WATER RESOURCES INVENTORY OF CONNECTICUT
PART 8
QUINNIPIAC RIVER BASIN

BY

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

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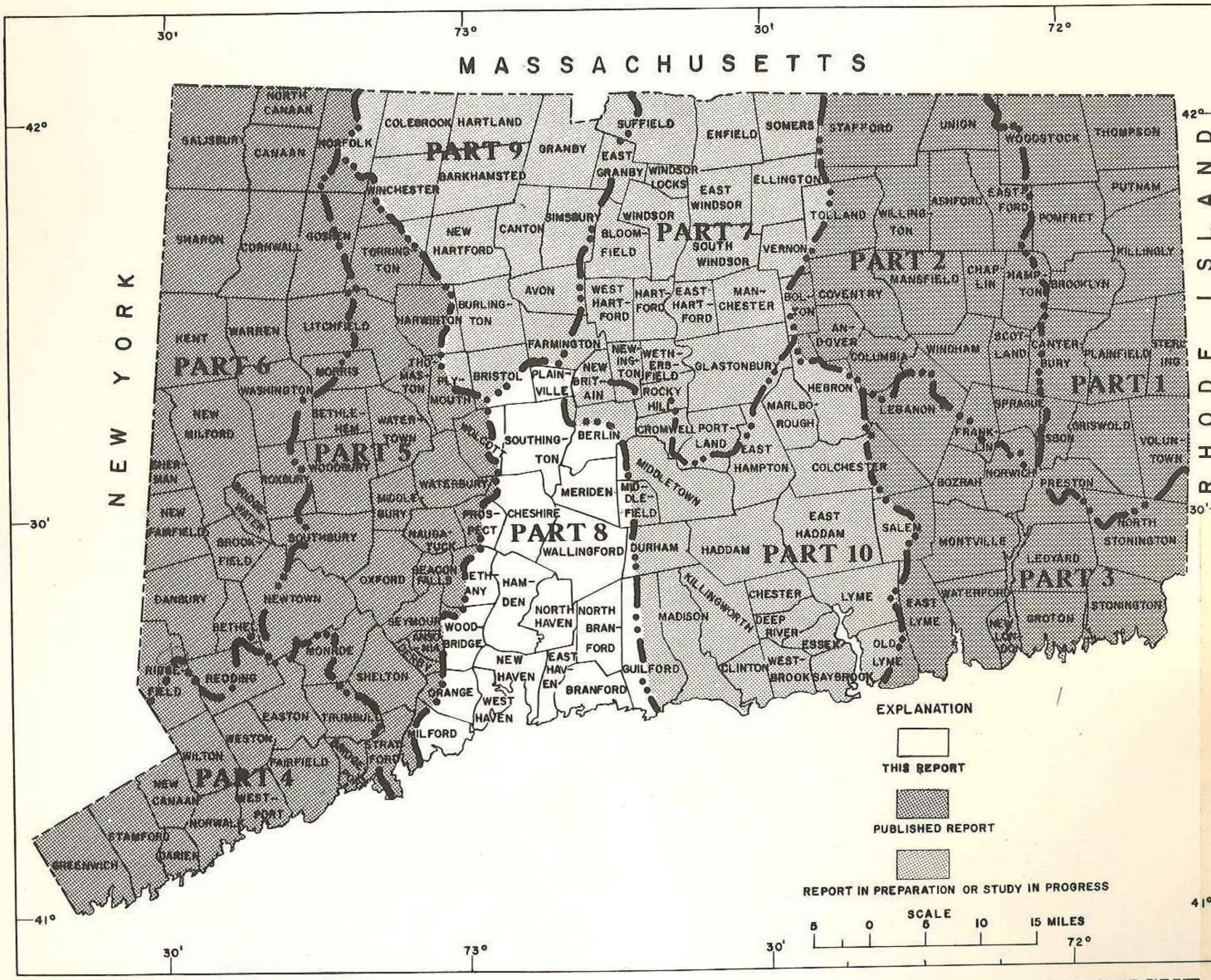
OUTSIDE COVER.--The Quinnipiac River Estuary and New Haven Harbor, looking north from Long Island Sound. Average flow of the Quinnipiac River, which drains 166 square miles, is 205 mgd. The Quinnipiac River, West River, which is seen in the left-center of the photograph, and several of the major streams in the basin drain directly to Long Island Sound and contain brackish water in their lower reaches. The city of New Haven, north of the harbor and west of the Quinnipiac River, is underlain by stratified drift. During much of the first half of the 20th century, large amounts of ground water were withdrawn from this aquifer; however, intrusion of salt water into the aquifer led to abandonment of most of the wells during the 1940-1950 period. In other areas of the basin, principally in the major river valleys that are not effected by salt-water intrusion, large amounts of ground water may be obtained from the stratified drift. Lake Saltonstall, seen in the lower right of the photograph, and several smaller reservoirs located in the West River valley are part of the New Haven Water Company supply system. The degree of urbanization shown in the photograph is typical of much of the central part of the Quinnipiac River basin. Along the eastern and western margins of the basin, woodlands, farmlands and low-density residential development predominate.

High altitude aerial photograph of New Haven, Connecticut flown by National Aeronautics and Space Administration, for U.S. Geological Survey "Census Cities" Project, June 28, 1970.



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

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SUMMARY

The Quinnipiac River basin area in south-central Connecticut covers 363 square miles, and includes all drainage basins that enter Long Island Sound from the Branford to the Wepawaug Rivers. Its population in 1970 was estimated at 535,000. Precipitation averages 47 inches per year and provides an abundant supply of water. Twenty-one inches returns to the atmosphere as evapotranspiration; the remainder flows directly to streams or percolates to the water table and discharges to Long Island Sound. Small amounts of water are exported from the basin by the New Britain Water Department, and small amounts are imported to the basin by the New Haven Water Company.

The average annual runoff of 164 billion gallons represents the amount of water potentially available in the report area over the long term, but only part of it is presently utilized. Data for 1970 show that only 22 percent was actually used during that year. Some industries along the Quinnipiac River reuse water; if industrial development continues, reuse will increase.

The amount of water that can be developed at a given place depends upon precipitation, variability of streamflow, hydraulic properties and areal extent of the aquifers, and hydraulic connection between the aquifers and major streams. The quality of the water is determined by the physical environment and the effects of man.

Stratified drift is the only aquifer capable of large sustained yields of water to individual wells. Yields of 64 screened wells tapping stratified drift range from 17 to 2,000 gpm (gallons per minute); their median yield is 500 gpm.

Till is widespread and generally provides only small amounts of water. Wells in till normally yield only a few hundred gallons of water daily and commonly are inadequate during dry periods. Till is generally used only as an emergency or secondary source of water.

Bedrock aquifers underlie the entire report area and include sedimentary, igneous, and metamorphic rock types. These aquifers supply small but reliable quantities of water to wells throughout the basin and are the chief source for many nonurban homes and farms. About 90 percent of the wells tapping bedrock yield at least 2 gpm, and much larger yields are occasionally reported. Maximum well yields of 305 gpm for sedimentary, 75 gpm for igneous, and 200 gpm for metamorphic bedrock have been reported.

Water potentially available from stratified drift was estimated on the basis of hydraulic characteristics of the aquifers and evaluation of natural and induced recharge. Long-term yields estimated for 14 favorable areas of stratified drift range from 0.8 to 16.1 mgd (million gallons per day), but detailed verification studies are needed before development.

The natural quality of water in the report area is good. The water is generally low in dissolved solids and is soft to moderately hard. Surface water is less mineralized than ground water, especially during high flow when it is primarily surface runoff. A median dissolved-solids concentration of 117 mg/l (milligrams per liter) and a median hardness of 58 mg/l was determined for water samples collected at 20 sites on 16 streams during high flow. A median dissolved-solids concentration of 146 mg/l and a median hardness of 82 mg/l was determined for samples collected at the same sites during low flow. In contrast, water from 130 wells had a median dissolved-solids concentration of 188 mg/l and a median hardness of 110 mg/l.

Iron and manganese occur in objectionable concentrations in parts of the report area, particularly in water from streams draining swamps and in water from aquifers rich in iron- and manganese-bearing minerals. Concentrations of iron in excess of 0.3 mg/l were found in 40 percent of the high-streamflow samples, 59 percent of the low-streamflow samples and 20 percent of the ground-water samples.

Human activities have modified the quality of water in much of the basin. Wide and erratic fluctuations in concentration of dissolved solids in streams, high bacterial content of the Quinnipiac River, and locally high nitrate and chloride concentrations in ground water are evidence of man's influence. Streams, wetlands, and some aquifers along the southern boundary of the basin contain salty water. Overpumping has caused extensive saltwater intrusion in aquifers in the southern and eastern parts of New Haven.

The total amount of fresh water used in the area during 1970 is estimated at 35,710 million gallons, or 183 gallons per day per capita. Public water-supply systems met the domestic requirements of about 90 percent of the population; all the systems supplied water that met the drinking water standards of the Connecticut Department of Health.

WATER RESOURCES INVENTORY OF CONNECTICUT PART 8 QUINNIPIAC RIVER BASIN

INTRODUCTION

PURPOSE AND SCOPE

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

In 1959 the Connecticut General Assembly, on recommendation of the Water Resources Commission, authorized a statewide water-resources inventory. Under this and supplemental authorizations of the General Assembly, the U.S. Geological Survey, in cooperation with the Water Resources Commission (later incorporated with the Connecticut Department of Environmental Protection), has undertaken a series of studies to determine the quantity and quality of water available. For these investigations, Connecticut was divided into 10 study areas, each bounded by natural drainage divides, State boundaries, and the ocean. (See map inside front cover.) The resulting reports are designed to be useful to planners; public officials; water-utility personnel; consulting hydrologists; well drillers; and others concerned with the development, management, use, conservation, and protection of water resources. This report describes one of the 10 study areas. A companion report (Mazzaferro, 1973) lists much of the basic data on which this report is based. A list of cooperative reports on the water resources of other areas of Connecticut is given on the back cover of this report.

THE QUINNIPIAC RIVER BASIN AREA

The term "Quinnipiac River basin," as used in this report, is a 363-square-mile area in south-central Connecticut drained principally by the Quinnipiac River and six smaller rivers that discharge directly to Long Island Sound. (See figure 1.)

Much of the basin is within the southern part of the Triassic Valley, a broad central lowland containing prominent basalt ridges. This lowland is flanked by uplands of moderate height to the east and west. Elevations range from sea level along the coast to over 1,000 feet in the towns of Meriden, Bristol, and Wolcott. Land surface is flat or gently rolling, but steep escaprments and adjacent talus slopes characterize the larger basalt ridges.

The Quinnipiac River is the major stream and drains about 166 square miles. Other large streams, which also drain directly to Long Island Sound, are the Branford, Farm, Mill, West, Indian, and Wepawaug Rivers.

Land use includes large-scale industrial and commercial development in New Haven, Wallingford, and Meriden; farms and woodlands along the eastern and western margins; and residential development in the central lowland. In the past three decades, much farmland has been converted to residential and commercial uses.

Transportation systems are well developed; three major highways, Interstate Routes 84, 91, and 95, serve the northern, central, and southern parts of the area. Rail services to Meriden, Wallingford, and New Haven are part of the Amtrak and Conrail systems, and spur lines serve several smaller towns. New Haven is Connecticut's chief seaport and handled 11.6 million tons of cargo in 1970.

Figure 1.--The Quinnipiac River basin and six smaller basins with areas of at least 13 square miles each make up most of the report area.

These and other small basins drain directly into Long Island Sound and many have estuaries near the coast.

ACKNOWLEDGMENTS

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

GUIDE FOR USE OF THIS REPORT

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

The availability of surface water is summarized on plate D, which shows the amount of available storage of selected reservoirs and low flows of major streams. Streamflow information in the text includes tables and graphs of flow duration, low-flow frequency and duration, flood peaks, frequency of floods, and draft-storage relations. Quality of surface water is discussed in the text in the section titled "Quality of surface water." Maximum dissolved-solids concentration in stream is shown on plate E.

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

Water use is shown on plate C and discussed in the text. Water quality data for the principal public water-supply systems are listed in tables 33 and 34, and a general illustration of water collection, use, and disposal appears in figure 56.

All data collection points referred to in this report are located on plate A which was previously published in the companion basic-data report (Mazzaferro, 1973). The basic-data report also contains well records, logs of wells and test holes, laboratory analyses of sediment samples, chloride analyses, and lists sources of other published hydrologic and water-quality information.

Recent reports on the water resources of the Quinnipiac River basin include ground-water studies of the Bristol-Plainville-Southington area (La Sala, 1964) and the Hamden-Wallingford area (La Sala, 1968).

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

THE HYDROLOGIC CYCLE

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

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

THE WATER BUDGET

The hydrologic cycle in a drainage basin can be described by a water budget, which, like a fiscal budget, lists receipts, disbursements, and amounts on hand. The receipts of water in the basin consist almost entirely of precipitation on the area. Disbursements consist of surface runoff, ground-water runoff, and evapotranspiration. The amount on hand--stored within the basin--is constantly changing. The amounts in each element of the budget may vary from year to year, but the budget always balances. Taking into account changes in storage, the disbursements are equal to the receipts. The approximate amounts involved in each of the major elements of the water budget, in an average year, are shown in figure 2.

SOURCES OF WATER

PRECIPITATION

The mean monthly and mean annual precipitation on the basin for the reference period October 1930 to September 1960 are given in table 1. The data were computed from records of three long-term weather stations and were weighted in proportion to the area represented by each station. Figure 3 which includes data from table 1, shows that mean monthly precipitation is fairly uniform throughout the year, ranging from 3.13 inches in February to 4.66 inches in March; the average is 3.95 inches per month.

Minimum monthly precipitation ranges from 0.12 inches (June 1949) to 1.67 inches (March 1946). Maximum monthly precipitation ranges from 6.46 inches (February 1936) to 14.52 inches (September 1938).

The mean annual precipitation of 47.34 inches is equivalent to 299 billion gallons of water on the report area of 363 square miles.

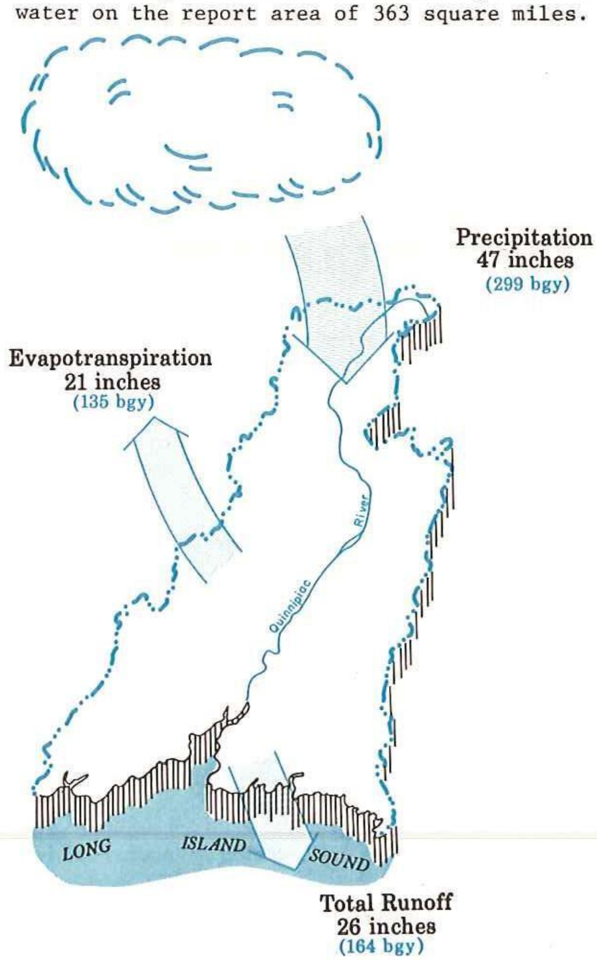


Figure 2.--Average annual water budget for the Quinnipiac River basin, 1931-60 water years.

Table 1.--Water budget of the Quinnipiac River basin

(Mean monthly budget, 1931-60 water years, in inches of water)

Month	Precipitation	Evapotranspiration	Precipitation minus evapotranspiration	Runoff	Storage 2/
Oct.	3.58	1.60	1.98	1.23	0.75
Nov.	4.38	.73	3.65	1.86	1.79
Dec.	4.03	1/ .20	3.83	2.26	1.57
Jan.	3.91	1/ .20	3.71	2.68	1.03
Feb.	3.13	1/ .20	2.93	2.51	.42
Mar.	4.66	.53	4.13	4.13	.00
April	4.10	1.33	2.77	3.64	-.87
May	3.90	2.58	1.32	2.52	-1.20
June	3.68	3.52	.16	1.70	-1.54
July	3.58	4.15	-.57	1.15	-1.72
Aug.	4.26	3.73	.53	1.07	-.54
Sept.	4.14	2.60	1.54	1.23	.31
Mean annual	47.35	21.37	25.98	25.98	0

1/ Estimated for times when air temperature was above freezing assumed to be zero when air temperature is at or below freezing.

2/ Minus sign indicates net loss in storage; no sign indicates net gain.

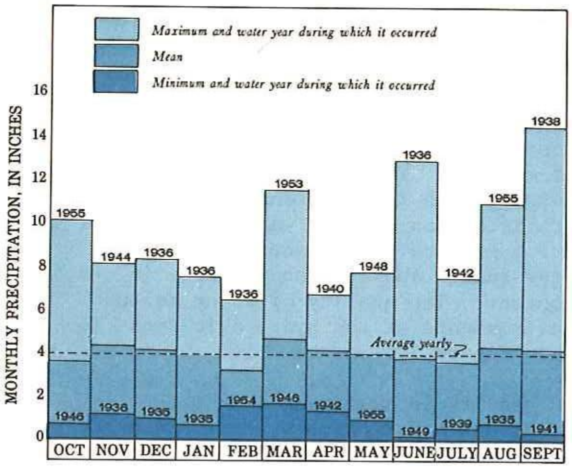


Figure 3.--Monthly precipitation, 1931-60 water years.

Mean monthly precipitation is fairly uniform but maximum and minimum monthly precipitation vary widely.

LOSSES OF WATER

RUNOFF

Long-term records of runoff are available for the Quinnipiac River basin. It has been measured since October 1930 at the stream-gaging station at Wallingford, 16 miles upstream from the mouth of the river. (See pl. A.) The records document runoff from 110 square miles of the total report area and are considered representative. Mean monthly and mean annual totals are given in table 1. Figure 4, shows that mean monthly runoff follows a marked seasonal cycle, being much lower for August (1.07 inches) than for March (4.13 inches). Minimum monthly values range from 0.44 inches (September 1957) to 2.05 inches (March 1957). This seasonal cycle reflects a combination of causes, among which are increased evaporation and transpiration during the summer, storage of water as ice and snow during the winter, and increased ground-water runoff in the spring. Maximum monthly runoff varies widely, but does not show a seasonal cycle since large floods can occur in any month. (See section on "Floods.") It ranges from 3.44 inches (July 1938) to 7.14 inches (March 1936).

Based on a mean annual runoff of 25.98 inches, the mean annual streamflow from the report area into Long Island Sound totals 164 billion gallons of water. This does not include a small but undetermined amount of ground water discharging directly into Long Island Sound.

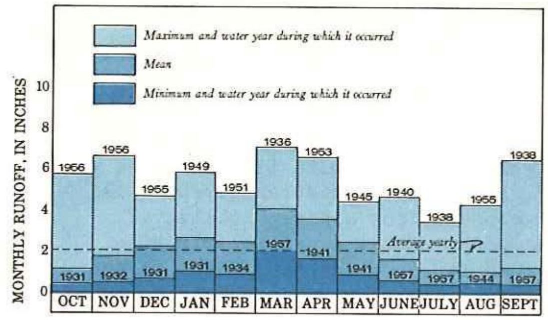


Figure 4.--Monthly runoff, 1931-60 water years.

Both mean monthly and minimum monthly runoff follow a marked seasonal cycle. Floods may occur in any month and cause maximum monthly runoff to vary widely.

EVAPOTRANSPIRATION

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

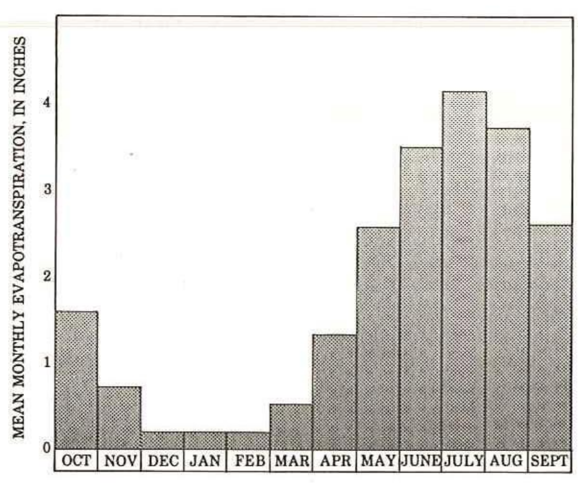


Figure 5.--Mean monthly evapotranspiration, 1931-60 water years.

mean annual precipitation (47.35 inches) minus mean annual runoff (25.98 inches), or 21.37 inches.

Evapotranspiration rates change throughout the year in response to changes in air temperature and duration of daylight (Thornthwaite, 1952, p. 382). They are highest during the growing season, April through October, when the temperature is high and daylight hours are increased. The cycle repeats itself with little change year after year, and annual evapotranspiration is relatively constant for a given locality. Theoretical mean monthly evapotranspiration rates are computed by a method similar to the one described by Thornthwaite and Mather (1957) and are shown in table 1 and in figure 5.

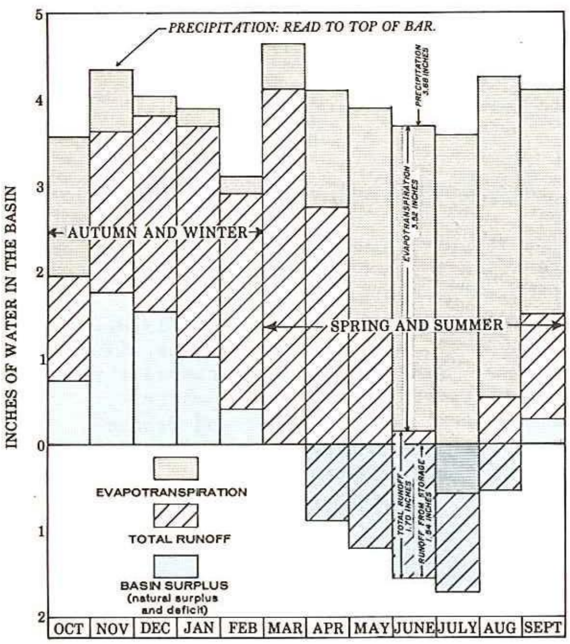


Figure 6.--Mean monthly water budget, 1931-60 water years.

SUMMARY OF WATER BUDGET

The mean monthly water budget for the basin is shown in figure 6 and tabulated in table 1. Precipitation in late autumn and winter exceeds evapotranspiration, which results in increased storage and abundant runoff. Precipitation in late spring and summer is generally less than evapotranspiration; this results in decreased storage and sharply reduced runoff. Storage of water may thereby change in lakes, stream channels, aquifers, and soils.

QUALITY OF WATER IN THE HYDROLOGIC CYCLE

Water moving through the hydrologic cycle undergoes changes in chemical and physical properties. Precipitation dissolves particles and gases from the atmosphere and is further modified by reactions with soils, rocks, and organic matter. The chemistry of water depends largely on the composition and physical properties of the materials it contacts and on the length of time of contact. Thus, ground water which moves slowly through its environment, is generally more mineralized than surface water. Lakes and streams are a mixture of surface runoff and ground-water runoff and are intermediate in mineral content. The quality of water in the diverse environments of the hydrologic cycle is described in figure 7.

Water quality is also modified by the activities of man. For example, soot and motor exhaust may affect the composition of precipitation; animal wastes, fertilizers, and petroleum residue may degrade the quality of surface runoff; leachate from landfills and septic tanks may contaminate ground water; and industrial wastes may contaminate streams. Water can also be treated to remove undesirable matter and improve its quality. Figure 8 shows man-induced changes in the quality of water in the hydrologic cycle.

QUALITY OF PRECIPITATION

Rainfall composition varies from place to place, from one storm to another, and within a single storm. The path of an air mass has a major influence on the composition of precipitation. Rain from oceanic storms commonly contains significant concentrations of chloride and sodium ions. Moisture in storms that pass over industrial areas contains impurities from fumes and smoke, particularly sulfate and nitrate ions. High sulfate concentration is usually associated with acidic rain near urban areas. Dust, salt spray, industrial wastes, unburned fuel, pesticides, and agricultural chemicals are dissolved and removed from the atmosphere by precipitation. Rain at the beginning of a storm may contain higher concentrations of dissolved solids than later rain. Between 1963 and 1969, 133 composite monthly samples of precipitation from 18 Connecticut locations were collected and analyzed. These samples had dissolved-solids concentrations ranging from 2 to 236 mg/l, with a median of 20 mg/l. The median concentration is equivalent to 4.5 pounds of dissolved solids falling on each acre of land with every inch of rain. A significant percentage of the dissolved-solids concentration in streams at high flow is derived directly from atmospheric precipitation.

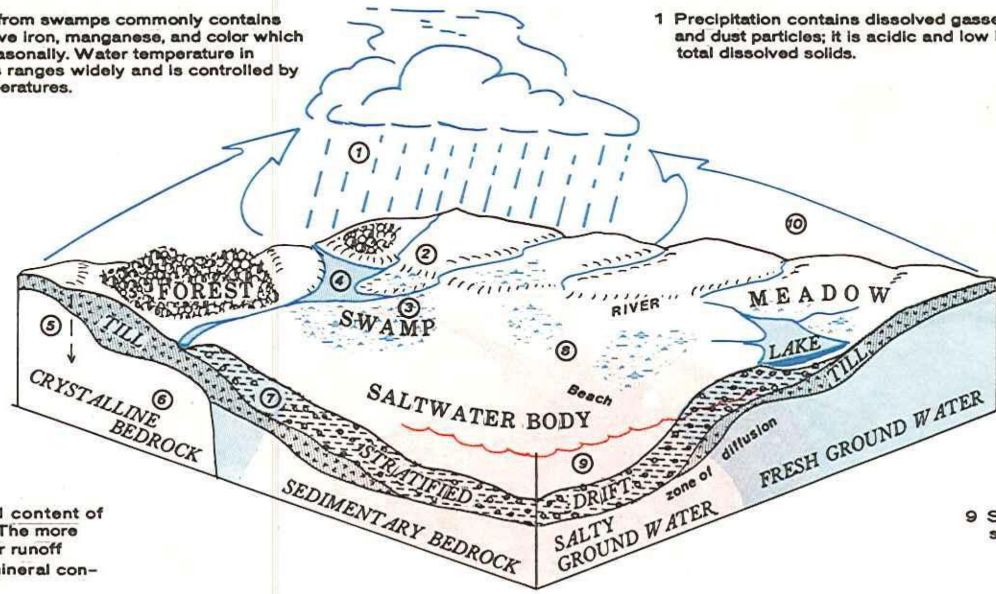
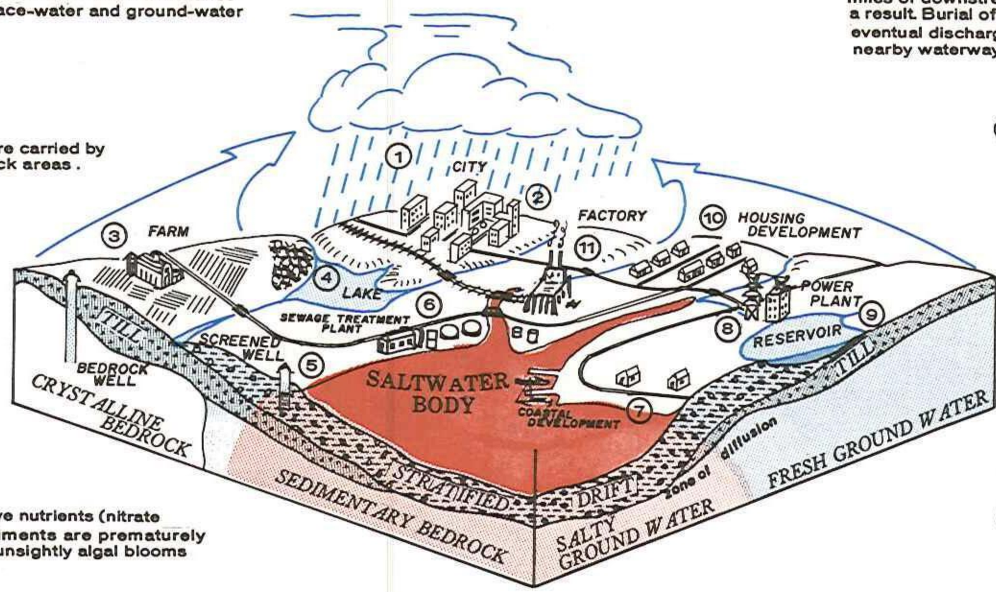


Figure 7.--Natural quality of water in the hydrologic cycle.

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



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

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

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

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

(5) Heavy pumping of wells near the coast may lead to salt water intrusion.

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

(7) Intensive development can cause ground-water contamination because of waste disposal problems; close spacing of wells may lead to saltwater intrusion.

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

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

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

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

Figure 8.--Effects of man's activities on water quality.

The chemical and physical properties are affected, usually resulting in deterioration in quality.

QUALITY OF RUNOFF

The quality of runoff under natural conditions is determined by the composition of precipitation, the type of earth materials it comes in contact with, and the duration of contact. During periods of high flow, most stream water is direct runoff and contains dissolved constituents similar to those of precipitation. It has a lower concentration of dissolved solids and a lower pH than stream water at low flow. During periods of low flow, most stream water is derived from ground-water runoff, and dissolved-solids concentration and pH are higher. These relationships are shown in table 2, which summarizes dissolved-solids concentration and pH of samples collected from streams draining undeveloped areas of the basin.

Water percolating into the ground dissolves more minerals than does water flowing over the surface. Thus, ground water contains higher concentrations of dissolved solids. The median dissolved-solids concentration of samples from 129 wells in the Quinnipiac River basin is 188 mg/1.

Table 2.--Dissolved solids and pH of water from natural streams 1/

(Dissolved-solids concentration in milligrams per liter)

		Streams draining areas underlain by			
		Sedimentary bedrock		Crystalline bedrock	
		at high flow 2/	at low flow 3/	at high flow 2/	at low flow 3/
Dissolved solids (residue on evaporation at 180°C)	Median	117	148	79	99
	Range	84-130	117-194	36-121	57-147
pH	Median	7.4	7.6	7.1	7.1
	Range	7.2-7.4	7.4-7.7	6.4-7.2	6.7-7.4
No. of samples		5		5	

1/ Streams draining relatively undeveloped areas.
2/ Ten percent duration flow.
3/ Ninety percent duration flow.

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

SURFACE WATER

STREAMS

The area described in this report includes the Quinnipiac River drainage basin of 166 square miles, six river basins with drainage areas ranging from 13 to 39 square miles, and several smaller drainage basins. These basins drain directly into Long Island Sound between Sachem Head in Guilford and Fort Trumbull in Milford. The complete drainage system is shown in figure 1 and on the five plates in the back pocket.

The amount of streamflow passing any point within the basins varies continuously. A continuous record for the Quinnipiac River at Wallingford (station no. 01196500) from October 1930 to the present is available. Ten other continuous or partial records for shorter periods for other streams are also available, as shown in table 3. Locations of stream-gaging stations are shown on plate A. Records of streamflow from their beginning through September 1970 have been published annually in a series of U.S. Geological Survey water supply papers entitled "Surface Water Supply of the United States." Records from October 1960 to September 1964 have also been published as "Surface Water Records of Connecticut," and from October 1964, as "Water Resources Data for Connecticut, part 1." All of these publications are listed under "U.S. Geological Survey" in the "Selected References" at the back of this report.

Table 3.--Streamflow records at gaging stations in the Quinnipiac River basin

Station no. (Pl. A)	Stream and location	Drainage area (sq mi)	Type of record	Period of record in water years
01195400	Farm River at Totoket	13.4	Low flow only	1962-65, 1967-73
01195500	Quinnipiac River at Southington	17.4	Continuous	1936-38, 1969-70
			Low flow only	1961-65
01196000	Eightmile River at Plantsville	14.6	Continuous	1936-38, 1969-70
			Low flow only	1961-65
01196100	Tenmile River at Milldale	20.5	Continuous	1969-70
01196220	Quinnipiac River near Meriden	68.3	Continuous	1969-70
01196500	Quinnipiac River at Wallingford	110	Continuous	1931-76
01196580	Muddy River near North Haven	18.0	Continuous	1963-73
			Peak flow only	1974-76
01196600	Willow Brook near Cheshire	9.34	Low flow only	1961-69, 1971-76
			Peak flow only	1961-76
01196620	Mill River near Hamden	24.5	Continuous	1969-70
01196680	Race Brook at Orange	3.19	Continuous	1969-70
01196700	Wepawaug River at Milford	18.4	Low flow only	1962-76
			Peak flow only	1962-76

Streamflow records are the basis for determination of water-supply potential and are used to estimate mean annual flows, duration of flows, frequency and duration of low and high flows, and magnitude and frequency of floods. All records are extended or shortened to the 30-year reference period, 1930-60, beginning in April or October 1930, so that comparable estimates may be made for any selected location. This reference period conforms with the practice recommended by the World Meteorological Organization (Searcy, 1959) and is consistent with previous reports in this series. Duration of flow and frequency and duration of low flow for each 30-year period of record are further adjusted to an average mean annual streamflow for the 30-year reference period of 1.16 million gallons per day per square mile (1.80 cubic feet per second per square mile) for the State as a whole.

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

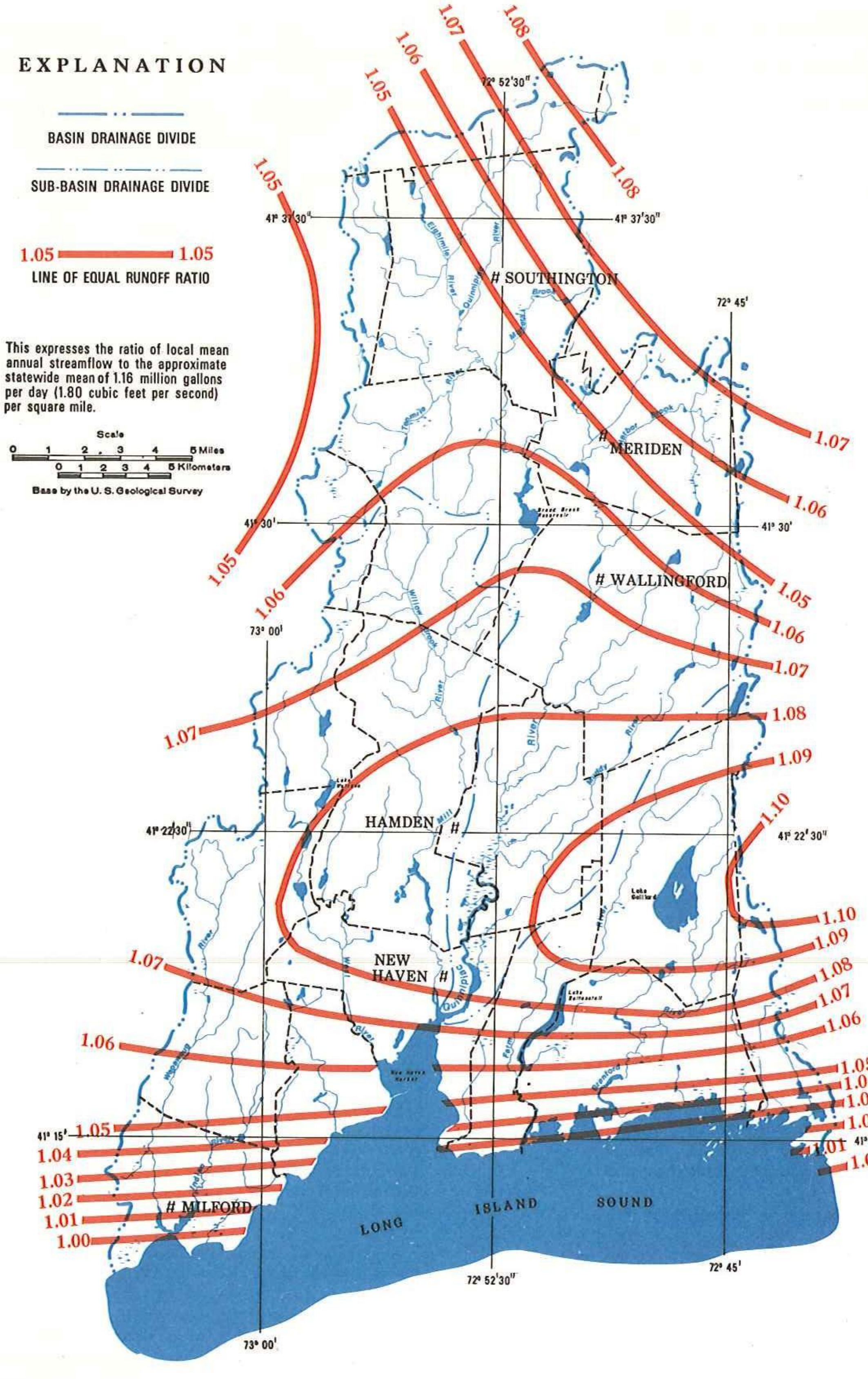


Figure 9.--Distribution of ratios of local mean annual streamflow to the statewide mean in the Quinnipiac River basin, 1931-60 water years.

The "Gazetteer of Natural Drainage Areas of Streams and Water Bodies within the State of Connecticut," (Thomas, 1972) lists the sizes of drainage areas at specific sites, and maps showing the drainage area delineations used as a ba for that report are available for reference in .e Hartford office of the U.S. Geological Survey.

MEAN ANNUAL STREAMFLOW

The amount of flow passing a point on a stream at any time depends upon size of the upstream drainage area, precipitation, evapotranspiration, surface and ground-water storage, topography, and the influence of man on the system. The areal variation in the mean annual streamflow of unregulated streams is shown by the lines of equal streamflow ratio in figure 9. These lines represent the ratio of local mean annual streamflow to the average statewide mean annual streamflow of 1.16 million gallons per day per square mile (1.80 cubic feet per second per square mile) for the reference period 1930-60. To determine the amount of streamflow at a specific site on a stream, use a weighted average ratio representative of the entire upstream drainage area.

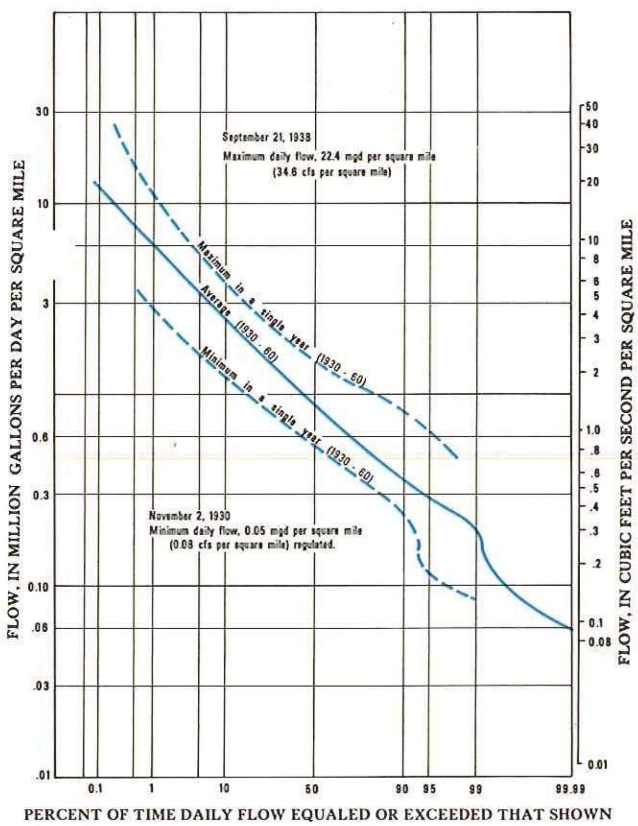


Figure 10.--Duration of daily mean streamflows of the Quinnipiac River at Wallingford, Station No. (Pl. A) 01196500.

DURATION OF STREAMFLOW

Cumulative frequency curves, called flow-duration curves, show the average percentage of time that specific daily flows are equaled or exceeded at sites where continuous records of daily flow are available. A flow-duration curve for the Quinnipiac River at Wallingford (station no. 01196500) for the base period 1930-60 is shown in figure 10. Also shown are the minimum and maximum limits of duration in a single year. This station has the only long-term streamflow record in the report area.

A family of regional flow-duration curves developed by Thomas (1966), for ungaged sites, shows the effect of basin surficial geology on the shape of the curves. Regional flow-duration curves based upon statewide data, are shown in figure 11. In general, the curves show that streamflow from areas having a large proportion of stratified drift is more evenly distributed in time than streamflow from areas mantled largely by till. This reflects the large infiltration and storage capacity of stratified drift and the resultant large proportion of ground-

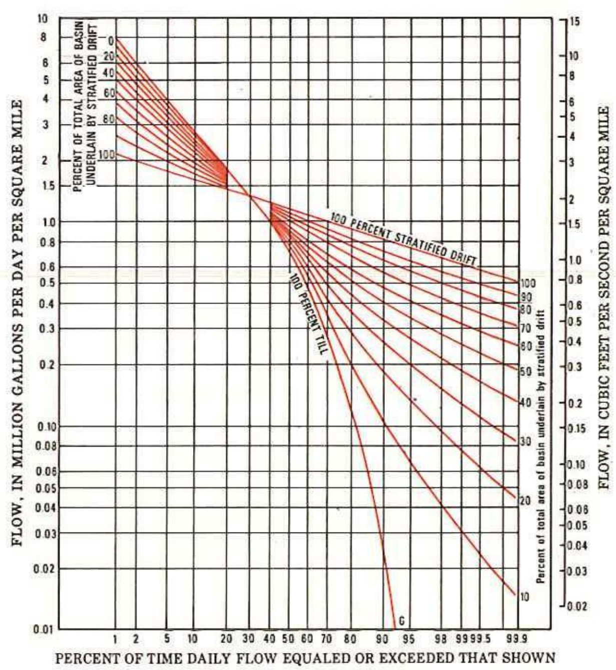


Figure 11.--Regional duration curves of daily mean streamflow.

These curves are for 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).

water runoff from these deposits. In contrast, the uneven distribution of streamflow from till areas reflects the poor infiltration and low storage capacity of these deposits and the resultant large proportion of surface runoff.

