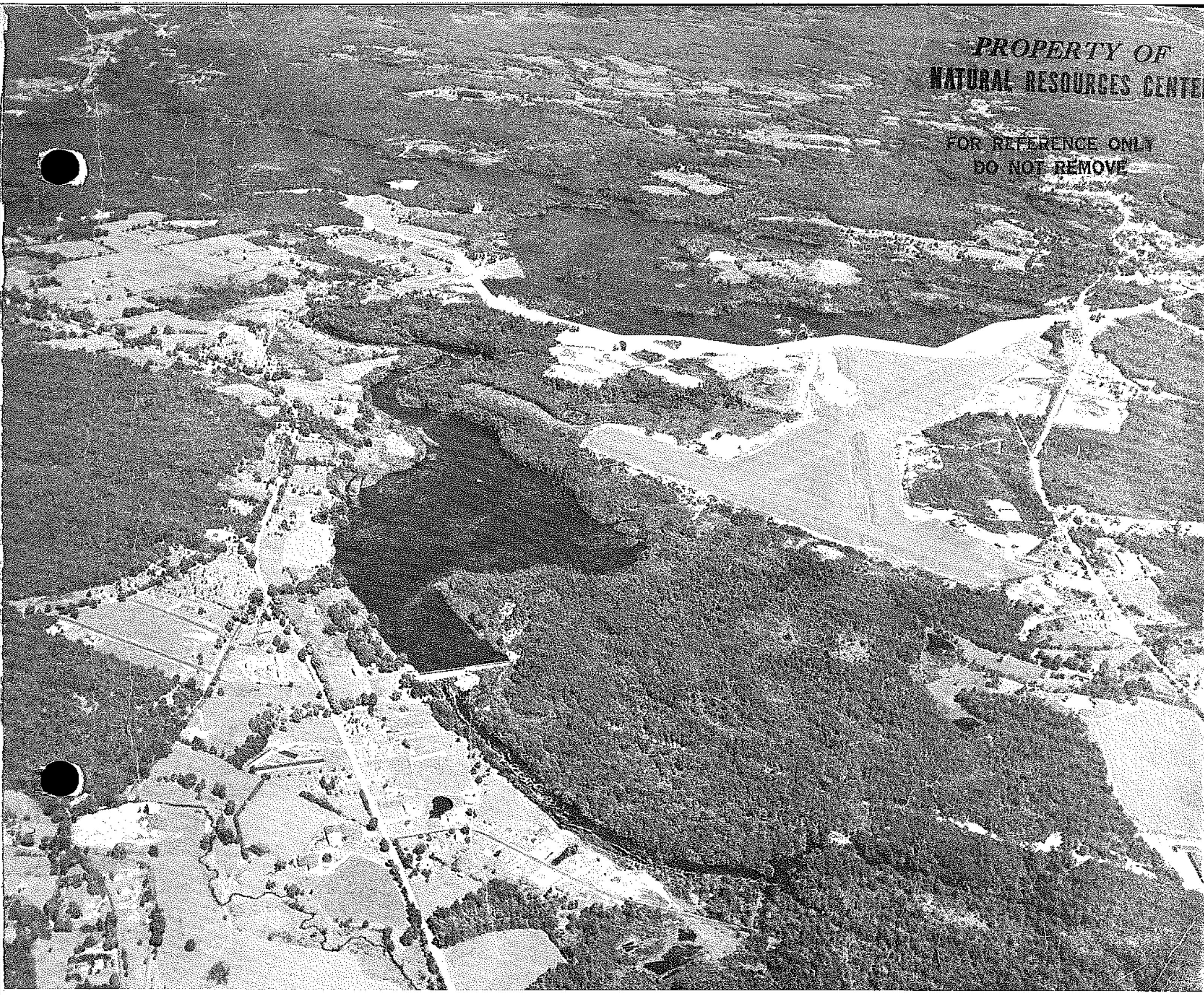


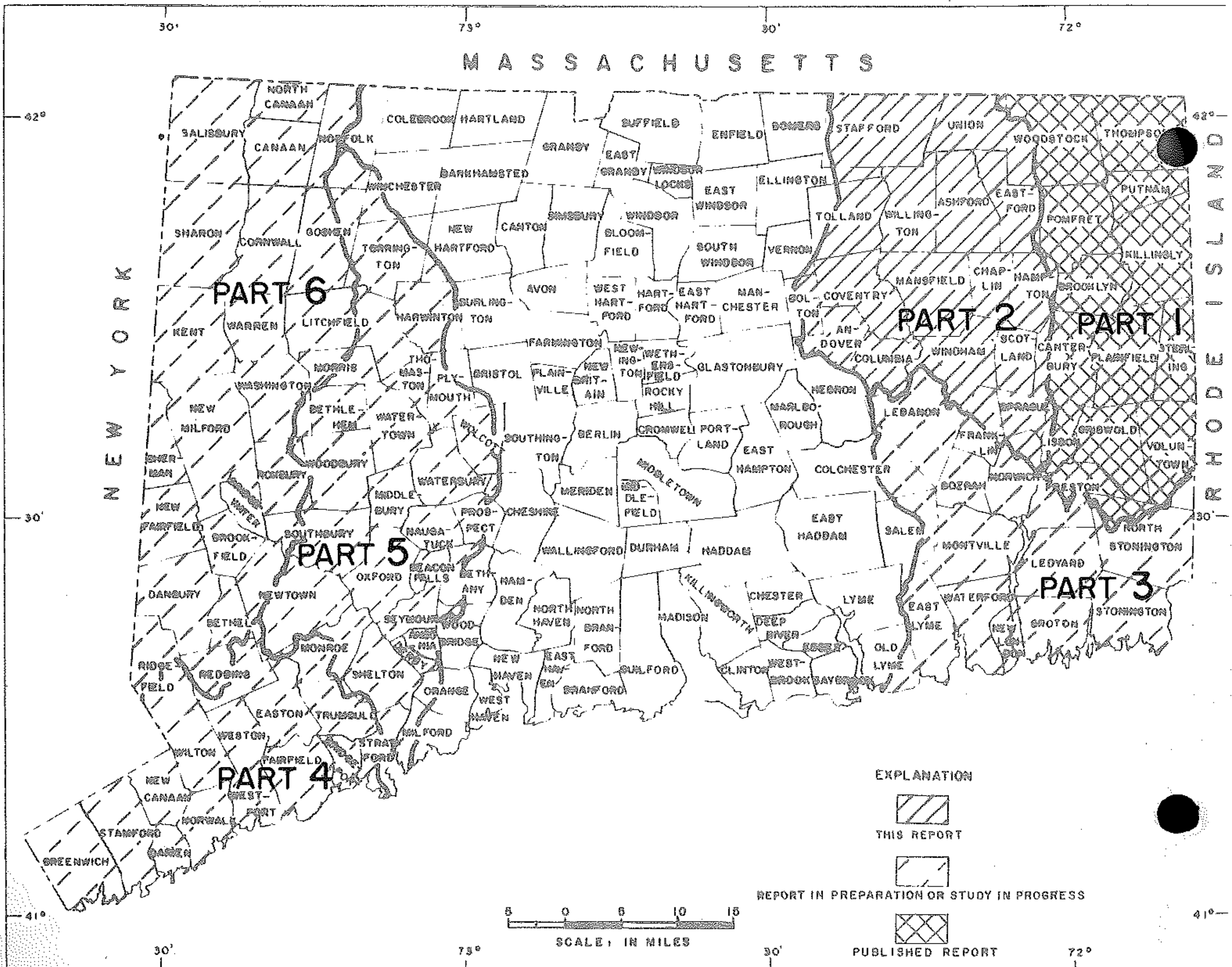
WATER RESOURCES INVENTORY OF CONNECTICUT
PART 2
SHETUCKET RIVER BASIN

BY
MENDALL P. THOMAS, GENE A. BEDNAR, CHESTER E. THOMAS, JR., AND WILLIAM E. WILSON
U.S. GEOLOGICAL SURVEY

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

CONNECTICUT WATER RESOURCES BULLETIN NO. 11

1967



THE WATER RESOURCES INVENTORY OF RIVER BASINS IN CONNECTICUT

PART I - Quinebaug River Basin
PART 2 - Shetucket River Basin
PART 3 - Lower Thames River and Southeastern Coastal River Basins
PART 4 - Southwestern Coastal River Basins
PART 5 - Lower Housatonic River Basin
PART 6 - Upper Housatonic River Basin

ON THE COVER--The Natchaug River near Willimantic, looking upstream; State Highway 195 at left and U.S. Highway 6 at right. Average river flow measured just downstream has been 195 million gallons per day.

Willimantic Reservoir, in the foreground, served an estimated population of 16,000 in 1962 with 1.5 million gallons per day of soft water with a low dissolved mineral content. A highly developed adequate treatment system nearby includes fluoridation.

Mansfield Hollow Reservoir, in the background, is operated by the Corps of Engineers, U.S. Army, for storage of water for flood control. The dam is 12,420 feet long with a maximum height of 70 feet. The reservoir has a total storage capacity of 17 billion gallons which is equivalent to 6.1 inches of runoff from 159 square miles of drainage area. In August 1955, the reservoir was filled to 67 percent of capacity, preventing a downstream loss of $3.2 million. If the record flood of September 1938 should recur, storage of f[illegible] waters would prevent $18.7 million in damages. The pool that appears above the dam represents about 20 percent of total storage capacity.

Most of the area in the foreground is the northern part of an area favorable for the development of large ground-water supplies of excellent quality now virtually untapped.

Photo and data for Mansfield Hollow Reservoir courtesy of Corps of Engineers, U.S. Army, New England Division.

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SUMMARY

The Shetucket River basin has 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 inches to 75 inches and has averaged about 45 inches over a 35-year period. Approximately 20 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 Shetucket River or as underflow through the deposits beneath. 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 mean monthly storage of water in the basin on an average is 3.5 inches higher in November than it is in June.

The amount of water that flows out of the basin in the Shetucket River represents the total amount of water potentially available for use by man. Annual runoff from the entire basin above the Quinebaug River has ranged from about 13 to 42 inches since 1929, and has averaged about 23 inches (300 billion gallons). Although runoff indicates the total amount of water potentially available, it is usually not economically or legally feasible for man to use all of it. 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 differences in the proportion of stratified drift in the drainage basin above each point, which affect the timing of streamflow, and to 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 upper Willimantic River or the Shetucket 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 almost anywhere in the Shetucket River basin, but the amount obtainable from individual wells at any particular point depends upon the type and water-bearing properties of the aquifers present. For practical purposes, the earth materials in the basin comprise three aquifers--stratified drift, till, and bedrock.

Stratified drift is the only aquifer generally capable of yielding more than 100 gpm to individual wells. This aquifer covers about 18 percent of the basin and occurs chiefly in lowlands where it overlies till or bedrock. Coefficient of permeability of the coarse-grained unit of stratified drift averages about 1,900 gpd per sq ft. Drilled, screened wells tapping this unit are known to yield from 200 to 675 gpm. Dug wells in coarse-grained stratified drift should supply at least 2 gpm per foot of drawdown over an 8-hour period. Fine-grained stratified drift has an average coefficient of permeability of about 400 gpd per sq ft and can usually yield to dug wells supplies sufficient for household use.

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 90 percent of which will supply at least 3 gpm. Very few, however, will supply more than 50 gpm.

The amount of ground water potentially available in an area depends upon the amount of ground-water outflow, the amount of ground water in storage, and the quantity of water available by induced infiltration from streams and lakes. From data on permeability, saturated thickness, recharge, yield from aquifer storage, well performance, and streamflow, preliminary estimates of ground-water availability can be made for any point in the basin. Long-term yields estimated for 15 areas especially favorable for development of large ground-water supplies ranged from 1.3 to 61.8 mgd. 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 Shetucket basin is generally good to excellent. Samples of naturally occurring surface water collected from 32 sites contained less than 61 ppm of dissolved solids and less than 32 ppm of hardness. Water from wells is more highly mineralized than naturally occurring water from streams. Even so only 7 percent of wells sampled yielded water with more than 200 ppm of dissolved solids and only 9 percent yielded water with more than 120 ppm of hardness.

Even in the major rivers, which are used to transport industrial waste, the dissolved mineral content is less than 100 ppm and hardness rarely exceeds 40 ppm. One notable exception occurs in the lower reaches of Little River where an

exceptional amount of industrial waste is discharged into the river near Versailles. This waste is particularly noticeable during low streamflow.

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. Most wells in the basin yield clear water with little or no iron or manganese, but distributed among them are wells with ground water that contains enough of these dissolved constituents to be troublesome for most uses.

Iron concentrations in naturally occurring stream water exceeded 0.3 ppm under low-flow conditions at 20 percent of the sites sampled. 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.

Ground water more than 30 feet below the land surface has a relatively constant temperature, usually between 48°F 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, though amounts large enough to be troublesome may occur locally at times.

The total amount of water used in the Shetucket River basin for all purposes during 1961 was about 5,810 million gallons, which is equivalent to 208 gpd per person. Public water systems supplied the domestic needs of nearly half the population of the basin; 10 systems were sampled, all of which provided water of better quality than the U.S. Public Health Service suggests for drinking water standards.

WATER RESOURCES INVENTORY OF CONNECTICUT
PART 2
SHETUCKET RIVER BASIN

By
Mendall P. Thomas, Gene A. Bednar, Chester E. Thomas, Jr., and William E. Wilson

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 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 of 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, has undertaken a series of studies to determine 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 subdivided into 10 study areas, each bounded by natural drainage divides. Reports resulting from studies of these areas 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.

Most of Connecticut is drained by the basins of three major streams: the Thames River drains the eastern portion of the State, the Connecticut River the central portion, and the Housatonic River much of the western portion. The Thames River basin, the first major drainage basin to be studied under the authorization, has been divided into three basins. A report on the water resources of the first of these areas, the "Quinebaug River Basin," part 1 of the 10-part series comprising the "Water Resources Inventory of Connecticut," was issued in 1966 as Connecticut Water Resources Bulletin No. 8. The present report on the "Shetucket River Basin" is part 2 of this series, and the forthcoming report on the "Lower Thames River and Southeastern Coastal River Basins" from the Rhode Island boundary to the mouth of the Connecticut River will be part 3. As of July 1966, studies have been started in three other areas. All six study areas for which reports have been or will be prepared are outlined on the map inside the front cover.

SHETUCKET RIVER BASIN

The location of the Shetucket River basin is shown in figure 1. In this report, the outlet of this basin is considered to be at the point of its confluence with the Quinebaug River, its largest tributary. That portion of the Shetucket River basin from the Quinebaug River to the mouth at Norwich will be covered by the forthcoming report on the lower Thames River and southeastern coastal river basins.

The Shetucket River above the mouth of the Quinebaug River drains a total area of 514 square miles through three principal tributaries, the Willimantic, Hop, and Natchaug Rivers. Seven square miles of the Willimantic River basin are in Massachusetts. The information presented in this report pertains to the 507 square miles of the basin located within Connecticut.

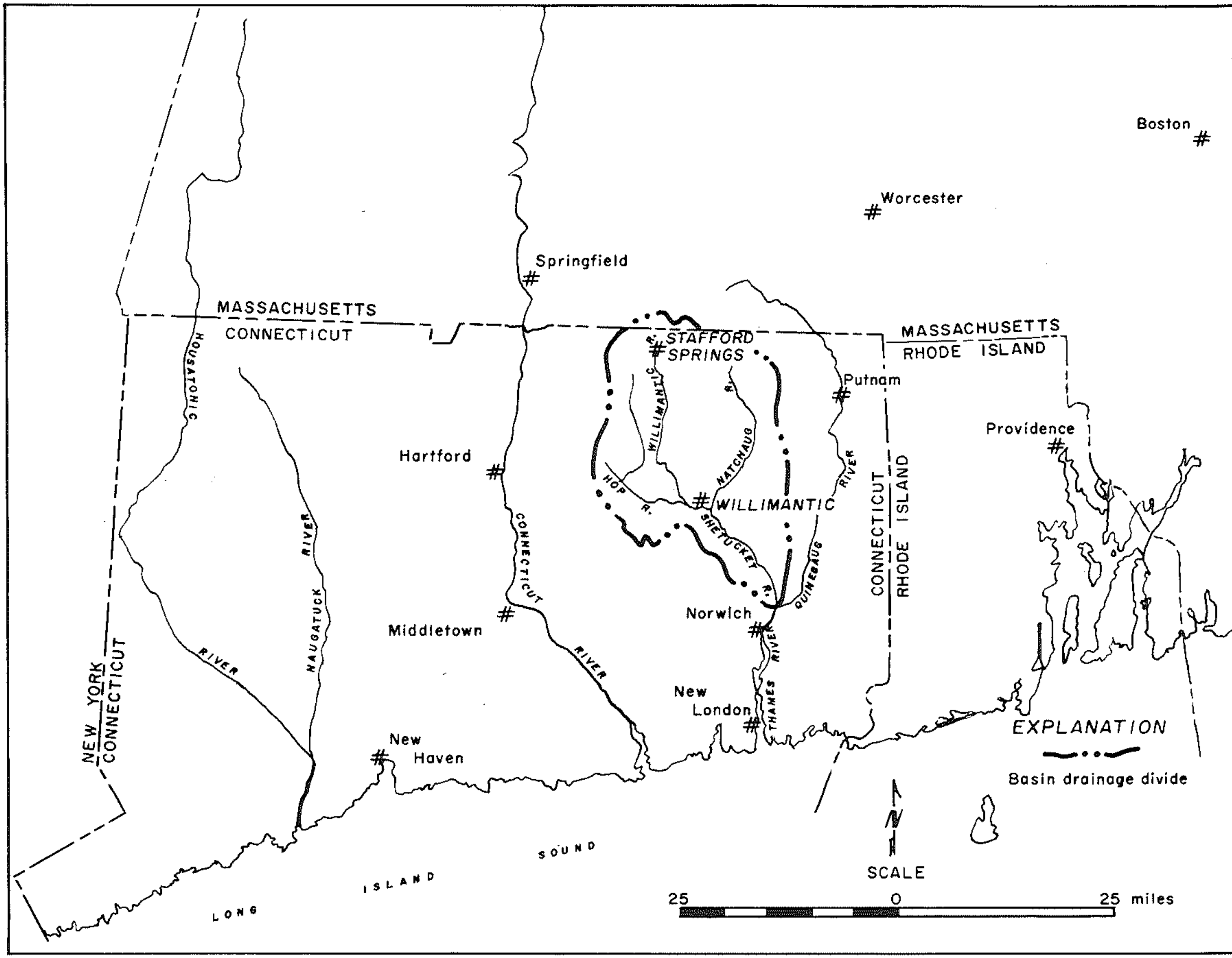


Figure 1.--Location of the Shetucket River basin.

The Shetucket River basin drains 507 square miles in northeastern Connecticut.

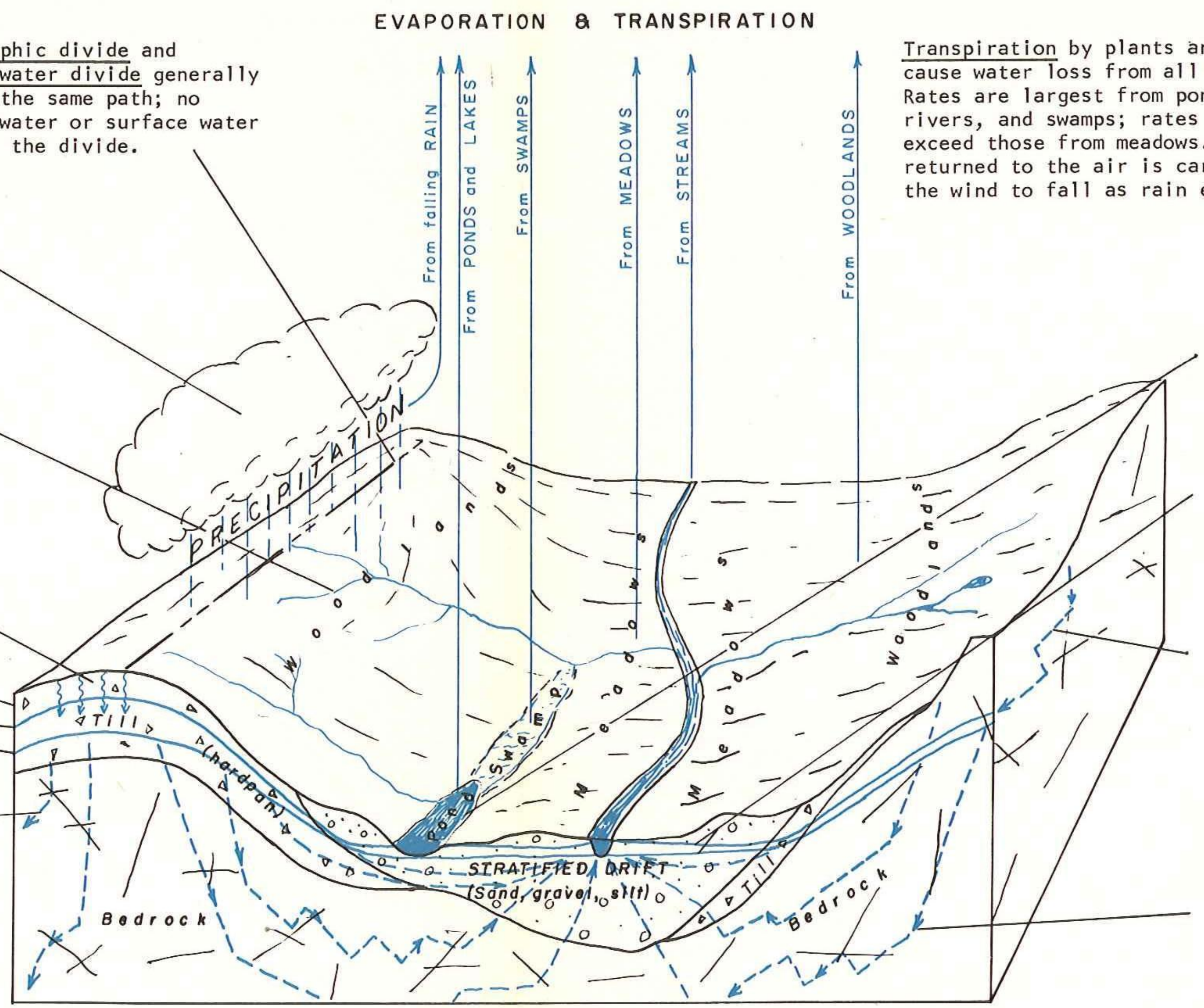


Figure 2.--Natural movement and distribution of water in the hydrologic cycle.

Precipitation is the source of all water in the basin and is disposed of by storage, runoff, evaporation, and transpiration.

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 of surface water in a particular part of the Shetucket River basin 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 the amount of usable storage. This same map shows, for all but very small streams, the streamflow that will be equaled or exceeded 90 percent of the time.

Additional information on surface water is contained in the text. Included are tables and graphs showing flow duration, low-flow frequency and duration, flood peaks, frequency of floods, storage required to maintain various flows, and chemical quality of water at specific locations in the basin. A method is also described whereby the relationship between surficial geology and runoff can be used to estimate flow duration, low-flow frequency, and storage required to maintain certain flows at any point along any stream in the basin.

The reader of this report who is primarily interested in determining the availability of ground water in a particular part of the Shetucket River basin should first refer to the geohydrologic map, plate B. From this map the reader may determine the principal water-bearing unit in the area of interest. If it is stratified drift, the saturated thickness may also be determined. 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 is shown on the map summarizing water available, plate D. This map delineates areas of stratified drift deposits that are especially favorable for the development of ground-water supplies and indicates the quantities of ground water potentially available in each of these areas.

The methods used in determining the ground-water information on plates B and D are described in greater detail in the text, pages 82 to 85.

The ground water in the basin is generally of excellent quality for both domestic and industrial uses. Localized problem areas are discussed in detail in the text, pages 71 to 75.

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 (1967). Considerable unpublished information used in the preparation of this report was obtained from the files of the State Water Resources Commission, the State Highway Department, the State Board of Fisheries and Game, the State Department of Health, and the U.S. Soil Conservation Service.

Abbreviations used and some convenient equivalents are presented on page 92. For readers unfamiliar with some of the technical terms that are used in this report, a glossary is also given at the end of the report.

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 water vapor in the atmosphere condenses to form clouds from which precipitation falls as rain or snow onto the land surface. Part of this water flows across the land surface to collect in streams and lakes 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 by a process known as transpiration. Some, however, moves slowly underground toward nearby streams into which it eventually seeps. Part of the water which reaches treams and lakes, and eventually the ocean, is also evaporated to complete the cycle. The hydrologic cycle as it occurs in its natural state is illustrated diagramatically in figure 2.

As water moves through the hydrologic cycle, large amounts are stored temporarily in the atmosphere as water vapor, on the land surface in streams and lakes, 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. The physical, chemical and biological properties of water are also constantly changing. Keeping track of and integrating these changing amounts and properties of water are the tasks of the hydrologist. The changes that take place in the Shetucket River basin are described more in detail in the following pages.

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. The receipt of water in the Shetucket River basin consists entirely of precipitation; disbursements consist of both direct runoff and ground-water runoff, and evapotranspiration from surface water, ground water, and the soil moisture above the water table. The amount of water on hand--stored within the basin--changes continuously in response to the changing rates at which water enters and leaves the basin. The approximate quantities of water involved in each of the major components of the water budget in an average year for the period October 1947 to September 1962 are shown in figure 3. Although the quantities vary from year to year, the water budget always balances--the disbursements equal the receipts, taking into account changes in storage.

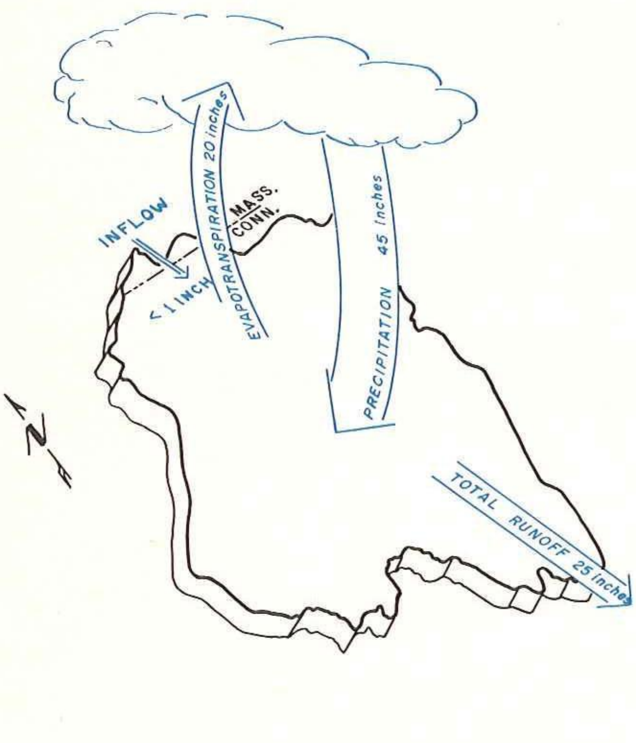


Figure 3.--Average annual water budget for the Shetucket River basin, 1948-62.

Changes in storage from year to year are negligible, and the amount of water leaving the basin equals the amount entering.

The components of the budget are discussed in greater detail on the following pages and are then summarized by means of a monthly water budget for the basin.

PRECIPITATION

Precipitation has been measured for many years at various points in and near the Shetucket River basin. The average amount of precipitation on the basin above the stream-gaging station near Willimantic for each month from October 1928 through September 1963 was computed from records at many U.S. Weather Bureau stations in and 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. 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. The average monthly and average annual precipitation for the period appear at the bottom of the table. Also shown is the average monthly and average annual precipitation for the total drainage area covered by this report for the reference period October 1930 to September 1960, for comparison with similar figures presented in other reports of this series for other drainage basins.

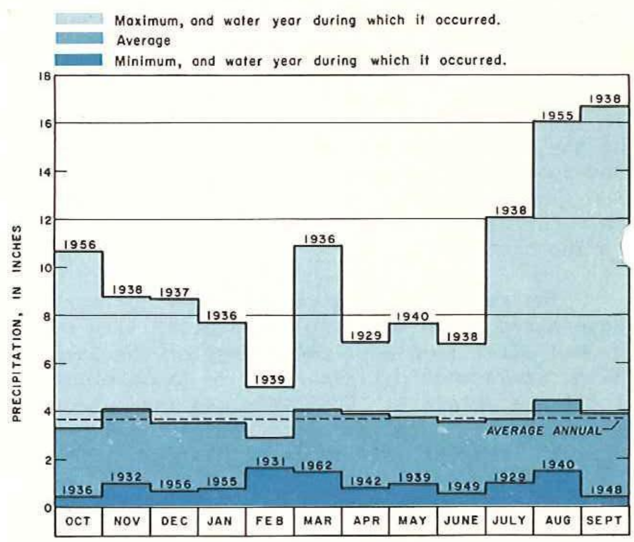


Figure 4.--Monthly precipitation on the Shetucket River basin, 1929-63.

Both average monthly and minimum monthly precipitation were relatively uniform throughout the years, but maximum monthly precipitation varied widely.

Figure 4, which is based on data in table 1, shows that average monthly precipitation is relatively uniform throughout the year, ranging from 2.96 inches in February to 4.43 inches in August; 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 1929-63 was 44.73 inches and ranged from 31.45 inches (1957 water year) to 74.59 inches (1938 water year). For the water years 1948-62 for which the water budget was compiled, the average annual precipitation was 44.86 inches.

Table 1.--Monthly and annual precipitation in inches for the Shetucket River basin above the gaging station near Willimantic for water years 1929-63 and averages for the same period, computed from records of the U.S. Weather Bureau and Connecticut Park and Forest Commission. Maximum and minimum amounts are underlined. Average monthly and average annual precipitation for the whole report area for reference period October 1930 to September 1960 are appended for comparison.

Water year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Annual
1929	2.30	2.09	1.97	4.30	3.72	3.84	6.91	5.19	2.14	1.01	2.15	1.21	36.83
1930	3.52	3.03	3.88	2.59	2.38	3.65	2.19	3.00	2.65	3.35	1.84	.80	32.88
1931	2.79	3.10	3.26	3.09	1.63	5.45	2.61	4.16	6.01	2.51	4.73	1.60	40.94
1932	1.79	1.01	3.20	4.45	2.07	4.41	2.23	2.12	2.09	4.57	7.93	5.04	40.91
1933	6.34	5.25	2.00	2.08	4.26	5.07	5.57	3.31	2.25	2.09	7.05	7.18	52.45
1934	1.91	1.58	3.45	4.00	3.49	3.42	4.19	5.18	3.84	2.37	2.88	10.09	46.40
1935	2.72	2.69	2.88	5.26	2.72	2.29	3.12	2.06	5.15	3.48	1.90	3.47	37.74
1936	.42	4.16	1.15	7.69	3.24	10.90	3.59	4.13	4.08	2.46	5.98	4.35	52.15
1937	5.14	1.30	8.70	5.88	2.71	3.87	4.99	3.26	4.63	2.99	8.41	4.50	56.38
1938	5.37	8.78	2.43	5.46	2.65	2.51	2.68	5.10	6.80	12.03	4.07	16.71	74.59
1939	1.51	3.30	3.70	3.37	5.00	4.69	5.08	.99	3.39	2.10	9.04	3.74	45.91
1940	6.55	1.10	4.13	3.68	3.08	5.53	6.06	7.62	3.40	3.60	1.57	2.48	48.80
1941	2.28	6.83	3.22	2.37	3.06	2.40	1.28	4.82	4.49	6.03	3.34	1.07	41.19
1942	2.33	3.24	3.65	3.53	2.08	7.83	.81	2.71	3.84	4.70	4.40	2.29	41.41
1943	3.53	6.29	5.68	2.94	1.79	3.67	3.85	4.85	2.29	3.82	1.62	.64	40.97
1944	5.62	4.66	.82	1.45	2.77	4.06	4.47	2.48	6.17	2.08	1.59	8.42	44.59
1945	1.93	6.12	2.99	2.50	3.19	2.23	4.90	5.88	4.55	3.67	3.06	1.49	42.51
1946	2.37	5.14	5.31	2.81	2.55	1.69	2.49	5.25	2.96	4.05	7.05	3.56	45.23
1947	.82	1.60	3.19	2.63	1.83	2.51	4.46	2.69	3.79	5.50	2.69	3.96	35.63
1948	2.38	5.42	2.39	3.54	1.80	4.01	3.85	5.80	5.90	3.54	1.87	.41	40.91
1949	2.41	5.64	3.11	4.48	2.78	1.86	3.56	4.67	.58	1.67	3.86	3.07	37.69
1950	2.19	2.38	2.79	3.75	3.50	2.70	3.43	4.29	3.86	2.77	6.13	1.46	39.25
1951	2.54	5.27	4.24	3.44	4.61	5.33	3.27	3.90	2.95	2.69	4.51	1.86	44.61
1952	3.63	7.49	4.74	4.53	1.95	3.34	5.61	3.90	4.80	2.69	7.56	2.81	53.05
1953	1.02	2.81	4.00	6.23	3.30	9.65	5.91	4.05	1.83	3.93	2.07	1.14	45.94
1954	5.51	4.34	5.23	1.86	2.22	4.20	4.66	3.97	2.96	2.23	6.39	8.50	52.07
1955	2.22	4.77	5.08	.80	3.54	4.24	3.61	1.79	3.28	3.33	16.05	4.04	52.75
1956	10.66	4.64	.68	2.72	3.57	5.06	2.90	2.13	3.69	3.75	1.64	4.52	45.96
1957	2.18	4.11	4.97	2.16	1.94	2.24	4.14	1.77	1.19	2.34	2.76	1.65	31.45
1958	2.67	4.50	7.16	5.75	2.41	2.67	6.16	3.95	2.19	5.08	4.71	5.70	52.95
1959	3.79	4.35	1.26	2.72	3.17	5.03	4.60	1.14	4.84	5.85	3.59	1.20	41.54
1960	8.07	5.89	4.44	3.21	4.49	3.19	3.75	4.15	2.77	7.91	3.11	6.78	57.76
1961	2.78	2.94	3.34	2.29	3.24	3.02	4.60	4.86	2.56	3.34	4.07	3.35	40.39
1962	2.33	3.16	3.44	3.66	3.72	1.53	3.31	2.50	4.10	1.83	3.81	3.31	36.70
1963	3.78	3.81	2.16	2.57	3.05	3.14	1.09	3.53	3.35	2.89	1.79	3.83	34.99
Average	3.35	4.08	3.56	3.54	2.96	4.04	3.88	3.75	3.58	3.66	4.43	3.89	44.72
Average 1931-60	3.41	4.31	3.70	3.67	2.93	4.23	3.94	3.70	3.58	3.83	4.56	4.05	45.91

STREAMFLOW, UNDERFLOW, AND DIVERSION INTO THE REPORT AREA

Precipitation is the sole source of water in the Shetucket River basin except for a small diversion into the basin at Taftville. 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 a small amount of water does enter Connecticut, both on the surface and underground from 6.78 square miles of the basin which are in Massachusetts. The average annual streamflow entering Connecticut is only about 300 million gallons and the net annual underground flow only about 200 million gallons.

Water is diverted into the report area from Taftville Reservoir No. 1 for the municipal supply of the town of Taftville. In 1963, 110 million gallons were diverted for this purpose.

RUNOFF

Runoff from the Shetucket River basin has been measured since 1928 at a stream-gaging station near Willimantic, 1.3 miles downstream from the confluence of the Willimantic and Natchaug Rivers. Records at this point represent runoff from 401 of the 514 square miles composing the entire basin above the Quinebaug River. Total runoff for each month from October 1928 through September 1963 is given in table 2. Annual runoff during this period ranged from 12.85 inches (water year 1930) to 42.10 inches (water year 1938) and averaged 23.15 inches. The average monthly and average annual runoff for the period appear at the bottom of the table. Also shown here is the average monthly and average annual runoff for the total drainage area covered by this report for the reference period October 1930 to September 1960 for comparison with similar figures presented in other reports of this series for other drainage basins.

Figure 5, which is based on data in table 2, shows that average monthly runoff follows a marked seasonal cycle, being much greater for March (4.11 inches) than for August (0.71 inches). Minimum monthly runoff also follows a similar cycle. These cycles reflect 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 every month of the year. The great flood of March 1936 was due to a combination of heavy rains and rapid snowmelt. The largest monthly totals recorded in July, August, September, and October were due to passage of severe storms and hurricanes across Connecticut.

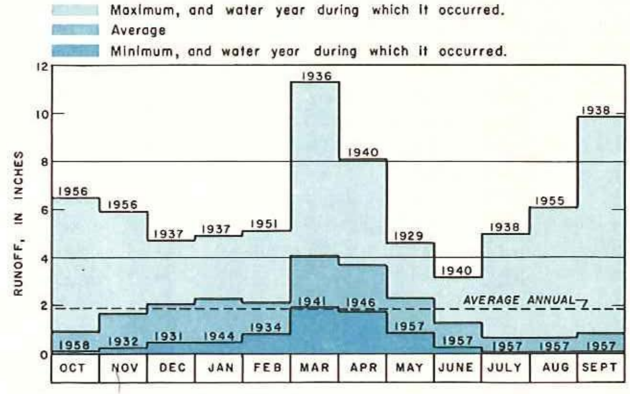


Figure 5.--Monthly runoff from the Shetucket River basin, 1929-63.

Average monthly and minimum monthly runoff followed a marked seasonal cycle. Floods occurred in nearly every month and caused maximum monthly runoff to vary widely and follow no seasonal cycle.

The relationship of total runoff to precipitation is plotted on figure 6. The straight line drawn through the plotted points represents the average relationship of precipitation minus runoff equals evapotranspiration. Most years in which precipitation 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 an excess of runoff during a dry year following a wet year because of the availability of this water in storage. Conversely, there appears to be too little runoff during a wet year following a dry year owing to the need to replace this storage. For example, precipitation in the 1959 water year was 11.4 inches less than the preceeding year. Because storage in the ground and surface reservoirs was relatively high at the beginning of the year and declined during the year, a relatively large proportion of the runoff was contributed from storage. As a result, runoff in 1959 amounted to 60 percent of the precipitation, or 8 percent above average.

Total runoff consists of both direct runoff and ground-water runoff. To determine the amount of ground-water runoff from the Shetucket River basin above Willimantic, and thereby also determine the amount of direct runoff, a ground-water rating curve, figure 7, was constructed using the record of month-end water-table levels in well Wil 1 in Willimantic for the period October 1947 to September 1962. 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 Shetucket River; these plots permitted the construction of the straight-

Table 2.--Monthly and annual runoff in inches for the Shetucket River basin above Willimantic for the water years 1929-63 and averages for the same period. Maximum and minimum amounts are underlined. Average monthly and annual runoff in inches for the whole report area for the reference period October 1930 to September 1960 are appended for comparison.

Water year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Annual
1929	0.97	0.85	1.18	2.57	2.34	4.80	5.11	4.62	0.84	0.53	0.48	0.36	24.65
1930	.43	.60	.95	1.38	1.56	2.58	2.12	1.14	.83	.54	.40	.32	12.85
1931	.20	.49	.48	.71	.94	4.02	3.01	2.65	2.52	.57	.57	.26	16.42
1932	.20	.23	.55	1.67	1.47	2.34	2.99	1.24	.61	.36	.70	.82	13.18
1933	1.97	3.90	1.81	1.91	2.14	4.37	5.44	1.54	.84	.31	.42	1.65	26.30
1934	.82	.78	1.22	3.14	.82	4.90	4.94	3.26	1.40	.43	.36	1.42	23.49
1935	2.13	1.87	2.71	3.08	2.10	4.30	2.71	1.54	1.51	.75	.29	.46	23.45
1936	.28	.57	.66	2.39	1.19	11.36	4.24	2.64	.99	.37	.36	.86	25.91
1937	1.56	.92	4.74	4.97	2.84	3.18	3.31	2.19	1.25	.65	.87	1.10	27.58
1938	1.57	4.17	3.27	3.91	2.87	2.77	2.35	2.09	2.23	5.05	1.88	9.94	42.10
1939	2.38	1.87	3.71	2.17	3.34	4.55	4.89	1.48	.61	.40	.60	.53	26.53
1940	.88	2.02	2.01	2.13	1.13	3.50	8.11	2.84	3.22	1.34	.35	.36	27.89
1941	.38	1.94	2.01	1.42	2.71	1.98	1.89	2.05	1.55	.82	.60	.25	17.60
1942	.26	.71	1.07	1.60	1.68	5.76	2.08	1.50	.90	.77	.71	.27	17.31
1943	.64	2.19	3.39	2.41	3.06	5.02	2.78	3.44	1.09	.40	.30	.16	24.88
1944	.42	1.26	.55	.48	.91	2.58	3.76	1.60	1.66	.61	.24	1.25	15.32
1945	.72	1.77	3.06	2.40	1.78	4.88	2.76	3.93	1.72	.73	.47	.24	24.46
1946	.35	1.10	2.52	3.19	2.19	3.60	1.80	2.63	2.03	.56	1.10	.43	21.50
1947	.84	.65	.88	1.63	1.40	2.87	2.99	2.09	1.09	.69	.44	.50	16.07
1948	.34	2.22	1.18	.89	1.94	6.42	3.86	3.58	3.16	1.19	.43	.17	25.38
1949	.27	.89	.88	3.04	2.74	2.84	2.59	2.12	.48	.17	.14	.16	16.32
1950	.16	.26	.79	1.31	1.49	3.33	2.76	2.79	1.98	.55	.62	.36	16.40
1951	.42	1.38	2.43	3.02	5.14	4.04	4.54	2.01	1.06	.55	.72	.33	25.64
1952	.56	3.17	3.36	4.12	2.84	4.09	3.70	2.72	2.61	.77	1.28	.62	29.84
1953	.50	.80	2.12	4.28	3.81	7.21	6.81	3.47	.67	.40	.26	.15	30.48
1954	.37	1.26	3.17	1.63	1.92	3.23	3.34	3.03	.89	.40	.63	3.47	23.34
1955	1.23	2.80	4.12	2.05	2.02	3.82	2.73	1.78	.88	.50	6.13	1.57	29.63
1956	6.50	5.95	1.63	1.76	2.47	3.56	6.24	2.38	1.89	.76	.25	.41	33.80
1957	.59	.96	2.34	2.06	2.01	2.62	3.50	.92	.31	.14	.13	.12	15.70
1958	.14	.44	2.34	3.95	1.92	4.17	4.85	3.58	.97	.79	.87	1.15	25.17
1959	1.97	2.38	2.19	1.79	1.94	4.37	4.80	1.65	1.09	1.48	.56	.55	24.77
1960	1.68	3.21	3.80	3.00	3.84	2.51	5.00	2.33	1.12	.90	.70	1.50	29.59
1961	1.14	1.64	2.09	1.44	3.03	4.42	3.76	3.24	1.60	.65	.53	.53	24.07
1962	.63	.91	1.01	2.93	1.03	3.84	3.44	1.48	1.01	.33	.32	.27	17.20
1963	.89	1.63	1.11	1.11	1.22	4.08	2.11	1.67	.96	.44	.18	.19	15.59
Average	.98	1.65	2.04	2.33	2.17	4.11	3.75	2.38	1.36	.74	.71	.94	23.16
Average 1931-60	1.01	1.76	2.19	2.44	2.24	4.17	3.84	2.34	1.37	.77	.74	1.02	23.89

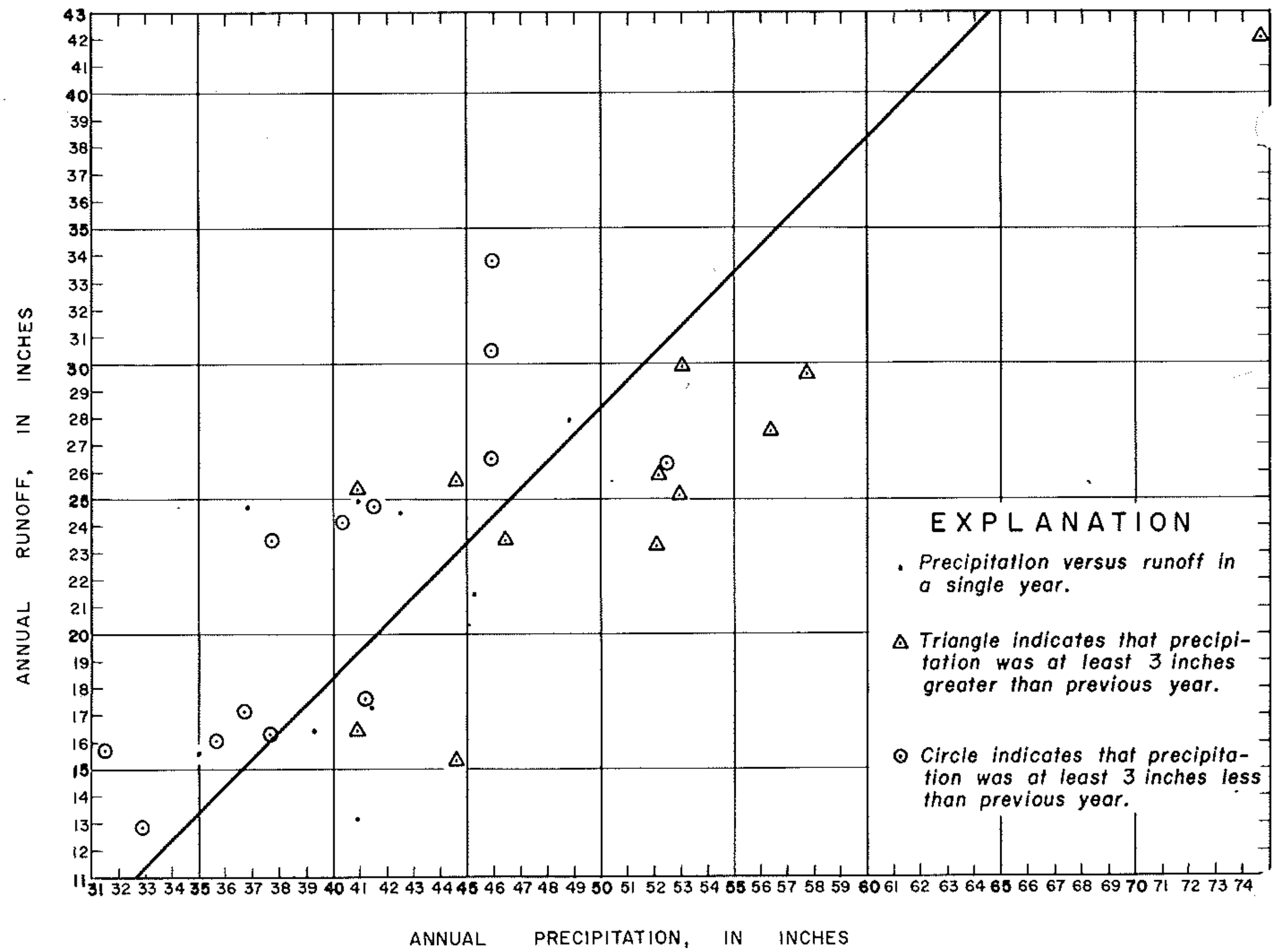


Figure 6.--Relation between precipitation and runoff for the Shetucket River basin, 1929-63.

The straight line indicates that, on the average, runoff from the basin is equal to precipitation minus 21.6 inches. The 21.6 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.

line graphs in figure 7. By means of these lines, the ground-water runoff corresponding to any measured water level in well Wil 1 could be estimated for the end of each month of the year. The average annual ground-water runoff for the period October 1947 to September 1962 was 10.58 inches. This is 43 percent of the average annual total runoff of 24.47 inches observed during the same period.

STREAMFLOW AND UNDERFLOW OUT OF THE REPORT AREA

The average annual streamflow leaving the portion of the Shetucket River basin above the mouth of the Quinebaug River, which is the extent of the area covered by this report, is about 210 billion gallons, and the net annual underflow at this location is about 100 million gallons per year.

EVAPOTRANSPIRATION

A substantial part of the water that falls on the Shetucket 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 almost continuously 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 to 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 directly, and was computed as a remainder after all other gains and losses were measured or estimated. That is, if it is assumed that long-term storage remains substantially the same (an assumption supported by evidence from ground-water levels and reservoir

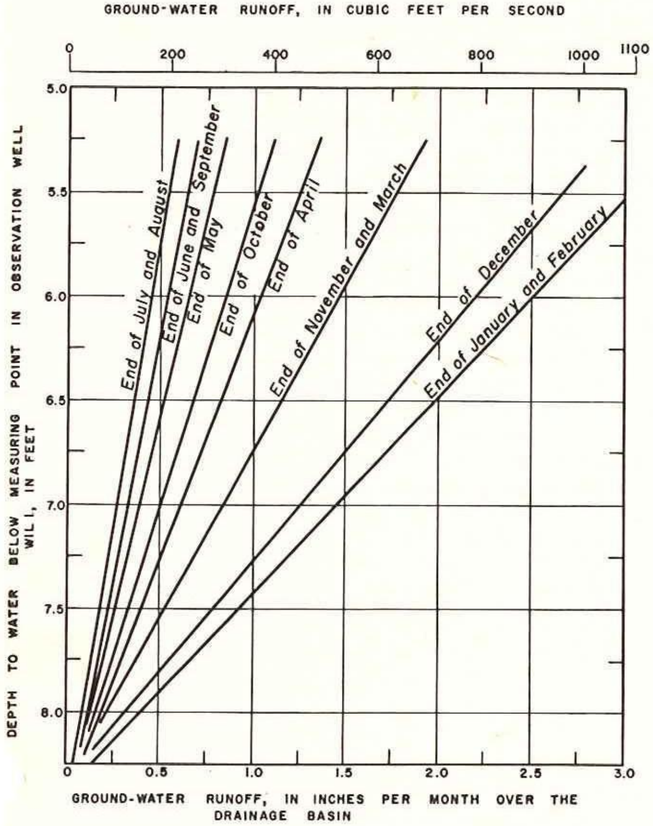


Figure 7.--Relation between ground-water level in well Wil 1 and ground-water runoff in the Shetucket River near Willimantic, 1948-62.

For any given depth to ground water as measured in wells, ground-water discharge to streams 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 the graph. The reduction in ground-water discharge during the growing season represents water loss by evapotranspiration.

levels), the average annual amount of evapotranspiration from the Shetucket River basin for the period October 1947 to September 1962 is equal to the average annual precipitation on the basin (44.86 inches) minus the average annual runoff (24.47 inches), or 20.39 inches.

The effects of evapotranspiration on ground-water levels and on ground-water runoff are indicated on figure 7. Studies have shown that changes in the potential 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 the 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 Shetucket River basin is known from the long-term relationship of precipitation and runoff discussed in a previous paragraph, so a theoretical average monthly distribution of evapotranspiration could be computed by a method similar to that of Olmsted and Hely (1962, p. 13). The monthly variations in evapotranspiration computed for the period 1947-62 are illustrated in figure 8.

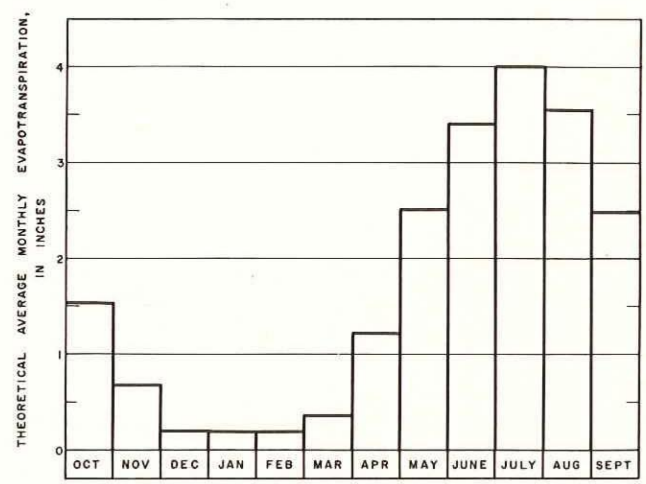


Figure 8.--Monthly evapotranspiration for the Shetucket River basin, 1948-62.

Evapotranspiration is greatest during the growing season (April to October) when plants use a large amount of water, temperatures are above freezing, and the days are longest.

