WATER RESOURCES INVENTORY OF CONNECTICUT

PART 3

LOWER THAMES

AND SOUTHEASTERN COASTAL RIVER BASINS

BY
CHESTER E. THOMAS, JR., MICHAEL A. CERVIONE, JR., AND I. G. GROSSMAN
U.S. GEOLOGICAL SURVEY

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

CONNECTICUT WATER RESOURCES BULLETIN NO. 15

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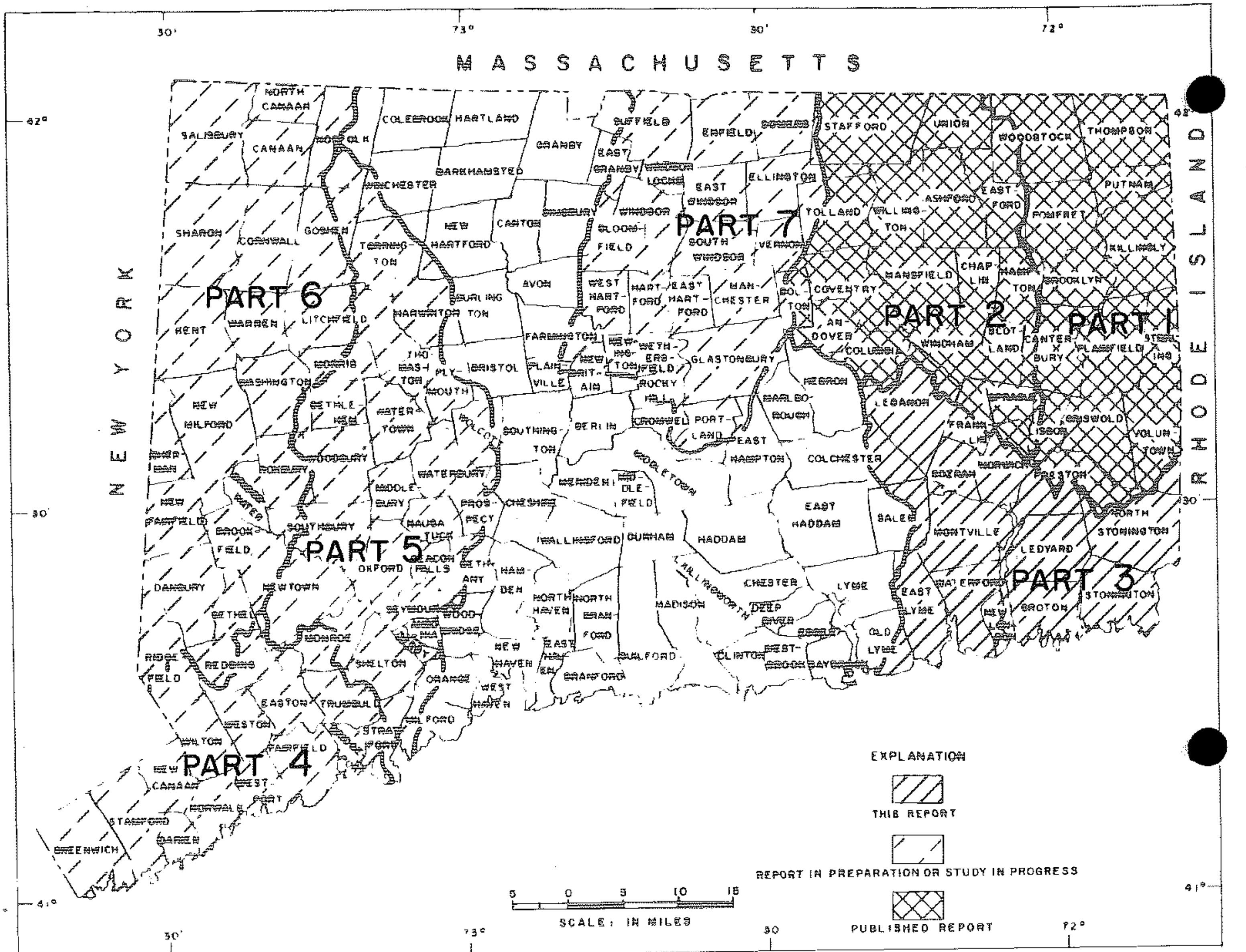

THE WATER RESOURCES INVENTORY OF RIVER BASINS IN CONNECTICUT

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
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OUTSIDE COVER--The Thames River Estuary, looking downstream from Norwich, in the foreground, to Long Island Sound, in the distance. The Shetucket River, which flows from the left and joins the estuary due south of Norwich, has an average flow of 1,450 mgd. The Yantic River, which flows from the right and also joins the estuary south of Norwich, has an average flow of 115 mgd. The estuary is a source of unlimited supplies of salty and brackish water for cooling and other uses where the quality of water is relatively unimportant. The New London-Groton area to the south is heavily urbanized, as is Norwich. Many adjacent lowlands and hillsides are cleared and suburbanized but most uplands remain heavily wooded.

Photo courtesy of Perry Studios, Waterford, Connecticut.

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SUMMARY

The lower Thames and southeastern coastal river basins have a relatively abundant supply of water of generally good quality which is derived from streams entering the area and precipitation that has fallen on the area. Annual precipitation has ranged from about 32 inches to 65 inches and has averaged about 48 inches over a 30-year period. Approximately 22 inches of water are returned to the atmosphere each year by evaporation and transpiration; the remainder of the annual precipitation either flows overland to streams or percolates downward to the water table and ultimately flows out of the report area through estuaries and coastal streams or as underflow through the deposits beneath. During the autumn and winter months precipitation normally is sufficient to cause a substantial increase in the amount of water stored underground and in surface reservoirs within the report area, whereas in the summer most of the precipitation is lost through evaporation and transpiration, resulting in sharply reduced streamflow and lowered ground-water levels. The mean monthly storage of water on an average is about 3.8 inches higher in November than it is in June.

The amount of water that flows through and out of the report area represents the total amount of water potentially available for use by man. For the 30-year period 1931 through 1960, the annual runoff from the report area has averaged nearly 26 inches (200 billion gallons), from the entire Thames River basin above Norwich about 24 inches (530 billion gallons), and from the Pawcatuck River basin about 26 inches (130 billion gallons). A total average annual runoff of 860 billion gallons is therefore available. Although runoff indicates the total amount of water potentially available, it is usually not economically feasible for man to use all of it. On the other hand, with increased development, it is possible that some water will be reused several times.

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

Differences in streamflow from point to point are due primarily to differences in the proportion of stratified drift in the drainage basin above each point, which affect the timing of streamflow, and to differences in precipitation, which affect the amount of streamflow.

Ground water can be obtained from wells almost anywhere in the area, but the amount obtainable at any particular point depends upon the type and water-bearing properties of the aquifers. For practical purposes, the earth materials in the report area comprise three aquifers--stratified drift, bedrock, and till.

Stratified drift is the only aquifer generally capable of yielding more than 100 gpm (gallons per minute) to individual wells. It covers about 20 percent of the area and occurs chiefly in lowlands where it overlies till and bedrock. The coefficient of permeability of the coarse-grained unit of stratified drift averages about 1,500 gpd (gallons per day) per sq ft. Drilled, screened wells tapping this unit are known to yield from 4 to 880 gpm and average 146 gpm. Dug wells in coarse-grained stratified drift supply about 2 gpm per foot of drawdown over a period of a few hours. Fine-grained stratified drift has an average coefficient of permeability of about 300 gpd per sq ft and can usually yield supplies sufficient for household use to dug wells.

Bedrock and till are widespread in extent but generally provide only small water supplies. Bedrock is tapped chiefly by drilled wells, about 90 percent of which will supply at least 3 gpm. Very few, however, will supply more than 50 gpm. Till is tapped in a few places by dug wells which can yield small supplies of only a few hundred gpd throughout all or most of the year. The coefficient of permeability of till ranges from about 0.2 gpd per sq ft to 120 gpd per sq ft.

The amount of ground water potentially available in the report area depends upon the amount of ground-water outflow, the amount of ground water in storage, and the quantity of water available by induced infiltration from streams and lakes. From data on permeability, saturated thickness, recharge, yield from aquifer storage, well performance, and streamflow, preliminary estimates of ground-water availability can be made for any point in the report area. Long-term yields estimated for 18 areas of stratified drift especially favorable for development of large ground-water supplies ranged from 1.3 to 66 mgd. Detailed site studies to determine optimum yields, drawdowns, and spacing of individual wells are needed before major ground-water development is undertaken in these or other areas.

The chemical quality of water in the report area is generally good to excellent. Samples of naturally occurring surface water collected at 24 sites contained less than 151 ppm (parts per million) of dissolved solids and less than 63 ppm of hardness. Water from wells is more highly mineralized than naturally occurring water from streams. Even so only 12 percent of the wells sampled yielded water with more than 200 ppm of dissolved solids and only 8 percent yielded water with more than 120 ppm of hardness.

Even in the major streams, which are used to transport industrial waste, hardness rarely exceeds 60 ppm and the dissolved mineral content is generally less than 200 ppm. At a few places in the town of Montville however, waters may contain dissolved mineral concentrations of 2,000 to 4,000 ppm.

Iron and manganese in both ground water and surface water are the only constituents whose concentrations commonly exceed recommended limits for domestic and industrial use. Most wells in the report area yield clear water with little or no iron or manganese, but distributed among them are wells yielding ground water that contains enough of these dissolved constituents to be troublesome for most uses.

Iron concentrations in naturally occurring stream water exceed 0.3 ppm under low-flow conditions at 33 percent of the sites sampled. Large concentrations of iron in stream water result from discharge of iron-bearing water from aquifers or from swamps where it is released largely from decaying vegetation.

Ground water more than 30 feet below the land surface has a relatively constant temperature, usually between 48°F and 52°F. Water temperature in very shallow wells may fluctuate from about 38°F in February or March to about 55°F in late summer. Water temperature in the larger streams fluctuates much more widely, ranging from 32°F at least for brief periods in winter, to about 85°F occasionally during summer.

The quality of suspended sediment transported by streams in the area is negligible. Turbidity in streams is generally not a problem although amounts large enough to be troublesome may occur locally at times.

The total amount of water used in the report area for all purposes during 1964 was about 118,260 million gallons, of which 105,600 million gallons was estuarine water used for cooling by industry. The average per capita water use, excluding estuarine, temporary summer residence, and institutional water was equivalent to 186 gpd. Public water systems supplied the domestic needs of nearly two-thirds the population of the report area. All of the 19 systems, which were sampled, provided water of better quality than the U.S. Public Health Service suggests for drinking water standards.

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WATER RESOURCES INVENTORY OF CONNECTICUT

Although an ample supply of water reaches Connecticut each year, ever increasing water demands beset management with numerous questions such as: Where is the water? How much is available, especially during a drought? What is its chemical and physical quality? Therefore, as the demand for water increases, accurate information and careful planning are needed to obtain the optimum use from the existing sources and to locate new ones.

Accordingly, in 1959 the General Assembly, on recommendation of the Water Resources Commission, authorized a "water resources inventory" of Connecticut. Under this authorization, and under a supplemental authorization by the General Assembly in 1963, the U.S. Geological Survey, in cooperation with the Water Resources Commission, has undertaken a series of studies to determine the quantity and quality of water that is available at any location in the State. The State has been subdivided into 10 study areas bounded by natural drainage divides to facilitate the calculations and description of water quantities and relationships. The information contained in reports on these study areas can be used by the State and regional planners, town officials, water-utility personnel, and others required to make decisions on the development, management, use, and conservation of water.

The Thames River basin, the first major drainage basin to be studied under the authorization, was divided into three subbasins, and reports on two of the three subbasins--the Quinebaug River basin, and the Shetucket River basin--have been issued by the Connecticut Water Resources Commission as parts 1 and 2 of the "Water Resources Inventory of Connecticut." This report is, therefore, the third prepared under the water resources inventory program.

LOWER THAMES AND SOUTHEASTERN COASTAL RIVER BASINS

The location of the lower Thames and southeastern coastal river basins, (hereafter referred to as SCRBA), is shown on figure 1. The area includes the Thames River--formed by the confluence of the Shetucket and Quinebaug Rivers--and several small but important streams that either flow to the Thames River or to Long Island Sound. The basins included in this report area drain a total area of 440 square miles, 5 of which are in Rhode Island. The Pawcatuck River, which forms the southeastern boundary between Connecticut and Rhode Island was not studied, but data pertinent to the water resources of the area are included where appropriate. A small area in Sterling and Voluntown that is within the Pawcatuck River basin and drains eastward into Rhode Island was included in the Quinebaug River basin report (Randall and others, 1966).

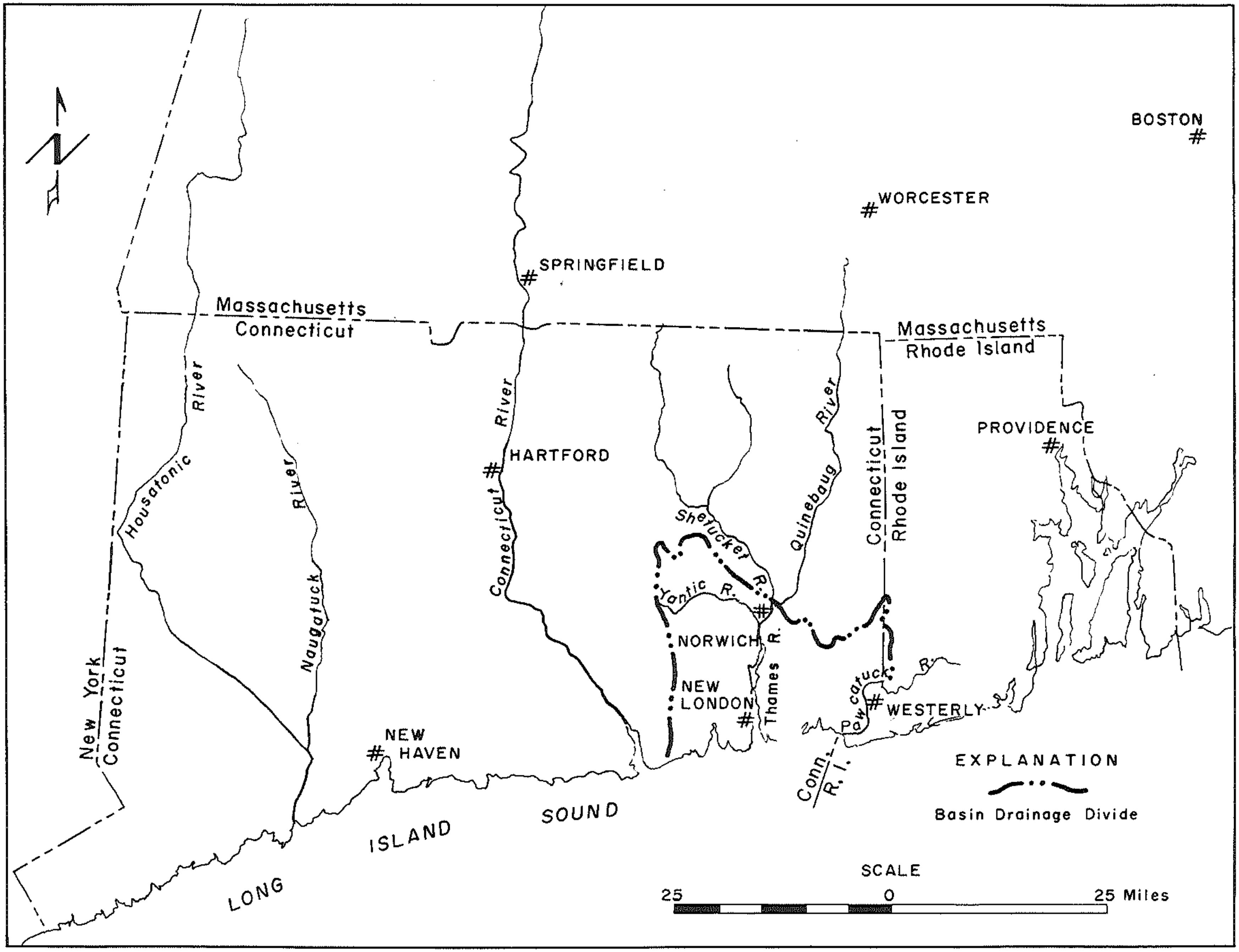


Figure 1.--Location of the lower Thames and southeastern coastal river basins

The report area drains about 440 [illegible]re miles of southeastern Connecticut.

ACKNOWLEDGMENTS

The data on which this report is based were collected and analyzed by numerous professional and technical employees of the Water Resources Division, U.S. Geological Survey. Considerable unpublished information was obtained from the files of the Water Resources Commission, the State Highway Department, and the State Board of Fisheries and Game. Technical reports and some unpublished data dealing with the economy of the basin were furnished by the Connecticut Development Commission. Records of wells and test borings were provided by a host of owners, drillers, and company officials too numerous to mention by name. Acknowledgment is also made to Richard B. Erickson, Executive Director, Southeastern Connecticut Regional Planning Agency, who provided valuable assistance. The contributions made by all these individuals and agencies have helped to make this report more complete and more useful.

The authors wish to gratefully acknowledge the interest and support extended by William S. Wise, former Director, Connecticut Water Resources Commission, and John J. Curry, present Director.