The flow-duration curves shown in the figure apply only to unregulated streams if their mean annual streamflow is 1.16 mgd (1.80 cfsm), the statewide average for the reference period 1930-60. They may be used with figure 9 and the diagram in figure 12 to estimate flow-

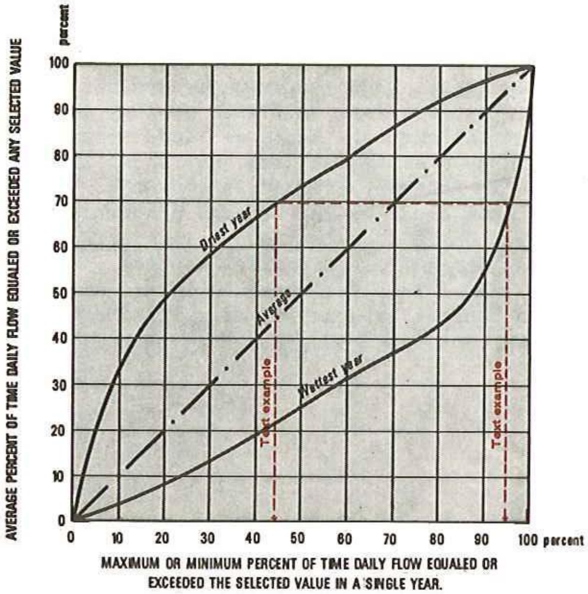


Figure 12.--Range in duration of streamflow, 1931-60 water years.

duration curves for ungaged sites on unregulated streams in the basin.

For example, assume that an average flow-duration curve is needed for the period 1930-60 for a site with a drainage area of 8.0 square miles, of which 1.6 square miles, or 20 percent of the total, consists of stratified drift. The site is located where the mean annual streamflow for the upstream drainage area (from fig. 9) is 1.06 times the statewide average. The flow-duration curve for this site is that shown in figure 11 for 20 percent stratified drift. Values of flow from this curve must be multiplied by the drainage area, 8.0 square miles, and by the ratio 1.06 to give the average-flow duration curve at this site for the period 1930-60. The result in tabular form is:

Percent of time	1	5	10	30	50	70	90	95	99
Average flow equaled or exceeded for period 1930-60, in mgd	55	30	22	11	6.8	3.6	1.6	1.2	0.85

Maximum and minimum flow-duration curves for single years may be estimated by relationships shown in figure 12. For example, if the flow of 3.6 mgd was equaled or exceeded 70 percent of the time on the average flow-duration curve shown in the table, then during the driest year of the period 1930-60 this flow was probably equaled or exceeded 45 percent of the time, and during the wettest year, 96 percent of the time.

Any diversion or regulation upstream from a selected site requires adjustments to the natural flow-duration curve to account for its influence.

FREQUENCY AND DURATION OF LOW STREAMFLOW

Flow-duration curves indicate the percentage of time a specified daily low streamflow is equaled or exceeded during a certain period, but do not indicate how often this low flow recurs or how long it will last. These parameters are shown by curves of lowest mean flows for various periods of consecutive days and their recurrence intervals that are derived from long-term stream-gaging records. Curves for the Quinnipiac River at Wallingford (station no. 01196500) are shown in figure 13. For short-term stream-gaging stations and ungaged sites, relations between curves of lowest mean flows and flow-duration curves are shown in table 4. If flow-duration curves are known or estimated for such sites, low-flow frequency curves can be estimated by use of table 4.

Commonly used indices of lowest mean flow are the lowest mean flow for 30 consecutive days with an average recurrence interval of 2 years (30-day, 2-year low flow), which is equivalent to the flow equaled or exceeded 90 percent of the time in table 4 and the lowest mean flow for 7 consecutive days with a recurrence interval of 10 years (7-day, 10-year low flow), which is equivalent to the flow equaled or exceeded 99 percent of the time in table 4. The 30-day, 2-year low flow is shown on plate D as an index of water availability for this report. The State of

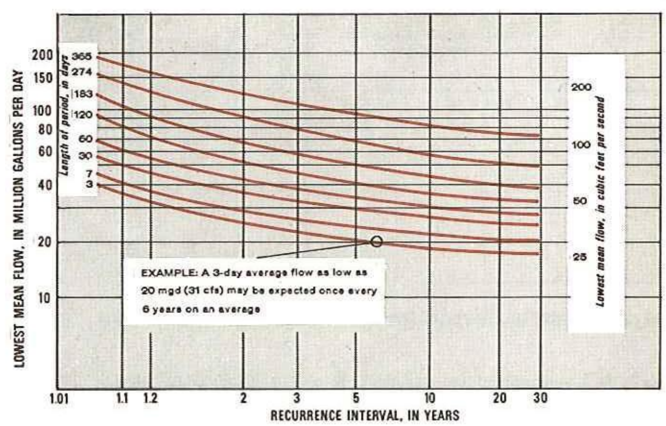


Figure 13.--Recurrence intervals of lowest mean flows for specified periods for the Quinnipiac River at Wallingford, Station No. (Pl. A) 01196500, 1931-60 water years.

Table 4.--Average duration of lowest mean flows of streams

(Example shows that, for any unmeasured site on an unregulated stream, the 30-consecutive-day lowest mean 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 in 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 yrs	2 yrs (median year)	3 yrs	5 yrs	10 yrs	20 yrs	31 yrs (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.

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

The lowest mean flows not exceeded during periods of 7, 15, 30, 60, and 120 consecutive days for the Quinnipiac River at Wallingford (station no. 01196500) during the period April 1930 to March 1960 are:

Consecutive days	7	15	30	60	120
Year	1949	1957	1944	1941	1931
Flow, cfs	37	41	52	71	108
Flow, mgd per sq mi	0.22	0.24	0.31	0.42	0.64
Percent of time flow was equaled or exceeded	98.5	98	94	84	65

For the example used in the section titled "Duration of streamflow" the data tabulation (p. 12) indicate that the average flow equaled or exceeded 90 percent of the time is 1.6 mgd (2.5 cfs) and the average flow equaled or exceeded 99 percent of the time is 0.85 mgd (1.3 cfs). Table 4 shows that the 90-and 99-percent duration flows are equivalent to the 30-day, 2-year, and the 7-day, 10-year duration flows, respectively.

STORAGE OF WATER

LAKES, PONDS AND RESERVOIRS

Table 5 presents storage information relative to major surface-water bodies in the basin. The volume of usable water in storage that may be withdrawn by gravity through a valve or gate is shown as usable storage in table 5 and on plate D. Additional information on the public water supply reservoirs is given in table 33.

Estimating the amount of storage needed

If the minimum flow of a stream is inadequate for a projected rate of use, a dam and reservoir may be constructed to store water for subsequent release to maintain the desired flow. Table 6 shows the frequency with which various amounts of storage are required to maintain selected rates of regulated flow for the Quinnipiac River at Wallingford (station no. 01196500) during the reference period. Values of storage required for a recurrence interval of 2 years apply for the condition of median annual streamflow, and values for a recurrence interval of 31 years apply for the condition of lowest annual streamflow. This table may be used at other sites along the Quinnipiac River provided the percentage of the upstream area underlain by stratified drift is similar. The underlined values in table 6 are greater than the total volume of streamflow in some years and would not be replaced every year. The figures are based on frequency-mass curves which in turn are based on low-flow frequency relationships for the Quinnipiac River at Wallingford.

Amounts of storage required to maintain various rates of regulated flow in previously unregulated streams are presented in table 7. These data are for the indicated percentage of the drainage area underlain by stratified drift. Interpolations between percentages given may be made if necessary. Storage used to provide regulated flow would be replaced within 1 year, except for the underlined values. Table 7 is based upon an average streamflow of 1.16 million gallons per day per square mile of drainage area for the reference period, 1930-60. Before the table can be applied to a particular site, the rate of regulated flow and the amount of storage required must be adjusted to the average streamflow at the site by using the appropriate ratio determined from figure 8.

The amounts of storage required shown in table 7 are smaller than the true values because they include a bias of about 10 percent, which results from the use of the frequency-mass curve. Moreover, losses due to evaporation and seepage from the reservoir are not included.

Table 5.--Lakes, ponds, and reservoirs in the Quinnipiac River basin

Station no. (Pl. A)	Name and location	Drainage area (sq mi)	Surface area (acres)	Surface elevation (ft above msl)	Maximum depth (ft)	Average depth (ft)	Total storage	Usable storage 2/ (mg)	Principal use
01195320	Lake Gaillard Reservoir at North Branford	7.63	1,115	193	100+	42.7	15,500	13,000	Public su
01195342	Linsley Pond near North Branford	.91	23.3	29	44	20.5	155	-	Recreation
01195360	Pistapaug Pond Reservoir near East Wallingford	.59	140	388	-	26.3	-	1,200	Public supply
01195420	Lake Saltonstall Reservoir at East Haven	3.92	413	24	1/ 108	1/ 40.7	5,500	1,500	Public supply
01195450	Plainville (Crescent Lake) Reservoir near Plainville	.37	56	422	25	8.8	160	160	Public supply
01195700	Lake Compounce near Forestville	.43	1/ 27.5	201	1/ 19	1/ 10.2	91	-	Recreation
01195800	New Britain (Wolcott) Reservoir near Wolcott	2.45	54.5	763	20.8	9.6	170	170	Public supply
01196010	Cheshire (Prospect Lake) Reservoir near Cheshire	1.99	9	425	9.8	6.5	19	19	Public supply
01196050	Southington Reservoir No. 2 near Marion	1.07	23.5	664	23.1	13.5	104	104	Public supply
01196060	Southington Reservoir No. 1 near Marion	1.83	1.05	380	24.1	7.5	2.5	2.5	Public supply
01196070	Southington Reservoir No. 3 near Marion	1.83	16.4	442	18.8	9.5	51	51	Public supply
01196225	Broad Brook Reservoir near Meriden	4.85	306	147	40	10.1	1,000	1,000	Public supply
01196231	Elmere Reservoir near Meriden	.03	4	415	19	-	18	18	Public supply
01196235	Black Pond Reservoir near Meriden	1.18	76	381	23	8.6	212	-	Recreation
01196240	Bradley Hubbard Reservoir near Meriden	.59	35	310	18	14.7	168	168	Emergency
01196490	Community Lake at Wallingford	109	-	38	-	-	-	-	Power(?)
01196510	North Farms Reservoir near Wallingford	.74	1/ 62.5	331	1/ 5	1/ 3.1	1/ 63	63	Recreation
01196540	Spring Brook Reservoir near East Wallingford	.74	129	324	-	20	850	850	Public supply
01196560	MacKenzie (Pine River) Reservoir at East Wallingford	8.92	70	195	1/ 25	10	225	225	Public supply
01196625	Lake Whitney Reservoir at New Haven	36.4	178	30	5.6	4.5	258	258	Public supply
01196630	Lake Bethany Reservoir near Bethany	3.87	105	432	30	17.6	603	603	Public supply
01196633	Lake Watrous Reservoir near Bethany	7.28	110	224	36	19.8	709	709	Public supply
01196635	Lake Chamberlain Reservoir near Bethany	4.08	110	363	70.5	25.0	894	894	Public supply
01196636	Glen Lake Reservoir near Bethany	5.80	26	215	41	18.1	153	153	Public supply
01196638	Lake Dawson Reservoir near Bethany	13.9	75	162	32	13.0	318	318	Public supply
01196650	Lake Wintergreen Reservoir near Westville	1.05	45	241	10	6.8	100	100	Public supply
01196653	Maltby Lakes Reservoir No. 3 near West Haven	.78	23	169	12	6.8	51	51	Public supply
01196654	Maltby Lakes Reservoir No. 2 near West Haven	.23	23	169	31	17	127	127	Public supply
01196655	Maltby Lakes Reservoir No. 1 near West Haven	1.29	26	133	25	9.7	82	82	Public supply
01196669	Wepawaug Reservoir near Orange	7.72	10	183	17	4.6	15	15	Public supply

1/ Data from State Board of Fisheries and Game

2/ Data from State Public Utilities Commission

Table 6.--Storage required to maintain indicated regulated flows on the Quinnipiac River at Wallingford, Station number, Pl. A, 01196500

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

Recurrence interval of annual lowest mean flow (years) 1/	Maximum amount of storage which would refill during year of 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
1.2	..	..	..	..	..	..	..	..	..	1	3	5	8	11	14	18	27	38
2	..	..	..	..	..	..	..	..	3	6	10	15	20	25	31	38	52	69
5	75	..	..	..	..	..	1	4	8	14	21	28	35	43	52	61	<u>82</u>	<u>106</u>
10	71	..	..	..	..	1	4	9	14	21	29	37	45	55	66	<u>77</u>	<u>101</u>	<u>127</u>
31	61	..	..	..	1	3	7	13	21	30	40	50	61	<u>73</u>	<u>85</u>	<u>98</u>	<u>124</u>	<u>152</u>

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

The amounts shown in the table are sufficiently accurate, however, for preliminary planning and for tentative site selection. Furthermore, regulated flow rates assume continuous use and may be increased proportionately if use is intermittent.

The example used in the section titled "Duration of streamflow," was for a site with a drainage area of 8.0 square miles, 20 percent of which is covered by stratified drift, and located where the mean annual streamflow is 1.06 times statewide average. Suppose it is necessary to determine the amount of storage required to maintain a regulated flow of 2.2 mgd at this site. Adjusting the desired regulated flow for the drainage area at this site results in a unit regulated flow of 0.28 mgd per square mile. The mean annual streamflow at this site is 1.06 times the statewide average of 1.16 mgd per square mile, so the rate of regulated flow and the amount of storage shown in table 7 must also be multiplied by 1.06. For a drainage area 20 percent of which is covered by stratified drift, a recurrence interval of 31 years (driest year), and an adjusted regulated flow of 0.30 mgd per square mile (0.28 x 1.06), the required storage is 25.5 million gallons per day per square mile (24 mg/mi^2 x 1.06), or a total of 204 million gallons for the 8.0 square mile area (25.5 x 8.0). Adjusting for bias, evaporation, and seepage raises this to about 225 million gallons.

FLOODS

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

Since the first settlement of the region in 1638 there have been many great floods. Notable historic floods are known to have occurred in February 1807, May 1854, October 1869, January 1874, March 1876, September 1882, February 1886, January 1891, and March 1896.

Notable floods since the start of continuous records on the Quinnipiac River at Wallingford (station no. 01196500) in October 1930, are shown below:

Date	Stage (ft above msl)	Discharge (cfs)
March 12, 1936	28.44	2,680
January 26, 1938	28.02	2,340
September 21, 1938	29.79	5,230
January 1, 1949	28.21	2,500
August 30, 1955	29.25	3,790
October 17, 1955	28.73	3,000
February 3, 1970	29.24	3,770
February 3, 1973	29.15	3,590
December 21, 1973	28.86	3,180

The flood of September 21, 1938, is the greatest known.

Descriptive information on the major floods in New England through 1955 is given by Thomson and others (1964). More detailed records of the major floods of 1936, 1938, and 1955, based primarily on gaging-station records, are given in Grover (1937), Paulsen and others (1940), U.S. Geological Survey (1947), and Bogart (1960). Flood peaks above 900 cfs for the Quinnipiac River at Wallingford (station no. 01196500) were compiled by Green (1964).

MAGNITUDE AND FREQUENCY OF FLOOD FLOWS

Knowledge of the magnitude and frequency of flood peak stages and discharges is essential for land-use planning; design of flood-control structures, highways, and bridges; and for delineation of flood prone areas. A flood-magnitude-frequency curve for the Quinnipiac River at Wallingford (station no. 01196500) based on the period 1930-75 is given in figure 14. The maximum flood peak of record--5,230 cfs--which occurred September 21, 1938, has a ratio of 3.1 to the median annual flood of 1,700 cfs and a recurrence interval of 100 years on this curve. The moderate slope of the curve is probably due to the large amount of overbank

Table 7.--Storage required to maintain indicated flows at unmeasured sites on unregulated streams in the Quinnipiac River basin

(Data are adjusted to the reference period April 1930 to March 1960 and to an average flow of 1.16 mgd per sq mi. Storage required would refill 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 would 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	64	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	..	..	.	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	[illegible]
	10	65	..	..	..	..	..	2	5	9	15	21	27	34	42	51	61	82	[illegible]
	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	..	..	..	..	..	..	..	..	..	..	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.

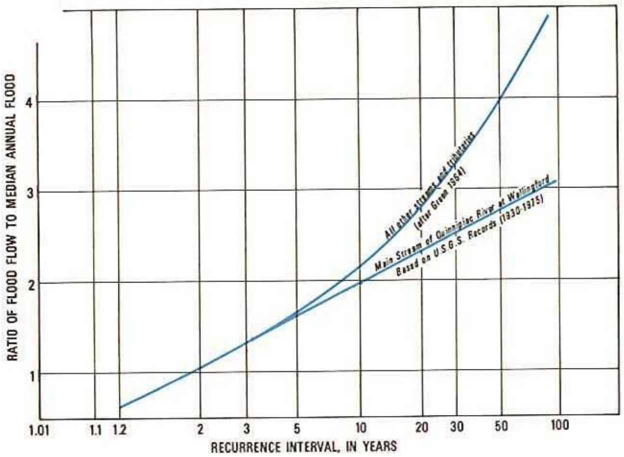


Figure 14.--Recurrence intervals of flood peak flows for the Quinnipiac River at Wallingford, Station No. (Pl. A) 01196500, and for all other streams in the basin.

storage in the lower reaches of the river. For preliminary planning, flood flows on streams other than the main stem of the Quinnipiac River can be estimated from the upper curves in figures 14 and 15, provided that overbank storage is not excessive. Streamflow must be unregulated, unaffected by storm sewers and have a drainage area of 2 square miles or more. Studies relating p[illegible] discharge to basin geometry (Bigwood and T[illegible]as, 1955) and to basin geometry and storm sewering (Weiss, 1975) are available.

The median annual peak discharge has a 50 percent chance of occurring in any year and may be estimated from the upper curve in figure 15 if the drainage area is known. Peak discharges for other recurrence intervals up to 100 years (1 percent chance of occurrence in any year) are obtainable by multiplying the median annual peak discharge by the appropriate ratio for any selected recurrence interval determined from figure 14. A peak-discharge-frequency tabulation for the gaging station on the Quinnipiac River at Wallingford (station no. 01196500) for the reference period 1930-60 is included in table 9 on the line numbered as "0" consecutive days (instantaneous peak discharges).

It is emphasized that the upper curves in figures 14 and 15 apply only to unregulated streams draining rural areas; flood peak discharges in urban areas are significantly higher owing to the presence of pavement and storm sewers, which shorten the concentration time of the runoff.

The terms "recurrence interval" or "return period," as commonly used in comparing the severity of floods, are based upon a continuous series of annual flood events. The reciprocal of the recurrence interval is the probability; i[illegible]s the percent chance of a flood of a given m[illegible]itude or greater occurring within any one year. In the design of structures such as bridges or culverts, it is necessary to consider the probability that a flood peak discharge with

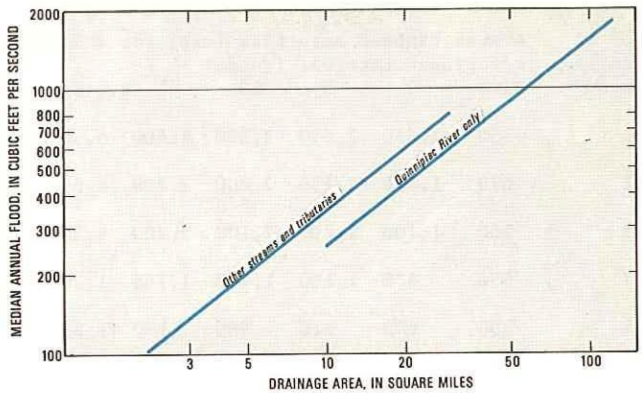


Figure 15.--Relationship between median annual flood and drainage area.

a selected annual recurrence interval will be exceeded within the design lifetime of the structure. Table 8 presents this relationship and is based upon the binomial distribution $P = 1-(1-p)^n$, where P is the probability that an annual flood with a selected recurrence interval, or its reciprocal "p," will be equaled or exceeded within "n" number of years. This relationship has been discussed and elaborated on by Markowitz (1971).

Table 8.--Probability of recurrence of annual flood peaks and high mean discharges

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

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

FREQUENCY AND DURATION OF HIGH FLOWS

The recurrence intervals of instantaneous peak discharges are shown in figure 14. For some purposes however, it is useful to estimate how long periods of high flow may last and how frequently they may recur. The recurrence intervals of highest mean flows observed for various periods of consecutive days at the gaging station on the Quinnipiac River at Wallingford (station no. 01196500) are shown in table 9. This table shows, for example, that for a period of 30 consecutive days a high mean flow of 760 cfs occurred on the average once in 10 years. Thus, there is a 10 percent chance of a 30-day high mean flow of 760 cfs in any one year. This flow corresponds to an average stage at the gage of 24.2 feet above mean sea level, as shown on the right side of the table. The instantaneous peak discharge recurring once in 10 years at this site is 3,300 cfs, with the corresponding stage of 29.0 feet above mean sea level. This discharge will probably occur in

Table 9.--Annual highest mean flows and corresponding average stages for indicated recurrence intervals for the Quinnipiac River at Wallingford, Station no. (Pl. A) 01196500

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

Period of consecutive days	Annual highest mean flow (cfs) for indicated recurrence interval (years) 1/							Annual highest average stage (ft above msl) for indicated recurrence interval (years)						
	1.03	2	5	10	25	50	100	1.03	2	5	10	25	50	100
0	750	1,650	2,550	3,300	4,400	5,300	6,300	24.2	26.9	28.3	29.0	..	..	..
1	670	1,400	2,150	2,800	3,700	4,500	5,400	23.9	26.3	27.8	28.6	29.2	..	..
3	560	1,100	1,700	2,100	2,700	3,300	3,800	23.3	25.5	27.0	27.7	28.5	29.0	37.3
7	450	800	1,100	1,400	1,700	1,900	2,200	22.8	24.4	25.5	26.3	27.0	27.4	27.8
15	350	600	810	960	1,150	1,300	1,400	22.3	23.5	24.4	25.0	25.6	26.0	26.3
30	280	480	640	760	900	1,000	1,100	21.8	22.9	23.7	24.2	24.8	25.1	25.5
60	250	400	520	600	830	820	900	21.6	22.5	23.1	23.5	24.5	24.5	24.8
150	190	310	390	450	510	560	600	21.2	22.0	22.5	22.8	23.1	23.3	23.5
274	150	240	300	350	390	420	450	21.0	21.6	22.0	22.3	22.5	22.6	22.8

1/ At gage

the same 30-day period during which the estimated high mean flow is 760 cfs.

Table 9 lists the recurrence intervals of annual highest mean flows for various numbers of consecutive days. The reciprocal of the recurrence interval is the probability of obtaining the mean flow or a greater flow for a specified number of consecutive days within any year. Table 8 can be used to determine the probability that the highest mean flow for a specified number of consecutive days with a selected annual recurrence interval will be exceeded within any design period.

HURRICANE TIDES

Hurricanes, or tropical cyclonic storms, have struck Connecticut frequently in the past. The first New England hurricane recorded occurred on August 15, 1635, and the greatest in the 20th century to date crossed the area September 21, 1938. This storm caused abnormally high tides and produced flood heights about 10 feet above mean sea level along the shore. Two major hurricanes, "Carol" and "Edna," hit the area only 11 days apart, on August 31 and September 11, 1954, causing loss of life and extensive property damage. Runoff from these storms is compared to monthly mean runoff of the Quinnipiac River at Wallingford (station no. 01196500) in figure 16.

The U.S. Army Corps of Engineers (1973) developed frequency relationships of maximum annual tides at New London and New Haven based on 34 years of record. Results for New Haven are summarized in the following table:

Table 10.--Frequency of maximum annual tides at New Haven

Height of tide at New Haven (feet above mean sea level)	Recurrence interval (years)
7.4	2
8.0	5
8.6	10
9.3	20
10.4	50
11.4	100
12.6	200

The table shows that the hurricane tide height on September 21, 1938, of about 10 feet above mean sea level at New Haven, has a recurrence interval of about 50 years.

QUALITY OF SURFACE WATER

DISSOLVED SOLIDS

Streams

The dissolved-solids concentration in streams during low flow is generally at a maximum and gives an indication of their overall chemical quality. Low-flow dissolved-solids concentrations observed in the Quinnipiac River basin during this study are shown on plate E. Maximum concentrations in upland area streams in the western and southeastern parts of the basin are 100 mg/l or less, whereas most streams in the central part ranged from 100 mg/l to about 500 mg/l. The relatively low values in the uplands

Table 11.--Source and significance of common constituents of water

Chemical constituent or physical property	Source and concentration	Significance and recommended maximum limit [1/]
Silica (SiO_2)	Dissolved from practically all rocks and soils. Most water in the basin contains amounts ranging from 1 to 20 mg/l.	High concentrations precipitate as hard scale in boilers, water heaters, and pipes. Inhibits deterioration of zeolite-type water softeners and corrosion of iron pipes.
Iron (Fe)	Dissolved from minerals that contain oxides, sulfides, and carbonates of iron. Decaying vegetation, iron objects that are in contact with water, sewage, and industrial waste are also major sources. Most water in the basin has less than 0.5 mg/l.	On exposure to air, iron in ground water oxidizes to a reddish-brown precipitate. More than about 0.3 mg/l stains laundry and utensils, causes unpleasant odors, and favors growth of iron bacteria. Iron in water is objectionable for food and textile processing. Most iron-bearing waters, when treated by aeration and filtration, are satisfactory for domestic use.
Manganese (Mn)	Dissolved from many rocks and soils. Commonly associated with iron in natural waters but less common. Most water in the basin has less than 0.01 mg/l.	More than 0.05 mg/l oxidizes to a black precipitate. Manganese has the same undesirable characteristics as iron but is more difficult to remove.
Calcium (Ca) and magnesium (Mg)	Dissolved from rocks and soils, especially those containing calcium silicates, clay minerals, and carbonate lenses.	Hardness and scale-forming properties of water are caused principally by dissolved bicarbonates and sulfates of calcium and magnesium. (See hardness.) Hard water is objectionable for electroplating, tanning, dyeing and textile processing. It also causes scale formation in steam boilers, water heaters, and pipes.
Sodium (Na) and potassium (K)	Dissolved from practically all rocks and soils. Sewage, industrial wastes, road salt, and sea water are also major sources. Most home water softeners increase the amount of sodium in water by exchanging it for calcium and magnesium.	Because the concentration of potassium is usually low, sodium and potassium are often calculated together and reported as sodium. Quantities found in the fresh water of the report area have little effect upon the usefulness of water for most purposes; however, more than 50 mg/l may cause foaming in steam boilers. Twenty mg/l is the maximum permitted for people restricted to a low salt diet. Recommended maximum 20 mg/l for finished water.
Carbonate (CO_3) and bicarbonate (HCO_3)	Dissolved from carbonate and calcium silicate minerals by reaction with carbon dioxide in water. Decaying vegetation, sewage, and industrial wastes are also important sources.	Carbonates of calcium and magnesium cause hardness, form scale in boilers and pipes, and release corrosive carbon dioxide gas. (See hardness.) Water of low mineral content and low bicarbonate content in proportion to carbon dioxide is acidic and corrosive.
Sulfate (SO_4)	Dissolved from rocks and soils containing sulfur compounds, especially iron sulfide; also from sulfur compounds dissolved in precipitation, and sewage and industrial wastes.	Sulfates of calcium and magnesium cause permanent hardness and form hard scale in boilers and hot water pipes. Recommended maximum 250 mg/l.
Chloride (Cl)	Dissolved from rocks and soils in small amounts. Other sources are animal wastes, sewage, road salt, industrial wastes, and sea water. Chloride concentration of natural fresh water in the basin is less than 20 mg/l.	Large amounts in combination with calcium will result in a corrosive solution and in combination with sodium will give water a salty taste. Recommended maximum 250 mg/l.
Fluoride (F)	Dissolved from minerals. Natural water in the basin has up to 0.3 mg/l. Added to public water supplies by fluoridation.	About 1.0 mg/l of fluoride reduces the incidence of tooth decay in young children; larger amounts may cause mottling of tooth enamel, depending on average water intake and climate (Lohr and Love, 1954, p. 39). Recommended limits: 0.8 to 1.2 mg/l for artificially fluoridated water; maximum 2.0 mg/l for natural water.
Nitrate (NO_3)	Sewage, industrial wastes, fertilizers, and decaying vegetation are major sources. Lesser amounts are derived from precipitation and solution processes.	Small amounts have no effect on usefulness of water. A concentration greater than 10 mg/l generally indicates pollution. Nitrate encourages growth of algae and other organisms which produce undesirable tastes and odors. Water containing more than 44 mg/l has reportedly caused methemoglobinemia, which is often fatal to infants (Comly, 1945). Recommended maximum 10 mg/l of nitrate expressed as N, which is equivalent to 44 mg/l nitrate expressed as NO_3.
Specific conductance	Specific conductance, or the capacity of water to conduct an electric current, is an index of total dissolved mineral content.	A specific conductance of 800 micromhos at 25°C is approximately equivalent to a dissolved-solids concentration of 500 mg/l.
Dissolved solids	Includes all dissolved mineral constituents derived from solution of rocks and soils. Locally augmented by mineral matter in sewage and industrial wastes. Measured as residue on evaporation at 180°C or calculated as numerical sum of amounts of individual constituents. In the basin, ground water generally has a higher concentration of dissolved solids than does surface water	Water containing more than 1,000 mg/l dissolved solids is undesirable for public and private supplies and most industrial purposes.
Hardness (as $CaCO_3$)	Primarily due to calcium and magnesium, and to a lesser extent to iron, manganese, aluminum, barium, and strontium. There are two classes of hardness, carbonate (temporary) and noncarbonate (permanent. Carbonate hardness refers to the hardness balanced by equivalents of carbonate and bicarbonate ions; noncarbonate refers to the remainder of the hardness. Most waters in the basin are classified as soft to moderately hard.	Hard water uses more soap to lather and deposits soap curds on bathtubs. Water having a hardness of more than 120 mg/l is commonly softened for domestic use. Hardness forms scale in boilers, water heaters, radiators and pipes, causing a decrease in rate of heat transfer and restricted flow of water. In contrast, water having a very low hardness may be corrosive. A classification of hardness appears under "Hardness" in the section entitled "Quality of surface water."
Hydrogen ion (pH)	Water having concentrations of acids, acid-generating salts, and free carbon dioxide has a low pH. Where carbonates, bicarbonates, hydroxides, phosphates and silicates are dominant, the pH is high. Most natural waters range between 6 and 8.	A pH of 7.0 indicates neutrality of a solution. Values higher than 7.0 denote alkaline characteristics; values lower than 7.0 indicate acid characteristics. Acid waters and excessively alkaline waters corrode metals. Recommended limits 6.4 to 8.5 for finished water.
Color	May be imparted by iron and manganese compounds, algae, weeds, and humus. May also be caused by inorganic or organic wastes from industry. True color of water is considered to be only that remaining in solution after the suspended material has been removed.	Water for domestic and some industrial uses should be free of perceptible color. Color in water is objectionable in food and beverage processing and many manufacturing processes. Usually expressed in units of color rather than in mg/l. Recommended maximum 20 standard units for raw water, 15 units for finished water.
Dissolved oxygen (D.O.)	Derived from the atmosphere and from photosynthesis by aquatic vegetation. Amount varies with temperature and pressure and decreases during breakdown of waste material. Concentration can be expressed in mg/l or as a percentage of saturation.	Dissolved oxygen in surface water is necessary for support of fish and other aquatic life. It causes precipitation of iron and manganese in well water and can cause corrosion of metals. Standards for many streams and lakes in the basin are given in "Revised water quality standards" (Connecticut Department of Environmental Protection, 1973).
Detergents as MBAS	MBAS (methylene blue active substance) is a measure of the concentrations of detergents in water. Primary sources of alkyl benzene sulfonate (ABS) and linear alkyl sulfonate (LAS) are synthetic household detergent residues in sewage and waste waters.	High concentration of ABS causes undesirable taste, foaming, and odors. Indicates presence of sewage or industrial waste. In mid-1965 ABS gradually replaced by LAS, which is more degradable. Recommended maximum for MBAS 0.5 mg/l.
Temperature	Fluctuates seasonally in streams and shallow aquifers. At depths of 30 to 60 feet, ground-water temperature remains within 2°C or 3°C of mean annual air temperature (9°C to 11°C for the report area). Disposal of water used for cooling or industrial processing may cause local temperature anomalies.	Affects the usefulness of water for many purposes. For most uses, especially cooling, water of uniformly low temperatures is desired. A rise of a few degrees in the temperature of a stream may limit its capacity to support aquatic life. Warm water carries less oxygen in solution and is more corrosive than cold water.
Turbidity	An optical property of water attributed to suspended or colloidal matter which inhibits light penetration. May be caused by microorganisms, algae, suspended mineral substances including iron and manganese compounds, clay, silt, sawdust, fibers, or other materials. May result from natural processes of erosion or from the addition of domestic sewage, wastes from industries such as pulp and paper manufacturing, or sediment from construction activities.	Excessive concentrations are harmful or lethal to fish and other aquatic life. Turbidity is also undesirable in waters used by most industries, especially in process water. Turbidity can modify water temperature. Expressed either in standard units or in mg/l silica. Recommended maximum 5 units for raw water, 1 unit for finished water.

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

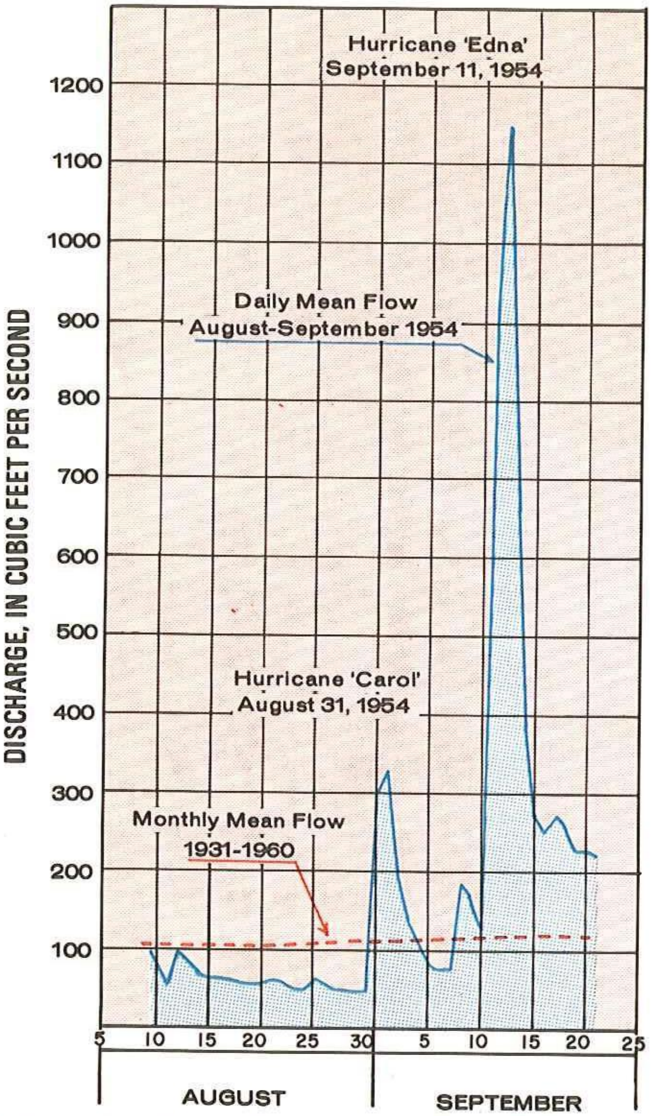


Figure 16.--Runoff from hurricanes "Carol" and "Edna" compared with monthly mean discharge of the Quinnipiac River at Wallingford, Station No. (Pl. A) 01196500.

are due to the following factors: (1) these areas lack extensive industrial and urban development and generally reflect the natural quality of water, (2) they are underlain by metamorphic rocks that are less soluble and less permeable than the sedimentary rocks of the central part of the basin, (3) the upland areas are more rugged and surface runoff is more rapid, allowing less time for solution of minerals, and (4) base flow is lower, hence a smaller part of the total runoff is from more highly mineralized ground water. To compare the relationships between dissolved-solids concentration in water, distribution of rock type, and urban development, see plates E and B, and figures 17 and 30.

Concentrations of dissolved solids generally increase from the headwaters to the mouths of streams, owing to prolonged contact of water with soils and rocks. Large changes in dissolved-solids concentrations may mark inflows of chemically different waters from tributary streams, springs, effluent outflows, or sea water. The source and significance of the most common constituents in water in the Quinnipiac River basin are listed in table 11. Silica, calcium, sodium, bicarbonate, sulfate and chloride, which together account for more than 90 percent of the dissolved solids in the samples analyzed, are derived from several sources. Silica, calcium, and bicarbonate are dissolved from soil and rock; sulfate is contributed by precipitation and by organic shale layers in sedimentary rocks; and sodium and chloride come mainly from sea water, sewage, industrial wastes, and road salts.

Table 12 summarizes the water quality data collected at 20 sites shown in figure 18. The concentrations of most constituents are higher in streams draining areas underlain by sedimentary bedrock. Calcium, magnesium, sulfate, and bicarbonate show the greatest differences between areas. Concentrations of most solutes are lower during high flow than during low flow. Variations in water quality with flow probably result from changes in the relative proportions of ground-water and surface-water runoff. The ground-water contribution to streamflow is fairly steady; surface runoff varies with rainfall and with the seasons. During low flow much of the water in a stream channel is contributed by ground-water runoff (base flow), which is generally more mineralized than surface runoff. The concentration of dissolved material in streams is, thus, inversely related to streamflow. This relationship is complicated by many factors, which cause variations in stream-water quality with time. Time and space differences in dissolved-solids concentrations of several streams in the Quinnipiac River basin at low and high flow are illustrated in figure 18.

Development affects the dissolved-solids concentration of surface water in many ways. Runoff from rural areas may contain animal wastes and fertilizers but generally is similar to that from natural areas. In suburbs there is a higher density of septic tanks and disposal basins that release wastes to the saturated zone from which ground water is discharged into streams and lakes. Cities have few septic tanks, yet the dissolved-solids load is high even in these areas because wastes from industries and sewage-treatment plants may be discharged directly to streams. In addition, runoff from streets and highways may contain litter, salts, herbicides, insecticides, and other contaminating substances.

The inverse relationship between streamflow and dissolved-solids concentration becomes more complex after development. Man-made changes in topography, vegetation, and percentage of impervious area in a basin affect the flow characteristics of streams. Stream quality generally deteriorates during low flow because treated sewage and other effluents are less diluted by surface runoff. If surface runoff is significantly contaminated, however, it will degrade rather than improve stream quality. Urban storm water may contain more dissolved solids than average

Table 12.--Chemical and physical properties of water from representative streams in the Quinnipiac River basin

(Concentrations of chemical constituents in milligrams per liter)

Constituent or property	Streams draining areas underlain by: Sedimentary rock 1/ At high flow 2/ Median	Range	At low flow 3/ Median	Range	Crystalline rock 1/ At high flow 2/ Median	Range	At low flow 3/ Median	Range
Silica (SiO_2)	7.2	6.3-9.0	10	7.9-14	6.0	4.8-8.2	4.8	1.8-11
Iron (Fe)	.24	.13-.58	.36	.06-.90	.22	.10-.50	.30	.01-.64
Manganese (Mn)	.04	.02-.18	.06	.01-.38	.06	.00-.20	.09	.02-.18
Calcium (Ca)	21	15-35	33	25-57	12	4.0-24	15	4.7-29
Magnesium (Mg)	4.1	2.3-7.1	5.9	2.8-9.9	3.2	1.2-5.2	3.4	1.4-6.5
Sodium (Na)	12	6.1-37	12	5.5-22	11	4.3-18	11	5.0-28
Potassium (K)	1.1	.6-1.7	1.2	.5-2.6	.9	.3-1.4	1.3	.4-2.6
Bicarbonate (HCO_3)	44	26-68	87	62-138	16	4-43	35	8-74
Sulfate (SO_4)	26	17-32	34	15-56	17	9.0-30	23	6.7-36
Chloride (Cl)	20	9.7-69	18	9.5-45	20	4.9-36	16	7.4-51
Fluoride (F)	-	-	.1	.1-.3	-	-	.1	.0-.2
Nitrate (NO_3)	4.5	1.6-8.4	6.5	3.8-11	2.8	.1-6.5	3.6	.4-5.4
Dissolved solids (residue on evaporation at 180°C)	124	84-249	156	117-272	93	36-155	106	57-174
Specific conductance (micromhos at 25°C)	217	135-432	270	196-450	163	58-265	196	70-329
Hardness, as $CaCO_3$, (Ca + Mg)	75	48-116	107	74-167	44	15-82	54	18-94
Hardness, as $CaCO_3$, (noncarbonate)	35	24-61	37	23-67	27	12-52	22	10-40
pH	7.3	7.0-7.5	7.6	7.4-8.0	6.9	6.4-7.3	7.2	6.7-7.4
Color, in platinum-cobalt units	12	4-39	5	2-8	8	3-30	4	0-55
Alkalinity, as $CaCO_3$	36	21-56	76	51-113	13	3-30	28	7-54
No. of samples	10		10		10		10	

1/ One sample each from 10 sites; complete analysis of each sample is in Water Resources Data for Connecticut (U.S. Geol. Survey, 1970-71).

2/ Ten percent duration flow, March 1970.

3/ Ninety percent duration flow, August 1970.

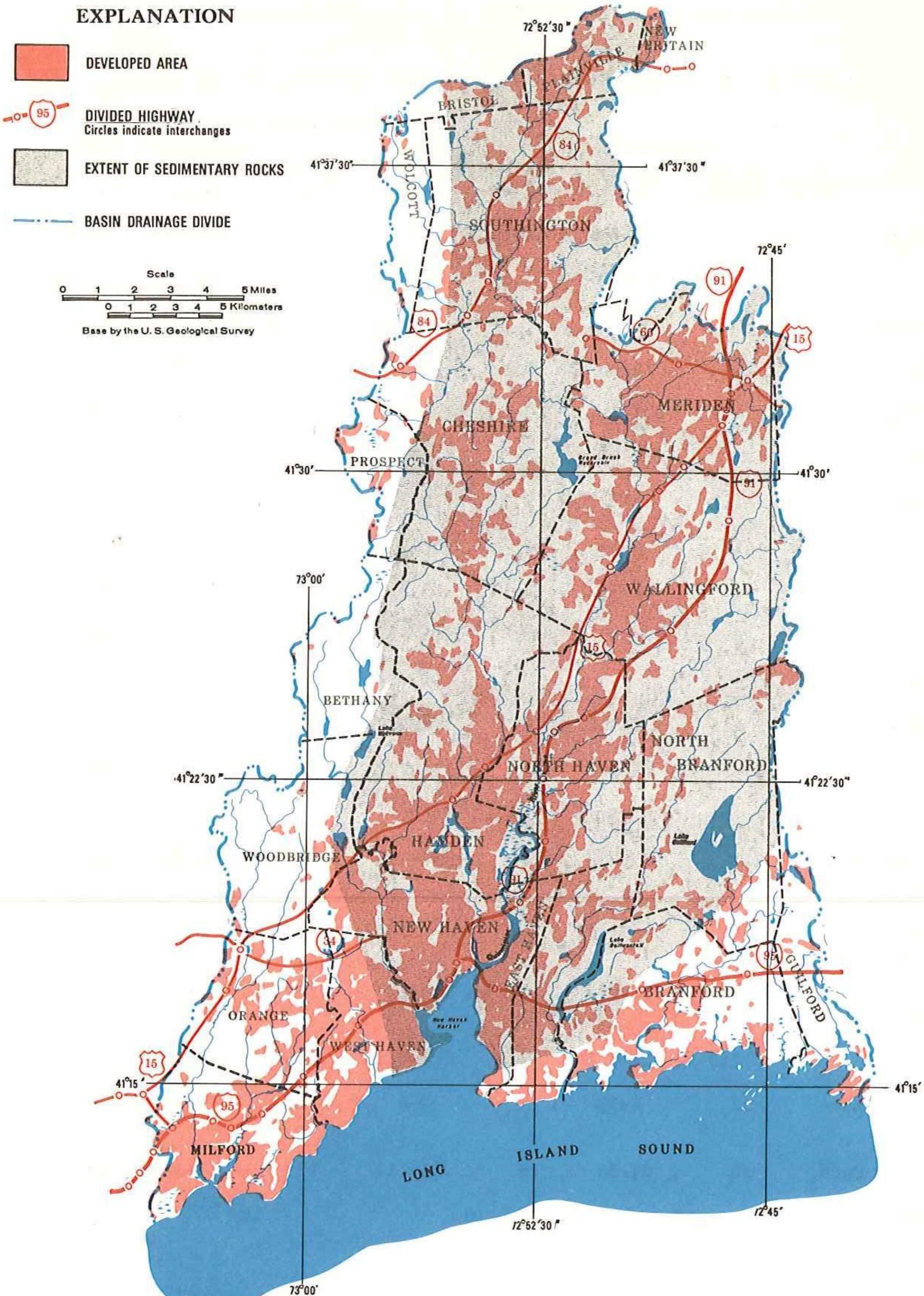


Figure 17.--Developed areas and major roads in the Quinnipiac River basin.