SUMMARY OF THE WATER BUDGET

An average monthly water budget for the Shetucket River basin above Willimantic, given in table 3, lists values for the factors of the budget discussed in the preceeding paragraphs. Precipitation during the late autumn and winter months is sufficient to cause substantial increases in storage and produces abundant runoff, as shown in figure 9. Similar amounts of precipitation in the late spring and summer months are not adequate to supply the large evapotranspiration losses. This results 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.

Table 3.--Monthly water budget for the Shetucket River basin, in inches of water over the basin. Average for water years 1949-62.

Month	Precipitation	Runoff		Evapotranspiration		Change in storage
		Total	Ground water	Total	Ground water	
October	3.63	1.10	0.34	1.54	0.42	+0.99
November	4.51	1.88	.58	e/.68	.22	+1.95
December	3.79	2.23	1.09	e/.20	.04	+1.36
January	3.41	2.48	1.57	e/.20	0	+ .73
February	3.08	2.54	1.71	e/.20	0	+ .34
March	3.87	4.03	1.81	e/.38	.10	- .54
April	4.22	4.13	1.35	1.23	.33	-1.14
May	3.52	2.47	.86	2.51	.53	-1.46
June	3.17	1.31	.47	3.41	.69	-1.55
July	3.53	.64	.32	4.00	.74	-1.11
August	4.81	.90	.24	3.55	.66	+ .36
September	3.32	.76	.24	2.49	.52	+ .07
Water year	44.86	24.47	10.58	20.39	4.23	0

e/ Estimated for periods during month when air temperatures were above freezing.

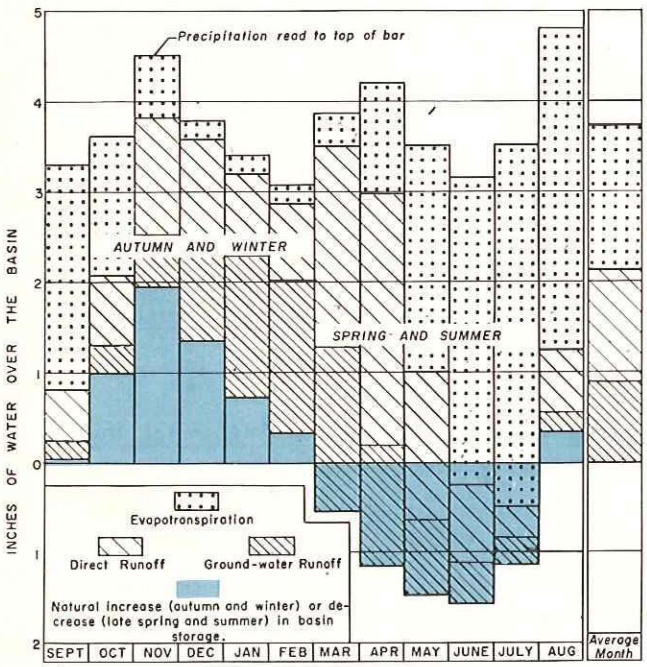


Figure 9.--Monthly water budget for the Shetucket River basin, 1948-62.

During the non-growing season (autumn and winter) precipitation on the Shetucket River basin produces substantial increase in water stored as well as providing abundant runoff; during the growing season (spring and summer) similar amounts of precipitation are not sufficient for sustaining runoff and replacing evapotranspiration losses and so substantial amounts of water are withdrawn from storage.

NATURAL WATER QUALITY IN THE HYDROLOGIC CYCLE

The natural chemistry of water changes as it moves through the various phases of 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, nitrogen in various forms, and sulfur dioxide, are also dissolved to some extent. Thus, even as it starts its journey to the land surface, water is no longer "pure." The part of this water that flows across the land surface is not significantly altered in chemical composition, but the part that seeps into the ground dissolves more mineral matter from the soils and rocks as it moves slowly toward nearby streams. Evaporation and transpiration return some of the water to the atmosphere to complete the cycle, but the result is an increase in the concentration of minerals in the water remaining. The chemical aspects of the hydrologic cycle in its natural state are illustrated in figure 10 and are discussed in greater detail in the following paragraphs.

QUALITY OF PRECIPITATION

Part of the dissolved mineral content of precipitation that falls on the Shetucket River basin is of local origin, but part is of distant origin having been transported into the basin by the wind. Most air masses approach the basin from the southwest, though some approach it from the northwest or south.

Table 4.--Summary of chemical analyses of precipitation samples of 0.25 inch or more collected between June 1963 and January 1964.

(Chemical constituents, in parts per million)

	Index number (Pl.A) and location								
	1P.. Stafford Springs			2P.. Coventry			3P.. Baltic		
	Number of analyses	Range	Median	Number of analyses	Range	Median	Number of analyses	Range	Median
Calcium (Ca)	8	0.4-3.8	1.1	9	0.8-4.1	2.8	9	0.7-2.6	0.8
Magnesium (Mg)	6	.0- .2	.2	9	.0- .6	.1	7	.0-1.0	.1
Sodium (Na)	10	.1- .7	.4	9	.2-1.7	.4	10	.3-1.6	.8
Potassium (K)	10	.1-2.6	.8	9	.1-1.7	.5	10	.0- .9	.4
Bicarbonate (HCO_3)	10	0 -8	1	9	2 -16	6	10	0 -2	0
Sulfate (SO_4)	9	3.2-7.8	4.9	9	.4-6.8	4.9	9	1.8-12	3.8
Chloride (Cl)	10	.0- .9	.3	9	.0-1.2	.0	10	.2-2.7	.6

Analyses of samples of precipitation collected at Stafford Springs, Coventry, and Baltic, summarized in table 4, show that the concentrations of each constituent at all three sites are similar

Water vapor in the atmosphere condenses upon and dissolves particles of dust and absorbs gases to form clouds of water droplets which are slightly mineralized.

Water evaporated or transpired is relatively pure, and the water remaining, therefore, has had its solute concentration increased.

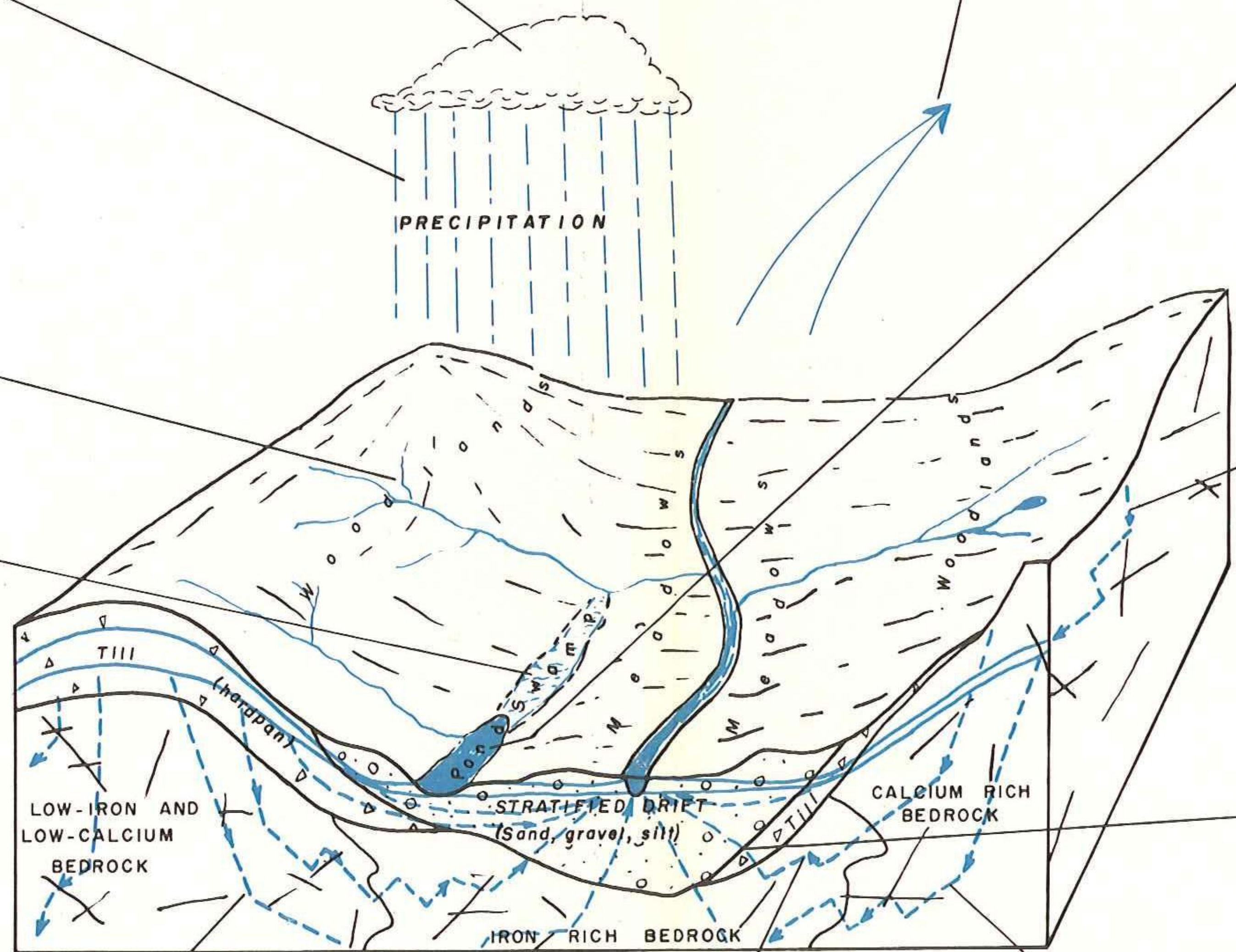
Precipitation contacts and dissolves other dust particles and gaseous matter as it falls and is normally slightly acidic with a low dissolved mineral concentration.

Storage of water in lakes and ponds generally modifies its physical, chemical, and biological properties. Some lakes and ponds are thermally stratified except in spring and fall when their turnover causes vertical mixing and resultant deterioration in quality. Thermal gradients sometimes differ considerably from air temperatures.

Overland runoff picks up and transports soil particles and dissolved organic and mineral matter. Sediment and turbidity contents change as erosion and deposition occur. In general, chemical and physical properties of overland flow are not altered significantly because of short period of contact with the land surface and the low solubility of the exposed minerals. Surface-water temperatures follow a seasonal trend in response to changes in air temperatures.

Infiltration results in higher mineralization because of longer periods of contact with minerals which may also have a higher solubility than those at the land surface. During periods of low streamflow, the more highly mineralized ground-water runoff may substantially increase the mineral content of the smaller streams. Ground-water temperatures become relatively more constant with depth. During periods of low flow in the summer, streams are noticeably cooler where the relatively cold ground water enters the channels.

Organic matter in swamps increases iron content and color seasonally, and water draining from swamps may affect the quality of water downstream in ponds or streams. Temperature of water in swamps is influenced directly by solar radiation.



Ground water in stratified drift and till will vary in hardness and iron content from place to place in the basin depending upon the mineral content of the bedrock from which it was derived. Under certain conditions the upward movement of ground water from the bedrock can also affect the quality of the water in the overlying stratified drift and till.

Ground water in bedrock will be soft and have a low iron content.

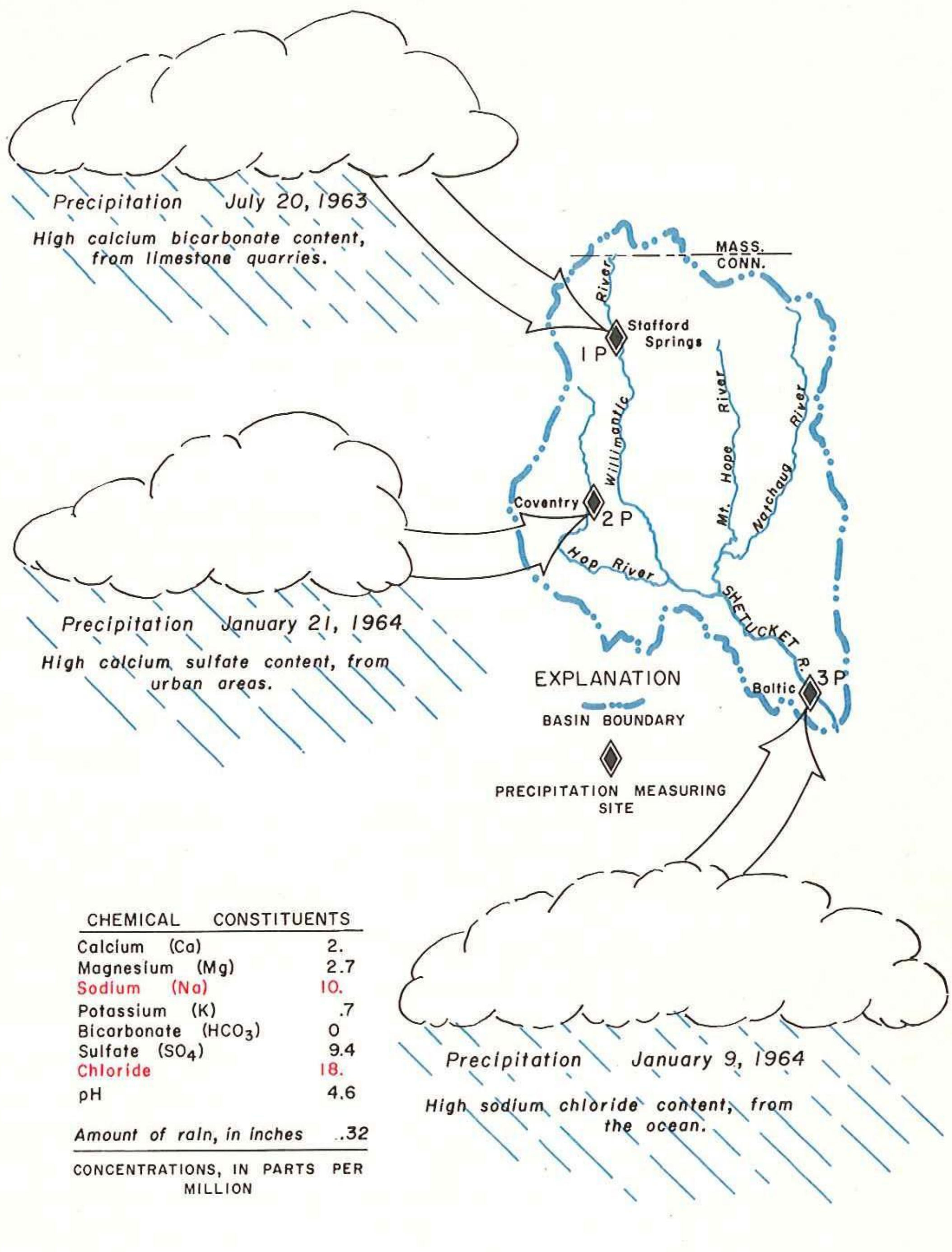
Ground water in bedrock will be soft and have a high iron content.

Ground water in bedrock will be moderately hard and have a high iron content.

Ground water in bedrock will be hard.

Figure 10.--Changes in the quality of natural waters during the hydrologic cycle.

As water moves through each phase of the hydrologic cycle it generally becomes more highly mineralized.



CHEMICAL CONSTITUENTS	
Calcium (Ca)	25.
Magnesium (Mg)	.4
Sodium (Na)	.3
Potassium (K)	1.9
Bicarbonate (HCO_3)	75.
Sulfate (SO_4)	5.1
Chloride (Cl)	.2
pH	7.3
Amount of rain, in inches	*.75*

CONCENTRATIONS, IN PARTS PER MILLION

CHEMICAL CONSTITUENTS	
Calcium (Ca)	17.
Magnesium (Mg)	1.3
Sodium (Na)	.7
Potassium (K)	.3
Bicarbonate (HCO_3)	15.
Sulfate (SO_4)	33.
Chloride (Cl)	.5
pH	6.4
Amount of rain, in inches	*1.8*

CONCENTRATIONS, IN PARTS PER MILLION

CHEMICAL CONSTITUENTS	
Calcium (Ca)	2.
Magnesium (Mg)	2.7
Sodium (Na)	10.
Potassium (K)	.7
Bicarbonate (HCO_3)	0
Sulfate (SO_4)	9.4
Chloride	18.
pH	4.6
Amount of rain, in inches	*..32*

CONCENTRATIONS, IN PARTS PER MILLION

Figure 11.--The influence of storm direction on the chemical quality of precipitation.

The chemical quality of precipitation falling upon the Shetucket River basin depends upon the path of approach of storms and reflects impurities picked up from limestone quarries to the northwest, urban areas to the west, or the ocean to the south.

except for the relatively high calcium and bicarbonate found in samples taken near Coventry and the slightly higher range in sulfate content of samples collected at Stafford Springs and Baltic. The relatively high calcium and bicarbonate content of samples taken near Coventry is probably caused by residues from the application of agricultural limestone ($CaCO_3$) to farmland in the immediate vicinity of the sampling site.

Most sulfate in precipitation is derived from airborne industrial wastes. The small differences in median sulfate contents of samples from three different parts of the basin suggest that storms moving across the basin pick up very little sulfate from local sources of air pollution. Most sulfate probably originates in large, thickly populated industrial areas west and southwest of the basin, and is carried into the basin by prevailing air mass movement from the southwest.

The relatively low chloride content in most samples indicates that very little airborne salts of spray from the ocean were carried inland into the basin by the rainstorms from which these samples were collected.

Individual storms may carry unusually large amounts of certain constituents. The chemical constituents of three such storms and the different directions from which these storms entered the basin are shown diagrammatically in figure 11. These analyses are not included in the summary, table 4. An unusually high concentration of calcium bicarbonate in a sample collected at Stafford Springs was brought in by a storm from the northwest. The calcium bicarbonate probably originated as dust from the limestone quarries and cement manufacturing plants in northwestern Connecticut and southwestern Massachusetts.

A rainfall sample collected near Coventry contained a particularly large concentration of calcium sulfate ($CaSO_4$) and calcium bicarbonate ($Ca(HCO_3)_2$), resulting from a storm whose path was northward over the industrial East Central states, and then eastward into New England.

Another rainfall sample collected at Baltic contained a significantly high amount of magnesium, sodium, and chloride. The presence of salts from ocean spray is indicated when the calcium/chloride (Ca/Cl) ratio is less than 1.0 (Gambell, 1962, p. 91-92). The Ca/Cl ratio of this sample was 0.1. Meteorological charts of the U.S. Weather Bureau confirmed that this storm had traveled northward along the Atlantic coastline before reaching Connecticut.

The median pH of samples collected at Stafford Springs and Baltic was less than 5.7 and substantially less than that of samples collected near Coventry, as shown in table 5. Atmospheric water will absorb carbon dioxide until equilibrium is reached at a pH value of 5.7 (Barrett and Brodin, 1955, p. 252), and, if the pH value is less than 5.7, will also contain significant amounts of acids of sulfur and/or nitrogen. In addition, a number of samples collected at Stafford Springs and Baltic had slightly higher sulfate content than those from Coventry. These characteristics of the samples suggest that those from Stafford Springs and Baltic contained oxides of sulfur from local sources of air pollution.

Table 5.--Summary of pH of precipitation samples collected between June 1963 and January 1964.

Index number (Pl. A)	Location	No. of measurements	pH Range	pH Median
1P	Stafford Springs	19	3.2 - 7.3	4.3
2P	Coventry	11	5.7 - 7.0	6.2
3P	Baltic	19	3.5 - 7.1	4.4

The quantity of minerals airborne into the Shetucket River basin in clouds to fall in precipitation is quite substantial. Using figures from table 4, one inch of rain on the basin brings approximately 0.4 pound of calcium (Ca) and 1.1 pounds of sulfate (SO_4) onto each acre of land. For the whole basin this amounts to about 66 tons of calcium and 180 tons of sulfate. Precipitation should therefore be considered as a significant source of dissolved minerals in natural waters.

QUALITY OF RUNOFF

The mineral content of overland runoff in the basin does not greatly exceed the mineral content of precipitation. The rocks and soils on the land surface have been so long exposed to chemical weathering that they have been thoroughly leached. Silicate minerals which have been left behind are only slightly soluble, and water running over the surface does not have time to dissolve these minerals and increase its concentration of dissolved solids.

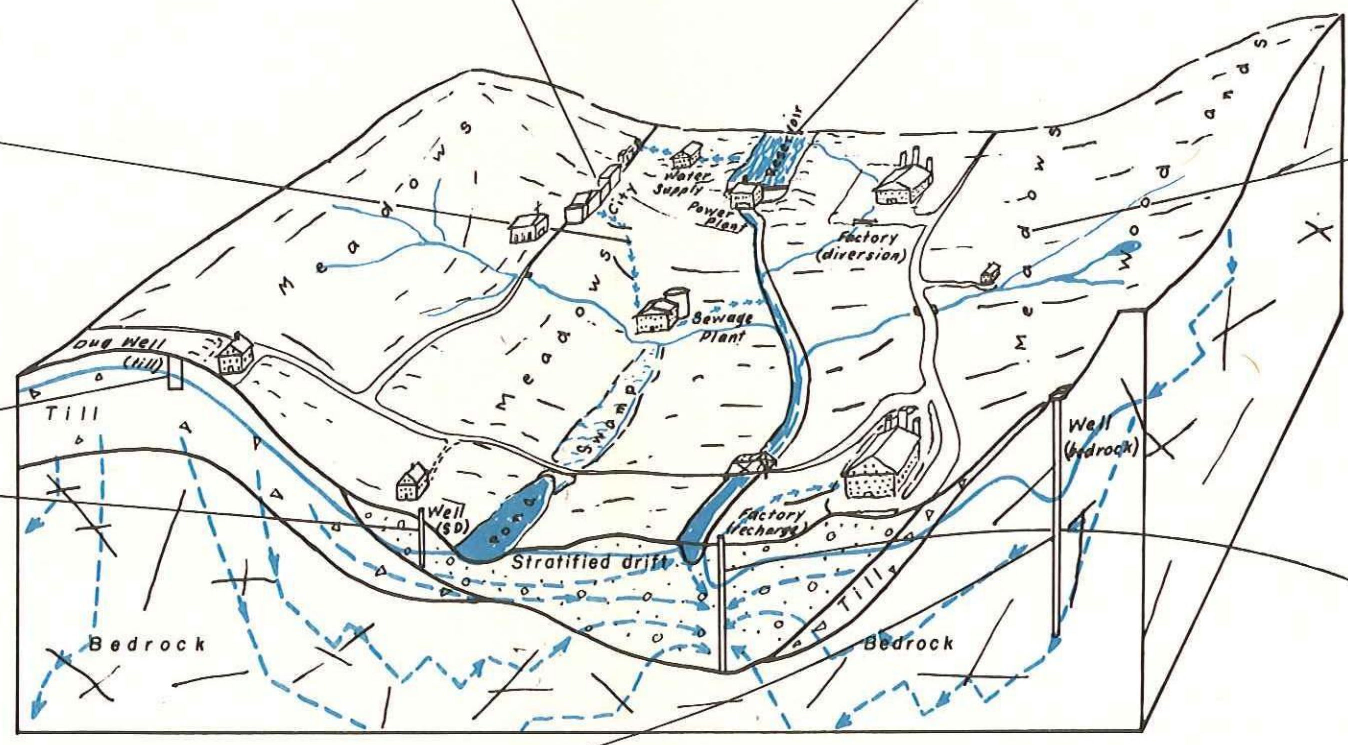
Water that percolates into the ground has much more opportunity to dissolve rock and rock materials than water which simply flows across the land surface. Accordingly, ground water contains higher concentrations of dissolved solids than does precipitation or water that flows overland. Most of the time, water in streams is a mixture of overland runoff and ground-water runoff. 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 is overland runoff. However, the amount of mineral matter transported in the same period of time is much greater at high flows than at low flows. 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 overland runoff is already present by the time the water reaches the land surface.

Paved areas, roofs, and storm water drains cause more rapid runoff, reduce evapo-transpiration, and reduce infiltration.

Storage of water in ponds and reservoirs for future use or flood control increases evaporation loss from the area and modifies the timing of streamflow downstream.

Water for municipal or industrial supply is removed from a stream in the same basin or an adjoining basin and released again at a different location causing changes in streamflow patterns.

Replacing of forested areas by meadows reduces transpiration losses and results in more rapid runoff from the land surface.



Individual homes get their water supply from a domestic well and return the same amount of water to the ground through septic tanks unless some is used for irrigation.

Large capacity industrial well in stratified drift obtains part of its supply from the river nearby by induced infiltration and part from ground-water storage. Such water is usually released again to the stream. If such a well is used for irrigation, most of the water is lost through evaporation.

Figure 12.--The effect of the activities of man upon the movement and distribution of water in the hydrologic cycle.

Man by his activities affects the timing, direction, and quantity of water moving through the phases of the hydrologic cycle.

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. 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. On the whole, however, soil erosion and sediment in streams are not problems in eastern Connecticut, due to the generally permeable soils and the nearly complete cover of vegetation that holds and protects the soil.

More detailed information on the quality of surface water and ground water is included in the sections, "Water in streams and lakes" and "Water in aquifers."

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 and coincidentally--the amount of water stored on the surface and underground, the relative proportion of direct runoff, ground-water runoff, and evapotranspiration, and also the quality of the water. The amount of his influence depends largely upon the density of population in the area. In rural areas, the clearing of forested areas, drainage of wetlands, irrigation of crops, and impoundment of water in reservoirs all change to some extent the natural hydrologic cycle which previously existed. More extensive changes occur when man builds towns and cities, and diverts water from streams and from the ground for many types of domestic and industrial uses. The physical effect of the works of man upon the natural hydrologic cycle is illustrated in figure 12.

In the Shetucket River basin, the amount of runoff has probably not been changed by man as much as the time within which runoff leaves the basin following storms. 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. Changes in land use in the last century may have altered the relative amounts of runoff and evapotranspiration. 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. These dams increase natural storage of surface water; they also increase ground-water storage by raising the local water table above its natúral level. The gradual urbanization of parts of the basin has the opposite effect: buildings, pavements, storm sewers, and similar structures increase direct runoff and bring it to the streams more quickly than normal, and at the same time prevent ground-water recharge and lower the water table locally.

The timing of runoff has been also altered by the storage and release of water at a few industrial dams. 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 basin to store the runoff from major floods and release it gradually over a period of days or weeks.

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 the total amount of 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, as illustrated in figure 13. 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 simply settles 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. Most of the water withdrawn from streams or wells and used by industry for cooling, washing, and other purposes is returned to streams or the ground with a somewhat higher temperature and dissolved-solids content than when withdrawn. Waste discharge into streams is diluted by surface runoff at high flows, but at low flows waste materials remain concentrated so that their presence is detectable by field observation as well as by chemical analysis. Disposal of domestic sewage to streams has created offensive conditions in a few congested areas, and may also contaminate wells near such streams if the wells obtain water by induced recharge. Disposal of domestic sewage to the ground has also contaminated nearby wells in a few densely populated areas. 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.

The sources and significance of a variety of chemical constituents and physical properties of water which are found in the Shetucket River basin are summarized in table 6. Excessively large (or small) concentrates of various constituents may prohibit certain uses, or at least increase the cost of its use because of the treatment required to make it suitable.

Water distributed by public water supplies may be suitable for drinking and hence must meet fairly stringent quality requirements. The drinking-water standards applicable to common carriers in interstate commerce, published by the

Table 6.--Source and significance of some of the chemical constituents in, and physical properties of water in the Shetucket River basin.

Chemical constituent or physical property	Source and concentration	Significance and maximum limit of tolerance
Silica (SiO_2)	Dissolved from practically all rocks and soils. Usually found in the basin in small amounts ranging from 1 to 30 ppm. Surface water usually has a smaller concentration than does ground water.	Forms hard scale in boilers, water heaters, and pipes. Inhibits deterioration of zeolite-type water softeners. The USPHS (U.S. Public Health Service, 1962) has not recommended a maximum limit for drinking water.
Iron (Fe)	Dissolved from many assorted minerals that contain oxides, sulfides, and carbonates of iron. Decaying vegetation and iron objects in contact with water, sewage and industrial waste are also major sources. Surface water in the basin in its natural state usually has less than 1.0 ppm. Ground water generally has higher concentrations than surface water.	On exposure to air, iron in ground water oxidizes to a reddish-brown precipitate. More than about 0.3 ppm of iron stains laundry and utensils, causes unpleasant odors, and favors growth of iron bacteria. Iron in water is objectionable for food and textile processing. Most iron-bearing waters when treated by aeration and filtration are satisfactory for domestic use. The USPHS recommends a maximum limit of 0.3 ppm for drinking water.
Manganese (Mn)	Dissolved from many rocks and soils. Often found associated with iron in natural waters but not as common as iron. Surface water in the basin usually has less than 0.1 ppm. Ground water generally has higher concentrations than surface water.	More than 0.2 ppm precipitates upon oxidation. Manganese has the same undesirable characteristics as iron but is more difficult to remove. The USPHS recommends a maximum limit of 0.05 ppm for drinking water.
Calcium (Ca) and magnesium (Mg)	Dissolved from practically all rocks and soils, especially calc-silicate and clay minerals.	Hardness and scale-forming properties of water are caused by dissolved bicarbonates and sulfates of these minerals (see hardness). These are objectionable for electroplating, tanning, dyeing and textile processing. They also cause scale formation in steam boilers, water heaters and pipes. The USPHS has not recommended a maximum limit for drinking water.
Sodium (Na) and potassium (K)	Dissolved from practically all rocks and soils. Sewage and industrial wastes are also major sources. Most home water softeners replace soluble hardness-producing minerals with sodium and thus increase amount of sodium present.	Since the concentration of potassium is usually low, sodium and potassium are calculated together and reported as sodium. Quantities found in the Shetucket River basin have little effect upon the usefulness of water for most purposes, however, more than 50 ppm may cause foaming of steam boilers. The USPHS has not recommended a maximum limit for drinking water, however, the Connecticut State Department of Health suggests a maximum limit of 20 ppm for municipal water supplies.
Carbonate (CO_3) and bicarbonate (HCO_3)	Results from chemical action of carbon dioxide in all natural water on calcite and calc-silicate minerals. Decaying vegetation, sewage and industrial wastes are also important sources.	Bicarbonates of calcium and magnesium cause hardness and form scale in boilers and pipes, and release corrosive carbon dioxide gas (see hardness). Water of low mineral content and low bicarbonate content in proportion to carbon dioxide is acidic and can be corrosive. The USPHS has not recommended a maximum limit for drinking water.
Sulfate (SO_4)	Dissolved from rocks and soils containing sulfur compounds, especially iron sulfide; also from sulfur compounds dissolved in precipitation, and sewage and industrial wastes.	Sulfates of calcium and magnesium form permanent hardness and hard scale in boilers and hot water pipes. (See hardness). The USPHS recommends a maximum limit of 250 ppm for drinking water.
Chloride (Cl)	Small amounts dissolved from metamorphosed sedimentary rocks and soils. Relatively large amounts are derived from animal wastes, sewage, road salt and industrial wastes. Chloride concentration of natural water in the basin seldom exceeds 10 ppm.	Large amounts of chloride in combination with calcium will result in a corrosive solution and in combination with sodium will give a salty taste. The USPHS recommends a maximum limit of 250 ppm for drinking water.
Fluoride (F)	Primary source of fluoride in the basin is weathering of the mineral scapolite; other possible sources include the minerals apatite and fluorite. Surface water in the basin rarely has more than 0.2 ppm; however, in one local area concentration of fluoride in ground water was as high as 2.2 ppm. Added to some waters by fluoridation of public water supplies.	About 1.0 ppm of fluoride is believed to be helpful in reducing the incidence of tooth decay in small children; larger amounts possibly cause mottle enamel on teeth (Lohr and Love, 1952, p. 39). The USPHS recommends the following control limits for drinking water in the Shetucket River basin: lower, 0.8 ppm; optimum, 1.0 ppm; upper, 1.3 ppm.
Nitrate (NO_3)	Very small amounts in natural waters from precipitation and decaying organic matter. Sewage, industrial wastes, fertilizers and decaying vegetation are major sources. Lesser amounts are derived from precipitation.	Small amounts of nitrate have no effect on usefulness of water. A concentration greater than 6 ppm generally indicates pollution. Nitrate encourages growth of algae and other organisms which produce undesirable tastes and odors. The USPHS recommends a maximum limit of 45 ppm for drinking water which is equivalent to 10 ppm of nitrate expressed as N in a sanitary analysis. Waters containing more than 45 ppm have reportedly caused methemoglobinemia which is often fatal to infants and, therefore such water should not be used in infant feeding.
Phosphate (PO_4)	Primary sources of phosphate are fertilizers, detergents, sewage and industrial wastes. Small amounts of polyphosphate are used in some water treatment plants and boiler systems.	Phosphates may stimulate the growth of algae which may cause taste and odor problems in water. Some phosphate fertilizers will increase the acidity of water. Generally, concentrations encountered in water are not toxic to man, animals, or fish. The USPHS has not recommended a maximum limit for drinking water.
Dissolved solids and specific conductance	Includes all mineral constituents dissolved in precipitation and from rocks and soils, locally augmented by mineral matter in sewage and industrial wastes. Measured as residue of evaporation at 180°C or calculated as numerical sum of amounts of individual constituents. Specific conductance, or the capacity of water to conduct an electric current, is used as an index of total mineral content. In natural waters in the basin, ground water usually has a larger concentration of dissolved solids than does surface water. All waters sampled had a dissolved-solids content much below the limit recommended by the USPHS.	Waters containing more than 1,000 ppm of dissolved solids are unsuitable for many purposes. The USPHS recommends a maximum limit of 500 ppm for drinking water but will permit up to 1,000 ppm. A dissolved-solid concentration of 500 ppm is approximately equivalent to a specific conductance of 800 micromhos at 25°C.
Hardness (as $CaCO_3$)	Hardness is primarily due to presence of calcium and magnesium, and to a lesser extent to iron, manganese, aluminum, barium, and strontium. There are two classes of hardness, carbonate (temporary) hardness and non-carbonate (permanent) hardness. Carbonate hardness refers to the hardness in equivalents with carbonate and bicarbonate; non-carbonate to the remainder of the hardness. Most waters in the basin are classified as soft with a hardness of less than 60 ppm.	Hard water consumes soap before lather will form and deposits soap curds on bathtubs. Water having a hardness of more than 120 ppm is commonly softened for domestic use. Hardness forms scale in boilers, water heaters, radiators and pipes causing a decrease in rate of heat transfer and restricted flow of water. In contrast, water having a very low hardness may be corrosive. Carbonate (temporary) hardness can be reduced by water softeners; non-carbonate (permanent) hardness cannot be readily dissolved. The USPHS has not recommended a maximum limit for drinking water. The U.S. Geological Survey classification of hardness appears on p 75.

Table 6.--Source and significance of some of the chemical constituents in, and physical properties of water in the Shetucket River basin--Continued

Chemical constituent or physical property	Source and concentration	Significance and maximum limit of tolerance
Hydrogen ion concentration (pH)	Water with a dominance of acids, acid-generating salts, and free carbon dioxide has a low pH. If carbonates, bicarbonates, hydroxides, phosphates, and silicates are dominant, the pH is high. The pH of most natural waters ranges between 6 and 8.	A pH of 7.0 indicates neutrality of a solution. Values higher than 7.0 denote alkaline characteristics; values lower than 7.0 indicate acid characteristics. Acid waters and excessively alkaline waters corrode metals. The USPHS has not recommended a maximum limit for drinking water.
Color	Color in water may be of natural, mineral, or vegetable origin such as iron and manganese compounds, algae, weeds, and humus material. May also be caused by inorganic or organic wastes from industry. True color of water is considered to be only that attributable to substances in solution after the suspended material has been removed.	Water from domestic and some industrial uses should be free of perceptible color. Color in water is objectionable in food and beverage processing and many manufacturing processes. Results are usually expressed as units of color and not as ppm. The USPHS recommends a maximum limit of 15 units for drinking water.
Dissolved oxygen (D.O.)	The amount of oxygen from the atmosphere that dissolves in surface water is a function of its temperature and various physical, chemical and bio-chemical characteristics.	Dissolved oxygen in surface water is necessary for the support of aquatic life which, in turn, is necessary for the removal of organic pollution. As the temperature of water increases, the solubility of oxygen decreases. During the summer months when streamflow is deficient and stream temperatures are highest there is less oxygen available for natural decomposition of organic matter. The presence of dissolved oxygen can cause corrosion of metals. In ground water dissolved oxygen causes precipitation of iron and manganese. According to most authorities, a dissolved-oxygen content of not less than 5.0 ppm is needed to support various types of fish life in good condition. The USPHS has not recommended a maximum limit for drinking water.
Alkyl benzene sulfonate (ABS)	Primary sources of alkyl benzene sulfonate (ABS) are synthetic household detergent residues in sewage and waste waters. In 1963 about 70% of all household detergents were of this type.	High concentrations of ABS cause undesirable taste, foaming, and odors. It often indicates presence of sewage or industrial waste. In mid-year 1965 ABS began to be replaced by linear alkylate sulfonate (LAS). Under similar optimum conditions, LAS is more degradable than ABS. The USPHS recommends for ABS a maximum limit of 0.5 ppm for drinking water.
Temperature	Temperature fluctuates widely in streams and shallow wells following seasonal climatic changes, but wells at depths of 30 to 60 feet remain within 2 or 3 degrees of mean annual air temperature (48°F for the Shetucket River basin). Disposal of water used for cooling or industrial processing causes local temperature abnormalities.	Temperature affects the usefulness of water for many purposes. For most uses, especially cooling, water of uniformly low temperatures is desired. A few degrees rise in the temperature of a stream may limit the capacity of a stream to support aquatic life. Warm water will carry less oxygen in solution than water at low temperatures, and a corrosive water will become more corrosive with increased temperatures.
Turbidity	An optical property of water attributed to suspended or colloidal matter which inhibits light penetration. May be caused by micro-organisms or algae, suspended mineral substances including iron and manganese compounds, clay or silt, or sawdust, fibers, and other materials. May result from natural processes of erosion or from the addition of domestic sewage or wastes from various industries, such as pulp and paper manufacturing.	Excessive concentrations are harmful or lethal to fish and other aquatic life; also very undesirable in waters used by most industries, especially in process water. Turbidity can modify water temperature. Results are expressed in standard units, not ppm. The USPHS recommends a maximum limit of 5 units for drinking water.

U.S. Public Health Service (1962), are widely accepted as standards for public water supplies. They appear in the last column of table 6 and are also given in various tabulations of chemical analyses throughout this report.

WATER IN STREAMS AND LAKES

Runoff from the Shetucket 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 gaging stations within the basin for periods ranging from 1 year to 36 years, as shown in figure 14. In addition, discontinuous or partial records, and single measurements of streamflow have been obtained for many other sites within the basin during the period from May 1962 to September 1964. The locations of these stream-gaging stations are shown on plate A. All records for 1962-64 are given either in annual publications entitled "Surface Water Records of Connecticut" or in the companion basic data report by C. E. Thomas, Jr. and others (1967), 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 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. This reference period represents the long-term flow of the stream if there have been no changes made in either regulation of storage or diversion of water into or out of the basin. The graphs or tables may then be used to estimate the amount 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. Consequently, in the following sections a method is described for determining similar information at any unmeasured point along any unregulated stream in the basin.

Information on streamflow within the basin 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 average low flows recur is given by low-flow frequency graphs, and by tables. Third, maximum safe draft rates are given for existing lakes and 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. 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. They show the percentage of time any specific flow was equaled or exceeded during a particular period. The variation in flow of the Willimantic River at South Coventry is shown by the flow-duration curve in figure 15; supplemental curves included on the same graph show the limits within which this variation in flow has ranged in single years. The same limits may be estimated from the curves in figure 22 for all partial-record or unmeasured sites in the basin.

Flow-duration curves for other long-term continuous-record stream-gaging stations in the basin are presented in figures 16-21. Flow-duration data and average flow for all stream-gaging stations in the basin are summarized in table 7. Locations of these stream-gaging stations appear on plate A. Streamflow data in table 7 are given as flow per square mile to facilitate comparison between streams. The data in table 7 may be used, as explained below, to estimate the average flow for selected consecutive-day periods of lowest flow in a year and the expected recurrence interval of that flow.

Areal variations in annual precipitation and in surficial geology cause substantial variations in streamflow within the Shetucket River basin. Streamflow on the western side of the basin is below average and on the eastern side above average, as shown by the isopleths on figure 23. 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 ratio of these average streamflows to the basin-wide average streamflow of 1.16 mgd per sq mi (1.80 cfs per sq mi).

While variations in precipitation cause variations in the amount of runoff, variations in geology cause variations in the timing of runoff. The variations in runoff caused by variations in geology for eastern and southern Connecticut, including the Shetucket River basin, have been discussed by M. P. Thomas (1966), and are

Water vapor in the atmosphere condenses upon and dissolves particles of mineral matter and gases originating from incomplete combustion in industries, homes and vehicles, dust from limestone quarries and cement plants, and dust from dry fertilizers spread upon farm land, all of which have been carried aloft by ascending air currents.

Precipitation contacts and dissolves more of the contaminants as it falls through the atmosphere thereby becoming acidic. This acidity increases its solvent power and its capacity to dissolve mineral matter.

Overland runoff from acidic precipitation has increased solvent power for minerals on the land surface. Runoff from roofs and pavements in municipal areas adds previously precipitated dry chemical and organic pollutants to the mineral content. Road salt used on highways in winter also is dissolved and carried into streams or percolates into the ground.

Loosened soil during construction of highways, buildings, and other structures makes possible rapid erosion, which temporarily increases sediment content and turbidity in streams.

Storage of flowing water in reservoirs modifies the chemical and physical characteristics of the water. Suspended-sediment and turbidity will decrease and accumulations of sediment on the bottom will gradually fill the reservoir.

Animal wastes, chemical fertilizers and pesticides spread upon agricultural lands increase the dissolved mineral content of the overland runoff and water infiltrating to the water table.

Quality of intake water and intended use govern the treatment needed. Chlorination, aeration, filtering, softening, coagulation, pH adjustment, fluoridation, etc. all change the chemical composition of the water.

Waste discharge from industrial plants is diluted by high flows in streams, but at times of low flow, the water available for dilution is reduced and the water quality deteriorates.

Disposal of untreated or poorly treated wastes can degrade quality of the surface water it enters. Waste water being carried by combined sewer systems to treatment plants often bypasses the plants during storm runoff and enters the stream untreated.

Changes in the chemical, physical, and biological properties of waste water depend upon type of treatment employed.

Seepage from septic tank effluents containing detergents may progressively deteriorate an aquifer. If they are not biodegradable, the damage caused, while not irreparable, may require a long time to correct.

Most of the water withdrawn from streams or wells and used by industry for cooling, washing, and other purposes, is returned to the streams or the ground at higher temperatures or with a higher dissolved mineral content than at its point of withdrawal.

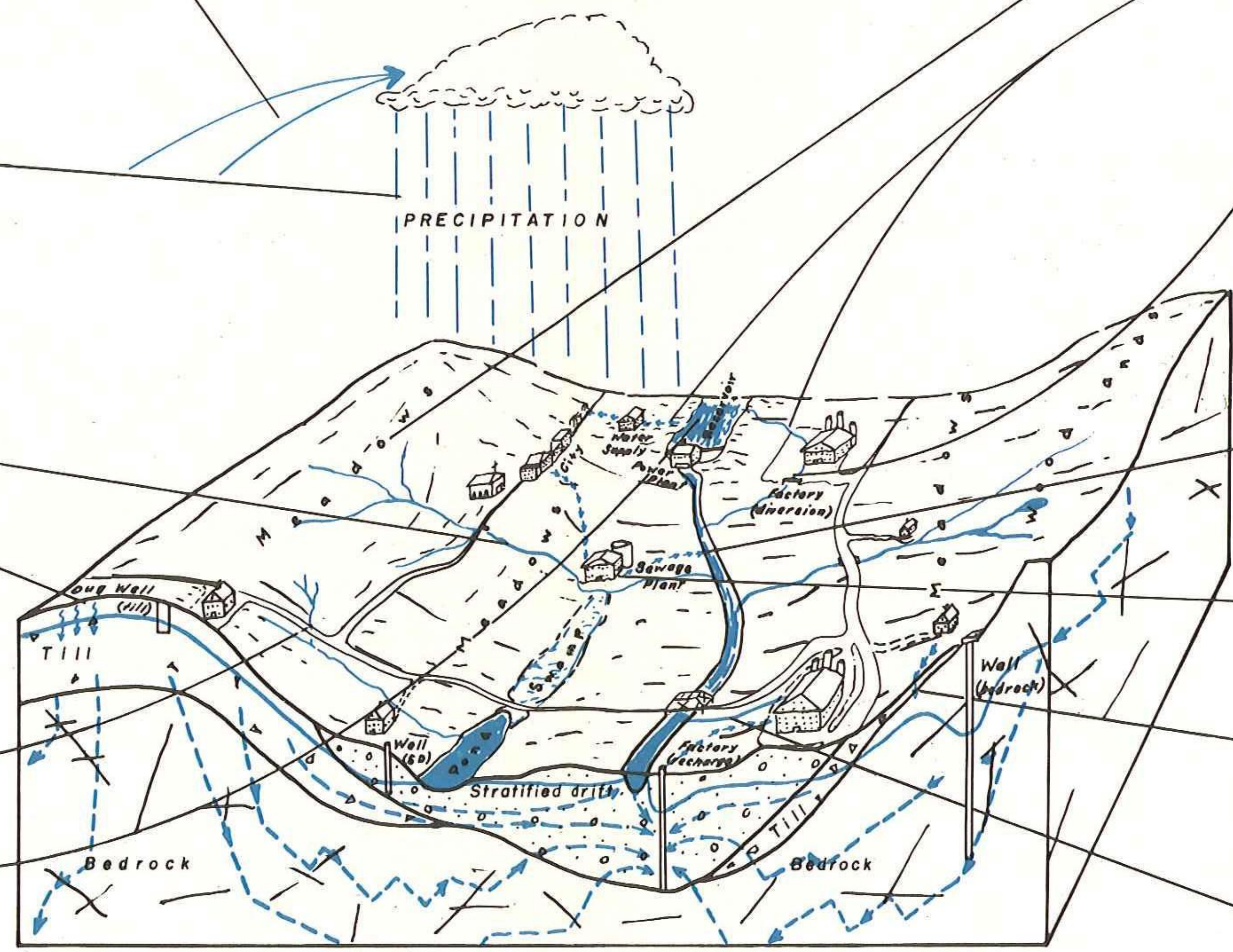


Figure 13.--The effect of the activities of man upon the chemical quality of water in the hydrologic cycle.

The chemical quality of water deteriorates as the result of man's activities.

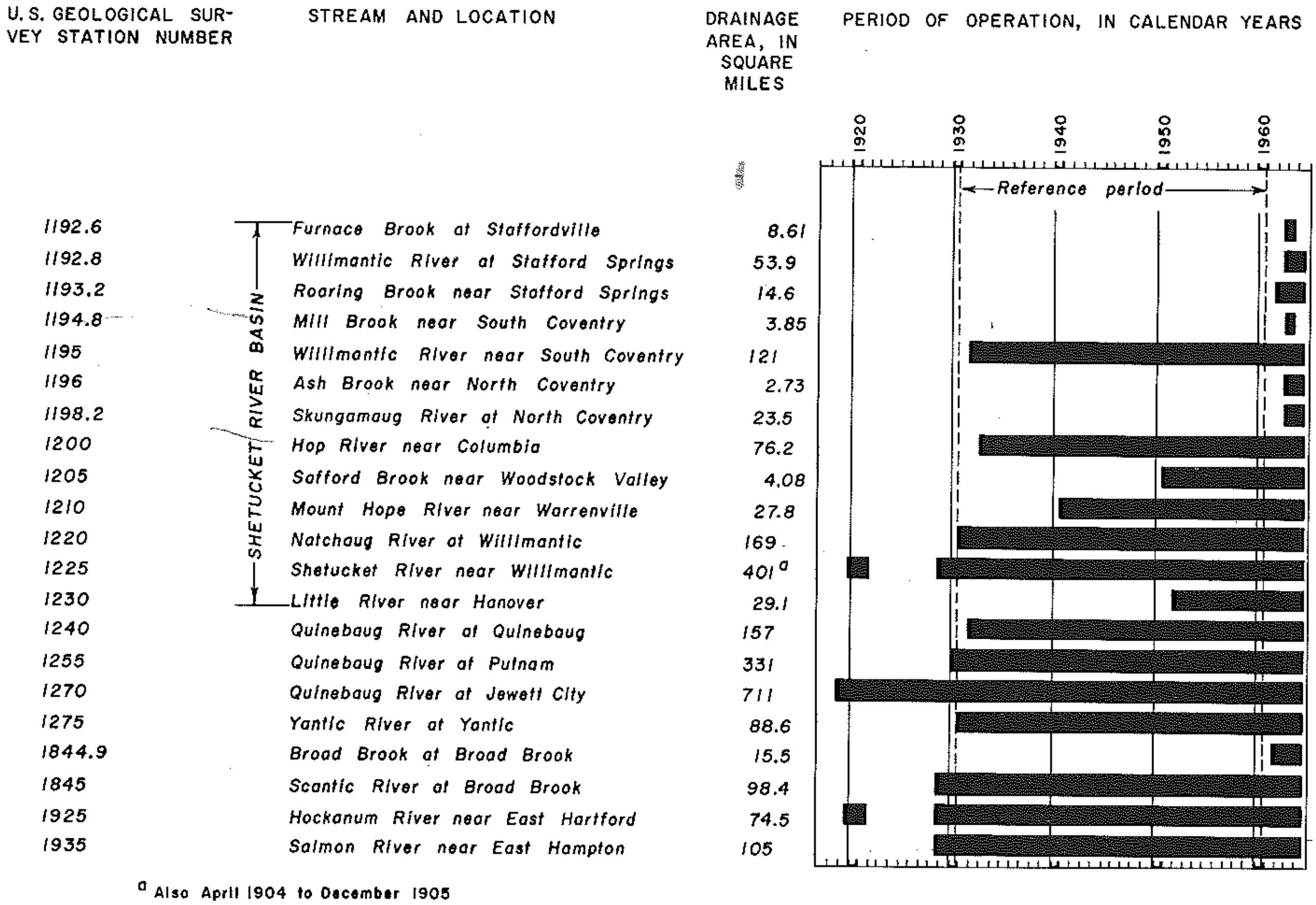


Figure 14.--Length of continuous streamflow records at gaging stations in the Shetucket River basin and vicinity.

