WATER RESOURCES INVENTORY OF CONNECTICUT
PART I
QUINEBAUG RIVER BASIN

BY
ALLAN D. RANDALL, MENDALL P. THOMAS, CHESTER E. THOMAS, JR., AND JOHN A. BAKER
U.S. GEOLOGICAL SURVEY

PREPARED BY THE
U.S. GEOLOGICAL SURVEY
IN COOPERATION WITH THE
CONNECTICUT WATER RESOURCES COMMISSION

CONNECTICUT WATER RESOURCES BULLETIN NO. 8

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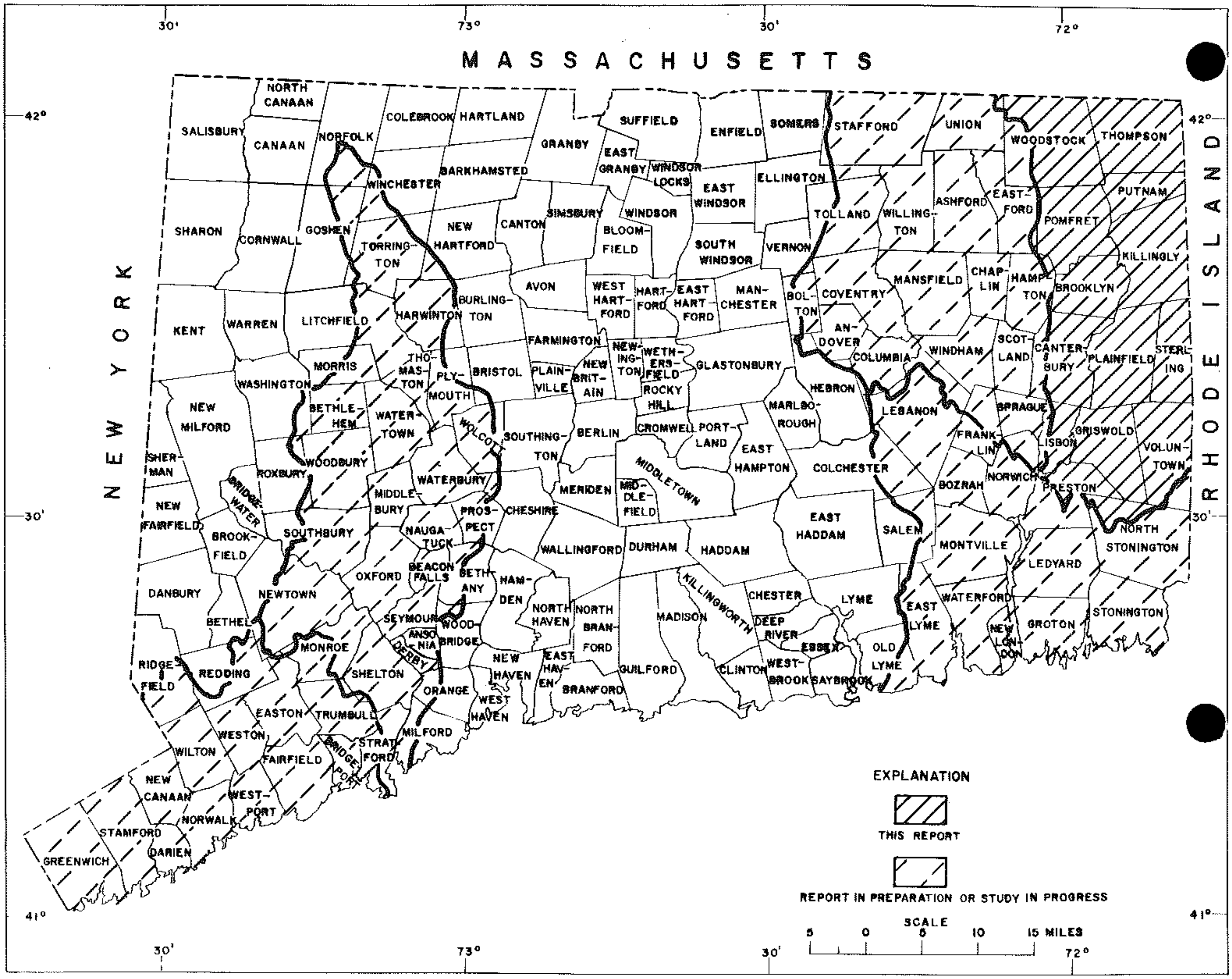

Five areas in Connecticut being studied in 1965 under the water resources inventory program.

ON THE COVER

The Quinebaug River near Jewett City, looking downstream; State Highway 12 and New Haven Railroad bridges at lower left, Connecticut Turnpike in middle distance. A good deal is known about the hydrology of this locality. River flow has been measured since 1918 just downstream from the railroad bridge; average flow has been 810 million gallons per day. Water temperature ranges from 32° to 84° F. During 1956, river water at this point contained an average dissolved mineral content of 53 parts per million. Test borings for the Route 12 and Connecticut Turnpike bridges suggest that the lowland along the railroad may be a good site for the development of large ground-water supplies. Photo courtesy of Connecticut Light and Power Co.

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SUMMARY

The Quinebaug River basin is blessed with a relatively abundant supply of water of generally good quality which is derived from precipitation that has fallen on the basin. Annual precipitation has ranged from about 30 to 67 inches and has averaged about 45 inches over a 44-year period. Approximately 21 inches of water are returned to the atmosphere each year by evaporation and transpiration; the remainder of the annual precipitation either flows overland to streams or percolates downward to the water table and ultimately flows out of the basin in the Quinebaug River. During the autumn and winter months precipitation normally is sufficient to cause a substantial increase in the amount of water stored underground and in surface reservoirs within the basin, whereas in the summer most of the precipitation is lost through evaporation and transpiration, resulting in sharply reduced streamflow and lowered ground-water levels.

The amount of water that flows out of the basin in the Quinebaug River represents water potentially available for use by man. Annual runoff from the entire basin has ranged from about 11 to 38 inches since 1918, and has averaged about 24 inches (310 billion gallons). Although runoff indicates the amount of water potentially available, part of the water could never be tapped by man. On the other hand, with increased development, it is possible that some water will be reused several times.

The water available may be tapped as it flows through the area or is temporarily stored in streams, lakes, and aquifers. The amounts that can be developed vary from place to place and time to time depending on the amount of precipitation, on the size of drainage area, on the thickness, permeability, and areal extent of aquifers, and on the variations in chemical and physical quality of the water.

Differences in streamflow from point to point are due primarily to 1) differences in the proportion of stratified drift in the drainage basin above each point, which affect the timing of streamflow, 2) and differences in precipitation, which affect the amount of streamflow. Information on streamflow from gaging stations may be extended to ungaged sites by accounting for both of these factors in calculations.

Future floods on the French River or the upper Quinebaug River are unlikely to cause major damage, so long as buildings are not constructed below the highest flood elevations to be expected with the present system of reservoirs for flood control.

Ground water can be obtained from wells anywhere in the Quinebaug River basin, but the amount obtainable from individual wells at any particular point depends on what aquifers are present. For practical purposes, the earth materials in the basin comprise three aquifers--stratified drift, till, and bedrock.

Till and bedrock are widespread in extent but can provide only small to moderate water supplies. Till is tapped chiefly by dug wells; permanent supplies of more than 200 gpd can be obtained from dug wells at a majority of sites in areas of till, but there are many sites where the till is too impermeable or too thin to provide this much water throughout the year. The coefficient of permeability of till ranges from about 0.2 gpd per sq ft to 55 gpd per sq ft. Bedrock is tapped chiefly by drilled wells, about 85 percent of which will supply at least 3 gpm. Very few, however, will supply more than 50 gpm.

Stratified drift is the only aquifer generally capable of yielding 100 gpm or more to individual wells. It occurs chiefly in lowlands, covers about 25 percent of the basin, and overlies till and bedrock except in a few narrow bedrock valleys where it occurs beneath till. Drilled wells in stratified drift with at least 9 feet of screen yield from 2 to 195 gpm per foot of drawdown. Tests of several dug wells suggest that most could supply 8 to 48 gpm per foot of drawdown for an 8-hour period. Permeability of stratified drift is related to grain size; coefficients of permeability range from 20 to 20,000 gpd per sq ft, and predominantly coarse deposits have an average coefficient of permeability of 900 gpd per sq ft over the basin.

The amount of ground water potentially available depends on the amount of water that infiltrates to the water table (natural recharge). Recharge in areas of stratified drift is more than twice that in areas of till. Recharge varies from year to year, but in stratified drift it exceeds 17 inches (equivalent to 0.82 mgd per sq mi) in 7 years out of 10 in most parts of the basin.

Wells tapping stratified drift can obtain additional amounts of water by means of induced infiltration from adjacent streams and lakes.

From data on permeability, saturated thickness, recharge, gravity yield, well performance, and streamflow, preliminary estimates of ground-water availability can be made for any point in the basin. Long-term yields were estimated for 29 areas that are especially favorable for development of large ground-water supplies. Detailed site studies to determine optimum yields, drawdowns, and spacing of individual wells are needed before major ground-water development is undertaken in these or other areas.

The chemical quality of water in the Quinebaug River basin is generally good to excellent. Samples of naturally occurring water collected from streams contained less than 74 ppm of dissolved solids and less than 36 ppm of hardness. Water from wells is more highly mineralized than naturally occurring water from streams. Even so only 5 percent of the wells sampled yielded water with more than 140 ppm of dissolved solids or water with more than 121 ppm of hardness. Ground water in the eastern one-third of the basin has

less than 60 ppm of hardness, and most streams in this area contain especially soft water.

Even in the major rivers, which are used to transport industrial waste, the dissolved chemical content is not great; the median dissolved-solids content of the Quinebaug River near its mouth is only 53 ppm. The French River, which carries the largest proportion of industrial wastes of any major stream in the basin, generally contains about 175 ppm of dissolved solids at low flow. Hardness rarely exceeds 40 ppm in the major streams, and trace elements such as copper, chromium, and lead in several samples are below the upper limits recommended for drinking water by the U.S. Public Health Service. However, consideration of factors such as dissolved oxygen, color, odor, and coliform bacteria has led the New England Water Pollution Control Commission to classify most Connecticut portions of the Quinebaug and French Rivers and some reaches of a few other streams as unacceptable for bathing, recreation, public water supply, and some agricultural uses.

Iron and manganese in both ground water and surface water are the only constituents whose concentrations commonly exceed recommended limits for domestic and industrial use. A large majority of the wells in the basin yield clear water with little or no iron or manganese. Nevertheless, there are several localities, chiefly in the western part of the basin, in which most wells contain enough iron and/or manganese to be troublesome for most uses. In many of these localities the poor water is restricted to certain bedrock units that contain abundant iron sulfide minerals. In a few other localities in lowland areas, iron-bearing ground water occurs in both the lower part of the stratified drift and the upper few feet of the bedrock.

Iron concentrations in naturally occurring stream water exceeded 0.3 ppm under low-flow conditions at 50 percent of the sites sampled; the percentage of samples containing more than 0.3 ppm of iron probably would have been higher had some of the sites been sampled at lower streamflows. Large concentrations of iron in stream water result from discharge of iron-bearing ground water or from the discharge of water from swamps. In swamps the iron is released largely from decaying vegetation.

The iron content of the Quinebaug River has been increased substantially above natural levels by the disposal into the river of industrial waste; iron exceeds 0.3 ppm 75 percent of the time where the river enters the State, and 45 percent of the time at Jewett City. Upstream from Putnam, iron-oxide sediment or sludge derived largely from industrial waste has accumulated on the river bottom. Little of this waste goes into solution at present, but should the acidity of the river increase sharply the dissolved iron content would increase also. Unless the method of disposal of the iron-oxide waste is changed and the present sludge removed from the strea, the esthetic and recreational value of the permanent pool above the West Thompson flood-control dam will be seriously limited.

Ground water more than 30 feet below land surface has a relatively constant temperature, usually between 48° and 50° F. Water temperature in very shallow wells may fluctuate from about 38° F in February or March to about 55° F in late summer. Water temperature in the larger streams fluctuates much more widely, ranging from 32° F at least for brief periods in winter, to about 85° F occasionally during summer.

The quantity of suspended sediment transported by streams in the basin is negligible. Turbidity in major streams generally has been about 8 ppm; values large enough to be troublesome may occur locally.

The total amount of water used in the Quinebaug River basin for all purposes in 1961 was about 4.8 billion gallons, which is equivalent to 243 gpd per person. Public water systems supplied the domestic needs of nearly half the population of the basin in 1961; 10 systems were sampled, all of which provided better water than specified in U.S. Public Health Service drinking-water standards.

WATER RESOURCES INVENTORY OF CONNECTICUT
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By

Allan D. Randall, Mendall P. Thomas, Chester E. Thomas, Jr., and John A. Baker

WATER RESOURCES INVENTORY OF CONNECTICUT

Connecticut, in common with many other States, has experienced a rapid increase in population over the past few decades, accompanied by industrial expansion, changes in agricultural technology, and a rising level of material culture. All of these changes have contributed to a steadily rising demand for water that is expected to continue into the foreseeable future. Although an ample supply of water reaches Connecticut each year, the amount and quality of the water vary 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 the optimum use from existing sources and to locate new ones.

Accordingly, in 1959 the General Assembly, on recommendation of the Water Resources Commission, authorized a "water resources inventory" of Connecticut. Under this authorization, and under a supplemental authorization by the General Assembly in 1963, the U.S. Geological Survey in cooperation with the Water Resources Commission is undertaking a series of studies aimed at determining the quantity and quality of water that is available at any location in the State. To simplify the calculation and description of water quantities and relationships, the State has been divided into 10 study areas bounded by natural drainage divides: five of the ten areas are being studied as of July 1965 and are shown on the map inside the front cover. Reports resulting from these studies will be useful to State and regional planners, town officials, water-utility personnel, consulting hydrologists, well drillers, and others concerned with the development and management of water resources.

This report, covering the Quinebaug River basin of northeastern Connecticut, is the first prepared under the water resources inventory program.

QUINEBAUG RIVER BASIN

The location of the Quinebaug River basin is shown in figure 1. The Quinebaug River drains a total area of 743 square miles, of which 425 square miles are in Connecticut, 260 square miles are in Massachusetts, and 58 square miles are in Rhode Island. Two major streams, the Quinebaug River itself and its largest tributary, the French River, enter the Connecticut portion of the basin from Massachusetts and one major stream, the Moosup River, enters Connecticut from Rhode Island.

The information presented in this report pertains only to the Connecticut portion of the basin except that enough data were collected in Massachusetts and Rhode Island to define the quantity and quality of water entering Connecticut.

ACKNOWLEDGMENTS

The data on which this report is based were collected and analyzed by numerous professional and technical employees of the Water Resources Division, U.S. Geological Survey. Considerable unpublished information was obtained from the files of the Water Resources Commission, the State Highway Department, and the State Board of Fisheries and Game. Mimeographed reports dealing with the economy of the basin were furnished by the Connecticut Development Commission. Field studies in the Pachaug State Forest were facilitated by Myron Hadfield, Ranger, and Douglas Barnes. Measurements of water level, stream stage, or stream temperature were made and/or samples of precipitation collected by Paul Bononsconi, John Cobb, Naimi Lehto, John Olsen, Aldege Robitaille, Stephen Smith, and Francis Szlosek. Permission to measure water levels in wells in selected key basins was given John Bronson, Col. Edward Dennis, Miss Jean Murphy, the Pendleton Hill Baptist Church, and John Robella. Records of wells and test borings were provided by a host of owners, drillers, and company officials too numerous to mention by name. The contributions made by all these individuals and agencies have helped to make this report more complete and more useful.

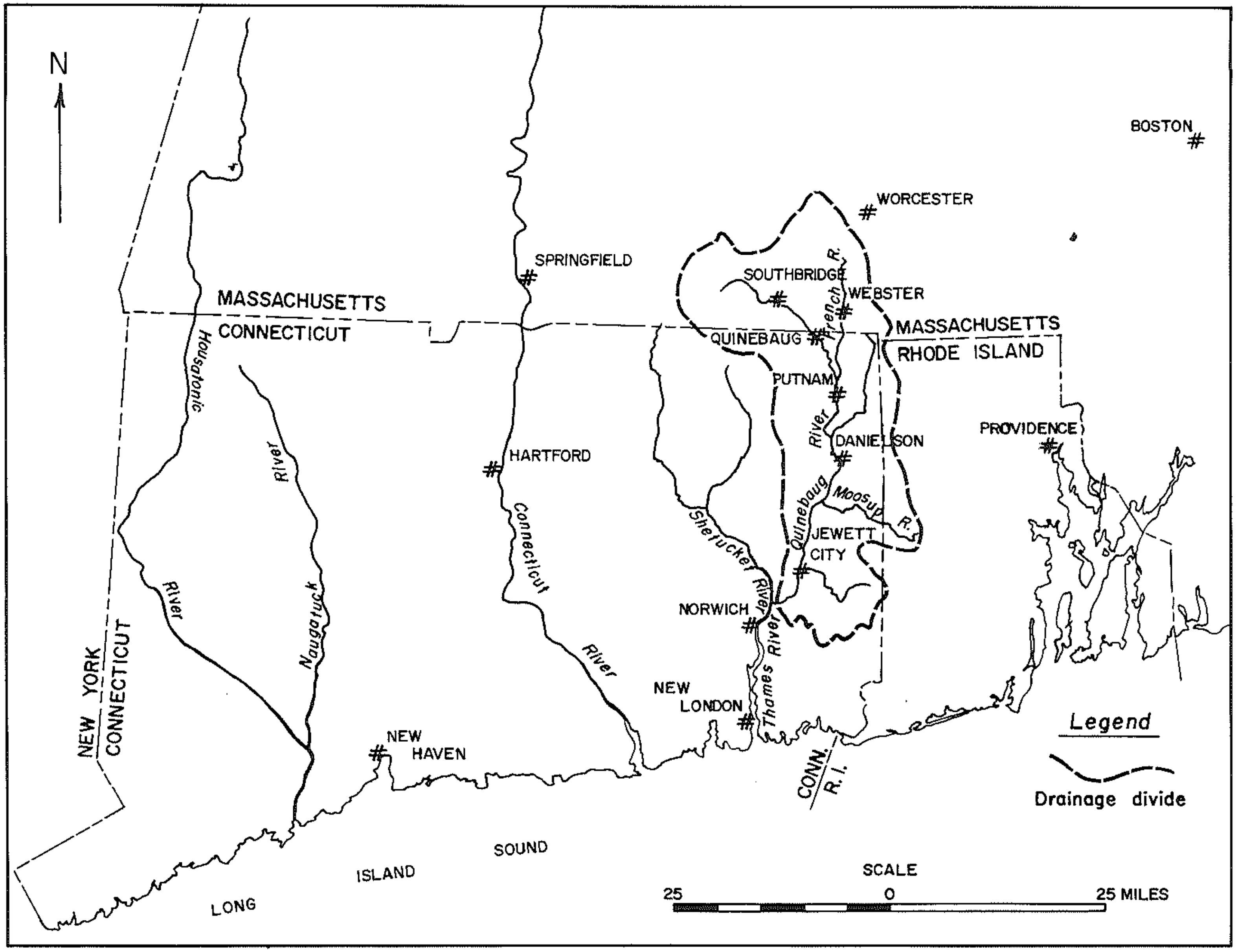


Figure 1.--The Quinebaug River basin is located in northeastern Connecticut and adjoining parts of Massachusetts and Rhode Island.

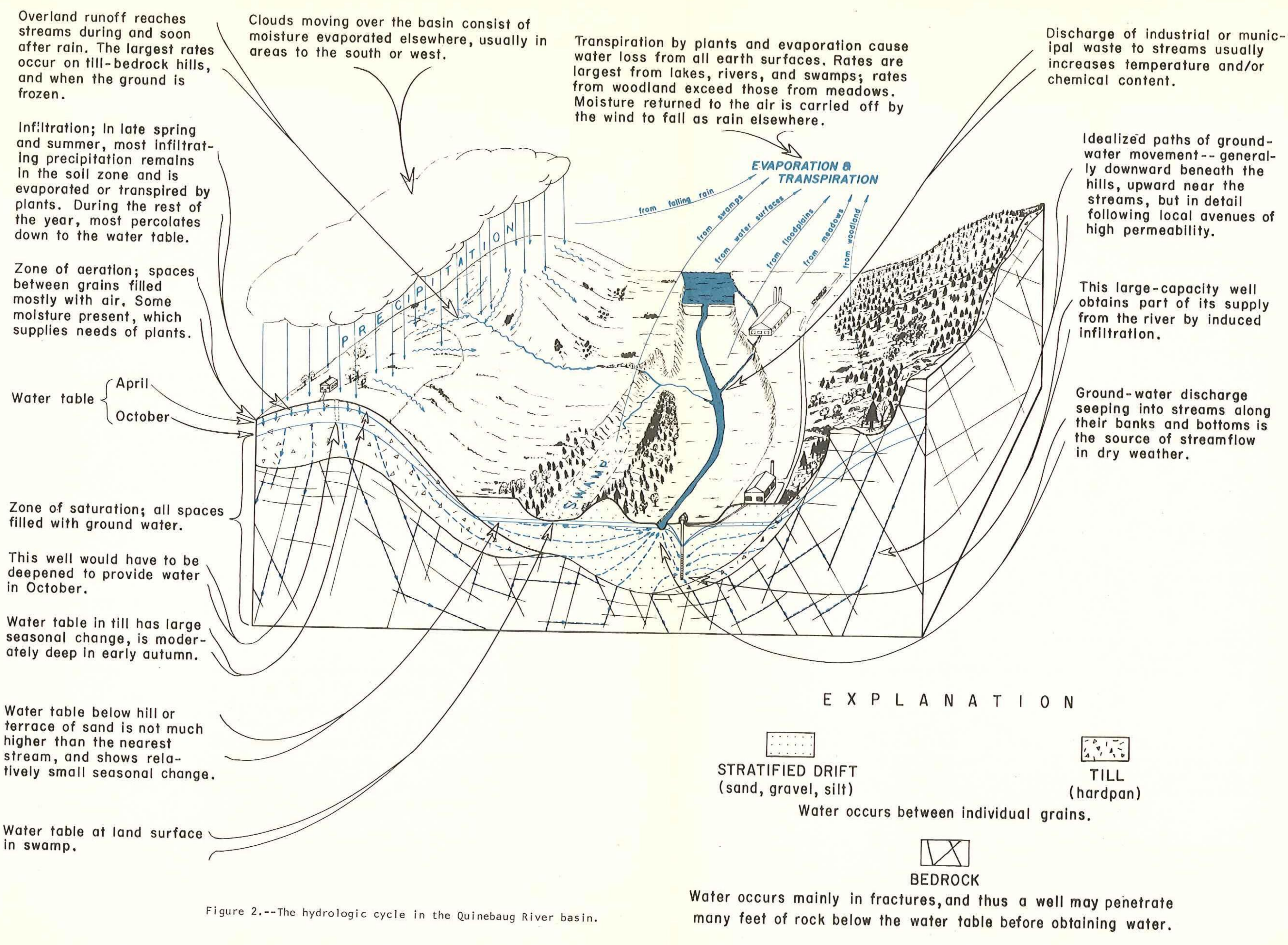


Figure 2.--The hydrologic cycle in the Quinebaug River basin.

GUIDE FOR USE OF THIS REPORT

Water supplies may be obtained from streams and lakes or from aquifers. Although the water from these two sources is so closely connected as to form one water supply for the area, the methods used for estimating the amount of water available from each source at a particular location and the techniques of development of each are sufficiently different that water in streams and lakes (surface water) and water in aquifers (ground water) are discussed in separate sections of this report.

The reader of this report who is primarily interested in determining the availability and quality of surface water in a particular part of the area should look first at the map summarizing the water available (plate D). From this map the reader may locate lakes and ponds which have water in usable storage and determine amounts of usable storage. The same map shows, for all but very small streams, the streamflow that will be equaled or exceeded 90 percent of the time at any point on the stream. Plate D also shows the stream reaches which contain less than 5 ppm (parts per million) of dissolved oxygen and/or objectionable amounts of dissolved or suspended matter or coliform bacteria, at least at low streamflow, as a result of activities of man.

Additional information on surface water is contained in the text. Included are tables and graphs showing flow duration, low-flow frequency, flood peaks, frequency of floods, and chemical quality of water. A method is described (p. 22) whereby the relationship between surficial geology and runoff can be used to estimate flow duration at any point along streams in the Quinebaug River basin.

The reader of this report who is primarily interested in determining the availability of ground water in a particular part of the area should look first at the geohydrologic map (plate B). From this map the reader may determine the principal water-bearing unit in the area of interest. The explanation on the map describes the permeability of each unit and the yields to be expected from individual wells.

Additional information on the availability of ground water and information on the quality of ground water is shown on the map summarizing water available (plate D). This map shows areas of stratified drift deposits that are favorable for the development of ground-water supplies, quantities of ground water available in each of these areas, and areas where ground water contains objectionable amounts of iron and manganese.

The methods used in determining the ground-water information shown on plates B and D are described in greater detail in the text, pages 85 to 89.

The tables and illustrations in this report serve to summarize large amounts of basic hydrologic data collected during this study. The detailed records and measurements of individual wells, streamflow, and quality of water are included in the companion basic data report by C. E. Thomas, Jr. and others (1966).

For readers of this report unfamiliar with some of the technical terms that are used, a glossary is given at the end of the report.

THE HYDROLOGIC CYCLE

In order to understand the occurrence and availability of water in the Quinebaug River basin, it is necessary to know something about the hydrologic cycle. The hydrologic cycle is a continuous natural phenomenon having no beginning and no ending. However, from man's viewpoint, it can be considered to begin when precipitation falls from clouds onto the land surface. Part of the water from precipitation flows across the land surface into streams and part seeps into the ground. Much of the water that remains in the ground or on the land surface is soon evaporated or taken up by plants and returned to the atmosphere. Some, however, moves slowly underground toward nearby streams into which it eventually seeps. Part of the water which reaches streams, lakes, and the ocean is also evaporated, thereby forming clouds and recommencing the cycle. The hydrologic cycle as it occurs in the basin is illustrated diagrammatically in figure 2.

As water moves through the hydrologic cycle, large amounts are stored in the atmosphere as water vapor, on the land surface in streams and larger bodies of water, and beneath the land surface as ground water. None of these amounts is constant in any given locality, as the water is constantly moving from place to place. Keeping track of these changing amounts of water is the task of the hydrologist. The changes that take place in the Quinebaug River basin are described in more detail on the following pages.

PRECIPITATION

Precipitation has been measured for many years at various points in and near the Quinebaug River basin. The average amount of precipitation on the basin for each month from October 1918 through September 1962 was computed from records at many U.S. Weather Bureau stations in or near the basin and is given in table 1. In computing these values, data from the different precipitation stations were weighted in proportion to the area within the basin represented by each station. Rain that falls near the end of a month and snow remaining on the ground at the end of a month frequently contribute to streamflow in the following month. Accordingly, to facilitate comparison with streamflow later in this report, the values in table 1 have been adjusted for temporary surface storage of snow or rain, if any, at the end of each month. The data are compiled in periods of 12 months, October 1 through September 30, which are known as "water years" and are the same periods for which streamflow data are reported.

Figure 3, which is based on data in table 1, shows that mean monthly precipitation is relatively uniform throughout the year, ranging from 4.77 inches in March to 3.02 inches in February; the average over the year is 3.73 inches per month. Minimum monthly precipitation is also relatively uniform, but maximum monthly precipitation varies widely. Average annual precipitation over the basin during the water years 1919-1962 was 44.81 inches, and ranged from 29.66 inches (1957 water year) to 67.24 inches (1938 water year).

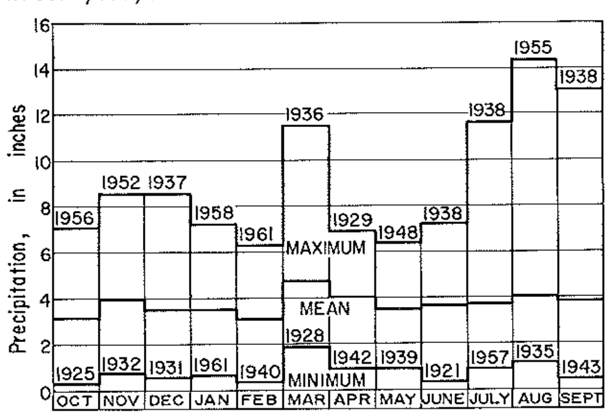


Figure 3.--Monthly precipitation.

Mean and minimum monthly precipitation in the Quinebaug River basin for the water years 1919-62 are both relatively uniform throughout the year, but maximum precipitation varies widely from month to month. The data have been adjusted for temporary surface storage of snow and rain at the end of each month. Water years in which maximum and minimum precipitation occurred are indicated.

STREAMFLOW AND UNDERFLOW INTO REPORT AREA

If the entire Quinebaug River basin is considered, precipitation is the sole source of water. There are no pipelines or canals that bring water into the basin. Furthermore, ground-water divides coincide with topographic drainage divides and no ground water enters the basin by underground flow from adjoining basins.

However, this report is concerned primarily with the Connecticut portion of the basin, and water does enter Connecticut from Rhode Island and Massachusetts, both on the surface and underground. The average annual streamflow entering the Connecticut portion of the basin is about 30 billion gallons from Rhode Island and 105 billion gallons from Massachusetts. The net annual underground flow into Connecticut is about 2 billion gallons from Rhode Island and 0.3 billion gallons from Massachusetts.

RUNOFF

Runoff from the Quinebaug River basin has been measured since 1918 at the Jewett City gaging station on the Quinebaug River about 6 miles above the mouth. Records at this point represent runoff from 711 of the 743 square miles composing the entire basin. Total runoff for each month from October 1918 through September 1962 is given in table 2: annual runoff during this period ranged from 11.39 inches (water year 1930) to 38.32 inches (water year 1938) and averaged 23.98 inches. Figure 4, which is based on data in table 2, shows that mean monthly runoff follows a marked seasonal cycle, being much greater for March (4.11 inches) than for August (0.88 inches); minimum monthly runoff follows a similar cycle. This cycle reflects a combination of causes, among which are increased loss of water by evaporation and transpiration during the summer months (see p. 8), melting in March and April of ice and snow stored on the land surface during the winter, and greater ground-water discharge in the spring due to the higher water table at that time. Maximum monthly runoff, like maximum monthly precipitation, varies widely, and does not show a seasonal cycle because occasional large floods have occurred in nearly all months of the year. The great flood of March 1936 was due to a combination of heavy rains and rapid snowmelt; the largest monthly runoff totals recorded in July, August, September, and October were due to passage of severe storms and hurricanes across Connecticut.

The relationship of total runoff to precipitation is plotted on figure 5. The straight line drawn through the plotted points represents the relationship "precipitation minus runoff equals evapotranspiration." Most years in which precipi-

Table 1.--Monthly and annual precipitation in inches for the Quinebaug River basin above Jewett City for water years 1919-62, computed from records of the U.S. Weather Bureau and Connecticut Park and Forest Commission. Figures have been adjusted for temporary surface storage of snow or rain, if any, at end of each month. Maximum and minimum amounts are underlined.

Water Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Annual
1919	1.36	2.63	3.35	4.97	2.88	6.42	3.70	5.77	3.20	4.52	3.28	8.03	50.11
1920	2.90	4.17	3.28	1.00	2.74	9.28	5.51	4.33	6.62	3.68	3.48	3.22	50.21
1921	4.84	4.90	4.88	2.09	2.16	4.24	4.73	3.70	.36	7.79	3.28	2.04	45.01
1922	1.45	6.65	2.71	1.55	2.94	5.00	4.04	4.12	6.94	5.49	6.05	4.49	51.43
1923	3.01	1.48	.92	5.61	2.02	6.25	2.85	4.17	4.34	3.10	2.47	2.72	38.94
1924	4.75	3.89	5.40	5.54	1.64	3.13	5.82	3.83	1.70	1.95	4.91	4.50	47.06
1925	.29	1.87	2.54	1.51	3.33	5.07	2.60	2.73	3.51	5.79	3.00	2.67	34.91
1926	4.29	3.47	2.88	2.77	4.09	4.33	2.51	2.31	1.88	4.96	4.09	1.72	39.30
1927	4.56	5.03	1.71	5.19	2.13	2.68	2.43	3.69	3.10	3.08	7.75	1.73	43.08
1928	6.15	6.32	5.86	2.49	4.21	1.88	3.86	1.64	5.03	5.34	4.78	3.33	50.89
1929	2.86	1.05	3.41	3.93	2.53	4.93	6.93	4.98	1.75	1.22	2.00	1.26	36.85
1930	2.34	3.06	3.68	2.49	3.06	2.93	1.86	3.02	2.67	2.85	1.68	1.37	31.01
1931	2.78	3.60	.59	3.27	3.10	6.63	2.96	4.49	6.65	2.98	5.68	1.26	43.99
1932	2.15	.76	3.77	5.12	2.09	4.95	2.59	2.23	3.23	2.28	5.77	7.03	41.97
1933	6.05	5.84	2.09	2.02	3.00	7.64	6.40	2.21	3.24	3.44	4.52	8.34	54.79
1934	3.20	1.79	1.53	6.11	.67	7.43	4.87	4.79	4.80	2.29	2.97	6.04	46.49
1935	5.22	2.06	5.21	4.63	2.01	3.61	2.93	2.05	6.58	3.26	1.19	3.90	42.65
1936	.51	3.84	1.02	5.45	3.66	11.53	3.17	2.18	2.85	1.91	4.88	4.27	45.27
1937	4.13	1.13	8.59	5.24	2.09	3.49	4.31	2.98	3.95	3.56	6.17	4.57	50.21
1938	4.26	3.44	5.93	5.39	2.43	2.56	2.74	4.16	7.24	11.64	4.36	13.09	67.24
1939	2.76	2.49	4.36	2.43	4.11	5.11	4.82	.94	3.27	1.69	7.18	3.07	42.23
1940	2.45	4.07	3.05	3.69	.34	7.09	6.15	2.82	5.68	4.94	1.38	2.88	44.54
1941	1.01	6.44	3.18	.77	3.31	2.53	1.20	3.62	4.15	5.54	3.51	.91	36.17
1942	1.99	2.92	3.16	3.33	3.57	7.44	.92	2.71	3.86	5.25	4.22	1.92	41.29
1943	4.05	5.60	4.38	3.93	3.65	3.73	3.47	4.74	2.01	3.80	1.71	.52	41.59
1944	5.26	4.35	1.01	1.30	2.34	4.78	4.36	1.37	5.07	1.70	1.36	8.49	41.39
1945	1.92	4.65	3.55	2.32	4.70	2.88	3.70	5.49	5.01	3.07	3.30	1.71	42.30
1946	2.11	4.70	4.90	3.25	3.15	3.01	2.20	5.46	3.70	3.22	7.99	1.70	45.39
1947	1.56	1.42	2.82	3.25	.59	4.54	4.90	3.06	3.64	4.77	2.45	3.24	36.24
1948	1.27	5.96	1.07	1.44	4.54	6.39	3.83	6.41	5.25	4.73	2.25	.69	43.83
1949	2.71	5.95	2.74	3.14	3.16	1.97	4.97	4.37	.47	1.20	2.95	5.26	38.89
1950	1.46	3.42	2.93	3.40	3.10	4.21	4.12	3.14	3.90	2.34	5.34	2.47	39.83
1951	2.25	5.45	1.66	4.31	5.82	4.32	4.49	4.60	3.05	2.64	5.35	2.31	46.25
1952	3.70	8.60	5.08	4.81	2.75	3.72	3.75	4.70	5.54	1.94	7.14	2.92	54.65
1953	1.74	2.20	3.79	6.22	3.92	9.00	5.61	4.33	1.97	3.82	2.31	1.39	46.30
1954	4.67	5.57	6.38	2.02	2.23	5.10	4.99	3.86	3.11	3.16	5.91	9.19	56.19
1955	2.20	4.92	5.24	1.89	4.21	4.26	3.20	1.90	3.22	3.10	14.36	3.85	52.35
1956	7.12	5.77	.74	2.77	5.46	2.39	6.68	2.37	3.03	4.23	1.26	4.81	46.63
1957	2.12	3.82	3.74	2.50	2.03	3.31	4.39	1.79	1.36	.89	2.19	1.52	29.66
1958	2.49	4.65	6.88	7.23	.63	4.86	6.07	4.55	2.19	5.78	4.34	5.69	55.36
1959	3.86	1.89	3.55	2.98	3.24	5.17	4.79	1.45	4.60	6.32	1.75	2.00	41.60
1960	7.08	5.55	3.51	3.81	5.68	2.28	4.70	4.58	1.72	6.42	2.67	6.73	54.73
1961	2.94	3.58	3.73	.61	6.32	3.44	5.09	4.85	2.70	2.54	3.78	5.60	45.18
1962	2.39	3.29	2.43	5.19	1.31	4.51	3.50	2.22	4.38	1.85	4.01	3.36	38.44
Average	3.14	3.96	3.48	3.48	3.02	4.77	4.06	3.52	3.69	3.77	4.11	3.81	44.81
Average 1931-60	3.14	4.10	3.55	3.60	3.05	4.86	4.11	3.45	3.81	3.73	4.22	4.06	45.68

Table 2.--Monthly and annual runoff in inches for the Quinebaug River basin above Jewett City for the water years 1919-62. Maximum and minimum amounts are underlined.

Water Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Annual
1919	1.09	1.35	1.95	2.99	1.80	5.22	4.25	3.19	1.24	1.11	0.82	2.21	27.22
1920	1.31	2.02	2.95	1.16	1.39	8.23	5.02	3.91	3.44	1.64	1.01	.66	32.74
1921	.91	1.50	3.31	2.48	1.55	4.16	3.09	2.74	1.24	1.99	1.18	.78	24.93
1922	.53	1.10	2.28	1.02	1.42	4.06	3.75	2.63	2.12	2.25	1.65	2.73	25.54
1923	1.30	1.07	1.01	3.15	1.70	4.95	3.75	2.88	1.12	.77	.68	.48	22.86
1924	.89	1.45	3.55	3.42	1.60	2.43	5.17	2.88	1.18	.61	.59	.64	24.41
1925	.50	.43	.73	.51	2.21	2.92	2.05	1.38	.80	.79	.79	.54	13.65
1926	.68	1.11	1.95	1.61	2.02	3.67	2.97	1.61	.88	.55	.71	.38	18.14
1927	.59	1.65	1.61	2.64	2.31	3.27	1.76	1.75	1.29	.66	1.29	.98	19.80
1928	1.75	4.56	4.72	2.69	3.32	2.50	2.89	2.43	1.82	1.79	1.16	1.07	30.70
1929	.99	.96	1.28	2.58	2.27	4.39	4.44	3.91	1.16	.62	.45	.32	23.37
1930	.34	.44	.80	1.51	1.67	2.20	1.85	1.01	.72	.39	.24	.22	11.39
1931	.21	.38	.46	.73	1.04	3.63	3.20	2.51	2.71	.91	.73	.52	17.03
1932	.37	.37	.70	1.82	1.67	2.47	3.41	1.37	.74	.48	.59	1.35	15.34
1933	2.22	4.32	1.98	2.14	2.30	4.66	5.95	1.90	1.24	.54	.51	1.74	29.50
1934	1.31	1.07	1.41	3.01	1.17	4.28	4.99	3.10	1.53	.61	.57	1.22	24.27
1935	1.94	1.68	2.88	4.18	2.52	4.18	3.29	1.78	1.82	1.01	.55	.63	26.46
1936	.38	.49	.86	2.43	1.46	11.24	4.57	2.04	.96	.57	.48	.76	26.24
1937	.99	.86	4.35	4.53	2.78	3.08	3.25	2.35	1.30	.82	.91	1.19	26.41
1938	1.20	3.11	3.66	3.58	2.93	2.69	2.34	1.79	2.23	6.66	2.63	5.50	38.32
1939	2.31	1.96	3.61	2.19	3.11	4.81	5.09	1.74	.88	.54	.61	.66	27.51
1940	.67	1.61	1.52	1.80	1.24	3.07	7.64	2.92	2.53	1.49	.65	.54	25.68
1941	.53	1.58	1.73	1.57	2.32	1.98	1.92	1.46	1.19	.79	.70	.47	16.24
1942	.31	.54	.83	1.28	1.74	5.83	2.15	1.27	.94	.94	.77	.48	17.08
1943	.67	1.53	3.39	2.78	2.95	4.60	2.58	3.40	1.27	.59	.55	.36	24.62
1944	.50	1.19	.76	.58	.96	2.50	3.44	1.78	1.26	.66	.36	1.02	15.01
1945	.80	1.60	2.76	2.62	1.86	5.16	2.38	3.61	1.98	1.04	.67	.50	24.98
1946	.45	1.07	2.76	3.44	2.52	3.64	1.64	2.28	2.40	.73	1.41	.76	23.10
1947	1.09	.65	.93	1.64	1.70	3.03	2.89	2.41	1.43	.75	.61	.68	17.81
1948	.43	1.73	1.29	1.24	2.18	6.27	4.00	3.86	3.83	1.79	.75	.39	27.76
1949	.42	1.17	1.16	2.92	2.74	3.00	2.76	1.99	.78	.30	.32	.39	17.95
1950	.30	.46	.86	1.56	1.93	3.30	3.25	2.63	1.78	.67	.70	.52	17.96
1951	.45	1.22	2.16	2.92	4.85	3.91	4.57	2.24	1.55	.77	.90	.50	26.04
1952	.63	3.89	3.78	4.34	3.31	4.32	3.19	2.78	2.60	.63	.95	.56	30.98
1953	.51	.54	1.43	3.48	4.02	6.46	6.64	3.49	.86	.49	.36	.26	28.54
1954	.37	1.48	3.72	1.86	2.24	3.56	3.64	3.15	.98	.59	.79	4.41	26.79
1955	1.71	3.29	4.58	2.71	2.49	4.02	2.54	1.95	1.02	.55	6.35	1.73	32.94
1956	5.32	5.40	1.65	2.42	2.90	3.74	6.56	2.40	1.54	.78	.34	.41	33.46
1957	.61	.89	2.10	2.11	1.85	2.71	3.86	1.04	.41	.22	.16	.15	16.11
1958	.22	.43	1.91	4.23	2.18	4.78	5.75	4.07	1.15	.87	1.11	1.17	27.87
1959	1.97	1.94	2.35	1.68	2.00	4.52	4.75	1.82	1.14	1.79	.48	.48	24.92
1960	1.21	2.22	3.95	2.88	3.74	2.47	5.02	2.41	1.03	.70	.73	1.28	27.64
1961	1.07	1.87	1.78	1.72	2.78	4.59	4.03	3.20	1.73	.63	.49	1.12	25.01
1962	1.16	1.06	1.26	3.34	1.36	4.17	3.97	1.65	1.16	.44	.36	.38	20.31
Average	0.98	1.57	2.15	2.40	2.23	4.11	3.78	2.43	1.48	0.99	0.88	0.98	23.98
Average 1931-60	1.00	1.62	2.18	2.49	2.36	4.13	3.91	2.38	1.50	.98	.91	1.02	24.48

tation was substantially greater than the previous year plot below the average line, whereas most years substantially drier than the previous year plot above it. This scatter is expected because the runoff lags behind the precipitation owing to storage in the ground and in lakes, ponds, and swamps. Consequently, there appears to be excess runoff during a dry year following a wet year because of the drainage of this water from storage. Conversely, there appears to be too little runoff during a wet year following a dry year owing to the replacement of storage. For example, precipitation in the 1959 water year was nearly 14 inches less than the preceding year, which resulted in generally lower ground-water levels (see figure 42) and probably also reduced the amount of water stored in lakes, ponds, swamps, and the ground. Thus the runoff in 1959 included moisture stored from the previous year(s), and amounted to 60 percent of the precipitation, or 7 percent above average.

Total runoff consists of both direct runoff and ground-water runoff. To determine the amount of ground-water runoff from the basin above Jewett City, and thereby also determine the amount of direct runoff, a ground-water rating curve, figure 6, was constructed using the record of water-table fluctuations in well Pl 1 in Plainfield, 7 miles north of Jewett City. For months in which rainfall was so small that nearly all the streamflow was ground-water runoff, month-end water levels in this observation well were plotted versus the corresponding flow of the Quinebaug River; these plots permitted the construction of the straight-line graphs in figure 6. By means of these lines, the ground-water runoff corresponding to any measured water level in well Pl 1 could be estimated for each month of the year.

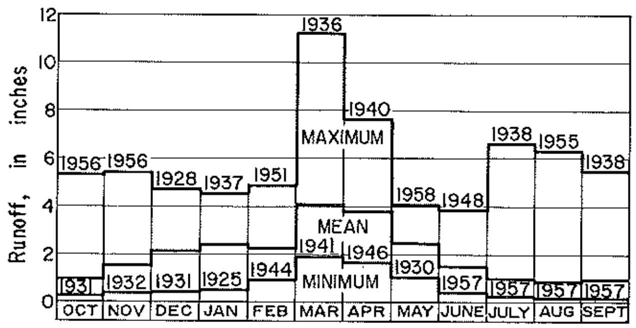
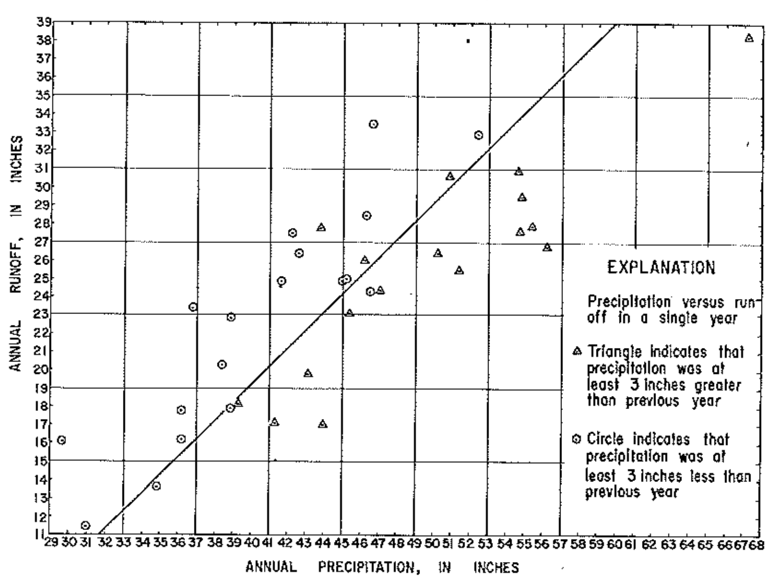


Figure 4.--Monthly runoff from the Quinebaug River basin.

Mean monthly and minimum monthly runoff from the Quinebaug River basin for the water years 1919-62 follow a marked seasonal cycle, being much greater for March than for August. Maximum monthly runoff varies widely and does not follow a seasonal cycle. Water years in which maximum and minimum runoff occurred are indicated.



The straight line indicates that, on the average, runoff from the Quinebaug River basin is equal to precipitation minus 20.8 inches (20.8 inches is the average evapotranspiration loss, which remains about the same each year). The scatter of data points is due largely to changes in the amount of water stored underground from year to year.

Figure 5.--Relation between precipitation and runoff.

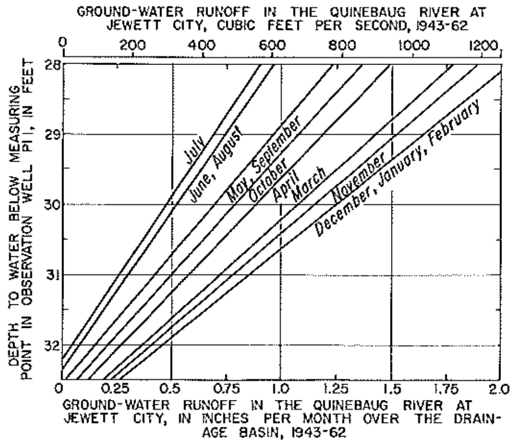


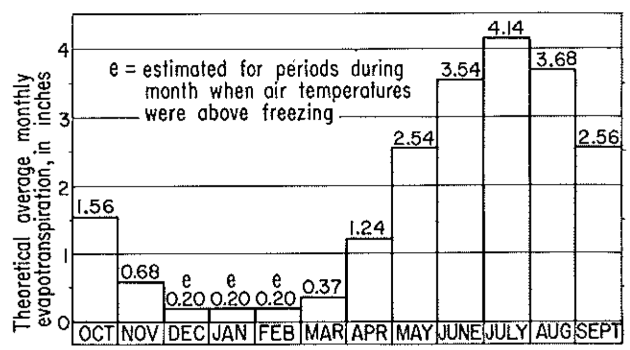
Figure 6.--Relation between ground-water level in well Pl 1 and ground-water runoff in Quinebaug River at Jewett City.

For any given depth to ground water as measured in wells, there is a corresponding amount of ground-water runoff. Ground-water runoff is greater during the non-growing season (late autumn and winter) than during the growing season (spring and summer), as shown by the series of sloping lines on this graph. The reduction in ground-water runoff during the growing season reflects water loss by evapotranspiration; evapotranspiration is negligible during the winter months.

EVAPOTRANSPIRATION

A substantial part of the water that falls on the Quinebaug River basin as rain or snow is returned to the atmosphere by means of evaporation and transpiration. Water left standing on the land surface after a rain is soon evaporated, and water is evaporated from the surfaces of lakes and streams and from pores in the soil. Plants withdraw large amounts of moisture from the soil and rocks both above and below the water table and control the temperature of their leaves by releasing this water to the atmosphere in a process known as transpiration. The total amount of evapotranspiration (evaporation plus transpiration) in a particular locality is difficult to measure, and was computed as a remainder after all other gains and losses of water were measured or estimated. That is, if it is assumed that long term storage remained substantially the same (an assumption supported by evidence from ground-water levels and reservoir levels) evapotranspiration is equal to the average precipitation on the basin (44.81 inches) minus the average runoff (23.98 inches), or 20.83 inches.

The effects of evapotranspiration on ground-water levels and on ground-water runoff are indicated on figure 6. Studies have shown that changes in the rate of evapotranspiration in a given locality from month to month are largely dependent on changes in air temperature and duration of daylight (Thornthwaite, 1952, p. 382; Olmsted and Hely, 1962, p. 12; Clark, 1963). Thus evapotranspiration is greatest during the growing season (April through October) when temperatures are above freezing and the days are longest. Because these major factors repeat themselves with relatively little change year after year, the annual amount of evapotranspiration and its distribution through the year are relatively constant for a given locality. The annual amount of evapotranspiration in the Quinebaug River basin is known from the long-term relationship of precipitation and runoff discussed in previous paragraphs, so a theoretical average monthly distribution of evapotranspiration was computed by a method similar to that of Olmsted and Hely (1962, p. 13). The monthly variations in evapotranspiration computed for the period 1943-62 are illustrated in figure 7.



Evapotranspiration in the Quinebaug River basin is greatest during the growing season (April - October) when temperatures are above freezing and the days are longest.

Figure 7.--Monthly evapotranspiration in the Quinebaug River basin.

THE WATER BUDGET

Just as the financial operation of a household or business firm can be expressed by a money budget, so the hydrologic operation of a drainage basin can be expressed by a water budget which lists receipts, disbursements, and water on hand. Receipts of water in the Quinebaug River basin consist of precipitation; disbursements consist of runoff, both direct runoff and ground-water runoff, and evapotranspiration, including evapotranspiration from ground water as well as from the surface water and the soil moisture above the water table. The amount of water on hand--stored within the basin--changes continuously in response to changing rates at which water enters and leaves the basin.

A monthly water budget for the Quinebaug River basin (table 3) lists values for the factors of the budget discussed in the preceding paragraphs. As illustrated in figure 8 the budget shows that precipitation during the autumn and winter months is sufficient to cause substantial increases in storage as well as to produce abundant runoff, whereas similar amounts of precipitation in the late spring and summer months are not adequate to supply the large evapotranspiration losses, resulting in sharply reduced runoff and a decrease in storage. The increase or decrease in storage within the basin, as shown in the last column of table 3 may be either as ground water, as surface water in lakes and stream channels, as soil moisture, or combinations of these. It should be noted that the precipitation values used (see table 1) have the effect of eliminating from the budget temporary storage of water as ice and snow.