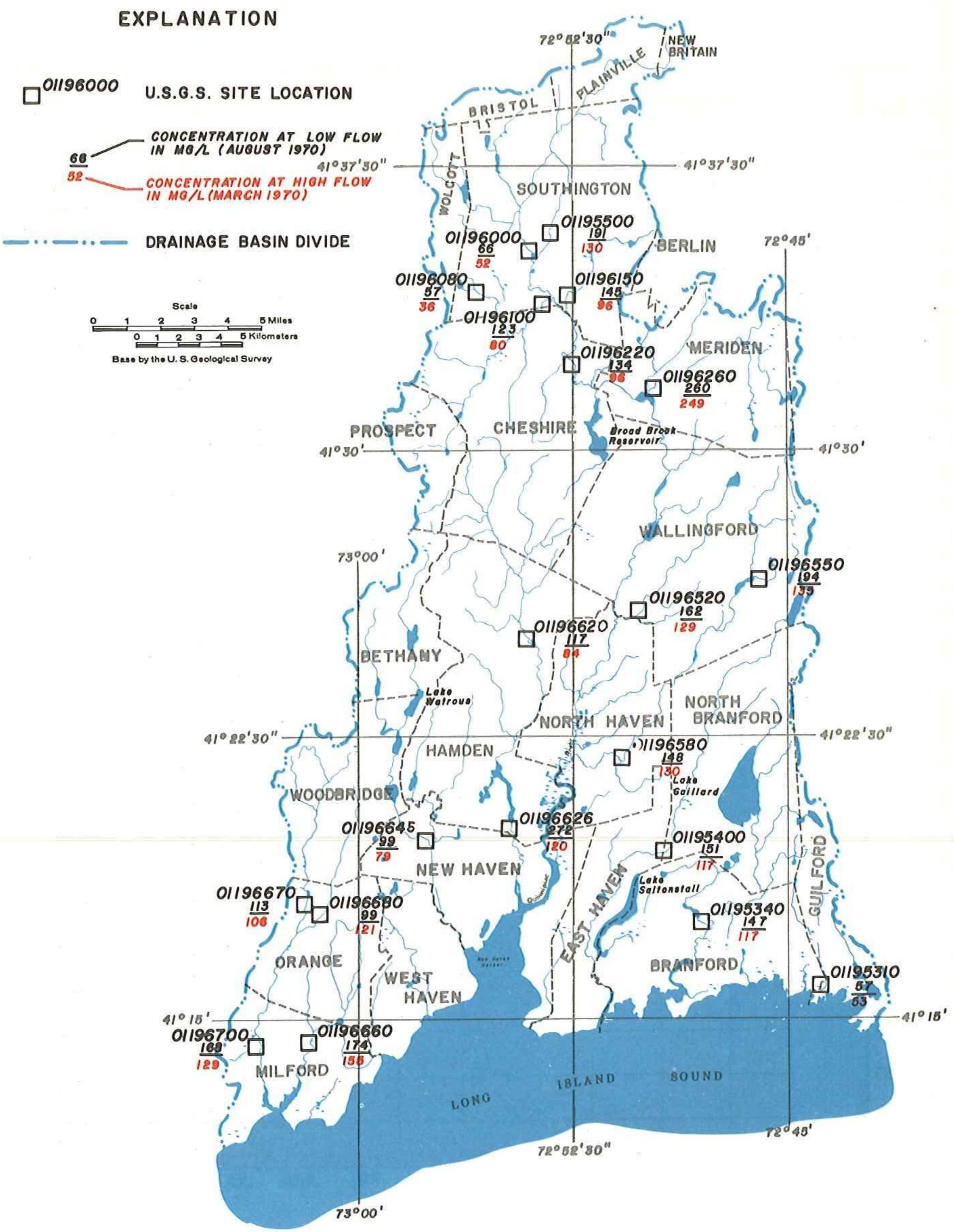


Figure 18.--Dissolved-solids concentrations in streams at low flow (90 percent duration) and high flow (10 percent duration).

Concentrations from residue on evaporation at 180°C, in milligrams per liter.

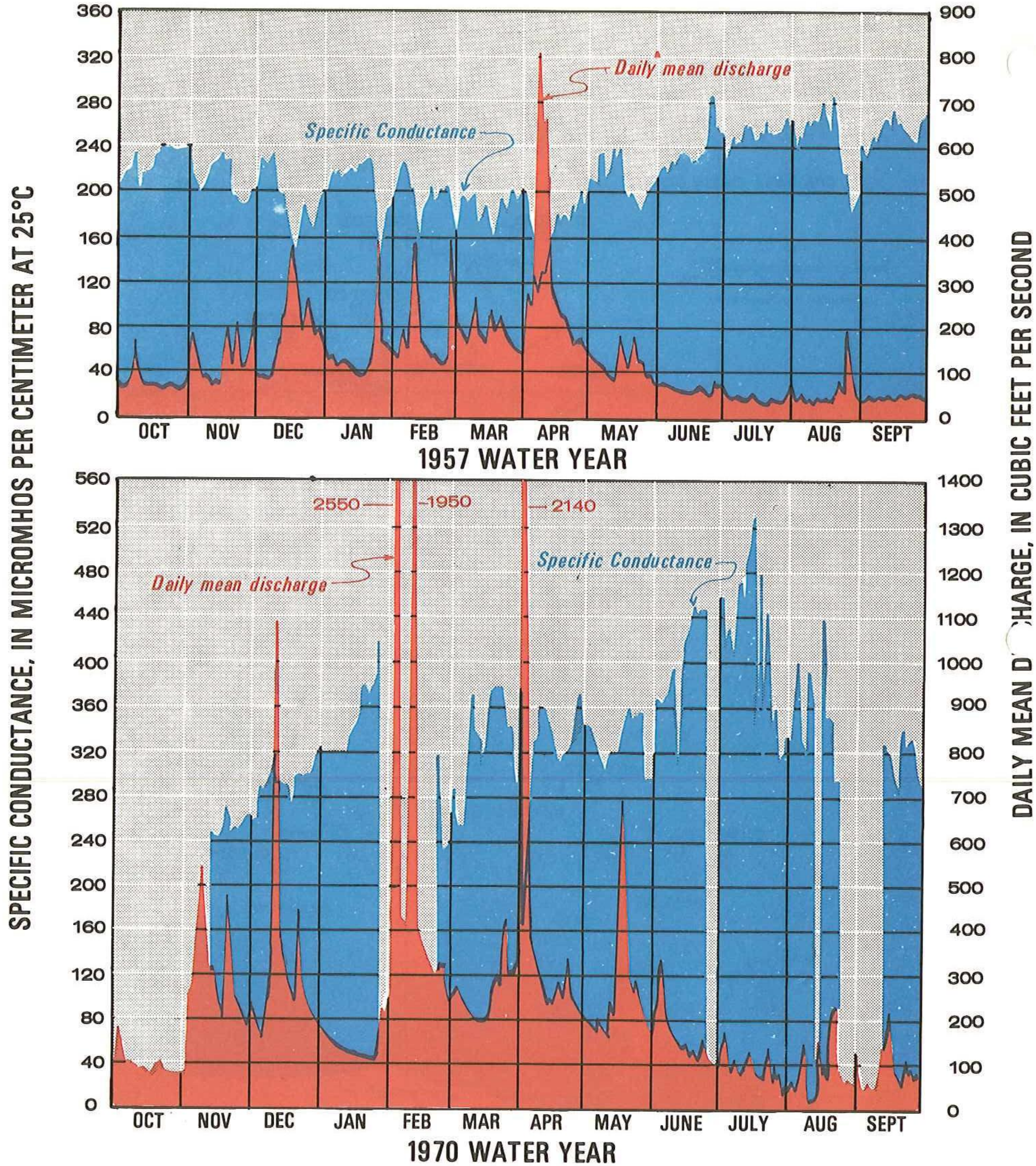


Figure 19.--Specific conductance and daily mean discharge, Quinnipiac River at Wallingford, Station No. (Pl. A) 01196500, 1957 and 1970 water years.

Specific-conductance record missing Oct. 1 - Nov. 12, Jan 28 - Feb. 23, June 25 - 28, Aug. 26 - Sept. 13, 1970 water year.

domestic waste water. Sartor and Boyd (1972) determined that urban runoff contributes more pollution load during the first hour of a moderate to heavy storm than does raw sanitary sewage from the same area during an equal period of ıe.

Selective discharge of industrial effluent during high flow, regulation of flow by reservoirs, diversion of water into and out of the basin and overflow from combined storm and sanitary sewer lines also influence the relationship between quality and streamflow. Dilution and assimilation of wastes in estuaries is affected by reversals of flow, differences in density between fresh water, salt water, and sewage and by the coagulation and flocculation effects of saline water; all these factors work against vertical mixing (McKee and Wolf, 1963) and influence waste assimilation rates.

Figure 19 shows specific conductance and daily mean discharge for the Quinnipiac River at Wallingford (station no. 01196500) for the 1957 and 1970 water years. The data show a greater variation in discharge, an increased mean annual discharge, and a higher average specific conductance in 1970. Also, correlation between discharge and specific conductance was less evident in 1970. The relationship between specific conductance and dissolved-solids concentration changed from 1957 to 1970, indicating that the types and proportions, as well as the amounts of solutes, had changed.

Water containing a higher proportion of sodium and chloride ions has a higher conductivity : a given dissolved-solids concentration than ..ater dominated by calcium and bicarbonate ions. Figure 20 shows the results of linear regression

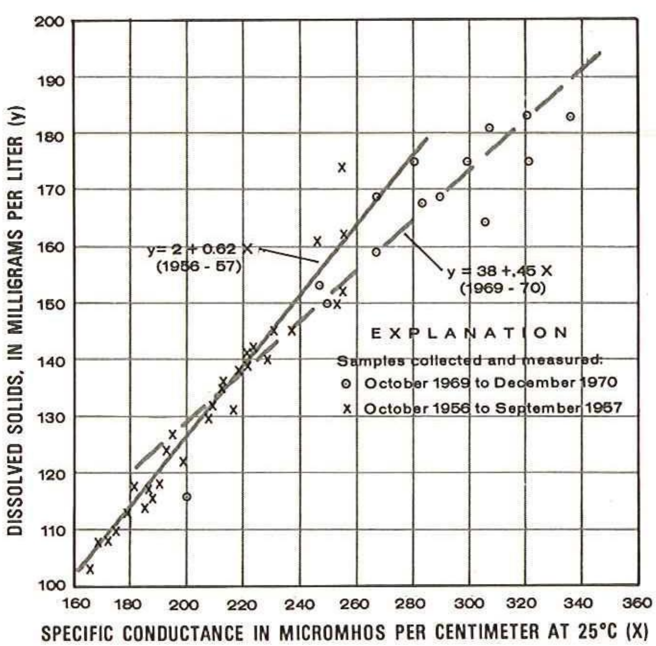


Figure 20.--Relationship between specific conductance and dissolved-solids concentration, Quinnipiac River at Wallingford, Station No. (Pl. A) 01196500.

analyses relating specific conductance to dissolved-solids concentration for the Quinnipiac River at Wallingford for water years 1957 and 1970. Concentrations of solutes during the 2 years are compared in table 13. Higher proportions of sodium and chloride ions in 1970 probably caused the change in the specific conductance versus dissolved-solids relationships shown in figures 19 and 20.

Table 13.--Comparison of water-quality data, Quinnipiac River at Wallingford, Station no. 01196500, 1957 and 1970 water years

(Concentrations of chemical constituents in milligrams per liter)

Constituent or property	1957 Water year 1/		1970 Water year 2/	
	Median	Range	Median	Range
Silica (SiO_2)	13	9.8 - 24	10	1.1 - 13
Iron (Fe)	.31	.12- .54	.61	.13- 3.0
Calcium (Ca)	22	16 - 28	28	17 - 33
Magnesium (Mg)	4.6	3.6 - 6.4	5	3.4 - 6
Sodium (Na)	9.6	6.8 - 14	16	12 - 21
Potassium (K)	1.7	1.2 - 2.7	2.0	1.2 - 3
Bicarbonate (HCO_3)	63	32 -110	70	34 - 84
Sulfate (SO_4)	24	16 - 29	28	23 - 39
Chloride (Cl)	9.4	6.5 - 13	26	19 - 30
Fluoride (F)	.1	.0 - .2	.2	.1 - 1.2
Nitrate (NO_3)	8.4	3.2 - 15	12	7.0 - 18
Dissolved solids 3/ (residue on evaporation at 180°C)	132	103 -174	169	116 -183
Specific conductance (micromhos at 25°C)	214	123 -257	312	247 -381
Hardness, as $CaCO_3$ (Ca + Mg)	75	46 - 95	94	56 -107
Hardness, as $CaCO_3$ (noncarbonate)	24	5 - 30	35	25 - 42
pH	6.9	6.6 - 7.1	7.3	7.0 - 7.9
Color in platinum-cobalt units	7	2 - 15	11	3 - 27

1/ Composite time-weighted samples collected daily.
2/ Single samples collected monthly.
3/ Daily specific conductances fluctuated over a wide range indicating a wider range of dissolved-solids concentrations in both years.

The differences between the 2 years result from changed patterns of industrial discharge, increased urban and industrial development, increased regulation of flow by reservoirs and mills upstream from the site, and diversion of water into and out of the basin. Population increased by about 25,000 between 1957 and 1970 in the 110-square-mile area drained by the Quinnipiac River upstream from the Wallingford site.

Growth has continued since 1970, but water samples collected monthly at this site (U.S. Geological Survey, 1971-75) show no significant changes in dissolved-solids concentration. Improved waste-water treatment during this period has apparently halted the deterioration of surface-water quality.

Lakes

Lake water has a more constant composition than stream water. Impoundment decreases turbidity, sediment load, and bacterial concentrations. Color is reduced by the bleaching effect of sunlight. Fluctuations in water quality follow annual and daily cycles that are related to seasonal climatic changes and the biological productivity of lakes. Temperature stratification occurs in some lakes and is discussed in the section titled "Temperature." Reducing conditions at the bottoms of thermally stratified lakes lead to the production of nitrite, ammonia, hydrogen sulfide and ferrous iron.

Most lakes in the study area are artificial impoundments used for public water supply. They are protected from contamination, and their quality is generally excellent. Table 14 summarizes the chemical quality of water samples from the 19 principal public-supply reservoirs serving the basin. The water has low dissolved-solids concentrations; the median value of 60 mg/l is less than half of the median, 132 mg/l, of water from streams in the basin.

Table 14.--Chemical and physical properties of water from public water-supply reservoirs serving the Quinnipiac River basin

(Concentrations of chemical constituents in milligrams per liter. Based on analyses of single samples collected in April and May, 1970, from 19 reservoirs)

Constituent or property	Median	Range
Silica (SiO_2)	5.3	2.2 - 9.8
Iron (Fe)	.07	.03 - .20
Manganese (Mn)	.00	.00 - .10
Calcium (Ca)	9.6	3.8 - 24
Magnesium (Mg)	2.2	.8 - 6.0
Sodium (Na)	4.1	1.8 - 9.6
Potassium (K)	.4	.0 - 1.1
Bicarbonate (HCO_3)	17	2.5 - 72
Sulfate (SO_4)	16	7.4 - 62
Chloride (Cl)	5.7	2.2 - 17
Fluoride (F)	.1	.0 - .7
Nitrite (NO_2)	.02	.00 - .05
Nitrate (NO_3)	.4	.0 - 3.7
Ammonium (NH_4)	.16	.04 - .25
Dissolved solids (residue on evaporation at 180°C)	60	28 - 137
Dissolved solids (sum of constituents)	56	30 - 123
Specific conductance (micromhos at 25°C)	88	43 - 224
Hardness, as $CaCO_3$ (Ca + Mg)	34	12 - 84
Hardness, as $CaCO_3$ (noncarbonate)	18	10 - 34
pH	7.1	5.9 - 8.0
Color, in platinum-cobalt units	5	1 - 14
Turbidity	.6	.2 - 1.0
MBAS	.02	.01 - .04

Two small ponds, Linsley and Cedar, contain higher dissolved-solids concentrations than the reservoirs. The high concentrations of dissolved sodium, chloride, phosphorus, and nitrogen and the highly eutrophic conditions in the ponds result largely from human activities and development in their drainage areas (Norvell and Frink, 1975).

IRON AND MANGANESE

Iron and manganese constitute only a small part of the dissolved- solids concentration in water in the Quinnipiac River basin. Although concentrations of these two ions are low, they are troublesome in places. Dissolved iron exceeding 0.3 mg/l and manganese exceeding 0.05 mg/l are problems for domestic and industrial users because they impart an objectional taste to water and precipitate on exposure to air. The reddish-brown iron oxides and black or gray manganese oxides discolor fabrics and plumbing fixtures. Many industrial processes, such as baking, canning, laundering, tanning, and textile manufacturing, require concentrations less than 0.2 mg/l of iron or manganese (table 36).

Table 15 summarizes iron and manganese content of surface water. Iron concentrations are higher than manganese concentrations in all samples tested. About half the stream-water samples contain objectionable amounts of these ions. The highest amounts are from streams draining swamps; the lowest are from public-supply reservoirs. Median concentrations are higher at low flow than at high flow because dilution of swamp discharge by surface runoff is less.

Table 15.--Iron and manganese in streams and reservoirs

(Concentrations in milligrams per liter)

Constituent		Streams draining areas underlain by: Sedimentary rock at high flow 1/	Sedimentary rock at low flow 2/	Crystalline rock at high flow 1/	Crystalline rock at low flow 2/	Reservoirs
Iron	Median	0.24	0.36	0.22	0.30	0.07
	Range	.13-.58	.06-.90	.10-.50	.01-.64	.03-.20
	Percent exceeding 0.3 mg/l	40	75	30	44	0
Manganese	Median	.04	.06	.06	.09	.00
	Range	.02-.18	.01-.38	.00-.20	.02-.18	.00-.10
	Percent exceeding 0.05 mg/l	40	50	70	67	10
Number of samples		10	8	10	9	19

1/ Ten percent duration flow, March 1970.
2/ Ninety percent duration flow, August 1970.

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

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

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

HARDNESS

Hardness in water results primarily from dissolved calcium and magnesium and to a lesser extent from dissolved barium, strontium, manganese, and iron. In the presence of soap, these ions precipitate and when heated, they form encrustations. Minerals in soil and rock, runoff containing agricultural lime, and calcium compounds used to deice roads contribute calcium and magnesium. A hardness classification (Durfor and Becker, 1964) and suitability of water of different hardness ranges for domestic and industrial use is given in table 16.

Table 16.--Hardness of water and resultant suitability

Descriptive rating	Hardness as $CaCO_3$, range in mg/l	Suitability
Soft	0-60	Suitable for many uses without softening
Moderately hard	61-120	Usable except for some industrial applications
Hard	121-180	Softening required by laundries and for most domestic uses
Very hard	181 or more	Softening required for most purposes

Surface water in the basin is soft to moderately hard (table 17). The hardness of stream water is greater during low flow because the proportion of ground-water runoff to surface runoff is greater. Streams draining areas underlain by sedimentary bedrock contain harder water than those draining crystalline bedrock because the calcium and magnesium carbonates in sedimentary rock are more abundant and more soluble than the calcium and magnesium silicates in crystalline rock. Hardness of stream water is further influenced by the exchange capacity of bottom sediments and suspended sediments. When sediment concentrations are high, more calcium may be adsorbed than dissolved.

Table 17.—Hardness of water in streams and reservoirs

(Concentrations in milligrams per liter)

		Streams draining areas underlain by: Sedimentary rock		Crystalline rock		
		at high flow 1/	at low flow 2/	at high flow 1/	at low flow 2/	Reservoirs
Calcium	Median	21	33	12	15	9.3
	Range	15-35	25-57	4.0-24	4.7-29	3.8-24
Magnesium	Median	4.1	5.9	3.2	3.4	2.1
	Range	2.3-7.1	2.8-9.9	1.2-5.2	1.4-6.5	0.8-6.0
Hardness, as $CaCO_3$ (Ca + Mg)	Median	75	107	44	54	34
	Range	48-116	74-167	15-82	18-94	12-84
Hardness, as $CaCO_3$ (noncarbonate)	Median	35	37	27	22	18
	Range	23-61	23-67	12-52	10-40	10-34
Percent of samples rated as: Soft		30	0	80	60	84
Moderately hard		70	70	20	40	16
Hard		0	30	0	0	0
Number of samples		10	10	10	10	19

1/ Ten percent duration flow, March 1970.
2/ Ninety percent duration flow, August 1970.

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

Hard water is commonly softened by the ion-exchange method in which sodium is exchanged for calcium. However, excessive sodium can be harmful to people who require a sodium-free diet. Extremely soft water is undesirable for some industrial uses, as it tends to be corrosive; it is also undesirable for irrigation, as it "puddles" on the soil surface (Swenson and Baldwin, 1965).

CHLORIDE AND NITRATE

Chloride in waters of the Quinnipiac River basin is derived principally from precipitation and salt spray in coastal areas, solution of soils and rocks, and tidal inflows. Additional amounts come from sewage, industrial wastes, road salts, fertilizers, animal wastes, and water softeners.

Most surface water is low in chloride. Before 1905, chloride ranged from 2 mg/l in the northern part of the basin to 6 mg/l along the coast (Jackson, 1905). These values were based on analyses of reservoir samples and represent minimum values for natural waters. Since 1905 concentrations in reservoirs have increased, as shown in table 18. The increase may be the result of changed storm paths or increased amounts of dissolved road salt and septic-tank effluent.

Increases in chloride concentrations were also observed in other reservoirs in Connecticut (Connecticut Department of Health, 1946, 1971) and in Massachusetts (Terry, 1974), suggesting that the trend is regional. Terry attributes the increase in Massachusetts to the application of road salt; this is probably the major cause

Table 18.--Chloride in selected reservoirs

(Concentrations as noted below)

Reservoir (Pl. D)		Period of record 1889-1902[1/]	1931-35[2/]	1936-40[3/]	1941-45[4/]	1966-70[5/]	1971-74[6/]
Lake Saltonstall	Mean	4.1	5.2	-	6.6	16.9	16.0
	Range	-	-	-	-	12-19	6-20
Lake Wintergreen	Mean	2.4	4.1	5.0	4.7	8.6	7.7
	Range	1.7-3.3	-	-	-	3.5-11	5-11
Merimere	Mean	1.9	3.3	2.6	3.0	6.3	4.4
	Range	1.1-2.4	-	-	-	4.5- 9	2-7
Maltby Lakes	Mean	2.3	4.3	4.2	4.2	22.6	22.3
	Range	1.3-3.1	-	-	-	19-28	10-32
Pistapaug Pond	Mean	2.6	3.3	3.0	3.3	8.2	7.3
	Range	2.4-3.4	-	-	-	7-9.5	3.5-13

1/ From Jackson (1905), concentration in ppm.
2/ From Connecticut Department of Health (1936), in ppm.
3/ From Connecticut Department of Health (1941), in ppm.
4/ From Connecticut Department of Health (1946), in ppm.
5/ From Connecticut Department of Health (1971), in mg/l.
6/ From unpublished data, Connecticut Department of Health, Environmental Services Division, in mg/l.

in most Connecticut reservoirs. The largest increase in chloride concentration was between 1945 and 1966, a period of rapid development. Many new roads were built and the use of salt compounds to deice pavement increased.

High chloride concentrations may not be toxic, but they affect the taste of water and increase its corrosiveness. Furthermore, chloride from road salt or from sea water can be accompanied by high concentrations of sodium, which are harmful to people restricted to low-sodium diets. Chloride from septic tank effluent or barnyard drainage can be accompanied by high concentrations of nitrate ions. Nitrate in water consumed by humans and some animals may be converted to nitrite by bacteria in their digestive tracts. Nitrite in the bloodstream converts hemoglobin to methemoglobin, resulting in oxygen deficiency, which can be fatal to infants (Committee on Water Quality Criteria, 1973). The Connecticut Department of Health (Connecticut General Assembly, 1975) recommends a maximum chloride concentration of 250 mg/l in drinking water, based on consideration of taste; a maximum sodium concentration of 20 mg/l, based on requirements of low-salt diets; and a maximum nitrate nitrogen, plus nitrite nitrogen, concentration of 10 mg/l (equivalent to 44 mg/l nitrate) for prevention of methemoglobinemia.

Table 19 shows chloride, sodium, and nitrate concentrations in surface water in the Quinnipiac River basin. No samples exceed the limit recommended for chloride or nitrate. Many stream samples, however, contain more than 20 mg/l of chloride, and two contain more than 10 mg/l of nitrate, probably indicating the effects of human activities. In more than half the streams sampled, the chloride and sodium concentrations were higher during high flow than during low flow, whereas nitrate concentrations of most samples were higher during low flow.

Coastal streams are affected by tidal fluctuations, whose extent depends on factors such as streamflow, tidal stage, weather, and man-made structures. Sea water in estuaries moves upstream during low flow and downstream during high flow. The zone where sea water mixes with fresh water changes its shape and position in response to tidal, seasonal, and climatic conditions. Plate E shows the northernmost extent of brackish water observed in coastal streams and estuaries during this study.

Table 19.--Chloride, sodium, and nitrate in streams and reservoirs

(Concentrations in milligrams per liter)

Constituent		Streams draining: Natural (rural) areas at high flow [1/]	Natural (rural) areas at low flow [2/]	Developed areas at high flow [1/]	Developed areas at low flow [2/]	Reservoirs
Chloride (Cl)	Median	16	16	26	27	5.7
	Range	4.9-29	7.4-26	8.3-69	14-51	2.2-17
	Percent of samples exceeding 20 mg/l	40	10	50	60	0
Sodium (Na)	Median	9.1	8.6	14	10	4.1
	Range	4.3-13	5.0-12	5.6-37	8.3-28	1.8- 9.6
	Percent of samples exceeding 20 mg/l	0	0	10	30	0
Nitrate (NO_3)	Median	2.4	4.2	4.4	5.3	0.4
	Range	0.1- 6.9	0.4-11	1.6- 8.4	2.9- 9.0	0.0- 3.7
	Percent of samples exceeding 10 mg/l	0	20	0	0	0
No. of samples		10	10	10	10	19

1/ Ten percent duration flow, March 1970.
2/ Ninety percent duration flow, August 1970.

TRACE ELEMENTS

Six reservoirs in the basin were sampled for trace elements on October 14, 1970, as part of a nationwide study of metropolitan water sources (Durum, and others, 1971). Trace elements in water can be indicators of industrial wastes and can be toxic. The Connecticut Department of Health has established maximum permissible levels for trace metals in drinking water (Connecticut General Assembly, 1975). The results of the survey are compared with analyses of water from the Quinnipiac River at Wallingford (station no. 01196500) and water from 12 wells in the basin sampled during the same water year (table 20). All samples contained trace element concentrations well below the Connecticut Department of Health standards.

Table 20.--Trace element data for waters from the Quinnipiac basin and other areas

(Water in reservoirs, Quinnipiac River, and wells in the Quinnipiac River basin compared with water from large North American streams and municipal supplies)

Name		Trace-element concentration, in micrograms per liter: Hexavalent chromium (Cr^{+6})	Lead (Pb)	Zinc (Zn)	Cobalt (Co)	Arsenic (As)	Cadmium (Cd)	Dissolved mercury (Hg)	Total mercury (Hg)
Reservoirs in Quinnipiac River basin:									
Lake Gaillard		0	0	0	1	0	1	0	0
Lake Saltonstall		0	0	0	2	0	1	0	0
Whitney Lake		0	0	10	1	0	1	0	0
Lake Watrous		1	2	0	2	0	1	0	0
Glen Lake		0	3	0	3	0	1	0	0
Lake Wintergreen		0	1	0	1	10	0	0	0
Quinnipiac River at Wallingford (station 01196500)		2	2	20	0	0	2	0	0
Large North American streams [1/]	Median	5.8	4.0	0	0	-	-	-	-
Treated water of 100 largest U.S. cities [2/]	Median	.43	3.7	-	-	-	-	-	-
	Range	0-35	0-62	0-610	-	-	-	-	-
Twelve wells in the Quinnipiac River basin	Median	0	3	45	0	0	0	0	0
	Range	0-5	0-8	3-630	0-2	0	0-21	0	0
Permitted maximum [3/]		50	50	-	-	50	10	2	2

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

BACTERIA

Coliform organisms in water are used by the Connecticut Department of Health as indicators of probable pollution by human or animal wastes. The Department recommends a limit of 20,000 coliform colonies per 100 ml (milliliters) in raw surface-water sources of drinking water. Concentrations up to this limit can be reduced to safe levels (1 colony/100 ml) by chlorination. Figure 21 summarizes bacterial concentrations in water samples from the Quinnipiac River at Wallingford (station no. 01196500) for the 6-year period ending in 1975. High coliform concentrations indicate pollution, and a high ratio of fecal coliform to streptococci shows that the pollution is partly a result of human wastes. The decrease in bacteria shown for the last few years is evidence of expanded sewage treatment in compliance with Public Act No. 57 the "Clean Water Act" (Connecticut General Assembly, 1967).

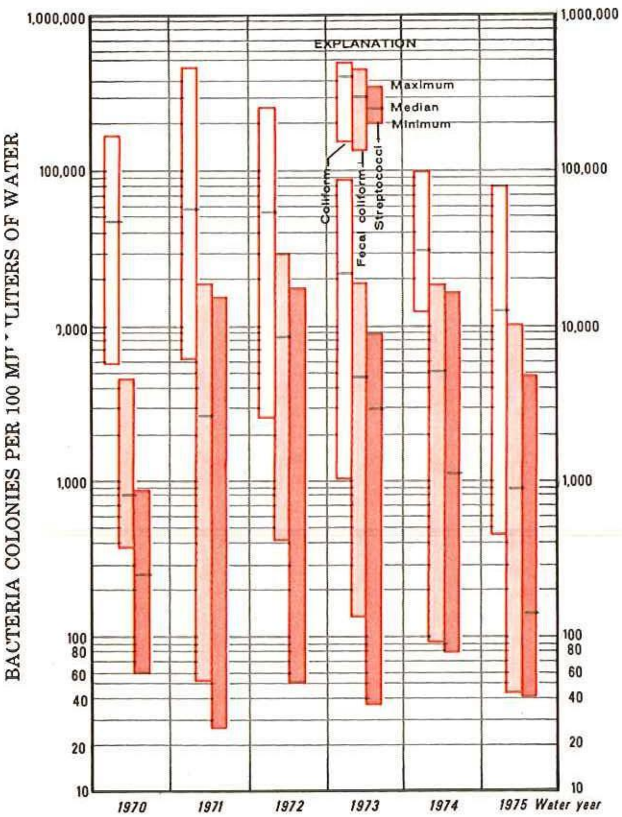


Figure 21.--Concentrations of bacteria in the Quinnipiac River at Wallingford, Station No. (Pl. A) 01196500.

Colonies of coliform, fecal coliform, and streptococci in stream-water samples.

SEDIMENT AND TURBIDITY

All streams carry sediments eroded from the land. The quantity carried at any time depends on the rate of erosion in the stream basin, which is related to climate, vegetation, slope, and soil and rock properties. The sediment load generally increases with increased streamflow. Clay and silt-sized sediments are transported in suspension by stream water; coarser-grained sand and gravel generally roll or bound along the stream bottom.

Turbidity, or cloudiness, of water is caused by the scattering and absorption of light by suspended particles. The particles may be organic substances or sediments.

Human activities alter the sediment regimen of a stream and may result in profound changes in sediment production. Runoff from agricultural land has a greater sediment yield than runoff from wooded land. Construction activities often produce large amounts of sediment. Urbanization increases the amount of overland flow and the frequency and magnitude of peak flows by increasing the number and size of impervious areas in a basin. This often results in increased erosion and sediment discharge. Storm sewers, however, can increase peak flows without increasing sediment discharge.

Highway construction may also lead to increased sediment loads. Parizek, 1971, reports sediment yields of 3,000 tons per mile during highway construction in Maryland. The sediment is derived from fresh excavations and destruction of vegetation. Divided highways require exposure and denudation of 10 to 35 acres per mile of road during construction. When completed, increased discharge and redirected runoff from pavements and embankments may result in further erosion. Another sediment load results from sanding roads in winter. Only about 40 percent of the 930,000 tons of sand used on Connecticut roads in a typical winter is recovered. The remainder is often washed into nearby streams, especially in rural areas where roads do not have catch basins.

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

Suspended particles reduce penetration of solar light and heat and cause a chain of reactions. Warming of water at the surface lowers its density and inhibits vertical mixing; this may reduce the downward transfer of oxygen required by plants and animals. Sediment and turbidity also affect the viscosity of water, the concentrations of dissolved solids, and the adsorption of toxic materials. These factors control the aquatic life and biologic productivity of a water body. Some sediment is beneficial, providing nutrients for plants. Increased sediment, however, can affect flora and fauna by abrasion, by reducing light transmission, and by destroying the habitat of bottom dwellers. Increased sediment and turbidity tend to decrease the recreational and esthetic value of a waterway.

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

Sediment and turbidity of streams in the Quinnipiac River basin are low except where affected by human activities. Samples collected monthly from the Quinnipiac River at Wallingford (station no. 01196500) had turbidity values ranging from 1 to 15 mg/l, with a median of 4 mg/l. Turbidity of public water-supply reservoirs serving the basin was considerably lower; no samples exceeded 1 mg/l. Although the amounts of suspended particles in streams in the basin are not generally objectionable, problems do occur during periods of construction. Such problems can be minimized by stabilizing exposed cuts and fills, constructing temporary barriers to reduce the velocity of storm runoff, adjusting time schedules to reduce exposure of soil, and by building streets parallel to topographic contours. Problems caused by road sanding in winter can be reduced by using less sand, sweeping more frequently, and constructing sediment traps.

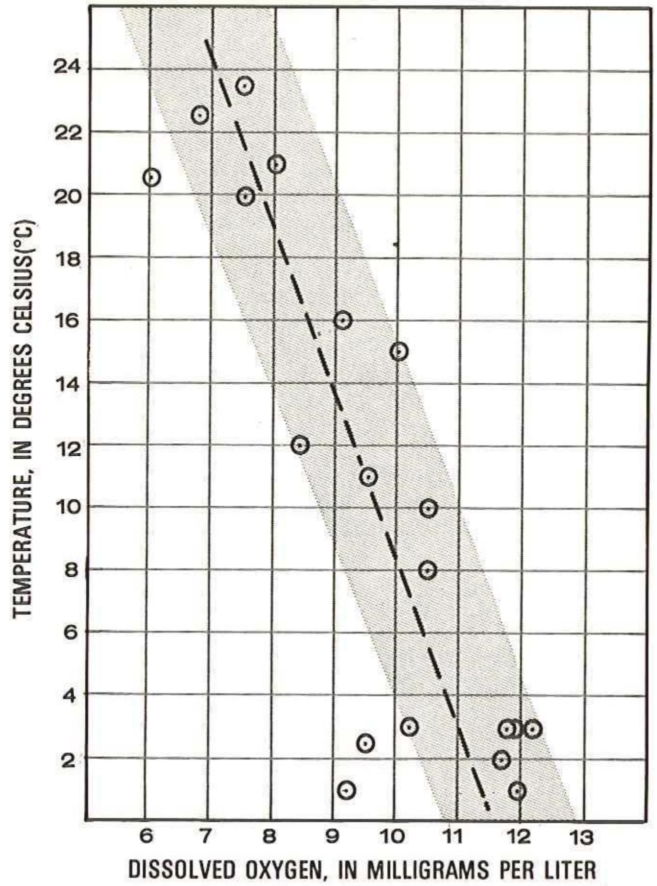


Figure 22.--Relationship between dissolved-oxygen content and water temperature, Quinnipiac River at Wallingford, Station No. (Pl. A) 01196500, Oct. 1969 to Apr. 1971.

Dissolved oxygen varies inversely with temperature.

DISSOLVED OXYGEN

The concentration of dissolved gases, controlled by the temperature, pressure, and biochemical condition of the water, has a significant effect on aquatic life. Adequate dissolved oxygen, for example, is necessary for survival and reproduction. Fish require concentrations above 4 mg/l to survive, and this minimum is not met in the deep layers of some lakes in summer. (See Linsley Pond in figure 27.) In surface water, dissolved oxygen is derived from the atmosphere and from photosynthesis of aquatic plants. It is consumed by aquatic life and the decay of organic materials. The amount present represents a balance between oxygen-producing and oxygen-consuming processes.

Dissolved oxygen decreases with increasing temperature. Figure 22 shows this relationship for the Quinnipiac River at Wallingford (station no. 01196500). Concentrations ranged from 6.0 mg/l, when the water temperature was 20.5°C, to 12.2 mg/l when the water was at 3.0°C. Monthly samples ranged from 65 to 97 percent saturation.

Waste assimilation consumes oxygen; therefore, the concentration of dissolved oxygen is an indirect measure of stream pollution. Consumed oxygen is replenished by reaeration, and both consumption and reaeration are functions of temperature. High water temperatures increase the activity of microorganisms but also deplete the dissolved oxygen they require. Optimum dissolved oxygen and temperature levels for waste assimilation depend on the composition of the wastes and on the species of microorganisms involved in their breakdown.

TEMPERATURE

Temperature affects the physical properties of water and the chemical and biological processes that take place in it. These processes affect man's use of water for many purposes. Cool water, up to 10°C, is desirable for domestic supply because chemical and biochemical reactions in warmer water produce undesirable tastes and odors. On the other hand, warmer water is treated more easily. Fish and other waterlife require a narrow range of temperature. A great or sudden increase can cause rapid death, and a moderate increase can cause slow death by increasing their metabolic rate and oxygen requirements and by decreasing their resistance to disease and toxic substances. Rapid warming can also lead to supersaturation of nitrogen and other gases and be harmful to fish. Irrigation requires moderate water temperatures because extreme temperatures affect crop growth. Some industrial uses, such as paper and pulp processing, require a uniform temperature; increases in the temperature of water used for cooling can increase costs.

Streams

A well shaded stream, fed primarily by ground water, has a narrow range of temperature generally similar to that of ground water except during freezing weather. Shaded streams fed by snowmelt also have a narrow temperature range. Temperatures of streams consisting largely of surface runoff show greater seasonal variation than those consisting largely of ground-water runoff.

Streams in the study area are fed by both ground water and surface runoff in varying proportions throughout the year. Their temperature follows a seasonal cycle corresponding to that of the air. This relationship is illustrated in figure 23. During the period November 1969 to December 1970, maximum water temperature of the Quinnipiac River near North Haven (station no. 01196520) was 26.5°C in July and August; minimum was 0°C in January and February. This range is representative of most streams in the basin.

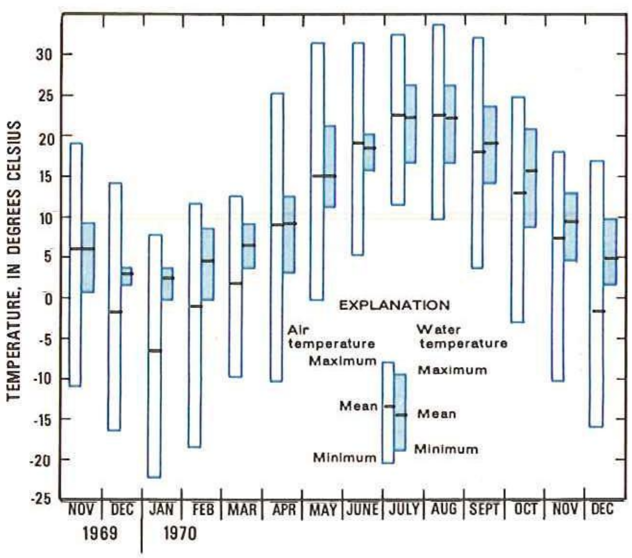


Figure 23.--Water temperature of the Quinnipiac River near North Haven, Station No. (Pl. A) 01196523, and air temperature at Mount Carmel.

Water temperatures based on continuous measurements; air temperatures from U.S. Weather Bureau, 1970.

Figure 24 shows duration curves of maximum and minimum daily temperature for the Quinnipiac River near North Haven. The median value at this station is 13°C, which is about 3 degrees

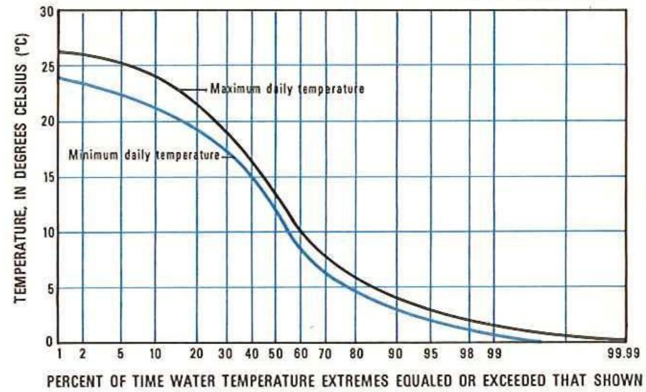


Figure 24.--Duration of maximum and minimum temperatures of the Quinnipiac River near North Haven, Station No. (Pl. A) 01196523, in 1970.

Percentages are based on continuous measurements.

