WATER RESOURCES INVENTORY OF CONNECTICUT
PART 6
UPPER HOUSATONIC RIVER BASIN

BY
MICHAEL A. CERVIONE, JR., DAVID L. MAZZAFERRO, ROBERT L. MELVIN
U. S. GEOLOGICAL SURVEY

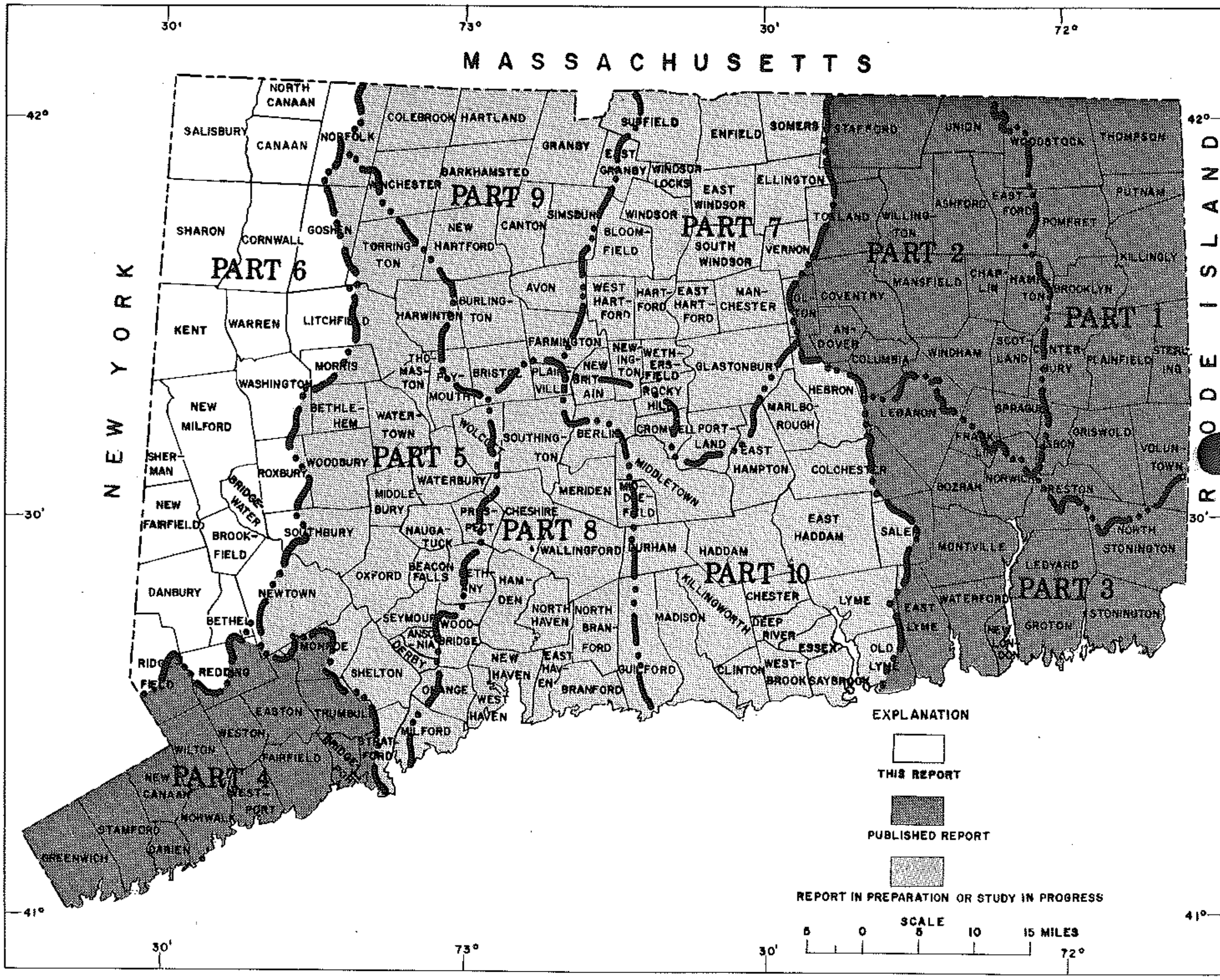
PREPARED BY THE
U. S. GEOLOGICAL SURVEY
IN COOPERATION WITH THE
CONNECTICUT DEPARTMENT OF ENVIRONMENTAL PROTECTION

CONNECTICUT WATER RESOURCES BULLETIN NO. 21

1972

OUTSIDE COVER.--Lake Candlewood, shown looking north from Danbury, is the largest body of fresh water in Connecticut; it has a surface area of 5,420 acres and a total storage of 51,750,000,000 gallons. Located in the towns of Brookfield, Danbury, New Fairfield, New Milford, and Sherman, the lake was created by the construction of a dam on Rocky River in 1928 to impound water for generating electricity. The embayed appearance of the lake is the result of the drowning of preexisting valleys by the rising waters. Water is stored behind the 90-foot dam from pumpage of the Housatonic River during off-peak power periods; it flows through the generating plant to produce power during peak periods, and then returns to the river. The lake has over 65 miles of shoreline, much of which is undeveloped because of steep cliffs at the water's edge. An important secondary use of the lake is for water-based recreation. The chemical quality of Lake Candlewood is generally good. Dissolved-solids content of one water sample taken in August 1967 from each of 6 sites near the lakeshore averaged about 85 milligrams per liter.

Photograph courtesy of Connecticut Light and Power Co.



THE WATER RESOURCES INVENTORY OF RIVER BASINS IN CONNECTICUT

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

WATER RESOURCES INVENTORY OF CONNECTICUT
PART 6
UPPER HOUSATONIC RIVER BASIN

BY
MICHAEL A. CERVIONE, JR.
DAVID L. MAZZAFERRO
ROBERT L. MELVIN
U.S. GEOLOGICAL SURVEY

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

CONNECTICUT WATER RESOURCES BULLETIN NO. 21

1972

CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS - CONT.

TABLES

SUMMARY

The upper Housatonic River basin report area has an abundant supply of water of generally good quality, which is derived from precipitation on the area and streams entering the area. Annual precipitation has averaged about 46 inches over a 30-year period. Of this, approximately 22 inches of water is returned to the atmosphere each year by evaporation and transpiration; the remainder flows overland to streams or percolates downward to the water table and ultimately flows out of the report area in the Housatonic River or in smaller streams tributary to the Hudson River. During the autumn and winter precipitation normally is sufficient to cause a substantial increase in the amount of water stored in surface reservoirs and in aquifers, whereas in the summer, losses through evaporation and transpiration result in sharply reduced streamflow and lowered ground-water levels. Mean monthly storage of water in November is 2.8 inches more than it is in June.

The amount of water that flows into, through, and out of the report area represents the total amount potentially available for use, ignoring reuse. For the 30-year period 1931 through 1960, the annual runoff from precipitation has averaged 24 inches (294 billion gallons). During the same period, inflows from Massachusetts and New York have averaged 220 and 64 billion gallons per year, respectively. A total average annual runoff of 578 billion gallons is therefore available. Although runoff indicates the total amount of water potentially available, it is rarely feasible to use all of it. On the other hand, with increased development, some water may 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 differ from place to place and time to time, depending on the amount of precipitation, on the size of drainage area, on the thickness, transmissivity, and areal extent of aquifers, and on the variations in chemical and physical quality of water.

Differences in precipitation cause differences in the amount of streamflow whereas differences in the proportion of stratified drift affect its timing.

Water can be obtained from wells almost anywhere in the area, but the amount obtainable at any particular point depends upon the type and water-bearing properties of the aquifers tapped.

Stratified-drift aquifers are the only ones generally capable of yielding more than 100 gpm (gallons per minute) to individual wells. Drilled, screened wells tapping this unit yield from 17 to 1,400 gpm, with a median yield of 200 gpm.

Till and bedrock are widespread but generally provide only small supplies of water. Till is tapped in a few places by dug wells, which can yield small supplies of only a few hundred gallons per day throughout all or most of the year. Bedrock is the chief aquifer for privately owned domestic and rural supplies; it is tapped by drilled wells, about 90 percent of which will supply at least 2 gpm. Only 1 of 10 bedrock wells, however, will supply more than 30 gpm.

The amount of ground water potentially available in the report area depends upon the thickness and hydraulic properties of aquifers, the amount of salvageable natural discharge of ground water, and the quantity of water available by induced infiltration from streams and lakes. From data on transmissivity, thickness, recharge, well performance, and streamflow, preliminary estimates of ground-water availability can be made for most stratified-drift aquifers in the report area. Long-term yields estimated for eight areas of stratified drift especially favorable for development of large ground-water supplies ranged from 0.6 to 5 mgd (million gallons per day). Detailed site studies are needed to verify these estimates and to determine optimum yields, drawdowns, and spacing of individual wells before major ground-water development is undertaken in these or other areas.

The chemical quality of water in the report area is generally good; carbonate-bedrock units exert considerable local influence on water quality. Samples of naturally occurring surface water collected at 24 sites during low flow averaged 90 mg/l (milligrams per liter) dissolved solids and 60 mg/l hardness. Water from wells is generally more highly mineralized than naturally occurring water from streams. About 37 percent of the wells sampled yielded water with more than 200 mg/l dissolved solids and 50 percent yielded water with more than 120 mg/l hardness. These concentrations reflect the high degree of mineralization of ground water in carbonate bedrock and unconsolidated deposits derived from this bedrock. The larger streams, which transport varying amounts of industrial and domestic effluents, averaged about 150 mg/l dissolved solids and 90 mg/l hardness.

Iron and manganese concentrations in both ground water and surface water at some places exceed recommended limits for domestic and industrial use. Most wells in the report area yield water with little or no iron or manganese. In certain localities however, the probability is high of encountering water with excessive concentrations of these constituents. Schists, especially the unit in the northwestern corner of the basin, are the likely sources of water with excessive iron and manganese.

Iron concentrations in naturally occurring stream water exceed 0.3 mg/l under low-flow conditions at 29 percent of the sites sampled. These excessive concentrations result from discharge of iron-bearing water from aquifers or from swamps where iron is released from decaying vegetation.

Water temperature in the larger streams ranges from 0°C (degrees Celsius) to about 28°C. Ground water between 30 feet and 200 feet below the land surface has a relatively constant temperature, usually between 8°C and 11°C.

The quantity of suspended sediment transported by streams under natural conditions is negligible. Even in streams affected by man, turbidity is rarely a problem.

The total amount of water used in the report area for all purposes during 1967 was about 6,360 million gallons, or 140 gpd per person. Public supplies furnished the domestic needs of nearly half the population of the area. All of the 14 public supplies sampled provided water that meets the drinking water standards of the U.S. Public Health Service.

WATER RESOURCES INVENTORY OF CONNECTICUT
PART 6
UPPER HOUSATONIC RIVER BASIN
BY

MICHAEL A. CERVIONE, JR., DAVID L. MAZZAFERRO, AND ROBERT L. MELVIN

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 in the standard of living. 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 supplemental authorizations by the General Assembly, the U.S. Geological Survey has undertaken a series of studies to determine the quantity and quality of water that is available at any location in the State. For these studies the State has been subdivided into 10 areas. (See map inside front cover.) Reports on the hydrology of these areas are designed for State and regional planners, town officials, water-utility personnel, consulting hydrologists, well drillers, and others concerned with the development, management, use, and conservation of water resources.

These studies began in 1961 in cooperation with the Water Resources Commission and continued in 1971 in cooperation with the Department of Environmental Protection.

The Housatonic River basin was subdivided into two study areas; this report on the UHRBA (upper Housatonic River basin area) is the sixth interpretative report prepared under the water resources inventory program. A companion basic data report on the UHRBA has been published (Melvin, 1970).

HOUSATONIC RIVER BASIN

The Shepaug Dam in Southbury and Newtown marks the downstream point of the Housatonic River basin for this report. The basin above Shepaug Dam drains a total area of 1,392 square miles, of which 497 square miles are in Massachusetts and 217 square miles are in New York. This report deals with the remaining 678 square miles of the basin in Connecticut above Shepaug Dam and a small part (22 square miles) of Hudson River basin drainage at the southwest corner of the report area--a total of 700 square miles. The location of the area discussed in this report is shown on the map inside the front cover. Although this report is chiefly concerned with the Connecticut part of the upper Housatonic River basin, enough data were collected in Massachusetts and New York to define the quantity and quality of water entering Connecticut.

Other reports on the water resources of the Housatonic River basin include a study of the basin above the Massachusetts-Connecticut boundary (Norvitch and others, 1968) and a study of the lower Housatonic River basin, extending from Shepaug Dam to Long Island Sound (Wilson and others, written communication).

ACKNOWLEDGMENTS

The data on which this report is based were collected and analyzed by employees of the U.S. Geological Survey. Much unpublished information was obtained from the files of State organizations, including the Department of Environmental Protection, Water and Related Resources Unit (formerly Water Resources Commission), the Fish and Water Life Unit (formerly Board of Fisheries and Game), the Policy, Planning, and Research Unit (formerly Connecticut Geological and Natural History Survey), and the Department of Transportation. Technical reports and some unpublished economic data were furnished by the Connecticut Development Commission. Records of wells and test borings were provided by a host of home owners, drillers, consultants, and company officials too numerous to mention by name. All these individuals and agencies have helped to make this report more complete and more useful.

GUIDE FOR USE OF THIS REPORT

Water supplies may be obtained from streams and lakes or from aquifers. Although water from these sources is closely interrelated, the methods used for estimating the amount potentially available from each source and the techniques of development of each are different; therefore, streams and lakes (surface water) and aquifers (ground water) are discussed in separate sections of this report.

The reader primarily interested in determining the availability of surface water at any site can start with plate D, which summarizes the amount of water available. This map shows the distribution of lakes and ponds having water in usable storage and indicates the amount of such storage. It also shows for all streams except the smallest ones, the flow that will be equaled or exceeded 90 percent of the time.

Additional streamflow information in the text includes 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. A method that can be used to estimate flow duration, low-flow frequency, and storage required at any point along any stream in the area is also described based on the relationship between surficial geology and runoff. Quality of surface water is discussed in the text in the section "Quality of water in streams and lakes."

The reader primarily interested in the availability of ground water can start with the geohydrologic map, plate B, which delineates the principal water-bearing units and the saturated thickness and transmissivity of stratified drift. The range in yields to be expected from individual wells in other water-bearing units is also shown.

Additional information on the availability of ground water is shown on plate D, which delineates stratified-drift aquifers that are especially favorable for the development of water supplies and indicates the amounts of ground water potentially available. The methods used to estimate the yields of the aquifers shown on plate D are described in the section "Large water supplies from stratified-drift aquifers." Quality of ground water is discussed in the text in the section so named.

Abbreviations used in this report and some convenient equivalents are presented at the end of the report. Technical terms are defined in a glossary also at the end of the report.

THE HYDROLOGIC CYCLE

The hydrologic cycle is the continual movement of water between the oceans, the atmosphere, and the land masses of the earth. It can be considered to begin when water vapor in the atmosphere condenses to form clouds from which rain or snow falls 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 collects on the land surface or seeps into the ground is soon evaporated or is taken up by plants and returned to the atmosphere by a process known as transpiration. Some water, however, moves underground through permeable soils and rocks toward nearby streams, into which it discharges. Part of the water that reaches the streams, lakes, and eventually the ocean, is also evaporated to complete the cycle.

As water moves through the hydrologic cycle, large amounts are stored temporarily in the atmosphere as vapor, on the land surface in streams and other bodies of water, and beneath the land surface as ground water. None of these amounts is constant in any given locality, as the water is continually moving from place to place. While moving, its physical, chemical, and biological properties are also constantly changing. The properties and their changes in the upper Housatonic River basin are described in more detail in the following paragraphs.

THE WATER BUDGET

The hydrologic system in a drainage basin can be expressed by a water budget, which, like a fiscal budget, lists receipts, disbursements, and water on hand. The receipts of water in the upper Housatonic River basin consist of precipitation on the area, inflow from the Housatonic and Tenmile Rivers, and inflow from many smaller streams

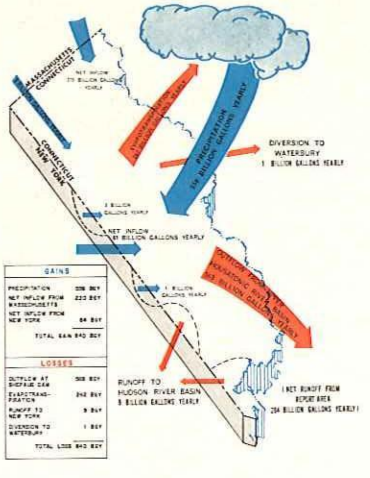


Figure 1.--Average annual water budget for the upper Housatonic River basin, in billion gallons per year (bgy), water years 1931-60.

Table 1.--Average monthly and annual precipitation and runoff in inches for the upper Housatonic River basin report area and for the Housatonic River basin above Shepaug Dam, for water years 1931-60

Month	Upper Housatonic River basin report area (1931-60)		Housatonic River basin above Shepaug Dam (1931-60)	
	Precipitation 1/	Runoff	Precipitation 1/	Runoff
Oct.	3.41	0.97	3.31	0.96
Nov.	4.19	1.75	3.97	1.70
Dec.	3.57	2.08	3.46	1.96
Jan.	3.41	2.41	3.31	2.28
Feb.	2.68	2.09	2.59	1.92
Mar.	3.70	3.96	3.55	3.71
Apr.	3.86	4.03	3.80	4.15
May	3.98	2.54	3.89	2.49
June	4.13	1.60	4.13	1.56
July	4.33	.90	4.42	.95
Aug.	4.19	.83	4.10	.84
Sept.	4.16	.83	4.25	.92
Annual (water year)	45.61	23.99	44.78	23.44

1/ Averages computed from records of the U.S. Weather Bureau.

entering the area from Massachusetts and New York. Disbursements consist of both direct runoff and ground-water runoff, evapotranspiration, and diversion of water from the report area. 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 amounts of water involved in each of the major components of the water budget in an average year are shown in figure 1. Although the amounts vary from year to year, the water budget always balances--the disbursements equal the receipts, taking into account changes in storage.

SOURCES OF WATER

PRECIPITATION

The average monthly and average annual precipitation on the report area for the reference period October 1930 to September 1960, as computed from records at four long-term weather stations, are given in table 1. The data are weighted in proportion to the area within the basin represented by each station. A significant amount of water available for use in the report area results from precipitation on parts of the Housatonic River basin in Massachusetts and New York. Accordingly, table 1 also includes the average monthly and average annual amounts for the entire Housatonic River basin upstream from Shepaug Dam.

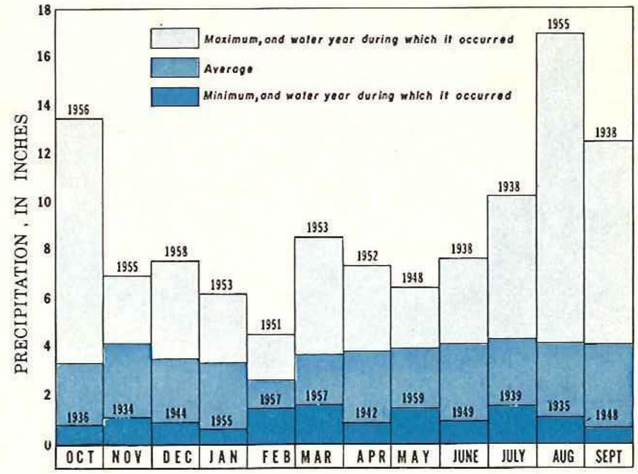


Figure 2.--Monthly precipitation on the upper Housatonic River basin, water years 1931-60.

Figure 2, which includes data from table 1, shows that average monthly precipitation on the report area is relatively uniform, ranging from 2.68 inches in February to 4.33 inches in July; the average is 3.80 inches per month. Minimum monthly precipitation is also relatively uniform, but maximum monthly varies widely. Extremes range from 0.65 inches (January 1955) to 16.94 inches (August 1955).

STREAMFLOW AND UNDERFLOW INTO THE REPORT AREA

Precipitation is the only natural source of water for all stream basins included entirely within the report area. However, a substantial resource is streamflow entering at many points from Massachusetts and New York. The net average annual inflow from Massachusetts is about 220 billion gallons per year (bgy) and that from New York is about 64 bgy. "Net" average annual inflow is used here because some streamflow originates in the report area, leaves the State, and then flows back in again. This streamflow might be used consumptively before it leaves the area, or before it returns, and thus would not be available as inflow. The inflow-outflow pattern of streamflow is detailed on figure 1.

A negligible amount of underflow enters the report area through fine-grained sediments at the Massachusetts State line, where the hydraulic gradient is slight (Norvitch and others, 1968).

LOSSES OF WATER

RUNOFF

Runoff from the Housatonic River basin has been measured since 1928 at a stream-gaging station at Stevenson, 11 miles downstream from Shepaug Dam. Runoff records presenting 1,545 square miles of the basin above this point have been adjusted to represent runoff from the 1,392 square miles of the basin above Shepaug Dam. Runoff has also been measured in the Housatonic River at Falls Village since 1912 and in the Tenmile River near Gaylordsville since 1929. Net average monthly and average annual values for the base period, October 1930 to September 1960, for the report area only and for the entire basin above Shepaug Dam are given in table 1.

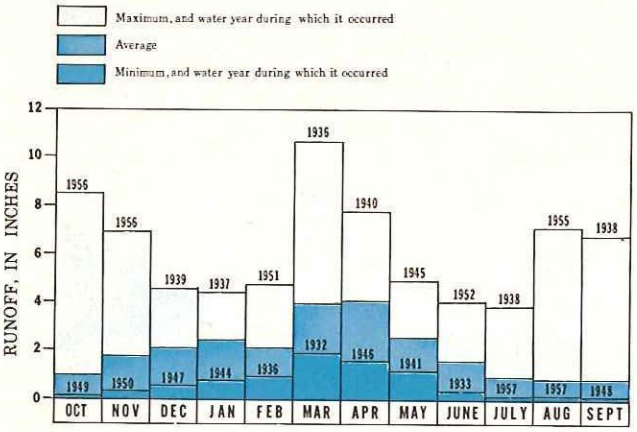


Figure 3.--Monthly runoff from the upper Housatonic River basin, water years 1931-60.

Figure 3 shows that average monthly runoff follows a marked seasonal cycle, being much lower in August or September (0.83 inch) than in April (4.03 inches). Minimum monthly values likewise indicate a seasonal cycle. This seasonal cycle reflects a combination of causes, among which are increased loss of water by evaporation and transpiration during the summer months; ice and snow stored on the land surface during the winter and melting in March and April; and a higher water table in the spring, resulting in greater groundwater discharge. Maximum monthly runoff, like maximum monthly precipitation, varies widely but shows a less well-defined seasonal cycle because large floods can occur in any month. (See page 22.)

STREAMFLOW, UNDERFLOW, AND DIVERSION OUT OF THE REPORT AREA

The average annual streamflow leaving the report area at Shepaug Dam (outlet of Lake Lillinonah) is about 568 billion gallons. An additional average annual streamflow of about 9 billion gallons leaves at the southwest corner and flows to the Hudson River in New York. A detailed depiction of the streamflow pattern is shown on figure 1. In comparison with average annual streamflow at Shepaug Dam, underflow is negligible.

Water is diverted out of the report area from the Shepaug River basin for the municipal supply of the city of Waterbury. Long-term records indicate that this diversion averages about 1 bgy. A negligible amount of water is also diverted by the Ridgefield Water Supply Company and by the Newtown Water Company.

EVAPOTRANSPIRATION

A substantial part of the rain and snow that falls on the upper Housatonic River basin is returned to the atmosphere by evaporation and transpiration. The combination--evapotranspiration--is difficult to measure directly or to estimate and is computed as a remainder after all other gains and losses are measured or estimated. If long-term storage remained substantially the same (an assumption supported by evidence from reservoir levels and groundwater levels), the average annual evapotranspiration during October 1930 to September 1960 is equal to the average annual precipitation of 45.61 inches minus the average annual runoff of 23.99 inches, or 21.62 inches.

The rate of evapotranspiration differs from month to month largely in response to changes in air temperature and duration of daylight (Thornthwaite, 1952, p. 382). Thus, it is greatest during the growing season, April through October, when the temperature is highest and the days are longest. These major factors repeat themselves with little change year after year, and the annual evapotranspiration and its distribution are relatively constant for a given locality. The annual evapotranspiration in the report area is known from the long-term relationship of precipitation and runoff discussed in the preceding paragraph; accordingly its potential average monthly distribution during 1930-60 may be computed by a method similar to that of Thornthwaite and Mather (1957). (See fig. 4.)

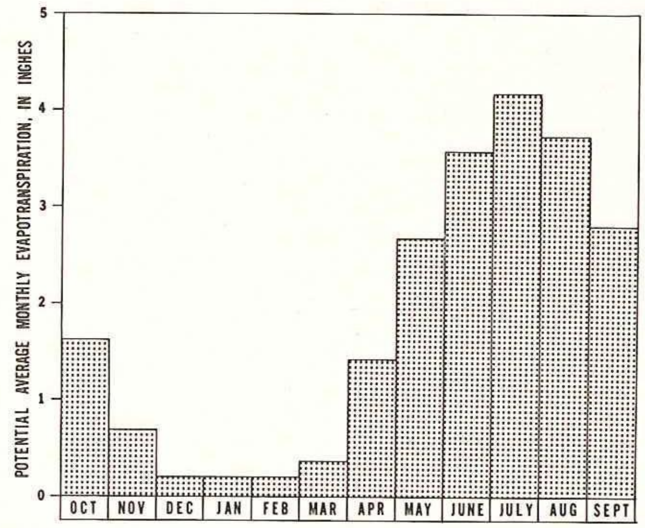


Figure 4.--Monthly evapotranspiration for the upper Housatonic River basin, water years 1931-60.

SUMMARY OF THE WATER BUDGET

An average water budget for the report area, illustrating the factors of the budget as derived by the methods previously described, is shown on figure 5 and tabulated in table 2. Precipitation during the late autumn and winter months is sufficit to cause a substantial increase in storage and to produce abundant runoff. Precipitation in the late spring and summer months is generally not adequate to supply the large evapotranspiration losses. This results in sharply reduced runoff and a decrease in storage. Storage within the report area may thereby change in lakes and stream channels, in aquifers, in soil moisture, or in combinations of these.

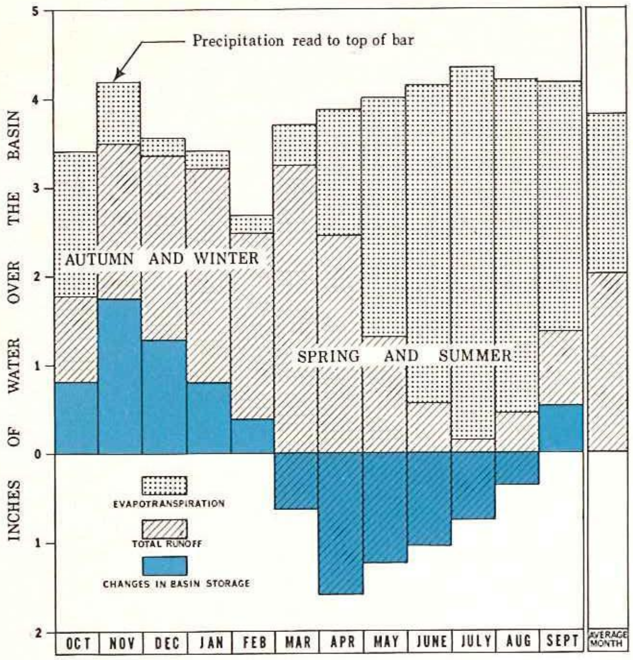


Figure 5.--Average monthly water budget for the upper Housatonic River basin, water years 1931-60.

WATER QUALITY IN THE HYDROLOGIC CYCLE

As water travels around the hydrologic cycle, its quality changes. These changes are closely related to the hydrologic cycle, and, in a given area, the natural quality is generally characteristic of that phase in which the water is found. Water that is evaporated from the surface of the land or the ocean, or that is transpired from plants, is in vapor form and is relatively "pure" (free from dissolved materials). When the vapor condenses to a liquid it begins to dissolve the materials with which it comes in contact. Dust, salt spray, and atmospheric gasses (largely natural materials), together with soot and unburned hydrocarbons (largely materials resulting from man's activities), modify the quality of the precipitation. As precipitation reaches the land surface, it continues to dissolve materials and to change in quality. Composition of rock material is the major factor controlling the amount of dissolved solids water will contain. Water in aquifers composed of relatively nonsoluble material (such as quartz sand) will be low in dissolved solids, whereas water in aquifers composed of more soluble material (such as carbonate bedrock) will be higher in dissolved solids. Surface waters, which represent an integration of direct runoff and ground-water runoff, generally have dissolved-solids levels that range between the values normal to the ground water and the values normal to precipitation. The quality aspects of the hydrologic cycle typical to the upper Housatonic River basin are shown on figure 6. The changes to this system that are brought about by man's activities are shown on figure 7.

Table 2.--Monthly water budget for the upper Housatonic River basin report area in inches of water over the area. Average for water years 1931-60

Month	Precipitation	Total runoff	Evapotranspiration	Change in storage
Oct.	3.41	0.97	1.62	+0.82
Nov.	4.19	1.75	.69	+1.75
Dec.	3.57	2.08	a/.20	+1.29
Jan.	3.41	2.41	a/.20	+ .80
Feb.	2.68	2.09	a/.20	+ .39
Mar.	3.70	3.96	.36	- .62
Apr.	3.86	4.03	1.41	-1.58
May	3.98	2.54	2.67	-1.23
June	4.13	1.60	3.57	-1.04
July	4.33	.90	4.18	- .75
Aug.	4.19	.83	3.72	- .36
Sept.	4.16	.83	2.80	+ .53
Annual (water year)	45.61	23.99	21.62	0

a/ Assumed to be zero for periods when air temperatures were at or below freezing; estimated for remainder of month.

QUALITY OF PRECIPITATION

As precipitation contains dissolved matter, it establishes an initial level of dissolved solids and gasses from the waters of the area. A knowledge of the types and amounts of chemical constituents typical to this precipitation is therefore a key element in the initial evaluation of the chemical quality of the water of the basin.

The type and amount of chemical matter carried by precipitation is determined by natural processes and the activities of man. Atmospheric dust, salt spray, industrial wastes, the effluent from home-heating systems, unburned hydrocarbons, pesticides, agricultural chemicals and other agents provide chemical constituents, which precipitation dissolves and removes from the atmosphere.

The quality of water from an individual storm may differ greatly from that of another storm, and the amount of dissolved material carried by initial precipitation may be greater than that carried by later precipitation. Areal and temporal variations in precipitation quality indicate that analysis of long-term, basinwide data holds greater significance than analysis of single-storm data.

Precipitation samples were collected at four sites in the basin during April - November 1967, as shown on figure 8. For each station, a composite sample containing all the precipitation and all the dry fallout for the month was analyzed, and the values shown on figure 8 represent material from both sources. The monthly composite analysis was weighted to the monthly precipitation total for each chemical parameter.

The results of the analyses for Norfolk, Bulls Bridge, New Milford and Danbury are summarized in table 3 and show a general southward increase in the quantity of materials carried by precipitation. This increase is primarily due to storms from the southwest, which carry airborne effluents northeastward from the New York metropolitan area and the lower Hudson River valley.

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

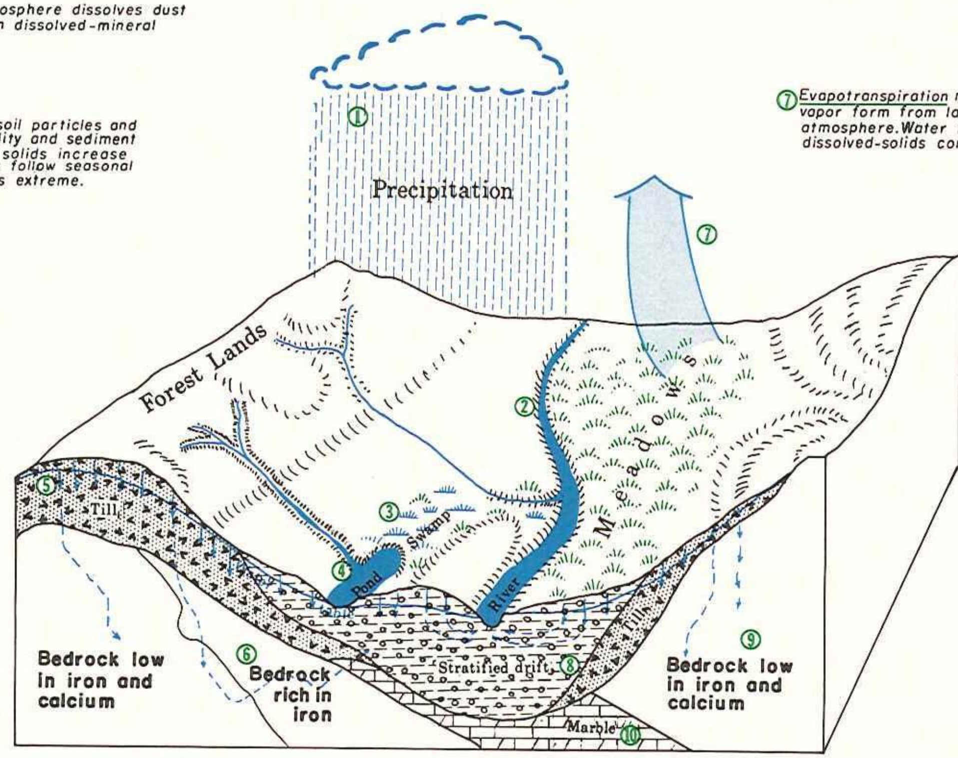
② Surface runoff carries soil particles and organic materials, turbidity and sediment loads increase. Dissolved solids increase moderately. Temperatures follow seasonal air temperatures but less extreme.

③ Iron, manganese and color in swamp water and downstream increase seasonally. Swamp water responds rapidly to variations in air temperature.

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

⑤ Infiltration increases the mineralization of water. During low-flow periods, the more highly mineralized ground-water runoff may substantially increase the mineral content of the smaller streams

⑥ Ground water in noncarbonate bedrock that is high in iron-bearing minerals is moderately hard with high iron content.



⑦ Evapotranspiration moves water in vapor form from land surface to the atmosphere. Water in this stage has the lowest dissolved-solids content of any in the cycle.

⑧ Ground water in stratified drift and till has a quality largely determined by composition of surficial materials. Dissolving of marble fragments increases hardness of ground water. Ground water also moves upward from the bedrock and influences the quality of water in the surficial deposits.

⑨ Ground water in noncarbonate bedrock low in iron-bearing minerals is moderately hard and low in iron concentrations.

⑩ Ground water in marble bedrock is hard to very hard. Iron concentrations are variable; local concentrations of iron-rich minerals increase iron values.

Figure 6.--The quality of water changes as it moves through the hydrologic cycle.

Liquid water becomes progressively more mineralized. Water vapor, returning to the atmosphere, is purified and begins the cycle anew.

① Water from the atmosphere dissolves dust particles and gasses but is low in dissolved-mineral concentrations and is acidic. Gaseous and solid materials produced by mans activities are dissolved and absorbed by precipitation and returned to earth. Sulfur, lead, unburned hydrocarbons, dust, soot, and fly ash all contribute to adulteration of precipitation before it reaches land surface.

② Petroleum residue from paved areas, leachate from everyday wastes, fertilizers from lawn and garden applications all are carried by runoff from populated areas. Construction in developing areas increases the turbidity. Salt used in winter road maintenance enters both surface-water and ground-water bodies.

③ Animal wastes and fertilizers are carried by runoff from agricultural regions.

④ Lakes and ponds which receive nutrients (nitrate and phosphate ions) and sediments have the eutrophication process accelerated. Unsightly algal blooms in summer are the result of continued addition of nutrients to water body.

⑤ Sewage treatment plants bring sewage effluents back to acceptable levels, but the nutrient value of the treated water is high. This nutrient-rich water speeds up the eutrophication process and stimulates algal bloom in downstream water bodies.

⑥ Reservoirs and other impoundments improve water quality by trapping sediments. Turbidity and color of the water improve with storage. Excess sediment loads will gradually fill reservoirs, reducing capacity and eventually end their usefulness.

⑦ Fossil fuel plants contribute large amounts of materials to the air which precipitation eventually returns to the earth. Water used to cool the generators of these plants is returned to the streams at an increased temperature.

⑧ Housing developments remote from urban areas lack central water supply and sewage treatment facilities. Improper design and placement of individual wells and septic tanks may lead to large-scale aquifer contamination and serious health problems.

⑨ Industry contributes waste to the air, water, and ground. Many industrial wastes are difficult and expensive to treat. Often direct discharge to streams is the disposal method employed and miles of downstream reach are contaminated as a result. Burial of solid waste merely delays the eventual discharge of the noxious material into nearby waterways and in the process contaminates the ground-water reservoir.

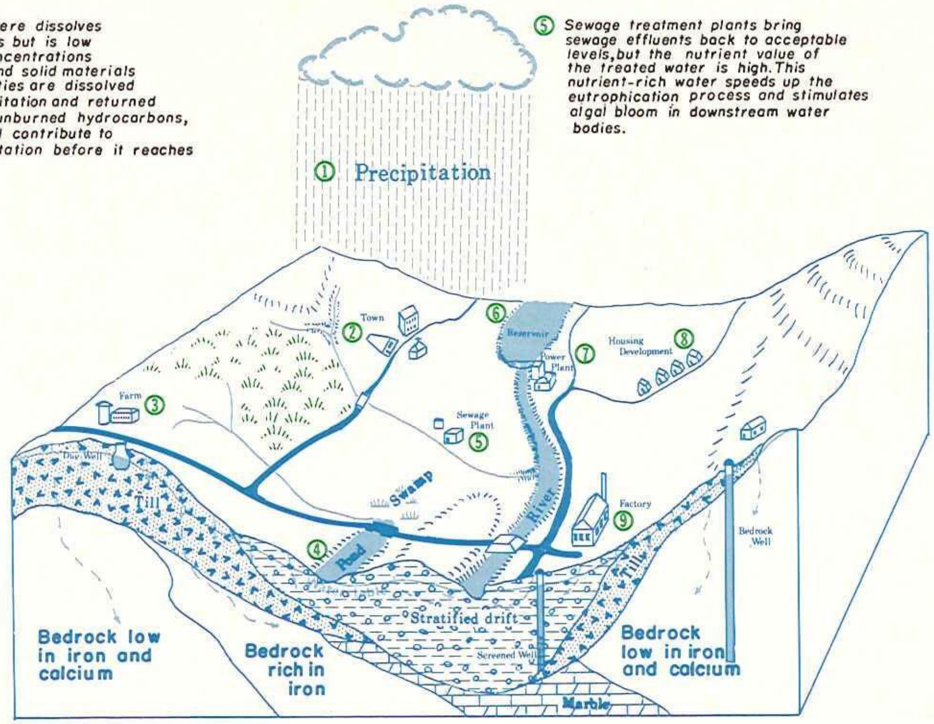


Figure 7.--The effect of man's activities upon the quality of water in the hydrologic cycle.

The activities of man modify both the chemical and physical quality of natural water. With rare exception, these modifications tend toward a deterioration of his water resources.

Table 3.--Summary of chemical analyses of monthly precipitation and dry fallout from four stations in the upper Housatonic River basin

(Locations of stations shown on figure 8)

Index no. and location		Cal-cium (Ca)	Mag-nes-ium (Mg)	Sodium (Na)	Potas-sium (K)	Bicar-bonate (HCO_3)	Sul-fate (SO_4)	Chlo-ride (Cl)	Ni-trate (NO_3)	Dissolved solids (residue at 180°C)	Carbonate hardness as $CaCO_3$	Non-carbonate hardness as $CaCO_3$	Specific conductance (micromhos at 25°C)	pH	Calcium-chloride ratio (Ca/Cl)
		Chemical constituents in milligrams per liter													
1 P Norfolk	Maximum	1.7	0.28	1.6	0.40	4.0	8.6	1.40	0.45	18	5	5	65	6.00	6.0
	Minimum	.5	.02	.4	.00	.0	3.4	.25	.00	8	2	.5	20	4.00	2.0
	Median	1.0	.10	.9	.20	.0	6.9	.35	.15	12	3	2	41	4.40	4.0
	No. of samples	8	8	8	8	8	8	8	5	8	8	8	8	8	8
2 P Bulls Bridge	Maximum	3.0	.88	3.6	5.9	6.5	20	4.20	11	55	11	8	185	6.20	3.2
	Minimum	.6	.11	.8	.3	.0	3.5	.80	.00	11	2	2	24	4.50	1.2
	Median	2.1	.33	1.3	1.3	.0	8.6	1.50	1.30	24	4	3	56	5.05	2.2
	No. of samples	7	7	7	7	7	7	7	3	7	7	7	7	7	7
3 P New Milford	Maximum	2.7	.69	18	4.7	9.0	22	1.80	1.20	94	9	8	203	6.70	4.0
	Minimum	.6	.16	.7	.2	.0	4.6	.80	.00	13	2	0	21	4.40	1.0
	Median	1.7	.19	1.7	.5	.0	9.4	1.20	.70	24	5	4	52	4.90	1.8
	No. of samples	7	7	7	7	7	7	7	4	7	7	7	7	7	7
4 P Danbury	Maximum	3.7	.35	3.2	1.8	4.0	15	1.80	3.20	41	10	10	71	6.00	5.5
	Minimum	.8	.09	1.0	.1	.0	4.3	.80	.00	11	2	2	26	4.30	.8
	Median	2.4	.26	1.4	.3	.0	9.2	1.20	.60	20	7	6	50	4.60	4.4
	No. of samples	8	8	8	8	8	8	8	6	8	8	8	8	8	8

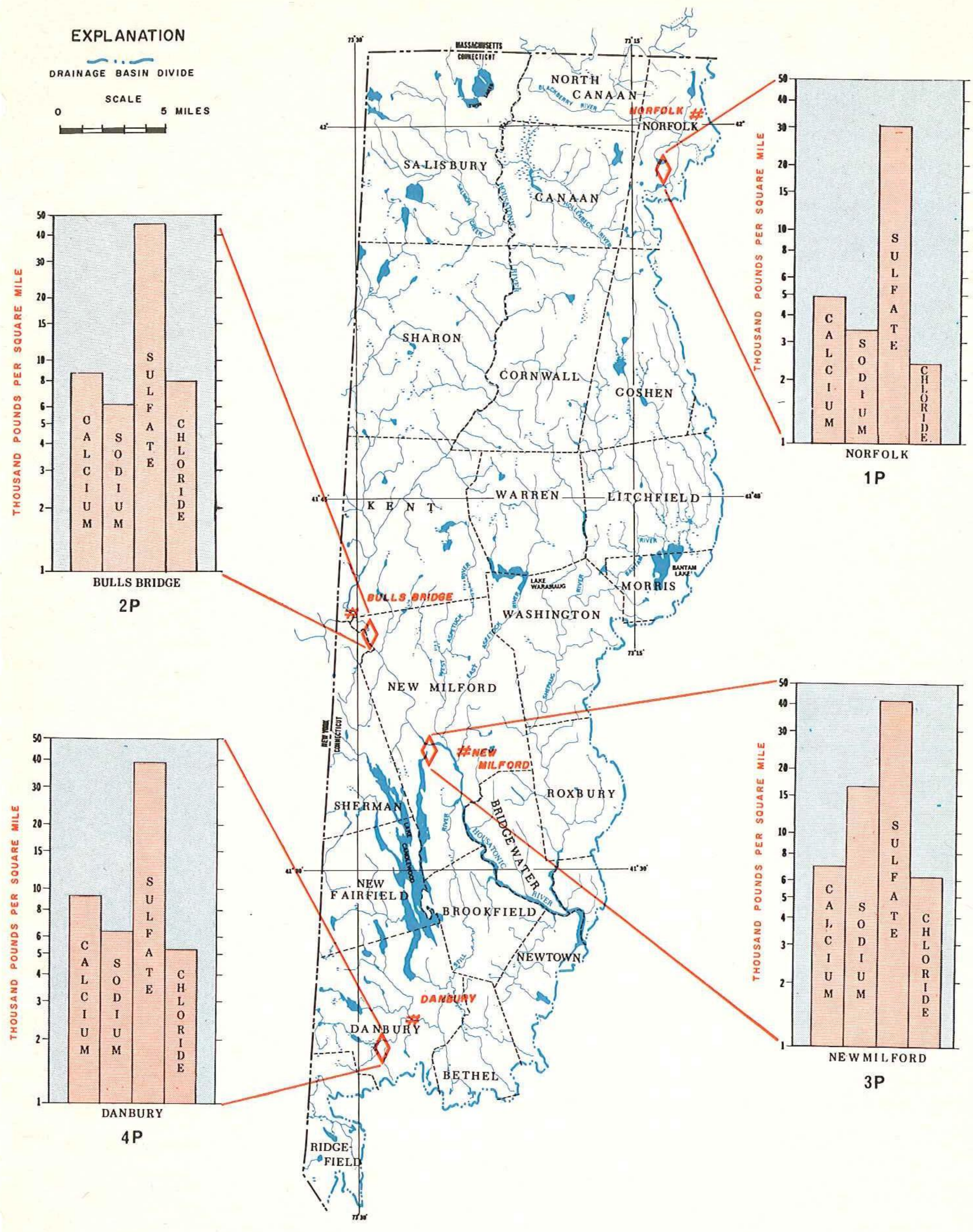


Figure 8.--Chemical quality of precipitation and dry fallout in the upper Housatonic River basin.