On many streams, continuous records have been kept since 1930.

summarized in the family of flow-duration curves shown in figure 24. These curves show that runoff from areas underlain 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 resultant high proportion of groundwater 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 24 may be used to estimate flow duration at any unmeasured site in the basin, provided the percent of stratified drift above the site is accurately determined from plate B and the runoff is adjusted, using the isopleths on figure 23, to account for the effect of variations in precipitation on the streamflow. As an example, to construct a flow-duration curve or table for a site on the Natchaug River just downstream from the confluence of Still River and Bigelow Brook near Phoenixville, first delineate the drainage divide for this basin on plate B. The total drainage area within this line is then measured as 55.4 square miles. The portion of this area having stratified-drift deposits, as indicated by the green shading, is also measured as 1.8 square miles, which is 14.6 percent of the total drainage area. Flow duration from this area can be represented on figure 24 by an interpolated curve for 14.6 percent of stratified drift for a statewide average streamflow of 1.16 mgd per sq mi (1.80 cfs per sq mi). From the location of the area on figure 23, however, the average streamflow on the basin is about 1.06 percent of the statewide average. The estimated flow-duration curve for the period of record 1931-60 for this location is, therefore, the product of the ordinates of the interpolated duration curve from figure 24, the total drainage area of 55.4 sq mi, and the factor 1.06. In tabular form the result is:

Flow, mgd, equaled or exceeded	510	210	150	76	42	20	7.0	4.4	2.3
Percentage of time	1	5	10	30	50	70	90	95	99

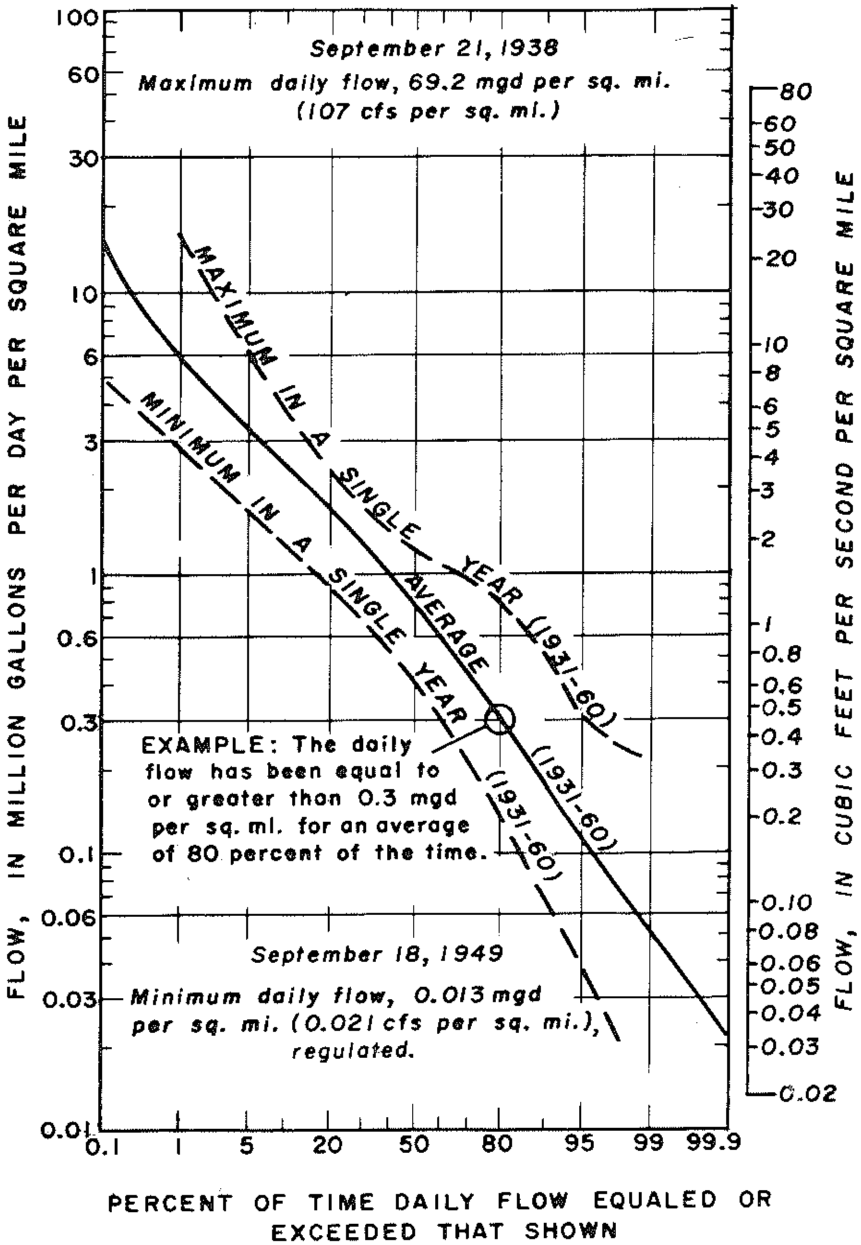


Figure 15.--Duration of daily mean streamflow of the Willimantic River near South Coventry.

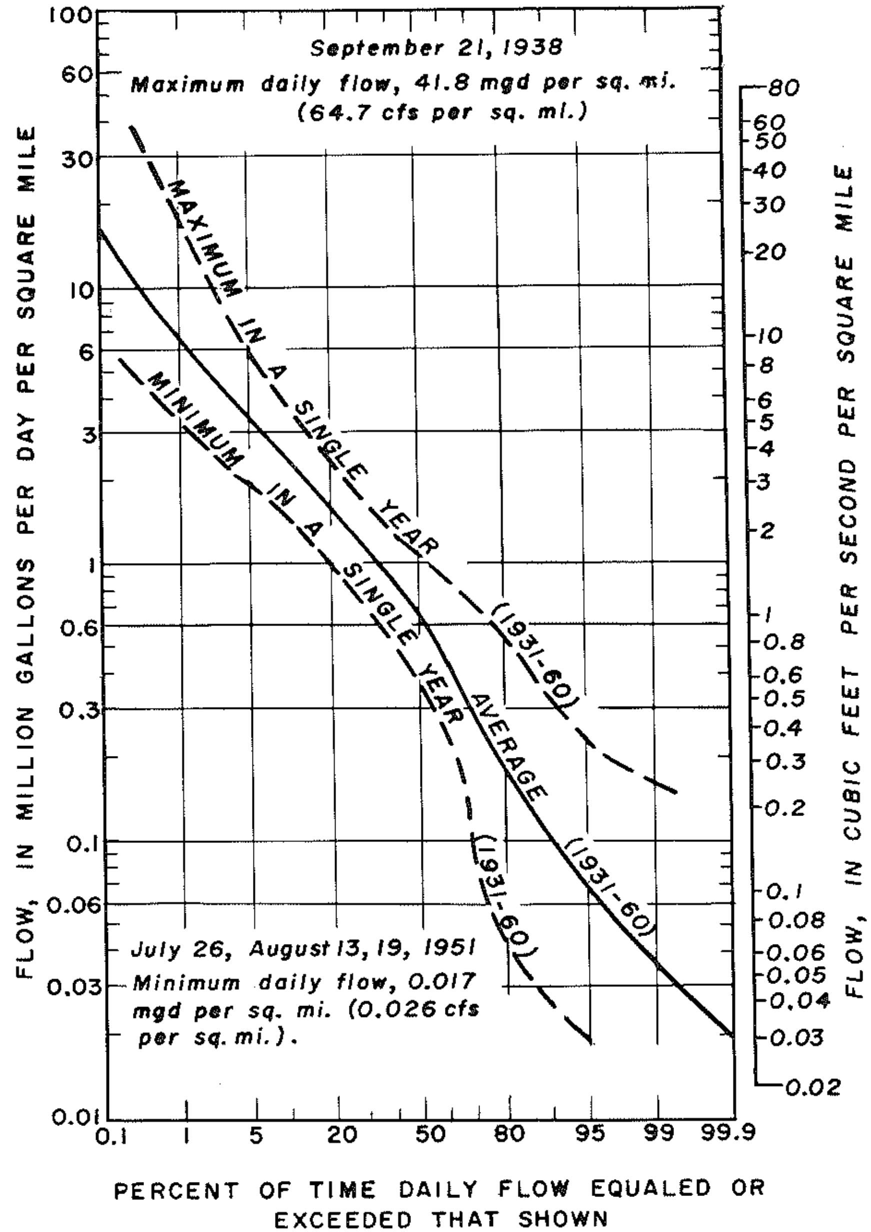


Figure 16.--Duration of daily mean streamflow of the Hop River near Columbia.

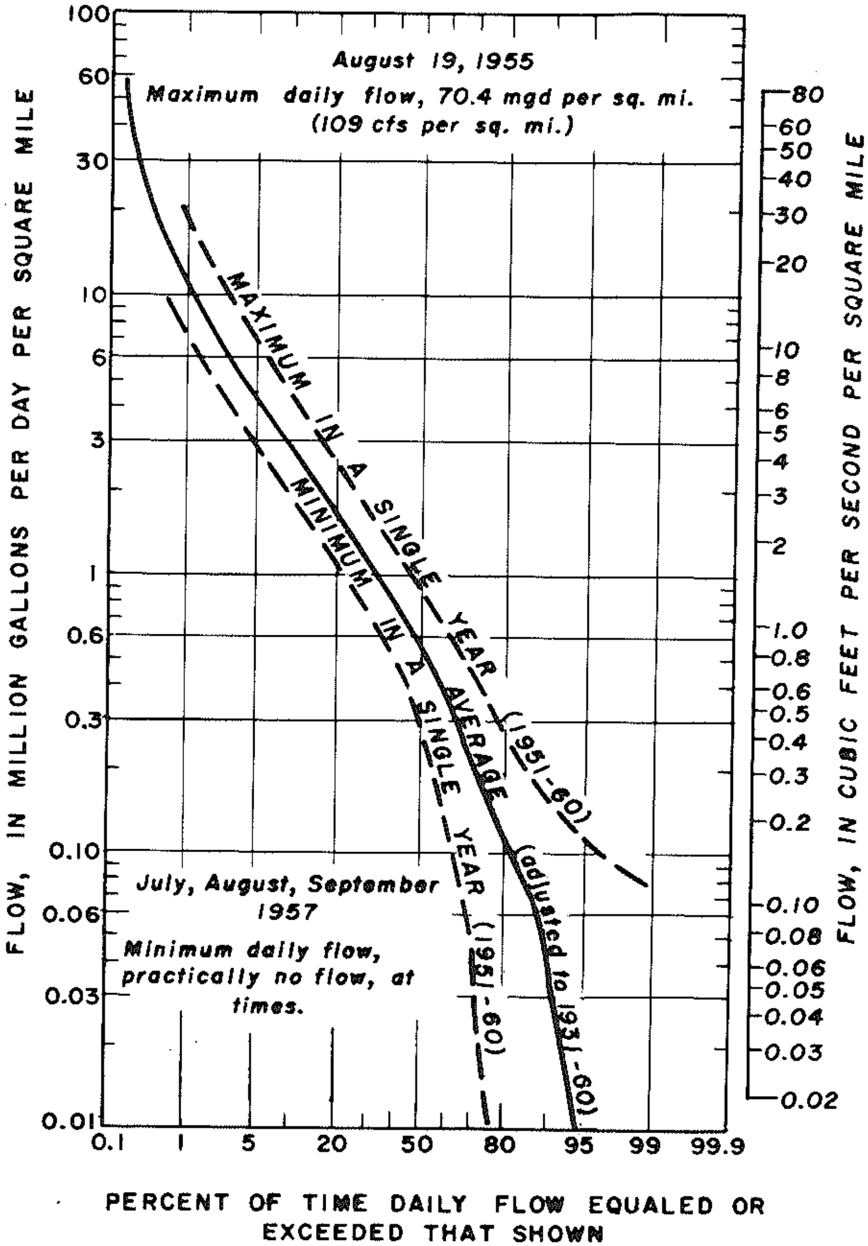


Figure 17.--Duration of daily mean streamflow of Safford Brook near Woodstock Valley.

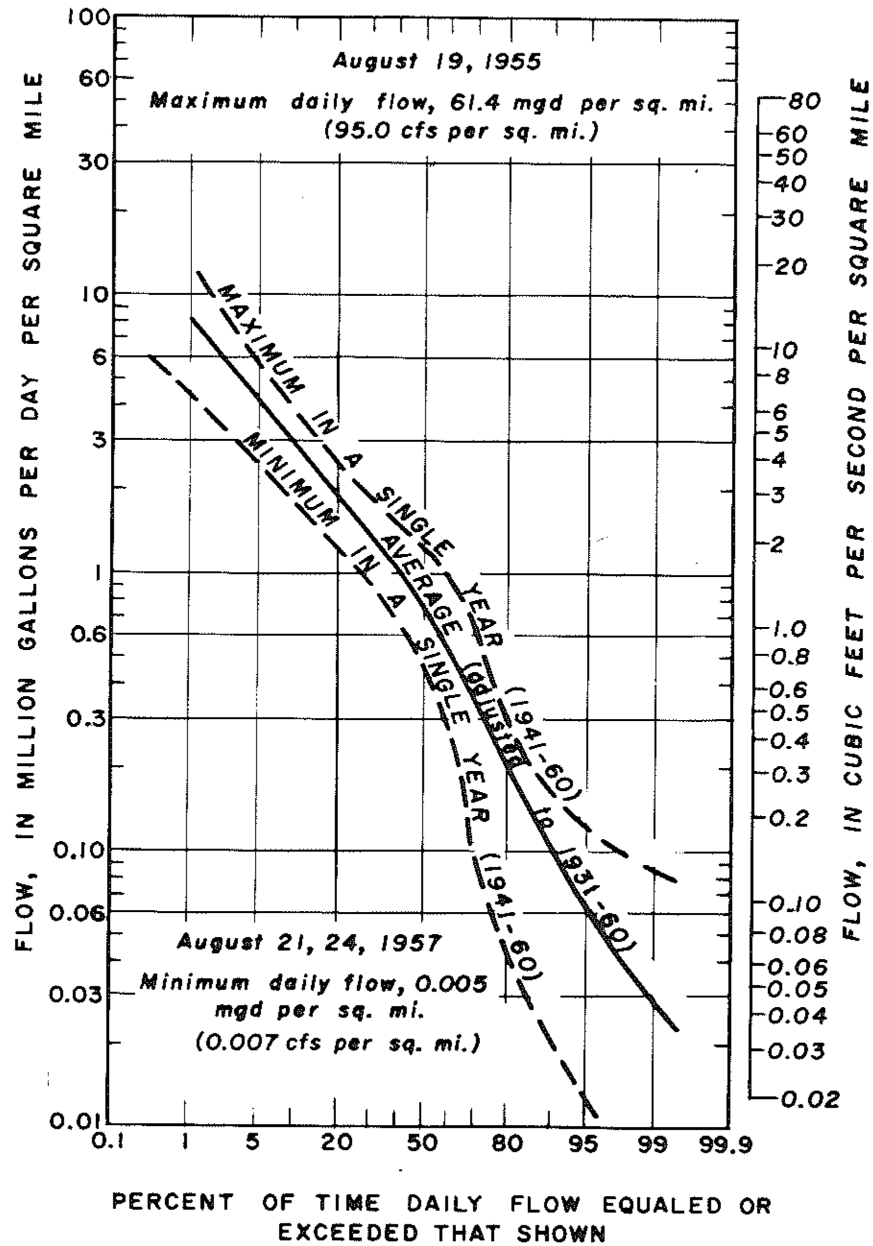


Figure 18.--Duration of daily mean streamflow of the Mount Hope River near Warrenville.

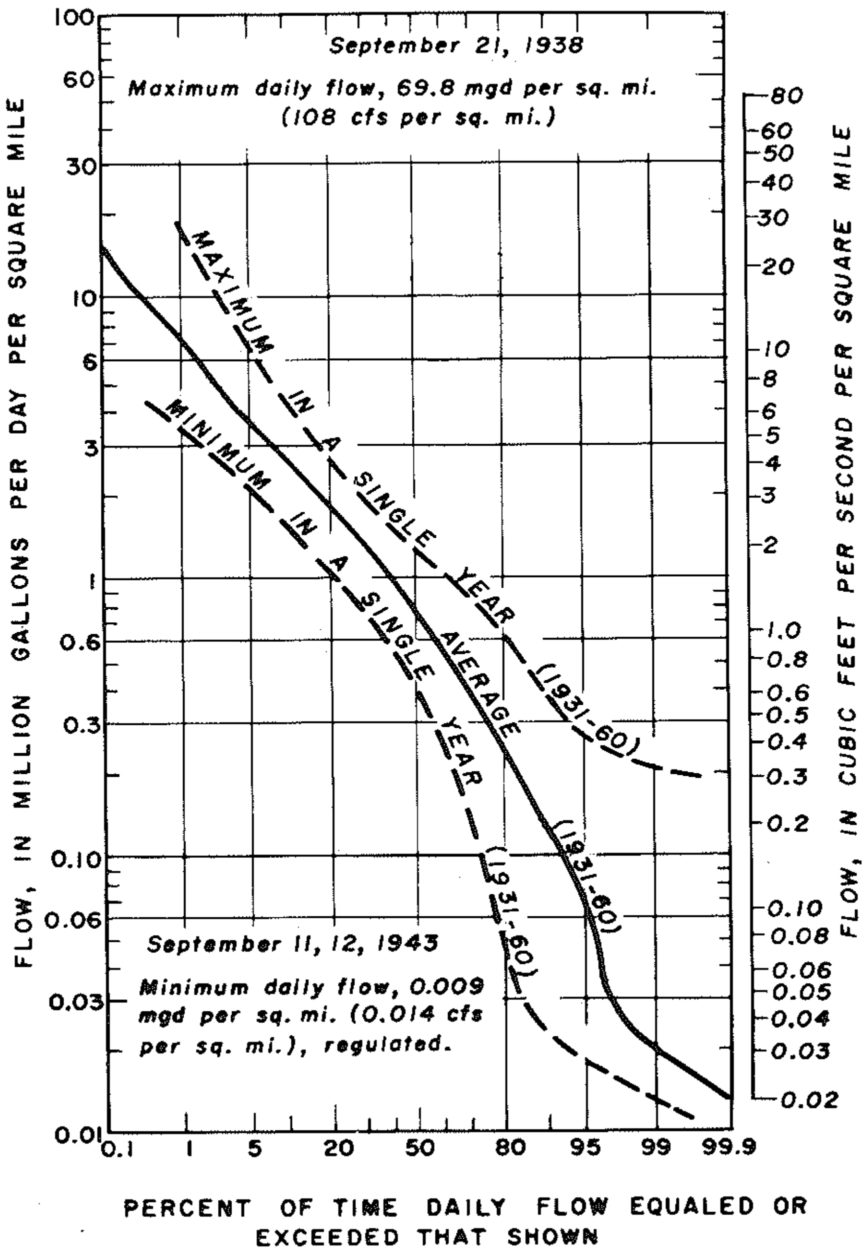


Figure 19.--Duration of daily mean streamflow of the Natchaug River at Willimantic.

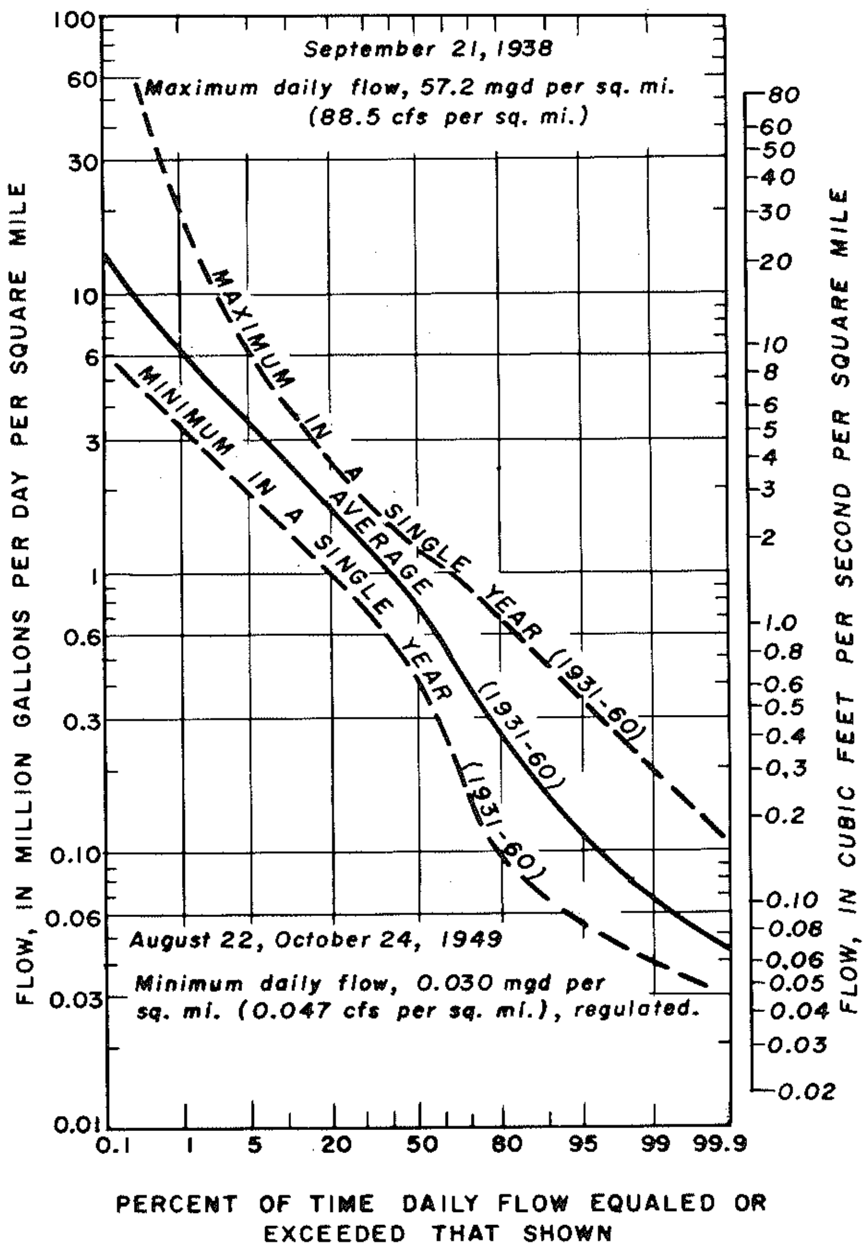


Figure 20.--Duration of daily mean streamflow of the Shetucket River near Willimantic.

Table 7.--Duration of daily flow at stream-gaging stations in the Shetucket River basin.
(Data are adjusted to period October 1930 to September 1960 on basis of long-term streamflow records)

Index No. (Pl.A)	Stream and place of measurement	Drainage area (sq mi)	Percent of drainage area covered by stratified drift	Average flow (mgd per sq mi)	Flow (mgd per sq mi) which was equaled or exceeded for indicated percentage of time: 1	5	10	20	30	40	50	60	70	80	90	95	99
1191.5	Middle River near Ellithorpe	6.66	16.8	1.13	7.1	3.5	2.5	1.7	1.25	0.90	0.68	0.49	0.27	0.14	0.06	0.05	0.02
1192	Middle River at Orcutts	12.3	24.5	1.13	7.1	3.6	2.5	1.75	1.25	.90	.68	.48	.30	.19	.09	.06	.03
1192.2	Crystal Lake Brook at Crystal Lake	2.80	23.8	1.08	7.1	3.5	2.5	1.7	1.2	.87	.63	.43	0	0	0	0	0
1192.3	Edson Brook at West Stafford	11.8	10.9	1.08	7.1	3.4	2.5	1.6	1.2	.87	.65	.45	.28	.17	.08	.05	.03
1192.55	Delphi Brook near Staffordville	2.48	9.4	1.19	7.8	3.8	2.7	1.8	1.3	.97	.68	.47	.29	.17	.08	.05	.03
1192.6	Furnace Brook at Staffordville	8.61	13.2	1.19	6.5	2.5	1.9	1.5	1.3	1.15	1.0	.90	.71	.23	.10	.08	.05
1192.8	Willimantic River at Stafford Springs	53.9	17.1	1.12	5.8	3.2	2.3	1.6	1.2	1.0	.74	.58	.42	.30	.19	.14	.08
1192.9	Bonemill Brook near Stafford Springs	2.50	2.5	1.12	6.3	3.4	2.4	1.7	1.2	.97	.71	.54	.37	.25	.14	.10	.06
1193	Roaring Brook near Staffordville	5.47	.9	1.22	7.8	3.8	2.7	1.8	1.35	1.0	.71	.53	.34	.21	.10	.08	.04
1193.2	Roaring Brook near Stafford Springs	14.6	6.2	1.19	7.1	3.6	2.6	1.8	1.3	1.0	.78	.53	.32	.18	.10	.06	.03
1193.6	Conat Brook at West Willington	2.21	39.5	1.10	5.9	3.2	2.3	1.6	1.2	.97	.71	.56	.40	.28	.17	.12	.07
1193.8	Willimantic River at Merrow	95.3	16.9	1.12	6.2	3.4	2.4	1.7	1.2	.97	.71	.54	.39	.25	.16	.11	.06
1194	Cedar Swamp Brook near Mansfield Depot	4.92	58.5	1.09	7.1	3.4	2.5	1.6	1.2	.87	.65	.45	.28	.17	.08	.05	.03
1194.8	Mill Brook near South Coventry	3.85	1.4	1.08	2.4	1.75	1.55	1.3	1.2	1.1	1.0	.90	.84	.78	.71	.65	.54
1195	Willimantic River near South Coventry	121	19.2	1.14	5.9	3.2	2.4	1.7	1.3	1.0	.78	.60	.44	.30	.18	.14	.11
1195.5	Bolton Pond Brook at Quarryville	3.96	0	1.05	8.4	3.6	2.5	1.6	1.15	.78	.54	0	0	0	0	0	0
1196	Ash Brook near North Coventry	2.73	0	1.06	8.4	3.6	2.5	1.6	1.15	.78	.54	.32	.15	.07	.02	.01	0
1196.5	Hop River near Andover	12.1	5.3	1.06	7.8	3.5	2.5	1.6	1.15	.84	.59	.38	.21	.12	.05	.03	.01
1197	Skungamaug River at Tolland	7.98	14.4	1.08	7.1	3.4	2.5	1.6	1.2	.87	.65	.45	.28	.17	.08	.05	.03
1198.2	Skungamaug River at North Coventry	23.5	19.7	1.07	5.9	3.2	2.3	1.6	1.2	.90	.68	.47	.30	.18	.09	.06	.04
1198.5	Skungamaug River near Andover	27.6	19.0	1.07	6.5	3.4	2.4	1.6	1.2	.87	.65	.47	.30	.18	.09	.06	.04
1199	Burnap Brook near Andover	6.82	10.6	1.08	6.2	3.2	2.4	1.6	1.2	.94	.68	.43	.21	.09	.03	.02	.01
1199.3	Andover Lake Brook near Andover	4.00	0	1.09	6.5	3.4	2.5	1.6	1.2	.90	.68	.50	0	0	0	0	0
1199.6	Columbia Lake Brook near Columbia	3.65	4.5	1.09	7.1	3.5	2.5	1.6	1.2	.90	.65	.45	0	0	0	0	0
1200	Hop River near Columbia	76.2	13.0	1.08	6.5	3.4	2.5	1.6	1.2	.90	.65	.46	.31	.19	.10	.06	.04
1202	Tenmile River near Willimantic	16.5	6.3	1.12	7.8	3.7	2.6	1.75	1.2	.87	.63	.43	.23	.13	.05	.03	.01
1204	Still River at Kenyonville	7.74	30.6	1.23	7.1	3.7	2.7	1.9	1.35	1.0	.78	.56	.37	.24	.13	.09	.05
1204.5	Bungee Brook near Kenyonville	7.36	12.8	1.23	7.8	3.8	2.7	1.9	1.35	1.0	.74	.54	.34	.21	.10	.07	.04
1205	Safford Brook near Woodstock Valley	4.08	.8	1.23	11	4.5	2.8	1.7	1.1	.78	.55	.37	.22	.12	.05	.01	0
1206	Still River at Phoenixville	30.9	18.8	1.23	7.8	3.9	2.8	1.9	1.35	1.0	.74	.53	.33	.21	.10	.06	.03
1206.5	Bigelow Brook near Union	1.16	26.3	1.23	8.4	3.9	2.8	1.9	1.35	.97	.71	.48	.28	.16	.07	.05	.02
1206.8	Bigelow Brook near Westford	12.0	8.3	1.23	7.8	3.9	2.8	1.9	1.35	1.0	.74	.53	.33	.21	.10	.06	.03
1207	Bigelow Brook near Phoenixville	21.2	6.7	1.23	7.8	3.9	2.8	1.9	1.35	1.0	.74	.52	.32	.19	.09	.06	.03
1207.5	Natchaug River near Phoenixville	58.4	15.1	1.23	7.1	3.7	2.7	1.8	1.35	1.0	.78	.54	.37	.23	.12	.08	.05
1208	Natchaug River at Chaplin	65.8	15.1	1.23	7.1	3.7	2.7	1.8	1.35	1.0	.78	.54	.37	.23	.12	.08	.05
1208.5	Natchaug River at North Windham	81.2	18.0	1.20	7.1	3.6	2.6	1.8	1.35	1.0	.78	.57	.39	.25	.14	.10	.06
1209.2	Mount Hope River at Westford	3.03	6.3	1.22	7.8	3.9	2.8	1.8	1.35	.97	.71	.51	.31	.19	.09	.06	.03
1209.4	Knowlton Brook at West Ashford	5.92	2.0	1.15	7.1	3.6	2.6	1.75	1.3	.90	.68	.48	.30	.18	.08	.06	.03
1210	Mount Hope River near Warrenville	27.8	7.0	1.21	7.8	3.9	2.7	1.8	1.3	.97	.71	.51	.34	.19	.10	.06	.03
1211	Mount Hope River at Atwoodville	34.8	8.4	1.19	7.8	3.7	2.7	1.8	1.3	.97	.71	.50	.30	.18	.09	.06	.03
1213	Fenton River at East Willington	11.5	10.3	1.16	7.8	3.7	2.6	1.75	1.3	.94	.68	.48	.29	.17	.08	.05	.03
1213.5	Fenton River at Gurleyville	23.0	12.2	1.13	7.1	3.6	2.5	1.75	1.25	.90	.68	.48	.30	.19	.09	.06	.03
1220	Natchaug River at Willimantic	169	17.5	1.16	7.1	3.6	2.6	1.75	1.3	.97	.74	.53	.37	.23	.12	.09	.05
1225	Shetucket River near Willimantic	401	18.0	1.14	6.3	3.4	2.5	1.7	1.25	.97	.74	.55	.38	.25	.16	.11	.06
1226	Obwebetuck Brook near South Windham	2.79	5.3	1.14	8.4	3.7	2.6	1.75	1.25	.87	.65	.41	.23	.13	.05	.03	.01
1226.5	Frog Brook near South Windham	3.94	35.8	1.15	6.1	3.3	2.5	1.7	1.3	1.0	.78	.58	.43	.30	.19	.14	.08
1226.8	Merrick Brook near Scotland	5.04	12.5	1.21	7.8	3.7	2.7	1.8	1.35	.97	.71	.52	.33	.20	.10	.06	.03
1227.5	Beaver Brook near Scotland	7.11	16.9	1.18	7.1	3.6	2.6	1.75	1.3	.97	.71	.52	.28	.14	.05	.03	.01
1227.6	Merrick Brook near Hanover	19.8	19.4	1.20	6.5	3.6	2.6	1.8	1.35	1.0	.78	.58	.40	.26	.16	.11	.06
1228	Beaver Brook at Baltic	9.21	23.7	1.14	6.0	3.3	2.5	1.7	1.25	1.0	.78	.58	.42	.30	.17	.13	.08
1228.5	Little River at Hampton	7.71	13.6	1.24	7.8	3.9	2.8	1.9	1.35	1.0	.78	.54	.35	.22	.11	.08	.04
1229	Little River near Scotland	17.4	17.2	1.24	7.1	3.7	2.8	1.9	1.35	1.0	.78	.57	.39	.25	.14	.10	.06
1230	Little River near Hanover	29.1	18.1	1.24	7.1	3.6	2.7	1.8	1.35	1.1	.78	.59	.43	.32	.23	.17	.11
1230.8	Blissville Brook near Taftville	3.39	28.3	1.14	7.1	3.6	2.5	1.75	1.25	.94	.71	.48	.30	.19	.09	.06	.03

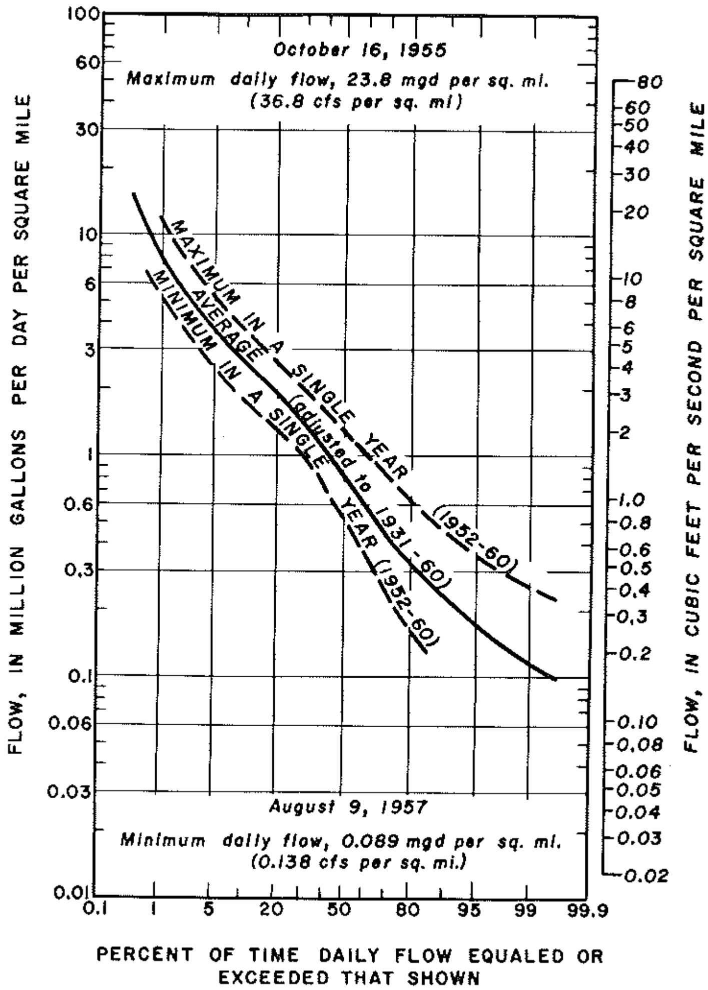


Figure 21.--Duration of daily mean streamflow of the Little River near Hanover.

FREQUENCY AND DURATION OF LOW FLOWS

Although flow-duration curves such as those shown in figures 15 through 22, and 24 indicate the minimum amounts of streamflow available for certain percentages of time, the water manager also finds it useful 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 Shetucket River basin, are given in table 8, and similar data for periods up to 30 years are given in table 9. Low-flow frequency data also may be presented in graphs, as illustrated in figure 25, for the stream-gaging station on the Willimantic River near South Coventry. Tables similar to those presented in table 8 can be constructed from the flow-duration data presented for partial-record gaging stations in table 7 as well as from flow-duration data for unmeasured sites estimated from figures 23 and 24 by use of table 10. To illustrate, the average 30-consecutive-day low flow that could be expected to recur on the average once in every two years according to table 10 is equivalent to the flow equaled or exceeded 90 percent of the time. For the unmeasured site used as an example at the end of the preceding section, the 90-percent flow in the flow-duration table is 7.0 mgd. Flows for other periods and recurrence intervals can be determined in a similar manner.

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 values are termed "indices of low-flow frequency" and are presented in table 11 for all gaging stations in the basin. The 7-day average flow is equivalent to that which is equaled or exceeded about 94 percent of the time and the 30-day average flow to that which is equaled or exceeded about 90 percent of the time.

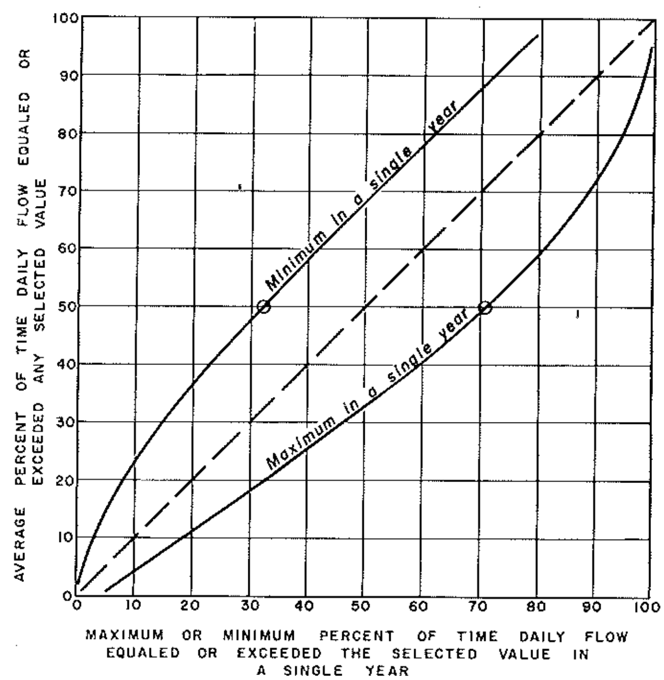


Figure 22.--Range in duration of streamflow in the Shetucket River basin, 1931-60.

Minimum and maximum duration curves for single years are related to the average duration curve for each stream within the basin.

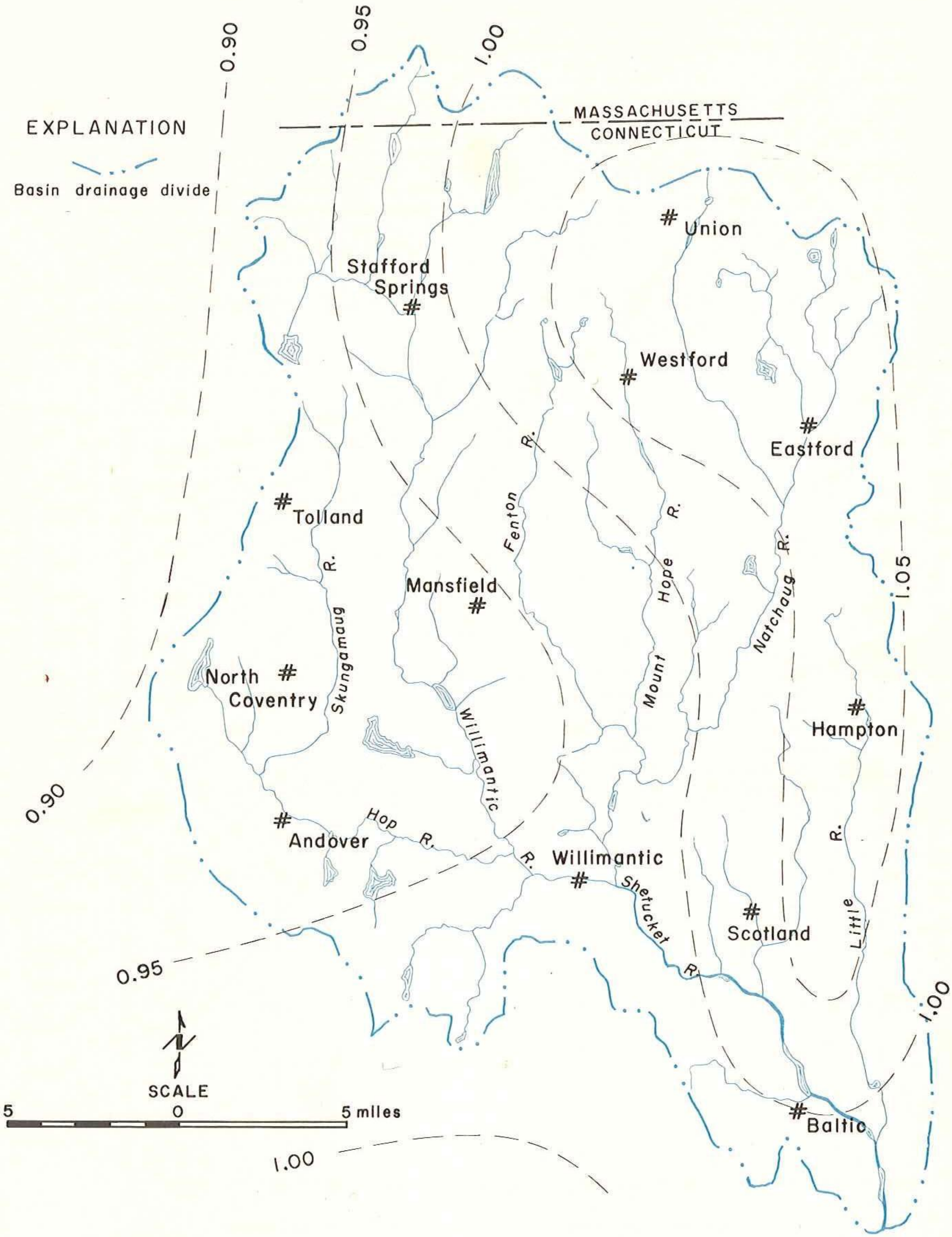


Figure 23.--Areal variations in average streamflow in the Shetucket River basin.

Isopleths express the ratio of average flow in any locality to the approximate basin-wide average of 1.16 million gallons per day per square mile.

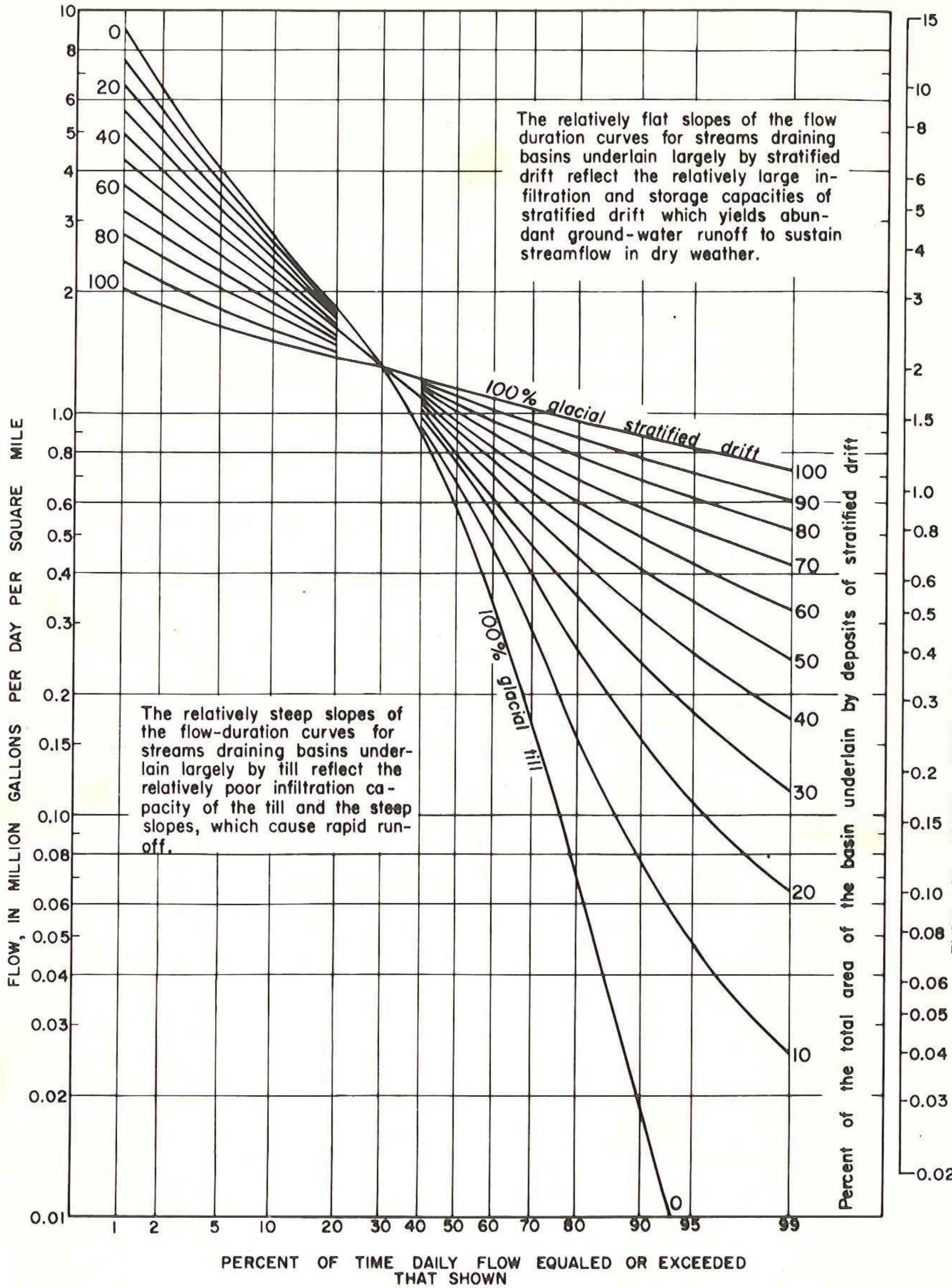


Figure 24.--Regional duration curves of daily mean streamflow.

These curves apply to unregulated streams having an average flow of 1.16 mgd per sq mi (1.80 cfs per sq mi).

Table 8.--Annual lowest mean flows for indicated recurrence intervals at long-term stream-gaging stations in the Shetucket River basin.
(Flows are adjusted to the reference period April 1930 to March 1960)

Index No. (Pl.A)	Stream and place of measurement	Drainage area (sq mi)	Period (consecutive days)	Annual lowest mean flow (cfs) for indicated recurrence interval (years)							Annual lowest mean flow (mgd per sq mi) for indicated recurrence interval (years)						
				1.2	2	3	5	10	20	31	1.2	2	3	5	10	20	31
1195	Willimantic River near South Coventry	121	3	25	17	14	12	8.9	6.9	5.9	---	---	---	---	---	---	---
			7	36	26	21	17	13	10	8.8	0.192	0.139	0.112	0.091	0.069	0.053	0.047
			30	49	36	30	24	18	14	12	.262	.192	.160	.128	.096	.075	.064
			60	64	46	38	31	24	18	16	.342	.246	.203	.166	.128	.096	.085
			120	94	68	56	45	35	27	23	.502	.363	.299	.240	.187	.144	.123
			183	130	93	77	63	48	37	32	.694	.497	.411	.336	.256	.198	.171
			274	200	140	120	95	74	58	49	1.07	.748	.641	.507	.395	.310	.262
			365	260	190	160	130	100	78	67	1.39	1.01	.854	.694	.534	.417	.358
1200	Hop River near Columbia	76.2	3	10	6.7	5.3	4.0	2.9	2.1	1.7	.085	.057	.045	.034	.025	.018	.014
			7	12	7.4	5.8	4.5	3.2	2.3	1.9	.102	.063	.049	.038	.027	.020	.016
			30	18	12	9.0	7.0	5.0	3.7	3.0	.153	.102	.076	.059	.042	.031	.025
			60	27	18	14	11	7.6	5.5	4.5	.229	.153	.119	.093	.064	.047	.038
			120	44	29	23	18	13	9.7	8.0	.373	.246	.195	.153	.110	.082	.068
			183	69	47	37	29	21	16	13	.585	.399	.314	.246	.178	.136	.110
			274	120	81	65	52	38	29	24	1.02	.687	.551	.441	.322	.246	.204
			365	170	120	96	77	58	44	37	1.44	1.02	.814	.653	.492	.373	.314
1205	Safford Brook near Woodstock Valley	4.08	3	.25	.06	.02	.01	0	0	0	.040	.009	.003	.002	0	0	0
			7	.37	.0	.04	.02	0	0	0	.058	.014	.006	.003	0	0	0
			30	.61	.17	.08	.04	.01	.01	0	.096	.027	.013	.006	.002	.002	0
			60	1.1	.35	.18	.09	.04	.02	.01	.174	.055	.028	.014	.006	.003	.002
			120	2.4	1.0	.60	.35	.17	.09	.06	.379	.158	.095	.055	.027	.014	.009
			183	4.2	2.3	1.6	1.1	.68	.43	.32	.664	.363	.253	.174	.107	.068	.051
			274	7.2	4.8	3.8	3.0	2.1	1.6	1.3	1.14	.758	.600	.474	.332	.253	.205
			365	9.3	7.2	6.3	5.4	4.5	3.7	3.3	1.47	1.14	.995	.853	.711	.585	.521
1210	Mount Hope River near Warrenville	27.8	3	3.1	1.8	1.3	.94	.62	.41	.32	.072	.042	.030	.022	.014	.010	.007
			7	4.0	2.2	1.6	1.1	.69	.45	.34	.093	.051	.037	.026	.016	.010	.008
			30	6.4	3.5	2.5	1.7	1.0	.66	.50	.148	.081	.058	.039	.023	.015	.012
			60	11	5.7	4.0	2.7	1.7	1.1	.80	.255	.132	.093	.063	.039	.026	.019
			120	19	11	8.2	5.9	3.8	2.6	2.0	.441	.255	.190	.137	.088	.060	.046
			183	28	18	14	11	7.6	5.5	4.5	.650	.418	.325	.255	.176	.128	.104
			274	48	34	28	23	17	13	11	1.11	.789	.650	.534	.394	.302	.255
			365	66	48	41	33	26	21	18	1.53	1.11	.951	.766	.603	.487	.418
1220	Natchaug River at Willimantic	169	3	15	8.8	6.4	4.6	3.0	2.0	1.6	---	---	---	---	---	---	---
			7	29	17	13	9.3	6.2	4.2	3.3	.111	.065	.050	.036	.024	.016	.013
			30	45	28	22	16	11	7.7	6.2	.172	.107	.084	.061	.042	.029	.024
			60	67	41	31	23	16	11	8.7	.256	.157	.118	.088	.061	.042	.033
			120	120	76	58	43	29	20	16	.458	.290	.222	.164	.111	.076	.061
			183	170	120	93	72	52	39	32	.649	.458	.355	.275	.199	.149	.122
			274	280	200	160	130	99	75	64	1.07	.764	.611	.497	.378	.286	.244
			365	370	280	230	200	160	130	110	1.41	1.07	.879	.764	.611	.497	.420
1225	Shetucket River near Willimantic	401	3	85	59	48	38	29	22	19	---	---	---	---	---	---	---
			7	110	74	60	48	36	28	23	.177	.119	.097	.077	.058	.045	.037
			30	130	93	76	60	46	35	30	.209	.150	.122	.097	.074	.056	.048
			60	175	120	100	79	60	46	38	.282	.193	.161	.127	.097	.074	.061
			120	270	190	150	120	92	70	60	.435	.306	.242	.193	.148	.113	.097
			183	410	280	230	180	140	105	89	.660	.451	.370	.290	.225	.169	.143
			274	650	450	370	300	220	170	140	1.05	.724	.596	.483	.354	.274	.225
			365	840	630	540	450	360	290	260	1.35	1.01	.869	.724	.580	.467	.419
1230	Little River near Hanover	29.1	3	10.5	7.9	6.7	5.6	4.5	3.7	3.2	.233	.175	.149	.124	.100	.082	.071
			7	11	8.1	7.0	5.9	4.7	3.9	3.4	.244	.180	.155	.131	.104	.087	.075
			30	13	10	8.6	7.2	5.8	4.7	4.2	.289	.222	.191	.160	.129	.104	.093
			60	17	13	11	9.1	7.3	6.0	5.2	.377	.289	.244	.202	.162	.133	.115
			120	24	18	15.5	13	10.5	8.6	7.5	.533	.400	.344	.289	.233	.191	.166
			183	33	25	21	18	14	11.5	10	.733	.555	.466	.400	.311	.255	.222
			274	54	40	34	28	22.5	18	16	1.20	.88	.755	.622	.500	.400	.355
			365	67	50	42	35	27.5	22	19	1.49	1.11	.932	.777	.610	.488	.422

Table 9.--Lowest mean flows for periods of one year or more at long-term stream-gaging stations in the Shetucket River basin.
(Flows are adjusted to the reference period April 1930 to March 1960.)