GUIDE FOR USE OF THIS REPORT

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

The reader who is primarily interested in determining the availability and quality of surface water in a particular part of SCRBA should look first at plate D, the map summarizing the water available. This map locates lakes and ponds which have water in usable storage, and indicates the amount of usable storage. This same map also shows for all but very small streams, the streamflow that will be equaled or exceeded 90 percent of the time.

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

The reader who is primarily interested in determining the availability of ground water in the area should first refer to the geohydrologic map, plate B. From it he may determine the principal water-bearing unit in the area of interest. If it is stratified drift, he may also determine its saturated thickness. The map explanation summarizes the permeability of each unit and the range in yields to be expected from individual wells.

Additional information on the availability of ground water and on the quality of ground water is shown on plate D, the map summarizing water available. This map delineates areas of stratified drift deposits that are especially favorable for the development of ground-water supplies, and indicates the quantities of ground water potentially available in each of these areas. The methods used in determining the ground-water information on plate D are described in the text, pages 89 to 92; quality of ground water is discussed in the text, pages 73 to 83.

The tables and illustrations summarize large amounts of basic hydrologic data collected and analyzed during this study. The detailed records and measurements of individual wells, streamflow, and quality of water are included in the companion basic data report by M. A. Cervione, Jr. and others (1968).

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

THE HYDROLOGIC CYCLE

The hydrologic cycle--the continual movement of water between the oceans, the atmosphere, and the land masses of the earth--is a natural phenomenon having no beginning and no ending. However, from man's viewpoint, it can be considered to begin when water vapor in the atmosphere condenses to form clouds from which precipitation falls as rain or snow onto the land surface. Part of this water flows across the land surface to collect in streams and lakes, and part seeps into the ground. Much of the water that seeps into the ground or collects on the land surface is soon evaporated or taken up by plants and returned to the atmosphere by a process known as transpiration. Some, however, moves slowly underground toward nearby streams or the ocean into which it eventually discharges. Part of the water which reaches the streams, lakes, and eventually the ocean, is also evaporated to complete the cycle. The hydrologic cycle as it occurs in its natural state is shown diagrammatically in figure 2.

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

THE WATER BUDGET

Just as the financial operation of a household or business firm can be expressed by a money budget, so the hydrologic operation of the report area can be expressed by a water budget which lists receipts, disbursements, and water on hand. The receipt of fresh water in the SCRBA consists of precipitation falling on the area, inflow from the Shetucket and Pawcatuck Rivers, and water supplied to the community of Pawcatuck from the Westerly Water Works; disbursements consist of both direct runoff and ground-water runoff, and evapotranspiration from surface water, ground water, and soil moisture above the water table. The amount of water on hand--stored within the SCRBA--changes continuously in response to the changing rates at which water enters and leaves the basin. The approximate quantities of water involved in each of the major components of the water budget for the report area in an average year are shown in figure 3. Although the quantities vary from year to year, the water budget always balances--the disbursements equal the receipts, taking into account changes in storage.

SOURCES OF WATER

PRECIPITATION

The average monthly and average annual precipitation on the SCRBA for the reference period October 1930 to September 1960 were computed from records at many weather stations and are given in table 1. In computing these values, data were weighted in proportion to the area represented by each station. Average monthly precipitation on the SCRBA was relatively uniform throughout the year, ranging from 3.28 inches in June to 4.71 inches in November; the average over the year was 4.02 inches per month.

Average monthly and average annual precipitation for the upper portion of the Thames River basin above where it enters the SCRBA, for the entire Thames River basin above its mouth, and for the entire SCRBA area are included in table 1. A great amount of the water available for use in the SCRBA results from precipitation falling on the upper portion of the Thames River basin. Figure 4, which is taken from table 1 shows that average monthly precipitation on the upper portion of the Thames River basin above the SCRBA is also relatively uniform throughout the year, ranging from 2.99 inches in February to 4.59 inches in March; the average over the year is 3.82 inches per month. Minimum monthly precipitation is likewise relatively uniform, but maximum monthly precipitation varies widely. Variations in monthly precipitation range from 0.45 inches (June 1949) to 14.45 inches (August 1955).

Table 1.--Average monthly and annual precipitation and runoff in inches for the Thames River basin at Norwich, for the Thames River basin at its mouth, and for the lower Thames and southeastern coastal river basins, for water years 1931-60

	Thames River basin at Norwich (1931-60)		Thames River basin at mouth (1931-60)		SCRBA (1931-60)	
Month	Precipitation[1]	Runoff	Precipitation[1]	Runoff	Precipitation[1]	Runoff
Oct.	3.25	1.00	3.31	1.01	3.65	1.08
Nov.	4.17	1.68	4.24	1.69	4.71	1.75
Dec.	3.59	2.18	3.67	2.22	4.19	2.51
Jan.	3.60	2.47	3.68	2.53	4.31	3.01
Feb.	2.99	2.31	3.03	2.39	3.50	3.05
Mar.	4.59	4.15	4.55	4.22	4.53	4.80
Apr.	4.04	3.88	4.05	3.87	4.17	3.85
May	3.57	2.36	3.60	2.34	3.74	2.23
June	3.76	1.45	3.70	1.42	3.28	1.19
July	3.78	.89	3.79	.87	3.75	.77
Aug.	4.42	.84	4.40	.82	4.32	.68
Sept.	4.08	1.02	4.10	1.02	4.06	.99
Annual (Water year)	45.84	24.23	46.12	24.40	48.21	25.91

1 Precipitation figures computed from records of the U.S. Weather Bureau and Connecticut Park and Forest Commission.

Topographic divide and ground-water divide generally follow the same path; no ground water or surface water crosses the divide.

Transpiration by plants and evaporation from all earth surfaces cause water loss. Rates are largest from ponds and lakes, rivers, and swamps; rates from woodland exceed those from meadows. Moisture returned to the air is carried off by the wind to fall as rain elsewhere.

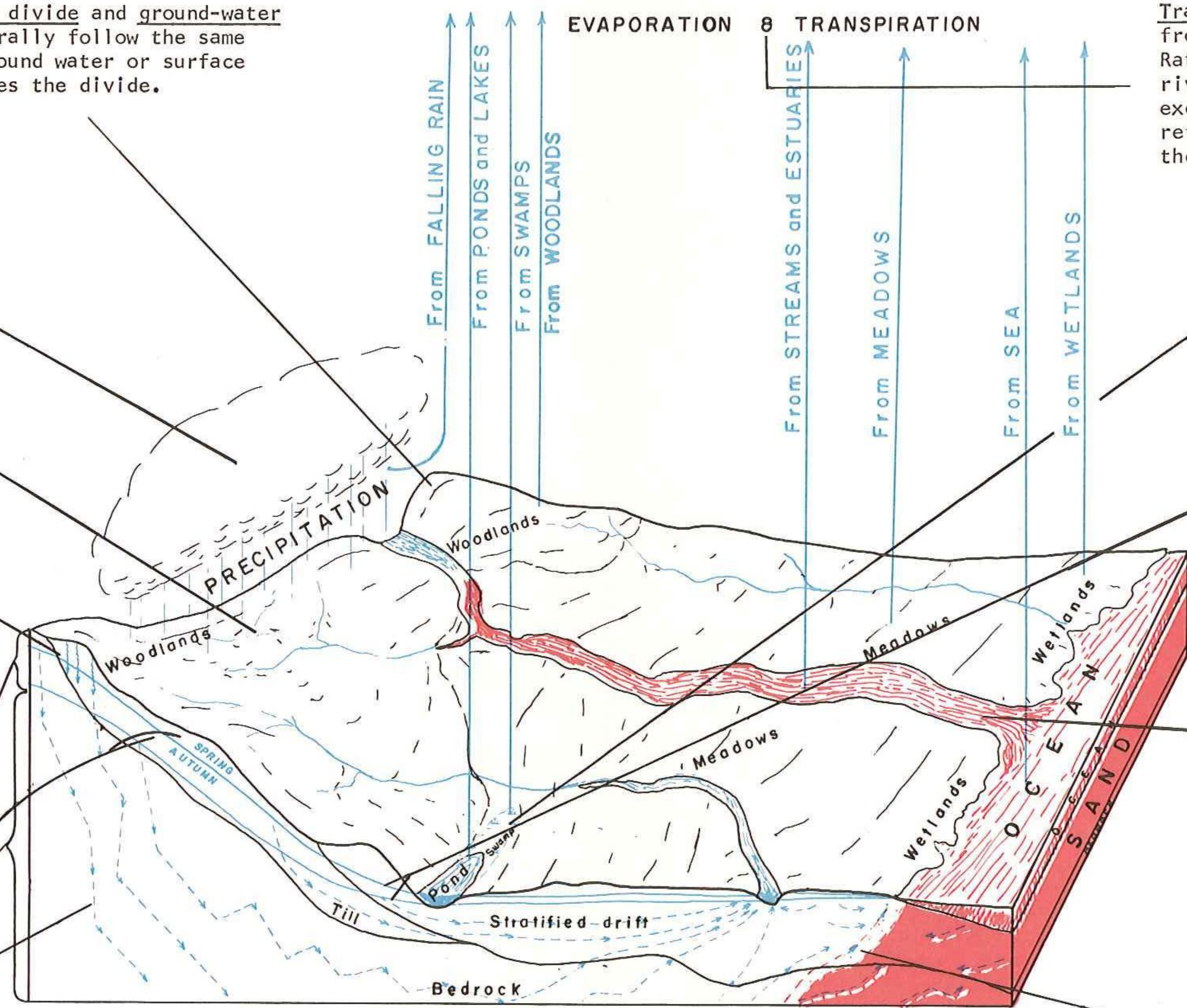
Clouds moving over the basin consist of moisture evaporated elsewhere, usually in areas to the south and west.

Water table is at land surface in swamps or at water surface in ponds, lakes and streams.

Overland runoff reaches streams during and soon after rain. The largest rates occur on till-bedrock hills, and when the ground is frozen.

Water table below hill or terrace of sand is not much higher than nearest pond or stream and has relatively small seasonal changes.

Infiltration from precipitation slowly percolates down to the water table except during late spring and summer when most remains in the soil and is evaporated or transpired by plants. Follows fractures in bedrock to the water table and is limited in quantity by their extent and dimensions.



Sea water is carried upstream in the estuaries by each flood tide and downstream by each ebb tide. In late summer and early fall, fresh-water flow is usually at a minimum, and upstream movement of the sea water in the estuary is at a maximum. During the spring, fresh-water inflow is at its maximum and sea water recedes downstream to its minimum position.

Zone of aeration in soil is above water table. Spaces between grains are filled mostly with air. Some moisture present which supplies need for most plants.

Water table in hill of till has large seasonal change, is highest in spring and lowest in early autumn.

Generalized path of ground-water movement is downward beneath hills, upward near streams.

Ground water flowing to estuaries and the sea mingles with sea water in a zone of diffusion. Thickness of the zone is influenced by tidal fluctuations. The water in this zone migrates seasonally a short distance landward when ground-water table is low and seaward when ground-water table is high.

Zone of saturation in soil and rock is below water table. All spaces are filled with ground water.

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

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

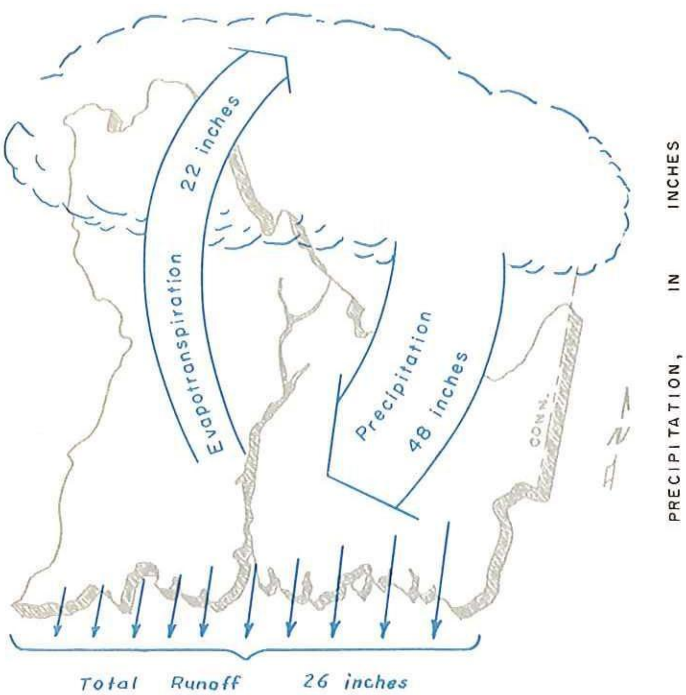


Figure 3.--Average annual water budget of the lower Thames and southeastern coastal river basins, 1931-60 water years. Inflows from the Pawcatuck and Shetucket River are excluded

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

STREAMFLOW, UNDERFLOW, AND DIVERSIONS INTO THE REPORT AREA

Precipitation is the sole source of fresh water for all stream basins included entirely within the SCRBA. However, about 530 billion gallons per year of fresh water enters the SCRBA in the Shetucket River near Norwich and is potentially available for use. Also the Pawcatuck River, flowing along the southeastern border of the SCRBA, has an average annual flow of about 130 billion gallons per year which is potentially available for use.

Underflow entering the report area is about 100 million gallons per year, a relatively small amount, which comes from the Shetucket River basin, for there is no underflow at the outlet of the Quinebaug River basin.

In 1964 about 330 million gallons of water were brought into the SCRBA from wells of the Westerly Water Works in Rhode Island to supply the city of Pawcatuck, Connecticut.

LOSSES OF WATER
RUNOFF

Long-term records of runoff within the SCRBA are available only for the Yantic River basin. Runoff from this basin has been measured since 1930 at a stream-gaging station at Yantic, 4.8 miles upstream from its mouth. Records at this point represent runoff from 88.6 square miles or about 20 percent of the SCRBA. They were used as a basis for correlating short-term records to compute runoff for the whole report area and to determine the areal distribution of runoff. Average monthly and average annual total runoff in inches are shown in table 1 for the SCRBA, for the upper Thames River basin above the report area and for the Thames River basin at its mouth. It is evident from the table that average monthly runoff follows a marked seasonal cycle, being much greater for March than for August. This is illustrated in figure 5 for the upper Thames River basin above the SCRBA. Minimum monthly runoff, also shown in this figure, likewise follows a similar cycle. These cycles reflect a combination of causes, among which are increased loss of water by evaporation and transpiration during the summer months (see p. 6), melting in March and April of ice and snow stored on the land surface during the winter, and greater ground-water discharge in the spring due to the higher water table at that time. Maximum monthly runoff, like maximum monthly precipitation, varies widely but does not show a seasonal cycle because occasional large floods have occurred in nearly every month of the year.

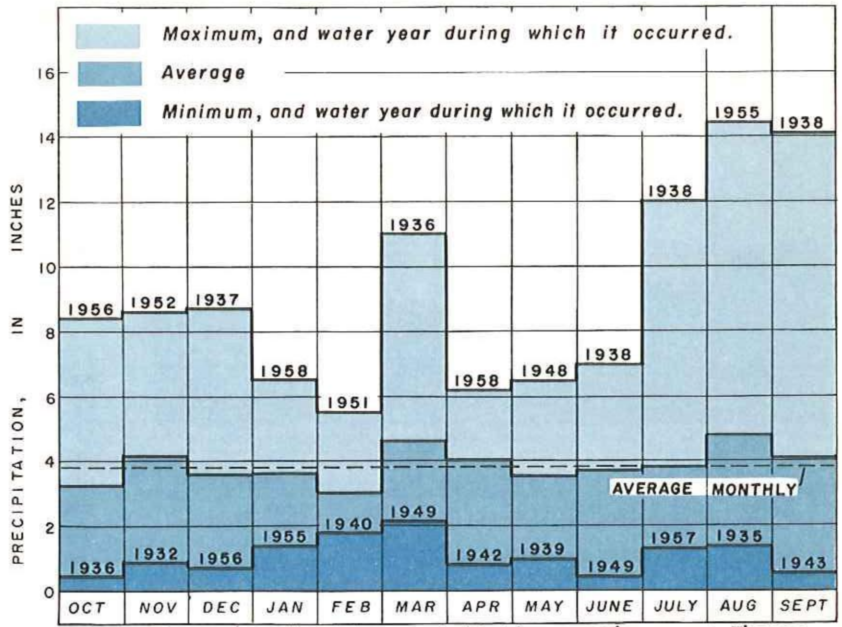


Figure 4.--Monthly precipitation on the upper Thames River basin above Norwich, 1931-60 water years

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

The average annual runoff from the SCRBA streams occurs at the rate of 25.91 inches or about 730 billion gallons per year. This includes the average annual flow of 530 billion gallons per year entering the SCRBA from the upper Thames River basin from the Shetucket River.

A part of all streamflow in the SCRBA is derived from water that has seeped into the streams from contiguous aquifers. During winter months when air temperatures are below freezing and there is no direct runoff from melting snow, and during rainless periods in summer months, the flow of many streams consists entirely of ground-water runoff.