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

Most of the precipitation is of predominantly continental origin, as indicated by the ratio of calcium to chloride in table 3. A calcium chloride (Ca/Cl) ratio of less than 1 indicates an oceanic rather than continental influence. Of a total of 30 composite monthly samples, only one showed a Ca/Cl ratio below 1. This composite sample was collected at the end of October 1967 at Danbury after a coastal storm from the 25th through the 27th of the month produced 2.12 inches of precipitation at the Danbury gage.

Although the amount of material carried into the basin by a single storm is small, the cumulative effect is substantial. During the 8-month sampling period, the total amount of precipitation-borne material that reached land surface in the basin was about 31,000 tons. The amount of calcium, sodium, sulfate, and chloride that entered the basin during this 8-month period are shown on figure 8.

QUALITY OF RUNOFF

The quality of natural runoff for a specific location and storm is determined by the quality of the incoming precipitation, the type of earth materials, and the length of time the runoff is in contact with surface and subsurface materials. Because of the time-quality relationship, direct runoff is not as mineralized as ground-water runoff and has a dissolved-solids content approaching that of rain water. Streamflow represents an integration of direct and ground-water runoff and as a consequence carries a dissolved-solids load proportional to the relative contributions of each of any given time.

During periods of high flow, when snowmelt and spring rains combine to produce high water conditions, most of the water in a stream channel is direct runoff, and the dissolved-solids content of such water is relatively low. During periods of low flow, as in late summer and early fall, most if not all the water in a stream channel is ground-water runoff and the dissolved-solids content is relatively high.

Dissolved-solids content and pH of 55 samples from 24 natural streams in the basin are summarized in the following table for periods of high and low flow:

Sampling conditions	Dissolved solids, mg/l		pH	
	Median	Range	Median	Range
High flow	56	24 - 105	6.7	6.0 - 7.5
Low flow	91	20 - 221	7.5	6.6 - 7.9

The low median value for dissolved solids and the slightly acidic median pH value shown for high flow show the influence of abundant precipitation and direct runoff on high flows.

Whereas the concentration of dissolved minerals may decrease during periods of high flow, the turbidity and sediment load commonly increase. When flows are high, stream volume and velocity increase, facilitating transport of larger amounts and larger sizes of particles. Data in table on page 37 show that median turbidity values of natural streams increased from 018 mg/l at low flow to 4 mg/l at high flow.

Erosion is not a major problem in the upper Housatonic River basin, and sediment loads are generally insignificant. The basin remains largely rural, and its extensive vegetation provides protective cover except where it is disturbed by highway construction or other large earth-moving activities.

INDEX NO. (Pl. A)	STREAM AND LOCATION	DRAINAGE AREA, IN SQUARE MILES
1982.4	Blackberry River at West Norfolk	13.5
1983	Whiting River at Canaan Valley	17.0
1985	Blackberry River at Canaan	48.2
1987	Brown Brook at Lower City	5.55
1990	Housatonic River at Falls Village	630
1990.3	Wachocastinook Creek at Salisbury	5.33
1990.33	Factory Brook at Salisbury	9.28
1990.5	Salmon Creek at Lime Rock	29.1
1992	Guinea Brook at Ellsworth	3.48
2000	Tenmile River near Gaylordsville	203
2005	Housatonic River at Gaylordsville	994
2011.9	West Aspetuck River near New Milford	23.3
2014.2	Still River at Danbury	13.1
2014.7	Still River near Danbury	38.4
2015	Still River near Lanesville	67.8
2015.1	Still River at Lanesville	69.8
2030	Shepaug River near Roxbury	133

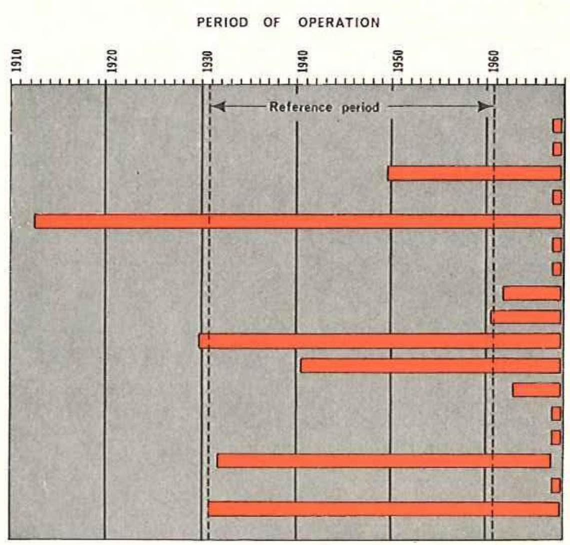


Figure 9.--Length of continuous streamflow records at gaging stations in the upper Housatonic River basin.

WATER IN STREAMS AND LAKES

The upper Housatonic River basin is drained by many large and small streams extending into all parts of the basin. The complete stream system is shown in blue on the plates in the back pocket.

The amount of streamflow varies from day to day, season to season, and year to year. Records of streamflow at 17 gaging stations within the basin are available for periods ranging from 1 year to 55 years (fig. 9). In addition, discontinuous or partial records of streamflow were obtained at many other sites within the basin during May 1966 to September 1967. All records for 1966-67 are given together with the long-term records in annual publications titled "Water Resources Data for Connecticut." Continuous records through 1965 are published in a series of U.S. Geological Survey Water-Supply Papers titled "Surface Water Supply of the United States." These reports are listed by number in the companion basic-data report (Melvin, 1970, p. 33). The locations of all stream-gaging stations are shown on plate A.

The variations in streamflow at gaging stations in the basin are summarized in this report by means of standardized graphs and tables. To facilitate comparison between graphs for different streams, the data for each stream have been adjusted to a 30-year reference period beginning in April or October 1930. Accordingly, the analyses, interpretations, and predictions with respect to streamflow are based on this 30-year reference period (Searcy, 1959). The flow in this reference period represents the long-term flow of the streams; the graphs or tables summarizing streamflow may be used to estimate the amount of streamflow at the measurement sites in the future, as long as the pattern of regulation of storage or diversion of water into or out of the basin remains unchanged.

The water-supply potential of streams is determined by the length of time indicated flows are available (duration of daily flows) and by the frequency with which low flows recur (frequency distribution of annual low flows). Duration of daily flows is given on figures 10 through 16; magnitude and frequency of annual low flows are given in table 4 and on figure 19. Because streamflow varies from place to place along each stream as well as from time to time, methods are described in the following sections for determining these streamflow parameters at any unmeasured point along any unregulated stream in the basin.

VARIATIONS IN STREAMFLOW

Areal differences in annual precipitation cause substantial differences in amounts of streamflow from place to place within the basin. Average streamflow per square mile of drainage area increases considerably from west to east across the basin, being lowest in the northwest corner and highest in the east-central part, as shown by the isopleths on figure 17. The isopleths express the ratio of average flow anywhere in the basin to the approximate Statewide average flow of 1.16 mgd per square mile (1.80 cfs per square mile). Long-term records from 40 stream-gaging stations throughout Connecticut were used to define average streamflow isopleths for the State; 12 of those gaging stations are in or immediately adjacent to the report area.

Whereas the amount of streamflow under natural conditions differs with the amount of precipitation, the time distribution of streamflow (flow duration) depends on the surficial geology of the area. M. P. Thomas (1966) developed a relationship that applies for most of Connecticut between flow duration and the proportion of a drainage area underlain by stratified drift. This relationship for the upper Housatonic River basin is shown on figure 18. The curves on figure 18 are based upon records from 26 gaging stations and apply to that part of the report area south of the Housatonic River designated "A" on figure 17. For that part of the area designated "B" on figure 17, another family of curves is shown on figure 18, which is based upon records from 8 gaging stations in the physiographic region known as the "Litchfield Hills." These latter curves are much steeper in the upper ranges than the area "A" curves, probably reflecting more rapid direct runoff from the more rugged terrain in the "B" area.

In general streamflow from areas having large proportions of stratified drift is more evenly distributed with time than streamflow from areas mantled largely by till. This reflects the greater infiltration and storage capacity of stratified drift compared with that of till; the relatively large amount of ground water stored in stratified drift is available for sustained release during dry weather.

Statistical analysis of the data for both sets of curves produced the following standard errors of estimate:

Percent of time flow was equaled or exceeded	1	5	10	30	50	70	90	95	99	99.9
Standard error of estimate, in percent	6	6	7	7	8	10	25	27	33	36

Large standard errors are restricted to small discharges and may be acceptable for practical purposes. If large errors are not acceptable for estimating low flows, a low-flow discharge measurement can be made at a specific site of interest and can be correlated with a record from a nearby site where the flow-duration relationship is known.

The flow-duration curves shown on figure 18, together with the isopleths on figure 17, may be used to estimate flow duration at any unmeasured site in the report area, as indicated by the following example. Assume that flow-duration characteristics are needed for a site on the Hollenbeck River directly downstream from Brown Brook at Lower City. On plate B, the site lies north of the Housatonic River and thus belongs in area "B". On the plate, the drainage area above the site is measured to be 16.3 square miles, and that part of the drainage area underlain by stratified drift is measured to be 1.68 square miles. Thus, with 10.3 percent of the area underlain by stratified drift, the flow-duration curve for this basin is the product of the ordinates of the curve

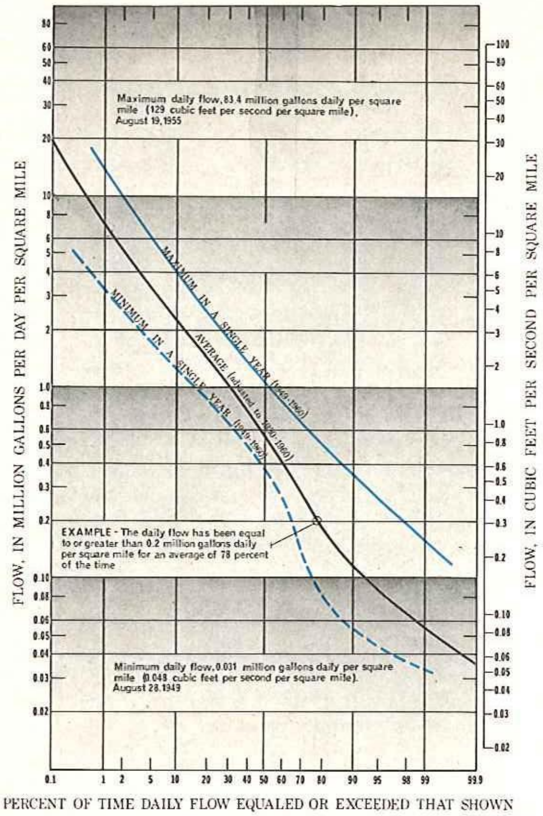


Figure 10.--Duration of daily mean streamflow of the Blackberry River at Canaan.

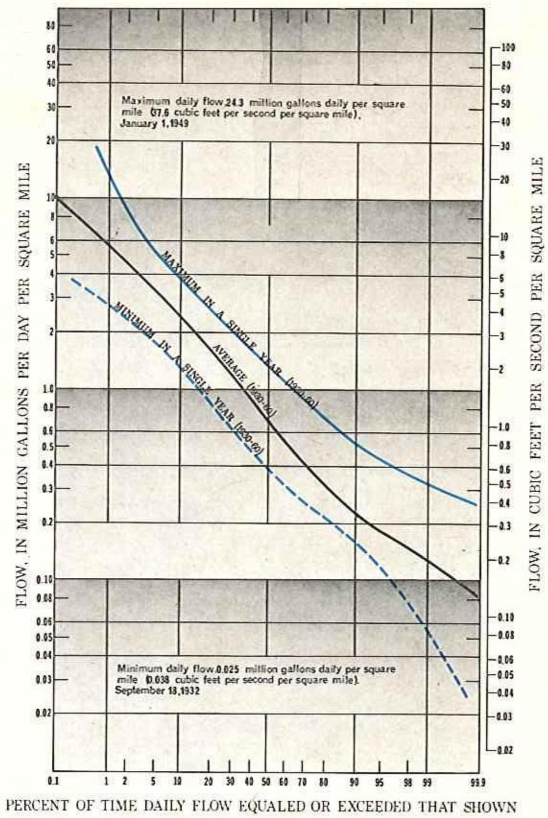


Figure 11.--Duration of daily mean streamflow of the Housatonic River at Falls Village.

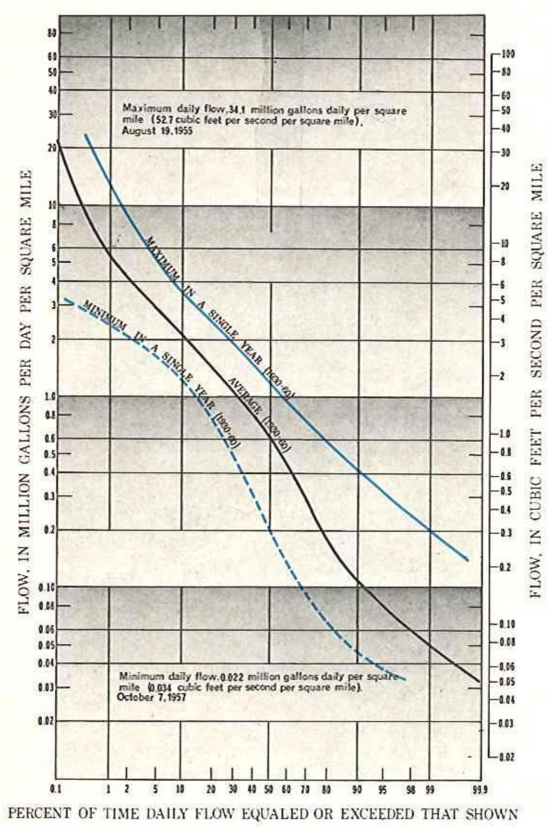


Figure 12.--Duration of daily mean streamflow of the Tenmile River near Gaylordsville.

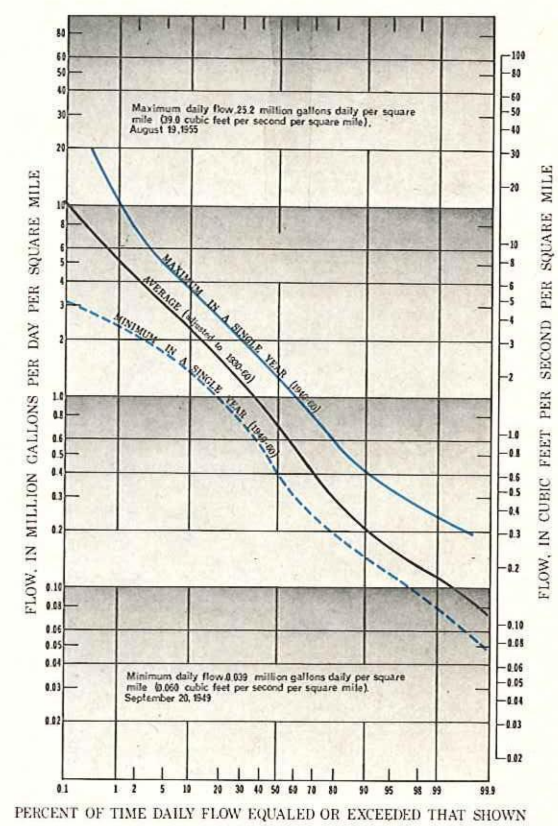


Figure 13.--Duration of daily mean streamflow of the Housatonic River at Gaylordsville.

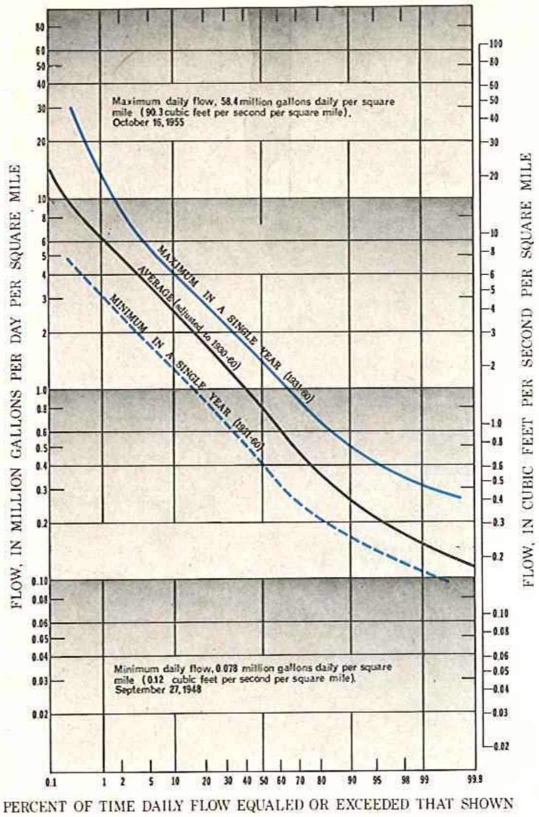


Figure 14.--Duration of daily mean streamflow of the Still River near Lanesville.

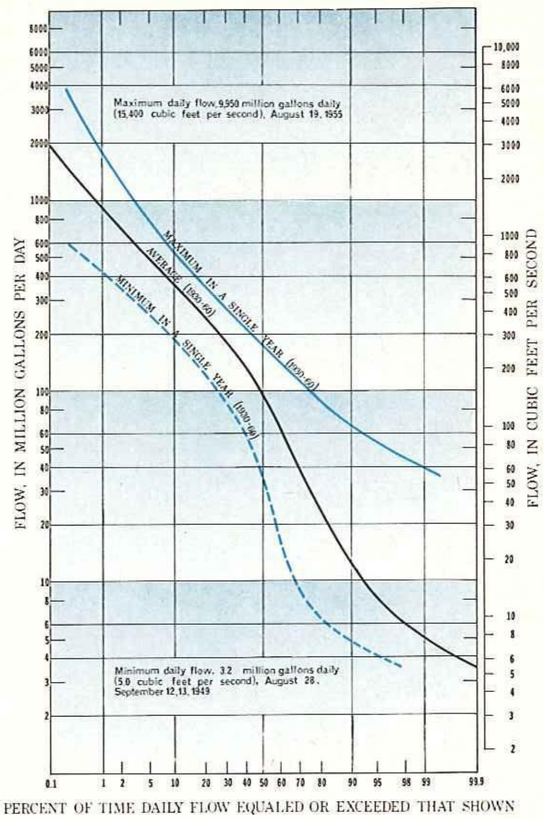


Figure 15.--Duration of daily mean streamflow of the Shepaug River near Roxbury. Unadjusted for regulation by and diversion from Cairns and Shepaug Reservoirs.

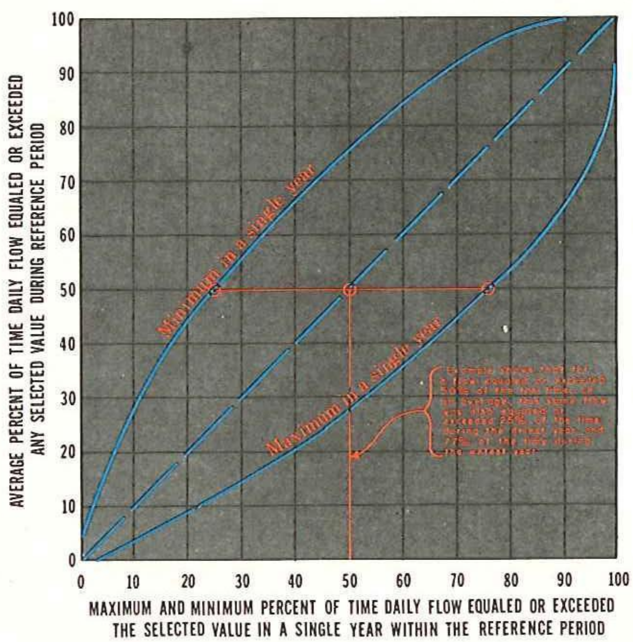


Figure 16.--Range in duration of streamflow in the upper Housatonic River basin, water years 1931-60.

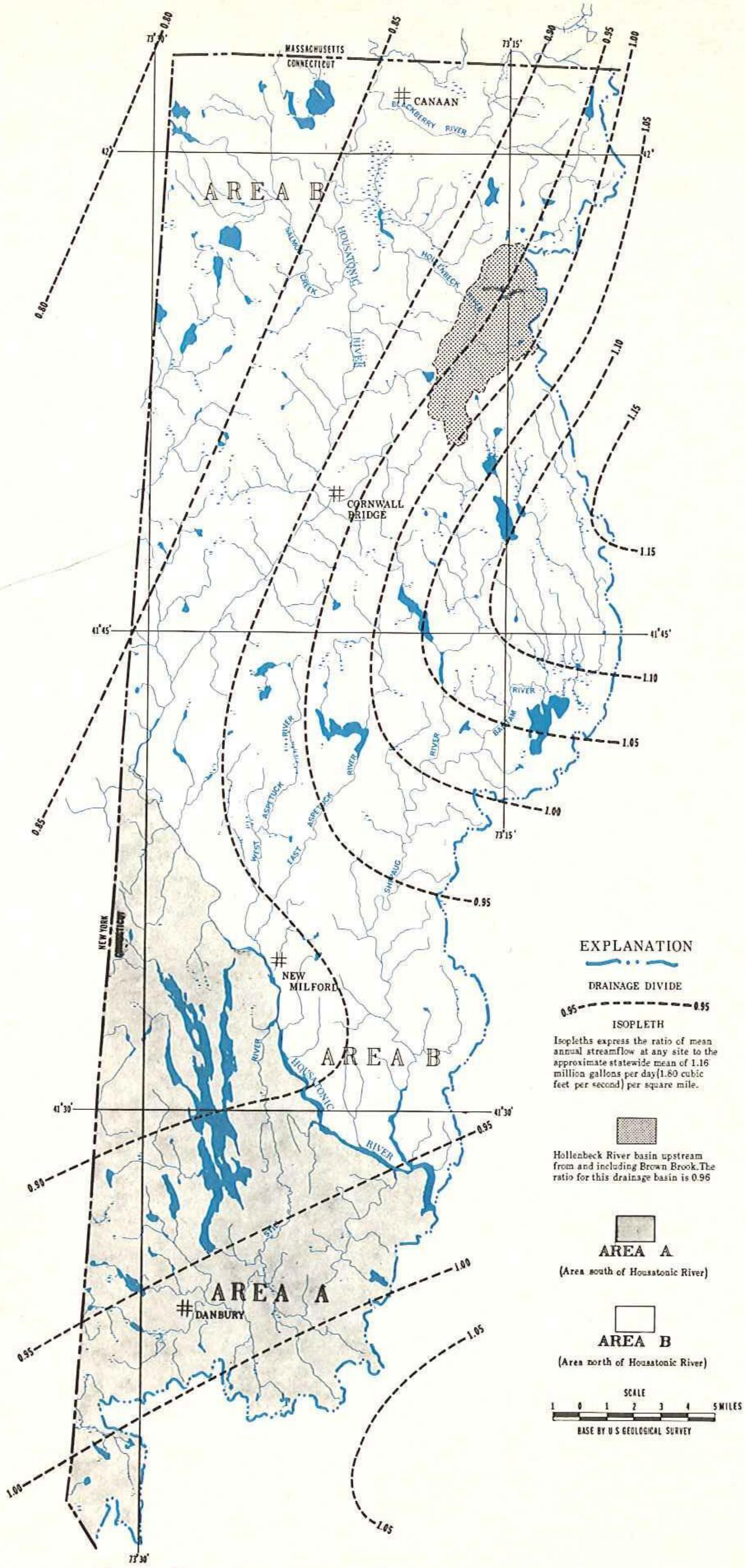


Figure 17.--Areal distribution of mean annual streamflow in the upper Housatonic River basin, water years 1931-60.

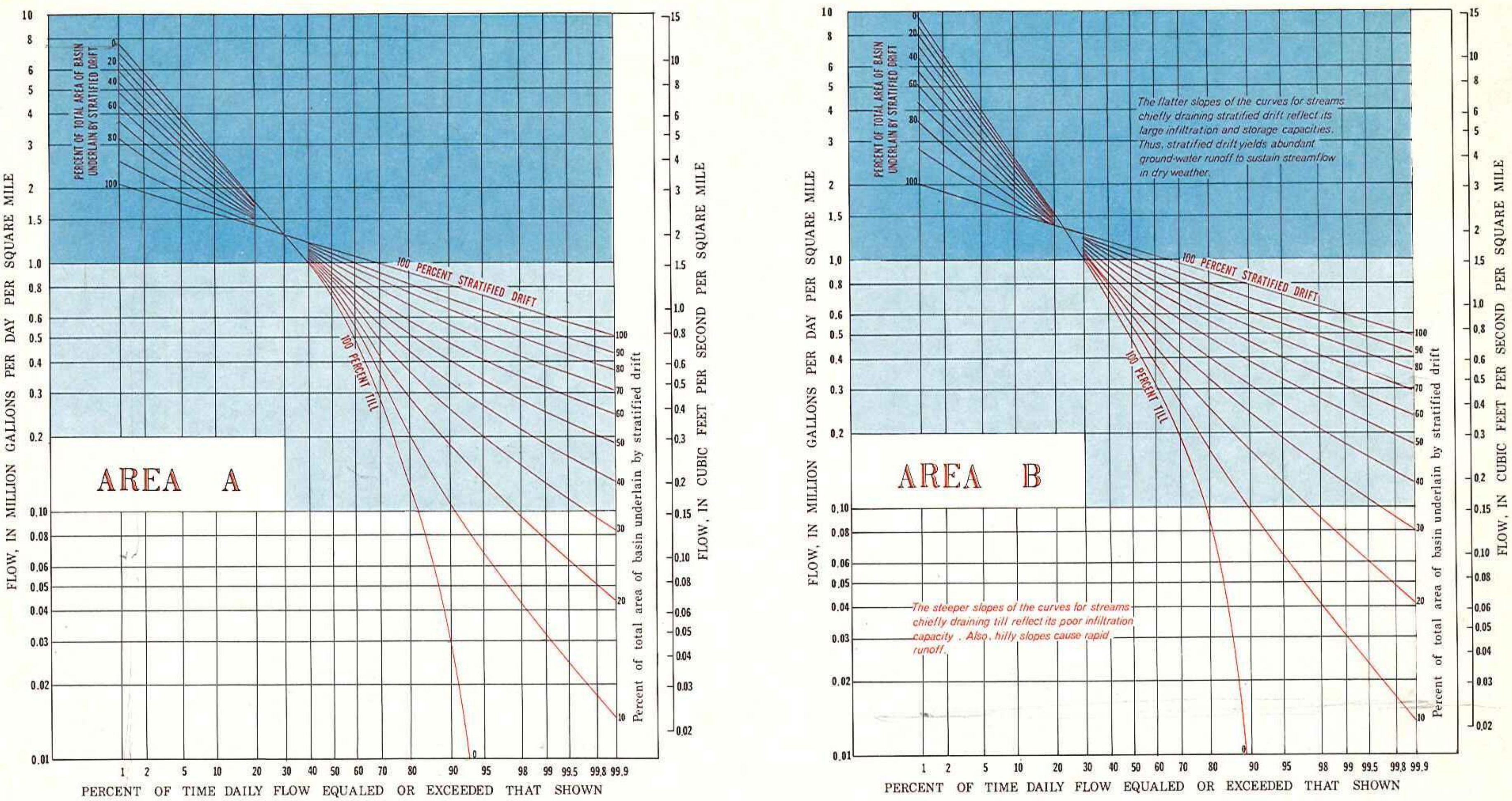


Figure 18.--Regional duration curves of daily mean streamflow for streams in areas A and B (areas shown on fig. 17).

These curves apply to unregulated streams having a mean annual flow of 1.16 mgd per sq mi (1.80 cfs per sq mi) and are based on the period 1930-60.

interpolated on figure 18 for this percentage of stratified drift multiplied by the drainage area of 16.3 square miles. However, figure 17 shows that the average streamflow in this basin is 4 percent less than 1.16 mgd per square mile, so the ordinate must be reduced by the factor 0.96. The resulting flow-duration table is:

Percent of time flow was equaled or exceeded	1	5	10	30	40	50	90	95	99	99.9
Flow equaled or exceeded, in mgd	140	63	40	17	8.7	4.2	1.6	1.0	0.5	0.2
Standard error of estimate, expressed in mgd	8.4	3.8	2.8	1.2	0.70	0.42	0.40	0.27	.16	.07

It is clear that, for percents of time from 90 to 99.9 (low flows), standard errors of estimate may be large in terms of percentage, as previously indicated, but are small in terms of discharge.

Once the average flow-duration curve for any ungaged site is determined, the probable maximum and minimum limits of duration in a single year may be estimated by using the curves on figure 16, which are based upon records from six long-term gaging stations in the basin. To illustrate: in the above example, a flow of 4.2 mgd was equaled or exceeded 50 percent of the time on an average. According to figure 16, this same flow was also equaled or exceeded 25 percent of the time during the driest year and 77 percent of the time during the wettest year during October 1930 to September 1960.

FREQUENCY AND DURATION OF LOW FLOWS

The lower part of flow-duration curves such as those shown on figures 10-15 and 18 indicate the minimum amounts of streamflow available for certain percentages of time. In planning the development and management of water resources, it may also be necessary to know how often specified streamflows are expected to recur and how long they are expected to last. Recurrence intervals of annual lowest mean flows for selected periods of consecutive days at long-term continuous-record gaging stations in the upper Housatonic River basin are given in table 4; frequency of high flows is discussed in a later section. Tables similar to table 4 can be constructed from flow-duration data for unmeasured sites that have been estimated from figures 17 and 18 by use of table 5. To illustrate: the average 30-consecutive-day low flow that could be expected to recur on the average once every 2 years, according to table 5, is the flow equaled or exceeded 90 percent of the time. Using the example for estimating flow duration at an unmeasured site on page 11, the 90-percent flow in the flow-duration table is 1.6 mgd (subject to a standard error of estimate of 0.4 mgd). Flows for other consecutive-day periods and other recurrence intervals can be determined in a similar manner.

Low-flow-frequency data also may be presented in graphs, as illustrated on figure 19, but the use of data from table 4 for the stream-gaging station on the Still River near Lanesville.

Connecticut Water Resources Commission (1970) listed water-quality standards for interstate and intrastate waters to implement pollution-control studies based on Public Act 57. It recommends that these standards apply to minimum average daily streamflow for 7 consecutive days with a 10-year recurrence interval. For unmeasured sites in the

Table 4.--Annual lowest mean flows for indicated periods of consecutive days and for indicated recurrence intervals at long-term stream-gaging stations in the upper Housatonic 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 of low flow (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
1985	Blackberry River at Canaan	48.2	3	10	6.4	5.2	4.1	3.2	2.5	2.2	0.134	0.086	0.070	0.055	0.043	0.034	0.030
			7	12	7.6	6.1	4.9	3.8	3.0	2.6	.161	.102	.082	.066	.051	.040	.035
			30	17	11	8.6	6.8	5.2	4.1	3.5	.228	.148	.115	.091	.070	.055	.047
			60	24	15	12	9.2	6.8	5.1	4.3	.322	.201	.161	.123	.091	.068	.058
			120	40	25	18	14	10	7.5	6.2	.536	.335	.241	.188	.134	.101	.083
			183	56	35	28	22	16	13	11	.751	.469	.375	.295	.215	.174	.148
			274	83	57	47	38	30	23	20	1.11	.764	.630	.510	.402	.308	.268
			365	100	77	67	58	49	42	38	1.34	1.03	.898	.778	.657	.563	.510
1990	Housatonic River at Falls Village	630	3	230	150	130	120	100	96	90	--	--	--	--	--	--	--
			7	260	180	150	140	120	110	100	.267	.185	.154	.144	.123	.113	.103
			30	340	220	190	170	150	140	130	.349	.226	.195	.174	.154	.144	.133
			60	430	260	220	200	180	160	150	.441	.267	.226	.205	.185	.164	.154
			120	640	350	280	240	210	190	180	.657	.359	.287	.246	.215	.195	.185
			183	850	480	390	320	260	230	220	.872	.492	.400	.328	.267	.236	.226
			274	1,100	740	600	500	400	330	300	1.13	.759	.616	.513	.410	.339	.308
			365	1,350	930	800	670	540	430	380	1.38	.954	.821	.687	.554	.441	.390
2000	Tenmile River near Gaylordsville	203	3	39	22	17	14	10	8.1	7.0	.124	.070	.054	.045	.032	.026	.022
			7	44	26	18	15	11	8.9	7.7	.140	.073	.057	.048	.035	.028	.025
			30	58	30	23	19	15	11	10	.185	.096	.073	.060	.048	.035	.032
			60	73	38	30	24	18	14	12	.232	.121	.096	.076	.057	.045	.038
			120	130	62	47	36	26	20	17	.414	.197	.150	.115	.083	.064	.054
			183	200	110	78	58	42	31	26	.637	.350	.248	.185	.134	.099	.083
			274	300	180	140	110	84	67	58	.955	.573	.446	.350	.267	.213	.185
			365	410	260	220	180	140	120	110	1.31	.828	.700	.573	.446	.382	.350
2005	Housatonic River at Gaylordsville	994	3	300	200	180	160	140	120	110	--	--	--	--	--	--	--
			7	350	240	210	190	170	150	140	.228	.156	.137	.124	.111	.098	.091
			30	440	300	260	230	210	190	180	.286	.195	.169	.150	.137	.124	.117
			60	590	360	310	270	240	210	200	.384	.234	.202	.176	.156	.137	.130
			120	850	490	400	340	290	250	230	.553	.319	.260	.221	.189	.163	.150
			183	1,200	710	560	450	360	300	270	.780	.462	.364	.293	.234	.195	.176
			274	1,600	1,100	900	750	600	480	420	1.04	.715	.585	.488	.390	.312	.273
			365	2,050	1,400	1,200	1,000	820	660	580	1.33	.910	.780	.650	.533	.429	.377
2015	Still River near Lanesville	67.8	3	26	19	16	15	13	12	11	--	--	--	--	--	--	--
			7	28	21	18	16	14	13	12	.267	.200	.172	.153	.133	.124	.114
			30	36	26	22	20	17	15	14	.343	.248	.210	.191	.162	.143	.133
			60	47	31	23	23	20	18	17	.448	.296	.248	.219	.191	.172	.162
			120	67	41	34	29	26	24	22	.639	.391	.324	.276	.248	.229	.210
			183	93	55	46	40	34	30	28	.887	.524	.439	.381	.324	.286	.267
			274	120	80	68	59	50	43	40	1.14	.763	.648	.562	.477	.410	.381
			365	170	110	93	80	69	60	57	1.62	1.05	.887	.763	.658	.572	.543
2030	Shepaug River near Roxbury	133	3	18	10	8.2	6.9	5.6	4.8	4.4	--	--	--	--	--	--	--
			7	22	12	9.3	7.7	6.3	5.3	4.8	--	--	--	--	--	--	--
			30	35	17	13	10	8.0	6.7	6.0	--	--	--	--	--	--	--
			60	57	23	17	13	10	8.6	7.6	--	--	--	--	--	--	--
			120	110	41	30	23	17	13	11	--	--	--	--	--	--	--
			183	180	72	52	40	32	27	24	--	--	--	--	--	--	--
			274	250	130	100	85	75	69	66	--	--	--	--	--	--	--
			365	330	200	160	140	130	120	110	--	--	--	--	--	--	--

Table 5.--Average duration of lowest mean flows of streams in the upper Housatonic River basin

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

Period of low flow (Consecutive days)	Average percent of time in which streamflow equaled or exceeded the lowest mean flow for indicated recurrence interval in years 1/: 1.2	2 (median year)	3	5	10	20	31 (driest year)
3	92	97	98	99.2	99.7	99.8	99.9
7	88	95	97	98	99.2	99.6	99.7
30	81	90	94	96	98	99	99.3
60	74	85	90	94	96	98	98
120	61	75	81	87	92	95	96
183	49	65	72	77	84	88	91
274	35	50	57	63	70	75	78
365	25	37	44	50	56	62	65

1/ Based on records from April 1930 to March 1960 at 34 continuous-record gaging stations throughout Connecticut.

report area, this would be equivalent to the flow equaled or exceeded 99.2 percent of the time.

The lowest daily flows of record during the reference period April 1930 to March 1960 that were not exceeded during periods of 7, 15, 30, 60, and 120 consecutive days at long-term gaging stations in the basin are given in table 6. Records after the reference period indicate that flows during low-flow periods in 1964 and 1965 at some of the long-term stations were lower than those listed in table 6 but not appreciably lower.

For any unmeasured site on an unregulated stream, the lowest daily flow not exceeded for periods of 7, 30, 60, and 120 consecutive days may be approximated by multiplying the lowest annual mean flow for any period having a 31-year recurrence interval by 1.1, 1.4, 1.7, and 2.3, respectively. These factors are average ratios derived from long-term records at five gaging stations in the basin.

STORAGE OF WATER

LAKES AND RESERVOIRS

Lakes, ponds, and reservoirs abound in the upper Housatonic River basin. Table 7 presents the salient features of the most important ones.

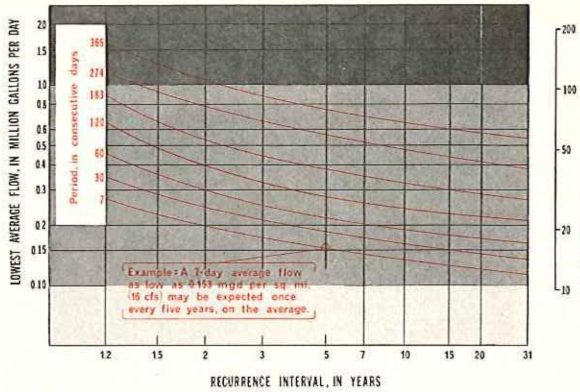


Figure 19.--Recurrence intervals of low flows of the Still River near Lanesville (drainage area, 67.8 square miles).

The volume of usable storage in lakes, ponds, and reservoirs is shown in table 7 and on plate D; additional information on the public-supply reservoirs is given in table 24.

More than half the lakes, ponds, and reservoirs listed in table 7 have usable storage; that is, some or all of their water may be withdrawn by gravity through a valve or gate. Table 8 lists the maximum safe draft rates obtainable from most of these surface-water bodies if refilling by natural runoff is to be accomplished within each year of the reference period. Maximum draft rates are given for the driest year and for the median year of the reference period. Note that the draft is based on 24-hour per day use, and rates may be correspondingly increased for shorter daily periods.

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 dam it and release water 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. Table 9 shows the frequency with which various amounts of storage would have been required

Table 6.--Lowest daily flows not exceeded during periods ranging from 7 to 120 consecutive days at long-term stream-gaging stations in the upper Housatonic River basin (Flows in the years indicated were the lowest during the period April 1930 to March 1960)

Index no. (Pl. A)	Stream and place of measurement	Natural (N) or regulated (R)	Lowest daily flow (cfs) not exceeded for indicated consecutive days: 7 days	Year	15 days	Year	30 days	Year	60 days	Year	120 days	Year
1985	Blackberry River at Canaan	N	2.8	1957	3.5	1957	7.2	1957	16	1957	22	1957
1990	Housatonic River at Falls Village	R	121	1957	158	1953	194	1953	300	1949 & 1957	408	1957
2000	Tenmile River near Gaylordsville	N	9.0	1957	11	1957	15	1957	22	1957	30	1957
2005	Housatonic River at Gaylordsville	R	189	1953	211	1953	294	1953	394	1957	481	1957
2015	Still River near Lanesville	R	13	1932	17	1941 & 1948	22	1948	31	1935	55	1949
2030	Shepaug River near Roxbury	R	6.2	1949 & 1953	7.5	1957	11	1949	19	1948	31	1949

Table 7.--Lakes, ponds, and reservoirs in the upper Housatonic River basin

Index no. (Pl. A)	Name and location	Source of data 1/	Natural (N) or Artificial (A) 2/	Drainage area (sq mi)	Surface area (acres)	Surface elevation (ft above msl)	Maximum depth (ft)	Average depth (ft)	Total storage (mg)	Usable storage (mg)	Principal use
1980.08	Washining (East Twin) Lake near Taconic	FG	N	3.93	562	732	80	32	5,940	None	Recreation
1980.09	Washinee (West Twin) Lake at Taconic	FG	N	7.23	281	732	23	8.7	797	None	Recreation
1982.2	Tobey Pond near Norfolk	FG	N	.99	53.6	1,267	49	24	419	None	Recreation
1982.3	Norfolk Brook Detention Reservoir at Norfolk	SC	A	1.00	49.4	1,333	34	10	168	168	Flood control
1982.35	Wood Creek Pond near Norfolk	FG	A	1.81	151	1,371	8	4.0	197	197	Recreation
1982.5	Thousand Acre Swamp Detention Reservoir near North Norfolk	SC	A	5.18	251	1,408	12	11	889	555	Flood control
1982.8	Whiting River Detention Reservoir at Canaan Valley	SC	A	9.66	165	871	68	22	1,173	1,173	Flood control
1990.2	Riga Lake near Salisbury	FG	NA	2.47	170	1,750	35	9.6	536	292	Recreation
1990.24	South Pond (Mount Riga Lake) near Salisbury	FG	NA	3.47	141	1,715	20	8.9	413	342	Recreation
1990.31	Wononskopomuc Lake at Lakeville	FG	NA	2.54	353	724	108	36	4,170	320	Recreation
1991.13	Cream Hill Lake near North Cornwall	FG	N	.61	72	1,110	43	15.7	364	None	Recreation
1993.4	Wononpakook Lake near Lakeville	FG	N	4.35	164	698	24	12	615	None	Recreation
1993.5	Mudge Pond (Silver Lake) at Sharon	FG	N	11.4	201	536	35	22	1,440	None	Recreation
2005.7	Hatch Pond at South Kent	FG	N	3.50	61.5	388	26	12	230	None	Recreation
2009	Ball Pond near New Fairfield	FG	N	.35	89.9	776	52	23	659	None	Recreation
2010	Lake Candlewood near New Milford	FG	A	40.4	5,420	429	85	29	51,750	46,450	Hydroelectric power
2010.49	Lake Waramaug at New Preston	FG	NA	14.3	680	694	40	22	5,046	450	Recreation
2011.1	South Spectacle Pond at East Kent	FG	N	.35	93.0	1,180	44	19	579	None	Recreation
2011.19	North Spectacle Pond at East Kent	FG	N	1.99	130	1,168	33	14	597	None	Recreation
2014.3	East Lake Reservoir near New Fairfield	Da	A	1.44	59.7	681	29	18	360	324	Public supply
2014.4	Margerie Lake Reservoir near New Fairfield	Da	A	1.17	199	626	20	16	1,057	951	Public supply
2014.5	West Lake Reservoir near Danbury	Da	A	3.17	222	604	27	17	1,265	1,138	Public supply
2018.5	Taunton Pond near Newtown	FG	NA	1.18	126	540	30	22	875	200	Public supply
2019.02	Mohawk Pond at East Cornwall	FG	N	.19	15.2	1,181	27	16	79	None	Recreation
2019.05	West Side Pond near West Goshen	FG	N	3.50	42.4	1,280	33	15	209	None	Recreation
2019.09	Tyler Lake at West Goshen	FG	NA	6.34	182	1,268	26	12	718	255	Recreation
2019.99	Cairns (Upper Shepaug) Reservoir near Woodville	Wa	A	10.1	337	910	70	24	2,693	2,693	Public supply
2020	Shepaug Reservoir at Woodville	Wa	A	38.0	96.4	820	55	18	575	575	Public supply
2026.19	Dog Pond near Goshen	FG	N	3.22	71.3	1,235	11	4.7	109	None	Recreation
2027.5	Bantam Lake at Bantam	FG	NA	29.6	916	894	25	14	4,270	1,825	Recreation
2028	Mount Tom Pond near Woodville	FG	N	.95	61.5	879	46	21	425	None	Recreation
2035	Lake Lillinonah near Newtown	FG	A	1,392	1,900	198	100	39	23,936	13,135	Hydroelectric power
3747.8	Mamanasco Lake near Ridgefield	FG	NA	.79	92	578	10	6.9	207	71	Recreation

1/ Data chiefly from (FG) State Board of Fisheries and Game; (SC) Soil Conservation Division, Connecticut Department of Agriculture and Natural Resources; (Da) City of Danbury, Water Dept.; and (Wa) City of Waterbury, Dept. of Engineering.