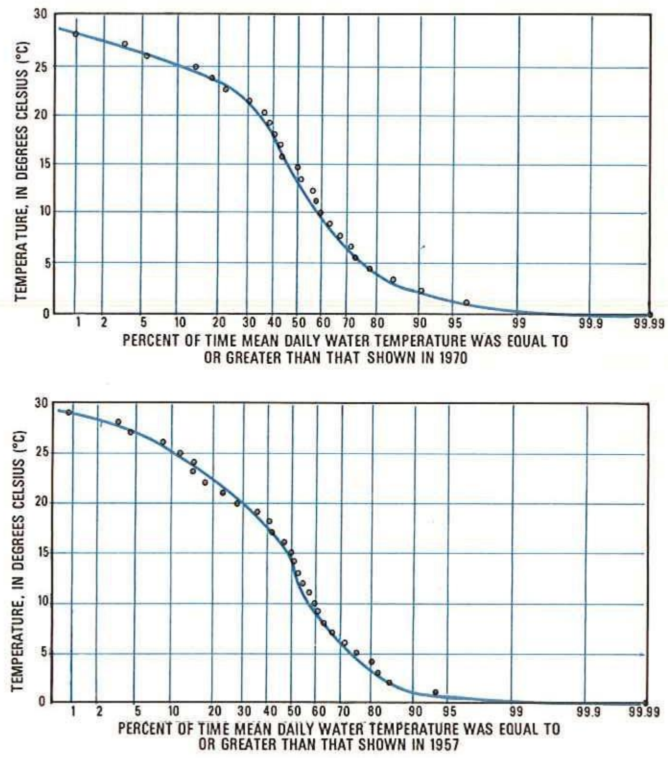


Figure 25.--Duration of mean daily temperatures of the Quinnipiac River at Wallingford, Station No. (Pl. A) 01196500, 1957 and 1970 water years.

higher than mean annual air temperature. Duration curves of mean daily temperature for the Quinnipiac River at Wallingford (station no. 01196500) for the 1957 and 1970 water years are shown in figure 25. In both water years, temperature duration was similar, although other characteristics, such as streamflow and dissolved-solids concentration, changed markedly. (See figures 19 and 20.)

Destruction of shading vegetation, deforestation of some reaches, and discharge of effluent into the Quinnipiac River contribute to its elevated temperature. Use of stream water can also affect its temperature. Reservoirs may alter downstream temperature, depending on their size, type of construction, and operation. Releases of water from selected depths in a stratified reservoir could permit management of downstream temperatures. Discharge of industrial wastes and water used for cooling generally increases stream temperature; discharge from power-generating plants causes the greatest increases. Constructing ponds, clearing streambanks of vegetation, installing sewers, and paving parts of a basin have been shown to significantly affect surface-water temperature in Long Island (Pluhowski, 1970).

Lakes

Temperature distribution in lakes is controlled by density, which can cause stratification. Thermally stratified lakes in the Quinnipiac River basin include Black Pond, Lake Gaillard, Linsley Pond, and Lake Saltonstall (Connecticut Board of Fisheries and Game, 1959). Temperature fluctuations and stratification in lakes follow a seasonal pattern, as illustrated in figure 26. In summer, warmer, less dense water (epilimnion) floats on deeper, cooler water (hypolimnion) separated by a narrow transition zone (metalimnion). Circulation between the layers is minimal. Dissolved oxygen concentration is low in the hypolimnion, making it unsuitable for fish and other aquatic life. In spring and fall, water temperature and density are uniform throughout the lake, allowing free circulation of the water. This brings iron, manganese, and decomposed organic materials to the surface, causing a seasonal increase in color and turbidity and a general deterioration of water quality.

Figure 27 shows profiles of selected quality constituents in stratified lakes in the basin. Data for Cedar Pond, an unstratified pond, is included for comparison. Dissolved oxygen and pH gradients are caused by diffusion of air at the surface, photosynthesis in shallow waters, respiration of aquatic life, and decay of organic matter at depth. The profiles are based on unpublished data collected by the Connecticut Bureau of Fisheries and Game (now the Connecticut Department of Environmental Protection, Fish and Water Life Unit).

Estuaries

The quality of water in estuaries is dominated by the great volumes of water flowing to and from the sea. Temperature at the mouth of an estuary is similar to that of the sea and fluctuates over a narrow range. Upstream, temperatures fluctuate more widely in response to seasonal climatic factors.

The relationship between fresh and salt water in an estuary ranges from simple to complex. In some estuaries, fresh water flows downstream over denser salt water without mixing. In others, complex mixing patterns develop; they may be influenced by river flow, tidal flow, and configuration of the estuary. The Quinnipiac estuary is partly mixed. Temperature of water in New Haven Harbor shows distinct seasonal fluctuations. The bottom temperature is generally colder than the surface temperature except during October and November, when the surface cools rapidly. During this period the temperature and density of the water column becomes nearly uniform, and vertical mixing takes place (Duxbury, 1963).

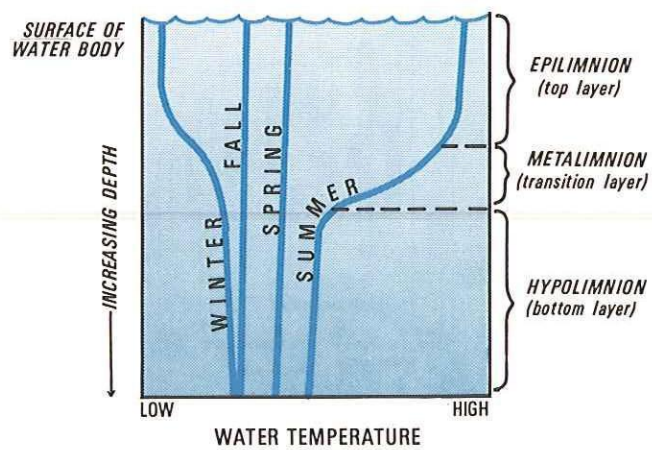


Figure 26.--Seasonal temperature variations in thermally stratified lakes, ponds, and reservoirs.

Generalized diagram adapted from Harmeson and Schneper, 1965, page 5.

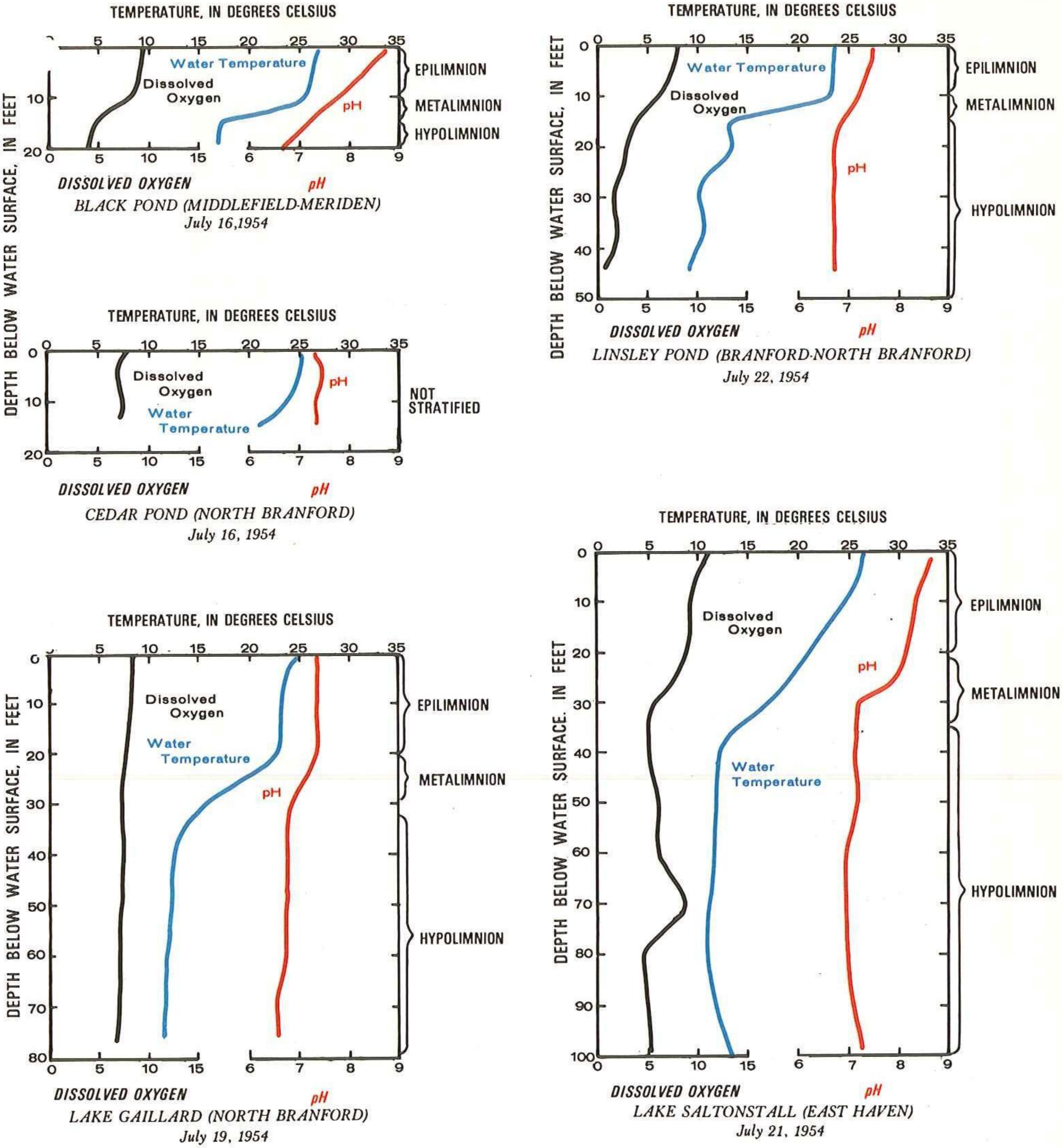


Figure 27.--Water-quality profiles of selected lakes and ponds.

Temperatures in degrees Celsius; dissolved-oxygen concentrations in milligrams per liter.

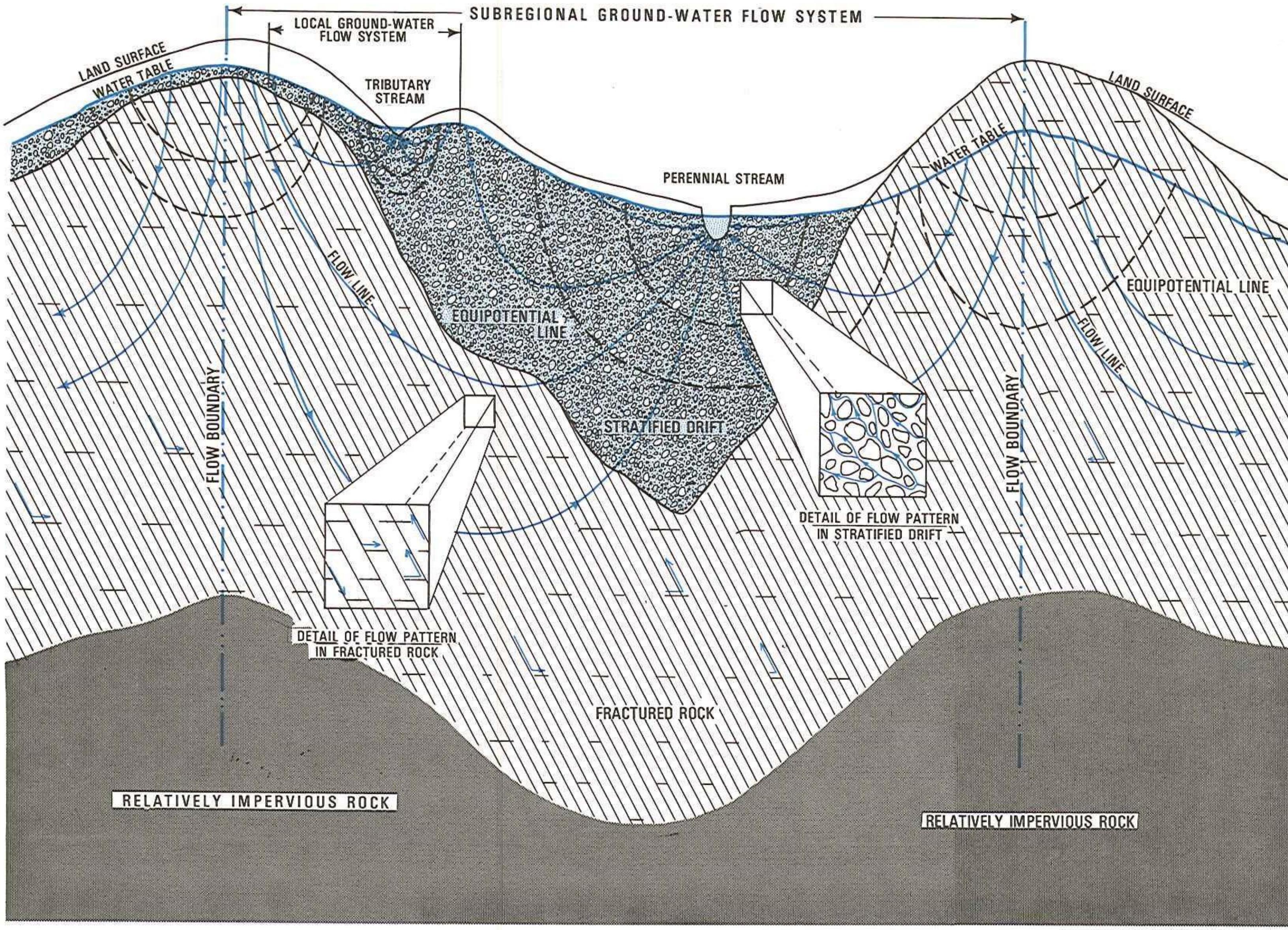


Figure 28.--Idealized pattern of water circulation in stratified drift and bedrock.

The direction of flow and distribution of head in stratified drift and fractured bedrock are depicted by flow and equipotential lines. The actual configuration of these lines in nature is more complex than shown principally because of variations in hydraulic conductivity of earth materials and the random occurence of fractures in bedrock.

GROUND WATER

MOVEMENT AND STORAGE

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

In bedrock, most open spaces occur as fractures (joints and faults). Bedrock has some intergranular (primary) porosity, but it is less significant than in unconsolidated materials. Primary porosity of crystalline bedrock in Connecticut ranges from 1 to 3 percent. Porosity of sedimentary rock is probably higher; data from other areas indicate it ranges from 5 to 15 percent (Todd, 1959). Many of the intergranular spaces in bedrock are not interconnected, however, and are of little consequence to ground-water circulation.

The head in a ground-water flow system is a measure of the potential energy of the fluid, and ground water flows in the direction of decreasing head. Differences in the water-table elevations of an unconfined flow system indicate the direction of horizontal ground-water flow.

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

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

(2) Subregional--moderately large ground-water flow systems that are generally confined to the areas drained by major perennial streams. They extend laterally from drainage divide to drainage divide and vertically downward to depths at which the bedrock has no interconnected fractures or a regional system predominates. Subregional systems occur in both unconsolidated deposits and bedrock. They are the most significant in respect to hydrologic analyses and are the ones most frequently tapped for ground-water supplies.

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

The general pattern of ground-water circulation is idealized in figure 28. At a given site, all three types of flow systems may exist. Several local systems may be incorporated within a subregional system, which, in turn, is part of a regional one.

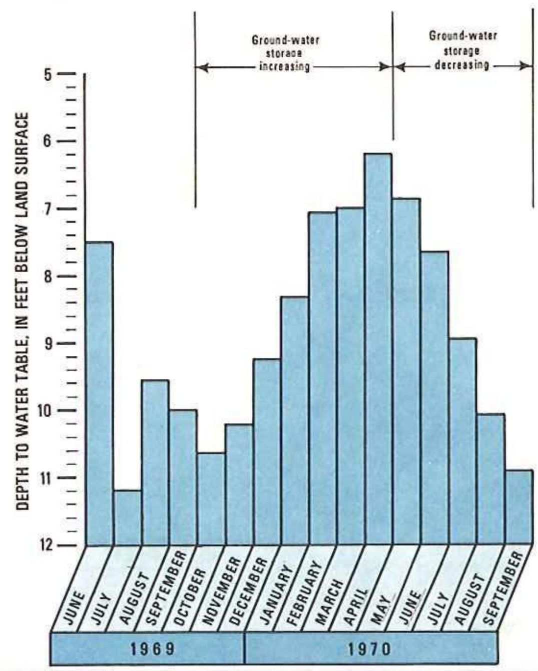


Figure 29.--Hydrograph of observation well NBR 79.

Water levels show changes in ground-water storage. May through September, 1970 shows a typical seasonal decline during the growing season. October, 1969 through April, 1970 shows a typical autumn and winter increase due to natural recharge. The unusual increase in storage in August, 1969 was due to heavy rainfall during the early part of the month.

Ground-water systems are dynamic, with water continually entering and leaving. The change in the quantity of water contained by the system is indicated by the periodic rise and fall of the water table. Figure 29 shows typical seasonal variations of water levels in observation well NBR 79, which is located in unconsolidated material in the Quinnipiac River basin. The water-level fluctuations represent changes in

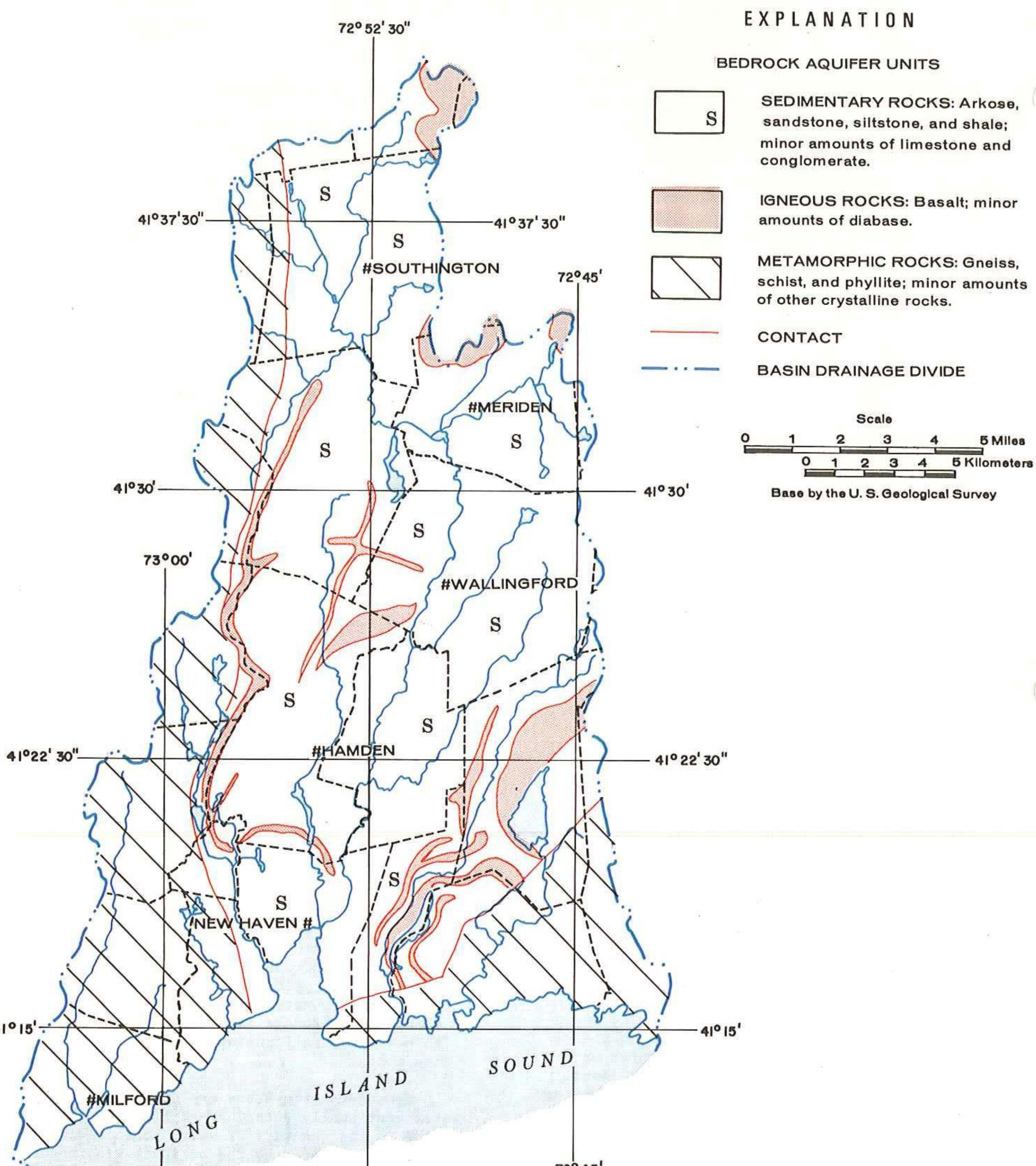


Figure 30.--Areal distribution of bedrock units.

ground-water storage due to variations in the recharge and discharge rates of the system. Under conditions of equilibrium, ground-water systems are in dynamic balance and water entering or leaving must be accounted for. In the equation t' ` describes this balance, water entering a g .d-water system is treated as one item, ground-water recharge; water leaving the system is divided into several components:

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

Where:

$GW_{(r)}$ = Ground-water recharge

$GW_{(ro)}$ = Ground-water runoff

$GW_{(et)}$ = Ground-water evapotranspiration

U = Underflow

S = Changes in ground-water storage

Ground-water recharge generally occurs during the nongrowing season (mid-October to mid-May). Ground-water discharge ($GW_{(ro)}$ + $GW_{(et)}$ + U) occurs throughout the year. The difference between recharge and discharge during any period is equal to the change in ground-water storage.

AQUIFERS

Aquifers are water-bearing subsurface units capable of yielding adequate quantities of water to wells. The composition, occurrence and hydrologic characteristics of the stratified d ˉt, till, and bedrock aquifers are discussed i. .ne sections that follow. Areal distribution of stratified drift and till is shown on plate B (back pocket); bedrock is shown in figure 30.

In most of the basin, bedrock is overlain by stratified drift or till. The spatial relationship between the three aquifer units is shown in figure 31.

STRATIFIED DRIFT

Stratified drift, the most productive of the aquifers, is composed of interbedded layers of gravel, sand, silt, and clay. These materials were deposited during the deglaciation of southern New England and generally occur in valleys and lowlands that were drainageways for glacial meltwaters or the sites of temporary glacial lakes. Minor amounts of unconsolidated sediments of nonglacial origin are also included with the stratified drift. About 25 percent of the basin is covered by stratified drift; its thickness exceeds 300 feet in places and averages about 100 feet.

Coarse sand and gravel generally occur in the narrow valleys and fine sand, silt, and clay, in the broad valleys. Extensive fine-grained deposits occur in the lower Quinnipiac valley south of Meriden and in the upper Quinnipiac, Eightmile, and Tenmile River valleys in the towns of Cheshire, Plainville, and Southington. (See plate B).

Stratified drift typically shows abrupt horizontal and vertical changes in texture. (See logs of selected wells and test holes in the companion basic-data report, Mazzaferro, 1973.) Although this variability often complicates ground-water exploration and development, the yields and response to pumping of individual aquifers can be evaluated. The amount of water that can be pumped from an aquifer depends on the following factors:

(1) Hydraulic properties
(2) Hydraulic boundaries

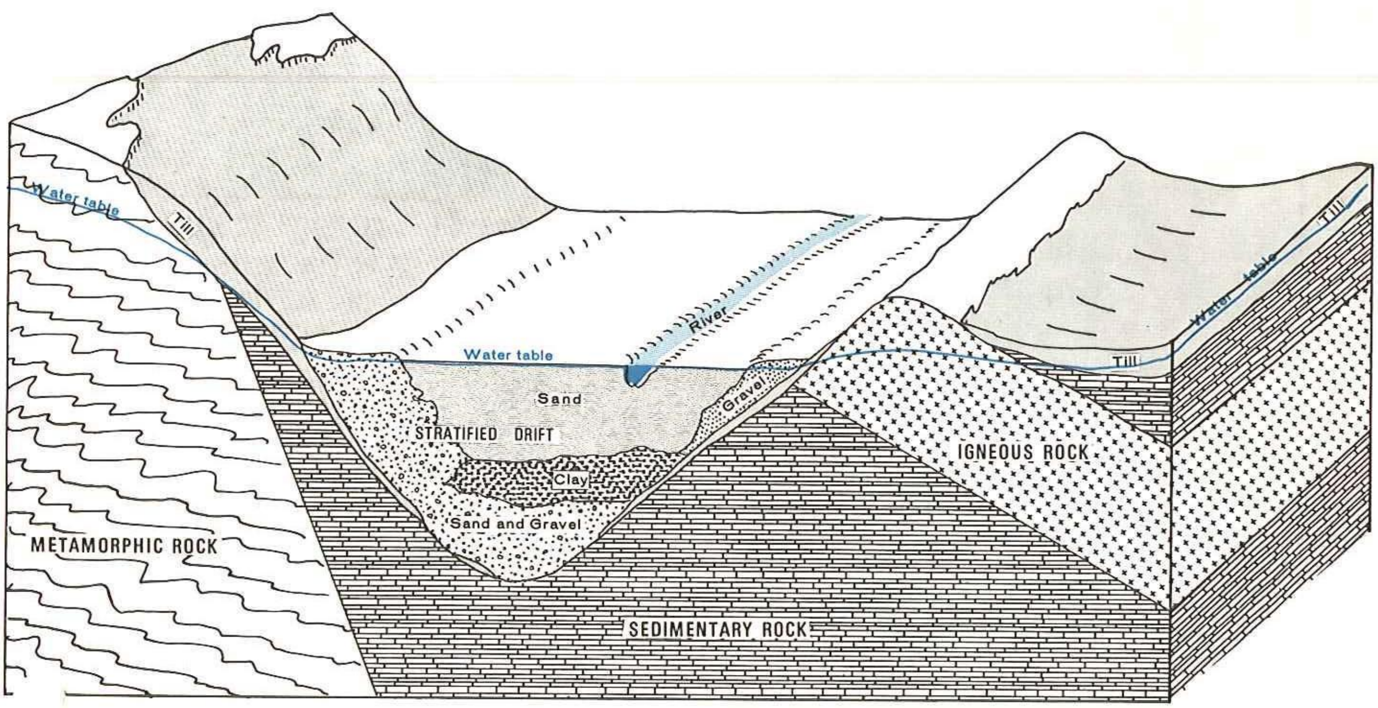


Figure 31.--Block diagram showing idealized spatial relationships between principal aquifers.

(3) Natural recharge
(4) Induced recharge
(5) Well characteristics

Each of these factors is discussed below. Yield data from wells tapping stratified drift are included in table 21, and yield frequency is shown in figures 32 and 33. The yields of screened wells give a better indication of the productivity of stratified drift than the yields of open-end wells because the latter are less efficient.

Table 21.--Yields of wells in the Quinnipiac River basin

(Maximum, minimum, and median yields of wells tapping bedrock and stratified drift)

Aquifer	Well type	No. of wells	Yield (in gallons per minute) Maximum	Minimum	Median
Crystalline bedrock					
Igneous (traprock) 1/	Open hole	45	75	2	7
Metamorphic 1/	Open hole	370	200	.1	8
Sedimentary bedrock 2/	Open hole	925	305	0	10
Stratified drift 1/	Open end	39	125	.2	12
Stratified drift 3/ 4/	Screened	64	2,000	14	500

1/ Well diameters 6 in.
2/ Well diameters 6-10 in.
3/ Screen diameters 6-24 in.
4/ Includes wire-wound and shutter screens.

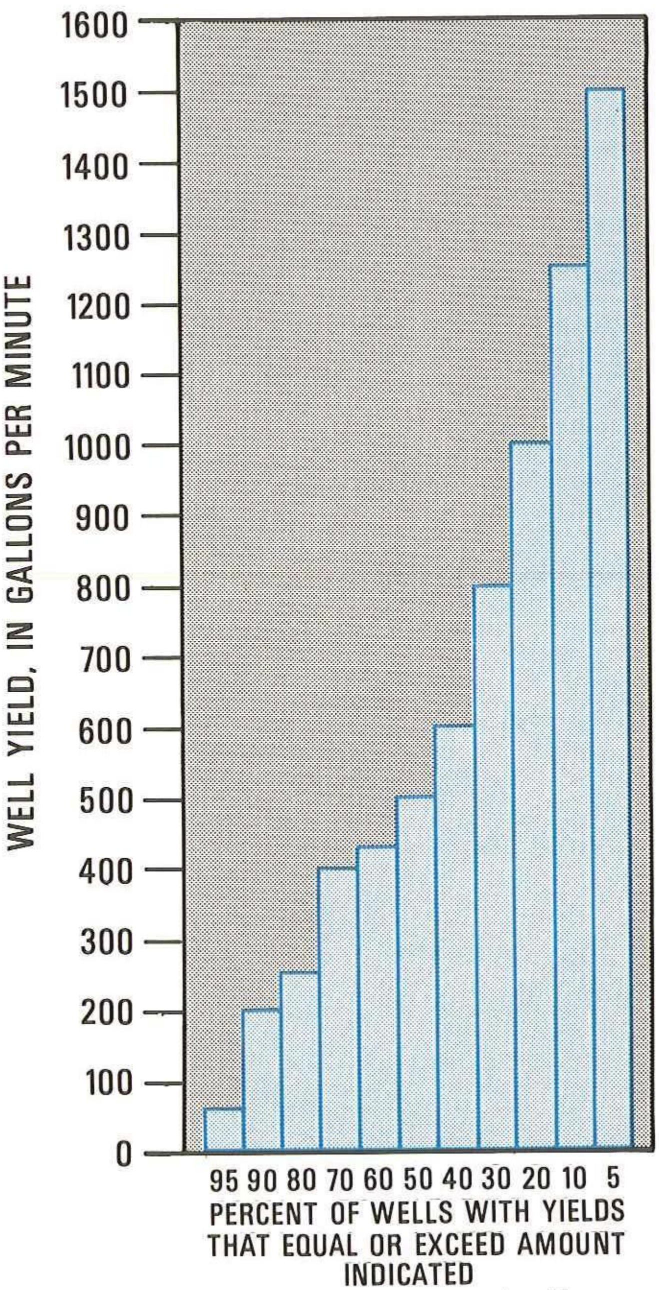


Figure 32.--Yield frequency of screened wells tapping stratified drift.

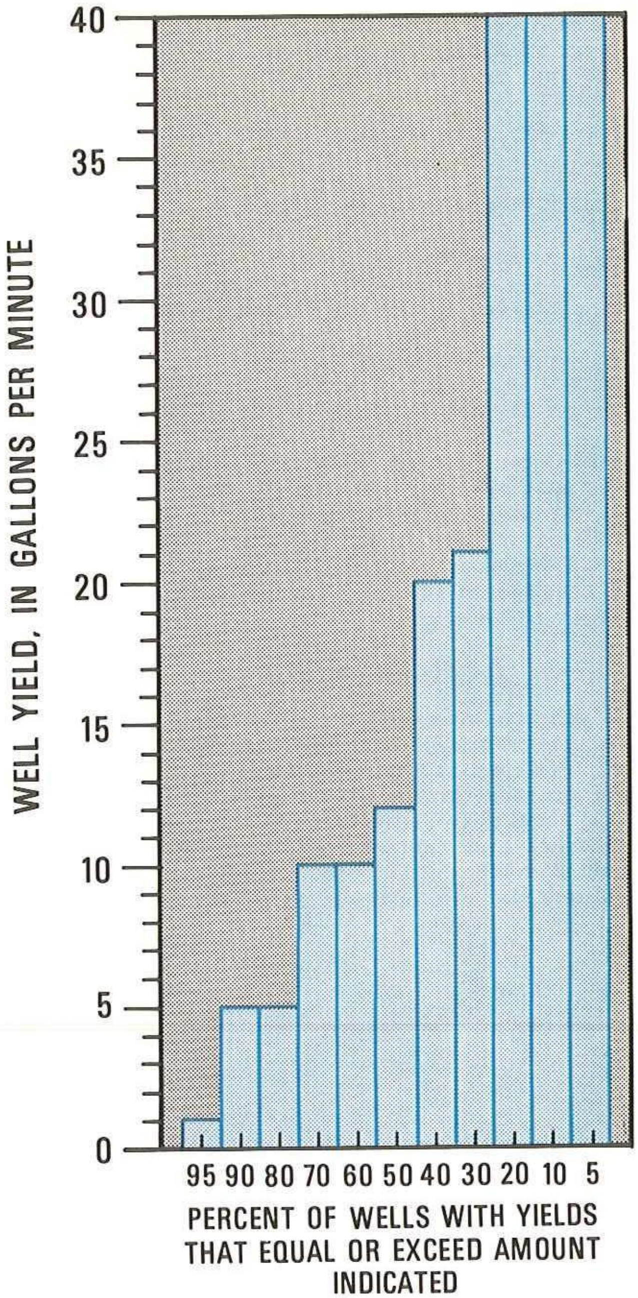


Figure 33.--Yield frequency of open-end wells tapping stratified drift.

Hydraulic properties

Saturated thickness, transmissivity, and storage coefficient are characteristics of stratified drift that describe its ability to store, transmit, and yield water. These characteristics enable prediction of the yield and drawdown of wells and head distribution in an aquifer due to withdrawal of water. Hydraulic boundaries, natural recharge, induced recharge, and well characteristics must also be considered to predict aquifer response accurately.

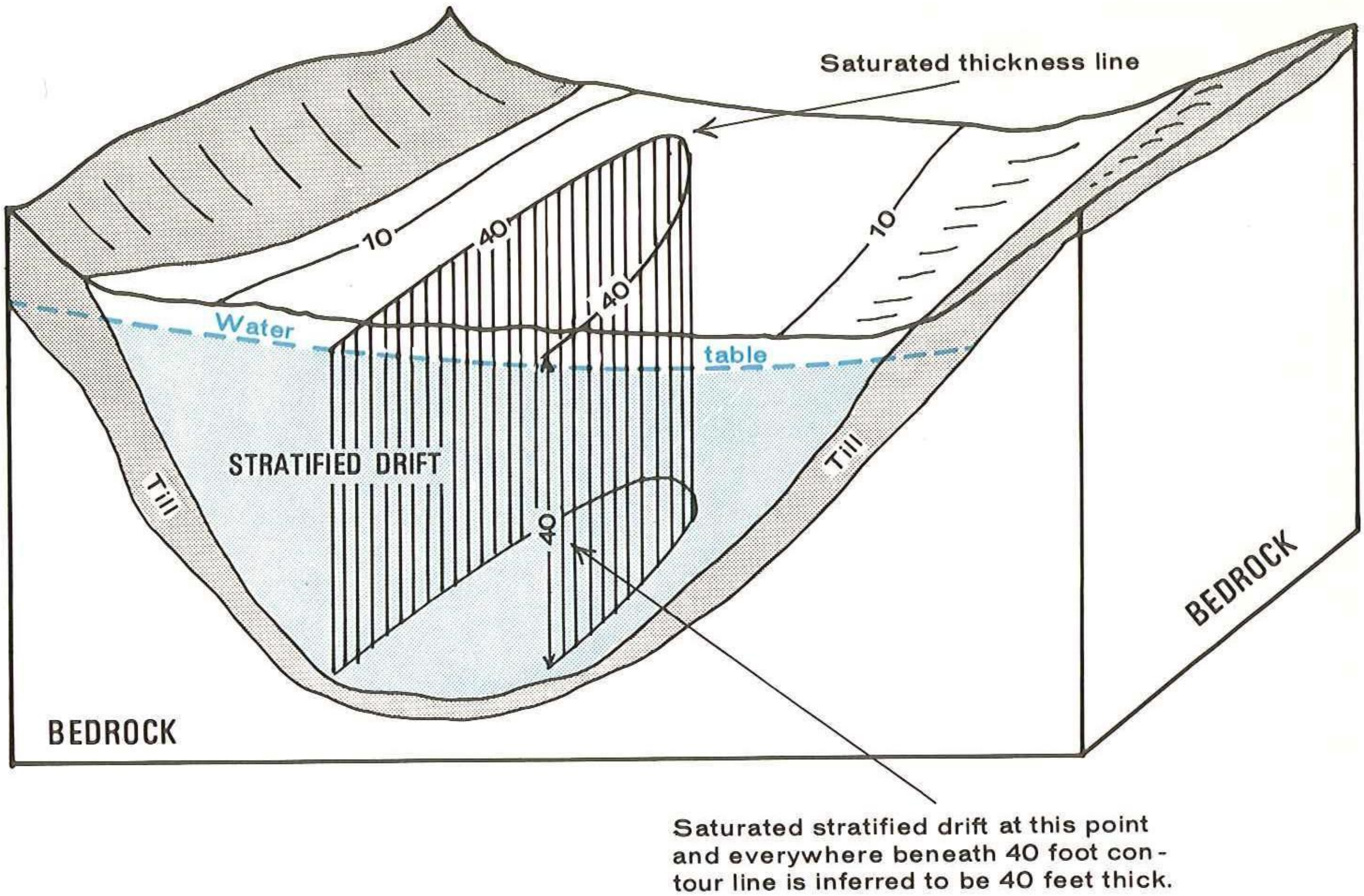


Figure 34.--Variations in saturated thickness of stratified drift are shown by lines of equal saturated thickness.

Saturated stratified drift extends from the water table to the underlying till or bedrock. Lines of equal saturated thickness for stratified drift in the basin are shown on plate B.

The saturated thickness of an unconfined, stratified-drift aquifer is the vertical extent from the water table to the bottom of the aquifer. (See figure 34.) Saturated thickness determines the amount of drawdown available at a well site. If the saturated stratified drift is coarse-grained throughout its vertical extent, the drawdown available for development is equal to the total saturated thickness; if it is coarse-grained at the surface and fine-grained at depth, drawdown available for development is equal to the saturated thickness of the coarse-grained, upper part of the section.

Plate B shows the total saturated thickness and general lithology of the major stratified-drift deposits in the basin. It identifies the predominantly coarse-grained deposits, the areas underlain by fine-grained deposits, and the areas known or inferred to have buried coarse-grained deposits. If the entire section is composed of fine-grained material, available drawdown is unimportant, as the satisfactory stallation of screened wells is precluded. If the section contains buried coarse-grained material, available drawdown is equal to total saturated thickness as in the case of sections that are coarse-grained throughout.

Saturated thicknesses range from less than 10 feet near the till-bedrock margins to more than 300 feet in parts of New Haven and Plainville. Generally, saturated stratified drift more than 100 feet thick contains significant amounts of fine-grained material.

Transmissivity is the property that describes the rate at which water moves through a unit width of the aquifer. It is equal to average hydraulic conductivity (a measure of the rate at which water moves through a unit area of the aquifer) times the saturated thickness. "Transmissivity" and "hydraulic conductivity" replace the former terms "coefficient of transmissibility" and "coefficient of permeability" respectively (Lohman and others, 1972). Conversion factors that equate the old and new terms are given at the end of this report. Transmissivity is expressed as "feet squared per day" (ft^2/day) and is a reduction of the equivalent dimensional term "cubic feet per day per foot", or (ft^3/day)/ft. Hydraulic conductivity is express as "feet per day" (ft/day).

Table 22.--Transmissivity of stratified drift in the Quinnipiac River basin

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

Well No. 1/	Pumping rate (gpm)	Drawdown (observed) (ft)	Specific capacity (observed)	Specific capacity (adjusted)	K_v/K_h 2/	Storage coefficient 2/	Transmissiv (ft2/day)
CS 66	127	29.0	4.4	12.2	0.10	0.15	2,100
CS 67	1,750	18.3	95.9	195.7	.20	.20	32,000
CS 138	250	49.0	5.1	26.0	.10	.20	4,200
CS 141	400	3.5	114.3	119.9	.20	.20	21,300
CS 204	1,500	43.0	34.9	82.4	.20	.20	14,800
HM 347	455	26.0	17.5	40.2	.10	.20	6,900
HM 348	1,000	22.0	45.5	165.0	.10	.20	28,600
HM 385	350	49.0	7.1	20.3	.10	.20	3,500
HM 386	353	46.0	7.7	22.7	.10	.20	4,000
HM 403	1,200	50.0	24.0	58.6	.20	.20	10,500
HM 404	1,000	15.7	66.7	107.5	.20	.20	16,400
HM 405	210	99.0	2.1	15.8	.10	.15	2,800
HM 407	250	7.0	35.7	107.3	.20	.20	15,800
HM 408	180	1.3	135.3	136.3	.20	.20	19,600
HM 410	500	18.0	27.8	59.9	.10	.20	9,600
HM 413	764	32.0	23.9	83.6	.10	.20	16,400
HM 414	2,000	35.5	56.3	136.1	.20	.20	21,300
HM 422	60	12.0	5.0	14.9	.10	.10	2,600
HM 426	1,000	75.0	13.3	46.9	.10	.20	8,600
HM 430	1,400	39.0	35.9	86.7	.20	.20	14,100
HM 441	400	46.5	8.6	41.1	.10	.20	6,600
HM 442	250	34.0	7.4	16.4	.10	.20	2,300
ME 197	600	19.0	31.6	69.7	.10	.20	12,700
ME 198	490	43.0	11.4	28.6	.10	.20	5,500
ME 206	500	68.0	7.4	32.4	.10	.20	5,400
ME 211	1,270	12.0	105.8	191.1	.10	.20	29,900
ME 212	810	29.0	27.9	88.3	.10	.20	15,400
ME 213	300	16.0	18.8	35.0	.10	.15	6,100
ME 214	1,000	13.0	76.9	163.6	.10	.20	32,800
ME 215	658	20.0	32.9	55.6	.20	.20	8,600
MI 6	247	25.0	9.9	20.1	.10	.20	3,400
MI 311	200	13.0	15.4	59.0	.10	.20	10,600
NHN 361	300	17.0	17.6	31.4	.10	.20	5,300
NHN 362	350	70.0	5.0	47.2	.10	.20	8,900
NHN 363	950	80.0	11.9	41.8	.10	.20	6,700
NHV 126	1,000	45.0	22.2	47.2	.10	.20	7,800
NHV 127	1,000	45.0	22.2	35.1	.10	.20	5,700
NHV 128	1,250	28.0	44.6	90.5	.10	.20	14,800
NHV 129	700	24.5	28.6	61.2	.10	.20	11,000
NHV 157	60	16.0	3.8	11.6	.10	.20	2,500
NHV 159	825	22.0	37.5	121.8	.10	.20	20,800
NHV 166	250	54.0	4.6	16.1	.10	.20	2,600
NHV 188	500	61.0	8.2	28.3	.10	.20	4,900
PV 1	680	13.7	49.6	126.2	.10	.20	19,500
PV 2	1,000	20.3	49.3	119.5	.10	.20	18,200
PV 64	250	25.0	10.0	27.7	.10	.20	4,600
PV 70	400	17.0	23.5	45.5	.10	.20	8,000
S 18	500	15.0	33.3	61.6	.10	.20	10,500
S 19	500	17.0	29.4	90.6	.10	.20	16,000
S 235	1,250	10.0	125.0	126.2	.20	.20	18,700
S 302	500	61.0	8.2	30.7	.10	.20	5,200
S 331	510	13.5	37.8	73.2	.10	.20	14,100
S 334	750	17.0	44.1	125.1	.10	.20	21,100
S 335	602	23.0	26.2	47.7	.10	.20	7,900
S 348	400	26.0	15.4	38.1	.10	.20	6,600
S 361	14	14.0	1.0	1.6	.10	.10	200
WLD 171	420	16.0	26.3	53.3	.10	.20	9,500
WLD 239	1,500	41.0	36.6	101.0	.10	.20	20,800
WLD 242	430	16.0	26.9	50.4	.10	.20	8,900
WLD 246	400	52.0	7.7	35.3	.10	.20	6,200
WLD 248	800	64.0	12.5	27.5	.10	.20	4,600
WLD 260	500	36.0	13.9	31.7	.10	.20	5,700
WLD 265	600	20.0	30.0	75.5	.10	.20	10,900
WO 266	30	12.0	2.5	4.6	.10	.10	600

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

Transmissivity values used in the "Areas favorable for ground-water development" section of this report are computed from specific-capacity data or estimated from the relationship between grain size and hydraulic conductivity (Krumbein and Monk, 1942; Rose and Smith, 1957; ...ch and Denny, 1966). Transmissivity values based on specific capacities of 64 wells tapping stratified drift are shown in table 22. The table also lists the field data used to calculate the values. The ratios between vertical and horizontal hydraulic conductivity (K_v:K_h) are estimates based on evaluations of the materials described in drillers' logs.