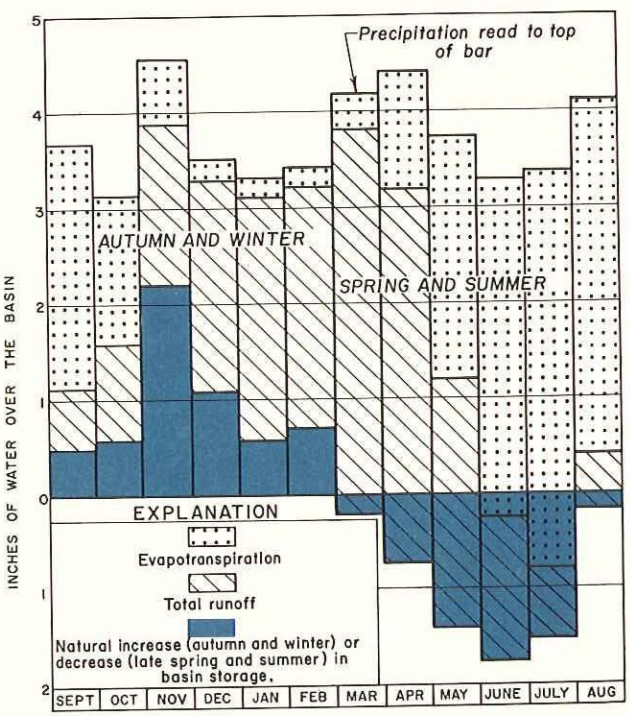


Figure 8.--Monthly water budget.

Table 3.--Monthly water budget for the Quinebaug River basin in inches of water over the basin. Average for water years 1943-1962.

Month	Precipitation	Runoff: Total	Runoff: Ground water	Evapotranspiration: Total	Evapotranspiration: Ground water	Change in storage
October	3.14	0.99	0.47	1.56	0.40	+0.59
November	4.57	1.68	.67	.68	.22	+2.21
December	3.51	2.22	.98	.20	.04	+1.09
January	3.32	2.53	1.18	.20	0	+ .59
February	3.44	2.52	1.31	.20	0	+ .72
March	4.21	4.04	1.35	.37	.10	- .20
April	4.44	3.90	1.26	1.24	.34	- .70
May	3.76	2.61	1.04	2.54	.55	-1.39
June	3.30	1.50	.71	3.54	.69	-1.74
July	3.38	.75	.47	4.14	.73	-1.51
August	4.12	.60	.36	3.68	.65	- .16
September	3.69	.63	.39	2.56	.52	+ .50
Water year	44.88	23.97	10.19	20.91	4.24	0

WATER QUALITY IN THE HYDROLOGIC CYCLE

Water that evaporates from the land and water surfaces and passes into the atmosphere is relatively pure. As water vapor condenses to form rain, snow, sleet or hail, it incorporates tiny particles of soot, dust, salt spray from the ocean, and other impurities from the air. Some of the mineral matter in these particles is dissolved by the water. The gases which make up the atmosphere, including carbon dioxide, oxygen, nitrogen in its various forms, and sulfur dioxide are dissolved to some extent also. Thus, even as it starts its journey to the land surface, water is no longer "pure." Samples of precipitation were collected for chemical analysis at three sites in the Quinebaug River basin. The analyses are summarized in table 4 and the locations of the sites are shown on plate A.

Part of the dissolved chemical content of precipitation that falls on the Quinebaug River basin is of local origin, but part has been transported from elsewhere by the wind. For this reason, the direction of movement of air masses influences the chemical quality of the precipitation. Most of the storms from which precipitation samples were obtained approached the basin from a westerly direction, and the proportion of different constituents was fairly uniform from storm to storm. However, a storm on June 4, 1963 yielded rain with substantially more sodium and potassium than other storms. This storm approached the basin from the south, having originated as a hurricane, though it was reduced to a minor storm before reaching Connecticut. The sodium and potassium probably were derived from salt spray over the ocean.

Sulfate is a substantial part of the dissolved-solids content in all samples, having values as high as 47 ppm. Carroll (1962, p. 7) suggests that industrial activity and ocean spray are the predominant sources of sulfate in precipitation. Because most storms from which samples

Table 4.--Summary of chemical analyses of precipitation samples from the Quinebaug River basin, Connecticut.

(Chemical constituents in parts per million)

Station number and location	1P: Collection site on River Road, 1 mile west of East Putnam	2P: Rain gage at Pachaug Forest Ranger Headquarters, 1.5 miles northeast of Voluntown	3P: Rain gage at State Forest Nursery, 0.5 mile south of Voluntown	All precipitation sampling sites
Period of Collection	June, July, August 1963	May, June 1963	Jan., April, May, June 1963	
Calcium (Ca)				
Median	1.6	4.0	3.0	2.8
Range	1.3-4.0	2.6-5.2	1.8-13	1.3-13
No. of samples	5	3	6	14
Sodium (Na)				
Median	0.5	0.6	0.8	0.6
Range	0.3-1.4	0.6	0.4-2.8	0.3-2.8
No. of samples	5	2	7	14
Potassium (K)				
Median	0.4	0.6	0.3	0.3
Range	0.1-.9	0.2-1.0	0.3-0.7	0.1-1.0
No. of samples	5	2	7	14
Bicarbonate (HCO_3)				
Median	6	13	10	10
Range	4-10	7-18	8-24	4-24
No. of samples	5	3	7	15
Sulfate (SO_4)				
Median	7.0	8.2	6.0	7.3
Range	4.5-14	7.3-8.9	4.9-47	4.5-47
No. of samples	5	3	7	15
Chloride (Cl)				
Median	0.4	1.2	1.0	0.6
Range	0.1-.6	1.0-1.4	0.2-1.9	0.1-1.9
No. of samples	5	3	7	15
Dissolved solids (Residue on evaporation at 180°C)				
Median	18	--	22	20
Range	11-27	--	16-31	11-31
No. of samples	5	--	4	9
Hardness as $CaCO_3$ Calcium, magnesium				
Median	12	11	18	12
Range	5-16		9-77	5-77
No. of samples	5	1	6	12
Noncarbonate				
Median	6	1	3	3
Range	1-13		2-9	1-9
No. of samples	5	1	4	10
Specific Conductance (micromhos at 25°C)				
Median	28	51	42	36
Range	18-54	31-60	26-188	18-188
No. of samples	5	3	7	15
pH				
Median	5.9	6.5	6.4	6.3
Range	5.8-6.3	6.2-8.1	5.9-6.8	5.8-8.1
No. of samples	5	3	7	15

were obtained approached the basin from the west, presumably industrial waste discharged into the atmosphere west of the basin was the principal source of sulfate in the precipitation.

The precipitation that reaches the land surface begins immediately to pick up additional quantities of solids eroded from the land surface and dissolved from earth materials at and beneath the surface. Water moving across the land surface and in the stream channels dislodges particles of soil, silt, sand, and occasionally gravel; this material is carried in suspension or is rolled along channel bottoms. Soil erosion is not a problem in eastern Connecticut due to the generally permeable soils and the nearly complete cover of vegetation that holds and protects the soil. Generally, sediment load increases as streamflow increases, and the highest sediment loads occur during the spring thaw and following severe storms such as hurricanes when streamflows are highest.

Water that percolates into the ground has much more opportunity to dissolve soil and rock materials than water which simply flows across the land surface. Accordingly, ground water contains higher concentrations of dissolved solids than do precipitation or water that flows overland. For this reason, streams generally contain the greatest concentrations of dissolved solids during periods of low streamflow when most of the water is ground-water runoff and contain the least concentrations of dissolved solids during periods of high flow when most of the water represents direct runoff mixed with ground water already present in the channel. Comparison of the average chemical character of streamflow during periods of high flow with the chemical character of precipitation suggests that a considerable part of the dissolved chemical content of direct runoff is already present by the time the water reaches the land surface.

MAN'S EFFECT ON THE HYDROLOGIC CYCLE

The hydrologic cycle is a fundamental process of nature, and the manner in which it operates cannot be altered by man. However, man can and does influence--deliberately or coincidentally--the amount of water stored on the surface and underground, the relative proportion of direct runoff, ground-water runoff, evapotranspiration, and also the quality of the water.

The amount of runoff from the Quinebaug River basin has probably not been changed significantly by man, but the time within which runoff leaves the basin following storms has been changed somewhat. During the 19th century the natural forests of the basin were largely converted to farmland, but during the 20th century forests have returned to cover much of the land surface. This reforestation may have resulted in a modest increase in evapotranspiration and a decrease in direct runoff, reducing total runoff slightly while making it more uniform throughout the year. (See Trousdell and Hoover, 1955; Schneider and Ayer, 1961.) There are many old industrial dams in the basin, most of which no longer operate to regulate streamflow, but which do delay and lower flood peaks; the numerous large ponds on the Pachaug River are partly responsible for the notably low stages that accompany floods of this stream. Obviously, these dams increase surface-water storage above natural conditions; they also increase ground-water storage by raising the local water table above its natural level. The gradual urbanization of parts of the basin has the opposite effect: buildings, pavement, storm sewers, and similar structures increase direct runoff and bring it to the streams more quickly than normal, but at the same time decrease ground-water recharge and lower the water table locally.

The timing of runoff has been altered by the storage and release of water from a few dams by industry: this regulation produces abrupt fluctuations in streamflow that are noticeable at low flow in a few places. In addition several flood-control reservoirs recently have been constructed in the northern part of the basin to store the runoff from major floods and release it gradually over a period of days or weeks.

The net effect of activities of man are difficult to evaluate, but it appears that in the Quinebaug River basin the timing of runoff is affected more than the quantity of runoff.

Only a slight amount of water is actually removed from the basin because of man's activities, including evaporation caused by man. A considerable amount of water is withdrawn from reservoirs and wells for various purposes, but even this is relatively small in relation to total runoff, and most of the water is returned to the ground or the streams within the basin no more than a few miles from the point of withdrawal.

Water quality is changed by man in numerous ways. Some of the smoke, soot, and fumes discharged into the air from industries, homes, and vehicles in and beyond the basin is incorporated in local precipitation, and some settles directly on the land surface. These materials contribute to the dissolved solids content of runoff. So do manures, chemical fertilizers, and pesticides spread on agricultural lands and leached by infiltrating precipitation. Most of the water withdrawn from streams or wells and used by industry for cooling, washing, and other purposes is returned to streams or to the ground at a higher temperature or with a higher dissolved solids content than when withdrawn. Waste discharge from most industrial plants in the basin is extremely diluted at high flow, but at low flow the quantity of stream water is not sufficient to dilute the waste and its presence is detectable along portions of the larger streams by field observation as well as by chemical analysis. Disposal of domestic sewage to streams has created offensive conditions in a few places, and disposal to the ground has contaminated nearby wells in a few crowded localities. The numerous excavations made during the construction of highways, buildings, and other structures result in temporary rapid erosion that contributes to the sediment and turbidity carried by streams. No matter how effective man's treatment of waste effluent, or curtailment of exhaust smoke, or stabilization of soil erosion, there will still be an increase in the dissolved mineral and suspended sediment content of the water in a habitated basin over the amounts supplied by natural processes. Keeping this increase within acceptable limits will be one of the major tasks of the future in the event of substantial urban expansion.

WATER IN STREAMS AND LAKES

Runoff from the Quinebaug River basin is carried by numerous streams, both large and small, which extend into all parts of the basin. The complete stream system is shown in blue on the large maps accompanying this report.

The amount of flow passing any given point on a stream varies from day to day, season to season, and year to year. Continuous records of streamflow have been obtained at 13 stream-gaging stations within the basin for periods ranging from 18 months to 45 years as shown in figure 9. In addition, discontinuous or partial records and single measurements of streamflow have been obtained at many other sites in the Connecticut portion of the basin during the period from July 1961 through September 1963. The locations of gaging stations within the Quinebaug River basin are shown on Plate A. All records for 1961-63 are given either in annual publications entitled "Surface-Water Records of Connecticut" or in the companion basic data report (Thomas and others, 1966), and continuous records are published in a series of U.S. Geological Survey Water-Supply Papers entitled "Surface Water Supply of the United States."

The variations in streamflow at the continuous-record and partial-record gaging stations are summarized in this report by means of standardized graphs and tables familiar to hydrologists. In order that the graphs for different streams be comparable, the data for each stream have been adjusted to represent a 30-year reference period beginning in either April or October 1930. This conforms with the practice agreed upon by the World Meteorological Organization (Searcy, 1959). Accordingly, the analyses, interpretations, and predictions with respect to streamflow are based on this 30-year reference period. Assuming that the flow during this reference period represents the long-term flow of the streams and there have been no changes in the pattern of regulation of storage within the basin or diversion of water into or out of the basin, the graphs or tables may be used to estimate the amounts of streamflow that will occur in the future at the measurement sites. Of course, streamflow varies from place to place along each stream as well as from time to time. Therefore, a method is described in a following section that permits the estimation of flow duration at any unmeasured point along the streams of the basin.

U.S. GEOLOGICAL SURVEY STATION NUMBER		STREAM AND LOCATION	DRAINAGE AREA (sq. mi.)
1180		Wood River at Hope Valley, R.I.	72.4
1183		Pendleton Hill Brook near Clarks Falls, Conn.	3.85
1205		Safford Brook near Woodstock Valley, Conn.	4.08
1210		Mount Hope River near Warrenville, Conn.	27.8
1230		Little River near Hanover, Conn.	29.1
1235	Quinebaug River Basin	Quinebaug River at Westville, Mass.	93.8
1240	Quinebaug River Basin	Quinebaug River at Quinebaug, Conn.	157
1245	Quinebaug River Basin	Little River at Buffumville, Mass.	27.7
1250	Quinebaug River Basin	French River at Webster, Mass.	85.3
1254.9	Quinebaug River Basin	Little River at Harrisville, Conn.	35.5
1255	Quinebaug River Basin	Quinebaug River at Putnam, Conn.	331
1256	Quinebaug River Basin	Mashamoquet Brook at Abington, Conn.	11.0
1260	Quinebaug River Basin	Five Mile River at Killingly, Conn.	58.2
1265	Quinebaug River Basin	Moosup River at Moosup, Conn.	83.5
1269.1	Quinebaug River Basin	Lowden Brook near Voluntown, Conn.	2.40
1269.23	Quinebaug River Basin	Denison Brook at Voluntown, Conn.	4.01
1269.5	Quinebaug River Basin	Pachaug River at Pachaug, Conn.	50.4
1270	Quinebaug River Basin	Quinebaug River at Jewett City, Conn.	711

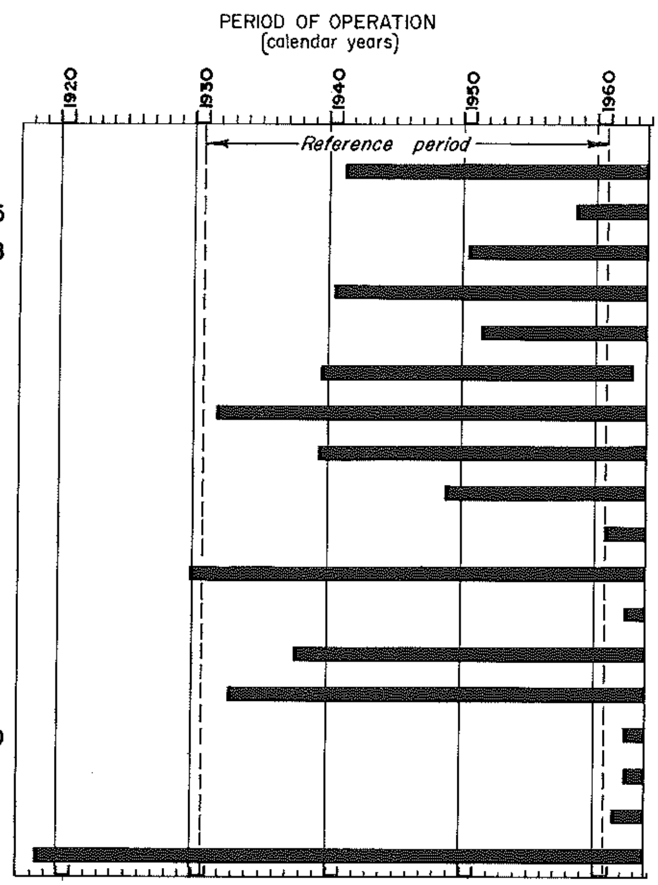


Figure 9.--Length of continuous records at stream-gaging stations.

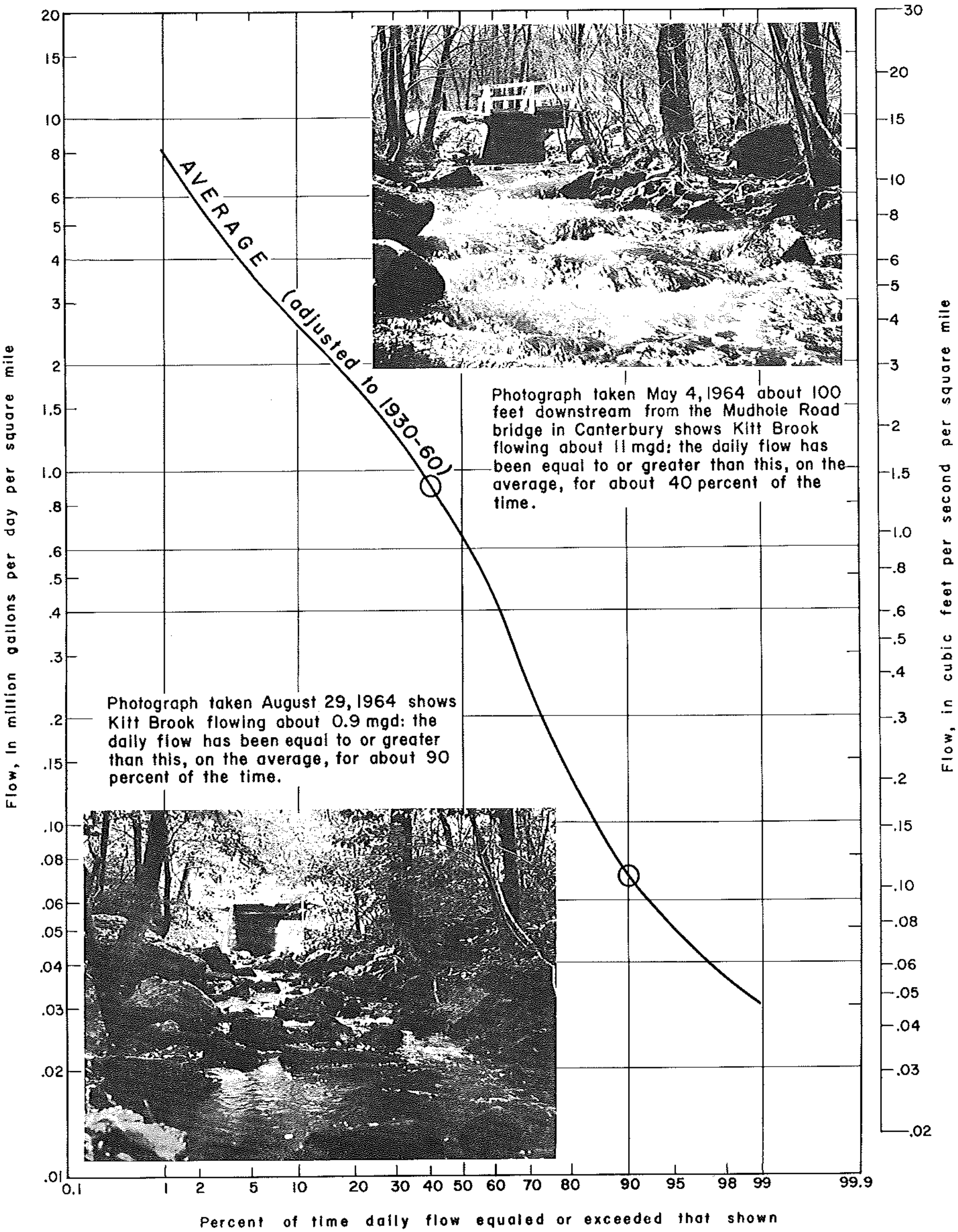


Figure 10.--Variation in flow of Kitt Brook.

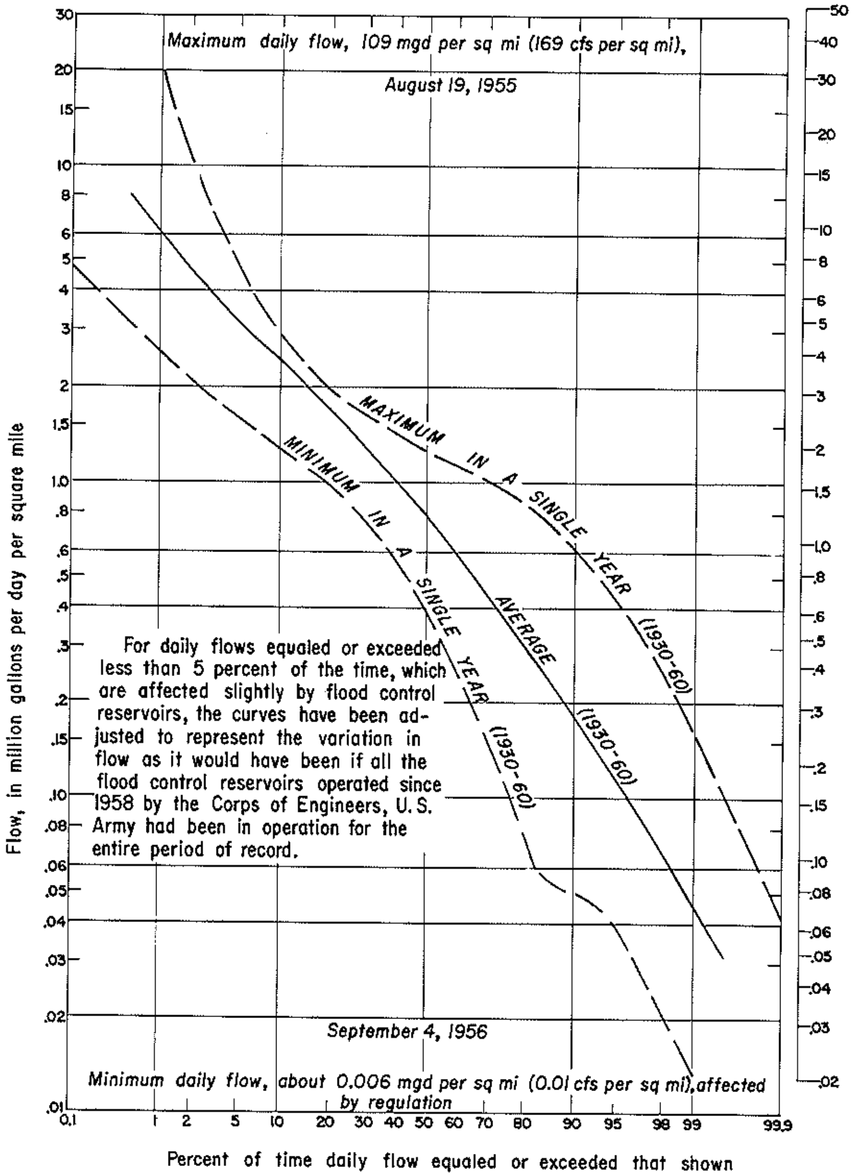


Figure 11.--Variation in flow of the Quinebaug River at Quinebaug.

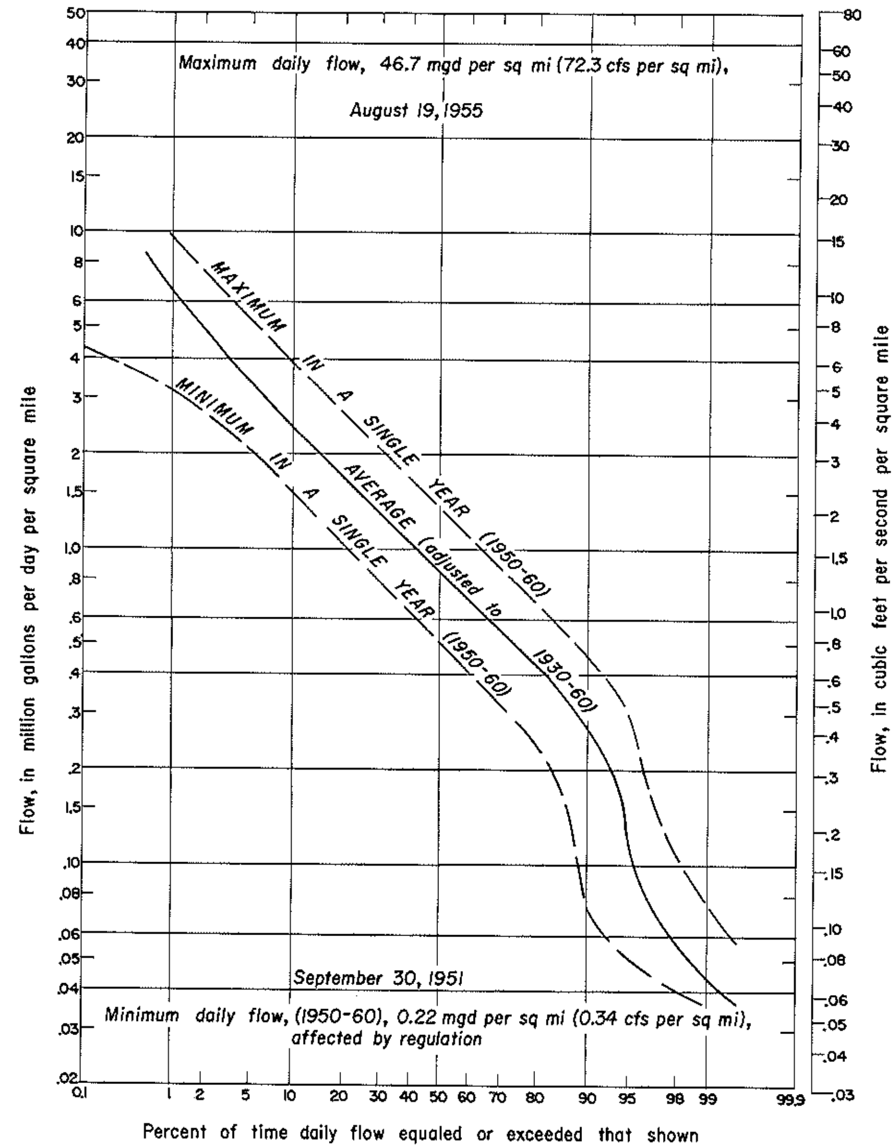


Figure 12.--Variation in flow of the French River at Webster, Massachusetts.

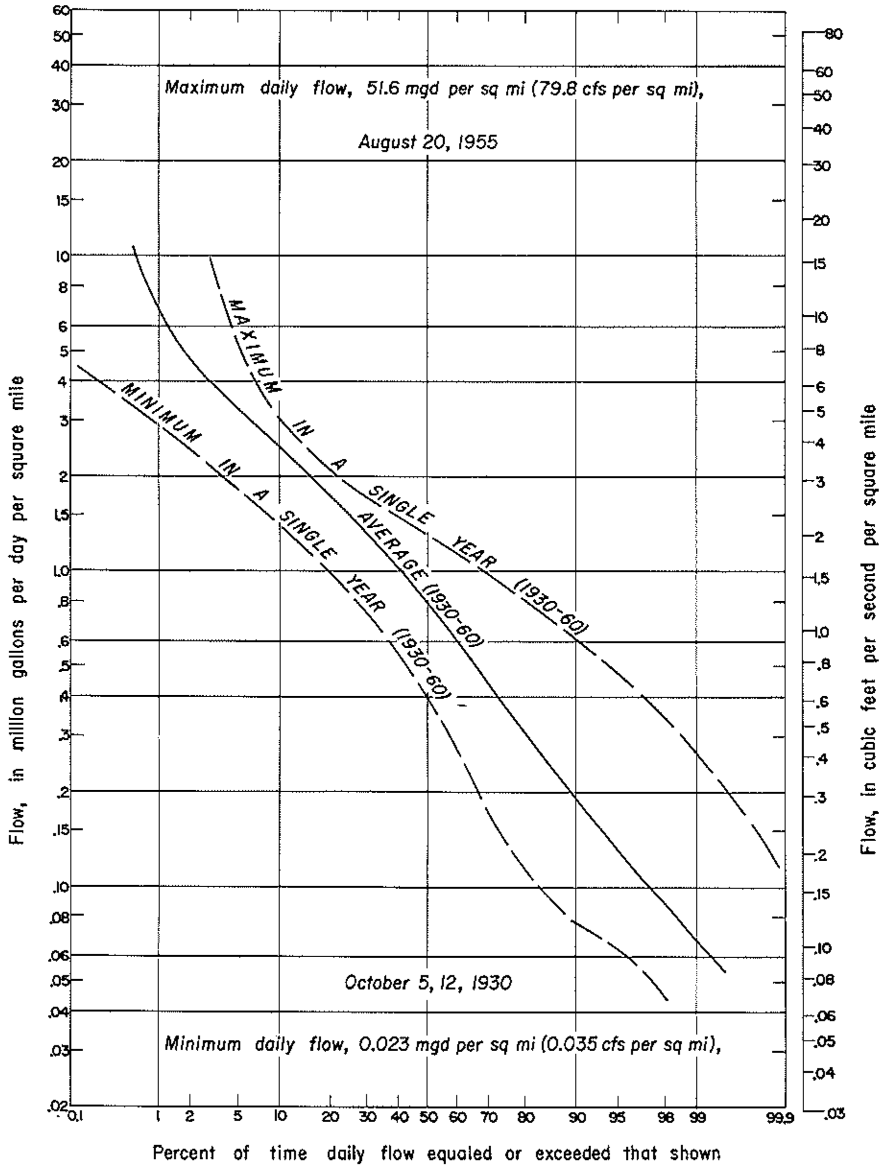


Figure 13.--Variation in flow of the Quinebaug River at Putnam.

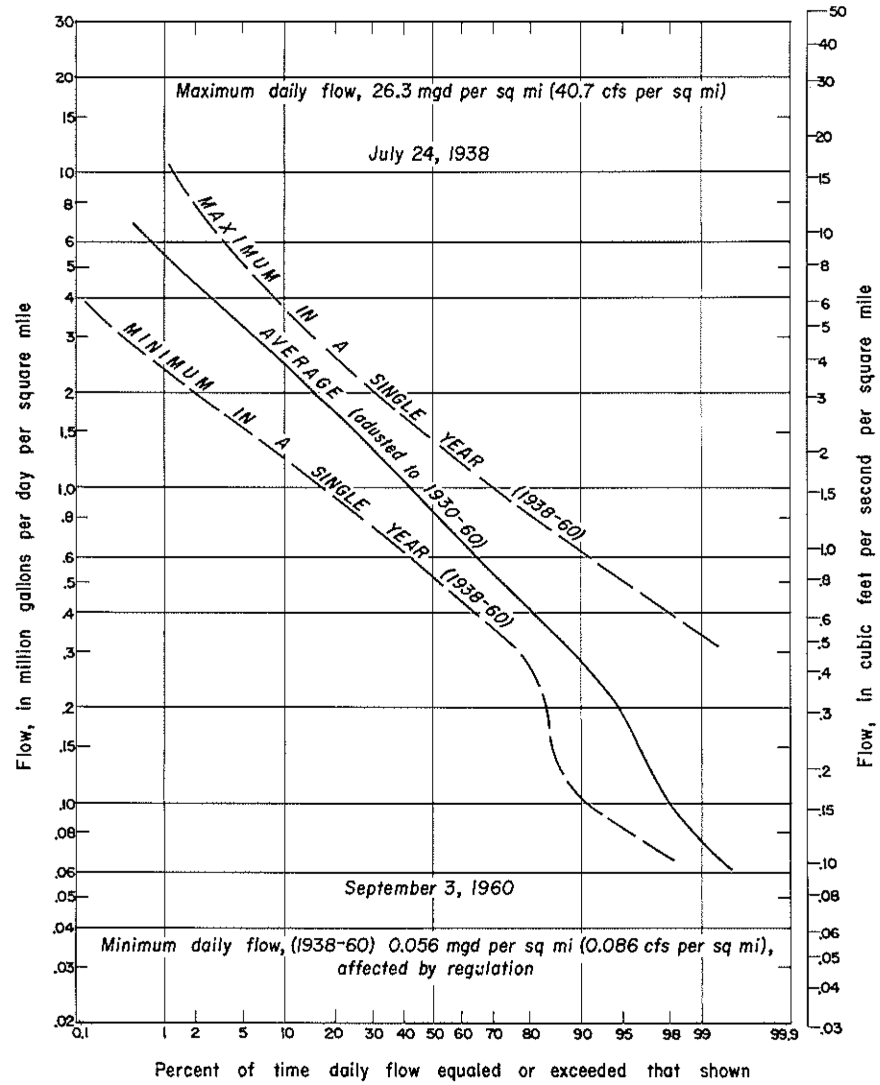


Figure 14.--Variation in flow of the Five Mile River at Killingly.

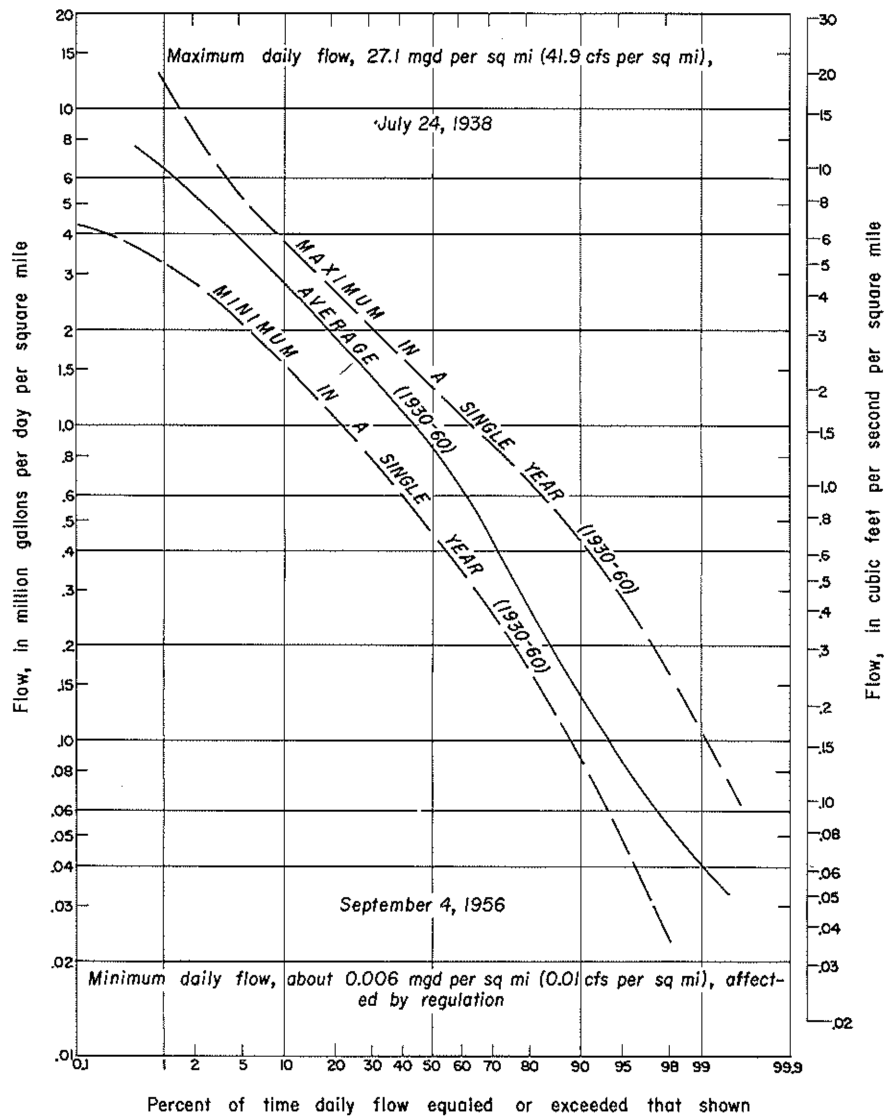


Figure 15.--Variation in flow of the Moosup River at Moosup.

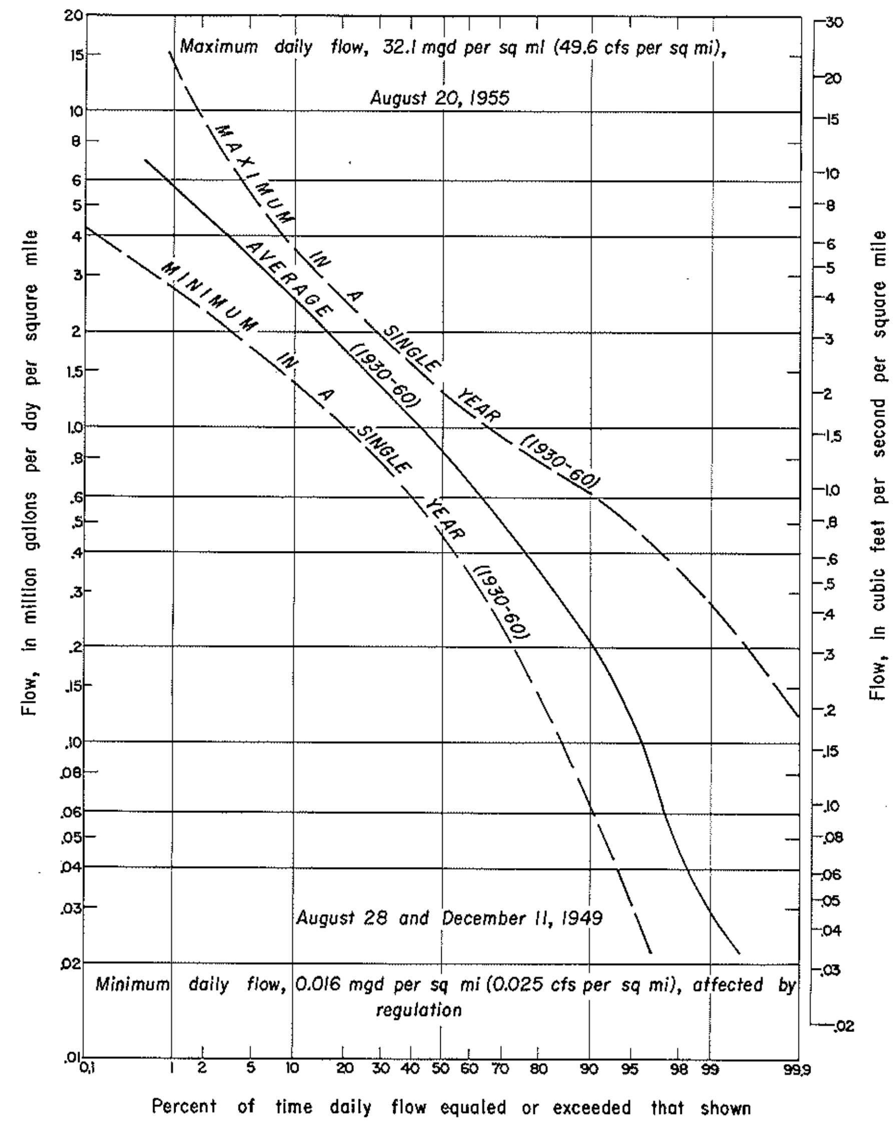


Figure 16.--Variation in flow of the Quinebaug River at Jewett City.

Information on streamflow is presented in the following order on succeeding pages: first, the continual variation in the rate of flow of streams is summarized by graphs, known as flow-duration curves, and by tables. Second, the frequency with which specified low flows recur is given by low-flow frequency graphs, and by tables. Third, maximum safe draft rates are given for existing lakes or reservoirs having usable storage, and the frequency with which various amounts of storage in a reservoir would be required to maintain selected rates of streamflow is indicated. Fourth, high streamflow is discussed, including historical accounts of major floods, since 1690. Tables indicating the magnitude and frequency of major floods and other periods of high streamflow at gaging stations and a method for estimating flood frequency at unmeasured sites are included.

VARIATION IN STREAMFLOW

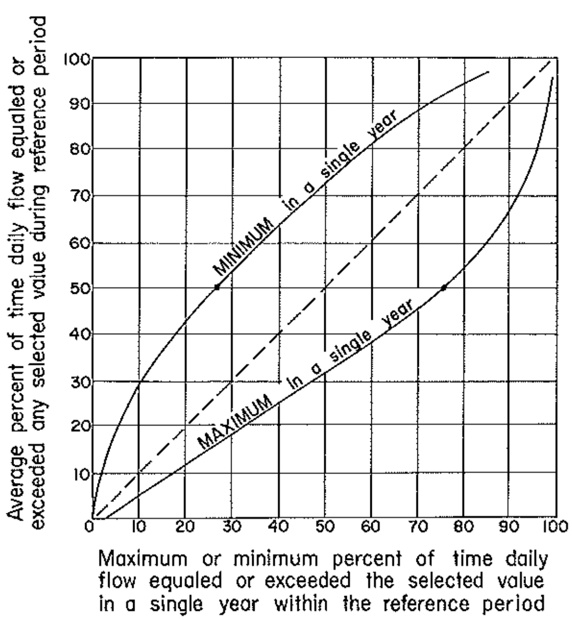
The variation in rate of flow of streams may be represented by graphs, known as flow-duration curves. Figure 10 includes the flow-duration curve and two photographs of Kitt Brook, one when the flow was at the rate equaled or exceeded 40 percent of the time and the other when it was at the rate equaled or exceeded 90 percent of the time.

The variation in flow of the Quinebaug River at Quinebaug is shown by a flow-duration curve in figure 11; supplemental curves included on the same graph show the limits within which this variation in flow has ranged in single years. These limits may be estimated for partial-record or unmeasured sites from the curves in figure 17.

Flow-duration curves for other long-term continuous-record gaging stations in the basin are presented in figures 12 to 16. Flow-duration data and average flow for all gaging stations in the Connecticut portion of the basin are summarized in table 5. Locations of these gaging stations appear on plate A. Streamflow data in table 5 are given as flow per square mile above the gaging station to facilitate comparison between streams: as explained beyond the data in table 5 may be used to estimate the average flow for selected consecutive=day periods of lowest flow in a year and the expected recurrence of that flow.

Areal variations in annual precipitation and in surficial geology cause significant variations in streamflow within the Quinebaug River basin. Annual precipitation is higher in the eastern part of the basin (Knox and Nordenson, 1955) and in the southern part (Gosslee and Brumbach, 1961, p.3) than in the central part. Streamflow reflects the variation in precipitation, for, as shown by isopleths on figure 18, streamflow is near or slightly below basin-wide average over a broad area through the center of the basin and notably above average near the southeastern border. The isopleths were drawn by determining the average streamflow at each gaging station in or near the basin, and plotting near the center of the areas drained the ratios of these average streamflows to the basin-wide average streamflow of 1.16 mgd per square mile (1.80 cfs per square mile).

While variations in precipitation cause variations in the amount of runoff, variations in geology cause variations in the timing of runoff. M. P. Thomas has discussed the variations in runoff caused by variations in geology for eastern and southern Connecticut (Thomas, M.P., in press) including the Quinebaug River basin.



These curves may be used to estimate the percents of time specific daily flows probably were equaled or exceeded during abnormally dry or abnormally wet years at partial-record stations or ungaged sites. For example, if a certain flow was equaled or exceeded 50 percent of the time on the average (as determined from table 5 or figure 19), then from these curves, during one dry year it is possible that the same flow was equaled or exceeded as little as 27 percent of the time (minimum in a single year), or during one wet year the same flow was equaled or exceeded as much as 77 percent of the time (maximum in a single year).

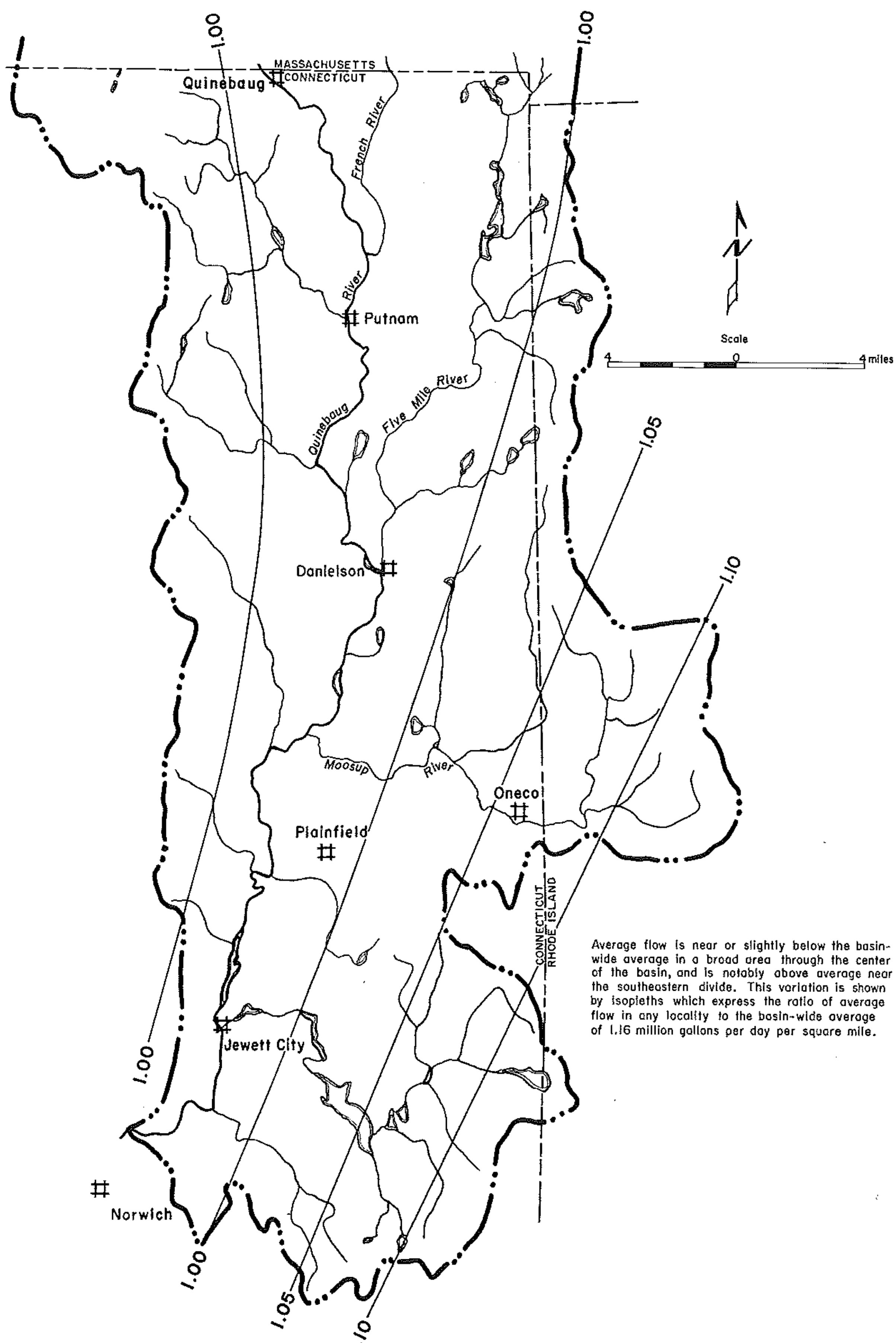
Figure 17.--Range in duration of streamflow, October 1930 to September 1960.