2/ NA, lake natural but has level raised by low dam.

Table 8.--Maximum safe draft rates (regulated flows) from principal lakes, ponds, and reservoirs in the upper Housatonic River basin based on the reference period April 1930 to March 1960

Index no. (Pl. A)	Name and location	Drainage basin	Drainage area (sq mi)	Usable storage (mg)	Maximum safe draft rate: Driest year (cfs)	Driest year (mgd)	Median year (cfs)	Median year (mgd)
1982.35	Wood Creek Pond near Norfolk	Wood Creek	1.81	197	a/0.69	a/0.45	a/2.2	a/1.4
1990.2	Riga Lake near Salisbury	Wachocastinook Creek	2.47	292	a/ .78	a/ .50	a/2.5	a/1.6
1990.24	South Pond (Mount Riga Lake) near Salisbury	Wachocastinook Creek	3.47	342	a/1.1	a/ .71	a/3.5	a/2.3
1990.31	Wononskopomuc Lake at Lakeville	Factory Brook	2.54	320	a/ .83	a/ .54	a/2.6	a/1.7
2010.49	Lake Waramaug at New Preston	East Aspetuck River	14.3	450	4.8	3.1	9.6	6.2
2014.3	East Lake Reservoir near New Fairfield	East Lake Brook	1.44	324	a/ .77	a/ .50	a/2.2	a/1.4
2014.4	Margerie Lake Reservoir near New Fairfield	Unnamed tributary to Padanaram Brook	1.17	951	a/ .63	a/ .41	a/1.8	a/1.2
2014.5	West Lake Reservoir near Danbury	Unnamed tributary to Kohanza Brook	3.17	1,138	a/1.7	a/1.1	a/4.9	a/3.2
2018.5	Taunton Pond near Newtown	Pond Brook	1.18	200	a/ .68	a/ .44	a/1.9	a/1.2
2019.09	Tyler Lake at West Goshen	West Side Pond Brook	6.34	255	2.9	1.9	5.1	3.3
2019.99	Cairns (Upper Shepaug) Reservoir near Woodville	Shepaug River	10.1	2,693	a/4.1	a/2.6	a/13	a/8.4
2020	Shepaug Reservoir at Woodville b/	Shepaug River	27.9	575	8.4	5.4	17	11
2027.5	Bantam Lake at Bantam	Bantam River	29.6	1,825	a/17	a/11	33	21
2035	Lake Lillinoah near Newtown	Housatonic River	1,392	13,135	520	340	860	560
3747.8	Mamanasco Lake near Ridgefield	Unnamed tributary to Titicus River	.79	71	a/ .46	a/ .30	1.1	.71

a/ All of the usable storage cannot be used if it is to be completely replenished in one year.

b/ Excludes area above and flow from Cairns Reservoir. If Cairns and Shepaug Reservoirs are used in combination, the maximum safe draft equals the sum of the draft rates from both reservoirs.

Table 9.--Storage required to maintain indicated flows at long-term stream-gaging stations in the upper Housatonic River basin

(Data are adjusted to the reference period April 1930 to March 1960. Storage required would refill within one year except for figures underlines; these would take longer. Storage is uncorrected for reservoir seepage, evaporation, and for computational bias, all of which would increase the amount of storage required.)

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/sq mi)	Storage required (mg/sq mi) to maintain indicated regulated flow (mgd/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
1985	Blackberry River at Canaan	48.2	1.2	..	..	..	..	..	1	3	5	7	10	13	16	19	23	27	32	43	55
			2	..	..	..	1	2	5	8	12	16	20	25	31	37	44	52	60	78	96
			5	91	..	1	4	8	13	19	25	31	39	47	56	65	75	85	95	116	140
			10	85	1	4	8	13	19	26	34	43	53	63	73	83	94	105	117	141	166
			31	71	3	7	13	20	28	37	47	58	69	81	94	107	120	133	146	173	200
1990	Housatonic River at Falls Village	630	1.2	..	..	..	..	..	..	..	1	3	5	7	9	12	15	19	23	31	41
			2	84	..	..	..	..	2	5	8	12	17	23	29	35	42	49	57	75	93
			5	66	..	..	1	3	7	12	18	25	33	41	50	59	68	78	89	111	135
			10	53	..	..	2	5	10	17	25	33	42	52	62	72	83	95	108	135	166
			31	30	..	1	3	7	14	23	32	42	53	66	80	95	113	132	150	187	223
2000	Tenmile River near Gaylordsville	203	1.2	..	..	..	..	2	4	7	10	13	17	21	25	30	35	40	46	58	72
			2	87	..	2	5	8	13	18	24	30	36	43	50	57	65	73	82	102	125
			5	76	2	5	10	16	23	31	40	50	60	70	81	92	103	114	126	151	178
			10	59	3	8	14	21	30	40	50	60	71	83	95	107	119	132	146	175	206
			31	52	6	13	21	31	41	52	64	76	88	101	114	127	141	156	171	203	238
2005	Housatonic River at Gaylordsville	994	1.2	..	..	..	..	..	..	1	3	5	7	10	13	16	20	25	30	41	54
			2	81	..	..	..	2	4	7	11	16	22	28	34	40	47	55	63	80	98
			5	65	..	..	1	5	10	16	23	31	39	47	56	65	74	84	94	116	140
			10	55	..	1	3	8	14	22	30	39	48	58	68	78	89	100	113	141	171
			31	38	1	2	6	14	23	32	42	53	64	76	90	104	119	136	154	190	227
2015	Still River near Lanesville	67.8	1.2	..	..	..	..	..	..	..	1	3	5	7	9	12	15	18	22	31	42
			2	..	..	..	..	..	1	2	5	9	14	19	25	31	38	45	53	69	87
			5	70	..	..	..	2	5	9	15	21	27	34	42	50	58	67	77	98	122
			10	61	..	..	1	3	6	11	18	25	33	41	50	60	70	81	92	116	143
			31	52	..	1	2	5	10	17	24	33	43	53	65	77	89	102	115	143	172

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 10.--Storage required to maintain indicated flows at unmeasured sites on unregulated streams in area A, south of the Housatonic River

(Date 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 within one year except for figures underlined; these would take longer. Storage is uncorrected for reservoir seepage, evaporation, and for computational bias, all of which increase 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/sq mi)	Storage required (mg/sq mi) to maintain indicated regulated flow (mgd/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	2	3	4	6	9	12	15	18	22	26	30	34	38	43	53	64
	2	..	2	5	8	12	16	21	26	31	37	43	49	56	63	71	79	96	115
	5	108	6	11	17	23	30	37	45	53	62	71	80	90	100	111	122	144	167
	10	97	10	16	23	31	39	48	58	68	79	90	101	113	125	137	149	174	200
	31	69	14	23	32	42	52	63	75	87	99	111	124	137	151	165	179	207	237
10	1.2	..	..	..	..	..	2	4	6	9	12	15	19	23	27	31	36	46	57
	2	..	..	1	3	6	9	13	17	22	27	33	40	47	54	61	68	84	102
	5	97	2	5	9	14	20	26	33	40	48	57	66	75	85	95	105	126	148
	10	90	3	7	13	20	27	35	44	53	63	73	84	95	106	118	130	154	179
	31	67	5	12	20	29	38	47	57	68	80	92	105	118	131	144	158	186	214
20	1.2	..	..	..	..	..	..	1	3	5	8	11	15	19	23	27	31	41	51
	2	..	..	..	..	1	3	6	10	15	20	25	31	37	43	50	58	74	92
	5	90	..	..	3	6	11	16	22	29	36	44	53	62	71	81	91	112	134
	10	83	..	2	6	10	16	23	31	39	48	57	67	77	87	99	111	136	162
	31	60	..	4	9	16	24	33	42	51	61	72	84	96	108	121	135	164	194
30	1.2	..	..	..	..	..	..	..	1	2	4	7	10	13	16	19	23	32	44
	2	..	..	..	..	..	1	3	5	8	12	16	22	28	34	41	48	63	80
	5	83	..	..	..	2	5	9	13	18	24	31	39	47	56	65	75	95	117
	10	77	..	..	1	4	8	14	20	27	34	43	52	62	72	83	94	117	141
	31	61	..	..	3	7	13	20	28	37	47	57	68	79	90	102	115	141	169
40	1.2	..	..	..	..	..	..	..	..	..	1	2	5	8	11	14	18	26	37
	2	..	..	..	..	..	..	..	1	3	6	9	13	18	24	31	38	53	69
	5	76	..	..	..	..	1	3	7	11	16	22	28	35	43	52	61	81	102
	10	72	..	..	..	..	2	6	11	17	24	31	39	48	57	67	78	100	123
	31	59	..	..	..	2	6	12	18	26	34	42	52	62	73	84	96	121	147
50	1.2	..	..	..	..	..	..	..	..	..	..	1	2	4	6	9	12	20	30
	2	..	..	..	..	..	..	..	..	1	3	5	8	12	16	21	27	42	58
	5	68	..	..	..	..	..	1	3	6	10	14	19	25	31	38	46	65	86
	10	65	..	..	..	..	..	2	5	9	15	21	27	34	42	51	61	82	105
	31	56	..	..	..	..	1	4	9	15	22	30	39	48	57	67	78	102	127
60	1.2	..	..	..	..	..	..	..	..	..	..	..	1	2	4	6	9	16	25
	2	..	..	..	..	..	..	..	..	..	..	2	4	7	10	14	19	31	47
	5	61	..	..	..	..	..	..	..	2	5	8	12	17	22	28	35	51	71
	10	59	..	..	..	..	..	..	1	3	7	11	17	23	30	38	47	66	88
	31	52	..	..	..	..	..	1	3	7	13	19	26	34	42	52	62	84	109
80	1.2	..	..	..	..	..	..	..	..	..	..	..	..	..	..	1	2	6	12
	2	..	..	..	..	..	..	..	..	..	..	..	..	1	2	4	6	12	24
	5	..	..	..	..	..	..	..	..	..	..	..	2	4	6	10	14	26	42
	10	50	..	..	..	..	..	..	..	..	..	1	3	6	10	15	21	35	53
	31	47	..	..	..	..	..	..	..	..	1	3	7	12	18	24	31	49	69
100	1.2	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	3
	2	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	3	11
	5	..	..	..	..	..	..	..	..	..	..	..	..	..	..	1	3	11	21
	10	..	..	..	..	..	..	..	..	..	..	..	..	..	1	2	6	15	29
	31	..	..	..	..	..	..	..	..	..	..	..	..	1	3	7	12	25	40

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

Table 11.--Storage required to maintain indicated flows at unmeasured sites on unregulated streams in area B, north of the Housatonic River

(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 within a year except for figures underlined; these would take longer. Storage is uncorrected for reservoir seepage, evaporation, and for computational basis, all of which increase 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/sq mi)	Storage required (mg/sq mi) to maintain indicated regulated flow (mgd/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	2	4	6	9	12	15	19	24	29	35	41	47	54	61	75	91
	2	102	3	6	9	13	18	24	31	38	46	54	63	72	82	92	102	123	146
	5	66	9	14	20	27	34	42	50	59	69	80	92	104	117	130	144	172	201
	10	61	11	18	26	35	45	56	67	78	90	102	114	126	139	152	167	197	228
	31	48	18	27	37	47	58	69	81	93	106	119	134	149	165	182	200	..	..
10	1.2	..	..	..	1	2	4	7	10	13	17	22	27	33	39	45	52	66	81
	2	95	..	1	3	7	11	16	22	28	35	43	51	60	69	79	89	109	131
	5	67	1	5	9	14	20	28	37	46	56	67	78	89	101	113	126	152	179
	10	59	3	7	13	20	29	39	49	60	71	82	94	106	119	132	146	175	205
	31	44	5	11	19	29	39	49	61	73	85	98	112	127	142	158	174	210	..
20	1.2	..	..	..	..	..	1	3	5	7	10	14	18	23	29	36	43	59	77
	2	90	..	..	..	1	4	8	12	18	24	31	39	47	55	64	73	92	114
	5	61	..	..	3	6	11	18	25	32	40	48	58	68	79	91	104	130	158
	10	55	..	2	6	11	17	24	32	41	51	61	72	84	97	110	124	152	183
	31	44	..	4	10	16	24	33	43	54	66	78	91	104	118	133	149	183	219
30	1.2	..	..	..	..	..	..	..	2	4	6	9	13	17	22	27	33	46	61
	2	82	..	..	..	..	1	3	6	10	15	20	27	34	42	50	59	77	98
	5	57	..	..	..	2	6	10	15	21	28	35	44	53	63	73	85	112	140
	10	52	..	..	1	4	8	14	21	29	37	46	56	66	77	89	102	130	160
	31	44	..	..	3	8	15	22	30	38	48	58	70	83	96	110	125	157	190
40	1.2	..	..	..	..	..	..	..	..	1	3	5	8	11	14	19	24	36	50
	2	78	..	..	..	..	..	..	2	5	8	12	18	24	31	39	47	65	84
	5	53	..	..	..	..	2	4	8	13	18	24	31	39	47	57	67	91	118
	10	48	..	..	..	1	3	7	12	18	24	31	40	49	59	70	82	109	138
	31	43	..	..	..	2	6	12	19	26	35	44	54	65	76	89	102	132	165
50	1.2	..	..	..	..	..	..	..	..	..	..	2	4	6	9	12	16	27	40
	2	..	..	..	..	..	..	..	..	1	3	5	9	13	18	24	32	48	67
	5	50	..	..	..	..	..	..	3	6	10	15	21	27	34	42	51	72	97
	10	49	..	..	..	..	..	1	5	10	15	22	29	37	45	54	64	87	113
	31	45	..	..	..	..	2	5	9	15	22	30	39	48	58	68	80	105	134
60	1.2	..	..	..	..	..	..	..	..	..	..	..	..	2	4	7	11	20	31
	2	..	..	..	..	..	..	..	..	..	..	1	4	7	11	16	22	36	54
	5	48	..	..	..	..	..	..	..	2	5	8	12	17	23	30	38	55	77
	10	47	..	..	..	..	..	..	1	4	7	12	17	23	30	39	48	70	94
	31	43	..	..	..	..	..	..	3	7	13	19	26	34	42	52	63	86	113
80	1.2	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	2	7	15
	2	..	..	..	..	..	..	..	..	..	..	..	..	..	1	4	7	16	29
	5	44	..	..	..	..	..	..	..	..	..	..	2	4	8	12	17	29	46
	10	43	..	..	..	..	..	..	..	..	..	1	3	7	12	17	23	38	58
	31	42	..	..	..	..	..	..	..	..	..	3	8	13	18	25	33	52	75
100	1.2	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	3
	2	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	3	11
	5	..	..	..	..	..	..	..	..	..	..	..	..	..	..	1	3	11	21
	10	..	..	..	..	..	..	..	..	..	..	..	..	..	1	2	6	15	29
	31	..	..	..	..	..	..	..	..	..	..	..	..	1	3	7	12	25	40

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

to maintain selected rates of regulated flow for five long-term continuous-record gaging stations in the upper Housatonic River basin during the reference period. Values required for a recurrence interval of 2 years represent median conditions, and values for a recurrence interval of 31 years represent very dry conditions. The rates of regulated flow are presented per square mile of drainage ares, so that the table may be used for other sites along the same stream, provided that the percentage of the area underlain by stratified drift is not appreciably different. Most 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 figures 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 on streams previously unaffected by regulation are presented in table 10 for unmeasured sites in area "A" and in table 11 for unmeasured sites in area "B". (For areas, see fig. 17.) The data are related to various percentages of area underlain by stratified drift; interpolations between percentages may be made. Storage used to provide regulated flow would be replaced within 1 year except for underlined values: these represent storage required to maintain relatively large regulated flows in dry years and, hence, would not be completely replaced during such dry years. Tables 10 and 11 are based upon an average streamflow of 1.16 mgd per square mile and, as previously indicated, must be adjusted to the average streamflow at that site by multiplying by an appropriate ratio determined from figure 17.

The storage-required values in tables 9, 10, and 11 are smaller than the values actually required because they include a bias of about 10 percent, which results from the use of the frequency-mass curve; moreover, losses due to evaporation and seepage from the reservoir are not included. These values are sufficiently accurate, however, for reconnaissance planning and for selection of a proposed site. Furthermore, draft rates assume continuous use and may be correspondingly increased for daily periods shorter than 24 hours.

FLOODS

HISTORY

Floods may occur in the upper Housatonic River basin in any season of the year. Spring floods are common and are sometimes accompanied by destruction from moving ice. Floods in late summer and fall are usually the result of hurricanes or other storms moving northeastward along the Atlantic coast. Winter floods result from occasional thaws, particularly in years of heavy snowfall.

Since 1693, there have been at least 26 major floods in the basin. General descriptive information concerning major floods through 1955, extracted from newspaper accounts and other public and private records, is published in U.S. Geological Survey Water-Supply Paper 1779-M (Thomson and others, 1964).

Records of major floods from gaging stations are summarized in table 12. Floods of moderate magnitude occurred in March 1936 during the spring thaw. At a time of an unusually high accumulation of snow on the ground two heavy rainstorms in close succession triggered the floods. Destruction was aggravated during the first storm, on March 12, by the break up of thick ice on the Housatonic. Flooding caused by this storm was greater in the lower part of the basin. The second storm, on March 18, caused greater flooding in the upper part of the basin. In September 1938, heavy rain associated with a hurricane produced severe flooding in the basin. Rain began as light showers during the afternoon of September 17 and continued with little interruption and increasing intensity until the late afternoon of September 21. Precipitation on the upper Housatonic River basin, fortunately, was not as great as on most other basins in Connecticut; however, the concentration of rainfall was sufficient to cause record-breaking stages and flows throughout the basin. The "New Year's Flood" of January 1, 1949, produced the all-time record flood on the Housatonic River above Falls Village. The flow in the main channel below Falls Village approached that of September 21-23, 1938, but the tributaries were only moderately flooded. The flood of August 19, 1955 was unprecedented in the basin. It was

Table 12.--Elevations of flood peaks and corresponding flows for notable floods of record at long-term stream-gaging stations in the upper Housatonic River basin

Index no. (Pl. A)	Stream and place of measurement	Nov. 5, 1927		Mar. 12, 13, 1936		Mar. 18, 19, 20, 1936		Sept. 21, 22, 23, 1938		Dec. 31, 1948, Jan. 1, 1949		Aug. 19, 1955		Oct. 16, 1955	
		Elevation (ft above msl)	Flow (cfs)	Elevation (ft above msl)	Flow (cfs)	Elevation (ft above msl)	Flow (cfs)	Elevation (ft above msl)	Flow (cfs)	Elevation (ft above msl)	Flow (cfs)	Elevation (ft above msl)	Flow (cfs)	Elevation (ft above msl)	Flow (cfs)
1985	Blackberry River at Canaan	--	--	--	--	--	--	--	--	657.7	7,000	658.7	14,200	654.8	2,830
1990	Housatonic River at Falls Village	538.0	11,700	538.4	12,500	539.8	14,500	543.0	19,900	545.2	23,900	545.2	22,700	535.5	8,940
2000	Tenmile River near Gaylordsville	--	--	316.0	10,200	313.0	5,440	317.2	12,500	313.7	6,360	319.3	17,400	315.4	9,620
2005	Housatonic River at Gaylordsville	--	--	249.4	26,000	248.3	21,000	251.3	37,000	251.6	32,300	255.4	51,800	249.2	21,600
2015	Still River near Lanesville	--	--	223.6	3,260	221.0	1,020	223.9	3,590	221.0	1,110	224.2	3,920	227.2	7,9[illegible]
2030	Shepaug River near Roxbury	--	--	292.8	7,480	291.7	5,750	294.8	10,500	292.4	7,010	299.2	50,300	293.5	7,760

preceded by a minor flood resulting from hurricane "Connie" on August 13, which set the stage for hurricane "Diane" on August 19 by soaking the ground and bringing the streams to medium-high stages. The torrential rains accompanying "Diane" produced record peak flows on all tributaries and on the Housatonic River, except for the reach of river above Falls Village, where the peak flow was slightly less than that of January 1, 1949. The flood of October 16, 1955 was only moderate over all but the southern part of the basin, however, it produced a peak flow on the Still River twice that of August 19, 1955.

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), 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.

Three floodwater-retarding structures have been constructed in the Blackberry River watershed since 1963. Norfolk Brook Detention Reservoir is located on the headwaters of the Blackberry River upstream from Norfolk. Thousand Acre Swamp and Whiting River Detention Reservoirs are located on the Whiting River, the main tributary to the Blackberry River. All were designed and constructed by the U. S. Department of Agriculture, Soil Conservation Service, for the State of Connecticut to protect low-lying areas from floods. Storage capacities and other data pertaining to these three reservoirs can be found in table 7.

Table 13.--Maximum flood of record and mean annual flood at stream-gaging stations in the upper Housatonic River basin

				Maximum flood of record					Mean annual flood		
					Elevation	Flow			Elevation	Flow	
Index no (Pl. A)	Stream and place of measurement	Drainage area (sq mi)	Period of continuous record	Date	(ft above msl)	(cfs)	(cfs per sq mi)	Ratio to mean annual	(ft above msl)	(cfs)	(cfs per sq mi)
1987	Brown Brook at Lower City	5.55	1960-67	Apr. 1, 1962	--	120	21.6	0.75	--	160	28.8
1990	Housatonic River at Falls Village	630	1912-67	Jan. 1, 1949	545.2	23,900	37.9	3.62	537.0	6,600	10.5
1990.3	Wachocastinook Creek at Salisbury	5.33	1966-67	Oct. 2, 1966	--	a/ 115	21.6	--	--	--	--
1990.33	Factory Brook at at Salisbury	6.51	1966-67	Apr. 2, 1967	--	118	18.1	--	--	--	--
1990.5	Salmon Creek at Lime Rock	29.1	1961-67 b/	Mar. 27, 1963 Aug. 19, 1955	623.7 633.9	500 6,300	17.2 216	.79 10.0	624.1	630	21.6
1991.5	Furnace Brook at Cornwall Bridge	13.2	1961-67 b/	Apr. 1, 1962 Aug. 19, 1955	-- --	300 4,060	22.7 308	.86 11.6	--	350	26.5
1992	Guinea Brook at Ellsworth	3.48	1960-67	Feb. 26, 1961	1,145.5	142	40.8	1.14	1,145.3	125	35.9
2000	Tenmile River near Gaylordsville	203	1929-67	Aug. 19, 1955	319.3	17,400	85.7	5.61	310.7	3,100	15.3
2005	Housatonic River at Gaylordsville	994	1940-67	Aug. 19, 1955	255.4	51,800	52.1	4.71	245.9	11,000	11.1
2011.9	West Aspetuck River near New Milford	23.3	1962-67	Mar. 27, 1963	246.2	390	16.7	.93	246.3	420	18.0
2014.2	Still River at Danbury	13.1	1966-67	Mar. 12, 1967	--	110	8.4	--	--	--	--
2014.7	Still River near Danbury	38.4	1966-67	Aug. 9, 1967	--	574	14.9	--	--	--	--
2015	Still River near Lanesville	67.8	1931-66	Oct. 16, 1955	227.2	7,980	118	7.25	221.0	1,100	16.2
2018.9	Pond Brook near Hawleyville	11.2	1962-67	Jan. 21, 1964	--	390	34.8	.98	--	400	35.7
2027	Butternut Brook near Litchfield	2.39	1960-67	Jan. 25, 1964	--	520	218	1.58	--	330	138
2030	Shepaug River near Roxbury	133	1930-67	Aug. 19, 1955	299.2	50,300	378	16.8	288.9	3,000	22.6
2031	Jacks Brook near Roxbury Falls	7.77	1960-67	Mar. 12, 1962	--	800	103	1.78	--	450	57.9

a/ Maximum observed flow. b/ Indirect measurement before establishment of gaging station.

Table 14.--Annual highest average flows and corresponding average elevations for indicated recurrence intervals at long-term stream-gaging stations in the upper Housatonic River basin

(Based on data adjusted to the reference period October 1930 to September 1960.)

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 msl for indicated recurrence interval (years)						
				1.03	2	5	10	25	50	100	1.03	2	5	10	25	50	100
1990	Housatonic River at Falls Village	630	0	3,500	6,100	9,200	12,000	18,000	24,000	33,000	534.6	536.6	538.9	540.9	544.7	548.4	553.4
			1	3,100	5,800	9,200	12,000	18,000	24,000	33,000	534.3	536.4	538.9	540.9	544.7	548.4	553.4
			3	2,800	5,400	8,600	11,000	17,000	23,000	30,000	534.0	536.0	538.4	540.2	544.1	547.8	551.8
			7	2,500	4,800	7,400	9,800	14,000	18,000	24,000	533.8	535.6	537.6	539.3	542.2	544.7	548.4
			15	2,200	3,800	5,600	7,300	10,000	13,000	16,000	533.5	534.8	536.2	537.5	539.4	541.6	543.5
			30	1,900	3,100	4,200	5,300	6,800	8,400	10,000	533.2	534.3	535.1	536.0	537.1	538.3	539.4
			60	1,600	2,400	3,100	3,700	4,700	5,500	6,500	532.9	533.7	534.3	534.7	535.5	536.1	536.9
			150	1,300	1,700	2,100	2,400	2,800	3,200	3,600	532.6	533.0	533.4	533.7	534.0	534.4	534.7
			274	1,100	1,300	1,600	1,800	2,000	2,200	2,500	532.3	532.6	532.9	533.1	533.3	533.5	533.8
			365	1,000	1,200	1,400	1,500	1,700	1,900	2,100	532.2	532.4	532.7	532.8	533.0	533.2	533.4
2000	Tenmile River near Gaylordsville	203	0	1,600	2,900	4,300	5,700	8,400	11,000	16,000	309.1	310.6	311.8	312.8	314.6	316.1	318.6
			1	1,300	2,500	3,900	5,400	8,000	10,000	14,000	308.7	310.2	311.4	312.6	314.4	315.5	317.7
			3	940	1,900	3,100	4,400	6,600	9,000	12,000	308.1	309.5	310.7	311.8	313.5	315.0	316.7
			7	740	1,500	2,300	3,100	4,600	6,000	8,000	307.7	309.0	309.9	310.7	312.0	313.0	314.4
			15	590	1,100	1,600	2,100	3,100	4,000	5,100	307.4	308.4	309.1	309.7	310.7	311.5	312.4
			30	480	840	1,200	1,600	2,100	2,700	3,400	307.1	307.9	308.6	309.1	309.7	310.4	311.0
			60	390	640	890	1,100	1,600	1,800	2,300	306.8	307.5	308.0	308.4	309.1	309.4	309.9
			150	300	460	600	730	930	1,100	1,400	306.6	307.0	307.4	307.7	308.1	308.4	308.8
			274	260	360	460	550	680	800	950	306.4	306.7	307.0	307.3	307.6	307.8	308.1
			365	230	330	410	480	580	680	800	306.3	306.6	306.9	307.1	307.4	307.6	307.8
2005	Housatonic River at Gaylordsville	994	0	5,400	10,000	16,000	20,000	30,000	40,000	55,000	243.3	245.5	247.6	248.8	251.2	253.2	255.9
			1	4,500	9,000	15,000	20,000	30,000	40,000	55,000	242.7	245.0	247.3	248.8	251.2	253.2	255.9
			3	4,000	8,200	14,000	19,000	28,000	38,000	51,000	242.4	244.7	247.0	248.5	250.8	252.8	255.2
			7	3,500	7,000	12,000	16,090	24,000	32,000	43,000	242.1	244.1	246.3	247.6	249.8	251.6	253.8
			15	2,900	5,500	8,600	12,000	17,000	22,000	29,000	241.6	243.3	244.9	246.3	248.0	249.4	251.0
			30	2,400	4,300	6,400	8,600	12,000	15,000	20,000	241.2	242.6	243.8	244.9	246.3	247.3	248.8
			60	2,000	3,400	4,900	6,400	8,600	11,000	13,000	240.9	242.0	243.0	243.8	244.9	245.9	246.6
			150	1,500	2,500	3,400	4,200	5,400	6,600	8,000	240.4	241.3	242.0	242.6	243.3	243.9	244.6
			274	1,300	2,000	2,600	3,200	4,000	4,800	5,700	240.2	240.9	241.4	241.9	242.4	242.9	243.4
			365	1,200	1,900	2,300	2,900	3,500	4,200	4,900	240.1	240.8	241.2	241.6	242.1	242.6	243.0
2015	Still River near Lanesville	67.8	0	520	980	1,500	2,100	3,000	4,000	5,500	219.8	220.8	221.6	222.4	223.4	224.3	225.5
			1	430	800	1,200	1,600	2,300	3,000	3,900	219.4	220.5	221.2	221.8	222.6	223.4	224.2
			3	340	620	940	1,300	1,800	2,300	2,900	218.7	220.1	220.8	221.3	222.0	222.6	223.3
			7	260	470	700	940	1,300	1,700	2,200	218.0	219.6	220.3	220.8	221.3	221.9	222.5
			15	210	360	540	700	980	1,200	1,600	217.5	218.8	219.9	220.3	220.8	221.2	221.8
			30	170	290	410	530	720	910	1,200	217.0	218.2	219.2	219.8	220.3	220.7	221.2
			60	140	230	320	400	540	660	820	216.6	217.7	218.5	219.2	219.9	220.2	220.5
			150	110	170	230	280	360	430	520	216.2	217.0	217.7	218.2	218.8	219.4	219.8
			274	90	140	180	220	280	330	390	216.0	216.6	217.1	217.6	218.2	218.6	219.1
			365	83	130	160	200	250	290	340	215.8	216.5	216.9	217.4	217.9	218.2	218.7
2030	Shepaug River near Roxbury	133	0	1,600	2,800	4,200	5,500	8,000	11,000	15,000	287.1	288.6	290.0	291.1	292.7	294.3	295.7
			1	1,100	1,900	2,900	3,800	5,200	6,800	8,600	286.0	287.5	288.8	289.7	290.8	292.0	293.0
			3	820	1,400	2,200	2,800	4,000	5,100	6,500	285.7	286.8	287.9	288.6	289.8	290.8	291.8
			7	630	1,100	1,700	2,200	3,100	3,900	4,900	285.3	286.0	287.2	287.9	289.0	289.8	290.6
			15	500	860	1,300	1,700	2,300	3,000	3,600	285.0	285.8	286.6	287.2	288.1	288.9	289.5
			30	410	680	960	1,200	1,700	2,100	2,600	284.7	285.4	286.0	286.4	287.2	287.8	288.4
			60	330	520	720	900	1,200	1,400	1,800	284.5	285.0	285.5	285.8	286.4	286.8	287.4
			150	250	370	490	580	730	860	1,000	284.2	284.6	284.9	285.2	285.5	285.8	286.0
			274	210	290	370	430	520	600	700	284.1	284.4	284.6	284.8	285.0	285.2	285.4
			365	190	260	330	380	440	510	590	284.0	284.2	284.5	284.6	284.8	285.0	285.2

Table 15.--Chemical quality and physical characteristics of water from representative streams under natural conditions in the upper Housatonic River basin

(Concentrations in milligrams per liter)

Constituent or property	Streams draining areas of carbonate bedrock (One sample each from seven sites)				Streams draining areas of noncarbonate bedrock (One sample each from 17 sites)				Recommended upper limit in drinking water 1/
	During high flow (1 percent flow duration)		During low flow (90 percent flow duration)		During high flow (1 percent flow duration)		During low flow (90 percent flow duration)		
	Median	Range	Median	Range	Median	Range	Median	Range	
Silica (SiO_2)	3.6	1.4 - 9.1	7.9	4.5 - 14	4.8	2.7 - 8.2	7.9	1.4 - 12	--
Iron (Fe)	.21	.01- .41	.22	.04- .38	.22	.02- .64	.13	.01- 1.0	0.30
Manganese (Mn)	.03	.01- .06	.11	.04- .20	.04	.00- .50	.14	.04- 4.6	.05
Calcium (Ca)	11	4.3 - 20	25	14 - 49	7.2	2.8 - 13	14	3.0 - 30	--
Magnesium (Mg)	3.7	1.9 - 7.8	12	5.0 - 16	1.8	.7 - 5.4	4.8	.2 - 13	--
Sodium and Potassium (Na + K)	2.3	1.2 - 7.4	5.3	3.7 - 10	3.2	1.4 - 11	5.3	2.1 - 9.4	--
Bicarbonate (HCO_3)	32	11 - 84	126	59 -210	13	4 - 54	56	7 -146	--
Sulfate (SO_4)	13	11 - 19	11	7.9 - 15	14	8.2 - 18	10	5.9 - 16	250
Chloride (Cl)	2.1	1.2 - 11	3.9	2.5 - 14	4.3	1.2 - 16	5.0	1.0 - 15	250
Nitrate (NO_3)	.3	.0 - 1.2	.4	.1 - 3.6	.2	.0 - .9	.3	.0 - 1.6	45
Dissolved solids (residue on evaporation at 180°C)	88	38 -105	127	91 -221	54	24 - 93	73	20 -141	500
Hardness as $CaCO_3$	42	18 - 82	112	56 -188	26	10 - 54	54	8 -129	--
Noncarbonate hardness	13	10 - 17	8	6 - 16	12	7 - 18	8	0 - 18	--
Specific conductance (micromhos at 25°C)	116	50 -171	224	151 -393	78	31 -141	126	33 -247	--
pH	7.0	6.7 - 7.5	7.7	7.2 - 7.9	6.6	6.0 - 7.1	7.3	6.6 - 7.8	--

1/ Recommended by U.S. Public Health Service (1962).

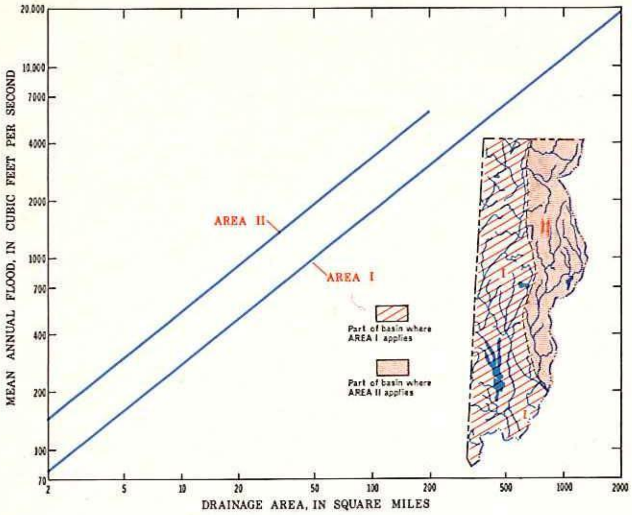


Figure 20.--Relationship between mean annual flood and drainage area in the upper Housatonic River basin.

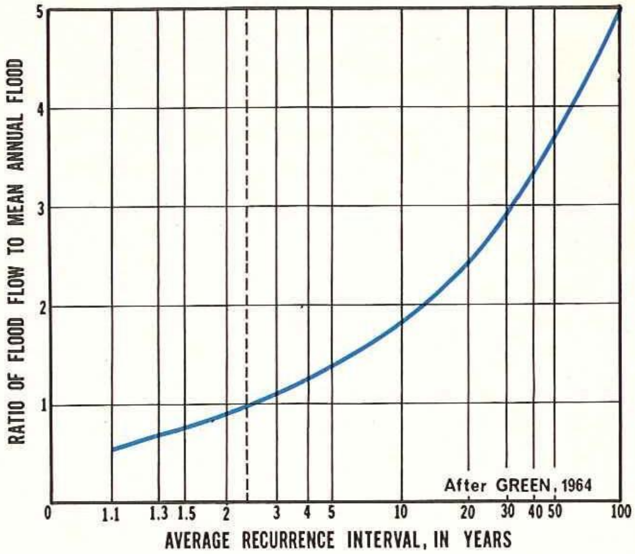


Figure 21.--Flood-magnitude frequency curve for the upper Housatonic River basin.

MAGNITUDE AND FREQUENCY

Knowledge of the magnitude and frequency of floods is essential to the water manager concerned with the location and design of control structures and the establishment of encroachment lines. The maximum flood of record and mean annual flood at gaging stations in the upper Housatonic River basin are given in table 13. Estimates of the flood flow for any recurrence interval at all the sites listed in the table and for all ungaged sites on streams within the basin where the drainage area is 2 square miles or more can be made from figures 20 and 21. The mean annual flood at a site can be found from figure 20 when the drainage area is known (drainage areas may be measured on plate B). Flows for other recurrence intervals up to 100 years are obtainable by multiplying the mean annual flood by the appropriate ratios for any selected recurrence interval from figure 21. The figure is based on a study by Green (1964). A flood-frequency table for long-term gaging stations in the basin is listed in table 14 opposite the period of "0" consecutive days (instantaneous flood peak).

FREQUENCY AND DURATION OF HIGH FLOWS

The flood-frequency information in table 13 and figures 20 and 21 is based on the recurrence of instantaneous peak discharges. For some purposes, however, estimates of the duration and frequency of periods of high flow are also useful. Table 14 presents the probable recurrence intervals of annual highest average flows for periods of 0, 1, 3, 7, 15, 30, 60, 150, 274, and 365 consecutive days at long-term continuous-record gaging stations in the basin. For example, the table indicates that the highest average flow of the Housatonic River at Falls Village for a period of 30 consecutive days would be 5,300 cfs once in 10 years, on the average, and, thus, the probability of 30-day average flows of this magnitude in any one year is 10 percent. The peak flow recurring once in 10 years at this site would be 12,000 cfs, with the corresponding peak elevation of 540.9 feet above mean sea level. This flood peak would probably occur within the same 30-day period for which the estimated average flow is 5,300 cfs.

QUALITY OF WATER IN STREAMS AND LAKES

NATURAL CONDITIONS

The chemical quality of streams in the upper Housatonic River basin under natural conditions is generally good, as indicated by the analyses summarized in table 15. The analyses represent samples collected at 24 sites, shown on figure 22, where streams are relatively unaffected by man's activities. The good chemical quality of these samples is emphasized by the contrast in table 15 between the maximum concentrations of dissolved mineral constituents of samples and the limits of these constituents recommended by the U.S. Public Health Service (1962) for drinking water.

Chemical constituents listed in table 16 are the most common in the natural streams of the upper Housatonic River basin and together constitute more than 95 percent of a typical dissolved-solids load. Silica, calcium, bicarbonate, and sulfate commonly average more than 80 percent of the dissolved solids at high flows and more than 85 percent at low flows. Of these constituents, all except sulfate are largely dissolved from soil and rock materials. Calculations for water year 1968 show that about 76 percent of the sulfate in surface waters of the basin was contributed by precipitation.

Differences resulting from source materials

The mineral composition of the unconsolidated deposits and the underlying bedrock largely determined the chemical quality of streams under natural conditions in the upper Housatonic River basin. Unconsolidated deposits and bedrock are of two main types: (1) carbonates, consisting principally of readily soluble fragments or bedrock composed largely of marble; and (2) noncarbonates, including all other rock types in the basin that are slightly soluble. Table 15 contrasts the chemical quality of water from these two major types of source materials.

Table 16.--Source and significance of some of the chemical constituents in, and physical properties of, water in the upper Housatonic 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 25 mg/l. Surface water usually has a smaller concentration than 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) has not recommended a maximum limit for drinking water.
Iron (Fe)	Dissolved from many minerals that contain oxide, sulfide, and carbonate 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 0.5 mg/l. Ground water generally has higher concentrations than surface water.	On exposure to air, iron in ground water oxidizes to a reddish-brown precipitate. More than about 0.3 mg/l 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 mg/l for drinking water.
Manganese (Mn)	Dissolved from many rocks and soils. Often found associated with iron in natural waters but not as common as iron. Surface water in the basin usually has less than 0.1 mg/l. Ground water generally has higher concentrations than surface water.	More than 0.2 mg/l precipitates upon oxidation. Manganese has the same undesirable characteristics as iron but is more difficult to remove. The USPHS recommends a maximum limit of 0.05 mg/l for drinking water.
Calcium (Ca) and magnesium (Mg)	Dissolved primarily from carbonate rocks. Ground water in the carbonate rocks of the basin may contain as much as 100 mg/l calcium and 40 mg/l magnesium. Surface water normally contains lower concentrations than ground water.	Hardness and scale-forming properties of water are caused by dissolved bicarbonates and sulfates of these elements (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, industrial wastes, and road salt are also major sources. Most home water softeners replace soluble hardness-producing minerals with sodium and thus increase the amount of sodium present.	Since the concentration of potassium is usually low, sodium and potassium are often calculated together and reported as sodium. Quantities found in the report area have little effect upon the usefulness of water for most purposes; however, more than 50 mg/l may cause foaming of steam boilers. The USPHS has not recommended a maximum limit for drinking water, however, the Connecticut State Department of Health suggests a maximum limit of 20 mg/l for municipal water supplies.
Bicarbonate (HCO_3)	Results from chemical action of carbon dioxide in 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, sewage and industrial wastes.	Sulfates of calcium and magnesium form permanent hardness and hard scale in boilers and hot water pipes. The USPHS recommends a maximum limit of 250 mg/l for drinking water.
Chloride (Cl)	Small amounts dissolved from rocks and soils. Larger amounts are derived from animal wastes, sewage, road salt, industrial wastes, and sea water. Chloride concentration of natural water in the basin seldom exceeds 10 mg/l.	Large amounts of chloride in combination with calcium will result in a corrosive solution and in combination with sodium will give a salty taste. The USPHS recommends a maximum limit of 250 mg/l for drinking water.
Nitrate (NO_3)	Sewage, industrial wastes fertilizers, and decaying vegetation are major sources. Minor sources are precipitation and decaying organic matter.	Small amounts of nitrate have no effect on usefulness of water. A concentration greater than 10 mg/l generally indicates pollution. Nitrate encourages growth of algae and other organisms which produce undesirable tastes and odors. The USPHS recommends a maximum limit of 45 mg/l for drinking water, which is equivalent to 10 mg/l of nitrate expressed as N in a sanitary analysis. Waters containing more than 45 mg/l have reportedly caused methemoglobinemia, which is often fatal to infants and, therefore, such water should not be used in infant feeding.
Phosphate (PO_4)	Major sources are fertilizers, domestic sewage, and detergents. Minor sources are minerals such as apatite. Concentrations in natural streams are generally low; in larger streams they occasionally exceed 1.0 mg/l.	Essential nutrient for free floating aquatic vegetation such as algae. Excess phosphate may encourage algal blooms and cause problems of odor, taste, and aesthetics. The USPHS has not recommended a maximum limit for drinking water.