Transmissivities estimated from the relationship between hydraulic conductivity and grain-size distribution are used to better define transmissivity distribution in the favorable areas. Logs of wells and test holes, together with grain-size analyses of sediment samples, allow reasonable estimates of transmissivity. Table 23 illustrates the procedure for estimating transmissivity from the log of a test boring. Values of hydraulic conductivity are assigned to each lithologic unit of the log. These values are multiplied by the saturated thickness of the unit and totaled to obtain the transmissivity of the section.

Hydraulic conductivity values are assigned to lithologic units described in each well and test-hole log by either of two methods. The first is based on materials descriptions commonly used by drillers in southern New England. (See table 24.) Values of hydraulic conductivity assigned to the drillers' descriptions listed ... table 24 are based on an evaluation of ...ected well and test-hole logs from areas where hydrologic information is reliable. The second method is used with test holes that have grain-size analyses of the materials penetrated. Values are based on relationships between median-grain size and uniformity coefficient (an index of sorting) of stratified drift samples and laboratory determinations of hydraulic conductivity (Randall and others, 1966; Thomas, M. P., and others, 1967; Thomas, C. E., and others, 1968; Ryder and others, 1970). The relationship between grain size and hydraulic conductivity is shown in figure 35. This method is probably more accurate than the first. The values estimated by both methods, however, are less reliable than those obtained from specific- capacity data or aquifer tests. The values at best are only fair approximations.

The storage coefficient of an aquifer is a measure of its ability to store or yield water. Storage coefficient under unconfined conditions is equivalent to specific yield and is determined by the gravity drainage of available pore spaces. It is dependent upon grain-size distribution of the sediment and time of drainage (Johnson, 1967; Lohman, 1972). The storage coefficient of unconfined aquifers generally ranges from 0.1 to 0.3 and averages about 0.2 (Lohman, 1972). Storage coefficients may vary with time, and data based on short drainage periods must be adjusted to compensate for the fact that gravity drainage or release from storage is not instantaneous. In this report, some analyses use adjusted storage coefficients where drainage periods are of short duration. Storage coefficients in table 22 are based on considerations of both drainage times and materials descriptions. Yield estimates for the analysis of the favorable areas are based

Table 23.—Example of estimating transmissivity from logs of wells and test holes

(Test hole NBR 4th. Drilled with power auger by U.S. Geological Survey, 1970. Depth to water, 5 feet below land surface)

Materials description	Depth below land surface From - To (ft)	Saturated thickness (b) (ft)	Assigned hydraulic conductivity (K) (ft/day)	Calculated transmissivity (b x K) (ft^2/day)
Soil and sandy gravel	0 - 4	0	-	-
Sand, medium; some fine sand	4 - 7	2	80	160
Sand, medium; trace gravel	7 - 17	10	90	900
Sand, fine to medium; some coarse sand	17 - 20	3	25	75
Sand, very fine, and silt	20 - 24	4	2	8
Sand, very fine to fine, and silt 1/	24 - 39	15	15	225
Gravel, fine to medium; some sand	39 - 41	2	300	600
Sand, very fine to fine, and silt 2/	41 - 44	3	3	9
Gravel, fine to coarse, and medium to very coarse sand 3/	44 - 55	11	200	2,200
Sand, very coarse, and poorly sorted gravel	55 - 57.5	2.5	100	250
Till	57.5 - 58.5	-	-	-
Refusal (till)	at 58.5	-	-	-
Transmissivity of saturated stratified-drift section				4,400 ft^2/day

1/ Split-spoon sample, 32-33.5 ft depth.
Median grain size, 0.14 mm.
Uniformity coefficient 10.0.

2/ Split-spoon sample, 42-43.5 ft depth.
Median grain size, 0.067 mm.
Uniformity coefficient 6.5.

3/ Split-spoon sample, 47-48.5 ft depth.
...dian grain size, 1.4 mm.
...iformity coefficient 23.0.

Table 24.--Hydraulic conductivity values for estimating transmissivity of stratified drift

(Modified from Ryder and others, 1970, page 21)

Description (from drillers' logs)	Estimated median grain size (mm)	Estimated hydraulic conductivity (K) (ft/day)
Clay	0.02	1
Very fine sand, silt, and clay	.07	5
Very fine sand	.08	7
Fine sand	.15	20
Fine to medium sand	.20	25
Sand	.23	40
Coarse sand and clay	.45	80
Dirty gravel	.55	100
Coarse sand	.70	100
Medium to coarse sand with gravel and layers of clay	.40	100
Fine to medium sand, some medium to coarse gravel	.25	125
Medium sand	.40	250
Medium to coarse sand, very fine gravel	.90	300
Medium sand and gravel	1.0	500
Coarse sand and gravel	2.0	650

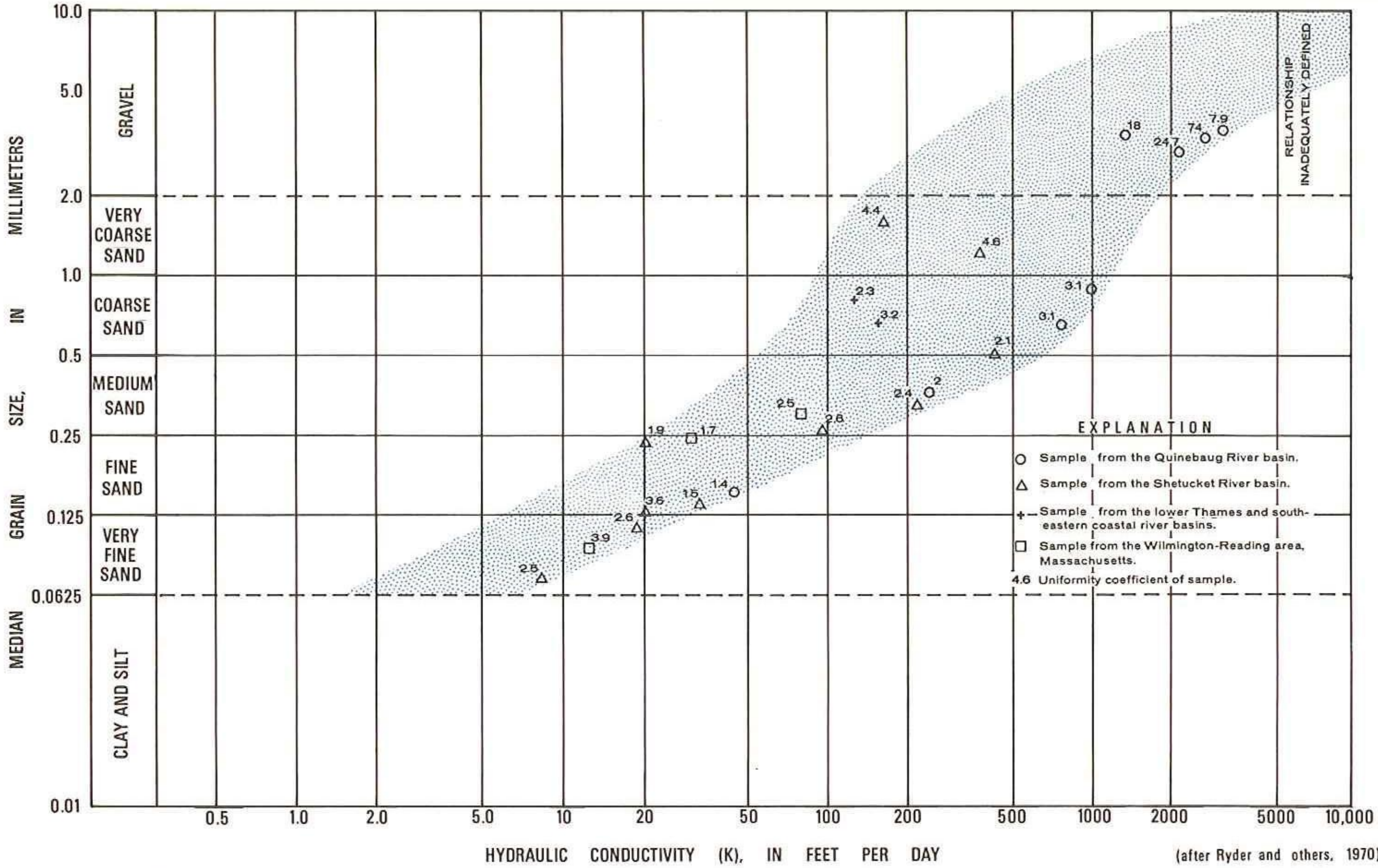


Figure 35.--Hydraulic conductivity of stratified drift in southern New England as a function of median grain size and sorting.

The values of hydraulic conductivity shown in this figure are laboratory determinations for undisturbed, horizontal samples. The range in hydraulic conductivity for a given median grain size results from differences in sorting, packing, and grain shape. Relationship is inadequately defined for clay, silt, and gravel.

on a drainage time equal to the period of pumping (180 days) and use storage coefficients of 0.2. Storage coefficient represents a volume-to-volume ratio and is dimensionless.

Hydraulic boundaries

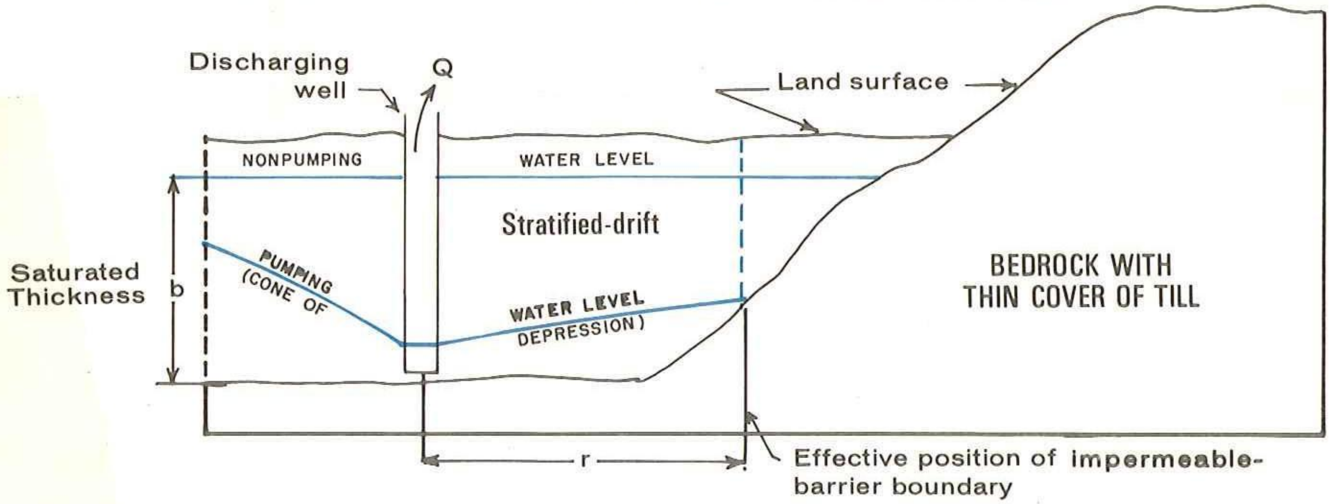
One of the assumptions of the nonequilibrium equation for ground-water flow to a well (Theis, 1935) is that the aquifer is of infinite areal extent. The stratified-drift aquifers in the Quinnipiac River basin are not infinite; they are limited by natural features that form hydraulic boundaries. Such boundaries affect the hydraulic continuity of aquifers and are of two types; line-source boundaries and impermeable-barrier boundaries. The effect of each type on the response of an aquifer to pumping is illustrated in figures 36 and 37 and described in Ferris and others (1962) and Lohman (1972). Contacts between stratified drift and till or bedrock are examples of impermeable-barrier boundaries. Perennial streams and lakes hydraulically connected to an aquifer are examples of line-source boundaries. The general effect of an impermeable-barrier boundary is to increase drawdown at a pumping well, whereas a line-source boundary reduces it. Both alter the shape of the cone of depression.

Hydraulic boundaries as used in this report, are idealized as vertical planes parallel to zones of zero or low transmissivity (impermeable-barrier boundaries) or parallel to major water bodies (line-source boundaries). The position of a line-source boundary will coincide with the stream channel only in places where the stream penetrates the full thickness of the aquifer. As this situation is rare, the effective distance between a line-source boundary and a pumping well is generally greater than the actual distance to the stream. The exact location of such boundaries requires detailed site investigation. The effective position of impermeable-barrier boundaries also requires detailed site data.

Natural recharge

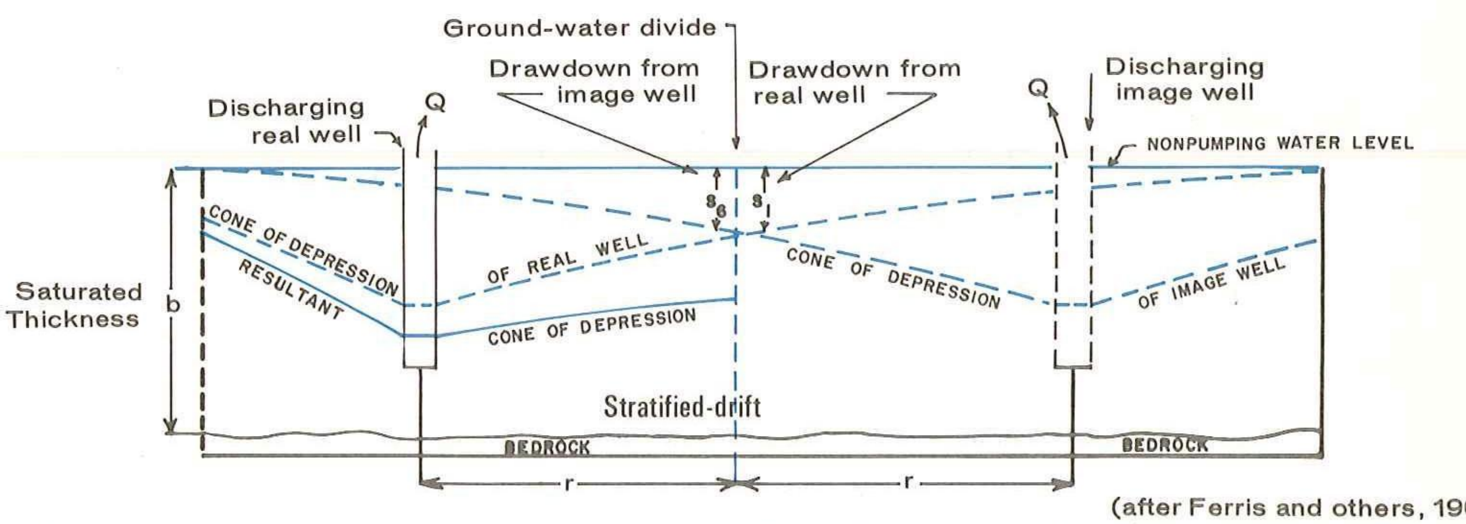
The amount of natural recharge to stratified drift is largely determined by the amount of precipitation that infiltrates to the water table and the amount of water that flows into the stratified drift from adjacent till and bedrock deposits. In areas where recharge by induced infiltration of surface water is unlikely, natural recharge is a measure of the amount of ground water available to sustain long-term pumpage from wells. If induced recharge is available, much higher pumping rates are feasible. If induced recharge is insignificant, long-term

A. REAL HYDRAULIC SYSTEM-IDEALIZED SECTION



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.

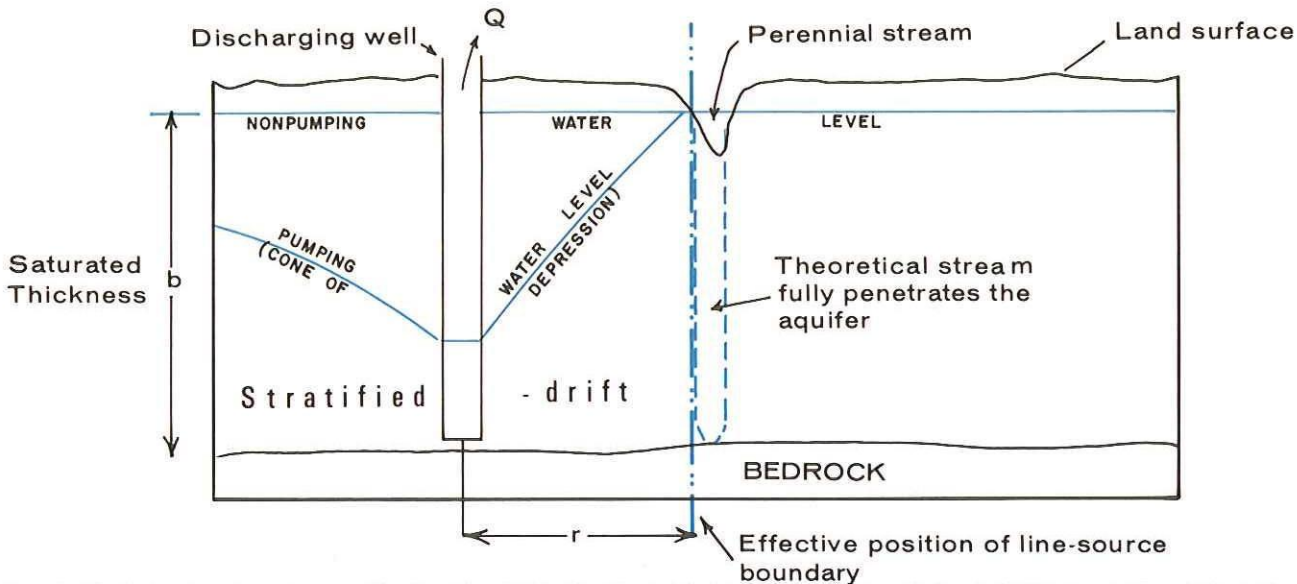
B. EQUIVALENT HYDRAULIC SYSTEM IN AN INFINITE AQUIFER



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.

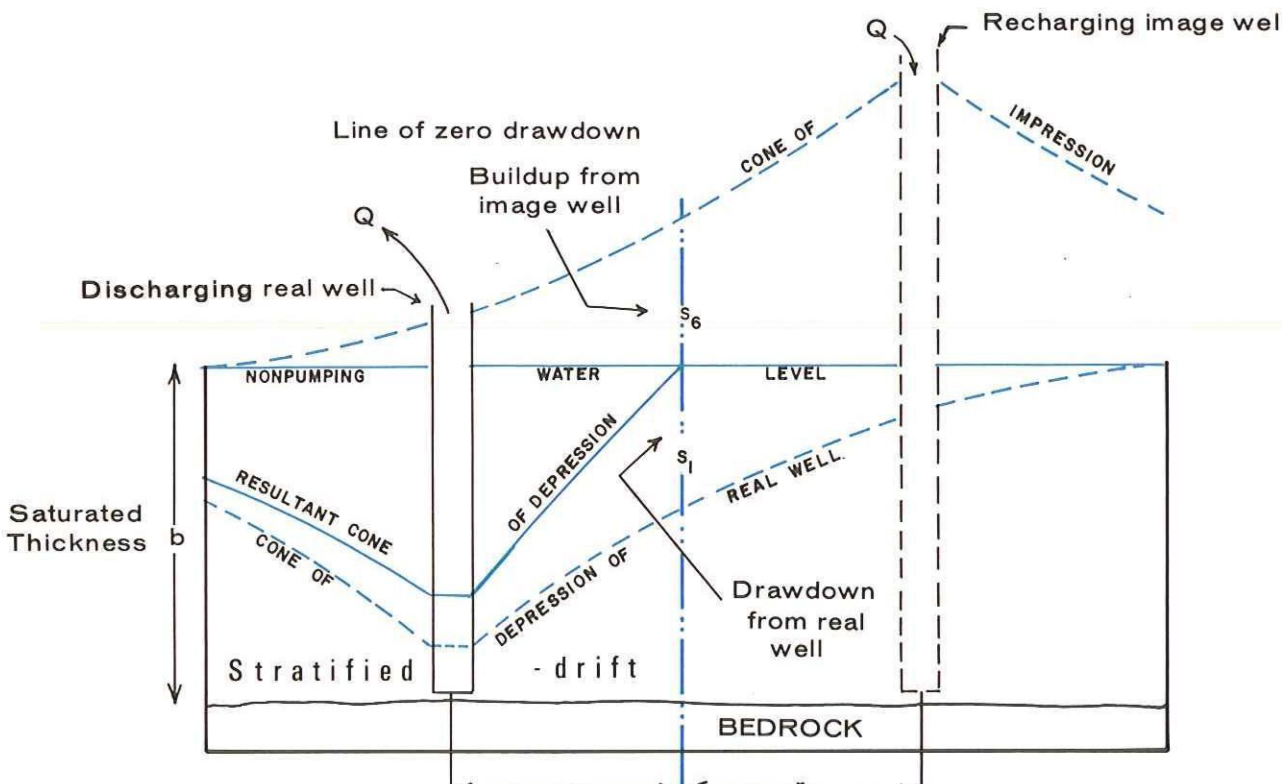
Figure 36.--Cross sections showing effects of an impermeable-barrier boundary on a stratified-drift aquifer.

A. REAL HYDRAULIC SYSTEM-IDEALIZED SECTION



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. EQUIVALENT HYDRAULIC SYSTEM IN AN INFINITE AQUIFER



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. **(after Ferris and others, 1962)**

Figure 37.--Cross sections showing effects of a line-source boundary on a stratified-drift aquifer.

withdrawals in excess of the average annual recharge are possible but will be accompanied by a decrease in storage and a corresponding decline in ground-water levels. Induced recharge is discussed in a later section.

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

1) Ground-water runoff
2) Underflow
3) Ground-water evapotranspiration
4) Pumpage

Ground-water runoff and underflow, when combined, are termed ground-water outflow and generally account for most of the discharge from an area of little pumpage. Ground-water outflow has been used as a conservative estimate of natural recharge for other areas in Connecticut (Randall and others, 1966; Ryder and others, 1970; Cervione and others, 1972). Table 25 shows ground-water outflow values computed for four small drainage basins.

Table 25.--Estimated ground-water outflow from four drainage areas in the Quinnipiac River basin, 1970 water year

Station no. (Pl. A)	Stream name and place of measurement	Drainage area (sq mi)	Total runoff (in)	Ground-water runoff (a) 1/ (in)	Under-flow (b) 2/ (in)	Ground-water outflow (a + b) (in)
01195500	Quinnipiac River at Southington	17.4	26.97	14.8	0.05	14.9
01196150	Misery Brook at Milldale	5.54	24.95	12.5	1.14	13.6
01196620	Mill River near Hamden	24.5	24.52	11.4	-	12.3 3/
01196680	Race Brook at Orange	3.19	22.93	8.3	-	8.3

1/ Determined by ground-water rating curve method of Schich and Walton (1961).
2/ Calculated from Darcy's law by method of Ferris and others (1962, p. 73) for gaging sites with significant thickness of saturated stratified drift.
3/ Adjusted for ground-water pumpage.

Accurate estimates of recharge require detailed data on the magnitude of ground-water evapotranspiration and pumpage from a basin. If it can be assumed that these factors are minor, ground-water outflow is a reasonable, conservative estimate of the amount of natural recharge.

Hydrologic studies elsewhere in Connecticut indicate that the amount of ground-water outflow is related to the percentage of stratified drift in the drainage basin (Randall and others, 1966; Thomas, M. P., and others, 1967; Ryder and others, 1970; Cervione and others, 1972). The relationship between the percentage of the total basin area underlain by stratified drift and average annual ground-water outflow is shown in figure 38. The data were derived from several small drainage basins in Connecticut, Massachusetts, and New York and include data from four basins in the study area (table 25). The line of relation in figure 38 was developed by linear regression and is described by the equation:

$$Y = 35 + 0.6X$$

Where:

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

X = percentage of total basin area underlain by stratified drift

This equation was used to determine average annual ground-water outflow and ground-water outflow equaled or exceeded 7 years in 10 from stratified-drift deposits in nonurbanized parts

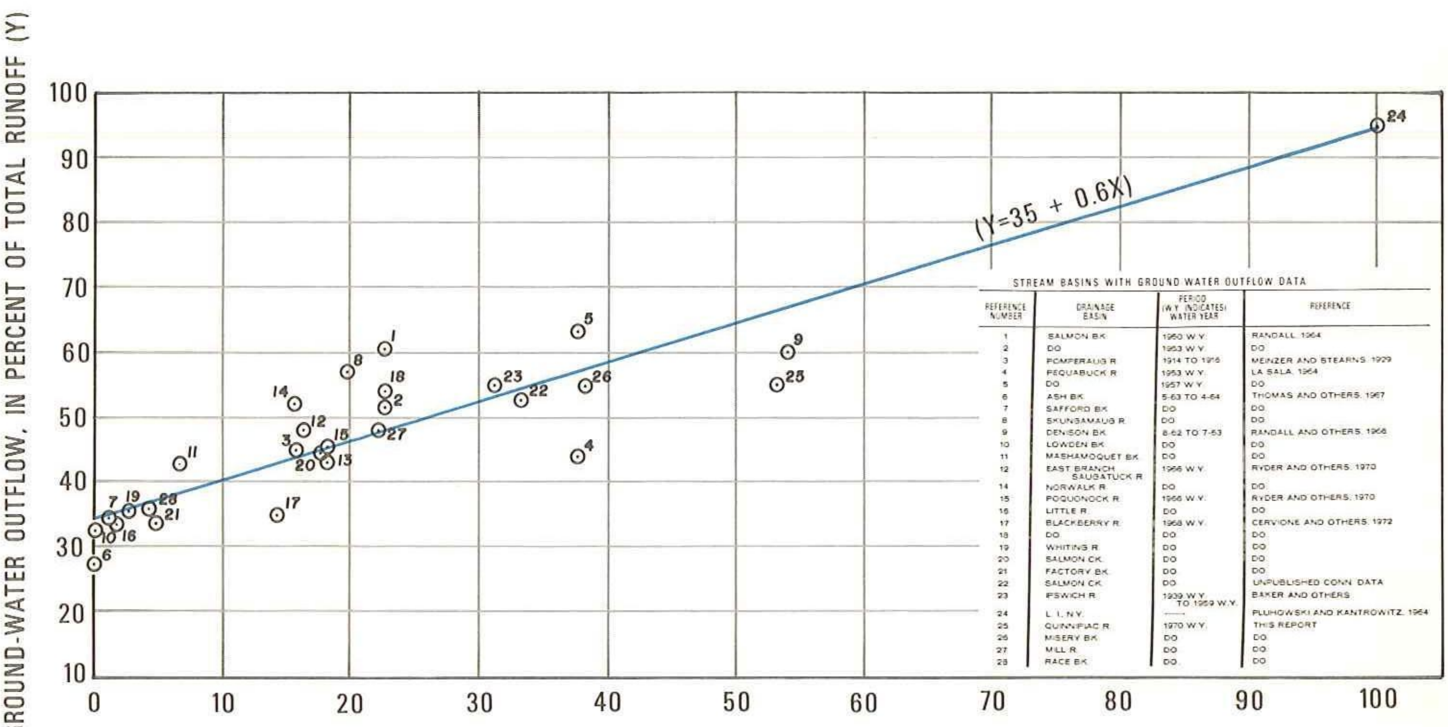
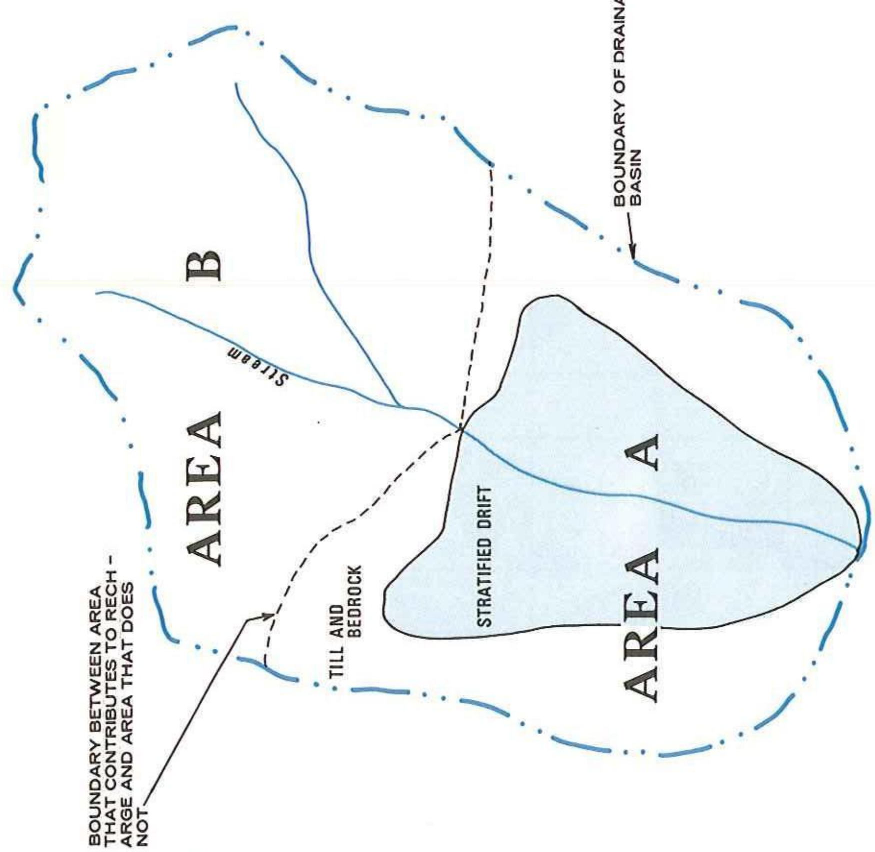


Figure 38.--Relation between ground-water outflow (Y) and percentage of drainage area underlain by stratified drift (X).



(1) Measure the area of stratified drift and adjacent till and bedrock (Area A) ------2.17 sq mi

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

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

(4) Calculate ground-water outflow (Y) from Area A as a percent of mean annual runoff from equation Y = 35 + 0.6X (Y = 35 + (0.6 x 66) ------ 75 percent

(5) Calculate mean annual runoff from Area A as determined from figure 9 (Runoff = 1.05 x 1.16 x 2.17) ------2.64 mgd

(6) Calculate average annual ground-water outflow (75 percent of 2.64 mgd) ------ 1.98 mgd

and:

ground-water outflow equaled or exceeded 7 years out of ten (0.76 x 1.98) ------ 1.50 mgd

Figure 39.--Sketch illustrating the method of estimating ground-water outflow from a stratified-drift aquifer.

Natural recharge is assumed to be equivalent to ground-water outflow (see text) from Area A. In the example shown, underflow from Area A is negligible and ground-water outflow is determined by steps outlined above. In Area B ground-water outflow occurs upstream of the stratified drift and there is no contribution from that area.

of the Quinnipiac River basin. The method is based on one developed by Cervione and others (1972) and assumes that the ratio of ground-water outflow to total outflow remains nearly constant from year to year. The procedure consists of six steps, which are illustrated and described in figure 39.

The constant (0.76) used in figure 39 is the ratio of the annual runoff equaled or exceeded 7 years in 10 to the mean annual runoff of the Quinnipiac River at Wallingford (station no. 01196500) during the 1931-60 period of record. The values, $GW_{(ro)}$ and $GW_{7,10}$, represent conservative estimates of natural recharge during average years and dry years, respectively.

Induced recharge

Withdrawal of water from wells near streams and lakes can lower ground-water levels to the extent that water flows from the surface-water body to the aquifer. Recharge by induced infiltration is illustrated in figure 40, which shows cross sections of a stream-aquifer system under natural and pumping conditions. In the Quinnipiac River basin, most of the stratified-drift aquifers are hydraulically connected to perennial streams,

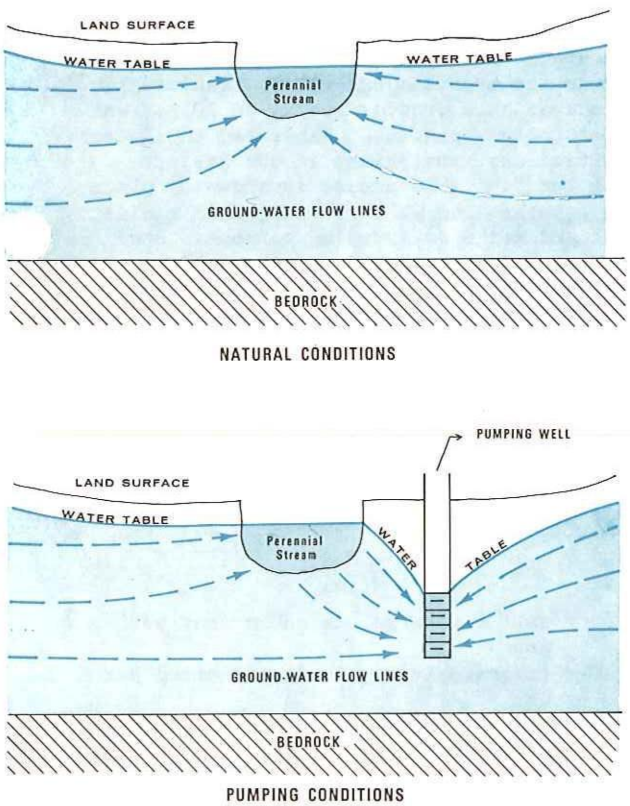


Figure 40.--Natural conditions in a stream-aquifer system contrasted with pumping conditions.

Under non-pumping conditions, ground water discharges to the stream. Pumping of a nearby well can reverse the hydraulic gradient in the vicinity of the stream causing surface water to move into the aquifer and toward the well.

and induced recharge can increase the long-term yield of the aquifers. If the adjacent surface-water body is a major stream, induced recharge can assure a continuous water supply substantially higher than the natural recharge rate. The quantity of water that will infiltrate from a stream or lake is determined by (1) vertical hydraulic conductivity and thickness of streambed materials, (2) viscosity of the surface water, (3) average head difference between the surface-water body and the aquifer, and (4) total area of the streambed through which infiltration takes place. These factors are used in a modified form of the Darcy equation to estimate potential induced recharge (Walton and others, 1967):

$$R_I = I_t \, S_r \, A_r$$

Where:

R_I = potential recharge by induced infiltration, in gallons per day (gpd)

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

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

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

Streambed materials have a major influence on infiltration rates and on the amount of induced recharge potentially available. Sediments in a streambed are variable because of current velocities, channel configuration, source material, aquatic vegetation, and other factors. These variations occur in three dimensions and streambed materials often occur as complex assemblages of organic and inorganic particles that range in size from clay to boulders. Streams in the basin alternately scour or deposit bed materials in response to seasonal runoff patterns. Layers of decaying foliage often constitute a significant part of the bed material along sections of the major streams during fall and winter months. The changes in sediment composition with time and distance cause variations in the vertical hydraulic conductivity of the streambed sediments and the dependent infiltration rate.

Temperature of surface water also effects the amount of induced recharge potentially available. As water temperatures decrease, viscosity increases, and infiltration rates are reduced. A decrease of 1°C lowers the infiltration rate 2.7 percent (Rorabaugh, 1951). During the 1970 water year, mean monthly surface-water temperatures of the Quinnipiac River at Wallingford (station no. 01196500) ranged from 25.5°C for August to 1°C for January. This seasonal decrease in water temperature would result in about a 50 percent decrease in the infiltration rate during the colder period.

Pumping wells located near a surface-water body that is hydraulically connected to an aquifer will generally obtain some water from induced recharge. Collector wells are commonly installed adjacent to surface-water bodies to increase induced recharge. A typical collector well consists of a large diameter concrete caisson with a group of horizontal collector pipes radiating from the bottom. The collector pipes are perforated and commonly extend toward, and beneath the surface-water body (Todd, 1959). A collector well (WLD 238) at the American Cyanamid Corporation in Wallingford, yielded more than 3,000 gpm with 50 feet of drawdown when first tested in 1945. Large yields are common to collector wells and illustrate the benefits of recharge from induced infiltration.

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

<u>Estimating the yields of screened wells</u>

Wells tapping the stratified-drift aquifers of the Quinnipiac River basin are generally the only ones capable of reliably yielding large amounts of water. (See table 21.) The evaluation of areas favorable for ground-water development is based on estimates of yields of hypothetical screened wells tapping these aquifers. The estimates take into consideration hydraulic properties of the aquifer (saturated thickness, transmissivity, and storage coefficient), characteristics of the hypothetical wells (depth, screen length, radius, and pumping period), effects of nearby pumping wells, and hydraulic boundaries.

The method used to estimate well yields consists of four principal steps:

1) Determine aquifer and well characteristics.
2) Calculate an initial discharge rate.
3) Calculate total drawdown in the well from data obtained in steps 1 and 2 above; include drawdown due to nearby pumping wells and hydraulic boundaries.
4) Adjust the discharge rate calculated in step 2 to insure that:
   a) Total drawdown does not exceed available drawdown.
   b) Drawdown due to aquifer and well characteristics (one of the components of total drawdown) does not exceed 30 percent of the aquifer saturated thickness.

The drawdown constraints listed in step 4 are required because (a) lowering water levels in the well below the top of the screen may lead to screen deterioration (b) ground-water flow equations require that drawdown due to aquifer and well characteristics be small relative to total saturated thickness. The four steps are explained in detail in the sections that follow.

<u>Determination of aquifer and well characteristics</u>.--Transmissivities for the favorable areas are estimated from specific capacity data or from logs of wells and test holes as described earlier. Maps showing transmissivity distribution (plate D) are used to calculate an average transmissivity for each favorable area. A storage coefficient of 0.2 is assigned to all the aquifers; this value is reasonable for unconfined sand and gravel aquifers and extended pumping periods. Maximum available drawdown is assumed to be equal to the saturated thickness of the aquifer above the top of the well screen.

Screen lengths equal to 30 percent of the total saturated thickness of the aquifer are assigned to the hypothetical wells, resulting in a maximum available drawdown equal to 70 percent of the saturated thickness. Saturated thickness of stratified-drift materials in the basin, including the favorable areas, is shown on plate B. Each hypothetical well is assigned a radius of 1 foot and a 180-day pumping period is used in all the evaluations. This time span is approximately equal to the growing season for hardy vegetation and represents the average period of little or no ground-water recharge.

<u>Calculation of initial discharge rate</u>.--Initial discharge rates for each of the hypothetical wells used in the favorable area evaluations are calculated using a form of the Theis nonequilibrium equation (Theis, 1935, p. 520; Ferris and others, 1962, p. 92):

$$Q = \frac{4\pi T s_i}{W(u)}$$

Where:

Q = well discharge, in cubic feet per day

T = transmissivity, in feet squared per day

s_i = initial aquifer drawdown at pumping well, in feet

and

$$W(u) = -0.5772 - \ln u + u - \frac{u^2}{2 \cdot 2!} + \frac{u^3}{3 \cdot 3!} - \frac{u^4}{4 \cdot 4!} + \dots \frac{u^n}{n \cdot n!}$$

Where:

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

r_w = radius of the pumping well, in feet

S = storage coefficient (dimensionless)

t = time of pumping, in days

Values are assigned to the variables on the right-hand side of the equation according to methods and criteria discussed in the preceding sections. Initial aquifer drawdown (s_i) is made equal to 25 percent of the aquifer saturated thickness at the well site. The well function W(u) is an exponential integral. It is replaced by a convergent series to allow simple mathematical solution. Values of W(u) versus u have been compiled by Wenzel (1942) and republished in Ferris and others (1962), Gray (1970), and Lohman (1972). An example of an initial pumping rate calculation follows:

Transmissivity (T).	5,000 ft^2/day
Saturated thickness	80 ft
Initial aquifer drawdown (s_1)	20 ft
Radius of pumping well (r_w)	1 ft
Storage coefficient (S) . .	0.2
Time of pumping (t)	180 days

n:

$$u = \frac{(1)^2 \ (0.2)}{(4)\ (5{,}000)\ (180)} = 5.56 \times 10^{-8}$$

$$W(u) = -0.5772 - \ln(5.56 \times 10^{-8}) + (5.56 \times 10^{-8}) - \frac{(5.56 \times 10^{-8})^2}{(2)\ (2!)} + \frac{(5.56 \times 10^{-8})^3}{(3)\ (3!)} - \frac{(5.56 \times 10^{-8})^4}{(4)\ (4!)} + \ldots \frac{(5.56 \times 10^{-8})^n}{(n)\ (n!)}$$

$$= 16.13$$

and the initial pumping rate is

$$Q = \frac{(4)\ (3.1416)(5{,}000)\ (20)}{(16.13)}$$

$$= 77{,}907 \ ft^3/day \ (405 \ gpm)$$

<u>Calculation of total drawdown</u>.--The total drawdown (s_t) in a pumping well tapping stratified drift includes some or all of the following components:

s_1, drawdown due to aquifer and well characteristics.

s_2, drawdown due to dewatering of the aquifer.

s_3, drawdown due to partial penetration of the aquifer.

s_4, drawdown due to flow through the screen and flow inside the well (well loss).

s_5, drawdown due to nearby pumping wells.

s_6, drawdown (or buildup) due to hydraulic boundaries.

The total drawdown (s_t) for a given well discharge is a summation of these components and is calculated by the following equation modified from Walton (1962):

$$s_t = s_1 + s_2 + s_3 + s_4 + s_5 + s_6$$

Hydraulic boundaries produce a drawdown or buildup of the water table. If buildup occurs, it is considered to be negative drawdown and assumes a negative sign in the above equation. Each of the drawdown components is discussed below.