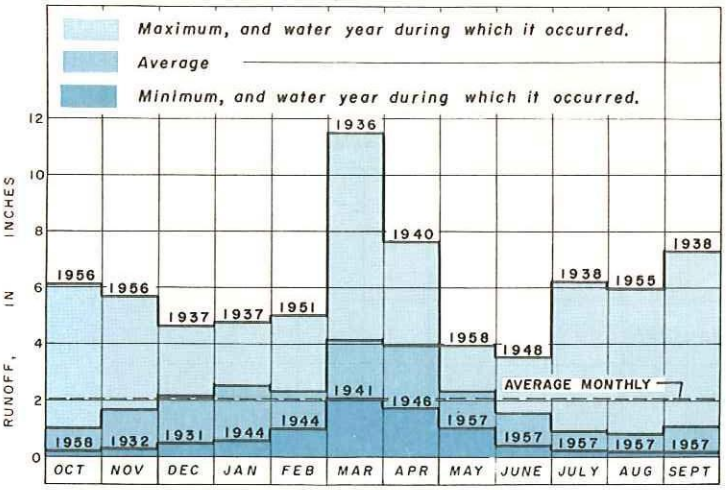


Figure 5.--Monthly runoff from the upper Thames River basin at Norwich, 1931-60 water years

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

Randall and others (1966, p. 9) and M. P. Thomas (1967, p. 10) estimated from hydrograph separation methods that average annual ground-water runoff in the Quinebaug River basin and Shetucket River basin was 10.19 inches (1943-62) and 10.58 inches (1945-62) respectively. The data required to determine ground-water runoff from hydrographs is not available in the SCRBA. However table 2 shows that the annual rate of precipitation and intensity of rainfall, annual runoff, and annual water loss, in the Quinebaug and Shetucket River basins, which comprise the upper Thames River basin, are practically the same as they are in the SCRBA, and the general character of the aquifers and conditions for infiltration and discharge are similar. Therefore, it is reasonable to assume that the rate of ground-water runoff in the SCRBA is also approximately the same. On this basis annual ground-water runoff to streams is estimated to occur at the rate of 11.14 inches or about 75 billion gallons per year. This compares favorably with estimates made from flow-duration data (see p. 64).

GROUND-WATER FLOW TO THE OCEAN

Because the SCRBA is adjacent to the sea coast, part of the ground-water lost from the report area is discharged directly into Long Island Sound (including the Thames River estuary). The amount may be computed by estimating the transmissibility of the deposits along the coastline, the length of the coastline and the hydraulic gradient (slope of the water table) toward the coast. Expressed mathematically, $Q = TIL$ where Q is the discharge in gallons per day, T is the transmissibility in gallons per day per foot, I is the hydraulic gradient in feet per mile, and L is the length of coastline in miles. It is estimated that ground water is discharged to the Sound at a rate of about 16 inches or 15 billion gallons per year from about 54 square miles of area along 140 miles of shoreline.

EVAPOTRANSPIRATION

A substantial part of the water that falls on the SCRBA as rain or snow is returned to the atmosphere by means of evapotranspiration (evaporation and transpiration). The total amount of evapotranspiration is difficult to measure directly and was computed as a remainder after all other gains and losses were measured or estimated. If it is assumed that long-term storage remained substantially the same (as assumption supported by evidence

Table 2.--Average annual water budget for the lower Thames and southeastern coastal river basins, in inches of water over the area, compared to water budgets for the Quinebaug River and Shetucket River basins

	Precipitation	Outflow				Evapotranspiration		Changes in Storage
		Total Runoff	Direct Runoff	Ground-water Runoff	Ground-water Underflow	Total	Ground Water	
Quinebaug River basin (1943-62)	44.88	23.97	13.78	10.19	0	20.91	4.24	0
Shetucket River basin (1949-62)	44.86	24.47	13.89	10.58	Negligible	20.39	4.23	0
Lower Thames and southeastern coastal river basins	[a] 48.21	[a] 25.91	[b] 14.77	[b] 11.14	[b] 1.96	[a] 22.30	[b] 4.53	[a] 0

a Based on records, water years 1931-60.

b Based on relationships in water budgets for Quinebaug and Shetucket River basins.
Direct runoff = 57 percent of total runoff
Ground-water runoff = 43 percent of total runoff
Ground-water underflow in Thames area = underflow directly to Sound and estuaries from 54 square miles bordering 140 miles along shoreline ($Q = TIL$)
Ground-water evapotranspiration = 17.5 percent of total runoff

from ground-water levels and reservoirs levels), the average annual amount of evapotranspiration from the SCRBA for the period October 1930 to September 1960 is equal to the average annual precipitation (48.21 inches) minus the average annual runoff (25.91 inches), or 22.30 inches.

Table 2 shows that evapotranspiration of ground water in the Shetucket and Quinebaug River basins amounted to about 17.5 percent of runoff and for the SCRBA probably was about the same, or 4.53 inches.

Changes in the potential rate of evapotranspiration in a given locality from month to month are largely dependent on changes in air temperature and duration of daylight (Thornthwaite, 1952, p. 382; Olmsted and Hely, 1962, p. 12; Clark, 1963). Thus evapotranspiration is greatest during the growing season, April through October, when the temperatures are above freezing and the days are longest. These major factors repeat themselves with relatively little change year after year, and the annual amount of evapotranspiration and its distribution through the year are relatively constant for a given locality. Since the annual amount of evapotranspiration in the SCRBA is known from the long-term relationship of precipitation and runoff discussed in the previous paragraph, a theoretical average monthly distribution of evapotranspiration, computed by a method similar to that of Thornthwaite and Mather (1957) for the period 1930-60, is illustrated in figure 6.

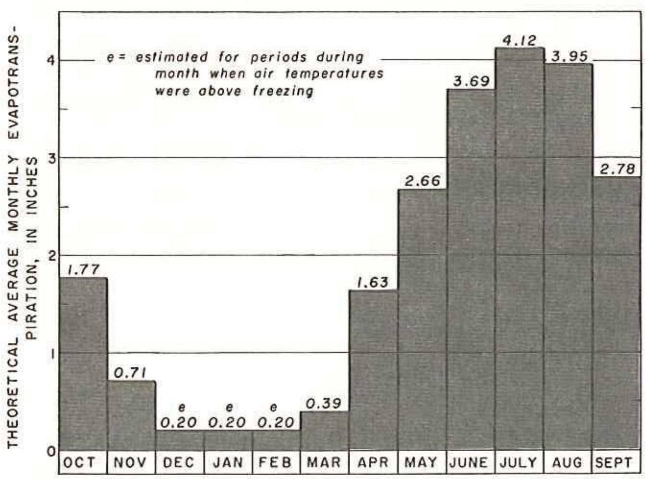


Figure 6.--Monthly evapotranspiration for the lower Thames and southeastern coastal river basins, 1931-60 water years

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

SUMMARY OF THE WATER BUDGET

An average monthly water budget for the SCRBA illustrating the factors of the budget discussed in preceding paragraphs, is shown in figure 7. Precipitation during the late autumn and winter months is sufficient to cause substantial increases in storage and produces abundant runoff. Similar amounts of precipitation in the late spring and summer months are not adequate to supply the large evapotranspiration losses. This results in sharply reduced runoff and a decrease in storage. The increase or decrease in storage within the report area may be either as ground water, as surface water in lakes and stream channels, as soil moisture, or combinations of these.

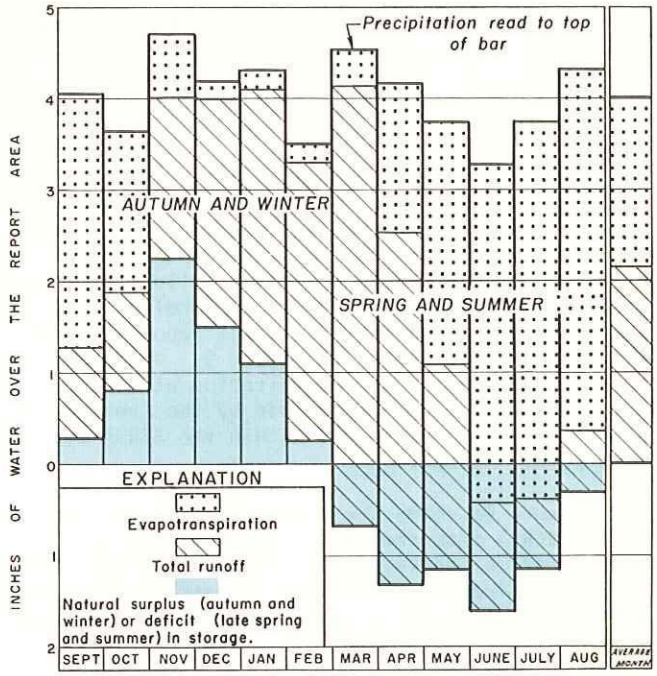


Figure 7.--Monthly water budget for the lower Thames and southeastern coastal river basins. Average for water years 1931-60

WATER QUALITY IN THE HYDROLOGIC CYCLE

Water, with its unique ability to dissolve more substances than any other liquid, increases its dissolved-solids concentration as it moves through the various phases of the hydrologic cycle as is illustrated in figure 8. Water that evaporates from the land and water surfaces and passes into the atmosphere is relatively pure. As water vapor condenses to form rain, snow, sleet, or hail, it incorporates tiny particles of soot, dust, salt spray from the ocean, and other impurities from the air. Some of the mineral matter in these particles is dissolved. The gases which make up the atmosphere, including carbon dioxide, nitrogen in various forms, and sulfur dioxide are dissolved to some extent also. Thus even as it starts its journey to the land surface, water is no longer "pure." On its descent, precipitation performs the most important function of removing many natural and artificial contaminants from the atmosphere. The part of this water that flows across the land surface in the report area is not significantly altered in chemical composition, but the part that seeps into the ground dissolves more mineral matter from the soil and rocks as it moves slowly toward nearby streams. Evaporation and transpiration return some of the water to the atmosphere and the result is an increase in concentration of chemical constituents in the water remaining.

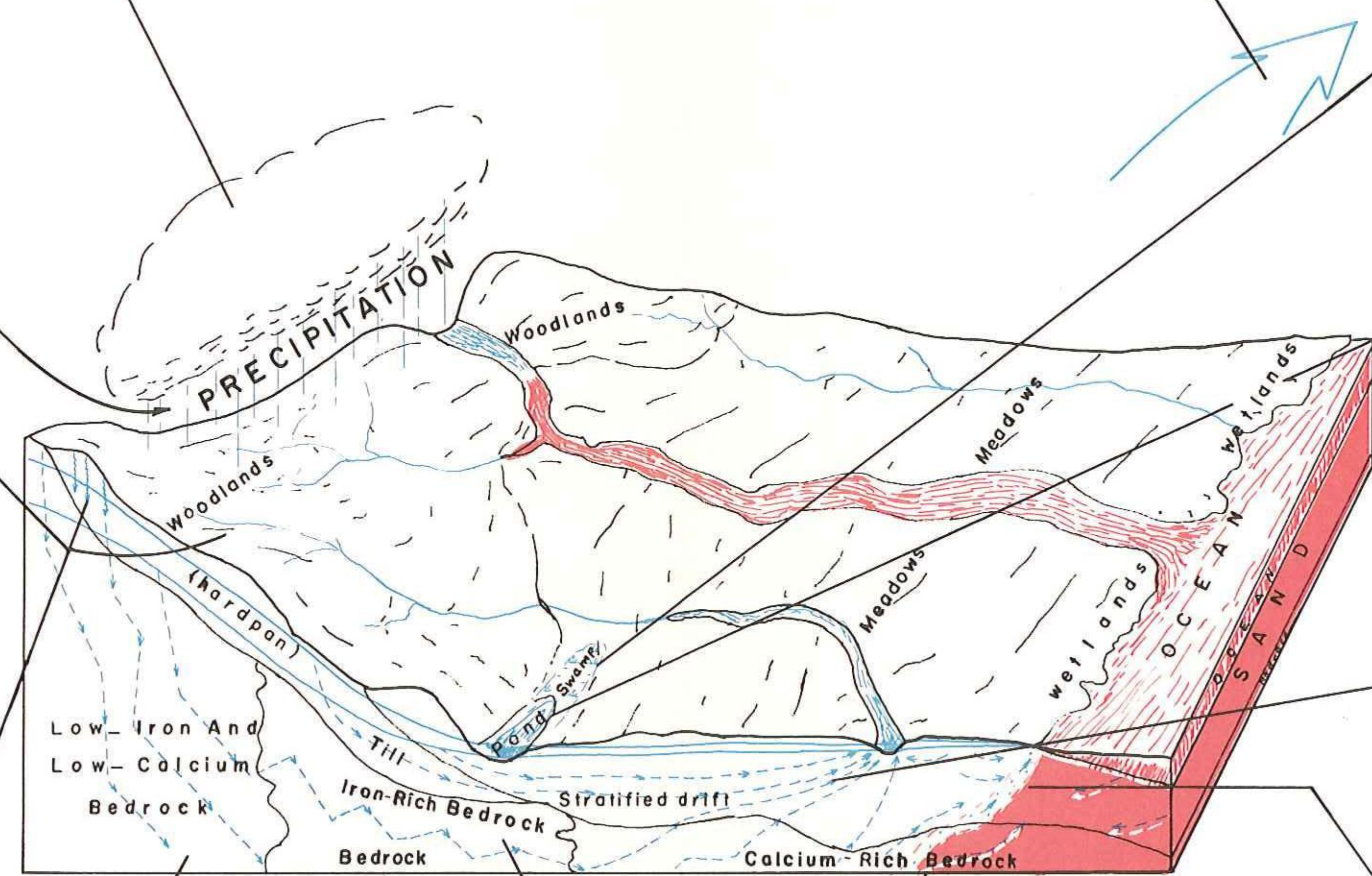
Water vapor in the atmosphere condenses upon and dissolves particles of dust and absorbs gases to form clouds of water droplets which are slightly mineralized.

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

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

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

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



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

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

Ground water in bedrock will be moderately hard.

Figure 8.--Changes in the quality of natural waters during the hydrologic cycle

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

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

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

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

Salt water invasion occurs in both tidal reaches of surface waters and in ground-water aquifers where permeable materials or fracture bedrock are in contact with sea water. The sea water mixes with the fresh water and proportionally increases the dissolved-mineral content of the integrated water.

QUALITY OF PRECIPITATION

The dissolved-solids concentration of precipitation can vary during a single storm and from storm depending on the direction from which a storm approaches, and the kind of gaseous or solid material dissolved from the atmosphere. Research has shown that the first drops of rain during a storm may contain over 150 ppm (parts per million) of dissolved solids, whereas later rainfall during the same storm will contain much less.

Analysis of all rainfall samples collected at Ledyard, Chesterfield, and Noank given in table 3 show a wide range in chemical quality; for example, the specific conductance ranged from 12 to 240 micromhos. Part of the dissolved solids in precipitation that falls on SCRBA is of local origin, but part has been transported into the report area by the wind as illustrated in figure 9. The variations in chemical quality of precipitation at the three sampling sites may be explained by the transportation of mineral matter into and within the SCRBA by movement of air masses.

Figure 9a shows the movement of air masses into the SCRBA from the west. Chemical analyses of precipitation indicate that the Chesterfield site (2P) is influenced primarily by mineral matter transported into the report area. Both the Ledyard and Noank sites (1P and 3P respectively) are influenced by contaminants discharged into the atmosphere from the works of man locally along the Thames River. The dominant contaminant here is sulfur dioxide as indicated by the low (acidic) values of pH in the following table:

Index number (Pl. A)	Location	No. of measurements	pH Range	pH Median
1P	Ledyard	5	3.8-5.1	4.5
2P	Chesterfield	6	5.9-6.3	6.2
3P	Noank	16	3.5-4.9	4.4

These are data from samples collected July 1963 to December 1964 when air mass movement was from the west. The main source of the sulfur dioxide is the burning of coal, oil, and natural gases. The principal source areas along the Thames River are the population centers of Groton, New London, and Norwich, and the Connecticut Light and Power Plant at Montville. Atmospheric water will absorb carbon dioxide until equilibrium is reached at a pH of 5.7 (Barrett and Brodin, 1955, p. 252). This value of 5.7 may be regarded as the neutral point, neither acidic nor basic, for atmospheric water solutions rather than

Table 3.--Summary of chemical analyses of all precipitation samples from three locations in the lower Thames and southeastern coastal river basins area

(Chemical constituents, in parts per million)