Index no. (Pl. A)	Stream and place of measurement	Lowest mean flow (cfs) for indicated period of consecutive months							
		12	18	24	36	60	120	180	360
1195	Willimantic River near South Coventry	67	119	150	168	172	180	188	213
1200	Hop River near Columbia	37	68	85	95	99	104	110	127
1220	Natchaug River at Willimantic	110	196	212	230	242	256	268	305
1225	Shetucket River near Willimantic	260	385	455	530	560	590	620	705

Table 10.--Average duration of lowest mean flows of streams in the Shetucket 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		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/							
Consecutive days	Consecutive months	1.03 wettest year	1.2	2 median year	3	5	10	20	31 driest year
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 11.--Indices of low-flow frequency at stream-gaging stations in the Shetucket 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 no. (Pl.A)	Stream and place of measurement	Drainage area (sq mi)	Annual lowest mean flow having a recurrence interval of 2 years for number of consecutive days indicated (cfs) 7 days	(cfs) 30 days	(mgd per sq mi) 7 days	(mgd per sq mi) 30 days
1191.5	Middle River at Ellithorpe	6.66	0.49	0.67	0.05	0.06
1192	Middle River at Orcutts	12.3	1.3	1.7	.07	.09
1192.2	Crystal Lake Brook at Crystal Lake	2.80	0	0	0	0
1192.3	Edson Brook at West Stafford	11.8	1.1	1.4	.06	.08
1192.55	Delphi Brook near Staffordville	2.48	.21	.30	.06	.08
1192.6	Furnace Brook at Staffordville	8.61	1.1	1.3	.08	.10
1192.8	Willimantic River at Stafford Springs	53.9	13	16	.15	.19
1192.9	Bonemill Brook near Stafford Springs	2.50	.41	.52	.11	.14
1193	Roaring Brook near Staffordville	5.47	.69	.88	.08	.10
1193.2	Roaring Brook near Stafford Springs	14.6	1.6	2.2	.07	.10
1193.6	Conat Brook at West Willington	2.21	.46	.57	.14	.17
1193.8	Willimantic River at Merrow	95.3	17	24	.12	.16
1194	Cedar Swamp Brook near Mansfield Depot	4.92	.46	.59	.06	.08
1194.8	Mill Brook near South Coventry	3.85	3.9	4.2	.66	.71
1195	Willimantic River near South Coventry	121	26	36	.14	.19
1195.5	Bolton Pond Brook at Quarryville	3.96	0	0	0	0
1196	Ash Brook near North Coventry	2.73	.03	.08	.01	.02
1196.5	Hop River near Andover	12.1	.56	.85	.03	.05
1197	Skungamaug River at Tolland	7.98	.73	.96	.06	.08
1198.2	Skungamaug River at North Coventry	23.5	2.6	3.3	.07	.09
1198.5	Skungamaug River near Andover	27.6	3.0	3.9	.07	.09
1199	Burnap Brook near Andover	6.82	.19	.34	.02	.03
1199.3	Andover Lake Brook near Andover	4.00	0	0	0	0
1199.6	Columbia Lake Brook near Columbia	3.65	0	0	0	0
1200	Hop River near Columbia	76.2	7.4	12	.06	.10
1202	Tenmile River near Willimantic	16.5	.89	1.3	.03	.05
1204	Still River at Kenyonville	7.74	1.2	1.5	.10	.13
1204.5	Bungee Brook near Kenyonville	7.36	.90	1.2	.08	.10
1205	Safford Brook near Woodstock Valley	4.08	.09	.17	.01	.03
1206	Still River at Phoenixville	30.9	3.6	4.6	.08	.10
1206.5	Bigelow Brook near Union	1.16	.09	.13	.05	.07
1206.8	Bigelow Brook near Westford	12.0	1.4	1.8	.08	.10
1207	Bigelow Brook near Phoenixville	21.2	2.2	3.0	.07	.09
1207.5	Natchaug River near Phoenixville	58.4	8.3	11	.09	.12
1208	Natchaug River at Chaplin	65.8	9.3	12	.09	.12
1208.5	Natchaug River at North Windham	81.2	13	18	.11	.14
1209.2	Mount Hope River at Westford	3.03	.31	.42	.07	.09
1209.4	Knowlton Brook at West Ashford	5.92	.59	.77	.06	.08
1210	Mount Hope River near Warrenville	27.8	2.2	3.5	.05	.08
1211	Mount Hope River at Atwoodville	34.8	3.5	4.8	.06	.09
1213	Fenton River at East Willington	11.5	1.0	1.4	.06	.08
1213.5	Fenton River at Gurleyville	23.0	2.5	3.2	.07	.09
1220	Natchaug River at Willimantic	169	17	28	.06	.11
1225	Shetucket River near Willimantic	401	74	93	.12	.15
1226	Obwebetuck Brook near South Windham	2.79	.14	.20	.03	.05
1226.5	Frog Brook near South Windham	3.94	.90	1.1	.15	.19
1226.8	Merrick Brook near Scotland	5.04	.57	.81	.07	.10
1227.5	Beaver Brook near Scotland	7.11	.34	.50	.03	.05
1227.6	Merrick Brook near Hanover	19.8	3.6	4.8	.12	.16
1228	Beaver Brook at Baltic	9.21	2.1	2.5	.14	.17
1228.5	Little River at Hampton	7.71	1.0	1.3	.08	.11
1229	Little River near Scotland	17.4	3.0	3.7	.11	.14
1230	Little River near Hanover	29.1	8.1	10	.18	.22
1230.8	Blissville Brook near Taftville	3.39	.37	.47	.07	.09

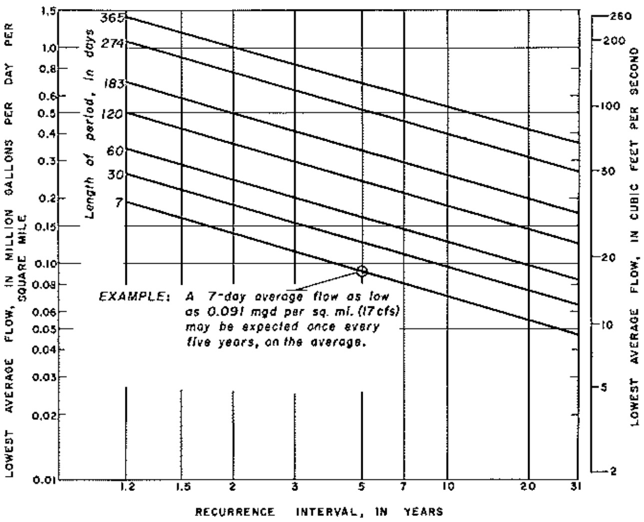


Figure 25.--Recurrence intervals of low flows of the Willimantic River near South Coventry.

The lowest daily flows of record (1928-64) of the Shetucket River at Willimantic not exceeded during periods of 7 to 120 days occurred during the climatic year April 1, 1957 to March 31, 1958. Records at the other long-term stations do not go back to 1928, but unless the pattern of regulation was quite different in the early years, it is likely that these lowest flows for all gaging stations since 1928 also occurred in the climatic year 1957. For each of these gaging stations, the lowest daily flow not exceeded for specified periods during the 1957 climatic year are given in table 12.

For any partial-record gaging station or unmeasured site on an unregulated stream, the lowest daily flow not exceeded for periods of 7, 30, 60, and 120 consecutive days during the 1957 climatic year may be approximated by multiplying the lowest annual mean flow for any period for a 31-year recurrence interval by 1.05, 1.3, 1.6, and 2.2 respectively. These factors are median ratios derived from long-term records at 8 gaging stations in and adjacent to the basin which are unaffected by regulation. Methods of estimating the lowest annual mean flow for selected periods of consecutive days for a 31-year recurrence interval are described above in the first paragraph of this section.

Table 12.--Lowest daily flow not exceeded during various numbers of consecutive days in the summer of 1957 at long-term stream-gaging stations in the Shetucket River basin. Flows during the summer of 1957 were the lowest during the period September 1928 to March 1965.

Index no. (Pl.A)	Stream and place of measurement	Drainage area (sq mi)	Lowest daily flow (cfs) not exceeded during indicated number of consecutive days					Lowest daily flow (mgd per sq mi) not exceeded during indicated number of consecutive days				
			7	15	30	60	120	7	15	30	60	120
1195	Willimantic River near South Coventry	121	12	15	18	18	42	0.064	0.080	0.096	0.096	0.224
1200	Hop River near Columbia	76.2	2.2	3.7	5.7	7.8	9.7	.019	.031	.048	.066	.082
1205	Safford Brook near Woodstock Valley	4.08	0	0	.01	.02	.74	0	0	.002	.003	.117
1210	Mount Hope River near Warrenville	27.8	.5	[a]1.2	[b]2.0	2.4	7.2	.012	.028	.046	.056	.167
1220	Natchaug River at Willimantic	169	5.0	7	[c]26	36	48	----	.065	.100	.138	.184
1225	Shetucket River near Willimantic	401	35	47	62	82	102	----	.076	.100	.132	.164
1230	Little River near Hanover	29.1	[d]5.1	[e]5.7	6.2	[f]10	14	.113	.127	.138	.222	.311

a A lower flow of 1.1 cfs (0.026 mgd per sq mi) occurred during the summer of 1953.
b A lower flow of 1.9 cfs (0.044 mgd per sq mi) occurred during the summer of 1953.
c A lower flow of 23 cfs (0.088 mgd per sq mi) occurred during the summer of 1943.
d A lower flow of 4.2 cfs (0.093 mgd per sq mi) occurred during the summer of 1963.
e A lower flow of 4.7 cfs (0.105 mgd per sq mi) occurred during the summer of 1963.
f A lower flow of 9.3 cfs (0.206 mgd per sq mi) occurred during the summer of 1964.

STORAGE OF WATER IN LAKES AND RESERVOIRS

EXISTING LAKES AND RESERVOIRS

There are many lakes, ponds, and reservoirs within the Shetucket River basin. The largest natural lake is Wangumbaug (Coventry) Lake which has a surface area of 377 acres, and the largest reservoir is Mansfield Hollow flood control reservoir which, at the crest of the spillway, has a surface area of 1,880 acres. Table 13 presents information concerning the more important lakes and ponds, with the exception of public water-supply reservoirs. Information about these is given in table 29.

All but two of the lakes, ponds, and reservoirs listed in table 13 have usable storage; that is, some or all of the water they contain may be withdrawn by gravity upon opening a valve or gate. Water released from all the flood control reservoirs listed, except Mansfield Hollow Reservoir, is uncontrolled. At this reservoir and all other ponds, lakes, and reservoirs having usable storage, withdrawal is through a valve or gate. For all of the ponds, lakes, and reservoirs listed in table 13, except Mansfield Hollow Reservoir, table 14 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 apply for 24-hour per day use and may be increased if the period of use is reduced.

Flow-duration and low-flow frequency data for streams at the outlet of each of these reservoirs were obtained either from data at gaging stations presented in tables 7 and 10 or by using the methods described for ungaged sties in the two preceeding sections.

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 15 for the seven long-term continuous-record gaging stations in the Shetucket 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 stream, provided that the percent of the area covered by stratified drift is not appreciably different. Most of the amounts of storage 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 curves were determined from frequency-mass curves based on low-flow frequency relationships for each gaging station.

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 16. The data are presented for various percentages of area covered by stratified drift; interpolations between percentages may be made. Storage used to provide regulated flow as indicated would be replaced each year except for underlined values. These 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 16 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 23.

The storage-required values in tables 15 and 16 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 the selection of a proposed site.

FLOODS

HISTORICAL ACCOUNT

Floods may occur in the Shetucket 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. More detailed records of the major floods of 1936, 1938, and 1955, based primarily on gaging-station records, are published in Water-Supply Papers 798 (March 1936), 867 (September 1938), 966 (January and July 1938), and 1420 (August and October 1955). 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 the first settlement of the region about 1690, there have been at least 16 major flood events which have occurred in the basin. The earliest of these took place in 1720, 1771,

Table 13.--Lakes, ponds, and reservoirs in the Shetucket River basin.
(Most of the data from Connecticut Board of Fisheries and Game and U.S. Soil Conservation Service)

Index no. (Pl.A)	Name and location	Natural (N) or Artificial (A)	Drainage area (sq mi)	Surface area (acres)	Surface elevation (ft)	Maximum depth (ft)	Average depth (ft)	Total storage (mg)	Usable storage (mg)	Maximum amount of storage released during water year 1963 (mg)	Present use
1191.49	State Line Pond near Ellithorpe	A	6.66	79.9	596	8	3.1	81.5	81.5	68.8	Recreation
1191.7	Ellithorpe Reservoir at Ellithorpe	A	10.3	367	--	27	10	1,270	1,270	--	Flood Control
1192.19	Crystal Lake at Crystal Lake	NA	2.80	201	636	50	20	1,287	314	232	Recreation
1192.21	Pomeroy Reservoir near West Stafford	A	1.48	42.0	--	31	11	150	150	--	Flood Control
1192.23	Whitney Reservoir at West Stafford	A	3.03	99.8	--	44	14	441	441	--	Flood Control
1192.28	Ellis Reservoir near West Stafford	A	1.52	45.7	--	30	12	183	183	--	Flood Control
1192.33	Bradway Reservoir near West Stafford	NA	1.20	87.5	--	--	--	--	113	--	Flood Control
1192.36	Shenipsit Reservoir at Orcutts	A	1.02	46.1	--	20	8.0	120	120	--	Flood Control
1192.57	New City Pond near Stafford-ville	A	1.58	36.6	890	10	5.7	68.0	68.0	--	Recreation
1192.59	Staffordville Reservoir at Staffordville	A	8.06	165	698	16	9.5	565	565	298	Industrial
1192.93	Dexter Moore Reservoir near Stafford Springs	A	1.21	53.9	935	--	2.9	51	51	--	Water Supply
1192.97	Mathews Pond near Stafford Springs	A	4.24	9.0	834	--	5.1	15	15	None	Water Supply
1194.69	Eagleville Lake at Eagleville	A	110	80.0	277	10	3.4	87.5	87.5	--	Not used
1194.79	Wangumbaug (Coventry) Lake at South Coventry	NA	3.17	377	515	41	18	2,222	396	396	Recreation
1195.48	Bolton Lake (Upper) near Bolton	A	3.08	150	674	26	8.1	397	334	19.4	Recreation
1195.49	Bolton Lake (Lower) near Bolton	A	3.81	178	667	26	11	657	482	180	Recreation
1199.29	Andover Lake near Andover	A	3.91	155	414	16	11	512	96.5	47.9	Recreation
1199.59	Columbia Lake near Columbia	A	2.85	282	498	26	17	1,549	1,549	486	Recreation
1203.95	Crystal Pond near Eastford	NA	.76	150	647	44	14	708	260	--	Recreation
1204.2	Chamberlain Pond near West Woodstock	A	2.51	48.9	673	10	3.9	62.5	62.5	--	Not used
1204.25	Black Pond near West Woodstock	N	.68	73.4	644	23	12	286	None	--	Recreation
1206.49	Bigelow Pond near Union	A	1.16	18.6	636	16	7.5	45.8	43.4	None	Recreation
1207.4	Halls Pond near Phoenixville	NA	1.28	82.3	514	14	6.7	179	179	--	Recreation
1210.5	Knowlton Pond near West Ashford	A	.89	98.5	524	7	3.0	96.5	None	--	Not used
1215	Mansfield Hollow Reservoir at Mansfield Hollow	A	159	1,880	--	62	28	16,900	16,900	--	Flood Control
1217	Willimantic Reservoir at Willimantic	A	161	83	182	20	4.6	125	125	--	Water Supply
1228.1	Baltic Reservoir at Baltic	NA	.32	23.3	268	24	14	105	105	--	Water Supply
1228.4	Hampton Reservoir near Hampton	A	.88	32.2	593	7	2.9	30.9	28.4	--	Not used
1230.25	Hanover Reservoir at Hanover	A	32.3	--	183	16	--	--	--	--	Water Supply
1230.5	Paper Mill Pond at Versailles Station	A	35.5	61.0	111	20	6.3	126	114	53.1	Industrial
1230	Taftville Pond at Taftville	A	510	120	45	21	8.5	331	331	--	Industrial

Table 14.--Maximum safe draft rates (regulated flows) from selected lakes, ponds, and reservoirs in the Shetucket River basin for the reference period April 1930 to March 1960.
(Lakes, ponds, and reservoirs will refill within a year)

Index no. (Pl.A)	Lake, pond, or reservoir and location	Drainage basin	Drainage area (sq mi)	Total usable storage (mg)	Maximum safe regulated flow					
					Driest year		Median year		Wettest year	
					(cfs)	(mgd)	(cfs)	(mgd)	(cfs)	(mgd)
1191.49	State Line Pond near Ellithorpe	Middle River	6.66	81.5	1.3	0.84	2.7	1.7	10	6.5
1192.19	Crystal Lake at Crystal Lake	Crystal Lake Brook	2.80	314	*1.2	*.78	*3.9	*2.5	*8.3	*5.4
1192.57	New City Pond near Staffordville	Furnace Brook	1.58	68.0	.46	.30	1.0	.65	3.8	2.5
1192.59	Staffordville Reservoir at Staffordville	Furnace Brook	8.06	565	*4.0	*2.6	8.8	5.7	24	16
1194.69	Eagleville Lake at Eagleville	Willimantic River	110	87.5	24	16	36	23	105	68
1194.79	Wangumbaug (Coventry) Lake at South Coventry	Mill Brook	3.17	396	*4.2	*2.7	*5.4	*3.5	*6.9	*4.5
1195.48	Bolton Lake (Upper) near Bolton	Bolton Pond Brook	3.08	334	*.88	*.54	3.6	2.3	9.4	6.1
1195.49	Bolton Lake (Lower) near Bolton	Bolton Pond Brook	3.81	482	*1.0	*.65	*4.8	*3.1	*12	*7.8
1199.29	Andover Lake near Andover	Andover Lake Brook	3.91	96.5	1.5	.97	2.7	1.7	7.9	5.1
1199.59	Columbia Lake near Columbia	Columbia Lake Brook	2.85	1,549	*1.3	*.84	*4.0	*2.6	*8.8	*5.7
1203.95	Crystal Pond near Eastford	Still River	.76	260	*.50	*.32	*1.2	*.78	*2.6	*1.7
1204.2	Chamberlain Pond near West Woodstock	Bungee Brook	2.51	62.5	.74	.48	1.8	1.2	5.3	3.4
1206.49	Bigelow Pond near Union	Bigelow Brook	1.16	43.4	.45	.29	.87	.56	2.8	1.8
1207.4	Halls Pond near Phoenixville	Natchaug River	1.28	179	*.41	*.26	*1.9	*1.2	*4.5	*2.9
1228.4	Hampton Reservoir near Hampton	Little River	.88	28.4	.33	.21	.70	.45	2.0	1.3
1230.5	Paper Mill Pond at Versailles Station	Little River	35.5	114	11	7.1	18	12	42	27
1230.69	Taftville Pond at Taftville	Shetucket River	510	331	78	50	130	84	420	270

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

Table 15.--Storage required to maintain indicated regulated flows at long-term stream-gaging stations in the Shetucket 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 no. (Pl.A)	Stream and place of measurement	Drainage area (sq mi)	Recurrence interval of annual lowest mean flow (years) 1/	Maximum amount of storage which would refill during the year of annual lowest mean flow (mg per sq mi)	Storage required (mg per sq mi) to maintain indicated regulated flow (mgd per sq mi)																
					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
1195	Willimantic River near South Coventry	121	1.2	--	--	--	--	--	1	2	4	6	9	12	15	19	24	29	35	48	62
			2	--	--	--	--	1	3	5	9	13	18	23	29	35	42	49	57	74	92
			5	66	--	--	2	4	8	13	18	24	31	39	48	57	67	77	88	110	135
			10	51	--	1	4	8	13	19	27	35	44	54	64	75	86	98	111	140	170
			31	35	1	4	9	15	24	33	43	54	66	79	93	108	125	143	161	198	236
1200	Hop River near Columbia	76.2	1.2	--	--	--	1	2	5	7	10	13	17	22	27	33	39	46	53	67	81
			2	--	--	1	3	6	10	14	19	24	30	36	43	50	57	65	73	91	111
			5	75	1	3	7	11	17	24	31	39	47	55	64	74	84	95	106	129	154
			10	59	2	6	11	16	23	32	41	51	61	72	83	94	106	118	131	160	190
			31	39	4	9	17	26	35	46	57	69	81	95	109	124	141	158	177	215	253
1205	Safford Brook near Woodstock Valley	4.08	1.2	--	--	1	3	5	7	10	14	18	22	26	31	36	41	46	51	62	75
			2	--	3	6	10	14	19	24	29	35	41	47	53	60	67	75	83	99	116
			5	126	6	11	17	23	30	37	45	53	61	69	78	87	96	105	114	134	155
			10	116	9	15	22	29	37	45	54	63	72	82	92	102	113	124	136	160	185
			31	95	11	19	28	37	47	57	68	79	90	102	114	126	139	152	165	191	218
1210	Mount Hope River near Warrenville	27.8	1.2	--	--	--	1	3	5	7	9	12	15	18	22	27	32	37	43	56	70
			2	--	--	1	4	7	10	14	19	24	29	35	42	49	57	65	73	89	107
			5	94	2	5	9	14	20	26	33	40	47	55	64	73	82	91	100	118	138
			10	69	5	11	17	24	32	41	51	61	71	82	93	104	115	127	139	164	191
			31	60	7	13	19	27	36	46	56	66	77	88	99	111	123	136	150	178	212
1220	Natchaug River at Willimantic	169	1.2	--	--	--	1	2	4	6	8	11	14	17	21	25	30	35	40	54	68
			2	--	--	1	3	5	8	12	17	21	26	31	37	43	49	56	64	80	98
			5	92	1	3	7	11	16	22	28	35	42	50	59	68	78	88	98	120	143
			10	78	3	7	11	16	22	29	37	46	55	65	75	86	97	108	120	145	170
			31	57	5	10	17	24	32	42	52	63	75	87	99	112	125	138	152	182	215
1225	Shetucket River near Willimantic	401	1.2	--	--	--	--	1	2	4	7	10	13	17	21	26	31	37	43	56	70
			2	--	--	--	1	3	6	9	13	17	22	28	34	41	48	56	64	82	100
			5	80	--	1	4	8	13	19	25	32	39	47	56	65	75	85	96	119	143
			10	68	1	3	7	12	18	25	32	40	50	61	72	84	96	109	122	149	176
			31	56	2	7	13	20	29	40	52	64	76	89	102	116	130	144	158	187	217
1230	Little River near Hanover	29.1	1.2	--	--	--	--	--	--	1	2	4	7	10	13	16	21	26	31	44	58
			2	--	--	--	--	--	2	4	7	10	13	18	23	29	36	43	50	66	82
			5	70	--	--	--	2	5	9	13	18	24	31	39	47	55	64	73	91	111
			10	55	--	--	2	5	9	14	20	27	35	43	52	61	70	80	90	112	140
			31	36	--	2	5	10	16	24	32	41	50	59	69	84	102	120	140	180	220

1/ 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 16.--Storage required to maintain indicated regulated flows at sites on unregulated streams in the Shetucket River basin. (Data are adjusted to the reference period April 1930 to March 1960 and to an average flow of 1.16 mgd per sq mi. 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) 1/	Maximum amount of storage which would refill during the year of annual lowest mean flow (mg per sq mi)	Storage required (mg per sq mi) to maintain indicated regulated flow (mgd per sq mi)																
			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

1/ 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.

1784, and 1789. On February 7, 1807, occurred a great flood which was associated with ice, the greatest inundation ever witnessed by the oldest inhabitants. The Shetucket River, it was said, rose 30 feet at Norwich and from 18 to 20 feet at Windham. It was 6 to 8 feet higher at Norwich than for the previous flood of 1789. This was followed by other major floods in 1823, 1835, and 1854, but not until February 9, 1857 was the supremacy of the flood of 1807 challenged. This flood, known as the "Half-Century" flood, occurred on the 50th anniversary of the flood of 1807 and was the highest ever known at Norwich except for the flood of February 7, 1807.

The great freshet of October 4, 1869 reached heights throughout the basin far above those of the flood of February 7, 1807, the maximum previously known. Streams were many times the capacity of their channels and destruction was widespread. On March 26, 1876, this flood was in turn exceeded. In the vicinity of Norwich it was 13 inches higher than that of 1857 and 5 inches higher than that of 1807. The river was full of cotton bales, sacks of wool, and the debris of mills, buildings, dams, and bridges. Ten years later, February 13, 1886, another flood occurred which was not as high as in 1869 or 1876 in the Shetucket River above Norwich, but at Norwich, due to a greater freshet in the Quinebaug River basin, the water rose higher than ever before to a point 4 inches higher than 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 was reached but damages were still extensive to bridges, building, 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, and even the flood of November 4, 1927, while it was the greatest in many years, did not approach the record high floods of 1869 and 1876 in magnitude.

Continuous records of streamflow have been kept at South Windham or near Willimantic since September 1928, and a quantitative summary of major flood events since that date appear in table 17. The two floods of March 1936, while they were about twice the magnitude of the flood of November 1927, did not approach in magnitude the previous record high floods of 1869 and 1876. Floods of moderate magnitude occurred November 29, 1937, January 26, 1938, and July 24, 1938. On September 21, 1938, however, all previous flood records were shattered by a hurricane flood of which the equal had never been seen. River stages were reached which inundated and damaged everything on the flood plains. When measured by the appalling loss of life and property due to the combined forces of hurricane winds, ocean storm waves and river floods, these events constituted the greatest catastrophe in New England since its first settlements. Flow in the Shetucket River at Norwich was about 1.6 times that which had occurred in the record flood of March 26, 1876, and just over the western edge of the basin, Shenipsit Lake measured a total runoff during the flood 2.2 times as high as was measured during the previous high flood of October 4, 1869. Not until August 19, 1955 was the magnitude of the September 1938 flood challenged. It was exceeded, however, only on the Willimantic River and its upper tributaries and on the upper tributaries of the Hop and Natchaug Rivers, for the heaviest rainfall fell on the upper reaches of the basin.

The principal storage development in the basin is the Mansfield Hollow flood-control reservoir operated by the Corps of Engineers near the mouth of the Natchaug River, with a usable capacity of 2,260 million cubic feet. It was completed in March 1952, and in August 1955 and again in October 1955 it impounded all of the flood waters from above this point, thus relieving the flood situation in the basin below. Modified flood elevations and flows at gaging stations on the Natchaug River and the Shetucket River at or near Willimantic, from studies made by the Corps of Engineers appear in table 17, and indicate the effect which Mansfield Hollow reservoir would have had upon major flood events of the past had it been in existence at those times. Also shown is an estimate of the peak flow which would have occurred in September 1954, August 1955, and October 1955 had the reservoir not been available for use. Future floods of similar magnitudes would be modified to the same degree by this reservoir, so that the possibility of major damage on the Natchaug River and Shetucket River downstream from the dam and near these gaging stations is remote as long as buildings are not constructed below the highest modified flood elevations shown in table 17.

Five floodwater retarding structures have been constructed since 1959 on the watershed of Middle River above Stafford Springs and one more will be built in the near future. All were designed and constructed by the U.S. Department of Agriculture, Soil Conservation Service, for the State of Connecticut to assist in protecting West Stafford and Stafford Springs from future floods. The watershed work plan for the Furnace Brook-Middle River watershed (Connecticut Dept. of Agriculture and Natural Resources and Hampden County, Massachusetts, Soil Conservation District, 1958) states that when all of these structures have been completed, the maximum detention capacity will be 310 million cubic feet, and runoff from 47 percent of the total watershed will be controlled. The work plan also states that the peak flow of the Middle River at Stafford Springs for August 1955 of about 11,000 cfs would have been reduced to 6,000 cfs by storage in these six retarding basins. This is equivalent to a reduction in stage of 5.2 feet. The August 1955 peak flow at the gaging station on the Willimantic River near South Coventry would then have been reduced to about 20,000 cfs.

MAGNITUDE AND FREQUENCY OF FLOODS

Knowledge of the magnitude and frequency of floods is essential to the water manager concerned with the location and establishment of floodplain encroachment lines. The maximum flood of record and mean annual flood at gaging stations in the Shetucket River basin are given in table 18. For the gaging stations on the Willimantic River at

Table 17.--Elevations of flood peaks and corresponding flows for notable floods of record at long-term stream-gaging stations in the Shetucket River basin, as observed, and with or without flood control.

Index no. (Pl.A)	Stream and place of measurement	Mar. 12, 1936		Mar. 18,19, 1936		Nov. 29, 1937		Jan. 25,26, 1938		July 23,24, 1938		Sept. 21, 1938		Sept. 11,12, 1954		Aug. 19, 1955		Oct. 16, 1955	
		Elevation (ft above M.S.L.)	Flow (cfs)	Elevation (ft above M.S.L.)	Flow (cfs)	Elevation (ft above M.S.L.)	Flow (cfs)	Elevation (ft above M.S.L.)	Flow (cfs)	Elevation (ft above M.S.L.)	Flow (cfs)	Elevation (ft above M.S.L.)	Flow (cfs)	Elevation (ft above M.S.L.)	Flow (cfs)	Elevation (ft above M.S.L.)	Flow (cfs)	Elevation (ft above M.S.L.)	Flow (cfs)
1195	Willimantic River near South Coventry																		
	Without flood control	251.2	7,880	250.7	6,620	248.5	3,290	248.9	3,770	248.1	2,950	257.1	15,500	248.4	3,100	257.7	24,200	248.3	2,990
	With flood control 1/	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	20,000	--	--
1200	Hop River near Columbia Observed	263.1	3,640	261.3	2,630	262.3	2,980	262.3	2,970	261.0	2,530	265.5	6,450	260.7	2,380	264.4	5,570	263.4	4,820
1205	Safford Brook near Woodstock Valley Observed	--	--	--	--	--	--	--	--	--	--	--	--	558.8	570	559.6	1,000	557.5	242
1210	Mount Hope River near Warrenville Observed	--	--	--	--	--	--	--	--	--	--	--	--	344.8	3,250	346.0	5,590	342.2	912
1220	Natchaug River at Willimantic																		
	Without flood control 2/	163.5	12,700	163.9	14,200	162.6	9,000	161.3	5,880	162.8	9,740	166.7	32,000	162.2	7,800	164.2	16,000	161.7	6,600
	With flood control 3/	158.3	2,800	158.3	2,800	158.0	2,800	158.0	2,800	158.0	2,800	159.2	3,500	157.2	2,150	158.9	3,250	158.9	3,230
1225	Shetucket River near Willimantic																		
	Without flood control 2/	149.8	23,900	149.4	23,100	146.3	15,800	144.7	12,600	146.0	15,300	159.0	52,200	144.4	12,000	153.1	33,200	145.6	14,400
	With flood control 3/	144.9	12,900	144.5	12,200	142.0	8,000	141.7	7,500	141.3	7,000	150.5	25,700	140.0	5,280	148.8	21,300	143.0	9,580
1230	Little River near Hanover Observed	--	--	--	--	--	--	--	--	--	--	--	--	226.5	935	227.7	1,400	227.2	1,220

1/ Storage in Pomeroy, Ellis, Kent Hollow, Bradway, Shenipsit, and Ellithorpe flood detention reservoirs. Flow estimated from data in "Work Plan for Watershed Protection and Flood Prevention for Furnace Brook - Middle River Watershed," 1958, p. 13.

2/ Estimated data after March 1952, when Mansfield Hollow flood control reservoir was constructed, was furnished by New England Division of the Corps of Engineers, U.S. Army.

3/ Estimated data prior to March 1952, when Mansfield Hollow flood control reservoir was constructed, was furnished by New England Division of the Corps of Engineers, U.S. Army.

Table 18.--Maximum flood of record and mean annual flood at stream-gaging stations in the Shetucket River basin, as observed, and as they might have been modified by flood control reservoirs constructed at a later date.

Index no. (Pl.A)	Stream and place of measurement	Observed or modified by flood control	Drainage area (sq mi)	Period of continuous records	Maximum flood of record					Mean annual flood		
					Elevation		Flow			Elevation	Flow	
					Date	(ft above M.S.L.)	(cfs)	(cfs per sq mi)	Ratio to mean annual flood	(ft above M.S.L.)	(cfs)	(cfs per sq mi)
1192.2	Crystal Lake Brook at West Stafford	Observed	5.83	--	Aug.19,1955	--	784	134	--	--	--	--
1192.8	Willimantic River at Stafford Springs	Observed Modified 1/	53.5	--	Aug.19,1955	-- --	14,500 9,000	271 --	-- --	-- --	-- --	-- --
1193	Roaring Brook near Staffordville	Observed	5.47	1960-64	Jan.25,1964	--	185	33.8	1.06	--	160	29.2
1193.2	Roaring Brook near Stafford Springs	Observed	14.6	1961-64	Jan.25,1964	186.4	430	29.5	1.20	586.2	360	24.6
1193.31	Roaring Brook near West Willington	Observed	18.0	--	Aug.19,1955	--	2,920	162	--	--	--	--
1193.6	Conat Brook at West Willington	Observed	2.21	1963-64	Jan.25,1964	--	30	13.6	.54	--	50	22.6
1194.5	Eagleville Brook at Storrs	Observed	.34	1953-64	Aug.21,1957	565.7	141	41.5	1.25	563.1	85	250
1195	Willimantic River near South Coventry	Observed Modified 1/	121	1931-64	Aug.19,1955	257.7 256.1	24,200 20,000	200 --	11.00 9.10	247.6 247.6	2,200 2,200	18.2 18.2
1196	Ash Brook near North Coventry	Observed	2.73	1960-64	Sept.12,1960	--	190	69.7	.90	--	210	76.9
1198	Skungamaug River near North Coventry	Observed	18.0	1961-64	Mar.27,1963	--	400	22.2	1.02	--	390	21.7
1198.2	Skungamaug River at North Coventry	Observed	23.5	1962-64	Jan.25,1964	--	310	13.2	.67	--	460	19.6
1200	Hop River near Columbia	Observed	76.2	1932-64	Sept.21,1938	265.5	6,450	84.6	3.40	259.0	1,900	24.9
1205	Safford Brook near Woodstock Valley	Observed	4.08	1950-64	Aug.19,1955	559.6	1,000	245	3.70	558.0	270	66.1
1210	Mount Hope River near Warrenville	Observed	27.8	1940-64	Aug.19,1955	346.0	5,590	201	5.88	342.2	950	34.2
1213	Fenton River at East Willington	Observed	11.5	1963-64	Jan.25,1964	--	380	33.0	1.03	--	370	32.2
1220	Natchaug River at Willimantic	Observed Modified 2/	169	1930-64	Sept.21,1938	166.7 159.2	32,000 3,500	189 --	8.65 1.25	159.4 158.3	3,700 2,800	21.9 --
1225	Shetucket River near Willimantic	Observed Modified 2/	401	1928-64	Sept.21,1938	159.0 150.5	52,200 25,700	130 --	6.96 3.43	141.7 141.3	7,500 7,000	18.7 17.5
1226.8	Merrick Brook near Scotland	Observed	5.04	1964	Jan.25,1964	--	330	65.5	1.50	--	220	43.6
1226.9	Merrick Brook near Scotland	Observed	5.76	1962-64	Mar.6,1963	--	130	22.9	.52	--	250	43.4
1227	Merrick Brook near Scotland	Observed	6.39	1960-62	Feb.26,1961	--	360	56.3	1.33	--	270	42.3
1230	Little River near Hanover	Observed	29.1	1951-64	Aug. 9,1955	227.7	1,400	48.1	1.75	226.2	800	27.5

1/ Modified by storage in Pomeroy, Ellis, Kent Hollow, Bradway, Shenipsit, and Ellithorpe flood detention reservoirs. Flow estimated from data in "Work Plan for Watershed Protection and Flood Prevention for Furnace Brook - Middle River Watershed", 1958, p. 13.

2/ Modified by storage in Mansfield Hollow flood-control reservoir. Data furnished by the New England Division of the Corps of Engineers, U.S. Army.

Stafford Springs and near South Coventry, the stages and flows actually measured before the completion of six flood detention reservoirs in the Middle River basin after 1959 are given, and in addition, modified figures are given indicating probable stages and flows that would have resulted had all six reservoirs been in existence at the time. Similarly, for the gaging stations on the Natchaug River and Shetucket River at or near Willimantic, the stages and flows actually measured before completion of the Mansfield Hollow flood-control reservoir in March 1952 are given, and in addition, modified figures are given indicating probable stages and flows that would have occurred had the reservoir been in existence at the time.

For all unmeasured sites on rural streams within the basin where the drainage area is 1 square mile or more, estimates of the flood flow for any recurrence interval can be made from figures 26 and 27. The mean annual flood at any site can be found from figure 26 where the effective drainage area is known. The effective drainage area is defined as that portion of the total drainage area which is not covered by ponds, swamps and deposits of stratified drift, and may be measured on plate B. 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 interval from figure 27.

A flood frequency table for each continuous record site in the basin is listed in table 19 opposite the period of 0 consecutive days.

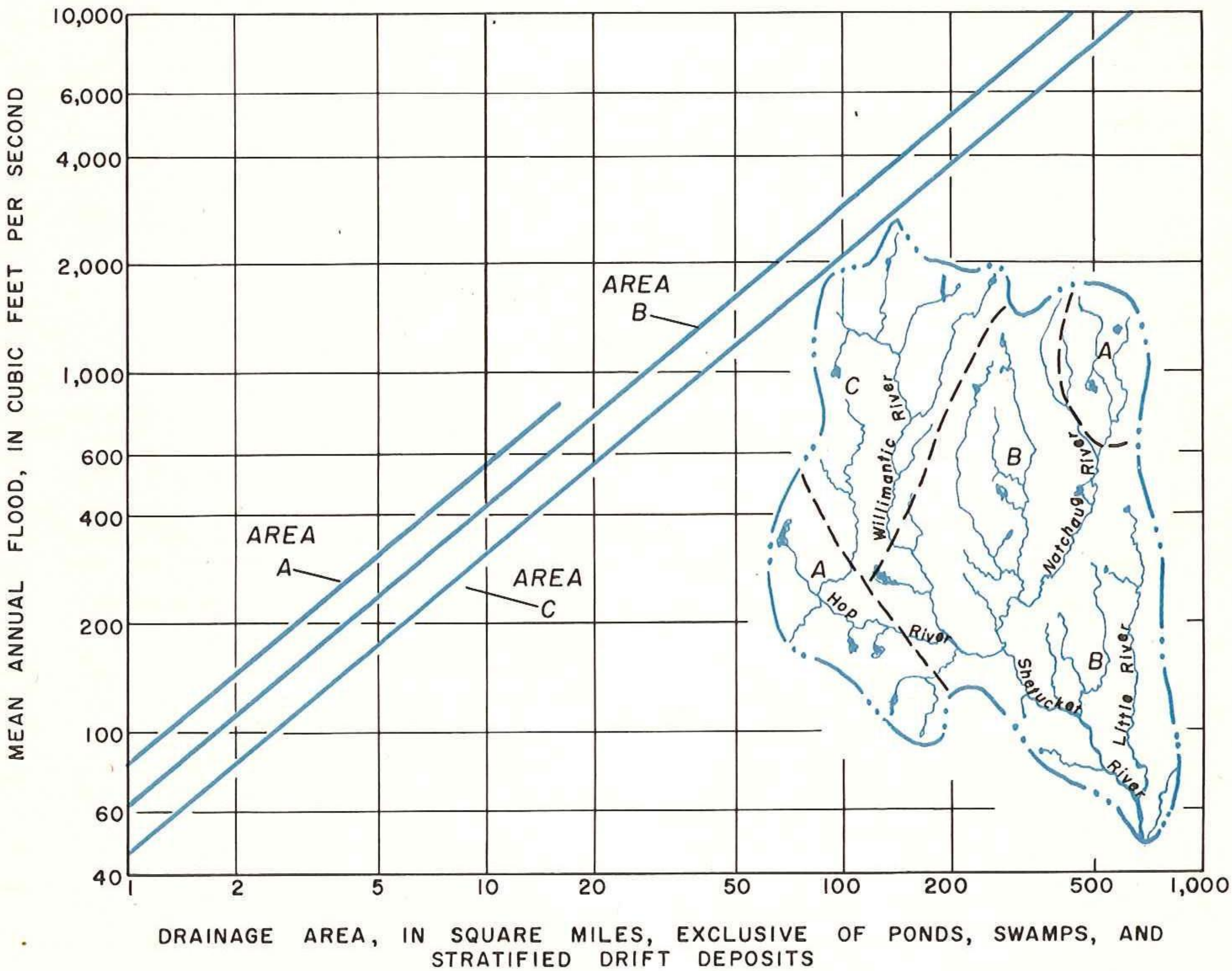
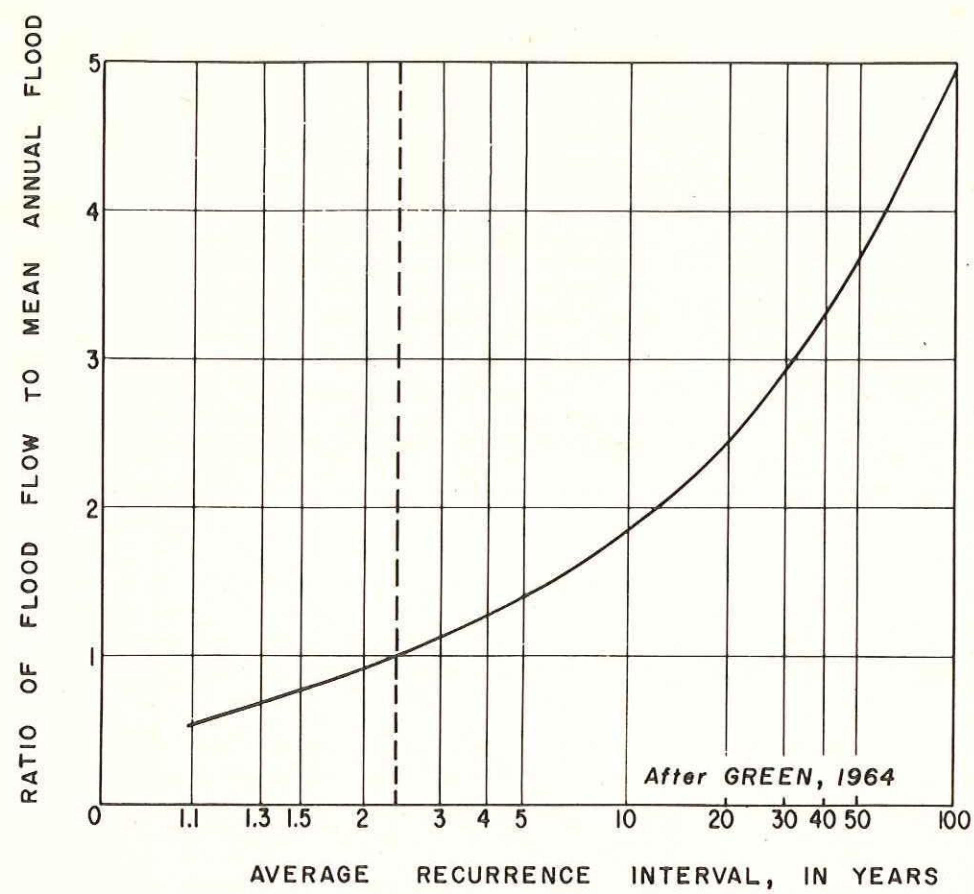


Figure 26.--Variation of mean annual flood with effective drainage area in the Shetucket River basin.



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 26, this figure 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 27.--Flood-magnitude frequency curve for the Shetucket River basin.

FREQUENCY AND DURATION OF HIGH FLOWS

The flood-frequency information in table 18 and figures 26 and 27 is presented in terms of the recurrence of instantaneous peak discharges. For some purposes, however, it is also useful to estimate how long periods of high flow may be sustained and how frequently these periods may recur. Table 19 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-record gaging stations in the Shetucket River basin. For the gaging stations on the Natchaug and Shetucket Rivers, adjustments have been made for the effect of storage in Mansfield Hollow flood-control reservoir based upon records prior to its construction. For example, table 19 indicates that the highest average flow of the Willimantic River near South Coventry for a period of 30 days would be 950 cfs once in 10 years, on the average, and thus there is a 10 percent probability that 30-day average flows of this magnitude would occur in any one year. The peak flow recurring once in 10 years would be 4,100 cfs with the corresponding peak elevation of 249.3 feet. This flood peak would probably occur within the same 30-day period for which the average flow is 950 cfs. No adjustments have been made in table 19 for the effect of storage in the 6 small flood-control reservoirs on Middle River in the headwaters, for their effect upon the flow at the gaging station near South Coventry is small for floods with a recurrence interval of less than 100 years.

QUALITY OF WATER IN STREAMS

NATURAL CONDITIONS

The chemical quality of water in a natural stream and its suitability for use by man is determined by the kind and amount of the dissolved minerals it contains. During periods of low streamflow, when the proportion of direct runoff is small and that of ground-water runoff is large, a stream generally contains the highest concentration of dissolved minerals, because water which percolates through the ground has greater opportunity to dissolve soil and rock materials than water flowing across the land surface. The types and amounts of the minerals in solution in ground-water runoff vary from place to place throughout the basin depending upon the types of geologic environment through which the water has passed.

Table 19.--Annual highest average flows and corresponding average elevations for indicated recurrence intervals at long-term stream-gaging stations in the Shetucket 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 Shetucket and Natchaug Rivers have been modified for the effect of flood control in Mansfield Hollow Reservoir.

Index no. (Pl.A)	Stream and place of measurement	Drainage area (sq mi)	Period (consecutive days)	Annual highest average flow (cfs) for indicated recurrence interval (years)							Annual highest average elevation (ft above M.S.L.) for indicated recurrence interval (years)						
				1.03	2	5	10	25	50	100	1.03	2	5	10	25	50	100
1195	Willimantic River near South Coventry	121	0	860	2,000	3,100	4,100	6,000	8,000	11,000	245.3	247.4	248.4	249.3	250.4	251.3	252.6
			1	730	1,600	2,500	3,400	4,800	6,400	8,800	245.0	246.9	247.9	248.7	249.7	250.6	251.6
			3	600	1,100	1,800	2,400	3,500	4,700	6,100	244.6	245.9	247.1	247.8	248.8	249.7	250.4
			7	490	860	1,300	1,800	2,600	3,500	4,600	244.3	245.3	246.4	247.1	248.0	248.8	249.7
			15	400	660	980	1,300	1,900	2,400	3,300	244.0	244.8	245.6	246.4	247.3	247.8	248.7
			30	320	530	760	950	1,300	1,600	2,200	243.8	244.4	245.0	245.6	246.4	246.9	247.6
			60	250	420	590	700	880	1,000	1,300	243.5	244.1	244.6	244.9	245.4	245.6	246.4
			150	180	310	420	470	540	590	680	243.2	243.8	244.1	244.3	244.5	244.6	244.8
			274	140	250	340	360	390	400	440	243.0	243.5	243.8	243.9	244.0	244.0	244.2
			365	130	230	300	310	330	340	350	243.0	243.4	243.7	243.8	243.8	243.8	243.9
1200	Hop River near Columbia	76.2	0	820	1,700	2,600	3,500	5,300	7,100	9,500	256.2	258.6	260.8	261.7	264.0	266.0	268.2
			1	580	1,200	1,800	2,400	3,700	5,000	6,600	255.4	257.5	258.8	260.0	262.0	263.7	265.5
			3	440	800	1,200	1,700	2,500	3,400	4,400	254.8	256.2	257.5	258.6	260.1	261.6	262.9
			7	340	580	880	1,200	1,700	2,300	3,300	254.4	255.4	256.4	257.5	258.6	259.8	261.4
			15	270	430	640	840	1,200	1,500	2,100	254.0	254.8	255.6	256.3	257.5	258.2	259.4
			30	210	330	490	610	820	1,000	1,400	253.8	254.4	255.0	255.5	256.2	256.8	258.0
			60	160	260	370	450	560	660	820	253.5	254.0	254.4	254.9	255.3	255.7	256.2
			150	110	200	260	290	330	370	410	253.2	253.7	254.0	254.2	254.4	254.6	254.7
			274	90	160	200	220	240	250	270	253.1	253.5	253.7	253.8	253.9	254.0	254.0
			365	80	150	180	190	200	210	220	253.0	253.4	253.6	253.6	253.7	253.8	253.8
1205	Safford Brook near Woodstock Valley	4.08	0	170	310	490	640	960	1,300	1,700	557.0	557.8	558.6	559.0	560.0	560.9	561.8
			1	90	150	210	260	360	480	580	556.4	556.9	557.3	557.6	558.1	558.6	558.8
			3	48	77	110	170	220	300	400	555.8	556.2	556.6	557.0	557.4	557.8	558.3
			7	32	48	70	100	140	180	260	555.6	555.8	556.1	556.5	556.8	557.1	557.6
			15	23	34	46	61	82	100	140	555.4	555.6	555.8	556.0	556.3	556.5	556.8
			30	17	26	32	40	50	61	70	555.3	555.5	555.6	555.7	555.9	556.0	556.1
			60	14	20	23	28	33	37	40	555.2	555.4	555.4	555.5	555.6	555.7	555.7
			150	10	14	16	18	20	21	22	555.1	555.2	555.3	555.3	555.4	555.4	555.4
			274	9	12	13	14	15	15	16	555.1	555.2	555.2	555.2	555.2	555.2	555.3
			365	8	11	12	12	13	13	14	555.0	555.1	555.2	555.2	555.2	555.2	555.2
1210	Mount Hope River near Warrenville	27.8	0	460	880	1,300	1,800	2,600	3,500	4,800	340.7	342.0	343.0	343.6	344.3	344.9	345.6
			1	300	560	820	1,100	1,600	2,100	2,900	339.6	341.2	341.8	342.5	343.4	343.9	344.5
			3	200	360	520	720	1,100	1,500	2,000	338.9	340.1	341.0	341.5	342.5	343.2	343.8
			7	150	250	370	490	720	1,000	1,300	338.6	339.2	340.2	340.9	341.5	342.3	343.0
			15	110	180	270	340	480	650	860	338.3	338.8	339.4	340.0	340.9	341.3	341.9
			30	88	140	200	250	330	420	520	338.1	338.5	338.9	339.2	340.0	340.5	341.0
			60	70	110	150	180	230	270	310	338.0	338.3	338.6	338.8	339.1	339.4	339.7
			150	49	81	100	120	140	150	160	337.7	338.1	338.2	338.4	338.5	338.6	338.7
			274	40	68	80	90	100	100	110	337.6	337.9	338.1	338.1	338.2	338.2	338.3
			365	36	62	72	80	84	86	90	337.6	337.9	338.0	338.1	338.1	338.1	338.1
1220	Natchaug River at Willimantic	169	0	1,600	2,800	3,000	3,200	3,500	3,600	3,800	156.4	158.3	158.6	158.9	159.2	159.3	159.5
			1	1,200	2,300	2,900	3,000	3,300	3,400	3,600	155.6	157.6	158.5	158.6	159.0	159.1	159.3
			3	980	1,700	2,800	2,900	3,000	3,000	3,100	155.2	156.6	158.3	158.5	158.6	158.6	158.7
			7	780	1,300	2,000	2,700	2,800	2,900	3,000	154.8	155.8	157.1	158.2	158.3	158.5	158.6
			15	630	1,000	1,500	2,000	2,600	2,800	2,800	154.5	155.2	156.2	157.1	158.0	158.3	158.3
			30	500	800	1,100	1,400	1,900	2,400	2,800	154.2	154.8	155.4	156.0	157.0	157.8	158.3
			60	390	640	880	1,000	1,300	1,500	1,800	153.9	154.5	155.0	155.2	155.8	156.2	156.8
			150	280	480	620	680	800	870	980	153.6	154.1	154.5	154.6	154.8	155.0	155.2
			274	210	390	490	520	560	600	640	153.4	153.9	154.1	154.2	154.3	154.4	154.5
			365	190	350	440	460	480	500	520	153.3	153.8	154.0	154.1	154.1	154.2	154.2
1225	Shetucket River near Willimantic	401	0	3,100	7,000	8,300	9,200	12,000	16,000	22,000	138.0	141.3	142.2	142.8	144.4	146.4	149.1
			1	2,800	5,400	7,600	8,800	11,000	15,000	20,000	137.7	140.1	141.7	142.5	143.8	145.9	148.2
			3	2,300	3,900	6,000	7,800	10,000	13,000	17,000	137.1	138.8	140.5	141.9	143.3	144.9	146.9
			7	1,800	2,900	4,300	5,800	8,000	10,000	14,000	136.5	137.8	139.2	140.4	142.0	143.3	145.4
			15	1,400	2,200	3,300	4,300	6,000	7,800	10,000	136.0	137.0	138.2	139.2	140.5	141.9	143.3
			30	1,100	1,800	2,500	3,200	4,100	5,200	6,000	135.5	136.5	137.4	138.1	139.0	139.9	140.5
			60	880	1,400	2,000	2,300	2,900	3,400	3,800	135.1	136.0	136.8	137.1	137.8	138.3	138.7
			150	620	1,000	1,400	1,600	1,800	1,900	2,000	134.6	135.3	136.0	136.3	136.5	136.6	136.8
			274	500	850	1,100	1,200	1,300	1,400	1,400	134.4	135.1	135.5	135.7	135.8	136.0	136.0
			365	450	780	980	1,100	1,100	1,200	1,200	134.3	135.0	135.3	135.5	135.5	135.7	135.7
1230	Little River near Hanover	29.1	0	360	720	1,100	1,500	2,200	3,000	4,000	224.8	226.0	226.9	227.7	228.9	230.1	231.2
			1	340	660	1,000	1,300	1,900	2,600	3,500	224.7	225.8	226.7	227.4	228.4	229.5	230.7
			3	230	420	640	860	1,300	1,700	2,500	224.2	225.0	225.8	226.3	227.4	228.1	229.4
			7	170	300	450	590	880	1,200	1,600	223.9	224.6	225.2	225.6	226.4	227.2	227.9
			15	130	220	330	410	570	760	1,000	223.7	224.2	224.7	225.0	225.6	226.1	226.7
			30	100	160	240	300	390	490	620	223.4	223.8	224.3	224.6	224.9	225.3	225.7
			60	78	130	180	210	260	310	370	223.2	223.7	224.0	224.2	224.4	224.6	224.8
			150	56	95	120	140	150	170	190	223.0	223.4	223.6	223.7	223.8	223.9	224.0
			274	45	79	96	100	110	120	130	222.9	223.2	223.4	223.4	223.5	223.6	223.7
			365	41	72	86	88	92	98	100	222.9	223.2	223.3	223.3	223.4	223.4	223.4

Table 20.--Summary of chemical analyses of samples representing natural conditions of low flow equaled or exceeded more than 92 percent of the time. 1/

(Chemical constituents, in parts per million)

Constituent or property	Range	Average	Upper limit in drinking water recommended by U.S. Public Health Service (1962)
Iron (Fe)	0.01 - 0.92	0.21	0.3
Manganese (Mn)	.00 - .52	.08	.05
Calcium (Ca)	3.2 - 8.8	6.5	--
Magnesium (Mg)	.7 - 3.2	2.0	--
Sodium (Na)	2.9 - 9.9	5.1	--
Potassium (K)	.4 - 2.1	1.3	--
Bicarbonate (HCO_3)	8 - 34	21	--
Sulfate (SO_4)	4.4 - 16	8.9	250
Chloride (Cl)	3.1 - 17	7.4	250
Nitrate (NO_3)	.2 - 2.1	.9	45
Dissolved solids (residue on evaporation at 180°C)	27 - 61	44	500
Hardness as $CaCO_3$	14 - 32	24	--
Noncarbonate hardness as $CaCO_3$	2 - 13	7	--
Specific conductance (micromhos at 25°C)	46 - 102	79	--
pH	5.6 - 7.4	--	--
Color 2/	2 - 30	8	15

1/ One sample from each of 32 sites.
2/ For 25 sites; expressed in color units.