Table 16.--Source and significance of some of the chemical constituents in, and physical properties of, water in the upper Housatonic River basin--Continued

Chemical constituent or physical property	Source and concentration	Significance and maximum limit of tolerance
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 dissolved mineral content. In natural waters in the basin, ground water usually has a larger dissolved-solids content than surface water. Nearly all waters sampled had a dissolved-solids content substantially below the limit recommended by the USPHS.	Waters containing more than 1,000 mg/l dissolved solids are unsuitable for many municipal and industrial purposes. The USPHS recommends a maximum limit of 500 mg/l for drinking water. A dissolved-solids content of 500 mg/l is approximately equivalent to a specific conductance of 900 micromhos at 25°C.
Hardness (as $CaCO_3$)	Primarily due to calcium and magnesium, and to a lesser extent, due to iron, manganese, aluminum, barium, and strontium. There are two classes of hardness, carbonate (temporary) hardness and noncarbonate (permanent) hardness. Carbonate hardness refers to the hardness balanced by equivalents of carbonate and bicarbonate ions; noncarbonate to the remainder of the hardness. In the basin, hardness ranges widely. Water from the carbonate bedrock and stratified-drift aquifers is hard to very hard. Most water from the noncarbonate bedrock aquifers is soft to moderately hard.	Hard water consumes soap before lather will form and deposits soap curds on bathtubs. Water having a hardness of more than 120 mg/l is commonly softened for domestic use. Hardness forms scale in boilers, water heaters, radiators, and pipes, causing a decrease in rate of heat transfer and restricted flow of water. In contrast, water having a very low hardness may be corrosive. The USPHS has not recommended a maximum limit for drinking water. The U.S. Geological Survey classification of hardness appears under "Hardness" in the section entitled "Quality of water in streams and lakes."
Color	Color in water may be of natural, mineral, or vegetable origin such as iron and manganese compounds, algae, weeds, and humus material. May also be caused by inorganic or organic wastes from industry. True color of water is considered to be only that attributable to substances in solution after the suspended material has been removed.	Water for domestic and some industrial uses should be free of perceptible color. Color in water is objectionable in food and beverage processing and many manufacturing processes. Results are usually expressed as units of color and not as mg/l. The USPHS recommends a maximum limit of 15 units for drinking water.
Dissolved oxygen (D.O.)	Sources are natural aeration and photosynthesis by aquatic vegetation. Concentrations vary mainly with temperature and pressure and are expressed as a percentage of saturation. Surface waters fluctuate widely in D.O. with biological activities; D.O. declines during the breakdown of waste material. Concentrations in the basin ranged from 0 to 140 percent saturation.	The dissolved-oxygen content of water is an indicator of its biochemical condition when measured. Fish and other desirable clean-water biota require consistently high D.O. levels. Standards for D.O. levels in many of the streams and lakes in the basin are given in "Water Quality Standards for Connecticut, 1970."
Temperature	Temperature fluctuates widely in streams and shallow wells following seasonal climatic changes, but wells at depths of 30 to 60 feet remain within 2 or 3 degrees of mean annual air temperature (8°C to 11°C for the report area). Disposal of water used for cooling or industrial processing 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 rise of a few degrees in the temperature of a stream may limit its capacity to support aquatic life. Warm water will carry less oxygen in solution than water at low temperatures, and a corrosive water will become more corrosive with increased temperatures.
Turbidity	An optical property of water attributed to suspended or colloidal matter which inhibits light penetration. May be caused by microorganisms or algae; suspended mineral substances including iron and manganese compounds, clay or silt, or sawdust, fibers, and other materials. May result from natural processes of erosion or from the addition of domestic sewage or wastes from various industries, such as pulp and paper manufacturing.	Excessive turbidity is harmful or lethal to fish and other aquatic life; also it is very undesirable in water used by most industries, especially in process water. Turbidity can modify water temperature. Results are expressed in standard units, not mg/l. The USPHS recommends a maximum limit of 5 units for drinking water.
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 water and excessively alkaline water corrode metals. The USPHS has not recommended a maximum limit for drinking water.

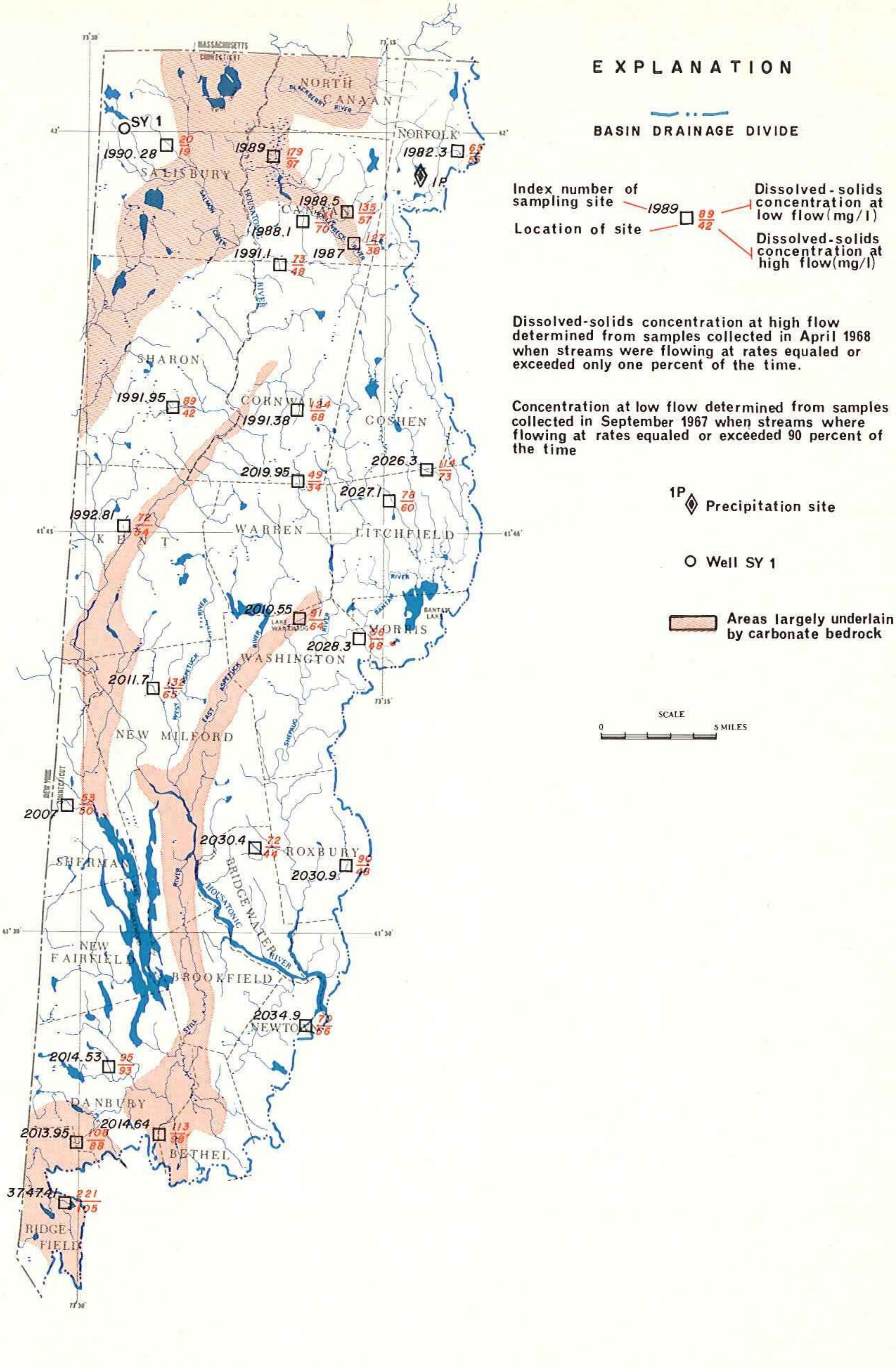


Figure 22.--Distribution of dissolved solids in streams of natural quality at high and low flow.

Variations related to streamflow

The amount of streamflow influences the chemical quality of streams in the basin under natural conditions. In general, the greater the streamflow, the better the quality. The dissolved-solids content of water in a stream under natural conditions generally decreases with an increase in streamflow owing to the dilution effects of direct runoff. This is illustrated on figure 22, which shows the dissolved-solids content in water at 24 natural stream sites for periods of high and low flow. Streamflow under low-flow conditions represents a greater relative ground-water contribution and normally contains water with the highest dissolved-solids content and the greatest degree of hardness; low-flow conditions represent the least desirable conditions in terms of water quality.

Wachocastinook Creek (station no. 1990.28), in the northwest corner of the basin, is unusual in that its water is low in dissolved solids during both high- and low-flow conditions. A comparison of the chemical analyses also shows significantly low values for pH and specific conductance; moreover both high- and low-flow samples indicate more sulfate than bicarbonate. This indicates that stream water in the Wachocastinook Creek basin is strongly influenced by the quality of basin precipitation. The similarity in quality of surface water, ground water, and precipitation here is illustrated by table 17.

Table 17.--Comparison of chemical quality of surface water, ground water, and precipitation, Wachocastinook Creek basin

(Concentrations in milligrams per liter)

Constituent or property	Surface water: Wachocastinook Creek, High flow	Surface water: Wachocastinook Creek, Low flow	Ground water: Bedrock well no. SY 1	Precipitation 1/: Norfolk gage (IP) April to Nov. 1967 2/
Silica (SiO_2)	2.7	2.3	5.0	not analyzed
Calcium (Ca)	2.8	3.0	4.8	1.0
Magnesium (Mg)	0.7	0.2	1.6	0.1
Sodium and potassium (Na+K)	1.4	3.0	2.3	1.1
Bicarbonate (HCO_3)	4	7	12	0
Sulfate (SO_4)	8.2	7.5	10	6.9
Chloride (Cl)	1.2	1.0	14	.4
Dissolved solids (residue on evaporation at 180°C)	19	20	34	12
Hardness as $CaCO_3$	10	8	18	3
Specific conductance (micromhos at 25°C)	31	33	58	41
pH	6.3	6.6	6.6	4.4

1/ Median for 8-month period of record.

2/ Gage about 12 miles east of Wachocastinook Creek basin.

Variations related to storage

Public water-supply reservoirs in the UHRBA are protected against man-made contamination and are, therefore, representative of impounded waters of natural quality. The chemical quality of water samples from the principal public-supply reservoirs in the basin is shown in table 25. The quality of these impounded waters is good; they have a median dissolved-solids content of 78 mg/l and a median hardness of 49 mg/l. These waters are generally alkaline; 11 of 13 raw water samples had a pH greater than 7.0.

Temperature changes and stratification follow a seasonal pattern in many lakes, as shown in figure 23. Thermal stratification has its greatest effect on water quality during the summer and during the spring and fall turnover. In the summer, shallow surface water becomes warm and less dense. Cold water remains in the deeper parts of the lake, and circulation between the upper and lower parts is minimal. As a result, the water of the hypolimnion (see fig. 23) remains cold. It has little dissolved oxygen and is, therefore, unsuitable for fish and other aquatic life. During the spring and fall, water temperature and density become uniform throughout, as complete circulation mixes the water in the lake. This mixing causes an increase in color and turbidity and brings some undesirable products of anaerobic decomposition to the surface. Iron and manganese in solution are also brought to the surface and distributed throughout the lake, resulting in a temporary deterioration in the quality of the water.

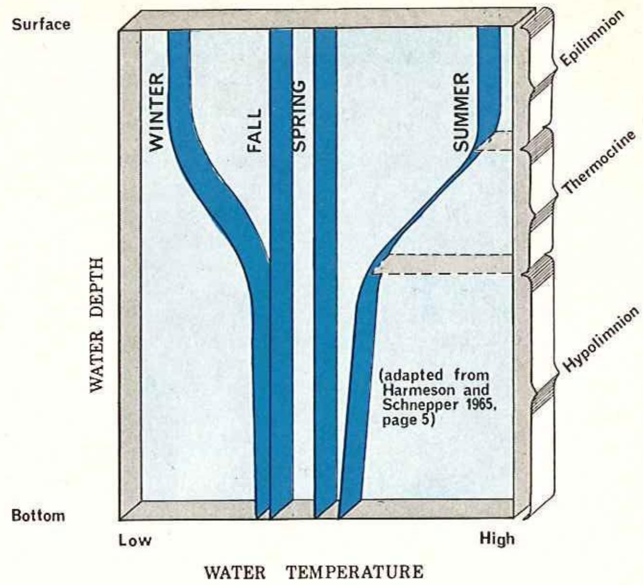


Figure 23.--Seasonal temperature variations in thermally stratified lakes, ponds, and reservoirs.

Figure 24 contrasts the vertical profiles of four thermally stratified lakes or ponds with four unstratified ones. The profiles are based on unpublished data collected by the Connecticut Board of Fisheries and Game. Water depth and surface area are the main factors influencing stratification of a lake or pond.

Chemical constituents and properties

The source and significance of some of the chemical constituents and physical properties of water in the UHRBA are given in table 16. Of the items listed, iron, manganese and hardness are of particular importance under natural conditions in the basin and are discussed in greater detail below.

Iron and manganese

The concentrations of iron and manganese naturally dissolved in surface waters of the basin are frequently high enough to concern both industrial and domestic users. Concentrations exceeding the U.S. Public Health Service's recommended limits do not render water unpotable, but excessive amounts of these elements decrease its value for some uses.

Some industrial processes are much more sensitive to iron and manganese concentrations than these limits indicate. The manufacture of clear plastics, for example, requires maximum limits of 0.02 mg/l for iron and the same for manganese; the production of viscose rayon requires complete absence of both. Samples from sites on 24 streams in the basin show that iron and manganese concentrations above the limits recommended by the Public Health Service for drinking water are common during periods of both low and high flow. The table below compares the data collected at these sites.

Dissolved constituent	Percent of samples collected exceeding USPHS limits during	
	High flow 1/	Low flow 2/
Iron	25	29
Manganese	25	83

1/ Streamflow was equaled or exceeded 1 percent of the time.
2/ Streamflow was equaled or exceeded 90 percent of the time.

The table indicates that the probability of excess dissolved iron is about 25 percent during conditions of both high and low streamflow, suggesting that available iron is rapidly dissolved by direct runoff and soon reaches an equilibrium level. During high-flow periods, stream discharges increase, but the total load of iron also increases, so that iron concentrations are not significantly reduced. During periods of low flow, on the other hand, the probability of excessive concentrations of manganese increases significantly. As the table indicates, more than 80 percent of the samples during low-flow periods had excessive concentrations. Manganese is contributed primarily by ground-water runoff, as suggested by the table in the "Iron and manganese" section under "Aquifers", which shows that 50 percent of the wells in stratified drift yielded water with manganese in excess of 0.05 mg/l.

The large streams in the basin (Bantam, Blackberry, Housatonic, Shepaug, Still and Tenmile Rivers) contain dissolved iron and manganese concentrations similar to those of the small natural streams. Samples from the large streams were collected during the 1968 water year and under diverse conditions of flow and thus represent an average basinwide condition.

Stream type and flow conditions	No. of samples	Percent of samples exceeding USPHS recommended limits	
		Iron	Manganese
Large streams at average flow	39	28	72
Small streams at low flow	24	29	83

As previously mentioned, water stored in lakes and reservoirs generally improves in quality. Analyses for 13 water-supply reservoirs showed that the raw water was of excellent quality, although some samples exceeded the recommended limits for iron and manganese. Treatment of the water reduces the concentrations of these elements to more desirable levels but adds to the cost of finished water. The concentration of iron and manganese tolerated by a user is a limiting factor in evaluating the surface-water resources of the basin.

Hardness

Hardness of water is due to the presence of alkaline-earth ions. Under natural conditions, calcium and magnesium are the principal alkaline-earth ions; barium and strontium are the minor ones. The most common sources of calcium and magnesium in the upper Housatonic River basin are the carbonate minerals, calcite and dolomite, which are the main constituents of the marble bedrock. In areas underlain by marble, only 14 percent of the natural streams sampled had water with a hardness of 60 mg/l or less. In other areas, 65 percent of the natural streams sampled had water in this range.

The term "hard" and "soft" water are not precise unless quantified. This report follows the U.S. Geological Survey in using the following ranges as a guide:

Hardness range (mg/l of $CaCO_3$)	Hardness rating	Suitability
0- 60	Soft	Suitable for many uses without softening.
61-120	Moderately hard	Commonly usable except in some industrial applications.
120-180	Hard	Softening required by laundries and some other industries.
181 or more	Very hard	Requires softening for most purposes.

CONDITIONS RESULTING FROM MAN'S ACTIVITIES

Man's utilization of water generally alters its physical, chemical, and biological characteristics. With rare exceptions, these alterations cause an overall deterioration in water quality. Industrial, agricultural, and domestic activities increase dissolved solids and suspended-sediment loads, raise water temperatures, and add oxygen-depleting organic materials to the waterways draining an area. Some activities, such as the discharge of sewage and industrial effluents into streams and lakes, may affect water quality directly. Others affect the quality indirectly but nonetheless significantly.

Figure 25 illustrates the dissolved-solids content characteristic of the surface waters of the upper Housatonic River basin during low flow. During these periods, maximum observed dissolved solids are 100 mg/l or less for half the basin. These low concentrations are common in areas underlain by noncarbonate bedrock. This bedrock forms hilly uplands that lack extensive industrial and urban development. Streams draining the rest of the basin have low-flow dissolved solids that range from 100 mg/l to more than 300 mg/l.

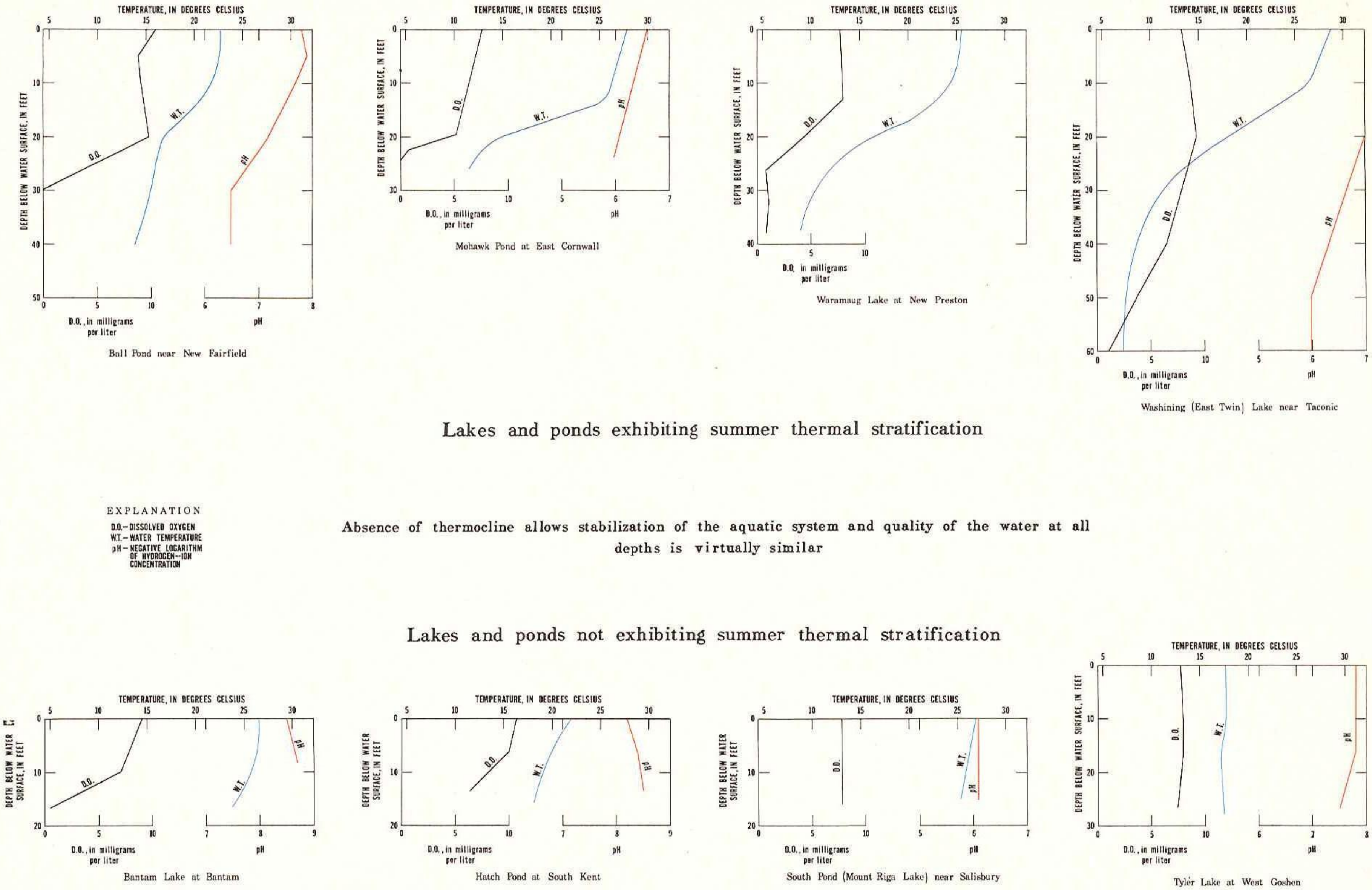


Figure 24.--Vertical profiles in eight selected lakes and ponds.

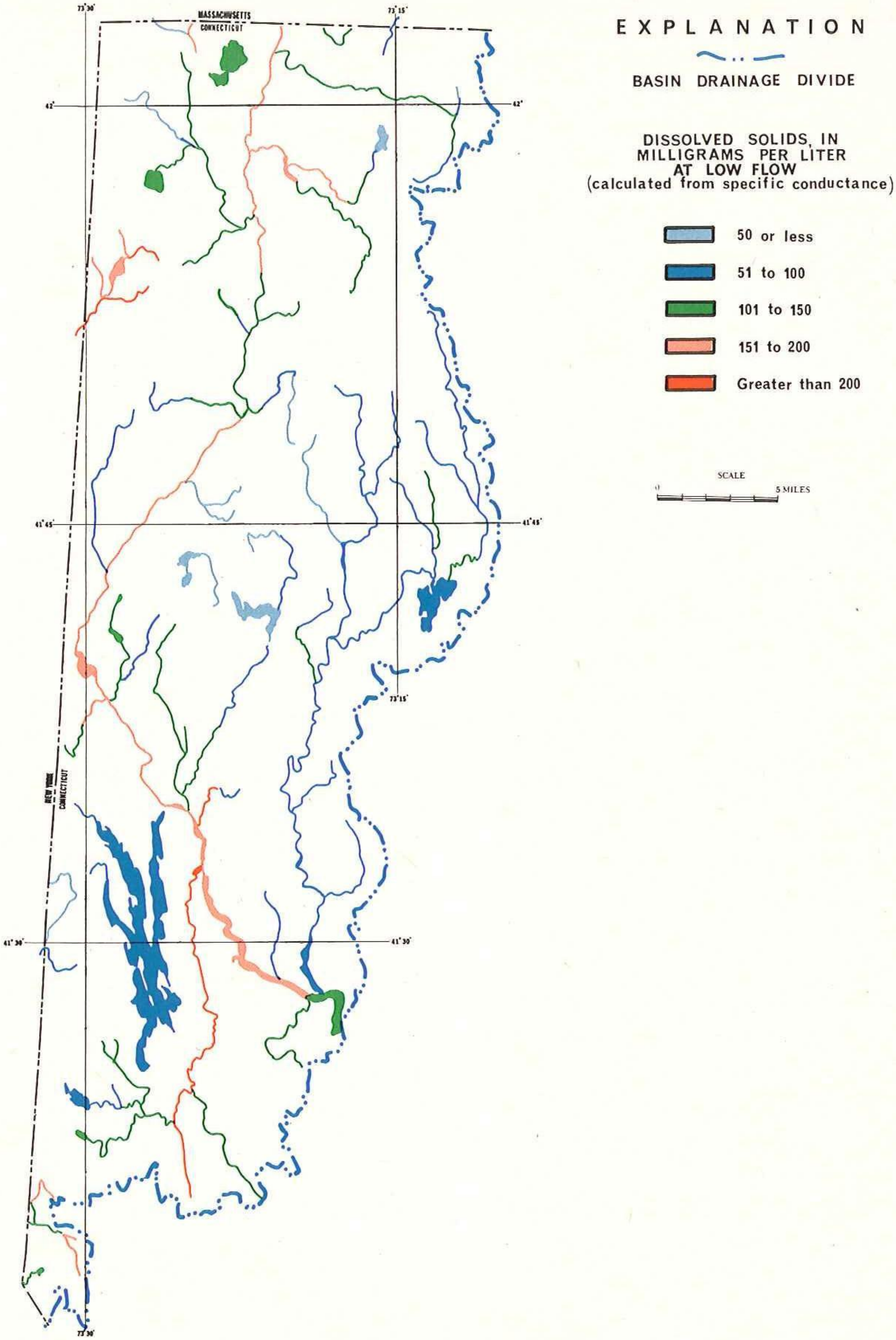


Figure 25.--Maximum observed concentration of dissolved solids in surface water in the upper Housatonic River basin.

Table 18.--Comparison of the low-flow dissolved-solids content in the upper Housatonic River basin, as influenced by bedrock composition and man's development

Sample source	Degree of development	No. of samples	Dissolved solids, mg/l Median	Range
Natural water-quality sites--noncarbonate areas	Undeveloped	17	73	20-141
All sites (natural and man-affected)--noncarbonate areas	Includes scattered developed areas	420	86	33-393
Natural water-quality sites--carbonate areas	Undeveloped	7	127	91-221
All sites (natural and man-affected)--carbonate areas	Developed areas widespread	141	163	33-312

Maximum values are encountered in tributary streams in the Danbury and New Milford areas. Here, likewise, bedrock composition and land development both influence the quality of surface waters. Marble bedrock underlies areas where streams have higher dissolved-solids content. Marble generally underlies lowlands, where much of the land is being developed. Thus, during low flow, surface waters in these areas consist of the more highly mineralized ground-water runoff characteristic of marble terranes augmented by varying amounts of effluent from agricultural, domestic, and industrial sources. This combination of water has a higher level of dissolved solids than water found in the noncarbonate areas. Table 18 compares the low-flow dissolved-solids content in the basin, as influenced by bedrock composition and degree of development.

As the ranges in the above table show, water with a dissolved-solids content in excess of 300 mg/l is found in both carbonate and noncarbonate areas. These high values however represent localized contamination of small volumes of water. Of more significance is the comparison of median values for the two areas of contrasting bedrock. The increase in dissolved-solids content for natural sites versus all sites is 18 percent in the noncarbonate areas and 28 percent in the carbonate areas. The greater increase in the carbonate areas is due to the greater degree of development in these areas.

Variations related to streamflow

Under man-affected conditions, the chemical quality of water in a stream is related to the amount of streamflow. During high flow, quality improves owing to dilution by large volumes of direct runoff. During low flow, direct runoff is minimal, and water quality deteriorates because sewage and other effluent discharges are not significantly diluted. Figure 26 shows the day to day relationships between streamflow and dissolved solids for the Still River near Lanesville, a stream containing much treated waste discharge.

The general chemical quality of the major streams in the basin, as indicated by dissolved solids (calculated from specific conductance), was measured continuously at three sites during the 1968 water year. The daily extreme specific-conductance values for these sites--Blackberry River at Canaan, Housatonic River at Gaylordsville and Still River near Lanesville are published in Water Resources Data for Connecticut (1968). Figure 27 shows the dissolved-solids versus discharge curves for the Blackberry, Housatonic and Still Rivers, in millions of gallons per day per square mile of drainage area.

As the figure shows, all three curves tend to converge at high discharges. At very high flows such a large proportion of stream discharge is direct runoff that its chemical quality approaches that of precipitation. Also, during high flow, dissolved solids from sewage and industrial effluents are diluted to almost insignificant levels. At flows of about 3 mgd per square mile and above, the Still and Housatonic Rivers have similar dissolved solids versus discharge relations. As flows decrease, however, the industrial effluent and municipal sewage from the Danbury-Bethel area progressively degrade the water quality of the Still River. By the time flows have decreased to about 0.3 mgd per square mile, the Still River contains about 25 percent more dissolved solids per square mile than the Housatonic River. For the Still River near Lanesville, flows of less than 0.3 mgd per square mile occurred about 10 percent of the time during water year 1968.

For high flows, the slope of the curve of the Blackberry River in figure 27 is similar to those of the Housatonic and Still Rivers, but the Blackberry carries only about two-thirds as much of a dissolved-solids load per square mile. For low flows, the slope of the Blackberry River curve is steeper than those of the other two streams because contributions of dissolved solids from all sources are comparatively small and have less effect on its overall water quality. The generally excellent quality of Blackberry River water is attributed to bedrock and surficial material that are largely free of soluble carbonates and to the slight development of the area. The higher levels of dissolved solids in the Still and Housatonic Rivers, especially at low flow, are primarily due to industrial-urban development. The Danbury-Bethel area in the Still River basin, and developed areas in the Massachusetts part of the Housatonic River basin, make substantial additions to the dissolved-solids levels of these streams.

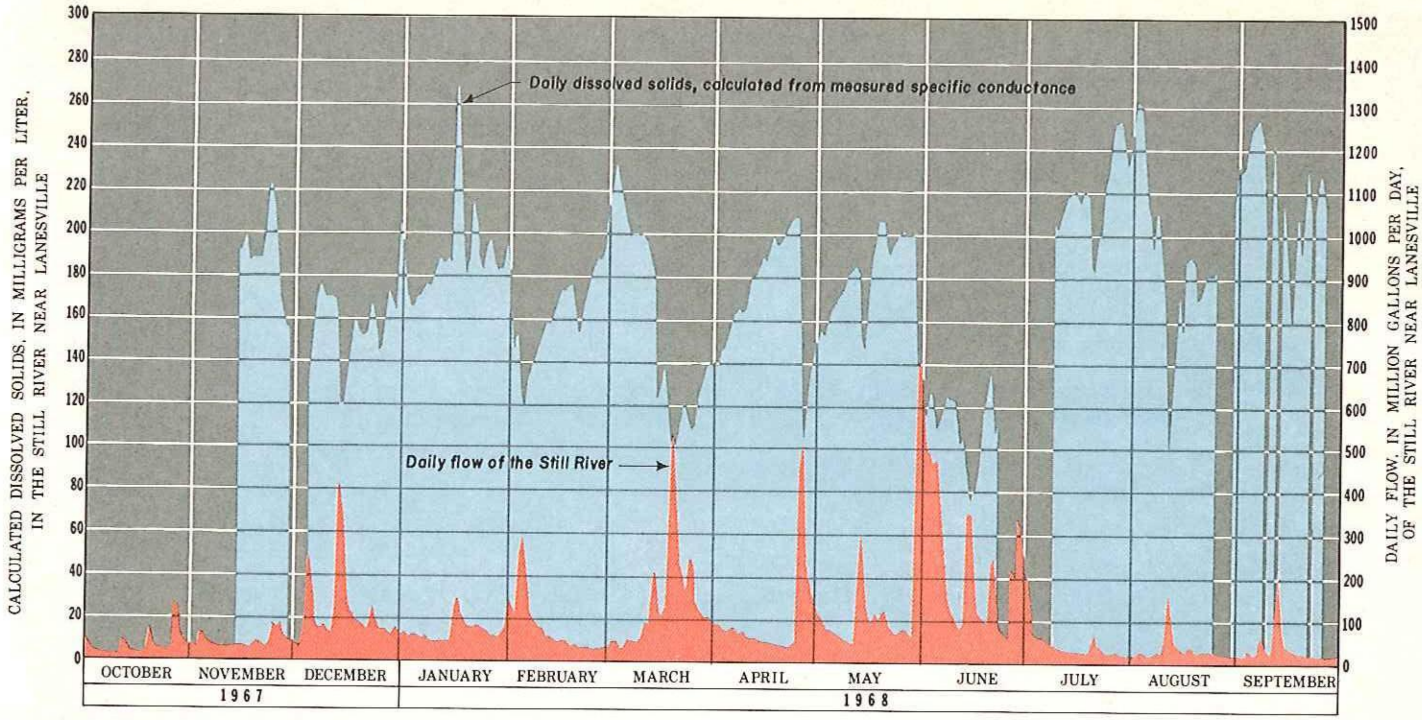


Figure 26.--Dissolved solids and daily mean discharge, Still River near Lanesville.

The dissolved-solids concentration of water in the Still River varies inversely with rate of flow.

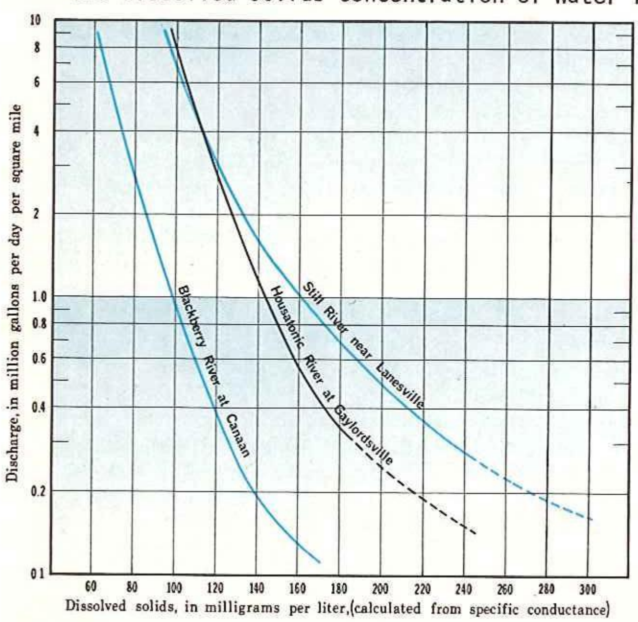


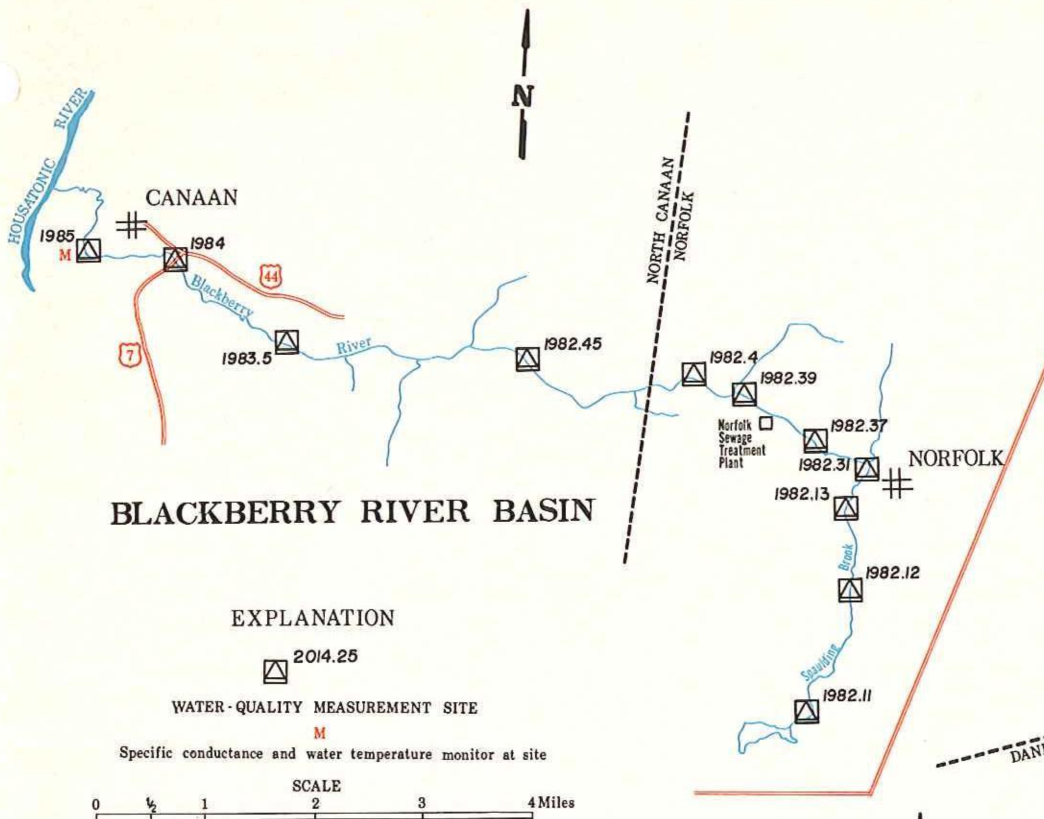
Figure 27.--Relationship of dissolved-solids concentration to stream discharge in Blackberry, Housatonic, and Still Rivers.

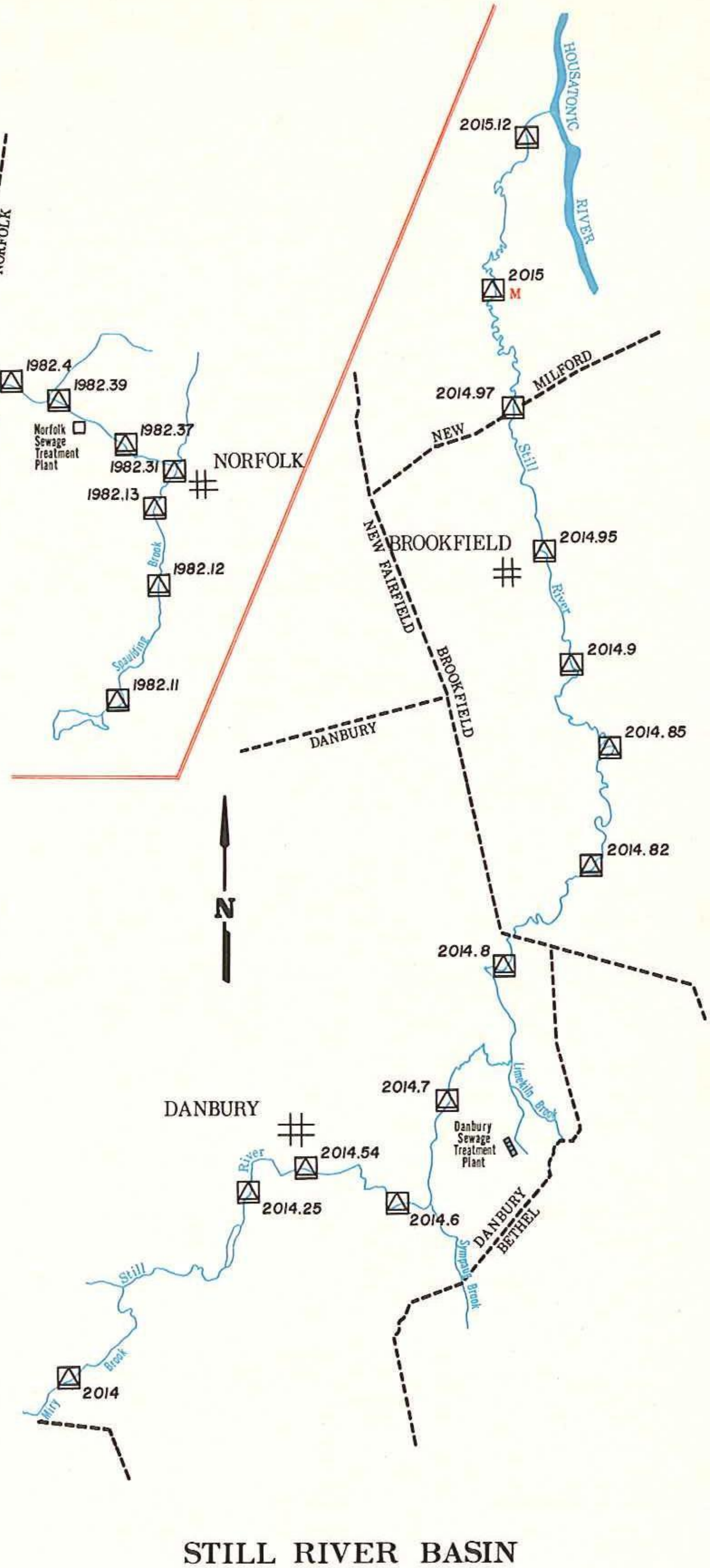
Stream profiles

The quality of water in two of the largest tributaries of the Housatonic River, the Blackberry and Still Rivers, are contrasted in graphic stream profiles based on data collected during low flow. These streams drain areas differing widely in industrial development and in population. The profiles are based on field measurements of specific conductance, dissolved oxygen, temperature, and other chemical analyses. The locations of the sampling points are shown on figure 28; dissolved-oxygen and specific-conductance profiles are shown on figure 29.

The Blackberry River valley has few industries and is sparsely populated, hence the stream is largely uncontaminated. Its profile shows a gradual increase in dissolved solids in a downstream direction, as indicated by specific-conductance values. These are as much as 300 micromhos in the lower part of the valley; values are typical for low-flow conditions in an unspoiled stream draining a carbonate area.

In contrast, the greater industrial development and larger population along the Still River significantly downgrade the quality of its water. In the reach upstream from Danbury, specific-conductance levels indicate largely uncontaminated conditions. Downstream from the initial sampling point, station 2014 (fig. 28), specific conductance increased from 154 to 283 micromhos along the 6.8 miles to the bridge on Triangle Street (station 2014.6). Farther downstream, at sampling point 2014.7, it increased to 413 micromhos. This sharp rise is attributed to contaminated water from Sympaug Brook, which joins the Still River between these two closely spaced stations. On the day of the profile, Sympaug Brook, which receives effluent from several industrial activities, had a specific conductance of 650 micromhos. For the next 6 miles downstream it remained above the 400 micromhos level. Downstream, at station 2014.9, it was diluted by less mineralized ground water, and at station 2015 specific conductance decreased to 272 micromhos, comparable with that measured more than 15 miles upstream.





U.S.G.S. STATION NUMBER	DISTANCE DOWNSTREAM FROM PREVIOUS STATION (MILES)	DISTANCE DOWNSTREAM FROM INITIAL STATION (MILES)	TEMPERATURE DURING A.M. (°C)	TEMPERATURE DURING P.M. (°C)	DISSOLVED OXYGEN DURING A.M. (MG/L)	DISSOLVED OXYGEN DURING P.M. (MG/L)	SPECIFIC CONDUCTANCE (MICROMHOS, AT 25° C)
BLACKBERRY RIVER BASIN (Profile of September 3,1968)							
1982.11	—	0	14	18	7.2	7.3	72
1982.12	1.40	1.40	13	22	7.5	9.4	258
1982.13	.75	2.15	13.5	19	7.6	7.0	268
1982.31	.40	2.55	15	18	9.5	8.0	247
1982.37	.60	3.15	15	20	10.1	8.8	244
1982.39	.70	3.85	16	21	9.9	7.1	247
1982.4	.55	4.40	14.5	20	10.3	9.2	265
1982.45	1.90	6.30	15	22	9.1	11.2	268
1983.5	2.30	8.60	16	20	9.2	9.6	268
1984	1.35	9.95	16.5	21	9.3	9.9	284
1985	.85	10.80	16.5	21	8.7	10.3	301
STILL RIVER BASIN (Profile of September 4,1968)							
2014	—	0	16	19	6.8	7.6	154
2014.25	4.50	4.50	17	21	6.9	8.2	250
2014.54	1.05	5.55	18	24	9.3	9.6	277
2014.6	1.25	6.80	17	23	8.2	10.9	283
2014.7	1.50	8.30	17	23	9.6	7.0	413
2014.8	2.45	10.75	18	23	6.8	7.3	418
2014.82	1.85	12.60	18	22	5.6	5.1	418
2014.85	1.80	14.40	19	20	3.2	4.8	407
2014.9	1.55	15.95	20	21.5	2.3	5.0	353
2014.95	1.20	17.15	18	22	6.6	8.3	313
2014.97	1.70	18.85	18	20.5	7.0	9.2	295
2015	2.15	21.00	18	22	6.5	8.3	272
2015.12	2.35	23.35	18.5	22.5	8.6	12.3	406

Figure 28.--Progressive downstream changes in quality of Blackberry River, a stream of natural quality, contrasted with Still River.

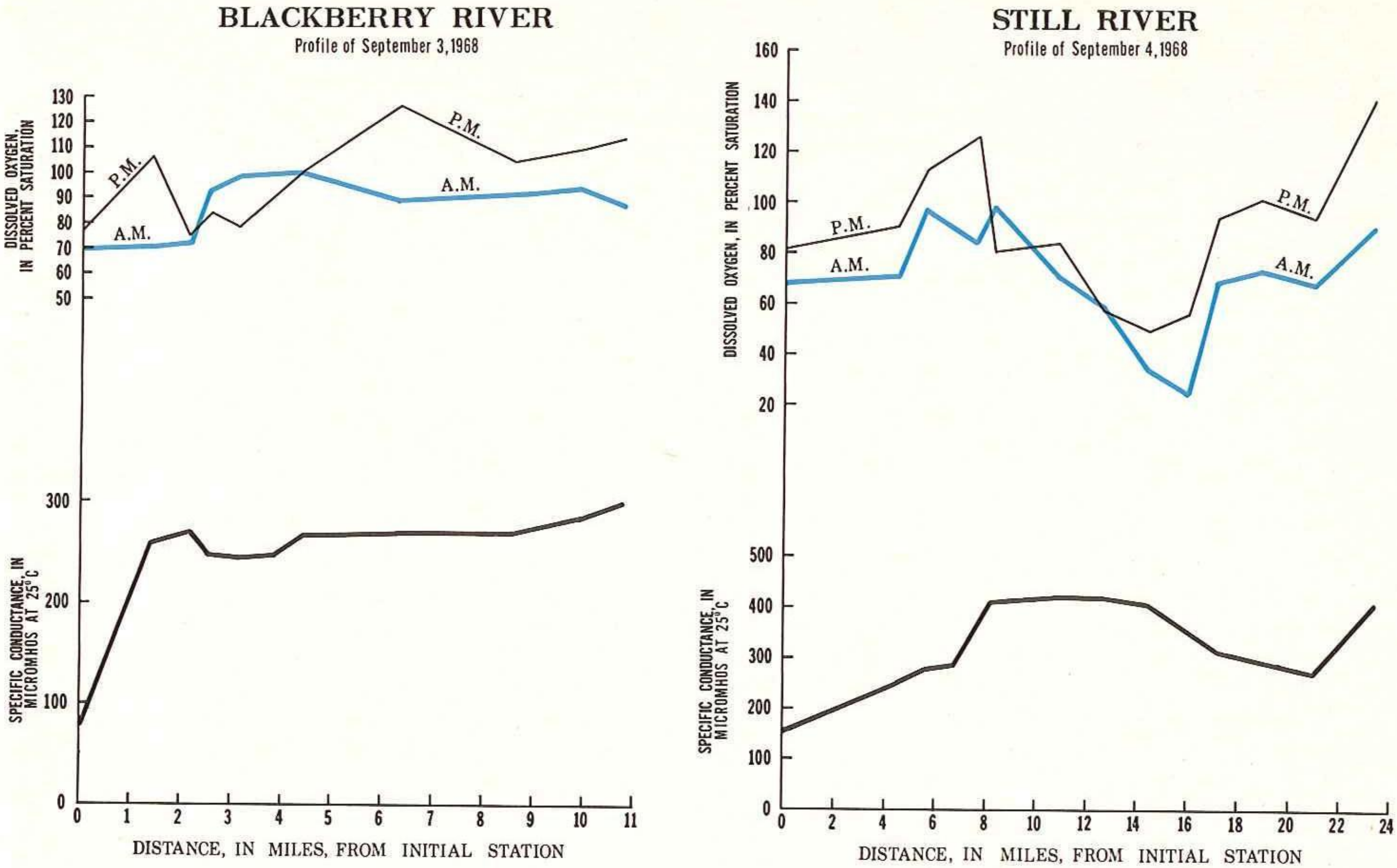


Figure 29.--Dissolved oxygen and specific-conductance profiles in the Blackberry and Still Rivers.