Drawdown due to aquifer and well characteristics (s_1) is also calculated from the Theis nonequilibrium equation. The rearranged form of the equation is:

$$s_1 = \frac{Q}{4 \pi T} \ W(u)$$

All variables are as previously defined. When the well discharge (Q) is equal to the previously calculated initial discharge rate, s_1 equals 25 percent of the saturated thickness, and a separate calculation to determine s_1 is unnecessary. In subsequent calculations, Q is adjusted to increase or decrease total drawdown as required. (See section titled "Adjustment of discharge rate.") An example of the calculation to determine drawdown due to aquifer and well characteristics follows. All values are the same as those used for the initial discharge-rate calculation with the exception of the well discharge (Q), which has been increased to 85,000 ft^3/day (442 gpm).

$$s_1 = \frac{85{,}000}{(4)(3.1416)(5{,}000)} \ (16.13)$$

$$= 21.8 \ ft$$

Drawdown due to dewatering of the aquifer (s_2) is the result of a decrease in the saturated thickness in the vicinity of the pumping well. Drawdowns at the pumping well are adjusted for the effects of dewatering by a form of the equation derived by Jacob (1944):

$$s_2 = b - \sqrt{b^2 - 2bs_1} - s_1$$

Where:

s_1 and s_2 are as previously defined

b = saturated thickness of aquifer, in feet

This equation is valid for values of s_1 that are small relative to the saturated thickness. In the evaluation of the favorable areas, s_1 is not allowed to exceed 30 percent of the saturated thickness. An example of the calculation to determine the dewatering correction using previously defined variables is shown below:

$$s_2 = 80 - \sqrt{(80)^2 - (2)(80)(21.8)} - 21.8$$

$$= 4.2 \text{ ft}$$

Where:

Drawdown due to aquifer and well characteristics (s_1) . . 21.8 ft

Saturated thickness (b) . . . . . 80 ft

Drawdown due to partial penetration of the aquifer (s_3) occurs when a well is screened in only part of the saturated section and flow converges toward the screen. This drawdown component is calculated using the following equation (Walton, 1962):

$$s_3 = \frac{s_1}{C_{pp}} - s_1$$

where:

s_1 and s_3 are as previously defined

C_{pp} = correction factor for partial penetration

Values of C_{pp} are calculated by the Kozeny equation (Butler, 1957):

where:

$$C_{pp} = \partial\left[1 + \left(7\sqrt{\frac{r_w}{2\partial b}}\sqrt{\frac{K_v}{K_h}} \cdot \cos\frac{\pi\partial}{2}\right)\right]$$

where:

∂ = screen length divided by saturated thickness

r_w = radius of pumping well, in feet

$\frac{K_v}{K_h}$ = ratio of vertical to horizontal hydraulic conductivity of the aquifer

b = saturated thickness of the aquifer, in feet

An example of the calculation to determine drawdown due to partial penetration using previously determined variables is shown below.

The $\frac{K_v}{K_h}$ value at a specific site is seldom known. In this example and in the evaluation of the favorable areas, a $\frac{K_v}{K_h}$ value of 0.1 is assumed. Other parameters and values are as before:

$$C_{pp} = 0.3\left[1 + \left(7\sqrt{\frac{1}{(2)(0.3)(80)}} \cdot \sqrt{0.1} \cdot \cos\frac{(3.1416)(0.3)}{(2)}\right)\right] = 0.452$$

and

$$s_3 = \frac{21.8}{0.452} - 21.8 = 26.4 \text{ ft.}$$

Drawdown due to flow through the well screen and flow inside the well to the pump intake (s_4) is termed well loss. It is related to screen design and development (Johnson, 1966) and is proportional to well discharge (Todd, 1959). Well loss is controlled by actual design, development, and discharge considerations, and its calculation for hypothetical wells is not practical. In the subsequent evaluation of the favorable areas, wells are assumed to be 100 percent efficient, and the drawdown component due to well loss is zero.

Drawdown due to nearby pumping wells (s_5) is calculated using a form of the Theis equation in which well radius (r_w) is replaced by the distance, in feet, between the wells (r). The equation is:

$$s_5 = \frac{Q}{4\pi T} W(u)$$

Where:

Q, T, and W(u) are as previous defined

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

The variables in the following example are as before except that (r) is 1,000 feet and both wells are assumed to have discharge rates of 85,000 cubic feet per day.

$$u = \frac{(1{,}000)^2(0.2)}{(4)(5{,}000)(180)} = 5.56 \times 10^{-2}$$

$$W(u) = 2.37$$

Then:

$$s_5 = \frac{(85,000)}{(4)(3.1416)(5,000)} \quad (2.37)$$

$$= 3.2 \text{ ft}$$

This example assumes that the nearby well is withdrawing water from the aquifer. If it were recharging or adding water, the sign of (s_5) would be negative.

Drawdown (or buildup) of the water table due to hydraulic boundaries (s_6) is calculated in the same manner as drawdown due to nearby pumping or recharging wells. Figures 36 and 37 show how impermeable-barrier and line-source boundaries affect the continuity of an aquifer and illustrate how such conditions may be analytically treated by use of discharging and recharging image wells. A detailed discussion of the theory of images and hydrologic boundary analysis is presented by Ferris and others (1962).

For one boundary and one pumping well as shown in figure 41, only one image well is needed to determine the effects of the boundary. For complex boundary conditions or multiple pumping wells, large arrays of image wells are required. In practice, image wells are added until adding one more to the array has a negligible effect on the cumulative drawdown at the original pumping well. In analyses of the favorable areas that follow, this generally occurs when drawdown (or buildup) due to an image well becomes less than 0.00001 foot.

Drawdown (or buildup) due to hydraulic boundaries (s_6) is calculated by the equation:

$$s_6 = \Sigma\, s_{iw}$$

where:

s_{iw} = drawdown (or buildup) at the pumping well for each image well, in feet.

The drawdown (or buildup) of each image well is calculated by a form of the Theis equation:

$$s_{iw} = \frac{Q}{4\,\pi\,T}\,W(u)$$

Where:

W(u) is as previously defined

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

r = distance from pumping well to image well, in feet and all other parameters are as previously defined.

In the case of a discharging image well, s_{iw} is positive. If it is a recharging image well, s_{iw} represents buildup and is negative. The final value of the drawdown (or buildup)

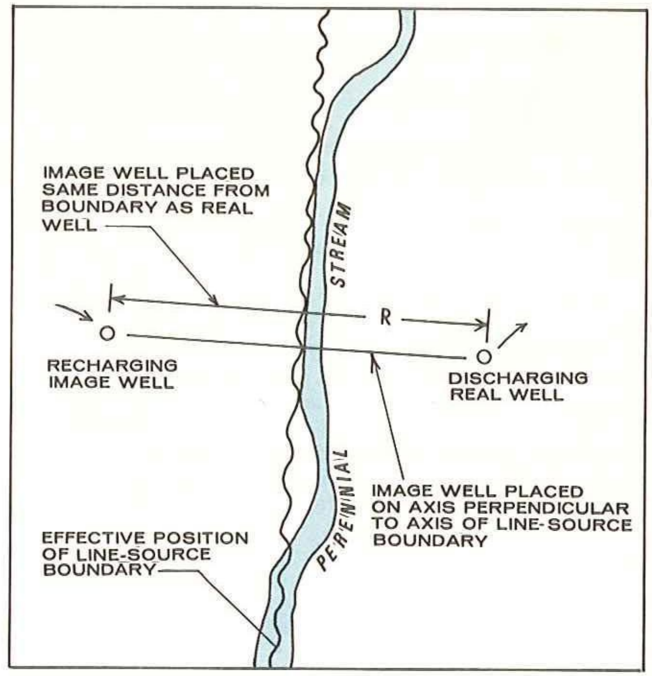


Figure 41.--Map view of a hypothetical aquifer with a single line-source boundary.

The discharging well in this system is balanced by a recharging image well located on the opposite side of the boundary.

due to hydraulic boundaries (s_6) is a summation of each individually calculated drawdown.

Calculations to determine the effect of a hydraulic boundary are shown below. A line-source boundary and one pumping well are used in the example, and only a single recharging image well is needed to calculate the boundary's effect. A map view of the hypothetical situation with line-source boundary, pumping well, and image well locations is shown in figure 41. The image well is recharging, so the effect is a buildup of the water table, indicated by a negative sign. The distance between the pumping well and the image well used in the example is 400 feet.

Then:

$$u = \frac{(400)^2\,(0.2)}{(4)\,(5,000)(180)}$$

$$u = 8.89 \times 10^{-3} \text{ and } W(u) = 4.15$$

and

$$s_{iw} = \frac{(85,000)}{(4)(3.1416)(5,000)} \quad (4.15)$$

$$= -5.6 \text{ ft}$$

Because there is only one image well, a summation is unnecessary and $s_6 = -5.6$ ft.

As stated earlier, the total drawdown in a pumping well (s_t) is a summation of some or all of the six components in the equation:

$$s_t = s_1 + s_2 + s_3 + s_4 + s_5 + s_6$$

Using values calculated in the preceding series of examples the total drawdown is:

$$s_t = (21.8) + (4.2) + (26.4) + (0) + (3.2) + (-5.6) = 50.0 \text{ ft}$$

This value represents the actual or observed drawdown that should result if the aquifer and well characteristics, discharge rate, time of pumping, and boundary conditions in the series of examples matched the actual field conditions. (See fig. 42.) In the analyses of the favorable areas, some parameter values, particularly storage coefficient and hydraulic conductivity (K_v:K_h) ratio are approximations. The yield and drawdown values that result are believed to be reasonable but are not exact.

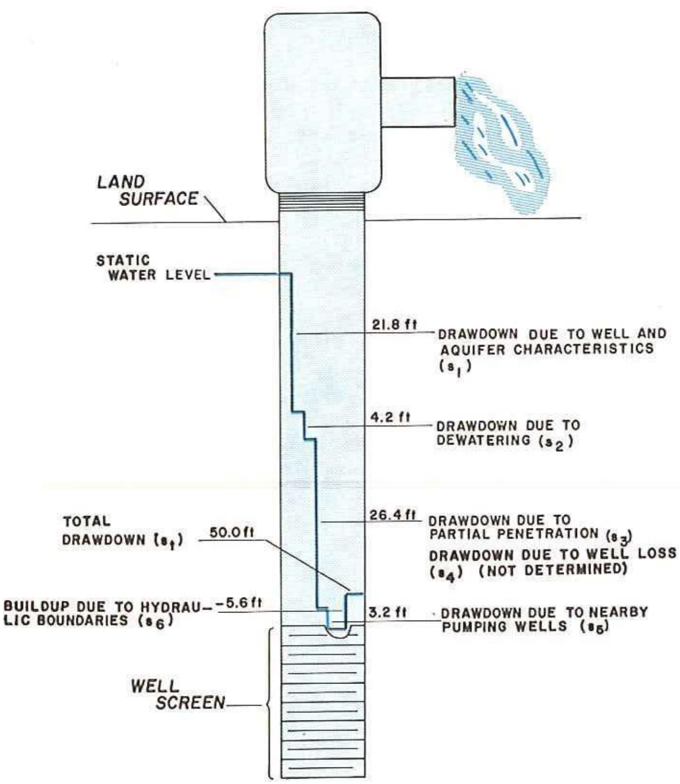


Figure 42.--Components of drawdown in a screened well tapping stratified drift.

Typical values of the drawdown components which combine to produce total drawdown in a pumping well are illustrated. Components s_5 and s_6 may be either positive or negative, depending upon whether nearby wells and hydraulic boundaries produce drawdown or buildup. Details of the calculations are given in the text.

Adjustment of discharge rate.--The total drawdown (s_t), calculated for an individual well, is compared to the maximum available drawdown and the drawdown due to aquifer and well characteristics (s_1) is compared to total saturated thickness to determine if the discharge rate (Q) should be increased or decreased. In the analyses of the favorable areas, two criteria are used to determine if adjustments are needed.

(1) Total drawdown (s_t) above, and within 1 foot of, the top of the well screen.
(2) Drawdown due to aquifer and well characteristics (s_1) less than, or equal to, 30 percent of the total saturated thickness of the aquifer.

If drawdowns for any well fall outside these limits, an adjustment to the discharge rate is made, and drawdowns are recalculated. When total drawdown cannot be brought to within 1 foot of the top of the screen without the drawdown due to aquifer and well characteristics (s_1) exceeding 30 percent of the total saturated thickness (b), a discharge rate based on that drawdown (s_1 = 0.3b) is considered to be the desired maximum. When total drawdown (s_t) can be brought to within 1 foot of the top of the screen without the drawdown due to aquifer and well characteristics exceeding 30 percent of the total saturated thickness, the discharge is adjusted to accomplish this.

Discharge rates are adjusted at each well with the following equation:

$$Q_a = Q_i \frac{s_m}{s_t}$$

Where:

Q_a = adjusted discharge, in cubic feet per day

Q_i = previous discharge, in cubic feet per day

s_m = maximum available drawdown, in feet

s_t = total drawdown (based on Q_i), in feet

The calculation to determine adjusted discharge (Q_a), using previously determined parameters and a maximum available drawdown (s_m) equal to 70 percent of total saturated thickness of the aquifer, is shown below:

Previous discharge (Q_i) . .	85,000 ft^3/day
Total drawdown (s_t) . .	50 ft
Saturated thickness (b) . .	80 ft
Maximum available drawdown (s_m = 0.7 b)	56 ft

Then:

$$Q_a = 85,000 \ \frac{56}{50} = 95,200 \text{ ft}^3\text{/day (493 gpm)}$$

The discharge rate is readily adjusted in this manner. After an adjusted rate is determined, a new total drawdown is computed and compared with maximum available drawdown. The process is repeated until the total drawdown is above, and within 1 foot of the top of the well screen. The discharge that yields this drawdown is the optimum rate for the well. If the variables used in the equations to adjust drawdown remain constant, drawdown is directly proportional to discharge, and only one adjustment is needed to determine the total drawdown. In the analyses of the favorable areas, adjustments to transmissivity, saturated thickness, and screen length factor are also required. These adjustments complicate the relationship between discharge and drawdown and require a series of calculations before the optimum discharge rate can be determined.

Areas favorable for ground-water development

The stratified-drift aquifers in the Quinnipiac River basin have the highest potential for development of large supplies of ground water. Data in this report and the companion basic-data report (Mazzaferro, 1973) are the basis for identifying favorable areas and estimating their yields. Estimates are based on methods and assumptions discussed in this and previous sections. The hypothetical well locations, transmissivities, and yield estimates for each area are shown on plate D. Estimates of water available, maximum pumpage, long-term yields, and required streambed infiltration rates are given in table 26.

The 14 stratified-drift areas considered favorable for ground-water development were selected on the basis of the following criteria:

(1) Transmissivity - maximum greater than 4,000 ft^2/day and average greater than 2,000 ft^2/day.

(2) Saturated thickness - maximum of at least 40 feet.

(3) Aquifer materials - grain sizes suitable for the installation of screened wells.

(4) Recharge - aquifer adjacent to a stream or lake potentially capable of supplying recharge by induced infiltration.

The estimated long-term yields of the 14 areas range from 0.8 to 16.1 mgd. Other areas of stratified drift may have good potential but were not analyzed because 1) adequate subsurface data are unavailable, 2) available pumping data indicate near-maximum development of the aquifer (Hamlin Pond area in Plainville), and 3) large-scale pumping may lead to saltwater intrusion (New Haven area).

The method used to estimate the amount of ground water available at each of the 14 areas consists of 4 general steps:

(1) Determine the amount of ground water potentially available over a long-term period.

(2) Calculate, by use of a mathematical model, the maximum amount of water that can be pumped from the aquifer.

(3) Select (1) or (2) above, whichever is smaller, as the estimated long-term yield.

(4) Calculate the streambed infiltration rate required to sustain the estimated long-term yield.

Under present management practices, ground-water withdrawals are fairly constant throughout the year but have the greatest effect on the aquifer during periods of little or no natural recharge. Also, much of the water withdrawn from an aquifer is normally discharged at some distance downstream from the point of withdrawal. These management constraints generally limit the amount of available water to natural recharge and induced recharge from streams and lakes.

For the favorable areas in this report, the amount of water available over a long-term period is assumed to be the sum of, (1) 75 percent of the ground-water outflow equaled or exceeded 7 years out of 10, and (2) the 90-percent duration flow of streams entering the favorable area. The method used to estimate total ground-water outflow is described in an earlier section of this report titled "Natural recharge." The method used to estimate the 90-percent duration flow is described in the section titled "Duration of streamflow." The ground-water outflow parameter is based on the assumptions that 75 percent of ground-water outflow from an aquifer area can be captured by wells and that ground-water outflow equaled or exceeded 7 years out of 10 is a reasonable estimate of the amount available over long periods. Use of the 90-percent duration flow assumes that drying up the adjacent reach of stream more than 10 percent of the time is undesirable.

The amount of water that can be pumped from each aquifer area is calculated by a mathematical model incorporating methods discussed in the section titled "Estimating yields of screened wells." This pumpage is the maximum amount of water obtainable and depends on hydraulic characteristics of the aquifer, number, spacing and construction characteristics of the hypothetical wells, hydraulic boundaries, and length of the period of little or no recharge.

For each favorable area, the estimated long-term yield is assumed to be equal to whichever is less, (1) the maximum amount of pumpage determined from the mathematical model or (2) the amount of water available over a long time period. Maximum pumpage estimated for each area is shown in table 26. For areas where the maximum pumpage exceeded the amount of water available (areas 3, 5, 6, 9, and 10), pumpage was reduced until it was equal to the amount available.

In the mathematical models, hypothetical wells are generally located in the thickest, most transmissive part of the aquifer and are assigned effective diameters of 24 inches, screen lengths equal to 30 percent of aquifer saturated thickness, and are assumed to be 100 percent efficient. Aquifers are assigned storage coefficients of 0.2 and vertical-to-horizontal hydraulic conductivity ratios of 0.1. A pumping period of 180 days is used because it approximates the period of little or no recharge. Line-source and impermeable-barrier boundaries are idealized as vertical planes and are positioned to generally represent hydraulic conditions. Pumping levels for each hypothetical well are not allowed to drop below the top of the screen.

Computations were made by means of a high-speed digital computer utilizing a program developed by the senior author. The areas and models are shown on plate D; an example of the computations is shown in figure 43.

Most of the favorable areas are analyzed with two models in order to compare the effects of different boundary conditions. The first model ignores the hydraulic effect of the adjacent surface-water body and assumes impermeable-barrier boundaries. The second assumes that the adjacent water body fully penetrates the aquifer and is a line-source boundary. Pumpages estimated under these two extreme conditions thus represent minimum and maximum long-term yields.

Four of the favorable areas (3, 5, 9, and 10) are analyzed only for the condition that assumes two parallel impermeable-barrier boundaries because the amount of water available is the limiting factor. Maximum pumpages estimated for these areas indicate that greater amounts of water could be pumped but this would cause the adjacent stream to go dry more than 10 percent of the time. To prevent this, restrictive boundary conditions are assumed and the long-term yield shown on plate D is based on pumpages that conform to the available streamflow.

The estimated long-term yields for the favorable areas would be sustained by capture of ground-water outflow and by induced recharge from streams and lakes. Ground-water outflows equaled or exceeded 7 years out of 10 and 90-perent duration flow of streams entering each favorable area are shown in table 26. If the hypothetical wells could capture 75 percent of the ground-water outflow, the remainder of the water required to sustain the estimated long-term yield would come from induced recharge. Estimated values of stream length, width, and depth at low flow are used with the equation $R_I = I_t S_r A_r$ (see section titled "Induced recharge") to calculate the infiltration rate (I_t) required to supply the water needed. These infiltration rates ranged from 1.1 to 34 gpd/ft^2/ft and are comparable to rates determined for similar streambed materials in other areas. The assumption that induced recharge would supply the remainder of the water needed to sustain estimated long-term yield is considered to be reasonable.

TILL

Till is composed of unsorted or poorly sorted gravel, sand, silt, and clay particles deposited directly by glacial ice. It forms a discontinuous mantle over most of the bedrock in the basin and covers about 70 percent of the surface. In the lowlands, till 5 to 10 feet thick is commonly overlain by stratified drift. In the uplands, till thickness averages about 25 feet and in places exceeds 100 feet. Figure 31 shows the general spatial relationship between till and other subsurface units in the basin. Areal distribution of till is shown on plate B.

Till was formerly an important aquifer, supplying water to farms, rural homes, some suburban dwellings, and commercial establishments. By 1970, less than 1 percent of the ground water pumped in the basin was from this source. Yields of individual wells in till are marginally adequate for the domestic needs of most households and water levels in till decline rapidly during periods of little or no ground-water recharge. These limitations and the thinness of till in many areas commonly led to well failures during the summer. A factor contributing to the abandonment of the till aquifer was the susceptibility of the typical dug or open-stone well to contamination by surface runoff, septic-tank effluent, barnyard drainage, and other pollutants.

The amount of water potentially available from individual wells in till is small. Data from other parts of southern New England indicate that the hydraulic conductivity of till is generally less than 5 feet per day (Randall and others, 1966; Sammel and others, 1966; Morris and Johnson, 1967), and its saturated thickness in the Quinnipiac River basin is generally less than 20 feet.

Plate B shows areas in the basin where till is known or inferred to be at least 40 feet thick. In these and other areas of thick deposits of saturated till, modest amounts of water may be developed. Wells in such areas might be adequate for uses requiring small quantities.

BEDROCK

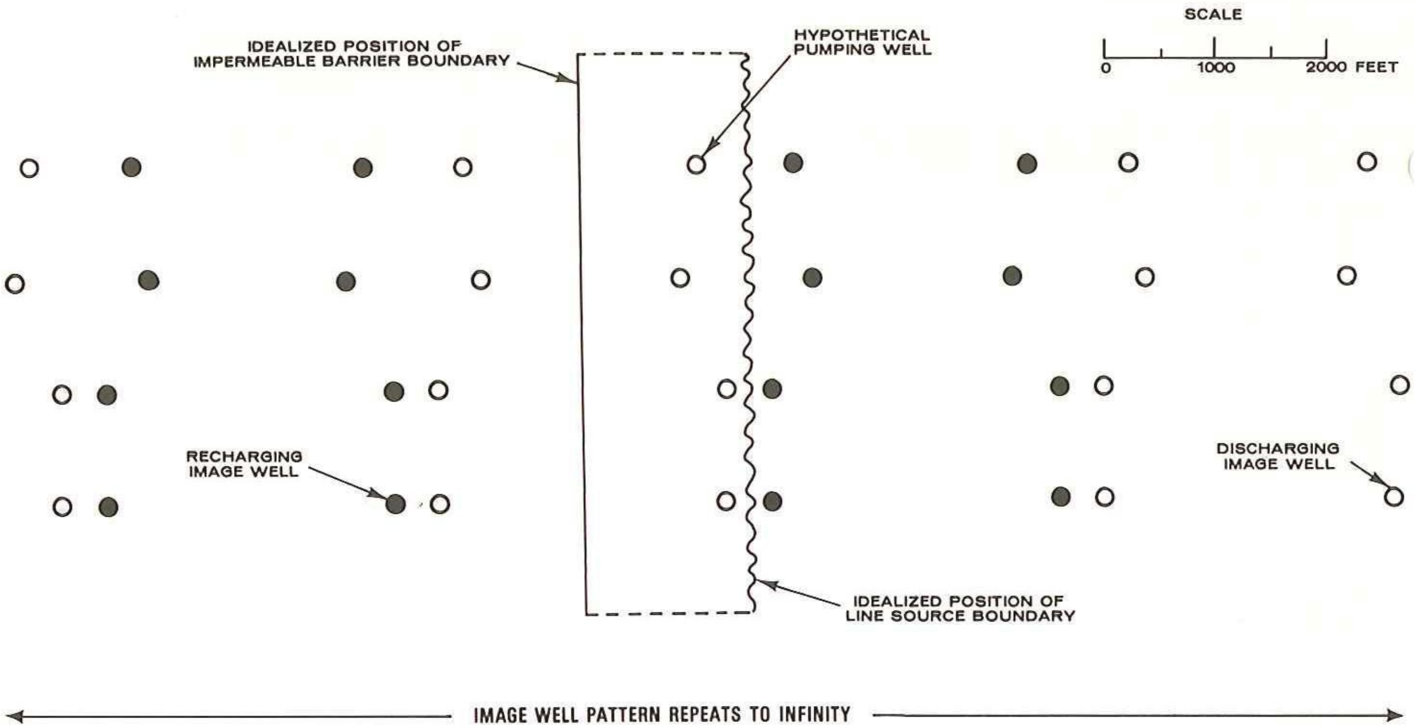
Bedrock aquifers in the Quinnipiac River basin include sedimentary, igneous, and metamorphic units. They are important sources of water for many homes, commercial establishments and institutions. Development of these aquifers is concentrated in areas where public water supplies are not available but moderate amounts of water can be obtained from the bedrock anywhere in the basin. Areal distribution of the bedrock aquifers is shown in figure 30.

Bedrock units in the Quinnipiac River basin are similar to those underlying adjacent areas of Connecticut. Metamorphic bedrock as used in

Table 26.--Estimated long-term yields from favorable ground-water areas

Favorable area: Area No. (Pl. D)	Favorable area: Location	Area of strip aquifer (sq mi)	Ground-water outflow: Total ground-water outflow area (sq mi)	Ground-water outflow: Percent of area underlain by stratified drift	Ground-water outflow: Ground-water outflow equaled or exceeded 7 years out of 10 (mgd)	Flow of principal streams entering favorable area equaled or exceeded 90 percent of the time (mgd)	Estimated maximum amount of water available over a long time period 1/ (mgd)	Estimated maximum pumpage from modeled area during 180-day period of little or no recharge (mgd)	Estimated long-term yields 2/ (mgd)	Induced recharge from streams required to sustain long-term yields 3/ (mgd)	Streambed infiltration rate required to sustain long-term yields 4/ (gpd/ft²/ft)	Remarks
1A	Eightmile River valley, north of Welch Road, Southington - Bristol	0.58	1.78	60	1.2	1.6	2.5	1.4	1.4	0.5	11	No line-source boundary in model 1A.
1B	do	.27	.95	49	.6	1.6	2.1	1.9	1.9	1.5	34	Eightmile River forms line-source boundary in model 1B.
2A	Quinnipiac River valley, north of Spring Street, Southington - Plainville	.65	2.65	73	1.9	3.7	5.1	2.2	2.2	.8	3.2	No line-source boundary in model 2A.
2B	do	.43	2.53	72	1.5	3.7	4.8	3.0	3.0	1.9	8.0	Quinnipiac River forms line-source boundary in model 2B.
3A	Patton Brook valley, south of Pattonwood Drive, Southington	.47	1.00	68	.7	.5	1.0	2.1	1.0	.5	9.8	No line-source boundary in model 3A. Pumping at constant rate of 1.0 mgd would dry up Patton Brook approximately 10 percent of the time.
4A	Quinnipiac River valley north of Center Street, Southington	.63	3.34	66	1.5	6.0	7.1	2.5	2.5	1.4	2.3	No line-source boundary in model 4A.
4B	do	.50	3.34	66	1.5	6.0	7.1	3.8	3.8	2.7	4.7	Quinnipiac River forms line-source boundary in model 4B.
5A	Woodbridge Pond area, north of Berlin Street, Southington	.49	2.57	71	1.8	.9	2.3	2.4	2.3	1.0	8.8	No line-source boundary in model 5A. Pumping at constant rate of 2.3 mgd would effect the level of Woodbridge Pond and dry up unnamed tributary approximately 10 percent of the time.
6A	Honeypot Brook valley, north of Blacks Road, Cheshire	.72	2.09	46	1.2	.8	1.7	3.9	1.7	.8	1.1	No line-source boundary in model 6A. Pumping at constant rate of 1.7 mgd would dry up Honeypot Brook approximately 10 percent of the time.
6B	do	.54	2.15	51	1.3	25.2	26.2	4.9	4.9	3.9	6.4	Quinnipiac River forms line-source boundary in model 6B.
7A	Sodom Brook valley, north of Hanover Pond, Meriden	.22	1.88	16	.8	.9	1.5	1.3	1.3	.7	11	No line-source boundary in model 7A.
7B	do	.16	1.79	13	.7	.9	1.4	2.5	1.4	.9	15	Sodom Brook forms line-source boundary in model 7B. Pumping at constant rate of 1.4 mgd would dry up Sodom Brook approximately 10 percent of the time.
8A	Quinnipiac River valley, south of Hanover Pond, Meriden - Wallingford	.75	2.49	42	1.4	33.9	35.0	4.7	4.7	3.7	2.7	No line-source boundary in model 8A.
8B	do	.63	2.38	42	1.3	33.9	34.9	7.5	7.5	6.5	4.9	Quinnipiac River forms line-source boundary in model 8B.
9A	Mill River valley, north of Cook Hill Road, Cheshire	.36	.77	60	.5	.7	1.1	1.5	1.1	.7	14	No line-source boundary in model 9A. Pumping at constant rate of 1.1 mgd would dry up Mill River approximately 10 percent of the time.
10A	Mill River valley, north of River Road, Hamden	.49	.90	51	.6	5.7	6.2	7.0	6.2	5.7	30	No line-source boundary in model 10A. Pumping at constant rate of 6.2 mgd would dry up Mill River approximately 10 percent of the time.
11A	Mill River valley, north of Ives Street, Hamden	.45	1.40	33	.8	7.0	7.6	2.6	2.6	2.0	8.7	No line-source boundary in model 11A.
11B	do	.36	1.30	34	.7	7.0	7.5	3.7	3.7	3.2	14	Mill River forms line-source boundary in model 11B.
12A	Quinnipiac River valley, south of Community Lake, Wallingford	1.43	3.77	42	2.1	37.4	39.0	11.4	11.4	9.9	4.5	No line-source boundary in model 12A.
12B	do	1.08	3.76	43	2.1	37.4	39.0	16.1	16.1	14.6	6.6	Quinnipiac River forms line-source boundary in model 12B.
13A	Quinnipiac River valley, south of Toelles Road, North Haven	2.76	5.08	62	3.5	40.1	42.7	10.2	10.2	7.6	2.1	No line-source boundary in model 13A.
13B	do	1.97	4.19	74	3.1	40.1	42.4	13.0	13.0	10.7	3.0	Quinnipiac River forms line-source boundary in model 13B.
14A	Farm River valley, north of Augur Road, North Branford	.36	1.60	27	.8	1.4	2.0	.8	.8	.2	2.5	No line-source boundary in model 14A.
14B	do	.27	1.50	26	.7	1.4	1.9	1.1	1.1	.6	9.2	Farm River forms line-source boundary in model 14B.

1/ Equivalent to streamflow equaled or exceeded 90 percent of the time plus 75 percent of ground-water outflow equaled or exceeded 7 years out of 10.
2/ Equivalent to maximum amount of water available or maximum pumpage, whichever is less. Development of long-term yield would reduce streamflow by an equivalent amount unless water is returned to stream.
3/ Equivalent to the long-term yield minus 75 percent of the ground-water outflow equaled or exceeded 7 years out of 10.
4/ Streambed infiltration rates lower than those shown in the table will result in reduced long-term yields.



BOUNDARY CONFIGURATION AND WELL ARRAYS FOR MODEL AREA 1B

1) Assign well, aquifer, and time parameters.

Number of Hypothetical Well	Well Radius	Saturated Thickness	Average Trans-missivity of Aquifer	Storage Coeffi-cient	K_v/K_h Ratio	Fractional Penetration $\frac{\text{Screen Length}}{\text{Sat. Thick.}}$	Well Effi-ciency	Time of Pumping
	(ft)	(ft)	(ft sq/day)				(percent)	(days)
1P	1.0	60.0	3,500	0.2	0.1	0.3	100	180
2P	1.0	70.0	3,500	.2	.1	.3	100	180
3P	1.0	85.0	3,500	.2	.1	.3	100	180
4P	1.0	90.0,	3,500	.2	.1	.3	100	180

2) Calculate maximum available drawdown for each hypothetical pumping well (assumed to be equal to 70 percent of the saturated thickness). Values are shown in step 8 below.

3) Calculate initial discharge for each hypothetical pumping well based on an initial draw-down equal to 25 percent of the saturated thickness. Discharges calculated in this step are intermediate values and may be adjusted as shown in step 7.

4) For each hypothetical pumping well, calculate the buildup due to recharging image wells (s_6), the drawdown due to discharging image wells (s_6), and the drawdown due to other pumping wells (s_5). If the drawdowns exceed buildups, the average transmissivity and saturated thickness are reduced proportionally.

5) For each hypothetical pumping well, calculate the drawdown due to well and aquifer characteristics (s_1), the drawdown due to dewatering (s_2), the drawdown due to partial penetration (s_3), and the drawdown due to well loss (s_4).

6) Calculate the total drawdown (s_t) for each hypothetical pumping well using the relationship; $s_t = s_1 + s_2 + s_3 + s_4 + s_5 + s_6$.

7) Compare the total drawdowns determined in step 6 to the maximum available drawdown determined in step 2. Adjust discharges proportionally and repeat steps 4 through 7 until the total drawdown is within one foot of, but not greater than, the maximum available drawdown for a hypothetical pumping well (see well 2P). If the adjusted discgarges increase to a point where s_1 exceeds 30 percent of the saturated shickness, stop adjusting discharge and use the value that results in an s_1 equal to 30 percent of the saturated thickness (see wells 1P, 3P, and 4P). If the initial comparison shows total drawdown approximately equal to maximum available drawdown, further adjustments of discharge are not required.

8) Discharge values and related drawdown components used to calculate the total drawdowns for the 4 hypothetical pumping wells in Model Area 1B.

Number of Hypothetical Well	Discharge	Drawdown Due to Aquifer and Well Characteristics (s_1) +	Drawdown Due to Dewatering (s_2) +	Drawdown Due to Partial Penetration (s_3) +	Drawdown Due to Well Loss (s_4)
	(gpm)	(ft)	(ft)	(ft)	(ft)
1P	260	18.0	4.0	19.8	0
2P	296	20.5	4.4	23.7	0
3P	369	25.5	5.7	31.5	0
4P	391	27.0	6.1	33.9	0

8) – Continued

Drawdown Due to Discharging Image Wells and Other Pumping Wells (s_5 and s_6) +	Buildup Due to Recharging Image Wells (s_6) =	Total Drawdown (s_t)	Maximum Available Drawdown
(ft)	(ft)	(ft)	(ft)
8.1	- 9.1	40.8	42.0
11.5	-11.4	48.7	49.0
11.0	-16.1	57.6	59.5
8.2	-14.2	61.0	63.0

9) Calculate the estimated daily pumpage for the area by summing the discharges of the individual wells.

Number of Hypothetical Well	Discharge	Discharge
	(gpm)	(mgd)
1P	260	0.37
2P	296	.43
3P	370	.53
4P	391	.56
Totals	1,317	1.89

Figure 43.--Estimating pumpage from a favorable area.

The potential yield of favorable areas of stratified drift in the basin are calculated by means of mathematical models of the aquifers. The essential steps used to estimate the maximum long-term yield are shown for Model Area 1B (pl. D). Computations of image well locations, drawdowns, discharge rates, and daily pumpages were facilitated by an IBM 370 series digital computer.

this report is equivalent to the crystalline bedrock discussed by Wilson and others (1974) in the report describing the neighboring lower Housatonic River basin. Sedimentary bedrock and igneous crystalline bedrock, which are discussed paratately in this report, were combined by .lson and others (1974) and termed sedimentary-volcanic bedrock.

On a regional basis, the yields of wells tapping bedrock are determined by the amount of recharge to the bedrock aquifers and their ability to transmit water. Natural recharge from precipitation is estimated to range from 7 to 10 inches per year for bedrock in the basin. A similar rate, 7 inches per year, was estimated for crystalline bedrock in the upper Housatonic River basin (Cervione and others, 1972).

The rate at which bedrock transmits water depends on the hydraulic gradient and the characteristics of the open spaces. In the igneous and metamorphic units, the intergranular (primary) openings are commonly small and poorly connected. Their contributions to the yields of wells is negligible. The primary openings in sedimentary bedrock are also small but are generally more abundant and better connected. Available evidence indicates that the primary openings in sedimentary rock transmit more water than those in igneous and metamorphic rock. The magnitude of this difference, however, is uncertain.

Secondary openings, formed after consolidation of the bedrock, include cracks, joints, faults, and other types of fractures. Fracture openings in bedrock are commonly found only within a few hundred feet of the bedrock surface. They are large in comparison to primary openings, are generally interconnected, and make up the network that transmits most of the water. For a given hydraulic gradient, the rate at which water moves through the secondary openings is determined by their size, distribution, orientation, and degree of interconnection. These characteristics are, in turn, influenced by bedrock composition, geologic history, topography, and other factors.

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

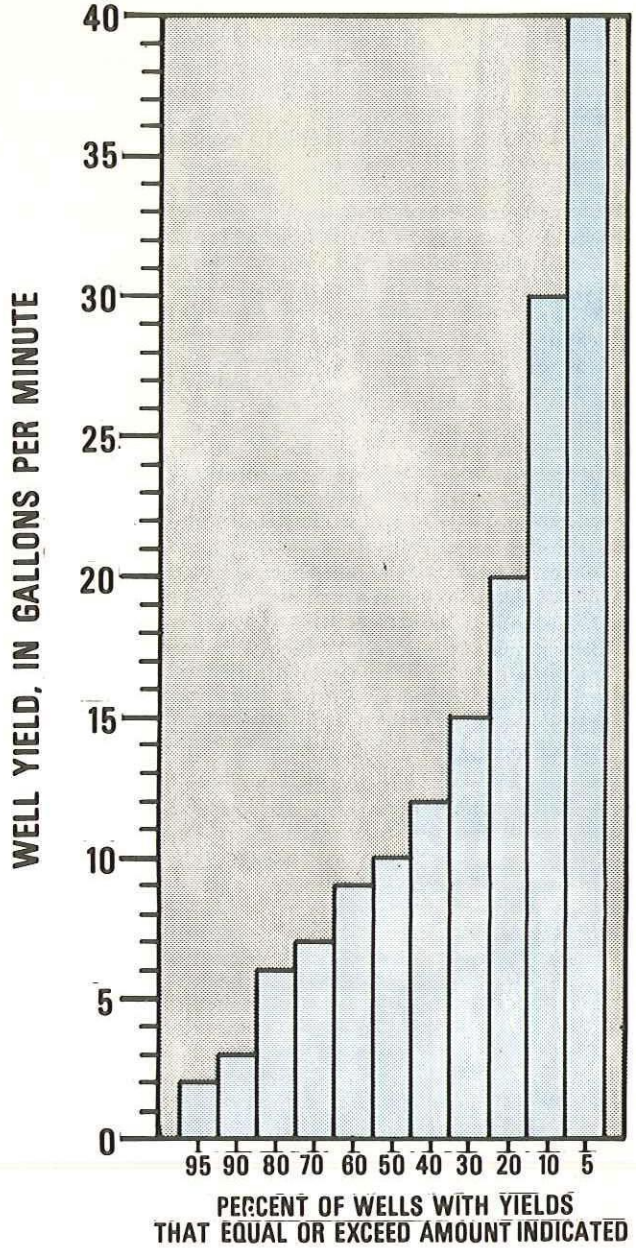


Figure 44.--Yield frequency of wells tapping sedimentary bedrock.

Sedimentary bedrock

Sedimentary bedrock underlies about 220 square miles of the central part of the Quinnipiac River basin (fig. 30) and is the chief bedrock aquifer in terms of areal extent, degree of development, and yields of individual wells. It consists of sandstone, siltstone and shale with lesser amounts of conglomerate and limestone. Basalt flows are interbedded with the sedimentary rocks but are part of the igneous aquifer and discussed separately below. The sedimentary rocks are extensively faulted and generally dip to the east. Thickness may be several thousand feet along the eastern contact (Krynine, 1950, p. 37), and the average thickness in the basin probably exceeds 4,000 feet.

Reported yields of 925 wells tapping sedimentary bedrock range from 0 to 305 gallons per minute (gpm); the median yield is 10 gpm. The maximum and median yields are greater than those of the other bedrock aquifers in the basin. The yield frequency data in figure 44 indicates that 95 percent of the wells in sedimentary bedrock yielded 2 gpm or more. The water needs of a family can be met with as little as 1 gpm, if storage is sufficient, and the chance of drilling a successful domestic well in sedimentary bedrock is high. Of the 925 wells, fewer than 1 percent were reported to yield less than 1 gpm.

All the rocks in the basin contain fewer openings and thus are less productive with increasing depth. North of the report area, productive zones in sedimentary bedrock may reach depths of 450 feet (Cushman,1964). Water-bearing fractures may be equally deep in the sedimentary rocks of the Quinnipiac River basin, as the relationship between median yield and thickness of saturated uncased rock penetrated shown in figure 45 suggests. The first three thickness intervals show a pattern of smaller

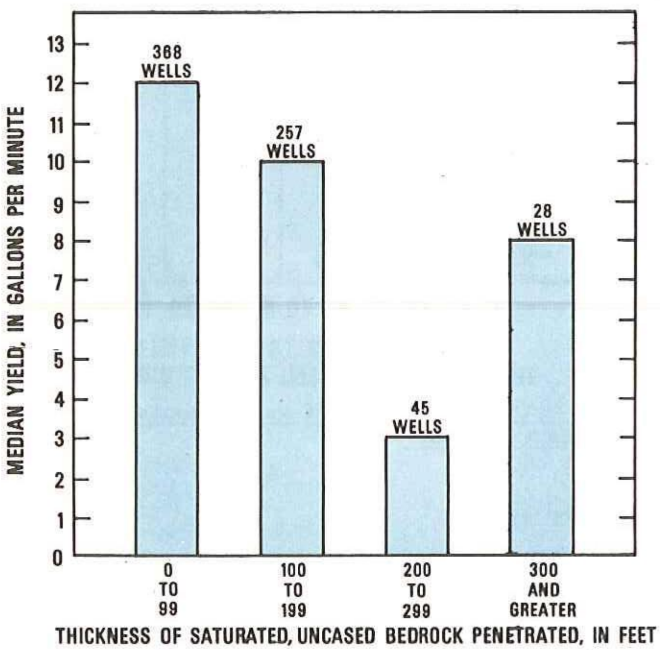


Figure 45.--Median yields of wells tapping different thicknesses of sedimentary bedrock.

yields with increasing depths, but the fourth and deepest interval shows a significantly higher median yield. This is probably because many of the wells drilled to greater depths are intended for commercial or industrial purposes and are required to yield more than domestic wells. The figure indicates that, although yields generally become smaller as greater

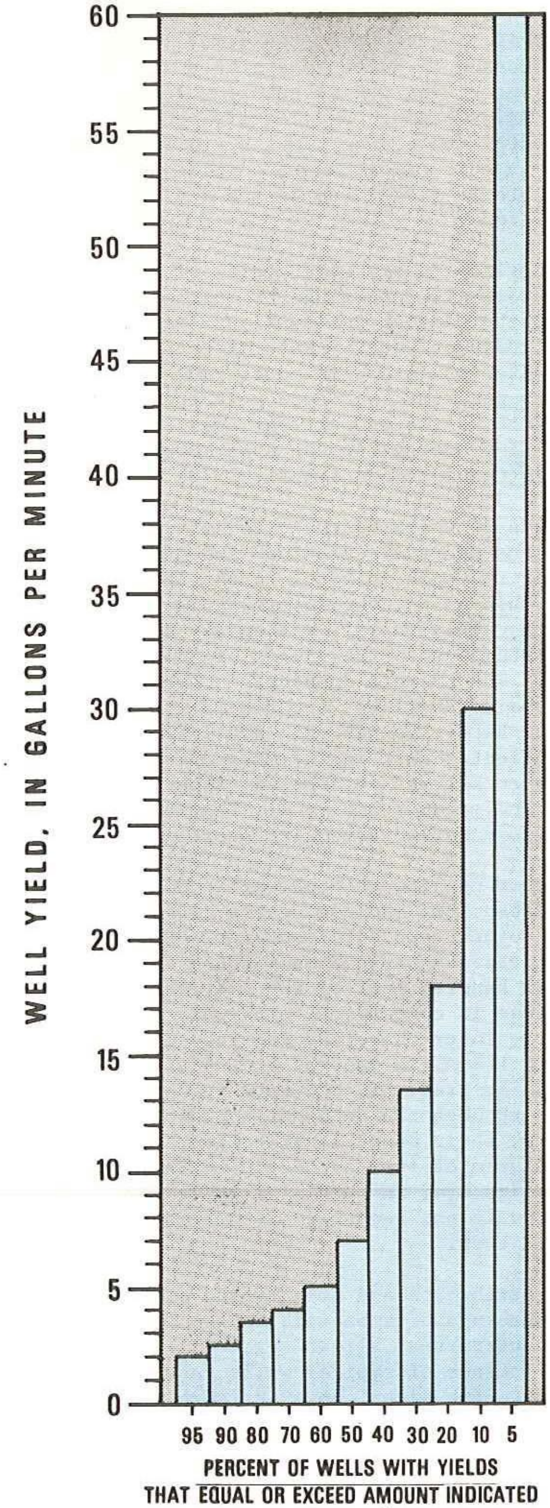


Figure 46.--Yield frequency of wells tapping igneous bedrock.

thicknesses of rock are penetrated, the chance of success beyond 300 feet is still relatively high. The characteristic of sedimentary bedrock to produce water at greater depths than the other bedrock units is also indicated by the occurrence of the deepest wells. In the group of 1,097 wells penetrating all 3 types of rock, the maximum depths reported were 746 feet in sedimentary bedrock, 400 feet in igneous bedrock, and 483 feet in metamorphic bedrock.

