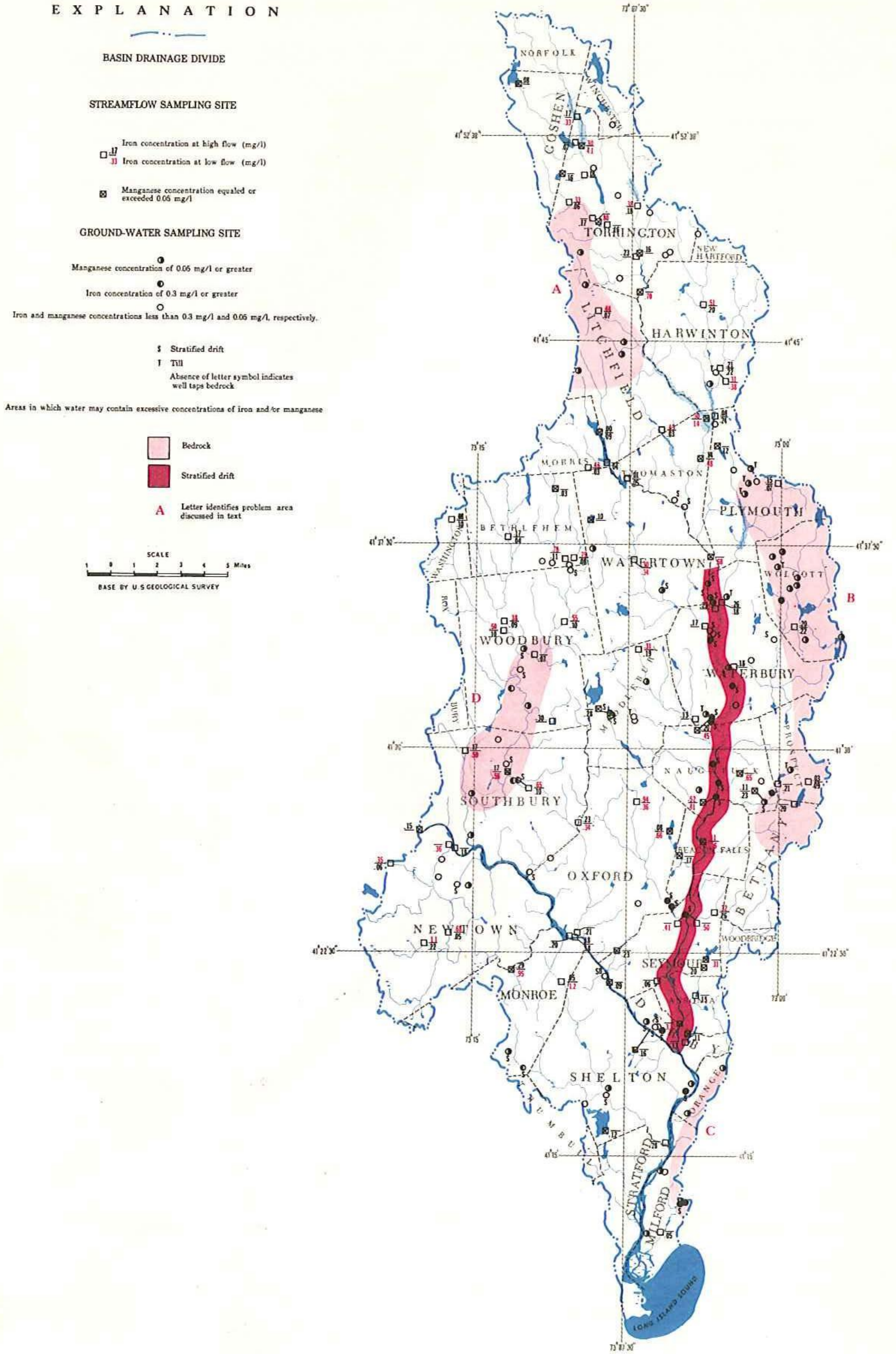


Figure 43.--Iron and manganese concentrations in water.

Table 22.--Comparison of calcium sulfate and calcium bicarbonate waters in the basin

(All values except number of samples are median values.)

Type of water	Bicarbonate (as carbonate) (percent)	Sulfate (percent)	Hardness as $CaCO_3$ (mg/l)	Noncarbonate (permanent) hardness as $CaCO_3$ (mg/l)	Specific conductance (micromhos at 25°C)	pH
Calcium-sulfate (16 samples)	14	27	45	22	135	6.8
Calcium-bicarbonate (23 samples)	38	14	78	4	215	7.5

The analyses of water from wells tapping the principal aquifers in the two basins (fig. 41) are considered to represent the natural ground-water quality throughout the lower Housatonic River basin. Ground water throughout the study area is principally of the calcium magnesium bicarbonate type (fig. 37), although 16 wells sampled yielded water of the calcium sulfate type. Of the 16 wells yielding calcium sulfate type water, 5 tap stratified drift, 4 tap till, and 7 tap bedrock. The unconsolidated aquifers may be yielding some water that has passed through bedrock and is, therefore, somewhat similar to water from bedrock. The Stiff-type diagrams (fig. 37) for water of the calcium sulfate type are skewed to the upper left and lower right. Such water has a lower pH and a higher noncarbonate hardness (table 22) than the dominant water of the calcium bicarbonate type.

The chemical quality of 30 lakes, ponds, and reservoirs, summarized in table 23, is generally excellent and is largely unaffected by man's activities. The median dissolved-solids concentration is 60 mg/l, median hardness is 32 mg/l, and most waters are slightly acidic.

The quality of lakes, ponds, and reservoirs is also measured by nutrient balance, dissolved-oxygen concentration, and thermal gradients. In the lower Housatonic River basin, studies of the chemical characteristics and limnology of Lake Zoar (plate B) have been made by the Connecticut Water Resources Commission and the State Board of Fisheries and Game. A detailed study on the nutrient balance of the lake by the Connecticut Agricultural Experiment Station at New Haven was under way in 1967.

Hardness

Hardness is a property of water that determines the quantity of soap required to produce a lather and is expressed as calcium carbonate ($CaCO_3$). (See table 20.) In this report, unless otherwise noted, hardness refers to carbonate hardness, commonly called temporary hardness. The familiar terms "hard water" and "soft water" are imprecise and not equally weighted by all authorities. The following classification is used by the U.S. Geological Survey:

Hardness as $CaCO_3$ (mg/l)	Hardness description	Suitability
0 - 60	Soft	Suitable for many uses without softening.
61 - 120	Moderately hard	Usable without softening except in some industries.
121 - 180	Hard	Softening required for laundries and some other industries.
181 or more	Very hard	Softening required for most purposes.

Table 23.--Chemical and physical quality of lakes, ponds, and reservoirs

(Chemical constituents in milligrams per liter)

Constituent or property	Median a/	Range a/
Silica (SiO_2)	3.0	0.2 - 5.1
Iron (Fe)	.16	.01 - .80
Manganese (Mn)	.05	.00 - .21
Calcium (Ca)	8.6	2.6 - 24
Magnesium (Mg)	2.1	.6 - 9.0
Sodium as sodium (Na) plus potassium (K)	5.0	1.5 - 9.2
Bicarbonate (HCO_3)	20	0 - 89
Sulfate (SO_4)	14	5.6 - 30
Chloride (Cl)	6.4	.2 - 19
Nitrate (NO_3)	.5	.1 - 1.6
Dissolved solids (residue on evaporation at 180°C)	60	20 - 134
Hardness as $CaCO_3$	32	9 - 97
Specific conductance (micromhos at 25°C)	85	22 - 187
pH	6.8	4.3 - 7.5
Color	5	3 - 20

a/ Based on analyses of single samples from 30 lakes, ponds, and reservoirs.

Water having a hardness of more than 120 mg/l is commonly softened for household use. Softening of municipal supplies is costly, but is generally advantageous if the hardness cannot be reduced to about 120 mg/l by dilution with softer water from other sources. The problem of hard water and use of water softeners has been fully described by Wilke and Hutcheson (1962).

Stream water throughout the basin is commonly soft (table 21), and, although ground water is typically harder, it is generally below 120 mg/l. Samples from 60 wells were analyzed for hardness; of these, 60 percent were soft, 33 percent moderately hard, and 5 percent hard. Water from stratified drift and till is commonly softer than water from bedrock.

Natural water that is moderately hard to hard is concentrated largely in three areas (fig. 42) based on analyses from 214 sampling sites reflecting either natural or man-affected ground and surface water. Bedrock units throughout the basin contain scattered limey lenses or concentrations of calcium silicate minerals, and these coincide in a general way with the patterned areas shown on figure 42. Water in these areas may be hard enough to be troublesome for some uses. Analyses of moderately hard to hard water are illustrated on figure 37 by the Stiff-type diagrams, which are characteristically enlarged, or "winged", along the calcium magnesium bicarbonate axis.

Water from the Housatonic River and nearby wells is harder than that from the streams in the basin as a whole. The hardness associated with the Housatonic River (stippled pattern, fig. 42) is the result of geologic conditions upstream from the report area. A part of the Housatonic River and many of its tributaries in western Massachusetts and northwestern Connecticut flow through extensive areas of carbonate-crystalline bedrock (mainly marble) and glacial sediments derived from it. Cervione and others (1972, p. 24, table 15) report that natural streams in the upper Housatonic River basin during low-flow conditions had a hardness ranging from 56 to 188 mg/l, with a median value of 112 mg/l for seven analyses. In the report area, Housatonic River water at Stevenson had a hardness ranging from 64 to 165 mg/l, with a median of 120 mg/l for 21 samples. The values for natural streams at low flow throughout the report area (table 21) had a median of 37 mg/l.

Thus the hardness characteristics of the Housatonic River and well water obtained from it through induced infiltration reflect upstream rather than local conditions, at least as far south as its confluence with the Naugatuck River.

Iron and manganese

Iron and manganese are only a minor part of the dissolved solids in the basin, but, because of their special characteristics, iron and manganese in concentrations of 0.3 mg/l and 0.05 mg/l or more, respectively, are objectionable for domestic uses (table 20). Even concentrations of iron and manganese less than 0.3 mg/l and 0.05 mg/l, respectively, can cause staining problems for the consumer with continued heavy water usage over a long time period. Iron concentrations as low as 0.2 mg/l may produce undesirable effects particularly if appreciable manganese is also dissolved in water. Manganese resembles iron in its general behavior; because manganese is commonly associated with iron, its effects may be masked by those of iron.

Iron and manganese concentrations are excessive in streams and aquifers in many parts of the basin, as shown on figure 43. Chemical analyses of 49 raw water sources from selected public-supply systems (table 29) show 9 contained excessive iron concentrations and 32 had excessive manganese concentrations.

Many streams in the lower Housatonic River basin that drain swamps contain objectionable concentrations of dissolved iron during high flow. Swamp vegetation assimilates iron during growth, and subsequent decay releases it to swamp water; evaporation concentrates the iron, and, during periods of heavy rainfall, the discharge from swamps carries large quantities of accumulated iron and also, presumably, organic matter, downstream. Table 21 indicates that the median iron concentration at 22 stream sites was 0.12 mg/l during a period of low flow in August 1965, compared with a median value of 0.32 mg/l during a period of high flow in March 1966. Only 27 percent of the low-flow samples contained 0.3 mg/l or more iron, whereas 59 percent of the high-flow samples contained 0.3 mg/l or more iron. The higher median concentration of iron and higher percentage of samples containing objectionable quantities of iron in 1966 are probably due to the flushing of swamp areas during the spring thaw and periods of heavy precipitation.

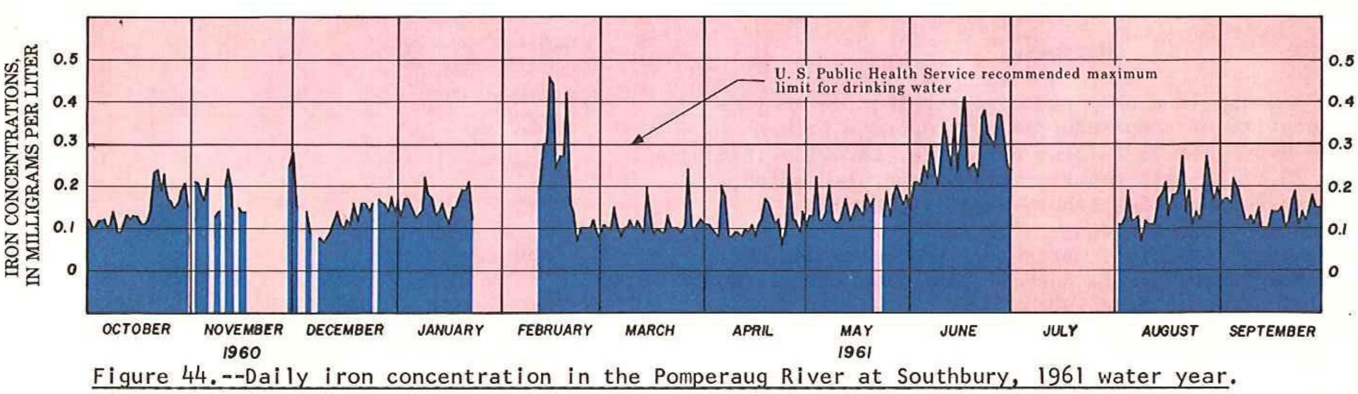


Figure 44.--Daily iron concentration in the Pomperaug River at Southbury, 1961 water year.

Iron concentration was 0.3 mg/l or greater 6 percent of the time, and 0.2 mg/l or greater 22 percent of the time.

Iron concentrations also are excessive during low flow in streams that receive ground water from iron-bearing aquifers. Examples in the lower Housatonic River basin include the Pomperaug River and lall Meadow Brook, as shown on figure 43. Excessive concentrations along the Naugatuck River are discussed in a subsequent section titled "Surface-Water Contamination."

Daily iron concentrations in the Pomperaug River at Southbury (fig. 44) vary widely but, like dissolved solids (fig. 38), are generally highest during periods of low streamflow and lowest during periods of high streamflow. During the 1961 water year, water samples had iron concentrations of at least 0.3 mg/l about 6 percent of the time, and of at least 0.2 mg/l 22 percent of the time. Flushing of swamps in the watershed probably accounts for the high concentrations during February and June. Iron concentrations exceeding 0.2 mg/l during the remainder of the summer-fall period probably resulted from ground-water discharge to the river.

Iron and manganese accumulate in the bottom material of lakes and ponds in the basin. During early stages of turnover these two constituents redissolve and circulate upward, remaining temporarily in solution until oxidation and precipitation transfer them downward again. Thus, these lakes and ponds intermittently discharge the iron and manganese to streams fed by them. This condition may account for the high concentrations of 0.66 mg/l iron and 0.28 mg/l manganese in water from the outflow of Seymour Reservoir No. 4 in September 1966.

Aquifers in the basin that are uncontaminated by wastes commonly yield clear water containing little or no iron or manganese. The percentage of wells sampled whose water contained iron or manganese at least equal to the limits recommended by the U.S. Public Health Service for drinking water is indicated on the following table.

	AQUIFER		
	Stratified drift	Till	Crystalline bedrock
No. of wells sampled for:			
Iron and manganese	19	7	34
Maximum concentration:			
Iron (mg/l)	0.71	0.14	0.57
Manganese (mg/l)	1.7	0.18	0.34
Percent of wells sampled containing at least:			
0.3 mg/l iron 1/	21	0	12
0.05 mg/l manganese 1/	37	86	41

1/ Upper limit recommended for drinking water by the U.S. Public Health Service.

These percentages may not reflect conditions for the report area as a whole because sampling was more intensive wherever iron and manganese bearing water was known to be a problem.

High concentrations of iron and manganese in ground water are widely distributed in the lower Housatonic River basin; figure 43 shows four areas where high concentrations are more common than elsewhere in the report area. In general, these areas are underlain either by schist, by undifferentiated crystalline rocks that may contain schist, or by the sedimentary-volcanic aquifer. (See fig. 17.) These rock types commonly contain iron sulfides, iron silicates, and associated manganese bearing minerals.

Area A on figure 43 is located in the northern part of the basin along the western drainage divide and includes parts of the towns of Litchfield, Morris, and Torrington. Analyses indicate that manganese may be more troublesome than iron here. Cervione and others (1972, p. 61) report that 8 of 11 bedrock wells sampled in the upper Housatonic River basin adjacent to area A yielded water exceeding the U.S. Public Health Service recommended drinking-water limits for iron or manganese.

Area B is along the eastern drainage divide and occupies parts of the town of Bethany, Naugatuck, Plymouth, Prospect, Waterbury, and Wolcott. Within the basin, it coincides with the distribution of a rusty colored weathered schist. Concentrations in this area were as high as 0.43 mg/l iron and 0.43 mg/l manganese, and water from approximately 90 percent of the wells sampled exceeded 0.05 mg/l manganese.

Area C is in the extreme southeast, along the eastern drainage divide and includes part of the towns of Milford and Orange. Iron concentrations in this area are generally less troublesome than in the two previously discussed, but locally excessive concentrations were found.

Area D is in the west-central part of the basin and occupies parts of the towns of Southbury and Woodbury. It coincides with the area of the sedimentary-volcanic aquifer in the Pomperaug River basin. The iron and manganese in the ground water in this area are probably attributable to iron sulfide minerals. Of five bedrock wells sampled, four had water with troublesome amounts of iron and manganese; the maximum concentrations were 0.57 mg/l and 0.34 mg/l, respectively. Four wells tapping the overlying stratified drift in the same area yielded samples with lesser amounts of these constituents.

Color

Small streams draining swamps in the basin are often colored light to dark amber owing to the presence of organic material, which releases plant substances, such as tannin, to water. Iron may be a significant constituent of color in water, but it is not the only one. In autumn, large accumulations of leaves release colored extracts to water. In addition, diatoms and algae may add color to streams. Surface water draining red or brown soils becomes highly colored during periods of high flow, owing to suspension of clay-size particles.