Two dissolved-oxygen profiles, one for early morning and one for midday, show the effects of photosynthesis in each major tributary. Aquatic vegetation releases oxygen to the water during daylight and may raise dissolved-oxygen concentrations to supersaturated levels. As figure 29 shows, these concentrations are generally higher in both streams during the afternoon than they are at morning or at night. At times they exceed 100 percent saturation because of the large amounts of oxygen released to the water by aquatic vegetation during periods of peak sunlight. The Blackberry River profile indicates dissolved-oxygen concentrations generally above 80 percent saturation and ranges from 70 to 127 percent saturation.

The dissolved-oxygen profile of the Still River shows the effects of the effluent from the Danbury sewage-treatment plant. In the headwaters, early morning levels ranged from 68 to 99 percent saturation. Limekiln Brook, carrying effluent from the Danbury sewage-treatment plant, joins the Still River 9.6 miles below the initial sampling point, causing a significant decline in the dissolved-oxygen levels of the main stream. This decline continues, as natural purification processes act to reduce the organic load. At station 2014.9, 6.4 miles below the confluence of Still River and Limekiln Brook, early morning dissolved oxygen dropped to 2.3 mg/l, about 25 percent saturation. Downstream from station 2014.9, reaeration begins to exceed oxygen demand, and dissolved oxygen begins to return to previous levels.

The condition of Still River at the northernmost sampling point, station 2015.12, deserves comment. Specific conductance exceeded 400 micromhos, whereas midday dissolved oxygen climbed to 140 percent saturation. This condition resulted from a nutrient load entering the Still River directly upstream. Effluent from a riverside lagoon holding septic-tank waste at a point 0.35 mile upstream from station 2015.12 presumably entered the ground and discharged into the stream. The high dissolved-solids content characteristic of this type of effluent is inferred from the increased specific conductance of the river water. Large amounts of inorganic nutrients (chiefly phosphate and nitrate) promote the growth of aquatic vegetation, which releases large amounts of dissolved oxygen to the river during daylight photosynthesis.

The specific-conductance and dissolved-oxygen profiles of water in the Blackberry and Still Rivers clearly delineate the contrasting effects of man's activities on water quality. Blackberry River assimilates the small effluent load it receives, and its overall water quality remains largely unimpaired. Still River receives a much greater volume of effluent, and the quality of its water is severely downgraded as a result. Both streams accomplish some natural purification even though they are loaded with contaminated effluents. The Blackberry River is successful, but the Still River, though comparable in size, is overloaded and retains evidences of contamination throughout its lower reaches.

Phosphate

Under natural conditions, high phosphate concentrations are rare in the surface waters of the upper Housatonic River basin. Phosphate samples from natural streams show concentrations substantially below the 1 mg/l level. Values for median concentrations at high and low flows are 0.06 mg/l and 0.07 mg/l, respectively. The major sources of phosphate entering the surface waters of the basin are industrial effluent and domestic sewage (both contain laundry detergents), and runoff from agricultural lands. The following table compares phosphate levels of natural streams, which are generally small, to those of the larger streams in the basin, which are more intensively used by man.

	Streams with natural quality		Streams affected by man's activities	
Sampling conditions	Median phosphate (mg/l)	No. of samples	Median phosphate (mg/l)	No. of samples
High flow	0.06	10	0.23	9
Low flow	.07	12	.38	14

Recommended levels of phosphate concentrations have not been established because of the complex nature of phosphate chemistry and a scarcity of basic data (FWPCA, 1968, p. 23-24). The greatest problem associated with high phosphate concentrations in the basin is the excessive growth of algae and other aquatic plants. The higher concentrations of the Bantam and Still Rivers probably contribute to the algal problems of Bantam Lake and Lake Lillinonah (Benoit, 1965; Frink, 1967). Additional work, including a nutrient budget study of Lake Lillinonah, was in progress in 1969 (Frink, oral communication).

SEDIMENT AND TURBIDITY

Transportation and deposition of sediment are continuous natural processes in the streams of the upper Housatonic River basin. The amount of material transported at any instant is chiefly governed by the velocity of the stream, the magnitude of the discharge, and the availability of sediment. Materials carried may range in size from clay-sized particles to coarse gravel; the finer fractions are carried in suspension, and the coarser fractions are bounced and rolled along the stream bottom. The sediment load carried by basin streams is not excessive and poses few problems because the well-developed vegetal cover protects the land surface, limits the amount of available sediment material, and prevents serious erosion.

Turbidity of water is the reduction of transparency caused by the presence of suspended particulate matter. Turbidity may result from natural erosion or from man's activities, such as sewage treatment and disposal, and industrial activities, including effluent release and dredging operations.

Excessive turbidity is undesirable in drinking water and for industries such as food processing and paper and textile manufacturing. Turbidity in water can be removed by coagulation, sedimentation, or filtration, but these operations increase costs.

The table below summarizes the turbidity measured in samples from streams in the basin during periods of high and low flow. It also contrasts these streams with six man-affected streams during high flow.

	Turbidity (mg/l SiO_2)		
Sample source	Median	Minimum	Maximum
Natural-quality streams during high flow	4	0.6	25
Natural-quality streams during low flow	0.8	.2	5
Man-affected streams during high flow	12	6	35

As the data show, turbidity is not a problem in the natural streams. The large streams in the basin are generally more turbid than the small ones because they drain larger proportions of cleared land and are more adversely affected by other activities of man.

Reaches where turbidity could be potentially troublesome during high flow include the Still River north of Danbury and the Housatonic River near New Milford. The high turbidity of the Still River results primarily from construction activity and release of waste effluents in the Danbury area. Turbidity of the Housatonic River is largely a consequence of extensive clearing and tilling of agricultural land upstream in Connecticut and Massachusetts.

TEMPERATURE

Temperature influences the chemical, biological, and physical aspects of a water resource. Small changes in the maximum or mean temperature of a stream or lake can encourage or discourage the growth of certain organisms and, in time, significantly change the ecosystem. Industries that use large amounts of cooling water may incur a considerable additional expense if the water temperature rises as little as 1 degree. Temperature influences concentrations of dissolved oxygen, other dissolved gases and suspended sediment in surface water. It is also a key factor in determining the ability of water to dissolve and precipitate solid materials.

Under natural conditions, water temperature is controlled by insolation and atmospheric temperature. Ground-water runoff commonly moderates natural surface-water temperature, especially during the summer and winter. Man's activities can also significantly affect surface-water temperature (Pluhowski, 1970).

Surface-water temperature in the basin follows the seasonal variations in air temperature. Minimum (freezing) temperatures are reached in most streams during the winter. At this time, lakes and ponds in the basin become ice bound and those in the north may remain so 4 months or more. Maximum surface-water temperatures occur in July and early August and rarely exceed 26.5°C. Water temperature in the Falls Village Reservoir at Falls Village reached 26.5°C only 1 day out of 5,060 in 14 years of record.

Curves of the monthly mean water temperature in the Blackberry, Housatonic, and Still Rivers during the 1968 water year, as indicated on figure 30, show that they are similar. They probably are representative of stream temperatures throughout the basin. Maximum temperatures for this period were 27°C for the Housatonic River and 25.5°C for the Blackberry and Still Rivers. During the winter, water at the surfaces of these streams reached 0°C. Mean water-temperature duration curves for the Blackberry River at Canaan, the Housatonic River at Gaylordsville, and the Still River near Lanesville are similar to one for the Falls Village Reservoir at Falls Village (fig. 31). The curves for the rivers are based on data for water year 1968; the curve for the reservoir represents 14 years of record, extending back to water year 1956.

A moderate southward increase in surface-water temperature is indicated by a comparison between the duration curves for the Blackberry and Still Rivers, streams of similar size. The Still River, in the southern part of the basin, has a higher mean over most of its temperature range. In addition, the greater utilization of water from the Still River for industrial purposes and transport of sewage contribute to higher temperature levels. A basinwide surface-water temperature of 21°C or less can be expected 80 percent of the time; in the cooler northern areas it can be expected 90-95 percent of the time.

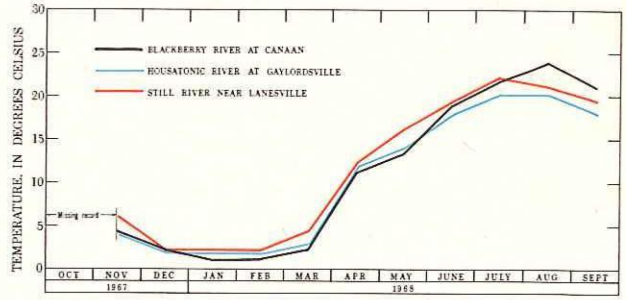


Figure 30.--Monthly mean water temperatures of the Blackberry, Housatonic, and Still Rivers. (Based on continuous records, 1968 water year.)

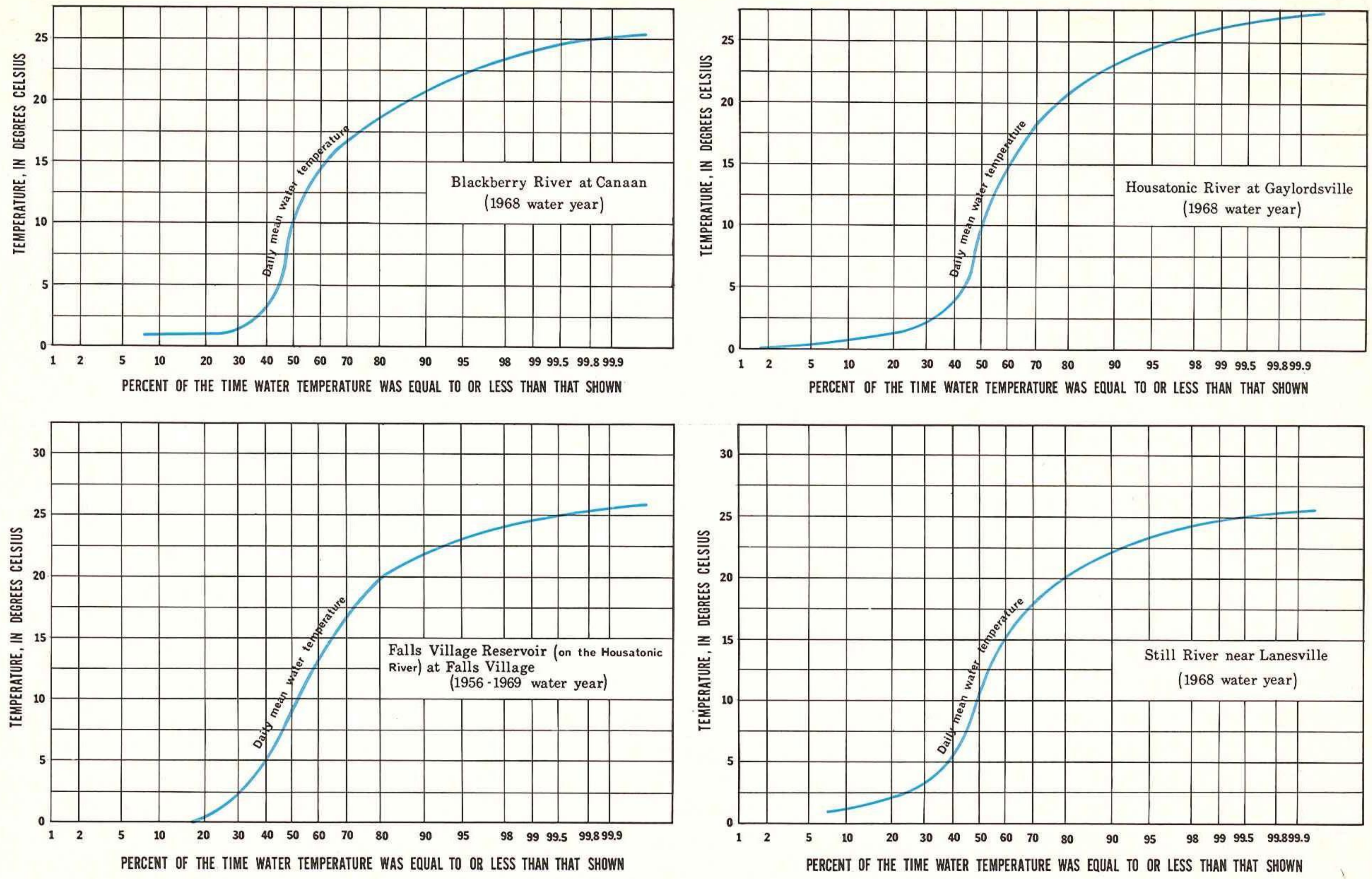


Figure 31.--Temperature-duration curves for representative streams and a reservoir in the upper Housatonic River basin.

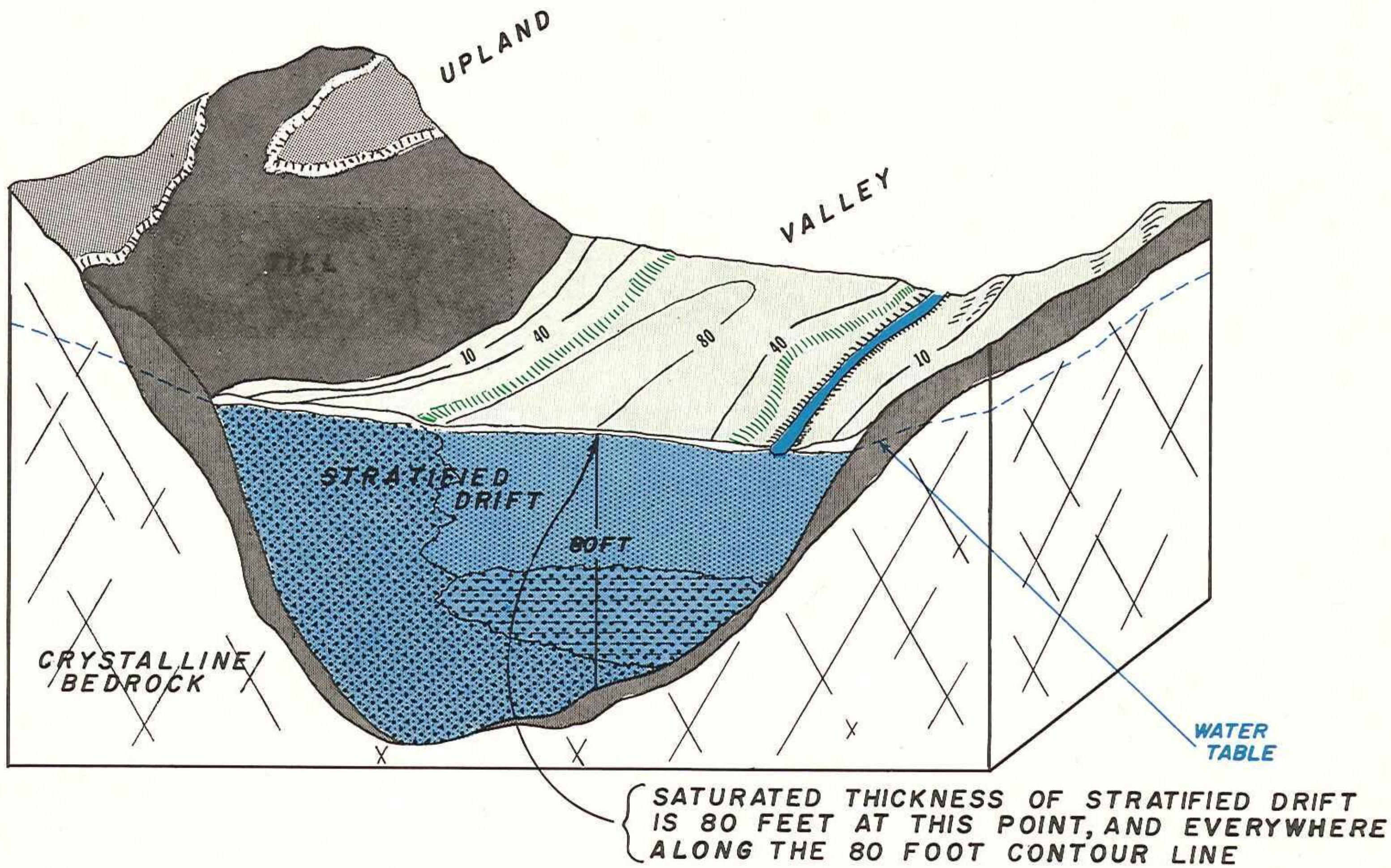


Figure 32.--Schematic block diagram showing general spatial relationships between stratified drift, till, and crystalline bedrock.

Water table marks the top of the saturated zone, and contours show saturated thickness of stratified drift.

WATER IN AQUIFERS

DISTRIBUTION AND GEOMETRY OF SUBSURFACE UNITS

The upper Housatonic River basin contains three major water-bearing subsurface geologic units: stratified drift, till, and crystalline bedrock. The crystalline bedrock underlies the entire basin but is discontinuously mantled by stratified drift and till. The spatial relationships between these units are shown on figure 32, and their areal distribution is shown on plate B.

Stratified drift is an unconsolidated sediment composed of interbedded layers of gravel, sand, silt, and clay. These materials were deposited during the deglaciation of the basin (Flint, 1930) and are generally restricted to the valley areas that served as drainageways for glacial melt water or were the sites of temporary glacial lakes. The stratified drift commonly forms a prismatic-shaped infilling of the preglacial bedrock valleys, as shown on figure 32.

Till is an unconsolidated, nonstratified, heterogeneous sediment deposited directly by glacial ice. Much of the bedrock in the basin is overlain by till that is less than 10 feet thick, although locally till may exceed 100 feet in thickness.

Crystalline bedrock in the basin consists of two general types, carbonate and noncarbonate. The carbonate type (marble) is composed predominantly of calcium and magnesium carbonate, whereas the noncarbonate type is of more diverse origin and composition. Generally, however, the noncarbonate type consists mainly of silicate minerals. All the crystalline bedrock is fresh and unweathered except in a few local areas (see section entitled "Weathered crystalline bedrock").

GROUND-WATER STORAGE AND CIRCULATION

Stratified drift and till contain open spaces or pores between individual grains, whereas the bedrock contains open spaces along cracks or fractures. Below the water table, which is the upper surface of the saturated zone, the pores and fractures are filled with water. Stratified drift and till have greater porosites than fractured bedrock, and, where saturated, they contain significantly more water per unit volume. The greatest quantities of ground water, therefore, underlie the areas that have the thickest saturated deposits of stratified drift and till, but the availability is dependent on factors other than the amount in storage (see section titled "Aquifers").

The size of the ground-water flow system is controlled by the hydrogeologic setting, whereas the direction and rate of ground-water movement are governed by the distribution of hydraulic head and the hydraulic characteristics of the subsurface units. Circulation, in general, is confined within each area drained by a major perennial stream. The saturated zone underlying such areas constitutes an underground reservoir, the vertical boundaries of which generally coincide with the surface-water drainage divides. Ground-water flow is also bounded by the depth of the fracture system in the crystalline bedrock. Previous studies in Connecticut (Ellis, 1909) indicate that at depths greater than 300 feet below the bedrock surface, water-bearing openings are few and the rock is relatively impervious.

Minor flow systems, either temporary or permanent, may exist within the major systems of circulation. Major and minor ground-water flow systems

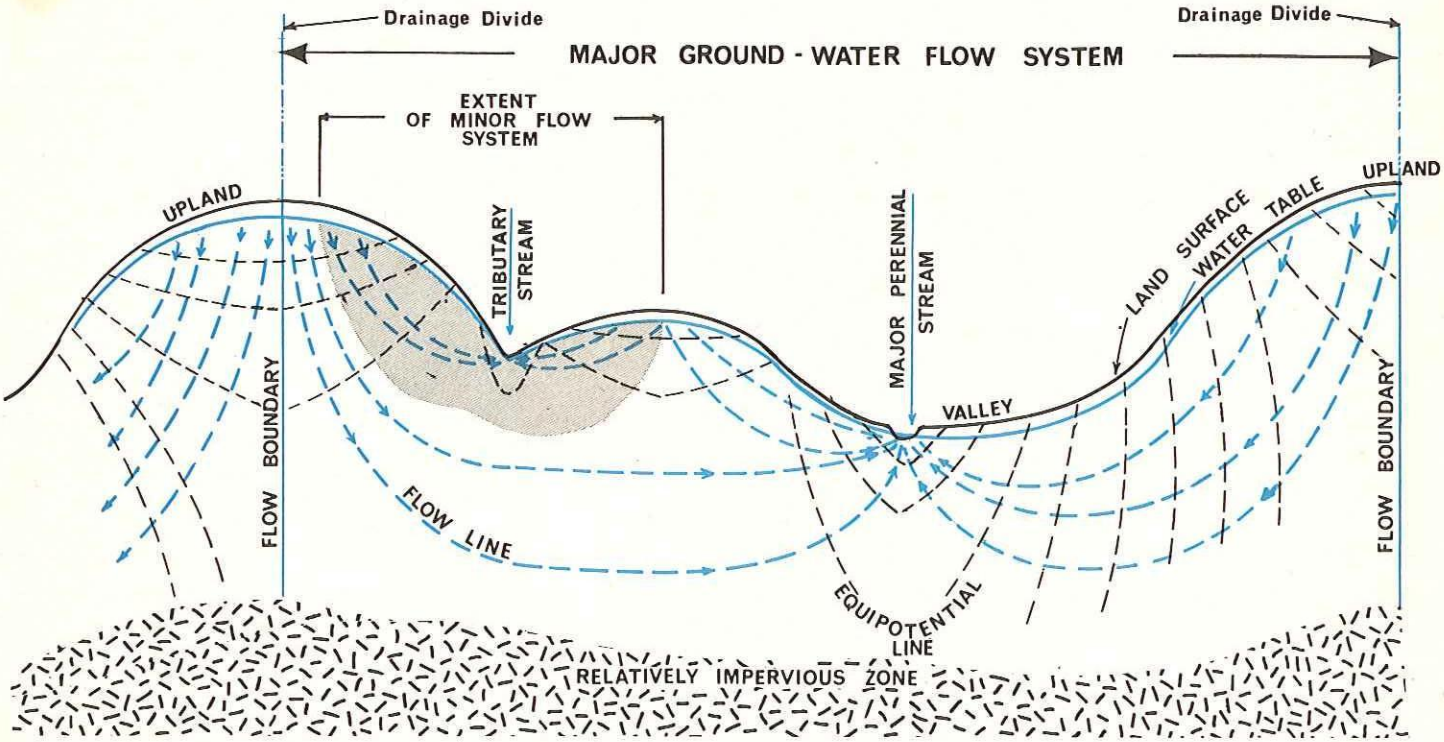


Figure 33.--Idealized section showing ground-water circulation in part of the upper Housatonic River basin.

The direction of ground-water flow and the distribution of hydraulic head are depicted by flow lines and equipotential lines. The actual configuration of these lines is more complex than that shown because of differences in hydraulic conductivity between the subsurface geologic units in the saturated zone and other factors.

and the general pattern of circulation from areas of inflow to areas of outflow are depicted on figure 33.

A quantitative expression of the ground-water circulation is given in the following equation (after Schicht and Walton, 1961):

$$G_{wr} = (G_{wro} + G_{wet} + U) \pm S$$

where G_{wr} = Ground-water recharge or inflow

G_{wro} = Ground-water runoff } ground-water discharge

G_{wet} = Ground-water evapor-transpiration } ground-water discharge

U = Underflow

S = Change in ground-water storage

All the items in the above equation may differ in amount and rate from one part of the basin to another, and all vary with time. This spatial and temporal diversity is due to hydrologic, geologic, climatologic, ecologic, and topographic factors. In general however, ground-water recharge is derived from precipitation and occurs mainly during the non-growing season (October through April), whereas ground-water discharge consists mainly of ground-water runoff to streams. Figure 34 is a hydrograph of observation well NOC 15 showing typical seasonal water-level changes that accompany changes in rates of ground-water recharge and discharge.

AQUIFERS

Stratified drift, till, and crystalline bedrock in the saturated zone are capable of yielding usable quantities of water throughout most of the basin and, therefore, constitute aquifers. These units, however, differ from one another in their ability to store and transmit water. Stratified drift,where it is composed principally of sand and gravel, is the only unit capable of supplying large quantities of ground water on a sustained basis. Wells tapping bedrock generally yield quantities of water adequate for domestic and commercial use, whereas till is an inadequate source for most modern requirements.

The ability of the stratified drift and till to yield water and their response to pumping may be determined by use of appropriate flow equations if the hydrologic system and hydraulic properties are known. The bedrock aquifer, because of the complexity of its hydraulic properties, is less amenable to mathematical analysis.

The properties of stratified drift and till that control their ability to yield water are the storage coefficient (or specific yield), saturated thickness, hydraulic conductivity, and transmissivity. These terms are defined in the glossary at the end of this report. Symbols and units of measurement used for these aquifer properties are as follows:

1. Storage coefficient is designated by the symbol S and is a dimensionless ratio expressed as a decimal fraction. Throughout the basin the stratified-drift and till aquifers are generally unconfined, and the storage coefficient is equivalent to the specific yield.

2. Hydraulic conductivity is designated by the symbol K and is expressed in units of feet per day. The hydraulic conductivity may vary with the direction of flow, particularly in stratified drift, and the symbols K_v and K_h are used for the hydraulic conductivity in the vertical and horizontal planes, respectively.

3. Saturated thickness, designated by the symbol b, is expressed in feet.

4. Transmissivity, designated by the symbol T, is expressed in units of feet squared per day. It is the product of the average hydraulic conductivity, and the saturated thickness of the aquifer ($T = K \times b$).

STRATIFIED DRIFT

Stratified drift underlies approximately 11 percent of the basin and is chiefly composed of interbedded layers of sand and gravel with minor amounts of silt and clay. (See pl. B.) In the Housatonic River valley upstream from Falls Village and in parts of the Still River, Bantam River, and Salmon Creek valleys, however, the stratified drift consists predominantly of sand, silt and clay. The lithology of the saturated section is commonly heterogeneous. Logs of wells and test holes in the companion basic-data report (Melvin, 1970) illustrate the lithologic diversity of the stratified drift.

Saturated and transmissive parts of the stratified-drift unit that are not physically and hydraulically connected are considered as separate aquifers in this report. The quantity of water that can be withdrawn on a temporary or sustained basis from a stratified-drift aquifer depends on: (1) the hydraulic properties of the aquifer, (2) the location and position of the hydraulic boundaries, (3) the quantity and variability of natural recharge and discharge, and (4) the quantity of water that can be induced to infiltrate from adjacent streams or lakes.

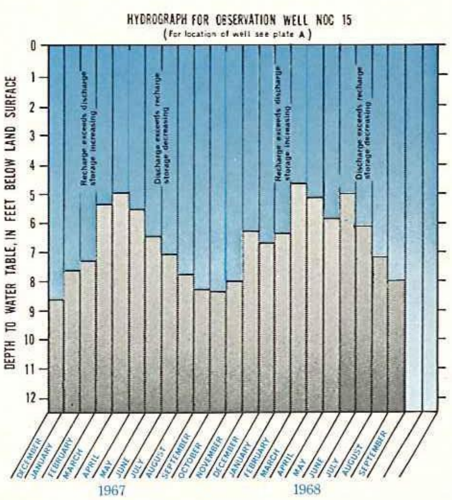
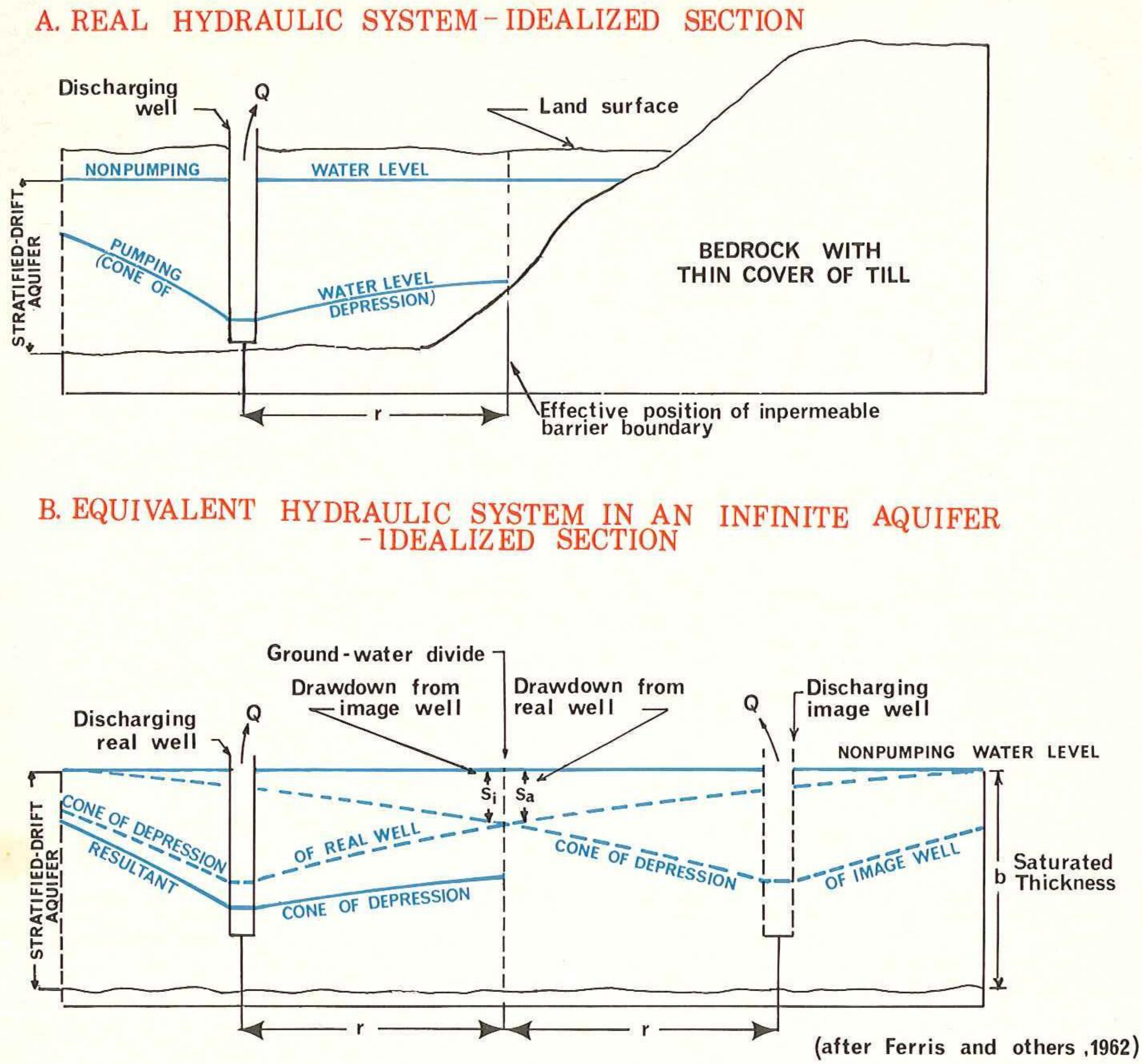


Figure 34.--Hydrograph of observation well NOC 15 illustrating the seasonal pattern of changes in ground-water storage.

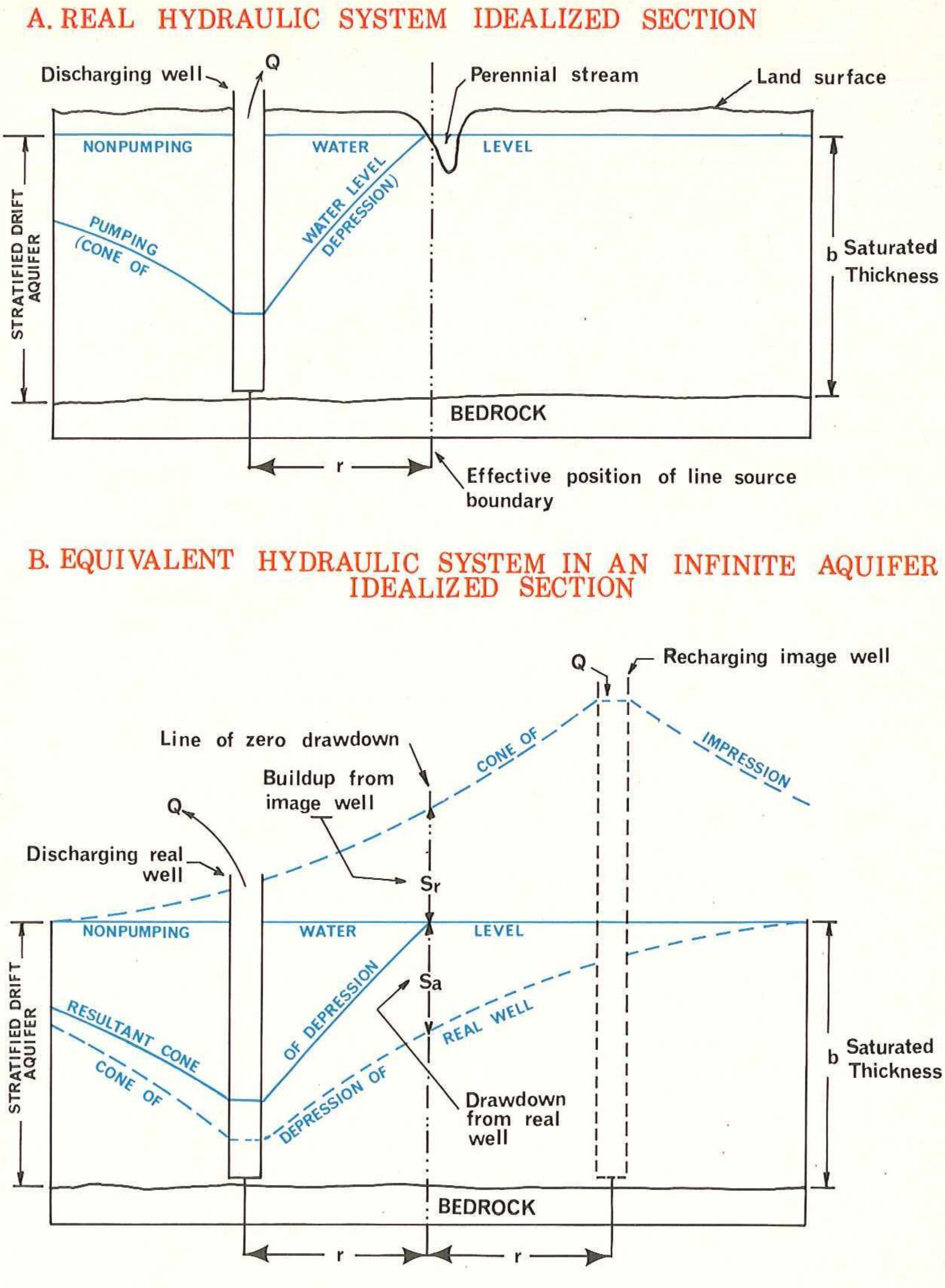
Water levels for 1967 are typical whereas those for 1968 reflect atypical late spring recharge owing to heavy precipitation. (Water levels are end-of-month readings.)



A. An impermeable-barrier boundary affects the distribution of drawdown produced by a pumping well. The cone shaped depression (termed cone of depression) of the water table, centered at the pumping well is steeper in profile on the side away from the boundary and flatter on the side toward the boundary than it would be if no boundary were present.

B. The hydraulic conditions resulting from an impermeable-barrier boundary can be made equivalent to those in an aquifer of infinite areal extent by the method of images (Ferris and others, 1962). The boundary is replaced by a ground-water divide by use of the image well. No flow crosses either the impermeable-barrier boundary or the ground-water divide.

Figure 35.--Hydraulic effect of an impermeable-barrier boundary on a stratified-drift aquifer.



(after Ferris and others, 1962)

A. A line-source boundary affects the distribution of drawdown produced by a pumping well. The cone of depression is steeper in profile on the side toward the boundary and flatter on the side away from the boundary than it would be if no boundary were present. The cone of depression extends to the line source and the drawdown at the effective position of the line-source boundary is zero.

B. The hydraulic equivalent of the line-source boundary in an aquifer of infinite areal extent is produced by use of a recharging image well. The buildup of the water table from injecting water into the aquifer results in zero drawdown at the effective position of the boundary.

Figure 36.--Hydraulic effect of a line-source boundary on a stratified-drift aquifer.

Table 19.--Estimates of transmissivity of the stratified drift in the upper Housatonic River basin. Values computed from specific capacity (Theis, 1963) using drawdown adjusted for the effects of partial penetration (Butler, 1957) unless indicated otherwise. K_v:K_h, assumed ratio of vertical hydraulic conductivity (K_v) to horizontal hydraulic conductivity (K_h); S, assumed storage coefficient.

Well no. (Pl. A)	Transmissivity (ft^2/day)	K_v:K_h	S
BT 2	16,000	1:10	0.1
BT 31	4,300	1:10	.1
BT 33	3,000	1:25	.1
BT 36	3,400	1:10	.1
BT 38	8,000	1:25	.05
BT 39	8,000	1:25	.05
BT 41	4,000	1:25	.1
BT 42	2,200	1:25	.1
BT 45	15,000	1:10	.1
DY 35	a/ 5,400		.05
DY 36	13,500	1:10	.05
DY 47	5,400	1:10	.1
DY 61	7,800	1:25	.05
DY 78	7,500	1:2	.15
DY 81	2,000	1:10	.1
DY 82	6,700	1:2	.15
KT 12	2,700	1:10	.2
KT 24	4,600	1:10	.2
LF 51	1,700	1:25	.05
NMI 3	13,500	1:10	.2
NMI 4	10,000	1:10	.2
NMI 5	6,700	1:10	.1
NMI 6	7,400	1:10	.1
NMI 7	7,000	1:10	.1
NMI 8	3,400	1:10	.1
NMI 16	6,700	1:25	.1
NMI 20	4,000	1:10	.1
NMI 21	4,800	1:10	.1
NMI 25	6,700	1:10	.1
NOC 22	1,350	1:10	.2
NOC 29	2,300	1:10	.2

a/ Computed from aquifer test using Boulton's curves (Boulton, 1963; Prickett, 1965).

Hydraulic properties

Storage coefficient, saturated thickness, and transmissivity are the physical properties that determine the ability of the stratified-drift aquifers to store, transmit, and yield water. The storage coefficient, together with transmissivity, can be used to estimate the water-table drawdown due to pumping wells for any given time period. The storage coefficient of unconfined stratified-drift aquifers depends on their grain-size distribution and the period of time the material is allowed to drain (Prill and others, 1965; Johnson, 1967). Values of S ranging from 0.05 to 0.2 have been used in this report to analyze data where the period of drainage is from 1 to 7 days. An S value of 0.2 is used in subsequent analyses where the drainage period is approximately 200 days. These selected values are considered to be representative for the materials being drained and for the drainage period.

The saturated thickness is equal to the difference in altitude between the water table in the stratified drift and the altitude of the underlying till-bedrock surface. (See fig. 32.) The saturated thickness is shown by contour lines on plate B; it is also shown on plate D which depicts selected stratified-drift aquifers. In most areas the saturated thickness is a measure of the drawdown or head available for development. However, in the Housatonic River valley between the Massachusetts stateline and Falls Village; in parts of the Hollenbeck, Still, and Bantam River valleys; and small areas elsewhere the saturated section of stratified drift generally consists of an upper zone of sand or sand and gravel underlain by very fine sand, silt, and clay. Wells cannot be completed in the fine-grained material, and the head available for development is limited to the upper part of the saturated section.

Transmissivity is a measure of the ability of an aquifer to transmit water. In conjunction with storage-coefficient values and a knowledge of the aquifer boundaries, it enables one to estimate the specific capacity of a proposed well and the spatial distribution of water levels around wells pumping at a constant rate for any given period of time. The transmissivities of the stratified drift at many points in the basin, as computed from specific capacity and pumping-test data, are shown in table 19. In addition, transmissivity was estimated at the sites of 335 wells and test holes for which geologists' or drillers' logs are available. The estimates utilize the relationship between hydraulic conductivity and grain-size distribution (Krumbein and Monk 1942, Masch and Denny 1966) and are less reliable than values calculated from specific-capacity and pumping-test data. The hydraulic conductivities assigned to the various sediments constituting the stratified-drift aquifers are listed in table 20.

Plate B shows the areal distribution of transmissivity for much of the stratified-drift unit. The transmissivities shown on this plate were delineated by 1) plotting the values determined by the methods described above and 2) interpolating between the data points to locate the approximate boundaries of each of the transmissivity ranges. Estimates are confined to areas for which subsurface data are available.

Table 20.--Values of hydraulic conductivity assigned to materials of stratified drift for estimating transmissivity

(Materials classification based on Wentworth Grade Scale)

Material	Hydraulic conductivity (ft/day)
Coarse gravel	400-670
Median gravel	270-670
Gravel	200-400
Fine gravel	200-400
Sandy gravel	135-400
Sand and gravel	135-335
Very coarse sand	135-400
Coarse sand	105-335
Median sand	33-135
Fine sand	7- 67
Very fine sand	3- 20
Silty sand	10- 16
Sand and silt	3- 10
Sand, silt, and clay	3- 6
Silt	3
Silt and clay	2- 3
Clay	1

Transmissivity depends on both hydraulic conductivity and saturated thickness and will differ where either or both of these characteristics change. Some stratified-drift areas, such as the valley between Robbins Swamp and the village of Canaan, have high transmissivity (see pl. B) because they have a thick saturated section, even though they are underlain by predominately fine-grained sediments. Conversely, coarse-grained stratified drift may be relatively thin yet have a high transmissivity.

Hydraulic boundaries

Hydraulic boundaries limit the continuity of an aquifer, thereby affecting the time-distance-drawdown relationships resulting from its development. Two types, termed impermeable-barrier boundaries and line-source boundaries, and their effect on the response of an aquifer to pumping are fully described in Ferris and others (1962). The till-bedrock valley walls constitute impermeable barrier boundaries for the adjacent stratified-drift aquifers, as shown on figure 35. To simplify the analyses of the hydrologic effect of these boundaries, they can be idealized as straight lines approximately coincident with the 10-foot saturated thickness contour lines. (See pl. D.) Major perennial streams or large lakes hydraulically connected to stratified-drift aquifers are considered line-source boundaries. (See fig. 36.) In subsequent analyses they are also idealized as straight lines coincident with the streams. Because the rivers and lakes in the basin do not penetrate the full thickness of the aquifer, it is not possible to define the effective location of a line-source boundary exactly without performing detailed site tests.

Amount and variability of natural recharge

Natural recharge to the stratified drift consists of 1) precipitation on this unit that infiltrates to the water table and 2) ground water that flows into the stratified drift from the adjacent till-bedrock uplands. Where recharge by induced infiltration from streams is small or nonexistent, well yields are sustained by natural recharge. Quantities of ground water greater than the average annual recharge may be developed from such areas but with a resulting net decrease in storage and with a decline in ground-water levels.

Natural recharge can be determined by measuring and summing the components of discharge over a period in which there is no net change in ground-water storage. Ground-water outflow, the sum of ground-water runoff to streams and underflow, accounts for the major part of ground-water discharge from most drainage areas in southern New England and has been used as a conservative estimate of natural recharge (Randall and others, 1965; Ryder and others, 1970). Detailed estimates of ground-water recharge require data on the magnitude of ground-water evapotranspiration and on discharge by pumping.