Table 5.--Duration of daily flow at gaging stations in the Quinebaug River basin.
(Data are adjusted to the reference period October 1930 to September 1960 on basis of long-term streamflow records)

Index number (Pl.A)	Stream and place of measurement (P indicates partial-record gaging station)	Drainage area (square miles)	Percent of drainage area covered by stratified drift	Average flow (million gallons per day per sq. mile)	Flow, in million gallons per day per square mile, which was equaled or exceeded for indicated percentage of time												
					1	5	10	20	30	40	50	60	70	80	90	95	99
1240	Quinebaug River at Quinebaug	157	-	1.13	5.8	3.2	2.4	1.65	1.25	1.05	0.80	0.61	0.45	0.31	0.19	0.12	0.05
1250	French River at Webster, Mass.	85.3	-	1.20	6.5	3.3	2.5	1.70	1.3	1.05	.85	.69	.56	.42	.26	.12	.05
1253	English Neighborhood Brook at North Woodstock P	4.99	1.8	1.18	8.7	3.9	2.8	1.8	1.3	.87	.62	.39	.19	.10	.04	.02	.01
1254	Muddy Brook at East Woodstock P	13.2	3.8	1.18	8.7	3.9	2.8	1.8	1.3	.90	.65	.41	.22	.11	.04	.01	.00
1254.4	Mill Brook at South Woodstock a/ P	5.56	0	1.16	7.7	3.7	2.6	1.8	1.3	.90	.65	.45	.26	.14	.06	.04	.02
1254.9	Little River at Harrisville b/ P	35.5	15.9	1.16	7.4	3.7	2.6	1.75	1.3	.94	.68	.50	.44	.28	.18	.15	.12
1255	Quinebaug River at Putnam	331	-	1.14	5.7	3.2	2.4	1.7	1.25	1.0	.79	.60	.44	.31	.19	.14	.07
1256	Mashamoquet Brook at Abington P	11.0	6.5	1.18	7.4	3.7	2.6	1.8	1.3	.97	.71	.51	.33	.20	.10	.07	.04
1256.5	Wappoquia Brook at Pomfret Landing P	4.28	4.6	1.17	8.4	3.9	2.8	1.8	1.3	.90	.63	.41	.22	.12	.05	.03	.01
1257	Mashamoquet Brook at Pomfret Landing P	28.6	6.6	1.17	8.1	3.8	2.7	1.8	1.3	.90	.65	.44	.25	.14	.06	.03	.01
1258	Five Mile River near East Thompson P	10.3	33.0	1.16	5.4	3.2	2.4	1.7	1.3	1.05	.84	.65	.51	.39	.26	.17	.04
1258.5	Five Mile River at Quaddick P	24.3	32.9	1.16	5.4	3.2	2.4	1.7	1.3	1.05	.84	.65	.51	.39	.26	.17	.05
1258.8	Mary Brown Brook at East Putnam P	8.42	22.1	1.16	7.8	3.7	2.7	1.75	1.3	.90	.65	.45	.29	.20	.13	.08	.03
1259	Cady Brook at East Putnam P	8.02	29.0	1.16	6.8	3.5	2.6	1.75	1.3	.97	.71	.54	.36	.24	.13	.09	.05
1259.5	Five Mile River near East Putnam P	47.8	30.4	1.16	6.3	3.6	2.5	1.75	1.3	1.0	.78	.58	.43	.30	.17	.11	.03
1260	Five Mile River at Killingly	58.2	29.0	1.16	5.5	3.2	2.4	1.7	1.3	1.05	.84	.64	.52	.41	.28	.19	.08
1260.4	Bog Meadow Reservoir outlet at East Killingly P	4.94	-	1.18	6.8	3.7	2.6	1.8	1.35	1.05	.87	.71	.58	.47	.36	.28	.20

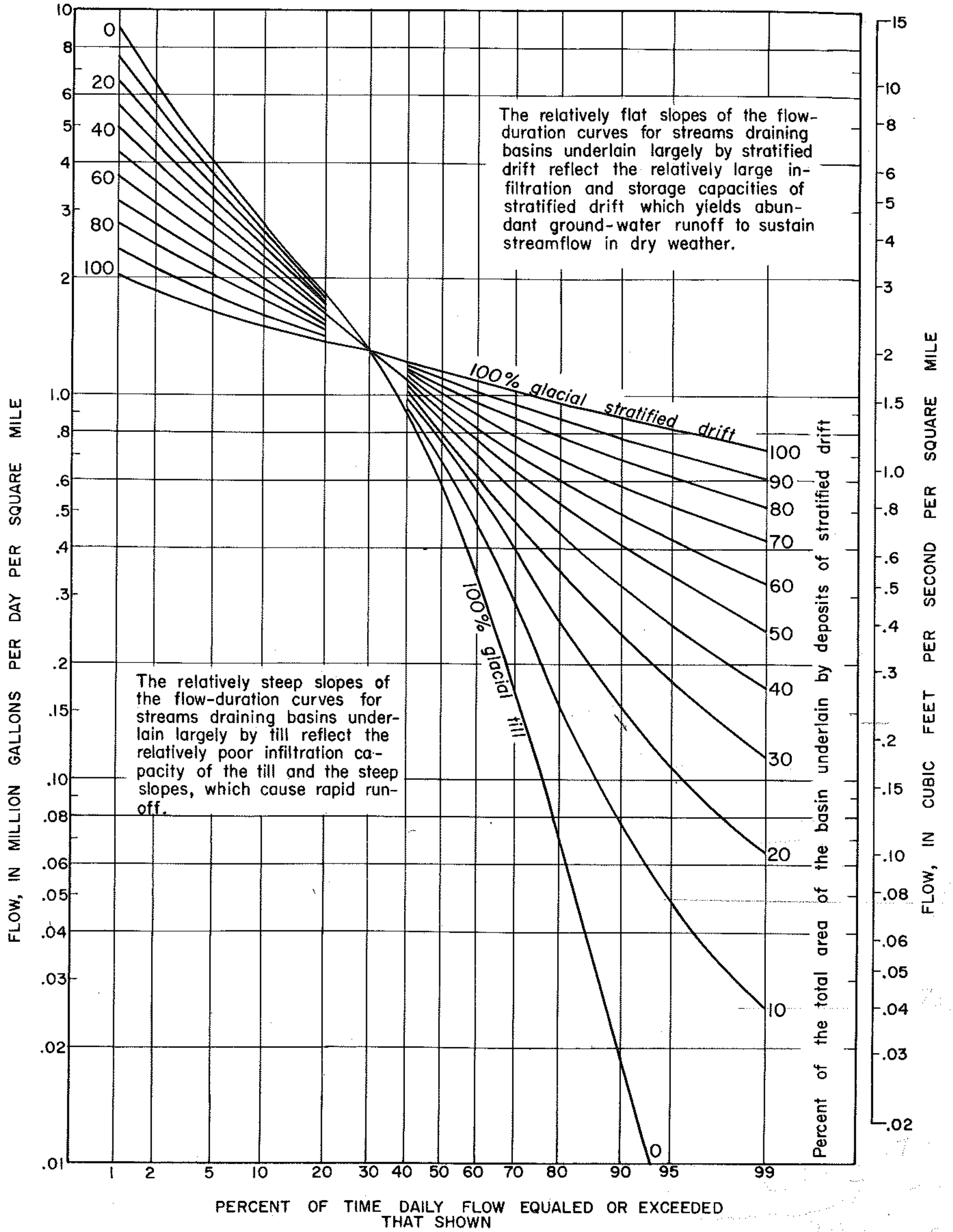
1261	Whetstone Brook at Elmville P	13.5	-	1.18	7.4	3.8	2.7	1.85	1.35	1.05	.81	.69	.55	.45	.37	.31	.23
1262.5	Moosup River at Sterling P	42.3	29.3	1.26	6.8	3.7	2.8	1.85	1.4	1.1	.84	.63	.45	.31	.19	.14	.08
1263	Quaduck Brook at North Sterling P	8.22	17.5	1.23	7.1	3.8	2.7	1.85	1.4	1.05	.78	.58	.41	.26	.14	.10	.06
1263.5	Quaduck Brook near Sterling P	18.8	18.6	1.24	7.1	3.8	2.7	1.85	1.4	1.05	.80	.59	.36	.17	.08	.05	.03
1264	Snake Meadow Brook near Almyville P	8.45	15.3	1.16	7.1	3.6	2.6	1.75	1.3	1.0	.71	.54	.36	.25	.16	.12	.06
1265	Moosup River at Moosup	83.5	24.4	1.23	6.5	3.8	2.7	1.85	1.4	1.05	.84	.65	.43	.26	.14	.08	.04
1266	Blackwell Brook near Brooklyn P	16.9	8.4	1.18	7.8	3.8	2.7	1.8	1.3	.94	.68	.47	.27	.16	.07	.05	.02
1266.5	Mill Brook at Packer P	17.1	32.4	1.16	7.4	3.7	2.6	1.75	1.3	.94	.68	.48	.36	.26	.19	.14	.09
1267	Kitt Brook near Canterbury P	11.1	22.8	1.15	8.1	3.7	2.6	1.75	1.3	.90	.65	.43	.24	.14	.07	.05	.03
1268	Cory Brook near Canterbury P	5.44	9.1	1.14	7.1	3.7	2.5	1.7	1.25	.97	.74	.54	.25	.10	.03	.02	.01
1269	Beach Pond outlet near Voluntown P	5.40	-	1.26	7.1	3.9	2.8	1.85	1.4	1.05	.82	.58	.34	.20	.11	.07	.04
1269.05	Great Meadow Brook near Voluntown P	5.14	17.5	1.23	6.8	3.7	2.6	1.8	1.35	1.05	.78	.59	.32	.11	.04	.02	.01
1269.1	Lowden Brook near Voluntown P	2.40	0	1.22	8.4	3.9	2.8	1.85	1.35	.97	.71	.48	.28	.16	.07	.04	.02
1269.2	Mount Misery Brook near Voluntown P	7.66	18.1	1.24	7.1	3.8	2.7	1.85	1.35	1.05	.81	.59	.41	.27	.15	.10	.06
1269.23	Denison Brook at Voluntown P	4.01	53.6	1.29	4.8	3.1	2.4	1.75	1.4	1.25	1.0	.84	.71	.58	.45	.37	.26
1269.25	Myron Kinney Brook near Voluntown P	4.25	30.1	1.25	7.1	3.8	2.7	1.95	1.4	1.05	.81	.60	.43	.29	.17	.12	.07
1269.3	Pachaug River at Glasgo P	37.0	31.0	1.28	6.0	3.5	2.6	1.85	1.4	1.15	.90	.71	.57	.43	.30	.23	.15
1269.4	Billings Brook at Glasgo P	5.69	44.3	1.26	5.0	3.2	2.5	1.75	1.4	1.15	.97	.81	.65	.52	.39	.32	.21
1269.5	Pachaug River at Pachaug P	50.4	37.7	1.28	6.0	3.5	2.6	1.85	1.4	1.15	.90	.71	.57	.43	.30	.23	.14
1269.8	Pachaug River at Hopeville P	58.6	38.0	1.28	6.0	3.5	2.6	1.85	1.4	1.2	.90	.71	.56	.40	.30	.23	.14
1270	Quinebaug River at Jewett City	711	-	1.16	5.4	3.3	2.5	1.7	1.3	1.05	.81	.65	.50	.36	.21	.13	.03
1271	Broad Brook near Preston P	12.7	21.8	1.21	6.8	3.6	2.6	1.8	1.35	1.05	.78	.58	.41	.27	.15	.10	.06

a/ Does not include area above or flow from Wappaquasset Pond.
b/ Flow has been adjusted to include an average of 1.4 million gallons per day (0.04 mgd per sq mi) diverted just upstream by city of Putnam.



Average flow is near or slightly below the basin-wide average in a broad area through the center of the basin, and is notably above average near the southeastern divide. This variation is shown by isopleths which express the ratio of average flow in any locality to the basin-wide average of 1.16 million gallons per day per square mile.

Figure 18.--Areal variation in average streamflow.



These regional flow-duration curves apply to unregulated streams having an average flow of 1.16 mgd per square mile (1.80 cfs per square mile).

Figure 19.--Variations in surficial geology cause variation in flow of streams.

His conclusions with respect to the variation of runoff with geology are summarized in the family of flow-duration curves shown in figure 19. These curves show that runoff from areas underlain largely by stratified drift is more evenly distributed throughout time than is runoff from areas underlain largely by till. These relationships reflect the poor infiltration capacity and resultant high proportion of direct runoff from till and the greater infiltration capacity and relatively high proportion of ground-water runoff from stratified drift. The stratified drift absorbs a relatively large proportion of the precipitation and stores it for sustained release during periods of dry weather.

The curves shown in figure 19 may be used to estimate flow duration at any unmeasured site in the basin, provided the percent of stratified drift above the unmeasured site is accurately determined from plate B and the runoff is adjusted by use of the isopleths on figure 18 to account for variations in precipitation on the streamflow.

FREQUENCY AND DURATION OF LOW FLOWS

Although flow-duration curves such as those shown in figures 10-16 and figure 19 indicate the minimum amounts of streamflow available for specified percentages of time, the water manager also needs to know how often specified low streamflows are expected to recur and for what periods of time they are expected to last. Recurrence intervals of annual lowest mean flows, averaged over periods as long as 365 consecutive days, at long-term continuous-record gaging stations in the Quinebaug River basin are given in table 6, and similar data for periods up to 30 years are given in table 7. Low-flow frequency data also may be presented in graphs as illustrated in figure 20 for the stream-gaging station on the Quinebaug River at Quinebaug. The average flow for a selected consecutive-day period of lowest flow in a year and the expected recurrence interval of that flow for all gaging stations in table 5 other than long-term continuous-record stations can be estimated by using tables 5 and 8. The same can be estimated for unmeasured sites on unregulated streams by using table 11 and figures 18 and 19. (See example on table 8.)

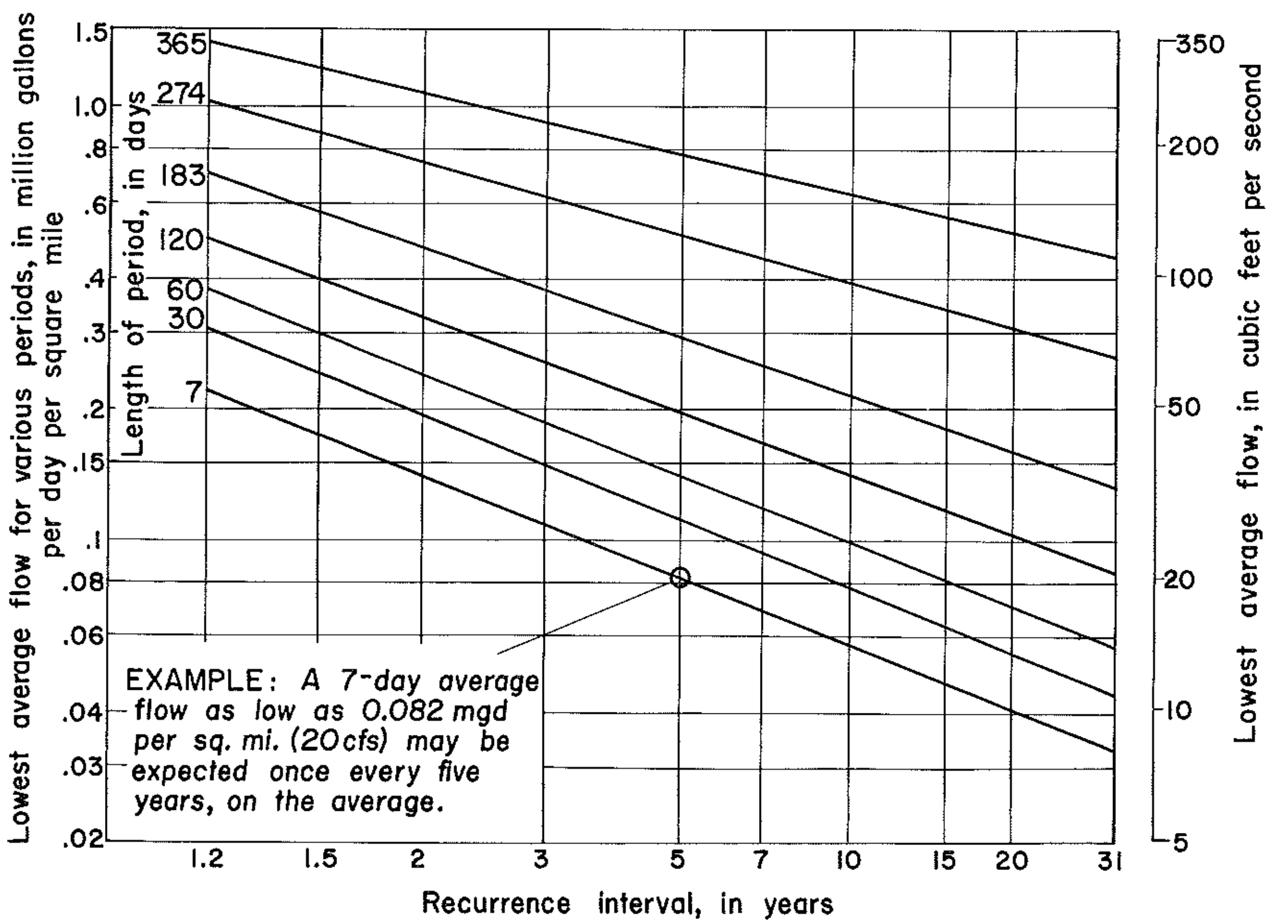


Figure 20.--Recurrence intervals of specified low flows of the Quinebaug River at Quinebaug.

Table 6.--Recurrence intervals of annual lowest mean flows at long-term stream-gaging stations in the Quinebaug River basin.
(Flows are adjusted to the reference period April 1930 to March 1960 except for French River at Webster which is based on period of record April 1949 to March 1960)

Index number (Pl. A)	Stream and place of measurement	Drainage area (square miles)	Period (consecutive days)	Annual lowest mean flow, in cubic feet per second, for indicated period of consecutive days and indicated recurrence interval, in years							Annual lowest mean flow, in million gallons per day per square mile, for indicated period of consecutive days and indicated recurrence interval, in years						
				1.2	2	3	5	10	20	31	1.2	2	3	5	10	20	31
1240	Quinebaug River at Quinebaug	157	3	36	23	18	13	9.2	6.6	5.4	-	-	-	-	-	-	-
			7	53	34	26	20	14	9.8	8.1	0.218	0.140	0.107	0.082	0.058	0.040	0.033
			30	74	46	36	27	19	13	11	.305	.189	.148	.111	.078	.054	.045
			60	91	59	45	34	24	17	14	.375	.243	.185	.140	.099	.070	.058
			120	120	80	63	49	35	25	21	.494	.329	.259	.202	.144	.103	.086
			183	170	115	91	72	52	39	33	.700	.473	.375	.296	.214	.161	.136
			274	250	180	150	125	96	75	65	1.029	.741	.618	.515	.395	.309	.268
			365	320	250	220	190	150	125	110	1.318	1.030	.906	.783	.618	.515	.453
1250	French River at Webster, Mass.	85.3	3	19	12	10	7.4	5.2	3.8	3.1	-	-	-	-	-	-	-
			7	41	28	22	17	13	9.5	8.0	.311	.212	.167	.129	.098	.072	.061
			30	55	38	30	23	17	12	10	.417	.288	.227	.174	.129	.091	.076
			60	69	47	37	29	21	16	13	.523	.356	.280	.220	.159	.121	.098
			120	82	56	45	35	25	19	16	.621	.424	.341	.265	.189	.144	.121
			183	110	74	59	46	34	25	21	.833	.561	.447	.349	.258	.189	.159
			274	170	115	91	71	52	39	33	1.288	.871	.690	.538	.394	.296	.250
			365	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1255	Quinebaug River at Putnam	331	3	87	61	50	40	31	24	20	-	-	-	-	-	-	-
			7	120	84	69	56	43	33	29	.234	.164	.135	.109	.084	.064	.057
			30	150	110	90	74	56	44	38	.293	.215	.176	.144	.109	.086	.074
			60	180	130	110	90	70	54	47	.351	.254	.215	.176	.137	.105	.092
			120	250	180	150	120	95	74	64	.488	.351	.293	.234	.185	.144	.125
			183	340	240	200	160	130	100	85	.664	.468	.390	.312	.254	.195	.166
			274	520	380	320	260	200	150	130	1.015	.742	.625	.508	.390	.293	.254
			365	700	540	460	380	300	240	210	1.367	1.054	.898	.741	.585	.468	.410
1260	Five Mile River at Killingly	58.2	3	19	15	13	11	9.0	7.4	6.7	-	-	-	-	-	-	-
			7	29	22	19	16	14	11	10	.322	.245	.211	.178	.155	.122	.111
			30	36	28	24	21	17	14	13	.400	.311	.266	.233	.189	.155	.144
			60	41	32	28	24	20	17	15	.455	.355	.311	.266	.222	.189	.166
			120	51	40	35	30	24	20	18	.566	.444	.388	.333	.266	.222	.200
			183	63	49	42	36	30	25	22	.699	.544	.466	.400	.333	.278	.244
			274	90	70	61	52	42	35	31	.999	.777	.677	.577	.466	.388	.344
			365	120	96	85	74	61	51	45	1.332	1.066	.944	.821	.677	.566	.500
1265	Moosup River at Moosup	83.5	3	13	7.8	6.2	5.0	3.9	3.2	2.9	-	-	-	-	-	-	-
			7	23	13	11	8.9	7.0	5.6	4.9	.178	.101	.085	.069	.054	.043	.038
			30	31	19	16	13	9.7	7.5	6.5	.240	.147	.124	.101	.075	.058	.050
			60	41	24	20	16	12	9.5	8.0	.317	.186	.155	.124	.093	.074	.062
			120	66	38	30	24	18	13	11	.511	.294	.232	.186	.139	.101	.085
			183	92	58	48	40	31	25	22	.712	.449	.372	.310	.240	.194	.170
			274	155	105	90	74	60	50	44	1.200	.813	.697	.573	.464	.387	.341
			365	195	150	130	110	91	76	70	1.509	1.161	1.006	.851	.704	.588	.542
1270	Quinebaug River at Jewett City	711	3	160	93	67	46	36	32	30	-	-	-	-	-	-	-
			7	280	200	170	140	110	87	76	.255	.182	.154	.127	.100	.079	.069
			30	330	250	200	170	130	100	90	.300	.226	.182	.155	.118	.091	.082
			60	400	300	250	200	160	120	110	.364	.273	.227	.182	.145	.109	.100
			120	570	410	350	290	220	170	150	.518	.373	.318	.264	.200	.155	.136
			183	770	550	460	380	290	230	200	.700	.500	.418	.345	.264	.209	.182
			274	1,160	870	730	610	480	390	340	1.054	.790	.664	.554	.436	.355	.309
			365	1,460	1,160	1,020	860	700	580	520	1.327	1.054	.927	.782	.636	.527	.473

Table 7.--Lowest mean flows for periods of 1 year or more at long-term stream-gaging stations in the Quinebaug River basin.
(Flows are adjusted to the reference period April 1930 to March 1960)

Index number (Pl. A)	Stream and place of measurement	Lowest mean flow, in cubic feet per second, for indicated period of consecutive months 12	18	24	36	60	120	180	360
1240	Quinebaug River at Quinebaug	110	160	183	200	215	230	248	278
1255	Quinebaug River at Putnam	210	350	390	410	440	470	530	585
1260	Five Mile River at Killingly	45	68	74	80	85	93	104	107
1265	Moosup River at Moosup	70	105	111	118	129	134	146	164
1270	Quinebaug River at Jewett City	520	750	830	900	970	1,050	1,100	1,280

Table 8.--Average duration of lowest mean flows for streams in the Quinebaug River basin.

Example shows that for any partial-record gaging station or unmeasured site on an unregulated stream the 30-consecutive-day low flow that could be expected to recur on the average every 2 years is equivalent to the flow equaled or exceeded 90 percent of the time.

Period of low flow: Consecutive days	Period of low flow: Consecutive months	Average percent of time during the reference period April 1930 to March 1960 in which streamflow equaled or exceeded the lowest mean flow for indicated recurrence interval in years a/: 1.03	1.2	2	3	5	10	20	31
3	--	73	94	97	98	98	99	--	--
7	--	66	89	94	96	97	98	98	99
30	1	55	83	90	93	95	96	97	98
60	2	42	78	85	89	92	95	96	97
120	4	30	67	77	82	86	90	94	95
183	6	22	56	68	73	78	84	88	91
274	9	17	39	51	57	63	71	77	81
365	12	15	29	39	44	51	58	64	68
--	18	--	--	--	--	--	--	--	53
--	24	--	--	--	--	--	--	--	50
--	36	--	--	--	--	--	--	--	47
--	60	--	--	--	--	--	--	--	44
--	120	--	--	--	--	--	--	--	42
--	180	--	--	--	--	--	--	--	39
--	360	--	--	--	--	--	--	--	35

a/ For periods of 12 months or less, the lowest mean flow is the annual lowest mean flow, and values for recurrence interval of 1.03 years represent the wettest year of the reference period, for 2 years, the median year, and for 31 years, the driest year. These percentages are based on long-term records from ten continuous-record gaging stations in and near the basin.

Table 9.--Indices of low-flow frequency at stream-gaging stations in the Quinebaug River basin. (Indices are medians of the annual lowest mean flow for periods of 7 and 30 consecutive days, adjusted to the reference period April 1930 to March 1960 on basis of long-term streamflow records)

Index number (Pl.A)	Stream and place of measurement	Drainage area (square miles)	Annual lowest mean flow having a recurrence interval of 2 years for number of consecutive days indicated (cubic feet per second)		(million gallons per day per square mile)	
			7 days	30 days	7 days	30 days
1240	Quinebaug River at Quinebaug	157	34	46	0.14	0.19
1250	French River at Webster, Mass.	85.3	28	38	.21	.29
1253	English Neighborhood Brook at North Woodstock	4.99	.2	.3	.03	.04
1254	Muddy Brook at East Woodstock	13.2	.4	.7	.02	.04
1254.4	Mill Brook at South Woodstock a/	5.56	.2	.5	.02	.06
1254.9	Little River at Harrisville b/	35.5	8.5	10	.15	.18
1255	Quinebaug River at Putnam	331	84	110	.16	.21
1256	Mashamoquet Brook at Abington	11.0	1.3	1.8	.08	.10
1256.5	Wappoquia Brook near Pomfret Landing	4.28	.2	.3	.03	.05
1257	Mashamoquet Brook at Pomfret Landing	28.6	1.6	2.6	.04	.06
1258	Five Mile River near East Thompson	10.3	3.1	4.2	.20	.26
1258.5	Five Mile River at Quaddick	24.3	7.5	10	.20	.26
1258.8	Mary Brown Brook at East Putnam	8.42	1.3	1.7	.10	.13
1259	Cady Brook at East Putnam	8.02	1.3	1.6	.11	.13
1259.5	Five Mile River near East Putnam	47.8	9.3	13	.13	.17
1260	Five Mile River at Killingly	58.2	22	28	.25	.31
1260.4	Bog Meadow Reservoir outlet at East Killingly	4.94	2.3	2.7	.30	.35
1261	Whetstone Brook at Elmville	13.5	6.8	7.7	.33	.37
1262.5	Moosup River at Sterling	42.3	9.9	12	.15	.19
1263	Quaduck Brook at North Sterling	8.22	1.4	1.8	.11	.14
1263.5	Quaduck Brook near Sterling	18.8	1.7	2.2	.06	.08
1264	Snake Meadow Brook near Almyville	8.45	1.8	2.1	.14	.16
1265	Moosup River at Moosup	83.5	13	19	.10	.15
1266	Blackwell Brook near Brooklyn	16.9	1.4	1.9	.05	.07
1266.5	Mill Brook at Packer	17.1	.4	.5	.15	.19
1267	Kitt Brook near Canterbury	11.1	.9	1.2	.05	.07
1268	Cory Brook near Canterbury	5.44	.2	.3	.02	.03
1269	Beach Pond outlet near Voluntown	5.40	.6	.9	.07	.11
1269.05	Great Meadow Brook near Voluntown	5.14	.2	.3	.03	.04
1269.1	Lowden Brook near Voluntown	2.40	.2	.3	.05	.07
1269.2	Mount Misery Brook near Voluntown	7.66	1.4	1.8	.12	.15
1269.23	Denison Brook at Voluntown	4.01	2.5	2.8	.40	.45
1269.25	Myron Kinney Brook near Voluntown	4.25	.9	1.1	.14	.17
1269.3	Pachaug River at Glasgo	37.0	14	17	.24	.30
1269.4	Billings Brook at Glasgo	5.69	3.1	3.4	.35	.39
1269.5	Pachaug River at Pachaug	50.4	19	23	.24	.30
1269.8	Pachaug River at Hopeville	58.6	19	23	.24	.30
1270	Quinebaug River at Jewett City	711	200	250	.18	.23
1271	Broad Brook near Preston	12.7	.2	.3	.10	.15

a/ Does not include area above or flow from Wappaquasset Pond.

b/ Flow has been adjusted to include an average of 1.4 million gallons per day (0.04 mgd per square mile) diverted just upstream by city of Putnam.

The curves shown in figure 19 may be used to estimate flow duration at any unmeasured site in the basin, provided the percent of stratified drift above the unmeasured site is accurately determined from plate B and the runoff is adjusted by use of the isopleths on figure 18 to account for variations in precipitation on the streamflow.

Perhaps the most widely used low-flow values are the 7-day and 30-day average flows with a 2-year recurrence interval. Streamflow will diminish below these values in 1 year out of 2, on the average. Accordingly, these two values are termed "indices of low-flow frequency" and are presented in table 9 for all gaging stations in the basin.

The lowest flows of record (1918-63) of the Quinebaug River at Jewett City for periods of 7 to 120 days occurred during the climatic year April 1, 1957 to March 31, 1958. Records at the other long-term gaging stations do not go back to 1918, but unless the pattern of regulation was quite different in the early years, it is likely that the lowest flows at all gaging stations since 1918 also occurred in climatic year 1957. For each of these gaging stations, the lowest daily flows not exceeded for specified periods during the 1957 climatic year are given in table 10. Data for the French River at Webster and the Five Mile River at Killingly are not shown on a per-square-mile basis; daily flows of these streams are greatly influenced by regulation at low stages and hence the data apply only at the gaging stations. Unit flow figures are given for gaging stations on the Quinebaug and Moosup Rivers, however, and can probably be applied to other locations on these streams. For the Quinebaug River, differences between the figures for successive gaging stations should be distributed proportionately.

Table 10.--Lowest daily flow not exceeded during various numbers of consecutive days in the summer of 1957 at long-term stream-gaging stations in the Quinebaug River basin. Flows during the summer of 1957 were the lowest during the period August 1918 to September 1963.

Index number (Pl.A)	Stream and place of measurement	Drainage area (square miles)	Lowest daily flow, in cubic feet per second, not exceeded during indicated number of consecutive days					Lowest daily flow, in million gallons per day per square mile, not exceeded during indicated number of consecutive days				
			7	15	30	60	120	7	15	30	60	120
1240	Quinebaug River at Quinebaug	157	11	15	17	23	43	0.045	0.062	0.070	0.095	0.177
1250	French River at Webster, Mass.	85.3	25	28	36	55	70	--	--	--	--	--
1255	Quinebaug River at Putnam	331	36	36	43	46	77	.070	.070	.084	.090	.150
1260	Five Mile River at Killingly	58.2	22 a/	27	31	37	44	--	--	--	--	--
1265	Moosup River at Moosup	83.5	7.8 b/	8.7	11	13	26	.060 b/	.067	.085	.101	.201
1270	Quinebaug River at Jewett City	711	99	118	133	177	256	.090	.107	.121	.161	.233

a/ A lower flow of 21 cfs occurred in 1943.

b/ A lower flow of 7.2 cfs (0.056 mgd per sq mi) occurred in 1953.

Table 11.--Lakes, ponds, and reservoirs in the Quinebaug River basin.
(Most of the data from the State Board of Fisheries and Game)

Index number (Pl.A)	Name and location	Natural (N) or Artificial (A)	Drainage area (square miles)	Area of water surface (acres)	Surface elevation (feet)	Maximum depth (feet)	Average depth (feet)	Total storage (million gallons)	Usable storage (million gallons)	Maximum amount of storage used during 1963 (million gallons)	Present use
1231.8	Mashapaug Lake at Mashapaug d/	NA	4.80	297	706	43	18	1,770	1,300	--	Industrial and Recreation
1234.8	Breakneck Pond near Union	N	1.65	105	679	14	5.0	171	None	--	Not used
1254.29	Wappaquasset Pond near South Woodstock	A	.97	100	572	11	5.8	194	159	159 a/	Recreation
1254.5	Roseland Lake at South Woodstock	N	30.2	88.0	286	20	10	296	None	--	Recreation
1257.29	Alexander Lake near Rogers	N	1.06	190	251	53	24	151	None	--	Recreation
1257.4	Danielson Mill Pond at Danielson	A	384	77.4	190	11	3.4	86.8	86.8	--	Not used
1257.5	Little Pond near East Thompson	N	.84	65.4	478	14	7.8	165	None	--	Recreation
1257.6	Long Pond near East Thompson	NA	.25	20.8	478	19	9.3	63.3	None	--	Not used
1258.49	Quaddick Reservoir at Quaddick	NA	24.0	467	403	22	6.4	1,010	957	340 b/	Recreation
1260.19	Killingly Pond at East Killingly	NA	1.31	137	587	20	16	518	490	88.3	Industrial
1260.3	Alvia Chase Reservoir at East Killingly	A	1.44	52.4	565	8	3.1	53.3	51.8	44.6	Industrial
1260.35	Middle Reservoir at East Killingly	A	4.55	116	563	5	3.1	116	116	29.9	Industrial
1261.1	Five Mile Pond at Danielson	A	77.6	43.0	210	13	2.4	58.8	57.1	--	Not used
1261.2	Quinebaug Pond near Danielson	N	1.26	70.6	197	31	16	368	None	--	Recreation
1264.49	Moosup Pond near Almyville	NA	1.06	97.2	280	26	9.3	295	None	--	Recreation
1266.49	Packer Pond at Packer	A	17.0	35.3	142	7	2.9	33.7	33.7	--	Not used
1268.9	Aspinook Pond at Jewett City	A	648	333	97	27	8.7	942	800	--	Not used
1268.99	Beach Pond near Voluntown	NA	4.70	394	296	65	20	2,633	1,290	59.8 c/	Recreation
1269.24	Beachdale Pond at Voluntown	A	30.7	45.9	266	10	2.8	42.2	35.9	--	Recreation
1269.29	Glasgo Pond at Glasgo e/	A	37.0	184	183	26	6.6	395	350	--	Recreation
1269.35	Billings Lake near Glasgo	NA	.66	105	353	33	14	469	205	--	Recreation
1269.37	WaWog Pond near Glasgo	A	1.44	54.3	292	7	4.0	70.7	None	--	Recreation
1269.49	Pachaug Pond at Pachaug	A	50.1	831	161	18	6.1	1,640	1,640	875 a/	Recreation
1269.79	Hopeville Pond at Hopeville	A	58.6	149	145	16	4.6	225	225	--	Recreation
1269.9	Ashland Pond at Jewett City	A	59.1	102	127	17	6.1	200	None	--	Not used

a/ Pond was drained; water was not used.
b/ Includes 142 million gallons over-crest storage behind 1.0 ft of stop planks.
c/ Over-crest storage behind 0.6 ft of stop planks.
d/ Located west of the area shown on Pl. A.
e/ Includes Doaneville Pond.

Table 12.--Maximum safe draft rates (regulated flows) from selected ponds and reservoirs or combinations thereof in the Quinebaug River basin for the reference period April 1930 to March 1960. (Ponds and reservoirs will refill within a year)

Index number (Pl.A)	Stream	Pond or reservoir, or combination thereof, and location	Drainage area (square miles)	Total usable storage (million gallons)	Maximum safe draft rates (regulated flows)					
					Driest year		Median year		Wettest year	
					(cubic feet per second)	(million gallons per day)	(cubic feet per second)	(million gallons per day)	(cubic feet per second)	(million gallons per day)
1231.8	Quinebaug River	Mashepaug Lake at Mashepaug	4.80 a/	1,300 a/	2.2 a/	1.4 a/	7.6 a/	4.9 a/	17 a/	11 a/
1254.29	Mill Brook	Wappaquasset Pond near South Woodstock	0.97	159	0.36	0.23	1.5	0.97	3.2	2.1
1257.4	Quinebaug River	Danielson Mill Pond at Danielson	384	86.8	45	29	120	78	340	220
1258.49	Five Mile River	Quaddick Reservoir at Quaddick	24.0	957	16	10	27	17	63	41
1260.19	Whetstone Brook	Killingly Pond at East Killingly	1.31	490	-	-	-	-	-	-
1260.3	" "	Alvia Chase Reservoir at East Killingly	1.44	51.8	-	-	-	-	-	-
1260.35	" "	Middle Reservoir at East Killingly	4.55	116	2.5	1.6	4.7	3.0	12	7.8
-	" "	Middle and Alvia Chase Reservoirs	-	168	3.7	2.4	5.4	3.5	13	8.4
-	" "	Middle and Alvia Chase Reservoirs and Killingly Pond	-	658	4.0 a/	2.6 a/	7.7 a/	5.0 a/	15 a/	9.7 a/
1261.1	Five Mile River	Five Mile Pond at Danielson	77.6	57.1	21	14	40	26	96	62
1266.49	Mill Brook	Packer Pond at Packer	17.1	33.7	4.0	2.6	6.4	4.1	18	12
1268.9	Quinebaug River	Aspinook Pond at Jewett City	648	800	130	84	260	170	720	460
1268.99	Pachaug River	Beach Pond near Voluntown	4.70	1,290	2.6 a/	1.7 a/	8.0 a/	5.2 a/	16 a/	10 a/
1269.24	" "	Beachdale Pond at Voluntown	30.7	35.9	-	-	-	-	-	-
1269.29	" "	Glasgo Pond at Glasgo	37.0	350	17	11	29	19	67	43
-	" "	Glasgo and Beach Ponds	-	1,640	29	19	47	30	100	65
1269.35	" "	Billings Lake near Glasgo	.66	205	-	-	-	-	-	-
1269.49	" "	Pachaug Pond at Pachaug	50.1	1,640	36	23	57	37	130	84
-	" "	Pachaug and Glasgo Ponds	-	1,990	38	25	61	39	140	90
-	" "	Pachaug, Glasgo and Beach Ponds	-	3,280	45 a/	29 a/	76	49	160	100
1269.79	" "	Hopeville Pond at Hopeville	58.6	225	22	14	38	25	82	53
-	" "	Hopeville and Pachaug Ponds	-	1,865	42	27	63	41	150	97
-	" "	Hopeville, Pachaug and Glasgo Ponds	-	2,215	43	28	67	43	160	100
-	" "	Hopeville, Pachaug, Glasgo and Beach Ponds	-	3,505	53 a/	34 a/	81	52	180	120

a/ If ponds and reservoirs are to refill within a year, total storage will not be used.

Table 13.--Storage required at long-term gaging stations in the Quinebaug River basin. (Data are adjusted to the reference period April 1930 to March 1960. Storage required would refill during a year except for figures underlined which would require more than a year to refill. Storage is uncorrected for reservoir seepage, evaporation, and for bias in computation procedure, all of which would increase somewhat the amount of storage required)

Index number (Pl.A)	Stream and place of measurement	Drainage area (square miles)	Recurrence interval of annual lowest mean flow (years) a/	Maximum amount of storage which would refill during the year of annual lowest mean flow, in million gallons per square mile	Storage required, in million gallons per square mile, to maintain indicated regulated flow, in million gallons per day per square mile																
					0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.65	0.70	0.75	0.80	0.90	1.00
1240	Quinebaug River at Quinebaug	157	1.2	-	-	-	-	-	-	1	2	4	7	10	14	18	23	29	35	49	63
			2	-	-	-	-	1	3	6	10	15	21	27	33	40	47	55	63	79	96
			5	87	-	1	3	7	12	17	24	31	39	47	56	65	74	83	93	116	140
			10	76	-	3	7	12	19	26	34	43	53	63	73	84	94	106	117	142	167
			31	61	2	7	14	22	31	40	50	61	72	84	97	110	123	132	146	174	204
1255	Quinebaug River at Putnam	331	1.2	-	-	-	-	-	-	2	3	5	8	12	16	20	25	30	36	50	65
			2	-	-	-	-	1	2	5	8	12	16	22	29	36	43	51	60	77	96
			5	77	-	-	1	4	8	12	19	26	34	42	51	60	69	79	91	115	140
			10	63	-	1	4	7	13	21	29	37	46	56	67	78	90	103	116	142	170
			31	49	1	3	9	16	25	36	47	59	72	84	97	109	122	136	150	177	208
1260	Five Mile River at Killingly	58.2	1.2	-	-	-	-	-	-	-	-	1	3	5	8	12	16	21	26	40	56
			2	-	-	-	-	-	-	2	3	5	8	12	18	24	32	40	48	65	83
			5	77	-	-	-	-	2	5	8	13	20	28	36	45	54	64	74	94	117
			10	64	-	-	-	2	4	9	17	24	32	40	49	59	69	80	93	118	145
			31	49	-	-	1	4	12	20	29	38	49	61	73	85	98	112	125	153	181
1265	Moosup River at Moosup	83.5	1.2	-	-	-	-	-	2	3	5	8	10	13	17	21	25	30	35	46	59
			2	-	-	-	-	3	6	10	14	19	24	30	36	42	50	58	66	83	100
			5	98	-	1	4	8	13	19	25	32	40	47	55	63	71	81	90	111	131
			10	84	-	3	8	13	20	26	33	41	49	57	66	75	84	94	104	127	152
			31	67	2	7	13	20	27	34	43	51	60	70	81	92	103	116	129	154	182
1270	Quinebaug River at Jewett City	711	1.2	-	-	-	-	-	-	1	3	5	8	12	16	20	24	29	34	46	58
			2	-	-	-	-	1	2	5	8	11	15	21	27	34	42	50	58	74	91
			5	79	-	-	1	4	8	12	17	23	30	38	47	56	65	74	83	104	128
			10	68	-	1	3	7	12	18	26	34	42	51	61	71	81	92	104	128	155
			31	56	1	3	8	15	22	31	41	52	63	74	86	97	110	122	136	162	190

a/ Values for recurrence interval of 2 years represent the median year of the reference period, and for 31 years, the driest year of this period.

Table 14.--Storage required for unmeasured sites on unregulated streams in the Quinebaug River basin. (Data are adjusted to the reference period April 1930 to March 1960 and to an average flow of 1.16 million gallons per day per square mile. Storage required would refill during a year except for figures underlined which would require more than a year to refill. Storage is uncorrected for reservoir seepage, evaporation, and for bias in computation procedure, all of which increase somewhat the amount of storage required)

Percent of area covered by stratified drift	Recurrence interval of annual lowest mean flow (years) a/	Maximum amount of storage which would refill during the year of annual lowest mean flow, in million gallons per square mile	Storage required, in million gallons per square mile, to maintain indicated regulated flow, in million gallons per day per square mile																
			0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.65	0.70	0.75	0.80	0.90	1.00
0	1.2	-	1	3	6	9	12	17	23	29	35	41	48	55	62	69	76	92	108
	2	137	3	7	13	19	26	33	41	49	57	66	75	84	93	102	112	132	152
	5	92	7	14	22	31	40	49	59	69	79	90	101	112	124	137	150	177	205
	10	66	11	20	30	41	52	64	76	88	101	114	127	140	153	167	181	209	239
	31	34	15	27	40	53	67	81	95	110	125	141	157	173	190	208	227	265	-
10	1.2	-	-	-	2	4	7	10	14	18	22	27	32	37	43	49	55	69	85
	2	118	-	2	5	9	15	21	28	35	42	49	57	65	73	81	90	108	126
	5	94	2	6	12	19	27	35	44	53	62	72	83	94	105	116	128	152	176
	10	70	5	11	18	26	35	44	53	64	75	86	98	111	124	137	150	178	207
	31	49	6	15	25	37	49	62	75	88	102	116	130	144	159	174	190	222	255
20	1.2	-	-	-	-	-	2	4	6	9	12	16	20	25	36	36	43	57	71
	2	-	-	-	-	2	5	9	14	19	25	32	39	46	54	62	70	87	105
	5	86	-	-	3	7	13	19	26	34	42	51	60	69	78	88	99-	122	146
	10	74	-	2	6	11	19	27	36	46	57	68	79	90	101	113	125	150	175
	31	57	-	4	11	20	30	41	53	65	77	89	102	115	128	142	156	184	214
30	1.2	-	-	-	-	-	-	-	2	4	6	9	13	18	23	29	35	48	64
	2	-	-	-	-	-	1	3	6	10	14	20	27	34	41	49	57	74	93
	5	78	-	-	-	1	4	8	14	20	27	34	43	52	62	72	82	103	126
	10	62	-	-	1	4	8	14	20	28	36	46	56	66	77	89	101	126	154
	31	51	-	-	2	8	14	23	33	44	56	68	80	92	104	117	131	159	190
40	1.2	-	-	-	-	-	-	-	-	1	2	5	8	11	14	19	24	36	50
	2	-	-	-	-	-	-	-	2	5	8	11	16	21	28	35	42	59	77
	5	72	-	-	-	-	1	3	6	10	15	21	29	37	45	54	64	84	105
	10	63	-	-	-	-	2	6	11	17	24	32	41	50	60	70	81	105	130
	31	51	-	-	-	1	6	12	19	27	37	47	58	70	82	95	108	135	165
50	1.2	-	-	-	-	-	-	-	-	-	-	1	3	5	8	12	16	27	40
	2	-	-	-	-	-	-	-	-	-	2	4	8	12	18	24	31	46	64
	5	66	-	-	-	-	-	-	1	3	6	11	16	22	29	37	46	67	88
	10	57	-	-	-	-	-	-	3	7	12	17	24	32	41	51	62	84	108
	31	47	-	-	-	-	-	2	7	13	20	29	39	49	60	71	83	110	138
60	1.2	-	-	-	-	-	-	-	-	-	-	-	-	2	5	7	10	19	31
	2	-	-	-	-	-	-	-	-	-	-	1	4	7	10	15	21	34	49
	5	59	-	-	-	-	-	-	-	-	2	5	8	13	19	26	34	52	70
	10	53	-	-	-	-	-	-	-	1	4	9	14	20	28	36	45	65	89
	31	46	-	-	-	-	-	-	1	4	9	15	24	33	42	52	63	87	114
80	1.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	6	13
	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	4	12	25
	5	-	-	-	-	-	-	-	-	-	-	-	-	-	2	5	10	22	38
	10	40	-	-	-	-	-	-	-	-	-	-	-	1	4	8	15	30	48
	31	38	-	-	-	-	-	-	-	-	-	-	1	5	10	17	24	41	66
100	1.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5
	5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	11
	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5	16
	31	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	9	26

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

STORAGE OF WATER IN LAKES AND RESERVOIRS

EXISTING LAKES AND RESERVOIRS

There are many lakes, ponds, and reservoirs within the Quinebaug River basin. The largest is Pachaug Pond on the Pachaug River, which has a surface area of 831 acres and usable storage capacity of 219 million cubic feet (1,638 million gallons). Table 11 presents information concerning the more important lakes and ponds, with the exception of the public-supply reservoirs for which information is given in table 31.

Many of the lakes, ponds, and reservoirs in the basin have no usable storage; that is, the water they contain is not subject to withdrawal by gravity upon opening a valve or gate. For those listed in table 11 as having usable storage, table 12 presents the maximum safe draft rates (regulated flows) that could be utilized at each site such that the reservoir would have refilled within each year of the reference period. Maximum draft rates are given for the wettest and driest years of the reference period and also for the median year. It should be noted that the draft rates shown apply for 24-hour per day use and may be increased if the period of use is reduced.

Since all reservoirs listed on Whetstone Brook in the Five Mile River basin and also those on the Pachaug River have a common ownership, each may be operated in combination with those upstream. Results of these combined operations also are shown in table 12.

Flow-duration and low-flow-frequency data for gaging stations at the outlet of these reservoirs, on which these draft-storage tables are based, have been presented in tables 5 and 8.

ESTIMATING THE AMOUNT OF STORAGE NEEDED

If the minimum flow of a stream is insufficient to supply a projected rate of use, it may be possible to construct a reservoir from which stored water can be released as needed to maintain the desired flow. If the frequency with which different amounts of storage would be required is known, then the cost of providing the storage may be balanced against the loss caused by insufficient supply. The information presented in table 13 for the five long-term continuous-record gaging stations in the Quinebaug River basin shows the frequency with which various amounts of storage would have been required to maintain selected rates of regulated flow during the reference period. Values of storage required for recurrence intervals of 2 years represent median conditions, and values for recurrence intervals of 31 years represent very dry conditions. The rates of regulated flow are presented per square mile of drainage area so that the table may be used for other sites along the same streams, provided that the percent of the area covered by stratified drift is not appreciably different. Most of the amounts of storage shown in the table would have been replaced every year, but the larger amounts which are underlined are greater than the total volume of streamflow in some years and hence would not have been replaced every year. The storage figures were determined from frequency-mass curves based on low-flow frequency relationships for each gaging station, using methods described by Hardison and Martin (1963).

Amounts of storage required to maintain various rates of regulated flow at unmeasured sites on streams not now affected by regulation are presented in table 14. The data are presented for various percentages of area covered by stratified drift; interpolations between these percentages may be made. Storage used to provide regulated flow as indicated would be replaced each year except for underlined values; the underlined values represent storage required to maintain relatively large regulated flows in dry years and hence would not be completely replaced during such dry years. Because table 14 is based upon an average streamflow of 1.16 mgd per square mile, before it can be applied to a particular site the rates of regulated flow and amounts of storage must be adjusted to the average streamflow at that site by multiplying by an appropriate ratio determined from figure 18.

The storage-required values in tables 13 and 14 are somewhat smaller than the true values that would actually be required, because they include a bias of about 10 percent that results from the use of the frequency-mass curve and because losses due to evaporation and seepage from the reservoir are not included. These values are sufficiently accurate, however, for reconnaissance planning and for comparison between proposed sites.

FLOODS

HISTORICAL ACCOUNT

Floods may occur in the Quinebaug River basin during any month of the year. Spring floods occur regularly in the basin, and are sometimes accompanied by destruction from moving ice. Floods also occur in late summer and fall, the result of tropical hurricanes or other storms moving northeastward along the Atlantic coastline. General descriptive information concerning major floods within the basin through 1955, extracted from newspaper accounts and other public and private records, is published in U.S. Geological Survey Water-Supply Paper 1779-M. Quantitative measurements of major floods of 1936, 1938, and 1955, based primarily on gaging-station records, are published in Water-Supply Papers 798, 867, 966, and 1420. A compilation of all flood peaks above selected magnitudes for continuous-record gaging stations within the basin is published in Water-Supply Paper 1671.

Since about 1690, when the region was first settled, at least 15 major floods have occurred in the basin. The three earliest floods known occurred in 1720, 1784 and 1789. On February 7,

Table 15.--Elevations of flood peaks and corresponding flows of notable floods of record at long-term stream-gaging stations in the Quinebaug River basin, as observed, and as they might have been modified by the flood control reservoirs.

(Flow data as modified by flood control in East Brimfield, Westville, Hodges Village, Buffumville and West Thompson Reservoirs was furnished by the New England Division of the Corps of Engineers, U.S. Army)

Index number (Pl.A)	Stream and place of measurement	Nov. 4, 5, 1927		Jan. 10,11,1935		Mar. 12,13,1936		Mar. 18,19,1936		July 23,24,1938		Sept.21, 22,1938		Sept. 11,12,1954		Aug. 19,20,1955		Oct. 16,17,1955	
		Elevation (feet above mean sea level)	Flow (cubic feet per second)	Elevation (feet above mean sea level)	Flow (cubic feet per second)	Elevation (feet above mean sea level)	Flow (cubic feet per second)	Elevation (feet above mean sea level)	Flow (cubic feet per second)	Elevation (feet above mean sea level)	Flow (cubic feet per second)	Elevation (feet above mean sea level)	Flow (cubic feet per second)	Elevation (feet above mean sea level)	Flow (cubic feet per second)	Elevation (feet above mean sea level)	Flow (cubic feet per second)	Elevation (feet above mean sea level)	Flow (cubic feet per second)
1240	Quinebaug River at Quinebaug																		
	Observed	-	-	347.7	2,140	352.3	6,880	355.0	10,500	349.5	4,390	357.7	19,000	350.6	5,990	360.5	49,300	348.2	2,830
	Modified by flood control	-	-	346.5	1,500	349.4	4,000	352.0	7,000	348.3	3,000	355.6	12,000	349.4	4,000	359.7	36,000	347.1	2,000
1250	French River at Webster, Mass.																		
	Observed	-	-	-	-	-	3,480	-	4,700	-	-	-	2,700	418.4	2,320	432.8	14,400	-	1,300
	Modified by flood control	-	-	-	-	-	1,100	-	1,500	-	-	-	1,200	414.2	1,000	423.0	4,900	-	1,000
1255	Quinebaug River at Putnam																		
	Observed	-	-	226.6	5,600	231.5	12,500	234.0	17,200	230.3	10,000	236.2	20,900	229.5	8,990	243.3	48,000	227.1	5,150
	Modified by flood control	-	-	224.3	3,000	226.5	5,000	227.7	6,500	226.5	5,000	227.0	5,600	226.4	5,000	231.6	12,000	225.5	4,000
1260	Five Mile River at Killingly																		
	Observed	-	-	-	-	-	1,600	-	-	230.7	2,480	227.4	1,060	227.3	920	228.0	1,190	227.5	1,020
1265	Moosup River at Moosup																		
	Observed	-	-	203.2	2,550	205.0	4,260	204.1	3,370	204.9	4,160	-	-	202.3	1,820	201.8	1,520	203.6	2,930
1270	Quinebaug River at Jewett City																		
	Observed	79.7	12,500	80.0	13,100	84.9	23,000	87.1	29,200	85.6	24,800	84.8	22,800	79.5	12,600	92.1	40,700	79.5	12,700
	Modified by flood control	77.9	10,000	78.5	11,000	81.5	16,000	84.9	22,900	84.1	21,000	79.1	11,900	77.9	10,000	83.0	17,500	78.8	11,500

1807, there occurred the greatest flood that the oldest inhabitants had ever witnessed. It was followed by other major floods in 1837 and 1867, and on October 4, 1869, there occurred another flood greater than the oldest inhabitants at that time had ever seen, surpassing the flood of 1807 over most of the basin. On March 26, 1876 there occurred an even greater flood which exceeded the previous record floods of October 4, 1869, and of February 7, 1807. Never within the memory of the oldest inhabitants of Putnam at that time had there ever been such a flood on the Quinebaug and French Rivers. Damages were the greatest ever experienced, and the rivers were full of cotton bales, sacks of wool and the debris of mills, buildings, dams and bridges. Ten years later, February 13, 1886, the basin was subjected to a flood that exceeded even that of March 26, 1876. It was the most severe flood ever known in New England up to that time and was occasioned by several inches of snow being carried off by a two-day rain. Most of the ice went out before the peak stages were reached, but damages were still extensive to bridges, buildings, and mill dams, many of which had survived several previous floods. During the next 40 years the flood events which occurred were of minor significance.

Continuous records of streamflow have been obtained at Jewett City since July 1918, and a summary of major flood events in the basin since that date appears in table 15. The flood of November 4, 1927, did not approach the magnitude of the great flood of 1886 except on the eastern tributaries where peak stages were about a foot lower than in 1886. The two floods of March 1936 were less in magnitude than the 1927 flood on the eastern tributaries, but in the remainder of the basin flows were from two to three times those observed in 1927 and the water was higher than it had been in the previous record flood of 1886. The flood of July 24, 1938, produced flows similar to those observed in March 1936 on the lower and eastern tributaries but no records were broken. On September 21, 1938, a severe hurricane again produced record-breaking floods in the upper part of the basin, but flooding in the eastern tributaries was nominal. The peak flow of the Quinebaug River at Putnam was 20,900 cfs and exceeded the flow in March 1936 by 3,700 cfs. There was considerable property damage in the upper end of the basin from these record-breaking flows, and throughout the basin wind destruction was very great. This event was the greatest catastrophe in New England since its first settlement by white man up to that time.

On August 19, 1955 there occurred the greatest flood of historic time in the upper part of the basin and along the main stream to its mouth. South of Putnam the tributaries were not greatly affected, since the heaviest rainfall (up to about 17 inches in a four day period immediately preceding the flood) occurred north of Putnam. On the eastern tributaries the record flood still remains that of February 13, 1886, and the second highest flood probably was either that of March 12, 1936, or July 24, 1938, for they were very similar in size. The small tributaries entering the river below Putnam from the west probably experienced their highest historic flood on September 21, 1938.

Since 1958 four large flood-control reservoirs have been constructed in Massachusetts at East Brimfield and Westville on the Quinebaug River and at Hodges Village and Buffumville on the French River. The total storage capacity of these reservoirs is 2.943 million cubic feet. Recently completed in 1965 is another flood-control reservoir at West Thompson, Connecticut, which has a storage capacity of 1.115 million cubic feet. The degree to which storage in all 5 of these reservoirs would have modified the river elevations and flows recorded in major floods of the past, from studies made by the Corps of Engineers, is included in table 15. Future floods of similar magnitudes would be modified to the same degree by these reservoirs, so that the possibility of major damage from future floods on the French or upper Quinebaug Rivers is remote, as long as buildings are not constructed below the highest modified flood elevations shown in table 15.