Color measurements in 22 streams sampled during the high-flow period ranged from 4 to 27 color units; the median was 14. During the low-flow period, the range was 3 to 200 color units, with a median of 5. Water from the site having 200 color units contained flow from a swamp. Of the 22 stream samples collected at the high-flow period, 10 exceeded the maximum recommended limit of 15 color units for drinking water (U.S. Public Health Service, 1962). However, of the same number of samples collected at low flow, only one exceeded the limit. Color in water is undesirable for laundering, ice-making, manufacturing pulp and paper and for many other industrial uses. Generally, 5 to 10 units is permissible in water for industrial use. Many streams in the basin exceed these limits at times, both at high flow and low flow.

Temperature

Temperature has varied effects on the chemical, physical, and biological properties of water. It influences the solubility of most minerals, the rate of oxidation of organic matter, the settling rate of suspended sediment, and the ease of mixing and the degree of stratification of ponded water. For industries using water for cooling, the temperature of water may be more important than its chemical quality.

The temperature of water changes continuously and differs from place to place. As shown on figures 45 and 46, stream temperature follows a seasonal pattern that closely corresponds with air temperature. Freezing-point temperature is reached, or nearly reached, in most streams during the winter months for at least brief periods of time; maximum temperatures commonly occur in July and August. This pattern is repeated from year to year, although it may be slightly out of phase in some years. The temperature of Hall Meadow Brook near Drakeville, in the northern part of the report area, ranged from 0° to 26°C during the 1967 water year. In this area the mean water temperature for this period (8.6°C) closely approximates the mean annual air temperature of the 1930-63 period (8.3°C) (Brumbach 1965, p. 18). The temperature of the Pomperaug River at Southbury, about 27 miles south of the Hall Meadow station, showed exactly the same range for the same period,

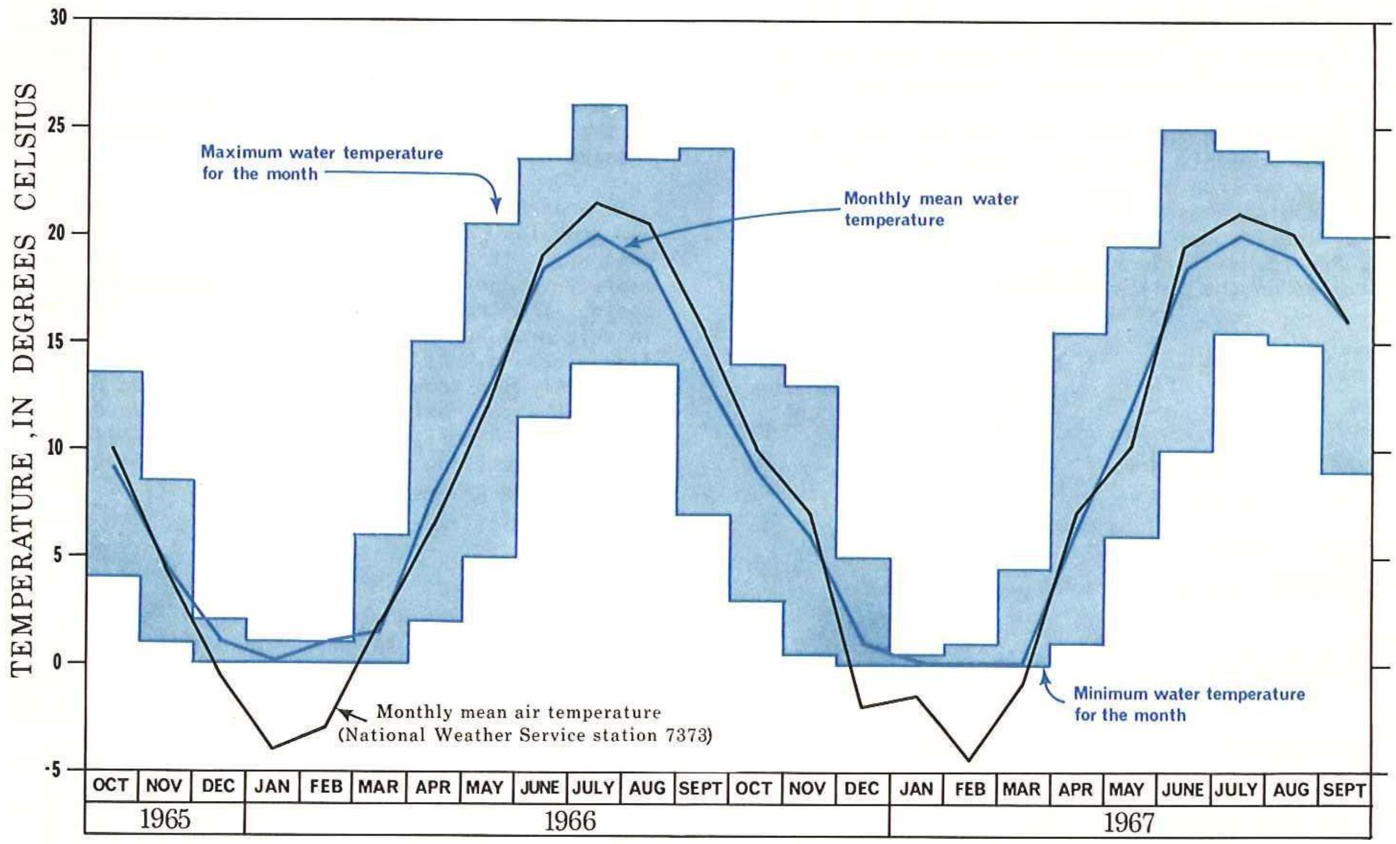


Figure 45.--Temperature of Hall Meadow Brook near Drakeville and air temperature at Shepaug dam, water years 1966-67.

Monthly temperature of Hall Meadow Brook closely follows mean monthly air temperature.

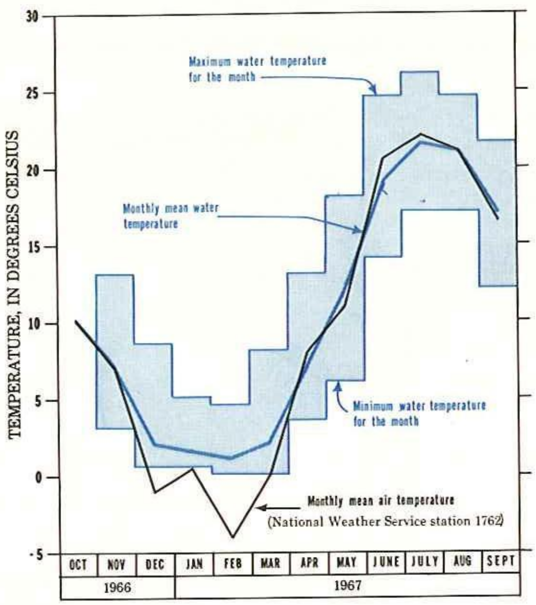


Figure 46.--Temperature of the Pomperaug River at Southbury and the air temperature at Danbury, 1967 water year.

and its mean water temperature for this period (11°C) also approximates the mean annual air temperature for this area (9.4°C).

Because the temperature of water is important for various industrial uses, it was measured continuously or once daily at five sites on streams in the basin. Table 24 shows the extremes of these measurements and the values equaled or exceeded for selected periods of time.

In the lower Housatonic River basin, parts of Beaver Dam Lake, Lake Quassapaug, Scoville Reservoir, Stillwater Pond, and Lake Zoar are thermally stratified (Connecticut Board of Fisheries and Game, 1959). In these lakes and others like them, temperature changes and stratification follow seasonal patterns. During certain seasons of the year thermal gradients exist between top and bottom, and bottom water temperature differs considerably from ambient air temperature, as shown on figure 47. In summer, a layer of warm water (epilimnion) is near the surface; below it, in the middle layer (thermocline), temperature decreases rapidly with depth; and in the lower layer (hypolimnion) the water is coldest, and the circulation is minimal.

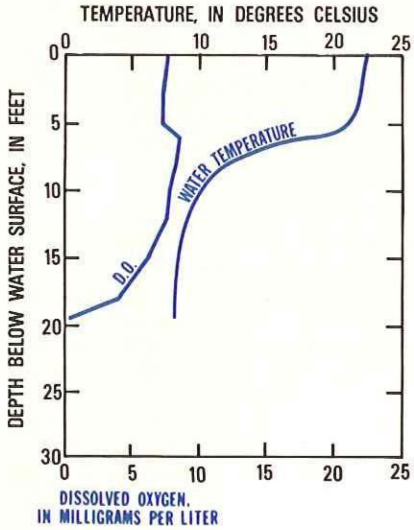
The relationship of water temperature, dissolved-oxygen concentration, and pH to depth of water is shown on figure 47 for selected water bodies, based on data collected by the Connecticut Board of Fisheries and Game. Lake Quassapaug and Stillwater Pond, in the upper part of the figure, show stagnant conditions, with warm water in the upper layer and cooler water in the lower layer. In the fall, the temperature of water in the upper layer drops, and mixing takes place until the entire lake is nearly uniform in temperature. Two periods of mixing each year, in the spring and autumn, break up the gradients and bring about a relatively uniform distribution of all dissolved materials in the water body. Hitchcock Lakes and Swans Lake, in the lower part of figure 47, lack thermal stratification.

Aquatic life may be able to adjust to a seasonal warming of water, but it can be destroyed by a lack of dissolved oxygen. Within the thermocline dissolved-oxygen content drops sharply, accompanied by a rise in the concentration of the gases resulting from the decomposition of aquatic biota. Below the thermocline, the concentration of dissolved oxygen reaches a minimum (often zero), while the concentration of gases of decomposition reaches a maximum.

During the spring and autumn overturns, the pH of water is generally uniform from surface to

Table 24.--Duration of surface-water temperature in the basin

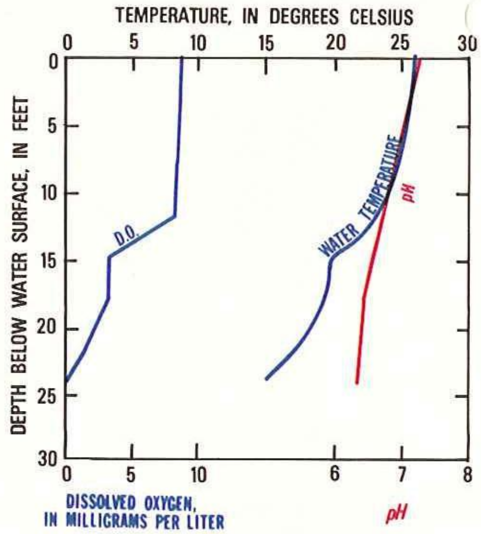
Station	Minimum	Water temperature (°C) Equal to or greater than values shown for indicated percentage of time	5	25	50	75	95	Maximum	Frequency of measurement	Water year(s)
2040 Pomperaug River at Southbury	0	Maximum	24	21	10	3	1.5	26	Continuous	1967
		Minimum	21	17.5	7.5	2	1			
2050 Lake Zoar at Stevenson	0		26	22	12	2.5	0	32	Once-daily	1961-67
2055.61 Hall Meadow Brook near Drakeville	0	Maximum	23	19	10.5	1.5	.5	26	Continuous	1966-67
		Minimum	19.5	15	7	1.5	0			
2060 Naugatuck River near Thomaston	0		26	20	12.5	4	.5	28	Once-daily	1958
2085 Naugatuck River at Beacon Falls	0	Maximum	28.5	23.5	14	7	3.5	30.5	Continuous	1966-67
		Minimum	24	19.5	10.5	4.5	1.5			



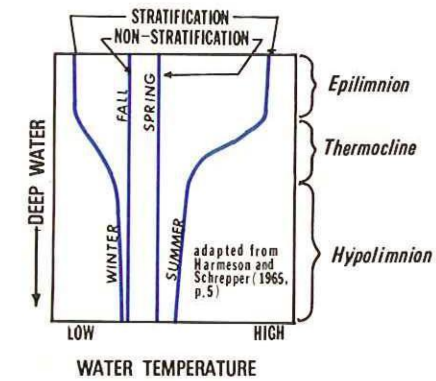
Lake Quassapaug
July 2, 1937

LAKES AND PONDS EXHIBITING THERMAL STRATIFICATION

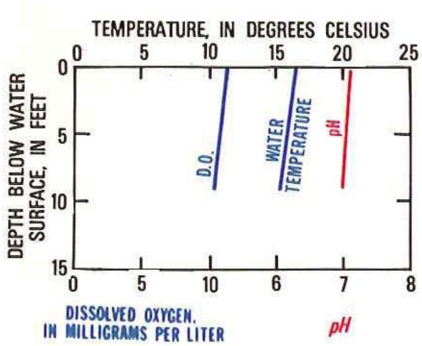
Water at depths below the thermocline becomes deficient in dissolved oxygen and noticeable water quality changes occur differences between epilimnion and hypolimnion.



Stillwater Pond
July 23, 1953



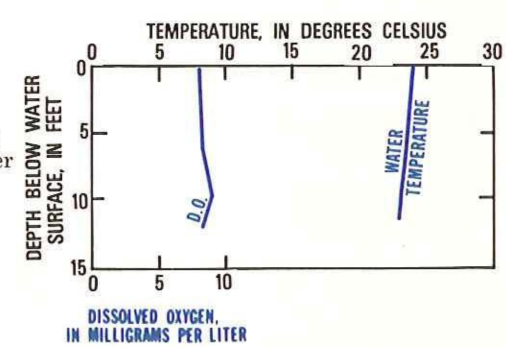
Idealized seasonal temperature variations in a thermally stratified lake, pond, or reservoir. Conditions represent stratification and non–stratification periods.



Hitchcock Lakes
October 23, 1947

LAKES AND PONDS NOT EXHIBITING THERMAL STRATIFICATION

Absence of thermocline allows stabilization of the aquatic system and the quality of the water at depths is essentially similar.



Swans Lake
September 8, 1946

Figure 47.--Vertical water-quality profiles contrasting thermal stratification and nonstratification in lakes, ponds, and reservoirs.

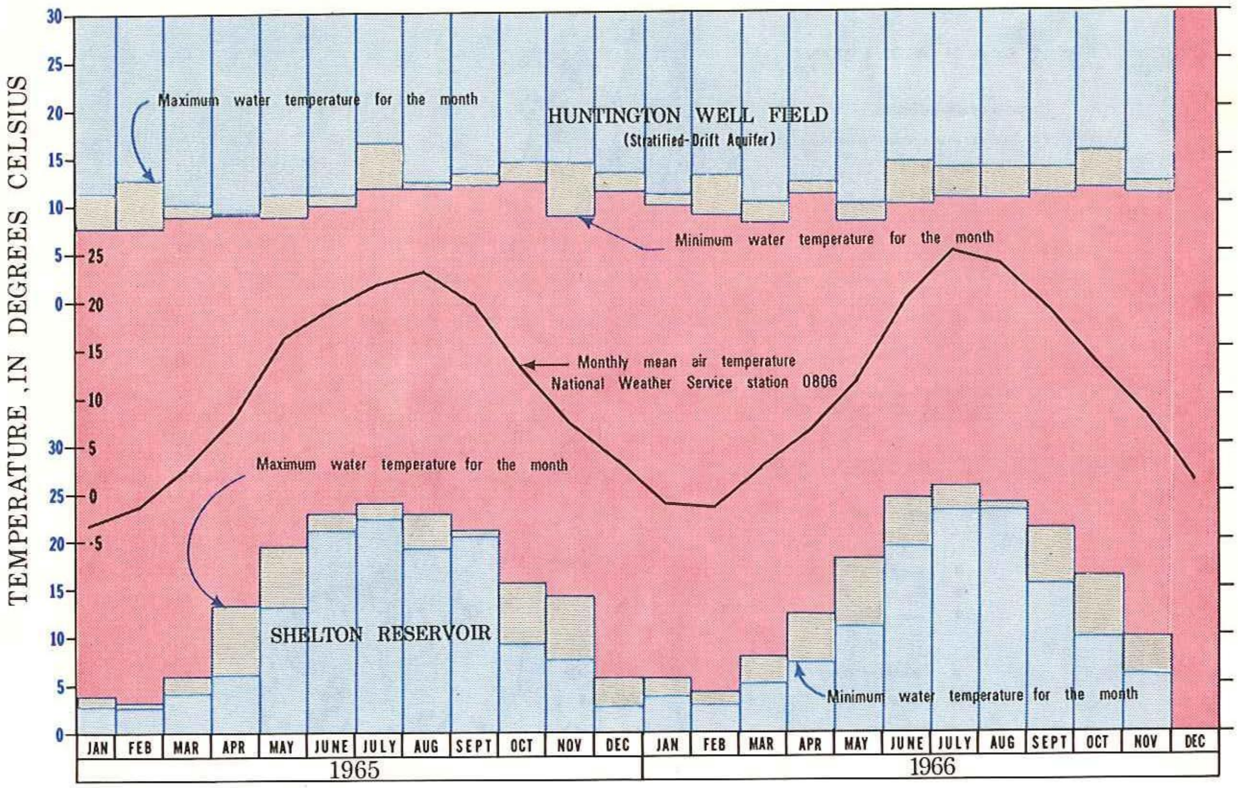


Figure 48.--Water temperature from Shelton Reservoir and Huntington well field, and air temperature at Bridgeport Airport, 1965-66.

(Water temperature supplied by Bridgeport Hydraulic Company)

bottom. Iron, manganese, color, and turbidity may increase as a result of the overturn, because oxidation-reduction processes are triggered by dissolved oxygen and cause the iron and manganese in the bottom materials to circulate. Thus, during the overturn, the vertical mixing of the waters results in a deterioration in quality.