When streamflow is high the concentration of dissolved minerals is low, for it represents chiefly the quality of the preceding precipitation modified slightly by materials on the land surface and mixed with the relatively small amount of ground-water runoff already in the stream channels.

The chemical quality of streamflows in the Shetucket River basin when natural flows are low is excellent as shown by the chemical analyses of samples of stream water collected at 32 sites as shown on plate A. These samples are representative of waters relatively unaffected by man's activities. The analyses are summarized in table 20 from data presented in the companion basic data report by C. E. Thomas, Jr. and others, (1967). The excellence of the chemical quality of these samples of stream water is emphasized by the contrast between the maximum amounts of dissolved mineral constituents of samples listed in table 20 and upper limits for the same constituents recommended by the U.S. Public Health Service (1962) for drinking water.

The most common constituents in naturally occurring water in streams in the basin are those listed in table 20: calcium, sodium, bicarbonate, sulfate, and chloride comprised an average of about 87 percent of the total dissolved solids in the 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 average hardness shown in table 20 is 24 ppm. Water with a hardness of less than 60 ppm is considered soft. Hardness of water is caused mainly by the presence of calcium and magnesium, and the concentration of these two constituents in natural surface water in the basin is low even at low flow. In addition to being soft, waters that contain few dissolved minerals are generally low in alkalinity. This together with the presence of dissolved carbon dioxide and organic acids, results in the slightly acidic waters which are found in the basin. Water of this type may be corrosive to some metals but this condition is easily remedied by the addition of lime.

Water-quality characteristics of streams are generally improved by impoundment in lakes, ponds, and reservoirs. Storage of water modifies the wide fluctuations in water quality which are characteristic of streams. Turbidity, sediments, suspended solids, and bacterial concentrations are reduced, and the bleaching action of sunlight reduces the color of impounded water.

Chemical quality of samples from many of the lakes, ponds, and reservoirs in the basin are included in the companion basic data report by C. E. Thomas, Jr. and others (1967). The chemical quality of these bodies of water is excellent and most are unaffected by man's activities. The dissolved mineral concentration is generally less than 70 ppm, the hardness less than 60 ppm, and the waters are slightly acidic.

The relationship of pH, dissolved oxygen

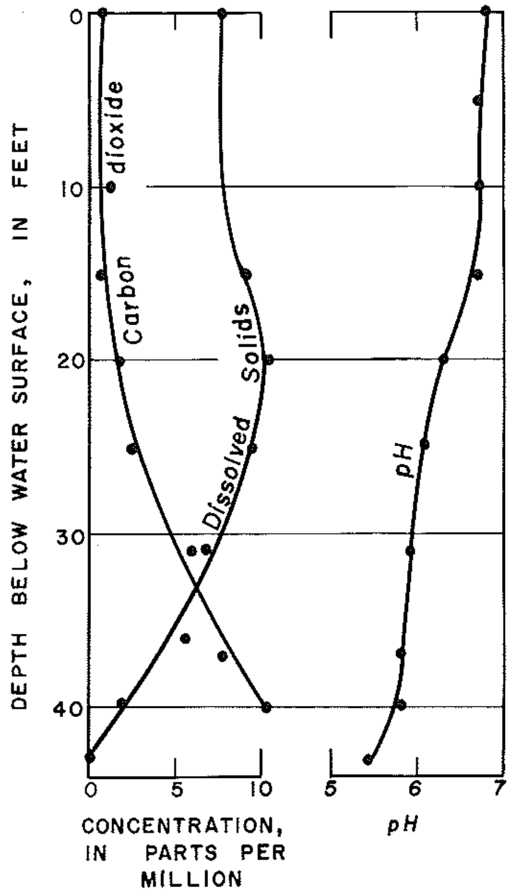


Figure 28.--Carbon dioxide, dissolved oxygen, and pH gradients in Crystal Lake.

In July 1955, during summer stagnation, dissolved oxygen at the lower depths was too low to support fish or aquatic life. (From Connecticut Board of Fisheries and Game)

content, and carbon dioxide content with depth of the water in Crystal Lake from its surface to a depth of 43 feet is shown in figure 28. The gradients of dissolved oxygen and carbon dioxide in unmixed standing bodies of water like Crystal Lake are largely determined by diffusion of atmospheric air at the surface, photosynthesis by biota in regions of light penetration, respiration of plants and animals, and carbon dioxide given off by decaying matter in the lower depths. These lakes and ponds are thermally stratified except for a brief period in the spring and fall when temperature changes cause a complete turnover of the water with vertical mixing and resultant deterioration in quality.

IRON AND COLOR

Iron makes up only a small fraction of the dissolved solids in stream waters in the Shetucket 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 uses, and it should be less than 0.2 ppm for many industrial uses. Iron in surface waters is derived either directly from minerals of rocks and soils in the basin or indirectly from decaying vegetation that has assimilated iron from the soils. The concentration of iron in streams varies inversely with the amount of streamflow and is generally highest from May through October and lowest from December through April.

Streams draining swamps usually contain water with a high iron concentration. Its source is the decaying vegetation in the swamp. All growing aquatic plants require a continuous supply of iron and extract it from water or soil. After their growing season, the decay of the vegetation releases dissolved iron to the swamp water. During succeeding summer months, when swamp waters are concentrated, the flow of streams draining swamps is low. The largest quantity of organic matter and iron from swamps enters streams during periods of heavy rainfall when swamps are flushed out, though the concentration of iron then is considerably reduced by dilution.

About 40 percent of the 32 samples used for table 20 for streams essentially unaffected by man had water containing more than 0.2 ppm at low flow and about 20 percent were more than 0.3 ppm. All water samples collected during low streamflow show, in general, that streams in the lower half of the basin have lower iron concentrations than streams in the upper half of the basin. Most streams in the upper half of the basin drain an area underlain by the Brimfield schists which are relatively abundant in iron bearing minerals.

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 concentration of iron does not necessarily correlate with the degree of organic color. Color decreases during periods of high streamflow as does the concentration of dissolved solids. Measured color in one of the 25 samples of water from natural streams in the basin at low flow, which are summarized in table 20, was as high as 30, and the average of all samples was 8, about half the upper limit of 15 recommended by the U.S. Public Health Service (1962) for drinking water. Color in water is expressed in terms of units between 0 and 500 or more based upon a standard scale (Hem, 1959, p. 49). Color as high as 200 has been observed in natural streams elsewhere in Connecticut.

CONDITIONS RESULTING FROM THE ACTIVITIES OF MAN

Man uses water for various domestic and industrial needs. During its use the quality of the water is almost always changed, and after use contains more dissolved minerals and is warmer than in its original state. All the major streams in the basin and a few of the smaller streams receive varying amounts of waste materials. Industrial wastes discharged into the streams of the Shetucket River basin include cyanides, copper, nickel, chromium, bleaches, dyes, soap, and acids and alkalis. Organic wastes, including sugar, starch, pulp fibers, blood, feathers, grease, and

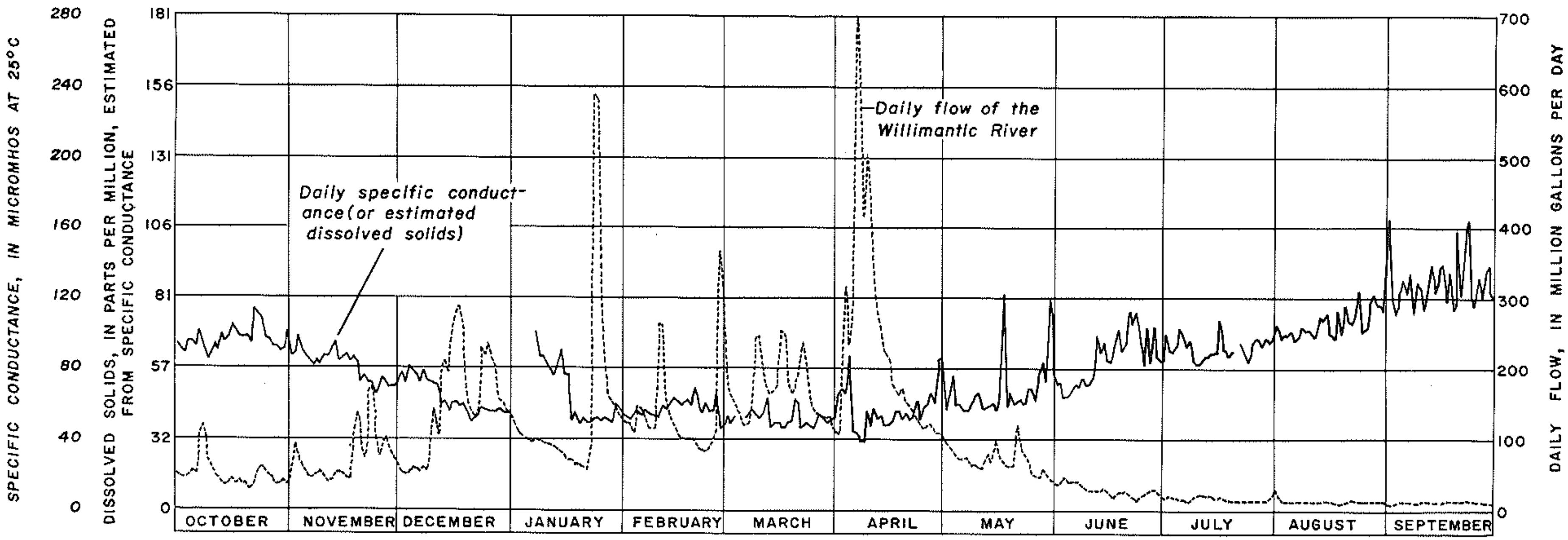


Figure 29.--Dissolved solids, as estimated from specific conductance, and daily mean discharge, Willimantic River near South Coventry, 1956-57.

The dissolved solids concentration of water in the Willimantic River near South Coventry varies inversely with rate of flow. An irregular increase in flow from October 1956 through April 1957 was accompanied by a decrease in dissolved solids concentration, but as flow declined from May to September 1957 dissolved solids increased once more. Analysis of 30 water samples showed that for this year dissolved solids concentration was approximately equal to 0.62 times specific conductance plus 7.

domestic sewage are also present. The principal objectionable pollutants in the streams are iron, detergents, dyes, pulp and paper wastes, and salts of metals from electro-plating operations; 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, or can cause toxicity to animals and aquatic life.

Chemical analyses of surface-water samples collected during this investigation are given in the companion basic data report by C. E. Thomas, Jr. and others (1967), and continuous records are published in a series of U.S. Geological Survey Water-Supply Papers entitled "Quality of Surface Waters of the United States."

The variation of chemical quality of water in streamflow at a point in the Shetucket River near Willimantic is illustrated in figure 29, which is a graph of daily mean discharge and a daily specific conductance measurement for the period October 1, 1956 to September 30, 1957. (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 concentration during periods of low streamflow, particularly during August and September, 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 the wastes, daily fluctuations in dissolved-solids concentration were relatively small.

A continuous record of specific conductance of the Shetucket River near Willimantic (station no. 1195) during the summer of 1963 shows that the dissolved-solids concentration is about the same as in 1957 at comparable streamflows. The continuous record also shows that the dissolved-solids concentration may fluctuate widely during the course of a day. Therefore, in most cases, single daily samples do not reflect average conditions, and the concentrations of such samples may in fact differ widely from the daily mean concentration at lower streamflows. Nonetheless, in the summer of 1963, during the course of each day, the dissolved-solids concentration generally stayed within certain limits defined by daily mean stream discharge, as shown in the following table.

On most days when the daily mean discharge was	The range between the maximum and minimum dissolved-solids concentration was between
less than 65 mgd	6 and 30 ppm
from 65 to 130 mgd	3 and 12 ppm
from 131 to 195 mgd	2 and 6 ppm

Daily iron concentrations in the Willimantic River near South Coventry and the Shetucket River near Willimantic, shown in figure 30, range widely but generally have the same relationship with streamflow as do total dissolved solids. Because iron concentration probably varies in proportion to total dissolved-solids concentration, large fluctuations may be expected during the course of a day, and single daily samples may differ widely from daily average conditions.

The maximum iron concentration in daily samples taken during the 1957 water year from the Willimantic River was 1.0 ppm and from the Shetucket River was 0.70 ppm. The mean daily iron concentration of the water of the Willimantic River for 1957 was 0.32 ppm and of the Shetucket River 0.26 ppm. Since the Natchaug River normally contributes 43 percent of the flow to the Shetucket River, the slightly lower average iron concentration of the Shetucket River suggests that the average iron concentration of the Natchaug River at Willimantic may be as low as 0.20 ppm. However, an iron concentration as high as 0.69 ppm has been observed at this point.

For the most part, the chemical quality of the water of the Shetucket River leaving the basin is practically the same as that of the water of other major streams throughout the basin, as is shown in figure 31. With the exception of one water sample, the dissolved-solids concentration of samples collected during April, July and September 1963 was below 100 ppm and the hardness of water was classified as soft. The exceptional sample was taken from the Little River near Versailles (station no. 1230.6) September 12, 1963, and had a dissolved-solids concentration of 212 ppm. Although the chemical quality of water in Little River at this location is considerably affected by industrial wastes, the dissolved-solids concentration is still comparatively low. However, this concentration was enough to affect the quality of water in the Shetucket River between Willimantic and Taftville on September 12, 1963, as is shown in figure 31. The water of Little River had a dissolved-solids concentration of 212 ppm for a flow of 30 cfs. The water of the Shetucket River had a dissolved-solids concentration of 82 ppm for a flow of 210 cfs. Little River was contributing 35 percent of the dissolved solids and only 14 percent of the flow to the Shetucket River at that time.

The generally low dissolved-solids concentration in streams throughout the Shetucket River basin, even at low flows, is illustrated in figure 32. The color patterns are based upon the chemical analyses of surface-water samples collected during periods of low flow between 1953 and 1963 and field specific-conductance measurements of surface waters at over 100 selected sites throughout the basin made August 7-9, 1963. The maximum dissolved-solids concentration at all points in the basin is markedly less than the 500 ppm suggested by the U.S. Public Health Service for potable water supplies. However, Masselli and others (1963) found that streams which receive white-water wastes from paper and paperboard production during drought conditions may, at times, contain dissolved solids in excess of 500 ppm. This condition might occur in Little River along its lower reaches.

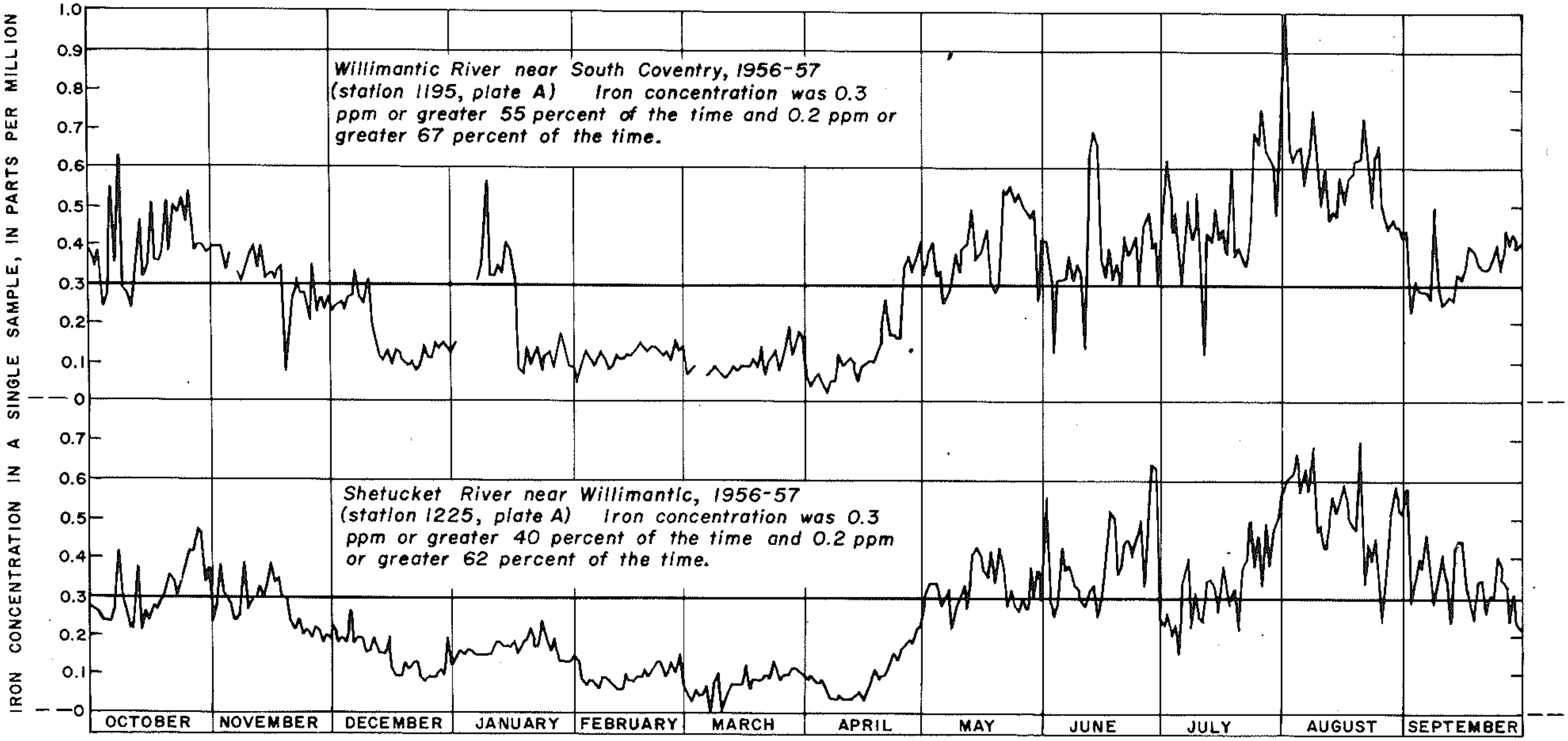


Figure 30.--Daily iron concentrations in the Willimantic River near South Coventry and the Shetucket River near Willimantic, 1956-57.

Iron concentrations are highly variable from day to day, but in general are greatest during the period of low streamflow from May through October (After Pauszek, 1961, p. 60).

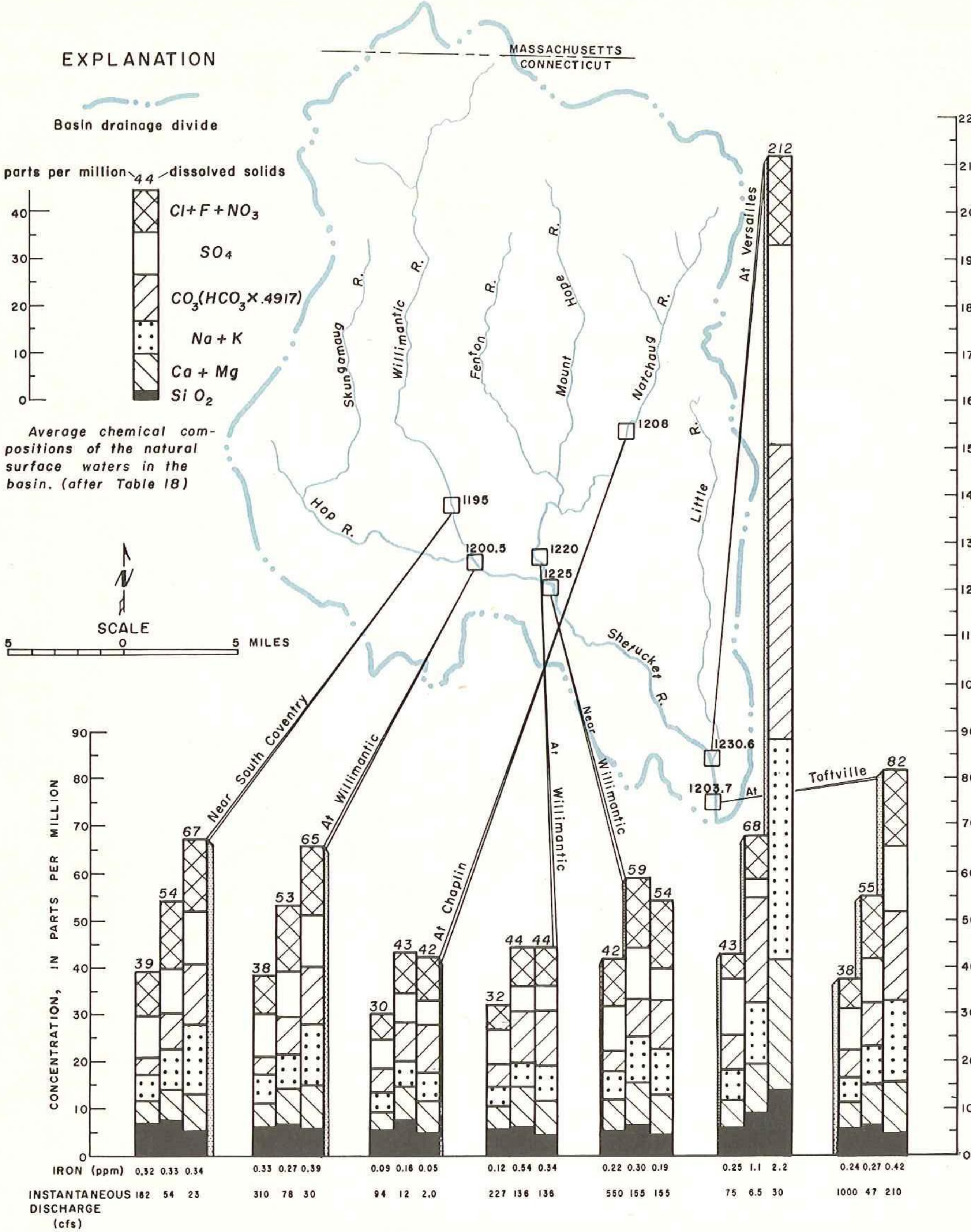


Figure 31.--Variations in composition of dissolved solids at several sites on streams in the Shetucket River basin during April, July, and September 1963.

At high flows, the chemical composition and concentration of surface waters is similar to that of natural waters illustrated in the legend. As flows decrease, the chemical composition and concentration increase as a result of an increase in the proportion of ground-water discharge, and the addition of domestic and industrial wastes.

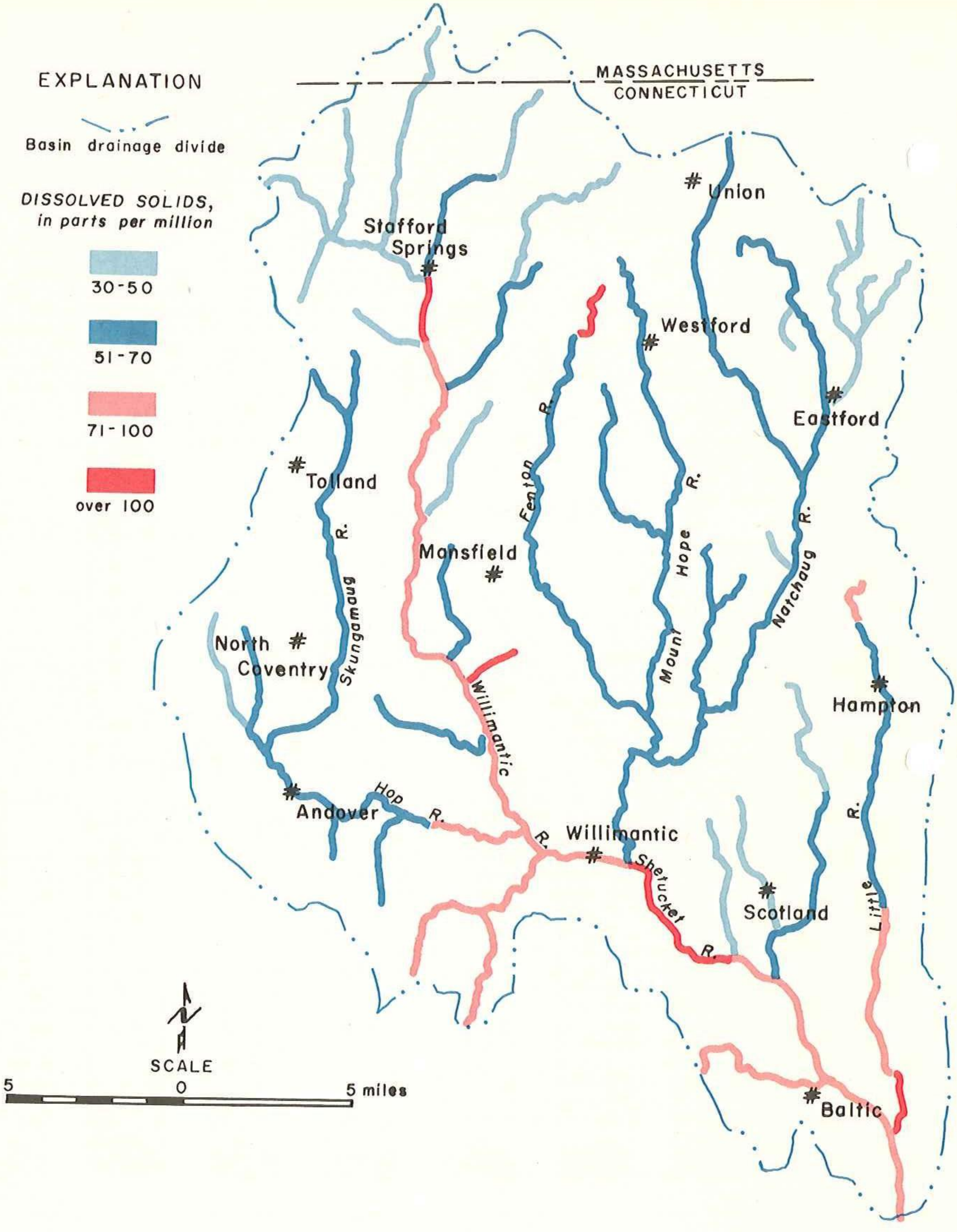


Figure 32.--Maximum concentration of dissolved solids to be expected in streams in the Shetucket River basin during periods of low flow.

Most streams in the basin, except those flowing through populated or industrialized areas, have a low dissolved-solids content and are of excellent quality.

Table 21.--Comparison of the chemical quality of Ash Brook at stream-gaging station near North Coventry under different flow conditions.

	Unit	Date		
		Sept. 10, 1963	Apr. 8, 1964	Apr. 15, 1964
Instantaneous flow	cfs	0.02	16.5	101
Precipitation[a/]	in.	.00	[b/]1.24	1.44
Sulfate (SO_4)	ppm	14	42	34
Specific conductance	[c/]	101	221	147
Dissolved solids (calculated)	ppm	61	133	88
pH		6.5	3.6	3.85

a/ Rainfall reported at U.S. Weather Bureau station at Coventry (No. 2P).

b/ Total for April 7 and 8.

c/ Micromhos at 25°C.

Overland runoff from heavily fertilized fields may cause a marked effect on the chemical quality of smaller streams. Records collected during the period December 12-17, 1963 indicate that the concentration of dissolved solids at the gaging station on Ash Brook near North Coventry increased when streamflow increased. This relationship is contrary to what usually occurs for streams with natural flow. Results of chemical analyses of samples at low, medium, and high flows are shown in table 21. At medium and high flows, samples largely composed of rainfall and surface runoff showed a marked increase in dissolved solids and a significantly lower pH value. The sample collected at low flow, largely composed of ground-water runoff, has a chemical quality that can be expected in streams in the basin. Further investigation revealed that this increase in acidity of the stream and corresponding increase in concentration of dissolved solids at medium and high flows resulted from surface runoff from a field upstream on a small tributary which had been heavily fertilized with a superphosphate fertilizer.

The quality of the water in certain reaches of the Willimantic River, Little River, and Shetucket River is at times adversely affected by inflow of municipal and industrial wastes during periods of low streamflow. In 1965, sewage treatment facilities were in operation at the municipalities of Willimantic and Stafford Springs, the University of Connecticut, and the Mansfield State Training School. Each facility discharges into the Willimantic River. The elimination of individual sources of sewage discharge, the treatment of community sources, the improvement of existing sewage treatment facilities, and the control of industrial pollution is part of a continuing program of the State Water Resources Commission. At present, streams in the Shetucket River basin are not classified; however, the Commission can provide current information on the extent and effect of existing pollution.

Chemical quality determinations were made from a series of samples collected along the Willimantic-Shetucket River system between West Stafford and Willimantic. Samples were taken at high flow (about 10-percent flow duration) and at low flow (above 85-percent flow duration). The chemical composition and properties of the water samples collected at most of these sites at high flow appear to be good except for a relatively high average iron content of 0.27 ppm and low median pH value of 5.7. The dissolved-mineral content of water samples collected during low flow is similar to that expected under natural conditions; the average iron content was 0.70 ppm and the median pH value was 6.6. Complete data from these samples are included in the companion basic data report by C. E. Thomas, Jr. and others (1967).

One sample from the Willimantic River at Merrow had an unusually low pH value of 4.3 and a relatively large copper content of 0.42 ppm, probably the result of waste effluents from electroplating processes. Although 0.42 ppm of copper is not considered toxic, significant quantities of other electro-plating chemicals such as cyanides, cadmium, zinc, and silver, if present in combination with this large amount of copper, might be toxic to animal and aquatic life.

Streams under natural conditions are able to decompose organic material in sewage through the chemical and biological activity of bacteria and aquatic life. The rate of decomposition depends upon the degree of activity of the organisms as they feed upon and digest the organic material present. Their activity is controlled by several factors, such as the rate of settling, the amount of sunlight, the temperature, and particularly the dissolved-oxygen supply which must be adequate at all times for the bacteria and aquatic life to survive. Though the dissolved-mineral content of the Willimantic River at low flow did not differ widely from natural conditions, organic wastes from sewage effluents noticeably lowered its dissolved-oxygen reserve to a point that is not conducive to the propagation of aquatic life. The dissolved-oxygen content was near 100-percent saturation from Stafford Springs to Willimantic at high flow, as shown in figure 33. At low flow, the dissolved oxygen content in the stream was at a 22-percent saturation level as a result of sewage effluents from Stafford Springs. Not until the water in the river travels about 5 miles downstream to West Willington did the dissolved-oxygen content recover to 59-percent saturation at 68°F or 5 ppm. Reaeration continued for the next 5 miles until the water reached Merrow and then gradually decreased to slightly over 70-percent saturation at Willimantic. If no additional sewage had been released into the Willimantic River near the Mansfield Training School and at Eagle-

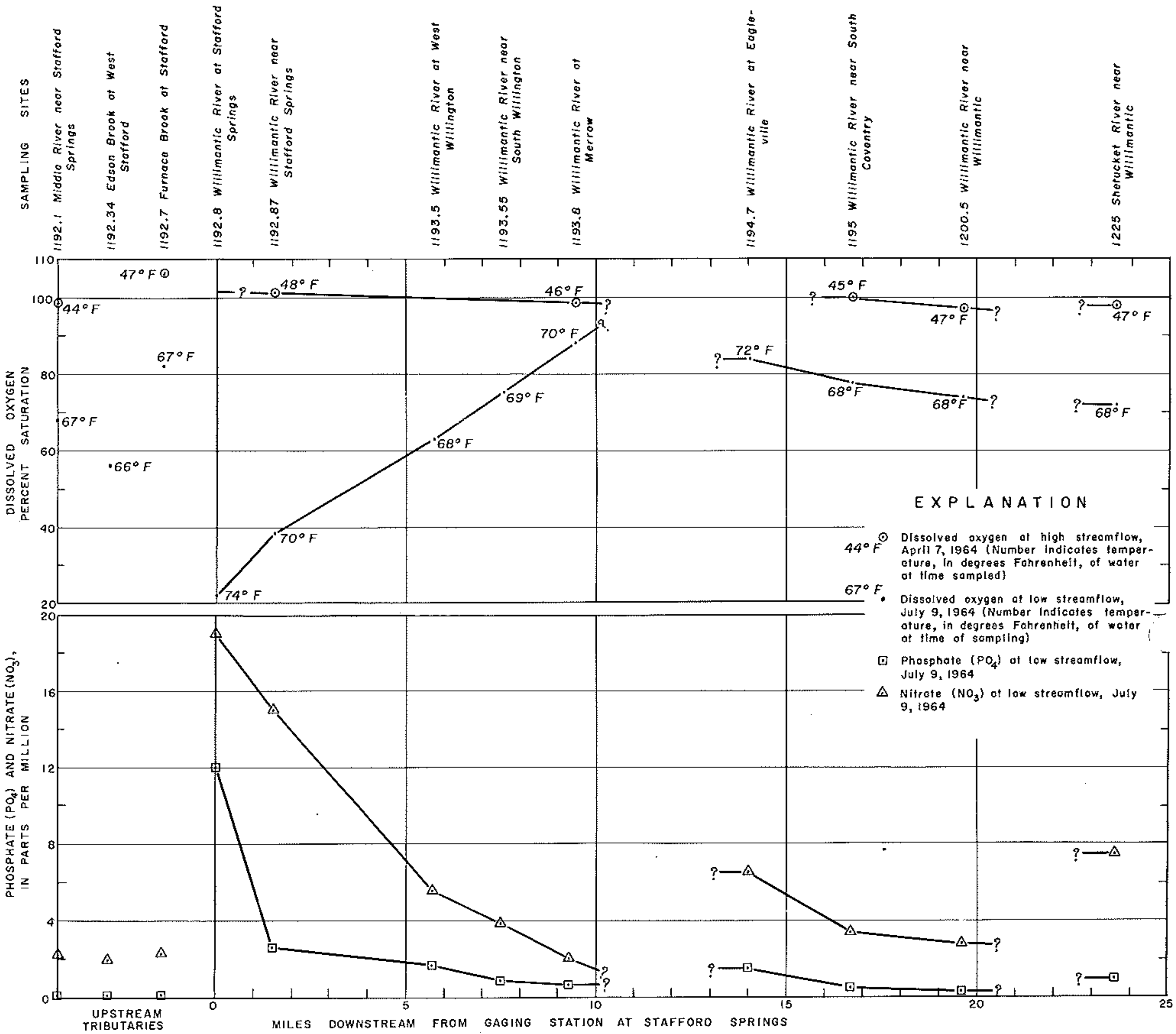


Figure 33.--Profile of concentration of dissolved oxygen, nitrate and phosphate in the Willimantic River between Stafford Springs and Willimantic, July 9, 1964.

Inadequate treatment of sewage and industrial waste causes a deterioration in water quality at low flows. Current plans of the Connecticut Water Resources Commission for adequate treatment will improve the stream quality here.

Table 22.--Analyses of suspended sediment at long-term stream-gaging stations in the Shetucket River basin.

Index no. (Pl.A)	Stream and place of measurement	Date	Instantaneous flow (cfs)	Percent of time flow is equaled or exceeded	Sediment measured	
					Concentration (ppm)	Load (tons/day) 1/
1200	Hop River near Columbia	3-19-64	161	24	3	1.3
		4- 8-64	385	5	4	4.2
1210	Mount Hope River near Warrenville	4- 8-64	149	6	5	2.0
1220	Natchaug River at Willimantic	3-19-64	426	22	14	16
		4- 8-64	915	5	10	25
1225	Shetucket River near Willimantic	3-19-64	980	26	2	5.3
		4- 7-64	2,080	5	9	50
		4- 9-64	2,560	3	8	55
1230	Little River near Hanover	3-19-64	66	26	7	1.2
		4- 8-64	171	4	8	3.7

1/ The tons of suspended sediment that would have been carried past each station during one day if the discharges and concentrations shown had remained the same throughout the day.

ville Brook from the University of Connecticut, the dissolved-oxygen content would probably have continued above the 80-percent saturation level. At low flow the temperature of the river water increased as a result of the inflow of sewage at Stafford Springs but returned to normal after the water had traveled about 3 miles downstream, as shown in figure 33.

Sewage contains relatively large quantities of nitrates (NO_3) and phosphates (PO_4). The phosphate and nitrate contents of water collected along the Willimantic River at a time of low streamflow decreased downstream as the dissolved oxygen increased. The most rapid decrease occurred while anaerobic bacteria were oxidizing organic substances by removing oxygen from inorganic compounds, such as nitrates, phosphates, and sulfates. The anaerobic decomposition of sulfate produces an offensive odor from hydrogen sulfide and the deterioration of a stream can readily be detected by the odors arising from it.

The presence of sewage in streams may be indicated by small amounts of detergents which cause white foam to develop on the surface of water in streams, particularly below mill dams or rapids. This foam rapidly disappears in the quiet waters below. Other factors, such as high concentrations of organic matter from sewage or from natural sources, may contribute to the foam.

Water samples collected from streams in the basin contained from 0 to 0.5 ppm of ABS (alkyl benzene sulfonate), a principal constituent of hard detergents. The upper limit for ABS concentration in drinking water is 0.5 ppm as recommended by the U.S. Public Health Service. Since July 1965 a new detergent material LAS (linear alkylate sulfonate), a principal constituent of soft detergents, has been gradually replacing ABS. Detergent residues of LAS are more readily biodegradable than those of ABS and can be reduced, but not eliminated, by secondary sewage treatment (Wayman, 1965).

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. More sediment is present at high flows than at low flows. Even at high flow the amount of suspended sediment in streams in the Shetucket River basin is quite low, as shown in table 22 by the results of analyses of samples from 5 streams. Sediment in streams is not a serious problem because even the less 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.

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, or in sewage or wastes. Turbid water 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 in the basin is generally not potentially troublesome except in the local area below Versailles on the Little River, where a sample was found to contain 40 ppm. High turbidity in this stream would have an appreciable effect on the quality of the Shetucket River into which it flows.

Table 23.--Variation in water temperature in the Willimantic River and Shetucket River during water year 1956-57 based on one measurement each day.

Index no. (Pl.A)	Stream and place of measurement	Minimum water temperature observed (°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 observed (°F)
1195	Willimantic River near South Coventry	32	32	38	52	65	72	77
1225	Shetucket River near Willimantic	32	33	38	55	70	78	81

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 air temperature. Freezing-point temperature is reached in most streams during the winter months, at least for brief periods. Maximum temperatures commonly occur in July or August. These conditions are reflected in the average temperature of the water in the Shetucket River at the gaging station near Willimantic for each month from October 1956 through September 1957 as appears in figure 34; monthly average temperatures at other locations on large streams in the basin would be very similar. Except when the water surface is frozen, diurnal temperature fluctuations occur, and these follow similar changes in air temperature. Daily average water temperature in the larger streams is more commonly above than below daily average air temperature during all seasons of the year.

River-water temperature was measured once daily during the water year 1956-57 at the gaging stations on the Willimantic River near South Coventry and the Shetucket River near Willimantic.

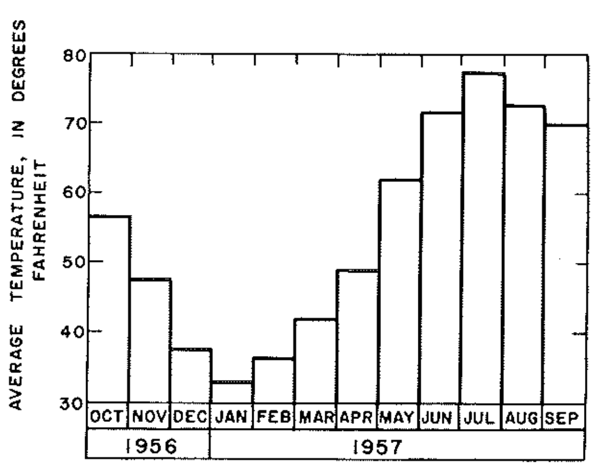


Figure 34.--Monthly average water temperature of the Shetucket River near Willimantic, 1956-57.

Water temperature of streams is directly influenced by air temperature. In January it is close to the freezing point and during the summer months it is about 70°F.

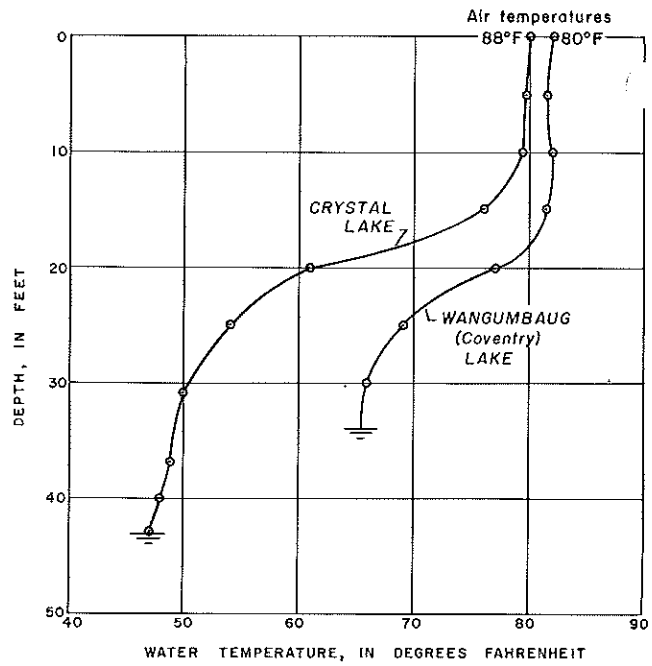


Figure 35.--Temperature gradients in Crystal Lake and Wangumbaug (Coventry) Lake.

In July 1955, during summer stagnation, high air temperatures warmed the water in the upper part of the lakes while the water in their lower depths was largely unaffected, causing stratification. (From Connecticut Board of Fisheries and Game).

Monthly average temperatures based on these readings are shown in figure 34, and table 23 shows the maximum and minimum temperatures observed during the year and the temperature duration of the river water at these locations.

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, daily temperature fluctuations and the annual range in monthly average temperatures are probably somewhat less in small streams than in the major rivers.

In bodies of quiet water, including lakes and natural pools along river channels, thermal gradients may exist between top and bottom, and bottom temperatures may depart considerably from air temperatures. Examples of the vertical temperature gradients in Crystal Lake and Wangumbaug (Coventry) Lake, which occurred during July 1955 are shown in figure 35. These gradients reflect heating of the surface water during the day and accumulation of cool ground-water inflow near the bottom. In pools of 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 Board of Fisheries and Game (1959) reports that portions of Bigelow Pond, Black Pond, Crystal Lake, Crystal Pond, and Wangumbaug (Coventry) Lake are thermally stratified.

WATER IN AQUIFERS

Water occurs beneath the land surface almost everywhere in the Shetucket River basin. However, the amount of water that may be pumped from the ground by wells varies greatly from place to place, and depends on both the water-bearing properties of the aquifers and the amount of water available. For example, the yield of an individual well, properly constructed, depends chiefly on the permeability and thickness of the aquifer it taps, because these properties determine the amount of water that the aquifer can transmit. On the other hand, the amount of water that can be pumped from aquifers on a regional and long-term basis depends in addition upon the amount of water available to be transmitted--that is, the amount of water from precipitation which infiltrates intermittently to the aquifers, the amount which can be induced to infiltrate from streams and lakes, and the amount stored in the aquifers. The water-bearing properties of aquifers and the sources and amounts of water available which are described in this section must be understood to insure sound development and management of ground-water supplies in the basin.

WATER-BEARING PROPERTIES OF AQUIFERS

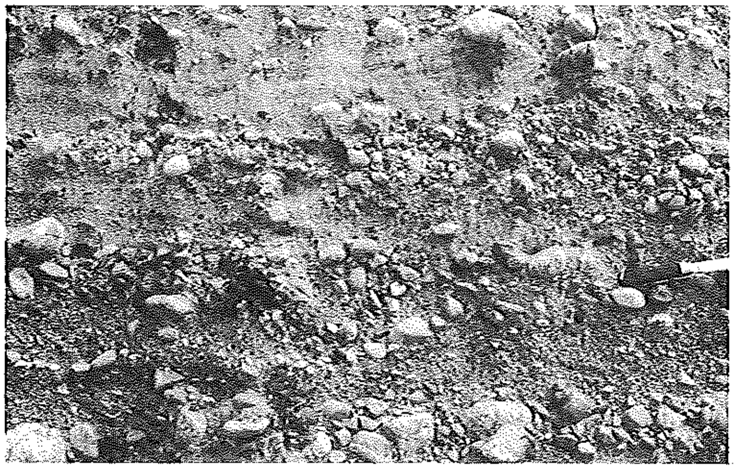
Wells in the basin obtain water from three aquifers--unconsolidated granular deposits of stratified drift, unconsolidated granular deposits of till, and fractured bedrock. Exposures of typical materials making up each aquifer are pictured in figure 36. Each aquifer has characteristic physical features and water-bearing properties which determine the amount of water that it can transmit and yield to wells.

Permeability is a direct quantitative expression of the water-transmitting ability of a unit of earth materials. The permeability of a deposit depends upon the size and degree of interconnection of the openings in it. These openings in the bedrock aquifer consist of extremely small pores between the crystals of the nearly solid rock, and, more importantly, fractures which cut the rock. Solid rock is practically impermeable, and even fractured bedrock has a relatively low permeability. The openings in the unconsolidated granular aquifers consist of pores between the grains that compose the deposit. Average grain size and sorting are good indices of the size and degree of interconnection of these pore spaces. Deposits which are coarse grained (gravel) have larger pores and thus higher permeabilities than those which are fine grained (silt and fine sand) or poorly sorted (till). Permeability values of materials in the basin range in amount from a minute fraction of a gallon per day for unfractured bedrock, to many thousands of gallons per day for some gravels.

The thickness of the water-bearing materials, or saturated thickness, as well as permeability, affects the yield of an aquifer. The product of average permeability and saturated thickness, called transmissibility, is a measure of the amount of water which will flow through the entire thickness of an aquifer in a section one foot wide. Transmissibility is a useful measure for comparing deposits of differing permeabilities and saturated thicknesses; even materials with low permeability can transmit substantial quantities of water if the cross section is sufficiently large.

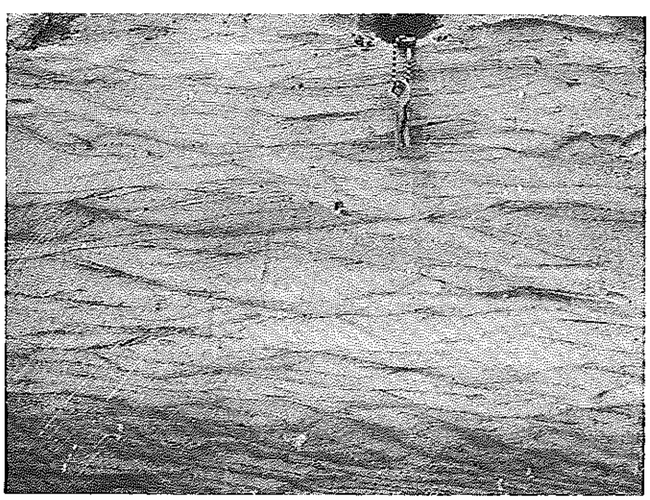
STRATIFIED DRIFT

Stratified drift is the most productive aquifer in the Shetucket River basin. It is the only aquifer capable of yielding 100 gpm (gallons per minute) or more to individual wells. Stratified drift in the basin consists of strata, or layers, of silt, sand, and gravel which were deposited by meltwaters from the glacial ice that covered

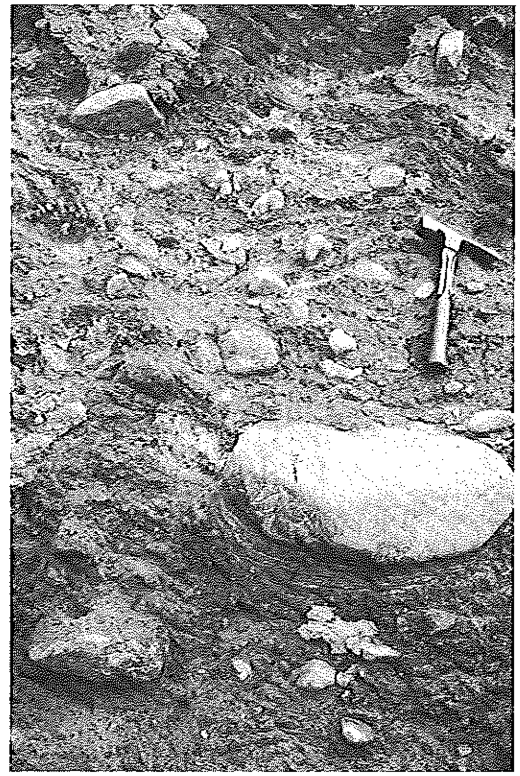


A. Stratified drift (coarse-grained, gravel)

B. Stratified drift (coarse-grained, sand)



C. Stratified drift (fine-grained)



D. Till

E. Fractured bedrock

Figure 36.--Aquifers in the Shetucket River basin.

Stratified drift, till, and fractured crystalline bedrock form the only aquifers in the basin.

all of Connecticut during the last stages of the "Ice Age." Although widely distributed throughout the area, stratified drift covers only about 18 percent of the area of the basin. It occurs chiefly in valleys, because these areas served as the major routes for the discharge of glacial meltwaters.

The extent of stratified drift at the land surface is indicated on plate B. The placement of the contact between till and stratified drift is based on surficial mapping techniques and is on the whole accurate. However, some areas, such as the major river valleys, were mapped in greater detail than others.

The average grain size of stratified drift varies widely from place to place, and thus even this aquifer is not everywhere suitable for obtaining large well yields. For this reason, the aquifer is subdivided into a coarse-grained unit and a fine-grained unit. This subdivision is based on the texture of the deposits in the saturated section. The extent of each unit was determined largely from logs and cuttings of wells and test borings, as well as from interpretations of landforms and the subsurface extent of surficial exposures. Consequently, the boundary between the fine-grained unit and coarse-grained unit is in most places only approximate.

Coarse-grained stratified drift deposits, like those shown in figure 36A, are the principal deposits in the valleys of most of the major rivers tributary to the Shetucket River, as well as segments of the Shetucket River valley itself. Areas indicated as coarse grained on plate B are those where medium sand to gravel predominate in the saturated section. Most of these deposits were laid down by rushing meltwater streams or in small ponds beside and atop masses of melting ice. Consequently, they are in most places quite heterogeneous and commonly exhibit abrupt changes in average grain size and sorting. Some sections, however, consist of relatively uniform medium-to-coarse sand similar to that shown in figure 36B, and some areas mapped as coarse grained include numerous beds of fine-grained deposits like those shown in figure 36C. Nevertheless, at most sites mapped as coarse grained, there are coarse deposits in the saturated section that are capable of transmitting a substantial amount of water.

Fine-grained stratified drift deposits occur in isolated patches throughout the basin and are extensive in the Hop River valley, in the northern half of the Little River valley, and in the Willimantic area, particularly northeast and southeast of the city. Areas indicated as fine grained on plate B are those where silt to fine sand predominate in the saturated section. Most of these deposits were laid down as deltas, bottom sediments, or flood-plain deposits in the relatively quiet waters of shallow lakes or sluggish streams that existed for a while after most of the nearby ice had melted. These deposits are generally well sorted, but their fine texture limits their water-transmitting capacity and is a hindrance to the construction of screened wells.