MAGNITUDE AND FREQUENCY OF FLOODS

Knowledge of the magnitude and frequency of floods is essential to the water manager concerned with the location and design of flood-control and routing structures and the establishment of flood plain encroachment lines. The magnitude and frequency of floods at twelve gaging stations in the Quinebaug River basin are given in table 16. For gaging stations on the Quinebaug and French Rivers, the stages and flows actually measured for the period before the construction of the flood-control reservoirs are given and, in addition, modified figures are given indicating probable stages and flows that would have resulted had the reservoirs been in existence at the time.

For unmeasured sites within the basin where the drainage area is 10 square miles or more, estimates of the instantaneous peak discharge of a flood flow for any recurrence interval can be made from figures 21 and 22 which have been reproduced from a flood-frequency study made by the U.S. Geological Survey (Green, 1964). The mean annual flood at any site can be found from figure 21 when the drainage area is known. Flood flows for other recurrence intervals up to 100 years are the product of the mean annual flood and the appropriate ratios for any selected recurrence intervals from figure 22.

FREQUENCY AND DURATION OF HIGH FLOWS

The flood-frequency information in table 16 and figures 21 and 22 is presented in terms of the recurrence of instantaneous peak discharges. For some purposes, however, it is also important to estimate how long periods of high flow may be sustained and how frequently these periods may recur. Table 17 presents the probable recurrence intervals of annual highest average flows for periods of 0 (flood peak), 1, 3, 7, 15, 30, 60, 150, 274, and 365 days at long-term continuous-

Table 16.--Maximum flood of record, mean annual flood, and magnitude and frequency of flood flows and corresponding flood elevations for gaging stations in the Quinebaug River basin.

(The table includes observed data which are based on actual measurements, and modified data which indicate the flood elevations and flows that would probably have occurred if the East Brimfield, Westville, Hodges Village, Buffumville, and West Thompson flood-control reservoirs had been in operation during the period of continuous records. Modified data were furnished by the Corps of Engineers, U.S. Army.)

Index number (Pl.A)	Stream and place of measurement	Observed or modified by flood control	Drainage area (square miles)	Period of continuous records	Date	Maximum flood of record: Elevation (feet above mean sea level)	Maximum flood of record: Flow, Cubic feet per second	Maximum flood of record: Flow, Cubic feet per second per sq mile	Ratio to mean annual flood	Mean annual flood: Elevation (feet above mean sea level)	Mean annual flood: Flow, Cubic feet per second	Mean annual flood: Flow, Cubic feet per second per sq mile	Flood flow, expressed as ratio to mean annual flood, for various recurrence intervals in years: 5	10	20	40	60	100	Flood elevation, in feet above mean sea level, for various recurrence intervals in years: 5	10	20	40	60	100
1240	Quinebaug River at Quinebaug	Observed	157	1931-63	Aug. 19, 1955	360.5	49,300	314	24.0	347.2	2,050	13.1	1.5	2.1	3.0	4.2	5.2	7.2	348.4	349.7	351.3	353.4	355.0	357.0
		Modified				359.7	e36,000	-	17.6	-	-	-	1.25	1.5	1.8	2.4	2.8	3.7	347.8	348.4	349.0	350.2	351.0	352.6
1250	French River at Webster, Mass.	Observed	85.3	1948-63	Aug. 19, 1955	432.8	14,400	169	13.7	414.3	1,050	12.3	1.45	2.1	3.1	4.8	6.3	9.1	415.5	417.2	419.8	423.2	426.2	431.5
		Modified				423.0	4,900	-	4.67	-	-	-	1.0	1.05	1.15	1.6	2.1	3.0	414.3	414.5	414.8	415.9	417.2	419.5
1253	English Neighborhood Brook at North Woodstock	Observed	4.99	1962-63	Apr. 1, 1962	-	115	23.0	e.82	-	e140	e28.0	-	-	-	-	-	-	-	-	-	-	-	-
1254.9	Little River at Harrisville	Observed	35.5	1961-63	Mar.19, 1936	-	2,920	82.2	e4.86	e260.5	e600	e16.9	-	-	-	-	-	-	-	-	-	-	-	-
1255	Quinebaug River at Putnam	Observed	331	1929-63	Aug.19, 1955	243.4	48,000	145	10.7	225.9	4,500	13.6	1.5	2.0	2.6	3.5	4.1	5.1	227.9	229.6	231.4	233.6	235.0	237.1
		Modified				231.6	12,000	-	2.67	-	-	-	1.05	1.1	1.15	1.2	1.4	1.6	226.2	226.4	226.5	226.8	227.5	228.1
1260	Five Mile River at Killingly	Observed	58.2	1937-63	July 24,1938	230.7	2,480	42.6	4.13	226.3	600	10.3	1.4	2.0	2.55	3.2	3.7	5.0	227.1	228.1	228.8	229.8	230.4	231.2
1263	Quaduck Brook at North Sterling	Observed	8.22	1961-63	Sept.21,1961	-	320	38.9	e1.60	-	e200	e24.3	-	-	-	-	-	-	-	-	-	-	-	-
1265	Moosup River at Moosup	Observed	83.5	1932-63	Mar. 12,1936	204.8	4,080	48.9	2.81	201.7	1,450	17.4	1.4	1.7	2.1	2.5	2.8	3.1	202.5	203.1	203.8	204.4	204.8	205.2
1266	Blackwell Brook near Brooklyn	Observed	16.4	1962-63	Apr. 1, 1962	141.9	660	40.2	e1.24	e141.4	e530	e32.3	-	-	-	-	-	-	-	-	-	-	-	-
1269.5	Pachaug River at Pachaug	Observed	49.9	1962-63	Sept.21,1961	150.5	728	14.6	.97	e150.6	e750	e15.0	-	-	-	-	-	-	-	-	-	-	-	-
1270	Quinebaug River at Jewett City	Observed	711	1918-63	Aug. 20,1955	92.1	40,700	57.2	4.79	76.8	8,500	12.0	1.35	1.7	2.1	2.5	2.9	3.3	78.8	80.6	82.5	84.1	85.5	86.7
		Modified				83.0	17,500	24.6	2.06	-	-	-	1.15	1.3	1.5	1.7	1.8	2.1	77.6	78.5	79.6	80.7	81.1	82.6
1271	Broad Brook near Preston	Observed	12.7	1962-63	Sept.21,1961	-	720	56.6	e1.44	-	e500	e39.4	-	-	-	-	-	-	-	-	-	-	-	-

e Estimated.

Table 17.--Magnitude and frequency of annual highest average flow at long-term gaging stations in the Quinebaug River basin.

(Data for indicated recurrence intervals and indicated periods of consecutive days have been adjusted to the reference period October 1930 to September 1960. Data for Quinebaug and French Rivers have been modified for the effect of flood control in East Brimfield, Westville, Hodges Village, Buffumville and West Thompson Reservoirs)

Index number (Pl.A)	Stream and place of measurement	Drainage area (square miles)	Period (consecutive days)	Annual highest average flow, in cubic feet per second, for indicated recurrence interval, in years 1.03	2	5	10	25	50	100
1240	Quinebaug River at Quinebaug	157	0	950	1,850	2,600	3,100	4,100	5,600	7,600
			1	820	1,600	2,300	2,800	3,700	5,000	6,800
			3	760	1,400	2,100	2,500	3,100	4,000	5,200
			7	660	1,100	1,650	2,100	2,600	3,200	4,000
			15	550	850	1,250	1,600	2,200	2,500	3,100
			30	450	700	1,000	1,250	1,700	2,100	2,400
			60	350	550	800	900	1,200	1,400	1,800
			150	250	450	550	600	700	800	950
			274	210	350	400	450	500	550	600
			365	190	310	350	400	420	450	500
1250	French River at Webster, Mass.	85.3	0	500	950	1,000	1,100	1,400	2,000	3,100
			1	450	900	1,000	1,000	1,300	1,700	2,600
			3	400	750	1,000	1,000	1,100	1,200	1,600
			7	350	600	950	1,000	1,000	1,100	1,200
			15	300	500	750	800	1,000	1,000	1,100
			30	250	400	550	650	750	950	1,000
			60	200	350	400	500	550	600	700
			150	150	250	300	350	350	400	400
			274	120	210	250	260	280	300	300
			365	110	190	210	230	250	250	250
1255	Quinebaug River at Putnam	331	0	1,900	3,800	4,700	5,000	5,200	5,800	7,000
			1	1,700	3,600	4,500	4,800	5,000	5,400	6,400
			3	1,550	3,000	4,500	4,600	4,900	5,000	5,200
			7	1,350	2,400	3,600	4,500	4,800	4,800	4,900
			15	1,100	1,900	2,800	3,600	4,500	4,500	4,700
			30	900	1,500	2,200	2,700	3,400	3,900	4,500
			60	750	1,200	1,650	1,950	2,400	2,700	3,200
			150	550	900	1,150	1,300	1,450	1,600	1,800
			274	450	700	850	950	1,050	1,100	1,200
			365	400	650	750	850	900	950	1,000
1260	Five Mile River at Killingly	58.2	0	300	550	850	1,200	1,750	2,300	3,000
			1	280	500	800	1,100	1,550	2,200	2,700
			3	250	450	700	900	1,250	1,700	2,200
			7	220	400	580	700	950	1,200	1,500
			15	180	300	450	500	700	800	1,000
			30	150	250	360	400	550	600	700
			60	130	200	270	300	400	420	450
			150	100	150	190	200	250	260	270
			274	80	130	150	160	180	190	190
			365	70	120	130	140	150	160	160
1265	Moosup River at Moosup	83.5	0	680	1,300	2,000	2,500	3,200	3,800	4,500
			1	580	1,200	1,700	2,200	2,800	3,500	4,200
			3	500	900	1,300	1,500	2,200	2,600	3,200
			7	430	650	950	1,100	1,500	1,800	2,200
			15	350	500	700	800	1,050	1,250	1,500
			30	280	400	550	600	650	900	1,050
			60	220	350	400	500	550	600	700
			150	160	250	300	320	350	400	400
			274	120	210	250	260	280	300	300
			365	110	190	210	230	250	250	250
1270	Quinebaug River at Jewett City	711	0	4,000	7,800	9,600	11,000	13,000	15,000	18,000
			1	3,900	7,200	9,600	11,000	13,000	15,000	18,000
			3	3,300	6,200	8,600	9,600	11,000	12,500	14,000
			7	2,700	4,900	7,200	8,600	9,600	10,500	11,500
			15	2,300	3,900	5,600	6,800	8,400	9,000	9,600
			30	1,900	3,200	4,500	5,200	6,400	7,000	8,000
			60	1,550	2,600	3,500	4,000	4,700	5,000	5,700
			150	1,200	2,000	2,500	2,700	3,000	3,200	3,500
			274	950	1,600	1,900	2,000	2,200	2,300	2,400
			365	850	1,400	1,700	1,800	1,900	2,000	2,100

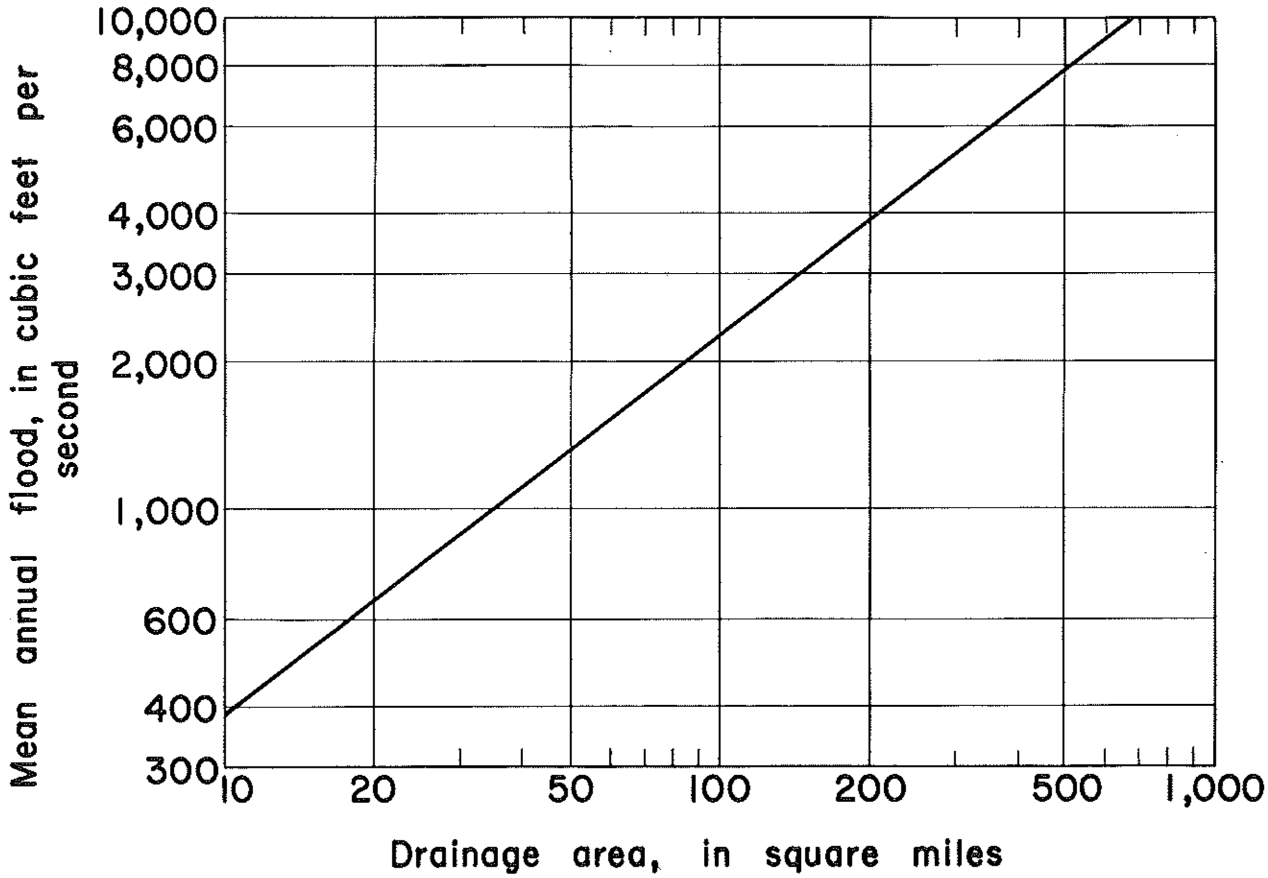


Figure 21.--Mean annual flood flows vary with size of area drained.

record gaging stations in the Quinebaug River basin. For the gaging stations on the Quinebaug and French Rivers, adjustments have been made for the effect of storage in flood-control reservoirs upstream. For example, table 17 indicates that the highest average flow of the Quinebaug River at Quinebaug for a period of 30 days would be 1,250 cfs once in 10 years, on the average, and thus there is a 10 percent probability that high flows of this magnitude would occur in any one year. The peak flow recurring once in 10 years would be 3,100 cfs and the corresponding peak elevation 348.4 feet; these flood peaks would probably occur within the 30-day period for which the estimated average flow is 1,250 cfs.

QUALITY OF WATER IN STREAMS

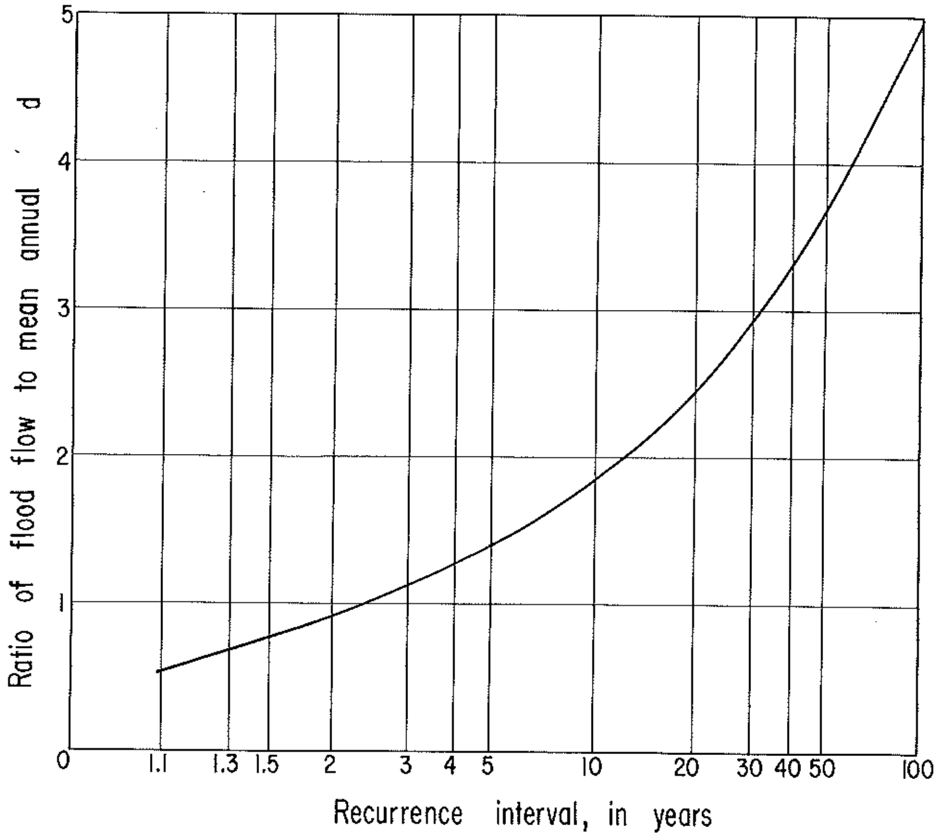
NATURAL CONDITIONS

The chemical quality of water in streams in the Quinebaug River basin under natural conditions is excellent. A summary of analyses of stream-water samples collected at 21 sites (see Plate A) substantially unaffected by man's activities is given in table 18. The complete analyses are given in the companion basic-data report (Thomas and others, 1966). The excellence of the chemical quality of stream water is emphasized by the contrast between the maximum amounts of dissolved mineral constituents of samples listed in table 18 and the upper limits for the same constituents recommended by the U.S. Public Health Service (1962) for drinking water. The maximum dissolved solids content of 74 ppm in these samples, for example, is far below the recommended upper limit of 500 ppm in drinking water. Hardness of these same samples ranged from 7 to 36 ppm; water having hardness in this range is classified as soft water.

The most common constituents in naturally occurring water in streams in the basin are those listed in table 18; silica, calcium, sodium, bicarbonate, and sulfate comprised about 80 percent of the dissolved solids in most samples collected. These mineral constituents are present largely as a result of the solution of soil and rock materials at and below the land surface; however; precipitation is also the source of relatively large amounts of mineral matter, chiefly calcium, bicarbonate, and sulfate.

The dissolved solids concentration of stream water varies with rate of streamflow. Streams generally contain the least concentrations of dissolved solids during periods of high streamflow when the stream water contains its highest proportion of direct runoff, and the greatest concentrations of dissolved solids during periods of low streamflow when the stream water contains its highest proportion of ground-water runoff.

The relatively low dissolved solids concentration of stream water during periods of high streamflow is shown in table 18 and also in



Floods several times as large as the mean annual flood will occur at infrequent intervals. If the mean annual flood for any particular site is read from figure 21, figure 22 may be used to estimate how frequently flood flows as much as 5 times the mean annual flood may be expected at that site.

Figure 22.--Magnitude of flood flows varies with average intervals between their recurrence.

figure 23. The remarkably uniform and low concentration of all mineral constituents in these samples indicates that the chemical quality of water in streams at high streamflow represents chiefly the quality of the preceding precipitation, modified somewhat as it flowed overland to streams and mixed with ground water already in the channels of the streams.

Table 18 and figure 23 also illustrate the relatively high mineral concentrations in stream water in the basin during periods of low streamflow. They indicate that the dissolved-solids concentration at low streamflow has ranged from 26 to 92 ppm. At all sites the dissolved-solids concentration of water in the streams is greater at low streamflow than at high streamflow. Silica, which makes up more than 50 percent of the mineral composition of the rocks of the basin, is a relatively minor constituent at high flow but averages about 20 percent of the dissolved solids concentration at low flow. These changes in silica and dissolved solids concentration result from the presence of relatively large proportions of ground water in the stream channels during periods of low streamflow. Even under low-flow conditions, however, it is important to note that half of the streams contained less than 55 ppm dissolved solids.

As stream water during periods of low streamflow is derived largely from ground-water runoff, the chemical quality of the stream water represents an average of the quality of ground water contributing to the streamflow. Thus, at low streamflow the dissolved solids concentration of stream water varies from place to place in the basin, showing the effect of different geologic environments on the chemical quality of stream water. For example, the dissolved solids concentration and hardness of stream water in the northwest corner of the basin, even though low, are relatively much higher than elsewhere (see figure 23). Also, the sulfate concentration in stream water on the east side of the basin at low flow averaged 6.8 ppm, not much above the concentration at high flow (6.0 ppm), and it was similar to concentrations measured in precipitation (table 4); on the other hand, streams on the west side of the basin increased in average sulfate concentration from 7.3 ppm at high flow to 14.8 ppm at low flow. The greater concentration of sulfate in streams in the western part of the basin parallels the occurrence of iron-bearing ground water (figure 43), which suggests there is a somewhat greater proportion of iron sulfide minerals in the bedrock west of the Quinebaug River.

IRON AND COLOR

Iron makes up only a small fraction of the total dissolved solids in naturally occurring stream waters in the Quinebaug River basin, but it deserves special discussion because it is the only constituent present in amounts large enough to be troublesome (an iron content of 0.3 ppm or more is objectionable for domestic and many industrial uses). More than 50 percent of the sites

Table 18.--Summary of chemical analyses of water from representative streams in the Quinebaug River basin under natural conditions.

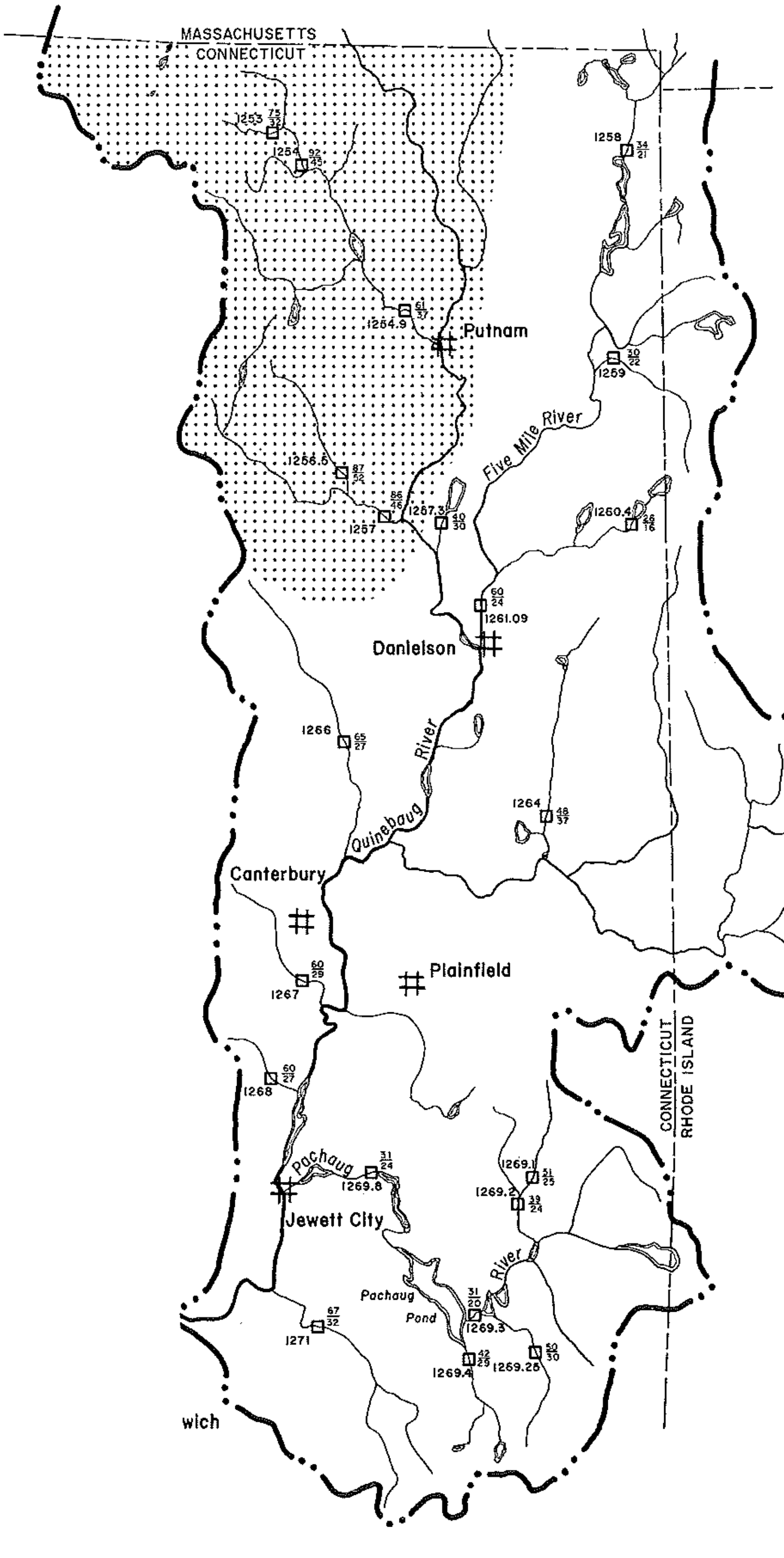
(Chemical constituents in parts per million)

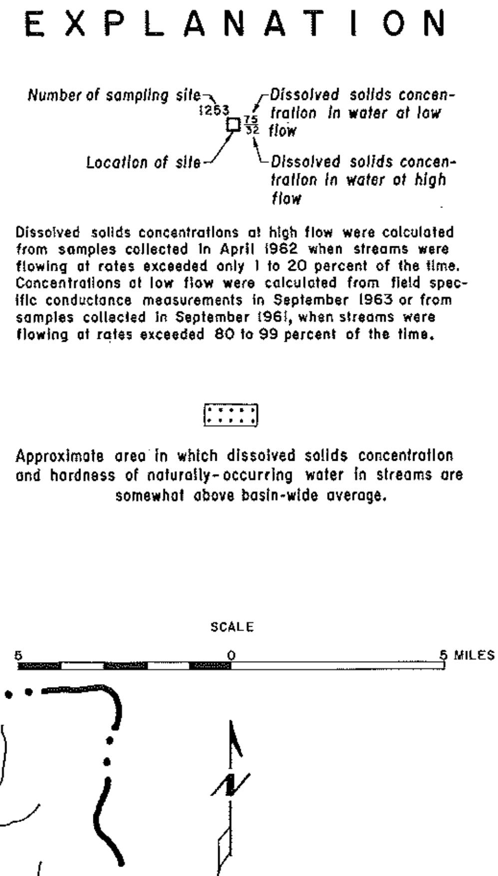
Constituent or property	Concentration in water samples collected at high flow (flow that was equaled or exceeded less than 20 percent of the time from 1930 to 1960 a/		Concentration in water samples collected at low flow (flow that was equaled or exceeded more than 65 percent of the time from 1930 to 1960 b/		Upper limit in drinking water, as recommended by U.S. Public Health Service (1962)
	Range	Average	Range	Average	
Silica (SiO_2)	14 - 0.5	5.2	18 - 4.3	11.1	-
Iron (Fe)	0.13 - .05	0.08	0.91 - 0.13	0.41	0.3
Calcium (Ca)	6.5 - 1.8	3.2	11 - 1.8	4.9	-
Magnesium (Mg)	1.8 - .5	1.3	2.7 - .8	1.8	-
Sodium (Na)	5.4 - 2.3	3.3	5.4 - 2.8	3.9	-
Potassium (K)	2.0 - .5	1.0	2.7 - .3	1.1	-
Bicarbonate (HCO_3)	17 - 4	10	29 - 8	16	-
Sulfate (SO_4)	10 - 4.4	6.8	29 - 4.5	9.6	250
Chloride (Cl)	8.1 - 1.8	4	5.2 - 2.1	3.8	250
Nitrate (NO_3)	1.6 - 0	.3	3.6 - .7	1.4	45
Dissolved solids (calculated)	52 - 16	30	74 - 26 c/	46 c/	500
Hardness as $CaCO_3$	22 - 7	13	36 - 11	20	-
Noncarbonate hardness as $CaCO_3$	9 - 1	5	23 - 1	7	-
Specific conductance (micromhos at 25°C)	91 - 32	51	104 - 45 d/	68 d/	-
pH	6.8 - 5.2	6	6.7 - 5.8	6.2	-
Color	25 - 1	12 e/	75 - 3	30	15

a/ One sample from each of 21 sites.
b/ One sample from 17 of the 21 sites sampled at high flow.
c/ Range 92-26 ppm, average 54 ppm, including values calculated from field specific conductance measurements and plotted in figure 22.
d/ Range 132-45, average 83 including field measurements made at streamflows equaled or exceeded more than 80 percent of the time.
e/ Only 4 values.

sampled on streams essentially unaffected by man had water containing more than 0.3 ppm of iron at low flow, and the percentage probably would have been higher if some of the sites had been sampled at lower streamflows. These excessive concentrations originate in iron-bearing ground water which is present locally in the western part of the basin and from water in numerous swamps which occur throughout the area.

To study the effect of swamp environments on the iron concentration of stream water, several water samples were collected in and near a swamp south of Quinebaug Pond shown in figure 24. Water entering the swamp from Quinebaug Pond and James Brook contains relatively little dissolved iron, but water in the swamp and in Quandock Brook just below the swamp outlet contains increased concentrations of dissolved iron at both high and low streamflow. The source of the iron is the decaying vegetation in the swamp. All plants require a continuous supply of iron during the growing process and extract it from water or soil during the growing season; after the growing season the iron requirements of the plants diminish and decay of vegetation releases dissolved iron to the swamp water. The table on figure 23 indicates that the iron content of the

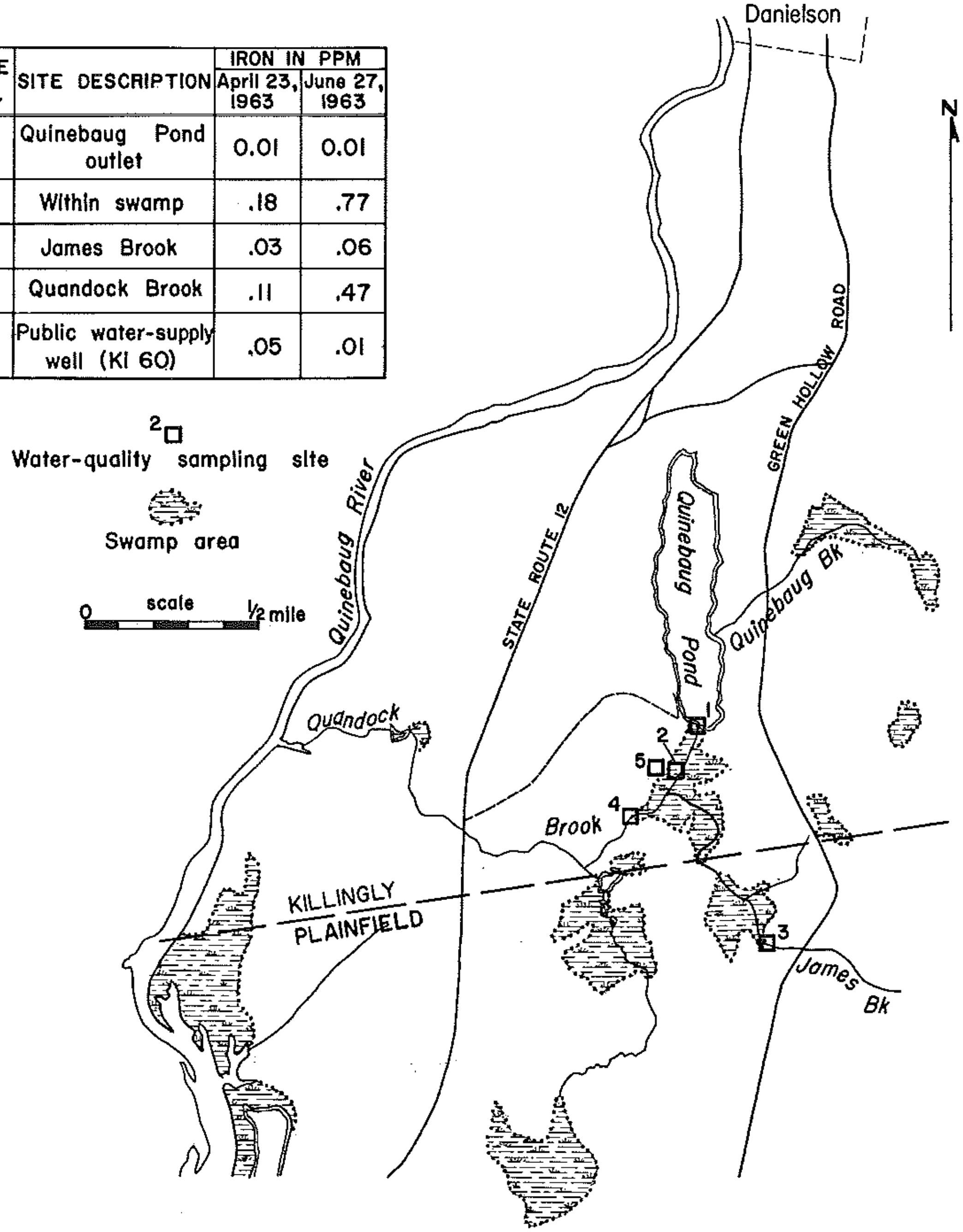




Under natural conditions, water in streams has a smaller dissolved solids concentration at high flow than at low flow, due to the large proportion of overland runoff in the stream at high flow. Areal variations in dissolved solids also occur, and both dissolved solids and hardness in stream water in the northwestern part of the Quinebaug River basin are consistently above basin-wide average. Despite these differences, quality is excellent throughout the basin under natural conditions.

Figure 23.--Areal variation in dissolved-solids content and hardness of naturally occurring stream water.

SITE NO.	SITE DESCRIPTION	IRON IN PPM April 23, 1963	IRON IN PPM June 27, 1963
1	Quinebaug Pond outlet	0.01	0.01
2	Within swamp	.18	.77
3	James Brook	.03	.06
4	Quandock Brook	.11	.47
5	Public water-supply well (Ki 60)	.05	.01



Water draining from swamps is likely to contain higher concentrations of dissolved solids than water entering the swamps, at both high and low streamflow. The iron concentration in swamp water commonly increases several-fold during the growing season.

Figure 24.--Dissolved-iron concentrations in water in and near swamp below outlet of Quinebaug Pond.

water in the swamp south of Quinebaug Pond increased four-fold between April 23 and June 27, 1963, as did the water in Quandock Brook, which drains the swamp. This sharp increase in iron content of swamp water so early in the normal growing season may be due to the premature death of a substantial part of the swamp vegetation resulting from the drying up of the swamps in the summer of 1963, a very dry year.

The decaying organic material in the swamps imparts a brownish-yellow color to water draining from them. Iron may be a significant constituent of organic color in water, but the amount of iron does not necessarily correlate with the amount of organic color. Like dissolved solids in general, color is greatest during periods of low streamflow and decreases during periods of high streamflow. Measured color in streams associated with swamps was as high as 75. The determination was made by comparing a column of the water sample with a column of equal height of an arbitrary standard whose color is rated at 500. (See Hem, 1959, p. 49).

CONDITIONS RESULTING FROM THE ACTIVITIES OF MAN

When man develops water for his use, the quality of water is almost always changed, and generally the quality of water after use is poorer than it was in its original condition. All the major streams in the basin and a few of the smaller tributaries are at places polluted. Industrial wastes discharged into the streams of the Quinebaug River basin in Massachusetts and Connecticut include cyanide, copper, nickel, chromium, grinding rouge (iron oxide), bleaches, dyes, soap, and acids and alkalis. Organic wastes, including sugar, starch, pulp fibers, blood, feathers, grease, and domestic sewage are also present. The principal objectionable pollutants in the streams are iron, detergents, dyes, textile wastes, pulp and paper wastes, and pickling liquors from metal fabrication; these wastes are objectionable because even in small amounts they may impart a color to the water or otherwise make it unsuitable for many uses.

Despite the fact that at places pollution increases the dissolved solids content of stream water significantly above that of the naturally occurring water, the maximum dissolved solids content observed was only about 214 ppm (in a sample from the French River collected on July 31, 1962), far below the upper limit of 500 ppm recommended for drinking water by the U.S. Public Health Service.

The chemical quality of stream water in the heads of the Quinebaug and French Rivers is similar to that of naturally occurring stream waters in the Quinebaug River basin in Connecticut; however, the Quinebaug and French Rivers are polluted by discharge of industrial wastes between their heads and the Massachusetts-Connecticut State line. The effect of this pollution is illustrated by figures 25 and 26. The variations of chemical quality of water with streamflow at a point in the Quinebaug River are illustrated in figure 25 which is a graph of daily mean discharge and a daily specific conductance measurement for the Quinebaug River at Putnam for the period October 1, 1957 - September 30, 1958. (Specific conductance is a rough measure of the dissolved solids concentration of water.) The graph shows that as streamflow decreases (from May to October) dissolved solids concentration increases, but as streamflow increases (from November to April) dissolved solids concentration decreases. Variations in amounts of industrial wastes discharged upstream caused rather large daily fluctuations in dissolved solids concentrations during periods of low streamflow, particularly during October and November 1957, when there was almost no variation in streamflow from day to day. On the other hand, during periods of high streamflow, when there was an abundance of water to dilute and transport the wastes, daily fluctuations in dissolved solids concentration were relatively small.

The variation in chemical quality of water along the Quinebaug River is illustrated in figure 26, which shows that at very high streamflow (2 percent duration flow) there is little change in the dissolved solids concentration of the water from Quinebaug to Jewett City. However, at very low streamflow (95 percent duration flow) not only is there a significant increase in the dissolved solids concentration but there also is significant variation in chemical quality along the river. From the sampling site at Quinebaug to that at Grosvenor Dale there is a slight decrease in the dissolved solids content of the water; at the sampling site at Putnam, however, the dissolved solids content is much greater due chiefly to the industrial waste carried by the French River which enters at West Thompson. This industrial waste is high in sodium and carbonate, as indicated in figure 26. At low flow sodium concentrations in the French River and in the Quinebaug River above Putnam exceed 50 ppm, which is enough to cause foaming in steam boilers. From Putnam to Jewett City, the most downstream sampling point, the dissolved solids concentration decreases from about 120 ppm to about 76 ppm due to inflow of less highly mineralized water from the ground and other tributaries.

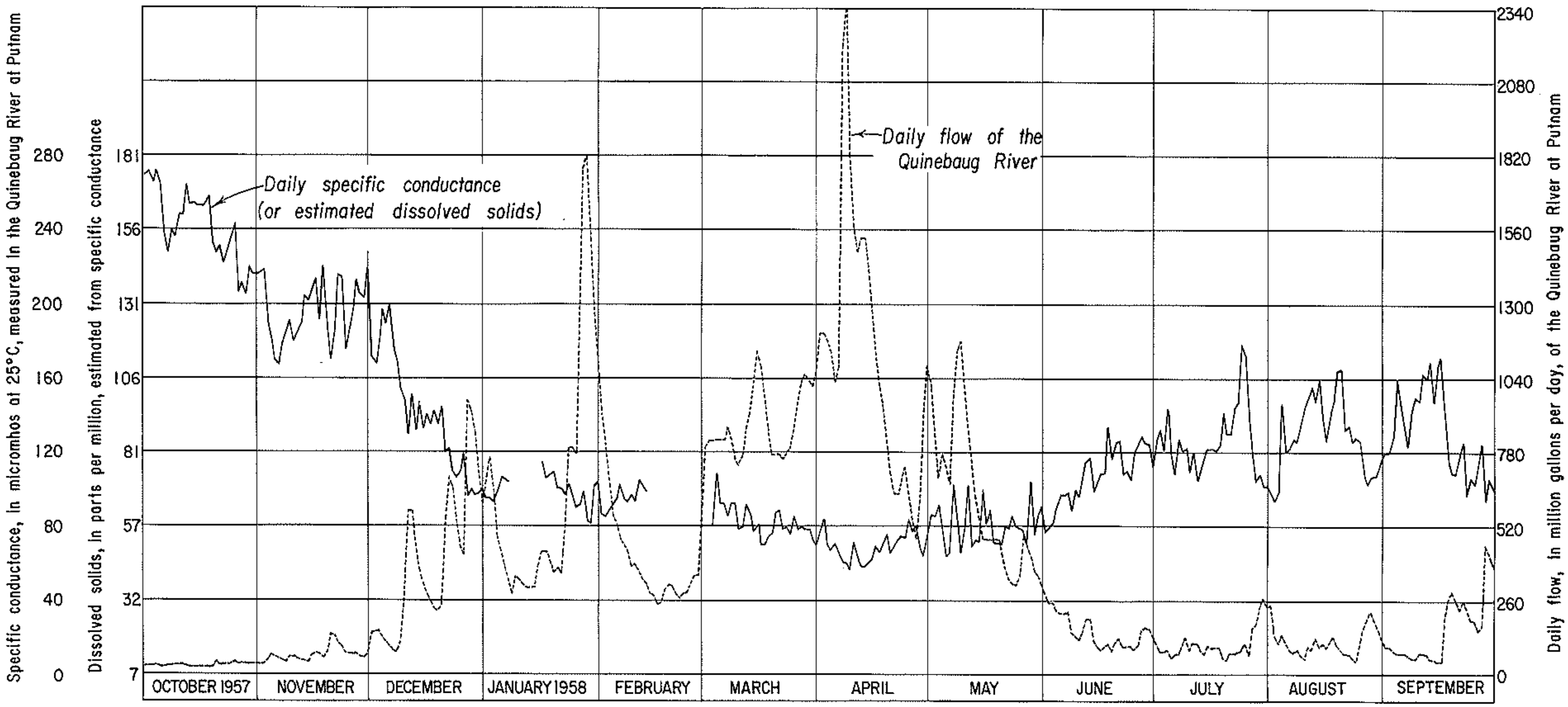
The effects of both pollution and seasonal variation in streamflow on chemical quality in the Quinebaug River are summarized by figure 27, which shows the variation in dissolved solids and hardness observed at 3 stations along the river. The slope of the lines reflects the increase in concentration from high to low flow. Both dissolved solids and hardness at all 3 stations remained well above the average values for naturally-occurring stream water at high and low flow (table 18), reflecting the presence of wastes in the Quinebaug River. However, even at Putnam the entire range represents soft water.

IRON IN THE QUINEBAUG RIVER

One of the most objectionable pollutants in the Quinebaug River is iron oxide. The iron oxide is in the form of grinding rouge discharged as waste into the river north of the Connecticut-Massachusetts boundary. The finely-ground iron oxide powder is carried downstream in suspension; as the water passes through relatively quiet stretches of the river, part of the suspended powder settles to the bottom. From the Massachusetts boundary to Putnam the Quinebaug River consists of a series of pools and riffles, and the largest accumulations of grinding rouge settle to the bottom within the quiet pools. No grinding rouge has been observed south of the northernmost dam at Putnam.

The waste water containing suspended grinding rouge also contains dissolved iron. Analyses of water collected during this investigation suggest that the waste water contains about 7 times as much iron in solution as does the water in the river above the disposal site in Massachusetts. Much of the dissolved iron in the waste probably is oxidized in the river and settles to the river bottom with the grinding rouge.

Iron concentration in the Quinebaug River increases as streamflow decreases, in general, but comparatively large fluctuations occur from day to day. Figure 28 shows graphs of iron concentration in the Quinebaug River at Jewett City, Putnam, and Quinebaug as determined once each day during the water years 1956, 1958, and 1960



The dissolved solids concentration of water in the Quinebaug River at Putnam varies inversely with rate of flow. An irregular increase in flow from October 1957 through April 1958 was accompanied by a decrease in dissolved solids concentration at Putnam, but as flow declined during May and June dissolved solids increased once more. Analyses of 24 water samples showed that for this year, dissolved solids concentration was approximately equal to 0.62 times specific conductance plus 7. (After Pauszek, 1961, p. 55.)

Figure 25.--Dissolved solids, as estimated from specific conductance, and daily mean discharge, Quinebaug River at Putnam.

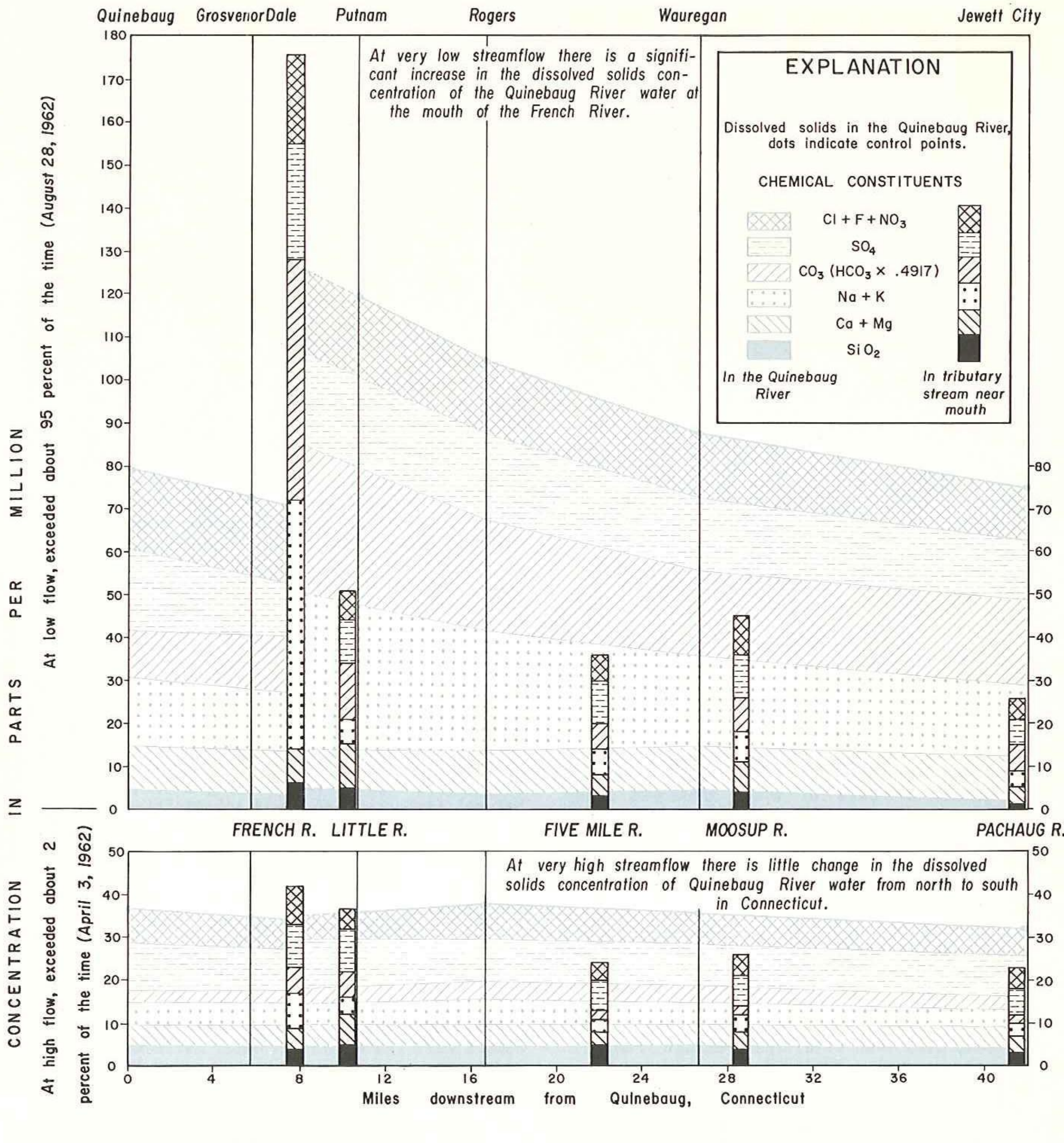
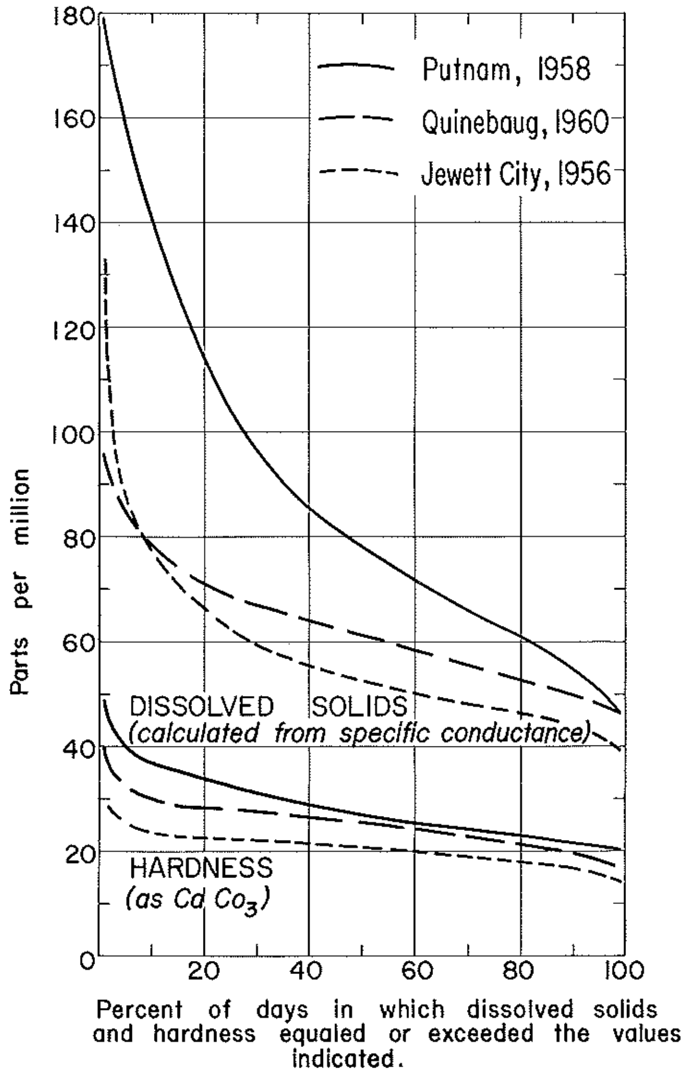


Figure 26.--Variation in chemical quality of water in the Quinebaug River from Quinebaug to Jewett City.



Because each of these curves represent only one year of record, they may not be representative of long-term conditions.

Figure 27.--Variation of dissolved solids and hardness at 3 stations on the Quinebaug River.

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respectively. At each site, the greatest iron concentrations occur during the summer period of low streamflow. However, the very sharp peaks and valleys in the graphs of iron concentration, which are especially prominent at Quinebaug and Putnam, are not due entirely to natural fluctuations in river flow and may be caused by variations in the discharge of industrial waste into the river above the sampling sites.

Figure 28 also shows that iron concentrations decrease downstream from Quinebaug to Jewett City at low streamflows, but even at the most downstream sampling point the concentration is 0.3 ppm or more (the limit above which iron becomes objectionable for most domestic and many industrial uses) for 45 percent of the time. Near the Massachusetts State line at Quinebaug, the iron content is 0.3 ppm or more for 75 percent of the time.

The large amount of suspended and dissolved iron in the Quinebaug River favors the growth of iron bacteria, as evidenced by reddish-brown "slime" growing on the rocks and streambed in the river channel. At times the "slime" apparently settles to the bottom and forms a reddish-brown sludge. This sludge, the growing slime, and grinding rouge in suspension or on the river bottom give the river a reddish appearance even though the water itself usually is not colored. The slime produced by iron-loving bacteria, like the grinding rouge, has not been observed south of the upstream dam in Putnam.

Because the grinding rouge tends to settle out in the quiet stretches of the river from the Connecticut-Massachusetts boundary to Putnam, accumulations of rouge can be expected in the recreational pool behind the flood-control dam recently completed at West Thompson. Such accumulations would seriously limit the esthetic and recreational value of the pool.