Igneous bedrock

Igneous bedrock underlies about 30 square -les of the central part of the Quinnipiac River basin (fig. 30). It consists principally of basalt and diabase units, which are interbedded with and intrude the sedimentary rocks. Three basalt flows from 50 to 500 feet thick (Krynine, 1950) account for most of the igneous rock in the basin; their average combined thickness is about 200 feet. At depth, the igneous rocks extend over a much larger area than their outcrops suggest. They are the same age as and are stratigraphically related to the sedimentary units, and it is not uncommon for individual wells to tap both types of rock. Only data from wells finished exclusively in igneous bedrock are used in the yield analyses of that aquifer. Although it occurs close to and is interbedded with sedimentary bedrock, igneous rock is more like metamorphic rock in its water-yielding characteristics.

Yields of 45 wells tapping these rocks range from 2 to 75 gpm, and the median is 7 gpm. Most wells tapping this aquifer will yield supplies of water adequate for domestic purposes. Yield-distribution data shown in figure 46 indicate that 95 percent of the wells tapping igneous bedrock yield 2 gpm or more. The median yield, however, is generally lower than that of sedimentary rock.

Figure 47 shows the relationship between -lian well yield and thickness of igneous rock -netrated. It indicates that wells that must penetrate greater thicknesses of rock to obtain water are likely to have smaller yields than successful shallower wells. A comparison with figure 49 shows a similar trend for the metamorphic rocks. This indicates that the rate at which water-bearing fractures decrease is similar for both types. The comparison also suggests that igneous rocks are more productive in each of the thickness intervals shown. However, as table 27 shows, the average well tapping igneous rock is deeper than its counterpart in metamorphic rock, and it must penetrate a greater average thickness of rock for each gallon per minute of yield obtained.

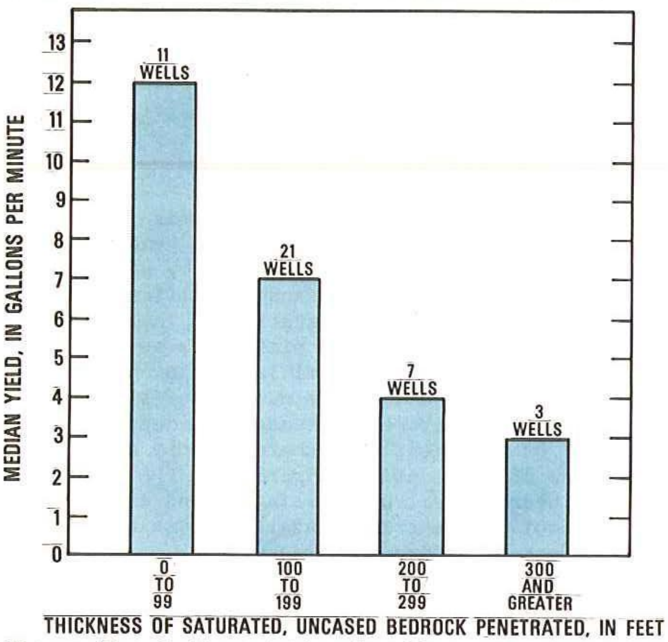


Figure 47.--Median yields of wells tapping different thicknesses of igneous bedrock.

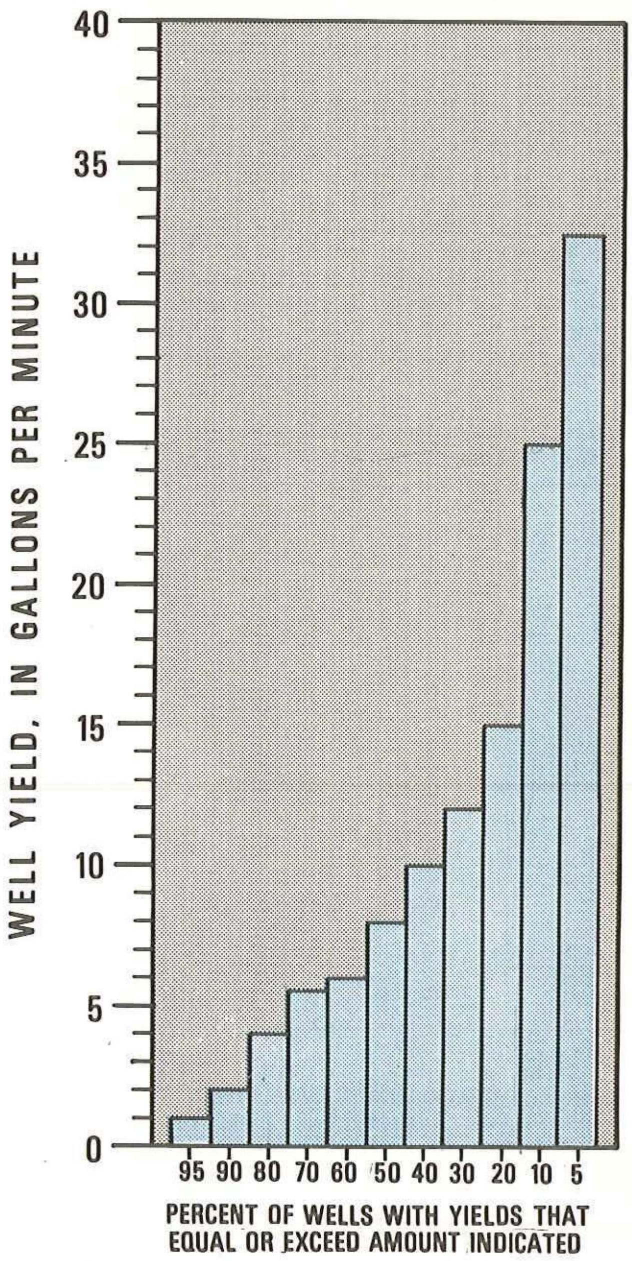


Figure 48.--Yield frequency of wells tapping metamorphic bedrock.

Metamorphic bedrock

Metamorphic bedrock directly underlies about 115 square miles of the Quinnipiac River basin and occurs chiefly along the western and southeastern margins. (See fig. 30.) It extends to great depths and is the basement complex beneath the sedimentary and igneous rocks of the region. The metamorphic rock aquifer consists principally of gneiss, schist, and phyllite and includes small amounts of other metamorphic or igneous rock types. Similar assemblages are collectively termed "crystalline bedrock" or "noncarbonate bedrock" in other reports of this series. Metamorphic rock is the second most important bedrock aquifer in the basin in terms of areal extent and ground-water development.

Yields of 370 wells tapping the metamorphic aquifer range from 0.1 to 200 gpm, with a median of 8 gpm. Figure 48 shows the well-yield frequency of this aquifer. The figure shows that 95 percent of the wells yield 1 gpm or more. This is about half the comparable figure (2 gpm or more) for the sedimentary and igneous rocks (see figs. 44 and 46) and indicates that marginal yields may be more common in wells drilled in metamorphic rocks. Nevertheless, the chance of obtaining a yield satisfactory for domestic needs is high.

Figure 49 shows the relationship between median yield and thickness of metamorphic rock

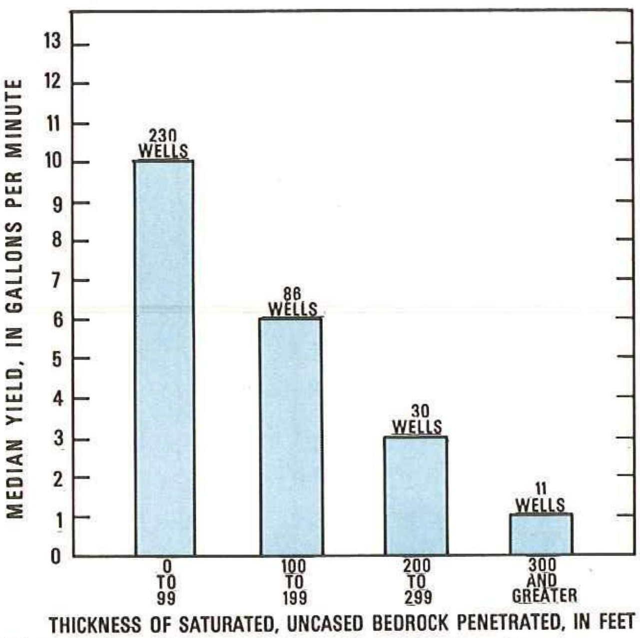


Figure 49.--Median yields of wells tapping different thicknesses of metamorphic bedrock.

penetrated. The decline in yield that occurs when greater and greater thicknesses of rock must be penetrated to obtain an adequate supply is typical of all bedrock in the basin. It shows that as wells are drilled deeper the chances of intercepting water-bearing fractures with adequate yields become smaller. A comparison of figures 45, 47, and 49 shows that for the 300-foot or greater range, the median yield of wells tapping metamorphic rock is lower than the median yields of the other principal bedrock types. Wells in metamorphic rock that had to penetrate 300 feet or more of saturated bedrock to obtain water have a median yield of only 1 gpm. Below this depth, the chance of obtaining a water supply is low.

Water supplies from bedrock

The bedrock aquifers of the Quinnipiac River basin can supply amounts of water adequate for domestic needs at most sites. The sedimentary bedrock aquifer is the most productive in terms of mean, median, and maximum well yields; the two crystalline bedrock aquifers are about equal. (See table 21.) Table 27 summarizes and compares the statistical data for the bedrock aquifers. Sedimentary rocks, on the average, yield more water with less saturated rock penetrated than crystalline rocks. Igneous rocks yield slightly more water than metamorphic rocks but require greater penetration of saturated rock to accomplish this.

Table 27.--Average depths, yields, and thickness of saturated bedrock penetrated by wells in the Quinnipiac River basin

Aquifer type	No. of wells	Mean depth (ft) 1/	Mean yield (gpm) 2/	Mean thickness of bedrock penetrated (ft) 1/	Mean thickness of bedrock penetrated for each gpm of yield (ft) 2/
Sedimentary bedrock	698	178	15.8	113	7.2
Igneous bedrock	42	190	13.7	145	10.6
Metamorphic bedrock	357	154	12.2	102	8.4

1/ Rounded to nearest foot.
2/ Rounded to nearest tenth.

Predictions of well yields at specific sites are not possible. Yields of wells penetrating the same thickness of aquifer, in the same area, may vary considerably because of difference in the size, spacing, and orientation of interconnected rock fractures. The yield of a well generally increases as it is drilled deeper but at a declining rate because the number and size of water-bearing fractures decrease with depth. Statistical data suggest that there is only a small chance of substantially increasing the yield of a bedrock well by drilling beyond a depth of about 300 feet in crystalline rock and about 450 feet in sedimentary rock.

QUALITY OF GROUND WATER

DISSOLVED SOLIDS

The major inorganic constituents of ground water in the Quinnipiac River basin are silica, calcium, sodium, bicarbonate, sulfate, and chloride. Their sources and significance are listed in table 11. Natural factors affecting ground-water quality include climate; subsurface flow patterns; the chemistry of precipitation, soil, organic debris, and aquifer materials; and biological processes. Human factors include discharge of sewage, industrial, and animal wastes; spreading of chemical fertilizer and road salt; solid waste disposal; and intrusion of salty water in coastal aquifers.

Table 28 summarizes the chemical and physical characteristics of water from the major aquifers. Water quality can be evaluated by comparing the concentrations of constituents with the maximum

Table 28.--Chemical and physical properties of ground water in the Quinnipiac River basin 1/

(Concentrations of chemical constituents in milligrams per liter)

Constituent or property	Stratified drift Median	Stratified drift Range	Sedimentary bedrock 4/ Median	Sedimentary bedrock 4/ Range	Crystalline bedrock 5/ Median	Crystalline bedrock 5/ Range
Iron (Fe)	0.06	0.01- 9.10	0.80	0.02- 4.30	0.11	0.04- 2.80
Manganese (Mn)	.00	.00- 5.90	.00	.00- .18	.00	.00- .43
Calcium (Ca)	46	6.0 - 180	33	1.0 -1,080	26	7.5 - 92
Magnesium (Mg)	7.9	.9 - 44	4.4	.0 - 460	5.2	1.3 - 14
Sodium + potassium (Na + K) 2/	10	3.2 - 146	14	.9 -3,800	12	3.5 - 47
Bicarbonate (HCO_3)	108	20 - 525	118	16 - 318	70	25 -201
Sulfate (SO_4) 2/	26	4.4 - 130	19	7.5 -1,000	20	4.8 -140
Chloride (Cl) 2/	20	2.5 - 240	14	2.8 -8,300	9.3	2.0 -130
Nitrate (NO_3) 2/	12	.0 - 53	5.0	.0 - 66	2.4	.0 - 40
Dissolved solids (residue on evaporation at 180°C)	218	50 - 965	207	64 -16,800	141	84 -501
Specific conductance (micromhos at 25°C)	345	58 -1,325	322	88 -21,900	214	114 -715
Hardness, as $CaCO_3$ (Ca + Mg)	136	20 - 581	114	4 -4,590	85	25 -260
Hardness, as $CaCO_3$ (noncarbonate)	44	0 - 244	24	0 -4,480	20	0 -154
pH	7.6	6.1 - 8.4	7.6	5.8 - 9.4	7.3	5.9 - 8.5
No. of wells sampled 3/	36		64		32	

1/ Wells sampled 1970-71; complete analysis of each sample is in "Water Resources Data for Connecticut" U.S. Geol. Survey, 1971)

2/ Upper limits recommended by the Connecticut Dept. of Health (Connecticut General Assembly, 1975) for drinking water: SO_4 (250 mg/l), Cl (250 mg/l), nitrate plus nitrite as N (10 mg/l), Na (20 mg/l).

3/ Concentrations based on analyses of single samples from most wells, mean values of periodic samples from a few wells are included.

4/ Some samples affected by salt water intrusion.

5/ Includes igneous and metamorphic rocks.

concentrations recommended for drinking water by the Connecticut Department of Health (Connecticut General Assembly, 1975). Locations of sampled wells are shown on plate A. Distribution of stratified-drift and till aquifers is shown on plate B; distribution of bedrock aquifers is shown in figure 30.

Predominant ions

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

Calcium and bicarbonate are the principal ions in water from 67 percent of the 132 wells sampled. Calcium bicarbonate water tends to be slightly basic and soft to moderately hard. Of the calcium bicarbonate waters tested, 80 percent have a pH equal to or greater than 7.0 (neutrality) and only 9 percent are rated as very hard. (Table 16 explains hardness classification.) Distribution systems carrying calcium bicarbonate water are unlikely to fail because of corrosion and are seldom plugged by hard scale precipitate.

Sodium bicarbonate water is obtained from some deep wells in the basin, and their water may have been naturally softened by ion exchange. Sodium and bicarbonate ions predominate in 19 percent of samples from sedimentary bedrock. Sodium bicarbonate water is basic (median pH 8.9) and very soft (median hardness 8 mg/l). The high sodium concentration makes this water unsuitable for people restricted to a low sodium diet (maximum 20 mg/l) and the high pH makes it corrosive and unacceptable for many uses.

Wells near the coast and along estuaries sometimes yield brackish water in which sodium and chloride ions predominate. Such waters are natural or may be the result of pumping. The maximum dissolved-solids concentration reported for wells affected by saltwater intrusion is 16,800 mg/l, almost half the concentration of undiluted sea water. Saltwater intrusion is discussed under "Saltwater intrusion and salinity."

Effects of aquifer type

Surficial materials in the Quinnipiac River basin have been transported some distance by glaciation or were derived from local bedrock. Bedrock is a complicated mixture of minerals and differs in composition areally and with depth. Waters from various sources mix and react as they move from one type of environment to another. Therefore, water composition is not specifically related to a single mineral species or simple assemblage. It differs areally with depth and with time. General characteristics of water from different aquifers in the basin are shown in table 28.

Dissolved-solids concentrations are high in water from unconsolidated sediments partly because large surface areas are available for chemical reactions. The quality of water from shallow wells in highly permeable sediments is susceptible to modification by chemical reactions in the soil and to pollution from surface and near surface sources. The concentrations of most solutes are generally lower in water from deeper wells in these aquifers.

The quality of water in stratified-drift aquifers reflects the composition of both the drift and the underlying bedrock, as well as factors discussed above. Stratified drift in most places is derived from and is similar in composition to the underlying bedrock. In other places, it consists of materials derived from bedrock of a different composition. Its water, therefore, may differ in quality from that of the underlying bedrock. Till is of minor importance in the Quinnipiac River basin; water from it has not been sampled for this study.

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

Sedimentary bedrock composed of sandstone, siltstone, conglomerate, and shale, is the most extensive aquifer in the basin. The stratigraphic and areal differences in composition of these rocks contribute to the wide range of solute concentrations in the water they yield; water from sedimentary bedrock is generally lower in solutes than that from stratified drift.

Crystalline-bedrock aquifers consist primarily of metamorphic rocks along the southeastern and western margins of the basin and northeast-southwest-trending igneous units in the central part. Water from these aquifers contains the lowest concentrations of dissolved solids (table 28). Water moves through them chiefly along joints and fractures, so that only a small surface area is open to chemical attack. Furthermore, crystalline rocks to a large degree are composed of slightly soluble minerals. These factors account for the low concentrations of solutes in water from crystalline bedrock.

Changes with time

Ground-water quality changes with time in response to changes in temperature, recharge, discharge, and land use. Figure 50 illustrates fluctuations in concentrations of silica, iron, chloride, nitrate, pH, sulfate, hardness, and dissolved solids in 2 wells during an 11-month period in 1970. Hardness remained fairly constant; other parameters varied in one or both wells. Variations may be related to seasonal changes in recharge, vegetation, and human activities. Induced recharge of surface water, a result of intense pumping, was the major cause of the fluctuations in these wells. Both wells are located near the Quinnipiac River, and large ground-water withdrawals have induced river water to infiltrate the aquifer. The effects of induced recharge on water quality are discussed in a later section.

IRON AND MANGANESE

Concentrations of iron and manganese in ground water generally are low. Locally they may exceed 0.3 mg/l of iron and 0.05 mg/l of manganese and be objectionable for domestic and industrial use. On exposure to air, the dissolved iron is oxidized to a reddish-brown precipitate, which discolors fabrics and plumbing fixtures. Manganese is oxidized in a similar fashion, causing gray or black stains. Table 29 summarized concentrations of these ions in ground water of the Quinnipiac River basin.

Table 29.--Iron and manganese in ground water in the basin

(Concentrations in milligrams per liter)

		Type of aquifer				
		Stratified drift				
Constituent		Underlain by sedimentary bedrock	Underlain by crystalline bedrock	All stratified drift	Sedimentary bedrock	Crystalline bedrock 1/
Iron	Median	0.05	0.24	0.06	0.08	0.11
	Range	.01-9.1	.01-2.0	.01-9.1	.02-4.3	.04-2.8
	Percent exceeding 0.3 mg/l	15	40	19	16	29
Manganese	Median	.00	.00	.00	.00	.00
	Range	.00-5.9	.00-.29	.00-5.9	.00-.18	.00-.43
	Percent exceeding 0.05 mg/l	7	20	9	6	34
No. of wells 2/		27	5	32	64	32

1/ Includes igneous and metamorphic rocks.
2/ Concentrations based on analyses of single samples from most wells, mean values of periodic samples from a few wells are included. Individual analyses are in "Water Resources Data for Connecticut" (U.S. Geol. Survey, 1971).

Crystalline bedrock and the stratified drift derived from it contain minerals rich in iron and manganese. Water from these aquifers is, therefore, more likely to contain excessive concentrations of these ions. Figure 51 shows the distribution of iron and manganese in ground water.

HARDNESS

Ground water in the basin ranges from soft to very hard and is influenced by the mineral composition of the soils and aquifers through which it passes. Local differences in hardness of water may also reflect differences in the mineral composition of zones within an aquifer. Most hardness results from solution of minerals containing calcium and magnesium. These minerals are most abundant in sedimentary bedrock and the consolidated materials derived from it. Additional calcium may come from infiltration of runoff containing dissolved calcium from road salt or from agricultural lime.

Solution of calcium and magnesium is complex and is partly controlled by dissolved carbon dioxide, pH, and organic processes in the soil. Soil organism populations and carbon dioxide concentrations are at a maximum in the zone near the surface, and decrease with depth. Shallow wells, therefore, are more likely to contain hard water than deeper wells.

Table 30 summarizes ground-water hardness.

Table 30.--Hardness of ground water

(Concentrations in milligrams per liter)

		Type of aquifer		
		Stratified drift	Sedimentary bedrock 1/	Crystalline bedrock 2/
Calcium	Median	46	33	26
	Range	6.0-180	1.0-1,080	7.5-92
Magnesium	Median	7.6	4.4	5.2
	Range	0.9-44	0.0-460	1.3-14
Hardness, as $CaCO_3$ (Ca + Mg)	Median	136	114	85
	Range	20-281	4-4,590	25-260
Hardness, as $CaCO_3$ (noncarbonate)	Median	44	24	20
	Range	0-244	0-4,480	0-154
Samples rated as:		Percent	Percent	Percent
Soft		12	31	19
Moderately hard		26	22	59
Hard		38	39	6
Very hard		24	8	16
Number of wells 3/		34	64	32

1/ Some samples affected by salt-water intrusion.
2/ Includes igneous and metamorphic rocks.
3/ Concentrations based on analyses of single samples from most wells, mean values of periodic samples from a few wells are included. Individual analyses are in "Water Resources Data for Connecticut" (U.S. Geol. Survey, 1970-71).

Hardness and suitability of water are classified in table 16. The occurrence of hard and very hard ground water, shown in figure 52 and in table 30, is more common in areas underlain by sedimentary bedrock but is not restricted to a specific aquifer or locality. The range of values is greatest in water from sedimentary bedrock because this unit is quite variable in composition and includes some beds of carbonate rock. Stratified drift has the highest percentage of wells yielding hard to very hard water, chiefly because it has a developed soil zone in which near-surface reactions increase calcium solubility. In the New Haven area, much of the hardness is caused by saltwater intrusion.

CHLORIDES AND NITRATES

Under natural conditions most ground water in the Quinnipiac River basin is low in chloride and nitrate. Near the coast and along estuaries, ground water containing high chloride concentrations may be natural or the result of pumping. In other areas concentrations of chloride greater than 20 mg/l generally indicate contamination by sewage, road salt, water softeners, and other sources. Leachate from stockpiles of highway deicing salts have also been known to contaminate wells. Nitrate concentrations greater than 10 mg/l may indicate infiltration of sewage, leachate from nitrate fertilizers,

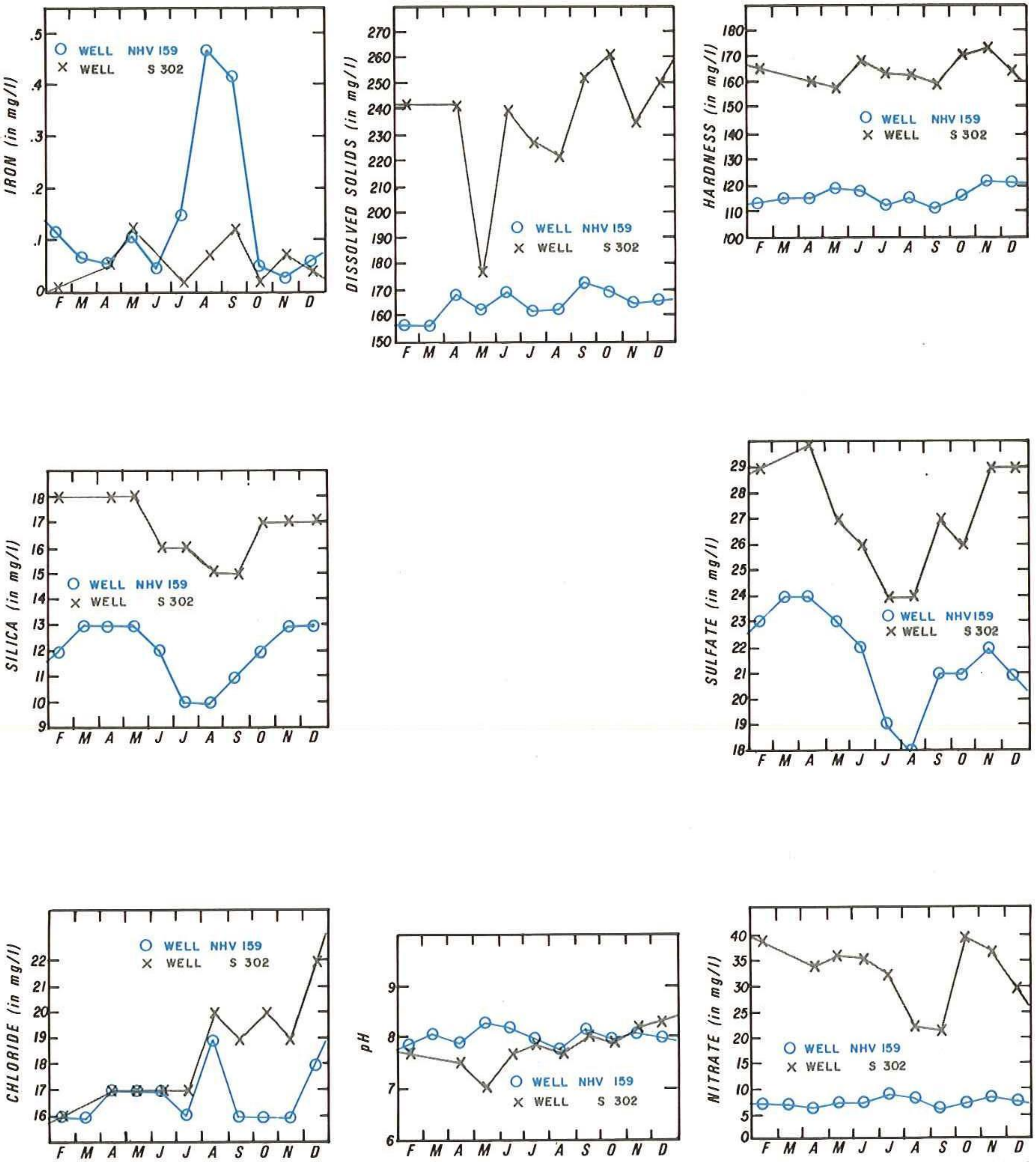


Figure 50.--Changes in quality of water from two wells tapping stratified drift.

Monthly values of iron, hardness, silica, sulfate, chloride, nitrate, dissolved solids, and pH from February to December 1970.

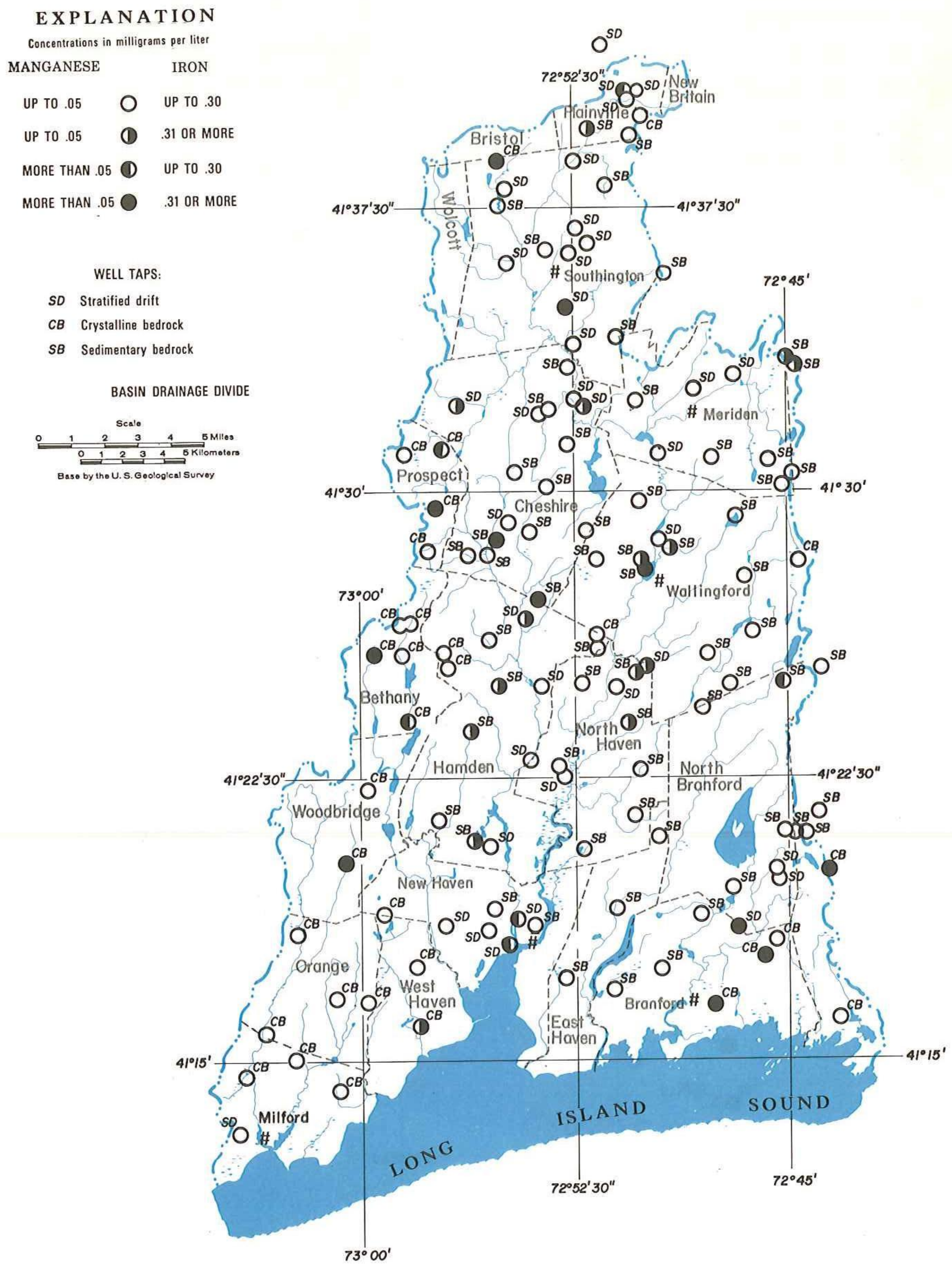


Figure 51.--Distribution of iron and manganese in ground water.

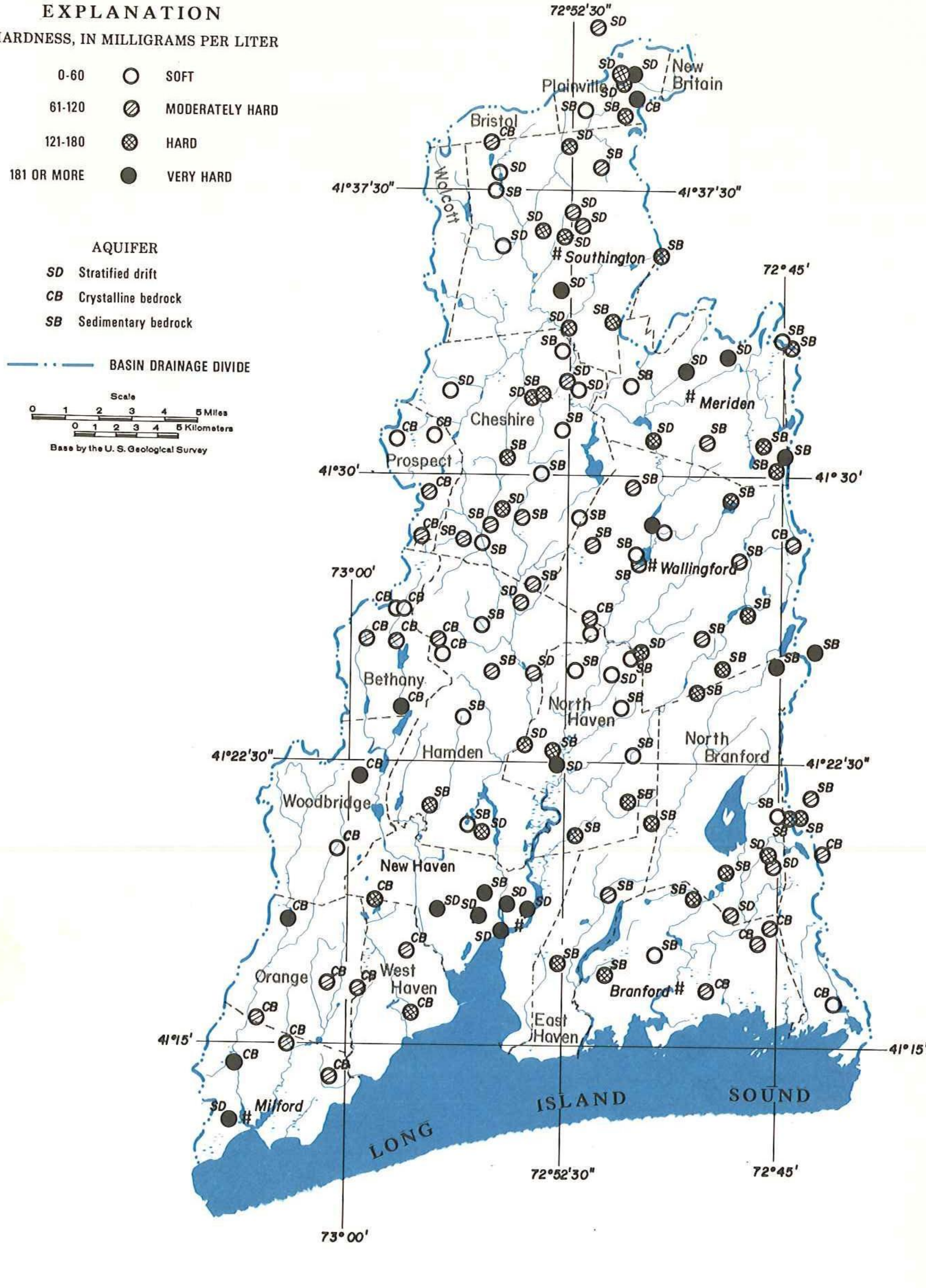


Figure 52.--Distribution of hardness in ground water.

animal wastes or decayed vegetation. High concentrations of chloride and nitrate may also be indicative of contamination from septic-tank effluent or leachate from landfills.

Table 31.--Chloride and nitrate in ground water

(Concentrations in milligrams per liter)

Constituent		Aquifer type: Stratified drift	Sedimentary bedrock	Crystalline bedrock 3/
Chloride	Median	20	14	9.3
	Range	2.5-240	2.8-8,300 1/	2.0-130
	Percent of samples exceeding 20 mg/l	47	36	25
Nitrate	Median	12	5.0	2.4
	Range	0.0-53	0.0-66	0.0-40
	Percent of samples exceeding 10 mg/l	91	31	25
No. of samples 2/		36	64	32

1/ Some wells affected by salt-water intrusion.
2/ Concentrations based on analyses of single samples from most wells, mean values of periodic samples from a few wells are included. Individual analyses are in "Water Resources Data for Connecticut" (U.S. Geol. Survey, 1971).
3/ Includes igneous and metamorphic rocks.

Table 31 summarizes chloride and nitrate concentrations in ground waters in the basin. The highest median concentrations are in water from shallow wells in stratified-drift aquifers. Almost half the samples from wells in stratified drift have chloride concentrations greater than 20 mg/l, and most have nitrate concentrations greater than 10 mg/l.

The Connecticut Department of Health (Connecticut General Assembly, 1975) recommends maximum concentrations of 250 mg/l chloride and 10 mg/l nitrate plus nitrite as N (equivalent to 44 mg/l nitrate) in drinking water. Although it may not be toxic, water containing high concentrations of chloride may taste salty. High chloride concentrations also increase the corrosiveness of water. Drinking water containing excess nitrate can cause or contribute to methemoglobinemia ("blue baby" disease), which can be fatal to infants. Nitrate does not affect most industrial use of water. Three of the 132 wells sampled contained chloride above the recommended limit and four contained excessive nitrate. The seven wells are located in New Haven (NHN 351, 355), North Haven (NHV 160, 161), and Wallingford (WLD 249, 256, 259). Their locations are shown on plate A.

SALTWATER INTRUSION AND SALINITY

Salty water is present in aquifers near the coast and along estuaries. In coastal aquifers, a thin layer of fresh water floats on the denser salt water and is separated from it by a zone of diffusion. A shallow well may tap fresh water, whereas a deeper well at the same site may tap salt water. (See fig. 53A.) The position of the freshwater-saltwater interface can be altered by pumping. As fresh water is pumped out of the aquifer salt water moves in, displacing or mixing with the fresh water. Prolonged heavy pumping can result in intrusion of salty water r inland. Figure 53B illustrates saltwater intrusion.

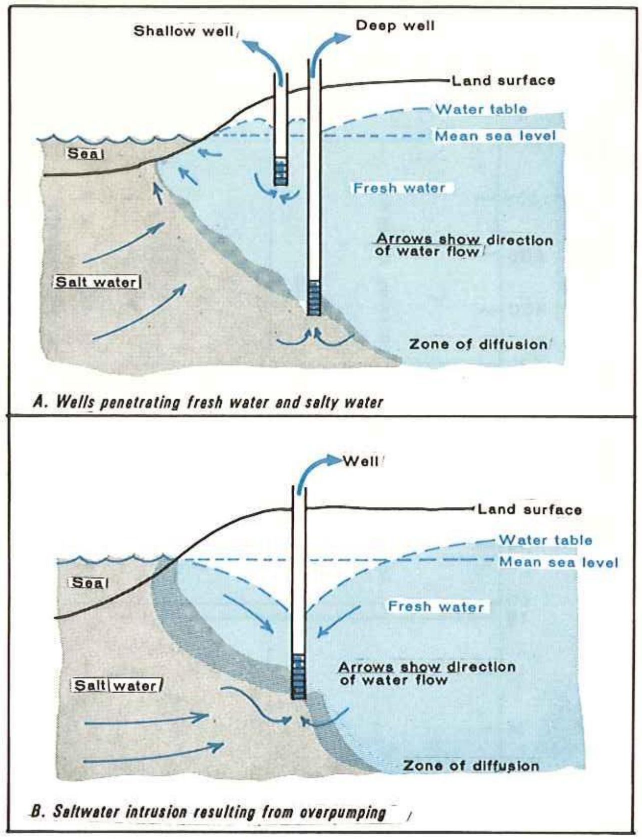


Figure 53.--Relationship between salt water and fresh water in a coastal aquifer during pumping.

Salinity can be classified as follows (modified from Swenson and Baldwin, 1965):

Degree of salinity	Dissolved solids concentration (mg/l)
Fresh	0- 1,000
Slighty saline	1,000- 3,000
Moderately saline	3,000-10,000
Very saline	10,000-35,000
(ocean water, average)	(35,000)
Brine	more than 35,000

According to the above classification, water from three wells in the study area, NBR 80, NHV 161, and WLD 249 is slightly saline, and that from one, NHN 351, is very saline. Each well is completed in sedimentary bedrock. Saline ground water can also result from solution of aquifer minerals, discharge of wastes, or other processes. Different sources of salinity can sometimes be distinguished by examining ionic ratios of the waters under investigation. The major ions in sea water (chloride, sodium, sulfate, magnesium, and calcium) occur in approximately fixed ratios and these ratios remain fairly constant when sea water is diluted by fresh water. If ionic ratios in saline ground water are similar to those of sea water, saltwater intrusion is probably occuring.