The fine-grained deposits are almost everywhere capped by gravel, and in many places they grade upward from silty very fine sand at the base of the section to medium to coarse sand beneath the cap, as is shown diagrammatically in figure 37. Such areas were mapped as fine grained, because the gravel cap and much of the underlying medium to coarse sand are in most places above the water table. Even in areas where these coarse-grained deposits are in part saturated, the deposits were mapped as fine grained if the saturated section includes a substantial thickness of underlying fine-grained deposits.

Coarse-grained deposits occur at the base of the saturated section of stratified drift in parts of many areas mapped as fine grained, as illustrated in figure 37. In such areas there are many feet of sediment too fine to yield water to screened wells, but the underlying coarse deposits can be an important source of supply. Individual sites where this sequence is known to exist are shown on plate B. These buried coarse-grained deposits may be widespread near the valley-wall margins of the fine-grained unit, especially where bounded by the coarse-grained unit. Where present they are an important aquifer, although they are thin in some places and the fine texture of the overlying deposits may limit recharge.

PERMEABILITY

Descriptions of the distribution and lithology of the stratified drift aquifer may be used qualitatively in conjunction with the geohydrologic map, plate B, to determine the relative favorability of different areas for obtaining a desired well yield. More quantitative estimates of anticipated well yields in different areas can be made by using values of the permeability and saturated thickness of stratified drift.

Laboratory measurements of permeability and particle-size distribution of 18 samples of stratified drift in the Shetucket and Quinebaug River basins indicate that permeability increases with increasing median grain size and degree of sorting. These relationships are illustrated by the three parallel lines in figure 38. The position of each line depends upon the degree of sorting of the samples used to define it. Those with poor sorting (high uniformity coefficients) plot above those with good sorting (low uniformity coefficients).

The position and slope of the top and bottom lines are well defined by the plotted points. The position and slope of the middle line were estimated by comparing the Connecticut data with those of other studies in which similar relationships between permeability and grain size were established (Rose and Smith, 1957, and Bedinger and others, 1960). The data from these studies plot as straight lines parallel to the Connecticut lines.

The Connecticut analyses were made on undisturbed, horizontally oriented samples of stratified drift in the two basins. The bottom line in figure 38 is considered representative of the permeability-median grain size relationship of very fine sand to coarse sand which is very well sorted. However, most sand sections in the basin are made up of individual sand layers with differing grain sizes, and although the individual layers are, like

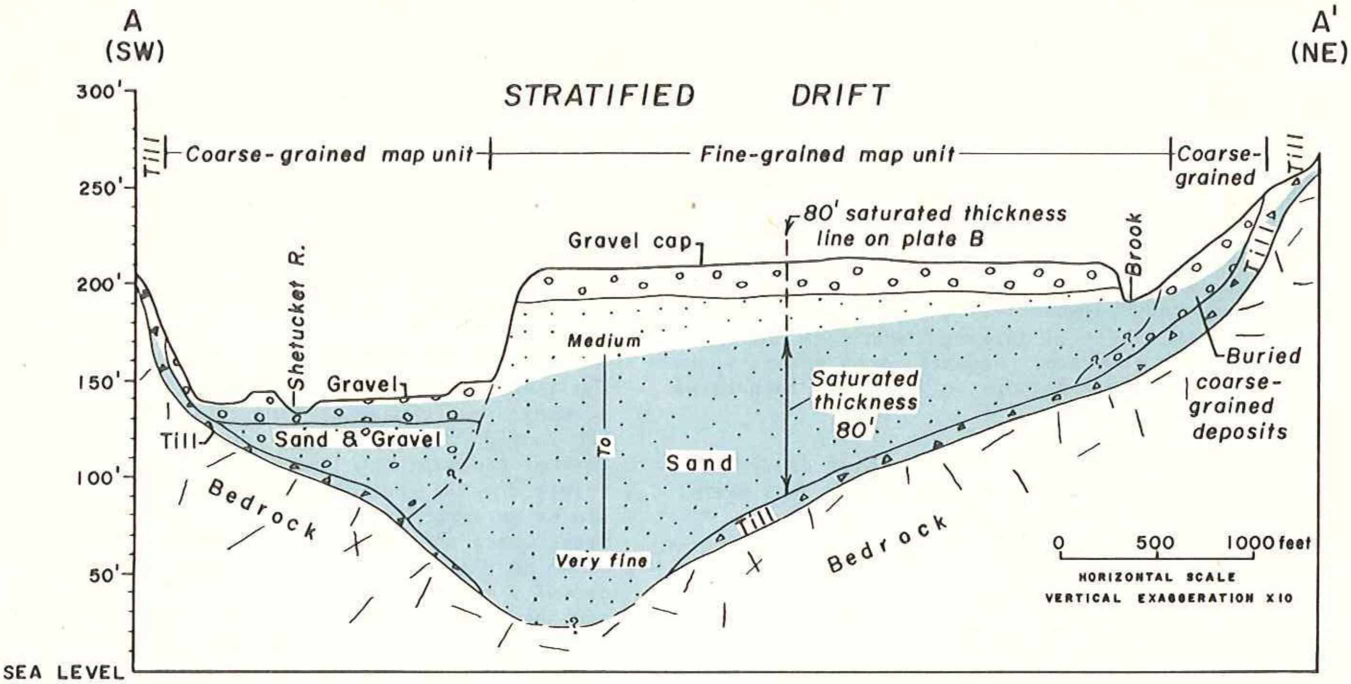


Figure 37.--Geologic section of the Shetucket River valley southeast of Willimantic along line A-A' on plate B.

In this broad area of stratified drift, the low terrace near the Shetucket River is mapped on plate B as coarse grained because of the predominance of sand and gravel in the saturated section. Gravel forms a cap beneath the high terrace east of the river, but the saturated deposits beneath this terrace are chiefly fine grained. Saturated thickness lines on plate B indicate the thickness of stratified drift below the water table, as illustrated in this cross section by the 80-foot line.

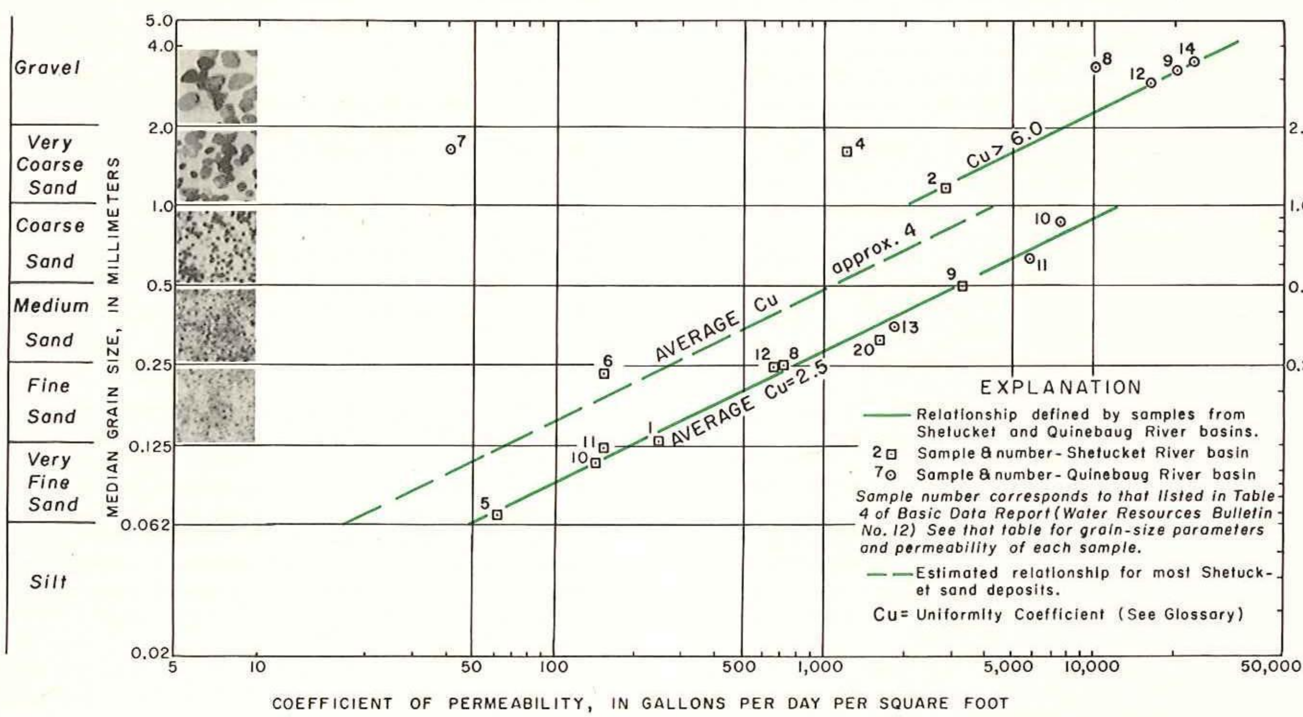


Figure 38.--Relation of permeability of stratified drift to median grain size and uniformity coefficient.

Permeability increases with increasing median grain size, and for a given median grain size, permeability is higher for well sorted deposits (those with low uniformity coefficient).

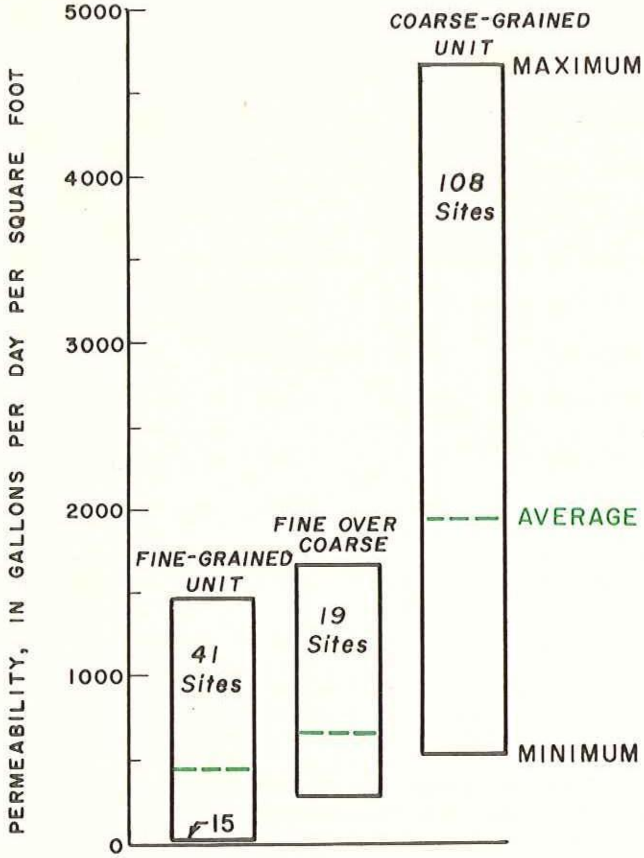


Figure 39.--Range in permeability of saturated sections of stratified drift in the Shetucket River basin.

Average permeability of the coarse-grained unit is nearly 5 times that of the fine-grained unit.

the samples, very well sorted, the total section of sand is less well sorted. Therefore a line shifted to the left (the middle line in figure 38), indicating a higher uniformity coefficient, is considered representative of most sections of very fine to coarse sand in the basin.

The top line in figure 38 is considered representative of the permeability-median grain size of most very coarse sand and of relatively "clean" gravel in the basin. These deposits have high permeabilities because they have large median grain sizes and contain relatively little material finer than medium sand. Although they are "clean," they have relatively high uniformity coefficients because their constituent grains include a wide range of sizes, from medium sand to pebbles. As a result, the line representing these deposits is located to the left of the middle line in figure 38. Points representing compact or "dirty" gravels plot even farther to the left, as indicated by the scatter of points above the top line.

Figure 38 can be used to estimate permeability of sand to fine gravel deposits in the Shetucket River basin. Median grain size and sorting can either be estimated or determined from the results of grain-size analyses. Median grain size can be estimated by visual comparison of a sample with the photographs of sand and gravel particles, which are shown in actual size. Average permeability of a saturated section can be determined by multiplying the permeability of each unit in the section, determined from figure 38, by the thickness of the unit, then totaling the products, and dividing their sum by the total thickness.

Using the above procedure, the average permeability of the saturated section of the coarse-grained stratified-drift unit at 108 sites was found to range from about 530 gpd per sq ft to nearly 4,700 gpd per sq ft with an average of about 1,900 gpd per sq ft, as is shown in figure 39. These results are based on analyses of descriptive logs of wells and test holes, most of which penetrate the full thickness of stratified drift. The average permeability of the fine-grained unit at 41 sites, also shown in the figure, is generally much lower, and ranges from 15 to 1,465 gpd per sq ft with an average of about 400 gpd per sq ft. The fine-grained unit has permeabilities greater than 1,000 gpd per sq ft at only 3 of the 41 sites (Wil 44, Wil 22th, and Ls 1th). At each of these the coarse cap of sand and gravel overlying the fine deposits is in part saturated, which accounts for the relatively high average permeability values of the full thickness of the saturated section. A separate analysis of logs of 19 wells and test holes where coarse-grained deposits are known to underlie fine-grained deposits indicates that average permeabilities at these sites are generally intermediate in range between those of the two principal units.

Permeability of an aquifer may also be estimated from the specific capacities (yields per foot of drawdown) of wells tapping the aquifer. Highly permeable aquifers can supply the amount of water being pumped under a lower hydraulic gradient (less drawdown) than deposits with low permeability. At the sites of five screened wells in coarse-grained stratified drift, listed in table 24, the average permeability estimated from specific capacity data, ranges from 1,750 to 3,000 gpd per sq ft.

Permeability values estimated from specific capacity are similar in magnitude to those determined from well logs at four of the sites, as shown in table 24. Analysis of data from a pumping test at one of the sites, Ms 25, gave a permeability value of 3,360 gpd per sq ft at that well, somewhat higher than that determined by the other methods (see p. 57). The pumping test probably provides the most reliable estimate of permeability; thus it can be assumed that estimates based on well logs and specific capacity are in general slightly conservative.

SATURATED THICKNESS

Saturated thickness of stratified drift in the Shetucket River basin ranges from 0 to more than 120 feet, as shown on plate B. Large well yields can be obtained where the saturated thicknesses of coarse-grained deposits exceed 40 feet. Such areas occur in parts of most river valleys in the basin and are particularly extensive in

Table 24.--Permeability of coarse-grained stratified drift in the Shetucket River basin.

Well no.	Length of test (hours)	Yield (gpm)	Drawdown (ft)	Specific capacity (gpm/ft) Unadjusted	Specific capacity (gpm/ft) Adjusted[1/]	Estimated transmissibility[2/] (gpd/ft)	Saturated thickness (ft)	Estimated average permeability (gpd/sq ft) From adjusted specific capacity	Estimated average permeability (gpd/sq ft) From well log and figure 38
Ms 24	24?	525	18.75	28.4	85	150,000	60?	2,500?	--
Ms 25	24	418	9	46.7	123	200,000	70	2,860	2,590
Ms 34	49	675	24.5	27.6	79	150,000	62	2,420	2,570
Ms 35	39	520	19	27.4	60	100,000	56	1,750	2,540
Ms 36	24?	500	20	25	71	150,000	50	3,000	3,010

1/ Adjustment based on methods described by Walton (1962, p. 7-8) to account for aquifer dewatering and inhomogeneity of the aquifer.

2/ Based on methods described by Meyer (1963).

the valleys of the Natchaug and Willimantic Rivers. Commonly, however, areas of greatest saturated thickness are those where fine-grained deposits predominate, as in Pleasant Valley north of Willimantic, and in parts of the Willimantic, Natchaug, and Shetucket River valleys.

Areas of stratified drift having less than 10 feet of saturated thickness cannot provide large water supplies, even where the deposits are coarse grained. These areas occur where the stratified drift is thin, such as along valley margins and in upland areas, or where most of the section of stratified drift is dry, such as in deposits located high on valley walls. The saturated thickness is generally less than 10 feet in those isolated areas of stratified drift shown on plate B where no saturated-thickness line occurs. In some of these areas, however, such as between South Willington and the University of Connecticut, the saturated thickness is very irregular and may in places exceed 10 feet.

YIELDS OF WELLS

The largest well yields in the basin are obtained from drilled wells which are screened in coarse-grained stratified drift. Of 13 such wells inventoried for this study, 8 equipped with large capacity pumps have reported yields of 200 gpm or more, and 5 with small capacity pumps have yields ranging from 13.5 gpm to 60 gpm, as listed in table 25.

The yield of a well expressed as gpm is only a rough index of its potential yield. Specific capacity, expressed as gpm per foot of drawdown, is a more significant measure because it includes the factor of drawdown. Firm specific capacity values could be calculated for only six of the wells listed. Some wells with high yields (e.g., Ms 24 and 34) have lower specific capacities than lower yielding wells (e.g., Nwh 30). Nonetheless, all six wells have relatively high specific capacities, reflecting their generally high yields.

Specific capacity values are not available for the group of wells with lower yields; therefore, it cannot be determined whether the large difference in yields between the two groups of wells reflects permeability differences or differences in water-supply requirements and well construction. All of the wells in the lower yielding group in table 25 are used for domestic and commercial purposes for which large supplies are not required, and all of the larger yielding wells listed are used for industrial and institutional purposes where large supplies are needed. For the 3 wells which tap coarse-grained deposits underlying fine-grained deposits, the lower yields undoubtedly do reflect in part lower specific capacities and lower permeabilities.

Adequate water supplies for many homes in the Shetucket River basin are provided from dug wells in stratified drift. From pumping tests of dug wells in the Quinebaug River basin, Randall and others (1966) concluded that a dug well pumped for 8 hours should supply at least 2 gpm per foot of drawdown for each foot of saturated coarse-grained stratified drift it penetrates. Similar yields can be expected in the Shetucket River basin. For example, a well dug 5 feet below the water table in coarse-grained stratified drift could be expected to pump 30 gpm with 3 feet of drawdown. Whereas it is difficult to construct a drilled screened well in fine-grained stratified drift, a dug well tapping these deposits can usually provide a supply sufficient for household use.

Two 6-foot diameter caisson wells (Stf 7 and Stf 9) tap coarse-grained stratified drift underlying swamp deposits in Cedar Swamp near Stafford Springs. These wells, whose initial yields are reported as 50-60 gpm each, combine the advantages of the large diameter of dug wells and the screen and gravel pack of drilled wells.

Table 25.--Yields of drilled and screened wells tapping coarse grained stratified drift in the Shetucket River basin.

Wells with large-capacity pumps			Wells with small-capacity pumps	
Well no. (Pl.A)	Yield (gpm)	Specific capacity (gpm/ft)	Well no. (Pl.A)	Yield (gpm)
Ms 24	525	28.4	Clb 13	20
Ms 25	418	46.7	Hb 8[a/]	60
Ms 34	675	27.6	Hb 9[a/]	60
Ms 35	520	27.4	Wil 28	13.5
Ms 36	500	25	Wil 31[a/]	14
Nwh 30	240	34.3		
Wil 4	200	-		
Wil 4a	200	-		

a/ Well is located in an area mapped as fine-grained stratified drift, but is screened in underlying coarse-grained deposits.

THE PUMPING TEST--A KEY TO LOCAL CONDITIONS

A controlled pumping test is one of the most useful tools available to the hydrologist for studying aquifers and determining the effects of large-scale withdrawals. Prior knowledge of aquifer permeability, saturated thickness, and yields of existing wells in an area provide a basis for making preliminary estimates of potential well yields, the effects of pumping on water levels, and the proper spacing of wells. But such estimates do not take into account the effects of local geologic and hydrologic conditions which influence yields and drawdowns. For example, in the Shetucket River basin most coarse-grained stratified drift occurs in relatively narrow river valleys, where the stream and valley walls act as boundaries to the aquifer. The manner in which these boundaries affect yields and drawdowns is generally the same from place to place but, because the geometry and effectiveness of the boundaries vary considerably, the magnitude of their influence is different at each site. Similarly, stratification affects the behavior of an aquifer in a predictable fashion, but the precise effect of the particular conditions of bedding and textural changes at a particular site is unique to that site. A pumping test at the site can provide this information.

As a well is pumped, the water table around the well assumes the shape of an inverted cone, or "cone of depression," with its apex at the pumped well. By analyzing the size, shape, and rate of growth of this cone, not only can the water-transmitting and water-storing characteristics of the aquifer at the test site be determined, but also the effects of local geologic conditions on yields and water levels can be evaluated. Such a test was conducted in the Willimantic River valley at wells of the Mansfield State Training School. The geohydrologic conditions and arrangement of wells at the site are shown in figure 40. Complete data for the test are included in the companion basic data report by C. E. Thomas, Jr., and others (1967). Although the data are applicable only to the test site, the results are similar to those which might be expected from coarse-grained stratified-drift deposits in many of the relatively narrow valleys of the Shetucket River basin.

In this test, one of the supply wells, Ms 25, was pumped continuously for 24 hours on July 23-24, 1964 at an average rate of 418 gpm, and periodic water-level measurements were made in the two observation wells Ms 25a and Ms 25b. Water pumped from Ms 25 was discharged into the storage tank at the school so that no recharge to the aquifer occurred from this source during the test.

With a constant pumping rate, the amount of water-level decline, or drawdown, in each observation well increased with time during the test. At any given time (t) the drawdown was greater in Ms 25b, nearer the pumping well, than in Ms 25a, farther away. To facilitate comparison and analysis of the two wells, the effects of different distances from the pumping well (r) were compensated for by plotting drawdown (s) versus t/r^2 on the single graph shown as figure 41. The measured values of drawdown were corrected, where significant, for the effects of partial penetration, dewatering of the aquifer, and rising trend of the water table prior to the start of pumping.

The aquifer characteristics were determined by fitting the Theis "type curve" (in Ferris and others, 1962) to the early part of the drawdown

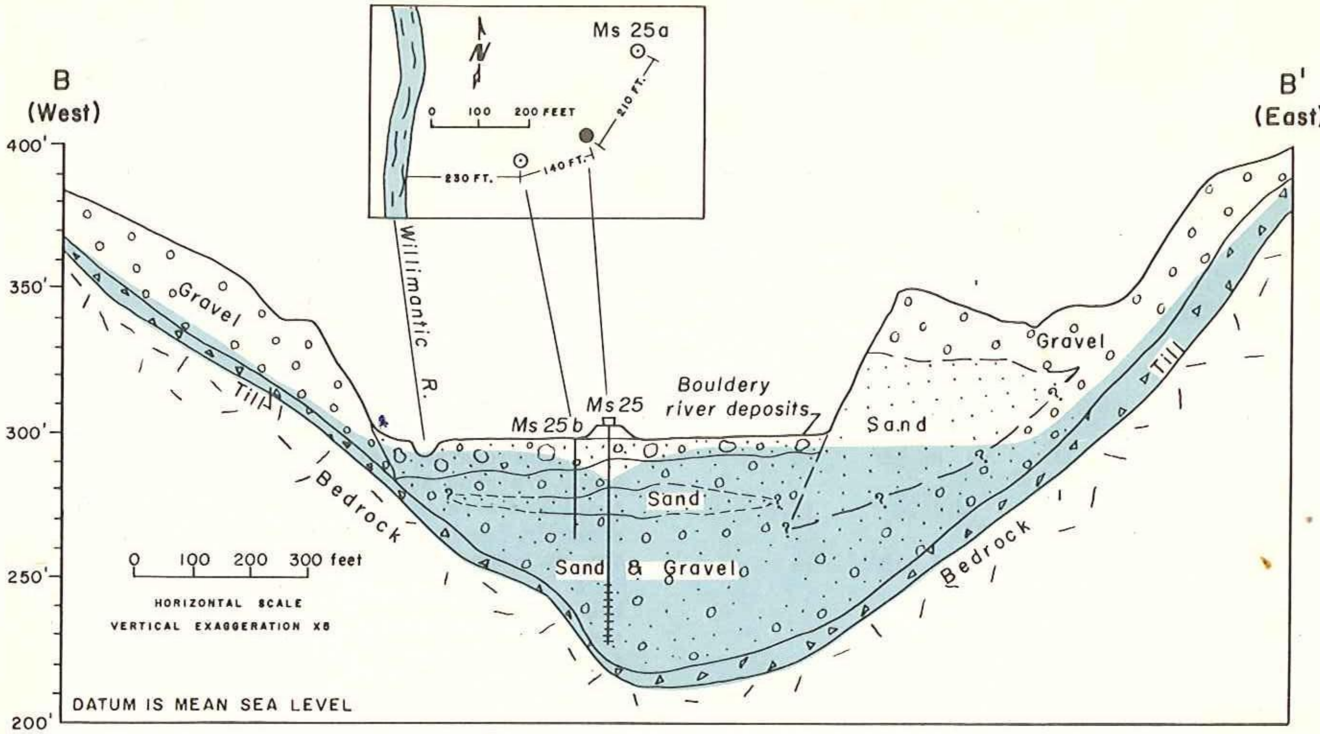


Figure 40.--Geologic cross section of the Willimantic River valley near the wells of the Mansfield State Training School, along line B-B' on plate B.

In a pumping test, Ms 25 was pumped at 418 gpm for 24 hours, causing a cone of depression to form in the water table. Average permeability of the stratified deposits was determined to be 4,170 gpd per sq ft.

data of Ms 25b, as plotted on figure 41. The curve of best fit represents a coefficient of transmissibility of about 242,000 gpd per ft. The saturated thickness of the section ranges from 44 feet at Ms 25b to 72 feet at Ms 25. Dividing transmissibility by an average saturated thickness of 58 feet gives a permeability of 4,170 gpd per sq ft, which is probably representative of the average permeability of the section. Dividing by the maximum and minimum saturated thicknesses gives permeabilities of 3,360 and 5,500 gpd per sq ft, respectively. These values are indicative of the high permeability of the sand and gravel deposits in the valley at this site.

The curve of best fit also indicates a coefficient of storage of 0.00082. This dimensionless parameter is an index of the amount of water released from storage when the aquifer is pumped (see glossary). The low value of 0.00082 indicates that artesian (confined) conditions existed at least during the early part of the test. Such conditions might be expected initially because of the stratification of the deposits. However, as the pumping proceeded, a gradual change to water-table (unconfined) conditions was expected, with a slower rate of drawdown and correspondingly higher storage coefficient eventually approaching a specific yield value of about 30 percent (see discussion of yield, p. 69). Under water-table conditions, the coefficient of storage is approximately equal to specific yield. After 30 minutes of pumping, however, the rate of drawdown in Ms 25b increased noticeably rather than decreased, as indicated in figure 41 by the downward divergence of the plotted points from the "type curve." This divergence suggests that the cone of depression had reached a barrier boundary between the aquifer and a comparatively impermeable zone which could not supply, under the same hydraulic gradient, the quantity of water needed to meet the pumping demands. A second barrier boundary is indicated by a second downward divergence of the plotted points from the refitted type curve.

The positions of the two boundaries cannot be determined precisely from an analysis of drawdowns in the single observation well, Ms 25b, and the boundaries were not reflected in the drawdowns of Ms 25a. However, from an examination of the geologic setting, shown in figure 40, it can logically be assumed that the relatively impermeable till-bedrock valley walls acted as the barrier boundaries. With this assumption, and by applying methods described by Walton (1962, p. 16), the boundaries were determined to be about 600 and 1,800 feet from Ms 25b. These distances correspond approximately to the distances to the west and east valley walls, respectively. The correspondence is only approximate because the boundaries are neither vertical nor completely impermeable, as is assumed in the methods of analysis.

The effects of the barrier boundaries predominated during the latter part of the test and

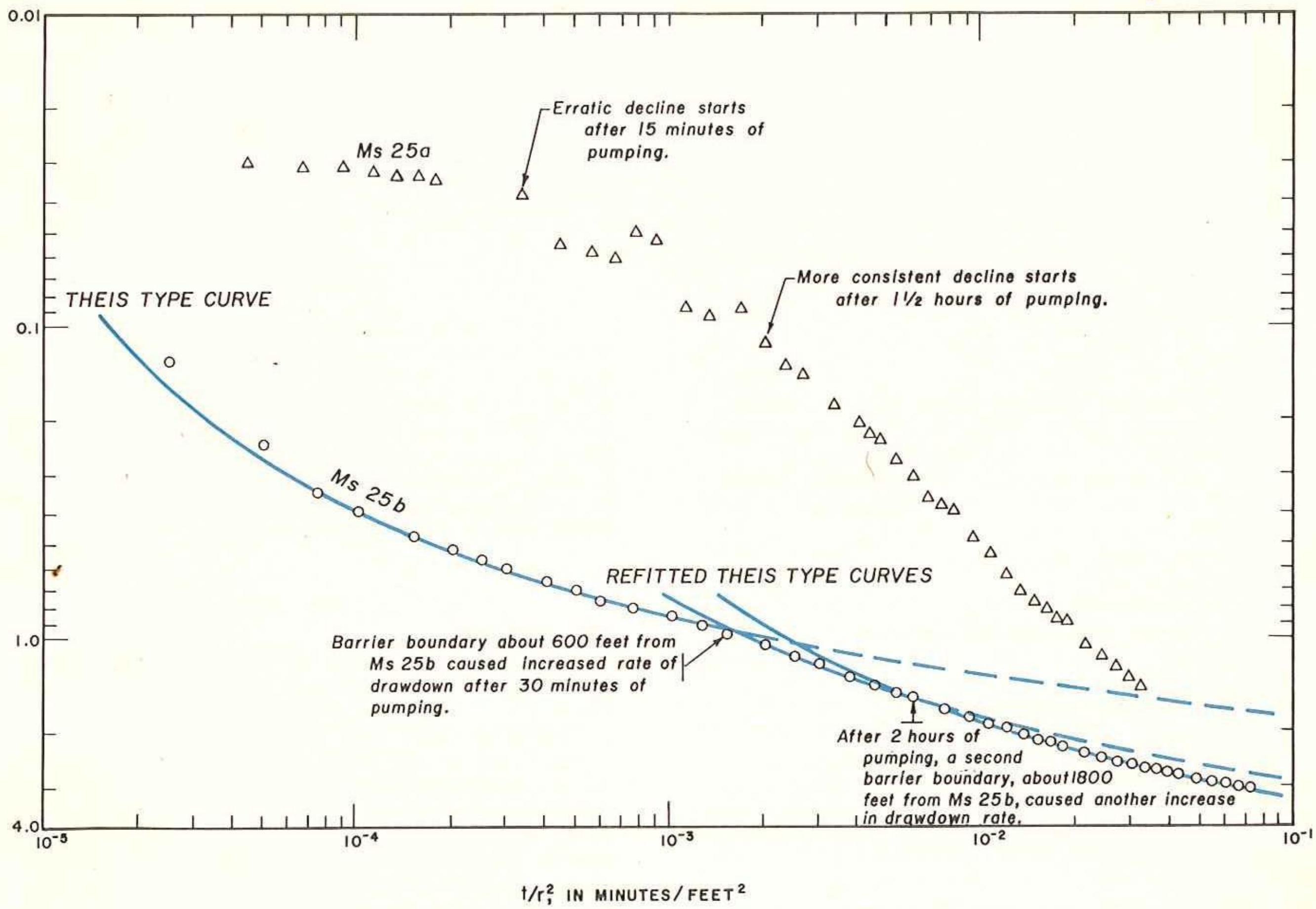


Figure 41.--Drawdowns in observation wells during pumping test at Mansfield State Training School.

The Theis type curve fits closely the plot of points for Ms 25b and permits determination of aquifer coefficients. Breaks in the curve indicate the cone of depression reached the relatively impermeable valley walls.

masked any evidence on the drawdown curve of the transition from artesian conditions to water-table conditions which would normally be expected under the prevailing hydrologic and geologic conditions. Also masked was the effect of the Willimantic River itself acting as a recharge boundary, a source of induced infiltration which would have the effect opposite that of a barrier boundary. If, as is likely, the hydraulic connection is poor between the river and the deep sand and gravel unit tapped by the pumping well, the effects of the recharge boundary would have been negligible as long as artesian conditions prevailed. However, if pumping continued long enough under water-table conditions, the cone of depression would have eventually intersected the river and induced infiltration would have occurred.

Theoretically, a single "type curve" should have fitted the plotted points (s versus t/r^2) for both observation wells. However, as can be seen from figure 41, the drawdown in Ms 25a lagged considerably behind that of Ms 25b. In fact, no significant drawdown occurred during the first 15 minutes of the test, and then the water level declined erratically for the next hour before steadily declining.

The differing responses of the two wells reflect the effects that well construction factors and stratification and heterogeneity of the deposits have on water-level declines. Ms 25b has a well point open to the same unit of sand and gravel as the pumping well, whereas the casing of Ms 25a is open to the sand layer overlying the sand and gravel unit. Because of the artesian conditions which existed in the sand and gravel unit, the water level in Ms 25b responded almost immediately to pumping, whereas the water level in Ms 25a, under water-table conditions, showed no response until the water-table cone of depression reached it. The bottom of Ms 25a is soft and appeared to be plugged with fine-grained sediment, which would in part account for its sluggish and erratic response. Although the artesian type curve could be fitted to at least two groups of data points of Ms 25a, no confidence could be placed in the results and the plot was not used to determine aquifer coefficients.

In summary, the general conditions at the well field of the Mansfield State Training School are probably characteristic of those in the other major but relatively narrow river valleys in the Shetucket River basin. At this site, a large supply is obtained from a relatively thick saturated section of coarse-grained stratified drift. However, in addition to permeability and saturated thickness, other local conditions at the site have a marked effect on yields and drawdowns. These include the valley walls acting as barrier boundaries, the river acting as a recharge boundary, the changing hydrologic conditions during pumping, and the construction and setting of the wells. The pumping test provides means for evaluating the effects of these conditions.

TILL

Till is a relatively minor aquifer in the Shetucket River basin in terms of yields to individual wells, but the aquifer covers about 80 percent of the basin and is an important source of water for many homes. Till (commonly called "hardpan") is a very poorly sorted and non-stratified deposit composed of clay, silt, sand, gravel, and boulders, as illustrated in figure 36D. This material was deposited directly by the glacial ice as it flowed southeastward across Connecticut, and it forms a mantle over the bedrock almost everywhere in the basin. It occurs just below the soil layer in all major hills and upland areas shown on plate B, and in most places underlies the stratified drift in the lowlands as illustrated in figure 37. Most till in the basin is massive, although thin lenses and irregular masses of stratified sand and gravel occur irregularly within the till.

Because till is a poor aquifer throughout the basin, no subdivision of it is made on the geohydrologic map, plate B. However, there are certain broad regional lithologic differences which have a noticeable influence upon its water-bearing characteristics. In the northern part of the basin the till commonly has a brownish color, contains more silt and clay, and is more compact than the till in the southern part, where it commonly has a grayish color and is relatively sandy. For example, in Eastford and Woodstock there occurs a very compact clayey fissile phase of till, and around Willimantic much of the till is sandy and relatively loose. The differences in color and texture generally reflect differences in the local bedrock type from which the till was derived. The varying degree of compaction represents differences in the manner of deposition: the very compact till was probably overridden by the advancing ice sheet, whereas the less compact till was laid down as the ice wasted away. Hydrologically these differences mean than, in general, the till in the southern part of the basin is somewhat more permeable than that in the northern part.

PERMEABILITY

Permeability of till in the Quinebaug River basin ranged from as little as 0.2 gpd per sq ft for compact silty till to as much as 55 gpd per sq ft for loose sandy till (Randall and others, 1966, tables 25 and 26). These values are based on laboratory analyses of undisturbed samples and on pumping tests of dug wells. They are probably representative of the range in permeability for most of the till in the Shetucket River basin, for field observations suggest that the till deposits in the two basins have similar physical characteristics. One undisturbed sample of the matrix of loose sandy till near Willimantic had a permeability of 120 gpd per sq ft. This deposit is representative of the most permeable phase of till in the basin.

THICKNESS

Till in the Shetucket River basin ranges in total thickness from less than a foot near bedrock outcrops to more than a hundred feet in some areas, but probably averages between 10 and 35 feet. Relatively thick accumulations of till, shown on plate B, occur scattered throughout the basin as rounded, "spoon-shaped" hills, or drumlins, and as irregular side-hill or valley-wall accumulations. Drumlins are particularly numerous in Woodstock.

YIELDS OF WELLS

Large-diameter dug wells are the most practical means of tapping the till aquifer. However, where the till is thin, the water table deep, or permeability very low, even a dug well may be impractical or may provide insufficient supplies for household use. Seasonal water-level fluctuations in till are usually large, and shallow dug wells tapping this aquifer are therefore susceptible to going dry in drought years. Nonetheless, where a well can be dug several feet or more below the annual low-water level, it can usually supply an average household throughout the year. Many gallons of water are stored in dug wells, available for use when needed, and the water withdrawn is replaced by slow seepage from the till during non-pumping periods. The permeability of the till at most sites will permit replenishment seepage of more than 200 gallons during the course of a day, enough to meet the household needs of an average family (Randall and others, 1966, p. 57).

BEDROCK

Bedrock underlies the entire Shetucket River basin. In this area bedrock (commonly called "ledge") is a hard, crystalline rock composed of interlocking minerals. Although there are several types of bedrock in the area, including schist and granite, no consistent differences have been recognized in the water-bearing properties of the various rock types, and the rocks are therefore not subdivided in this report.

At most places in the basin bedrock is overlain by unconsolidated deposits. In general the shape of the land surface conforms to that of the bedrock surface, but in detail, there are many irregularities in the bedrock surface not expressed by land surface topography. As a consequence the depth to bedrock beneath the land surface varies greatly from place to place and in some areas is more than 100 feet. Depth to bedrock through unconsolidated deposits is usually greater in valleys than in upland areas, where bedrock is exposed in many places or covered by only a thin mantle of till. In most valleys the bedrock surface is relatively shallow near the margins and deepest near the valley center.

PERMEABILITY

The upper few hundred feet of bedrock in the basin is cut by many irregularly spaced fractures, such as those shown in figure 36E, and it is along these avenues that virtually all water movement occurs. Many of these fractures are steeply dipping; others are more nearly horizontal and follow the general configuration of the bedrock surface. The spacing and size of individual fractures vary widely with no discernable systematic pattern which would allow prediction of the depths and yields of fractures that might be encountered when drilling at a particular site. However, evidence from field observations, the experience of drillers, and other studies (Ellis, 1909; Cushman and others, 1953; and Randall and others, 1966) has indicated that water-bearing fractures in crystalline bedrock in Connecticut tend to become tighter and more widely spaced with depth. The data in Ellis' report (p. 94) suggest that there is only a slight probability of encountering a significant water-yielding fracture at rock depths greater than 200-250 feet, and data in the report of Cushman and others (p. 95) indicate a limiting depth of about 300 feet.

Because of the variability in size and spacing of individual fractures, the permeability of fractured crystalline bedrock has significance only when large volumes of rock are considered; furthermore, permeability values cannot be extrapolated from one site to another. An analysis of the specific capacities of 134 bedrock wells in the Shetucket River basin indicated that the average permeability of the fractured bedrock tapped by these wells is from 2 to 3 gpd per sq ft. That permeability varies widely from site to site, however, is indicated by the results of pumping tests of 10 bedrock wells penetrating similar crystalline rocks in the adjacent Quinebaug River basin; permeability values derived from those tests ranged from 0.025 to 1,100 gpd per sq ft (A. D. Randall, written communication, 1965).

YIELDS OF WELLS

Several thousand drilled wells tap the bedrock aquifer in the Shetucket River basin. Most of them provide small but adequate supplies for homes or farms. Drillers' reported yields in a sampling of 134 domestic wells in the basin range from 0.5 gpm to 112 gpm, averaging about 13 gpm. Ninety percent of these wells yield at least 3 gpm, enough for an average home; few wells yield more than 50 gpm. Only a few instances are known where yields of holes drilled in bedrock were insignificant or there was no water at all.

The measured yield of a well tapping fractured bedrock is the net result of many interacting factors which determine the potential yield of the bedrock at the well site and also the degree to which the potential yield is realized in drilling and testing the well. The potential yield is controlled by the number, distribution, and yield of fractures in the bedrock at the site; these in turn are indirect expressions of many geologic factors, such as the type and thickness of overburden, topographic location, and the type of bedrock. The proportion of the potential yield which is realized is affected largely by the amount of bedrock penetrated and testing procedure, especially the amount of drawdown. Because of the complex interaction of the many factors which influence yield, it has not been possible to isolate each factor and determine its relative effect on yield. Nonetheless, an analysis of drillers' records of a sample of 134 bedrock wells in the Shetucket River basin has led to some general conclusions, discussed on the following pages. These wells are all domestic wells drilled by the cable tool method, and tested at least an hour by bailing or pumping. Rock type was not evaluated in this study.

Potential yields.--Geologic factors which may influence potential yields at a given site have been discussed by Cushman and others (1953). Some of their pertinent general conclusions, based on average yields of hundreds of crystalline-bedrock wells throughout southern New England, are summarized in the following table:

Geologic factors	Conditions at the well site which tend to result in--	
	Above-average yields	Below-average yields
Rock type	Granite	Granite-gneiss Schist Gneiss
Topographic location	Valley	Hill
Type of overburden	Stratified drift (sand and gravel)	Till
Thickness of overburden	No relationship determined	

The authors did not isolate the relative effects of each factor, and they point out the difficulty in doing so. For example, most stratified drift areas are also in valleys, and thus for these sites it is difficult to separate out the relative influence of overburden type and topography on well yields.

In the Shetucket River basin, analysis of the sample of 134 wells shows that wells drilled at sites where stratified drift is the overburden have a slightly higher average yield than wells drilled where till is the overburden, as shown in figure 42. The till/bedrock wells have a lower average yield even though they penetrate an average of 40 feet more of bedrock and were tested with a slightly greater average drawdown. The yield differences are more striking when the average yields per foot of bedrock penetrated are compared: the gpm per foot penetrated for stratified-

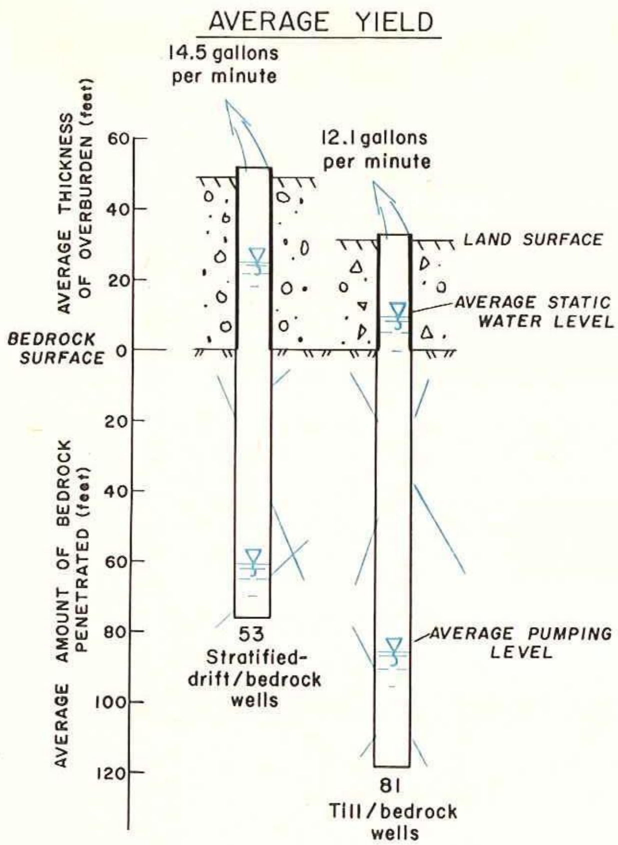


Figure 42.--Average hydrologic and geologic conditions for 134 bedrock wells in the Shetucket River basin.

On the average stratified-drift/bedrock wells have higher yields than till/bedrock wells, despite smaller bedrock penetration and smaller drawdowns in the stratified-drift/bedrock wells.

drift/bedrock wells (0.19) is nearly twice that of till/bedrock wells (0.10).

A variety of factors explains the higher average yield of stratified drift/bedrock wells. Because of its greater permeability, stratified drift may transmit water downward to fractures more readily than the less permeable till when wells are being pumped (Cushman and others, 1953, p. 92-93). However, the presence of a layer of till between the stratified drift and bedrock (a common occurrence) would tend to diminish the influence of this factor. Bedrock beneath valleys, where stratified drift is most widespread, receives ground-water seepage from the adjoining slopes, whereas ground water in bedrock moves away from hilltop sites, where till is most commonly the overburden. These conditions are reflected in the higher position of the static water level relative to the bedrock surface in the stratified-drift/bedrock wells than in the till/bedrock wells in figure 42. The static water level is actually below the bedrock surface in 30 percent of the till/bedrock wells, but this situation exists in only 13 percent of the stratified-drift/bedrock wells.

In the sample of wells, stratified drift has a greater average thickness than till. Where the stratified drift is thick it is usually in part saturated and it can thus serve as a storage reservoir to replenish the bedrock fractures when a well is pumped. Where overburden is thin or absent, as is common in the till-bedrock uplands, no such overlying reservoir exists, and even the fractures in the upper part of the bedrock may be dry.

Effect of bedrock penetration on yields.--The amount of bedrock penetrated by wells in the Shetucket River basin ranges widely, from a few feet to several hundred feet. The greatest known rock penetration by a well in the basin is 841 feet (Ellis, 1909, p. 82). This well was reported to have yielded 40 gpm and obtained its major supply from a rock depth of 800 feet. Most wells, however, penetrate less than 300 feet of rock. The greatest reported thickness of bedrock penetrated for wells drilled during the course of this study was 497 feet; this well yielded only 0.75 gpm. Of the 134 wells sampled in the basin, the amount of bedrock penetrated ranged from 6 to 284 feet and averaged 100 feet.

The total yield of a bedrock well will increase as it is deepened as long as additional water-bearing fractures are encountered. Nonetheless, many deeply penetrating wells have low yields. In fact, among the wells analyzed, figure 43 shows that most of those penetrating large amounts of bedrock had lower yields than those penetrating small amounts of bedrock, despite larger drawdowns in the deeply penetrating wells. This relationship supports the concept that the upper part of the bedrock is generally higher yielding than the lower, but also indicates that there are sites where the bedrock section is low yielding throughout. Only rarely are relatively large yields obtained exclusively from the deeper parts of the section, as in the case of the 841-foot well described above. Because the size and density of fractures diminish with depth, the probability of substantially increasing the yield of a well becomes less as a well is deepened. Thus, if the yield from the upper part of the bedrock is low, the well will probably be completed with a low yield, even if it is drilled to great rock depths.

The effective yield of a well can be augmented by considering the amount of water stored in the hole itself. The water in most fractures is under artesian pressure, and when a fracture is intercepted by the drill hole, the water level rises to some level in the well above the fracture. In the sample of wells, the static water level stood in the casing at an average of about 17 feet above the bedrock surface and a column of water 118 feet

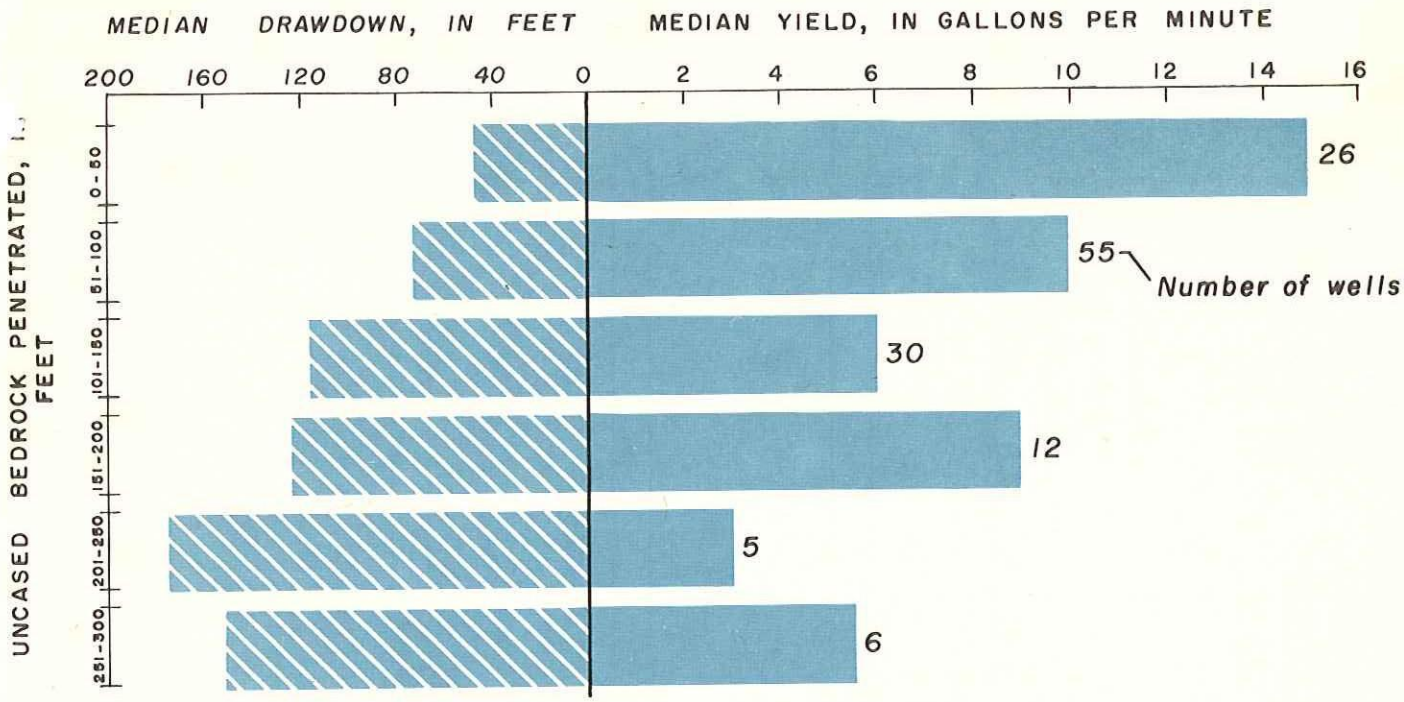


Figure 43.--Median yields and median drawdowns of bedrock wells in the Shetucket River basin for various ranges in depth of uncased bedrock penetrated.

In the sample of 134 wells, those penetrating small amounts of bedrock generally had higher yields with smaller drawdowns than deeply penetrating wells.

high stood in the well. Every foot of water standing in a 6-inch diameter well contains about 1.5 gallons. Thus in the average well (from the sample) there was stored about 177 gallons which could be utilized before drawing wholly upon the actual yield of the well.

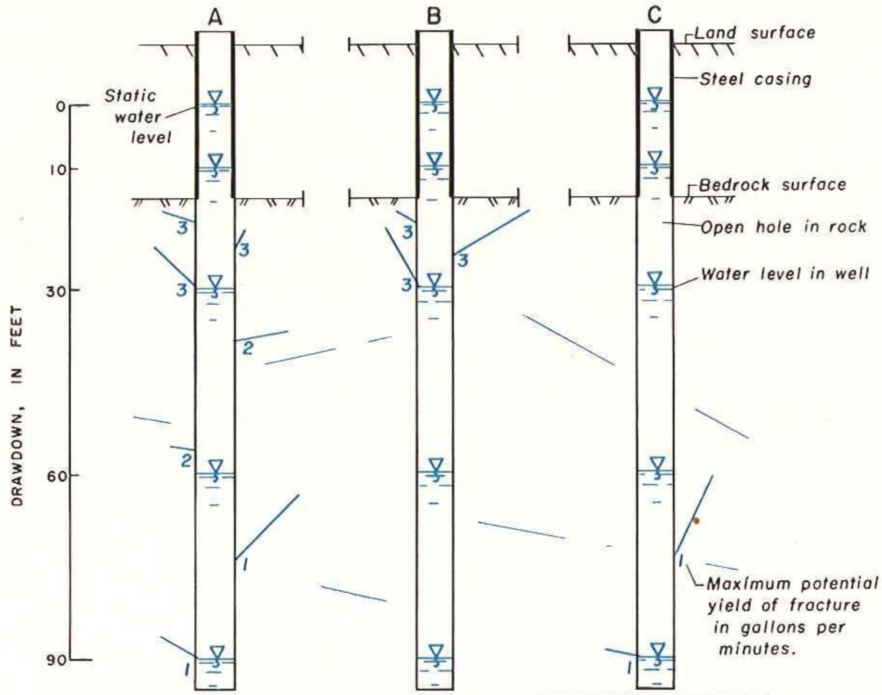
Effect of drawdown on yields.--Unlike wells which tap a stratified-drift aquifer, the drawdown in a bedrock well does not always increase in proportion to an increase in the rate of pumping, and the specific capacity of such a well is therefore not necessarily constant in value. An understanding of the relationship between yield and drawdown for wells tapping the bedrock aquifer aids in interpreting yield data and in determining whether a well has been tested to its maximum capacity.