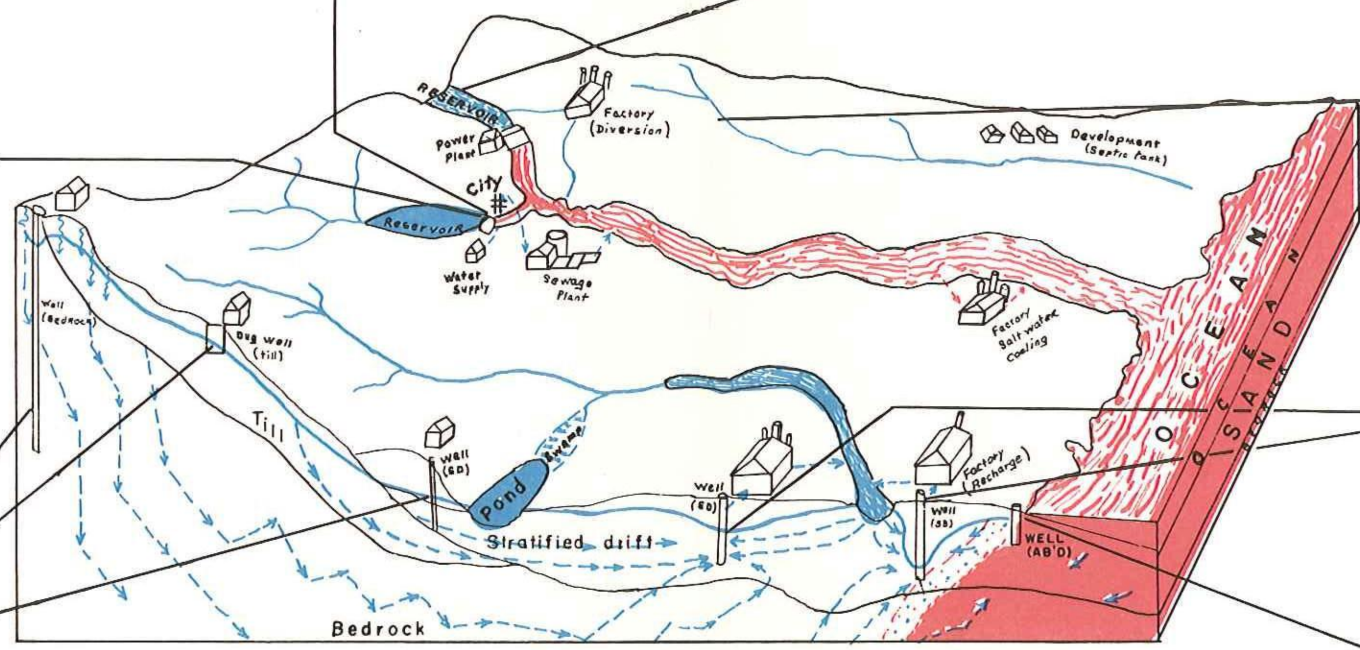
	1P...Ledyard			2P...Chesterfield			3P...Noank			All precipitation sampling sites		
Period of collection	Aug. - Nov., 1964			Aug., Oct., Dec., 1964			July - Sept., Nov., 1963; June, Aug. - Nov., 1964					
	Number of analyses	Range	Median	Number of analyses	Range	Median	Number of analyses	Range	Median	Number of analyses	Range	Median
Calcium (Ca)	7	0.6-1.4	0.8	7	1.7 - 9.0	4.0	22	0.7 - 16	1.4	36	0.6 - 16	1.5
Magnesium (Mg)	7	.0- .4	.1	7	1.2 - 3.2	1.8	21	.0 - 2.6	.2	35	.0 - 3.2	.2
Sodium (Na)	7	.1-1.1	.4	6	.4 - 1.9	.8	19	.7 - 20	3.2	32	.1 - 20	1.9
Potassium (K)	7	.1-1.1	.6	6	.3 - .4	.3	18	.2 - 3.4	.5	31	.1 - 3.4	.4
Bicarbonate (HCO_3)	7	0 -2	0	7	3 - 7	5	23	0 - 34	0	37	0 - 34	0
Sulfate (SO_4)	7	.2-6.8	1.8	7	3.0 -17	7.8	19	2.2 - 29	6.2	33	.2 - 29	6.2
Chloride (Cl)	7	.0- .6	.0	7	.0 - .2	.0	24	.0 - 32	3.2	38	.0 - 32	1.2
Dissolved solids (Residue on evaporation at 180°C)	7	7 -13	8	3	8 -30	11	14	11 - 75	20	24	7 - 75	15
Hardness as $CaCO_3$	7	2 - 5	2	7	9 -36	16	22	2 - 38	4	36	2 - 38	4
Specific conductance (micromhos at 25°C)	7	12 -73	17	7	12 -69	35	24	26 -240	60	38	12 -240	52
pH	7	3.8- 5.1	4.7	7	5.9 - 6.3	6.2	24	3.5 - 7.2	4.4	38	3.5 - 7.2	4.7

Paved areas, roofs, and storm water drains cause more rapid runoff, reduce evapotranspiration, and reduce infiltration.

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

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

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



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

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

Where permeable materials and rocks are in contact with sea water, wells near the sea may become very salty, if they are pumped excessively. The pumping upsets the delicate balance between fresh and salt water and the salt water then mixes into and encroaches upon the fresh water.

Figure 10.--The effect of the activities of man upon the movement and distribution of water in the hydrologic cycle

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

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

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

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

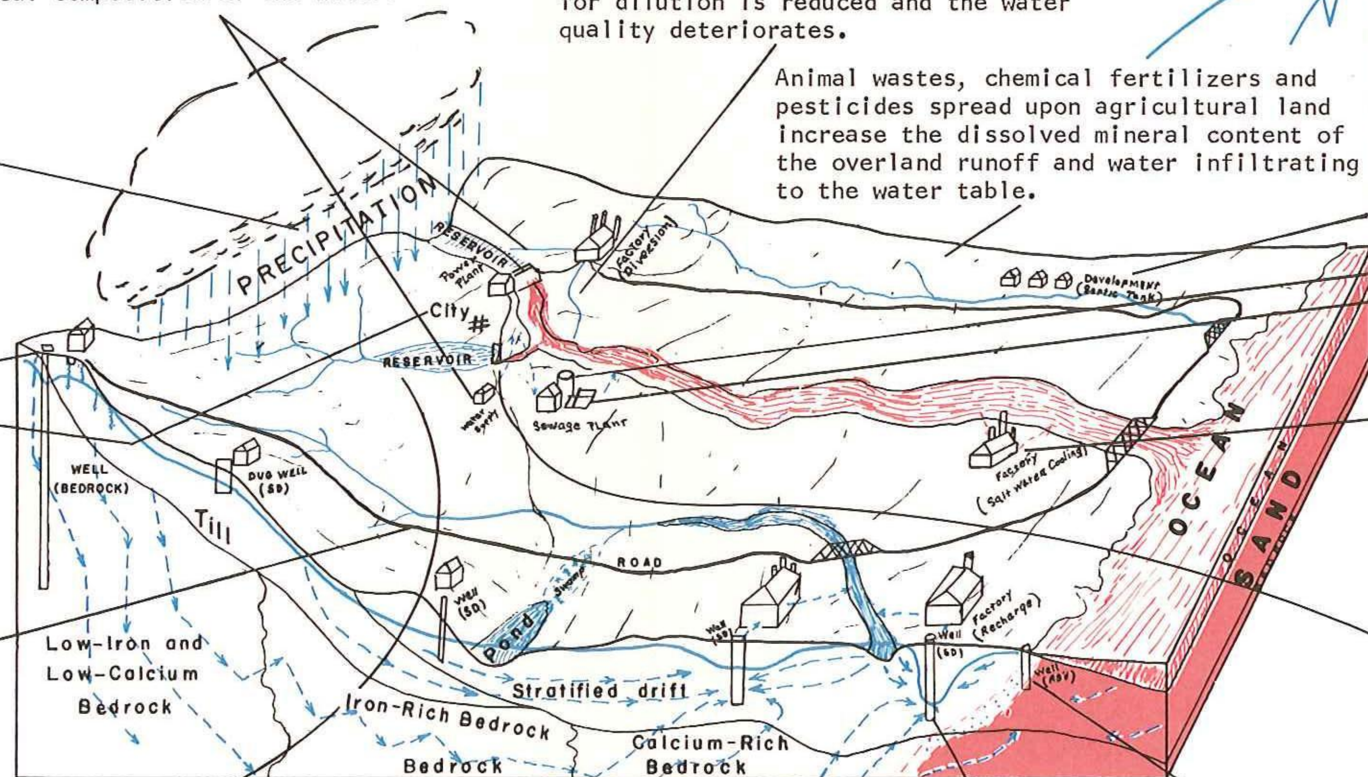
Animal wastes, chemical fertilizers and pesticides spread upon agricultural land increase the dissolved mineral content of the overland runoff and water infiltrating to the water table.

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

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

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

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



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

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

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

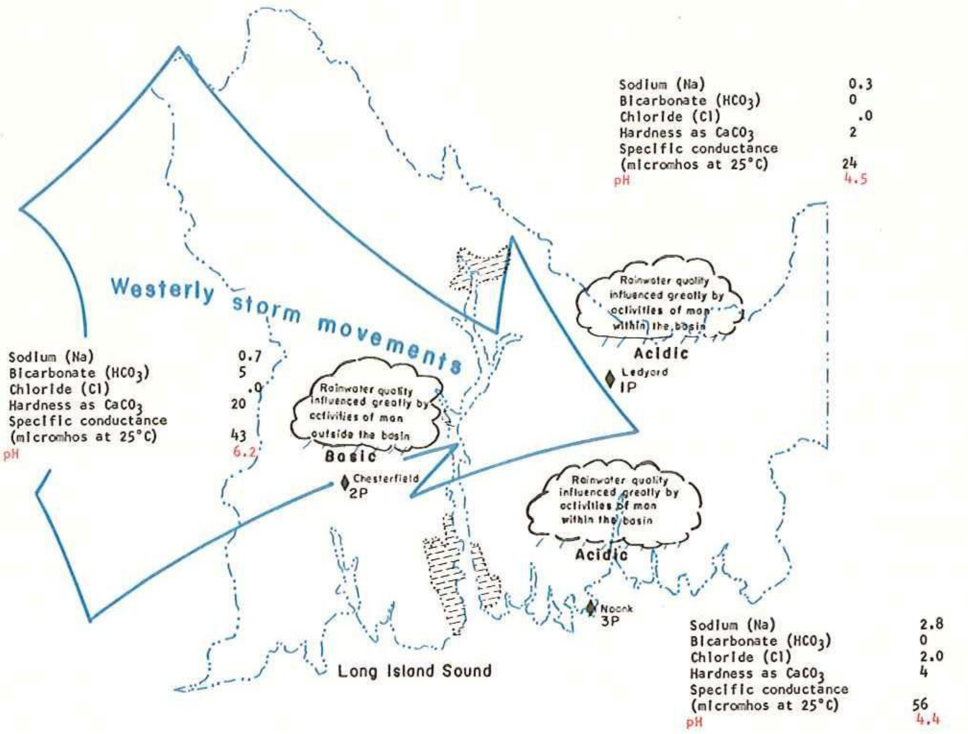
Most of the water withdrawn from streams or wells and used by industry for cooling, washing, and other purposes is returned to the streams or the ground at higher temperatures or with a higher dissolved mineral content than at its point of withdrawal.

Regulation of streamflow may cause further upstream movement of salt water in estuaries and coastal streams, prohibiting their domestic and industrial use because of increased mineral concentration.

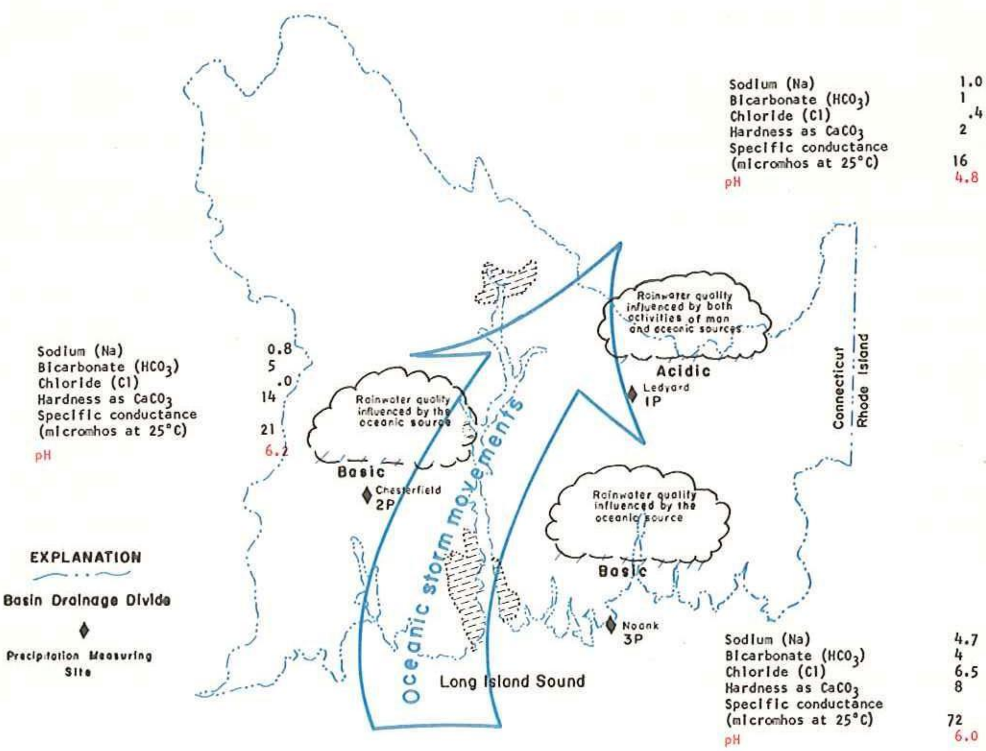
Salt-water encroachment in aquifers caused by extensive pumping upsetting the delicate fresh water-salt water balance results in the increase of the dissolved mineral content of the water as the encroachment moves further inland. In some cases with reduced pumping rates, the excess salts may eventually be flushed out by fresh water recharging the aquifer, or stabilize the salt water front. When salt water encroachment is severe, the aquifer at particular sites may be spoiled for future use and abandonment of wells necessiated.

Figure 11.--The effect of the activities of man upon the chemical quality of water in the hydrologic cycle

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



a. Median chemical analyses (in ppm) of rainwater from westerly air masses. Rainwater quality is acidic in the eastern portion of the basin and basic in the west. Shaded areas represent possible source areas where air pollution controls rainwater quality.



b. Median chemical analyses (in ppm) of rainwater from oceanic air masses. The quality of rainwater from the Chesterfield and Noank sites is influenced by sea-salt aerosols. The quality at the Ledyard site is the resultant of the sea-salt aerosols and the contaminants from the shaded source areas, as exhibited by an increase in chloride content and/or acid pH (less than 5.7).

Figure 9.--Results of median chemical analyses of precipitation at three sampling sites relating air mass movement with chemical quality

the value of 7.0 as in water solutions. The pH for all samples collected at the Ledyard and Noank sites (1P and 3P respectively) during air mass movement from the west is acidic, for pH values were all below 5.7.

Figure 9b shows the movement of air masses into the report area from the south, representing an oceanic influence. Chemical analyses of rainwater from the Chesterfield and Noank sites indicate that these two sites are influenced to some degree by sea-salt aerosols. Both sites have rainfalls with a pH above 5.7 indicating a gain in a sufficient quantity of alkaline salts (usually sodium salts) resulting in basic (non-acidic) water. The Noank site shows a large increase in the sodium and chloride concentrations over that in figure 9a and, since it is situated on the coast, is always under some influence of the sea-salt aerosol. The presence of salts from ocean spray is indicated when the calcium chloride (Ca/Cl) ratio is less than 1.0 (Gambell, 1962, p. 91-92). The Ca/Cl ratio of this site was 0.6 during westerly air mass movements and 0.2 during oceanic air mass movements. Data derived from various studies in the U.S. and abroad showed the drop in chloride concentration is rather sharp within the first 6 to 12 miles from the shoreline and then decreases more gradually inland. The south shore of Long Island should be considered as the shoreline for Connecticut when chloride concentrations in rainwater are being considered. The Ledyard site besides being under an oceanic influence as noted by a small increase in sodium and chloride concentrations, also is under the influence of the local air pollution along the Thames River as indicated by the low (acidic) pH.

A few rainwater samples collected in the recent inventory studies of the Quinebaug and Shetucket River basins had relatively high calcium concentrations. The calcium originated as dust from the limestone quarries and cement plants in the northwestern Connecticut-southwestern Massachusetts region. Analyses of rainwater samples collected during this study given in table 3 indicates that the SCRBA is not affected by contamination from this source as are the Quinebaug and Shetucket River basins.

The quantity of minerals airborne in clouds over the SCRBA that falls in precipitation is quite substantial. Using values from table 3, one inch of rain on the report area brings approximately 1.4 pounds of sulfate (SO_4) and 3.4 pounds of dissolved solids onto each acre of land. For the entire study area this amounts to about 200 tons of sulfate and 480 tons of dissolved solids. Conway (1943) concluded that on a global scale a considerable amount of sulfate carried by the rivers into the ocean cannot be accounted for by weathering of rocks and soils, but must be from rain. The chemical constituents in precipitation should therefore be considered as a significant source of dissolved minerals in natural waters.

QUALITY OF RUNOFF

The dissolved-solids concentration of direct runoff in the SCRBA does not greatly exceed the dissolved-solids concentration of precipitation because the rocks and soils on the land surface have been so long exposed to chemical weathering that they have been thoroughly leached and silicate minerals which have been left behind are only slightly soluble.

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

Water moving across the land surface and in the stream channels dislodges particles of soil, silt, sand and occasionally gravel; this material is carried in suspension or is rolled along channel bottoms. Generally, sediment load increases and the highest sediment loads occur during the spring thaw and following severe storms such as hurricanes, when streamflows are highest. On the whole, however, soil erosion and sediment in streams are not problems in eastern Connecticut, due to the generally permeable soils and the nearly complete cover of vegetation that holds and protects the soil.

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

MAN'S EFFECT ON THE HYDROLOGIC CYCLE

The hydrologic cycle is a fundamental process of nature, and the manner in which it operates cannot be altered by man. However, man can and does influence--deliberately and coincidentally--the amount of water stored on the surface and underground, the relative proportion of direct runoff, ground-water runoff, and evapotranspiration, and also the quality of the water. The extent of his influence depends largely upon the density of population in the area. In rural areas, the clearing of forested areas, draining of wet areas, irrigating of crops, and impounding of water in reservoirs all change to some extent the natural hydrologic cycle. More extensive changes occur when man builds towns and cities, and diverts water from streams and from the ground for many types of domestic and industrial uses. The physical effect of the works of man upon the natural hydrologic cycle is illustrated in figure 10.