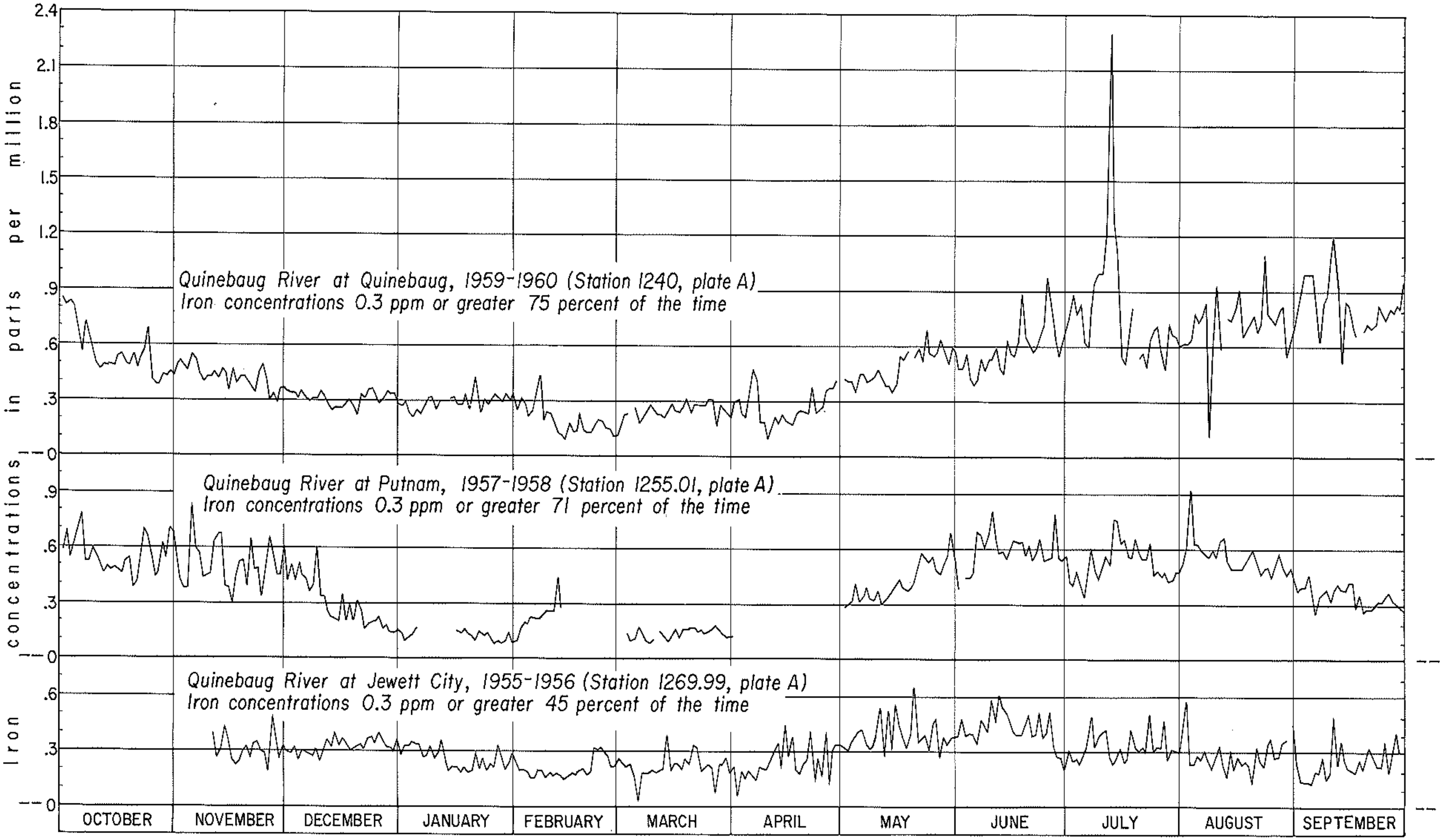
Through the years, large quantities of iron oxide have accumulated on the river bottom above Putnam. Little of this iron waste goes into solution under present conditions, but should the acidity of the water rise sharply due to future waste-disposal practices or an accidental spill, increased concentrations of dissolved iron would be expected along the entire length of the Quinebaug River in Connecticut.

Recent research has demonstrated that various processes may be used to remove grinding rouge from the waste discharged into the streams, and steps are anticipated to alleviate this source of pollution of the Quinebaug River (oral communication, W. H. Taylor, in testimony before the Natural Resources and Power subcommittee of the Committee on Government Operations of the U.S. House of Representatives, Hartford, Connecticut, October 4, 1963). However, present river-bottom accumulations are beyond the reach of any such treatment, and would require many years to dissipate by natural processes.

DETERGENTS

Detergents are objectionable pollutants in streams because even small amounts not toxic to humans will cause foam on water surfaces. Large quantities of foam have been observed from time to time at the base of several of the old textile-mill dams in the basin, such as the dam on the Quinebaug River at Danielson or that on the French River at Grosvenor Dale shown in figure 29. The foam quickly disappears in the quiet waters below the dams. Only small quantities of detergents are present in the major streams, but these quantities are sufficient to cause foaming where the water is aerated as it spills over riffles or dams. Other factors, such as high concentrations of organic matter from sewage or from natural sources, may contribute to the foam.

Concentrations of ABS (alkyl benzene sulfonate), a principal constituent of "hard" detergents, were generally less than 0.5 ppm, the upper limit recommended for drinking water by the U.S. Public



Iron concentrations in the Quinebaug River are highly variable from day to day, but in general are greatest during the period of low streamflow from June through October; for example, compare the iron content at Putnam shown above with the daily streamflow for the same period in figure 25. Iron content decreases downstream from Quinebaug to Jewett City, indicating that a substantial part of the iron enters the river north of the Massachusetts line.

Figure 28.--Iron concentrations in the Quinebaug River at Quinebaug, at Putnam, and at Jewett City.

Figure 29.--Foam on the surface of the French River below the dam at Grosvenor Dale.

Health Service. The maximum concentration of ABS in water samples from 13 sites along the Quinebaug, French, Little, Five Mile, Moosup, and Pachaug Rivers was 0.8 ppm, in a sample from the French River at Wilsonville: although this concentration does not indicate that the water is toxic, it does indicate the presence of sewage in the water.

As of July 1965 the detergent industry has replaced the "hard" ABS material in household detergent with a readily biodegradable LAS (linear alkylate sulfonate) material. This means that where there is proper sewage treatment, the esthetic problem of foam from detergents residues will no longer occur when only LAS is present.

SEWAGE

Sewage from several community-wide sewer systems, individual homes, and groups of homes discharged directly into streams at several locations in the basin. In 1965 treatment was provided to sewage discharged from the municipalities of Putnam, Plainfield Village, and Danielson. The elimination of individual sources of sewage discharge, the treatment of community sources, and the improvement of existing sewage treatment facilities is part of a continuing program of the State Water Resources Commission. At any given time the Commission can provide current information on the extent and effect of this type of pollution.

SEDIMENT AND TURBIDITY

Most streams carry at times various amounts of gravel, sand, silt, and clay eroded from their banks and channels or carried into the streams by water running overland. In the Quinebaug River basin, sediment in streams is not a serious problem because even the least permeable soils in areas of till absorb a substantial part of the precipitation and the complete vegetative cover protects the land surface from erosion by water flowing overland.

A reconnaissance inventory of sediment in streams was made in 1962-1963 during periods of high streamflow following storms. Sediment concentrations were determined for 15 sites on 8 streams. In addition, data are available from a few measurements made in 1956 and in 1959. Sediment concentrations ranged only from 2 to 32 ppm and when converted to sediment loads (concentration times discharge) ranged from less than 1 ton per day to more than 215 tons per day. These measurements represent near-peak sediment loads for the storms sampled; average loads would be much less. The measured sediment loads varied widely and should not be used as a basis for long-term predictions. The larger loads occur during spring thaws, intense thunderstorms, or other periods of high runoff. The highest loads during the sampling period appear to have resulted from sediment contributions from areas of bridge or residential construction.

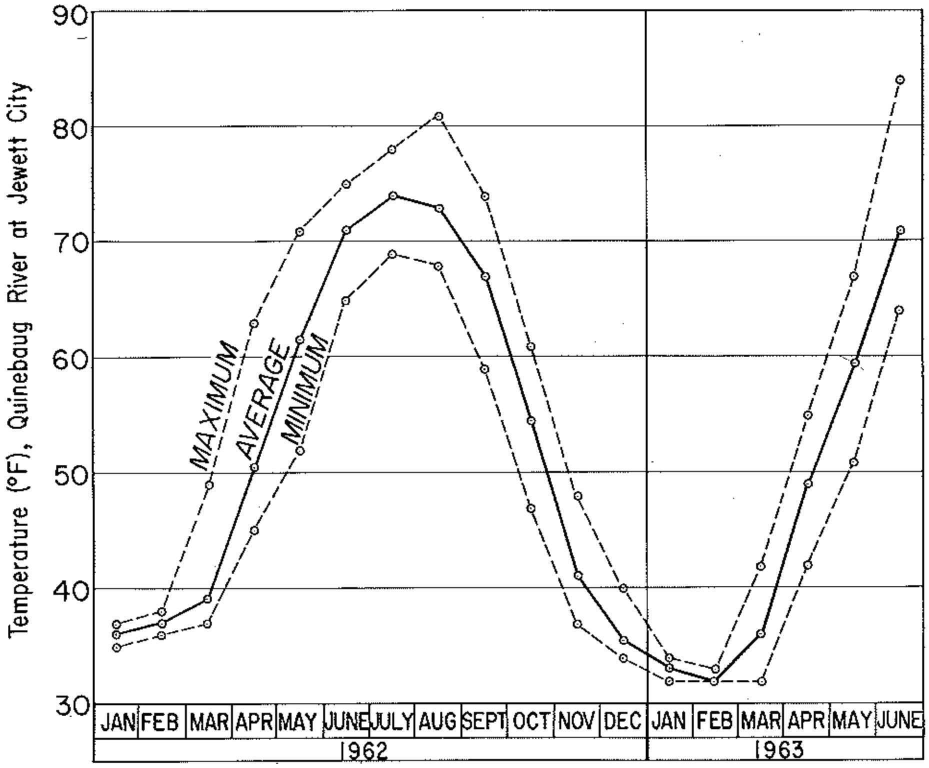
Turbidity of water is caused by suspended or colloidal silt or clay particles, microorganisms, pulp fibers, or other material originating in the natural process of erosion, in sewage, or in industrial wastes. It is objectionable for many industrial uses, notably for use by the food industry, the paper industry, and the textile industry, and large amounts may injure fish and other aquatic life.

The available data suggest that turbidity of stream waters is potentially troublesome at least locally within the basin. The variation of turbidity with streamflow at a site is illustrated by data collected from 1950-1953 by the Water Resources Commission on the Quinebaug River at West Thompson. The data show that the turbidity ranged from 1 to 40 ppm, and that the highest values were reached immediately following intense storms during August, September, and October when streamflow is low. Studies by the Water Resources Commission on the major streams of the basin indicate that the larger streams have the higher turbidities because they contain greater amounts of industrial wastes; generally the turbidity was about 8 ppm.

TEMPERATURE

The temperature of water in streams and lakes changes continuously and varies in a complex fashion from place to place. Temperature patterns are therefore difficult to describe in detail, but the major features can be outlined.

The temperature of all surface-water bodies follows a seasonal cycle in response to changes in air temperature. Freezing-point temperature is reached in most streams during the winter months, at least for brief periods. Maximum



The temperature of the Quinebaug River fluctuates seasonally. The highest, lowest, and average water temperatures in the Quinebaug River at Jewett City for each month were determined from continuous temperature measurements obtained about 3 feet above the river bottom. During low-flow periods in 1962 and 1963, the river averaged about 4.5 feet deep at the measurement site.

Figure 30.--Temperature of the Quinebaug River at Jewett City

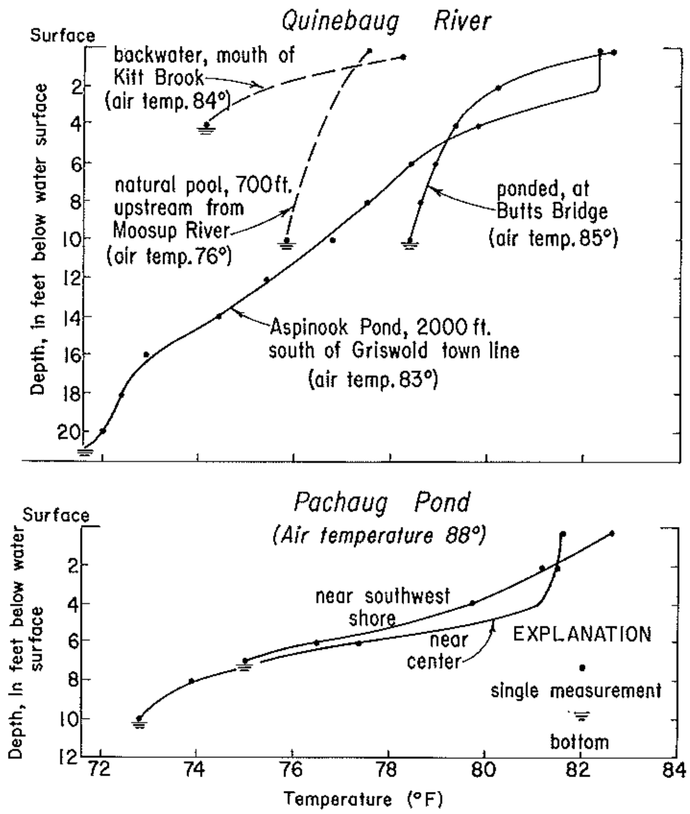
Table 19.--Variation in water temperature in the Quinebaug River.

Station	Type of measurement	Water years	Minimum water temperature (°F)	Water temperature (°F) which was equal to or less than values shown for indicated percentage of time: 5	25	50	75	95	Maximum water temperature (°F)
Quinebaug River at Quinebaug	Once-daily	1960	32	33	37	56	70	78	82
Quinebaug River at Putnam	Once-daily	1958	32	34	43	56	68	78	80
Quinebaug River at Jewett City	Continuous	1959-1963	32	33	38	52	70	78	84

temperatures commonly occur in July or August. The maximum, minimum, and average temperature of the water in the Quinebaug River at Jewett City for each month from January 1962 through June 1963 is plotted in figure 30; monthly average temperatures at other locations on large streams in the basin would probably be very similar. Except when the water surface is frozen, diurnal temperature fluctuations occur following similar changes in air temperature. Mean daily water temperature in the larger streams is more commonly above than below mean daily air temperature during all seasons of the year.

Because of the importance of temperature in various industrial uses of water, a continuous record of the temperature of the Quinebaug River at Jewett City has been obtained since 1958. River temperature was also measured daily for 1-year periods at Quinebaug and at Putnam. Table 19, based on these records, shows what temperatures the river water remained below during 5, 25, 50, 75, and 95 percent of the time.

The data in table 19 and additional information collected from reconnaissance temperature surveys indicate that there is generally only a few degrees difference in the temperature of the Quinebaug River between the Quinebaug, Putnam, and Jewett City sites. Accordingly, the continuous thermograph at Jewett City can be used as an approximate index of temperature along the entire length of this river in Connecticut. Records are



On a sunny summer day, water temperature in pools along stream channels and in lakes decreases with depth. Measurements of selected points in the Quinebaug River and Pachaug Pond on July 17-19, 1963 are shown. Air temperature was measured at sites a few miles away.

Figure 31.--Vertical temperature gradients at selected points along the Quinebaug River and in Pachaug Pond.

published in an annual series of U.S. Geological Survey Water-Supply Papers, and current information can be obtained from the Hartford, Connecticut office of the U.S. Geological Survey.

In many small streams, a considerable proportion of the flow represents ground-water runoff that entered the channel a short distance upstream and has not been long in contact with the air. By contrast, most of the water in the major streams has been flowing in stream channels for some distance, and may have been detained in one or more ponds. Therefore, because ground water enters streams at a relatively uniform temperature, diurnal temperature fluctuations and the annual range in monthly average temperatures are probably somewhat less in small streams than in the major rivers. During hot weather in July, 1963, all but one of the tributaries entering the Quinebaug River between Wauregan and Jewett City were observed to contribute water several degrees cooler than the main river (the exception being Mill Brook, on which there is a large pond just above the mouth).

In bodies of quiet water, including lakes and natural pools along river channels, thermal gradients may exist between top and bottom, and bottom temperatures sometimes depart considerably from air temperature. During hot, sunny weather in July, 1963, vertical temperature gradients were noted almost everywhere in Pachaug and Hopeville Ponds, and also in pools or ponds on the Quinebaug River which were deeper than 6 feet or out of the main current (figure 31). These gradients reflect heating of the surface water during the day and accumulation of cool ground-water discharge near the bottom. In streams with appreciable flow, these gradients probably disappear on cool days or at night. On some of the larger lakes, however, thermal stratification is maintained throughout the summer and winter seasons, with vertical circulation occurring only in the spring and fall when the water is near its greatest density at 39.2° F (Nordell, 1951, p. 118). This spring and fall turnover or thermocline effect sometimes causes troublesome turbidity in reservoirs. The Connecticut State Board of Fisheries and Game (1959) reports that portions of Alexander Lake, Beach Pond, Beachdale Pond, Long Pond, Moosup Pond, Packer Pond, and Roseland Lake are thermally stratified.

Return of water that has been used for industrial cooling and air conditioning to streams may have a marked effect on stream temperature and may cause local thermal stratification. However, temperature irregularities due to waste discharge are few and small in the basin.

WATER IN AQUIFERS

The amount of water that may be obtained from a well at any site within the Quinebaug River basin depends chiefly on the capacity of the water-bearing deposits to transmit water and on the thickness of those deposits. On the other hand, the amount of water that can be obtained on a long-term basis over a wide area depends not only on the water-transmitting capacity and thickness of the underlying deposits but also on the amount of water that infiltrates the deposits from precipitation, the amount of water that can be induced to infiltrate the deposits from streams or lakes, and the amount of water that is stored in the deposits. These factors, which must all be considered in developing and managing ground-water supplies in the basin, are evaluated in this section of the report.

AQUIFERS

With respect to the development of water, the water-bearing deposits in the basin can be grouped into 3 principal aquifers: bedrock, which underlies the entire basin; till, which directly overlies the bedrock at most places throughout the basin; and stratified drift, which overlies till and bedrock within most valleys. The relative position of each aquifer is shown in figure 2 and in figure 32, diagram D.

STRATIFIED DRIFT

The stratified drift is the most important aquifer in the Quinebaug River basin, as it is the only one generally capable of yielding 100 gpm (gallons per minute) or more to individual wells. Although widely distributed, it occurs chiefly in lowlands and covers only about 25 percent of the basin (plate B). It consists of layers of sand, gravel, silt, and (in a few places) clay. Variations in the proportions of these different-sized materials are important, because layers composed of the coarser sizes--gravel or medium to very coarse--are the only ones that can transmit large quantities of water to wells. Therefore, on plate B the stratified drift is subdivided into coarse-grained deposits and fine-grained deposits.

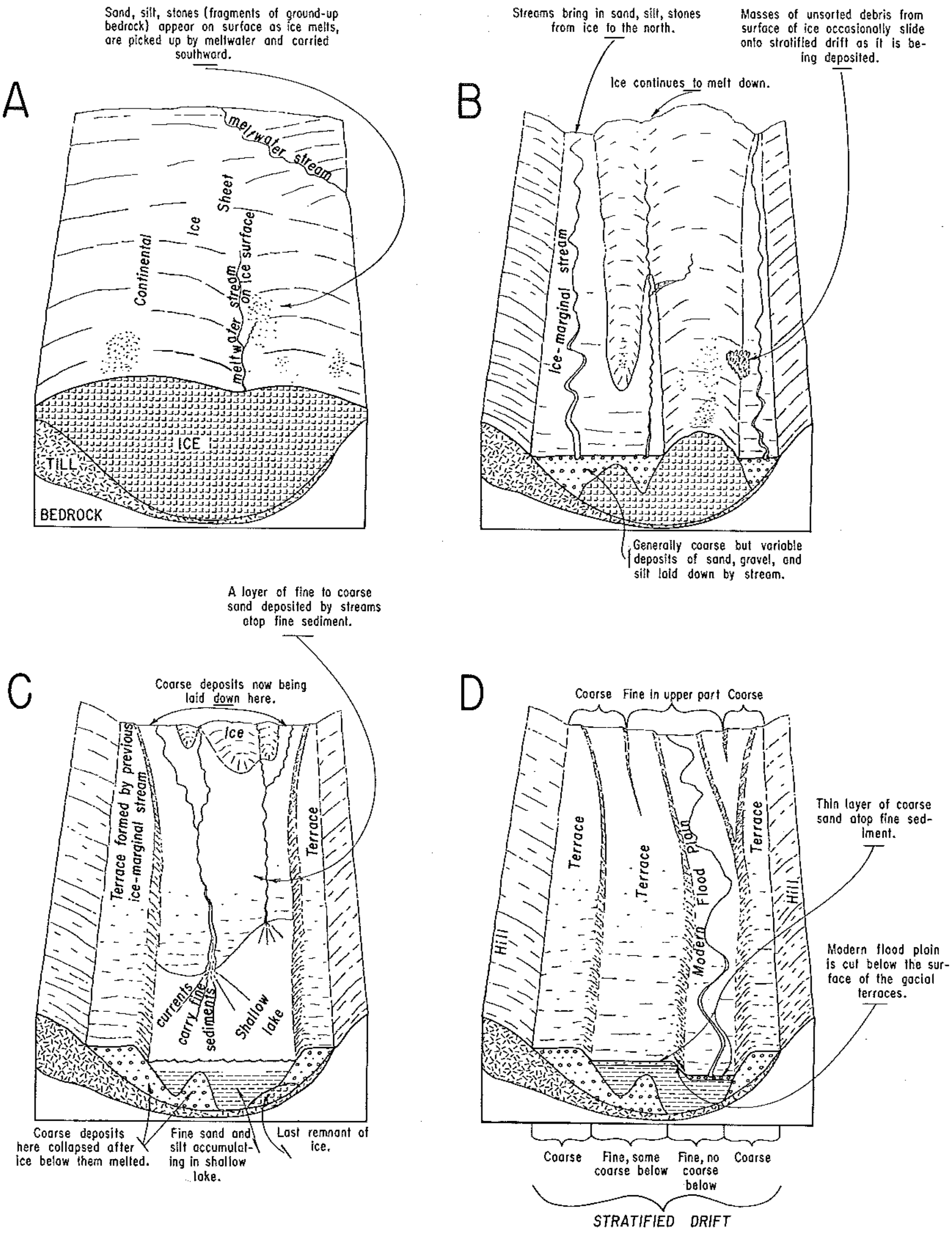
The distribution of these deposits reflects their manner of origin, as shown in figure 32. Nearly all of them were laid down by or in melt-water released as the ice sheet which formerly covered Connecticut melted (figure 32, diagram A). The deposits mapped as coarse grained were laid down by rushing melt-water streams along channels or in small ponds beside and atop masses of melting ice (figure 32, diagram B). These deposits are extremely heterogeneous. Individual layers range in average grain size from cobble-boulder gravel to silt. Some layers are well sorted; that is, they contain grains all about the same size. Others, poorly sorted, contain mixtures of many different sizes; some very poorly sorted layers consist of a tough mass of silty sand and gravel resembling concrete. The important thing about these deposits is that some coarse, well sorted beds capable of transmitting a substantial amount of water are present at most sites, although the heterogeneity of the deposits means that some sites are much more favorable for well construction than others.

Most of the deposits mapped as fine grained were laid down in shallow lakes and broad flood plains which occupied many of the larger valleys for a while after most of the nearby ice had melted (figure 32, diagram C). Commonly these fine-grained deposits consist of silt or silt and clay at the bottom but grade upward to very fine and fine sand. These fine-grained deposits are almost everywhere capped by a layer of pebbly medium to coarse sand 5 to 25 feet thick, which originated as glacial stream-bed or delta deposits. Where present-day rivers cross the fine-grained deposits, relatively coarse alluvium forms the capping layer. The coarse capping layer that overlies fine-grained deposits is commonly above the water table, but in some natural depressions or broad flood plains the capping layer extends below the water table and can be tapped by shallow wells.

Some predominantly coarse-grained deposits were laid down atop glacial ice and they collapsed when the ice melted. In some places they were later buried or overlapped by fine-grained deposits, as shown in figure 32, diagrams B and C. The fine-grained deposits can be mapped with fair accuracy, but it is much more difficult to map the areal extent of the underlying coarse-grained deposits. In areas mapped as partly or entirely fine grained, there are many feet of sediment too fine to yield water to a screened well, but coarse-grained deposits may be present below the fine-grained deposits. Areas where coarse-grained deposits are known or inferred to underlie the fine-grained deposits are shown on plate B. Such buried coarse-grained deposits appear to be widespread; where present they are an important aquifer, although they are thin in some places, and the overlying fine material may limit recharge.

PERMEABILITY

Descriptions of aquifers must be translated into quantitative hydrologic terms to be of maximum value in estimating the yields of wells. One of the most useful terms is the coefficient of permeability (hereafter called simply permeability) which is a quantitative expression of the water-transmitting capacity of earth materials. The permeability is defined as the rate in gpd (gallons per day) at which water will pass through a cross-sectional area of 1 square foot under a hydraulic gradient of 1 foot per foot. The permeability, which depends on the size and degree of interconnection of openings in water-bearing materials,



In an idealized valley like many in the Quinebaug River basin, glacial ice sheet fills the valley, but is beginning to melt (A). Predominantly coarse stratified drift is deposited by streams (B). Some coarse deposits collapse as buried ice melts, and fine sediment capped by a thin coarse layer is deposited (C). The present-day situation (D); the 3 different classes of stratified drift labeled at the base of the block are represented by map patterns on plate B.

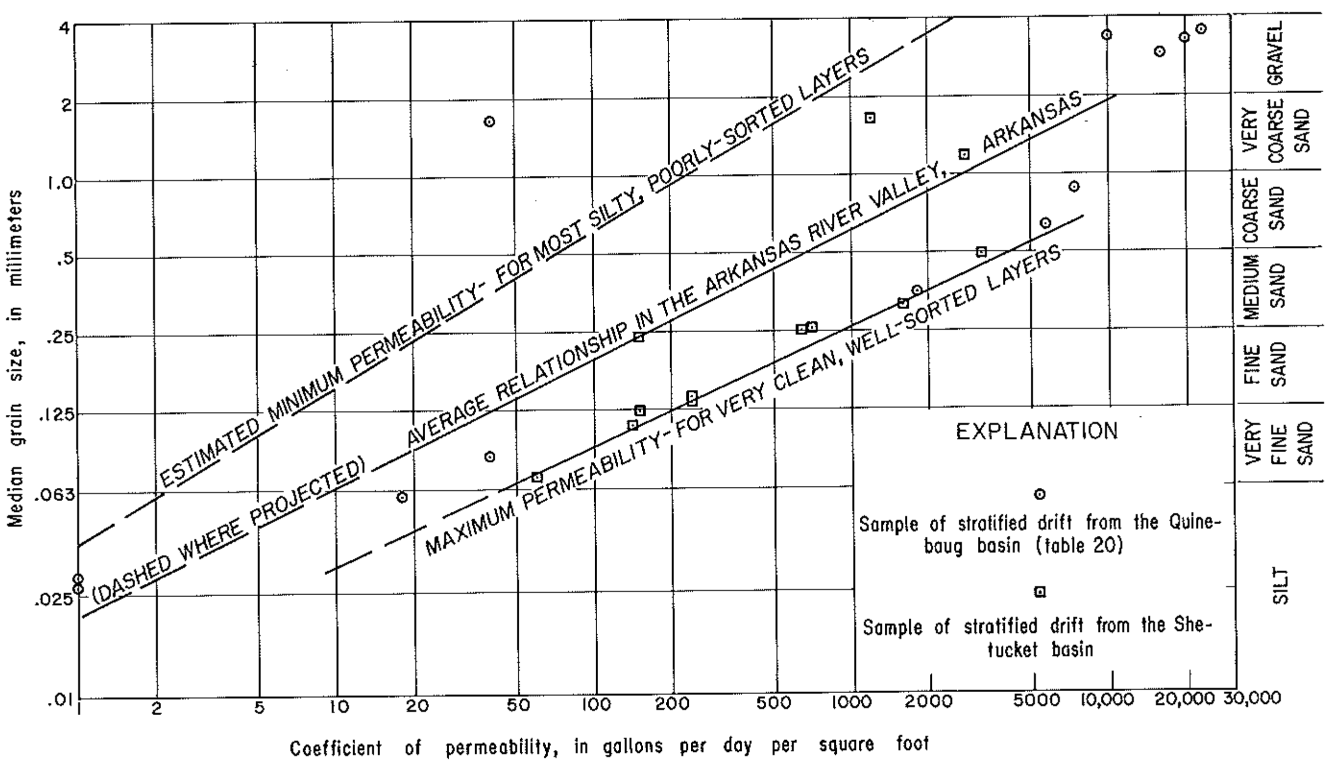
Figure 32.--Origin of stratified drift deposits.

was determined for materials from aquifers in the Quinebaug River basin by laboratory methods and for saturated sections of aquifers by analyses of water-level data collected during pumping tests of wells.

Laboratory measurements of permeability and grain-size distribution were made on 14 undisturbed samples of stratified drift (table 20). Included in these 14 samples were 6 samples of fine-grained deposits and 8 samples of coarse-grained deposits. The coarse-grained deposits include several of the best sorted layers examined during field work, and 2 unusually poorly sorted layers; their permeability ranged from 40 to 23,000 gpd per sq ft. The samples of fine-grained deposits were oriented vertically because their permeability in this direction (which is generally smaller than horizontal permeability) affects the rate of recharge to any underlying coarse-grained deposit; values ranged from 0.2 to 39 gpd per sq ft.

Permeability increases with increasing median grain size. A plot of permeability versus median grain size is shown in figure 33 for each of the samples in table 20, and for 12 samples of stratified drift from the Shetucket River basin, which adjoins the Quinebaug River basin on the west. For comparison, a line is included that represents the average relation between permeability and grain size of alluvial materials in the Arkansas River valley of Arkansas, plotted from adjusted data given by Bedinger (1961, p. C32). The scatter of data is related in part to differences in sorting or siltiness of the different samples. Most of the Connecticut samples plot to the right of the Arkansas line, which is not surprising because many of the samples from both the Quinebaug and Shetucket River basins were deliberately collected as examples of the materials in the best sorted layers of the stratified drift. This group of especially well sorted samples (including those with sorting coefficients of 1.3 to 1.4 in table 20) appear to define a line representative of maximum permeability (figure 33)--that is, if the median grain size of a layer is known, its permeability is unlikely to exceed that corresponding to this line, and may be less. A tentative line of minimum permeability versus grain size, intended to represent typical poorly sorted layers, is sketched on figure 33; data for 2 samples of sandy till (table 23) were considered. Not enough is known concerning the proportion and permeability of moderately to poorly sorted layers in the stratified drift, but available data suggest that average conditions in Connecticut are no less favorable than the average line based on Arkansas data, and may be very similar to it.

Using the relationship shown in figure 33 between permeability and median grain size for the Quinebaug and Shetucket River basins, it was possible to estimate the permeability of stratified drift at many places where descriptive logs of materials penetrated by wells are the only data



The line of maximum permeability was defined by undisturbed samples from Connecticut tested in the laboratory. The Arkansas average line was defined by laboratory tests of drill cuttings, adjusted by the results of pumping tests (Bedinger, 1961), and may approximate average conditions in Connecticut.

Figure 33.--Relationship between permeability and median grain size of stratified drift.

Table 20.--Laboratory determinations of permeability of stratified drift from the Quinebaug River basin.

Description	Particle-size analysis: Percent clay (<0.004 mm)	Percent silt (0.004-0.0625 mm)	Percent fine sand-very fine sand (.0625-0.25 mm)	Percent medium sand-very coarse sand (0.25-2 mm)	Percent gravel (>2 mm)	Median grain size (millimeters)	Sorting coefficient 1/	Sample orientation	Specific yield (percent)	Laboratory coefficient of permeability (gpd per sq ft)
Sandy gravel 2/	1.8 3/		2.1	29.0	67.1	3.5	2.36	Horizontal	36.1	23,000
Sandy gravel	2.4		8.4	24.4	64.8	3.4	2.71	do	35.3	10,000
Sandy silty gravel 4/	2.4	8.0	3.0	18.7	67.9	3.3	1.96	do	24.6	20,000
Sandy gravel 2/	5.1		8.2	21.3	65.4	2.95	1.93	do	36.6	16,000
Gravelly silty sand 4/	7.6	10.0	9.5	32.0	40.9	1.65	3.84	do	24.1	40
Gravelly sand	0.6		4.0	75.2	20.2	0.88	1.77	do	43.6	7,400
Sand	1.3		9.1	82.6	7.0	0.64	1.49	do	46.8	5,700
Sand	0.4		20.6	79.0	0	0.36	1.31	do	44.4	1,800
Silty sand	0.2	22.8	76.2	0.8	0	0.084	1.33	Vertical	41.4	39
Sandy silt	0.2	55.4	44.2	0.2	0	0.059	1.41	do	40.4	18
Sandy silt	2.4	85.6	12.0	0	0	0.029	1.64	do	31.0	1
Sandy silt	2.0	80.0	16.8	1.2	0	0.027	1.64	do	27.5	1
Silt	5.4	92.8	0.8	1.0	0	0.0185	1.56	do	25.7	0.7
Clayey silt 5/	14.5	82.5	3.0	0	0	0.0145	1.81	do	13.9	0.2

1/ The sorting coefficient is an index to the mixtures of grain sizes in earth materials. A material with a sorting coefficient of 1 is perfectly sorted; that is, it consists entirely of grains of the same size. A material with a sorting coefficient of less than 2.5 is considered well sorted, and a material with a coefficient of more than 4.5 is considered poorly sorted.

2/ Selected as probably the most permeable beds observed in surface exposures, with the exception of some openwork pebble gravels which were too coarse to fit in sample can.

3/ Percent clay and silt combined.

4/ Selected as examples of coarse sand to granule gravel that were well sorted except for a substantial silt content. Such beds are fairly common in the predominantly coarse-grained deposits. In the first sample the silt formed a coating on each grain; in the second it partially filled the interstices.

5/ Includes one layer 3/8-inch thick that is about 90 percent clay broken into blocks along joints.

Table 21.--Results of pumping tests on wells in stratified drift in the Quinebaug River basin.

Type of material at well site: Inferred from geohydrologic map at dug well sites and from driller's log at site of Pl 185.
Type of analysis: B, "bailer" method (Ferris and others, 1962, p. 92); N, Theis non-equilibrium method (ibid. p. 103).
Specific capacity from test: Based on rate of recovery of water level during first minute after shutdown of pump.

Estimated specific capacity after 8 hrs pumping: Estimated by method described by Walton (1962, p. 12).
Dug wells: Dug wells are constructed with fieldstone linings.
Drilled well: Drilled well is cased to 50 ft, screened 50-64 ft.

Well no.	Saturated thickness penetrated (feet)	Type of material at well site	Duration of test (minutes)	Pumping rate (gpm)	Coefficient of transmissibility (gpd/ft)	Type of analysis	Coefficient of permeability (gpd/sq ft)	Specific capacity from test (gpd/ft)	Estimated specific capacity after 8 hrs pumping (gpm/ft)	8-hour specific capacity per foot of saturated penetration
Dug wells										
Sg 79	4.37	Fine-grained deposit; coarse cap may be thin	3	45	577	B	120	2.3	0.8	0.2
Th 21	2.35	Fine-grained deposit; coarse cap may be thin	5	28	4,200	B	1,400	16.7	8	3.3
Pl 5	1.3	Fine-grained deposit, with coarse cap	5	27	5,600	B	2,500	19	9.7	7.5
Ki 55	4.08	Fine-grained deposit, with coarse cap	4 90	42.5 20	5,410 5,400	B N	1,150	18 10.5	8.7 9.7	2.1 2.4
Vo 14a	5.63	Coarse-grained deposit	7 50	38 36.5	30,000 (?)	B,N	4,000 (?)	-- 58	-- 48	-- 8.6
Vo 7	5.2	do	8 75	28 36.5	11,000 16,300	B N	2,400	31 23	17.5 21	3.3 4
Vo 93a	5.0	Coarse-grained deposit; may bottom in till	4	30.5	5,000	B	900	20	9.7	2
Drilled well										
Pl 185	50	Coarse-grained deposit; overlain by about 20 ft of fine-grained deposits	1,140	1,500	100,000	N	2,000			

available. From these data it is estimated that the average permeability of the predominantly coarse-grained deposits shown on plate B ranges from 200 to 4,000 gpd per sq ft and averages about 900 gpd per sq ft over the basin. The average permeability of the fine-grained deposits may range from 50 to about 500 gpd per sq ft, exclusive of the thin and commonly dry coarse capping layer which has a permeability of 500 to 4,000 gpd per sq ft. Vertical permeability of the fine-grained deposits is controlled by the finest layers and may be as low as 0.2 gpd per sq ft where clay layers are present (table 20).

Permeability of stratified drift was also estimated from specific capacity data based on drillers' reports of yield and drawdown for 16 wells with 9 to 18 feet of screen. Methods described by Theis (in Bentall, 1963) and Walton (1962, p. 12) were used. Permeability thus estimated ranged from more than 40 to more than 3,500 gpd per sq ft and the median was 400 gpd per sq ft. Many of the results are probably lower than the true values because the methods used assume that the wells tap the aquifer with maximum efficiency, but the figures are useful because they approximate the average for the entire saturated thickness of the aquifer at the well sites.

Analyses of pumping tests on wells at 8 sites in the Quinebaug River basin gave values of permeability that ranged from 120 to 4,000(?) gpd per square foot. Complete analyses of the water-level data collected during the pumping tests are not given here, but the data are given in a basic-data report companion to this report (Thomas and others, 1966) and the results are summarized in table 21. The values of permeability computed from these pumping tests are similar to those for similar stratified drift materials determined from pumping tests in nearby Rhode Island (Allen and others, 1963; Allen, written communication) and in New York (Heath and others, 1963, p. 107-125).

SATURATED THICKNESS

Stratified drift that is above the water table during dry weather is of little value as a source of water, no matter how thick and permeable it may be. The water-yielding potential of stratified drift is directly proportional to how far it extends below the water table--that is, to its saturated thickness. Saturated thickness of stratified drift within the Quinebaug River basin is shown on plate B.

As indicated by plate B, saturated thickness exceeds 40 feet over large areas, and in a very few places the saturated thickness exceeds 120 feet. Commonly, however, areas of greatest saturated thickness are also areas with a substantial thickness of fine-grained relatively impermeable sediment (see figure 32, diagram D). There are also many areas where the stratified drift is only a few feet thick or is located high on valley walls where it is easily drained, and thus the saturated thickness is small. In areas indicated on plate B as having saturated thickness less than 10 feet the stratified drift cannot provide large water supplies.

DEVELOPMENT BY WELLS

Drilled wells.--More than half the wells in the Quinebaug River basin reported to yield more than 100 gallons of water per minute are drilled, screened wells tapping stratified drift, as are many wells that yield 50 to 100 gpm. The characteristics of wells in this basin drilled for industrial, commercial, or public-supply purposes

Table 22.--Characteristics of drilled industrial, public-supply, and commercial wells tapping stratified drift in the Quinebaug River basin.

Characteristic		Range	Median	Number of wells
Depth (feet)		37± - 85	61	24
Saturated penetration (feet) 1/		24 - 70	39	24
Length of screen (feet)		0 - 18	10	23
Reported yield (gpm)		6 - 1500	95	24
Specific capacity (gpm/ft) 2/		0.4 - 195	7	23
Specific capacity per foot of saturated penetration		0.007- 3.7	.18	23
Diameter	6 inches	-	-	10
	8 inches	-	-	6
	10 inches	-	-	6
	12 inches	-	-	1
	18 inches	-	-	1
Wells with 9 to 18 feet of screen	Specific capacity 2/	2± - 195	12	16
	Specific capacity per foot of saturated penetration	0.04 - 3.7	.29	16

1/ Six wells reported to penetrate full thickness of stratified-drift aquifer; several others may closely approach full penetration.

2/ Adjusted to 8-hour pumping period by use of curves presented by Walton (1962, p. 13).

and finished in stratified drift are summarized in table 22. The last 2 lines of the table show that the median specific capacity of wells of this type with at least 9 feet of screen is 12 gpm per foot of drawdown, and for each foot penetrated below the water table the specific capacity increased by a median value of 0.29 gpm per foot of drawdown. These values probably come closest to approximating the potential of wells tapping stratified drift in favorable localities.

Dug wells.--Dug wells tapping stratified drift are in common use in the Quinebaug River basin, expecially for supplying private homes. Most are reported to provide sufficient water for the intended purpose, but few owners know just how many gallons per minute their wells will deliver. Results of pumping tests on 7 such wells are given in table 21. At 4 of the well sites fine-grained deposits occur beneath a coarse cap, but test results suggest that only well Sg 79 penetrates the fine-grained deposits. It is concluded from the last column in table 21 that a dug well pumped for 8 hours should be able to obtain about 2 gpm per foot of drawdown for each foot of saturated medium to coarse sand or gravel that it penetrates, and might obtain more at some locations.

Dug wells are especially suited to areas of stratified drift where the water table is close to land surface but the saturated thickness is too small for other types of wells, or where only a few feet of saturated coarse-grained deposits overlies fine-grained sediment. In such areas, several dug wells spaced 100 ft or more apart might together be able to provide a few hundred gpm. Small supplies, such as for private homes, can be obtained from fine-grained deposits. For maximum yield, perforated concrete or metal casing, laid stones, concrete blocks, or some other open construction should be used below the water table rather than solid tiles, and a gravel envelope around the well may be desirable in sand deposits. The principal difficulty with this type of well is that of digging far enough below the water table so that adequate drawdown can be maintained when water levels are low in late summer. For this reason, the best time to dig a well is when water levels are already low, and it is desirable to construct the well so that it can later be deepened if necessary. Where bacterial purity is important, as in domestic or public supplies, care in location and in construction of the upper part of a shallow well is necessary; suggestions are provided in a pamphlet by the Connecticut State Department of Health (1948).

Driven wells.--Driven wells ("drive points") are fairly common in the basin; most of them utilize screened well points 2 or 3 feet long and supply a few gpm for private homes and camps. Little specific information on driven wells was obtained during the investigation. Where the stratified drift is neither too gravelly for easy driving nor too fine to yield water, this is the most economical form of well construction, although selection of the screen size best matched to the grain size of aquifer materials is a matter of trial and error. In areas underlain by fine-grained deposits (plate B), a well driven too deeply will encounter non-water-yielding fine and very fine sand or silt; pulling the point back into the coarser capping layer (if saturated) is easier than driving deeper and in many places is more likely to produce an adequate quantity of water.

Jetted wells.--Many test wells in the basin have been constructed by the jetting method, but only a few permanent wells. They cannot penetrate gravelly stratified deposits. Jetted wells may have longer, more carefully chosen screens than driven wells,hence larger yields. In some places, groups of jetted or driven wells pumped together provide substantial supplies of water. For example, six 2-inch wells, each about 30 feet apart, owned by the Jewett City Water Company have been pumped at 180 gpm together; the wells average 50 feet in depth and have 6-7 feet of screen exposed to the aquifer.

TILL

Till occurs just below the land surface over large parts of the Quinebaug River basin, including all major hills and uplands (see plate B), and underlies stratified deposits in the lowlands. It is a predominantly nonsorted, nonstratified material, composed of clay, silt, sand, gravel, and boulders mixed in various proportions. Thin lenses and irregular masses of stratified sand, silt, or gravel occur interbedded with the till here and there.

Till is made up of particles scraped and plucked from the bedrock as the ice sheet flowed southeastward across the Connecticut landscape. Part of the till was probably smeared onto the rock surface beneath the moving ice, and part was debris in or on the ice sheet that was let down on the land surface as the ice melted. The lenses of stratified material probably are deposits from glacial meltwater laid down in tunnels in or below the ice.

PERMEABILITY

The permeability of till varies from place to place in the basin depending on the proportion of silt and clay in the till and on whether lenses of stratified material are present. As determined in the laboratory, the permeability of 6 undisturbed samples of till ranged from 0.2 to 30 gpd per square foot (see table 23). Included in these 6 samples are 4 samples of relatively silty till which have the lower permeability values in the table and 2 samples of relatively sandy till which have the higher values.

As determined from pumping tests on 8 unused dug wells lined with fieldstone, the permeability of till ranged from 0.48 to 55 gpd per square foot. Each well was pumped for 4 to 7 minutes at rates as great as 45 gpm, and the volume of water pumped

Table 23.--Laboratory determinations of permeability of till from the Quinebaug River basin.

(All samples oriented in a vertical direction)

Location	Depth below natural land surface (feet)	Particle-size analysis: Percent clay	Percent silt	Percent sand	Percent gravel	Sorting coefficient	Specific yield (percent)	Coefficient of permeability (gpd per sq ft)
Black Hill Rd., 1,200 ft. east of Exley Rd., Plainfield 1/	17	12.0	27.4	48.1	12.5	4.33	4.6	0.2
Pit, 500 ft. north of Ennis Rd.--Allen Hill Rd. intersection, Brooklyn 1/	5?	11.8	37.0	34.7	16.5	4.59	4.1	.7
West end large pit west of Green Hollow Rd., 500 ft. south of Fall Brook, Killingly 1/	Pit floor	10.0	34.8	40.7	14.5	5.58	3.9	.6
East of new Rt. 12 expressway, just north of Killingly Drive, Killingly 1/	6	5.0	34.5	42.5	18.0	4.50	12.2	.4
Pit, 700 ft. east of Connecticut Turnpike, south of Moosup River, Plainfield 2/	9	3.5	29.4	44.3	22.8	6.07	20.3	17
Roadcut north of Evergreen St., east of Evergreen Cemetery, Plainfield 2/	3	4.0	26.8	45.8	23.4	6.18	20.9	30

1/ Selected as example of firm, relatively silty till.

2/ Selected as example of moderately sandy, easily-crushed, till.

was measured in large cans. Complete analyses of the water-level data are not given here, but the water-level data are given in the companion basic data report (Thomas and others, 1966). Water-level recovery was analyzed by the "bailer" method, and transmissibility and permeability were computed in the same manner as in similar tests on wells penetrating stratified drift (see p. 54). Results of the tests are summarized in table 24.

Pumping tests of wells NSn 25, Po 60, and Th 57 indicate permeabilities similar to those determined in the laboratory for samples of firm, silty till (table 23), and tests of Wk 19 and Vo 88 indicate permeabilities similar to those determined in the laboratory for samples of moderately sandy till, though for Vo 88 the result may be an average of the relatively permeable fine sand reported at the bottom of the well and less permeable till opposite the sides. Wells Bk 54, Po 64, and Po 62 probably penetrated sand lenses or very sandy till, because the permeabilities are higher than would be expected of most of the till in the basin. In general, the permeabilities determined from the pumping tests appear to be consistent with the laboratory determinations of permeability.

THICKNESS

Where till immediately underlies the land surface, it is generally between 10 and 35 feet thick. At many places, however, outcrops of the underlying bedrock protrude through the till cover. Although the actual patches of bare bedrock are small, ranging in area from a few square feet to a few hundred square feet, in localities where they are numerous the till is only a few feet thick. A layer of till atop the bedrock is also assumed to be present beneath the stratified drift in lowlands.

Abnormally thick accumulations of till occur in some bedrock valleys, in drumlins (see figure 34), and in sidehill accumulations within the basin. Most of the valleys in which streams flowed before the last glaciation had a roughly north-south trend, and thickness of till in these valleys is generally within the range given above. However, there also were short valleys or valley segments that trended east-west. These east-west valleys were more or less perpendicular to the direction of ice movement, and some of them were almost completely filled with till.

Locally within the basin thick accumulations of till occur on the flanks of large bedrock hills; some form lobes or mounds resembling drumlins, others lack any special shape. They appear to be most numerous on the north or northwest sides of bedrock hills, but other orientations are also common.

Most areas of thick till are small--nearly all occupy much less than one square mile--and the information available from well records and outcrops is sparse. Areas in bedrock valleys, in drumlins, or in sidehill accumulations where till is known or inferred from the available data to be more than 40 feet thick are indicated on

A well (Po 93) drilled at the house visible at the highest point on this hill reached bedrock at a depth of 188 feet. The smoothly-rounded shape evident from the photograph is also clearly shown on the topographic map. (See plates A-D; well location on plate A.) Drumlins are especially numerous in Pomfret and Woodstock.

Figure 34.--A drumlin near Pomfret Center: the hill north of Hamlet Farm Road, viewed from the northeast.

plate B. Till of this thickness affords important protection to drilled wells tapping the underlying bedrock, because bacteria present in septic-tank effluent discharged near the land surface stand very little chance of penetrating to the bedrock.

DEVELOPMENT BY WELLS

Drilled wells.--Till itself is much too impermeable to yield a significant amount of water to a drilled well, and sand or gravel lenses sufficiently thick and permeable to do so are rarely found within the till. However, permeable coarse-grained stratified drift, which can be tapped by drilled wells, does occur beneath the thick till in most of the east-west-trending bedrock valleys previously discussed. In nearly all of these valleys, one or more drilled wells are reported to penetrate several feet of gravel or sand between till and bedrock, or are cased through many feet of unconsolidated deposits but completed in some permeable layer above bedrock. Most of these wells are domestic or farm wells whose average reported yield and specific capacity are about half as large as corresponding values for similar wells tapping stratified drift where it lies atop the till in major valleys. These deeply-buried sand and gravel deposits may have been laid down by meltwater flowing away from the advancing ice sheet and later buried by till as the ice flowed over them. Their thickness is not generally known, but is estimated to range from about 10 to 40 feet. Because of their small extent, shown on plate B, and the likelihood that all recharge must move through relatively impermeable till or bedrock, they are probably not of major importance, although they undoubtedly are capable of further development.

Dug wells.--Large-diameter dug wells are the only practical means of tapping impermeable materials such as till. Many gallons of water are stored within such wells, ready for immediate withdrawal; the water withdrawn is replenished in the well by slow seepage from the till during non-pumping periods. Thirty years ago, nearly all homes, farms, and shops in upland areas depended for water supply on wells dug in till. Many of these dug wells have been replaced by drilled wells tapping bedrock, commonly because their yields were inadequate, at least during periods of drought, but many others are still in use and new ones are continually being dug.

The yields of 8 dug wells tapping till in the Quinebaug River basin were tested during this investigation; results are summarized in table 24. The figures in line I indicate the slow rate of replenishment in these wells; for example, if each well had 3 feet of water in it and were pumped down 2 feet, water would enter at rates ranging between 0.01 and 1.7 gpm. The 3 least productive of these wells would be inadequate for most homes today. At the other 5 sites, however, according to rough estimates in line L total replenishment would probably exceed 200 gallons in the course of a day, enough for the average family, as long as the water table did not drop within 2 feet of the pump intake. It is concluded that permanent supplies of better than 200 gallons per day could be obtained from dug wells at a majority of sites in areas of till, but that there are many sites where the till is too impermeable or too thin to provide this amount of water throughout the year. Modern excavating equipment permits digging farther below the water table than is normally possible by hand labor, and the current practice of digging a large hole and surrounding the lower few tiles with gravel increases the amount of water in storage in the well and, to some extent, increases the yield. Nevertheless, a well dug when water levels are not near their seasonal low should be constructed so that it can be deepened if need be, unless it already bottoms on bedrock or a large boulder.

BEDROCK

Bedrock underlies the entire basin, and though it is covered by till or stratified drift in most places, bedrock commonly crops out on hilltops and roadcuts. The cover of till and stratified drift deposits is thin compared to the relief of the bedrock surface, so the major

Table 24.--Results of pumping tests on dug wells in till in or near the Quinebaug River basin.