The relationships between drawdown, yield, and specific capacity of bedrock wells are illustrated in figure 44 by three wells which penetrate bedrock under different conditions of fracture distribution and fracture yield. The conditions depicted are hypothetical generalizations of three situations likely to be encountered in drilling through crystalline bedrock: (A) where fracture yield and fracture density gradually decrease with depth, (B) where there is little or no yield from the lower part of the bedrock, and (C) where there is little or no yield from the upper part of the bedrock, and only a small yield from the lower part.

The yields tabulated in figure 44 were calculated by first determining for each fracture what proportion of its maximum potential yield would be contributed under a given condition of drawdown, and then totaling the yields from all the fractures. The specific capacity was then determined by dividing the sum of the yields by the drawdown.

The tabulations show that the total yield of a bedrock well increases with drawdown until the water level in the well is drawn below the lowermost water-bearing fracture. Then the yield remains constant, and is equal to the sustained yield of the fractures. The specific capacity, however, is constant only until the water level is lowered below the uppermost water-bearing fracture. Then the specific capacity decreases with additional drawdown.

These relationships suggest that the rate at which water can be pumped when the water level is lowered below the deepest water-bearing fracture is a more significant index of the maximum potential yield of a bedrock well than either the yield alone or the specific capacity. A simple method of determining this value would be to lower the water level as close as possible to the bottom of the well by pumping or bailing and then measure either the early rate of rise of the water level, or the pumping rate required to hold it steady. If a jet pump is to be installed, a practical well yield can be determined by lowering the water level to the depth at which the jet will be located in the



	Well A		Well B		Well C	
	Fracture yield and fracture density gradually decrease with depth.		Little or no fracture yield in lower part of rock.		Little or no fracture yield in upper part of rock.	
DRAW-DOWN (ft)	YIELD (gpm)	SPECIFIC CAPACITY (gpm/ft)	YIELD (gpm)	SPECIFIC CAPACITY (gpm/ft)	YIELD (gpm)	SPECIFIC CAPACITY (gpm/ft)
10	4.8	0.48	3.7	0.37	0.24	0.024
30	12.3	.41	9.0	.30	.73	.024
60	14.5	.24	9.0	.15	1.47	.024
90	15.0	.17	9.0	.10	2.0	.022

Figure 44.--Effect of drawdown and fracture distribution on yield and specific capacity of bedrock wells.

Yield may increase or remain constant with drawdown, and specific capacity may decrease or remain constant with drawdown, depending on the yield and distribution of water-bearing fractures tapped by the well.

well, and then measure the recovery rate or the pumping rate necessary to hold the water level steady.

SUMMARY OF YIELDS OF BEDROCK WELLS

Some water can be obtained from bedrock almost anywhere in the Shetucket River basin. Above-average well yields are most likely to be obtained at valley sites where the overburden is saturated stratified drift, and below-average yields at upland sites where the overburden is dry till or is absent. Water-bearing fractures diminish in number and yield with depth. Most wells penetrate less than 300 feet of bedrock, and the probability is small of substantially increasing the yield of a well beyond that rock depth. The maximum yield is obtained only by lowering the water level in the well below the lowermost water-bearing fracture.

WATER AVAILABLE TO WELLS

The amount of water available to wells over an extended period of time is governed by (1) the amount which would be discharged as ground-water outflow under natural conditions, (2) water that is available from stream channels, and (3) water that is available from aquifer storage. Possibly some additional water could be obtained by reduction of ground-water evapotranspiration. Ground-water evapotranspiration is not included as a source of water available to wells, however, because the amount which could be recovered and used by man is both relatively insignificant and impractical to ascertain.

It should be emphasized that it may be uneconomical or impractical to develop all or even most of the water available. For example, in till areas, or where stratified drift is fine grained, a great many closely spaced wells of small capacity would be required to obtain most of the available water. If most ground-water outflow were intercepted or if large quantities of streamflow were induced to flow toward wells, streamflow would be significantly reduced, and during dry periods much of the streambed would be completely dry. If water taken from aquifer storage were not replaced over a period of time, declining water levels and reduced well yields would result.

Examples of the methods described in the following pages for determining water available to wells are given in the discussion of favorable areas for the development of large supplies from stratified drift, starting on p. 83.

GROUND-WATER OUTFLOW

Under natural conditions ground-water outflow occurs as ground-water runoff in stream channels and as underflow in deposits underlying streams. Before reaching these discharge outlets, the amount of ground water that under natural conditions would become ground-water outflow may be intercepted by wells and used as a major source of supply. This quantity is an index to the amount of ground water which may be withdrawn over a period of time without depleting the ground-water reservoir and causing a long-term decline in water levels.

In most parts of the Shetucket River basin, underflow is relatively insignificant and although the amount of underflow varies from place to place depending on geologic and hydrologic conditions, at any one place it remains relatively constant with time. On the other hand, ground-water runoff, by far the largest component of ground-water outflow, varies in amount during the year, from year to year, and from place to place. In an average year, approximately 10.58 inches of ground-water outflow passes the Shetucket River gage, of which only 0.02 inch is underflow. Annual ground-water outflow from a drainage area underlain entirely by till may range from a few inches to nearly 9 inches, whereas in a drainage area underlain largely by stratified drift annual ground-water outflow may range from about 10 inches to more than 20 inches.

SEASONAL VARIATIONS

Ground-water runoff, and thus ground-water outflow, varies throughout the year in much the same manner as total streamflow. In most years ground-water runoff steadily diminishes throughout a 4- to 6-month period from late spring to early fall, and rises erratically during the remainder of the year. These fluctuations are illustrated by the trends in the magnitude of the ground-water runoff segment of the Shetucket River basin water budget shown in figure 9. Average ground-water runoff of the Shetucket River is lowest during the months of August and September (0.24 inch), and highest during March (1.81 inches), as shown in table 3.

Hydrographs for Connecticut wells show that in most years there is a steady lowering of the water table during the 4 to 6 months of diminishing ground-water runoff (La Sala, 1960, p. 8). This water-table decline is illustrated for the Shetucket River basin in hydrographs of wells Wk 200 and Cv 11 in figure 45. The nearly steady decline of the water table from late spring to early fall indicates that during this period there is practically no recharge from precipitation to the ground-water reservoir. This period, hereafter termed the period of no recharge, corresponds

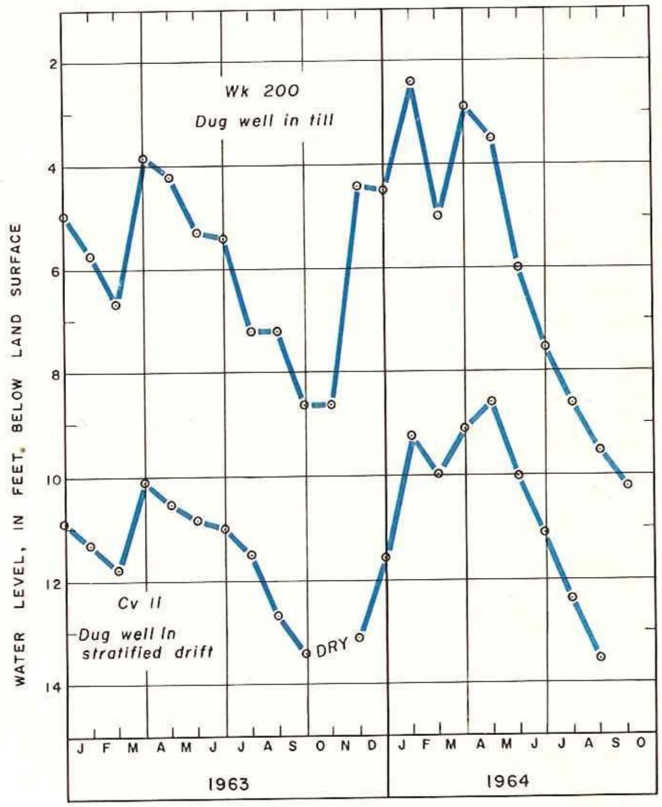


Figure 45.--Typical hydrographs of monthly water levels in wells dug in till and in stratified drift in the Shetucket River basin, 1963-64.

Ground-water levels decline during the growing season when most precipitation is evaporated or used by plants, and while ground water continues to discharge into stream channels. Water levels rise during late fall to spring when precipitation and snowmelt replenish ground-water storage.

closely with the growing season, and the reduction in recharge is attributed largely to the demands of evapotranspiration. Ground-water runoff, though it flows at a diminishing rate, exceeds recharge during this period, resulting in a net depletion of water stored in the aquifers. As water is removed from storage, the water table declines. Lowering of the water table results in a decreasing water-table gradient, which accounts for the diminishing rate of ground-water runoff.

During the remaining months of the year recharge by precipitation to the ground-water reservoir exceeds ground-water runoff, as indicated by the net rise in the water table. Because of the steepening hydraulic gradients, the ground-water runoff rate increases during this period, hereafter referred to as the recharge period.

Although ground-water outflow varies seasonally during the year, wells intercepting this ground water can nevertheless pump at a constant daily rate without permanently lowering the water table, as long as total pumpage does not exceed the total annual ground-water outflow, assuming adequate water is available from storage. During the period of no recharge, all withdrawals will in effect be coming from ground-water storage. During the recharge period, some of the recharge, which under natural conditions would become ground-water outflow, will satisfy pumping demands, and some will be used to replenish the ground-water reservoir. Thus the amount of water available through the interception of ground-water outflow is determined by the total annual ground-water outflow and the availability of water from storage, more than by the seasonal fluctuations of ground-water outflow.

AREAL AND ANNUAL VARIATIONS

Ground-water outflow also varies from place to place and from year to year, owing to differences in geology and variations in precipitation. Analysis of outflow characteristics of seven tributary basins in the Shetucket and Quinebaug River basins shows that ground-water outflow varies directly with the percent of stratified drift contained within the drainage area, as shown in figure 46. Knowing the percent of stratified drift in the watershed draining toward an area of interest, these graphs may be used to estimate the average and minimum annual ground-water outflow to be expected, and the amount exceeded seven out of ten years.

Data used to construct the curves in figure 46 are based on analyses of streamflow hydrographs and comparison of short-term records of the seven tributary streams with long-term records of the Shetucket and Quinebaug Rivers, with results as shown in table 26. Ground-water runoff hydrographs were constructed for each of these seven streams, using the recession method (Riggs, written communication, 1958) in conjunction with ground-water rating curves. From the hydrographs, total runoff and ground-water runoff were determined for a 12-month period in which there was no net change in storage. Ground-water underflow at each stream-gaging site was evaluated, and where significant was added to both total runoff and ground-water runoff. In this way all recoverable ground-water discharge was accounted for.

In the analyses, runoff values for the seven small basins were adjusted to average regional runoff conditions in order to eliminate the effects of local variations in precipitation. Average total runoff in eastern Connecticut is 1.16 mgd per square mile, or 24.43 inches per year (see p. 16). This value is equivalent to average total outflow, because in determining this value underflow was considered negligible. Thus, in using figure 46 to determine ground-water outflow for a particular area, the values taken from the graph should be adjusted back to local conditions by using the isopleths in figure 23, as described on p. 17.

In determining the values used to construct the three curves in figure 46, it was assumed that the ratio of ground-water outflow to total outflow in a given basin remains constant from year to year (see below for a discussion of this assumption). The average ground-water outflow of each basin was determined by first converting the single-year values of ground-water outflow to average annual values, and then adjusting to regional runoff conditions.

The minimum annual ground-water outflow to be expected was evaluated by first determining the minimum total outflow of the Shetucket River (13.20 inches in 1932) during the reference period 1931-60. This value was then adjusted to a regional figure (13.48 inches), and the average annual ground-water outflow for each subbasin was multiplied by the ratio of 13.48 inches to 24.43 inches (average annual total outflow of the region). Ground-water outflow exceeded seven years out of ten was evaluated by first determining from the annual runoff records of the Shetucket River, the total runoff exceeded seven years out of ten (19.5 inches), during the reference period, and then using the same procedure as described above for the minimum values.

In a drainage area containing 100 percent stratified drift, a very large proportion of the total runoff would consist of ground-water runoff. Assuming 95 percent of the total runoff in such a basin would be ground-water runoff, theoretical values of ground-water outflow were plotted on the 100-percent line of figure 46 and used as guides in sketching in the curves.

The assumption that the ratio of ground-water outflow to total outflow in a given basin remains constant from year to year is not entirely valid. Variations in yearly total outflow are absorbed mostly in surface-water runoff; ground-water runoff fluctuates less widely, and underflow is nearly constant. The resulting errors are less significant for basins with small percentages of stratified drift than for those with large percentages. This is because in till basins, variations in ground-water runoff parallel those of total runoff more closely than in basins with large amounts of stratified drift.

Despite the limitations in the method used, the curves in figure 46 provide useful estimates of ground-water outflow. The data are probably

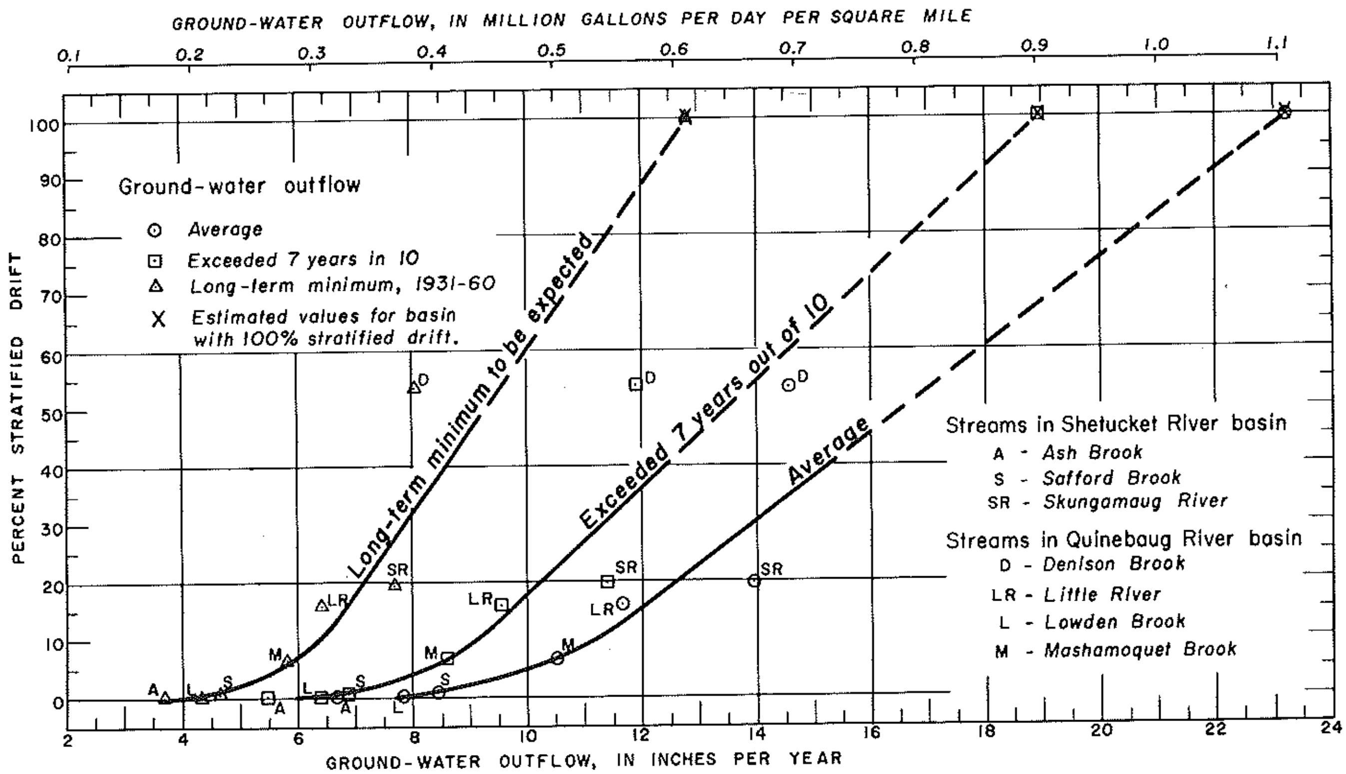


Figure 46. Relation of ground-water outflow to percent of drainage area underlain by stratified drift, for average annual runoff of 24.43 in. (1.16 mgd per sq mi).
Ground-water outflow increases with increasing percent of stratified drift. Ground-water outflow from a basin underlain entirely by stratified drift would be about three times that from an all-till basin.

Table 26.--Runoff and outflow characteristics from basins of seven tributary streams in the Shetucket and Quinebaug River basins.

	Tributary basin	Percent stratified drift	Underflow (in)	Total runoff (in)	Total outflow (runoff & underflow) (in)	Ground-water runoff (in)	Ground-water outflow (runoff & underflow) (in)	Average annual ground-water outflow (in)
			12 month period May 1963 through April 1964					Base period 1931-60
Shetucket River basin	Ash Brook	0	0	20.76	20.76	5.71	5.71	6.72
	Safford Brook	.8	.06	19.77	19.83	6.78	6.84	8.43
	Skungamaug River	19.7	0	18.31	18.31	10.46	10.46	13.95
			12 month period August 1962 through July 1963					Base period 1931-60
Quinebaug River basin	Denison Brook	53.8	.37	27.77	28.14	16.42	16.79	14.57
	Lowden Brook	0	.20	25.21	25.41	7.96	8.16	7.84
	Mashamoquet Brook	6.5	0	22.50	22.50	9.70	9.70	10.53
	Little River	15.9	.13	20.49	20.62	9.72	9.85	11.67

most reliable for drainage areas with less than 20 percent stratified drift, which includes most areas in the Shetucket River basin.

INDUCED INFILTRATION

Under natural conditions the flow of ground water in the Shetucket River basin is usually toward streams and lakes. But pumping from wells in stratified drift near streams and lakes can create a cone of depression which extends to the surface-water body, thereby reversing the water-table gradient and causing water to infiltrate into the ground-water reservoir toward the wells. Thus where coarse-grained stratified-drift deposits border and are hydraulically connected to a stream or lake, surface water can be an important potential source of ground-water supply.

The quantity of water which could potentially be induced to infiltrate stratified-drift deposits from a surface-water body can be expressed by a modified form of Darcy's law, as adapted from Walton (1962, p. 14):

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

Q = Vertical leakage of water from the stream or lake, in gpd

p' = Coefficient of permeability of the bottom deposits underlying the stream or lake, in gpd per sq ft

$\frac{\Delta h}{m'}$ = Vertical hydraulic gradient between the surface-water body and the aquifer, where

Δh = Change in hydraulic head, in feet, and

m' = Thickness of the deposits tending to restrict infiltration, in feet

A = Area of contact between the surface-water body and the underlying deposits, in square feet.

In lakes and ponds, permeability of the bottom deposits may be the limiting factor to induced infiltration. The bottom deposits of most lakes and ponded streams are largely fine-grained muck, silt, and fine sand which would severely restrict induced infiltration. More favorable conditions exist along major non-ponded streams, where streambed materials are almost everywhere gravel. Even in these areas, though, examinations of stream channels and logs of borings suggest that the vertical permeability of bottom deposits is highly variable, perhaps ranging from 1 to 1,000 gpd per sq ft. No quantitative determinations of the permeability of these deposits or of infiltration rates have been made in the area. In evaluating areas favorable for the development of large ground-water supplies, average vertical permeability of fine-grained bottom deposits was estimated as 1 gpd per sq ft, and of coarse-grained bottom deposits as 50 gpd per sq ft. These estimates are tentative and subject to considerable local variation.

The effective permeability of the deposits increases with increased water temperature. When surface water is warm, its viscosity decreases, and it can infiltrate more readily than when it is cold. Thus during summer months, when stream temperatures may reach 80 degrees or more, infiltration potential is considerably greater than average, and during winter months, when water temperatures approach 32 degrees, infiltration potential is much less than average.

Potential infiltration from streams increases also during times of high flow, when not only is there more water available, but the water is in contact with a larger area of stream channel. The factors of temperature and of area of contact tend to offset each other, however, because most high flows occur during the winter and spring, when the water is relatively cool.

The maximum vertical hydraulic gradient between a stream or lake and an aquifer can be obtained by lowering the water table below the bottom sediments that tend to restrict infiltration. Under these conditions, Δh equals m' plus the depth of the water body, and $\frac{\Delta h}{m'}$ is greater than 1. Thus where the restricting deposit is thin and the overlying water body is deep, the maximum vertical hydraulic gradient may be several times 1.

Regardless of how favorable conditions may be for induced infiltration, the water potentially available cannot, of course, exceed the amount of water in the stream or lake, and estimates of the amount of water available from this source should take into account the amount and variations of streamflow or lake storage.

WATER FROM AQUIFER STORAGE

Aquifers act not only as media for transmitting water, but as storage reservoirs. Much like surface reservoirs, water may be withdrawn from aquifer storage when other supply sources are deficient, to be replaced during times of more abundant supply.

Natural discharges from storage occur continuously, but net depletion of storage occurs every year during the period of no recharge, which may last as long as six months. This natural depletion of storage during the period of no recharge is the result of two factors: (1) the discharge by evapotranspiration during the growing season, which both reduces recharge to the ground-water reservoir and depletes the reservoir itself, and (2) the continued though steadily diminishing discharge of ground-water outflow. During the period that the ground-water reservoir is being depleted naturally by evapotranspiration and ground-water outflow, any withdrawals by pumping, exclusive of induced infiltration, must also come from storage. Thus, if wells are to sustain their yields on a year-round basis, they must depend in part upon water available from storage for perhaps as long as six months at a time. The amount of water which will drain from an aquifer in a six-month period is therefore a significant factor in evaluating the amount of water available to wells. This storage factor has been determined only for the stratified-drift aquifer because only in that aquifer is the value likely to have any practical application in evaluating and developing water supplies.

STRATIFIED DRIFT

Large volumes of water--many billions of gallons--are stored in the stratified-drift aquifer in the Shetucket River basin. However, not all of this water is available to wells, even under conditions of maximum development. Ground water moves through stratified drift to wells under the influence of gravity, but some of the stored water is held against gravity by molecular and surface tensional forces. Specific yield expresses the maximum amount of water that will drain by gravity from a volume of earth materials and is therefore potentially available to wells. The laboratory specific yield of 12 samples of stratified drift in the basin ranged from 30.4 percent to 46.3 percent and averaged 41.0 percent.

Several factors tend to make the practical yield from storage less than the laboratory specific yield. Laboratory results may be as much as 5 percent higher than true specific yields owing to limitations inherent in the laboratory method (A. I. Johnson, oral communication, 1964). Furthermore, the amount of water that drains from a deposit is a function of time, and specific yield represents the time of essentially complete gravity drainage. It is estimated that for the Shetucket River basin the yield of a unit of deposits which has drained six months would be approximately 98 percent of the specific yield (A. I. Johnson, oral communication, 1965). These two factors alone would reduce the average practical yield value to about 38 percent.

The effects of other factors are less easily evaluated. When the water table declines for six months, only the uppermost part of the dewatered zone drains the full time. The lowermost part drains only a very short time, and under these conditions the practical yield value of the dewatered deposits is less than if the entire section had drained the full six months. Most of the samples analyzed for specific yield were relatively homogeneous and well sorted, whereas most natural deposits of stratified drift are bedded and have abrupt textural changes. These features tend to reduce the amount of water which would drain from natural deposits in a given amount of time. Although each of these factors tends to lower the practical yield value, their effects cannot be evaluated quantitatively.

Considering the values of specific yield as determined in the laboratory and the factors that affect this value under field conditions a practical yield of 30 percent is judged reasonable for use in estimating the amount of water available from storage during a six-month drainage of stratified drift in the basin. For each foot of stratified drift that is dewatered under these conditions, approximately 3.6 inches of water, or 0.35 mgd per sq mi, is potentially available from storage.

QUALITY OF GROUND WATER

The chemical quality of ground water in the Shetucket River basin 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. Of the wells sampled, 91 percent yielded water with a hardness of less than 120 ppm, and 93 percent had a dissolved-mineral concentration of less than 200 ppm. The quantities and kinds of dissolved constituents, though generally low, vary widely from place to place and reflect the solubility and chemical composition of the different rock types with which the ground water has been in contact.

The chemical and physical properties of ground water in stratified drift and crystalline bedrock are summarized in table 27. Comparable information for the adjoining Quinebaug River basin is also shown. These data indicate that the chemical quality of ground water from stratified-drift and crystalline-bedrock aquifers is very similar. This resemblance is due to the similarity of the rock types in the two basins. No samples were taken in till in the Shetucket River basin. However, since the chemical quality of water from bedrock and stratified-drift wells in both the Shetucket River basin and Quinebaug River basin are similar, it may be assumed that water quality from till deposits is also similar, for till is composed largely of material derived from crystalline bedrock. Individual analyses of samples are presented in the companion basic data report by C. E. Thomas, Jr. and others (1967).

The most abundant dissolved chemical constituents in ground water are silica, sodium, calcium, bicarbonate, and sulfate. The observed range in concentration of silica in the basin was from 6.3 ppm to 34 ppm, and the median was 17 ppm. These quantities are satisfactory for domestic use, but concentrations above 10 ppm are excessive for some industrial uses (American Water Works Assoc., 1951). Sodium ranged in concentration from 2.6 ppm to as high as 63 ppm in the samples collected, but generally did not exceed 10 ppm. Since the amount of potassium present was generally insignificant, it was included with sodium in the calculations. None of the three other constituents occurred in concentrations large enough to limit the use of ground water for most purposes.

Generally calcium, magnesium, and sodium are present in the form of bicarbonate and sulfate in various proportions and quantities which determine the chemical and physical characteristics of natural water. Most samples of natural ground water collected throughout the basin were of the calcium bicarbonate type and were not excessively hard. The low concentrations are not corrosive to water-supply systems and the samples have a proportionately lower noncarbonate hardness than calcium-sulfate type water. A few samples were distinctly of calcium-sulfate type water with a

Table 27.--Comparison of chemical and physical characteristics of ground water in the Shetucket and Quinebaug River basins.

Water-bearing unit	Basin	Range	(Chemical constituents, in parts per million) Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium and Potassium (Na+K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Nitrate (NO_3)	Dissolved solids (calculated)	Hardness (as $CaCO_3$)	Specific conductance (micromhos at 25°C)	pH
Crystalline Bedrock	Shetucket River basin	Maximum	29	7.6	0.95	60	14	52	197	62	63	401	210	617	8.0
		Minimum	6.3	.00	.00	3.2	.4	3.0	3	3.4	.0	31	12	42	5.3
		Median	17	.07	.01	15	2.4	8.0	39	17	.7	91	45	143	7.0
	Quinebaug River basin	Maximum	34	4.8	.94	97	14	a/56	197	39	60	b/409	279	617	8.6
		Minimum	6.9	.00	.00	1.4	.2	a/ 2.4	2	2.4	.0	b/ 24	7	33	5.1
		Median	17	.07	.00	16	2.2	a/ 7.6	52	13	.9	b/100	54	153	7.0
	Total number of wells sampled		163	173	170	170	168	171	172	135	164	165	168	172	172
Stratified Drift	Shetucket River basin	Maximum	22	.35	.89	29	5.6	21	50	27	42	167	90	260	7.6
		Minimum	6.8	.00	.00	4.0	.6	3.9	13	5.8	.1	46	14	60	6.0
		Median	12	.14	.01	11	1.8	9.2	20	11	5.8	74	36	120	6.8
	Quinebaug River basin	Maximum	21	2.8	5.7	40	6.8	a/63	47	37	44	b/330	108	455	9.3
		Minimum	7.3	.00	.00	2.4	.3	a/ 2.6	4	.2	.0	b/ 31	9	39	4.8
		Median	14	.06	.01	11	1.8	a/ 5.3	25	12	2.9	b/ 80	37	117	6.5
	Total number of wells sampled		43	45	44	51	51	51	51	50	43	50	51	51	51
Till	Quinebaug River basin	Maximum	34	.49	.10	72	11	a/47	93	26	26	b/434	211	550	7.7
		Minimum	9.1	.00	.00	4.2	1.2	a/ 3.6	15	6.9	.3	b/ 79	38	61	5.8
		Median	15	.09	.00	17	3.0	a/ 8.0	44	13	8.3	b/108	50	147	6.6
	Total number of wells sampled		12	14	12	14	13	14	14	12	12	13	12	14	14

a/ For comparison, determined sodium and potassium calculated as sodium.

b/ Dissolved solids residue on evaporation at 180°C.

Table 28.--Comparison of some properties of calcium-sulfate type and calcium-bicarbonate type waters in the Shetucket River basin.

Well no.	Bicar-bonate 1/	Sul-fate 2/	Hardness as $CaCO_3$ (ppm)	Non-carbonate (permanent) hardness as $CaCO_3$ (ppm)	Specific conduct-ance (micro-mhos at 25°C)	pH
			Calcium-sulfate type water			
Nwh 31	6.9	42	40	30	128	6.2
Sp 1	5.9	43	42	35	119	5.9
Sp 6	10	46	75	53	204	6.2
Sp 8	4.5	53	64	55	183	5.7
			Calcium-bicarbonate type water			
Af 9	30	15	64	9	159	8.0
Bo 7	34	16	90	21	205	7.4
Clb 11	31	12	56	4	144	7.3
Ms 22	30	10	44	2	118	7.0

1/ Percent of dissolved-mineral content as carbonate.

2/ Percent of dissolved-mineral content.

lower pH value and a higher noncarbonate (permanent) hardness than calcium-bicarbonate water. Noncarbonate hardness due to the presence of sulfates and chlorides may form scale in pipes and boilers that cannot readily be removed. A comparison of some properties of calcium-sulfate and calcium-bicarbonate type water from selected wells in the basin is shown in table 28.

IRON AND MANGANESE

Iron and manganese are the only constituents present in concentrations large enough to be troublesome for industrial and household use, but relatively high iron and manganese concentrations in ground water generally appear to be confined to only a few wells, and these are scattered throughout the basin.

Most wells sampled in the Shetucket River basin yielded clear water containing little or no iron or manganese. Only 22 percent of the samples collected contained concentrations that equaled or exceeded 0.3 ppm of iron or 0.05 ppm of manganese, and the maximum concentration of iron and manganese in any of the samples was 7.6 ppm and 0.95 ppm, respectively. However, a well almost anywhere in the basin may tap ground water containing troublesome amounts of iron or manganese.

Whenever ground water containing more than about 0.3 ppm of dissolved iron is pumped from a well and exposed to the air, the water becomes cloudy, and usually an orange-brown film forms and deposits on the surface it contacts. Prolonged contact forms a film or scale that is difficult to remove. It also causes staining of laundered fabrics. In addition, iron precipitates can clog filters, nozzles, well screens and other appliances. The presence of certain iron-metabolizing bacteria ("crenothrix") can further complicate these conditions by forming colonies that later break loose in massive accumulations. High iron concentrations will also impart a metallic taste in water supplies.

Manganese resembles iron in its general chemical behavior. Water containing more than 0.05 ppm 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 may be accomplished in a variety of ways. Methods suitable for homes and small commercial establishments include water softeners (most units will remove up to 2 to 3 ppm effectively), chlorination-filtration units (especially suitable if chlorination to kill bacteria is also desired) and manganese-greensand filters. An excellent discussion of the iron and manganese problem as it applies to the domestic use of water, and controls that can be applied to remedy the situation is presented in Wilke and Hutcheson (1963).

It is possible that a well almost anywhere in the basin may tap ground water containing troublesome amounts of iron or manganese. However, the higher concentrations of iron and manganese in the bedrock aquifers in the basin are found within schists and gneisses which contain small amounts of pyrite, iron sulfides, and iron silicate minerals. The weathering of these minerals leaves a characteristic rust-colored oxide coating on surfaces of exposed bedrock. These schists and gneisses for purposes of discussion have been divided into three units which are delineated as A, B, and C on figure 47.

Unit A.--This unit occupies almost all of the northern half of the Shetucket River basin and extends into the Quinebaug River basin. The bedrock in this area is a dark rusty-weathering Brimfield schist containing graphite, purplish biotite, pyrite, and garnet, among other minerals (Rodgers and others, 1959). Of 20 wells sampled from this unit, 10 yield water with more than 0.3 ppm iron and/or 0.05 ppm manganese, and concentrations ranged as high as 5.0 ppm iron and 0.26 ppm manganese. Commercial analyses have reported iron concentrations as high as 9.4 ppm in this unit. Wells that obtain water with low concentrations of iron from the bedrock in this area probably tap thin layers of lime-silicate rock and quartzose gneiss that are found within the Brimfield schist. The Brimfield schist around Stafford, Stafford Springs, and Westford may contain a rusty-weathering pyritic graphite phase which has a higher concentration of iron and manganese minerals. Iron and manganese in water from many wells in these towns have large concentrations that require treatment. However, these concentrations are localized as they are in the other units delineated in figure 47.

Unit B.--The iron-bearing ground water in

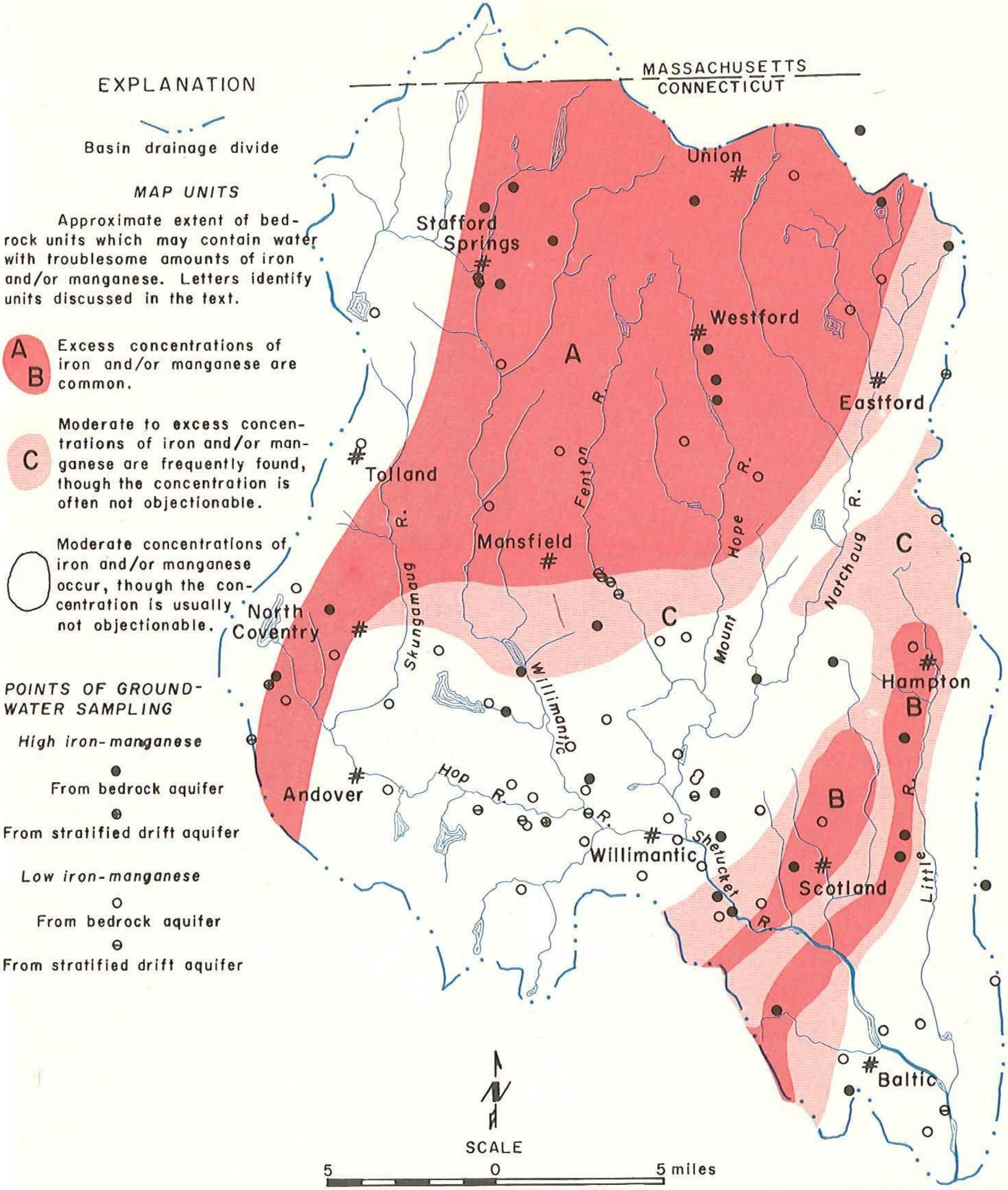


Figure 47.--Areal distribution of iron and manganese in ground water in the Shetucket River basin.

Ground water in many wells tapping bedrock in the northern and southeastern parts of the basin contains troublesome amounts of iron and manganese.

unit B, located in the southeastern portion of the basin, is restricted to a rusty-weathering muscovite schist. A characteristic bright rust-colored oxide coating on surfaces of exposed bedrock is evidence of the presence of iron-bearing minerals in these areas. Water samples from 7 wells tapping this bedrock aquifer contained from 0.02 to 7.6 ppm of iron and from 0.00 to 0.16 ppm of manganese. Limits for iron and/or manganese recommended by the USPHS (1962) were exceeded in five of the wells.

Unit C.--Several different rock types with a great variety in mineral composition make up this unit, which underlies parts of the central and eastern portions of the basin. The purplish to brownish stain noted on some outcrops of bedrock indicates at least local occurrence of iron-bearing ground water. Water samples collected from wells tapping bedrock contained from 0.00 to 3.3 ppm of iron and 0.00 to 0.25 ppm of manganese. In the same unit in the Quinebaug River basin, only 15 percent of the samples contained more than 0.3 ppm of iron, but approximately 60 percent contained quantities that could cause slight staining of porcelain and utensils after prolonged use (Randall and others, 1966).

Problem areas cannot be defined for the stratified-drift aquifer because only a relatively small number of water samples were collected. However, since the lithologic characteristics of the Quinebaug and Shetucket River basins are similar and data in table 27 indicate similarity in chemical quality of the ground water, it may be assumed that iron and manganese problems in stratified drift are similar to those in the Quinebaug River basin. Usually wells tapping the upper part of the stratified drift yield water that does not contain objectionable amounts of iron. However, in areas underlain by the Brimfield and Scotland schists, shown in figure 47 as units A and B, iron-bearing ground water may occur both in the lower part of the stratified drift and in the upper part of the underlying bedrock.

FLUORIDE

Fluoride comprises a very small percent of the dissolved mineral content of both ground and surface waters in the Shetucket River basin. It is generally present in surface waters in concentrations of 0.2 ppm or less and in ground waters in concentrations of less than 0.5 ppm. However, 6 out of 75 wells sampled in the basin contained fluoride concentrations of from 0.6 ppm to 2.0 ppm. These 6 wells are located on an axis through North Coventry, South Coventry, and Willimantic. Only one of these wells taps sand and gravel; the rest tap bedrock.

The Connecticut Department of Health had previously analyzed water from wells in this area for fluoride. Eighteen of the wells sampled contained fluoride in concentrations ranging from 0.6 ppm to 2.2 ppm. The location of these eighteen wells and those sampled by the U.S. Geological Survey are shown on figure 48.

Fluoride in ground water is derived from scapolite and other complex fluoride-bearing minerals associated with metamorphic rocks. It may also be concentrated along thin mineralized veins or in pegmatites. Ground water dissolves the fluoride from the minerals as it moves along fractures in the rocks. The low solubility of these fluoride minerals limits the concentration of fluoride in ground water.

The wells yielding comparatively large concentrations of naturally fluoridated ground water are aligned in a northwest-southeast direction, as shown in figure 48. This alignment is believed to be related to prominent east-west trending lineations described by Aitken (1951). Compatible with the structures are well developed and complicated fracture systems. The fluoride content of ground water is governed by the mineralogic content of the bedrock, the structural features and associated fracture patterns, and is, in general, highest on the south side of Wangumbaug (Coventry) Lake and Mill Brook in South Coventry.

The wells sampled indicated that naturally fluoridated ground water is more prevalent in bedrock aquifers than in sand and gravel. The occurrence of the higher concentrations of fluoride in ground water along this North Coventry-South Coventry-Willimantic axis is found in several bedrock formations, though not all wells sampled in any of the formations had high concentrations.

Fluoride in water supplies is thought by many to be beneficial in decreasing the incidence to tooth decay. According to Foote (1962), a study of dental caries of school children using water from a small public supply in Coventry has indicated that the water obtained from deep wells has a sufficient fluoride content to be beneficial to its users. The upper limit of 1.3 ppm of fluoride in drinking water, shown in table 6, as suggested by the U.S. Public Health Service for this area, does not imply that consumption of water containing fluoride in excess of this amount is necessarily harmful. The suggested limit is designed to control the intake of fluoride by children during periods of bone calcification in order to prevent mottling to teeth.

HARDNESS

Hardness is a property of water that 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. Hardness 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, these elements 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

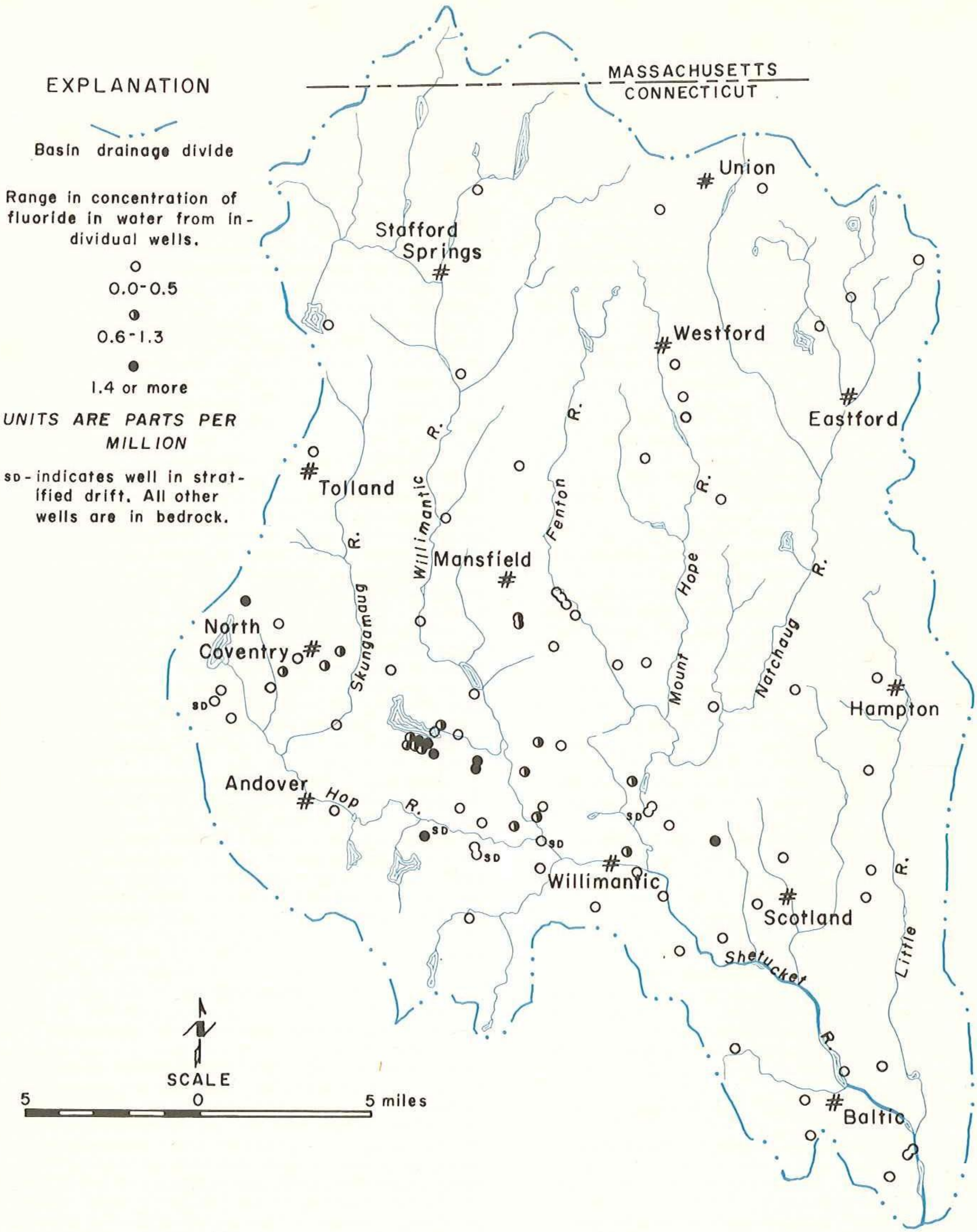


Figure 48.--Areal variation in concentration of fluoride in ground water in the Shetucket River basin.

High fluoride concentrations occur in ground water from many wells tapping bedrock in a broad band extending northwest from Willimantic through North Coventry.

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. The problems of hard water and use of water softeners has been fully described by Wilke and Hutcheson (1962).

Ground water in the Shetucket River basin is generally below 120 ppm in hardness. Samples from 88 wells were analyzed for hardness; of these, 68 percent were soft, 23 percent moderately hard, 8 percent hard and 1 percent very hard. Table 27 gives the maximum, minimum, and median hardness of water from the crystalline-bedrock and stratified-drift aquifers.

Water from these wells was found to be at least moderately hard at the scattered locations shown in figure 49. There are no large bedrock or stratified-drift aquifers composed principally of calcium or magnesium carbonates in the basin; therefore, no specific water-bearing formation will always yield water with hardness in concentrations large enough to be troublesome to the water user. Water having an objectionable degree of hardness in many cases also had objectionable amounts of iron and manganese, as shown by a comparison of data points in figures 47 and 49.

NITRATE, CHLORIDE, ABS, AND LAS AS INDICATORS OF POSSIBLE POLLUTION

Under natural conditions nitrate and chloride are absent or present only in low concentrations in the ground water of the basin, and ABS (alkyl benzene sulfonate) and LAS (linear alkylate sulfonate) are absent. Therefore, unusually large quantities of these constituents represent a departure from normal conditions, and, 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 81 wells in the basin were analyzed for nitrate and 15 percent were found to contain more than 10 ppm. Although many of the larger concentrations were probably derived from waste disposal, this does not mean that 15 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, as indicated in table 6. 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 2 well samples 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 2.7 ppm as shown in table 4, p. 23. Chloride-bearing minerals are scarce in the crystalline bedrock of the basin, usually less than 0.05 percent of total rock volume. Samples from 83 wells were analyzed for chloride and 83 percent of them were found to have a chloride concentration of less than 20 ppm with an average of 7.2 ppm. This concentration is within the range expected for naturally occurring ground water in the basin.

The average chloride concentration of the water from the remaining 17 percent of the wells sampled was 51 ppm. Sodium chloride or a mixture of sodium and calcium chloride are used extensively as road-salting chemicals for protection against hazardous icing of roads and because some wells along such roads yield noticeably salty water, it is believed that road salt has infiltrated into portions of some aquifers in the Shetucket River basin. However, even the largest observed concentration of 107 ppm is far below the 250 ppm limit recommended for drinking water by the U.S. Public Health Service.

ABS was the principal component of household detergents prior to mid-year 1965. Its presence

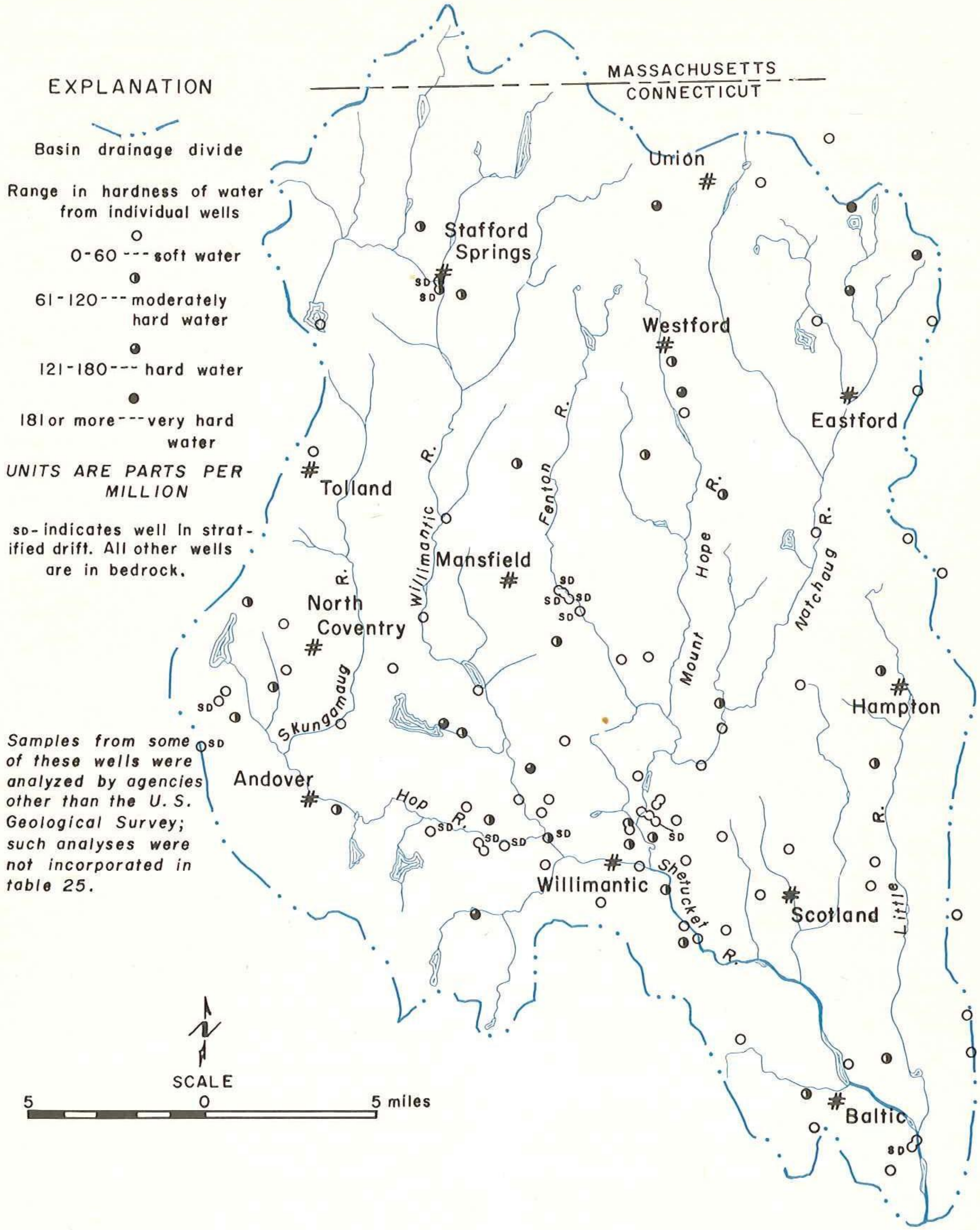


Figure 49.--Areal variation in hardness of ground water in the Shetucket River basin.

Ground water in most wells tapping bedrock is relatively soft, and few wells obtain hard or very hard ground water.

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 of ABS in drinking water can be tasted and can cause frothing of the water. Although larger concentrations of ABS are not toxic, esthetic considerations have caused the U.S. Public Health Service (1962, p. 24) to recommend that concentrations in drinking water not exceed 0.5 ppm. The maximum ABS content in samples collected from 7 wells during the study was 0.1 ppm, which is not enough to cause problems. However, a few wells in the basin were reported to yield water that frothed noticeably, suggesting much larger concentrations.

Since July 1965 the ABS component of household detergents has been gradually replaced by LAS, which 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 Shetucket River basin continues to expand, the nitrate, chloride, and detergent concentrations of ground water are likely to increase also, especially in areas not served by sewage systems. 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 in the basin is 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, it is not within the scope of this study to pinpoint localities where ground water is unfit for human use.