While man has not substantially changed the amount of runoff from streams in the SCRBA, he has affected the timing of runoff on some streams. There are a few old industrial dams in the SCRBA, most of which no longer operate to regulate streamflow, but which do delay and lower flood peaks. These dams increase natural storage of surface water;

they also increase ground-water storage by raising the local water table above its natural level. The gradual urbanization of part of the SCRBA has the opposite effect: buildings, pavements, storm sewers, and similar structures increase direct runoff and bring it to the streams more quickly than normal, and at the same time inhibit ground-water recharge and lower the water table locally. During the 19th century the natural forests of the basin were largely converted to farmland, but during the 20th century forests have returned to cover much of the land surface. Changes in land uses in the last century may have altered the relative amounts of runoff and evapotranspiration.

There are numerous water-supply reservoirs on small streams scattered throughout the report area. These reservoirs have the effect of severely regulating streamflow, and waters from reservoirs are diverted to other points generally within the SCRBA to meet man's needs.

The quality of water now is a reflection of the interplay between natural and cultural environments. It is changed by man in numerous ways as illustrated in figure 11. Some of the smoke, soot, and fumes discharged into the air from industries, homes, and vehicles in and beyond the report area is incorporated in local precipitation, and some simply settles on the land surface. These materials contribute to the dissolved-solids content of runoff. So do manures, chemical fertilizers, and pesticides spread on agricultural lands and leached by infiltrating precipitation. Most of the water withdrawn from streams or wells and used by industry for cooling, washing, and other purposes is returned to streams or the ground at higher temperatures or with a higher dissolved-solids content than when withdrawn. Industrial waste discharged into streams is diluted by high streamflows, but during periods of low streamflow, the water available for dilution is reduced and the resultant deterioration in water quality is detectable along portions of the larger streams by field observations as well as by chemical analysis. Disposal of domestic sewage to streams has created offensive conditions in a few places, and disposal to the ground has contaminated nearby wells in a few crowded localities. The numerous excavations made during the construction of highways, buildings, and other structures result in temporary rapid erosion that contributes to the sediment and turbidity carried by streams. No matter how effective man's treatment of waste effluent or curtailment of exhaust smoke, or stabilization of soil erosion, there will still be an increase in the dissolved-solids concentration and suspended sediment content of the water in a habitated basin over the amounts supplied by natural processes. Keeping this increase within acceptable limits will be one of the major tasks of the future in the event of substantial urban expansion.

The sources and significance of a variety of chemical constituents and physical properties of water which are found in the SCRBA are summarized in table 4. Excessively large (or small) concentrations of various constituents may prohibit certain uses, or at least increase the cost of its use because of the treatment required to make it suitable.

Water distributed by public water supplies must be suitable for drinking and hence must meet fairly stringent quality requirements. The drinking-water standards applicable to common carriers in interstate commerce, published by the U.S. Public Health Service (1962) have generally been accepted as standards for public water supplies in Connecticut. They appear in the last column of table 4 and are also given in various tabulations of chemical analyses throughout this report.

Table 4.--Source and significance of some of the chemical constituents in, and physical properties of water in the lower Thames and southeastern coastal river basins

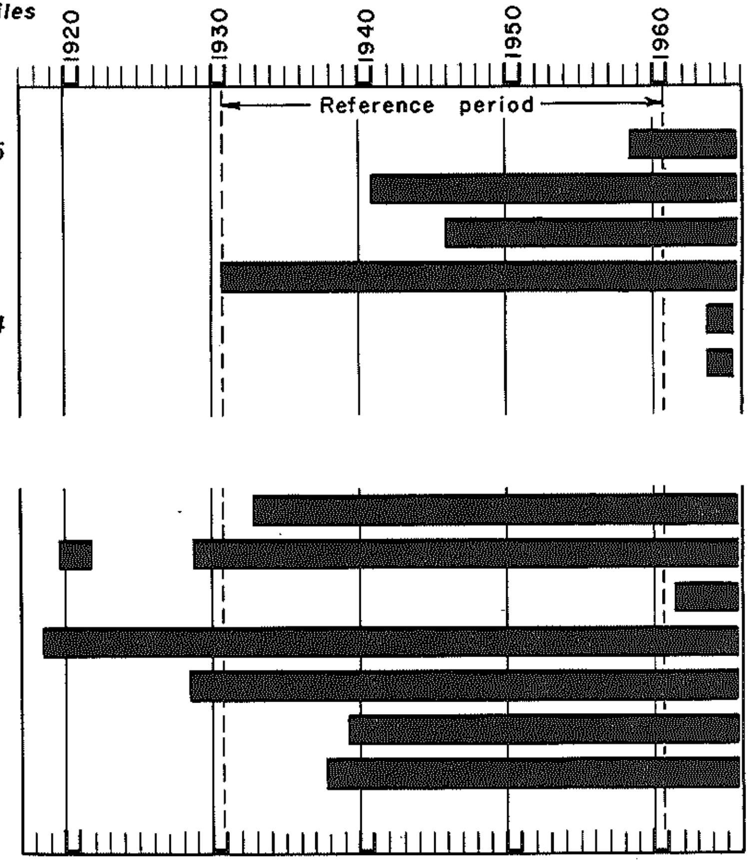
Chemical constituent or physical property	Source and concentration	Significance and maximum limit of tolerance
Silica (SiO_2)	Dissolved from practically all rocks and soils. Usually found in the basin in small amounts ranging from 1 to 30 ppm. Surface water usually has a smaller concentration than does ground water.	Forms hard scale in boilers, water heaters, and pipes. Inhibits deterioration of zeolite-type water softeners. The USPHS (U.S. Public Health Service, 1962) has not recommended a maximum limit for drinking water.
Iron (Fe)	Dissolved from many assorted minerals that contain oxides, sulfides, and carbonates of iron. Decaying vegetation and iron objects in contact with water, sewage, and industrial waste are also major sources. Surface water in the basin in its natural state usually has less than 1.0 ppm. Ground water generally has higher concentrations than surface water.	On exposure to air, iron in ground water oxidizes to a reddish-brown precipitate. More than about 0.3 ppm of iron stains laundry and utensils, causes unpleasant odors, and favors growth of iron bacteria. Iron in water is objectionable for food and textile processing. Most iron-bearing waters when treated by aeration and filtration are satisfactory for domestic use. The USPHS recommends a maximum limit of 0.3 ppm for drinking water.
Manganese (Mn)	Dissolved from many rocks and soils. Often found associated with iron in natural waters but not as common as iron. Surface water in the basin usually has less than 0.1 ppm. Ground water generally has higher concentrations than surface water.	More than 0.2 ppm precipitates upon oxidation. Manganese has the same undesirable characteristics as iron but is more difficult to remove. The USPHS recommends a maximum limit of 0.05 ppm for drinking water.
Calcium (Ca) and magnesium (Mg)	Dissolved from practically all rocks and soils, especially calcium silicates, clay minerals, and impure limestone lenses.	Hardness and scale-forming properties of water are caused by dissolved bicarbonates and sulfates of these minerals (see hardness). These are objectionable for electroplating, tanning, dyeing and textile processing. They also cause scale formation in steam boilers, water heaters and pipes. The USPHS has not recommended a maximum limit for drinking water.
Sodium (Na) and potassium (K)	Dissolved from practically all rocks and soils. Sewage, industrial wastes, road salt, and sea water are also major sources. Most home water softeners replace soluble hardness-producing minerals with sodium and thus increase the amount of sodium present.	Since the concentration of potassium is usually low, sodium and potassium are 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 ppm may cause foaming of steam boilers. The USPHS has not recommended a maximum limit for drinking water, however, the Connecticut State Department of Health suggests a maximum limit of 20 ppm for municipal water supplies.
Carbonate (CO_3) and bicarbonate (HCO_3)	Results from chemical action of carbon dioxide in all natural water on calcite and calcium silicate minerals. Decaying vegetation, sewage and industrial wastes are also important sources.	Bicarbonates of calcium and magnesium cause hardness and form scale in boilers and pipes, and release corrosive carbon dioxide gas (see hardness). Water of low mineral content and low bicarbonate content in proportion to carbon dioxide is acidic and can be corrosive. The USPHS has not recommended a maximum limit for drinking water.
Sulfate (SO_4)	Dissolved from rocks and soils containing sulfur compounds, especially iron sulfide; also from sulfur compounds dissolved in precipitation, and sewage and industrial wastes.	Sulfates of calcium and magnesium form permanent hardness and hard scale in boilers and hot water pipes (see hardness). The USPHS recommends a maximum limit of 250 ppm for drinking water.
Chloride (Cl)	Small amounts dissolved from metamorphosed sedimentary rocks and soils. Relatively large amounts are derived from animal wastes, sewage, road salt, industrial wastes, and sea water. Chloride concentration of natural fresh water in the basin seldom exceeds 10 ppm.	Large amounts of chloride in combination with calcium will result in a corrosive solution and in combination with sodium will give a salty taste. The USPHS recommends a maximum limit of 250 ppm for drinking water.
Fluoride (F)	Dissolved from assorted minerals, such as apatite, fluorite, mica, and scapolite. Surface water in the basin rarely has more than 0.2 ppm; however, in one local area concentration of fluoride in ground water was as high as 1.4 ppm. Added to some waters by fluoridation of public water supplies.	About 1.0 ppm of fluoride is believed to be helpful in reducing the incidence of tooth decay in small children; larger amounts possibly cause mottle enamel on teeth (Lohr and Love, 1954, p. 39). The USPHS recommends the following maximum limits for drinking water in the report area: lower, 0.8 ppm; optimum, 1.0 ppm; upper, 1.3 ppm.
Nitrate (NO_3)	Very small amounts in natural waters from precipitation and decaying organic matter. Sewage, industrial wastes, fertilizers and decaying vegetation are major sources. Lesser amounts are derived from precipitation.	Small amounts of nitrate have no effect on usefulness of water. A concentration greater than 6 ppm generally indicates pollution. Nitrate encourages growth of algae and other organisms which produce undesirable tastes and odors. The USPHS recommends a maximum limit of 45 ppm for drinking water which is equivalent to 10 ppm of nitrate expressed as N in a sanitary analysis. Waters containing more than 45 ppm have reportedly caused methemoglobinemia which is often fatal to infants and, therefore such water should not be used in infant feeding.
Dissolved solids and specific conductance	Includes all mineral constituents dissolved in precipitation and from rocks and soils, locally augmented by mineral matter in sewage and industrial wastes. Measured as residue of evaporation at 180°C or calculated as numerical sum of amounts of individual constituents. Specific conductance, or the capacity of water to conduct an electric current, is used as an index of total mineral content. In natural waters in the basin, ground water usually has a larger concentration of dissolved solids than does surface water. Nearly all waters sampled had a dissolved-solids content much below the limit recommended by the USPHS.	Waters containing more than 1,000 ppm of dissolved solids are unsuitable for many purposes. The USPHS recommends a maximum limit of 500 ppm for drinking water but will permit up to 1,000 ppm. A dissolved-solid concentration of 500 ppm is approximately equivalent to a specific conductance of 800 micromhos at 25°C.

Table 4.--Source and significance of some of the chemical constituents in, and physical properties of water in the lower Thames and southeastern coastal river basins--Continued

Chemical constituent or physical property	Source and concentration	Significance and maximum limit of tolerance
Hardness (as $CaCO_3$)	Hardness is primarily due to presence of calcium and magnesium, and to a lesser extent to iron, manganese, aluminum, barium, and strontium. There are two classes of hardness, carbonate (temporary) hardness and non-carbonate (permanent) hardness. Carbonate hardness refers to the hardness in equivalents with carbonate and bicarbonate; non-carbonate to the remainder of the hardness. Most waters in the basin are classified as soft, with a hardness of less than 60 ppm.	Hard water consumes soap before lather will form and deposits soap curds on bathtubs. Water having a hardness of more than 120 ppm is commonly softened for domestic use. Hardness forms scale in boilers, water heaters, radiators and pipes causing a decrease in rate of heat transfer and restricted flow of water. In contrast, water having a very low hardness may be corrosive. Carbonate (temporary) hardness can be reduced by water softeners; non-carbonate (permanent) hardness cannot be readily dissolved. The USPHS has not recommended a maximum limit for drinking water. The U.S. Geological Survey classification of hardness appears on p.
Hydrogen ion concentration (pH)	Water with a dominance of acids, acid-generating salts, and free carbon dioxide has a low pH. If carbonates, bicarbonates, hydroxides, phosphates, and silicates are dominant, the pH is high. The pH of most natural waters ranges between 6 and 8.	A pH of 7.0 indicates neutrality of a solution. Values higher than 7.0 denote alkaline characteristics; values lower than 7.0 indicate acid characteristics. Acid waters and excessively alkaline waters corrode metals. The USPHS has not recommended a maximum limit for drinking water.
Color	Color in water may be of natural, mineral, or vegetable origin such as iron and manganese compounds, algae, weeds, and humus material. May also be caused by inorganic or organic wastes from industry. True color of water is considered to be only that attributable to substances in solution after the suspended material has been removed.	Water from domestic and some industrial uses should be free of perceptible color. Color in water is objectionable in food and beverage processing and many manufacturing processes. Results are usually expressed as units of color and not as ppm. The USPHS recommends a maximum limit of 15 units for drinking water.
Alkyl benzene sulfonate (ABS)	Primary sources of alkyl benzene sulfonate (ABS) are synthetic household detergent residues in sewage and waste waters. In 1963 about 70% of all household detergents were of this type.	High concentrations of ABS cause undesirable taste, foaming, and odors. It often indicates presence of sewage or industrial waste. In mid-year 1965 ABS began to be replaced by linear alkylate sulfonate (LAS). Under similar optimum conditions, LAS is more degradable than ABS. The USPHS recommends for ABS a maximum limit of 0.5 ppm for drinking water.
Temperature	Temperature fluctuates widely in streams and shallow wells following seasonal climatic changes, but wells at depths of 30 to 60 feet remain within 2 or 3 degrees of mean annual air temperature (50°F for the report area). Disposal of water used for cooling or industrial processing causes local temperature abnormalities.	Temperature affects the usefulness of water for many purposes. For most uses, especially cooling, water of uniformly low temperatures is desired. A few degrees rise in the temperature of a stream may limit the capacity of a stream to support aquatic life. Warm water will carry less oxygen in solution than water at low temperatures, and a corrosive water will become more corrosive with increased temperatures.
Turbidity	An optical property of water attributed to suspended or colloidal matter which inhibits light penetration. May be caused by microrganisms or algae; suspended mineral substances including iron and manganese compounds, clay or silt, or sawdust, fibers, and other materials. May result from natural processes of erosion or from the addition of domestic sewage or wastes from various industries, such as pulp and paper manufacturing.	Excessive concentrations are harmful or lethal to fish and other aquatic life; also very undesirable in waters used by most industries, especially in process water. Turbidity can modify water temperature. Results are expressed in standard units, not ppm. The USPHS recommends a maximum limit of 5 units for drinking water.

U. S. GEOLOGICAL SURVEY STATION NUMBER	STREAM AND LOCATION	DRAINAGE AREA in square miles
	STREAM GAGING STATIONS IN REPORT AREA	
1183	*Pendleton Hill Brook near Clarks Falls, Conn.*	3.85
1185	*Pawcatuck River at Westerly, R. I.*	295
1190	*Great Brook at Poquonock Bridge, Conn.*[1]	14.3
1275	*Yantic River at Yantic, Conn.*	88.6
1276.8	*Trading Cove Brook near Montville Center, Conn.*	5.04
1277.5	*Oxoboxo Brook at Montville, Conn.*	10.2
	STREAM GAGING STATIONS IN VICINITY OF REPORT AREA	
1200	*Hop River near Columbia, Conn.*	76.2
1225	*Shetucket River near Willimantic, Conn.*	401
1269.5	*Pachaug River at Pachaug, Conn.*	50.4
1270	*Quinebaug River at Jewett City, Conn.*	711
1935	*Salmon River near East Hampton, Conn.*	105
1940	*Eightmile River at North Plain, Conn.*	18.6
1945	*East Branch Eightmile River near North Lyme, Conn.*	22.0

PERIOD OF OPERATION
in
calendar years



1 Monthly discharge only

Figure 12.--Length of continuous streamflow records at gaging stations in the lower Thames and southeastern coastal river basins and vicinity

WATER IN STREAMS AND LAKES

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

The amount of flow passing any given point on a stream varies from day to day, season to season, and year to year. Continuous records of streamflow have been obtained at six gaging stations within the report area for periods ranging from 19 months to 35 years as indicated in figure 12. In addition, discontinuous or partial records and single measurements of streamflow have been obtained for many other sites within the SCRBA during the period from May 1963 to September 1964. The locations of these stream-gaging stations are shown on plate A. All records for 1963-64 are given either in annual publications entitled "Surface Water Records of Connecticut" or in the companion basic data report by M. A. Cervione, Jr. and others (1968), and continuous records are published in a series of U.S. Geological Survey Water-Supply Papers entitled "Surface Water Supply of the United States."