Well no. (A)	Bk 54	Po 64	Po 62	Vo 88 3/	Wk 19	Th 57	Po 60	NSn 25
Depth (feet) (B)	14.7	12.4	12.9	12.0	14.4	21.9	17.6	27.0
DATA FROM PUMPING TEST: Saturated thickness penetrated at time of test (feet) (C)	4.23	2.0	5.54	6.53	3.35	4.6	1.10	5.46
Length of time pumped (minutes) (D)	7	4	5	4.5	4	5	4	7
Volume pumped (gallons) (E)	77.5	137	151.3	180	118.5	135	139	213
Maximum drawdown during test (feet) (F)	.33	1.87	1.12	2.20	1.28	1.08	1.08	3.34
Average rate of recovery during first 0.1 ft of recovery (gpm) (G)	.26	.81	1.74	2.3	.41	.03	.0053	.038
Specific capacity based on first 0.1 ft of recovery (gpm/ft) (H)	.93	.44	1.63	1.07	.34	.03	.0052	.012
Specific capacity per foot of saturated thickness penetrated (gpm/ft/ft) (I)	.22	.22	.29	.16	.10	.007	.005	.002
Amount of recovery during 1st 24 hours of recovery (gallons) (J)	75 2/	125.4	146 2/	175 2/	105	30	8.8	35.8
Average drawdown during 1st 24 hours of recovery (feet) (K)	.17	.97	.57	1.11	.69	.92	1.04	3.02
Estimated recovery in 24 hours with an average drawdown of 2 feet (gallons) (L)	880	260	510	310	300	66	17	24
Coefficients of:								
Transmissibility (gpm/ft) (M)	264	137	280	150	77	9.7	2	2.6
Permeability (gpm/sq ft) (N) 1/	55	50	45	21	20	2	.75	.48

1/ The coefficient of permeability is the coefficient of transmissibility divided by the saturated thickness and is reduced slightly to allow for the entrance of water through the bottom of the well.

2/ Recovered virtually to extrapolated static water level in one day or less.

3/ Owner reports bottom of well is fine sand.

hills and valleys in the present landscape reflect the hills and valleys in the bedrock surface. The bedrock extends downward many thousands of feet, although only the uppermost few tens or hundreds of feet are of any significance as an aquifer.

The bedrock consists entirely of hard, crystalline rocks. Geologists have divided these rocks into several formations and groups, but because there are no significant differences in their water-bearing characteristics, they are not differentiated as formations for purposes of this discussion. Rodgers and others (1956, 1959) and Dixon (1964) give detailed descriptions of the lithology and mineralogy of these rocks; some additional information appears in this report in the section on chemical quality of ground water.

Nearly all of the bedrock in the basin is solid and unaltered by weathering. The mantle of soft, weathered rock that lay on the ground surface prior to glaciation was largely removed by the ice, so there are only a very few localities, protected from glacial erosion or underlain by rock extraordinarily subject to weathering, in which the upper few feet of the bedrock are soft and rotten.

PERMEABILITY

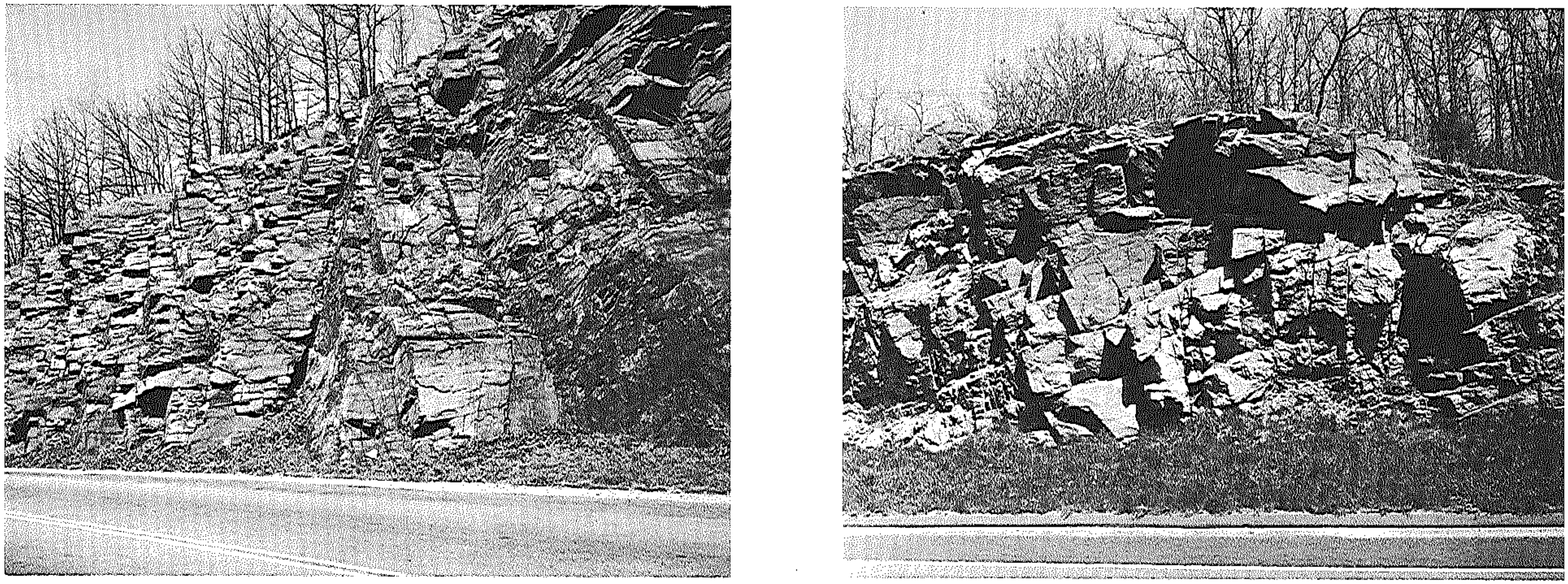
Spaces between the individual mineral crystals that make up crystalline bedrock are few, microscopically small, and poorly connected. Consequently, the intergranular permeability of crystalline bedrock is so minute as to be insignificant. Samples of several types of bedrock from the basin were tested in the laboratory and found to range in permeability from 0.00002 to 0.0004 gpd per sq ft (table 25). A drilled well penetrating 200 feet of such bedrock would have a yield of only 0.007 gpm, if all the water had to enter through intergranular pore spaces. Virtually all bedrock wells yield considerably more than 0.007 gpm, so it is apparent that water reaches such wells along avenues other than intergranular pore spaces. Many studies have shown that in crystalline bedrock, virtually all water movement occurs along fractures (also referred to as joints, "veins", or "seams") in the rock. Fractures are readily visible in most roadcut outcrops, and following a rainstorm water may occasionally be observed seeping from these fractures. Two good examples of fractured bedrock are shown in figure 35.

The occurrence and distribution of fractures in the crystalline bedrock of Connecticut are described and related to well yields in a classic study by Ellis (1909); nothing as complete has been published since. One of the most important characteristics of fractures is their irregular spacing; Ellis noted that in every quarry where fractures were developed over a considerable area they constituted a series of zones of close fracturing separated by intervals in which the distance between fractures was much greater (see figure 35, photograph B). Because of this irregular spacing, some wells penetrate many tens of feet of "dry" rock, not having intersected any significant water-bearing fractures; yet there may be nearby wells which obtained substantial yields from water-bearing fractures at shallow depth.

To learn more about the water-bearing characteristics of bedrock, pumping tests were run on 10 drilled wells tapping bedrock, and results were compared with drillers' yield tests of the same wells. Data collected during the pumping tests are given in the companion basic-data report (Thomas and others, 1966), and are summarized in table 26 along with data from the drillers' tests. Even though pumping levels were not measured exactly in many of the drillers' tests, specific capacities based on drillers' data fall in nearly the same rank as those computed from pumping tests. After adjusting test results to represent a time interval similar to that used by drillers, the ratios in the last column were computed; for most wells, multiplying the drillers' specific capacity by 1.5 gives a value close to the adjusted

Table 25.--Laboratory determinations of permeability of non-fractured bedrock from the Quinebaug River basin.
(All samples cored parallel to foliation or lineation)

Site from which sample was collected	Rock type	Specific gravity of rock material	Porosity (percent)	Specific yield (percent)	Coefficient of permeability (gpd/sq ft)
Quarry off Pine Hill Road, Sterling	granitic gneiss	2.67	1.5	0.7	0.0004
State Route 14, first roadcut east of Kitt Brook, Canterbury	mica schist	2.82	2.8	1.7	.00004
Quarry south of All Hallows Road Wauregan, Plainfield	hornblende-feldspar gneiss	2.80	0.7	0.0	.00004
Quarry on State Route 49, southern Voluntown	quartzite	2.68	2.2	1.2	.00003
Conn. Turnpike at Taylor Hill, Griswold	amphibolite	3.07	2.0	1.7	.00002



A. State Route 14, near Moosup, just west of Moosup River bridge. Bedrock outcrops in highway cuts exhibit more fractures than are present in similar rock some distance below the surface, but the series of flat, parallel fracture surfaces which can be seen sloping steeply downward and to the left across this entire outcrop may extend to considerable depth and serve as avenues of water movement.

B. U.S. Route 6, Killingly, just west of Franklin Avenue. Zones of closely-spaced vertical fractures near the right-center and left of the photograph alternate with zones in which the fractures are more widely separated. A series of widely-spaced fractures sloping gently to the left is also visible.

Figure 35.--Fractures in crystalline bedrock.

Table 26.--Results of pumping tests on wells in bedrock in the Quinebaug River basin.

Well no. (observation wells in parentheses) a/	Distance from pumped well (feet)	Data based on drillers' measurements: Penetration of saturated bedrock below casing (feet)	Data based on drillers' measurements: Yield (gpm)	Data based on drillers' measurements: Specific capacity (gpm/ft)	Data from pumping test a/: Length of time pumped (minutes)	Data from pumping test a/: Average rate of pumping (gpm)	Data from pumping test a/: Specific capacity, from recovery rate except as noted (gpm/ft)	Ratio of specific capacity from pumping test (adjusted to 2-hour basis), to specific capacity from drillers' measurements
Ki 193	-	100	12	≥ .48 >.99	123	8.0	7.0 b/	6.7
(Ki 202)	151		(>20)	>1.5				
Bk 49	-	118	30	.24 c/	59.5	8.1	1.8 d/	7
Ki 199	-	100±	16	.18 .26c/	120.8	7.3	.32 b/	1.2
(Ki 200)	133		(40)	(.34)				
Ki 201	-	120	8	.07 .21c/	70	6.4	.29 b/	1.3
(Ki 200)	195		(40)	(.34)				
Pl 294	-	92	5	.054	11.3	4.1	.10	1.4
Ki 218	-	112	4	.03	9.5	4.4	.06	1.5
Wk 72	-	337	1.25	.017	- e/	- e/	.04	1.8
Cy 115	-	150	4	.028 c/	8.5	1.3	.08	2.1
Vo 145	-	155	6.5	.04 c/	35.5	6.9	.09	2
Vo 146	-	312	0.75	.002 c/	10	4.3	.017	6.5

a/ Tests using observation wells, all water-level measurements in observation well. Other tests, all measurements in pumped well.

b/ Estimated from transmissibility and storage values computed from test.

c/ Water pumped with compressed air, reportedly from bottom of well; no pumping water level existed, but a pumping level 10 feet above the bottom was assumed in order to estimate specific capacity.

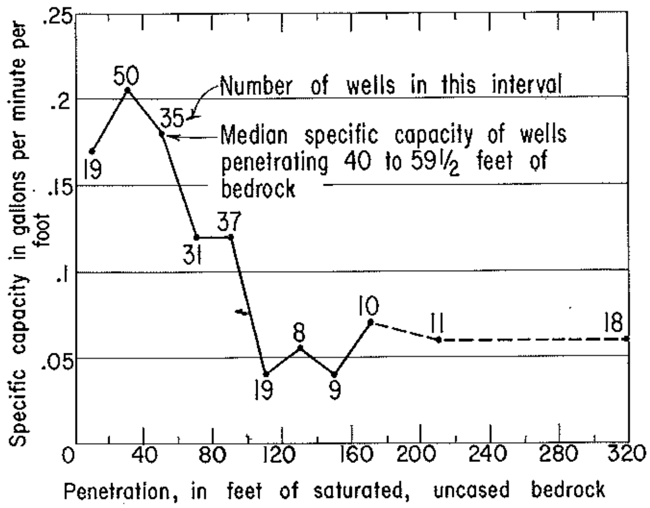
d/ Computed from pumping rate and drawdown at time of shutdown.

e/ Slug test; 10.2 gallons of water added in one-half minute.

test results. Thus, the data reported by drillers appear to provide a consistent and reasonable means of evaluating the water-yielding capacity of bedrock.

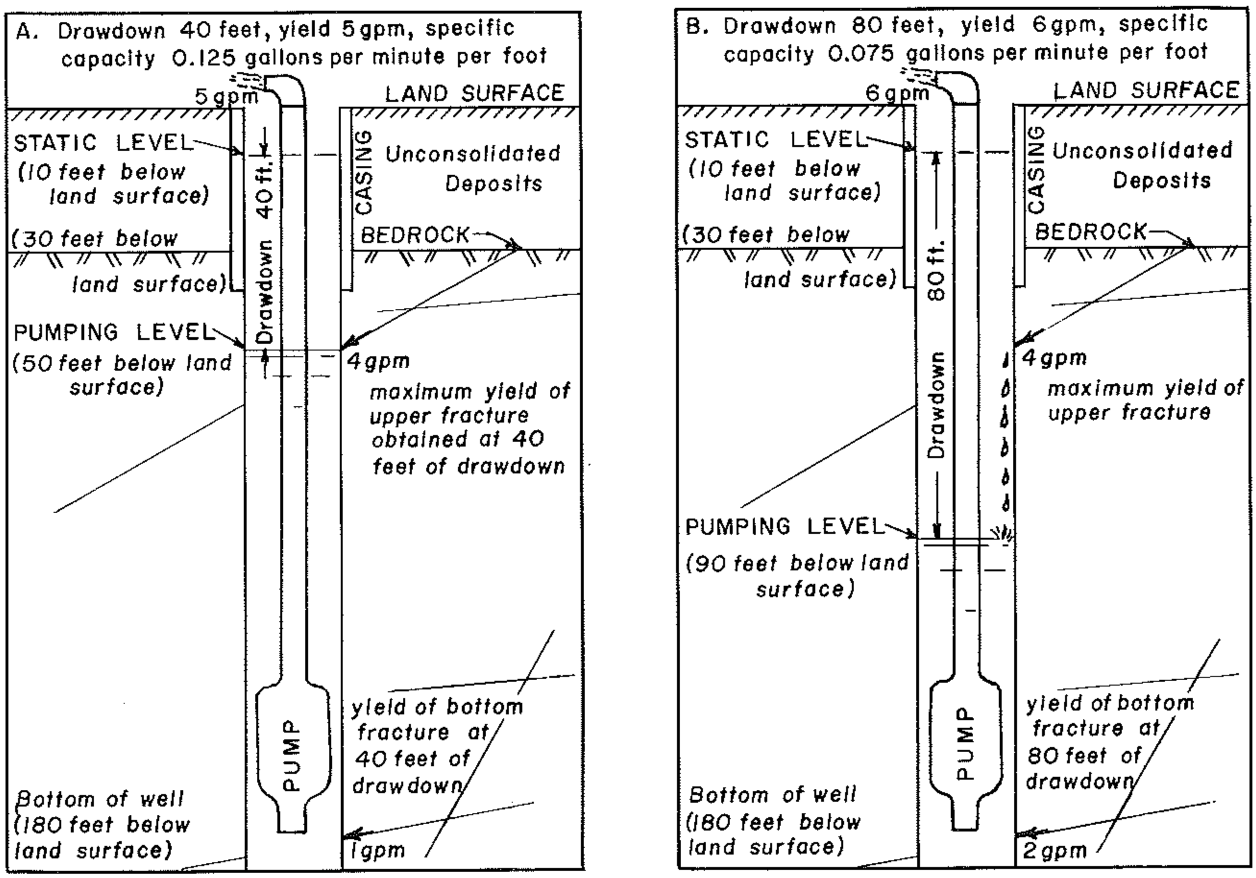
Specific capacities were computed for 247 wells in the Quinebaug River basin from drillers' measurements of yield and water level. These data plotted versus the saturated, uncased thickness of bedrock penetrated (figure 36) show that on the average, wells penetrating less than 60 feet of bedrock have larger specific capacities than deeper wells. This cannot mean, of course, that after a well is drilled deeper a larger drawdown is required to obtain the same yield. It may be that some of the deeper wells had relatively large specific capacities at shallow depths, but as they were drilled deeper two factors operated to reduce specific capacity: (a) pumping could now lower water levels below the shallow fractures, so their yield no longer responded to increased drawdown (see figure 37), and (b) the deeper parts of the bedrock were lacking in fractures. On the other hand, it may be that the deeper wells were drilled at sites where there were no fractures at depths less than about 60 feet and only a few fractures at greater depths. Thus, the variations in specific capacity shown in figure 37 could reflect either irregularity in the areal spacing of fractures or a decrease in the number and size of fractures with depth.

These results are compatible with those of other writers (Ellis, 1909; Cushman and others, 1953) who concluded that fractures decrease in number and size with depth, hence the chances of obtaining additional yield decreases as a well is



Median specific capacities of drilled wells are greatest for wells penetrating less than 60 feet of bedrock. The medians are plotted at the midpoints of the successive penetration intervals from which they were computed.

Figure 36.--Median specific capacities of wells penetrating bedrock in the Quinebaug River basin.



The well obtains all its yield from 2 fractures, one 40 feet below the static water level and the other 150 feet below static water level near the bottom of the well. If the water level is drawn down 40 feet by pumping (diagram A) the maximum yield of the upper fracture, 4 gpm, is obtained, and the yield of the lower fracture is 1 gpm; the specific capacity is $\frac{4\ \text{gpm} + 1\ \text{gpm}}{40\ \text{ft}}$ = 0.125 gpm per foot. If the water level is drawn down 80 feet by pumping (diagram B) the head on the lower fracture is doubled and therefore its yield is doubled; however, the head on the upper fracture could not be increased after the water level dropped below it, and therefore its yield remains 4 gpm, the same as it was at 40 feet of drawdown. The specific capacity at 80 feet of drawdown is therefore $\frac{4 + 2}{80}$ = 0.075 gpm per foot, or a little more than one-half the specific capacity at 40 feet of drawdown.

Figure 37.--Decrease in specific capacity with increased drawdown in a well penetrating fractured bedrock.

drilled deeper, especially if penetration of bedrock exceeds 250 feet.

The average permeability of bedrock as a whole--that is, the net permeability of the nearly impermeable non-fractured rock and the relatively permeable fractures in it--was estimated to be about 4 gpd per sq ft on the basis of the specific capacity data for 247 wells mentioned previously. The data were analyzed by slightly extrapolating theoretical graphs presented by Walton (1962) and assuming an average coefficient of storage (.001) and average test duration (2 hours for domestic wells, 6 hours for commercial or industrial wells). The computations are summarized below.

		Domestic-farm wells	Commercial-industrial wells
Number of wells		219	28
Median specific capacity (gpm/ft)		.12	.25
Median specific capacity adjusted to 6-inch radius (gpm/ft) 1/		.126	.263
Specific capacity increased to represent conditions of small drawdown (gpm/ft) 2/		.19	.30
Estimated coefficient of transmissibility (gpd/ft) 3/	2 hrs	230	-
	6 hrs	-	400
Median saturated thickness of bedrock penetrated (feet)		66	87
Average permeability (gpd/sq ft)		3.5	4.6
Average permeability of bedrock (rounded)			4

1/ Virtually all wells tested had 6-inch diameter (3-inch radius).

2/ Value for domestic-farm wells multiplied by 1.5 (typical ratio from last column of table 30). Increase for commercial-industrial wells should be less, as many such wells are tested with moderate drawdowns.

3/ Interpolated between graphs for 60-minute and 8-hour pumping periods presented by Walton (1962).

In view of the irregular distribution of water-bearing fractures in bedrock, evidenced by the range of specific capacities, this value of average permeability is significant chiefly for regional study of water movement or for comparison with other aquifers.

DEVELOPMENT BY WELLS

Drilled wells.--There are several thousand drilled wells tapping bedrock within the Quinebaug River basin. Most of them provide small supplies for homes or farms, and are reported to be adequate. Using the data plotted in figure 36 it is estimated that at 85 percent of the sites in the basin, a well penetrating 100 feet of bedrock could supply at least 3 gpm, which is enough for an average home. Wells reported to yield more than 50 gpm are rare.

One locality, namely that part of the community of Moosup west of Lake Street and Whitney Hill, is unusually favorable for development. Nearly half of the 46 bedrock wells inventoried there were reported to yield 20 gpm or more. This locality is astride the largest fault in eastern Connecticut (see Goldsmith, 1963). However, records of scattered wells along the fault zone north as far as Killingly Center indicate no continuation of the favorable conditions at Moosup. Typical outcrops in the fault zone are a ground-up, fine-grained, tightly packed rock which suggests very high pressure at the time of faulting (Dixon, written communication); hence there is little likelihood that rock movement along the fault would have produced many openings along which ground water could now travel easily. Possibly the higher permeability of the bedrock at Moosup and locally for about 2 miles to the south is due to related but younger minor faults which produced near-vertical intensely fractured zones here and there along the main fault (Dixon, written communication).

Dug wells.--In some localities within the basin where the overburden is only a few feet thick, a few large-diameter dug wells have been extended several feet into bedrock, usually by blasting. Wells of this type are fairly numerous in north-central Voluntown. Their water-yielding potential appears to be similar to those of wells dug in till.

WATER AVAILABLE TO WELLS

GROUND-WATER RECHARGE

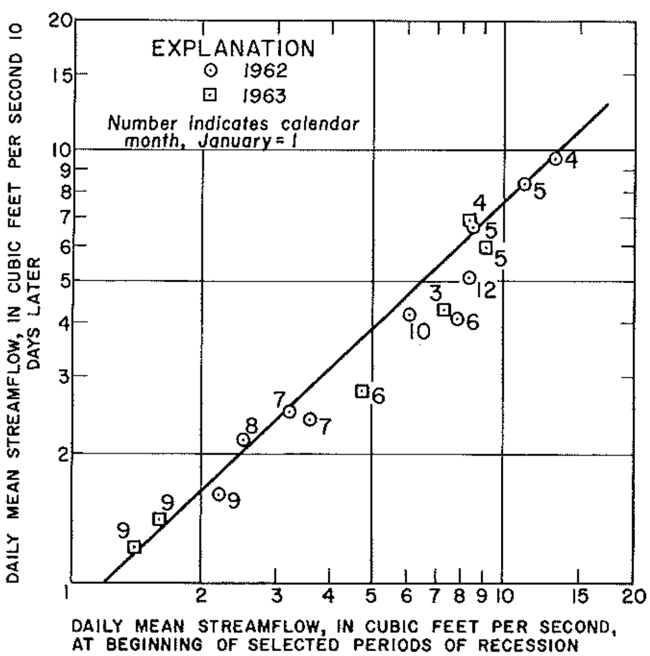
The amount of water that could be pumped out of an aquifer over a period of years without excessive local water-level decline depends on the amount of water that enters or recharges the aquifer during the same period. The minimum amount of recharge that might be expected in a very dry one-year period is of particular interest in estimating potential development because it sets the upper limit at which ground water can be withdrawn year after year without removal of ground water from storage. Therefore, it is important to evaluate the amount of recharge to aquifers in the Quinebaug River basin.

NATURAL RECHARGE

During any period when there is no net change in the amount of water stored underground, recharge must be balanced by an equal amount of discharge. Therefore, recharge conveniently may be estimated indirectly from studies of ground-water discharge.

Ground water is discharged chiefly by ground-water runoff (seepage into streams). It was estimated previously (table 3) that ground-water runoff from the Quinebaug River basin averages about 10 inches per year. This represents ground-water runoff from terranes of many kinds within the basin. Records of streamflow indicate, however, that ground-water runoff is greater from areas underlain by stratified drift than from areas underlain by till (figure 19); to evaluate the ground-water runoff from areas underlain by various proportions of these deposits, detailed studies were made in four small stream basins listed in table 27. As an example, computations used in the evaluation of ground-water runoff from Denison Brook are illustrated in figures 38-40. Similar analyses were used for all four stream basins listed in table 27.

For each small stream basin a hydrograph of mean daily streamflow (see figure 40) was computed from daily or continuous stage records. Daily ground-water runoff was computed from the streamflow data using both the rate of streamflow recession during long rainless periods (figure 38) and the relation of water levels in wells to



Each point represents a 10-day period during which the streamflow declined steadily and probably consisted wholly of ground-water runoff.

Figure 38.--Composite streamflow recession curve for Denison Brook at Collins Dam near Voluntown.

ground-water runoff in the streams (figure 39). For each day on which ground-water levels were measured, the corresponding ground-water runoff was determined from the curves in figures 38 and 39, and hydrographs of ground-water runoff were constructed beneath the hydrograph of mean daily streamflow on figure 40. The best estimate of ground-water runoff probably is intermediate between the extremes as determined from the recession curve and the ground-water rating curve. Accordingly, an adjusted ground-water runoff hydrograph was constructed on figure 40 using the shape of the hydrograph of ground-water runoff plotted from the ground-water rating curve and the troughs on the hydrograph based on streamflow recession as guides.

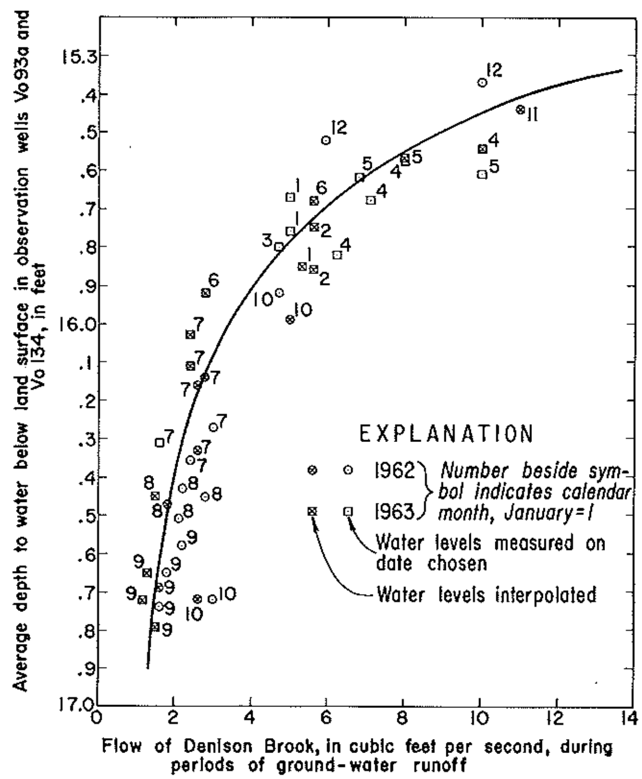


Figure 39.--Ground-water rating curve for Denison Brook basin.

Ground-water discharge also takes place by underflow, by pumping, and by evapotranspiration. The computed underflow is small but is included in the estimated recharge for the four small stream basins studied. Pumping was neglected, as the net discharge by this means is insignificant in the key basins. The average amount of ground-water evapotranspiration over the Quinebaug River basin as a whole is somewhat less than half as great as ground-water runoff (table 3). Ground-water evapotranspiration could not be accurately estimated in the key basins, and because it is uncertain how much could be salvaged by man under conditions of maximum development, ground-water evapotranspiration was neglected in the computation of recharge. Thus, ground-water recharge as estimated in this report is slightly conservative.

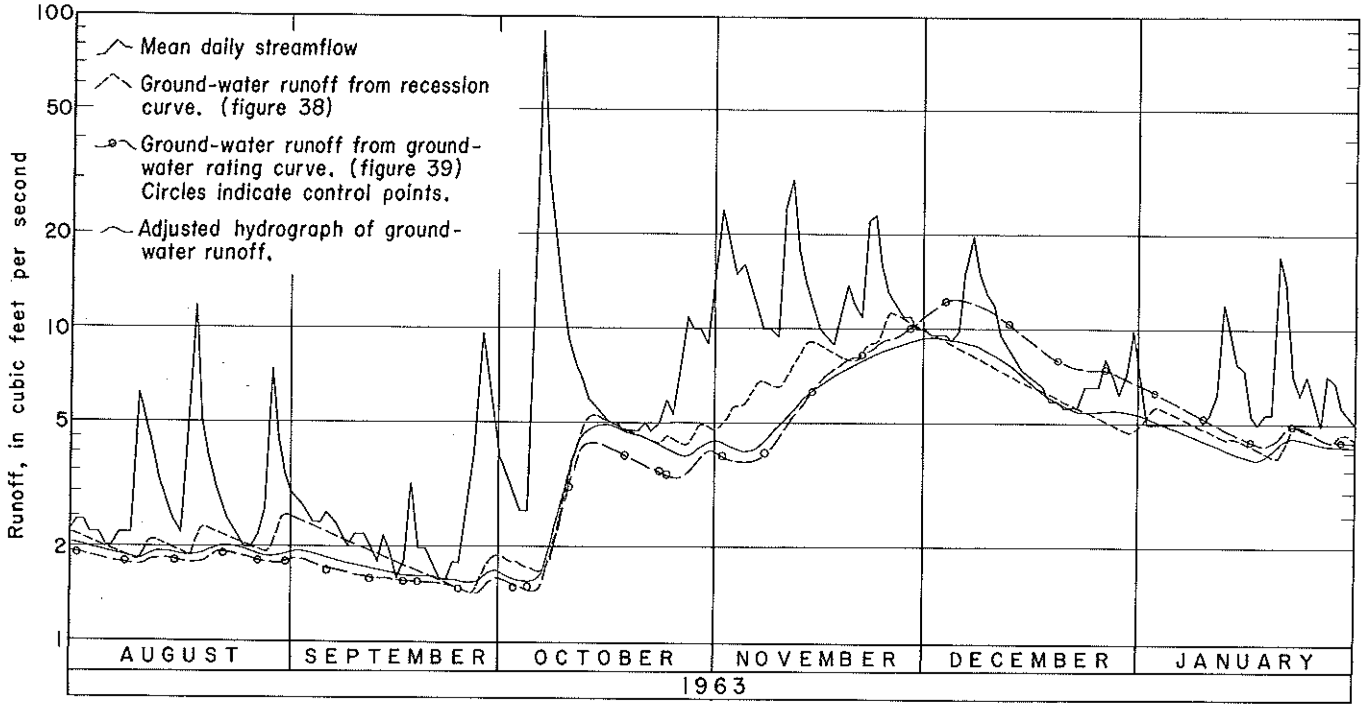


Figure 40.--Hydrographs of streamflow and ground-water runoff from Denison Brook basin.

Because discharge can be equated to recharge only if there is no net change in storage, annual recharge was computed for the 12-month period from August 1962 through July 1963 in which there occurred the smallest net change in ground-water levels and thus a negligible change in storage.

Recharge, considered equivalent to ground-water runoff plus underflow is given for this period for each key basin in table 27, column F. These values apply only to the basins studied and to a particular year. Differences in precipitation that occur from year to year and from place to place within the Quinebaug River basin may be expected to cause differences in natural recharge. The many years of hydrologic records in selected tributary basins that would be needed to define such differences in recharge are not available. However, if it is assumed that recharge varies from place to place and from year to year in the same manner as total runoff, then by comparison with total runoff the recharge rates in the four basins studied can be adjusted to represent long-term average climatic conditions over the entire basin. This is done in column H of table 27, using long-term average runoff from the Quinebaug River measured at Jewett City as an index of basin-wide average climatic conditions.

Table 27.--Ground-water runoff and underflow from 4 small stream basins in the Quinebaug River basin, August 1962 to July 1963.

Key basin (A)	Index no. (Plate A) (B)	Area (sq mi) (C)	Stratified drift in basin (per-cent of area) (D)	Runoff, August 1962 to July 1963, plus underflow: Total (inches) (E)	Runoff, August 1962 to July 1963, plus underflow: Ground water (inches) (F)	Ratio of long-term average total annual runoff from Quinebaug River basin (24.4 inches) to total in column E (G)	Long-term average ground-water run-off plus underflow, adjusted for areal variations in climate (product of columns G and F) (inches) (H)
Denison Brook	1269.23	4.01	53.6	27.77	16.79	0.878	14.74
Lowden Brook	1269.1	2.40	0	25.21	8.16	.968	7.90
Mashamoquet Brook	1256	11.0	6.5	22.50	9.70	1.084	10.51
Little River	1254.9	35.5	15.9	20.49	9.85	1.190	11.72

Table 28.--Estimated average and minimum natural ground-water recharge in areas of till and of stratified drift in the Quinebaug River basin.

Hydrologic conditions	Annual recharge 1/			
	Till-covered upland		Areas of stratified drift	
	inches (rounded)	mgd/sq mi	inches (rounded)	mgd/sq mi
Long-term average	9	0.43	21	1.00
Values exceeded about 7 years in 10	7.5	.35	17	.82
Long-term minimum (1918-1963)	4	.20	10	.47

1/ For localities in the southeastern part of the basin (in the towns of North Stonington, Voluntown, Sterling, and southern Griswold recharge values in this table should be multiplied by ratios shown in figure 18, to allow for the greater average annual rainfall and runoff in this area.

As can be seen from table 27, ground-water recharge increases as the percentage of stratified drift in the area drained increases. It is therefore possible to compute average annual recharge rates for till and for stratified drift in the Quinebaug River basin from the adjusted rates in column H of table 27, by means of simultaneous equations. Values which most closely satisfy the equations for all four tributary basins appear as long-term average values in table 28. The values for annual recharge exceeded about 7 years in 10 and the long-term minimum in table 28 were computed from the long-term average values by correlation with the long-term streamflow record at Jewett City, again assuming that recharge varies in proportion to total runoff.

The recharge rates for till and stratified drift in table 28 may be used to estimate the amount of natural ground-water recharge available in any locality with the basin, as explained in figure 41. The proportion of the natural recharge that could practicably be recovered by wells before it is discharged to a stream depends partly on the number, arrangement, and yield of the wells. Where coarse grained and permeable stratified drift is present, it should be possible to extract nearly all the recharge by several widely spaced wells yielding 100 gpm or more. Where stratified drift is predominantly fine grained, and in till areas, a great many closely spaced wells of small capacity would be required to obtain most of the water available.

INDUCED INFILTRATION

Where stratified-drift deposits border and are hydraulically connected to a stream or lake, the water in the stream or lake is an important potential source of recharge. Pumping large amounts of water from wells tapping the stratified drift can lower the water table enough to cause it to slope away from the stream or lake, and therefore induce water to flow from the surface-water body toward the pumped wells. Two large-capacity wells in the basin that are in a position to cause fairly substantial amounts of induced infiltration are Ki 60 and Th 31 (see plate A for locations), which provide water for public-supply systems operated by Wauregan Mills and the Masonville Spring Water Co., respectively.

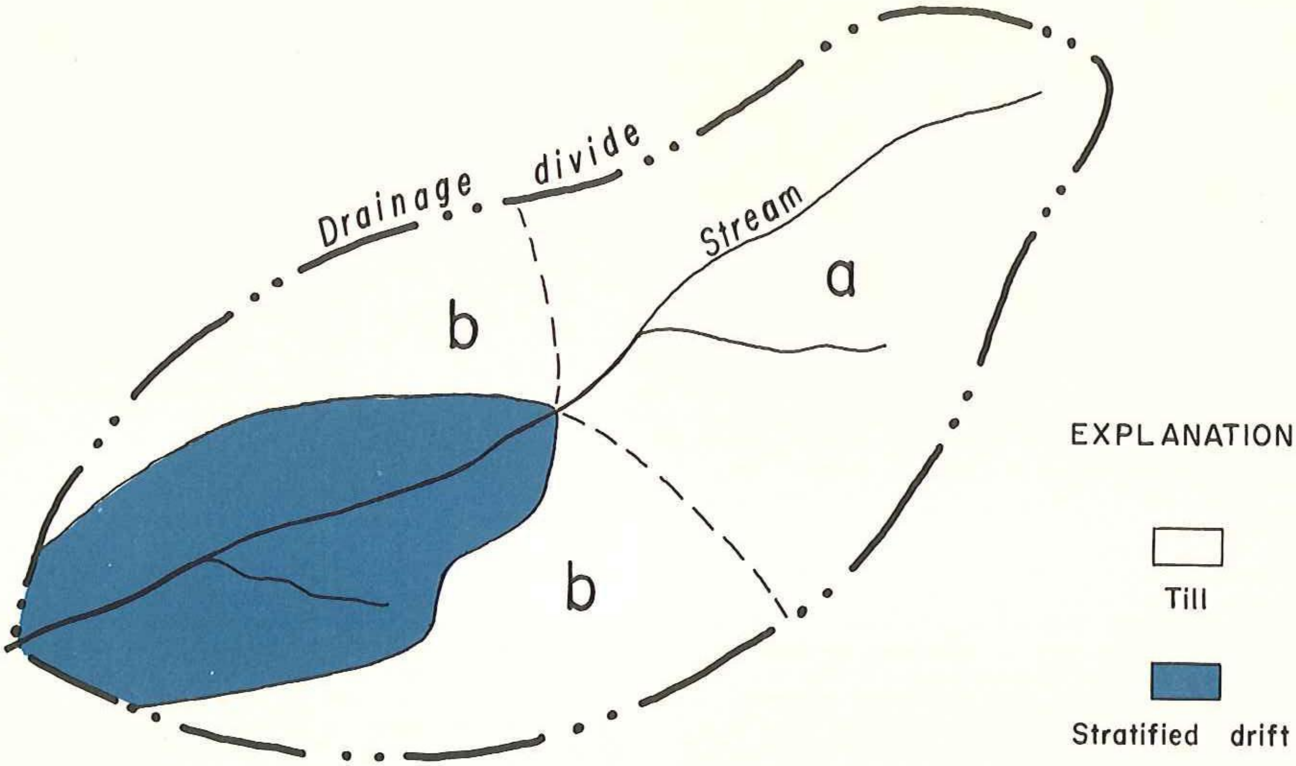
Most areas of stratified drift in the basin are crossed by a major stream, part of whose flow is potentially available for induced infiltration. One index of streamflow, the flow equaled or exceeded 90 percent of the time, is shown on plate D.

The amount of streamflow that can be induced to infiltrate at any location depends in large measure on the permeability of the stream bed and the materials immediately underlying it. No quantitative determinations of stream-bed permeability or of induced infiltration rates have been made in the Quinebaug River basin, and thus precise estimates of potential induced infiltration at specific localities cannot be made. However, the bottoms of the numerous old artificial ponds along the larger streams commonly consist of soft silt, muck, and fine sand which would severely limit induced infiltration. By contrast, unponded stream channels have gravelly beds almost everywhere, hence these beds should present no special barrier to infiltration. The best potential for induced infiltration probably occurs in areas where the streams are not ponded and are bordered by predominantly coarse-grained stratified drift.

In order to estimate long-term yields from areas selected as favorable for ground-water development later in this report, estimates of the vertical permeability of materials that underlie ponded and unponded reaches of stream channels were used to calculate approximate potential induced infiltration (p. 88). These permeability estimates are tentative and may be subject to considerable local variation. Any locality of interest should be tested to determine the actual degree of hydraulic connection between aquifer and stream.

WATER IN USABLE STORAGE

During periods of little or no recharge, wells that are not close to major streams or lakes must depend for water supply on water that is stored in the ground. Gravity yield is the most



In this hypothetical small basin, there are 3 square miles of till, 2 of which (area a) drain directly to the stream and 1 of which (area b) border 1 square mile of stratified drift. Use of the estimated recharge rates for the Quinebaug River basin given in table 28 can be illustrated by means of this basin. If it is located in the central or northern part of the basin, then during an average year, recharge equivalent to 2 sq mi x 0.43 mgd per sq mi = 0.86 mgd would reach the water table in area a, and would be potentially available to wells as it moves slowly toward the stream channel. Recharge would be equivalent to 1 sq mi x 0.43 mgd per sq mi = 0.43 mgd in area b. In the 1 square mile of stratified drift, recharge would be equivalent to 1 sq mi x 1.00 mgd per sq mi = 1.00 mgd; however, because ground water from area b drains into the stratified drift on its way to the stream, wells in the stratified drift would have 1.00 mgd + 0.43 mgd = 1.43 mgd available. In the driest year of record, all these quantities would be reduced by about 53 percent. (Only natural recharge is included in these computations; in addition, some of the streamflow leaving area a is available for induced recharge downstream.)

Figure 41.--Sketch illustrating how recharge may be estimated for an area.

useful index of ground-water storage that is available for use. Gravity yield depends on the number, size, and degree of interconnection of water-filled openings in different earth materials, and on the length of time the materials are subject to drainage. The hydrograph of well Pl 1 (figure 42) shows that annual periods of steep water-level decline, which represent periods of drainage (periods of little or no recharge), were 4 to 6 months in length in nearly every one of the past 20 years.

Gravity yield values computed for the three major aquifers in the Quinebaug River basin are given in the following table:

Material	Estimated gravity yield for 4-6 months of uninterrupted drainage (percent)	Most probable average gravity yield of an entire section dewatered during 4-6 months without recharge (percent) a/
Stratified drift	30	23
Till	10-13 b/	6-8 b/
Bedrock	0.5	0.5

a/ The upper part of the section would have drained for the full 4-6 months, the lower part for only a few days.

b/ Increases from northwest to southeast.

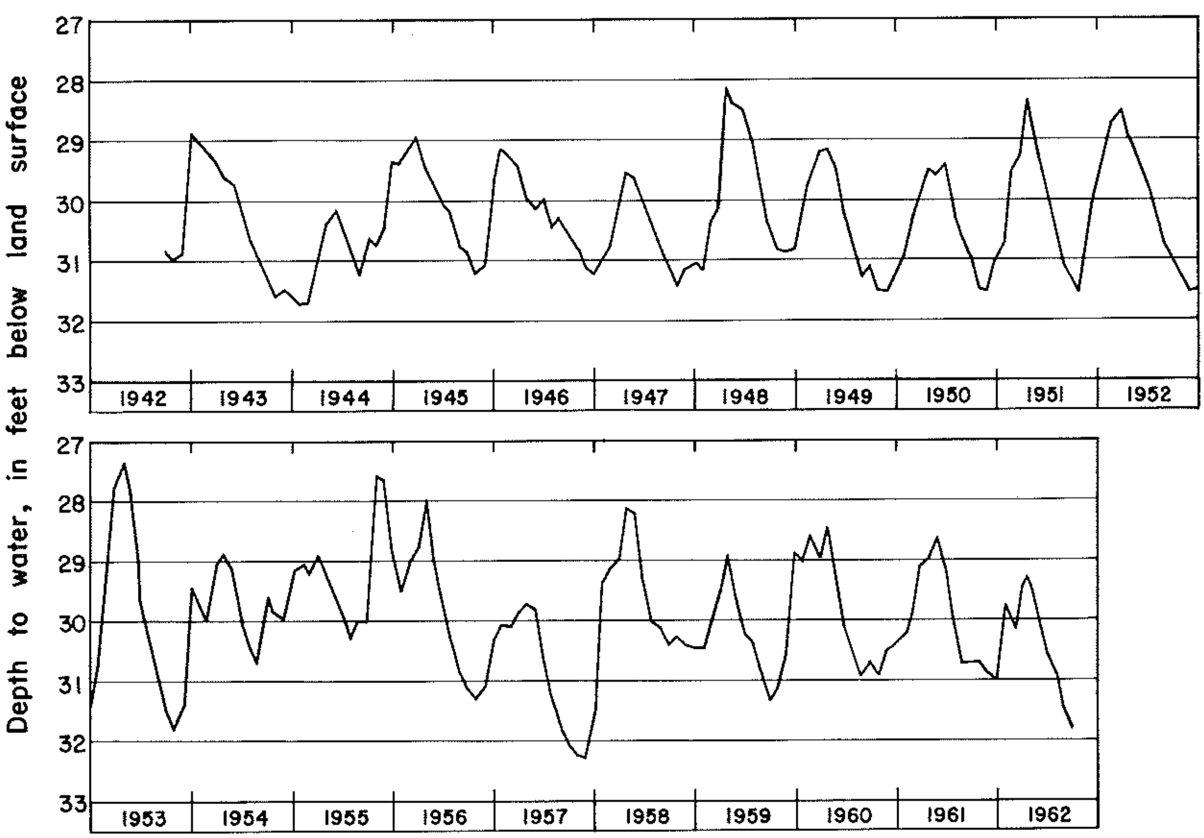
These values were computed using laboratory determinations of specific yield (given in tables 20, 23, and 25) which were adjusted downward to allow for incomplete drainage of dewatered sections of the aquifers during 4-6 months of no recharge. The values are those most likely to represent average conditions in the basin.

The amount of ground water in storage at the beginning of the period of little or no recharge varies each year, as indicated by water levels in wells. The variations, as exemplified by the hydrograph of well Pl 1 in figure 42, reflects differences in the recharge each year. However, the natural variation from year to year is only a small part of the total amount of water in storage--no more than 3 percent in areas of thick stratified drift, such as near well Pl 1, but perhaps as much as 20 percent in some areas of till and thin stratified drift. Even though variations do occur from one year to the next, water-level measurements in observation wells throughout Connecticut show no persistent upward or downward trend over the past 20 years, and show that there are no long-term changes in storage due to natural causes. Pumping from wells can lower water levels below natural levels in local areas; for example, pumpage of the Gallup Water Service well (Pl 185) could have lowered the water level slightly in observation well Pl 1, 2,000 feet away.

QUALITY OF GROUND WATER

The chemical quality of ground water in the Quinebaug River basin under natural conditions is generally good. The crystalline bedrock underlying the basin and the glacial drift derived from it are composed largely of minerals which are only slightly soluble in water, and the dissolved solids concentration of the ground water is correspondingly low. The basin-wide average concentration of dissolved solids in ground water, based on samples collected from wells (table 29) and from streams at low streamflow (table 18), is about 92 ppm; average hardness is about 45 ppm. Iron and manganese are the only constituents found in a substantial number of samples from wells in concentrations large enough to be troublesome for household use; the occurrence of these two constituents are discussed in detail on later pages.

The results of 222 chemical analyses of water from 156 wells and springs sampled during this investigation are summarized in table 29. Individual analyses are presented in the companion basic-data report (Thomas and others, 1966). The most abundant dissolved chemical constituents in ground water from the basin are silica, calcium, sodium, potassium, bicarbonate, and sulfate. The observed range in dissolved silica was from 6.9 to 34 ppm, the median being 16 ppm. These quantities are



Well Pl 1 is 34 feet deep and penetrates stratified drift. The periods of steep water-level decline, which are generally 4 to 6 months in length, represent periods of little or no recharge and decreasing ground-water storage. Although such periods occur each year, the graph shows that there is no long-term downward trend during the 20-year period.

Figure 42.--Water-level fluctuations in well Pl 1, at Plainfield, 1942-62.

entirely satisfactory for domestic use, but concentrations above 10 ppm are excessive for some industrial uses (American Water Works Assn. 1951). Sodium concentrations ranged as high as 60 ppm in the samples collected, but generally did not exceed 10 ppm; potassium was even less abundant. None of the other major constituents occurs in concentrations large enough to limit the use of water for most purposes.

Concentrations of dissolved constituents, though generally low, vary widely from place to place; such variations commonly reflect the distribution of different rock types within the basin. Because many of the geologic formations mapped in the basin contain several rock types (see Dixon, 1964; Rodgers and others, 1956), concentrations of individual constituents may vary considerably even within a single formation. Only the Sterling Gneiss in the eastern part of the basin yields water below average in most constituents (table 29). Calcium is dissolved to some extent from all rocks in the basin, but samples from a few scattered wells that contained far more calcium than the basin-wide median of 16 ppm suggest that these wells penetrate lenses of impure limestone or dolomite marble that have been observed in various rock units (Sclar, 1958, p. 22; Rodgers and others, 1956; Dixon, personal communication). In most water samples sodium substantially exceeds potassium; locally, however, especially in the Scotland Schist in western Pomfret, the presence of more potassium than sodium in water samples indicates a large quantity of potash feldspar or potash mica in the rock make-up. Iron and sulfate are notably higher than average in water from areas in the western part of the basin that are underlain by schist containing relatively abundant iron sulfide minerals such as pyrite and pyrrhotite.

Table 29.--Summary of chemical and physical characteristics of ground water in the Quinebaug River basin.

(Nomenclature for bedrock units follows Rodgers and others (1956) or Dixon (1964). Chemical constituents in parts per million)

Water-yielding unit		Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Nitrate (NO_3)	Dissolved solids (residue at 180°C)	Hardness as $CaCO_3$	Specific conductance (micromhos at 25°C)	pH
Stratified Drift	No. of wells sampled	30	34	33	35	35	35	35	35	34	30	34	35	35	35
	maximum	21	2.8	5.7	40	6.8	60	4.4	47	37	44	330	108	455	9.3
	minimum	7.3	.00	.00	2.4	.3	2.4	.2	4	.2	.0	31	9	39	4.8
	median	14	.06	.01	11	1.8	4.4	1.7	25	12	2.9	80	37	117	6.5
Till	No. of wells sampled	12	14	12	14	13	14	14	14	12	12	13	12	14	14
	maximum	34	.49	.10	72	11	39	13	93	29	26	434	211	550	7.7
	minimum	9.1	.00	.00	4.2	1.2	3.1	.6	15	6.9	.3	79	38	61	5.8
	median	15	.09	.00	17	3.0	6.7	2.2	44	13	8.3	108	50	147	6.6
Brimfield Schist	No. of wells sampled	4	4	4	4	4	4	4	4	--	4	4	4	4	4
	maximum	32	3.3	.26	60	14	50	3.3	197	--	1.9	409	210	617	7.6
	minimum	20	.09	.03	13	.9	3.6	1.5	38	--	.0	97	46	126	6.5
	median	27	1.8	.11	18	3.4	6.2	2.2	68	--	.0	114	55	152	6.9
Scotland Schist (phase of Hebron Formation)	No. of wells sampled	3	3	3	3	3	3	3	3	--	3	3	3	3	3
	maximum	31	.14	.03	35	2.6	7.8	9.2	78	--	37	183	98	269	7.4
	minimum	15	.03	.00	18	2.2	6.5	5.4	53	--	.0	122	55	186	6.7
	median	15	.11	.03	24	2.4	6.5	6.1	60	--	12	133	69	202	6.9
Hebron Formation (exclusive of Scotland Schist)	No. of wells sampled	13	13	13	13	13	13	13	13	8	13	13	13	13	13
	maximum	29	.84	.12	37	3.8	15	4.0	82	27	8.9	169	97	261	8.0
	minimum	6.9	.00	.00	11	.2	2.5	.5	14	7.1	.0	72	31	113	6.0
	median	17	.11	.00	15	2.2	8.2	3.0	48	13	.4	103	48	156	7.2
Canterbury Gneiss	No. of wells sampled	5	6	6	6	6	6	6	6	--	6	4	6	6	6
	maximum	29	.34	.40	24	5.4	22	2.8	114	--	12	157	82	252	8.3
	minimum	16	.03	.00	9.6	1.7	5.5	.8	20	--	.0	89	31	103	6.4
	median	22	.06	.05	12	2.8	9.2	1.8	44	--	.8	126	39	134	7.0
Putnam Group															
Tatnic Hill Formation															
Yantic Member	No. of wells sampled	2	2	2	2	2	2	2	2	--	2	2	2	2	2
	maximum	23	.52	.04	21	1.3	7.7	2.9	78	--	.7	108	58	164	7.4
	minimum	9.7	.04	.00	2.9	1.0	3.8	1.2	5	--	.1	37	11	58	5.2
	median	16	.28	.02	12	1.2	5.8	2.0	32	--	.4	72	34	111	6.3
Fly Pond Member	No. of wells sampled	3	3	3	3	3	3	3	3	--	3	3	3	3	3
	maximum	34	.14	.01	20	2.2	14	2.4	90	--	5.0	104	54	175	7.9
	minimum	11	.05	.00	7.8	.2	3.0	1.1	22	--	.0	46	22	70	7.2
	median	13	.13	.00	18	.6	9.1	1.8	67	--	.2	92	51	151	7.2
lower member	No. of wells sampled	23	26	26	24	23	25	25	25	13	23	22	23	25	25
	maximum	33	4.8	.76	97	8.9	21	6.1	116	38	41	249	279	560	8.6
	minimum	12	.00	.00	3.2	.7	3.1	.6	12	9.6	.0	36	12	54	5.9
	median	18	.08	.01	16	2.9	6.3	2.5	40	16	1.1	113	64	179	6.9
Quinebaug Formation															
upper member	No. of wells sampled	7	7	7	7	7	7	7	7	7	7	7	7	7	7
	maximum	23	3.7	.40	18	5.0	7.2	3.8	70	13	16	128	58	176	8.2
	minimum	13	.01	.00	9.4	.7	4.5	1.1	26	3.3	.0	61	33	94	6.4
	median	20	.08	.05	15	2.1	5.4	2.8	54	8.6	1.0	91	48	130	7.1
Black Hill Member	No. of wells sampled	6	7	7	7	7	7	7	7	7	7	6	7	7	7
	maximum	17	.17	.04	29	8.4	9.0	5.8	76	24	9.6	206	92	358	8.2
	minimum	10	.00	.00	19	.4	3.6	1.9	32	9.2	1.6	100	54	149	4.6
	median	13	.06	.00	24	3.5	5.5	2.7	57	16	3.3	120	80	178	6.9
lower member	No. of wells sampled	11	11	11	11	11	11	11	11	11	11	11	11	11	11
	maximum	22	2.9	.94	50	5.4	17	6.5	116	39	37	219	138	337	8.5
	minimum	10	.00	.00	2.6	.4	3.0	.5	10	5.5	.0	40	10	45	6.0
	median	12	.05	.00	19	1.6	5.5	2.6	52	14	.5	98	56	167	7.0
Plainfield Quartz Schist	No. of wells sampled	6	5	6	6	6	6	6	6	6	6	6	6	6	6
	maximum	24	.09	.05	37	3.9	12	3.9	77	12	28	172	99	234	8.5
	minimum	13	.01	.00	5.0	1.6	4.9	.5	18	3.8	.3	57	19	66	6.1
	median	16	.04	.00	16	2.0	5.7	1.9	57	7.4	7.3	91	42	161	6.8
Sterling Gneiss	No. of wells sampled	14	17	17	17	16	17	17	17	16	15	16	15	17	17
	maximum	20	.55	.44	33	7.1	14	3.6	88	17	60	204	109	297	8.0
	minimum	7.6	.01	.00	1.4	.4	2.4	.1	2	2.4	.0	24	7	33	5.1
	median	16	.06	.00	9.0	1.9	6.3	1.2	40	10	.4	68	34	110	6.8
All bedrock units	No. of wells sampled	97	104	105	103	101	104	104	104	68	100	97	100	104	104
	maximum	34	4.8	.94	97	14	50	9.2	197	39	60	409	279	617	8.6
	minimum	6.9	.00	.00	1.4	.2	2.4	.1	2	2.4	.0	24	7	33	5.1
	median	17	.07	.00	16	2.2	6.2	2.4	52	13	.9	100	54	153	7.0

IRON AND MANGANESE

CHEMICAL BEHAVIOR AND EFFECTS

Whenever ground water containing more than about 0.3 ppm of dissolved iron is pumped out of a well and exposed to the air, the water becomes cloudy, and usually an orange-brown film forms on the water surface or the sides of the container. This iron precipitate causes yellow to brown staining of sinks, tubs, glassware, and other utensils, and laundered clothes; it also clogs filters and interferes with manufacture of many industrial products. Excessive iron will also impart a metallic taste to the water, or to beverages prepared with the water. Furthermore, certain bacteria (such as "crenothrix") frequently grow in iron-bearing water, and these growths sometimes break loose and clog nozzles, pumps, and other appliances, or give the water bad tastes.