Hydrologic studies in nonurbanized areas elsewhere in Connecticut show that differences in amounts of ground-water outflow between basins are related to differences in the proportion of stratified drift they contain (Randall and others, 1965; Thomas and others, 1967; Ryder and others, 1970). Figure 37 shows the relation between the percentage of total area underlain by stratified drift and the annual ground-water outflow from small drainage basins in Connecticut, Massachusetts, and New York. Data from five areas within the upper Housatonic River basin are included on figure 37 and are also listed separately in table 21. The scatter of points about the curve on figure 37 is probably due to a combination of the following factors: rough approximations of ground-water outflow; inclusion of upland areas of unsaturated stratified drift; changes in ground-water storage over the period of analysis; areal differences and annual variations in the amount of ground-water evapotranspiration; and unmeasured ground-water discharge from pumping.

If the ratio of ground-water outflow to total outflow from an area is assumed to be nearly constant from year to year, a conservative estimate of aquifer recharge for any nonurbanized area and for any critically dry period can be made. The average annual ground-water outflow, the ground-water outflow equaled or exceeded 7 years in 10, and the long-term minimum ground-water outflow from stratified drift underlying any nonurbanized part of the basin are estimated from plate B and figures 17 and 37 as follows:

Table 21.--Estimated ground-water outflow from five drainage areas in the upper Housatonic River basin, 1968 water year

Index no. (I. A)	Stream and place of measurement	Drainage area (sq mi)	Total runoff (in.)	Ground-water runoff (in.) 1/2/	Under-flow (in.) 3/	Ground-water outflow (ground-water runoff and underflow)2/ (in.)
1982.4	Blackberry River at West Norfolk	13.5	27.42	11.8	-	11.8
1985	Blackberry River at Canaan	48.2	21.21	7.4	.06	7.5
1990.33	Factory Brook at Salisbury	9.3	23.55	7.9	-	7.9
1990.5	Salmon Creek at Limerock	29.1	22.46	9.9	-	9.9
1983	Whiting River at East Canaan	17.0	22.15	7.8	-	7.8

1/ Determined from records of streamflow and ground-water levels by ground-water rating curve method (Schicht and Walton, 1961, p. 16).

2/ Ground-water runoff and outflow rounded to nearest 0.1 inch.

3/ Computed by Darcy's law (Ferris and others, 1962, p. 12) only for gage sites with significant deposits of stratified drift.

1. Determine from plate B the areal extent of the stratified-drift aquifer and the adjacent till-bedrock drainage area from which ground water flows into the stratified drift.

2. Measure the total area delineated; also measure the area of stratified drift, in square miles. Compute the percentage of the total area underlain by stratified drift.

3. Determine the mean annual runoff in millions of gallons per day, for the area, by use of the isopleths on figure 17.

4. From figure 37 determine the percentage of mean annual runoff that consists of ground-water outflow.

5. Compute the average annual ground-water outflow (approximately equal to average annual natural recharge) by multiplying the mean annual runoff (mgd) by the appropriate percentage.

6. Compute the ground-water outflow equaled or exceeded 7 years in 10 by multiplying the average annual ground-water outflow by 0.84; also compute the long-term minimum outflow by multiplying the average annual ground-water outflow by 0.4. These coefficients are the ratios of total runoff equaled or exceeded 7 years in 10 and the minimum total runoff to the mean annual runoff of the Housatonic River at Falls Village (56 years of record). This technique of estimating ground-water recharge is illustrated on figure 38.

Induced infiltration

Sustained pumping of wells tapping stratified drift can lower the water table beneath adjacent stream and lake beds, inducing recharge from these surface-water bodies to the aquifer. Walton and Ackroyd (1966, p. 3) state "When a well is pumped, water is first withdrawn from storage within the aquifer in the immediate vicinity of the well. The cone continues to spread, drawing water from storage within an increasing area of influence. Water levels in the vicinity of the stream are lowered and more and more of the water which under natural conditions would have discharged into the stream as ground-water runoff or into the atmosphere as evapotranspiration is diverted toward the well. Ultimately water levels may be lowered below all or part of the surface of the stream in the immediate vicinity of the well and the aquifer is recharged by the influent seepage of surface water." Several large-capacity industrial and public-supply wells in the basin have derived much of their water by induced infiltration.

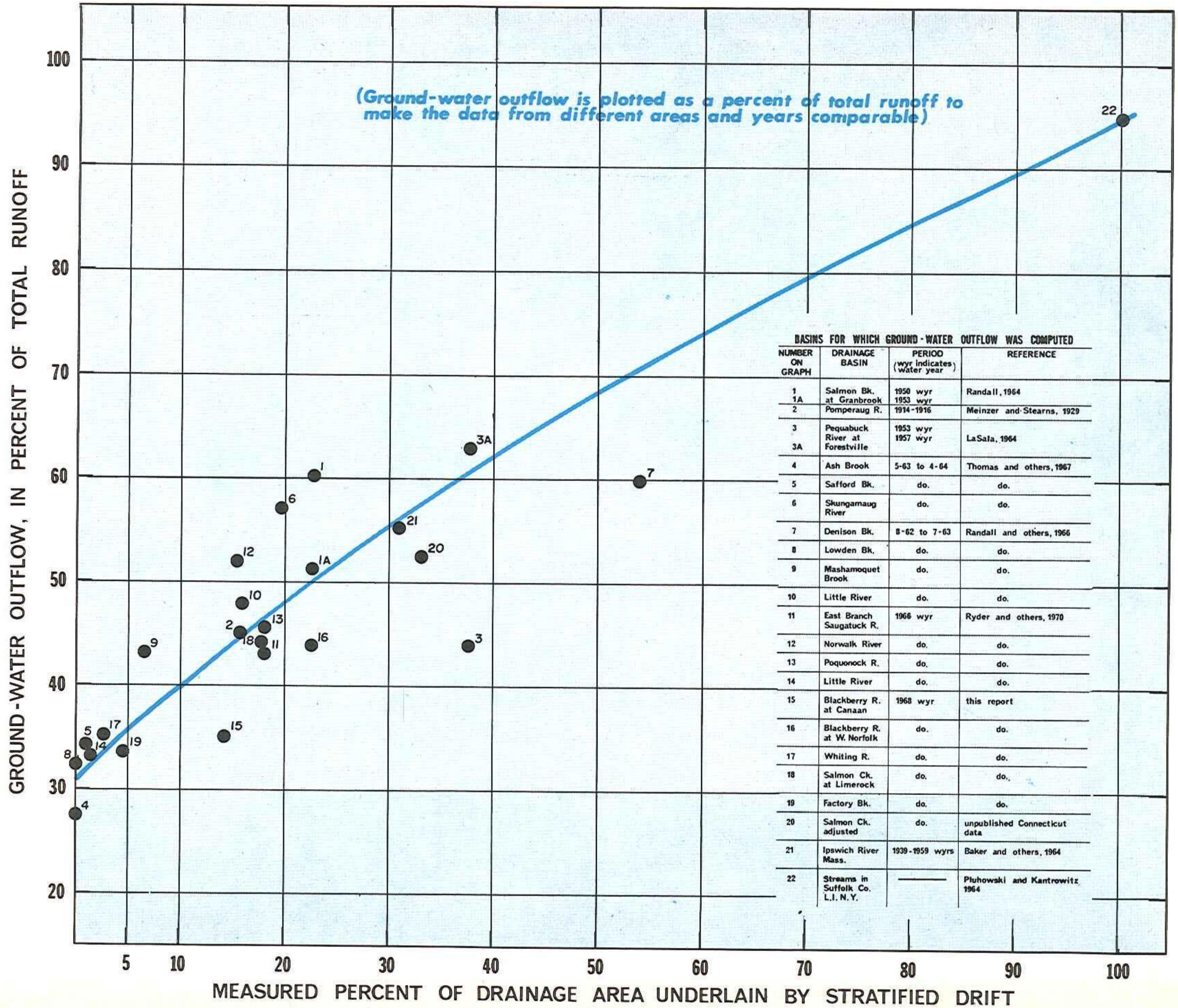
Potential recharge from induced infiltration can be estimated from the following modified form of the Darcy equation, as adapted from Walton and others (1967, p. 4):

$$R = I_t S_r A_r$$

Where:

R = potential recharge by induced streambed infiltration, in gallons per day (gpd).

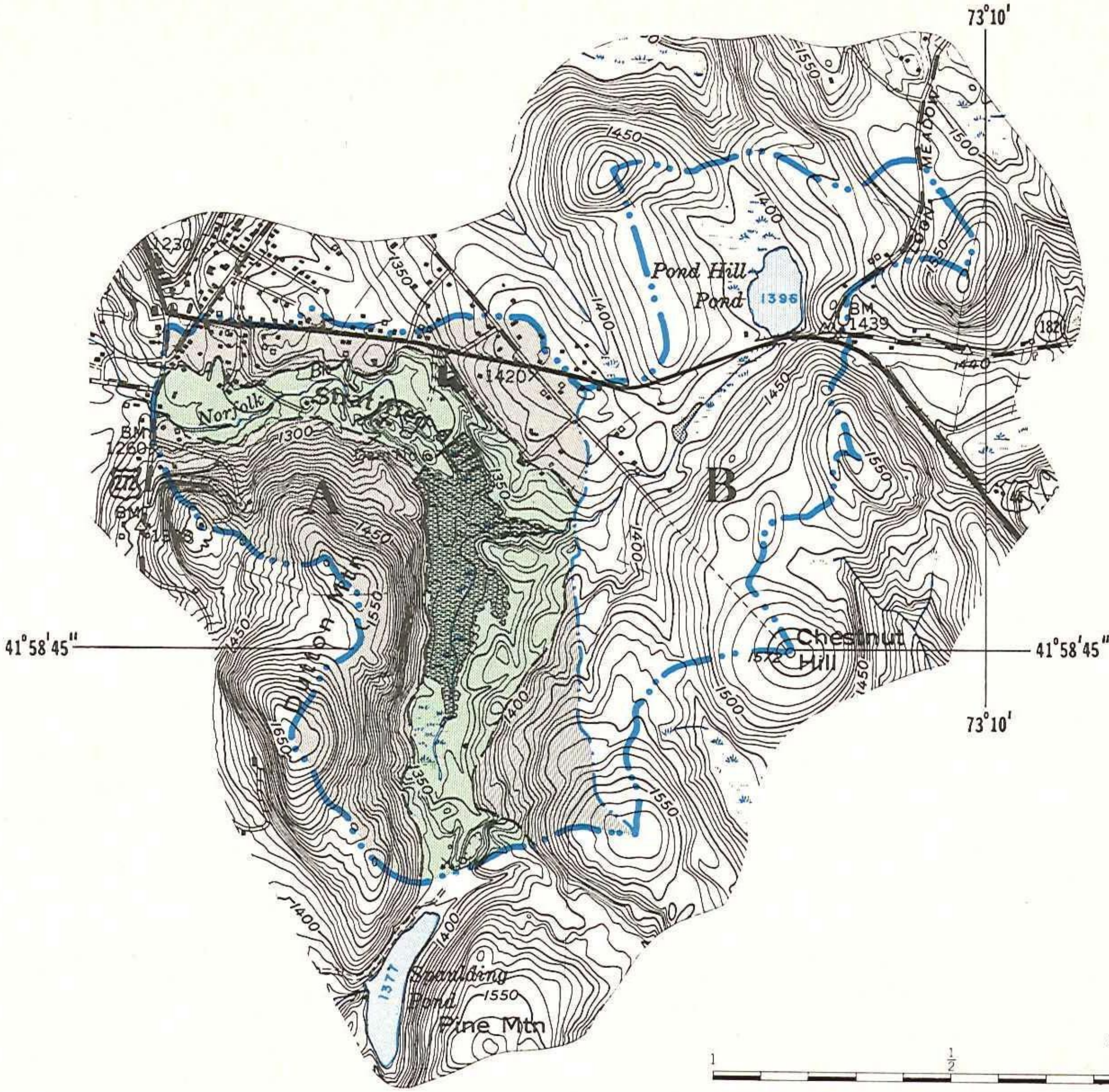
I_t = average infiltration rate of streambed for a particular surface-water temperature, in gpd per square foot of streambed per foot of head loss.



BASINS FOR WHICH GROUND-WATER OUTFLOW WAS COMPUTED

NUMBER ON GRAPH	DRAINAGE BASIN	PERIOD (wyr indicates water year)	REFERENCE
1 1A	Salmon Bk. at Granbrook	1950 wyr 1953 wyr	Randall, 1964
2	Pomperaug R.	1914-1916	Meinzer and Stearns, 1929
3 3A	Pequabuck River at Forestville	1953 wyr 1957 wyr	LaSala, 1964
4	Ash Brook	5-63 to 4-64	Thomas and others, 1967
5	Safford Bk.	do.	do.
6	Skungamaug River	do.	do.
7	Denison Bk.	8-62 to 7-63	Randall and others, 1966
8	Lowden Bk.	do.	do.
9	Mashamoquet Brook	do.	do.
10	Little River	do.	do.
11	East Branch Saugatuck R.	1966 wyr	Ryder and others, 1970
12	Norwalk River	do.	do.
13	Poquonock R.	do.	do.
14	Little River	do.	do.
15	Blackberry R. at Canaan	1968 wyr	this report
16	Blackberry R. at W. Norfolk	do.	do.
17	Whiting R.	do.	do.
18	Salmon Ck. at Limerock	do.	do.
19	Factory Bk.	do.	do.
20	Salmon Ck. adjusted	do.	unpublished Connecticut data
21	Ipswich River Mass.	1939-1959 wyrs	Baker and others, 1964
22	Streams in Suffolk Co. L.I. N.Y.	———	Pluhowski and Kantrowitz 1964

Figure 37.--Relation between ground-water outflow and percentage of area of a drainage basin [illegible]erlain by stratified drift.



TOTAL AREA OF STRATIFIED DRIFT AQUIFER AND ADJACENT TILL-BEDROCK DRAINAGE AREA (A) = 0.76 square mile

AREA UNDERLAIN BY STRATIFIED DRIFT = 0.3 square mile

PERCENT OF TOTAL AREA (A) UNDERLAIN BY STRATIFIED DRIFT = 39 percent

MEAN ANNUAL RUNOFF FROM FIGURE 17.(0.98) (1.16 MGD)(0.76 sq mi) = 0.86 million gallons daily

PERCENT OF MEAN ANNUAL RUNOFF THAT CONSISTS OF GROUND-WATER OUTFLOW FROM FIGURE 37 = 60 percent

AVERAGE ANNUAL GROUND-WATER OUTFLOW (.6) (0.86 mgd) = 0.52 million gallons daily

GROUND-WATER OUTFLOW EQUALED OR EXCEEDED 7 YEARS IN 10 (0.84) (0.52 mgd) = 0.44 million gallons daily

LONG-TERM MINIMUM GROUND-WATER OUTFLOW (0.4) (0.52 mgd) = 0.21 million gallons daily

Figure 38.--Sketch illustrating method of estimating ground-water recharge to a stratified-drift aquifer.

The valley of Norfolk Brook upstream from Route 272 is underlain by a stratified-drift aquifer. Underflow is negligible and ground-water outflow is equivalent to ground-water runoff from the area identified by the letter A. In the rest of the Norfolk Brook drainage area (letter B), ground water discharges to the stream before it reaches the stratified drift.

S_r = average head loss within streambed area of infiltration or average depth of water in a stream for a particular stream stage, depending on the position of the water table, in feet.

A_r = streambed area of infiltration, in square feet.

The average infiltration rate, I_t, under conditions of constant temperature and gradient is controlled by the vertical hydraulic conductivity of the streambed sediments. Although the materials underlying streams that traverse a stratified-drift aquifer may be described in general terms as silty, sandy, or gravelly, they are, in detail, a complex association of inorganic and organic-rich sediments, the composition of which may be altered by erosion or deposition. The vertical hydraulic conductivity is related to sediment lithology and is, therefore, subject to significant spatial and temporal variability.

Changes in stream-bottom sediments can significantly affect the yield of a nearby well. For example, five wells of the Kimberly Clark Corporation, NMI 3, 4, 5, 6, and 7 (see plate A), drilled close to the Housatonic River at New Milford, yielded 533 to 1,404 gpm each when completed in 1956-58. Subsequent changes in streambed sediments, probably resulting from the impoundment of the river downstream at Shepaug Dam, produced a significant decline in well yields. Recharge pits were thereupon constructed, and well yields were restored to their original rates. Sedimentation on the bottoms of the recharge pits again reduced the stream infiltration, and the wells were abandoned.

Infiltration rates also vary with the temperature of the surface water. A change in the temperature of the water changes the viscosity and thus the infiltration rate. Temperature-induced changes in infiltration rates can be computed by use of temperature and viscosity data, as shown in Walton and Ackroyd (1966, p. 11). Variations in temperature of water in the Housatonic River (fig. 30) indicate that, for a constant stream stage, the infiltration rate may be as much as 57 percent higher and 25 percent lower than it would be at the median temperature of 9°C.

Data on the infiltration rates of streambed materials in Connecticut is scant. Ryder and others (1970) determined an infiltration rate of 59 $gpd/ft^2/ft$ at 10°C for streambeds consisting of sand and gravel in southwestern Connecticut. An infiltration rate of 105 $gpd/ft^2/ft$ at 10°C was computed for a 632-foot reach of streambed in the lower Housatonic River basin (Wilson and others, written communication) where the sediments consist of poorly sorted gravel.

Estimating well yields

Water is withdrawn from stratified drift by drilled, dug, and driven wells, which differ in depth, diameter, finish, and other construction details. The techniques commonly used in constructing such wells are given in Johnson (1966). Most wells tapping stratified drift that yield more than 50 gpm are drilled or dug, are 6 inches or more in diameter, and are finished with a screen (hereafter termed screened wells). Sixty-four such wells inventoried during this basin study (Melvin, 1970) yield from 17 gpm to 1,404 gpm and have a median yield of 200 gpm. The specific capacities of 44 of these wells range from 0.4 gpm/ft to 49 gpm/ft with a median value of 11.1 gpm/ft.

Estimates of the potential yields of screened wells tapping stratified-drift aquifers are required in the evaluation of areas favorable for ground-water development. (See section titled "Large water supplies from stratified-drift aquifers"). The procedure used is based on determining the drawdown in a well (or wells) for a given constant pumping rate after 200 days without recharge. If, after this period, the water level in the well is above the top of the well screen, continuous pumping at the proposed rate is considered feasible. A 200-day pumping period is used, as it approximates the longest known period of little or no ground-water recharge in the basin. The maximum available drawdown in a well is considered to be equal to the thickness of saturated material above the top of the screen and can be determined from plate B. For example, at a site on plate B where the average saturated thickness is 100 feet and the screen is to be set in the lower 30 feet, the maximum available drawdown is 70 feet.

An estimate of the yield of a screened well tapping stratified drift can be made at any site where the hydraulic characteristics of the aquifer and the approximate location of hydraulic boundaries are known. The saturated thickness and transmissivity data for many stratified-drift areas in the basin are shown on plate B, and the method used to determine the drawdown in a well is outlined in the following section.

Estimating drawdown

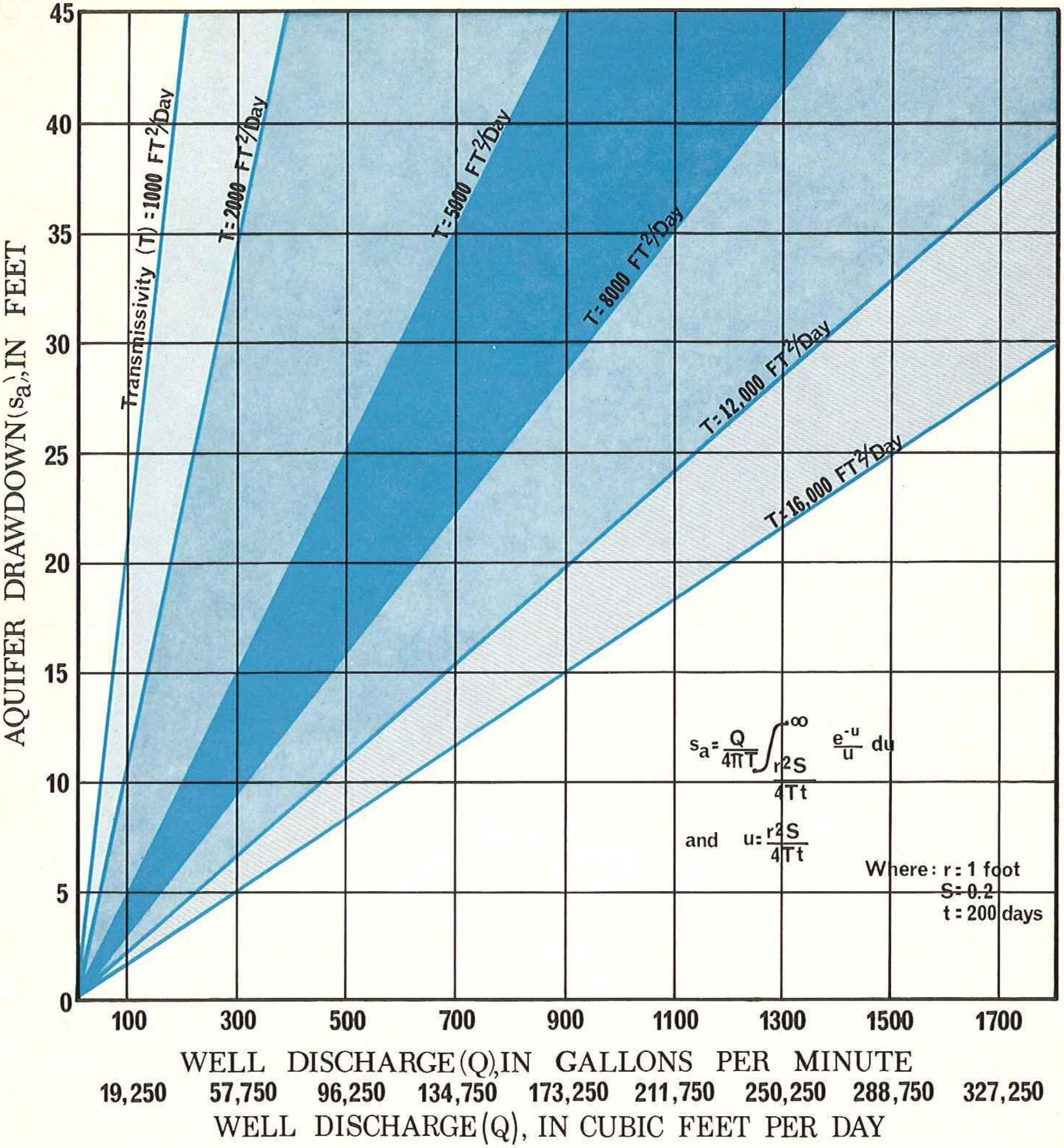
The drawdown in a pumping well that taps the stratified-drift aquifer includes at least three, and may include all, of the following components:

1. s_a, the aquifer drawdown for a specific discharge and transmissivity
2. s_d, drawdown due to dewatering of the aquifer
3. s_p, drawdown due to partial penetration of the aquifer
4. s_e, drawdown due to moving water from the aquifer into the well, termed entrance loss
5. s_i, drawdown due to other pumping wells
6. s_b, drawdown due to impermeable-barrier boundaries
7. s_r, buildup due to line-source boundaries

For a specific well discharge, Q, the total drawdown in the pumping well can be expressed as:

$$s_{total} = s_a + s_d + s_p + s_e + s_i + s_b - s_r$$

The aquifer drawdown, s_a, is computed by the Theis equation (Theis, 1935, p. 520; Ferris and others, 1962, p. 92):



$$s_a = \frac{Q}{4\pi T}\int_{\frac{r^2S}{4Tt}}^{\infty} \frac{e^{-u}}{u}\,du$$

$$u = \frac{r^2S}{4Tt}$$

Figure 39.--Relation between aquifer drawdown and well discharge.

$$s_a = \frac{Q}{4\pi T} \int_{r^2S/4Tt}^{\infty} \frac{e^{-u}}{u} \, du$$

Where: $u = r^2S/4Tt$

s_a = aquifer drawdown, in feet at any point of observation in the vicinity of a well discharging at a constant rate

Q = constant well discharge, in cubic feet per day

T = transmissivity, in feet squared per day

r = distance in feet from the center of the discharging well to the point of observation

S = storage coefficient

t = time, in days since pumping started

When determining the aquifer drawdown in the pumping well itself, the distance r is generally taken as equal to the well radius.

Figure 39 shows the relationship between s_a in a pumping well and various discharge rates (Q), calculated for the upper Housatonic River basin where:

T, transmissivity = 1,000, 2,000, 5,000, 8,000, 12,000, and 16,000 ft^2/day

r, radius of the pumping well = 1 foot

S, average storage coefficient = 0.2

t, time since pumping began = 200 days

As previously stated, impermeable-barrier and line-source boundaries limit the hydraulic continuity of an aquifer. Figures 35 and 36 illustrate how boundary conditions are equated to a system of infinite areal extent by use of recharging and discharging image wells. Different configurations of boundaries and pumping wells in aquifers can also be made hydraulically equivalent to an aquifer of infinite areal extent by use of arrays of image wells. (See Ferris and others, 1962, p. 144.) The drawdown (s_b) or buildup (s_r) of the water table produced by the resulting image wells can be estimated from figure 40 or calculated by use of the Theis equation. (See fig. 43.)

The drawdown in a well can be approximately adjusted for dewatering of the aquifer by the following equation (Jacob, 1944; Walton, 1962, p. 7):

$$s' = s-(s^2/2b)$$

Where:

s' = the drawdown, in feet, that would occur if the saturated thickness of the aquifer did not decrease (equal to s_a as previously defined)

s = observed drawdown, in feet, under water table conditions (equal to $s_a + s_d$ as previously defined)

b = initial saturated thickness of the aquifer in feet

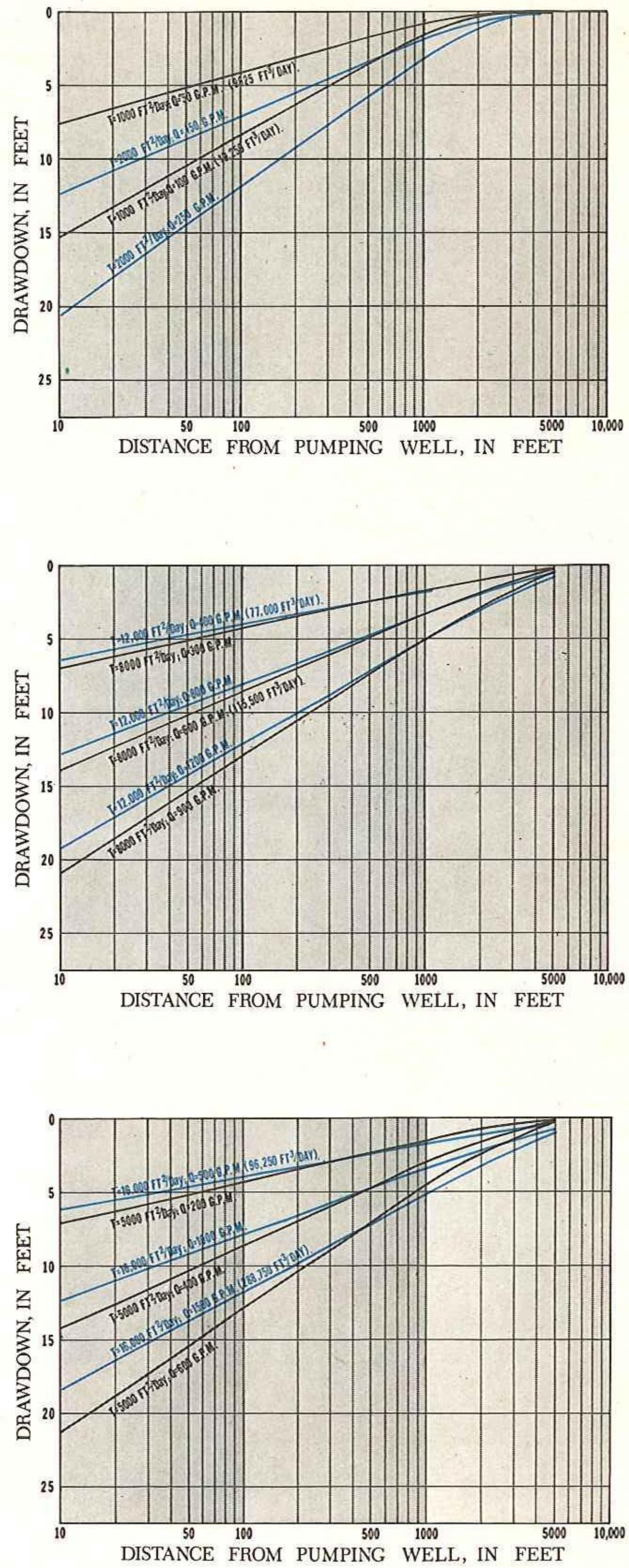


Figure 40.--Distance-drawdown curves for selected values of transmissivity (T) and pumping rates (Q). Time (t) since pumping started is 200 days and storage coefficient (S) is 0.2.

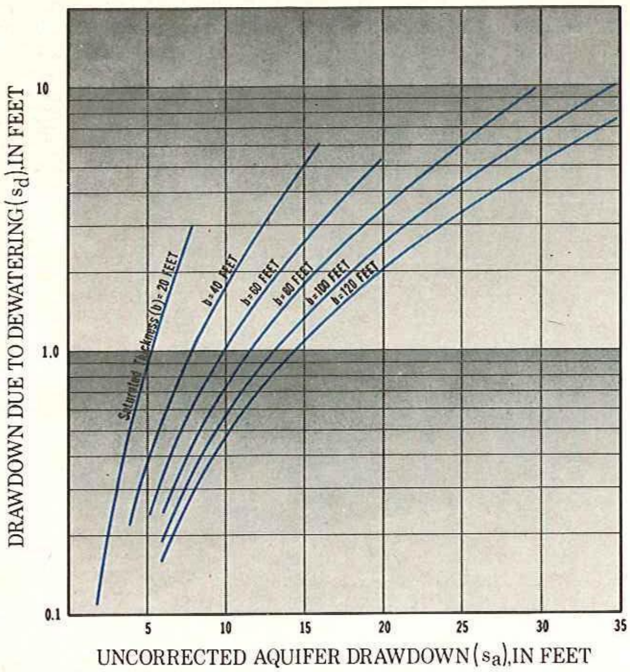


Figure 41.--Drawdown correction for dewatering of an aquifer.

The drawdown due to dewatering, s_d, is equal to s-s' in the preceding equation. Figure 41 is a graph that can be used to quickly correct drawdowns for the effects of dewatering of the aquifer; it relates values of s_d to values of s_a for representative saturated thicknesses ranging from 20 to 120 feet.

Wells in stratified drift are generally screened in only a part of the total saturated thickness which results in the convergence of flow toward the screened section. The drawdown in a pumping well can be approximately adjusted for the effects of this partial penetration by the following equation (Walton, 1962, p. 8):

$$\frac{s_a}{Cpp} = s''$$

Where:

s_a = the aquifer drawdown in feet for a well screened and open to the entire saturated thickness of the aquifer (fully penetrating well)

s'' = the drawdown in feet for a partially penetrating well (equal to $s_a + s_p$ as previously defined)

Cpp = the correction factor for partial penetration

Values of Cpp are calculated by the Kozeny equation. (See Butler, 1957, p. 160.):

$$Cpp = \alpha\left[1+\left(7\sqrt{\frac{r_w}{2\alpha b}}\sqrt{\frac{k_v}{k_h}}\cdot\cos\frac{\pi\alpha}{2}\right)\right]$$

Where:

α = $\frac{\text{screen length}}{\text{saturated thickness}}$

r_w = radius of the well in feet

K_v = hydraulic conductivity of the aquifer in the vertical direction

K_h = hydraulic conductivity of the aquifer in the horizontal direction

b = initial saturated thickness, in feet

Values of Cpp are shown on figure 42 for selected values of α and b were calculated for 24-inch diameter wells and a ratio K_v:K_h of 0.1. As the actual K_v:K_h value at a site is seldom known, the drawdown adjustments for partial penetration are approximate.

The drawdown required to move the water from the aquifer into the well, termed entrance loss (s_e), is related to screen design and well development (Johnson, 1966, p. 128-130). The data required to determine this component of total drawdown were not available. Therefore, in estimating yields in subsequent sections of this report, the wells are assumed to be 100 percent efficient, and no drawdown correction for entrance loss is made.

The Theis equation and other equations used to evaluate the components of drawdown are based on a constant value of transmissivity; when pumping produces substantial thinning of an aquifer, transmissivity decreases significantly. For this reason, it is rarely possible to determine, for a well tapping stratified drift, its maximum potential yield; that is, the pumping rate that would lower the water level in the well to the top of the screen after 200 days of pumping. The pumping rates used in subsequent analyses are limited to those producing drawdowns (s_a values) in the hypothetical wells equal to about 25 percent of the saturated thickness of the aquifer. An example illustrating how the various drawdown components are evaluated and summed is shown on figure 43.

Large water supplies from stratified-drift aquifers

The planned development of the stratified-drift aquifers should be based on data adequate to answer the following questions:

1. How much ground water can be obtained from a well or group of wells tapping any of these aquifers?

2. What is the maximum amount of water that can be withdrawn on a sustained basis under a given management scheme?

3. What will be the effect of any proposed plan of ground-water development on the hydrologic system?

The information in this report cannot answer all these questions for any particular site in the basin but is adequate to (1) define the geohydrologic setting of many of the stratified-drift aquifers (2) identify and delineate areas potentially favorable for development and (3) allow semiquantitative

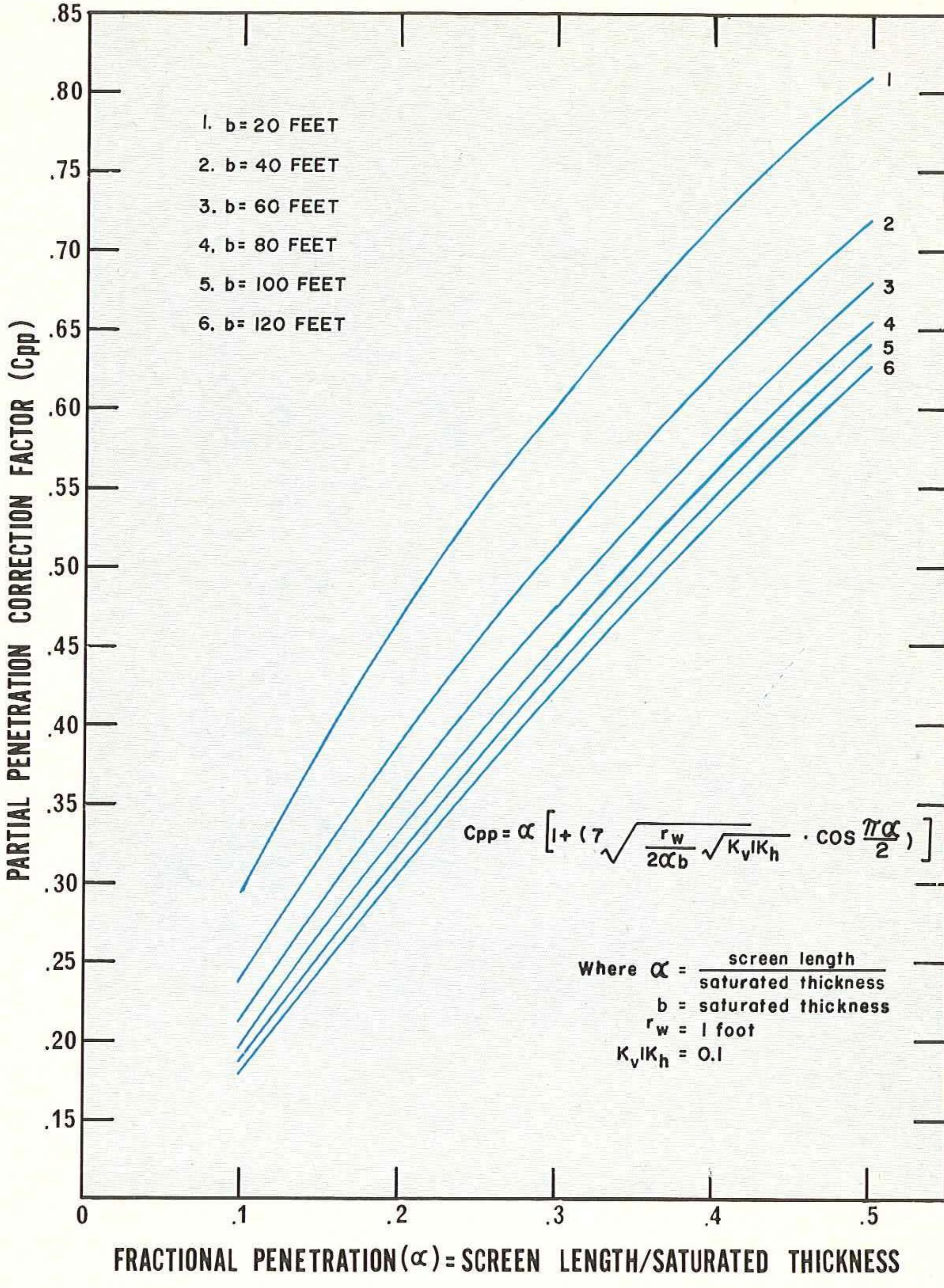
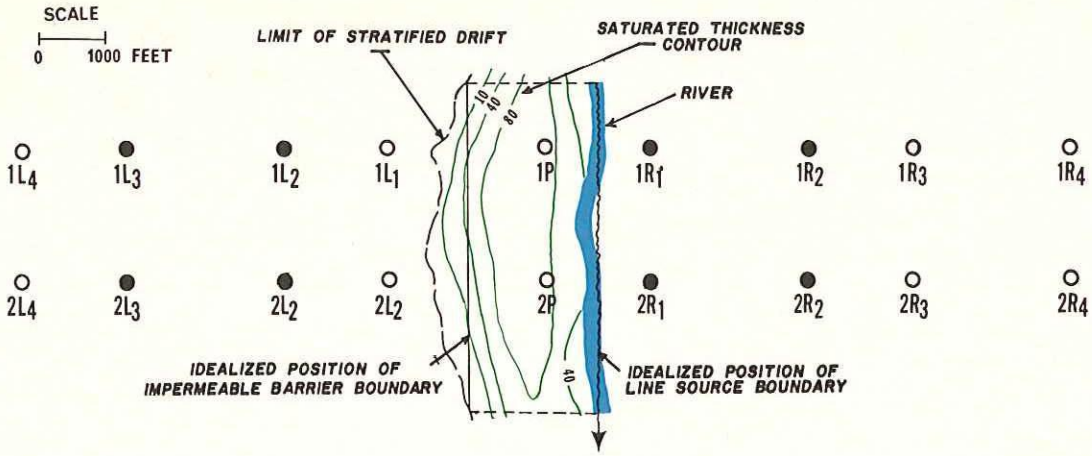


Figure 42.--Correction factor for partial penetration for selected values of saturated thickness and fractional penetration.



A. COMPUTATION OF S_r AND S_b AT 1P
(FROM THEIS EQUATION OR FIG 40)

RECHARGING IMAGE WELL	DISTANCE FROM PUMPING WELL 1P (FT)	BUILDUP S_r (FT)
$1R_1$	1,600	1.95
$1R_2$	4,000	.38
$2R_1$	2,550	1.02
$2R_2$	4,450	.27
$1L_2$	4,000	.38
$1L_3$	6,400	.05
$2L_2$	4,450	.27
$2L_3$	6,700	.05
TOTAL BUILDUP		4.37

DISCHARGING IMAGE WELL	DISTANCE FROM PUMPING WELL 1P (FT)	DRAWDOWN S_b (FT)
$1R_3$	5,600	0.11
$1R_4$	8,000	.01
$2R_3$	5,950	.08
$2R_4$	8,250	.01
$1L_1$	2,400	1.14
$1L_4$	8,000	.01
$2L_1$	3,100	.72
$2L_4$	8,250	.01
TOTAL DRAWDOWN		2.09

B. S_i, DRAWDOWN DUE TO PUMPING OF WELL 2P, 2000 FT. FROM 1P (FROM THEIS EQUATION OR FIG 39)

$S_i = 1.5$ FT

C. $S_b - S_r + S_i = 2.09\text{ FT} - 4.37\text{ FT} + 1.5\text{ FT} = -0.78\text{ FT}$

NOTE: IF THE SUM $S_b - S_r + S_i$ HAD PRODUCED A DRAWDOWN RATHER THAN A BUILDUP AT WELL 1P THE VALUES OF TRANSMISSIVITY AND SATURATED THICKNESS USED IN SUBSEQUENT STEPS D THRU F WOULD HAVE BEEN PROPORTIONATELY ADJUSTED DOWNWARD (ie $S_b - S_r + S_i$ EQUAL TO 10 PERCENT OF INITIAL SATURATED THICKNESS THEN DECREASE T AND b BY 10 PERCENT)

D. COMPUTATION OF S_a AT 1P
(FROM THEIS EQUATION OR FIG 39)

FOR $r = 1$ ft
$S_a = 19.9$ FT. (APPROXIMATELY 25 PERCENT OF b)

E. DRAWDOWN DUE TO DEWATERING OF THE AQUIFER S_d
(FROM JACOB EQUATION OR FIG 41)

FOR $S_a = 19.9$ FT
$S_d = 3.4$ FT

F. COMPUTATION OF DRAWDOWN DUE TO PARTIAL PENETRATION.
(FROM KOZENY EQUATION OR FIG 42)

FOR $\alpha = 0.3$
$C_{pp} = 0.45$ $\quad \frac{S_a}{C_{pp}} = 44$ FT
$S_p = 24.1$ FT

G. S_e, ENTRANCE LOSS = 0
(WELL ASSUMED TO BE 100 PERCENT EFFICIENT)

H. TOTAL DRAWDOWN AT HYPOTHETICAL PUMPING WELL 1P

$$S_{total} = S_a + S_d + S_p + S_e + S_i + S_b - S_r$$
$$= 19.9\text{ FT} + 3.4\text{ FT} + 24.1\text{ FT} + 0\text{ FT} + 1.50\text{ FT} + 2.09\text{ FT} - 4.37\text{ FT} = 46.6\text{ FT}$$

MAXIMUM AVAILABLE DRAWDOWN = 56 FT

Figure 43.--Estimation of drawdown in a hypothetical well.

Stratified-drift aquifer depicted with idealized straight-line hydraulic boundaries is tapped by two hypothetical wells (1 and 2P). These wells are 24-in. diameter, are screened in the lower three-tenths (0.3) of the aquifer and discharge at a rate of 400 gpm (77,000 cubic ft per day) each. The initial average transmissivity of the aquifer is 5,000 ft^2/day, the saturated thickness is 80 ft, and the storage coefficient is 0.2. The image well system used to balance the hydraulic boundaries consists of recharging wells (solid circles) and discharging wells (open circles) and extends to a distance where the drawdowns or buildups as measured at well 1P are less than 0.01 ft. Drawdowns are calculated for a pumping period of 200 days.

estimates of well and aquifer yields in selected areas. Quantitative appraisals of well and aquifer yields and the effects of development on the hydrologic system will require detailed site tests. In addition, possible economic and legal constraints are beyond the scope of this report.

Eight areas in the basin underlain by stratified drift are considered favorable for the development of large ground-water supplies. The areas and their estimated long-term yields are shown on plate D and are also listed in table 26. These areas were selected for evaluation because 1) the average transmissivity of the stratified drift is relatively high (greater than 4,000 feet squared per day) and the saturated thickness is at least 40 feet 2) moderate to large quantities of streamflow enter the areas and 3) the aquifers are wide enough to minimize the effects of impermeable-barrier boundaries.

In each area an estimate was made of the total quantity of water potentially available over a long period of time and the proportion of this quantity that can be withdrawn on a sustained basis. Under present management schemes, ground-water withdrawals are relatively constant throughout the year or high during the period of little or no recharge. In addition, the water is generally not returned to the aquifer or stream traversing the aquifer. The ground-water pumpage over a long period of time is therefore limited to the quantity available from natural recharge and induced infiltration from streams.

For the favorable areas in this basin, the quantity of water potentially available is considered to be the sum of 1) the ground-water outflow that is equaled or exceeded 7 years in 10 from the favorable area and also from the adjacent till-bedrock drainage area and 2) the 90-percent flow duration of streams entering the area. The procedure for determining the ground-water outflow is contained in the section titled "Amount and variability of natural recharge." The 90-percent flow duration of streams entering a favorable area can be determined by the methods described in the section titled "Variations in streamflow."