The variations in streamflow at the continuous-record and partial-record gaging stations are summarized in this report by means of standardized graphs and tables familiar to hydrologists. In order that the graphs for different streams be comparable, the data for each stream have been adjusted to represent a 30-year reference period beginning in either April or October 1930. This conforms with the practice agreed upon by the World Meteorological Organization (Searcy, 1959). Accordingly, the analyses, interpretations, and predictions with respect to streamflow are based on this 30-year reference period. This reference period represents the long-term flow of the stream if there have been no changes made in the pattern of regulation of storage or diversion of water into or out of the SCRBA. The graphs or tables may then be used to estimate the amount of streamflow that will occur in the future at the measurement sites.

The water-supply potential of streams is determined by the length of time indicated flows are available (duration of daily flows) and by the frequency with which annual low flows recur (frequency distribution of annual low flows). Data showing duration of daily flows are given in table 5, and figures 13-16; statistical analyses of streamflow data showing magnitude and frequency of annual low flows are given in tables 6 and 7 and figure 19. Because streamflow varies from place to place along each stream as well as from time to time, methods are described in the following sections for determining streamflow parameters at any unmeasured point along any unregulated stream in the report area.

VARIATIONS IN STREAMFLOW

Areal variations in annual precipitation cause substantial variations in amounts of runoff from place to place within the report area. Average streamflow in the central portion is 1.16 mgd per sq mi or slightly less, which approximately equals the average streamflow in the whole Thames River basin. Above average streamflow occurs on the western side and much above average streamflow occurs on the eastern side as shown by the isopleths on figure 17. The isopleths are based on the average streamflow at each gaging station in or near the report area; the ratios of these average streamflows to 1.16 mgd per sq mi (1.80 cfs per sq mi) were plotted near the center of the basins drained to guide the location of isopleths.

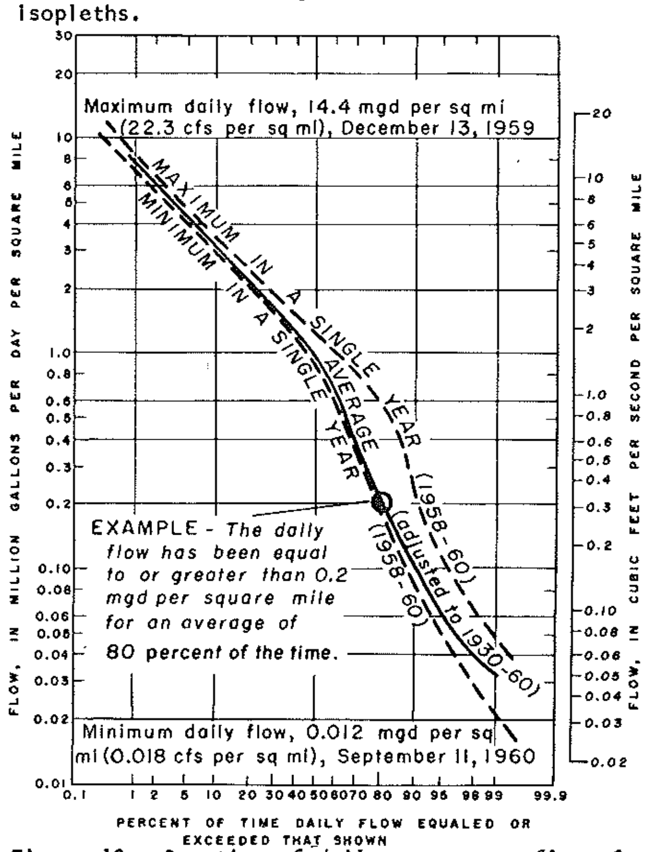


Figure 13.--Duration of daily mean streamflow of Pendleton Hill Brook near Clarks Falls

While variations in precipitation cause variations in the amount of runoff, variations in geology cause variations in the timing of runoff. The variations in runoff caused by variations in geology for eastern and southern Connecticut, including the report area, have been discussed by M. P. Thomas (1966), and are summarized in the family of flow-duration curves shown in figure 18. These curves show that runoff from areas underlain by stratified drift is more evenly distributed throughout time than is runoff from areas underlain largely by till. These relationships reflect the poor infiltration capacity and resultant high proportion of direct runoff from till, and the greater infiltration capacity and resultant high proportion of ground-water runoff from stratified drift. The stratified drift absorbs a relatively large proportion of the precipitation and stores it for sustained release during periods of dry weather.

The flow-duration curves in figure 18 and the

Table 5.--Duration of daily flow at stream-gaging stations in the lower Thames and southeastern coastal river basins

(Data are adjusted to period October 1930 to September 1960 on basis of long-term streamflow records)

Index no. (Pl.A)	Stream and place of measurement	Drainage area (sq mi)	Percent of drainage area covered by stratified drift	Average flow (mgd per sq mi)	Flow (mgd per sq mi) which was equaled or exceeded for indicated percentage of time												
					1	5	10	20	30	40	50	60	70	80	90	95	99
1182.55	Green Fall River at Laurel Glen	6.79	8.4	1.36	7.8	4.1	3.0	2.0	1.5	1.15	0.84	0.65	0.44	0.28	0.16	0.12	0.06
1183	Pendleton Hill Brook near Clarks Falls	3.85	7.8	1.39	7.8	4.1	3.0	2.1	1.55	1.2	.90	.68	.37	.20	.10	.06	.03
1183.5	Green Fall River at Clarks Falls	19.8	14.4	1.36	7.8	4.1	3.0	2.0	1.5	1.15	.84	.65	.44	.28	.16	.12	.06
1183.7	Yawbucs Brook near North Stonington	2.42	13.2	1.28	7.8	4.0	2.9	1.9	1.4	1.05	.78	.56	.36	.22	.10	.08	.04
1183.75	Assekonk Brook near North Stonington	1.66	2.9	1.28	7.8	3.9	2.8	1.9	1.4	1.05	.78	.50	.26	.12	.04	.01	0
1183.8	Assekonk Brook at North Stonington	4.00	17.8	1.28	7.1	3.8	2.8	1.9	1.4	1.1	.84	.56	.36	.20	.07	.04	.01
1184	Shunock River near North Stonington	16.2	26.2	1.28	7.1	3.8	2.8	1.9	1.4	1.1	.84	.61	.43	.28	.16	.12	.06
1185	Pawcatuck River at Westerly, R.I.	295	--	1.22	4.4	3.2	2.6	1.9	1.55	1.3	1.05	.74	.53	.38	.27	.21	.14
1185.5	Anguilla Brook at Wequetequock	7.18	26.2	1.29	7.4	3.9	2.8	1.9	1.4	1.1	.84	.59	.41	.26	.14	.10	.06
1187	Whitford Brook at Old Mystic	14.4	26.2	1.16	6.8	3.5	2.5	1.7	1.3	.97	.74	.49	.31	.18	.07	.04	.01
1187.5	Haleys Brook near Old Mystic	4.25	11.1	1.16	6.8	3.6	2.6	1.7	1.3	1.0	.74	.48	.29	.16	.05	.03	.01
1188.5	Eccleston Brook at Noank	2.94	11.9	1.16	6.8	3.6	2.6	1.7	1.3	1.0	.74	.48	.29	.16	.05	.03	.01
1272	Bartlett Brook near Colchester	13.3	21.9	1.16	7.4	3.7	2.6	1.7	1.3	.94	.71	.48	.30	.18	.08	.06	.03
1272.5	Deep River near Colchester	3.97	13.4	1.23	7.8	3.9	2.8	1.8	1.35	1.0	.74	.53	.35	.21	.10	.08	.04
1272.9	Yantic River at Gilman	37.4	20.8	1.18	7.1	3.6	2.6	1.7	1.3	1.0	.74	.56	.38	.25	.14	.10	.06
1273	Pease Brook at Lebanon	3.11	3.3	1.16	8.4	3.9	2.7	1.8	1.3	.90	.63	.40	.21	.11	.04	.02	.01
1273.1	Pease Brook near Lebanon	7.77	8.6	1.16	7.8	3.7	2.6	1.7	1.3	.94	.68	.46	.27	.16	.07	.05	.02
1273.55	Gardner Brook near Bozrah Street	7.60	34.2	1.23	6.8	3.8	2.7	1.8	1.35	1.05	.78	.52	.33	.21	.10	.07	.03
1273.6	Gardner Brook at Bozrah Street	12.8	29.4	1.23	6.8	3.8	2.7	1.8	1.35	1.05	.78	.52	.33	.21	.10	.07	.03
1273.8	Susquetonscut Brook at Lebanon	5.41	9.4	1.16	7.4	3.7	2.6	1.7	1.3	.94	.68	.48	.30	.18	.02	.01	0
1273.9	Susquetonscut Brook at Franklin	12.7	14.5	1.16	7.4	3.7	2.6	1.7	1.3	.94	.68	.48	.30	.18	.02	.01	0
1274	Susquetonscut Brook at Yantic	15.4	16.4	1.16	7.4	3.7	2.6	1.7	1.3	.97	.71	.50	.31	.19	.05	.02	.01
1275	Yantic River at Yantic	88.6	19.8	1.18	7.4	3.7	2.6	1.7	1.3	.97	.71	.52	.36	.21	.10	.07	.05
1276.8	Trading Cove Brook near Montville Center	5.04	8.3	1.21	7.1	3.7	2.7	1.8	1.35	1.0	.78	.53	.25	.06	0	0	0
1277	Trading Cove Brook near Thamesville	8.70	13.1	1.16	7.1	3.6	2.6	1.7	1.3	.97	.71	.50	.32	.20	.10	.07	.04
1277.2	Indiantown Brook near Shewville	6.53	21.9	1.16	7.1	3.6	2.6	1.7	1.3	.97	.71	.50	.32	.20	.10	.07	.04
1277.25	Shewville Brook at Shewville	11.7	29.3	1.16	7.1	3.6	2.6	1.7	1.3	.97	.71	.50	.32	.20	.10	.07	.04
1277.3	Crowley Brook at Poquetanuck	2.24	23.7	1.16	7.1	3.6	2.6	1.7	1.3	.97	.71	.50	.32	.13	.04	.02	0
1277.35	Billings Avery Brook near Poquetanuck	2.77	27.4	1.16	7.1	3.6	2.6	1.7	1.3	.97	.71	.50	.32	.20	.10	.07	.04
1277.4	Stony Brook near Uncasville 1/	4.72	16.1	1.16	7.1	3.6	2.6	1.7	1.3	.97	.71	.51	.34	.21	.10	.07	.04
1277.45	Oxoboxo Brook near Oakdale	3.58	38.5	1.23	7.1	3.7	2.6	1.8	1.35	1.05	.78	.59	.42	.28	.16	.12	.07
1277.5	Oxoboxo Brook at Montville	10.2	26.8	1.16	7.1	3.6	2.6	1.7	1.3	.97	.71	.54	.45	.36	.27	.24	.17
1277.6	Hunts Brook at Quaker Hill	11.3	9.0	1.18	6.8	3.6	2.6	1.7	1.3	1.0	.74	.54	.37	.25	.13	.09	.05
1277.7	Jordan Brook at Waterford	3.53	19.8	1.18	6.1	3.4	2.5	1.7	1.3	1.05	.78	.62	.46	.33	.21	.16	.10
1277.8	Latimer Brook at Chesterfield 2/	4.25	19.3	1.23	6.1	3.4	2.6	1.8	1.35	1.1	.84	.65	.50	.37	.25	.18	.12
1277.9	Latimer Brook at East Lyme 2/	12.5	15.8	1.23	6.1	3.4	2.6	1.8	1.35	1.1	.84	.65	.50	.37	.25	.18	.12
1277.95	Pataquanset River at Niantic	7.38	37.8	1.23	6.5	3.6	2.6	1.8	1.35	1.05	.81	.61	.45	.31	.18	.14	.08
1278	Fourmile River near East Lyme	4.29	33.8	1.23	7.4	3.8	2.7	1.8	1.35	1.05	.74	.54	.36	.22	.11	.08	.04

1/ Does not include area above or flow from Stony Brook Reservoir.
2/ Does not include area above or flow from Fairy Lake, Barnes and Bogue Brook Reservoirs.

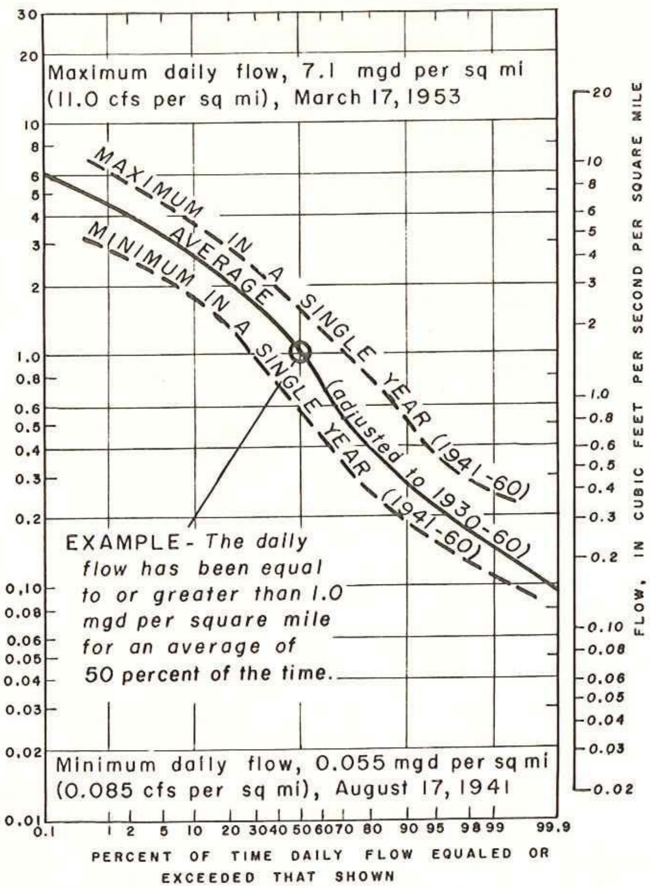


Figure 14.--Duration of daily mean streamflow of the Pawcatuck River at Westerly, Rhode Island

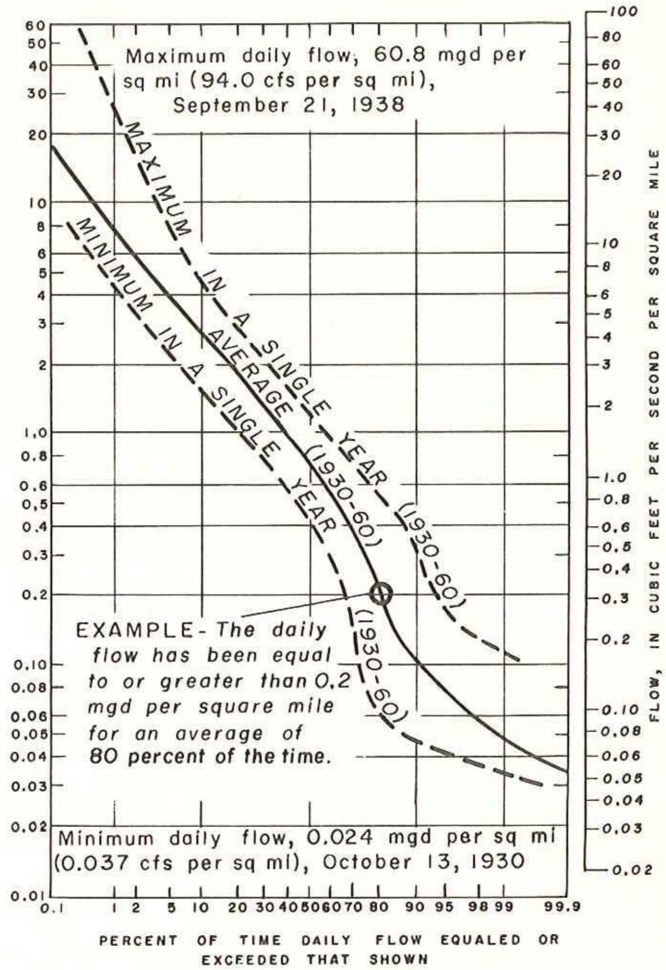


Figure 15.--Duration of daily mean streamflow of the Yantic River at Yantic

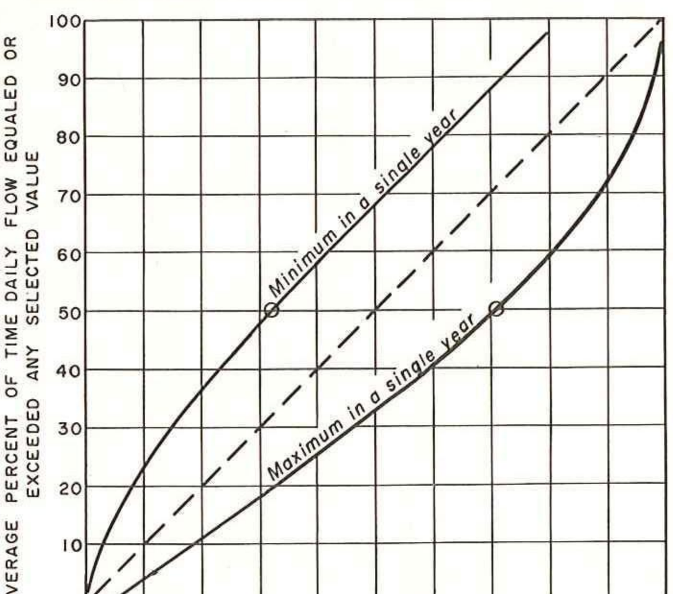


Figure 16.--Range in duration of streamflow in the lower Thames and southeastern coastal river basins, 1931-60 water years