Manganese resembles iron in its general chemical behavior. Water containing a large amount of manganese will darken when exposed to air or to laundry bleach, as if black ink had been added to the water. Manganese precipitate causes a black film on porcelain sinks and kitchen utensils. Because manganese is commonly associated with much larger quantities of iron, however, its effects may be masked by those of iron.

Removal of excessive iron and manganese can be accomplished in a variety of ways. Methods especially suitable for homes and small commercial establishments include water softeners (most units will not remove more than 2-3 ppm effectively), chlorination-filtration units (especially suitable if chlorination to kill bacteria is also desired) and manganese-green sand filters. Further details are given by Wilke and Hutcheson (1963).

DISTRIBUTION IN GROUND WATER

Most wells in the Quinebaug River basin yield clear water containing little or no iron or manganese. The percentage of wells sampled whose water contained more iron and manganese than the limits recommended by the U.S. Public Health Service for drinking water are indicated in the following table. Even these percentages are probably too high for the basin as a whole, because sampling was more intensive in and near areas where iron-bearing water was known to be a problem.

It is possible that a well almost anywhere in the basin may tap ground water containing troublesome amounts of iron or manganese. In general, however, such wells are most numerous in the western and northwestern parts of the basin. In the eastern part of the basin, water from the bedrock is relatively free of iron, although some wells which tap deep layers within the stratified drift or immediately subjacent portions of the bedrock yield water with excessive amounts.

	Aquifer		
	Crystalline bedrock	Stratified drift	Till
No. of wells sampled for			
iron	104	34	14
manganese	105	33	12
Maximum concentration			
iron (ppm)	4.8	2.8	.49
manganese (ppm)	.94	5.7	.10
Percent of wells sampled containing			
0.3 ppm or more of iron 1/	20	12	7
0.05 ppm or more manganese 1/	24	24	17

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

There are at least 7 areas in the basin in which the concentration or areal extent of iron-bearing ground water deserve special attention. In 3 of these areas, the iron-bearing ground water is obtained from a schist which contains small amounts of pyrite (or other iron sulfides) and graphite, and has a rusty appearance in weathered outcrops. The dissolved iron presumably is derived from weathering of the iron sulfide minerals. In the other 4 areas, the source of the excessive iron concentrations is not certain. These 7 areas are shown on figure 43, and discussed below.

Area A.--Area A occupies the northeast corner of the Quinebaug River basin (figure 43). The bedrock in this area has been assigned to the Brimfield Schist (Rodgers and others, 1956), and consists chiefly of a dark rusty-weathering schist that contains graphite, purplish biotite, pyrite, and garnet among other minerals. Of 4 wells sampled in this area, 3 yielded water with more than 0.3 ppm iron; concentrations ranged as high as 3.3 ppm iron and 0.26 ppm manganese. Several other wells were reported by owners to yield iron-bearing water. Wells that obtain iron-free water from the bedrock in this area probably tap thin layers of limestone, lime-silicate rock, and quartzose gneiss reported within the Brimfield Schist. Available data suggest that at least 75 percent of the wells drilled in Area A will yield water that requires treatment to remove excess iron and manganese before it is satisfactory for domestic or most industrial purposes. The Brimfield extends north into Massachusetts and south into the adjacent Shetucket River basin of Connecticut, and iron-bearing ground water is commonly found in those areas also.

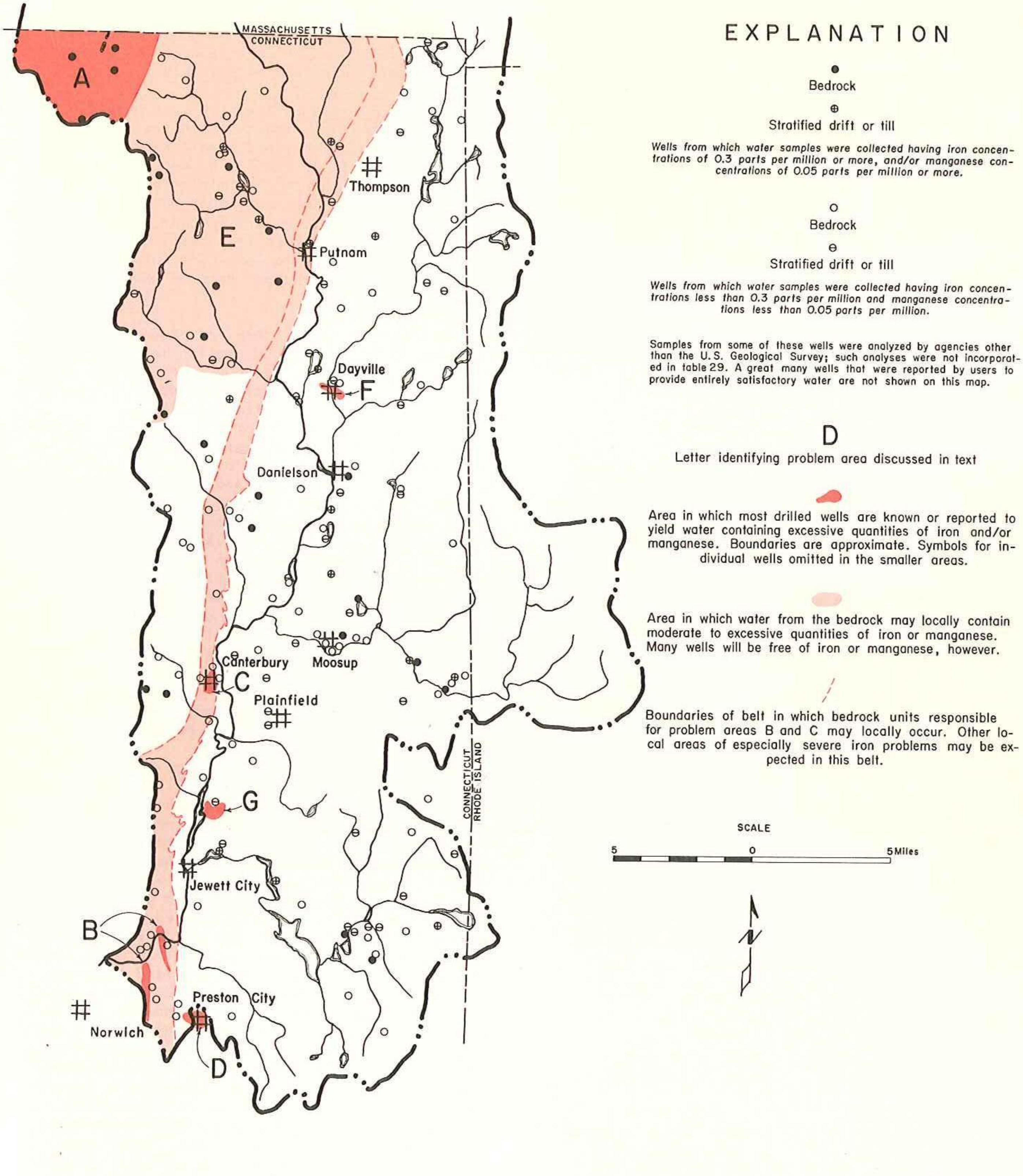


Figure 43.--Areal distribution of iron and manganese in ground water in the Quinebaug River basin.

Areas B and C.--Occurrences of iron-bearing ground water in southern Lisbon and western Preston (Area B) and in Canterbury (Area C) are clearly restricted to a particular bedrock unit. Snyder (1961) mapped a rusty-weathering graphite schist phase of the Putnam Group in southern Lisbon and western Preston. Similar rocks were reported to the east by Sclar (1958, p. 33). The graphite schist contains pyrite, and chemical analyses of rock samples show that it has nearly twice the percent of iron and manganese constituents present in other rock units (Snyder, 1964). In figure 44 the extent of the graphite schist mapped by Snyder in Area B is compared with the distribution of wells yielding iron-bearing or iron-free water.

In Area C, centered around Canterbury, a very rusty-weathering pyrite-bearing graphite schist is exposed in roadcuts along State Route 14. Dixon reports (written communication) that fresh roadcuts in this schist along the newly-reconstructed highway developed a rusty coating within several months after exposure to the atmosphere. The extent of the graphite schist in Area C is compared with the known distribution of iron-bearing ground water in figure 45. Dug wells tapping till in this area yield water of low pH, but the dissolved iron content is apparently not excessive.

Dixon (written communication) has determined that the rusty-weathering graphite schist in Area C extends as a continuous unit to Area B, and also extends northward from Area C for several miles at least. The probable extent of a belt within which this graphite schist may be found is shown by dashed lines on figure 43. It seems likely that additional areas of iron-bearing ground water with pyritic graphite schist will be revealed in this belt as more wells are drilled.

Area D.--Severe iron problems also occur in a small area around Preston City designated Area D (figure 43). Water from one well contained 4.8 ppm iron, and several well owners complained of iron-bearing water. Bedrock types in this vicinity include black biotite and biotite-hornblende schists, but none of the rock types described by Sclar (1958) is known to coincide with the area of iron-bearing water.

Area E.--Area E includes much of the northwestern part of the basin (figure 43). The purplish to brownish stain noted on some outcrops in this area indicates at least local occurrence of iron-bearing ground water. Water samples collected during this study from 16 wells tapping bedrock contained from 0.00 to 0.84 ppm iron and from 0.00 to 0.12 ppm manganese. Only 15 percent of the samples contained more than 0.3 ppm of iron, but approximately 60 percent contained 0.1 ppm or more, which is enough to cause slight staining of porcelain and utensils after prolonged use. By contrast, only 22 percent of the samples from wells tapping bedrock outside the problem areas shown in red on figure 43 contained 0.1 ppm or more iron.

Several different rock types occur in the Hebron Formation which underlies most of the area, among them a rusty-weathering muscovite schist, but their relative extent is not well known. When modern detailed maps of the bedrock become available, identification of units containing iron-bearing ground water may be possible.

Areas F and G.--Area F is at Dayville in the town of Killingly, and Area G is just east of the Quinebaug River in Griswold near the Plainfield town line (figure 43). By contrast with Areas A to E which are predominantly till-covered uplands where iron-bearing ground water occurs in schist, Areas D and E are lowland areas covered by stratified drift where iron-bearing ground water occurs both in the lower part of the stratified drift and in the upper part of underlying gneiss.

The occurrence of iron- and manganese-bearing ground water appears to be similar in both areas. Shallow wells tapping the upper part of the stratified drift yield water that does not contain objectionable amounts of iron. Drilled wells tapping the lower 20 feet or so of the stratified drift or the upper 10-20 feet of the bedrock generally yield water high in iron and manganese. As much as 3.7 ppm of iron and 0.94 ppm of manganese were present in samples from individual wells. Drilled wells penetrating many feet below the bedrock surface yield satisfactory water if they are tightly cased through the zone of poor quality. The record of well Ki 351, located on Lake Road just west of Dayville, illustrates these relationships. This well was drilled to replace an earlier well that obtained iron-bearing water from coarse sand or gravel at a depth of 89 feet. At 95 feet, 3 feet below the bedrock surface, a fracture yielding 45 gpm of iron-bearing water was cased off, and drilling continued to 118 feet where water of good quality was obtained.

The primary source of the iron and manganese in Areas F and G is not clear. There are some indications that the top part of the rock is unusually soft and broken, thus might represent weathered bedrock not removed by the ice sheet. Also, there is evidence in a few places that layers of sand and gravel near the base of the stratified drift are heavily coated with iron and manganese deposits, possibly derived from local bedrock or deposited by meltwater during a period of stability early in the deglaciation of the area when these sediments lay near the land surface. Wells penetrating the upper few feet of the bedrock could obtain iron-and manganese-bearing water drawn from the overlying stratified drift through local fractures by pumping. In any case, wells tapping shallow levels of the stratified drift would obtain oxygen-rich, iron-free water derived chiefly from very local precipitation and moving at shallow levels toward the streams.

Areas F and G are probably not unique within the basin. There are several other places along major valleys where one or two isolated wells tapping deep stratified drift or bedrock yield iron-bearing water, but where lack of nearby data makes it impossible to determine if the poor water has significant extent. In general, however, water from deep layers of the stratified drift is of good quality.

Iron and manganese concentrations in water from several wells shown in illustration.

WELL NUMBER	DEPTH TO BEDROCK (feet)	IRON (ppm)	MANGANESE (ppm)
Ls 12	14	0.05	0.00
Ls 13	16±	.03	.03
Ls 17	22	.04	.03
Ls 18[a]	22	1.4	.04
Ls 23	<20	.05	.01
Ps 53	67	1.2	.07

[a] *Sample collected after passing through water softener.*

EXPLANATION

Ls 12 ○
Well in bedrock

Solid circle indicates excessive iron concentration; number is U.S. Geological Survey well number.

[Presence or absence of excessive iron in water determined from chemical analyses in table or from reports by well owners.]

Graphite schist

Other rock types

[Geologic units simplified from Snyder, 1961]

0 1 2 3 4 5000
SCALE IN FEET

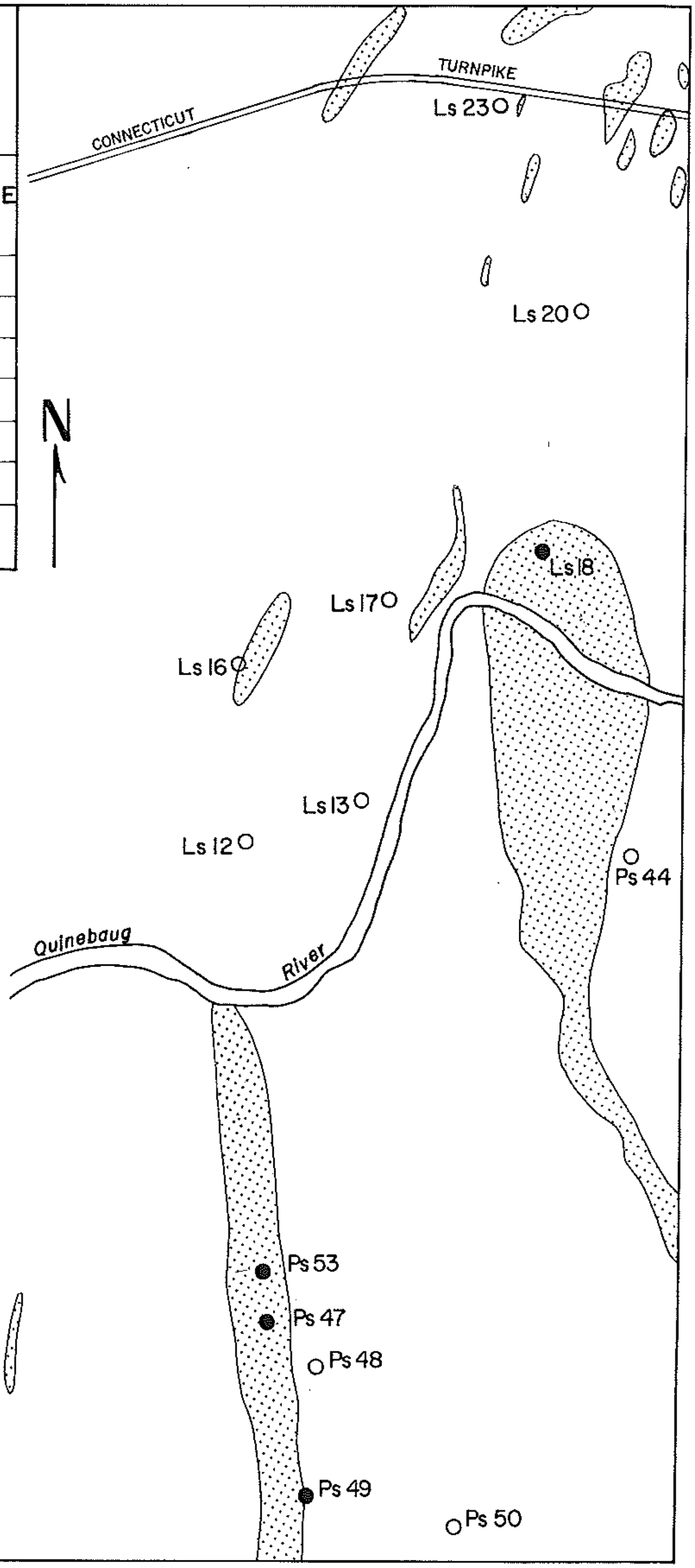
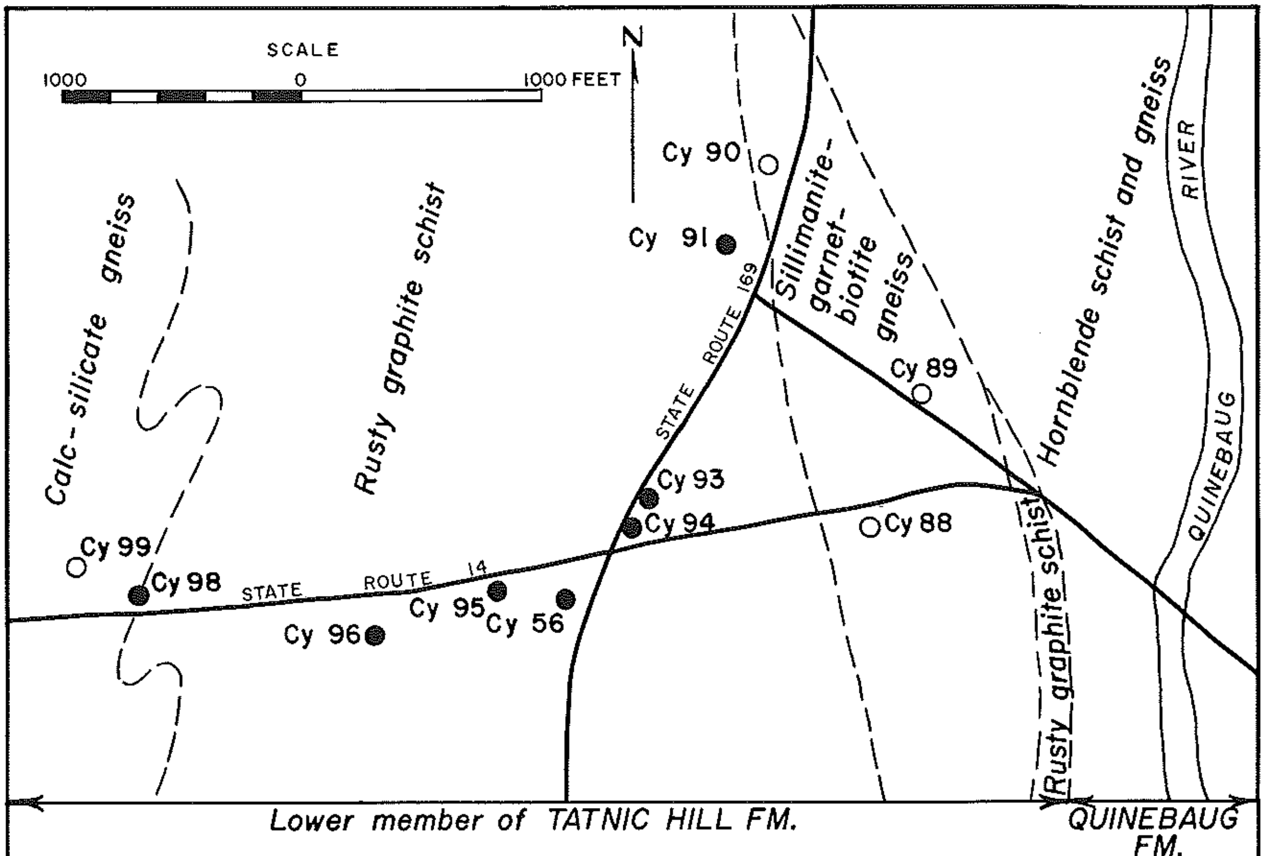


Figure 44.--Iron concentrations in ground water in southern Lisbon and western Preston.



Iron and manganese concentrations in water from several wells shown in illustration.

WELL NUMBER	DEPTH TO BEDROCK (feet)	IRON (ppm)	MANGANESE (ppm)
Cy 56	14	0.45	0.55
Cy 88	0	.03	.00
Cy 93	–	2.2	.49
Cy 94	28	.72	.10
Cy 95	15	2.9	.76
Cy 96	<20	.48	.10
Cy 99	8	.08	.00

EXPLANATION

Cy 99 ○

Well in bedrock

Solid circle indicates excessive iron concentration; number is U.S. Geological Survey well number.

[Presence or absence of excessive iron in water determined from chemical analyses in table or from reports by well owners.]

Approximate boundary between geologic units. Geologic units after Dixon (written communication)

Figure 45.--Iron concentrations in ground water near Canterbury.

HARDNESS

Hardness is an important property of water because it determines the quantity of soap required to produce a lather and the quantity of insoluble mineral scale formed in pipes or containers in which the water is heated. It is caused almost entirely by calcium and magnesium, and generally is expressed as the amount of calcium carbonate ($CaCO_3$) that would be necessary to produce the observed effect. Other dissolved constituents, such as iron, aluminum, strontium, barium, and zinc also cause hardness; as a rule, however, they are not present in sufficient quantities to have any appreciable effect.

The terms "hard water" and "soft water" are to some extent relative terms, and not all authorities apply them to the same ranges of measured hardness. The following ranges are used by the U.S. Geological Survey:

Hardness as $CaCO_3$ (ppm)	Rating	Suitability
0 - 60	Soft	Suitable for many uses without further softening.
61 - 120	Moderately hard	Usable except in some industrial applications.
121 - 180	Hard	Softening required by laundries and some other industries.
181 or more	Very hard	Requires softening for most purposes.

Water having a hardness of more than 120 ppm commonly is softened for household use. Softening of municipal supplies is costly, but is generally to the advantage of the community if the hardness cannot be reduced to about 120 ppm by dilution with softer water from other sources.

Ground water in the Quinebaug River basin is generally below 120 ppm in hardness. Samples from 148 wells were analyzed for hardness; of these, 67 percent were soft, 28 percent moderately hard, 3 percent hard, and 2 percent very hard. Table 29 gives the maximum, minimum, and median hardness of water from various aquifers.

Areal variations in hardness of ground water are shown by figure 46. Water at least moderately hard occurs at scattered locations, chiefly in the western part of the basin, but because there are no large bedrock units composed of calcium or magnesium carbonate there are no large areas of consistently hard water. Most of the rock types within the Black Hill Member of the Quinebaug Formation contain some calcium carbonate (Dixon, 1964), and 6 of 7 wells sampled that tap this unit yielded moderately hard water. The narrow band of moderately hard water from bedrock shown in figure 46 includes the known extent of this unit. In the eastern part of the basin, where the Plainfield Quartz Schist and the Sterling Gneiss form the bedrock, most wells yield soft water.

NITRATE, CHLORIDE, AND ABS AS INDICATORS OF POSSIBLE POLLUTION

Nitrate and chloride are absent or present only in low concentrations and ABS is absent in the ground water of the basin under natural conditions. Therefore, unusually large quantities of these constituents represent a departure from normal conditions, which in some cases may be due to pollution.

Nitrate is not dissolved from rocks or mineral grains as are most of the chemical constituents of ground water. The amount of nitrate in precipitation when it reaches the land surface is very small; samples collected in Connecticut by Voight (1960) had an average nitrate concentration of 0.2 ppm. In some localities, high nitrate concentrations in ground water can be attributed to infiltration of recharge through soils heavily treated with chemical fertilizers. However, most of the nitrate in water represents the end product of aerobic decomposition of organic matter. Small amounts occur naturally due to the decay of fallen leaves, roots, and small organisms in the soil. Large amounts generally reflect concentrated disposal of sewage or animal wastes. Samples from 141 wells in the basin were analyzed for nitrate (table 29), and 30 percent were found to contain more than 5 ppm. Although many of the larger concentrations were probably derived from waste disposal, this does not mean that 30 percent of the wells sampled were polluted, for in many cases the source of the nitrate may have been distant enough so that the water was safe to drink by the time it reached the well. Other forms of nitrogen that are determined in a sanitary analysis, such as nitrite, ammonia, and albuminoid, are more reliable indicators of incomplete decomposition and genuinely unsafe water. The upper limit for nitrate recommended by the U.S. Public Health Service is 45 ppm. Water containing nitrate in excess of 45 ppm (equivalent to 10 ppm of nitrate expressed as N in a sanitary analysis) is unsafe for domestic supply because it can cause methemoglobinemia (infant cyanosis or "blue baby disease") when fed to infants (Comly, 1945). Only one of the wells sampled yielded water with more than 45 ppm of nitrate.

Chloride is present in ground water throughout the basin, but normally in quite low concentrations. Only a small amount reaches the basin in precipitation; the maximum chloride concentration detected in the rainfall from several storms was 1.9 ppm (table 4). Chloride-bearing minerals are scarce in the crystalline bedrock of the basin, usually less than 0.05 percent of total rock volume. Samples from 37 wells were analyzed for chloride, and several contained substantially more than 10 ppm; the range in concentration was 2.2 to 30 ppm for wells tapping crystalline bedrock

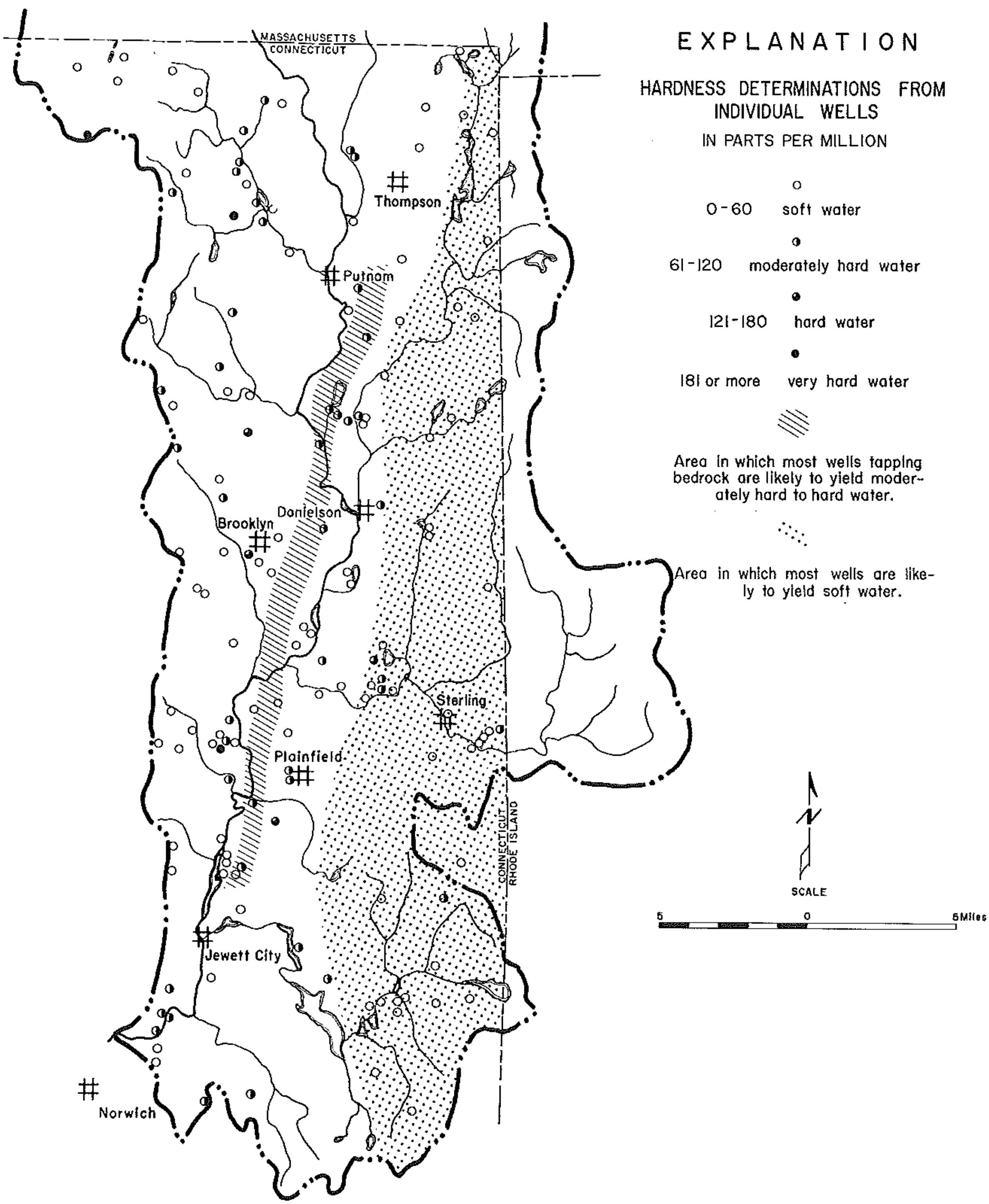


Figure 46.--Areal variation in hardness of ground water in the Quinebaug River basin.

and 2.8 to 84 ppm for wells tapping stratified drift. Even the largest observed concentration is far below the 250 ppm limit recommended for drinking water by the U.S. Public Health Service; however, as in the case of nitrate, concentrations above natural levels probably reflect nearby disposal of sewage or animal wastes.

ABS has been the principal component of household detergents prior to mid-year 1965. Its presence in ground water results from disposal of sewage from homes or factories to the ground. ABS concentrations of about 10 ppm are typical of municipal sewage. Various studies have shown that 1 ppm ABS in drinking water can be tasted and can cause frothing of the water. Although 1 ppm is not known to be toxic, esthetic considerations have caused the U.S. Public Health Service to recommend (1962, p. 24) that concentrations in drinking water not exceed 0.5 ppm. The maximum ABS content in samples collected from 24 wells during the study was 0.1 ppm, which is not enough to cause any problem. However, a few wells in the basin were reported to yield water that frothed noticeably, suggesting much larger concentrations.

In the future both residual ABS and LAS (see p. 46) constituents will be found in ground water that contains effluent from sewage disposal. As pointed out on page 46 the LAS is biodegradable and will disappear more readily than ABS. However, if the conditions for bacterial actions in cesspool or septic tank effluents are unfavorable, the LAS will have little or no opportunity to decompose.

If the population of the Quinebaug River basin continues to expand, the nitrate, chloride, and the detergent contents of ground water are likely to increase also, especially in built-up areas. Although none of these constituents is toxic in the concentrations ordinarily present even in polluted ground water (except nitrate of more than 45 ppm, as noted above), the presence of large amounts of any or all suggests that a substantial part of the water pumped was probably derived from disposal of sewage or other wastes nearby, and that disease bacteria or other hazardous substances may be present.

SUSCEPTIBILITY OF WELLS TO POLLUTION

Pollution of ground water has been due primarily to 3 causes: disposal of domestic sewage into cesspools or septic-tank fields; disposal of industrial waste into leaching pits or lagoons; and infiltration of water in barnyards, fields treated with manure, or other sites of abundant animal droppings. Although individual instances of pollution arising from each type of source could be cited, the data collected in this study are in general not adequate to pinpoint localities where ground water is unfit for human use. It is apparent, however, that such localities must be of very small extent as of 1963.

The susceptibility of any given well to pollution depends on three factors.

1. The distance to the nearest source of pollution. Bacteria seldom migrate more than 100 feet from a source of dilute sewage effluent (Mallman and Mack, 1961), but nitrate and ABS may maintain objectionable concentrations for greater distances; few data are available on how far viruses can travel.

2. The direction to the source of pollution. As a general rule, ground water flows slowly in the direction of the average land-surface slope toward the nearest permanent stream. All contaminants will travel farthest in the direction of natural ground-water flow; dissolved chemical pollution will continue with the ground water until it reaches the stream.

3. The depth at which water can enter the well. Polluted water introduced to the ground at or near the land surface will seep downward to the water table, then move laterally in one or more directions. If the water table is relatively deep, the distance the polluted water must travel to reach a well is thereby increased, and oxidation in the zone above the water table will purify organic wastes and bacteria rapidly. If a well is lined with solid casing many feet below the water table, polluted water may not reach the zone from which water enters the well.

Data collected during this investigation show the importance of casing length in reducing the chances of a well becoming polluted. Fifty-seven wells tapping bedrock in the basin were sampled twice in 1963, in April and in August. The water in some of these wells had virtually the same dissolved solids content on both occasions, as measured by specific conductance, whereas other wells showed large changes. The degree of change was unrelated to the age of the well or to whether the location was in a housing development or isolated. Increases in specific conductance from April to August were much more common than decreases. Table 30 shows that on the average, the greatest changes took place in wells with 0 to 30 feet of casing. The most probable explanation is that many wells with relatively little casing permit entry of water near the land surface. Following heavy rainfall or snowmelt, water that has recently infiltrated into the ground and hence is relatively unmineralized may enter such wells. At other times, water in such wells may be relatively mineralized either because a larger proportion of the water is derived from deeper zones where it has been in contact with earth materials longer or because the water entering at shallow depth contains a larger proportion of effluent from local sewage-disposal facilities. In either case, the entry of water near the land surface in wells with less than 30 feet of casing means that these wells are more susceptible to pollution than wells with more than 40 feet of casing. Evidence that water derived from sewage or other wastes is indeed reaching some of these wells is provided by the summary of nitrate concentrations in table 30.

Table 30.--Relation of casing length to nitrate content and variation in specific conductance of water from wells in the Quinebaug River basin.

Length of solid casing	None (dug wells)	9 to 30 ft	31 to 41 ft	40 ft or more
Number of wells sampled	11	18 a/	9 a/	19 b/
Average percentage change in specific conductance from April to August 1963	21	39	14	5
Nitrate content in August, 1963				
Median concentration (ppm)	7.1	3.7	2.3	.5
Percent of wells with nitrate greater than:				
5 ppm	55	44	33	16
10 ppm	36	39	22	0

a/ 1 well finished in stratified drift, the others in bedrock.

b/ 5 wells finished in stratified drift, the others in bedrock.

Many people are aware that water in dug wells is susceptible to pollution unless the well is tightly constructed and properly located with respect to sewage-disposal facilities. Table 30 shows that drilled wells with less than 30 or 40 feet of casing are equally susceptible to pollution, a fact that is not so widely realized. Because drillers almost always set the foot of their steel well casing some 2 to 10 feet below the top of the bedrock (unless the well can be completed in a sand or gravel layer above rock), the influence of casing length on the variations in nitrate and specific conductance shown in table 30 cannot be distinguished from the influence of thickness of unconsolidated deposits. Therefore, it is not known whether drilled wells that reach bedrock at shallow depths would be made substantially safer from pollution by driving the casing to 40 feet. However, it is clear that domestic wells penetrating 30 to 40 feet or more of stratified drift or till and cased to at least 40 feet are very unlikely to be polluted, under conditions existing in the basin as of 1963. Accordingly, areas where the glacial drift is at least 40 feet thick are the most favorable for home development utilizing individual wells and sewage disposal, from the viewpoint of water quality.

TEMPERATURE OF GROUND WATER

Ground water is relatively constant in temperature by comparison with streams and ponds. Nevertheless, there are small differences in temperature from well to well, and seasonal temperature fluctuations occur in many wells.

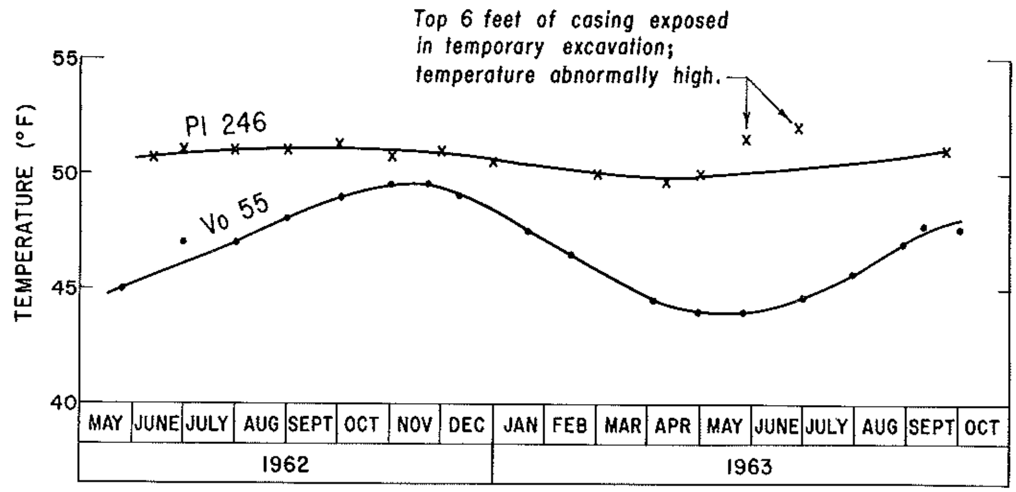
Seasonal fluctuations in ground-water temperature are greatest near the land surface, and disappear with increasing depth. This difference between shallow and deep ground water is illustrated by measurements in two flowing wells in the basin in figure 47 and by two non-flowing wells in figure 48. The temperature of water in very shallow wells can fluctuate as much as 20° F each year, with a low of 35° to 40° F and a high near 55° F. As illustrated by figure 48, water temperature in such wells rises during the spring and summer to a peak in late September, begins to decline when average air temperature drops below water temperature, and continues to decline until average air temperature once again rises above water temperature in March or April. By contrast, in localities where the water table remains more than 30 feet below land surface, ground water is insulated from changes in air temperature and seasonal temperature fluctuations are small. Water obtained from depths greater than 60 feet is nearly constant in temperature.

The temperature of ground water 30 to 60 feet below land surface in most localities is within 2 or 3 degrees of the annual mean air temperature, which is about 48° F throughout the Quinebaug River basin (Gosslee and Brumbach, 1961, p. 9, p. 26). Local conditions cause variations; for example, ground-water temperatures are lower below forested areas than below open fields (Pluhowski and Kantrowitz, 1963), and may also be slightly lower than average on north-facing slopes. Below 60 feet, the earth's temperature increases about 1° F for every 60 feet of depth, so that water obtained a few hundred feet below the surface is likely to be a few degrees warmer than 48° F. The differences in average temperature of the water from two flowing wells in figure 47 may reflect both location and depth. Well Vo 55 is 9 feet deep in dense woods; well Pl 246 is 315 feet deep on a southwest-facing grassy to bushy hillside.

EFFECT OF INDUCED RECHARGE ON QUALITY

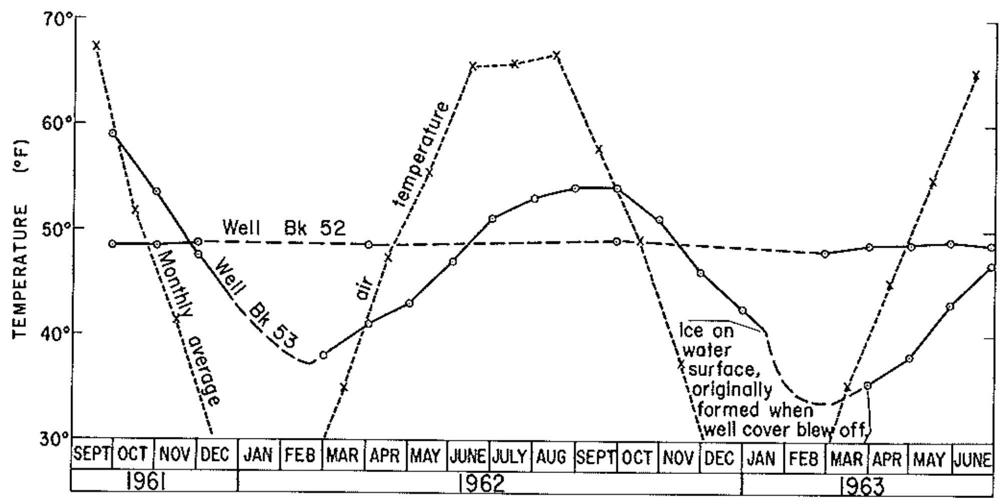
As pointed out on page 66 , the pumping of wells finished in permeable stratified drift bordering a major stream can lower the water table enough to cause substantial amounts of water from the stream to infiltrate the aquifer. Such induced recharge influences water quality in several ways.

Water pumped from a well which depends on induced recharge is likely to vary widely in temperature,



Measurements were made by inserting a 6-inch thermometer into the casing at the point of overflow. Vo 55 is a driven well 9 feet deep measured below a 3-ft trench at the center of a wooded valley; it has about 6 feet of casing and flowed at 10 gpm (estimated) at trench level. Pl 246 is a drilled well 315 feet deep located at the base of a southwest-facing grass- and brush-covered hillside; it has 28 feet of casing and flowed at 1½ gpm (estimated) through a plug in the top of the casing 2 feet above land surface. (Measured temperature variation in Pl 246 may be due in part to heat exchange with the atmosphere through the top 2 ft of casing.)

Figure 47.--Temperature of ground water from two flowing wells in the Quinebaug River basin.



Water-temperature measurements were made by lowering a can containing a 6-inch thermometer into the water, allowing 2-3 minutes for the equipment to adjust to water temperature, then hauling up the water-filled can and reading the thermometer. Well Bk 52 is located on a terrace; depth to water ranged from 36.6 to 39.3 feet below land surface during the period of temperature measurements. Well Bk 53 is 400 feet away in a swale; depth to water ranged from 0.1 to 4.6 feet below land surface during the same period. Mansfield Hollow Dam, near Willimantic, is the nearest location at which a continuous record of air temperature was obtained; it is similar in latitude and topographic situation to the well sites.

Figure 48.--Temperature of ground water in two non-flowing wells in the Quinebaug River basin, with monthly average air temperature at Mansfield Hallow Dam.

because of the large seasonal temperature changes in the surface water. Annual variations of 20° to 30° F are possible (Winslow, 1962). Minimum and maximum well-water temperatures lag behind the corresponding minimum and maximum temperatures in the stream; the farther the wells are from where the induced recharge enters the aquifer, the longer the lag (Simpson, 1952; Schneider, 1962).

The chemical quality of the water pumped will be intermediate between the river water and the natural ground water in the aquifer (Klaer, 1953; Rorabaugh, 1956). Surface water in the Quinebaug River basin is generally less mineralized than ground water, so that induced recharge will normally result in an improvement of chemical quality in the aquifer. However, along reaches of the major streams into which considerable industrial wastes are dumped, the water in the streams may at low flow have a much higher mineral content than natural ground water, temporarily reversing the normal condition. The sand and gravel beds through which the induced recharge travels serve as large natural filters, generally removing all or nearly all of the bacteria, turbidity, and suspended solids that may be present in the stream.

Where ponds exist on major streams, the water table may be considerably higher bordering the pond than along the stream below the dam or along parallel streams close to the pond. Consequently, there may be some seepage of water from the pond into the ground and toward the lower stream channel, especially near the dam. The effect on water quality would be the same as that of infiltration induced by pumping.

Public-supply well Ki 60, which taps stratified drift 50 feet from a swamp through which a small brook flows (figure 24), probably obtains part of its yield by induced infiltration of water in the swamp. On April 23, 1963 the nitrate content of water in the swamp was 46 ppm, while water from the well contained 4.5 ppm. As there is no waste disposal and no agricultural land anywhere nearby, the nitrate content of the well water probably originates in the swamp, and might increase with increased pumpage. The iron content of 0.05 ppm in the well water compares with 0.18 in the swamp on the same date.

DEVELOPMENT OF WATER

WATER USE IN 1961

The total amount of water used in the Quinebaug River basin for all purposes during 1961 is estimated to have been about 4,780 million gallons, which is equivalent to an average of 243 gpd per capita. More than half of this total was withdrawn by industrial firms for their own use. Use of surface water far exceeded that of ground water. Other aspects of the source, use, and disposal of water in the basin are summarized by figure 49. Most of the data on which this figure is based were supplied by water utilities and major industrial firms or by State agencies. Domestic use in homes having their own sources of water was computed by multiplying an estimated per capita use of 65 gpd by the difference between total population and population served by public water-supply systems. The estimate for agricultural use represents chiefly the water needed to supply dairy cows, poultry, and other livestock in the basin; very little water was used for irrigation.

Plate D shows the locations and amounts of all major withdrawals of water from surface-water and ground-water sources and the points at which the water is returned to streams or to the ground. There are no diversions of water into or out of the basin. Even within the basin, few points of return are much more than 2 miles from the corresponding points of withdrawal.

Ten public water-supply systems supplied the domestic water needs of nearly half the population of the basin and provided about 20 percent of the water used by industry in 1961. The water supplied to homes by these systems amounted to about 65 gpd per capita. The source of water, capacity, type of treatment, population served, and other important features of each of these 10 systems are described in table 31. Plate C shows the general area served by each system and the location of all water sources.

In addition to the 10 systems listed in table 31, a few small community systems serve from 10 to 60 homes; the areas served by some of them are also shown on Plate C. Much of Moosup is supplied by one or another of these small community systems.

Residents served by the 10 water-supply systems listed in table 31 receive soft water with very low concentrations of dissolved solids, as shown by the analyses given in table 32. All these public water-supply systems supply water of better quality than specified by U.S. Public Health Service drinking-water standards, although water from the Gallup Water Service had an unusually high nitrate content.

WATER USE IN THE FUTURE

It is quite likely that the amount of water used in the Quinebaug River basin in 1961 will be exceeded in future years. The increase in use will depend upon changes in the population and in the degree of industrial and agricultural development. Forecasts of such changes rely largely on study and projection of past trends. The Connecticut Development Commission (1962, p. 79) forecasts a population increase of 30 percent by the year 2000 for the Northeastern Connecticut Planning Region, which comprises most of the basin. The Commission further predicts an expansion of the labor force of at least 35 percent during the same period and an increase of more than 100 percent in per capita use of water for all purposes, including industrial as well as domestic use (Conn. Development Comm., 1963, p. 47). If these predictions are realized, total water demand in the basin in the year 2000 would be three times as great as the use in 1961, or about 14.3 billion gallons per year.

The basin can certainly provide this amount of water.

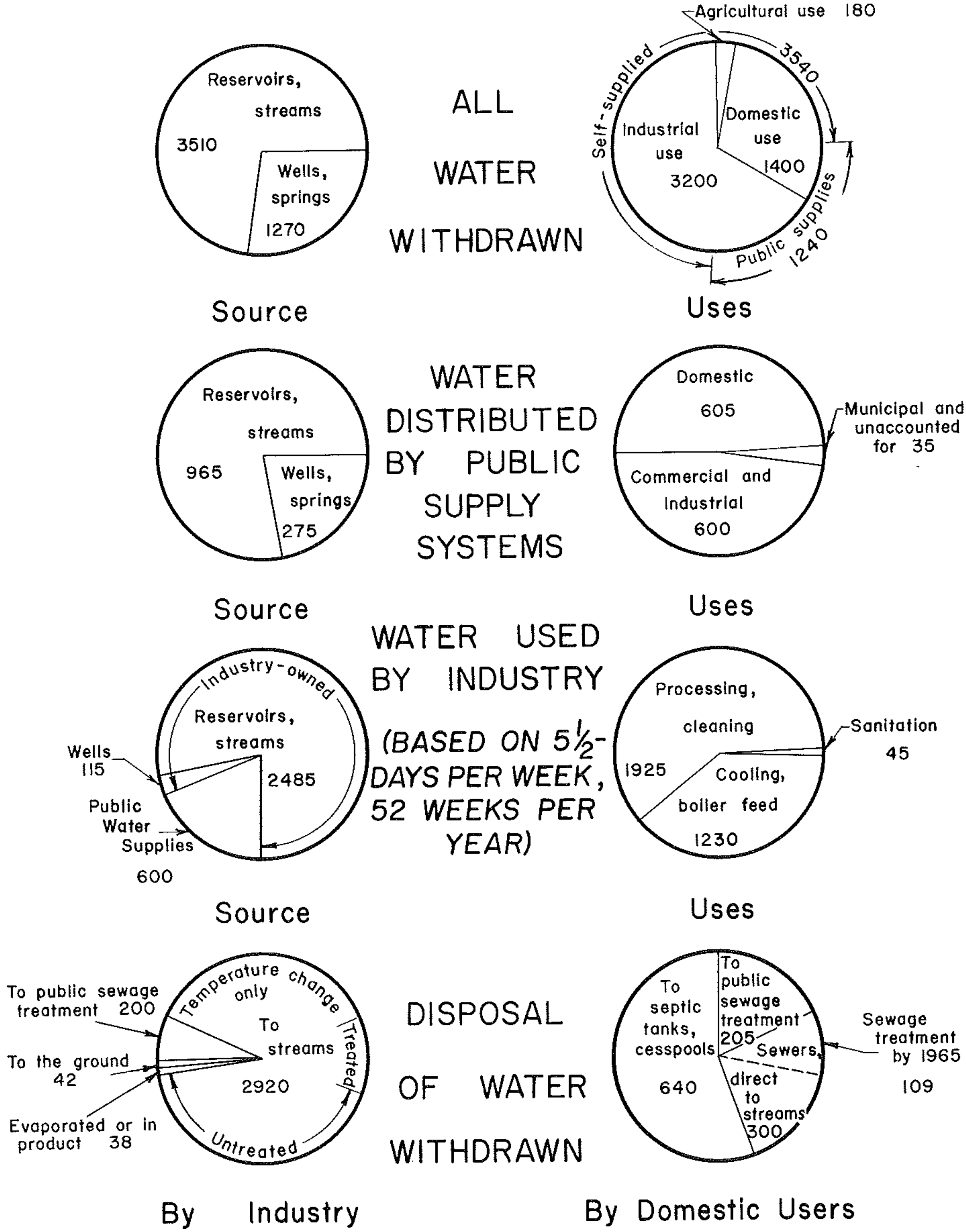
GUIDELINES FOR MANAGEMENT DECISIONS

SMALL SUPPLIES FOR HOMES AND SHOPS

Enough water for the average home or small business establishment can be obtained from wells almost anywhere in the Quinebaug River basin. As pointed out under "Water from aquifers", about 85 percent of the domestic wells drilled into bedrock will supply 3 gpm or more. Water supplies of several gpm can be obtained in areas of stratified drift from drilled, dug, or driven wells finished in sand or gravel. Even glacial till, the poorest aquifer among the various types of earth materials, will provide enough water from a home at a majority of sites.