The ground-water outflow and streamflow parameters selected as the quantity of water potentially available limit the stress on a stream-aquifer system. Withdrawal of this amount of water under the present management scheme would dry up an adjacent reach of stream approximately 10 percent of the time and would not result in a long-term decrease in ground-water storage. Alternative management schemes, that utilize low-flow augmentation, artificial recharge, or increased withdrawal rates during periods of high streamflow would require different estimates of the total quantity of water potentially available.

The proportion of potentially available water that can be withdrawn on a sustained basis was computed by use of methods discussed in the sections of this report entitled "Estimating well yields," "Estimating drawdown," and "Induced infiltration." The hydraulic boundaries of the stratified-drift aquifer underlying each favorable area were idealized as straight lines, and the average transmissivity within these boundaries was computed.

Favorable areas A, C, D, and G are traversed by fairly large perennial streams, which would most likely constitute line-source boundaries under conditions of development. Because the effectiveness and position of these line-source boundaries are uncertain, two analytical models were made for these areas. In one model the stream was treated as fully penetrating, and a line-source boundary was positioned approximately coincident with the stream. A second model contained only impermeable-barrier boundaries. The long-term yields corresponding to the two models represent estimated maximum and minimum values for each area.

Hypothetical wells were located in the thickest and most transmissive sections of the aquifers and as close as feasible to any streams. The hypothetical wells, with the exception of those in favorable area H, are all 24-inch diameter, are screened in the lower three-tenths (0.3) of the aquifer, and are 100 percent efficient. In area H, two real wells (DY 36 and 37) rather than hypothetical wells, were utilized. The construction characteristics of these real wells are given in the companion basic-data report (Melvin, 1970, p. 8). For all areas, the ratio of vertical to horizontal conductivity (K_v:K_h) is assumed to be 1:10, and the long-term storage coefficient is 0.2.

The total drawdown in either real or hypothetical wells resulting from constant pumping over a 200-day period of little or no recharge was computed. An example of drawdown computation is shown on figure 43. The maximum withdrawal rate that the aquifer as modeled could sustain without 1) producing excessive drawdown in the wells at the end of 200 days, or 2) exceeding the total quantity of water potentially available is the estimated long-term yield. During the yearly 165 days of recharge the aquifer is assumed to be capable of sustaining the long-term yield without drawing water levels below the top of the well screen.

The long-term yields would be sustained by a combination of the capture of ground-water outflow and induced recharge from streams. It is assumed that the wells, as situated in the various models, could capture at least 75 percent of the ground-water outflow equaled or exceeded 7 years in 10. The additional amount of water required to sustain the long-term yield would come from the streams by induced infiltration. To determine if the required rate of induced recharge is reasonable, values of stream length, width, and depth measured at low flow were substituted into the equation $R = I_t S_r A_r$. (See section titled "Induced infiltration.") The average infiltration rate per foot of streambed (I_t) necessary was computed and compared with known values for similar streambed materials. All computed rates were lower than the known values, and the anticipated recharge by induced infiltration is, therefore, considered to be reasonable.

TILL

Till was a major source of water for domestic and farm supplies but has been largely supplanted by crystalline bedrock. Inadequate yields with respect to modern requirements, the susceptibility to pollution, and the economic ability of homeowners to pay for drilled bedrock wells are the principal reasons for the general abandonment of till as an aquifer.

The hydraulic conductivity of till is low, and the saturated section is generally thin and variable. Laboratory values of the hydraulic conductivities of till in other parts of southern New England (Randall and others, 1966; Allen and others, 1966; Sammel and others, 1966; Baker and others, 1964) ranged from 0.01 to 41 feet per day.

Areas in the basin where till is known or inferred to be at least 40 feet thick have been delineated on plate B. These relatively thick accumulations of till are significant in that 1) if located in areas where the water table is near the land surface they may be tapped by shallow wells for small water supplies 2) one can estimate the depth to the underlying bedrock aquifer before drilling a well and 3) such areas may in the future be suitable for certain types of subsurface waste disposal.

CRYSTALLINE BEDROCK

In areas not served by a public water supply, most homes and commercial establishments depend on wells that tap crystalline bedrock. A brief description of the extent, composition, and hydrologic characteristics of this aquifer is given in the section titled "Hydrologic Framework." The quantity of water that may be pumped continuously from a well in bedrock is dependent on the amount of recharge the aquifer receives and the rate at which it transmits water to the well. Natural recharge, derived from precipitation on the till-bedrock uplands, is estimated to average 7 inches a year. Under conditions of development, additional recharge may be derived from overlying saturated till and stratified drift or from nearby surface-water bodies. Some recharge may also result from disposal of septic wastes to the ground.

The rate at which water will move through crystalline bedrock under a given hydraulic gradient is dependent on several factors. The water circulates through secondary openings collectively termed fractures, and the rate of water movement is a function of the distribution, orientation, size, spacing, continuity, and degree of interconnection of these of these fractures. In turn, the fracture pattern is related to the type of rock, the geologic history, and the topography.

Development of a water supply

The most frequently asked questions concerning crystalline bedrock aquifers are:

1. How much water will a well yield?

2. How deep must a well be?

3. Where is the best place to drill?

Exact answers to these questions are not possible because answers are dependent on several interrelated factors. For example, the yield of a well is in part governed by the number and size of water-bearing fractures that it intersects, which, in turn, may be a function of rock type; thickness of saturated rock penetrated; topographic position; and depth to the water table. Statistical answers, however, such as "75 percent of the bedrock wells yield at least 3.5 gpm" can be given.

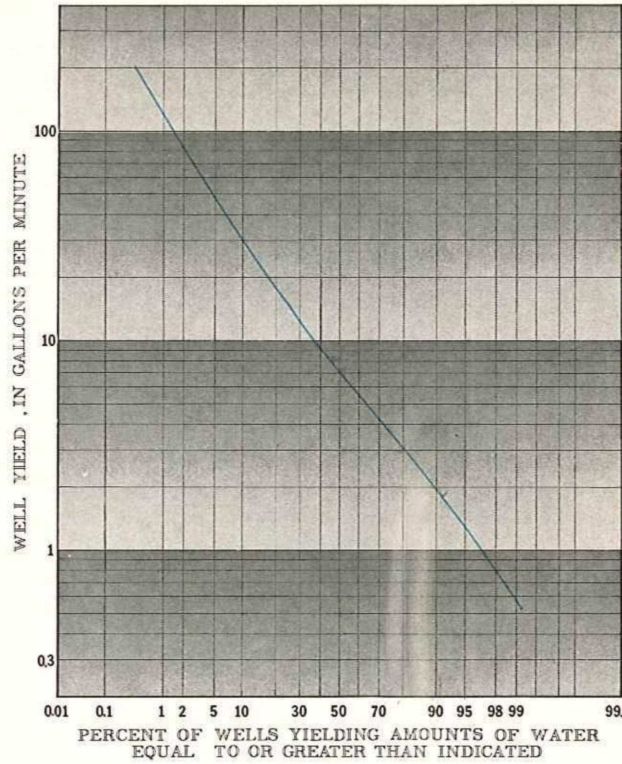


Figure 44.--Cumulative-frequency distribution of yields from wells tapping bedrock.

Records of 734 wells were selected from those available to evaluate the frequency distribution of yields from crystalline bedrock. These wells are all 6 or 8 inches in diameter and were drilled by the cable-tool or air-percussion method. They differ in the thickness of saturated bedrock penetrated, topographic position, type of bedrock, and type of overburden. Wells in which more than 35 feet of the upper part of the bedrock was unsaturated or cased off and those tapping weathered bedrock were excluded.

The cumulative frequency distribution of the yields of the bedrock wells is shown on figure 44. From this figure it can be seen that the reported yields range from less than 1 to 200 gpm, also that 50 percent of the wells yield 7 gpm or more and 95 percent yield more than 1 gpm. The frequency distribution shown on figure 44 is similar to that of crystalline bedrock well yields in the adjacent lower Housatonic River basin (Wilson and others, written communication).

To estimate the optimum depth of a bedrock well, it is instructive to compare the yields of wells that penetrate different thicknesses of saturated bedrock. Ellis (1909) observed that the distribution of water-bearing fractures differs from place to place and that they diminish in size and frequency with increasing depth. Accordingly, the yields of wells penetrating equal thicknesses of bedrock will vary considerably, but at a given site the yield should increase as a well is drilled to greater depth. The rate at which the yield increases however should become progressively smaller with depth.

A sample of 824 well records from the basin (the 734 wells used on figure 45 plus 90 others) was selected to examine the relationship between yield and thickness of saturated uncased bedrock penetrated. The wells were divided into 11 classes, each class containing those wells that terminate in the same depth interval. For example, wells that penetrate between 51 and 75 feet of saturated uncased bedrock are grouped in the same class. The statistical summary of the data is shown on figure 45 and confirms the areal variability of fracture distribution in that yields within each class interval differ considerably. The progressively lower median yields with increasing depth suggest that many of the deeper wells in the basin were drilled at sites where the upper part of the bedrock was unproductive. The data on figure 45, however, cannot be used to predict the additional quantity of water that will be obtained by drilling a well to greater depths. It does show, for example, that from 10 to 90 percent of the wells penetrating from 101 to 125 feet of saturated uncased rock yield from 2.5 to 35 gpm, whereas wells penetrating 301 to 400 feet yield 0.5 to 15 gpm. If 20 gpm is not obtained after tapping 125 feet of saturated rock, the probability of obtaining this yield by drilling deeper seems to become progressively less.

Fracture patterns of bedrock, and, consequently, well yields, are a function of rock type, geologic history, and topography. An attempt to evaluate the relationship of rock type to well yield, is shown on figure 46. The evaluation was made because of the large amount of carbonate bedrock in the basin, a rock type present only in a few other small parts

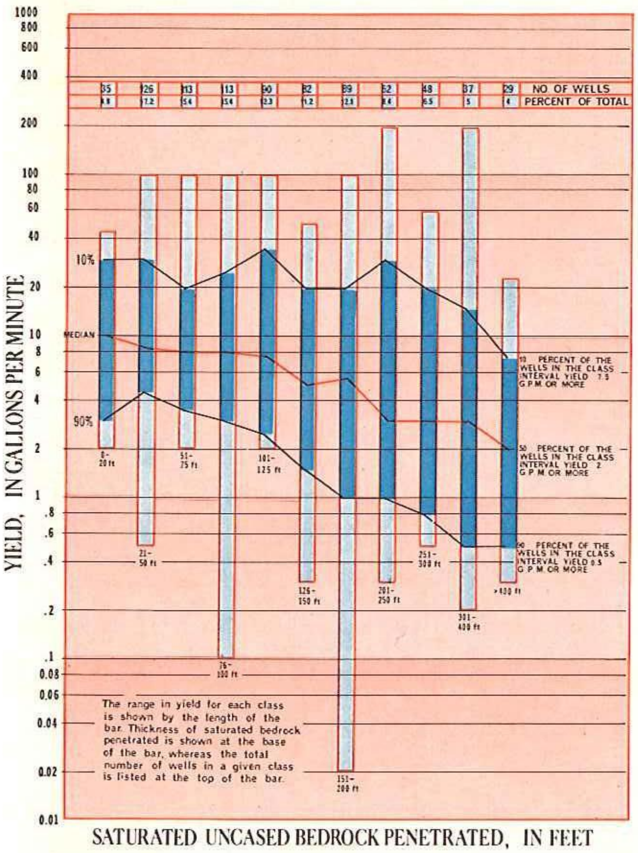


Figure 45.--Summary of yields of wells tapping various thicknesses of saturated uncased bedrock.

of Connecticut. In addition to that for carbonate bedrock, the frequency distribution of well yields for noncarbonate rocks is shown on figure 46. The noncarbonate rocks are subdivided into granular (gneiss, granite, diorite, and related rocks) and schistose (schist, phyllite, and related rocks) varieties. The general distribution of carbonate bedrock is shown on figure 49. Detailed descriptions and maps of various crystalline rocks in the basin are contained in maps and reports by Rodgers and others (1959), Gates (1951, 1952, 1959, 1961), Gates and Christensen (1965), Clarke (1958), Zen and Hartshorn (1966), and Prucha and others (1968).

The cumulative frequency distributions of well yields on figure 46 indicate that carbonate bedrock is significantly more productive than the noncarbonate rocks and that the schistose rock type is the least productive. This evaluation, like previous studies that have attempted to relate well yields to factors such as rock type and topography (Ellis, 1909, Cushman and others, 1953, Thomas and others, 1967), cannot be considered conclusive. Yield-affecting factors are interrelated, and the effect of rock type cannot be completely isolated from topographic position, type and thickness of overburden, and depth of saturated bedrock penetrated.

WEATHERED CRYSTALLINE BEDROCK

Weathered crystalline bedrock of both the carbonate and noncarbonate type underlies a few small parts of the basin. The extent and thickness of this semiconsolidated material cannot be delineated. The area of largest known extent consists of a nearly 2,000-foot-long section of undetermined thickness exposed in Shepaug Aqueduct Tunnel near Bantam, Connecticut (Agar, 1927, p. 35). In other parts of Connecticut, wells in weathered crystalline bedrock yield more water than those tapping nonweathered rock. Ryder and others (1970, p. 26) state that weathered carbonate bedrock can yield as much as 200 gpm to individual drilled wells. Seventeen wells in the upper Housatonic River basin believed by the authors to tap weathered bedrock yield 3.5 to 36 gpm. In most of these wells however a large proportion of the weathered rock was cased off to prevent caving.

QUALITY OF GROUND WATER

The quality of ground water in the upper Housatonic River basin is influenced by both natural and man-related conditions. Natural factors that influence its chemical quality include 1) chemical content and pH of precipitation; 2) mineral and organic composition of the soil and the associated cover of organic debris (leaf mold and decaying vegetation); and 3) mineral composition of the aquifers. Man-made factors include contamination by domestic sewage, animal waste, chemical fertilizers and road salt. The major constituents dissolved in ground water in the basin are silica, calcium, magnesium, bicarbonate, and sulfate; most of these are in ionic form and represent various combinations of calcium and magnesium bicarbonate and calcium and magnesium sulfate. Calcium is predominant, and ground water in the area is of the calcium bicarbonate or calcium sulfate type. This classification is based upon a comparison of the equivalent weights of bicarbonate and sulfate in the water samples. Water that approximately equal bicarbonate and sulfate equivalent weights is

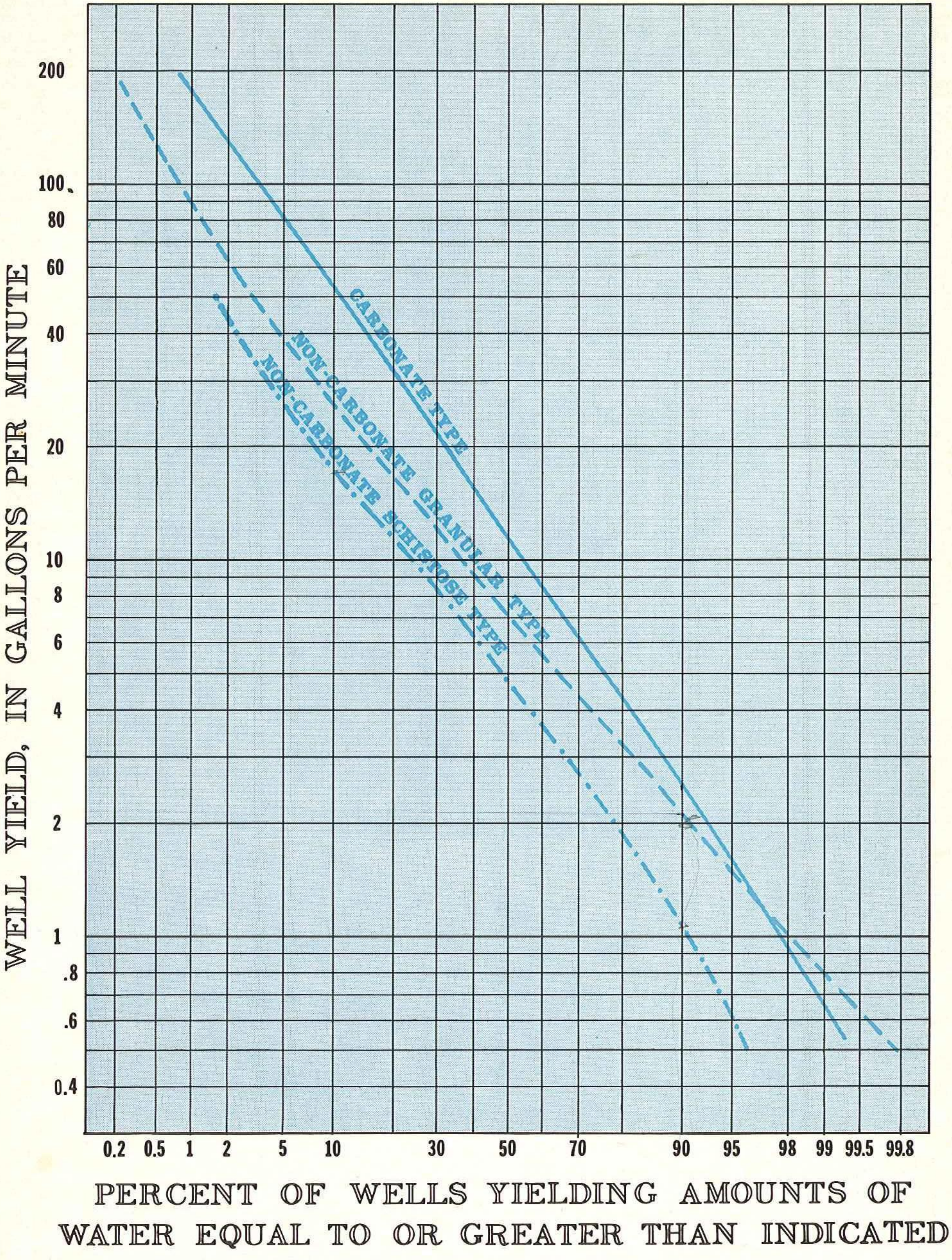


Figure 46.--Cumulative-frequency distribution of yields from wells tapping carbonate, noncarbonate granular, and noncarbonate schistose types of crystalline bedrock.

classed as intermediate. The following table summarizes the comparison of calcium bicarbonate versus calcium sulfate type water for the main aquifers of the basin.

Water type	Aquifer: Stratified drift (58 samples) percent	Carbonate bedrock (27 samples) percent	Noncarbonate bedrock (76 samples) percent
Calcium bicarbonate	97	100	82
Calcium sulfate	0	0	9
Intermediate	3	0	9
Percent (total)	100	100	100

The predominance of water of the calcium bicarbonate type in the basin is an asset; such water tends to be less acidic and has a lower hardness than water of the calcium sulfate type. As a result, distribution systems carrying water of the calcium bicarbonate type are less likely to fail through corrosion and less likely to be plugged by hard scale, which is difficult to remove.

The quality of the ground water in the basin may change over a period of time especially in the shallow stratified-drift aquifers. Figure 47 shows such changes in chloride, nitrate, iron, and dissolved solids for water from three wells in stratified drift during a 6-month period ending in May 1967. The wells were nearly unused; therefore, all samples are believed by the authors to show the chemical quality of the undeveloped aquifer. Figure 47 shows that in some places water-quality parameters remained constant throughout the period (for example, hardness of water from well NOC 15). In other places, the quality varied considerably. The increase in chloride content of water from well NOC 16 from 4 to 14 mg/l during a 4-month time span is an example. Water from this well also increased in hardness from about 140 to 170 mg/l in 1 month. The figure also shows the variation in iron content of water from the three wells. Soluble iron is released both to surface water and ground water during natural reducing processes associated with vegetal growth and decay cycles. The variations in iron concentration shown by the monitored wells may reflect such a seasonal pattern.

The wide ranges of iron concentrations in water from wells NOC 16 and SY 16 probably result from natural processes. Chloride fluctuations in water from wells NOC 15 and NOC 16, on the other hand, probably result from the use of salt for winter road maintenance. Either condition indicates that periodic sampling of water in the stratified-drift aquifer may be required to delineate the overall quality in the area.

DIFFERENCES RESULTING FROM SOURCE MATERIALS

The natural chemical quality of ground water in the upper Housatonic River basin is largely influenced by the mineral composition of the aquifers. The chemical quality of water in stratified drift may reflect both the mineral composition of the drift and that of the underlying bedrock. In places, the drift is composed of material derived from a bedrock unit of different mineral composition; thus, the composition of the drift differs from that of the underlying bedrock. Accordingly, the chemical quality of water from the drift may be quite different than that from the bedrock.

The gneiss and schist, which constitute the bulk of the noncarbonate bedrock, generally yield water of good quality with moderate amounts of dissolved solids and with hardness averaging less than 100 mg/l. The carbonate bedrock commonly yields water that has significantly more dissolved solids and is harder than that from areas of noncarbonate rock. As previously indicated, water exceeding 180 mg/l in hardness commonly requires softening for most purposes; 70 percent of the carbonate bedrock wells sampled produced water that would require treatment. A summary of the chemical characteristics of water from the major aquifers of the basin is shown in table 22.

Table 22.--Summary of chemical and physical characteristics of ground water in the upper Housatonic River basin

(Chemical constituents in milligrams per liter)

Type of aquifer and no. of samples	Range	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na+K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Nitrate (NO_3)	Dissolved solids (residue on evaporation at 180°C)	Hardness, as $CaCO_3$: Calcium, magnesium	Hardness, as $CaCO_3$: Non-carbonate	Specific conductance (micromhos at 25°C)	pH
Stratified drift (29 wells)	Maximum	15	2.1	0.59	87	37	67	372	178	92	25	513	365	136	836	8.1
	Minimum	3.0	0.00	.00	9.8	2.9	0.9	26	7.2	0.3	0.0	60	36	0	95	6.7
	Median	8.8	.06	.04	44	19	8.5	195	23	8.0	1.0	237	190	25	387	7.7
Carbonate bedrock (27 wells)	Maximum	14	3.4	.23	92	39	21	342	74	72	16	496	378	98	779	8.1
	Minimum	2.3	.00	.00	16	1.4	.7	82	8	.9	0	84	76	0	154	7.1
	Median	9.0	.06	.01	54	25	5.8	246	23	8.0	4.6	275	230	30	476	7.7
Noncarbonate bedrock (76 wells)	Maximum	23	1.0	.65	71	26	31	269	178	78	39	404	264	127	623	7.9
	Minimum	5.0	.00	.00	3.6	1.2	1.6	11	3.2	.8	0	34	15	0	46	6.4
	Median	13	.09	.02	24	6.8	8.5	88	19	5.4	.6	136	85	14	220	7.4

IRON AND MANGANESE

Iron and manganese are dissolved in most ground water in the upper Housatonic River basin. In low concentrations, they are of little consequence, but in moderate to high concentrations, they are of major importance. Iron and manganese are in solution in ground water as the ferrous iron; the ferric ion is relatively insoluble. When water containing bicarbonate is withdrawn from an aquifer, the soluble ferrous iron is oxidized to form ferric hydroxide, which precipitates as a reddish brown flocculate. This precipitates discolors clothing, porcelain fixtures, and any item in prolonged contact with the water. In addition, the oxidation of ferrous iron removes bicarbonate ions from solution and lowers the pH. Where iron-rich ground water is in extended contact with air, such as in vent pipes and storage tanks, corrosive water may be a serious problem. The chemical activity of manganese is similar to that of iron except that its precipitate is gray or black. The manganese precipitate is often masked by the color of the more abundant iron precipitate.

Stratified drift, which has a high potential for ground-water development, also has the greatest number of problems with excessive iron and manganese. Water from 27 percent of the wells tapping stratified drift had excessive iron concentrations, and water from 50 percent had excessive manganese concentrations, as shown in table 23.

Table 23.--Iron and manganese in ground water related to type of aquifer or bedrock underlying aquifer

	Aquifer				
	Stratified drift			Bedrock	
	Underlain by carbonate bedrock	Underlain by noncarbonate bedrock	All stratified drift combined	Carbonate	Noncarbonate
No. of wells sampled	22	8	30	27	76
Percent of wells sampled with water containing:					
Iron greater than 0.3 mg/l 1/	18	50	27	7	18
Manganese greater than 0.05 mg/l 1/	50	50	50	7	30
Maximum concentration:					
Iron (mg/l)	3.5	2.1	3.5	3.4	1.0
Manganese (mg/l)	.59	.26	.59	.23	.65

1/ Limit recommended for drinking water by the U.S. Public Health Service (1962).

Iron and manganese concentrations in water from stratified drift are frequently troublesome even in areas underlain by carbonate bedrock because most of the stratified drift is derived from upland regions consisting of noncarbonate bedrock. Table 23 contrasts iron and manganese concentrations in stratified drift underlain by carbonate and noncarbonate bedrock.

Bedrock in the upper Housatonic River basin is the source of the iron and manganese in the ground water. The noncarbonate rocks, especially schist, are the chief contributors of these elements. Table 23 shows the percentage of wells sampled in carbonate and noncarbonate bedrock producing water that equaled or exceeded the U.S. Public Health Service drinking water standards of 0.3 mg/l iron and 0.05 mg/l manganese.

Areas in the basin with an average or greater-than-average probability of yielding ground water with excessive iron or manganese concentrations are shown on figure 48. In three of these areas (A, B, and C) the troublesome concentrations are in water from bedrock. In the fourth area, (D), the high concentrations are in water from stratified drift. A brief discussion of each problem area is given below.

Area A is in the northwest corner of the basin in the towns of Salisbury and Sharon. The bedrock believed by the authors to be the source of iron and manganese is a schist unit associated with the old Salisbury iron district, where small bodies of ore were once mined. Chemical analyses of water from a formation of similar lithology in Massachusetts (Berkshire Schist), show significantly high values of iron and manganese (Norvitch and Lamb, 1966). Water from all three of the wells sampled showed iron or manganese concentrations above the U.S. Public Health Service recommended limits. Wachocastinook Creek, which drains a large part of Area A also showed an extremely high manganese concentration (4.6 mg/l), when sampled under low-flow conditions.

Area B lies along the Goshen-Cornwall boundary and extends south into the town of Litchfield. The bedrock underlying the area is a large body of gneiss composed of at least four rock types. The rock unit responsible for the iron- and manganese-rich ground water in the area is probably a local one within the larger gneiss body. Of the seven ground-water sites sampled in area B, six yielded water that exceeded the U.S. Public Health Service recommended limits for iron and manganese. Ground water from other areas underlain by the same gneiss unit, especially to the south and west of area B, has generally low concentrations of these elements.

Area C is located along the central part of the eastern drainage divide of the basin and includes parts of the towns of Goshen, Litchfield, Morris, Roxbury, and Washington. The bedrock probably responsible for the excessive iron and manganese is part of a large formation composed primarily of quartzite, schist, and gneiss. In the adjacent lower Housatonic River basin, high concentrations of iron and manganese are also associated with parts of the same formation (Wilson and others, written communication). In area C, 8 of 11 bedrock wells sampled yielded water that exceeded the U.S. Public Health Service recommended limits for iron or manganese.

Area D is in the upper Still River valley and includes part of the town of Bethel and the area east of the city of Danbury. The high iron and manganese concentrations of the water here are primarily caused by the stratified drift. Of the eight stratified-drift wells that were sampled, six yielded water having excess iron or manganese. Excessive concentrations in water from the area probably do not originate in the bedrock, even though two of three bedrock wells yielded water with excessive concentrations. Much of the area is underlain by carbonate bedrock that is commonly low in iron and manganese. (See table 23.) However, the two main waterways of the area, Still River and Sympaug Brook, carry industrial wastes, and they may contribute to water pumped from riverside wells. Fluctuations in pH and high iron and manganese concentrations in these streams may

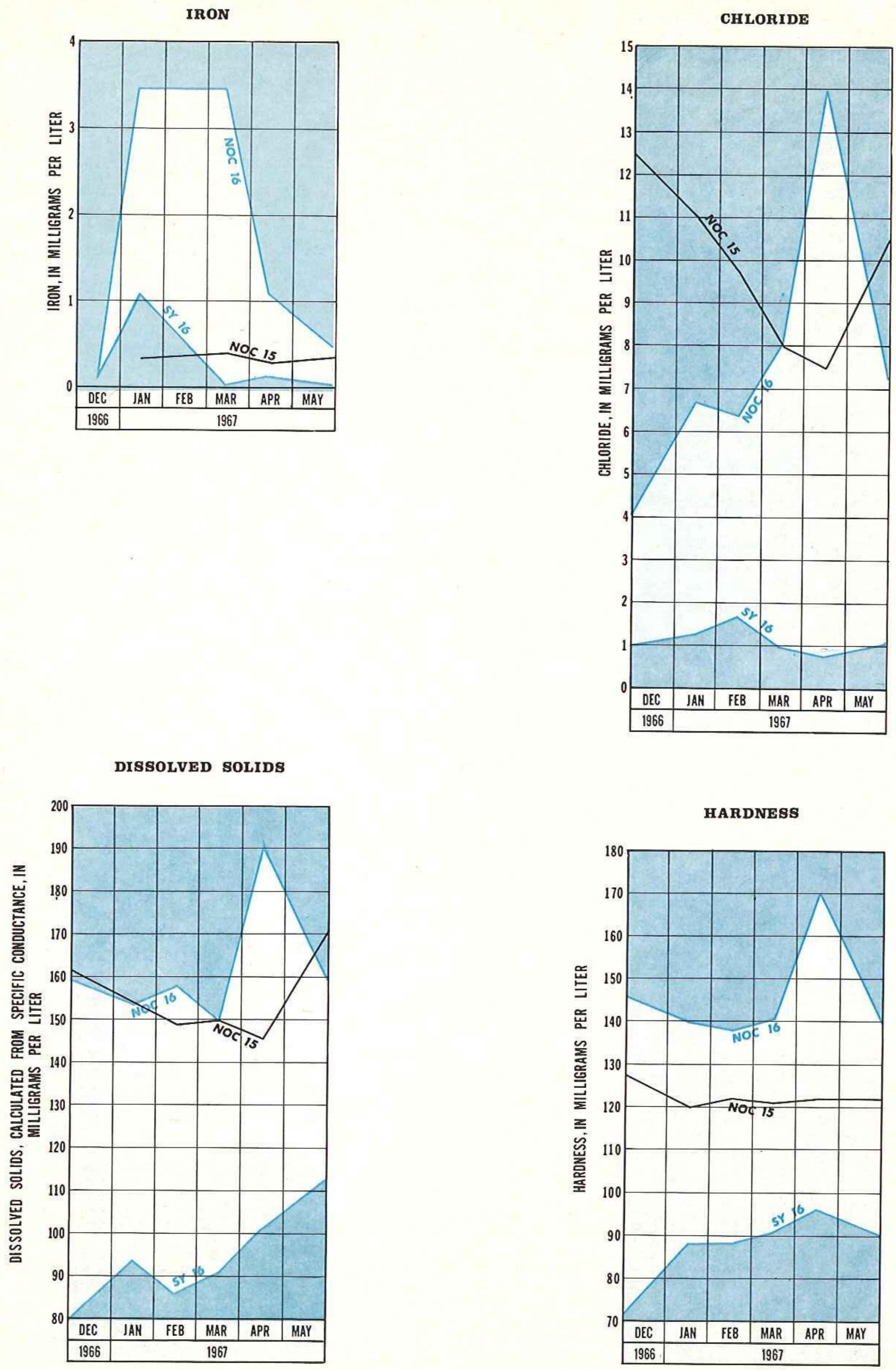


Figure 47.--Changes in quality of water from three wells tapping stratified drift in the upper Housatonic River basin.

(Monthly values of dissolved solids, hardness, chloride, and iron from December 1966 to May 1967)

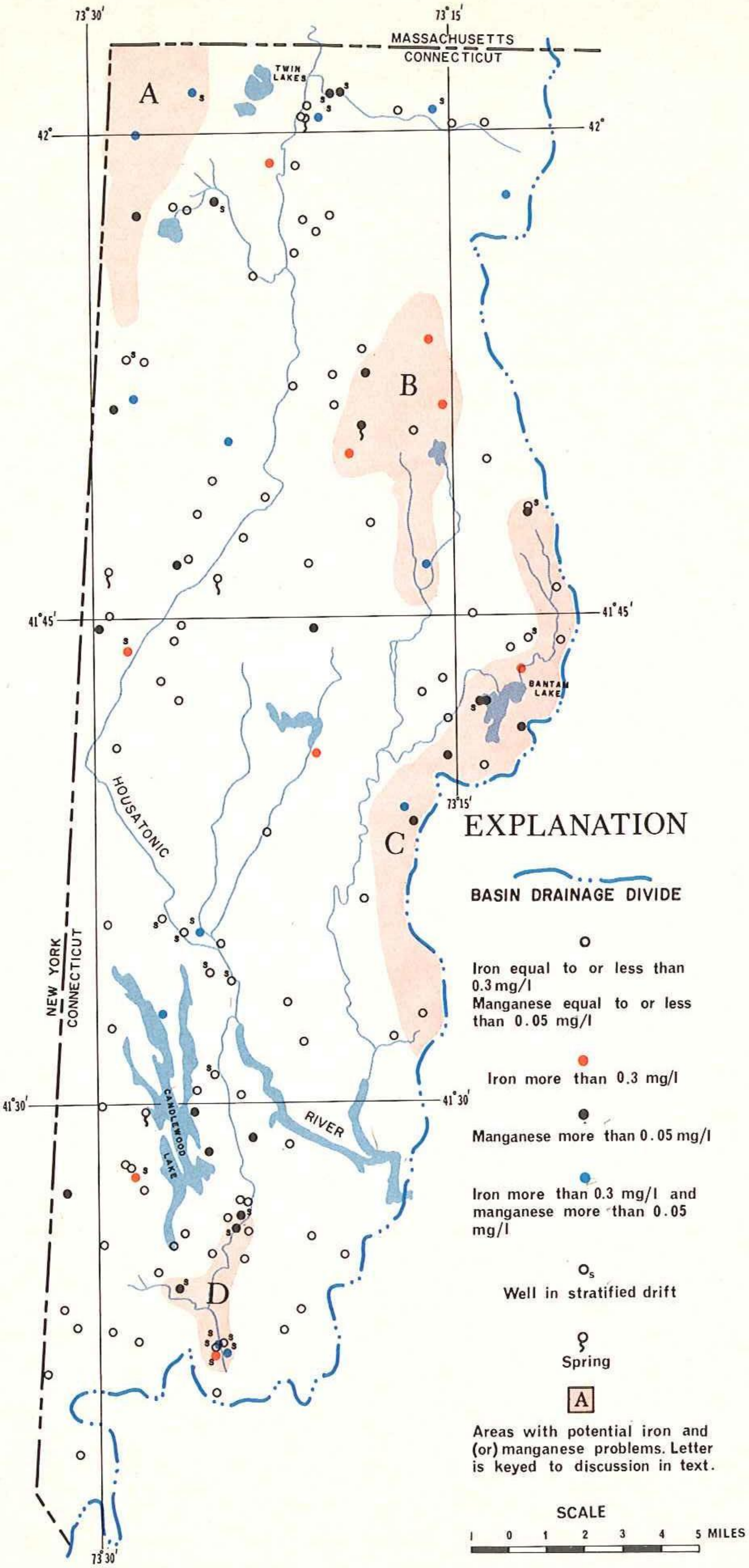


Figure 48.--Distribution of iron and manganese in ground water in the upper Housatonic River basin.

increase the iron and manganese concentrations of water from wells pumping at rates high enough to induce infiltration from the streams.

HARDNESS

In the upper Housatonic River basin, as elsewhere, hardness of ground water is dependent upon the mineral composition of the aquifer. The hardness of water from the stratified-drift, carbonate, and noncarbonate aquifers is summarized in the following table. A table giving ranges of hardness of water and resultant suitability is in the section titled "Quality of water in streams and lakes."

	Aquifer		
	Stratified drift	Carbonate bedrock	Noncarbonate bedrock
Number of wells sampled	29	27	76
Hardness, as $CaCO_3$, in mg/l			
Maximum	365	378	264
Minimum	36	76	15
Median	194	230	85
Percent of wells producing water rated as:			
Soft: 0-60 mg/l	7	0	20
Moderately hard: 61-120 mg/l	24	15	50
Hard: 120-180 mg/l	10	22	13
Very hard: 181 or more mg/l	59	63	17

As the table indicates, ground water in the basin commonly is moderately hard to very hard. The probability of obtaining soft water from stratified drift or carbonate bedrock is small, whereas the probability of obtaining very hard water from these aquifers is more than 50 percent. Of the 29 wells in stratified drift that were sampled, 59 percent yielded water with hardness in excess of 180 mg/l. This is significant in view of the fact that only stratified drift can yield large supplies of water to individual wells. It is clear that the chemical quality of ground water, especially its content of iron and manganese and its hardness, will be important aspect of any future planning for large supplies from the aquifers in the basin.

The mineral composition of the underlying bedrock significantly affects the hardness of water obtained from stratified drift. In areas underlain by noncarbonate bedrock, water from eight wells tapping stratified drift had a median hardness of 91 mg/l. By contrast, in areas underlain by carbonate bedrock, samples from 21 wells tapping stratified drift, had a median hardness of 204 mg/l.

Differences in hardness of ground water in the basin are shown on figure 49. Hard to very hard water is obtainable throughout the basin. However, where carbonate bedrock underlies an area, the probability of obtaining very hard water from either bedrock or from stratified drift is more than 60 percent. Of the 49 wells sampled in areas of carbonate rock, two out of three produced water with a hardness exceeding 180 mg/l. Several scattered wells tapping noncarbonate bedrock also produced water with hardness exceeding 180 mg/l. Many of the noncarbonate rocks contain small amounts of carbonate and calc-silicate rock (Rodgers and others, 1959). These minerals probably account for the excessively hard water in the areas of noncarbonate rocks. Stratified-drift aquifers in areas underlain by carbonate bedrock are the most productive in the basin. Because ground water from these areas is likely to be very hard, plans for large-scale development should consider practical methods for softening or dilution. Dilution with softer surface-water supplies may involve induced recharge of surface water. The effect of induced recharge on quality is discussed in a following section.

In areas of noncarbonate bedrock, ground water is generally soft to moderately hard. The median hardness from such areas was 85 mg/l for water from the bedrock wells and 91 mg/l for water from the stratified-drift wells. Of the eight stratified-drift wells sampled in these areas only 1, LF 51, situated north of Bantam Lake (see pl. A), had water with hardness in excess of 180 mg/l.

NITRATE AND CHLORIDE AS INDICATORS OF POSSIBLE POLLUTION

Under natural conditions, most ground water in the upper Housatonic River basin has low nitrate and chloride concentrations. Excessive concentrations of either of these constituents suggest contamination by domestic sewage, animal wastes, chemical fertilizers, or road salt. The following table summarizes the nitrate and chloride content of 132 water samples from the aquifers of the basin.

Aquifer
(All chemical values in mg/l)

	Stratified drift (29 wells sampled)		Carbonate bedrock (27 wells sampled)		Noncarbonate bedrock (76 wells sampled)	
	nitrate	chloride	nitrate	chloride	nitrate	chloride
Maximum	25	92	16	72	39	78
Minimum	0	0.3	0	0.9	0	0.8
Median	1.0	8.0	4.6	8.0	0.6	5.4

Water from only 12 of these wells, representing less than 10 percent of those sampled, had nitrate concentrations greater than 10 mg/l. A nitrate level above 10 mg/l does not necessarily mean a well is contaminated. However, if it has a concentration higher than the "background" level, the possibility of contamination from septic-tank effluent or fertilizers should be investigated.

Nitrate nitrogen is the most completely oxidized form of nitrogen commonly found in a water supply; it is an end product in the decomposition cyle of nitrogenous waste material. Other less completely oxidized forms of nitrogen, such as nitrite, ammonia, and albuminoid, are more reliable indicators of pollution from sewage. These forms of nitrogen are normally determined in a "sanitary" analysis. In low concentrations, nitrate in drinking water is not hazardous to health. Cyanosis resulting from methemoglobinemia may occur in infants if drinking water contains high concentrations (45 mg/l or more) of nitrate. None of the wells sampled in the upper Housatonic River basin yielded water exceeding this limit.

The chloride ion is not toxic in the concentrations normally found in natural ground water in the basin; 6.6 mg/l was the median concentration for

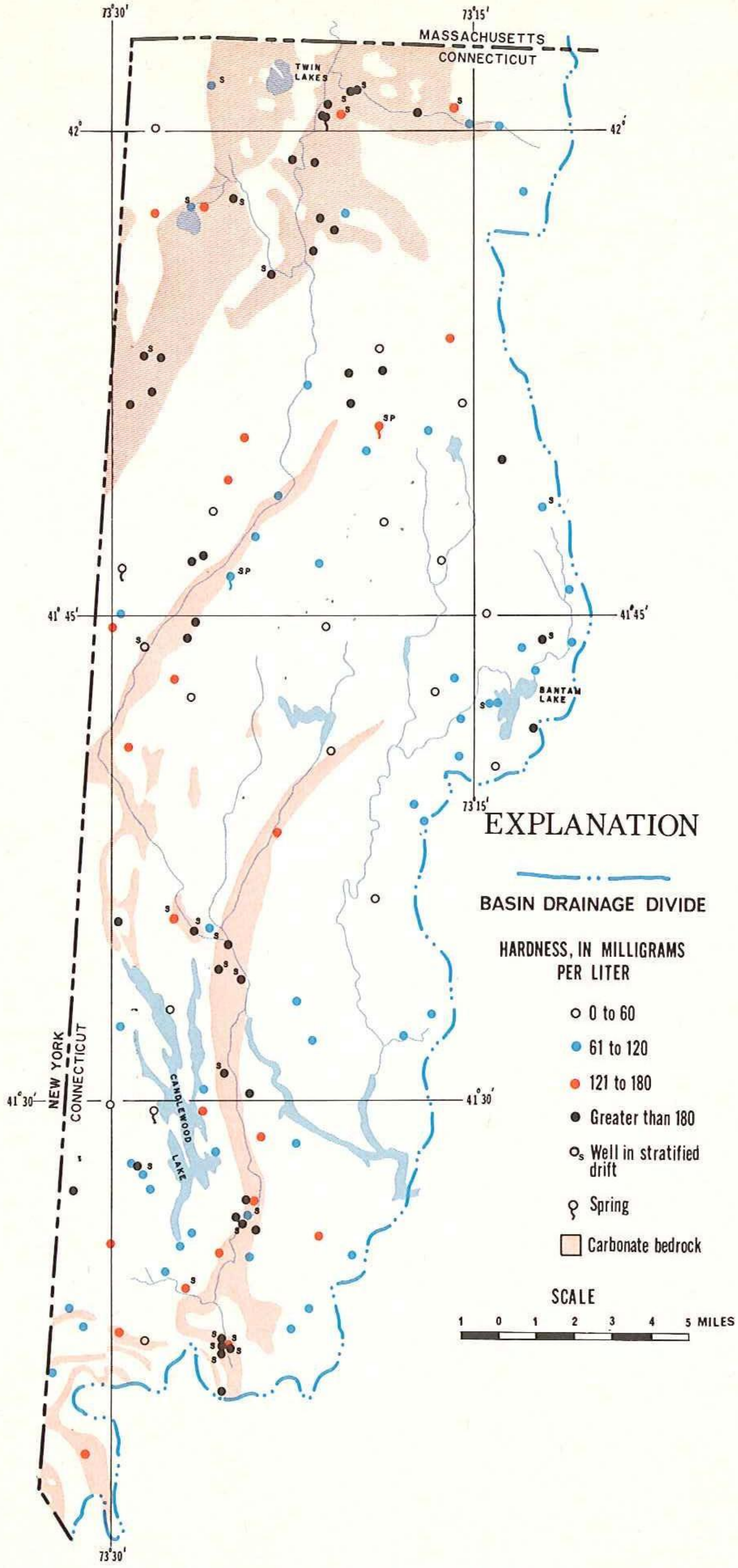


Figure 49.--Distribution of hardness in ground water in the upper Housatonic River basin.

water from 132 wells sampled. Concentrations in excess of 20 mg/l indicate some outside source of chloride. Chloride and nitrate largely remain in solution in ground water, so that anomalously high levels may be indicators of potential contamination.

Of the 132 wells sampled, 25, or about 19 percent, yielded water that exceeded 20 mg/l chloride. A comparison of chloride content of water from each of the major types of aquifers in the basin is shown in the following table.

	Aquifer		
	Stratified drift	Carbonate bedrock	Noncarbonate bedrock
No. of wells sampled	29	27	76
Percent of wells sampled which exceeded 20 mg/l chloride	14	30	21

More than 20 mg/l chloride in a sample does not necessarily mean the water is contaminated with sewage. Chloride in ground water in excess of natural amounts can be the result of the use of salt on the roads in winter or the regeneration (backflushing) of ion exchange water-softening units.