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

isopleths in figure 17 may be used to estimate flow duration at any unmeasured site in the SCRBA as indicated by the following example. Assume that flow-duration characteristics are needed for a site on the Yantic River just downstream from Pease Brook near Gilman. On plate B the drainage area above this site is measured to be 50.6 square miles and that portion of the drainage area underlain by stratified drift deposits is measured to be 9.0 square miles. Thus, with 17.8 percent of the area underlain by stratified drift, the flow-duration curve for this area is the product of the ordinates to the type curve interpolated on figure 18 for this percent stratified drift times the drainage area of 50.6 square miles. However, from figure 17 it is found that this drainage basin is located where the average streamflow is 3 percent greater than 1.16 mgd per sq mi, so the ordinates must be further increased by the factor 1.03. In tabular form the result is:

Flow, mgd, equaled or exceeded	350	190	140	68	38	20	7.3	4.9	2.9
Percentage of time	1	5	10	30	50	70	90	95	99

EXPLANATION

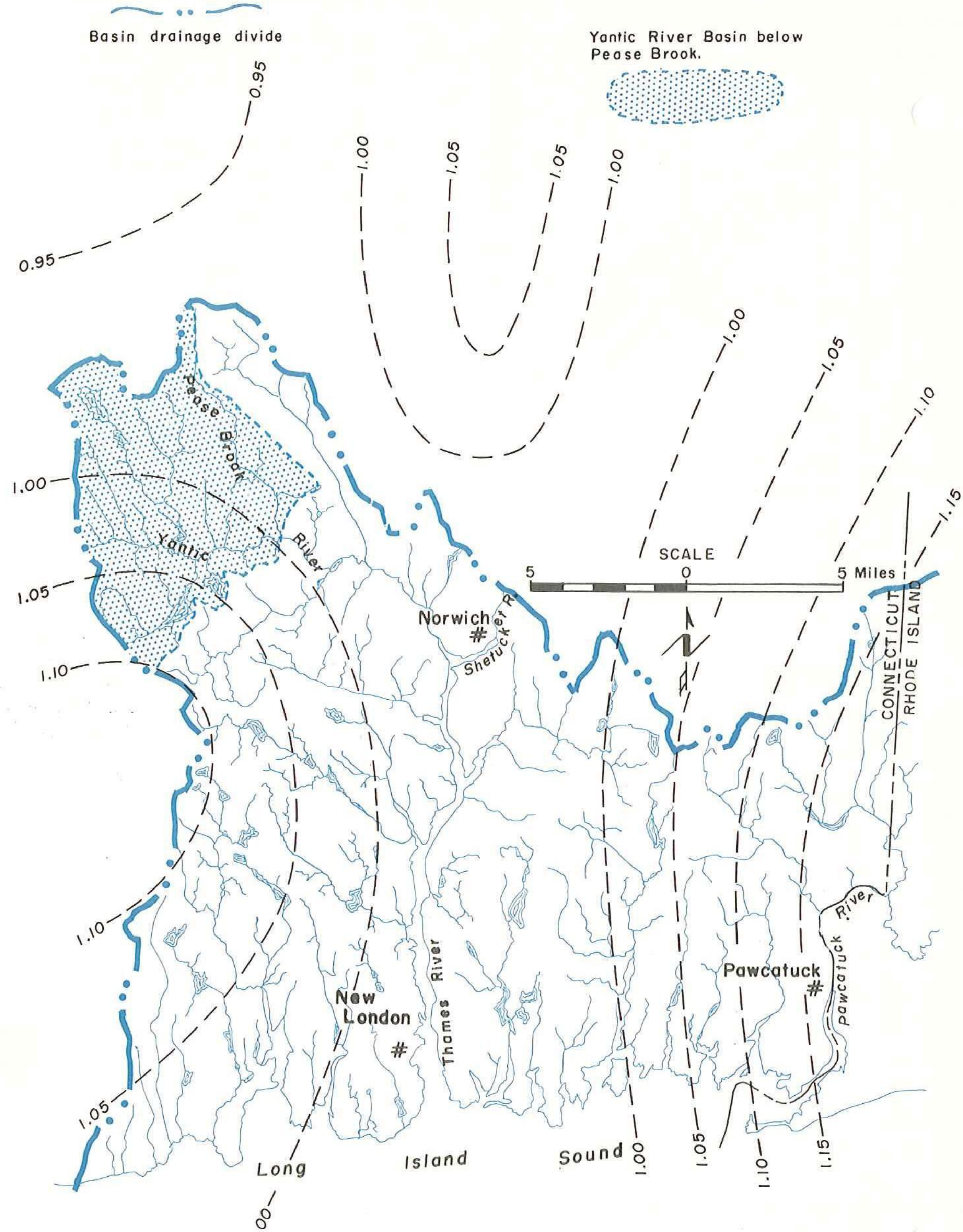


Figure 17.--Areal variations in average streamflow in the lower Thames and southeastern coastal river basins

Isopleths express the ratio of average flow in any locality to 1.16 mgd per sq mi, which approximately equals the average streamflow in the whole Thames River basin. The ratio for the drainage basin of the Yantic River below Pease Brook is 1.03.

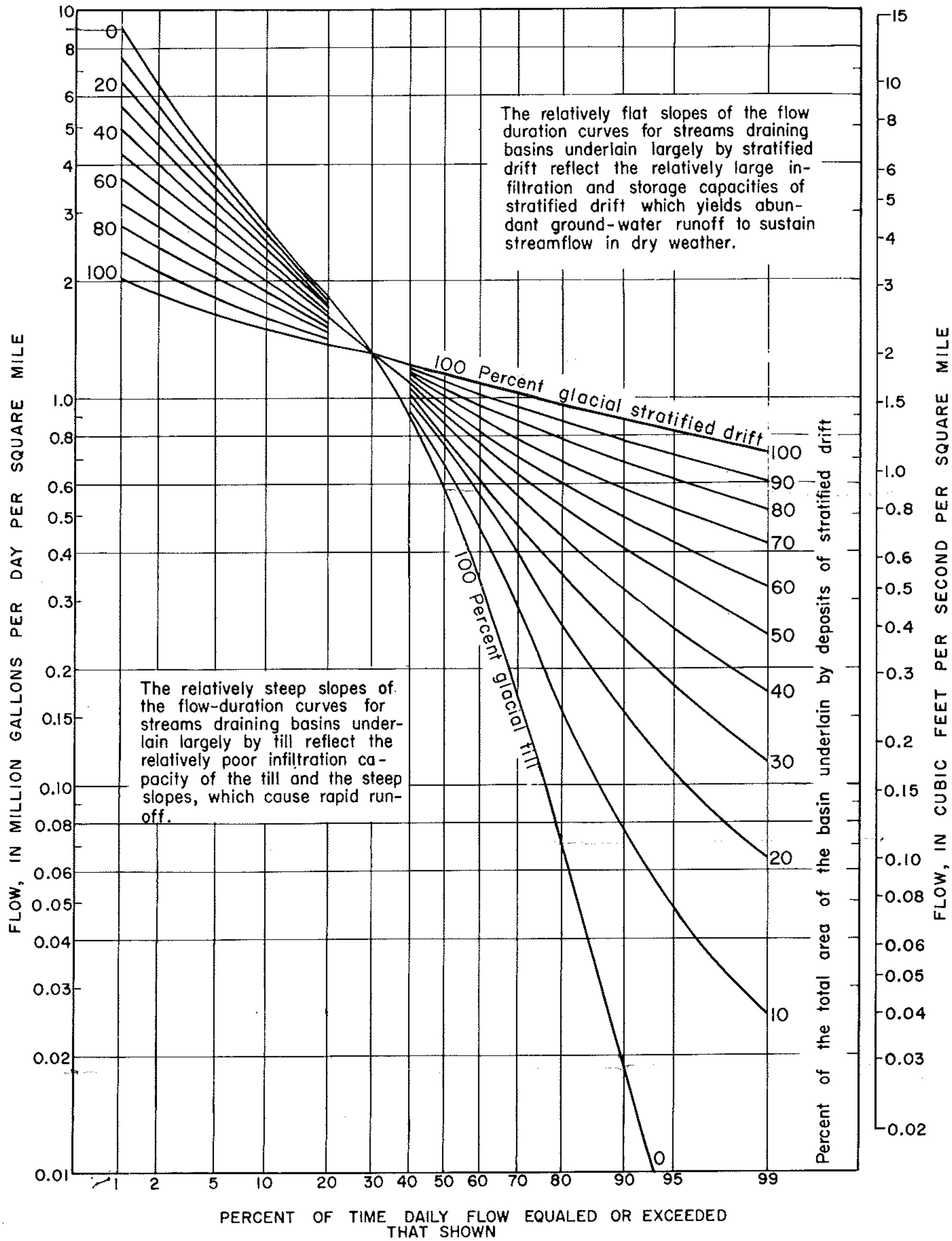


Figure 18.--Regional duration curves of daily mean streamflow

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

FREQUENCY AND DURATION OF LOW FLOWS

Although flow-duration curves such as those shown in figures 13, 14, 15, and 18 indicate the minimum amounts of streamflow available for certain percentages of time, the water manager also finds it useful to know how often specified low streamflows are expected to recur and for how long a period of time they are expected to last. Recurrence intervals of annual lowest average flows for periods as long as 365 consecutive days, for the Pawcatuck River at Westerly, Rhode Island and Yantic River at Yantic, stream-gaging stations are given in table 6, and similar data for periods up to 30 years are given in table 7 for the Yantic River at Yantic. Low-flow frequency data also may be presented in graphs as illustrated in figure 19 for the stream-gaging station on the Yantic River at Yantic. Tables similar to those presented in table 6 can be constructed from the flow-duration data presented for partial-record gaging stations in table 5 as well as from flow-duration data for unmeasured sites estimated from figures 17 and 18 by use of table 8. To illustrate: The average 30-consecutive-day low flow that could be expected to recur on the average once in every two years according to table 8 is equivalent to the flow equaled or exceeded 90 percent of the time. For the unmeasured site used as an example at the end of the preceding section, the 90-percent flow in the flow-duration table is 7.3 mgd. Flows for other periods and recurrence intervals can be determined in a similar manner.

Perhaps the most widely used low-flow values are the 7-day and 30-day average flows with a 2-year recurrence interval. Streamflow will diminish below these values in 1 year out of 2, on the average. Accordingly, these values are termed "indices of low flow frequency" and are presented in table 9 for all gaging stations in the report area. The 7-day average flow is equivalent to that which is equaled or exceeded about 94 percent of the time and the 30-day average flow to that which is equaled or exceeded about 90 percent of the time.

In pollution control studies, based on Public Act 57, the State Water Resources Commission, in their report on criteria for water quality standards for interstate and intrastate waters, recommends that the streamflow to which their standards apply be the minimum average daily flow for 7 consecutive days with a 10-year recurrence interval. In the SCRBA, this flow for unmeasured sites would be equivalent to the flow which is equaled or exceeded 98 percent of the time.

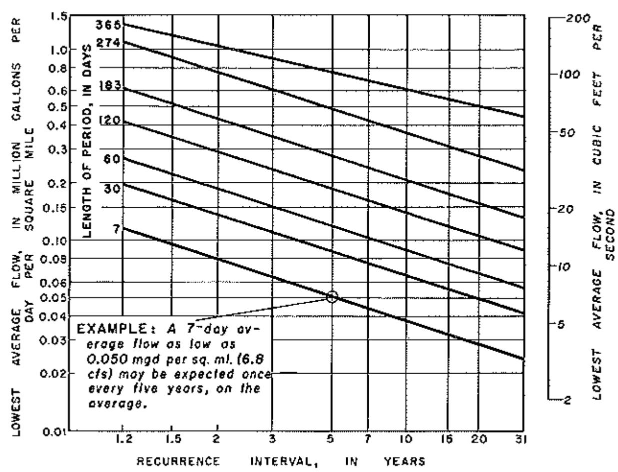


Figure 19.--Recurrence intervals of low flows of the Yantic River at Yantic

The lowest daily flows of record (1930 to 1965) of the Yantic River at Yantic not exceeded during periods of 7 to 120 days occurred during the climatic year April 1, 1957 to March 31, 1958 with one exception. Records at other gaging stations in the report area do not go back to 1930, but unless the pattern of regulation was quite different in the early years, it is likely that these lowest flows since 1930 for

Table 6.--Annual lowest mean flows for indicated recurrence intervals at Pawcatuck River at Westerly, R.I. and Yantic River at Yantic
(Flows are adjusted to the reference period April 1930 to March 1960)

Index no (Pl. A)	Stream and place of measurement	Drainage area (sq mi)	Period of low flow (consecutive days)	Annual lowest mean flow (cfs) for indicated recurrence interval (years)							Annual lowest mean flow (mgd per sq mi) for indicated recurrence interval (years)						
				1.2	2	3	5	10	20	31	1.2	2	3	5	10	20	31
1185	Pawcatuck River at Westerly, R.I.	295	3	100	80	70	60	49	41	36	--	--	--	--	--	--	--
			7	130	100	86	74	60	50	45	0.285	0.219	0.188	0.162	0.131	0.110	0.099
			30	150	115	100	84	70	58	52	.329	.252	.219	.184	.153	.127	.114
			60	180	140	120	100	84	70	62	.394	.307	.263	.219	.184	.153	.136
			120	240	180	160	135	110	92	80	.526	.394	.351	.296	.241	.202	.175
			183	330	250	220	190	150	125	110	.723	.548	.482	.416	.329	.274	.241
			274	510	400	350	300	240	200	180	1.12	.876	.767	.657	.526	.438	.394
			365	660	510	440	380	310	260	230	1.45	1.12	.964	.833	.679	.570	.504
1275	Yantic River at Yantic	88.6	3	12	8.6	7.0	5.6	4.2	3.1	2.6	--	--	--	--	--	--	--
			7	16	11	8.6	6.8	5.1	3.9	3.2	.117	.080	.063	.050	.037	.028	.023
			30	26	18	15	12	8.7	6.6	5.5	.189	.131	.109	.087	.063	.048	.040
			60	36	25	20	16	12	9.0	7.6	.262	.182	.146	.117	.087	.066	.055
			120	56	39	32	25	19	14	12	.408	.284	.233	.182	.138	.102	.087
			183	84	58	47	37	28	21	18	.612	.423	.343	.270	.204	.153	.131
			274	150	100	82	66	49	37	31	1.09	.730	.598	.481	.357	.270	.226
			365	180	140	120	100	82	67	59	1.31	1.02	.873	.730	.598	.489	.430

Table 7.--Lowest mean flows for periods of one year or more at Yantic River at Yantic, index no. 1275 (Flows are adjusted to the reference period April 1930 to March 1960)

Lowest mean flow (cfs) for indicated period of consecutive months							
12	18	24	36	60	120	180	360
59	90	105	120	125	135	145	160

Table 8.--Average duration of lowest mean flows of streams in the lower Thames and southeastern coastal river basins

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

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

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

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

Index no. (Pl. A)	Stream and place of measurement	Drainage area (sq mi)	Annual lowest mean flow having a recurrence interval of 2 years for number of consecutive days indicated (cfs) 7 days	(cfs) 30 days	(mgd per sq mi) 7 days	(mgd per sq mi) 30 days
1182.55	Green Fall River at Laurel Glen	6.79	1.3	1.7	0.12	0.16
1183	Pendleton Hill Brook near Clarks Falls	3.85	.40	.58	.07	.10
1183.5	Green Fall River at Clarks Falls	19.8	3.8	5.0	.12	.16
1183.7	Yawbucks Brook near North Stonington	2.42	.31	.39	.08	.10
1183.75	Assekonk Brook near North Stonington	1.66	.03	.09	.01	.04
1183.8	Assekonk Brook at North Stonington	4.00	.29	.44	.05	.07
1184	Shunock River near North Stonington	16.2	3.1	3.9	.12	.16
1185	Pawcatuck River at Westerly, R.I.	295	100	115	.22	.25
1185.5	Anguilla Brook at Wequetequock	7.18	1.2	1.6	.11	.14
1187	Whitford Brook at Old Mystic	14.4	1.0	1.6	.05	.07
1187.5	Haleys Brook near Old Mystic	4.25	.20	.34	.03	.05
1188.5	Eccleston Brook at Noank	2.94	.14	.24	.03	.05
1272	Bartlett Brook near Colchester	13.3	1.3	1.7	.06	.08
1272.5	Deep River near Colchester	3.97	.52	.64	.08	.10
1272.9	Yantic River at Gilman	37.4	6.0	7.9	.10	.14
1273	Pease Brook at Lebanon	3.11	.11	.19	.02	.04
1273.1	Pease Brook near Lebanon	7.77	.61	.82	.05	.07
1273.55	Gardner Brook near Bozrah Street	7.60	.87	1.1	.07	.10
1273.6	Gardner Brook at Bozrah Street	12.8	1.5	1.9	.07	.10
1273.8	Susquetonscut Brook at Lebanon	5.41	.07	.16	.01	.02
1273.9	Susquetonscut Brook at Franklin	12.7	.17	.38	.01	.02
1274	Susquetonscut Brook at Yantic	15.4	.68	1.1	.03	.05
1275	Yantic River at Yantic	88.6	11	18	.08	.13
1276.8	Trading Cove Brook near Montville Center	5.04	0	0	0	0
1277	Trading Cove Brook near Thamesville	8.70	1.0	1.3	.07	.10
1277.2	Indiantown Brook near Shewville	6.53	.75	.98	.07	.10
1277.25	Shewville Brook at Shewville	11.7	1.3	1.8	.07	.10
1277.3	Crowley Brook at Poquetanuck	2.24	.07	.13	.02	.04
1277.35	Billings Avery Brook near Poquetanuck	2.77	.32	.42	.07	.10
1277.4	Stony Brook near Uncasville 1/	4.72	.59	.76	.08	.10
1277.45	Oxoboxo Brook near Oakdale	3.58	.72	.90	.13	.16
1277.5	Oxoboxo Brook at Montville	10.2	3.9	4.3	.25	.27
1277.6	Hunts Brook at Quaker Hill	11.3	1.7	2.3	.10	.13
1277.7	Jordan Brook at Waterford	3.53	.92	1.1	.17	.21
1277.8	Latimer Brook at Chesterfield 2/	4.25	1.3	1.6	.20	.25
1277.9	Latimer Brook at East Lyme 2/	12.5	3.8	4.8	.20	.25
1277.95	Pataguanset River at Niantic	7.38	1.7	2.1	.15	.18
1278	Fourmile River near East Lyme	4.29	.56	.73	.08	.11

1/ Does not include area above or flow from Stony Brook Reservoir.