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, ABS and LAS may maintain objectionable concentrations for greater distances; some dissolved chemical pollutants may even remain in ground water indefinitely. 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 and transports contaminants in the direction of the average land-surface slope toward the nearest permanent stream. Therefore, wells located downslope from a source of pollution are usually more susceptible to contamination.

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 the direction of ground-water flow. 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 a solid casing many feet below the water table, polluted water may not reach the zone from which water enters the well.

The likelihood of well contamination from bacteria in septic tank èffluent can be evaluated according to a system devised by LeGrand (1964). The method involves estimates of depth to water table, sorptive characteristics and permeability of overburden, gradient of the water table, distance between well and septic tank, and thickness of overburden. Using conservative and slightly unfavorable values for the first five factors, the possibility of contamination of a bedrock well at a site with 40 feet of till overburden is, according to this system, "possible but not likely." With normal precautions taken in the placement and construction of the well and septic tank, the possibility becomes very unlikely. Areas where till is known to be at least 40 feet thick are shown on plate B.

TEMPERATURE OF GROUND WATER

Ground water is relatively constant in temperature in comparison with streams and ponds. Nevertheless, there are small differences in water temperature from well to well, and seasonal fluctuations which occur are greatest near the land surface and decrease with increasing depth.

Randall and others (1966) reported that the temperature of water in very shallow wells in the Quinebaug River basin can fluctuate as much as 20°F each year, with a low of 35°F to 40°F and a high near 55°F. The 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 rises once again above water temperature in March or April. In localities where the water table remains more than 30 feet below the land surface, ground water is insulated from changes of air temperature and seasonal fluctuations are small. The temperature of ground water 30 to 60 feet below the land surface in most localities is within 2 or 3 degrees of the annual mean air temperature, which is about 48°F throughout the Shetucket River basin (Goslee and Brumbach, 1961, p. 9, p. 26). Water obtained from depths greater than 60 feet is nearly constant in temperature.

WATER USE-PRESENT AND FUTURE

WATER USE IN 1961

The total amount of water used in the Shetucket River basin for all purposes during 1961 is estimated to have been 5,810 million gallons. This is equivalent to an average of approximately 208 gpd per capita exclusive of that used by the University of Connecticut and Mansfield State Training School. If the water used by these institutions is included, the average per capita use is estimated to be 167 gpd. A little over one half of the total used was withdrawn by industries for their own use. Almost all of the water used was for non-consumptive purposes. Approximately 90 percent of the water used by industry was withdrawn from surface supplies; of this, about 88 percent was returned to streams. Cooling and processing accounted for the largest use of water by industry; cooling accounted for about 59 percent and processing for about 40 percent of the water used.

The source, use, and disposal of water in the basin are summarized by figure 50. The data on which this figure is based were supplied by water utilities and major industrial firms or by State agencies. The domestic use in homes having their own sources of water was computed by multiplying an estimated per capita use of 70 gpd by the difference between total population and population served by public water systems. The estimate for agricultural use represents, for the most part, the water needed to supply dairy cows, poultry, and other livestock in the basin. Very little water was used for irrigation. The actual quantity of domestic disposal of water to public and institutional sewage treatment plants is probably lower than that estimated. There are indications that sewage treatment facilities in the basin are at times overloaded and proper sewage treatment of all effluent is not accomplished. Pollution abatement planned by the Connecticut Water Resources Commission should eliminate these adverse conditions.

Eleven public and institutional water-supply systems supplied the domestic water needs of nearly half the population of the basin. Public water supplies provided about 6 percent of the water used by industry in 1961. The source of water, capacity, type of treatment, population served, and other important features of each of the 11 systems are described in table 29. There are a few small community systems that are not included in this tabulation.

Residents served by the 11 water-supply systems listed in table 29 generally receive soft water with low concentrations of dissolved solids. Chemical analyses of 10 of the 11 water-supply systems are shown in table 30. In general, all these public and institutional water supplies serve water of good chemical quality. With the exception of a few relatively high iron or manganese concentrations, the chemical quality of most of the water-supply systems is far below the maximum concentrations suggested by the U.S. Public Health Service. The fluoride concentrations in the water of the Mansfield State Training School and the City of Willimantic water-supply system are near the optimum value suggested by the U.S. Public Health Service. They are the only systems that fluoridate. Color, iron, and manganese vary considerably from time to time, and the relatively high concentrations shown in table 30 may not represent average conditions. Such variation is particularly evident when the source of water is from a surface supply. Abnormally high color and high iron or manganese concentrations may also be the result of some localized condition.

WATER USE IN THE FUTURE

The amount of water used in the Shetucket River basin in 1961 will quite likely 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 (1964, p. 124) forecasts for the Windham Planning Region, which comprises most of the basin, a population increase of 94 percent by the year 2000 and an increase of 122 percent in per capita use of water for all purposes, including industrial as well as domestic use (Connecticut Development Commission, 1963, p. 59). If these predictions are realized, the total water demand in the basin in the year 2000 would be 4.3 times as great as the use in 1961, or 25 billion gallons per year. The basin can certainly provide this amount of water.

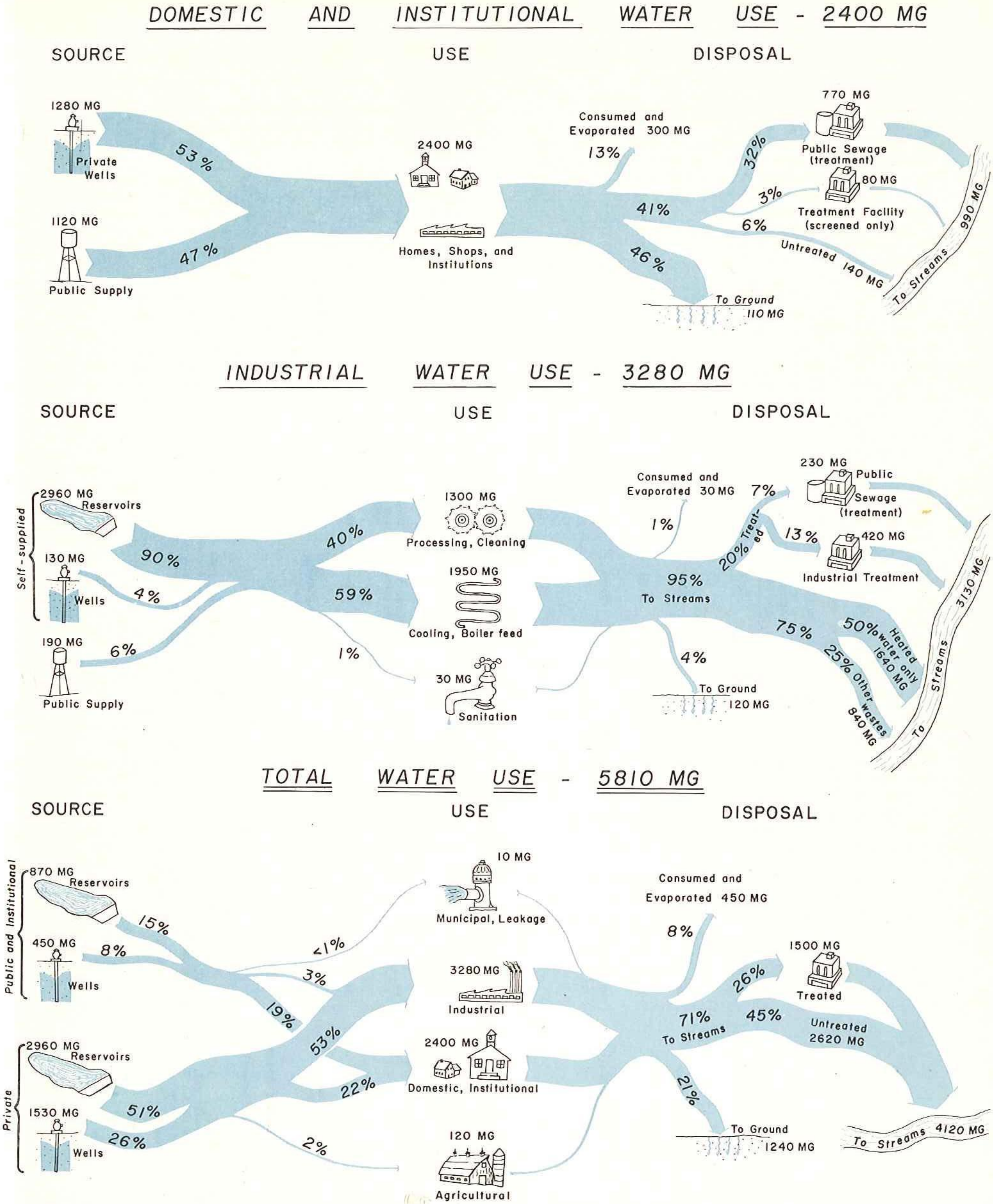


Figure 50.--Source, use, and disposal of water, in million gallons, in the Shetucket River basin during 1961.

Most water used in the basin is obtained from surface-water sources, although homes and institutions obtain their greatest supplies from private wells. Industry is the largest user of water, most of which is used for cooling and boiler feed. Streams receive the largest proportion of discharge water, most of it untreated. Most water discharged from homes and institutions goes into the ground through septic tanks.

Table 29.--Description of selected public and institutional water-supply systems in the Shetucket River basin.

Water-supply system	Community supplied	Estimated population served	Primary source of water	Auxiliary or emergency sources	Treatment	Capacity of treatment plant (mgd)	Raw water storage (mg)	Finished water storage (mg)	Amount used (mg)	Amount used year
Angus Park Woolen Company	Hanover	150	Hanover Reservoir	None	Soda ash, alum, pressure filtration, chlorination	--	--	0.05	[a,b] 35	1963
Baltic Water Company	Baltic	1,200	Baltic Reservoir	None	Chlorination	--	110	--	54	1963
City of Norwich, Water Department	Taftville	4,000	3 Reservoirs	None	Chlorination	--	110	None	110	1963
City of Willimantic, Water Department	Willimantic	[c] 16,200	Willimantic Reservoir	None	Aeration, alum, lime, sedimentation, rapid sand filtration, activated carbon, chlorination, fluoridation, calgon	2.50	120	5.60	561	1962
Connecticut Water Company	Stafford Springs	3,000	3 Reservoirs	2 Caisson wells	Chlorination and lime	.86	1.46	.18	101	1962
Lakeview Terrace Supply Company	Coventry	600	7 Wells	None	--	--	--	--	[a,d] 15	1963
Mansfield State Training School	--	3,000	2 Wells	Univ. of Connecticut	Chlorination and fluoridation	.60	None	1.50	[e] 140	1964
Occum Water Company	Occum	350	5 Wells	None	Chlorination	--	--	--	[a] 8	1963
South Coventry Water Supply Company	South Coventry	600	[f] 2 Wells	Wangumbaug Lake	Chlorination	--	None	.06	[g] 12	1963
Tolland Aqueduct Company	Tolland Center	260	Tolland Reservoir	[h] 2 Wells	Chlorination	--	--	--	[e] 6	1963
University of Connecticut	--	[i] 15,000	3 Wells	Well	None	--	1.90	1.90	[e] 276	1963

a Estimated.
b 88% domestic use, 12% industrial.
c Includes about 300 families outside of Willimantic.
d Entirely domestic use.
e 80% domestic use, 15% industrial use, 5% other uses.
f Supplemented by water from Wangumbaug Lake.
g 85% domestic, 15% commercial.
h Will become a primary source of water.
i Varies with student enrollment.

Table 30.--Chemical analyses of water from selected public and institutional water-supply systems in the Shetucket River basin.

(Chemical constituents, in parts per million.
Source: F, finished water; R, raw water. Analyses by the U.S. Geological Survey)

Public water-supply system	Date of collection	Source	Silica (SiO_2)	Iron (Fe)	Man-gan-ese (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 $CaCO_3$		Specific conductance (micromhos at 25°C)	pH	Color	ABS	Turbidity
																Calcium, magnesium	Non-carbonate					
U.S. Public Health Service 1962 drinking water standards (upper limits)	--	--	--	0.3	0.05	--	--	--	--	--	250	250	a/1.3	45	500	--	--	--	--	15	0.5	5
Angus Park Woolen Company	3-19-64 R	Hanover Reservoir	7.6	.07	.06	4.4	0.7	4.2	0.4	8	9.2	4.8	.1	1.0	39	14	8	51	6.4	8	.0	1
	3-19-64 F	Hanover Reservoir	7.4	.67	.01	4.0	1.9	8.2	.5	11	16	5.8	.1	.6	54	18	9	77	6.5	7	.0	1
	6-24-64 R	Hanover Reservoir	--	.11	--	--	--	--	--	--	--	--	--	--	--	--	--	62	6.9	--	--	--
	6-24-64 F	Hanover Reservoir	--	.10	--	--	--	--	--	--	--	--	--	--	--	--	--	74	7.1	--	--	--
Baltic Water Company	8-22-63 R	Baltic Reservoir	2.7	.09	.17	4.4	1.2	3.9	.8	10	8.2	6.0	.0	.4	33	16	8	59	6.2	3	--	.4
City of Norwich, Water Department	1- 9-64 R	Taftville Reservoir	.9	.06	.08	3.8	1.1	7.6	1.0	5	14	10	.1	.5	45	14	10	77	6.4	3	.0	--
City of Willimantic, Water Department	7-17-63 R	Willimantic Reservoir	5.9	1.4	.21	7.2	1.6	4.0	1.2	21	6.8	6.8	.0	1.2	50	25	8	73	6.2	36	.1	.6
	7-17-63 F	Willimantic Reservoir	6.2	.05	.18	13	1.5	4.7	1.3	22	18	8.3	1.2	.2	66	39	21	114	6.5	3	--	1
Connecticut Water Company, Stafford Springs Division	8-21-63 R	Reservoir No. 2	4.4	.36	.08	3.3	2.4	2.1	.7	13	4.4	4.9	.0	.6	31	18	8	42	6.2	17	--	.5
	8-21-63 F	Reservoir No. 2	4.2	.24	.03	20	2.0	1.8	1.5	36	7.6	20	.1	.2	91	58	29	138	7.2	3	--	.6
Mansfield State Training School	5-28-64 R	Well Ms 24	13	--	--	13	4.5	b/9.2	--	22	27	14	.1	6.9	c/99	51	33	155	6.2	--	--	--
	7-24-64 F	Well Ms 25	13	.00	.00	10	1.8	6.0	2.0	25	13	6.0	1.0	2.8	68	33	12	114	6.3	2	--	--
Occum Water Company	1- 9-64 R	Well Nwh 37	9.4	.01	.02	8.8	1.5	7.8	1.6	14	7.2	12	.0	15	78	28	17	112	6.8	3	.1	--
	1- 9-64 R	Well Nwh 38	15	.06	.01	11	2.1	5.7	1.8	31	7.8	8.0	.0	8.0	78	36	11	109	6.9	2	.0	--
South Coventry Water Supply Company	7-18-63 F	Wells Cv 21 & Cv 22	14	.03	.01	48	2.4	21	4.2	104	22	50	.4	5.1	235	130	45	390	6.9	3	.0	--
	7-18-63 F	Well Cv 23	9.6	.54	.04	32	2.9	42	7.6	49	19	88	.1	11	248	92	52	436	6.2	2	--	--
	7-18-63 F	Wangumbaug Lake	1.8	.07	.03	7.4	1.3	5.7	1.6	20	10	8.0	.1	.1	51	24	8	85	6.7	3	.0	1
Tolland Aqueduct Company	8-21-63 R	Tolland Reservoir	11	.15	.03	15	1.7	4.1	.8	47	9.2	5.0	.1	.3	73	45	6	109	7.8	8	--	.3
University of Connecticut	1-10-64 R	Well Ms 33	11	.00	.00	6.6	1.8	3.8	.7	18	8.2	7.4	.0	.4	52	24	9	73	6.9	1	.0	--
	1-10-64 R	Well Ms 34	12	.00	.00	6.4	1.0	3.4	.9	16	7.4	6.0	.0	.5	46	20	7	65	6.9	3	.0	--
	1-10-64 R	Well Ms 35	12	.00	.01	6.0	1.2	4.2	.8	18	6.8	5.3	.1	.6	47	20	5	60	6.7	1	.0	--
	1-10-64 R	Well Ms 36	14	.04	.03	12	2.4	7.0	3.9	28	12	12	.0	12	94	40	17	136	6.5	2	.0	--

a/ For optimum and lower limits see table 6, pages 14 and 15.
b/ Sodium plus potassium.
c/ Sum of dissolved constituents.

DEVELOPMENT OF WATER SUPPLIES

Some water may be obtained from aquifers or streams nearly everywhere in the Shetucket River basin. But requirements for water vary according to the intended use, and not all sources of water are equally suitable for all uses. Large supplies of water can only be obtained from some streams and some stratified-drift aquifers; those seeking smaller supplies generally have greater choice of source and location. An understanding of the potential yield of the alternative sources of water in an area of interest allows the farmer, the homeowner, the industrialist, or the water manager to determine whether he can obtain a supply which is both economical to develop and satisfactory for his needs.

SMALL SUPPLIES FOR HOMES AND SHOPS

Enough water for the average home or small business establishment can be obtained from aquifers almost anywhere in the Shetucket River basin. About 90 percent of the domestic wells drilled into bedrock supply 3 gpm or more, and water supplies of at least several gpm can be obtained in many areas of stratified drift from drilled, dug or driven wells finished in sand and gravel. Even glacial till, the poorest aquifer among the various types of earth materials, can provide enough water for a home at many sites.

Application of geologic factors may assist in selecting a site for a bedrock well in situations where there are several alternatives, such as in the initial choice of a building lot, but the precise yields to be expected at a specific site are generally unpredictable in advance of drilling. It should be emphasized, however, that yields sufficient for most domestic uses have been obtained at a very large percent of the sites drilled in the basin. Therefore, on most house lots, convenience may be the deciding factor in selecting a site for a domestic bedrock well. Even where fracture yield is low, adequate supplies for domestic purposes can be obtained at most sites by drilling deeply enough to provide for storage in the well.

Dug or driven wells are most practical to construct at sites where there is both a relatively shallow water table and a substantial thickness of saturated deposits, and where the likelihood of pollution is small. Dug wells in till usually require penetration of a greater saturated thickness than do those in stratified drift, because in till the drawdowns are greater and the seasonal fluctuations of the water table are larger at most sites. Driven wells may be installed at sites where the overburden is sand or fine gravel. Determining the suitability of conditions at a particular site for dug or driven wells generally requires preliminary test drilling, digging, or probing. Where there is a substantial saturated thickness of coarse-grained stratified drift, drilled screened wells can provide satisfactory supplies for small as well as large water needs.

The quality of naturally occurring ground water is satisfactory for domestic and commercial use in most places. In some wells iron problems may occur, but iron may be removed from the water by treatment. Pollution may occur in some heavily populated areas utilizing underground waste disposal unless wells are cased to a depth of at least 40 feet.

LARGE SUPPLIES FOR COMMUNITIES AND INDUSTRIES

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, and the ground-water runoff which sustains streamflow during dry weather comes largely from stratified drift. In addition, the yields of large-capacity wells in stratified drift are commonly sustained in part by induced infiltration from streams. The potential for large water supplies within the Shetucket River basin is summarized on plate D.

LARGE SUPPLIES FROM STREAMS

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." The yields available from existing ponds and reservoirs are summarized in table 14, p. 31.

Table 31.--Estimates of long-term yields

FAVORABLE AREA			GROUND-WATER OUTFLOW			INDUCED INFILTRATION					
			Favorable area plus adjacent territory which contributes ground water under natural conditions		(1) Ground-water outflow exceeded 7 years in 10	Drainage area of principal streams entering favorable area		(2) Streamflow equaled or exceeded 90 percent of the time during 1931-60 for principal streams entering favorable area	(3) Maximum potential induced infiltration capacity of stream- and lake-bottom deposits	(4) Maximum number of consecutive days during 1931-60 that streamflow of principal streams was less than column (2) or column (3), whichever is less	(5) Average streamflow during time listed in column (4)
Symbol (Pl.D)	Location	Size (sq mi)	Total area (sq mi)	Percent stratified drift	(mgd)	Total area (sq mi)	Percent stratified drift	(mgd)	(mgd)	(days)	(mgd)
A	Willimantic River near West Willington	0.71	6.45	24.2	3.1	79.3	13.4	12.3	55.2	63	7.6
B	Willimantic River, Baxter Road to South Coventry Station	1.75	16.3	24.9	7.8	97.9	18.8	13.6	94.3	52	8.9
C	Willimantic River near Perkins Corner	.55	3.32	42.5	1.9	121	19.2	21.8	24.7	105	13.8
D	Natchaug River, Phoenixville to Chaplin Center	1.36	14.0	18.6	7.0	55.4	14.6	6.5	105	65	4.0
E	Natchaug River, Bedlam Corner to North Windham	.82	3.52	60.8	2.5	77.2	16.1	11.0	35.0	70	6.4
F	Mount Hope River, Mount Hope to Atwoodville	.43	3.76	23.1	1.8	31.1	7.5	2.8	25.0	88	.9
G	Fenton River below U.S. Highway 44A	.90	13.6	13.7	5.9	17.4	12.6	1.6	37.5	82	.9
H	Fenton and Mount Hope Rivers at Turnip Meadow	.51	1.51	62.9	1.1	68.4	11.0	5.9	.2	0	--
J	Natchaug River, South of Willimantic Reservoir	.41	1.29	86.0	1.1	167	17.3	19.3	37.2	38	4.5
K	Potash Brook above State Highway 14	.83	2.67	61.4	1.8	[a] 0	--	--	.2	--	--
L	Shetucket River near South Windham	1.01	11.0	32.0	5.9	401	18.0	64.2	160	112	37.0
M	Merrick Brook near Scotland Center	.23	.89	41.6	.5	8.18	14.0	.8	3.6	86	.5
N	Little River near Hampton Center	.83	4.78	28.7	2.7	8.61	6.8	.8	9.1	58	.5
P	Little River near Hanover	.14	.66	36.4	.4	33.9	18.6	7.8	7.7	63	4.0
Q	Shetucket River near Taftville	.16	.57	77.2	.4	514	19.1	77.5	34.3	6	33.0

a Favorable area includes all of Potash Brook above State Highway 14 except for one very small tributary.

from selected favorable ground-water areas in the Shetucket River basin.

GROUND-WATER STORAGE		ESTIMATED LONG-TERM YIELDS					
(6)	(7)	A	B	C	D	E	
		During recharge period (185 days)	During period of no recharge (180 days of withdrawal from storage)				Average daily yield for the year, exceeded 7 years out of 10
			During days of deficient streamflow		During days of adequate streamflow		
Water in aquifer storage which would drain during the six-month period of no recharge	Practical yield from aquifer storage during the six-month period of no recharge; 1/3 of column 6	2 x column (1) - column (7) + column (2) or column (3), whichever is less	Column (4)	Column (1) or column (7), whichever is less, + column (5)	180 - column (4)	Column (1) or column (7), whichever is less, + column (2) or column (3), whichever is less	(185 x column A + column B x column C + column D x column E) ÷ 365
(mgd)	(mgd)	(mgd)	(days)	(mgd)	(days)	(mgd)	(mgd)
8.3	2.8	15.7	63	10.4	117	15.1	14.6
26.3	8.8	21.4	52	16.7	128	21.4	20.7
16.6	5.5	23.7	105	15.7	75	23.7	21.4
15.1	5.0	15.5	65	9.0	115	11.5	13.1
13.6	4.5	13.5	70	8.9	110	13.5	12.6
4.0	1.3	5.1	88	2.2	92	4.1	4.1
15.2	5.1	8.3	82	6.0	98	6.7	7.4
8.3	2.8	1.3	0	1.1	180	1.3	1.3
23.6	7.9	20.4	38	5.6	142	20.4	18.9
16.4	5.5	1.8	180	1.8	--	--	1.8
55.4	18.5	70.1	112	42.9	68	70.1	61.8
2.8	.9	1.3	86	1.0	94	1.3	1.2
9.3	3.1	3.5	58	3.2	122	3.5	3.5
1.8	.6	8.1	63	4.4	117	8.1	7.5
1.9	.6	34.7	6	33.4	174	34.7	34.7

LARGE SUPPLIES FROM STRATIFIED DRIFT

Large supplies of ground water can be obtained from stratified drift in many parts of the Shetucket River basin. Average long-term yields of 15 such areas, shown on plate D, which were selected as the most favorable areas for ground-water development in the basin, are estimated to range from 1.3 mgd to 60.2 mgd, as shown in table 31. These areas are deemed favorable for the development of large ground-water supplies on the basis of several criteria:

1. They are located within areas mapped as coarse-grained stratified drift.

2. Maximum saturated thickness of stratified drift is at least 40 feet.

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

In general, each area is suitable for the construction of large capacity screened wells because of the predominance of coarse-grained stratified drift. Nevertheless, the great variability of the thickness and texture of these deposits means that not every point is equally favorable, and test drilling to locate the most favorable well sites should therefore precede final development within an area.

Yields of 100 gpm or more from individual wells can be obtained in other areas of the basin where there is a substantial saturated thickness of coarse-grained stratified drift. It may be possible to obtain long-term yields similar in magnitude to those listed in table 31 in some of these areas, but in most of them the lower saturated thickness and smaller areal extent will result in smaller long-term yields.

METHOD OF ANALYSIS

The long-term yield represents the amount of water which could be withdrawn by pumping from an area as a whole for an extended period of time. In effect, the value is the sum of estimates of water available from ground-water outflow and from induced infiltration, adjusted as necessary where the amount of ground water available from storage imposes limitations.

In estimating long-term yields, data and relationships presented in earlier sections of this report were applied to the 15 selected areas deemed most favorable for the development of large ground-water supplies. The method could also be applied to estimate the long-term yields of any other area in the basin. Certain assumptions were made in selecting the hydrologic parameters used. These were based largely on an understanding of the hydrologic and geologic environment, but in addition, some consideration was given to the practical aspects of development, because it may not be feasible to obtain all the water available.

In each area efficiently developed screened wells yielding more than 100 gpm and situated along the principal streams would be needed to obtain the estimated long-term yields. Such a system of wells could most effectively intercept ground-water outflow and induce stream infiltration. At each site tests would be required to determine specifically the number, spacing, and yields of wells needed to obtain the long-term yields efficiently and economically. To withdraw all or even half of the water available from storage would require a great many small-capacity wells distributed throughout each area, an impractical measure. It is estimated that it would be practical to obtain one-third of the available storage with a system of large-capacity wells, and this value was used in determining the water potentially available from storage.

Ground-water outflow exceeded seven years in ten was selected as a practical value of water available from this source. The minimum annual ground-water outflow to be expected, as determined from figure 46, was considered too restrictive, because it represents a condition which occurred only once in 30 years of previous record. The average was considered too high, because there would be many years in which ground-water outflow would be below average, and annual yields would therefore have to be adjusted frequently. Ground-water storage or induced infiltration of surface water can be used to sustain yields during the occasional year that ground-water outflow fails to equal the values used.

Ground-water outflow exceeded 7 years out of 10, shown in column 1 of table 31, was obtained from figures 46 and 23. The values were based on the percent of stratified drift in each favorable area and adjacent territory draining toward it.

Streamflow exceeded 90 percent of the time during 1931-60 was selected as a practical value for water available from induced infiltration and is indicated for most streams in the basin on plate D. This index of low flow expresses the minimum amount of streamflow potentially available nearly all of the time, and therefore the length of time that stream channels would be dry--an undesirable condition in most areas--is relatively short. Nevertheless, there are certain times of most years when streamflow drops below the 90-percent duration value, thereby reducing the amount of water available from this source. The maximum number of consecutive days of such a deficiency and the average streamflow during those periods during 1931-60 was used to take this condition into account. The maximum potential induced infiltration capacity of the bottom deposits was used as the limiting factor where this value was less than the 90-percent flow duration. In each area it was assumed that the time of deficient streamflow occurs during the six-month period of no recharge, which is, in fact, the time of lowest streamflow.

Streamflow equivalent to the 90-percent duration flow, shown in column 2 of table 31, was determined for all principal streams entering each favorable area, using where possible, the actual flow-duration curves of the streams. Where these curves were not available, regional flow-duration curves in figure 24 based on percent of stratified drift in the drainage area were used and values were adjusted to local conditions using the isopleths in figure 23.

Maximum potential infiltration capacity of the bottom deposits, shown in column 3, was calculated using the equation shown on page 68. Stream widths were measured in the field during low-flow conditions or estimated from topographic maps; stream lengths were determined from topographic maps. Permeability of 50 gpd per sq ft was assumed for coarse-grained bottom deposits, and 1 gpd per sq ft for fine-grained bottom deposits.

Usable streamflow was considered to be either the 90-percent duration flow or the maximum potential induced infiltration capacity, whichever is less. The maximum number of days that actual streamflow was less than the usable streamflow during 1931-60, shown in column 4, and the average streamflow during this period, shown in column 5, were interpolated from graphs based on lowest annual average flow for a 31-year recurrence interval for periods of 7, 30, 60, and 120 days from table 10, and the lowest daily flow not exceeded during the same periods from ratios given in paragraph 2 on page 28.

Ground water available from storage during a six-month period of no recharge, shown in column 6, was evaluated by first determining the volume of saturated stratified drift in each favorable area by using planimetered areas between the saturated thickness contours on plate B and estimates of average thickness of each area. Volume was multiplied by a six-month yield figure of 30 percent and converted to mgd for 180 days. Under practical conditions of development, one-third of this ground water available from storage was considered obtainable during the six-month period, as shown in column 7.

SUMMARY OF ESTIMATED LONG-TERM YIELDS

Water available in a given area varies from time to time and the long-term yields in table 31 are therefore given for several specific conditions of water availability: (1) for a recharge period of approximately six months (185 days); (2) for a six-month period (180 days) of no recharge, during part of which (a) there is also deficient streamflow into the favorable area, and during part of which (b) there is adequate streamflow entering the favorable area; and (3) the average daily yield for a complete year, exceeded seven years out of ten. It should be noted that the yield during condition (2a) represents the maximum yield which can be sustained continuously throughout the year without having to adjust withdrawals to account for seasonal changes in hydrologic conditions.

The magnitude and timing of differences in yields during the course of a particular year depend largely upon the adequacy of water available from storage and variations in streamflow. For example, along the Willimantic River from Baxter Road to South Coventry Station, designated as Area B, the average yield from usable aquifer storage of 8.8 mgd is more than enough to sustain withdrawals at the average ground-water outflow rate of 7.8 mgd during the 180 days of no recharge when the entire supply must come from storage. Thus in this area withdrawals can be sustained at the average ground-water outflow rate throughout the year, plus the amount available from induced infiltration.

In Area B, water available from induced infiltration from streams is considered to be determined by the 90-percent flow duration, or 13.6 mgd, which is less than the induced infiltration capacity of the bottom deposits of 94.3 mgd. During 1931-60 the streamflow dropped below 13.6 mgd for a maximum of 52 consecutive days, during which the average streamflow was 8.9 mgd. The average rate of induced infiltration during a similar 52-day period must therefore be reduced to 8.9 mgd.

Thus, in any area similar to Area B where there is sufficient water available from ground-water storage, there are just two different yield values during the year: one for periods of adequate streamflow, when flow is above that exceeded 90 percent of the time, and one for periods of deficient streamflow, when flow is less than this. In Area B the average yield for the 52 days of deficient streamflow is 7.8 + 8.9, or 16.7 mgd, and for the rest of the year, 313 days, when there is adequate streamflow, the average yield is 7.8 + 13.6, or 21.4 mgd. The average daily yield for the entire year is the weighted average of these two values, or 20.7 mgd.

In four of the favorable areas, A, D, F, and G, the average yield from aquifer storage is less than the average ground-water outflow rate. In areas such as these, withdrawals during the 180 days of no recharge, when supplies must come entirely from aquifer storage, must be less than the average outflow rate. On the other hand, during the recharge period withdrawals can exceed the average outflow rate. Thus the average withdrawal rate for the year would equal the average outflow rate, and aquifer storage would not be permanently depleted. For example, along the Willimantic River near West Willington, designated as Area A, the average withdrawal rate during the period of no recharge must not exceed 2.8 mgd (the average yield available from aquifer storage) but can equal 3.4 mgd during the recharge period. The average for the year is 3.1 mgd and is equal to the average ground-water outflow rate for the year. Under these conditions recharge is sufficient both to sustain withdrawals and to replenish aquifer storage fully.

Thus, in any area such as Area A where the amount of usable storage is a limiting factor, the average yield is different for three periods during the year. In the example, for the 185 days of the recharge period, the yield is 3.4 + 12.3, or 15.7 mgd; for the 63 days when streamflow was deficient, or below the flow equaled or exceeded 90 percent of the time, the yield is 2.8 + 7.6, or 10.4 mgd; and for the remaining 117 days of the period of no recharge the yield is 2.8 + 12.3, or 15.1 mgd. The average yield for the year is the weighted average of these three yields, or 14.6 mgd.

EFFECT OF WATER QUALITY ON DEVELOPMENT

The adequacy or utility of a water source is dependent on the quality as well as the quantity of water available. Excessively large (or small) concentrations of various constituents may prohibit certain uses, or at least increase cost because of the treatment required. Table 6 lists the effects and significance of a variety of constituents and properties of water found in the Shetucket River basin.

Water distributed by public water supplies must meet certain water quality standards. In the Shetucket River basin the quality of such water supplies is within the drinking-water standards applicable to common carriers in interstate commerce recommended by the U.S. Public Health Service (1962), and which are widely accepted as standards for public water supplies. They appear in table 6 and are also given in various tabulations of chemical analyses throughout this report.

Industrial water-quality requirements vary according to the specific use of the water. For example, water used in the manufacture of textiles and fine paper must be soft, colorless, and low in iron, manganese, and dissolved solids. Boiler operations require low concentrations of calcium, magnesium, sulfate, and silica to avoid deposition of hard scale which reduces efficiency. Excessive iron, manganese, or turbidity causes spots and discolorations in tanning of hides and leather goods. Water-quality requirements for many industries are more stringent than those for public water systems. Table 32 lists some of the tolerances that have been established for certain industries, and for comparison gives the ranges in concentration of selected constituents and properties found in water in the basin during this study.

The chemical quality of most of the water in the Shetucket River basin in its natural state is satisfactory for a wide variety of uses, and with suitable treatment may be used for most purposes. However, the water in certain reaches of the Shetucket River and some tributaries at low streamflow contain sufficient industrial and municipal waste to prohibit use for public water supply or recreation and for many industrial purposes. Scattered wells indicated on figure 47 yield iron-bearing water, and water from about 8 percent of the wells in the basin is classified as hard. No other serious water-quality problems occur in the basin.

EFFECT OF INDUCED RECHARGE ON QUALITY

Pumping from wells in 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 because of the large seasonal temperature changes in the surface water. Annual variations of 20°F 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 river water and the natural ground water in the aquifer (Klaer, 1953; Rorabaugh, 1956). Surface water in the Shetucket River basin is generally less mineralized than ground water, so that induced recharge will normally result in an improvement of water 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 natural sand and gravel beds through which the induced recharge travels serve as large filters, which remove most of the bacteria, turbidity, and suspended solids that may have been present in the water of the recharging 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.

CONSEQUENCES OF DEVELOPMENT

Development of any water supply affects to some extent the availability of water in the vicinity of development. If large supplies are withdrawn, the effects may extend to downstream parts of the basin. Although the precise consequences of development usually cannot be predicted, in most cases in the Shetucket River basin the principal effect is that of lowered ground-water levels, decreased water quality, altered streamflow patterns or a combination of these. Withdrawal of water from a stream naturally reduces streamflow unless equal quantities are returned to the stream. Impounding water behind a dam across a stream may result in more uniform streamflow downstream if such an impoundment is used to reduce peak flows or increase low flows. On the other hand, flow below an industrial dam may be erratic if water is not released continuously.

Induced infiltration from streams reduces streamflow along those reaches where pumping has reversed the water-table gradient. The effects are particularly noticeable during times when

Table 32.--Water-quality limitations for industrial use and range in water quality available in the Shetucket River basin.

Industrial use	Turbidity (ppm)	Color c/	Color + O_2 consumed (ppm)	Dissolved oxygen (ppm)	Odor	Hardness (as $CaCO_3$) (ppm)	Alkalinity (as $CaCO_3$) (ppm)	pH	Total solids (ppm)	Calcium (Ca) (ppm)	Iron (Fe) (ppm)	Manganese (Mn) (ppm)	Iron + Manganese (Fe+Mn) (ppm)	Aluminum oxide (Al_2O_3) (ppm)	Silica (SiO_2) (ppm)	Copper (Cu) (ppm)	Fluoride (F) (ppm)	Carbonate (CO_3) (ppm)	Bicarbonate (HCO_3) (ppm)	Hydroxide (OH) (ppm)	Calcium sulfate ($CaSO_4$) (ppm)	Sodium sulfate to sodium sulfite ratio ($NaSO_4$ to Na_2SO_3) (ppm)	Hydrogen sulfide a/ (H_2S) (ppm)	Remarks b/
	Maximum limits or ranges in limits of significant properties and constituents of waters acceptable for certain industrial uses. (Source of data: American Water Works Assn., 1951, Water Quality and Treatment, p. 66-67, unless otherwise noted)																							
Air conditioning d/	--	--	--	--	--	--	--	--	--	--	0.5	0.5	0.5	--	--	--	--	--	--	--	--	--	1	A,B
Baking	10	10	--	--	--	e/	--	--	--	--	.2	f/.2	.2	--	--	--	--	--	--	--	--	--	.2	C
Boiler feed:																								
0-150 psi	20	80	100	1.4	--	75	--	8.0 & up	3,000-1,000	--	--	--	--	5	40	--	--	200	50	50	--	1:1	5	--
150-250 psi	10	40	50	.14	--	40	--	8.5 & up	2,500-500	--	--	--	--	.5	20	--	--	100	30	40	--	2:1	3	--
250 psi and up	5	5	10	.0	--	8	--	9.0 & up	1,500-100	--	--	--	--	.05	5	--	--	40	5	30	--	3:1	0	--
Brewing: g/																								
Light	10	h/0-10	--	--	Low	--	75	6.5-7.0	500	100-200	.1	.1	.1	--	h/50	--	1.0	h/50-68	--	--	100-200	--	.2	C,D
Dark	10	h/0-10	--	--	Low	--	150	7.0 & up	1,000	200-500	.1	.1	.1	--	h/50	--	1.0	h/50-68	--	--	200-500	--	.2	C,D
Canning:																								
Legumes	10	--	--	--	Low	25-75	--	--	--	--	.2	.2	.2	--	--	--	--	--	--	--	--	--	1	C
General	10	--	--	--	Low	--	--	--	h/850	--	.2	.2	.2	--	--	--	1.0	--	--	--	--	--	1	C
Carbonated beverages: i/	2	10	10	--	0	250	50	--	850	--	.2	.2	.3	--	--	--	.2	--	--	--	--	--	.2	C
Confectionary	--	--	--	--	Low	--	--	j/	100	--	.2	.2	.2	--	--	--	--	--	--	--	--	--	.2	--
Cooling k/	50	--	--	--	--	50	--	--	--	--	.5	.5	.5	--	--	--	--	--	--	--	--	--	5	A,B
Food, general	10	h/5-10	--	--	Low	h/10-250	h/30-250	--	h/850	--	.2	.2	.2	--	--	--	h/1.0	--	--	--	--	--	--	C
Ice (raw water) l/	1-5	5	--	--	--	--	30-50	--	300	--	.2	.2	.2	--	10	--	--	--	--	--	--	--	--	C
Laundering	--	--	--	--	--	50	h/60	h/6.0-6.8	--	--	.2	.2	.2	--	--	--	--	--	--	--	--	--	--	--
Plastics: clear, uncolored	2	2	--	--	--	--	--	--	200	--	.02	.02	.02	--	--	--	--	--	--	--	--	--	--	--
Paper and pulp: m/																								
Groundwood	50	20	--	--	--	180	--	--	--	--	1.0	.5	1.0	--	--	--	--	--	--	--	--	--	--	A
Kraft pulp	25	15	--	--	--	100	--	--	300	--	.2	.1	.2	--	--	--	--	--	--	--	--	--	--	--
Soda and sulfite	15	10	--	--	--	100	--	--	200	--	.1	.05	.1	--	--	--	--	--	--	--	--	--	--	--
Light paper, high grade	5	5	--	--	--	50	--	--	200	--	.1	.05	.1	--	--	--	--	--	--	--	--	--	--	B
Rayon (viscose) pulp:																								
Production	5	5	--	--	--	8	50	--	100	--	.05	.03	.05	8.0	25	5	--	--	--	--	--	--	--	--
Manufacture	.3	--	--	--	--	55	--	7.8-8.3	--	--	.0	.0	.0	--	--	--	--	--	--	--	--	--	--	--
Tanning n/	20	10-100	--	--	--	50-135	135	8.0	--	--	.2	.2	.2	--	--	--	--	--	--	--	--	--	--	--
Textiles:																								
General	5	20	--	--	--	20	--	--	--	--	.25	.25	--	--	--	--	--	--	--	--	--	--	--	--
Dyeing o/	5	5-20	--	--	--	20	--	--	--	--	.25	.25	.25	--	--	--	--	--	--	--	--	--	--	--
Wool scouring p/	--	70	--	--	--	20	--	--	--	--	1.0	1.0	1.0	--	--	--	--	--	--	--	--	--	--	--
Cotton bandage p/	5	5	--	--	Low	20	--	--	--	--	.2	.2	.2	--	--	--	--	--	--	--	--	--	--	--

Range in limits of selected properties and constituents of waters from various sources found in the Shetucket River basin.

Source																								
Natural streams	--	2-30	--	--	--	14-32	1-41	5.6-7.4	27-61	3.2-8.8	.01-92	.00-.52	--	--	--	--	--	0	8-34	--	--	--	--	--
Contaminated streams	3.1-15	3-65	--	--	--	12-100	6-154	3.6-7.9	35-327	3.2-26	.06-2.2	.00-.38	--	--	3.1-15	--	.0-.2	0	5-126	--	--	--	--	--
Bedrock wells	--	--	--	--	--	12-210	4-240	5.3-8.0	31-401	3.2-60	.00-7.6	.00-.95	--	--	6.3-29	--	.0-1.6	0	3-197	--	--	--	--	--
Stratified drift wells	--	--	--	--	--	14-90	16-61	6.0-7.6	46-167	4.0-29	.00-.35	.00-.89	--	--	6.8-22	--	.0-2.0	0	13-50	--	--	--	--	--

a/ Moore, E. W., 1940, Progress report of the committee on quality tolerances of water for industrial uses: Jour. New England Water Works Assoc., v. 54, p. 271

b/ A - No corrosiveness; B - No slime formation; C - Conformance to USPHS drinking-water standards necessary (see table 6); D - Maximum limit of NaCl, 275 ppm.

c/ Color units, described on page 41.

d/ Waters with algae and hydrogen sulfide odors are most unsuitable for air conditioning.

e/ Some hardness desirable.

f/ Figure given in original table has been corrected.

g/ Water for distilling must meet the same general requirements as for brewing (gin and spirits mashing water of light-beer quality; whiskey mashing water of dark-beer quality).

h/ McKee, J.E., and Wolf, H.W., 1963, Water quality criteria: California State Water Pollution Control Board, 2nd ed., Publication No. 3-A, p. 94-101.

i/ Clear, odorless, sterile water for syrup and carbonization. Water consistent in character. Most high quality filtered municipal water not satisfactory for beverages.

j/ Hard candy requires pH of 7.0 or greater, as low values favor inversion of sucrose, causing sticky product.

k/ Control of corrosiveness is necessary, as is control of organisms such as sulfur and iron bacteria which tend to form slimes.

l/ $Ca(HCO_3)_2$ particularly troublesome. $Mg(HCO_3)_2$ tends to cause greenish color. CO_2 assists in preventing cracking. Maximum limit of sulfates and chlorides of Ca, Mg, Na is 300 ppm (White butts).

m/ Uniformity of composition and temperature desirable. Iron objectionable since cellulose adsorbs iron from dilute solutions. Manganese very objectionable, clogs pipelines and is oxidized to permanganates by chlorine, causing reddish color.

n/ Excessive iron, manganese or turbidity creates spots and discoloration in tanning of hides and leather goods.

o/ Constant composition; residual alumina must be less than 0.5 ppm.

p/ Calcium, magnesium, iron, manganese, suspended matter and soluble organic matter may be objectionable.

natural streamflow is near the 90-percent flow-duration value. At such times such reaches may become completely dry. The precise changes in streamflow pattern cannot be predicted because they depend in large degree upon the pattern of discharge of the water used. However, unless water is actually transported across the divide of the watershed of the developed area, most of the water withdrawn will eventually return to the stream or ground-water reservoir within the area and thus become available for reuse in the basin.

Ground-water levels are lowered in the vicinity of any well from which water is pumped. Theoretically, knowing the transmissibility and storage characteristics of the aquifer, it is possible to predict the amount of water-level decline at any point for any given values of pumping rate and time. In the Shetucket River basin, however, because of the nonhomogeneity and limited extent of the aquifers, and the effects of induced infiltration, the procedures involved in predicting water-level declines are exceptionally complex and the validity of the results is uncertain. For the stratified-drift aquifer, a pumping test similar to that conducted at the Mansfield State Training School, discussed on pages 57 to 60, is a more practical way to determine the effects of pumping on water levels in a particular area.

Development invariably results in a change in the quality of water--usually a deterioration. The type and degree of change depends on the use to which the water is put and the treatment it receives before being returned to the system.

FUTURE DEVELOPMENT-ITS EFFECT ON THE AVAILABILITY OF WATER

Accurate measurements and complete records of past hydrologic events cannot reflect the effects of the man-made changes that may take place in the future. 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 1965 nearby or in portions of the Shetucket 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 the report where necessary, in such a way that the report can be useful for many years. The effects of future development can be measured 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.

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ABBREVIATIONS

p.	-	page(s)
pl.	-	plate(s)
°C	-	degree(s) Celsius (Centigrade)
°F	-	degree(s) Fahrenheit
in.	-	inch(es)
ft	-	foot (feet)
sq ft	-	square foot (feet)
sq mi	-	square mile(s)
mcf	-	million cubic foot (feet)
mg	-	million gallon(s)
cfs	-	cubic foot (feet) per second
gpm	-	gallon(s) per minute
gpd	-	gallon(s) per day
ppm	-	part(s) per million
M.S.L.	-	mean sea level

EQUIVALENTS

1 cfs = 646,317 gpd = 0.646317 mgd.

1 mgd = 694 gpm = 1.547 cfs.

1 cfs per sq mi = 13.57 in. of runoff per year (expressed in same type of unit as inches of rainfall).

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

1 in. of water upon 1 sq mi = 17.4 mg = 2.32 mcf.

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.

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

Aquifer: A geologic formation or deposit that contains considerable amounts of obtainable ground water.

Artesian condition: A condition in which an aquifer is confined above and below by rocks or deposits of lower permeability. Ground water in such an aquifer is under sufficient head, or pressure, to rise above the aquifer if tapped by a well.

Bedrock: The solid rock which forms the earth's crust; in the Shetucket River basin it is locally exposed at the surface but more commonly is buried by a few inches to as much as 200 feet of unconsolidated deposits.

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.

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

Chemical weathering: The chemical reaction between precipitation and the rocks and soils upon which it falls, and the selective removal of the more soluble minerals to leave behind only slightly soluble silicate minerals.

Clay: Particles of sediment smaller than 0.004 millimeter in diameter. Most clay in the basin consists chiefly of finely ground rock particles rather than clay minerals.

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 in which it begins and that includes 9 of the 12 months.

Coliform bacteria: Any of several 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 toxic themselves.

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

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

Crystalline bedrock: Bedrock composed of closely interlocking crystals; the only kind of bedrock in the Shetucket River basin.

Cubic feet per second (cfs): A unit expressing rate of discharge. One cubic foot per second is equal to the discharge of a stream of rectangular cross section one foot wide and one foot deep with water flowing at an average velocity of one foot per second.

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.

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

Drawdown, in a well: The distance at any time 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. In the Shetucket River basin, drilled wells tap only the bedrock and stratified-drift aquifers.

Driven well: A well constructed by driving one or more lengths of pipe into the ground, at the bottom 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 fieldstone.

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

Evapotranspiration: Water returned to the atmosphere by direct evaporation from water surfaces and moist soil and by transpiration from 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: The percent of time during which specified daily discharges were equaled or exceeded in a given period. The sequence of daily flows is not chronological.

Fracture: An opening or crack in rocks along which water can move.

Frequency: See "recurrence interval."

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

Glacial drift: All of the earth materials in the basin which were deposited by the ice sheet or by glacial meltwater, including stratified drift and till.

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

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

Ground water: Water in the zone of saturation.

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

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

Hardness of water: The property of water generally attributable to salts of the alkaline earths. It has soap consuming and encrusting properties, and 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 presumably formed by the partial decay of organic matter.

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

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.

Isopleth: Line on a map connecting points at which a given variable has a specified constant value.

Leach: To dissolve out by a percolating liquid.

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

Lithology: The physical characteristics of a rock or sediment.

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

Mineral content, of water: The dissolved inorganic substances, most of which are derived from the minerals in rocks. It is generally assumed to be equivalent to the dissolved solids.

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

Parts per million (ppm): A unit for expressing the concentration of chemical constituents by weight. A part per million is a unit weight of a constituent in a million unit weights of the water solution. Parts per million, for suspended sediment, is computed as one million times the ratio of the weight of sediment to the weight of the mixture of water and sediment.

Pegmatite: A coarse variety of granite occurring in dikes or veins.

Permeability: The ability of a rock or soil to transmit water. Coefficient of permeability is the rate of flow of water, at the prevailing water temperature, in gallons per day, through a cross sectional area of 1 square foot under a hydraulic gradient of 1 foot per foot.

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 or alkaline. Values lower than 7.0 denote acidity and above 7.0 denote alkalinity.

Pollution, of water: The introduction of some substance or organism in 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 total volume of rock or sediment that is occupied by void spaces.

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

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

Recovery, in a well: The rise of the water level in a well after pumping has stopped; the distance at any time 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 climatic years 1930 to 1959 or water years 1931 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, known as surface or overland runoff, or water that has become ground water and has seeped into stream channels from saturated earth materials, known as ground-water runoff.

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

Schist: A medium- or coarse-grained metamorphic rock with sub-parallel 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 the surrounding earth material into the well.

Sediment: Fragmental material that originates from weathering of rocks and is transported by, suspended in, or deposited by water.

Sewage: Liquid or solid waste carried off in sewers.

Silt: Particles of rock materials bigger than clay and smaller than sand, or between 0.004 and 0.0625 millimeter in diameter.

Sorting: An expression of the variability of grain sizes in a sediment. Poorly sorted deposits have a wide range in grain sizes; well sorted deposits have nearly uniform grain sizes.

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 water to conduct an electric current, expressed in micromhos per centimeter at 25°C. 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 or unconsolidated material will yield by gravity drainage, given sufficient time, to the total volume of the rock or unconsolidated material, commonly expressed as a percent.

Storage coefficient: The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer, per unit change in the component of head normal to that surface. Under water-table conditions, coefficient of storage is virtually equivalent to specific yield.

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

Streamflow: The discharge that occurs in a natural channel.

Texture: The general grain-size characteristics of a deposit.

Theis type curve: A curve which theoretically can be fitted over some segment of any plot involving water-level drawdown and time or distance measured during a pumping test of a well, and which can be used graphically to determine aquifer coefficients. The coordinates of this type curve were first determined by C. V. Theis.

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

Transmissibility: The ability of a vertical section of a rock or sediment to transmit water. Coefficient of transmissibility is the rate of flow of water, at the prevailing water temperature, in gallons per day, through a vertical strip of the aquifer 1 foot wide extending the full saturated height of the aquifer under a hydraulic gradient of 1 foot per foot. It is equal to the product of the coefficient of permeability and saturated thickness.

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 soluble material. Residual turbidity is that portion of turbidity caused by insoluble material which remains in suspension after a long settling period. It represents that which might be termed "permanent" turbidity.

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

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

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

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

Water-table condition: A condition in which the water table forms the upper surface of an aquifer, ground water is unconfined, and the water moves solely under the influence of gravity.

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.