Despite favorable conditions nearly everywhere, occasional sites will be found where a drilled well penetrates a few hundred feet of bedrock without obtaining enough water, and where the overlying stratified drift or till is largely above the water table or is too impermeable to supply a dug or driven well. Such conditions are generally unpredictable in advance of well construction, especially with respect to bedrock; they are probably most common, though still relatively rare, in hilly areas with numerous bedrock outcrops. Such areas are also less favorable from the standpoint of pollution, as pointed out in a later section of this report.

The quality of naturally occurring ground water is satisfactory for domestic use in most places, but locally ground water contains excessive



Quantities given are millions of gallons per year.

Figure 49.--Source, use, and disposal of water during 1961 in the Quinebaug River basin.

Table 31.--Descriptions of 10 selected public water-supply systems in the Quinebaug River basin.

(Data are for 1961, except as noted, and are based on estimations and records received from water utility officials)

Public water-supply system	Community(ies) supplied	Total population served	Primary source of water	Auxiliary or emergency sources	Treatment	Capacity of treatment plants (gpm)	Raw water storage (gallons)	Finished water storage (gallons)	Total use in 1961 (mg)	Percentage of use				Remarks
										Domestic	Municipal	Commercial	Industrial	
City of Putnam, Water Department	Putnam Harrisville a/	8,165	Impounding dam on Little River	none	Soda ash, alum, chlorination, activated carbon and sand filters	2,100 b/	c/	2,000,000	485.4	35-40	< 1	60-65		a/ 2 percent of the population served are in Harrisville b/ 3 mgpd to be increased to 4 mgpd c/ Unknown, study in progress
Crystal Water Company	Danielson East Brooklyn a/	5,880	Chase Reservoir b/ and Hygeia Reservoir	3 wells c/	Chlorination	420 d/ 700 e/	110,000,000 f/ 15,135,000 g/	500,000	222.2	70	5	25		a/ Total population served is estimated from 1960 census figures for borough of Danielson plus 15 percent of the population of East Brooklyn b/ Water from Chase Reservoir flows into and fills Hygeia Reservoir, which in turn flows to pumphouse c/ Used only during dry spells, may supply more than 50 percent of daily use during severe droughts d/ Reservoir - 600,000 gpd e/ 2 wells - 1 mgpd f/ Chase Reservoir g/ Hygeia Reservoir
Gallup Water Service, Inc.	Plainfield	1,300	well	spring	Chlorination	450 a/	47,000 b/	250,000	108.8	33		66		a/ Capacity of pump b/ In spring basin
Jewett City Water Company	Jewett City a/	5,000	Stone Hill Reservoir	7 wells b/	Chlorination	--	90,000,000 to 100,000,000	none	257.0	45-55	5	40-50		a/ Also small areas elsewhere in Griswold and in Lisbon b/ 1 well supplies 50 to 100 percent of daily use during droughts; other 6 wells in reserve
Masonville Spring Water Company	Grosvenordale, North Grosvenordale	3,600	well	well	Chlorination	110 a/ 60 b/	0	300,000	45.0	50	<.5	45	5	a/ Capacity of pump - primary supply b/ Capacity of pump - auxiliary supply. Third well added to system in 1963
Mechanicsville Supply Co., Inc.	Mechanicsville	256	2 wells	none	Chlorination	--	0	60,000	6.1 a/	90	--	10	0	a/ Estimated, assuming use of 75 gpd/family
Sterling Water Company	Sterling	125	well	well a/	Chlorination	--	90,000	0	4.8	90	<.5	10		a/ May supply 40 to 100 percent of daily use during droughts
The Cranska Company	Moosup (part)	350	well	well	Chlorination	35 a/	0	6,200 b/	18.2 c/	70	--	10	20	a/ Capacity of pump b/ 1 tank at pumphouse, 1 tank at Griswold Rubber Co., connected to system c/ Based on estimated average use of 50,000 gpd
Wauregan Mills, Inc.	Wauregan	850	well a/	well	Chlorination	500 b/	0	300,000	51.3	48	--	2	50	a/ In 1961 used Quinebaug Pond for source, have since changed to wells b/ Capacity of pump
Williamsville Water Company	Rogers	1,000	well	Alexander Lake	Untreated a/	--	0	100,000	18.2	75	1	24		a/ Approved by the Connecticut State Public Health Department

Table 32.--Chemical analyses of water from 10 selected public water-supply systems in the Quinebaug River basin.

(Chemical analyses in parts per million.
Source: D, sample collected from distribution system; S, sample collected at source.
Analyses by the U.S. Geological Survey)

Public water-supply system	Date of collection	Source	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 $CaCO_3$: Non-carbonate	Specific conductance (micromhos at 25°C)	pH	Color	ABS	Turbidity
U.S. Public Health Service 1962 drinking water standards (upper limits)	--	--	--	0.3	0.05	--	--	--	--	--	250	250	1.3[a]	45	500	--	--	--	--	15	0.5	5
City of Putnam, Water Department	2/6/62	S Little River	8.7	0.11	0.00	6.6	1.6	4.0	1.8	15	11	6.0	0.1	2.0	55	23	11	80	6.8	7	0.0	0.0
	2/6/62	D Little River	8.6	.09	.00	6.5	1.6	18	1.8	40	21	7.1	.1	2.0	92	23	0	144	7.6	1	.0	.4
Crystal Water Company	2/7/62	S Hygeia & Chase Reservoirs	6.5	.25	.00	4.9	.8	2.7	1.0	13	6.0	3.0	.1	2.9	38	16	5	54	6.6	4	--	.3
	2/7/62	D Hygeia & Chase Reservoirs	6.5	.14	.00	4.8	.8	2.7	1.0	11	6.6	4.2	.1	2.9	41	16	7	53	6.4	4	.0	.2
Gallup Water Service, Inc.	10/10/62	D Well	14	.03	.00	19	3.3	7.6	3.3	40	14	9.3	.1	27	138	61	28	185	6.7	2	--	--
	10/24/62	S Spring	12	.06	.03	18	2.7	5.9	2.8	38	14	9.8	.1	20	114	56	25	167	6.3	2	.1	.4
Jewett City Water Company	2/8/62	S Stone Hill Reservoir	5.2	.06	.01	2.1	1.4	2.6	.2	4	7.8	2.8	.2	.1	28	11	8	37	5.6	2	.0	.2
	2/8/62	D Stone Hill Reservoir	5.2	.09	.01	2.1	1.4	2.6	.2	4	7.7	3.8	.2	.1	31	11	8	41	5.5	2	.0	.2
	6/27/63	S Well	14	.03	.00	14	1.7	6.6	2.3	35	14	--	--	11	101	42	14	117	6.6	--	--	--
Masonville Spring Water Company	2/6/62	D Well	11	.25	.02	7.2	1.3	5.6	1.7	15	9.7	7.7	.1	5.1	60	24	11	89	6.0	2	.0	--
Mechanicsville Supply Company, Inc.	10/16/62	D Well	11	.03	.03	17	1.6	4.0	2.3	50	19	2.6	.1	.2	85	49	8	132	7.4	2	--	--
Sterling Water Company	2/7/62	S Well	9.3	--	.03	1.4	.7	2.4	.2	2	7.5	2.5	.2	.0	27	7	5	33	5.1	3	.0	--
The Cranska Company	3/5/62	S Well	17	.06	.01	14	3.3	9.0	1.9	56	13	5.8	.4	.6	98	49	3	142	6.8	2	.0	--
Wauregan Mills, Inc.	6/27/63	S Well	12	.01	.00	7.6	2.0	3.9	1.6	23	7.9	5.2	.0	4.6	57	26	8	81	7.0	2	--	--
Williamsville Water Company	2/7/62	D Well	15	.06	.01	19	5.8	5.2	3.3	76	15	4.2	.1	1.7	112	72	9	178	7.1	2	.0	--

a/ Recommended control limits: lower, 0.8 ppm; optimum, 1.0 ppm; upper, 1.3 ppm, based on the annual average of maximum daily air temperatures at Putnam, Connecticut, 1957-1961.

amounts of iron. Iron concentrations rarely exceed 4 ppm, however, and iron can be removed from water by treatment. Areas where iron is likely to be a problem in ground water are described in the section on ground-water quality. Pollution may occur in some heavily populated areas utilizing underground waste disposal; the potential hazard is evaluated in a later section (p. 92 - 93).

LARGE SUPPLIES FOR COMMUNITIES AND INDUSTRIES

The potential for large water supplies within the Quinebaug River basin is summarized by plate D. The only sources from which supplies of 100 gpm (0.14 mgd) or more can generally be obtained are the larger streams and the stratified drift. These sources are closely related, for the larger streams are bordered by stratified drift nearly everywhere. Moreover, the ground-water runoff which sustains streamflow during dry weather comes largely from stratified drift, whereas the yields of large-capacity wells in stratified drift are commonly sustained in part by induced infiltration from streams.

LARGE SUPPLIES FROM STREAMS, LAKES, AND RESERVOIRS

Streamflows equaled or exceeded 90 percent of the time are shown on plate D as an index of surface-water availability from unregulated streams. These values of streamflow could be considered as a first approximation of the average yield available from a low "run of the river" impoundment dam, as only a small amount of surface storage or supplemental ground-water supply would be needed to provide these amounts of water continuously in most years. The volume of usable storage in existing lakes and ponds is also shown on plate D. Thus, the general nature of the distribution and magnitude of surface-water resources in the basin can be seen at a glance from this map. However, the reader who is concerned with developing a particular stream as a source of water supply or waste dilution may compute in greater detail such streamflow characteristics as flow duration, low-flow frequency, and storage-required frequency, at the site of interest as outlined in the section "Water in streams and lakes."

If demand for water is small in relation to streamflow during periods of low flow, development of a water supply may require only a small impoundment dam and intake facilities, such as used by the City of Putnam on Little River (figure 50), or by the Rogers Corp. on the Quinebaug River. If demand is large, then large reservoirs may be required for the storage of water, such as those used by the Crystal Water Co. and the Acme Cotton Products Co. on tributaries of Whetstone Brook (figure 51). This report does not include any selection or evaluation of individual sites as to suitability for dam construction; such evaluation would require consideration of the engineering geology of the proposed dam sites, economic losses in the areas flooded, and other questions beyond the scope of this report.

The yields available from existing ponds and reservoirs are summarized in table 12. In addition, there are 3 sites which were selected as highly-rated potential reservoir sites by the Southeastern Connecticut Regional Planning Association (1963), based in part on a technical study of possible reservoir sites by Metcalf & Eddy (1962). Table 33 shows the yields that these proposed reservoirs could supply under various hydrologic conditions, as computed from streamflow data tabulated in this report.

LARGE SUPPLIES FROM STRATIFIED DRIFT

Areas believed to be especially favorable for development of large ground-water supplies from stratified drift in the basin are delineated on plate D, and the estimated long-term yield of each area is given. The areas were selected according to the following criteria:

1) The stratified drift in each area has a relatively large permeability as nearly as can be determined from the available data.

2) Saturated thickness of stratified drift in each area is at least 40 feet as determined from plate B, except in a very few places where the deposits have an especially large permeability and so deposits slightly less than 40 feet thick were included.

3) Each area is reasonably large, and/or has a good potential for induced infiltration.

There are 29 areas in the basin in Connecticut that meet these criteria.

The yield estimated for each area represents the total of two components: 1) estimated natural recharge in and adjacent to the area; 2) potential induced infiltration from streams or lakes crossing or bordering the area. For some areas, however, the estimated potential rate of induced infiltration exceeds the expected rate of flow of the stream during occasional periods of low flow; therefore, for these areas it is necessary to determine if the amount of water stored underground would be sufficient to sustain well yields during such low-flow periods. The components of long-term yield as applied to the favorable areas are evaluated in the following paragraphs.

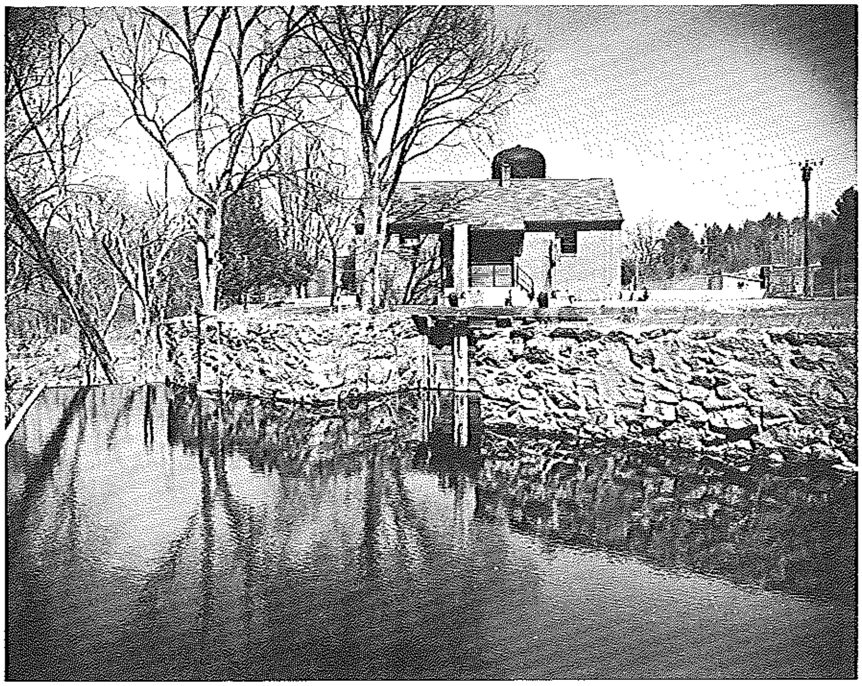
In estimating natural recharge for each favorable area, recharge rates per sq mi of till and of stratified drift that are exceeded 7 years in 10 (table 28) were used. In addition, recharge by underflow from adjacent territory was included. Under pumping conditions it is possible that additional water could be obtained from territory upstream or downstream, beyond ground-water divides, or across streams, but no estimate of this potential recharge was made.

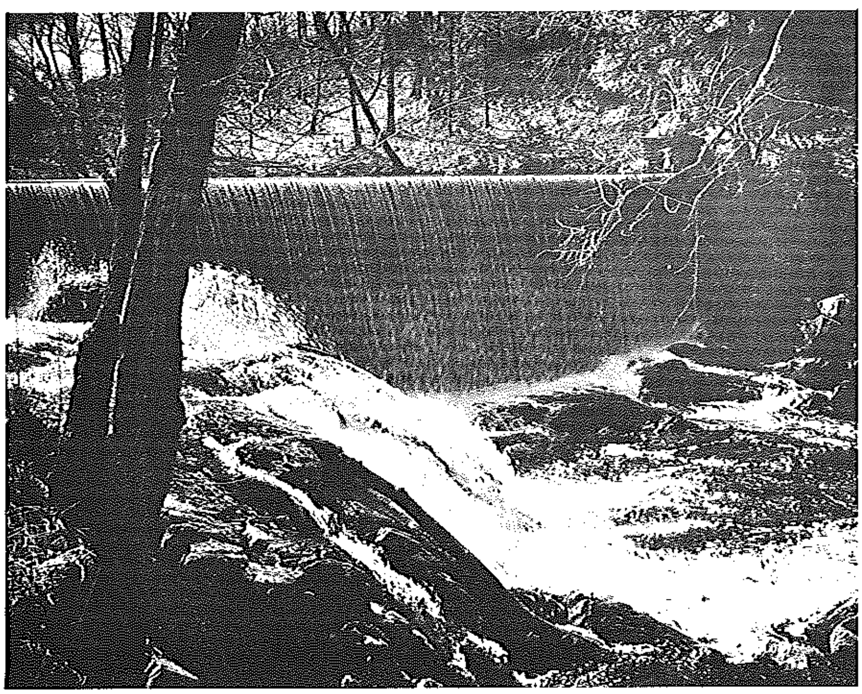
Induced infiltration.--Induced infiltration was estimated by means of a modified form of Darcy's

Table 33.--Yields available from proposed reservoirs in Voluntown and Preston.

Stream, location	Myron Kinney Brook near Voluntown	Broad Brook at Parks Rd. near Preston City	Broad Brook at Jewett City Rd. near Preston City
Station number, shown on plate A	1269.26	1270.9	1271.1
Reservoir site number 1/	13	14	15
Approximate drainage area, from plate A (sq mi)	5.4	12.3	15.3
Percent of drainage area covered by stratified drift, from plate B	37.4	23.4	22.5
Average flow, from table 5 or figure 18 (mgd per sq mi)	1.27	1.22	1.22
Altitude of proposed spillway (ft) 2/	240	175	130
Usable storage in proposed reservoir (75 percent of total capacity) (million gallons) 2/	2040	4220	1420
Reservoir yield under various conditions, based on reference period 1930-1960:			
A. For reservoir to refill during the driest year of the reference period (recurrence interval 31 years): Storage used (million gallons) 3/	299	701	872
Regulated flow, unadjusted (mgd) 3/	2.76	5.33	6.62
Suggested adjustment (10 percent) for bias in computation procedure (mgd)	-0.28	-0.53	-0.66
Allowance for evaporation (mgd) 4/	- .59	- .74	- .31
Reservoir yield (mgd)	1.9	4.1	5.6
B. For reservoir to refill during the median year of the reference period (recurrence interval 2 years): Storage used (million gallons) 3/	609	1410	1420
Regulated flow, unadjusted (mgd) 3/	6.09	13.1	14.4
Adjustment for bias (mgd)	-.61	-1.31	-1.44
Allowance for evaporation (mgd) 4/	-.59	- .74	- .31
Reservoir yield (mgd)	4.9	11.0	12.6
C. For reservoir to refill during the driest part of the 30-year reference period:			
Total usable storage (million gallons) 2/	2040	4220	1420
Time for reservoir to refill (years) 5/	18	15	1.2
Maximum regulated flow, unadjusted (mgd) 5/	6.27	13.0	8.98
Adjusted for bias (mgd)	-.63	-1.30	-.90
Allowance for evaporation (mgd) 4/	-.59	-.74	-.31
Reservoir yield (mgd)	5.0	11.0	7.8

1/ Southeastern Connecticut Regional Planning Association, 1963, p. 38
2/ Metcalf & Eddy, 1962, p. 41-42
3/ As computed from frequency-mass curves developed for each site from data in this report, or as estimated by interpolation in table 14
4/ Metcalf & Eddy, 1962, fig. 2, p. 38
5/ As computed from frequency-mass curves developed for each site from data in this report





This small dam and intake facilities on Little River at Harrisville, from which the City of Putnam obtains its water supply, impounds only enough water to facilitate the process of withdrawal, and depends on the continuing flow of the river for its yield.

Figure 50.--Impoundment dam on Little River at Harrisville.

Killingly Pond, formed behind a dam on Whetstone Brook, is a storage reservoir owned and operated by Acme Cotton Products Co. The reservoir provides water for mill operations at East Killingly, and insures the required water supply during periods when streamflow would be insufficient. The pond is also used for recreation by adjacent property owners, as evidenced by the raft and cottages near the center of the picture.

Figure 51.--Killingly Pond on Whetstone Brook.

law, as adapted from Walton (1962, p. 14):

$$Q = p' \frac{\Delta h}{m'} A, \text{ where}$$

Q = Vertical leakage of water from stream, in gpd

P' = Coefficient of vertical permeability of sediment underlying the stream bottom, in gpd per sq ft

$\frac{\Delta h}{m'}$ = Vertical hydraulic gradient between stream and aquifer

A = Area of stream or pond bottom, in sq ft.

The factors as applied to determine the quantity of water (Q) that could potentially be induced to flow into the stratified deposits underlying the streams in each area under conditions of maximum development are evaluated below.

Vertical permeability (P') of sediment underlying stream bottoms may vary widely as suggested by the examination of stream channels and logs of borings on flood plains. A range in vertical permeability from 1 to 1,000 gpd per sq ft, which seems possible on the basis of available data, would cause great differences in infiltration potential from place to place. However, no quantitative study of the variation was made, so a reasonable estimate of the average vertical permeability of stream-bottom sediments, 50 gpd per sq ft, was used in these computations.

The vertical hydraulic gradient between stream and aquifer ($\frac{\Delta h}{m'}$) would approximate 1/1 for stream channels, because in most places pumping should be able to lower the head in the aquifer below the stream-bottom materials, which range in saturated thickness from about 5 feet along small streams to about 25 feet along the Quinebaug River.

Along ponded streams and in swamps, the chief barrier to induced infiltration is a layer of organic muck on the bottom whose permeability is likely to be about 1. The factor $\frac{\Delta h}{m'}$ below a pond would be somewhat greater than 1/1, depending on the depth of water in the pond.

The factor A for ponds was measured on the topographic map; for stream reaches, including channels within swamps, length was measured on the map and width was estimated for low-flow conditions from field observation. In order to produce the required vertical gradient over the entire channel or pond bottom area thus computed, large-capacity wells spaced a few hundred to 1 or 2 thousand feet apart near the stream along the entire length of the favorable area would be needed.

In computing values of induced infiltration, it was assumed that water temperature was about 55° F, which is the average temperature of the Quinebaug River. To compensate for varying rates of infiltration that accompany changes in the water temperature and viscosity from season to season infiltration per square foot at minimum water temperature (32° F for the Quinebaug River) would be about 1/3 lower than computed, and infiltration at maximum river temperature of 82° F would be about 1/3 higher. This variation is dampened to some extent by changes in river-bottom areas, which is greatest in winter or early spring and least during the period of maximum water temperature.

Flow-duration data (figures 11-16 and 19, table 5) indicate that for most of the areas delineated on plate D as favorable for development of large ground-water supplies, there is more water flowing in the stream than could be induced to infiltrate at least 90 percent of the time. The longest period of consecutive days (if any) in which the flow of the stream is likely to remain below an estimated potential infiltration rate was computed, and estimates were made of the average flow during such a deficient period. The flow thus estimated represents the minimum amount available from induced infiltration. During such a deficient period, under postulated conditions of maximum development, the entire streamflow would infiltrate and leave the channel dry at the lower end of the developed area.

Storage.--If ground-water withdrawal is to be sustained during periods of no recharge and deficient streamflow, the additional water must come from ground-water storage. Total storage in each area was estimated by multiplying the volume of saturated stratified drift (determined from saturated thickness contours on plate B), including adjacent territory from which underflow enters the area under non-pumping conditions, by a gravity yield of 0.23 (from p. 67). To withdraw all or even half of the ground-water storage would require a great many small-capacity wells distributed throughout the area--an impractical measure. However, it is estimated that 1/3 of the ground-water storage in each area could be withdrawn by a line of wells spaced 500 to 1,000 feet apart along the entire length of the area, each pumped at 100 to 600 gpm (a similar design would be required to obtain the maximum induced infiltration). In computing the yields available from these favorable areas, it is assumed that such a design for development of ground-water supplies is feasible.

As explained on page 67, periods of little or no natural recharge may last as long as 6 months. Available storage in each of the selected areas is ample to sustain well yields at the annual natural recharge rate during such a 180-day period. For areas in which streamflow may occasionally drop below the estimated potential infiltration rate for many days, available storage may not be sufficient to sustain well yields at that rate during the period of deficient flow. Accordingly, for such areas, long-term yields were adjusted downward so that withdrawals would not exceed the amount of storage assumed available.

Summary of computations.--The computations of long-term yield from the 29 areas most favorable for development of large ground-water supplies are summarized by table 34. The accuracy of the estimates of long-term yields depends on the accuracy of the determinations of recharge, frequency of low streamflow, saturated thickness of the deposits, gravity yield of the deposits, and potential for induced infiltration. However, the assumptions that necessarily were made in determining values for these factors were so chosen as to give conservative estimates of yields. Furthermore, 3 factors which should act to increase the estimates given for yield were neglected. They are: (1) increased recharge owing to a reduction of ground-water evapotranspiration within areas where water levels are depressed by pumping, (2) increased recharge and storage potential owing to enlargement of the favorable areas under pumping conditions, and (3) increased induced recharge owing to enlargement of the stream-channel areas during periods of moderate and high streamflow. In view of all these considerations, the estimated potential long-term yields given are expected to be smaller than the maximum long-term yields that could be developed; this is especially true for areas along the smaller streams. Refinement of these estimates by more detailed site investigations should precede final development of large water supplies. Furthermore, full development of ground-water supplies is subject to the practical considerations inherent in installing the many wells and pipelines that would be needed.

In addition to the 29 areas in the Quinebaug River basin that are designated as especially favorable for the development of large ground-water supplies, there are other areas favorable for the development of small to moderately large supplies as indicated on plate D. The latter areas include places where it may be possible to complete individual wells in stratified drift that would yield 100 gpm or more but long-term sustained yields are limited because the permeability of the stratified drift is low or the saturated thickness relatively small.

Drilled, screened wells, such as those shown being pumped in figure 52, are generally the most effective means of obtaining large water supplies from the stratified drift. Where a supply will be sustained largely by induced infiltration, collector wells may also be effective. Where the saturated thickness of the stratified drift is small, or where the stratified drift is fine grained except for a thin surface layer of coarse sand that extends a short way below the water table, it may be feasible to develop supplies of a few tens or hundreds of gallons per minute from a group of shallow dug wells, or from several small-diameter driven or jetted wells connected to a common suction line.

EFFECT OF WATER QUALITY ON FUTURE DEVELOPMENT

The adequacy or utility of a water source is dependent on the quality as well as the quantity of water available. In general, the chemical quality of most of the water in the Quinebaug River basin is suitable for a wide variety of uses in its natural state, and with suitable treatment can be improved to meet most requirements. However, the water in certain reaches of the Quinebaug River and some tributaries at low streamflow contains sufficient industrial and municipal waste to prohibit use for public water supply or recreation and for many industrial purposes. Ground water in some localities contains so much iron and manganese that treatment for many purposes would be excessively costly in view of the fact that water of better quality is readily available elsewhere. Stream reaches and ground-water localities in which these serious quality problems exist as of 1963 are indicated on plate D.

Table 34.--Computation of yields available on a long-term basis from favorable ground-water areas in the Quinebaug River basin.

Location of area (Areas can be identified on plate D from this description and from estimated long-term yield in Column K) (A)	Extent of area, plus adjacent territory from which ground water drains to area under natural conditions (square miles) (B) stratified drift	till	Annual rate of ground-water recharge that is exceeded 7 years in 10 (mgd) (C)	Streamflow equalled or exceeded 90 percent of the time, for all streams crossing or bordering area (mgd) (D)	Estimated rate of induced infiltration possible under conditions of maximum development, assuming adequate streamflow (mgd) (E)	Maximum number of consecutive days in which the flow of streams crossing or bordering area was less than Column E during period of record 1931-60 (F)	Average streamflow during period of time listed in Column F (mgd) (G)	Amount of ground water in storage in stratified drift within area listed in Column B (mg) (H)	Available storage less amount required to sustain withdrawal at average recharge rate throughout the year (1/3 Column H) - (180 x Column C) (mg) (I)	Ground-water storage assumed usable during period when streamflow is less than estimated infiltration (Column I ÷ Column F) (mgd) (J)	Estimated long-term yield from area (mgd) a/ (Col. C + Col. E, or Col. C + Col. G + Col. J, whichever is less) (K)
Along Little River, north of Roseland Lake	0.85	0.78	0.99	3.2	2.0	35	1.6	1581	349	10.	3
Along Little River, east of South Woodstock	.44	.29	.46	4.9	1.2	0	-	b/	-	-	1.7
Along Little River, near Harrisville	.36	.26	.39	5.0	3.3	30 (75 c/)	2.6 (1.1 c/)	360	50	1.7 (.67 c/)	2.2 c/
Along Quinebaug River, south of Fabyan	.52	.94	.77	30.	33.	135 ±	16.	630	71	.53	17
Along Quinebaug River, northern Putnam	.63	.07	.55	59.	8.5	0	-	-	-	-	9
Along Quinebaug River, southern Putnam	2.14	.98	2.13	68.	47.	112	40	5174	1342	12	49
Along White Brook near Pomfret Landing	.49	.35	.54	77.	2.2	90 d/	1.2 d/	672	127	1.4	2.7
Near northern part of Quaddick Reservoir	.75	.16	.68	6.3	9.1	100	4.4	936 e/	190	1.9	7
Near East Putnam	.64	.09	.61	1.9	3.7	145	1.3	1659	443	3.1	4
Along Five Mile River, north of Dayville	.62	.47	.68	13.	4.2	0	-	-	-	-	5
Along Five Mile River, south of Dayville	1.53	.35	1.40	21.	11.6	0	-	-	-	-	13
Along Quinebaug River near Danielson	.84	.38	.84	96.	14.9	0	-	-	-	-	16
Along Quinebaug River, between Danielson and Wauregan	.42	.08	.38	113.	14.2	0	-	-	-	-	15
Plainfield-Killingly town line, south of Quinebaug Pond	1.26	.58	1.26	0.04	.16	200 ±	.04	-	-	-	1.4
Along Quinebaug River at West Wauregan	.49	.09	.44	113.7	14.3	0	-	-	-	-	15
Along Quinebaug River, south of Wauregan	.45	.14	.42	114.	16.4	0	-	-	-	-	17
Along Moosup River, near Oneco	1.89	.54	2.07	6.	4.5	40	3.3	4306	1062	26.	7
Along Moosup River, near Sterling	.58	.47	.76	8.	4.8	20	4.2	1103	231	11.5	6
Along Snake Meadow Brook, south of Connecticut Turnpike	.49	1.11	.92	0.5	2.5	210 ±	.67	603	35	.17	1.8
East of Moosup Pond	.92	.67	1.08	9.6	2.9	0	-	-	-	-	4
Along Quinebaug River, near Blackwell Brook	.64	.09	.56	127.	10.	0	-	-	-	-	11
Near Plainfield village	1.98	.37	1.77	1.7	.53	0	-	-	-	-	2.3
South of Packer, southeast corner Canterbury	1.32	.07	1.13	0	0	-	-	-	-	-	1.1
Near Clayville Pond, north of Jewett City	1.07	.23	.97	151.	14	0	-	-	-	-	15
Along Quinebaug River, south of Jewett City	1.00	.50	1.01	153.	76	15	53	1633	362	24	77 f/
Along Pachaug River, near Pachaug	.34	0	.28	15.	3.3	0	-	-	-	-	3.6
Along Billings Brook, south of Pachaug Pond	1.34	.66	1.57	1.3	1.7	85	.90	2205	452	5.3	3.3
Along Myron Kinney Brook, near Hodge Pond	.65	.20	.72	.7	1.6	145	.57	961	190	1.3	2.3
Along Pachaug River, near Voluntown	.95	.23	1.02	4.0	1.7	<3	-	-	-	-	2.7

a/ Values above 4 rounded to whole numbers

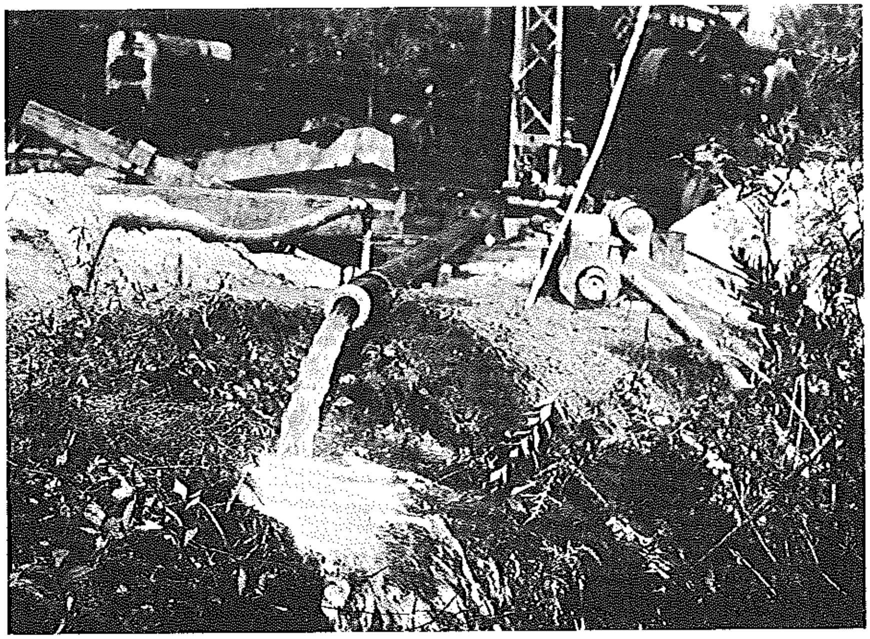
b/ Not computed if Column F is less than 3 or Column G is negligible

c/ Assuming average withdrawal of 2 mgd for City of Putnam water supply just above site

d/ Quinebaug River disregarded

e/ Also, about 104 mg of surface storage in top 6 ft of southern part of reservoir could flow northward into part of this area; 50% of this storage was assumed available for infiltration in this area

f/ A yield as large as this could probably be developed only if conditions prove favorable for construction of 10-15 horizontal collector wells. Because of the narrow valley and modest saturated thickness, long-term yield using vertical screened wells probably would not exceed 45 mgd, which would require wells 500 ft apart on both sides of the river yielding an average of 800 gpm



Two drilled wells being tested to determine water-yielding capacity of the stratified drift near Danielson. A, well Bk 115, owned by Crystal Water Company, being pumped at 265 gpm (photo courtesy of William S. Duncan). B, well Ki 60, owned by Wauregan Mills, being pumped at 510 gpm (photo courtesy of J. A. Atwood III).

Figure 52.--Wells Bk 115 and Ki 60 being pumped to determine water-yielding capacity of stratified drift.

Scattered wells outside the problem areas shown on plate D yield iron-bearing water, and about 5 percent of the wells in the basin yield water classified as hard or very hard. The iron and manganese concentrations and color present in most streams at low flow are excessive for many purposes. No other serious quality problems occur in the basin.

EFFECT OF FUTURE DEVELOPMENT ON QUALITY AND QUANTITY OF WATER

No matter how accurate our measurements and how complete our records of past hydrologic events, they cannot reflect the effects of the man-made changes that may take place in the future. For example: (1) The construction and operation of a water-supply reservoir on Broad Brook east of State Route 165 would greatly alter the time-distribution of daily flows at station 1271 (table 5) and other points downstream. (2) The estimated long-term yields for many of the favorable ground-water areas (plate D) depend largely on induced infiltration, and yet, if large quantities of water are withdrawn but not returned to the stream or the ground nearby, streamflow will be reduced just as if the water had been pumped from the channel. Consequently, the potential yield of other areas downstream would be affected--indeed, in some areas withdrawal of the full estimated yield presumably would dry up the stream during rare periods of extremely low flow. (3) The time-distribution of dissolved solids in the Quinebaug River at Jewett City in 1958 (figure 27) will undoubtedly be modified somewhat over the next 1 or 2 decades as a result of the pollution-control programs administered by the Connecticut Water Resources Commission and the Massachusetts Department of Public Health, and also by changes in industrial and agricultural technology and development within the basin. (4) Additional subsurface waste-disposal resulting from population increases and industrial expansion may result in greater dissolved mineral content of ground water.

Because of the numerous and varied effects that future development may have on water resources, the reader who wishes to use this report to evaluate the quantity and quality of water available at some location should consider whether any major development has taken place since 1963 nearby or in portions of the Quinebaug River basin upstream from that location. Has there been any important water-regulating structure erected upstream? Have any municipal, industrial, or agricultural users begun to withdraw large amounts of water from the stream or adjacent stratified drift? If so, and the water is returned to the stream, how has the quality been changed? If the water is being diverted elsewhere, how much is being taken and when? Are there any new waste-treatment plants upstream? Are there any new major well fields or waste-disposal facilities nearby? Careful consideration of questions such as these should permit local modification of conclusions presented in this report where necessary, in such a way that the report can be useful for many years. It would be wise to measure the effects of future development by continued operation of gaging stations on selected streams, measurement of water levels in selected observation wells, and monitoring of chemical, bacteriological, and physical quality of the water. Such measurements would permit a thorough reappraisal of the water resources of the basin should it become necessary sometime in the future.

ALTERNATIVE CHOICES FOR WATER SUPPLY AND WASTE DISPOSAL IN AREAS OF URBAN OR SUBURBAN DEVELOPMENT

In planning for water supply and waste disposal in areas of urban or suburban development, it is possible to choose among several alternative arrangements. Most of the water used in densely-populated urban areas is provided by public water-supply systems and disposed of via public sewers, although some large industrial users may also have their own facilities. In many lower-density urban or suburban areas, or isolated villages, other arrangements have been used, such as private wells and individual underground sewage-disposal facilities, or a public water-supply system and individual sewage disposal facilities, or individual wells with public sewers and sewage treatment. Several important hydrologic factors that should be considered in choosing one or another of the latter three alternatives within the Quinebaug River basin are discussed below.

INDIVIDUAL WELLS AND UNDERGROUND SEWAGE DISPOSAL

Enough water for the average home can be obtained from wells almost anywhere in the basin. Infiltration rates of sewage effluent in different earth materials were not studied in this investigation, but the experience of many homeowners indicates that underground sewage-disposal systems adequate for an individual home can be constructed almost anywhere in the basin also, with the exception of small areas where bedrock or the water table is very near the land surface. However, where the same or closely-related aquifers are used both for individual wells and individual sewage-disposal systems, a part of the water obtained from wells may be recirculated sewage. Coliform bacteria or objectionable concentrations of nitrate or detergents are likely to be found in the water from some wells under such conditions.

Suburban residential development in the basin has been rather scattered as of 1963, so that recirculation of sewage has not caused major problems. However, a few wells are known to have been abandoned due to pollution, and concentrations of nitrate far above average were noted in samples from several wells. Wells in hilly areas in which bedrock outcrops are numerous and the overburden is generally less than 20 feet thick are especially susceptible to pollution; so are shallow dug or driven wells tapping stratified drift in areas where the water table is within a few feet of the land surface (see p. 77). Use of individual wells and individual sewage disposal in developments of many homes in such areas would probably result in some cases of pollution.

There are, however, localities in the basin where suburban development utilizing properly designed and located individual wells and sewage-disposal facilities is relatively unlikely to result in pollution. Among these are localities in which the bedrock is mantled by 40 feet or more of till, as shown on plate B. Sewage disposal would normally be by septic tanks and shallow leaching fields in the till. Drilled wells tapping bedrock, if constructed so that the casings fit tightly against the till without water- or sand-filled annular spaces around them, should be virtually free from bacterial pollution, although in many cases some nitrate, detergents, and other dissolved constituents might eventually migrate downward into the bedrock aquifer.

Localities in which the stratified drift is relatively thick are similarly favorable. Wells finished in stratified drift or bedrock that are cased to a depth of at least 40 feet are rather well protected from bacterial pollution; because the natural hydraulic gradient is upward in many valley areas it is possible that recirculated sewage may never reach some deep wells in valleys. Furthermore, where the unsaturated zone is 30 to 70 feet thick, which is true on many isolated knolls or terraces, nearly all the bacteria present in sewage effluent near the land surface are likely to die before reaching the water table, so that deep wells in such localities should be especially safe.

Wide spacing between individual wells and septic tanks will minimize the possibility of pollution. Large lot sizes permit greater distances between wells and leaching fields, and a well that yields 7 gpm or more can be used to supply at least 2 homes. Wells should not be located downslope from leaching fields; driving and cement-grouting casing to a depth of about 40 feet even in areas of shallow bedrock may help by reducing the movement of water into the wells from near-surface zones.

PUBLIC WATER SUPPLY, INDIVIDUAL SEWAGE DISPOSAL

The chief hydrologic considerations regarding this arrangement appear to be: (1) Where can a sufficiently large supply of water of satisfactory quality be found? The location and character of streams and stratified drift aquifers from which large amounts of water could be obtained for public water supplies are described at length in foregoing sections of this report. There are many potential sources of public water supplies in the Quinebaug River basin, but in particular localities the distance to the nearest adequate source may be excessive from the standpoint of cost. (2) Will the water discharged from individual disposal systems pollute a major aquifer needed to provide water supplies at or downgradient from the development? If the development will cover the only important stratified-drift aquifer in the immediate vicinity, which may be needed for future water supplies, this pattern of development may be unwise.

INDIVIDUAL WELLS WITH PUBLIC SEWERS AND SEWAGE TREATMENT

If water removed from the ground is largely returned to the ground via sewage-dispoal systems in that same locality, there is little chance of running out of water. If, however, much of the water pumped from individual wells is collected and removed via public sewers, it is reasonable to expect a lower water table and reduced ground-water storage throughout that locality. Obviously, there is some limit to the amount of water that can be removed from a locality in this fashion without causing failure of numerous wells. Using the values for ground-water recharge (p. 66) and gravity yield (p. 67) determined for till and stratified drift, and the value for per capita water use (p. 81) it is estimated that during the driest year on record a population density of no more than about 1,000 persons per square mile ($1\frac{1}{2}$ persons per acre) could be adequately supplied by individual wells in areas of broad till-covered bedrock hills (such as Shephert Hill in Plainfield) that are also served by public sewers. On the other hand, a population density at least ten times greater could be supplied by individual wells and public sewers in valley areas underlain by stratified drift. These are the extremes--most areas within the small valleys among the till-covered hills have an intermediate potential.

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GLOSSARY

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

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

Aquifer: A relative term that designates geologic formations or deposits that contain considerable amounts of obtainable ground water.

Bedrock: The solid rock, locally exposed at surface of the earth but more commonly underlying a few inches to as much as 200 feet of soil, sand, or other unconsolidated material in the Quinebaug River basin.

Bedrock valley: A valley cut in bedrock prior to and during glaciation but now partly or entirely filled with glacial drift.

Calcic: Containing calcium, as calcic feldspar or calcic igneous rocks.

Casing, of wells: Solid pipe, lacking open joints or perforations, used to seal out both water and unconsolidated sediment from wells.

Cement grouting: Application of cement slurry to a well, usually under pressure, in such a way that any annular spaces between the casing and the earth materials are filled and sealed with cement.

cfs: cubic feet per second. A unit expressing rates of discharge. One cubic foot per second is equal to the discharge of a stream of rectangular cross section, 1 foot wide and 1 foot deep, flowing water at an average velocity of 1 foot per second. One cfs is equivalent to 646,317 gallons per day.

Chemical quality of water: The quantity and kinds of material in solution and the resulting water properties.

Clay: Particles of sediment smaller than 0.004 millimeters in diameter. Most clay beds in the Quinebaug River basin were deposited in glacial lakes, and presumably consist chiefly of finely-ground rock particles rather than "clay minerals" such as kaolinite or montmorillonite.

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

Coliform bacteria: Any of several varieties of bacteria which commonly inhabit the intestinal tract of vertebrate animals. The presence of coliform bacteria in a water sample is regarded as evidence of sewage pollution and fecal contamination, although these bacteria are not themselves toxic.

Color, in water: The extent to which a water is colored by material in solution.

Continuous-record gaging station: A site on a particular stream at which measurements of stream elevation are made continuously, by automatic equipment, or by observation at least once per day. These records are readily converted to daily flow when calibrated by occasional flow measurements.

Crystalline bedrock: Bedrock composed of closely interlocking mineral crystals.

Direct runoff: The water that moves over the land surface directly to streams promptly after rainfall or snowmelt.

Discharge: The rate of flow of water at a given instant from a pipe, an aquifer, a lake, or a drainage basin, in terms of volume per unit of time.

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

Dolomite: Rock composed chiefly of calcium and magnesium carbonate.

Draft, from a reservoir: A rate of regulated flow at which water is withdrawn from the reservoir.

Drawdown, in a well: The distance between the water level during pumping and the water level had the well not been pumped.

Drilled well: A well constructed by chopping or grinding a hole in the earth. Two types of drilling machines were in common use in the Quinebaug River basin in 1964, cable-tool and air-rotary or mud-rotary machines.

Driven well: A well constructed by driving one or more lengths of pipe into the ground, at the bottom end of which is a "drive point" consisting of screen sections to admit water and a sharp point to facilitate penetration. Such wells cannot penetrate bedrock, till, or coarse gravel.

Dug well: A well constructed by excavating a hole in the ground, usually at least 2 feet in diameter, by means of hand tools or with power equipment such as clamshell buckets or augers. Occasionally explosives are used to penetrate a few feet into bedrock. Such wells are commonly lined with tiles or with laid fieldstone.

Erosion: All processes by which earth materials are loosened and removed from place to place.

Evapotranspiration: Water returned to the atmosphere by direct evaporation from water surfaces and moist soil and by transpiration of plants.

Fault: A fracture or fracture zone along which there has been displacement of the two sides relative to one another parallel to the fracture.

Feldspar: A group of abundant rock-forming minerals composed of silica, aluminum, oxygen, and mixtures of potassium, sodium, and calcium.

Ferric iron: An oxidized or high-valence form of iron (Fe^{+3}). Ferrous iron changes to ferric iron by combining with oxygen when natural water containing ferrous ions is exposed to air.

Ferrous iron: A reduced or low-valence form of iron (Fe^{+2}), quite soluble in the absence of oxygen but unstable in solution when oxygen is present.

Flood: Any relatively high streamflow overtopping the natural or artificial banks in any reach of a stream.

Flow duration, of a stream: A period of time, or percent of a period of time, during which daily flow equals or exceeds any specific magnitude. The days are not necessarily consecutive.

Fracture: Breaks, or the process of breaking, in rocks due to intense folding or faulting.

Frequency: See "recurrence interval."

Gaging station: A particular site on a stream, lake, or reservoir where systematic observations of gage height or discharge are obtained.

Glacial drift: In the Quinebaug River basin, all earth material deposited by glacial ice or by glacial meltwater; it includes stratified drift and till.

Gneiss: A coarse-grained crystalline rock in which bands of granular minerals alternate with bands of platey minerals.

Gravity yield: The ratio of (1) the volume of water which a rock or sediment, after being saturated or partly saturated, will yield by gravity during a period of ground-water recession, to (2) the volume of the rock or sediment.

Ground water: Water in the zone of saturation.

Ground-water runoff: The part of the precipitation that has become ground water and has seeped into stream channels from saturated earth materials.

Hardness, of water: The property of water attributable to the presence of alkaline earths. It has soap-consuming and encrusting properties. It is expressed as the concentration of calcium carbonate ($CaCO_3$) that would be required to produce the observed effect.

Humic acid: Any of various complex organic acids supposedly formed by the partial decay of organic matter.

Inches of water: A measurement of water volume, expressed as the depth in inches to which the water would accumulate if spread evenly over a particular area. One inch of water on one square mile is equivalent to 17.4 million gallons.

Induced infiltration: Water which infiltrates from a stream or lake into an aquifer because of lowered water levels in the aquifer due to pumping of nearby wells.

Jetted well: A well constructed by forcing water under pressure out the end of a column of pipe, thereby washing away the earth materials ahead of the pipe.

Leach: To dissolve out by a percolating liquid.

Limestone: A sedimentary rock consisting chiefly of calcium carbonate ($CaCO_3$) which yields lime (CaO) when burned.

Lithology: The physical characteristics of a rock or sediment.

Meltwater: Water produced by the melting of glacial ice or snow.

mgd: million gallons per day. One mgd is equivalent to 694 gallons per minute, or 1.55 cubic feet per second.

Mineral: A homogeneous naturally occurring solid, produced by inorganic processes of nature, whose chemical composition is definite or varies within definite limits. Most rocks are made up of many different minerals.

Mineral content, of water: The total of all dissolved inorganic substances (except gases), most of which were originally derived from the minerals in rocks. For most water samples, it is very nearly equivalent to dissolved solids.

Ordinate: On a graph, the vertical distance to a point.

Outcrop: An area of bedrock exposed at the land surface, with no cover of overburden.

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

Partial-record gaging station: A site at which measurements of stream elevation or flow are made at irregular intervals, less frequently than once per day.

pH: The negative logarithm of the hydrogen-ion concentration. Acidity or alkalinity is indicated by the pH value. Ordinarily a pH value of 7.0 indicates that the water is at its neutral point, being neither acidic nor alkaline; values lower than 7.0 denote acidity, and values higher than 7.0 denote alkalinity.

Pickling liquors: Any of various acid solutions used for chemical baths in industrial cleaning or processing.

Pollution, of water: The introduction of some substance or organism to water, as a result of the activities of man, in sufficient quantity to render the water unfit for some uses.

Porosity: The property of containing void spaces, expressed as the percent of the volume of void spaces to total volume.

Potash: A term used loosely to refer to potassium oxide, potassium hydroxide, or potassium in feldspar minerals.

ppm. parts per million: A unit for expressing the concentrations of dissolved chemical constituents. A part per million is a unit weight of a constituent in a million unit weights of the water solution. For example, a concentration of 20 parts per million of calcium in water means that a million pounds of that water would contain 20 pounds of calcium.

Precipitation: The discharge of water, in liquid or solid state, out of the atmosphere.

Pyrite: An iron sulfide mineral having a chemical composition of FeS_2. Commonly known as Fool's Gold.

Pyrrhotite: A magnetic iron sulfide mineral having a chemical composition $Fe_{n-1}S_n$, with n ranging from about 5 to 16.

Recharge: The process(es) by which water is added to an aquifer; also used to express the amount of water added.

Recovery, in a well: The rise of the water level in a well after pumping has stopped. The distance between the water level in a well after pumping stops and the water level that would have been if pumping had continued at the same rate.

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

Reference period: A period of time chosen so that various data may be collected or computed for that period and thus be directly comparable. Streamflow data in this report are based on a reference period 1930 to 1960.

Riffle: A reach of stream channel characterized by greater slope than adjacent reaches, relatively shallow water depth, and relatively rapid flow.

Runoff: The part of the precipitation that appears in surface streams, including water that flows across the land surface to stream channels (surface or overland runoff) or water that has become ground water and has seeped into stream channels from saturated earth materials (ground-water runoff).

Schist: A medium- or coarse-grained metamorphic rock with subparallel orientation of the micaceous minerals which dominate its composition.

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

Sediment: Fragmental material in suspension in water.

Sewage: Refuse liquids or waste matter carried off in sewers.

Silt: Particles of rock materials smaller than sand and bigger than clay (between .0625 and .004 millimeters in diameter).

Specific capacity, of a well: The yield of the well, in gallons per minute, divided by the corresponding drawdown, in feet.

Specific conductance: A measure of the ability of a substance to conduct an electric current; specifically, the conductance of a cube of the substance 1 centimeter on a side, measured as reciprocal ohms or "mhos." In most water, the conductance is so low that millionths of a mho, or micromhos, are used as the unit of measurement. Specific conductance of a water solution is related to the dissolved-solids content, and serves as an approximate measure thereof.

Specific yield: The ratio of the amount of water that a fully saturated rock will yield by gravity drainage, given sufficient time, to the total volume of rock.

Stratified drift: Rock materials laid down by or in meltwater from a glacier; includes gravel, sand, silt, and clay, arranged in layers, and more or less well sorted.

Streamflow: The discharge that occurs in a natural channel.

Tannic acid: A type of organic acid present in many plants. It forms organic complexes with iron and retards the oxidation of ferrous iron in water. It can change ferric iron to ferrous iron.

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

Transpiration: The process whereby plants withdraw water, which is above or below the water table, from the soil or deeper earth strata and release it to the atmosphere.

Turbidity, of water: The extent to which normal penetration of light is restricted by suspended sediment, microorganisms, or other insoluble material. Residual turbidity is that portion of turbidity caused by insoluble material which remains in suspension after a long settling period. It nearest represents that which might be termed "permanent" turbidity.

Unconsolidated: Refers to materials whose constituent grains are not firmly cemented together and are easily separated from one another.

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

Water table: The upper surface of the zone of saturation, below which all earth materials are saturated. Water levels in shallow wells stand at the water table when the wells are not in use.

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