Ground water generally has a narrower range in seasonal temperature than surface water. For many uses it is, therefore, a more desirable source than surface water, particularly in summer when cool water is needed for industrial operations and for air conditioning. The seasonal temperature fluctuations of shallow ground water lag behind those of atmospheric temperature, but for the year, average ground-water temperature is about the same as the mean annual air temperature. Temperatures of shallow ground water, surface water, and air for 1965-66 are compared on figure 48. The ground-water temperature only varied about 9°C throughout the year, as compared with 23°C for surface water from the Shelton Reservoir. Brumbach (1965, p. 18) reports that the mean annual air temperature in the area of these two sites is about 10°C; the ground-water temperatures illustrated in figure 48 remained within a few degrees of this mean.

SURFACE-WATER CONTAMINATION

Man's use of water almost always changes its quality. Most water withdrawn from streams and wells for domestic and industrial use is returned to streams or to the ground with its dissolved-solids concentration increased and its temperature changed. The extent of manmade changes in quality depends largely on the degree of agricultural development, population density, urban development, and industrialization.

Manmade changes in the quality of surface water in the lower Housatonic River basin can be recognized by a high dissolved-solids concentration, excessive amounts of certain trace elements, a low dissolved-oxygen concentration, and abnormally high temperatures.

Dissolved-solids concentration

The commonest effect of manmade change in the quality of surface water in the basin is an increase in dissolved-solids concentration. Figure 49 shows relatively high concentration of dissolved solids in water of a few small tributaries, along much of the Naugatuck River, and the estuarine part of the Housatonic River. The values shown are close to maximum because measurements were made during the low streamflow period in 1965, when most streamflow was in the range 90- to 99-percent duration flow. Dissolved-solids concentration was determined from specific conductance measured in the field at more than 300 sites. The relationships used for converting specific conductance to dissolved-solids concentration were determined from laboratory analyses of water samples from the basin.

The Naugatuck River serves as a striking example of a stream whose chemical quality is largely determined by the amount, type, and timing of manmade wastes discharged into it. During the last century the Naugatuck valley from Torrington to Ansonia has become highly industrialized and urbanized, and the River has long served as a

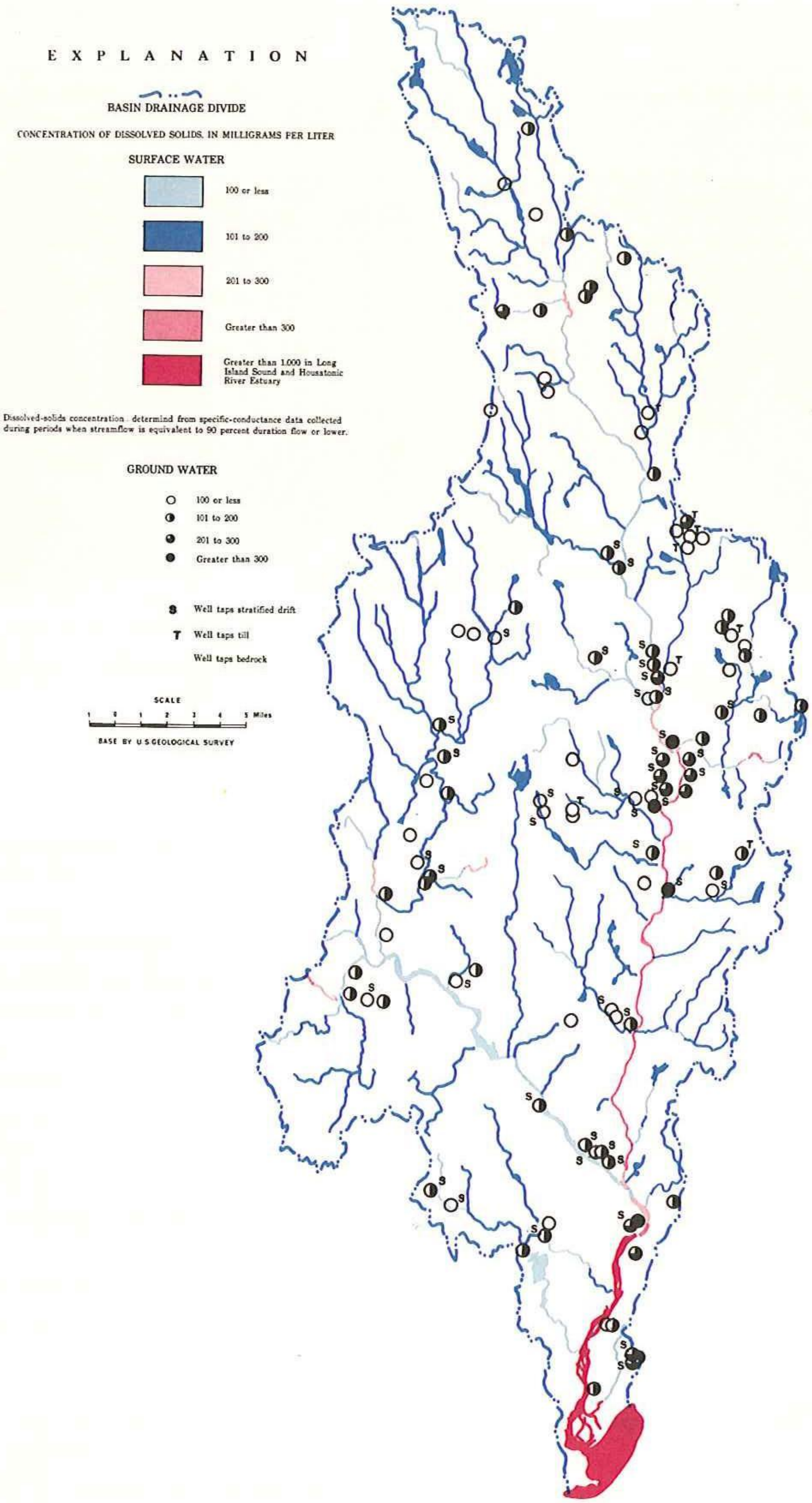


Figure 49.--Maximum observed concentrations of dissolved solids in streams and in ground water during low flow in 1965.

During low streamflow periods the dissolved-solids concentration of streamflow reflects the water quality of the contributing ground water except in areas where stream-water quality is heavily affected by man's activity.

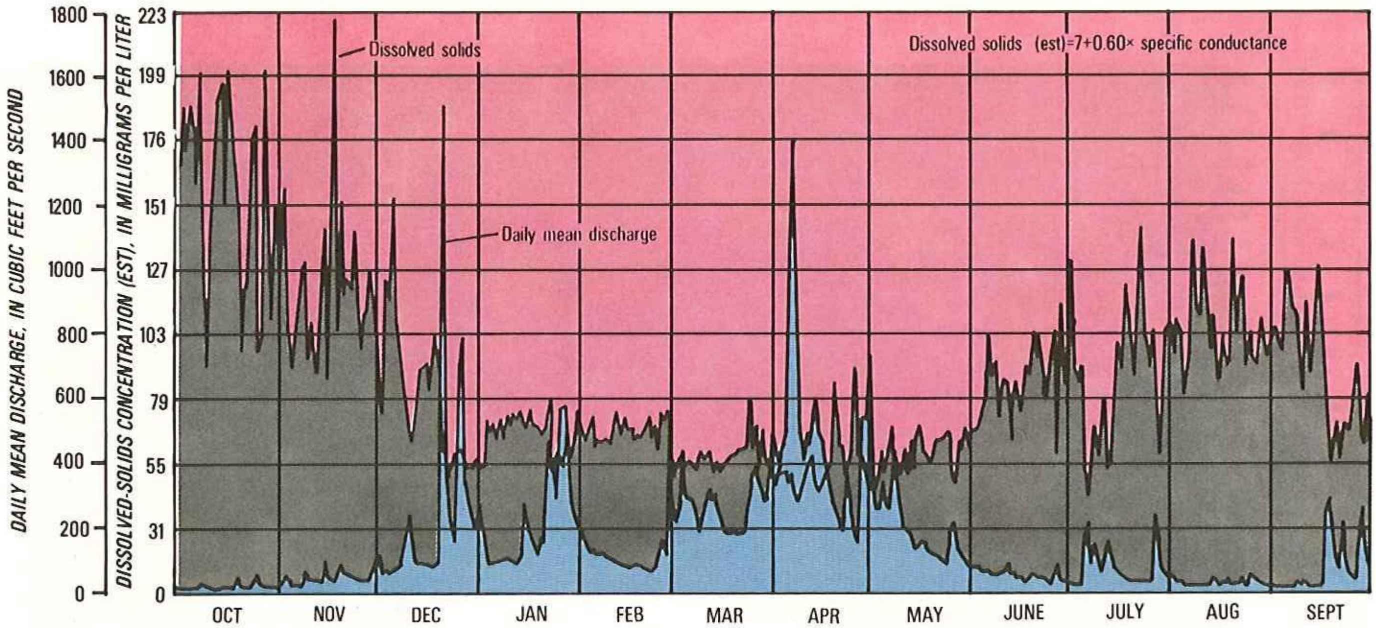


Figure 50.--Dissolved-solids concentration and daily mean discharge of Naugatuck River near Thomaston, 1958 water year (after Cushman and others, 1965).

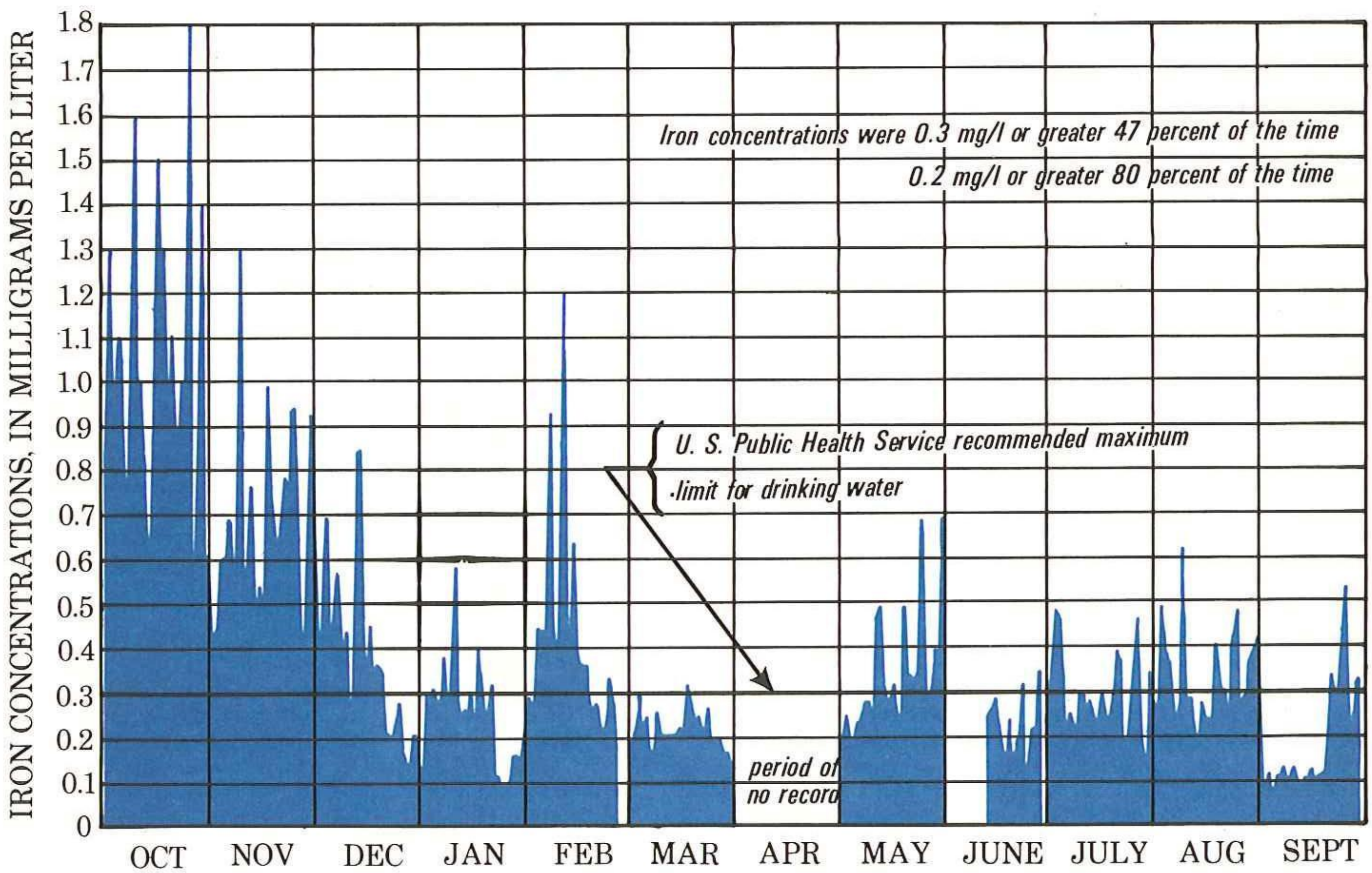


Figure 51.--Daily iron concentration in Naugatuck River near Thomaston, 1958 water year (after Cushman and others, 1965.)

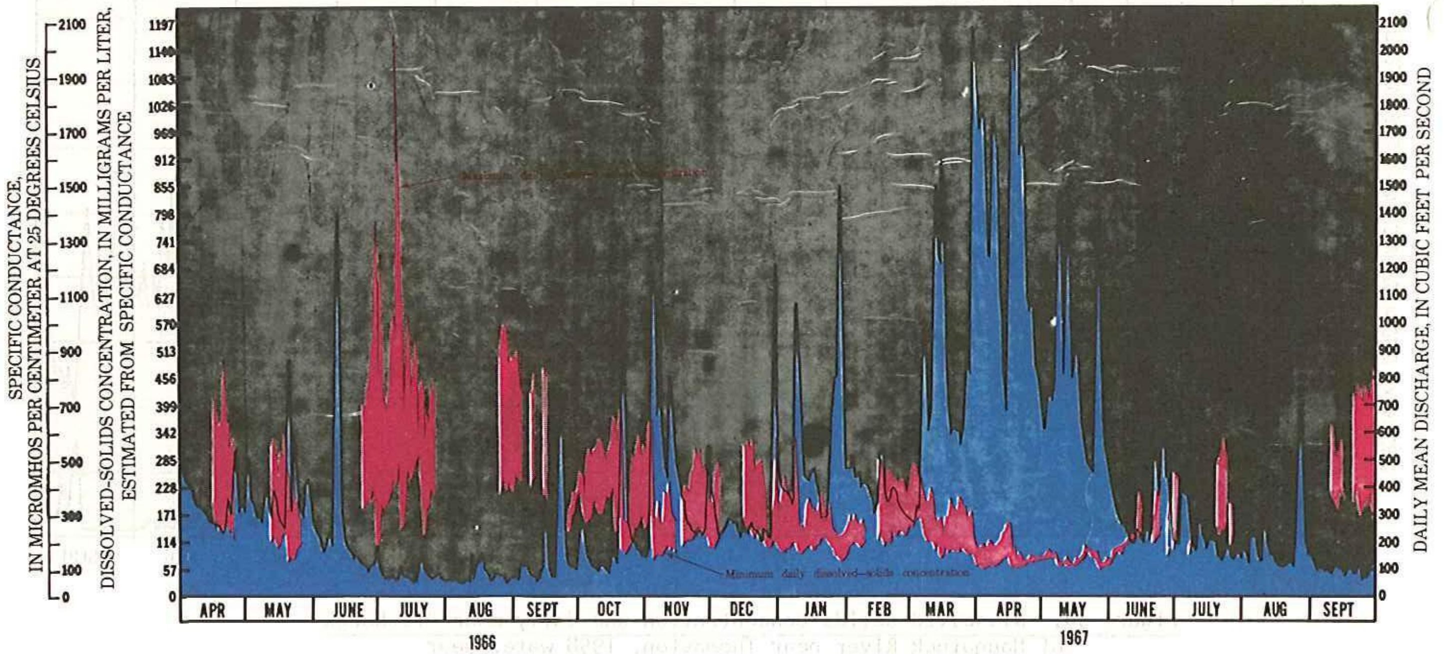


Figure 52.--Range of dissolved-solids concentration and daily mean discharge for the Naugatuck River at Beacon Falls, April 1966 through September 1967.

convenient receptacle for a growing volume of wastes. The abruptness and frequency with which water quality changes along the stream course during the day are striking, and manmade effects are so pronounced that they are easily distinguishable and readily measured, even during periods when increased runoff is effective in diluting wastes.

Daily and seasonal variations in dissolved-solids and iron concentrations in the Naugatuck River at Thomaston during water year 1958 were reported by Cushman and others (1965). As shown on figure 50, the dissolved-solids concentration, as estimated from specific conductance, ranged from 40 to 220 mg/l; the time-weighted average for the 1958 water year was 82 mg/l. Changes from day to day were more pronounced during low streamflow periods than during high periods (fig. 50), although the pattern of seasonal change is similar to the pattern in the Pomperaug River, which is relatively unaffected by man's activities. Daily iron concentrations in the Naugatuck River during the 1958 water year ranged from 0.04 mg/l to 1.8 mg/l and fluctuated widely in short periods of time, as shown on figure 51. Iron concentrations for the period sampled were at least 0.3 mg/l 47 percent of the time and at least 0.2 mg/l 80 percent of the time. In contrast, iron concentrations in the Pomperaug River fluctuated over a relatively narrow range, and iron concentrations exceeded 0.2 mg/l only 22 percent of the time. (See fig. 44.) Although the two rivers were sampled at different times, conditions in the Pomperaug River have probably changed little over the years.

Conditions similar to those at Thomaston, but with a wider range in dissolved-solids concentration have been observed in the Naugatuck River at Beacon Falls. Figure 52 shows maximum and minimum daily dissolved-solids concentration as estimated from specific conductance, and mean daily discharge from April 1966 through September 1967; and figure 53 illustrates the character of wide and erratic hourly changes in dissolved-solids concentration. Much of the time during the 12-day record (July 1 to 12, 1966) shown on figure 53, dissolved-solids concentration fluctuated between 240 and 420 mg/l. However, on July 8 it rose to about 1,300 mg/l, maximum for the period of record, in only 4 hours. In contrast to these wide fluctuations, the dissolved-solids concentration of water of Hall Meadow Brook, a stream free of industrial discharges in the headwaters, remained uniformly low during the same 12-day period. Fluctuations of dissolved-solids concentration in the Naugatuck River at Beacon Falls were the smallest for the period of record from April to June 1967, a time of reduced industrial activity in the Naugatuck-Waterbury area (fig. 52).