Table 32 compares the ionic ratios of water from four wells in the basin with those of sea

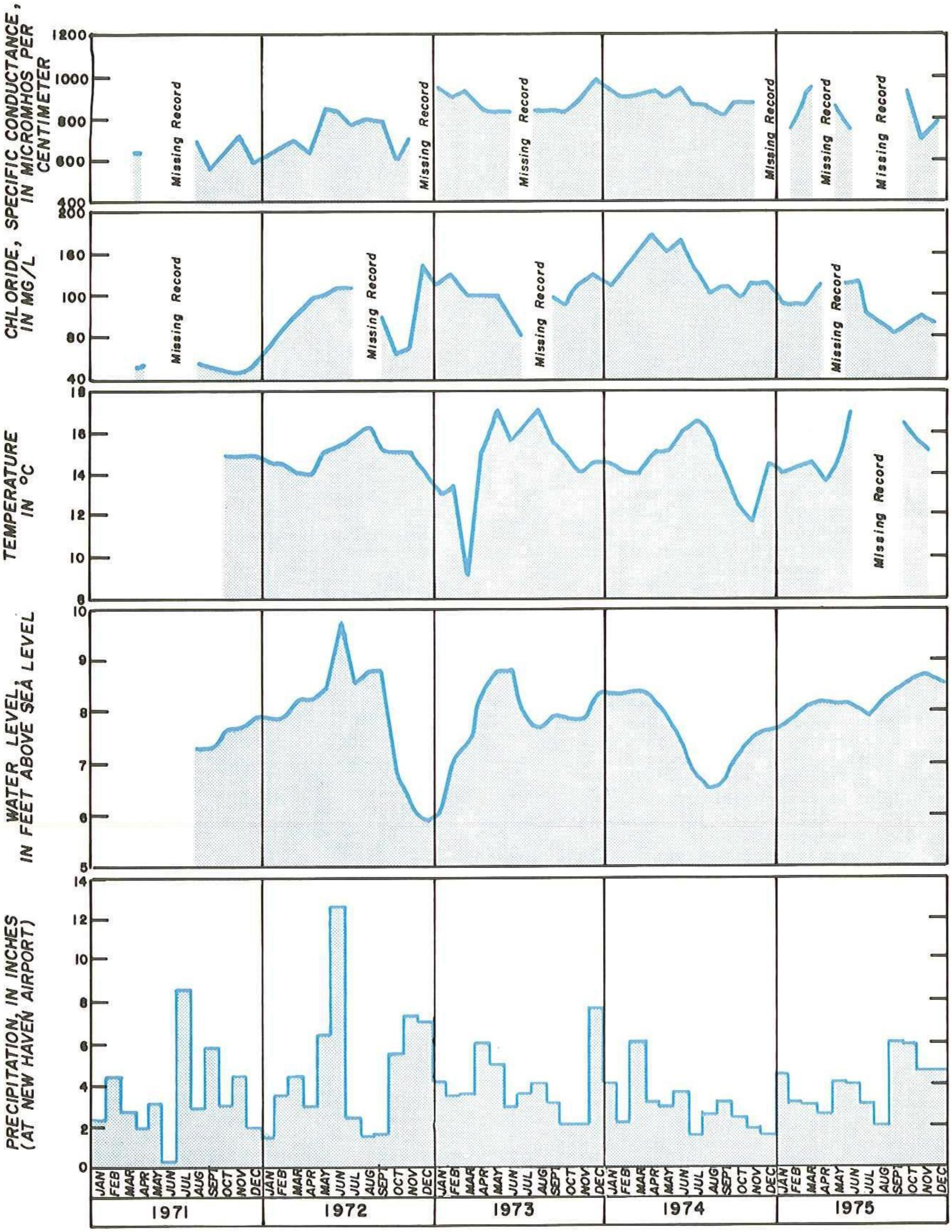


Figure 54.--Fluctuations in selected physical and chemical properties of water from a well affected by saltwater intrusion (Well NHN 354).

Well data based on monthly measurements.

Table 32.--Salinity and ionic ratios of sea water contrasted with ground water from four wells

	Source of water				
	Sea water 1/	Well NHN 351 2/	Well NBR 80 2/	Well EHV 102 2/	Well NHN 354 2/
Aquifer		Sedimentary bedrock	Sedimentary bedrock	Sedimentary bedrock	Stratified drift
Salinity	Very saline	Very saline	Slightly saline	Not saline	Not saline
Dissolved solids concentration, mg/l	35,000	16,800	1,930	187	548
Predominant ions	Sodium, chloride	Sodium, chloride	Calcium, sulfate	Calcium, bicarbonate	Calcium, chloride
Ionic ratios: Chloride/sodium	1.81	2.18	0.50	0.67	2.72
Magnesium/sodium	.13	.12	.98	.73	.27
Sulfate/chloride	.14	.12	43.48	2.20	.43
Calcium/chloride	.02	.13	16.30	3.50	.75

1/ Complete analysis in Hem (1970, p. 11.)
2/ Complete analysis in "Water Resources Data for Connecticut" (U.S. Geol. Survey, 1971).

water. The predominant ions in water from NHN 351 are sodium (Na + K, 3,800 mg/l) and chloride (8,300 mg/l) and their ratios are similar to those of sea water. The chemistry and ionic ratios of water from this well and its location in an area of intense pumping between the Quinnipiac and Mill River estuaries indicate contamination by sea water. Water from NHN 351 is a mixture of about 40 percent sea water and 60 percent fresh ground water.

Well NBR 80 yields slightly saline water. Ionic ratios, however, differ from those of sea water. Predominant constituents are calcium and sulfate, which are common in sedimentary rocks. The well is located far from the coast and from estuaries. The salinity is probably caused by solution of aquifer materials. The well taps sedimentary bedrock containing layers of organic-rich shale. Oxidation of organic materials in shale is a possible source of the high sulfate concentrations. Evaporite minerals may also occur at depth in this aquifer. Well EHV 102 yields water more typical of wells tapping sedimentary bedrock and is included for comparison.

Aquifers in the city of New Haven are affected by saltwater intrusion from the Green south to the harbor, east to the Quinnipiac River estuary, and for more than a thousand feet inland along the West River estuary. Ground water in New Haven contained high chloride concentrations as long ago as 1919 (Brown, 1928; Mazzaferro, 1973). During the 1940's, a period of heavy pumping, chloride concentrations exceeded 3,000 mg/l. Although pumping has since decreased, chloride concentrations are still higher than they were under pre-pumping conditions. Figure 54 shows fluctuations in water level, temperature, chloride concentration, and specific conductance in a nonpumping well, NHN 354, on the Green in New Haven. Total monthly rainfall at the New Haven airport is also shown. Although water from this well is not saline, it has a high chloride concentration (average 115 mg/l from 45 monthly samples) and is very hard. Ionic ratios show some similarity to sea water (see table 32) but not as much as water from NHN 351. Water from NHN 354 is a mixture of sea water and calcium bicarbonate ground water. The well is probably screened in the zone of diffusion.

EFFECT OF INDUCED RECHARGE

Induced recharge can change the quality of water in an aquifer. As surface water infiltrates into an aquifer in response to pumping, its quality is modified by filtration and biological action. Sediments lining the stream or lake filter bacteria and suspended solids, but most dissolved constituents pass through. Water from an area of induced recharge is a mixture of ground water and surface water. Its quality depends on relative proportions of these two components. Surface water is generally less mineralized than ground water, hence recharge by induced infiltration is likely to dilute the ground water and improve its quality. If surface water is polluted, however, induced recharge may cause a deterioration in quality. Deterioration is most likely during periods of low streamflow when streams carrying wastes may be more highly mineralized than ground water. Figure 50 shows the effects of induced recharge on water quality in two wells near the Quinnipiac River.

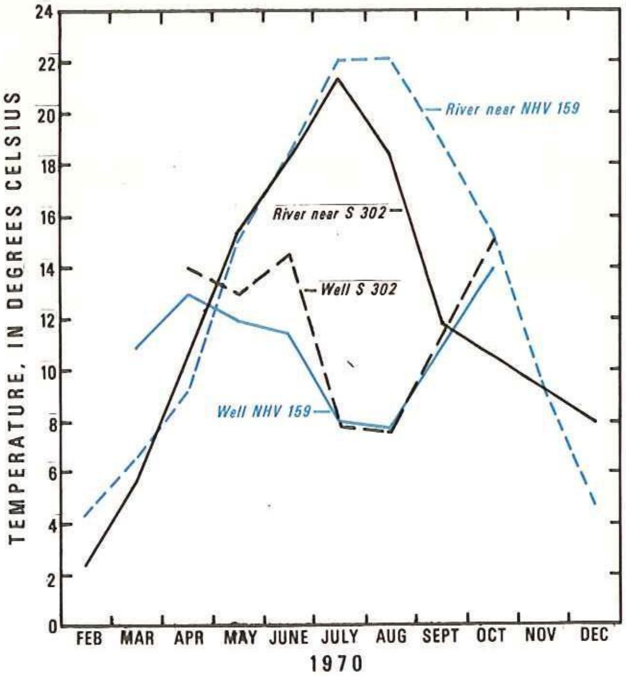


Figure 55.--Temperature fluctuations in water from wells, Quinnipiac River near Southington, Station no. (Pl. A) 01195468 and North Haven, Station no. (Pl. A) 01196523.

Well water temperatures are from monthly samples. River water temperatures are monthly means.

Induced recharge also affects the temperature of water in an aquifer. Ground-water temperatures below depths of approximately 30 feet are nearly constant and are about equal to the mean annual air temperature. The temperature of stream water, however, varies with that of the air, as shown in figure 23. It is cooler in winter and warmer in summer than ground water. Ground-water temperature fluctuates seasonally in areas of induced recharge, but to a lesser degree than surface water. Figure 55 compares temperature fluctuations in the Quinnipiac River and in two nearby wells in heavily pumped areas. Ground water was coldest in July and August, indicating a lag before cold stream water that infiltrated in the winter reached the wells. Lag and seasonal range in temperature are also influenced by transmissivity of the aquifer, pumping rates, distance of the wells from the surface-water source, recharge, discharge, flow path, and other factors. Figure 54 shows a narrow range of temperature fluctuations in a well about a mile inland in an area affected by saltwater intrusion.

Table 33.--Principal public-water supply systems serving the basin
(Based on records and estimates from water utilities for 1970)

Water-supply system	Towns served	Estimated population served 1/	Source 2/	Treatment 3/	Safe yield (mgd)	Storage capacity (mg)	Total use 4/ (mg/yr)	Percent of use: Industrial	Municipal and institutional	Residential and commercial	Other 5/
Blue Trail Acres Association	North Branford	265	Total supply:		0.11			0	0	100	0
			Ground water:								
			Drilled well	None							
Gaylord Water Company	Hamden	112	Total supply		.01			0	0	100	0
			Ground water:								
			Drilled well	None							
Meriden, city of, Water Dept.	Meriden	57,205	Total supply		9.6		2,543.0	25	15	45	15
	Cheshire		Surface water:				1,940.4				
			Broad Brook Reservoir	Cl,Cc,F,Fl,T		1,000					
			Elmere Reservoir	Cl,Cc,F,Fl,T		18					
			Merimere Reservoir	Cl,Cc,F,Fl,T		357					
			Bradley Hubbard Reservoir	Cl,Fl		168					
			Hallmere Reservoir	-		140					
			Black Pond Reservoir	-		212					
			Kenmere Reservoir	-		133					
			Ground water:				602.6				
			Mule Well	Cl,Fl			11.7				
			Columbus Park Well	Cl,Fl			119.3				
			Cuno Well	Cl,Fl			46.7				
			Evansville Ave. Wells (2)	Cl,Fl			139.0				
			Kensington Well	None			15.4				
			Brittania St. Well	Cl,Fl			224.3				
			Platt High School Well	Cl			-				
			Golf Course Well	-			46.2				
New Haven Water Company	New Haven	394,504	Total supply		66.4		20,740.0	25	4	57	14
	Hamden		Surface water:				19,995.1				
	North Haven		Lake Saltonstall Reservoir	Cl,Cc,Fl		1,500					
	East Haven		Maltby Lakes Reservoirs	Cl,Cc,Fl		260					
	West Haven		Milford (Beaver Brook) Reservoir	Cl,Cc,Fl		22					
	Branford		Lake Gaillard Reservoir	Cl,Fl		13,000					
	North Branford		Cheshire (Prospect Lake) Reservoir	Cl,Cc,Fl		19					
	Orange		Lake Bethany Reservoir	Cl,Cc,Fl		603					
	Cheshire		Lake Wintergreen Reservoir	Cl,Cc,Fl		100					
	Woodbridge		Lake Watrous Reservoir	Cl,Cc,Fl		709					
	Milford		Glen Lake Reservoir	Cl,Cc,Fl		153					
	Bethany		Lake Chamberlain Reservoir	Cl,Cc,Fl		894					
			Lake Dawson Reservoir	Cl,Cc,Fl		318					
			Lake Whitney Reservoir	Cl,Cc,F,Fl		258					
			Menunkatuck Reservoir	-		197					
			Lake Hammonasset Reservoir	-		1,080					
			Wepawaug Reservoir	-		15					
			Ground water:				744.4				
			Mt. Carmel Wells	Cl,Cc,Fl			180.4				
			Sleeping Giant Wells	Cl,Cc,Fl			385.0				
			Honey Pot Brook Well	Cl,Fl			179.0				
Plainville Water Company	Plainville	14,929	Total supply:		2.7		643.5	34	6	52	8
	Farmington		Surface water:				25.4				
	Bristol		Plainville (Crescent Lake) Reservoir	Cl,Cc,F,T		160					
	Southington		Ground water:				618.1				
			Woodford Wells Nos. 1,2,4,5	Cl			423.2 6/				
			Johnson Well	Cl			194.9 6/				
			Bristol Water Dept.	Cl,Cc,Fl							
			New Britain Water Dept.	-							
Southington, town of, Water Dept.	Southington	25,000	Total supply:		4.2		1,019.2	23	1	59	17
	Cheshire		Surface water:				204.0				
			Southington Reservoir No. 1	Cl,Cc,Fl		2.5					
			Southington Reservoir No. 2	-		104					
			Southington Reservoir No. 3	-		51					
			Ground water:				815.2				
			Well No. 1A, High St.	Cl,Fl			205.7				
			Well No. 2, Rt. 66	Cl,Fl			208.7				
			Well No. 3, Hobart St.	Cl,Fl			97.7				
			Well No. 4, Curtis St.	Cl,Fl			301.1				
			Well No. 5	Cl,Fl			0				
Wallingford, town of, Water Dept.	Wallingford	33,500	Total supply		5.7		1,580.0	37	5	55	3
			Surface water:				1,220.0				
			MacKenzie (Pine River) Reservoir	Cl,Cc,F,T		225					
			Pistapaug Pond Reservoir	Cl,Cc		1,200					
			Lane Pond Reservoir	-		50					
			Spring Brook Reservoir	-		850					
			Ground water:				360.0				
			Well No. 1, Ridgeland St.	Cl,S			280.1				
			Well No. 2, Oak St.	Cl,Cc			78.6				

1/ Includes some population outside the basin.
2/ Includes some sources outside the basin and emergency supplies.
3/ Cl = chlorination, Cc = corrosion control, F = filtration, Fl = fluoridation, S = softening, T = taste and odor control.
4/ Includes some water used outside the basin.
5/ Includes leakage, pipe flushing, fire fighting.
6/ Estimated.

Table 34.--Chemical analyses of water from principal public water-supply systems

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

Public water-supply system [1]	Date of collection	Source of water	Site No. [1]	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 on evaporation at 180°C)	Hardness, as $CaCO_3$: Ca + Mg	Hardness, as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25°C)	Temperature (°C)	pH	Color	Detergents as MBAS	Turbidity	Alkalinity as $CaCO_3$
Blue Trails Association, North Branford	4-29-70	Drilled well	NBR 86	19	0.06	0.00	59	18	7.9	0.8	200	40	22	0.1	7.3	305	221	57	517	11.5	7.7	-	-	-	-
Meriden, city of, Water Dept.	4-28-70	Bradley Hubbard Reservoir	01196240	9.8	.04	.00	14	5.8	2.8	.1	30	38	2.7	.5	.0	86	59	34	138	13.5	7.4	4	0.02	0.6	25
	4-28-70	Broad Brook Reservoir	01196225	4.7	.07	.00	13	1.8	4.3	.5	28	16	7.5	.1	.7	64	40	17	105	15.0	7.2	6	.03	.8	23
	4-28-70	Merimere Reservoir [2]	01192682	7.8	.03	.00	9.8	2.2	2.6	.1	22	17	4.0	.7	.2	60	34	16	84	10.0	7.1	3	.04	.3	18
	4-28-70	Columbus Well	ME 196	14	.02	.00	57	12	10	.5	106	96	16	.9	12	273	192	104	405	11.0	7.5	-	-	-	-
	4-28-70	South Meriden Well	ME 197	11	.01	.00	52	9.9	10	.8	161	24	22	.1	11	238	170	38	361	12.0	8.1	-	-	-	-
	4-28-70	Brittania Well	ME 198	15	.02	.00	74	12	14	.7	174	74	34	.1	11	325	234	92	540	12.4	7.6	-	-	-	-
New Haven Water Company	4-29-70	Cheshire (Prospect Lake) Reservoir	01196010	8.8	.09	.00	9.6	2.0	6.8	.7	14	14	14	.2	3.7	70	32	20	102	15.0	7.0	6	.01	.6	11
	4-29-70	Glen Lake Reservoir	01196636	5.5	.07	.00	8.7	1.9	6.5	.9	12	15	12	.1	1.7	61	30	20	93	13.5	7.0	6	.01	.5	10
	5-07-70	Lake Hammonasset Reservoir [2]	01195120	2.2	.07	.02	3.8	.8	3.4	.5	4	10	5.7	.1	.0	28	12	10	51	14.0	6.4	14	.01	1.0	3
	4-29-70	Lake Bethany Reservoir	01196630	6.5	.07	.00	7.3	1.8	5.6	.5	10	14	11	.2	.9	60	26	18	82	16.0	6.9	9	.02	.3	8
	5-07-70	Lake Gaillard Reservoir	01195320	4.2	.09	.00	7.6	2.2	4.1	.8	17	14	5.0	.1	.4	45	28	14	81	11.0	7.1	9	.01	.3	14
	5-07-70	Lake Saltonstall Reservoir	01195420	2.8	.04	.00	24	5.9	8.9	1.1	72	25	16	.1	1.4	137	84	25	224	10.0	8.0	5	.01	.6	59
	4-29-70	Lake Watrous Reservoir	01196633	5.8	.06	.00	8.9	1.9	5.6	.4	13	14	11	.2	.8	60	30	20	86	16.0	6.9	2	.01	.7	11
	4-29-70	Lake Wintergreen Reservoir	01196650	5.9	.09	.10	6.7	1.7	3.1	.2	6	17	5.7	.0	.0	50	24	18	65	16.5	6.5	9	.02	.7	5
	4-29-70	Maltby Lakes Reservoir No. 1	01196655	5.4	.07	.00	15	2.2	9.1	.4	22	24	17	.2	1.3	94	46	28	142	17.0	7.1	4	.02	.8	18
	5-07-70	Menunkatuck Reservoir [2]	01195280	7.6	.09	.00	9.0	2.7	3.4	.3	25	13	4.0	.1	.7	55	34	13	88	12.5	7.3	11	.02	1.0	21
	4-29-70	Honeypot Well No. 1	CS 67	14	.02	.00	29	3.1	6.5	.5	68	19	11	1.2	12	125	86	30	197	8.5	7.5	-	-	-	-
	4-29-70	Mount Carmel Well No. 1	HM 413	10	.05	.00	20	3.8	7.6	.7	53	17	14	1.0	3.6	97	66	22	166	8.5	7.1	-	-	-	-
	4-29-70	Sleeping Giant Well No. 1	HM 414	13	1.20	.01	24	2.3	6.4	.4	62	13	11	.6	4.4	103	70	18	166	8.0	7.9	-	-	-	-
Plainville Water Company	4-28-70	Plainville (Crescent Lake) Reservoir	01195450	2.3	.08	.00	10	2.4	2.7	.1	31	16	2.7	.0	.0	58	35	10	86	-	7.2	2	.01	1.0	25
	4-28-70	Woodford Well No. 1	PV 1	14	.08	.07	40	9.0	17	1.3	130	29	29	.1	6.1	218	137	30	340	11.2	7.3	-	-	-	-
	4-28-70	Woodford Well No. 2	PV 2	17	.05	.03	47	10	9.2	.9	136	44	20	.2	8.2	231	158	46	350	11.0	7.6	-	-	-	-
	4-28-70	Johnson Ave. Well	PV 63	14	.03	.00	35	3.4	6.7	.3	86	15	15	.0	13	144	102	31	228	10.5	8.2	-	-	-	-
	4-28-70	Woodford Well No. 4	PV 64	20	.02	.01	58	12	7.0	.4	184	39	15	.2	8.2	259	194	43	392	11.0	7.9	-	-	-	-
Southington, town of, Water Dept.	4-28-70	Southington Reservoir No. 3	01196070	3.7	.10	.08	3.8	.9	7.7	.2	3	7.4	13	.1	.1	42	13	10	66	16.0	5.9	2	.01	.3	2
	4-28-70	Well No. 2, Rt. 66	S 19	15	.03	.02	44	6.3	37	.9	110	28	61	1.2	5.2	270	136	46	449	9.4	8.0	-	-	-	-
	4-28-70	Well No. 3, Hobart St.	S 331	15	.04	.00	38	4.7	7.4	.4	98	21	6.6	1.1	19	162	114	34	253	9.8	7.2	-	-	-	-
	4-28-70	Well No. 4, Curtis St.	S 334	15	.07	.00	39	4.3	7.8	.7	98	22	11	.1	13	166	115	34	259	9.5	7.3	-	-	-	-
	4-28-70	Well No. 1A, High St.	S 335	16	.05	.00	49	5.1	17	1.7	120	23	31	.1	14	220	143	44	340	11.5	7.5	-	-	-	-
Wallingford, town of, Water Dept.	4-28-70	Lane Pond Reservoir [2]	01195270	5.7	.11	.00	4.0	1.3	1.8	.0	7	12	2.2	.1	.0	34	16	10	43	14.5	6.6	11	.03	.2	6
	4-28-70	MacKenzie (Pine River) Reservoir	01196560	5.1	.20	.00	22	6.0	9.6	.8	61	29	17	.1	3.1	134	80	30	210	15.0	7.7	4	.04	.9	50
	4-28-70	Pistapaug Pond Reservoir	01195360	2.8	.03	.01	14	4.2	3.6	.3	42	20	5.6	.0	.0	71	52	18	126	12.5	7.3	1	.04	.3	34
	4-28-70	Spring Brook Reservoir	01196540	4.2	.10	.00	19	5.3	3.9	.7	62	22	5.1	.0	.3	93	70	18	154	16.0	7.5	4	.02	.7	51
	4-28-70	Ridgeland Well No. 1	WLD 248	11	.01	.03	61	8.6	12	.9	175	33	20	.1	15	263	188	94	400	11.5	7.7	-	-	-	--
Drinking water standards: [3]		Raw water		-	-	-	-	-	-	-	-	-	250	2.0	45	-	-	-	-	-	-	20	.5	1.0	-
		Finished water		-	-	-	-	-	20	-	-	-	-	2.0	45	-	-	-	-	-	6.4-8.5	15	-	1.0	-

1/ Locations are on plate A.

2/ Reservoir is outside of basin.

3/ Recommended by Connecticut Dept. of Health (Connecticut General Assembly, 1975).

WATER USE

USE IN 1970

The total amount of fresh water used in the Quinnipiac River basin in 1970 is estimated at 35,710 million gallons. This is equal to a per capita average of 183 gallons per day. Public supply systems in the basin provide nearly 90 percent of the domestic and commercial water and 39 percent of the industrial water used during the year. Surface-water sources supplied 75 percent of the total amount used in the basin. Ground water accounted for the remaining 24 percent and for 41 percent of the self-supplied amount used by industry. Agricultural use was less than 1 percent of the basinwide total and was from private surface-water and ground-water sources. An estimated 34,000 million gallons of saline water was also used during 1970, mostly as a coolant in the production of electric power.

The source, use, and disposal of fresh water are summarized in figure 56. Data on which this figure is based were supplied by water utilities, major industries, and State agencies. Water for domestic use from privately owned wells was estimated by multiplying the population not served by public systems times a per capita consumption of 70 gallons per day. Agricultural use consisted chiefly of water supplied to dairy herds, poultry, and other livestock.

Although much of the water used in the basin receives some treatment, the quality of the treated effluent varies considerably, owing to factors such as size, age, and type of treatment facility and water use. From 1960 to 1975, the upgrading of waste-treatment systems and the constructing of new facilities has generally improved surface-water quality in the basin. The service areas and the locations of the sewage-treatment facilities of the major municipal systems in the basin are shown on plate C.

Five public supply systems served about 90 percent of the population in 1970 and supplied 39 percent of the water used by industry. The sources of water, capacities, populations served, and other features of these systems are shown in table 33. Plate C shows the general areas served by these systems, the locations of water sources, and the amounts supplied. The plate also shows the sites and estimated amounts of major ground-water withdrawals in 1970.

The principal water utilities listed in table 33 supply soft to moderately hard water with low dissolved-solids content. Chemical analyses of samples from each of these systems are shown in table 34. The water is of good chemical quality and is within standards required by the Connecticut Department of Health (Connecticut General Assembly, 1975). Surface-water reservoirs supplied 88 percent of the water provided by public-supply systems during 1970; ground water supplied the remainder. A comparison of the percentages of surface water and ground water used for public supplies in the Quinnipiac River basin, the State of Connecticut, and the United States is shown in table 35.

Table 35.--Sources of water and total water supplied by public systems in 1970

Area	Total water supplied (mgd)	Sources: Surface-water (percent)	Sources: Ground-water (percent)
Quinnipiac River basin	66	88	12
Connecticut 1/	360	75	25
United States 1/ 2/	27,000	67	33

1/ Murray and Reeves (1972).
2/ Includes Puerto Rico.

FUTURE USE

Projections of population and water consumption to the year 2000 have been prepared for the South Central Connecticut Planning Region by the Connecticut Development Commission (1963a, 1963b). This planning region covers approximately the same area as the Quinnipiac River basin, and these projections are applicable to the basin. Using figures adjusted to 1970 population and water use, the projected water demand in the year 2000 is about 62,500 million gallons, a 75 percent increase over 1970. The projected water demand represents 38 percent of the average annual runoff for the 1931-60 period of record. This indicates that the water needs in the year 2000 can be met by sources in the basin. Ground water will probably play an expanded role in the future, and water reuse will increase.

DEVELOPMENT OF WATER SUPPLIES

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

Large supplies of water can be obtained only from the larger streams and from stratified-drift aquifers with favorable hydraulic character-

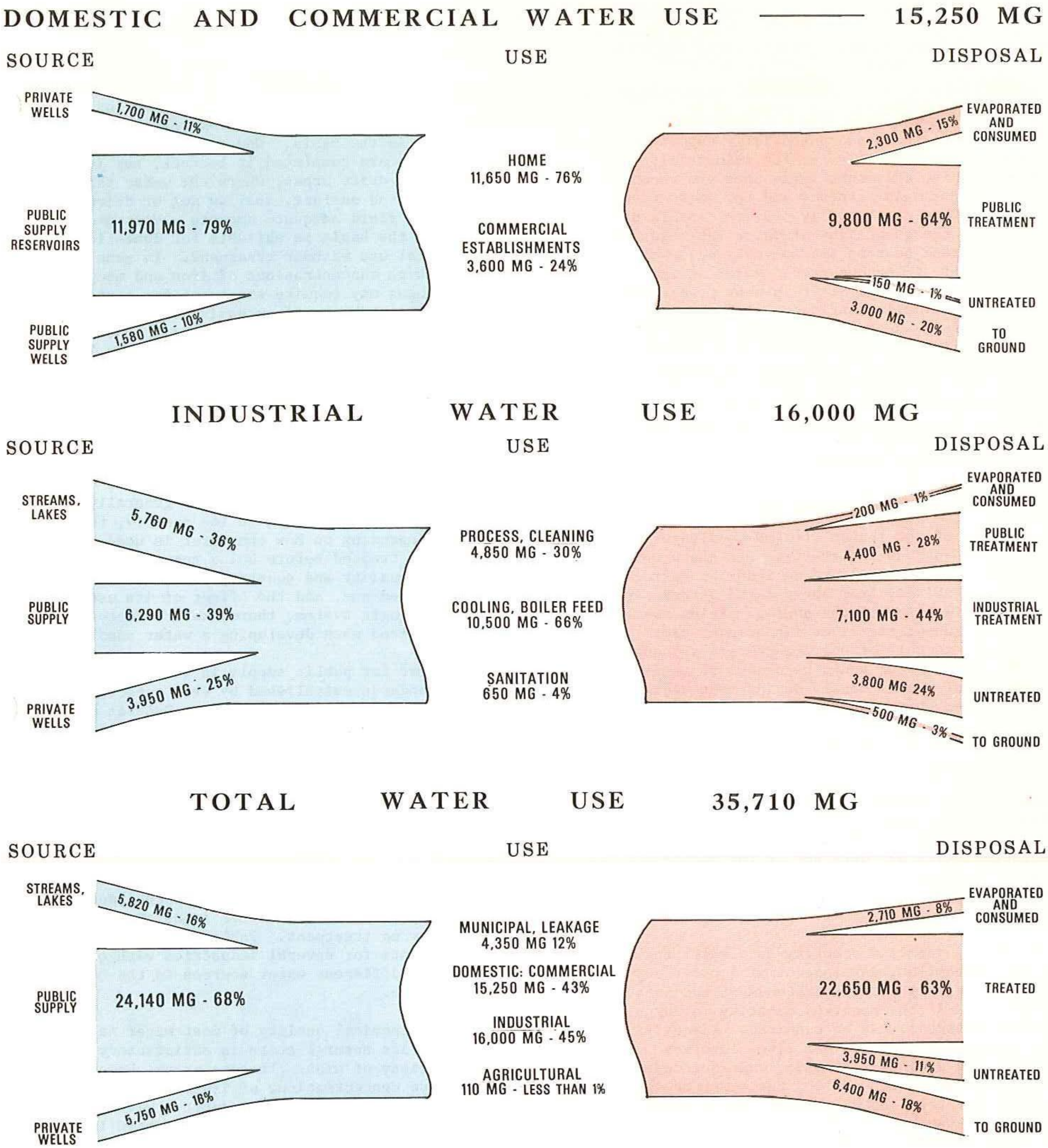


Figure 56.--Source, use, and disposal of water in the Quinnipiac River basin during 1970. Amounts in millions of gallons (MG).

istics. Smaller supplies can be obtained from a wide variety of sources and locations including smaller streams, ponds, bedrock, till, and the less favorable stratified-drift aquifers.

LARGE SUPPLIES

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

SURFACE WATER

Flows of the larger streams equaled or exceeded 90 percent of the time are shown on plate D. These values are an index of surface-water availability from unregulated streams and are approximations of the average yields available from low, run-of-the-river impoundment dams. Only small amounts of surface storage or supplemental ground water would be needed to maintain these amounts continuously during most years. Plate D also shows the storage capacities and locations of selected surface-water reservoirs. In addition to the 90-percent duration-flow figures shown on the plate, developing a particular stream for water supply or effluent dilution requires more detailed information, such as flow duration, low-flow frequency, and storage-required frequency. Methods to determine these characteristics are outlined in the section titled "Surface Water." Yields available from selected lakes and ponds are summarized in table 5.

If the required quantity is a small fraction of low streamflow, development of a water supply may require only a small impoundment and intake structure. If the required quantity is large, a storage reservoir may be required. Identifying and evaluating suitable dam sites involves engineering geology, economic, and environmental policy considerations beyond the scope of this report, but topography, geology, and population density of the basin indicate that construction of large storage reservoirs is impractical in many areas.

GROUND WATER

The long-term ground-water yields of fourteen areas underlain by stratified drift were evaluated. The areas are shown on plate D, and information for each site is listed in table 26. The methods used to determine long-term yields are described in the ground-water section of this report.

SMALL SUPPLIES

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

WATER QUALITY AND DEVELOPMENT

Water-quality requirements for public supply, industry, and agriculture differ widely. Although water of poor quality can be treated to meet the minimum standards for most uses, costs may be prohibitive. Use of water generally results in deterioration in its quality, the amount depending on how the water is used and how it is treated before being returned to the system. Quality and quantity of water available, its intended use, and the effect of its use on the hydrologic system, therefore are factors to be considered when developing a water supply.

Water for public supply in Connecticut must meet standards established by the Connecticut Department of Health (Connecticut General Assembly, 1975). Concentrations that exceed the limits can generally be reduced to acceptable levels by dilution or treatment. Table 34 lists the principal sources of public supply serving the basin, their physical and chemical properties, and the standards for drinking water. Water from these sources meets the recommended standards.

Some industries require water that is less mineralized than drinking water; such industries routinely treat water. Other industries require little or no treatment. Table 36 compares the requirements for several industries with quality data from different water sources in the Quinnipiac River basin.

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

Table 36.--Limitations on water quality for industrial use and range of water quality in the Quinnipiac River basin (Maximum limits or ranges in limits of significant properties and constituents of waters acceptable for industrial uses. Source of data: Water Quality and Treatment, American Water Works Association, 1951, p. 66-67, unless otherwise noted. Chemical constituents in milligrams per liter)

Industrial use	Turbidity 1/	Color 2/	Hardness (as $CaCO_3$)	Alkalinity (as $CaCO_3$)	pH	Total dissolved solids	Calcium (Ca)	Iron (Fe)	Manganese (Mn)	Silica (SiO_2)	Fluoride (F)	Carbonate (CO_3)	Bicarbonate (HCO_3)	Remarks 3/
Air conditioning 4/	--	--	--	--	--	--	--	0.5	0.5	--	--	--	--	A,B
Baking	10	10	5/	--	--	--	--	.2	6/ .2	--	--	--	--	C
Boiler feed:														
0-150 psi	20	80	75	--	8.0 & up	3,000-1,000	--	--	--	40	--	200	50	--
150-250 psi	10	40	40	--	8.5 & up	2,500-500	--	--	--	20	--	100	30	--
250 psi and up	5	5	8	--	9.0 & up	1,500-100	--	--	--	5	--	40	5	--
Brewing: 7/														
Light	10	8/ 0-10	--	75	6.5-7.0	500	100-200	.1	.1	8/ 50	1.0	8/ 50-68	--	C,D
Dark	10	8/ 0-10	--	150	7.0 & up	1,000	200-500	.1	.1	8/ 50	1.0	8/ 50-68	--	C,D
Canning:														
Legumes	10	--	25-75	--	--	--	--	.2	.2	--	--	--	--	C
General	10	--	--	--	--	8/ 850	--	.2	.2	--	1.0	--	--	C
Carbonated beverages 9/	2	10	250	50	--	850	--	.2	.2	--	.2	--	--	C
Confectionery	--	--	--	--	10/	100	--	.2	.2	--	--	--	--	--
Cooling 11/	50	--	50	--	--	--	--	.5	.5	--	--	--	--	A,B
Food, general	10	8/ 5-10	8/ 10-250	8/ 30-250	--	8/ 850	--	.2	.2	--	8/ 1.0			C
Ice (raw water) 12/	1-5	5	--	30-50	--	300	--	.2	.2	10	--	--	--	C
Laundering	--	--	50	8/ 60	8/ 6.0-6.8	--	--	.2	.2	--	--	--	--	--
Plastics: clear uncolored	2	2	--	--	--	200	--	.02	.02	--	--	--	--	--
Paper and pulp 13/														
Groundwood	50	20	180	--	--	--	--	1.0	.5	--	--	--	--	A
Kraft pulp	25	15	100	--	--	300	--	.2	.1	--	--	--	--	--
Soda and sulfite	15	10	100	--	--	200	--	.1	.05	--	--	--	--	--
Light paper, high grade	5	5	50	--	--	200	--	.1	.05	--	--	--	--	B
Rayon (viscose) pulp:														
Production	5	5	8	50	--	100	--	.05	.03	25	--	--	--	--
Manufacture	.3	--	55	--	7.8-8.3	--	--	.0	.0	--	--	--	--	--
Tanning 14/	20	10-100	50-135	135	8.0	--	--	.2	.2	--	--	--	--	--
Textiles:														
General 15/	5	20	20	--	--	--	--	.25	.25	--	--	--	--	--
Dyeing 15/	5	5-20	20	--	--	--	--	.25	.25	--	--	--	--	--
Wool scouring 16/	--	70	20	--	--	--	--	1.0	1.0	--	--	--	--	--
Cotton bandage 16/	5	5	20	--	--	--	--	.2	.2	--	--	--	--	--
Range of selected constituents in and properties of water in the Quinnipiac River basin														
Source														
Surface water:														
Reservoirs:	0.2-1.0	1-14	12-84	2-59	5.9-8.0	28-137	3.8-24	.03-.20	.00-.10	2.2-9.8	.0-.7	0	3-72	
Streams draining undeveloped areas underlain by:														
Sedimentary bedrock	--	2-39	50-130	25-87	7.2-7.7	84-194	16-36	.06-.90	.02-.06	6.8-12	.1-.3	0	30-106	
Crystalline bedrock	--	0-55	15-84	3-61	6.4-7.4	36-147	4.0-23	.01-.64	.00-.16	1.8-11	.1-.1	0	4-74	
Streams draining developed areas underlain by:														
Sedimentary bedrock	--	3-23	48-167	21-113	7.0-8.0	96-272	15-57	.15-.86	.01-.38	6.3-14	.1-.5	0	26-138	
Crystalline bedrock	--	2-24	24-94	7-54	6.8-7.4	52-174	7.6-29	.13-.50	.06-.20	3.1-8.1	.0-.2	0	9-66	
Ground water:														
Aquifers:														
Stratified-drift	--	--	20-581	--	6.1-8.4	50-965	6.0-180	.01-9.10	.00-5.90	10-20	.0-1.2	0-2	2-525	
Sedimentary-bedrock	--	--	4.4-590	--	5.8-9.4	64-16,800	1.0-1,080	.02-4.30	.00-.18	15-20	.0-.1	0-26	16-318	
Crystalline bedrock 17/	--	--	25-260	--	5.9-8.5	84-501	7.5-92	.04-2.80	.00-.43	--	--	0	25-201	

1/ Reported in milligrams per liter silica.
2/ Color units, not ppm as erroneously shown in original table.
3/ A - no corrosiveness, B - no slime formation; C - conformance to drinking-water standards (U.S. Public Health Service, 1962); D - maximum limit of NaCl, 275 mg/l.
4/ Waters with algae and hydrogen sulfide odors are unsuitable for air conditioning.
5/ Some hardness desirable.
6/ Figure has been corrected from data source.
7/ Water for distilling must meet the same general requirements as for brewing (gin and spirits mashing water of light-beer quality; whiskey mashing water of dark beer quality).
8/ McKee, J. E., and Wolf, H. W. (1963, p. 94-101).
9/ Clear, odorless, sterile water for syrup and carbonization. Water consistent in character. Most high quality filtered municipal water not satisfactory for beverages.
10/ Hard candy requires pH of 7.0 or greater, as low values favor inversion of sucrose, causing sticky product.
11/ Control of corrosiveness is necessary, as is control of organisms such as sulfur and iron bacteria which tend to form slime.
12/ $Ca(HCO_3)_2$ particularly troublesome. $Mg(HCO_3)_2$ tends to cause greenish color. CO_2 assists in preventing cracking. Maximum combined concentration of sulfates and chlorides of Ca, Mg, Na is 300 mg/l.
13/ Uniformity of composition and temperature desirable. Iron objectionable since cellulose adsorbs iron from dilute solutions. Manganese very objectionable; clogs pipelines and is oxidized to permanganates by chlorine, causing reddish color.
14/ Excessive iron, manganese or turbidity creates spots and discoloration in tanning of hides and leather goods.
15/ Constant composition; residual alumina must be less than 0.5 mg/l.
16/ Calcium, magnesium, iron, manganese, suspended matter, and soluble organic matter may be objectionable.
17/ Includes igneous and metamorphic rocks.

ABBREVIATIONS

^oC	- degrees Celsius (Centigrade)
bgy	- billion gallons per year
cfs	- cubic feet per second
csm	- cubic feet per second per square mile
cu ft/day	- cubic feet per day
^oF	- degrees Fahrenheit
fig.	- figure
ft	- feet
gpd	- gallons per day
gpm	- gallons per minute
in	- inches
mcf	- million cubic feet
mgd	- million gallons per day
mg/l	- milligrams per liter
mi	- miles
ml	- milliliters
mm	- millimeters
msl	- mean sea level
p.	- page
pl.	- plate
ppm	- parts per million
R.I.	- recurrence interval
sq ft	- square feet
sq mi	- square miles
ug/l	- micrograms per liter
umho	- micromhos

EQUIVALENTS

$^{o}C = (^{o}F - 32) \times 0.555$

1 cfs = 646,317 gpd = 0.646317 mgd

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

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

1 mgd = 694 gpm = 1.547 cfs

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

1 mm = 0.001 meter = 0.039 in

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

Transmissivity (ft sq/day) x 7.48 = coefficient of transmissibility in gpd/ft.

GLOSSARY

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

Adsorption: The adhesion of molecules to surfaces of the solids or liquids with which they are in contact.

Anaerobic bacteria: Bacteria which live in the absence of free oxygen.

Anion: A negatively charged ion.

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

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

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

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

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

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

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

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

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

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

Catch basin: A basin to collect and retain material from a street gutter that might otherwise clog the sewer system.

Cation: A positively charged ion.

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.

Coagulation: The process by which material clumps together or becomes viscous or thickened.

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.

Coliform bacteria: Any of a group of bacteria, some of which, inhabit the intestinal tracts of vertebrates. Their occurrence in a water sample is regarded as evidence of possible sewage pollution and fecal contamination, although these are generally considered to be nonpathogenic.

Color unit: A standard of color in water measured the platinum-cobalt method. The color produced by 1 mg/l of platinum in water equals 1 color unit.

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

Contact: A plane or irregular surface between two different types or ages of rocks.

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 measurements.

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

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.

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

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

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

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

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

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

Estuary: A body of water where fresh water mixes with and measurably dilutes sea water and where tidal effects are evident.

Eutrophic lake: A lake rich in dissolved nutrients, commonly shallow and having seasonal oxygen deficiency.

Evaporite mineral: A mineral precipitated as a result of evaporation, such as gypsum, anhydrite or halite.

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

Exchange capacity: The property of clay to carry ions that may be exchanged for other ions in aqueous solutions. It varies with particle size and is related to crystal structure.

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

Ferrous iron: A reduced or low-valence form of iron (Fe^{+2}). More soluble in water than ferric iron. Oxidizes to ferric iron when exposed to air.

Flocculation: The process by which clumps of material in a liquid aggregate or increase in size.

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 have been equaled in magnitude within a given time period.

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

Frequency: See "recurrence interval."

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

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

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

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

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

Ground water: Water in the saturated zone.

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

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

Ground-water evapotranspiration: Ground water 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; it includes 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 dense layer of water below the metalimnion in a thermally stratified lake, pond, or reservoir.

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

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.

Ion: An atom or group of atoms that carries an electric charge as a result of having lost or gained electrons.

Isochlor: A line on a map connecting points having equal chloride concentrations.

Isopleth: Line on a map connecting points of equal value of a variable.

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 their total number. Also referred to as the "average."

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

Metalimnion: The middle zone in a stratified lake, pond, or reservoir, between the epilimnion and the hypolimnion, in which the temperature decreases rapidly with depth.

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

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

Micrograms per liter (ug/l): A unit for expressing the concentration of chemical constituents in solution by weight per unit volume of water. One thousand micrograms is equivalent to 1 milligram.

Mho: The practical unit of electrical conductance equal to the reciprocal of the ohm.

Micromho (umho): A unit of electrical conductance, equal to one millionth of a mho.

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

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.

Oxidation potential: The relative intensity of oxidizing or reducing conditions in solutions.

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 random 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 concentration. A pH of 7.0 indicates neutrality; values below 7.0 denote acidity, those above 7.0 denote alkalinity.

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

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 to contain voids or open spaces; it may be expressed quantitatively as the ratio of the volume of its open spaces to its total volume.

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

Reaeration: The physical absorption of oxygen from the atmosphere.

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 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.

Saltwater intrusion: Decrease or reversal of the seaward flow of ground water causing sea water to penetrate inland.

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

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

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

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

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

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

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

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

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

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

Thermal stratification: Formation of layers of water having different temperatures in deep open-water bodies.

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 vapor 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.

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

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

Water table: The upper surface of the saturated zone.

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

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

Zone of diffusion: The mixed layer between fresh and salty water in a coastal aquifer or estuary.

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