EFFECT OF INDUCED RECHARGE

When a well near a surface-water body is pumped, so that the natural hydraulic gradient toward the body is reversed, surface water is drawn into the aquifer. Water from such a well is a mixture, and its quality is intermediate between that of ground water and surface water. The quality of the unmixed waters and their relative amounts chiefly determine the quality of the resultant mixture.

In the upper Housatonic River basin, as elsewhere in Connecticut, surface water is generally less mineralized than ground water. Thus, induced infiltration normally results in an improvement in the quality of the water withdrawn. However, in areas where streams are contaminated, industrial wastes may comprise a significant part of stream discharge. During low flow, such streams may contain more dissolved matter than natural ground water, and the quality of induced recharge may deteriorate correspondingly. Such seasonal deterioration in water quality is restricted to a short period each year. However, even temporary changes in water quality may result in long lasting undesirable consequences, such as screen encrustations, rapid casing failure, and shortened pump life.

The unconsolidated materials lining the stream act as large filters during periods of induced recharge. These materials, chiefly silt, sand, and gravel, remove nearly all the bacteria, turbidity, and suspended solids from water as it moves from stream or lake to the aquifer. Dissolved constituents, organic and inorganic, rarely are removed by streambed filtration. Some may be adsorbed by clay minerals in the streambed, but most pass directly into the aquifer. Ions discharged by many industrial processes, principally those of copper, zinc, chromium, and lead, pass directly into the aquifer.

Ground water has a narrower annual temperature range than surface water. A consequence of induced recharge is the increase in seasonal range of water temperature resulting from infiltration of surface water into the aquifer. The change in temperature range attributable to induced recharge depends upon the annual temperature range of the recharging surface-water body and the proportionate amount it contributes to water pumped from the well. Seasonal maximum and minimum ground-water temperatures lag behind corresponding maximum and minimum surface-water temperatures (Schneider, 1962, p. B-4).

WATER USE - PRESENT AND FUTURE

USE IN 1967

The total amount of water used in the upper Housatonic River basin report area during 1967 is estimated to have been 6,360 million gallons. This is equivalent to an average of approximately 140 gpd per capita. Domestic and institutional use accounted for two-thirds of all water, and more than half of this large fraction was from public supplies. Industries obtained more than half of their water from privately owned surface sources; 97 percent of industrial use was for processing and cooling water. Agricultural use amounted to 3 percent of the total in the basin; all of it from private sources.

The source, use, and disposal of water in the upper Housatonic River basin are summarized on figure 50. The data on which this figure is based were supplied by water utilities, major industrial firms, and State agencies. Privately owned domestic use was computed by multiplying an estimated per capita use of 70 gpd by the total population not served by public systems. Agricultural use consisted chiefly of water to supply dairy cows, poultry, and other livestock in the basin. Little water was used for irrigation. The actual quantity of water disposed to public sewage-treatment plants was probably lower than that estimated; some sewage-treatment facilities in the basin were overloaded at times and effluent bypassed these facilities. A few communities or parts of communities had no sewage treatment during the period of this study. Pollution abatement pursued by the Connecticut Water Resources Commission under Public Act 57 of 1967 should improve these conditions.

Fifteen public and institutional systems supplied water for nearly half the population of the basin in 1967. They also provided about 30 percent of the water used by industry that year. The sources of water, system capacities, types of treatment, population served, and other important features of these major systems are listed in table 24. Plate C shows the general area served by each of these principal systems and the location of the water sources.

The major water systems listed in table 24 generally supply soft to moderately hard water with low dissolved-solids content. Chemical analyses of samples from 14 of these 15 systems are shown in table 25. In general the water is of good chemical quality and is well within the standards suggested by the U.S. Public Health Service. Iron and manganese and color vary considerably with time, and the few high concentrations shown in table 25 are considered to be exceptional. Such variations are more common in water from a surface supply. They may also be the result of some localized conditions.

FUTURE USE

State projections of population and water consumption to the year 2000 (Connecticut Development Commission, 1963a, 1963b) cover all the southern half and much of the northern half of the report area. These projections indicate a doubling of population with an increase of more than 220 percent in water use in the "Danbury Region" in the south and about a 30 percent increase in population with an increase of nearly 50 percent in water use for the "Northwestern Connecticut Region" in the north. A more recent study for the city of Danbury (Manganero, Martin, and Lincoln, 1967, p. 8-13), likewise shows a doubling of population by the year 2000 and a tripling of average daily demand for water from about 1.7 billion gallons per year in 1967 to more than 5 billion gallons per year in the year 2000. Thus, it seems likely that the major demands for water in the report area for the future will be concentrated in the Danbury-Bethel-New Milford area. Local sources may not be able to supply these burgeoning and concentrated demands, but if the entire report area is considered, the water needs in the year 2000 can easily be met by sources within the upper Housatonic River basin.

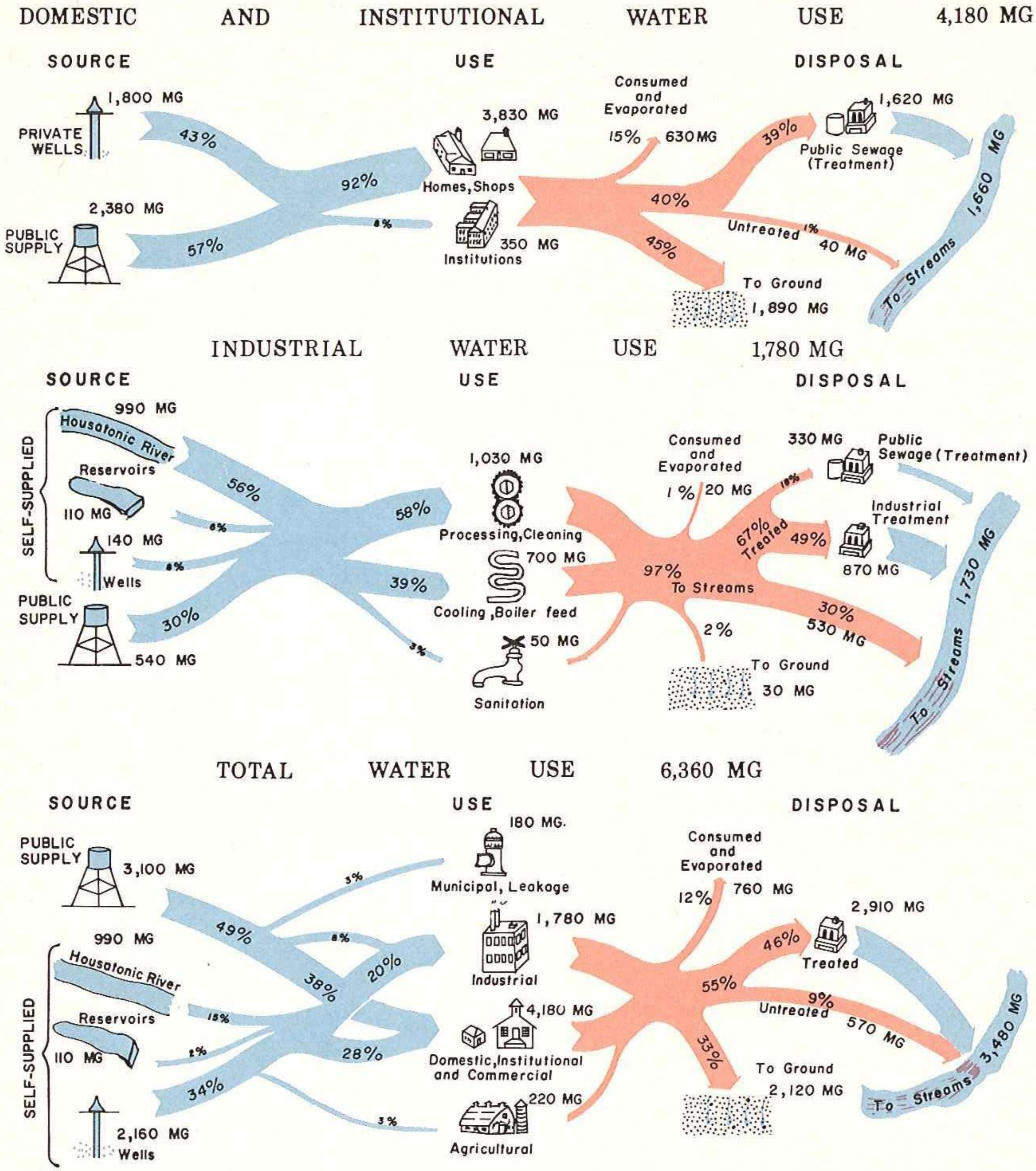


Figure 50.--Source, use, and disposal of water, in million gallons (mg), in the upper Housatonic River basin during 1967.

Table 24.--Principal public and institutional water-supply systems in the upper Housatonic River basin

(Descriptions are for 1967, except as noted, and are based on records and estimates from water utility officials.)

Public or institutional water-supply system (shown on pl. C)	Communities supplied	Estimated population served	Primary source of water	Auxiliary or emergency sources	Treatment or additives	Capacity of treatment plant (mgd)	Raw water storage (mg)	Finished water storage (mg)	Total use (mg)	Percent of use		
										Domestic and commercial	Industrial	Institutional
Ball Pond Estates Water Supply Co.	Ball Pond Estates	660	2 wells	None	Chlorination	--	--	0.04	16	100	0	0
Bethel, village of, Water Dept.	Bethel	5,000	Chestnut Ridge Reservoir Eureka Lake Mountain Pond	Well	Filtration, chlorination; (also; alum, soda ash, lime, and calgon at Chestnut Ridge Reservoir)	--	63 68 64	--	387	69	26	5
Canaan, town of, Water Dept.	Falls Village	275	3 wells	None	None	--	--	.05	6.2	84	0	16
Candlewood Lake Club	Candlewood Lake Club	424	6 wells	None	--	--	--	.15	--	100	0	0
Cornwall Water Co. 1/	Cornwall	200	Springs	None	Chlorination	--	--	.22	6.6	48	0	52
Danbury, city of, Water Dept.	Danbury	33,000	East Lake Reservoir Padanaram Reservoir Margerie Lake Reservoir Boggs Pond West Lake Reservoir Upper Kohanza Lake Lower Kohanza Lake	5 wells	Coagulation (alum, lime), sedimentation, rapid sand filtration, chlorination, calgon	5 (Margerie system) 5 (West Lake system)	360 42 1,057 92 1,265 140 60	2.09	1,734	72	21	7
Judea Water Co.	Washington	325	5 wells	None	None	--	0.08	--	9.1	100	0	0
Kent Water Co.	Kent	600	Kent Reservoir and well (well pumps into reservoir)	Well	Chlorination	--	4 .01	--	38	90	2	8
Kent School for Boys	Kent School for Boys	500	Kent School Reservoir	Well	Chlorination	--	65	.01	18 (1966)	0	0	100
Lakeville Water Co. 1/	Lakeville Salisbury	3,120	Reservoir No. 2 Reservoir No. 3 2 wells	5 wells	Chlorination	--	34 2	.02	138	82	1	17
Litchfield Water Co. 1/	Litchfield	2,320	4 wells	Litchfield Reservoir	None for well water. Reservoir is chlorinated when used.	--	10	.04	84	69	0	31
New Milford Water Co.	New Milford	4,600	Reservoir No. 1 Reservoir No. 2 Reservoir No. 3 Reservoir No. 4	Well	Chlorination	--	5 14 71 137	.50	211	48	32	20
Norfolk Water Co.	Norfolk	1,700	Wangum Lake	None	Chlorination	--	200	--	123	96	1	3
North Canaan Water Co. 1/	Canaan	1,600	North Canaan Reservoir 2 wells	2 wells	None for well water. Reservoir is chlorinated when used.	--	3	--	66	73	19	8
Sharon Water Co.	Sharon	1,096	Beardsley Pond Cauklintown Reservoir	None	Chlorination	--	73 5	--	10 (1966)	60	0	40

1/ Subsidiary of Bridgeport Hydraulic Co.

Table 25.--Chemical analyses of water from principal public and institutional water-supply systems in the upper Housatonic River basin

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

Public or institutional water-supply system	Date of collection	Source F, finished water R, raw water	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (residue at 180°C)	Hardness as $CaCO_3$: Calcium magnesium	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25°C)	Temperature (°C)	pH	Color	Detergents as MBAS
U.S. Public Health Service 1962 drinking water standards (upper limits)	--	--	--	0.3	0.05	--	--	--	--	--	250	250	a/1.3 a/1.0 a/0.8	45	500	--	--	--	--	--	15	0.5
Ball Pond Estates Water Supply Co.	11-19-68	R Well NFF 13	16	0.05	0.09	52	13	15	2.1	216	14	22	0.1	0.0	244	183	6	415	12	7.8	2	0.04
Bethel, village of, Water Dept.	9- 6-67	R Chestnut Ridge Reservoir	0.2	.65	.05	4.6	1.5	3.3	.7	5	13	8.1	.2	.1	37	18	14	66	--	6.6	18	--
	9- 6-67	F Chestnut Ridge Reservoir	.4	.09	.03	4.9	1.5	79	.9	105	22	13	.5	.0	242	18	0	420	--	9.7	5	--
	9- 6-67	R Eureka Lake	1.1	.08	.05	13	4.7	3.4	.8	41	19	7.0	.2	.0	73	52	18	133	--	7.5	10	--
	5- 2-68	R Well BT 39	14	.70	.35	87	36	20	8.0	339	61	48	.1	6.1	513	365	87	773	--	7.9	1	.08
Canaan, town of, Water Dept.	4-30-68	R Well CN 20	5.3	.02	.02	87	39	18	3.4	342	74	46	.0	1.6	496	378	98	779	13	8.1	2	.07
Candlewood Lake Club	9-13-67	R Well BD 11	19	.01	.15	27	9.4	4.7	1.3	128	9.1	2.8	.3	.2	135	106	1	225	--	7.6	2	.05
Cornwall Water Co.	9-18-67	R Spring CRN 1sp	11	.03	.19	34	14	5.5	2.2	141	14	18	.2	.7	171	143	27	303	10	7.5	2	.05
Danbury, city of, Water Dept.	10-20-66	R Well DY 35	10	.01	.10	35	16	5.2	2.4	147	28	8.2	.1	5.9	178	154	33	317	11	7.8	3	.04
	10-21-66	R Well DY 35	10	.01	.10	34	16	4.9	2.5	144	27	7.2	.1	4.0	177	151	33	308	11	7.7	4	.05
	8-28-67	R Margerie Lake Reservoir	.7	.14	.15	12	4.2	6.3	1.4	39	12	14	.2	.7	75	47	15	139	22	6.9	5	.02
	8-28-67	F Margerie Lake Reservoir	1.0	.00	.05	20	4.3	6.7	1.4	48	25	15	.2	.0	105	68	28	182	22	7.2	7	.01
	8-28-67	F West Lake Reservoir	1.4	.03	.05	19	4.4	5.3	1.0	38	33	9.5	.1	.0	80	66	34	169	22	7.2	1	.01
	4-23-68	R Well DY 55	22	.10	.00	35	11	b/10	--	128	17	21	--	3.2	198	133	28	309	11	7.4	--	--
Kent Water Co.	8-17-67	R Kent Reservoir	6.3	.53	.04	20	9.0	8.3	2.3	102	15	9.3	.2	.0	134	87	4	217	--	7.6	3	--
	4-30-68	R Well KT 23	13	.30	.03	38	12	10	3.0	176	20	1.8	.5	.6	189	145	0	315	13	7.9	4	.03
Kent School for Boys	8-17-67	R Kent School Reservoir	9.6	.03	.01	8.2	1.8	3.0	1.2	20	14	7.0	.2	.0	68	28	12	85	--	7.1	3	--
	4-30-68	R Well KT 24	7.7	2.1	.01	9.8	2.9	2.4	1.7	26	19	2.5	.2	.0	60	36	15	95	12	6.7	3	.03
Lakeville Water Co.	9-18-67	R Reservoir No. 2	5.5	.02	.04	11	2.4	1.4	.4	36	12	1.8	.1	.0	60	38	8	88	--	7.1	3	--
	10-29-68	F Well SY 20	6.8	.10	.00	23	8.1	b/8.5	--	92	14	13	--	1.0	124	91	16	212	10	7.5	--	--
Litchfield Water Co.	8-25-67	R Litchfield Reservoir	.2	.14	.04	15	6.2	4.1	3.1	63	14	4.8	.2	.7	84	63	12	149	17	7.5	35	--
	8-25-67	R Well GO 70	9.3	.00	.05	33	14	2.9	2.4	147	28	4.0	.0	.0	163	140	20	286	--	7.6	0	.02
	8-25-67	R Well GO 71	7.9	.02	.04	23	11	2.4	1.6	112	16	3.5	.0	.1	119	102	10	218	8	7.4	1	.02
	4-26-68	R Well LF 51	10	.02	.00	48	23	3.6	2.2	220	14	18	.1	3.8	239	215	34	419	9	7.7	0	.04
New Milford Water Co.	8-22-67	R Reservoir No. 2	3.9	.14	.17	12	4.3	3.5	1.2	34	17	8.3	.2	.2	66	48	20	122	22	7.4	6	--
	8-22-67	R Reservoir No. 4	.9	.11	.03	8.9	3.1	3.4	1.0	20	18	8.1	.2	.0	60	35	18	100	26	7.2	6	--
Norfolk Water Co.	8-23-67	R Wangam Lake	.5	.03	.02	4.6	1.6	1.1	.4	14	8.9	2.7	.2	.0	28	18	6	50	22	7.1	4	--
North Canaan Water Co.	8-23-67	R Well NOC 17	5.8	.05	.19	58	27	12	2.3	208	68	30	.0	.6	343	256	85	548	--	7.7	2	.03
	5-13-68	R Well NOC 22	5.2	.05	.13	37	20	8.0	2.0	152	46	18	.1	.0	218	175	50	377	8	7.4	2	.04
	5-14-68	R Well NOC 22	5.3	.05	.21	43	23	9.4	2.1	161	61	23	.1	.1	257	202	70	436	8	7.6	3	.04
	6-18-68	R Well NOC 29	6.0	.00	.12	64	34	16	2.2	212	102	42	.1	.1	400	300	126	642	9	7.6	13	.05
Sharon Water Co.	8-18-67	R Beardsley Pond	4.9	.18	.08	32	13	3.9	1.7	144	12	8.1	.1	.5	155	134	16	271	21	7.5	4	--
	8-18-67	R Couklintown Reservoir	8.9	.04	.05	40	20	4.0	3.0	198	19	9.0	.0	1.1	204	182	20	384	17	7.8	8	.02

a/ Upper, optimum, and lower limits in descending order.

b/ Sodium plus potassium.

DEVELOPMENT OF WATER SUPPLIES

Water may be obtained from streams and aquifers nearly everywhere in the upper Housatonic River basin. However, requirements for water differ considerably according to the intended use, and few sources are suitable for all uses without augmentation or treatment. Large supplies of water can only be obtained from the major streams and stratified-drift aquifers; smaller supplies generally can be obtained from a wider choice of sources and locations. An understanding of the alternative potentials for yield and quality of water in an area of interest allows the industrialist, the water manager, the farmer, or the homeowner to determine whether he can obtain a supply that is both economical to develop and satisfactory for his needs.

LARGE SUPPLIES FOR COMMUNITIES AND INDUSTRIES

Areas in the basin capable of providing large water supplies are shown on plate D. The only source from which supplies of 100 gpm (0.14 mgd) or more can generally be obtained are the major streams and the stratified-drift aquifers. These sources are closely related, as the major streams are bordered by stratified drift in many places. The ground-water runoff, which sustains streamflow during dry weather, comes largely from bordering stratified drift, and the yields of large-capacity wells in stratified-drift aquifers may be sustained or augmented by induced recharge from streams.

FROM STREAMS, LAKES, AND RESERVOIRS

Streamflows equaled or exceeded 90 percent of the time are shown on plate D as an index of surface-water availability from unregulated streams. These values of streamflow are first approximations of the average yields available from low run-of-the-river impoundment dams, as only small amounts of surface storage or supplemental ground-water supply would be needed to maintain these amounts continuously in most years. The volume of usable storage in lakes and ponds is also shown on plate D. Thus, it shows the general distribution and magnitude of surface-water reservoirs in the UHRBA. However, development of a particular stream as a source of water supply or for waste dilution may entail more detailed computation of 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 lakes, ponds, and reservoirs are summarized in table 8.

If demand for water is a small part of streamflow during low flow, development of a water supply may require only a small impoundment dam and corresponding intake facilities. However, if the demand is a large proportion of low flow, sizeable storage reservoirs may be required. Identification and evaluation of individual sites for suitability for dam construction involves considerations of engineering geology, land values, and ecological considerations beyond the scope of this report.

FROM STRATIFIED-DRIFT AQUIFERS

Eight areas within the basin underlain by stratified drift (shown on plate D and listed in table 26) are capable of yielding large amounts of ground water. The methods used to determine these long-term yields are detailed in a previous section titled "Aquifers."

SMALL SUPPLIES FOR HOMES AND SHOPS

Water adequate in quantity for the average home or small business can be obtained from wells almost anywhere in the basin. Most wells are drilled into the bedrock, but in lowland areas stratified drift may be more accessible to shallow dug or driven wells. Naturally occurring ground water is satisfactory in quality for domestic and commercial use without treatment except in scattered localities, where it contains excessive concentrations of iron and manganese or is excessively hard. Areas where iron and manganese, or hardness, are likely to cause problems are described in the section on ground-water quality.

WATER QUALITY AND DEVELOPMENT

The value of a water supply depends upon both its quantity and quality, and the importance of these two factors is in turn dependent upon its intended use. The requirements of agriculture, industry, and public supply differ considerably, so that valid appraisal of the quality of water in the basin must take into consideration the specific needs of the contemplated development. In most instances, natural and slightly contaminated waters can be treated for a specific use if necessary. Such treatment increases costs and often is a key factor in deciding whether to proceed with development in a particular area.

In Connecticut, water intended for public supply must meet State quality standards. The Public Health Service drinking water standards (1962) originally developed for interstate carriers and others subject to Federal quarantine regulations, are widely accepted by public water suppliers throughout the country as well as the State of Connecticut. Chemical analyses of "raw" or untreated water samples from public supplies having surface sources, showed iron and manganese occasionally in excess of the recommended limits. (See table 25.) However, high concentrations of these constituents can be reduced either by dilution with water of better quality or by treatment that removes most of the objectionable ions.

Hard ground water is of concern to public water suppliers in at least two areas of the basin. The North Canaan Water Company, at its well field south of the Blackberry River in North Canaan, has three wells (NOC 17, NOC 22 and NOC 29) that have yielded water with hardness in the 200-300 mg/l range. This water is diluted with softer surface water to provide a more acceptable product. In the

Table 26.--Estimated long-term yields from favorable ground-water areas in the upper Housatonic River basin

Favorable area			Ground-water outflow			Flow of principal streams entering favorable area equaled or exceeded 90 percent of the time (mgd)	Maximum amount of water potentially available over a long time period (mgd)	Pumpage from aquifer during 200-day period of little or no recharge, as determined from mathematical model (mgd)	Induced recharge from streams necessary to sustain pumpage (mgd) 1/	Streambed infiltration rate required to provide induced recharge (gpd/ft²/ft)	Estimated long-term yields (mgd) 2/	Remarks
Symbol and model no. (Pl. D)	Location	Area of strip aquifer (sq mi)	Total ground-water outflow area (sq mi)	Percent of area underlain by stratified drift	Ground-water outflow equaled or exceeded 7 years out of 10 (mgd)							
A, Model 1	Housatonic River valley south of Salisbury-Canaan and Sharon-Cornwall town lines	0.32	2.02	19	0.8	150	151	2.4	1.8	2.0	2.4	Housatonic River modeled as line-source boundary.
A, Model 2		.37	3.33	14	1.2	150	151	1.5	.6	.7	1.5	No line-source boundary in model.
B, Model 1	Hollenbeck River upstream from Cornwall Hollow	.33	1.01	38	.5	.7	1.2	1.1	.7	19	1.1	No line-source boundary in model Pumping at constant rate of 1.1 mgd would dry up the stream traversing the favorable area approximately 10 percent of the time.
C, Model 1	Housatonic River valley, downstream from Cornwall Bridge	.13	.70	23	.3	167	167	2.2	2.0	5.0	2.2	Housatonic River modeled as line-source boundary.
C, Model 2		.28	1.22	45	.7	167	168	1.4	.9	1.2	1.4	No line-source boundary in model.
D, Model 1	Housatonic River valley, downstream from North Kent	.44	2.50	25	1.2	170	171	5.0	4.2	3.3	5.0	Housatonic River modeled as line-source boundary.
D, Model 2		.44	3.43	19	1.4	170	171	1.7	.7	.6	1.7	No line-source boundary in model.
E, Model 1	Macedonia Brook valley, near Kent	.16	1.12	19	.4	.3	.7	.6	.3	50	.6	No line-source boundary in model. Pumping at constant rate of 0.6 mgd would dry up Macedonia Brook approximately 10 percent of the time.
F, Model 1	Housatonic River valley, west side at Cornwall Bridge	.17	.54	37	.3	165	165	2.9	2.7	3.6	2.9	This area modeled only with line-source boundary owing to lack of transmissivity data for east side of valley.
G, Model 1	Bantam River valley, near Litchfield	.30	.54	90	.5	1.0	1.5	1.0	.6	4.1	1.0	Bantam River modeled as line-source boundary.
G, Model 2		.34	.54	90	.5	1.0	1.5	.9	.5	3.4	.9	No line-source boundary in model.
H, Model 1	Lake Kenosia, north shore at Danbury	.34	1.40	39	.8	.5	1.3	1.3	.7	.1	1.3	Lake Kenosia modeled as line-source boundary. Pumping at constant rate of 1.3 mgd may affect level of Lake Kenosia approximately 10 percent of the time.

1/ Estimated to be equivalent to the long-term yield minus 75 percent of the ground-water outflow equaled or exceeded 7 years out of 10.

2/ Development of long-term yield would reduce streamflow by an equivalent amount unless water is returned to stream.

southern part of the basin, the town of Bethel has been advised against further development of the stratified-drift aquifer for public supply because of the excessive hardness of the water from the Maple Avenue and Grassy Plain wells. Samples of water from these wells showed maximum hardness of 240 mg/l and 348 mg/l, respectively (Cahn Engineers, Inc., 1970, p. 23, app. B-2).

Table 27 lists the water-quality limitations for some industrial uses. Many industrial requirements are much stricter than those for drinking water. In many industries water is routinely treated to insure its suitability for a specific process. In contrast, water may be acceptable for some uses, such as cooling and cleaning without treatment. Adequate treatment can make water of almost any quality suitable for almost any use; the prime consideration is cost. Industrial developers must, therefore, balance the improved quality of treated water against the added costs.

In the upper Housatonic River basin, much of the natural water is suited to a wide variety of uses with little or no treatment. The natural constituents and the property most likely to be troublesome in both surface water and ground water are iron, manganese, and hardness. Of these, hardness ranks as the number one potential quality problem for any development plans for the area.

In some parts of the basin, notably the Still River area, industrial and domestic wastes have rendered the water unfit for public supply, recreation, and many industrial uses. However, as indicated previously, State Public Act 57 (Connecticut General Assembly, 1967) is aimed at abatement of such contaminated conditions and a general upgrading of the waterways.

CONSEQUENCES OF DEVELOPMENT

Development of any water supply affects to some extent the availability of water in the vicinity. If large amounts are withdrawn, the effects are more likely to extend to remote parts of the basin. Although the precise consequences can rarely be predicted, in the report area the principal effects are altered streamflow patterns, lowered ground-water levels, degraded water quality, or a combination of these. Withdrawal of water from a stream naturally reduces its flow unless equal quantities are returned. Impounding stream water behind a dam may result in more uniform flow downstream if such an impoundment reduces peak flow or increases low flows. On the other hand, flow downstream from a dam may be erratic if water is not released continuously.

Induced infiltration from streams reduces their flow by the amount of water that has infiltrated. The effects are particularly striking when natural streamflow is near the 90-percent flow-duration value. At such times some reaches may become completely dry. The precise changes in flow pattern cannot be predicted because they depend largely upon the location and timing of water disposal. However, unless water is exported beyond the watershed of the developed area, most of it will eventually return to the stream or ground-water reservoir and thus become available for reuse downbasin.

Ground-water levels are lowered in the vicinity of a pumping well. Knowing the transmissivity and storage characteristics of the aquifer and the hydrologic boundaries, it is possible to predict the amount of water-level decline at any point for any given pumping rate for any elapsed time of continuous pumping.

Development invariably results in a change in the quality of water after use--usually a deterioration. The type of change and its magnitude depend 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 AVAILABILITY OF WATER

Accurate measurements and complete records of past hydrologic events cannot portray the effects of subsequent man-made changes. The reader who wishes to evaluate the quantity and quality of water available at any site should consider whether any major development has taken place nearby or upbasin from his site of interest since 1968, the year when active collection of data for this report ended. Have any industrial, municipal, or agricultural users begun major withdrawals from the stream or adjacent stratified drift? If withdrawals are returned to the streams, how has the quality been changed? Have any important water-regulating structures been erected upstream? If the water is being diverted elsewhere, how much is being taken and when? Are there any new major well fields or waste-disposal facilities nearby? Are there any new waste-treatment plants upstream? Have any other new stresses, natural or man-made, affected the hydrologic system in the basin? Conversely, will construction and use of a new water supply at any site of interest to the reader adversely affect the hydrologic system or related parts of the environment in the area?

Careful consideration of questions such as these should facilitate local modification and updating of this report, so that its usefulness may be prolonged. The effects of future development can be measured by continued operation of gaging stations on representative streams, measurements of water levels in key observation wells, and monitoring of chemical, physical, and bacteriological quality of water. Such measurements would also permit a thorough reappraisal of the water resources of the report area should it become necessary in the future.

Table 27.--Water-quality limitations for industrial use and range in water quality available in the upper Housatonic River basin

(Maximum limits or ranges in limits of some significant properties and constituents of waters acceptable for certain industrial uses)1/

Industry or process	Turbidity	Color (color units)	Hardness (as $CaCO_3$)	Alkalinity (as $CaCO_3$)	pH	Total dissolved solids	Iron (Fe)	Manganese (Mn)	Iron and manganese (Fe + Mn)	Aluminum oxide (Al_2O_3)	Silica (SiO_2)	Carbonate (CO_3)	Bicarbonate (HCO_3)	Other requirements 2/
	Chemical constituents in milligrams per liter													
Air conditioning	--	--	--	--	--	--	0.5	0.5	0.5	--	--	--	--	A, B
Baking	10	10	--	--	--	--	.2	.2	.2	--	--	--	--	C
Boiler feed														
0-150 psi	20	80	75	--	8.0 & up	1,000-3,000	--	--	--	5.0	40	200	50	--
150-250 psi	10	40	40	--	8.5 & up	500-2,500	--	--	--	.5	20	100	30	--
250 psi and up	5	5	8	--	9.0 & up	100-1,500	--	--	--	.05	5	40	5	--
Canning														
Legumes	10	--	25-75	--	--	--	.2	.2	.2	--	--	--	--	C
General	10	--	--	--	--	850	.2	.2	.2	--	--	--	--	C
Carbonated beverages	2	10	250	50	--	850	.2	.2	.3	--	--	--	--	C
Confection	--	--	--	--	--	100	.2	.2	.2	--	--	--	--	--
Cooling	50	--	50	--	--	--	.5	.5	.5	--	--	--	--	--
Ice (raw water)	1-5	5	--	30-50	--	300	.2	.2	.2	--	--	--	--	C
Laundering	--	--	50	60	6.0-6.8	--	.2	.2	.2	--	--	--	--	--
Plastics: clear, uncolored	2	2	--	--	--	200	.02	.02	.02	--	--	--	--	--
Paper and pulp 3/														
Ground wood	50	20	180	--	--	--	1.0	.5	1.0	--	--	--	--	A
Kraft paper	25	15	100	--	--	300	.2	.1	.2	--	--	--	--	--
Soda and sulfite pulp	15	10	100	--	--	200	.1	.05	.1	--	--	--	--	--
Light paper, high grade	5	5	50	--	--	200	.1	.05	.1	--	--	--	--	C
Rayon (viscose) pulp														
Production	5	5	8	50	--	100	.05	.03	.05	8.0	25	--	--	--
Manufacture	0.3	--	55	--	7.8-8.3	--	.0	.0	.0	--	--	--	--	--
Tanning	20	10-100	50-135	135	8.0	--	.2	.2	.2	--	--	--	--	--
Textiles														
General	5	20	20	--	--	--	.25	.25	--	--	--	--	--	--
Dyeing	5	5-20	20	--	--	--	.25	.25	.25	--	--	--	--	--
Wool scouring	--	70	20	--	--	--	1.0	1.0	1.0	--	--	--	--	--
Cotton bandage	5	5	20	--	--	--	.2	.2	.2	--	--	--	--	--
	Range in limits of selected properties and constituents of waters from the upper Housatonic River basin													
Source														
Natural (minor) streams	0.2-90	--	8-188	3-172	6.0-7.9	20-221	0.01-1.0	0.00-4.60	--	--	1.4-14	0	4-210	
Man-affected (major) streams	0.1-35	--	42-212	--	6.8-7.8	60-351	.00-.53	.00- .22	--	--	.4-11	0	34-213	
Carbonate bedrock wells	--	--	76-378	67-280	7.1-8.1	84-496	.00-3.4	.00- .23	--	--	2.3-14	0	82-342	
Noncarbonate bedrock wells	--	--	15-264	9-221	6.4-7.9	34-404	.00-1.0	.00- .65	--	--	5.0-23	0	11-269	
Stratified-drift wells	--	--	36-365	21-305	6.7-8.1	60-513	.00-2.1	.00- .59	--	--	3.0-15	0	26-372	

1/ Adapted from American Water Works Association, 1951, p. 66-67.

2/ A - no corrosiveness; B - no slime formation; C - conformance to USPHS drinking-water standards is required (see table 16).

3/ Uniform composition and temperature desirable. Iron objectionable because cellulose adsorbs it from dilute solutions. Manganese extremely objectionable; it clogs pipelines and is oxidized to permanganates by chlorine, causing reddish color.

ABBREVIATIONS

p.	-	page(s)
pl.	-	plates(s)
°C	-	degree(s) Celsius (Centigrade)
°F	-	degree(s) Fahrenheit
mm	-	millimeter(s)
in.	-	inch(es)
ft	-	foot (feet)
mi	-	mile(s)
sq ft	-	square foot (feet)
sq mi	-	square mile(s)
mcf	-	million cubic foot (feet)
mg	-	million gallon(s)
mgd	-	million gallon(s) per day
cfs	-	cubic foot (feet) per second
gpm	-	gallon(s) per minute
gpd	-	gallon(s) per day
mg/l	-	milligram(s) per liter
msl	-	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

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

1 mm = 0.001 meter = 0.04 in.

1 mg/l = 1 part per million (ppm) for solutions with densities about 1.000

Hydraulic conductivity (ft/day) = 0.134 multiplied by the coefficient of permeability (gal/day/ft^2)

Transmissivity (ft^2/day) = 0.134 multiplied by the coefficient of transmissibility (gal/day/ft)

GLOSSARY

Acid: A substance containing hydrogen, which dissociates to yield excess hydrogen ions when dissolved in water. Acid solutions can dissolve many metals.

Alluvium: Sediment composed of various proportions of gravel, sand, silt, clay, and organic matter deposited by streams.

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

Base: A substance containing hydrogen and oxygen, which dissociates to form hydroxide ions when dissolved in water. Basic solutions neutralize acidic solutions.

Bedrock: The solid rock, commonly called "ledge," that forms the earth's crust. In the report area, it is locally exposed at the surface but more commonly is buried beneath a few inches to as much as 200 feet of unconsolidated deposits.

Buildup: The raising of the water level or the equivalent increase in the pressure of the water in a well. The opposite of drawdown.

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

Calc-silicate rock: A rock with conspicuous calcium and/or magnesium silicate minerals.

Carbonate: A compound containing the radical CO_3^{--}.

Carbonate bedrock: Bedrock composed primarily of calcium and magnesium carbonate minerals.

Carbonate hardness: A measure of the amount of alkaline-earth cations effectively balanced by carbonate (and bicarbonate) anions.

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

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

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

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

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

Continuous-record gaging station: A site on a stream at which continuous measurements of stream stage are made by automatic equipment or made manually at least once a day. These records are converted to daily flow after calibration by flow measurements.

Cone of depression: The depression produced in the water table by the withdrawal of water from an aquifer; in cross section, shaped like an inverted cone with its apex at the pumping well.

Crystalline bedrock: Any metamorphic or igneous bedrock composed of closely interlocking minerals.

Cubic feet per second (cfs): A unit expressing rate of discharge. One cubic foot per second is equal to the discharge of a stream 1 foot wide and 1 foot deep flowing at an average velocity of 1 foot per second.

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

Discharge: The rate of flow of water 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 for one hour at 180°C; consist 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 a reservoir.

Drawdown: The lowering of the water level or the reduction in the pressure of the water in a well caused by the withdrawal of water.

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

Equivalent weight: The number of parts (by weight) of a substance that combines with, or is otherwise chemically equivalent to, 8.0 parts (by weight) of oxygen.

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

Ferric iron: An oxidized or high-valence form of iron (Fe^{+3}) having a low solubility in water solutions. Formed from ferrous iron that combines with oxygen when water containing ferrous ions is exposed to air.

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

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

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

Frequency: See "recurrence interval."

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

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

Ground water: Water in the saturated zone.

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

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

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

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

Ground-water recharge: The amount of water that is added to the saturated zone.

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

Hardness, of water: The property of water generally attributable to salts of the alkaline earths. Hardness 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.

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

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

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

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

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

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

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

Image well: An imaginary well so placed with respect to a real well and hydrologic boundary that by discharging or recharging it produces a ground-water divide or condition of no drawdown along the boundary position.

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

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

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

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

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

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

Line-source boundary: A boundary formed by a surface-water body that is hydraulically connected to an adjacent aquifer. Ideally there is no drawdown along such a boundary.

Mean (arithmetic): The sum of the individual values of a set, divided by the number of values in the set; popularly called the "average."

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

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

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 unless substantial amounts of nonvolatile organic substances are present.

Noncarbonate bedrock: Bedrock composed primarily of quartz and silicate minerals.

Noncarbonate hardness: A measure of the amount of alkaline earth cations in excess of available carbonate (and bicarbonate) anions.

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

Partially-penetrating well: A well that is not open to the entire saturated thickness of the aquifer.

Partial-record gaging station: A site at which measurements of stream elevation or flow are made at irregular intervals exceeding a day.

Perennial stream: A stream that flows during all seasons of the year.

pH: The negative logarithm of the hydrogen-ion concentrations. Ordinarily a pH value of 7.0 indicates that the water is at its neutral point; values lower than 7.0 denote acidity, those above 7.0 denote alkalinity.

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

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

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

Quartz: A mineral (SiO_2). A common constituent of many rock types.

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

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

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

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

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

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

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

Sewage: Liquid or solid waste commonly carried off in sewers.

Siliceous: Containing abundant quartz or silica.

Specific capacity, of a well: The rate of discharge of water divided by the corresponding drawdown of the water level in the well (gpm/ft).

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

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

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

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

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

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

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

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

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

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

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

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

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

Unsaturated zone: The zone between the water table and the land surface in which the open spaces are not all filled (except temporarily) with water.

Water table: The upper surface of the saturated zone.

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

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

SELECTED REFERENCES

Agar, W. M., 1927, the geology of the Shepaug aqueduct tunnel, Litchfield County, Connecticut: Connecticut Geol. Nat. History Survey Bull. 40, 38 p.

American Geological Institute, 1957, Dictionary of geological terms: Garden City, N.Y., Doubleday, 545 p.

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

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

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

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

Benoit, R. J., 1965, Investigation and control of algae blooms in Bantam Lake: General Dynamics, Electric Boat, Research and Develop. Dept., Groton, Conn., duplicated rept. U-413-65-087, 12 p.

Benoit, R. J., and Curry, J. J., 1961, Algae blooms in Lake Zoar, Connecticut in Algae and metropolitan wastes: U.S. Public Health Services Tech. Rept. W61-3, p. 18-22.

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

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

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

Boulton, N. S., 1963, Analysis of data from non-equilibrium pumping tests allowing for delayed yield from storage: London Inst. Civil Engineers, Proc. v. 26, no. 6693, p. 469-482.

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

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

Cahn Engineers, 1970, Report on improvements to the municipal water systems, town of Bethel, Connecticut (with supplement): New Haven, Conn., Cahn Engineers, Inc., 63 p.

Clarke, J. W., 1958, The bedrock geology of the Danbury Quadrangle: Connecticut Geol. Nat. History Survey Bull. 7, 47 p.

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

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

Connecticut Board of Fisheries and Game, 1959, A fishery survey of the lakes and ponds of Connecticut: Connecticut Board of Fisheries and Game Rept. No. 1, 395 p.

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

__________, 1966, Connecticut Health Bulletin 80, Sewage disposal in Connecticut, 25 p.

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

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

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

Connecticut General Assembly, 1967, Public act no. 57 of the 1967 session.

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

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

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

Fair, G. M., and Geyer, J. C., 1954, Water supply and waste-water disposal: New York, John Wiley, 973 p.

Federal Water Pollution Control Administration, 1968, Report of the committee on water quality criteria: Federal Water Pollution Control Adm., 234 p.

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

Flint, R. F., 1930, The glacial geology of Connecticut: Connecticut Geol. Nat. History Survey Bull. 47, 294 p.

Frink, C. R., 1967, Nutrient budget: Rational analysis of eutrophication in a Connecticut lake: Environ. Sci. Tech., v. 1, no. 5, p. 425-428.

__________, 1969, Water pollution potential estimated from farm nutrient budgets: Agronomy Jour. v. 61, p. 550-553.

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

__________, 1952, The geology of the New Preston quadrangle, part 1, The bedrock geology: Connecticut Geol. Nat. History Survey Misc. Series No. 5, 46 p.

__________, 1959, Bedrock geology of the Roxbury quadrangle, Litchfield and New Haven Counties, Connecticut: U.S. Geol. Survey Quad. Map GQ-121.

__________, 1961, The bedrock geology of the Cornwall quadrangle: Connecticut Geol. Nat. History Survey Quad. Rept. No. 11, 35 p.

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

Geraghty and Miller, 1967, Investigation of groundwater resources in the city of Danbury, Connecticut: Port Washington, New York, Geraghty and Miller, 40 p.

Goldschmidt, V. M., 1958, Geochemistry: London, Oxford University Press, 730 p.

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

Gregory, H. E., and Ellis, A. J., 1916, Ground water in the Hartford, Stamford, Salisbury, Willimantic, and Saybrook areas, Connecticut: U.S. Geol. Survey Water-Supply Paper 374, 150 p.

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

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

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

Holmes, G. W., and Newman, W. S., 1971, Surficial geologic map of the Ashley Falls quadrangle, Massachusetts and Connecticut: U.S. Geol. Survey Quad. Map GQ-936.

Holmes, G. W., Newman, W. S., and Melvin, R. L., 1970, Surficial geologic map of the South Canaan quadrangle: U.S. Geol. Survey open-file map.

Jacob, C. E., 1944, Notes on determining permeability by pumping tests under water-table conditions: U.S. Geol. Survey open-file report.

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

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

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

Krumbein, W. C., and Monk, G. D., 1942, Permeability as a function of the size parameters of unconsolidated sand: Am. Inst. Met. Engr., Tech. Pub. 1492.

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

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

Lohman, S. W., and others, 1970, Definitions of selected ground-water terms, revisions and conceptual refinements: U.S. Geol. Survey open-file report, 54 p.

Mackenthun, K. M., Ingram, W. M., and Porges, R., 1964, Limnological aspects of recreational lakes: U.S. Public Health Service, Pub. No. 1167, 176 p.

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

Manganaro, Martin, and Lincoln, 1967, City of Danbury, Connecticut comprehensive water supply study: New York, N.Y., Manganaro, Martin, and Lincoln, 45 p.

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

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

Melvin, R. L., 1970, Hydrogeologic data for the upper Housatonic River basin, Connecticut: Connecticut Water Resources Bull. No. 22, 33 p., 1 pl.

Nebergall, W. H., and Schmidt, F. C., 1959, General chemistry: Boston, D. C. Heath, 723 p.

Norvitch, R. F., and Lamb, M. E. S., 1966, Housatonic River basin: Massachusetts Basic-Data Rept. No. 9, Ground-Water Series, 40 p., 1 pl.