Analyses of 22 water samples collected at Beacon Falls during 1966 and 1967, span a wide range of quality conditions and therefore can be used in a general way to contrast the quality of the Naugatuck River with that of the Pomperaug River (fig. 54). Median and extreme values for hardness, sulfate, chloride, dissolved solids, and iron were all substantially higher in the Naugatuck River than in the Pomperaug River.

An example of the type and magnitude of variations in water quality that may occur along the Naugatuck River is shown diagrammatically on figure

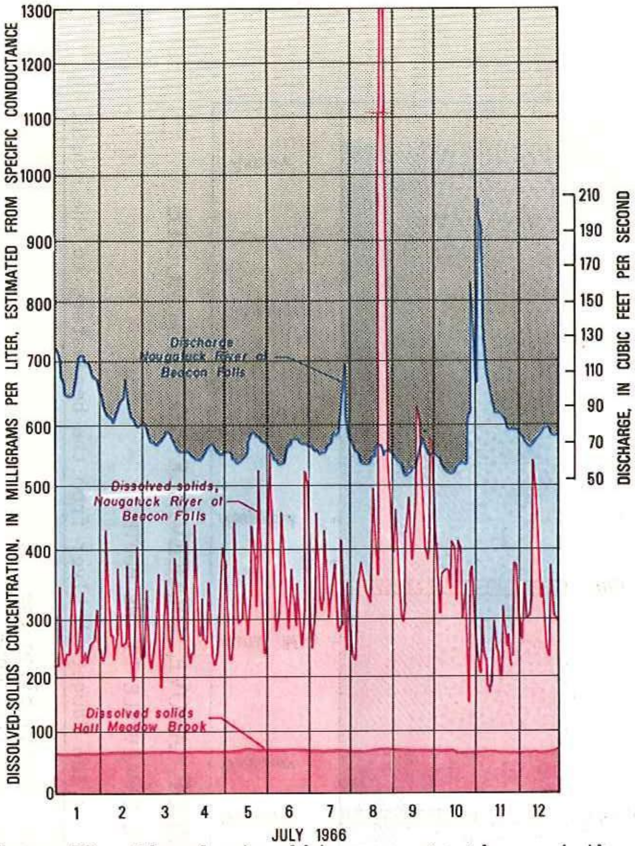


Figure 53.--Dissolved-solids concentration and discharge of Naugatuck River at Beacon Falls, and dissolved-solids concentration of Hall Meadow Brook, July 1966 (after Wilson and others, 1968).

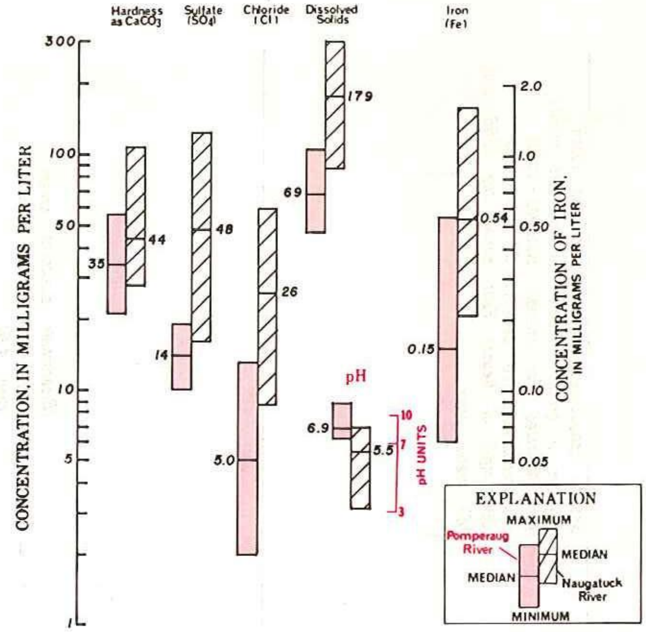


Figure 54.--Range in concentration of selected constituents of Pomperaug River and Naugatuck River (after Wilson and others, 1968).

55, based on samples collected in August 1965 and October 1967. The low dissolved-solids concentration of water in Hall Meadow Brook, a headwater tributary of the Naugatuck River, indicates water relatively unaffected by man at the upstream end of the profile. Dissolved-solids concentration of water in the Naugatuck River in the Torrington area about doubled, owing chiefly to increases in sulfate, sodium, chloride and nitrate. Between Torrington and Thomaston Dam, water of relatively good quality enters from tributaries, diluting the concentration of dissolved solids of the River. Increased dissolved solids at Thomaston resulted from the addition of waste effluents there, followed by normal dilution downstream to Waterville. From there to Ansonia, changes were erratic, with the highest concentrations at Beacon Falls, probably owing to effluents discharged in the Naugatuck area. Data collected during a period of a year showed that the magnitude of downstream changes in chemical characteristics is at times even greater than that shown on the profile of figure 55. For example, downstream increases in dissolved-solids concentrations may be greater than a hundredfold in this reach.

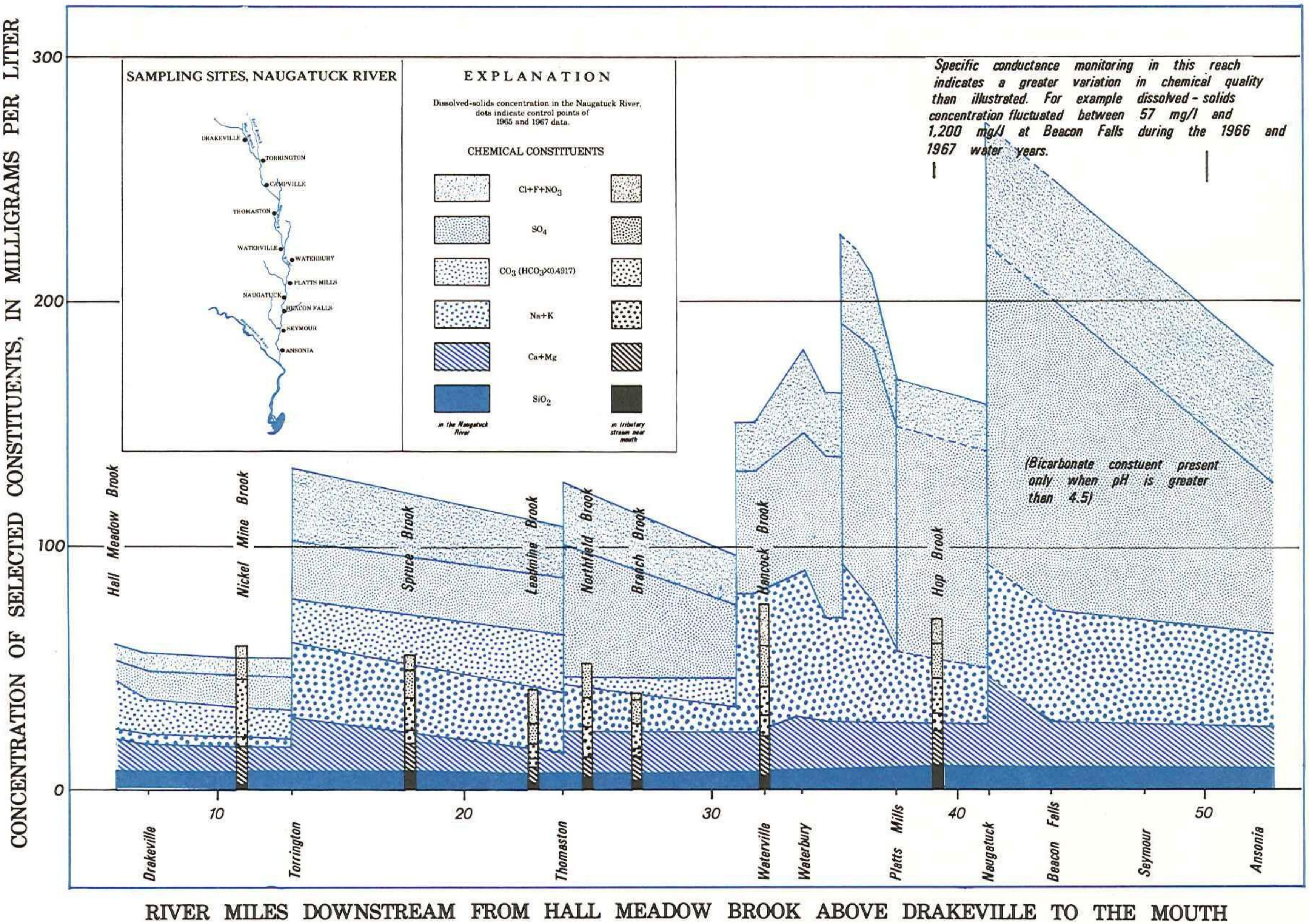
Characteristic of the Naugatuck River during the period of study was its marked change in pH. The lowest pH of the Naugatuck samples was 3.1 units. When water becomes strongly acid (below 4.5 units) the bicarbonate constituent becomes zero, as shown on figure 55. Such drastic changes in pH facilitate mobilization of metals that have attached themselves to the fine sediment or in organic coatings on sand and gravel along the streambed.

Trace elements

Examination of the concentrations of trace elements in water of the Naugatuck River provides a basis for evaluating the effects of industrial developments on water quality. Plate B shows the location of 7 sites on the Naugatuck River where samples were collected for spectrographic analysis by the residue method of Haffty (1960). A total of 15 samples were collected during 1961, 1966, and 1967; 1 to 3 samples were collected for analysis at each site. More than 60 trace elements were sought in the first samples collected, but only 17 trace elements were present in concentrations above the limit of detection in most of the samples.

The relatively large concentrations of trace elements in the Naugatuck River at the time the samples were collected (fig. 56) demonstrate the presence of industrial wastes in the river. The median values of these elements were substantially above the medians of major North American rivers (Durum and Haffty, 1963), also shown on figure 56, and most were above the highest values determined in the headwater tributary (Hall Meadow Brook). Concentrations of chromium, copper, and zinc were higher than other trace elements detected in the Naugatuck River. The median values for concentrations of chromium and copper were approximately 100 times those of the major North American rivers; the median concentration of zinc was more than 1 mg/l in the Naugatuck River, but was below the level of detection in more than half of the observations in the major North American rivers. The concentration of a few trace elements in the basin had so wide a range that further discussion is merited.

Aluminum is the most abundant metal on the



RIVER MILES DOWNSTREAM FROM HALL MEADOW BROOK ABOVE DRAKEVILLE TO THE MOUTH

Figure 55.--Profile showing downstream changes in chemical quality of water in the Naugatuck River from the headwaters to the mouth.

The generalized profile showing variations of water quality along the Naugatuck River is based mainly on water samples and specific conductance measurements collected in August 1965 and October 1967.

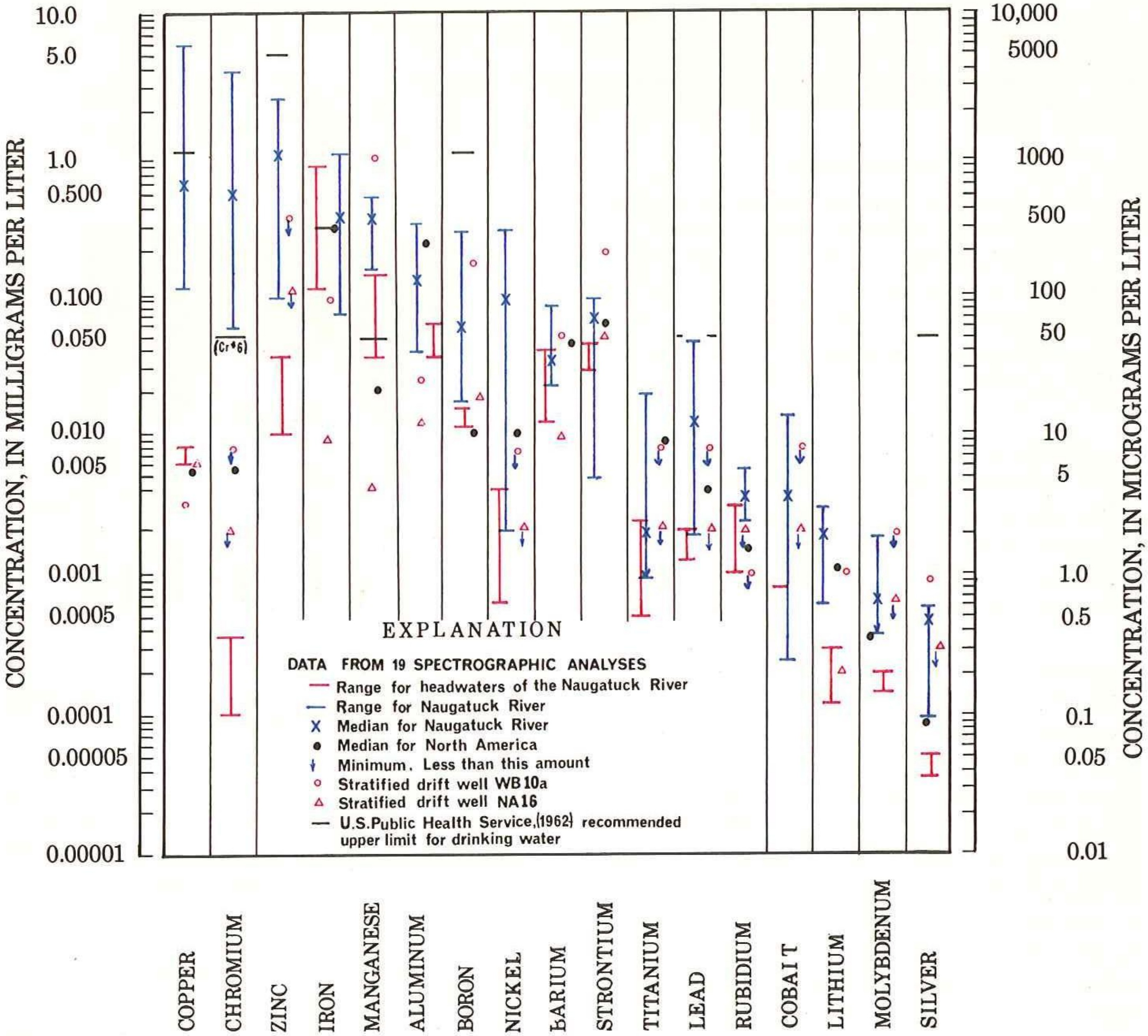


Figure 56.--Concentrations of trace elements.

Medians and extremes of selected trace constituents in water from the Naugatuck River valley compared to medians of major streams in North America.

earth's surface, but its concentration in natural water is commonly less than 1 mg/l. Its disassociated ion, Al^{+++}, can be abundant in acid waters with a pH below 5, or as a hydroxide. The concentrations of aluminum detected in the Naugatuck River ranged from 0.040 mg/l to 0.320 mg/l, with a median concentration of 0.150 mg/l, slightly below the median for most North American rivers (fig. 56), but higher than concentrations in the headwaters, which ranged from 0.035 to 0.061 mg/l.

Chromium (total) had a median concentration of 0.5 mg/l in the Naugatuck River, approximately 100 times greater than the median observed for the major North American rivers and more than 1,000 times greater than that of the natural water of the basin. The minimum concentration was approximately 10 times greater than the median for North American rivers. Very little chromium in water is from natural sources, so the values on figure 56 indicate significant introduction of chromium into the Naugatuck River at the time of the study.

Copper had a median concentration of 0.58 mg/l in the Naugatuck River, more than a 100 times the median of 0.005 mg/l for major North American rivers (fig. 56); concentrations of copper in the River ranged from 0.130 to 5.8 mg/l. Together with chromium, copper concentrations were among the highest of the concentrations of trace elements in the Naugatuck River, indicating significant introduction of copper into the River at the time of the study.

Figure 56 shows that lead, molybdenum, nickel, silver, and zinc are a few of the other trace elements detected that had ranges and median concentrations greatly exceeding those of the headwaters in the basin and the median values for major North American rivers.

Dissolved oxygen

Dissolved-oxygen concentration of water is an indirect measure of pollution loads of streams. The solubility of oxygen in water is mainly a function of temperature and pressure and in fresh waters ranges from 14.6 mg/l at 0°C to about 7 mg/l at 35°C under 1 atmosphere of pressure (sea level). The dissolved-oxygen concentration of a stream is commonly expressed as a percentage of the saturation (amount of oxygen the stream can hold at a given temperature).

Oxygen in a polluted stream may be severely depleted by oxidation of the biodegradable material but it may also be removed by vegetal decay and plant respiration. On the other hand, oxygen may be added by photosynthesis of aquatic vegetation and by mechanical aeration of flowing water. If the rate of depletion of oxygen is greater than the rate at which oxygen is replenished, the stream condition will tend to worsen.

A dissolved-oxygen survey of the Naugatuck River on October 5, 1967 (fig. 57), showed substantial variations in the percentage saturation of dissolved oxygen along the stream. Measurements were made during a time of low streamflow, when, other things being equal, pollution loads of streams could be expected to be highest and dissolved-oxygen deficiencies could be expected to be greatest owing to minimum dilution. In areas of abundant aquatic vegetation, such as in the headwaters area, measurements were made between 7 and 8 a.m., to minimize the effects of additional oxygen contributed by photosynthesis. Downstream from Waterville, aquatic vegetation is sparse, and temporal variations of dissolved oxygen are controlled largely by variations in opaqueness of the water and the amount of wastes in the stream. Although the measurements shown on figure 57 span a period of only 10 hours, they probably delineate the nature of major variations in dissolved oxygen from headwaters to mouth with reasonable accuracy.

The Survey showed that the headwaters of the Naugatuck River upstream from Torrington were well saturated with dissolved oxygen and that aquatic life was abundant. However, at Torrington, the dissolved-oxygen concentration of the stream was only 16 percent of saturation, largely because of sewage. In the reach between Torrington and Campville, many riffles produced mechanical aeration, and the saturation increased to 68 percent. Upstream from Thomaston, reaeration further increased saturation to nearly 100 percent, but, farther downstream, discharge of sewage decreased saturation by 20 percent. In the Waterville-Waterbury area, prevailing chemical toxicity probably eliminated the bacteria population; however, oxygen demand on the stream continued, owing to chemical and organic decomposition of wastes, and there was a 40-percent depletion in oxygen saturation between the Waterbury sewage-treatment plant and Beacon Falls.

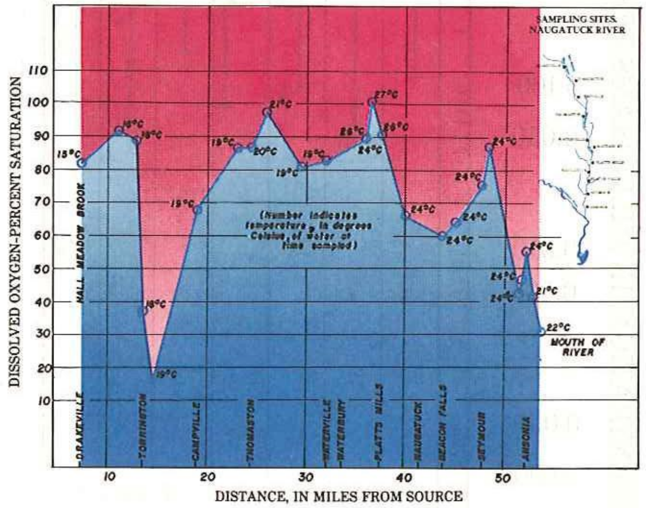


Figure 57.--Profile of dissolved-oxygen saturation in the Naugatuck River, October 5, 1967.

North of Seymour, constrictions, riffles, and fall promoted reaeration before the final oxygen depletion in the tidal section upstream from the confluence with the Housatonic River. The 30-percent saturation measured in the last reach was equivalent to 2.7 mg/l dissolved oxygen.

Temperature

As in other streams in the basin, temperature changes of water in the Naugatuck River follow a seasonal pattern (fig. 58), similar to the pattern followed by air temperature; temperature decreases in the fall, is near freezing in winter, and gradually increases in the spring. However, comparison of water temperatures given in table 24 shows that temperature in the Naugatuck River at Beacon Falls ranges consistently from 2°C to 4°C higher than that in the Pomperaug River at Southbury, even though, according to Brumbach (1965, p. 18), air temperature is similar. The same condition is true most of the time for the Naugatuck River at Thomaston. These data suggest that water in the Naugatuck River below Torrington during the period of study was warmed by heated discharges.

GROUND-WATER CONTAMINATION

Ground-water quality in parts of the lower Housatonic River basin has been altered by the movement of industrial and domestic wastes into aquifers. The alteration has resulted principally from induced infiltration of stream water containing chemical wastes, from storage of wastes on the

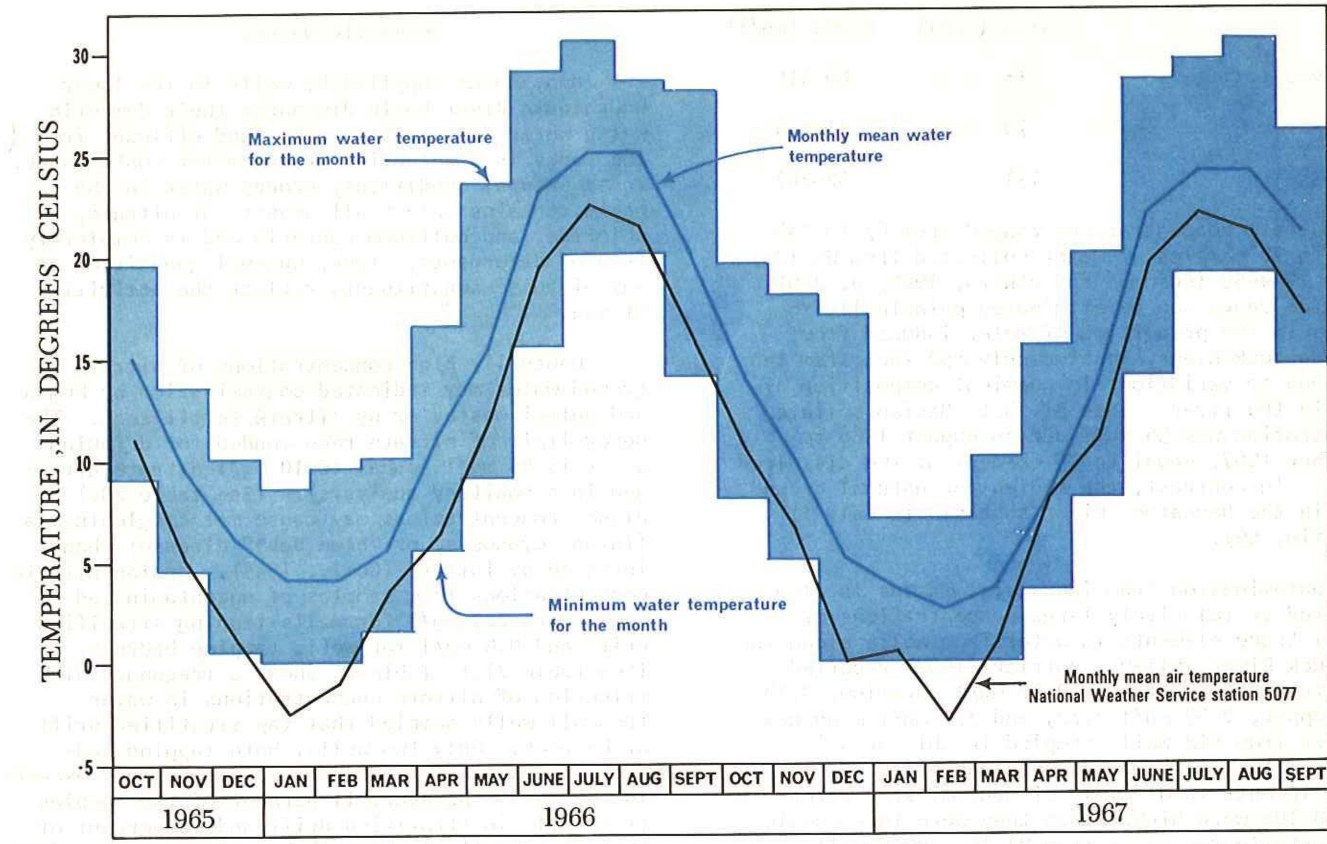


Figure 58.--Temperature of Naugatuck River at Beacon Falls and air temperature at Mt. Carmel (9 miles east of Beacon Falls).

ground surface, and from septic-tank effluents. Contamination may be suspected in well water that contains unusually high concentrations of dissolved solids, sulfate or trace elements, or that contains nitrate, chloride, detergents, coliform bacteria, or other constituents that are usually absent or insignificant in natural water. Based on analytical determinations and an understanding of the local environment, the contaminants were grouped into two classes, industrial wastes and domestic wastes.

Industrial wastes

Water from wells tapping stratified drift in the Naugatuck River valley contains high concentrations of dissolved solids (fig. 49), is commonly hard (fig. 42), and has high concentrations of iron and manganese (fig. 43). Induced infiltration of contaminated water from the Naugatuck River is largely responsible for the poor quality of ground water here, although chemical wastes dumped on the ground are also a source of contamination. Figure 59 compares the chemical characteristics of 29 samples of water from wells probably affected by industrial contaminants with those of water from 33 wells in the Naugatuck River subbasin unaffected by industrial contaminants.

The type and degree of ground-water contamination by industrial wastes depend upon a variety of complexly interrelated factors. These include: mineral equilibrium of the water, type and concentration of contaminants, distance of the well from the source of contamination, rate and frequency

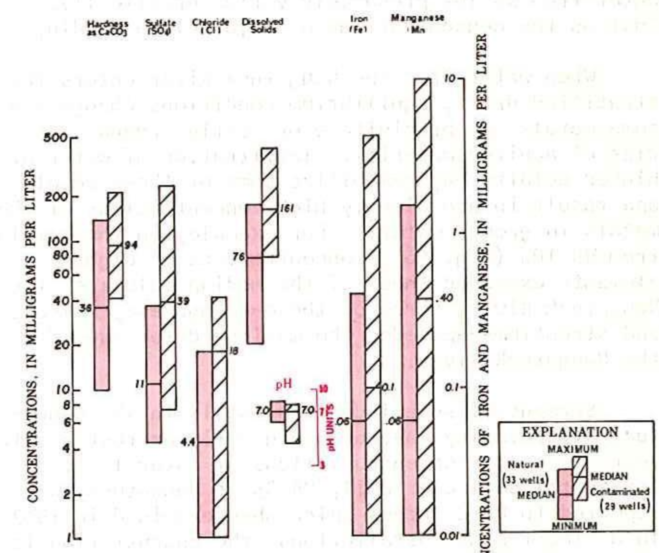


Figure 59.--Range in concentration of selected constituents of natural and contaminated ground water in the Naugatuck River basin.

of pumping, characteristics of well construction, and aquifer and soil characteristics. Commonly, water from neighboring wells differs widely in quality, and the chemical character of water from single wells changes from month to month. Analyses of samples from 17 wells tapping stratified drift along the Naugatuck River in the Waterbury-Naugatuck area showed the following median and extreme values for selected characteristics:

	Median (mg/l)	Range (mg/l)
Dissolved solids	215	80-415
Sulfate	79	21-234
Hardness	131	32-202

Sulfate concentrations ranged from 67 to 234 mg/l (in 70 samples of water collected from WB 10a) during 1944-59 (Cushman and others, 1965, p. J59). This wide range can be attributed principally to changes in the proportion of water induced from the Naugatuck River, located only 250 feet from the well, and to variations in chemical composition of water in the river. (See pl. B.) Median sulfate concentration was 94 mg/l during August 1966 to September 1967, equal to 35 percent of the dissolved solids. In contrast, the median for natural ground water in the Naugatuck River subbasin is only 11 mg/l (fig. 59).

Contamination from industrial wastes is also indicated by relatively large concentrations of several trace elements in water from wells along the Naugatuck River valley. Dorrler (1968) reported concentrations as high as 0.37 mg/l chromium, 0.28 mg/l copper, 0.47 mg/l zinc, and 3.1 mg/l manganese in water from six wells sampled in this area. Figure 56 shows that concentrations of 15 of 17 trace elements in a sample of contaminated water from WB 10a were higher than they were in a sample of uncontaminated water from NA 16. Both wells tap stratified drift, but NA 16 is in a tributary valley upstream from sources of industrial contamination. The concentrations of trace elements in water from WB 10a presumably varied erratically, just as the concentrations of major elements did.

When water from the Naugatuck River enters the stratified drift, equilibrium conditions change and some metals may precipitate or settle around particles of aquifer material. Infiltration of water of higher acidity may remobilize some of these metals and result in anomalously high concentrations of the metals in ground water. For example, in the sample from WB 10a (fig. 56), concentrations of eight elements exceeded those of the median values of the Naugatuck River; three of these--manganese, silver, and strontium--exceeded the maximum determined for the Naugatuck River.

Screens of some industrial wells in the Naugatuck River valley have become heavily encrusted after years of use. The encrustations of laterals of a horizontal collector well, NA 35 at Naugatuck, were reported to be 2 inches thick when examined in 1967. In at least some installations, the encrustation is related to the high iron and manganese contents of well water. Commercial analyses of water collected during 1952-66 from well NA 35 showed an average concentration of 7.3 mg/l iron and 5.7 mg/l manganese. Concentrations as high as 14 mg/l iron and about 10 mg/l manganese were reported. Neither the Naugatuck River nor the natural ground water in the area is known to have such high concentrations of these constituents. (See figs. 43 and 59.) Probably much of the iron and manganese was redissolved from the stratified drift by infiltrating river water of low pH as it moved toward the well.

Domestic wastes

Many homes supplied by wells in the lower Housatonic River basin discharge their domestic waste water into septic tanks, and effluent from the tanks is a potential ground-water contaminant. Under natural conditions, ground water in the basin contains only small amounts of nitrate, chloride, and coliform bacteria and is completely free of detergents. Thus, unusual quantities of any of these constituents reflect the activities of man.

Unusually high concentrations of nitrate in ground water may indicated contamination by human and animal wastes or by nitrate fertilizers. The upper limit of nitrate recommended for drinking water is 45 mg/l (equal to 10 mg/l nitrate nitrogen in a sanitary analysis). (See table 20.) Higher concentrations may cause methemoglobinemia (infant cyanosis, or "blue baby" disease) when ingested by infants (Comly, 1945). Median nitrate concentrations from samples of uncontaminated water were 2.7 mg/l for wells tapping stratified drift and 0.4 mg/l for wells tapping bedrock. (See table 21.) Table 25 shows a frequency distribution of nitrate concentrations in water from all wells sampled that tap stratified drift or bedrock. Only two wells, both tapping bedrock, had water with nitrate concentrations exceeding 45 mg/l. However, 11 percent of the samples from wells in stratified drift and 18 percent of those from wells in bedrock had nitrate concentrations exceeding 10 mg/l. Where analyses also include high chloride concentrations, the water has probably been contaminated by septic-tank effluent.

Table 25.--Frequency distribution of nitrate in samples of ground water in the basin

(Frequency analysis of nitrate concentrations exceeded in water from stratified drift and bedrock.)

Nitrate (NO_3) concentrations greater than value shown (mg/l)	Aquifer: Stratified drift (45 wells) No. of wells	Stratified drift (45 wells) Percentage of wells	Bedrock (55 wells) No. of wells	Bedrock (55 wells) Percentage of wells
45	0	0	2	4
20	1	2	3	5
10	5	11	10	18
5	20	44	19	35

Concentrations of chloride in fresh water throughout the basin are normally low. Only small amounts are carried into the area by precipitation (table 21), and the medians for samples of natural ground water were 11 mg/l (stratified-drift aquifer) and 3.8 mg/l (bedrock aquifers). (See table 21.) In ground water unaffected by salt-water encroachment, a chloride concentration of 20 mg/l or more probably indicates man's influence. Sources of chloride include dissolution of road salt, discharge of domestic sewage, and backflushing of water softeners. Of 106 wells in the basin analyzed for chloride, the water of 17 percent had concentrations of at least 20 mg/l.

The principal components of household detergents, ABS (alkyl benzene sulfonate) and, more recently, LAS (linear alkylate sulfonate), may contaminate ground water through discharge of sewage and other waste waters. Even large amounts of detergents in water are not toxic, but, because of esthetic considerations, the recommended upper limit has been set at 0.5 mg/l for ABS (U.S. Public Health Service, 1962). In mid-1965 ABS was replaced by LAS, which is more degradable under similar conditions. Of samples from 26 wells in the area tested by use of the MBAS (Methylene Blue Active Substance) test, 9 had measurable concentrations of detergents (at least 0.1 mg/l). Ground water in the vicinity of these wells presumably contained some septic-tank effluent.

Water is considered to be of safe bacteriological quality for drinking if the number of coliform bacteria is no more than 1 per 100 ml (milliliter) (membrane filter method) or is less than 2.2 per 100 ml (MPN method) (Woodhull, 1971, p. 57); a greater count in ground water is probably indicative of pollution by sewage. In general, bacteria from septic-tank effluent are removed near their point of introduction by adsorption on soil particles or by filtration. In some places, the aquifer material or the material in solution, such as detergents, enable bacteria to move more rapidly and to penetrate farther into the aquifer. The likelihood of ground-water contamination from bacteria in septic-tank effluent can be evaluated by use of a system devised by LeGrand (1964). This method, modified for use in Connecticut, indicates that contamination of a bedrock well is possible but unlikely if at least 40 feet of till overlies bedrock at the well site. Areas where till is known to be at least 40 feet thick are shown on plate C.

TURBIDITY

Turbidity of water is the reduction of transparency owing to the presence of suspended particulate matter that causes light to be scattered and absorbed. Turbidity values from 2 to 10 mg/l can be objectionable for many industrial uses, notably the production of food, paper, and textiles (McKee and Wolf, 1963, p. 290). Moreover, high turbidity may injure fish and other aquatic life. Turbidity values are low for most streams in the basin (table 26), except for the Naugatuck and Mad Rivers, where they were above 10 mg/l and therefore high enough to be objectionable for some uses.

SALT WATER IN STREAMS AND AQUIFERS

Most natural water in the basin generally contains less than 12 mg/l chloride, as shown by median values on table 21. In the southern part of the area, however, the estuary, marshes, and wetlands are exposed to tidal surges from Long Island Sound, and chloride contents are much higher. In the estuary, the position of the zone between fresh water and salt water fluctuates in response to tidal and seasonal forces. The zone moves upstream during high tides and downstream during low tides. In late summer and fall, low streamflow allows the upstream migration of salty water. In the spring and after heavy rains, high streamflow forces salty water downstream. The maximum upstream extent of salt water in the estuary during the study period is shown on figure 49.

Sea water generally contains about 35,000 mg/l dissolved solids, of which about 19,000 mg/l is chloride (Hem, 1970, p. 11). Measurements of specific conductance during low-flow conditions in 1969 indicate that the dissolved-solids concentration of water in the estuary ranged from 210 mg/l near Twomile Island, south of the confluence of the Naugatuck and Housatonic Rivers, to 20,000 mg/l near the mouth. The chloride concentration of water in the same reach ranged from 60 mg/l in the north to approximately 10,500 mg/l in the south.

Ground water near the coast may be naturally salty, or it may become salty where overpumping causes salt water to encroach upon fresh-water aquifers. A survey during 1934-38 in coastal Connecticut (Works Progress Administration for Connecticut, 1938) showed that many wells in the towns of Milford, Orange, and Stratford yielded water with chloride concentrations greater than 10 mg/l; a maximum concentration of approximately 1,800 mg/l was reported in water from a well tapping stratified drift near the mouth of the estuary. Most of these wells are no longer in use.

In 1954, salty water was reportedly pumped from test wells at Sikorsky Aircraft Division plant north of the Merritt Parkway. During the basin study, chloride concentrations of 72 mg/l and 172 mg/l were determined in samples from two wells adjacent to the Housatonic River, the first in stratified drift and the second in bedrock. These wells are located in Shelton opposite Twomile Island, near the upstream limit of salty water in the estuary.

MAN'S USE OF THE RESOURCE

SUITABILITY

The adequacy or utility of a water source is dependent on the quality as well as the quantity of water available. Excessively large concentrations of some constituents and even minute amounts of others may prohibit certain uses, or at least increase the cost of treatment. Table 20 lists the source and significance of the principal constituents and properties of the water in the lower Housatonic River basin.

Water distributed for public consumption must meet prescribed minimum quality standards. In the basin, the quality of such supplies, based on the constituents determined, is generally within the drinking-water standards accepted for public-water supplies by the State. The standards appear on table 20 and are also given in relevant tabulations elsewhere in the report.

Industrial water-quality requirements differ, according to the specific use of the water. For

Table 26.--Turbidity of water at miscellaneous stream sites

(Locations of sites shown on plate B)

Station no.	Stream	Turbidity, in milligrams per liter SiO_2 April 19, 1967	October 5, 1967	March 22, 1968
2035	Lake Lillinonah near Newtown	2		6
2035.05	North Branch Pootatuck River near Botsford	2		.7
2035.06	Pootatuck River near Botsford	.8		.7
2035.1	Pootatuck River at Sandy Hook			1
2035.2	Nonewaug River near Bethlehem	2		2
2035.4	East Spring Brook near Bethlehem	2		1
2036	Nonewaug River at Minortown	2		1
2037.5	Weekeepeemee River near Hotchkissville	.8		2
2038	Sprain Brook at Hotchkissville	1		.3
2040	Pomperaug River at Southbury	4		1
2044	Transylvania Brook at South Britain	3		1
2050	Lake Zoar at Stevenson	2		6
2055	Housatonic River at Stevenson	2		10
2055.2	Eightmile Brook at Southford	.7		.4
2055.55	Hall Meadow Brook near Winchester	4		1
2055.61	Hall Meadow Brook near Drakeville	2	2	.8
2055.96	West Branch Naugatuck River at West Torrington		.8	
2056	West Branch Naugatuck River near Torrington		6	
2056.55	East Branch Naugatuck River near Torrington		2	
2057	East Branch Naugatuck River at Torrington		25	
2057.5	Naugatuck River near Torrington	4	2	2
2058.9	Naugatuck River at East Litchfield		4	
2059.5	Naugatuck River at Campville		3	
2063	Rock Brook near Harwinton	6		.4
2064	Leadmine Brook near Harwinton	4		2
2067.9	Naugatuck River near Thomaston		3	
2069	Naugatuck River at Thomaston	11	4	7
2069.5	Northfield Brook at Thomaston		4	
2069.6	Naugatuck River at Reynolds Bridge		4	
2078	East Morris Brook near Morris	3		.8
2080.49	Naugatuck River near Waterbury		5	
2080.95	Naugatuck River at Waterbury	8	7	30
2081.4	Hancock Brook near Terryville	3	1	5
2081.7	Steel Brook at Waterbury	2	1	10
2081.71	Naugatuck River at Waterbury		5	
2081.73	Naugatuck River at Waterbury		6	
2081.74	Naugatuck River at Waterbury		4	
2083.2	Mad River at Waterbury	5	25	3
2083.3	Naugatuck River at Hopeville		15	
2083.4	Naugatuck River at Hopeville		4	
2083.5	Naugatuck River at Platts Mills	8	2	
2084.25	Naugatuck River at Naugatuck		5	15
2085	Naugatuck River at Naugatuck	13	35	20
2085.6	Naugatuck River at Pine Bridge		30	
2086	Bladens River near Seymour			.7
2086.05	Bladens River at Seymour		8	
2086.1	Naugatuck River at Seymour		7	
2087.13	Little River at Seymour		2	
2087.15	Naugatuck River at Seymour		10	
2087.21	Naugatuck River near Ansonia		20	
2087.26	Naugatuck River at Ansonia		18	
2087.27	Naugatuck River at Ansonia		20	
2087.28	Naugatuck River at Ansonia	8	15	
2087.36	Naugatuck River at Ansonia		20	
2087.37	Naugatuck River at Derby		15	

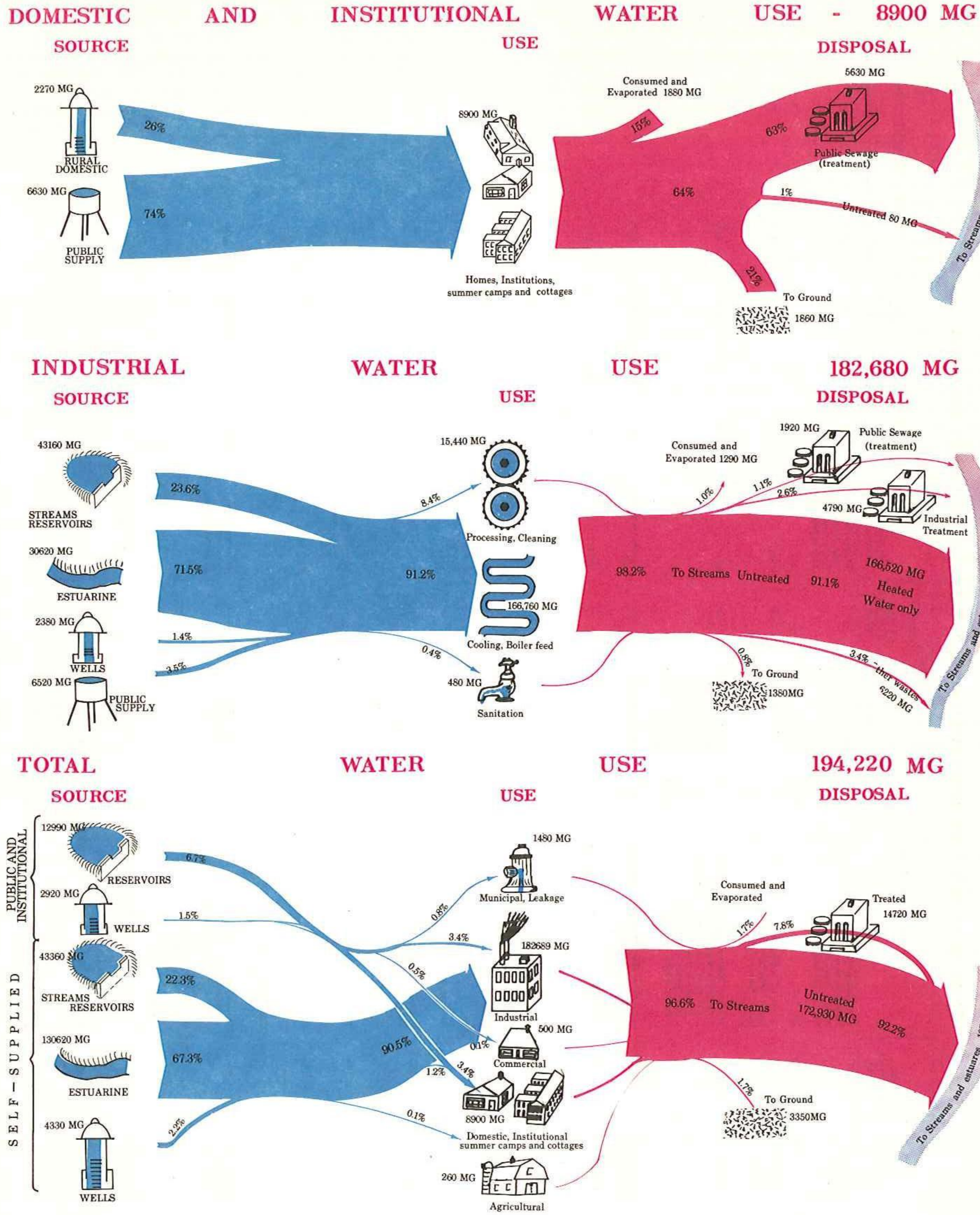


Figure 60.--Source, use, and disposal of water in the basin in 1967.

Most water used in the basin was from surface-water sources. Industry was the largest user of water, most of which was used for cooling and boiler feed. Most water discharged from homes and institutions was treated before being discharged to the streams in the basin. The Housatonic River estuary was the final receiving water body in the basin.

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

(Based on records from water utilities for 1967, supplemented by estimates.)

Public water-supply system	Town(s) supplied	Total population served	Primary source of water: Name	Percent of supply	Treatment: Type(s)	Treatment: Capacity of treatment plant(s) (mgd)	Auxiliary or emergency sources	Storage (mg): Raw water	Storage (mg): Finished water	Total supplied in 1967 (mg)	Percentage of supply by type of use: Domestic	Commercial	Industrial	Municipal and leakage
Ansonia Water Co.	Ansonia Derby Seymour	19,771	Peat Swamp (Beaver Lake) Reservoir Fountain Reservoir Middle Reservoir Quillinan Reservoir	88 3.3 2.2 6.5	Chlorination	14	Bungay Reservoir Hopp Brook Moulthrop Brook Birmingham Water Co.	610	None	826	a/45		43	12
Artesian Well Projects, Inc.	Torrington	1,550	Wells	100	Chlorination	--	Wells	.03	None	40	99	0	0	1
Birmingham Water Co.	Ansonia Derby Seymour	11,385	Great Hill Reservoir Lower Reservoir) Upper Reservoir) Wells	34 34 32	Chlorination	4.4	None	123	.02	819	a/55		30	15
Bridgeport Hydraulic Co.	Shelton	b/60,700	Shelton Reservoirs, nos. 2 and 3 Trap Falls Reservoir System Far Mill (Isinglass) Reservoir Housatonic well field Huntington well field Means Brook Reservoir	1.2 24.5 47.3 2.1 24.9	Chlorination, pH adjustment with lime or caustic soda, addition of calgon, fluoridation	1.6 50	c/	2,514	.2	6,547	a/42		48	10
Connecticut Water Co. (Naugatuck Division)	Beacon Falls Naugatuck Waterbury	17,000	Long Hill (New Naugatuck) Reservoir Moody (Old Naugatuck) Reservoir Mulberry Reservoir	60 35 5	Chlorination	4.8	Candee Reservoir Wells	966	None	1,233	a/28		65	7
Hillcrest Fire District, Water Department	Middlebury	165	Waterbury, city of, Water Department	-	-	-	None	-	None	3.5	a/75		0	25
Monroe Consolidated Water Co., Inc.	Monroe	b/ 1,060	Wells	100	None	-	None	.02	-	20	91	8	0	1
New Haven Water Co. (Milford District)	Milford	b/49,100	Beaver Brook Reservoir New Haven Water Co. distribution system	23 77	Chlorination	5.0	Wells	.26	1.6	1,764	a/60		38	2
Newtown Water Co.	Newtown	b/ 2,970	d/Taunton (Pond) Lake	100	Chlorination, addition of calgon	.6	None	875	.2	77	a/97		2	1
Oakville Fire District, Water Department	Waterbury Watertown	7,000	Waterbury, city of, Water Department	100	-	-	None	-	.2	173	63	3	18	16
Seymour Water Co.	Beacon Falls Oxford Seymour	8,850	Reservoirs, nos. 1, 2, and 3 Wells	52 48	Chlorination, pH adjustment with caustic soda, addition of calgon	3.2	Toby Brook	431	.3	550	34	5	51	10
Suburban Water Service	Thomaston	2,783	Thomaston (Plymouth) Reservoir Well	58 42	Chlorination	-	Waterbury, city of, Department	93	None	311	a/17		67	16
Torrington Water Co.	Torrington	24,050	Crystal Lake System Allen Dam Reservoir North Pond Whist Pond Hart Brook System Reuben Hart Reservoir	41 59	Chlorination, fluoridation	8.5	None	1,745	1.3	1,323	22	9	54	7
Waterbury, city of, Water Department	Middlebury Waterbury Watertown	116,481	d/Shepaug Watershed Shepaug Reservoir Upper Shepaug Reservoir West Branch Watershed Morris Reservoir Pitch Reservoir Wigwam Reservoir	50 50	Chlorination, pH adjustment with lime	35	East Mountain Reservoir Waterbury Reservoir no. 2	7,397	4.6	e/6,348	a/69		19	12
Watertown Fire District, Water Department	Bethlehem Watertown	5,560	Hart Farm Well Field System Judd (Big Meadow) Pond Reservoir Lockwood Reservoir Watertown (Bethlehem) Reservoir	100	Chlorination	1.0	Waterbury, city of, Water Department	321	1.0	239	55	16	19	10
Westover Water Co.	Middlebury	200	Wells	100	Chlorination, pH adjustment with soda ash	.2	Lake Elise	.01	.3	15	15	1	0	85
Woodbury Water Co.	Woodbury	1,400	Woodbury Reservoir Wells	3 97	Chlorination	-	None	.01	.2	46	75	20	1	4

a/ Includes commercial and domestic use.
b/ Company also serves area outside of basin.
c/ Additional sources are listed in Connecticut Water Resources Bull. No. 17, 1970, p. 47.
d/ Source area located outside of basin.
e/ Includes water sold to Hillcrest Fire District, Oakville Fire District, Suburban Water District, and Watertown Fire District.

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

(Chemical constituents in milligrams per liter. Analyses by U.S. Geological Survey.)

Public water-supply system	Date of collection	Source F, finished water R, raw water	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (residue at 180°C)	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25°C)	Temperature (°C)	pH	Color	Detergents as MBAS
U.S. Public Health Service (1962) drinking-water standards--recommended maximum	--	--	--	0.30	0.05	--	--	--	--	--	250	250	a/ 1.3	45	500	--	--	--	--	--	15	0.5
Ansonia Water Co.	10-11-66	R Peat Swamp Reservoir	5.0	0.31	0.05	6.8	1.9	3.8	1.0	10	19	6.4	0.2	0.1	55	25	17	82	14	6.6	6	0.0
	7-17-51	F Middle Reservoir	6.6	.15	.0	7.2	1.3	2.6	.8	10	12	6.1	.2	.7	41	23	15	63	--	6.8	8	--
	10-11-66	R Middle Reservoir	5.0	.20	.07	6.9	2.9	3.9	1.0	9	19	6.9	.1	.2	51	29	22	83	14	6.8	6	.0
	7-17-51	R Fountain Reservoir	7.8	.02	.0	5.1	1.8	3.1	.8	12	12	4.5	.2	.8	41	20	10	61	--	6.5	12	--
	10-11-66	R Fountain Reservoir	4.8	.06	.03	8.8	1.8	7.6	1.1	11	19	15	.2	.1	67	30	20	108	21	6.8	5	.0
	10-11-66	R Quillinan Reservoir	1.2	.15	.04	9.7	3.3	6.2	1.6	18	18	16	.2	.3	67	38	22	107	14	6.9	6	.1
Artesian Well Projects, Inc.	7- 7-66	R Well HA 3	14	.01	.08	29	6.5	9.5	1.5	134	7.5	5.8	.2	1.9	143	102	0	239	--	8.1	6	.1
	8-17-67	R Well HA 3	--	.17	.03	--	--	--	--	161	--	--	--	--	177	140	8	304	--	7.6	--	--
	7- 7-66	R Well T 22	15	.01	.04	19	7.6	7.6	1.6	110	6.6	5.2	.2	.7	125	78	0	207	--	7.3	0	.1
	7- 7-66	R Well T 23	21	.02	.08	14	5.8	5.8	1.6	60	8.7	4.0	.1	5.4	99	59	10	142	--	7.3	5	.1
	2-17-67	R Well T 23	--	.05	.00	--	--	--	--	65	--	--	--	--	115	69	16	166	--	6.8	--	--
Birmington Water Co.	10-10-66	R Great Hill Reservoir	5.1	.23	.07	8.3	2.2	7.5	1.5	15	17	15	.2	.3	69	30	18	113	13	6.9	9	.1
	10-10-66	R Lower Reservoir	.6	.13	.04	11	3.0	7.2	1.6	27	20	13	.1	.7	73	40	18	130	18	6.9	3	.0
	10-10-66	R Upper Reservoir	.3	.11	.05	8.6	2.5	7.2	1.1	11	30	8.0	.1	1.6	72	32	22	116	17	6.6	4	.0
	10-10-66	R Well DE 2	11	.18	.15	25	6.8	7.2	3.0	84	19	10	.2	1.6	133	90	22	215	14	7.7	1	.0
	10-10-66	R Well DE 3	13	.37	.05	30	5.2	20	3.0	78	28	36	.1	4.1	186	96	32	319	14	7.5	4	.0
	11-16-66	R Well DE 7	12	.09	.04	25	8.0	7.8	2.7	96	19	13	.2	3.2	136	96	17	236	12	7.7	--	.0
Bridgeport Hydraulic Co.	5-15-62	F Trap Falls Reservoir	7.7	.19	.02	10	1.5	4.1	1.0	10	16	11	.1	1.2	68	31	23	91	13	6.7	6	--
	6- 1-62	R Trap Falls Reservoir	7.7	.12	.03	7.3	1.6	3.8	1.0	12	14	6.4	.1	1.0	57	25	15	79	17	6.6	12	--
	8- 4-67	R Trap Falls Reservoir	7.0	.12	.09	13	3.2	6.6	1.6	30	20	12	.1	.5	84	46	21	142	15	7.0	12	.0
	8- 4-67	F Trap Falls Reservoir	7.5	.13	.17	18	3.4	6.9	1.6	40	20	15	.8	.3	101	59	26	169	--	7.1	8	.0
	8-10-67	R Well SH 10	14	.04	.05	24	7.5	8.3	2.5	89	20	12	.1	.0	138	91	18	226	18	7.3	6	--
	8- 4-67	R Well SH 27	13	.01	.04	13	3.3	11	2.8	22	21	--	--	4.0	103	46	28	169	11	6.7	2	.0
	8- 4-67	F Well SH 27	13	.00	.04	13	3.2	25	2.9	58	21	18	1.2	3.0	134	46	0	220	--	7.5	2	.0
Connecticut Water Co. (Naugatuck Div.)	9- 1-66	R Long Hill Reservoir	4.1	.20	.02	5.8	1.5	4.6	.7	7	16	8.2	.1	.1	52	20	15	76	26	6.4	4	.0
	9- 1-66	R Moody Reservoir	2.1	.21	.04	4.1	1.4	2.9	.7	5	13	4.9	.2	.1	38	16	12	58	26	6.3	4	.1
	9- 1-66	R Mulberry Reservoir	3.9	.65	.09	6.6	1.4	4.3	1.6	14	15	6.6	.2	.2	54	22	11	79	25	6.9	6	.1
	9- 1-66	R Well NA 16	13	.06	.02	9.4	2.6	5.4	1.6	19	10	12	.2	5.2	80	34	18	112	12	7.1	3	.0
	11- 2-66	R Well NA 16	13	.01	.06	9.9	2.6	5.9	1.7	19	10	11	.2	5.9	101	35	20	116	--	7.1	2	--
	12-13-66	R Well NA 16	13	.06	.03	9.7	2.6	5.8	1.6	20	12	13	.1	6.5	75	34	18	116	--	7.0	3	--
	1-11-67	R Well NA 16	--	.03	.02	10	2.6	b/6.4	--	19	11	12	--	6.7	85	36	10	117	--	6.8	--	--
	2-14-67	R Well NA 16	--	.06	.03	10	3.2	b/6.2	--	19	11	14	--	6.3	83	38	22	117	--	6.5	--	--
	9-21-67	R Well NA 16	13	.10	.19	14	3.6	9.5	3.0	21	13	21	.2	17	108	50	33	177	11	6.9	2	--
	10-31-67	R Well NA 16	--	.03	.00	11	3.0	b/8.0	--	20	11	16	--	8.9	86	40	24	135	10	6.9	--	--
	12- 6-67	R Well NA 16	--	.05	.01	11	2.9	b/8.5	--	20	11	16	--	9.6	85	40	23	133	10	6.7	--	--
Monroe Consolidated Water Co., Inc.	4-12-67	R Well MO 40	15	.00	.06	15	4.6	7.6	1.9	38	22	12	.2	8.5	104	56	26	169	--	6.7	3	.0
	9- 2-66	R Well MO 41	17	.41	.04	12	3.3	5.4	.4	28	8.4	13	.2	6.5	91	44	20	125	13	6.9	4	.1
New Haven Water Co. (Milford Dist.)	7-16-51	R Beaver Brook Reservoir	8.6	--	--	14	4.2	b/6.0	--	25	21	14	--	3.9	84	52	32	155	--	6.8	7	.0
	5-14-62	F Beaver Brook Reservoir	4.8	.07	.01	18	5.8	11	2.4	28	34	23	.1	6.4	133	69	46	209	15	6.7	2	--
	10-10-66	R Beaver Brook Reservoir	8.8	.05	.03	25	9.0	17	3.8	37	38	44	.2	7.4	205	100	69	321	17	7.3	1	.0
	10-10-66	R Well MI 1	15	.03	.08	30	5.2	24	4.0	48	32	49	.1	12	203	96	57	337	12	7.3	3	.0
	10-10-66	R Well MI 2	15	.38	.05	30	5.2	26	4.3	52	37	49	.1	10	214	96	54	363	13	7.3	5	.0
Newtown Water Co.	8- 1-66	R Taunton Lake	.2	.09	.03	8.6	2.8	4.7	1.5	24	14	9.0	.1	.2	60	33	14	100	--	6.9	4	.0
Seymour Water Co.	9- 2-66	R Seymour Reservoir no.1	3.0	.17	.17	3.5	1.2	2.6	.6	5	12	4.0	.2	.1	33	14	10	50	24	6.2	3	.0
	9- 2-66	F Seymour Reservoir no.1	3.2	.32	.14	3.4	1.2	5.6	.6	9	13	6.1	.2	.1	38	14	6	64	23	6.8	5	.0
	9- 1-66	R Seymour Reservoir no.4	3.6	.66	.28	2.6	1.0	2.2	.4	0	14	3.8	.2	.7	33	10	10	69	24	4.3	3	.0
	4-17-67	R Seymour Reservoir no.4	3.5	.08	.21	2.6	.6	2.1	.4	0	14	2.8	.2	.3	27	9	9	57	7	4.6	3	.0
	9- 2-66	R Well OX 4	9.3	.29	1.7	8.0	1.9	7.2	2.0	26	10	11	.2	2.0	70	28	6	110	19	7.1	3	.0
	9- 2-66	R Well OX 6	9.5	.71	.39	10	2.3	7.3	1.7	17	16	18	.1	1.3	75	34	20	128	12	7.0	3	.0
Suburban Water Service	8- 1-66	R. Thomaston Reservoir	2.6	.12	.10	4.3	1.5	3.8	.6	12	6.6	4.8	.1	.5	45	16	6	60	26	6.4	5	.0
	8- 2-66	R Well TM 14	9.0	.01	.01	15	4.4	5.5	1.9	38	17	13	.1	3.2	102	56	24	154	--	7.2	5	.0
Torrington Water Co.	7- 6-66	R Reuben Hart Reservoir	1.0	.07	.03	5.7	2.3	1.3	.8	15	10	2.0	.1	.6	31	24	12	59	26	6.6	3	.0
	7- 6-66	R North Pond	.2	--	--	3.0	1.0	1.0	.5	4	8.3	.2	.3	.5	20	12	9	34	25	6.0	5	.1
	4-11-67	R North Pond	--	.08	.05	--	--	--	--	2	--	--	--	--	19	15	14	36	3	5.6	--	--
	7- 6-66	R Whist Pond	.4	.16	.06	8.8	4.2	1.3	1.0	30	12	3.0	.0	.9	57	39	14	85	27	6.9	4	.1
	7- 6-66	R Allen Dam Reservoir	2.9	.17	.03	12	5.4	2.6	1.7	53	11	3.8	.1	.2	75	52	8	122	24	7.4	5	.0
	7- 6-66	R Hart Brook Reservoir	4.2	--	--	12	3.8	3.1	1.3	40	14	5.0	.1	.7	69	46	12	112	24	7.5	5	.1
	7- 6-66	R Crystal Lake	.8	.80	.08	13	5.3	5.8	1.5	53	9.6	11	.2	.3	86	54	11	187	26	7.3	4	--
Waterbury, city of, Water Dept.	4-11-67	R Wigwan Reservoir	4.9	.01	.12	7.1	2.3	3.4	1.1	16	15	7.2	.2	1.0	50	27	14	85	6	7.0	15	.0
	4-11-67	R Pitch Reservoir	5.3	.00	.12	7.6	2.6	2.4	.8	21	15	4.0	.2	.1	53	30	12	81	5	7.0	20	.0
	4-11-67	R Shepaug Reservoir	4.5	.01	.06	5.5	2.0	2.1	.9	14	12	3.0	.2	.4	42	22	10	63	4	6.7	22	.0
Watertown Fire Dist., Water Dept.	7- 7-66	R Judd Pond Reservoir	1.2	--	--	7.0	2.1	4.3	.8	23	7.4	6.3	.2	.5	52	26	7	80	--	7.1	14	.1
	4-11-67	R Judd Pond Reservoir	--	.10	.05	--	--	--	--	6	--	--	--	--	45	18	13	64	9	6.2	--	--
	7- 7-66	R Watertown Reservoir	.6	.03	.06	10	4.2	5.2	3.0	22	22	7.5	.1	1.5	70	42	24	123	--	6.6	3	.0
	7- 7-66	R Wells WY 12-16	7.4	.03	.00	10	3.2	5.3	1.3	20	16	10	.2	2.7	68	38	22	113	--	7.1	4	.0
Westover Water Co.	8- 2-66	R Lake Elise	3.3	.28	.12	10	3.3	8.6	1.5	26	5.6	19	.1	.8	71	38	17	130	--	6.6	3	.0
	8- 2-66	R Wells MD 1-3	8.4	.06	.09	5.8	1.9	5.7	1.1	18	5.4	5.0	.0	5.6	52	22	8	81	--	6.4	3	.1
	8- 2-66	F Wells MD 1-3	15	.16	.07	5.1	1.7	8.8	1.0	21	6.6	5.0	.3	4.7	70	20	2	90	--	6.4	3	.0
	8- 2-66	R Wells MD 4,5	6.6	.28	.61	7.4	2.5	10	1.9	23	5.0	18	.0	.7	62	28	10	121	--	6.8	4	.0
	8- 2-66	F Wells MD 4,5	6.1	.08	.04	7.6	2.5	8.6	1.6	21	6.9	18	.1	.3	67	29	12	111	--	6.8	4	.0
	2-20-67	R Wells MD 4,5	--	.16	.13	--	--	--	--	17	--	17	--	--	71	32	18	114	--	6.3	--	--
	2-20-67	F Wells MD 4,5	--	.37	.30	--	--	--	--	14	--	17	--	--	71	32	18	114	--	6.3	--	--
Woodbury Water Co.	8- 1-66	R Woodbury Reservoir	4.4	--	--	7.7	2.5	5.2	1.0	28	8.9	6.5	.1	.5	58	29	6	89	19	7.1	14	.0
	4-17-67	R Woodbury Reservoir	--	.30	.02	5.6	1.4	--	--	7	--	--	--	--	61	20	14	76	6	6.5	--	--
	8- 1-66	R Well WY 11	14	.06	.09	20	4.0	4.9	1.7	42	23	7.5	.0	6.0	102	66	32	158	--	7.0	3	.0

a/ Recommended control limit: lower, 0.8 mg/l; optimum, 1.0 mg/l.

b/ Calculated as sodium (Na) + potassium (K).

ABBREVIATIONS

fig.	-	figure(s)
p.	-	page(s)
pl.	-	plate(s)
°C	-	degree(s) Celsius (Centigrade)
ml	-	milliliter(s)
°F	-	degree(s) Fahrenheit
mm	-	millimeter(s)
in	-	inch(es)
ft	-	foot (feet)
mi	-	mile(s)
sq ft	-	square foot (feet)
sq mi	-	square mile(s)
mcf	-	million cubic feet
cu ft/day	-	cubic foot (feet) per day
cfs	-	cubic foot (feet) per second
csm	-	cubic foot (feet) per second per square mile
gpm	-	gallon(s) per minute
gpd	-	gallon(s) per day
mgd	-	million gallons per day
mg/l	-	milligrams per liter
µg/l	-	micrograms per liter
msl	-	mean sea level
R.I.	-	recurrence interval

EQUIVALENTS

1 cfs = 646,317 gpd = 0.646317 mgd

1 mgd = 694 gpm = 1.547 cfs

1 cfs per sq mi = 13.57 in of runoff per year

1 mgd per sq mi = 21.0 in of runoff per year

1 in of water upon 1 sq mi = 17.4 million gallons = 2.32 mcf

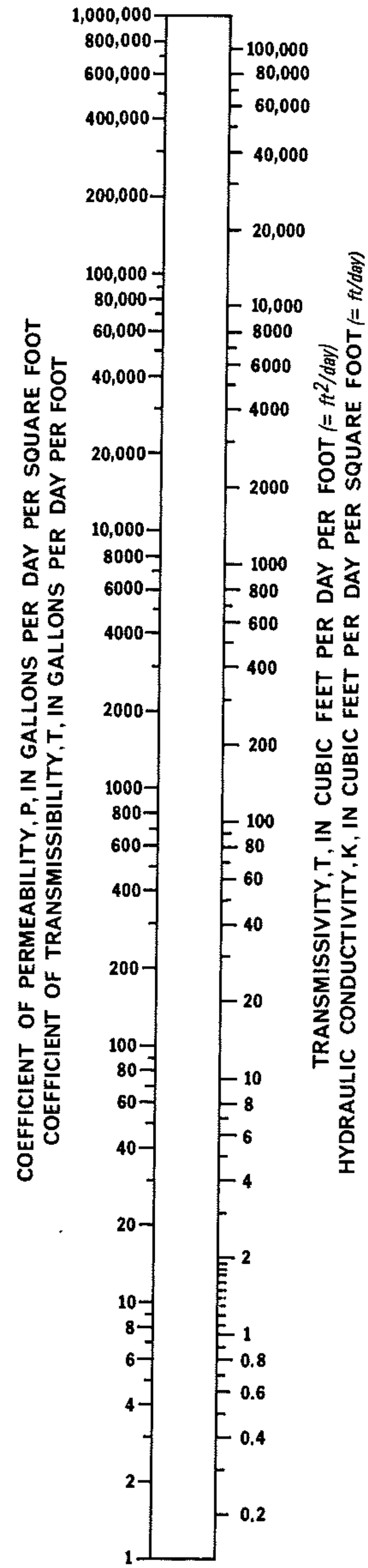
1 mm = 0.001 meter = 0.04 in

1 mg/l = 1 part per million (ppm) for solutions with a density of 1.000 gram per milliliter

°C = 5/9 (°F-32)

Transmissivity (ft^2/day) x 7.48 = coefficient of transmissibility (gpd/ft)

Hydraulic conductivity (ft/day) x 7.48 = coefficient of permeability (gpd/sq ft)



Logarithmic nomograph used to relate coefficient of transmissibility and transmissivity; coefficient of permeability and hydraulic conductivity.

GLOSSARY

Acid: A water-soluble substance containing hydrogen that can be replaced by metal elements; hence, an acid solution can dissolve many metals.

Aerosol: A suspension of microscopically small solid or liquid particles in air or gas.

Alkali: A water-soluble substance that has the ability to neutralize acid.

Annual flood: The highest peak discharge in a water year.

Aquifer: A geologic formation, group of formations, or part of a formation that can yield significant quantities of ground water.

Barrier boundary: An aquifer boundary formed by earth materials of low hydraulic conductivity and across which little or no ground water can flow.

Caisson well: A well with a large-diameter casing of concrete, commonly at least 6 feet in diameter and finished either open ended or with a short section of screen at the bottom.

Calcite: A common mineral, calcium carbonate ($CaCO_3$); the principal constituent of limestone and marble.

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

Climatic year: A continuous period, April 1 through March 31, delimiting a complete annual streamflow cycle from high flow to low and back to high flow. It is designated by the calendar year in which it begins.

Coefficient of permeability, P: The volume of water, in gallons, that an isotropic porous medium will transmit per day at 16°C (60°F) through a cross sectional area of 1 square foot, measured at right angles to the direction of flow, under a hydraulic gradient of 1 foot change in head per foot of length of flow path; expressed in gallons per day per square foot. Use of term has been discontinued in reports of U.S. Geological Survey; see "Field coefficient of permeability."
<u>Field coefficient of permeability</u> is the same except that it is measured at the prevailing water temperature. Replaced by U.S. Geological Survey with <u>hydraulic conductivity</u> (in this Glossary). Also, see "Equivalents" in preceding section.

Coefficient of transmissibility, T: The volume of water, in gallons, that the full vertical thickness of an isotropic aquifer will transmit per day at the prevailing water temperature across 1 foot of aquifer width, under a hydraulic gradient of 1 foot change in head per foot of length of flow path; expressed in gallons per day per foot. Replaced by U.S. Geological Survey with <u>transmissivity</u> (in this Glossary). Also see "Equivalents" in preceding section.

Coliform bacteria: Any of a group of bacteria, some of which inhabit the intestinal tract of vertebrate animals. The presence of coliform bacteria in a water sample is regarded as evidence of possible sewage pollution and fecal contamination, although these bacteria are generally considered to be nonpathogenic.

Color unit: A standard of color of water measured by the platinum-cobalt method, with the unit being 1 mg/l of platinum in water. Results are conventionally expressed as units of color, and not as mg/l.

Cone of depression: A depression produced in the 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 well.

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

Dissolved solids: The residue from a clear sample of water after evaporation and drying for 1 hour at 180°C; consists primarily of dissolved mineral constituents, but may also contain organic matter and water of crystallization.

Drawdown, s: 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 level.

Estuary: A body of water in which river water mixes with and measurably dilutes sea water.

Evapotranspiration: The combined processes by which water is changed from a liquid to a gas and enters the atmosphere from (1) free water surfaces and from the land surface (evaporation), and (2) from living plants (transpiration).

Flow duration, of a stream: The percentage of time during which specified daily flows are equaled or exceeded in a given period. The sequence of daily flows is not chronological.

Fracture: An opening or crack in bedrock.

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

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.

Hydraulic conductivity, K: The volume of water, in cubic feet, that an isotropic porous medium will transmit per day at the prevailing water temperature through a cross sectional area of 1 square foot, measured at right angles to the direction of flow, under a hydraulic gradient of 1 foot change in head per foot of length of flow path; expressed in feet per day. Replaces coefficient of permeability and field coefficient of permeability as the quantitative expression of permeability formerly used by the U.S. Geological Survey.

Hydraulic gradient, I: The slope of the water table or potentiometric surface per unit distance in a given direction; generally refers to maximum slope at a given point.

Hydrograph: A graph showing stage (height), flow velocity, or other property of water with respect to time.

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 of causing water in a stream or lake to move into an aquifer by establishing a hydraulic gradient from the surface-water body toward a pumping well or wells.

Isopleth: Line on a map connecting points at which a given variable has a specified constant value. The U.S. Geological Survey favors the term line of equal value.

Line of equal value: See isopleth.

Lithology: The physical characteristics of bedrock or unconsolidated deposits.

Mean: The sum of a set of individual values of any quantity, divided by the number of values in the set; popularly called the average.

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

Median grain size: A measure of average grain size obtained graphically by locating the diameter associated with the midpoint of a particle-size distribution.

Methylene blue active substance (MBAS): A measure of apparent detergents, as indicated by the formation of a blue color when methylene blue dye reacts with synthetic detergent compounds.

Micrograms per liter: A precise unit for expressing the concentration of chemical constituents in solution. One thousand micrograms per liter is equivalent to 1 milligram per liter.

Milliequivalents per liter: A measure whereby unit concentrations of all ions are chemically equivalent.

Milligrams per liter (mg/l): A unit for expressing the concentrations of chemical constituents in solution in weight per unit volume of water.

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

Pollution: "Harmful thermal effect or the contamination or rendering unclean or impure of any waters of the State by reason of any wastes or other material discharged or deposited therein by any public or private sewer or otherwise so as directly or indirectly to come in contact with any waters" (Public Act No. 57, 1967).

Recharge boundary: An aquifer boundary formed by a stream or lake that is a source of recharge to the aquifer.

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 is the average number of extremes during the same period. The occurrence of a drought or flood of a given magnitude cannot be predicted, but the probable number of such events during a sufficiently long period of time may be estimated with reasonable 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 or water years 1931 to 1960.

Runoff: That part of the precipitation that appears in streams. It is the same as streamflow unaffected by artificial diversions, storage, or other works of man in or on the stream channels.

Sand: Unconsolidated rock material composed principally of particles between 0.0625 and 2 mm in diameter.

Screen, of a well: A cylindrical device designed to admit water but prevent the passage of most or all of the surrounding earth material into a well.

Sedimentary: Pertaining to rocks deposited as sediments and later compacted or cemented to form consolidated rock.

Siliceous: Containing abundant silica, commonly quartz.

Silt: Unconsolidated earth materials composed principally of particles between 0.004 and 0.0625 mm in diameter.

Specific capacity, of a well: The rate of discharge of water per unit drawdown of a pumping well; commonly expressed as gallons per minute per foot of drawdown.

Specific conductance: A measure of the ability of water to conduct an electric current, expressed in micromhos per centimeter at 25°C. It is related to dissolved-solids concentration of water and serves as an approximate measure thereof.

Spectrographic analysis: An analytical method based on the measurement of the spectra of light emitted by individual elements in a sample that has been volatilized and ignited by an electric arc.

Storage coefficient, S: The volume of water a porous medium releases from or takes into storage per unit surface area of the medium per unit change in head; dimensionless.

Streamflow: The discharge of water in a natural channel without regard to the effect of diversion or regulation.

Thermal stratification: The persistence of horizontal layers of water with different temperatures in most deep open-water bodies.

Till: A predominantly nonstratified, nonsorted earth material deposited directly by a glacier.

Transmissivity, T: The rate at which water is transmitted at the prevailing water temperature, through a cross sectional area of the aquifer of 1 square foot, measured at right angles to the direction of flow, under a hydraulic gradient of 1 foot change in head per foot of length of flow path; expressed in cubic feet per day per foot (ft^2/day). Replaces coefficient of transmissibility, expressed in gallons per day per foot of vertical thickness of the aquifer. Transmissivity, T, equals hydraulic conductivity, K, times aquifer thickness, b.

Turbidity, of water: The extent to which penetration of light is restricted by suspended sediment, microorganisms, or insoluble material.

Turnover (or overturn): A natural mixing of thermally stratified waters that commonly occurs during early spring and early autumn. Generally results in a uniformity of the physical and chemical properties of the water.

Unconsolidated: Pertaining to earth materials whose constituent particles are loose, not firmly cemented or interlocked.

Uniformity coefficient (C_u): A quantitative expression of sorting of an earth material. It is the quotient of (1) the diameter of a grain that is just too large to pass through a sieve that allows 60 percent of the material, by weight, to pass through, divided by (2) the diameter of a grain that is barely too large to pass through a sieve that allows 10 percent of the material, by weight, to pass through. Poorly sorted deposits such as dirty gravel have high uniformity coefficients; well sorted deposits such as uniform sands have low uniformity coefficients.

Unit runoff: The runoff distributed over a unit area, commonly the drainage area, expressed in cubic feet per second per square mile (csm) or inches.

Volcanic: Pertaining to rocks formed by the cooling of lava.

Water year: A continuous 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.

SELECTED REFERENCES

Allen, W. B., Hahn, G. W., and Brackley, R. A., 1966, Availability of ground water, upper Pawcatuck River basin, Rhode Island: U.S. Geol. Survey Water-Supply Paper 1821, 66 p.

Allen, W. B., Hahn, G. W., and Tuttle, C. R., 1963, Geohydrological data for the upper Pawcatuck River basin, Rhode Island: Rhode Island Water Resources Coordinating Board, Geol. Bull. 13, 68 p.

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

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

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

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

Brumbach, J. J., 1965, The climate of Connecticut: Connecticut Geol. Nat. History Survey Bull. 99, 215 p.

Carr, M. H., 1960, The bedrock geology of the Naugatuck quadrangle, with map: Connecticut Geol. Nat. History Survey Quad. Rept. no. 9, 25 p.

Cassie, R. M., 1965, The evolution of a domal granitic gneiss and its relation to the geology of the Thomaston quadrangle, Connecticut: University of Wisconsin, unpub. PhD dissertation.

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 Bull. no. 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 Bull. no. 21, 84 p.

Colton, R. B., 1968, Surficial geologic map of the West Torrington quadrangle, Litchfield County, Connecticut: U.S. Geol. Survey Geol. Quad. Map GQ-727.

______ 1969, Surficial geology of the New Preston quadrangle, Litchfield County, Connecticut: U.S. Geol. Survey Geol. Quad. Map GQ-782.

Comly, H. H., 1945, Cyanosis in infants caused by nitrates in well waters: Am. Med. Assoc. Jour., 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 Rept. no. 1, 395 p.

Connecticut Department of Health, 1964, Public water supply information: Connecticut Dept. of Health, 28 p.

______ 1966, Sewage disposal in Connecticut: Connecticut Health Bull. 80, 25 p.

Connecticut Development Commission, 1962, Population: Connecticut Interregional Planning Program Tech. Rept. 131, 105 p.

______ 1963a, Community services, part 1: Connecticut Interregional Planning Program Tech. Rept. 150, 103 p.

______ 1963b, Water, a resource inventory: Connecticut Interregional Planning Program Tech. Rept. 124, 92 p.

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

Connecticut Water Resources Commission, 1970, Water quality standards, Connecticut Water Resources Comm., 41 p.

Crowley, W. P., 1968, The bedrock geology of the Long Hill and Bridgeport quadrangles, with maps: Connecticut Geol. Nat. History Survey, Quad. Rept. no. 24, 87 p.

Cushman, R. V., 1964, Ground-water resources of north-central Connecticut: U.S. Geol. 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 Assoc. Jour., v. 67, no. 2, p. 77-95.

Cushman, R. V., Pauszek, F. H., Randall, A. D., and Thomas, M. P., revised by Baldwin, H. L., 1965, Water resources of the Waterbury-Bristol area, Connecticut: U.S. Geol. Survey Water-Supply Paper 1499-J, 86 p.

Dorrler, R. C., 1968, Water quality changes at induced infiltration sites along the Naugatuck River, Connecticut: Univ. of Connecticut unpub. master's thesis, 67 p.

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

Ellis, A. J., 1916, Ground Water in the Waterbury area, Connecticut: U.S. Geol. Survey Water-Supply Paper 397, 73 p.

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

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

Fisher, D. W., 1968, Annual variations in chemical composition of atmospheric precipitation, eastern North Carolina and southeastern Virginia: U.S. Geol. Survey Water-Supply Paper 1535-M, 21 p.

Flint, R. F., 1962, The surficial geology of the Mount Carmel quadrangle: Connecticut Geol. Nat. History Survey Quad. Rept. no. 12, 25 p.

______ 1968, The surficial geology of the Ansonia and Milford quadrangles: Connecticut Geol. Nat. History Survey Quad. Rept. no. 23, 36 p.

Fritts, C. E., 1963a, Bedrock geology of the Mount Carmel quadrangle, Connecticut: U.S. Geol. Survey Geol. Quad. Map GQ-199.

______ 1963b, Bedrock geology of the Southington quadrangle: U.S. Geol. Survey Geol. Quad. Map GQ-200.

______ 1965a, Bedrock geologic map of the Ansonia quadrangle, Connecticut: U.S. Geol. Survey Geol. Quad. Map GQ-426.

______ 1965b, Bedrock geologic map of the Milford quadrangle, Connecticut: U.S. Geol. Survey Geol. Quad. Map GQ-427.

Gates, R. M., 1951, The bedrock geology of the Litchfield quadrangle: Connecticut Geol. Nat. History Survey Misc. Series no. 3, 13 p.

______ 1954, The bedrock geology of the Woodbury quadrangle: Connecticut Geol. Nat. History Survey Quad. Rept. no. 3, 23 p.

______ 1959, Bedrock geology of the Roxbury quadrangle: U.S. Geol. Survey Geol. Quad. Map GQ-121.

Gates, R. M., and Bradley, W. C., 1952, The geology of the New Preston quadrangle: Connecticut Geol. Nat. History Survey Misc. Series no. 5, 46 p.

Gates, R. M., and Christensen, N. I., 1965, The bedrock geology of the West Torrington quadrangle: Connecticut Geol. Nat. History Survey Quad. Rept. no. 17, 38 p.

Gates, R. M., and Martin, C. W., 1967, The bedrock geology of the Waterbury Quadrangle: Connecticut Geol. Nat. History Survey Quad. Rept. no. 22, 36 p.

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. Geol. 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 Bull. no. 20, 50 p., 1 pl.

Grover, N. C., 1937, The floods of March 1936, part 1, New England rivers: U.S. Geol. Survey Water-Supply Paper 798, 466 p., 14 pl.

Haffty, Joseph, 1960, Residue method for common minor elements: U.S. Geol. Survey Water-Supply Paper 1540-A, 9 p.

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

Hem, J. D., 1970, Study and interpretation of the chemical characteristics of natural water: U.S. Geol. Survey Water-Supply Paper 1473, 363 p.

Hovey, E. O., 1890, The oil well at Southbury, Connecticut: Scientific American, v. 62, no. 18, p. 275.

Junge, C. E., and Werby, R. T., 1958, The concentration of chloride, sodium, potassium, calcium, and sulfate in rain water over the United States: Jour. Meteorology, v. 15, p. 417-425.

Krynine, P. D., 1950, Petrology, stratigraphy and origin of the Triassic sedimentary rocks of Connecticut: Connecticut Geol. Nat. History Survey Bull. 73, 248 p.

LaSala, A. M., Jr., 1961, Surficial geology of the Southington quadrangle, Connecticut: U.S. Geol. Survey Geol. Quad. Map GQ-146.

LeGrand, H. E., 1964, A system for evaluating the contamination potential of some waste sites: Am. Water Works Assoc. Jour., v. 56, no. 8, p. 959-974.

Lohman, S. W., and others, 1972, Definitions of selected ground-water terms--revisions and conceptual refinements: U.S. Geol. 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. Geol. Survey Water-Supply Paper 1299, 639 p.

Malde, H. E., 1967, Surficial geologic map of the Roxbury quadrangle, Connecticut: U.S. Geol. Survey Geol. Quad. Map GQ-611.

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.

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

Meinzer, O. E., and Stearns, N. D., 1929, A study of ground water in the Pomperaug basin, Connecticut, with special reference to intake and discharge: U.S. Geol. Survey Water-Supply Paper 597-B, p. 73-146.

Meyer, R. R., 1963, A chart relating well diameter, specific capacity, and the coefficients of transmissibility and storage, _in_ Bentall, Ray, Methods of determining permeability, transmissibility and drawdown: U.S. Geol. Survey Water-Supply Paper 1536-I, p. 338-341.

Murray, C. R., 1968, Estimated use of water in the United States, 1965: U.S. Geol. Survey Circ. 556, 53 p.

Paulsen, C. G., Bigwood, B. L., Harrington, A. W., Hartwell, O. W., and Kinnison, H. B., 1940, Hurricane floods of September 1938: U.S. Geol. Survey Water-Supply Paper 867, 562 p., 20 pl.

Pauszek, F. H., and Edmonds, R. J., 1965, A preliminary appraisal of water quality in the Housatonic River basin in Connecticut: Connecticut Water Resources Bull. no. 6, 70 p.

Pessl, Fred, Jr., 1970, Surficial geology of the Woodbury quadrangle, Connecticut: U.S. Geol. Survey Geol. Quad. Map GQ-896.

Rainwater, F. H., and Thatcher, L. L., 1960, Methods for collection and analysis of water samples: U.S. Geol. Survey Water-Supply Paper 1454, 301 p.

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 Bull. no. 8, 102 p., 4 pl.

Riggs, H. C., and Hardison, C. H., 1973, Storage analyses for water supply: U.S. Geol. Survey Techniques Water-Resources Inv., book 4, ch. B2, 20 p.

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

Rossby, C. G., and Egner, H., 1955, On the chemical climate and its variation with the atmospheric circulation pattern: Tellus, v. 7, p. 118-133.

Ryder, R. B., Cervione, M. A., Jr., Thomas, C. E., Jr., and Thomas, M. P., 1970, Water resources inventory of Connecticut, part 4, southwestern coastal river basins: Connecticut Water Resources Bull. no. 17, 54 p., 3 pl.

Sammel, E. A., Baker, J. A., and Brackley, R. A., 1966, Water resources of the Ipswich River basin, Massachusetts: U.S. Geol. Survey Water-Supply Paper 1826, 83 p., 3 pl.

Schutz, D. F., 1956, The geology of Pomperaug valley, Connecticut: Yale University, unpub. senior essay, 44 p.

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

Simpson, H. E., 1961, Surficial geology of the Bristol quadrangle, Connecticut: U.S. Geol. Survey Geol. Quad. Map GQ-145.

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

Theis, C. V., 1935, Relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using ground-water storage: Am. Geophys. Union Trans., pt. 2, p. 519-524.

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 Bull. no. 12, 48 p., 1 pl.

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 Bull. no. 15, 105 p., 4 pl.

Thomas, C. E., Jr., Randall, A. D., and Thomas, M. P., 1966, Hydrogeologic data in the Quinebaug River basin, Connecticut: Connecticut Water Resources Bull. no. 9, 84 p., 1 pl.

Thomas, M. P., 1966, Effect of glacial geology upon the time distribution of streamflow in eastern and southern Connecticut: U.S. Geol. Survey Prof. 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 Bull. no. 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 Bull. no. 11, 96 p., 4 pl.

Thomas, M. P., Ryder, R. B., and Thomas, C. E., Jr., 1969, Hydrogeologic data for the southwestern coastal river basins, Connecticut: Connecticut Water Resources Bull. no. 18, 45 p., 1 pl.

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

Thornthwaite, C. W., 1948, An approach toward a rational classification of climate: Am. Geog. Soc. Geographical Review v. 38, p. 55-94.

______ 1952, An approach toward a rational classification of climate: Readings in the geography of North America, Am. Geog. Soc. Repr. Ser. No. 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, v. 10, no. 3, 311 p.

U.S. Congress, 1956, Water pollution control act, public law 84-660, as amended by the federal water pollution control act amendments of 1961-(PL 87-88), the water quality act of 1965-(PL 89-234), and the clean water restoration act of 1966-(PL 89-753).

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

______ issued annually through 1960, 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. Geol. Survey Water-Supply Papers.

U.S. Geological Survey, 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. Geol. Survey Water-Supply Paper 1301, 380 p., 1 pl.

_____ 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. Geol. Survey Water-Supply Paper 1721, 317 p., 1 pl.

_____ issued annually, 1966-69, Water resources data for Connecticut: Hartford, Conn.

_____ 1968, Geological Survey research 1968, Chapter A: U.S. Geol. Survey Prof. Paper 600-A, p. A-52.

_____ 1969, Surface water supply of the United States, 1961-65, part 1, North Atlantic slope basins, v. 1, Basins from Maine to Connecticut: U.S. Geol. 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.

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

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

Warren, C. R., 1970a, Surficial geology of the Litchfield quadrangle, Connecticut: U.S. Geol. Survey Geol. Quad. Map GQ-848.

_____ 1970b, Surficial geology of the Winsted quadrangle, Connecticut: U.S. Geol. Survey Geol. Quad. Map GQ-871.

Wilke, Harvey, and Hutcheson, Ruth, 1962, Water softening for the home: Purdue Univ. Coop. Ext. Circ. 505, 8 p.

_____ 1963, Iron water control for the home: Purdue Univ. Coop. Ext. Circ. 507, 8 p.

Wilson, W. E., Ryder, R. B., and Thomas, C. E., Jr., 1968, Hydrogeology of southeastern Connecticut, in New England Intercollegiate Geol. Conf. Guidebook no. 2, 60th Ann. Meet., Yale Univ., Connecticut, 1968: Connecticut Geol. Nat. History Survey, Trip B-3, 33 p.

Woodhull, L. S., 1971, Well water quality and treatment, interpretation of laboratory analysis reports: Connecticut Health Bull., v. 85, no. 2, p. 57.

Works Progress Administration for Connecticut, 1938a, Records of wells, springs, and ground-water levels in the towns of Bridgeport, Easton, Fairfield, Stratford, and Trumbull, Connecticut: Connecticut Ground Water Survey Bull. GW-1, 242 p.

_____ 1938b, records of wells, springs, and ground-water levels in the towns of Bethany, East Haven, Hamden, Milford, North Haven, Orange, West Haven, and Woodbridge, Connecticut: Connecticut Ground Water Survey Bull., GW-3, 247 p.