2/ Does not include area above or flow from Fairy Lake, Barnes and Bogue Brook Reservoirs.

Table 10.--Lowest daily flow not exceeded during various numbers of consecutive days at Pawcatuck River at Westerly, R.I. in the summer of 1964 and at Yantic River at Yantic in the summer of 1957. These flows were the lowest which occurred during the period October 1930 to March 1965.

Index no. (Pl.A)	Stream and place of measurement	Drainage area (sq mi)	Year	Lowest daily flow (cfs) not exceeded during indicated number of consecutive days					Lowest daily flow (mgd per sq mi) not exceeded during indicated number of consecutive days				
				7	15	30	60	120	7	15	30	60	120
1185	Pawcatuck River at Westerly, R.I.	295	1964	58	65	74	123	[a]174	--	--	--	--	--
1275	Yantic River at Yantic	88.6	1957	[b]4.9	5.7	6.8	9.6	13	--	0.042	0.050	0.070	0.095

a A lower flow of 168 cfs occurred during the summer of 1949.

b Lower flows occurred during the summers of 1944 (4.6 cfs) and 1963 (3.6 cfs).

all gaging stations in the report area occurred in the climatic year 1957. This is further substantiated by the fact that these lowest flows of record at 13 other long-term gaging stations in the Thames River basin, with few exceptions, also occurred in the 1957 climatic year. The lowest daily flows not exceeded for specified periods for the Pawcatuck River at Westerly, Rhode Island and Yantic River at Yantic gaging stations are given in table 10.

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

STORAGE OF WATER IN LAKES AND RESERVOIRS

EXISTING LAKES AND RESERVOIRS

There are many lakes, ponds, and reservoirs within the area covered by the SCRBA. The largest is Gardner Lake which has a surface area of 487 acres, a total storage capacity of 2,177 million gallons and a usable storage capacity of 1,055 million gallons. Table 11 presents information concerning the more important lakes, ponds, and reservoirs within the report area. Additional information on the public-water supply reservoirs is given in table 38.

All but three of the lakes, ponds, and reservoirs listed in table 11 have usable storage; that is, some or all of the water they contain may be withdrawn by gravity by opening a valve or gate. For nearly all of these surface water bodies, table 12 presents the maximum safe draft rates (regulated flows) that could be utilized at each site such that the reservoir would have refilled within each year of the reference period. Maximum draft rates are given for the wettest and driest years of the reference period and also for the median year. It should be noted that the draft rates apply for 24-hours per day use and may be increased if the period of use is reduced.

Flow-duration and low-flow frequency data for streams at the outlet of each of these reservoirs were obtained either from data at gaging stations presented in tables 5 and 8 or by using the methods described for ungaged sites in the two preceding sections.

ESTIMATING THE AMOUNT OF STORAGE NEEDED

If the minimum flow of a stream is insufficient to supply a projected rate of use, it may be possible to construct a reservoir from which stored water can be released as needed to maintain the desired flow. If the frequency with which different amounts of storage would be required is know, then the cost of providing the storage may be balanced against the loss caused by insufficient supply. The information presented in table 13 for the Pawcatuck River at Westerly, Rhode Island and Yantic River at Yantic gaging stations shows the frequency with which various amounts of storage would have been required to maintain selected rates of regulated flow during the reference period. Values of storage required for recurrence intervals of 2 years represent median conditions, and values for recurrence intervals of 31 years represent very dry conditions. The rates of regulated flow are presented per square mile of drainage area so that the table may be used for other sites along the same stream, provided that the percent of the area covered by stratified drift is not appreciably different. Most of the storage would have been replaced every year. The storage curves were determined from frequency-mass curves based on low-flow frequency relationships for each gaging station.

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

Table 11.--Lakes, ponds, and reservoirs in the lower Thames and southeastern coastal river basins

Index no. (Pl.A)	Name and location	Source of data[1]	Natural (N) or Artificial (A)	Drainage area (sq mi)	Surface area (acres)	Surface elevation (ft)	Maximum depth (ft)	Average depth (ft)	Total storage (mg)	Usable storage (mg)	Maximum amount of storage released during 1964 water year (mg)	Present type of use
1182.5	Green Fall Pond near Voluntown	FG	A	2.41	47.8	312	27	13	197	197	--	Recreation
1182.79	Wyassup Lake near North Stonington	FG	NA	.79	92.7	301	28	8.9	267	174	97	Recreation
1186.35	Mystic (Dean) Reservoir near Mystic	MV	A	5.26	12.5	49	10	8.6	35	35	--	Public water supply
1186.4	Mystic (Palmer) Reservoir near Mystic	MV	A	5.98	23.9	42	12	10	80	80	--	Public water supply
1186.5	Lantern Hill Pond near Shewville	FG	NA	1.82	15.1	117	32	15	72	None	None	Recreation
1186.6	Long Pond near North Stonington	FG	NA	4.45	98.6	95	72	15	488	245	None	Recreation
1189	Ledyard Reservoir near Groton	Gr	A	5.15	95	94	24	15	476	476	459	Public water supply
1189.6	Buddington Pond near Groton	Gr	A	11.1	5	23	--	12	20	20	20	Public water supply
1189.7	Pohegnut Reservoir near Groton	Gr	A	1.36	80	38	9	8.6	223	223	223	Public water supply
1189.8	Smith Lake near Groton	Gr	NA	1.84	42	25	67	32	436	436	316	Public water supply
1189.9	Groton Reservoir near Groton	Gr	A	14.3	115	23	12	4.3	256	256	146	Public water supply
1271.45	Taftville Reservoir at Taftville	No	A	.25	22	255	20	12	88	88	--	Public water supply
1271.9	Williams Pond near Amston	FG	A	2.40	272	445	10	4.5	396	396	351	Recreation
1272.51	Deep River Reservoir near Gilman	No	A	7.27	119	330	35	9.9	384	384	339	Public water supply
1273.49	Gardner Lake near Fitchville	FG	NA	5.31	487	384	43	14	2,177	1,055	209	Recreation
1273.7	Fitchville Pond at Fitchville	FG	A	69.3	69.2	152	20	6.2	140	140	140	Recreation
1275.4	Fairview Reservoir near Norwichtown	No	A	.74	68	249	30	20	450	450	205	Public water supply
1277.05	Amos Lake at Preston	FG	NA	1.48	105	129	48	19	655	65	--	Recreation
1277.1	Avery Pond near Preston	FG	N	2.98	46.1	116	14	6.8	101	None	None	Recreation
1277.15	Lake of Isles near Shewville	FG	NA	.60	87.1	261	10	6.1	172	100	79	Recreation
1277.39	Stony Brook Reservoir near Oakdale	No	A	2.46	73	273	30	21	500	500	78	Public water supply
1277.44	Oxoboxo Lake near Montville	FG	NA	3.24	164	394	37	19	1,077	613	210	Industrial
1277.75	Fairy Lake near Chesterfield	NL	NA	.89	84	358	60	8.6	235	235	235	Public water supply
1277.77	Barnes Reservoir near Chester-field	NL	A	2.98	46.5	214	25	11	170	170	--	Public water supply
1277.79	Bogue Brook Reservoir near Chesterfield	NL	A	1.62	72	204	25	9.0	212	212	--	Public water supply
1277.91	Lake Konomoc near Chesterfield	NL	NA	1.57	225	180	60	9.2	672	672	--	Public water supply
1277.92	Powers Lake near East Lyme	FG	A	1.02	153	156	14	8.9	442	442	None	Recreation
1277.93	Pataguanset Lake at East Lyme	FG	NA	3.69	123	63	34	12	497	105	33	Recreation
1277.94	Dodge Pond at Niantic	FG	N	.53	33.8	8	51	21	227	None	None	Scientific investigations

1 Most of the data from (FG) State Board of Fisheries and Game, (MV) Mystic Valley Water Company, and municipal water departments of (Gr) Groton, (No) Norwich, and (NL) New London.

Table 12.--Maximum safe draft rates (regulated flows) from selected lakes, ponds, and reservoirs in the lower Thames and southeastern coastal river basins for the reference period April 1930 to March 1960

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

Index no. (Pl.A)	Name and location	Drainage basin	Drainage area (sq mi)	Total usable storage (mg)	Maximum safe regulated flow: Driest year (cfs)	Driest year (mgd)	Median year (cfs)	Median year (mgd)	Wettest year (cfs)	Wettest year (mgd)
1182.5	Green Fall Pond near Voluntown	Green Fall River	2.41	197	*1.8	*1.2	3.5	2.3	8.3	5.4
1182.79	Wyassup Lake near North Stonington	Wyassup Brook	.79	174	*.27	*.17	*1.3	*.84	*3.0	*1.9
--	Mystic (Dean) and Mystic (Palmer) Reservoirs near Mystic	Copps Brook	5.98	115	1.8	1.2	3.6	2.3	11	7.1
1186.6	Long Pond near North Stonington	Whitford Brook	4.45	245	2.3	1.5	4.3	2.8	12	7.8
--	Smith Lake, Buddington Pond, and Groton, Ledyard, and Pohegnut Reservoirs near Groton	Great Brook	14.3	1,411	*12	*7.8	24	16	*49	*32
1271.9	Williams Pond near Amston	Bartlett Brook	2.40	396	*1.2	*.78	*3.6	*2.3	*7.9	*5.1
--	Deep River Reservoir near Gilman, Fairview Reservoir near Norwich-town, and Stony Brook Reservoir near Oakdale	--	--	1,334	*6.0	*3.9	*16	*10	*34	*22
1273.49	Gardner Lake near Fitchville	Gardner Brook	5.31	1,055	*3.0	*1.9	*9.0	*5.8	*18	*12
1273.7	Fitchville Pond at Fitchville	Yantic River	69.3	140	12	7.8	19	12	68	44
1277.05	Amos Lake at Preston	Indiantown Brook	1.48	65	.72	.47	1.3	.84	3.7	2.4
1277.15	Lake of Isles near Shewville	Indiantown Brook	.60	100	*.34	*.22	*.93	*.60	*1.9	*1.2
1277.44	Oxoboxo Lake near Montville	Oxoboxo Brook	3.24	613	*2.3	*1.5	*5.0	*3.2	*11	*7.1
--	Fairy Lake, Lake Konomox, and Barnes and Bogue Brook Res-ervoirs, near Chesterfield	Lakes Pond Brook	--	1,289	*5.1	*3.3	*11	*7.1	*20	*13
1277.92	Powers Lake near East Lyme	Pataguanset River	1.02	442	*.75	*.48	*1.7	*1.1	*3.4	*2.2
1277.93	Pataguanset Lake at East Lyme	Pataguanset River	3.69	105	1.8	1.2	3.3	2.1	8.4	5.4

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

Table 13.--Storage required to maintain selected regulated flows at Pawcatuck River at Westerly, R.I. and Yantic River at Yantic

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

Index no. (Pl. A)	Stream and place of measurement	Drainage area (sq mi)	Recurrence interval of annual lowest mean flow (years) 1/	Maximum amount of storage which would refill during the year of annual lowest mean flow (mg per sq mi)	Storage required (mg per sq mi) to maintain indicated regulated flow (mgd per sq mi)																
					0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.65	0.70	0.75	0.80	0.90	1.00
1185	Pawcatuck River at Westerly, R.I.	295	1.2	..	..	..	..	..	..	..	2	4	6	9	12	16	21	26	32	45	58
			2	..	..	..	..	..	1	3	6	10	14	19	24	30	36	42	49	65	82
			5	76	..	..	..	2	5	9	14	19	24	30	37	44	52	61	70	88	107
			10	64	..	..	2	4	8	13	19	26	33	41	49	58	67	76	86	116	130
			31	48	..	1	4	9	15	22	30	38	47	56	66	76	87	98	111	145	180
1275	Yantic River at Yantic	88.6	1.2	..	..	..	..	1	3	5	8	11	15	19	24	29	35	41	47	60	74
			2	..	..	..	2	4	7	10	14	19	25	31	38	45	52	60	69	86	105
			5	85	..	2	5	9	14	20	26	34	42	51	60	70	80	90	100	122	146
			10	76	1	4	8	13	20	28	36	45	55	66	77	88	100	112	124	150	176
			31	60	3	8	14	22	32	42	53	65	78	91	104	117	130	144	158	186	216

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

rates of regulated flow and amounts of storage must be adjusted to the average streamflow at that site by multiplying by an appropriate ratio determined from figure 17.

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

FLOODS

HISTORICAL ACCOUNT

Floods may occur in the SCRBA during any month of the year. Spring floods commonly occur in the report area and are sometimes accompanied by destruction from moving ice. Floods also occur in late summer and fall, the result of hurricanes or other storms moving northeastward along the Atlantic coastline. Hurricanes, as they apply to the report area, are discussed in a separate section.

Since the first settlement of the region about 1660, at least 19 major flood events have occurred in the report area. General descriptive information concerning major floods within the SCRBA through 1955, extracted from newspaper accounts and other public and private records, is published in U.S. Geological Survey Water-Supply Paper 1779-M.

A quantitative summary of the major flood events of 1936, 1938, and 1955 on the Pawcatuck, Shetucket, and Yantic Rivers appears in table 15. Floods of moderate magnitude occurred in March 1936 and January and July 1938. The greatest flood of record in the SCRBA occurred on September 21, 1938. Rainfall on the Shetucket and Yantic River basins averaged about 14 inches and 12 inches respectively; both basins produced eight inches of runoff. The Shetucket River at Norwich peaked at 77,700 cfs exceeding the March 19, 1936 peak flow by over 30,000 cfs while the Yantic River at Yantic had a peak flow of 13,500 cfs, nearly twice that of July 24, 1938. Not until August 19, 1955 was the magnitude of the September 1938 flood challenged. It was exceeded, however, only on the upper tributaries of the Thames River, for heaviest rainfall occurred along the Connecticut-Massachusetts boundary. On October 17, 1955, flood peaks on the Pawcatuck and Yantic Rivers exceeded those of August 19, 1955 and were about the same magnitude as those of March 12, 1936.

More detailed records of the major floods of 1936, 1938, and 1955, based primarily on gaging-station records, are published in Water-Supply Papers 798 (March 1936), 867 (September 1938), 966 (January and July 1938), and 1420 (August and October 1955). A compilation of all flood peaks above selected magnitudes for continuous-record gaging stations within the report area is published in Water-Supply Paper 1671.

The magnitude of flood events in the Thames River basin has been modified considerably by the development and operation of several large flood-control reservoirs in the upper part of the basin by the Corps of Engineers. The largest of these is Mansfield Hollow Reservoir, completed in 1952, which can impound 2,260 million cubic feet of flood water in the Shetucket River basin. In the Quinebaug River basin, five major reservoirs constructed since 1958 have a total storage capacity of 4,058 million cubic feet. Modified river elevations and flows at the Greenville Dam on the Shetucket River at Norwich, from studies made by the Corps of Engineers, appear in table 15 and indicate the effect which these six storage reservoirs would have had upon major flood events of the past had they been in existence at the time. Also shown is an estimate of the peak flow which would have occurred in August and October 1955 had Mansfield Hollow Reservoir not been available for use. Future floods of similar magnitudes would be modified to the same degree by the combined effect of all of these reservoirs, so that the possibility of major damage on the Shetucket River at Greenville Dam is remote as long as buildings are not constructed below the highest modified flood eleva-

Table 14.--Storage required to maintain selected regulated flows at sites on unregulated streams in the lower Thames and southeastern stal river basins

(Data are adjusted to the reference period April 1930 to March 1960 and to an average flow of 1.16 mgd per sq mi. Storage required would refill during a year except for figures underlined which would require more than a year to refill. Storage is uncorrected for reservoir seepage, evaporation, and for bias in computation procedure, all of which increase somewhat the amount of storage required.)

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

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

Table 15.--Elevations of flood peaks and corresponding flows for notable floods of record on the Pawcatuck, Shetucket, and Yantic Rivers in southeastern Connecticut

Index no. (Pl. A)	Stream and place of measurement	Mar. 12, 1936 Elevation (ft above M.S.L.)	Mar. 12, 1936 Flow (cfs)	Mar. 18, 19, 1936 Elevation (ft above M.S.L.)	Mar. 18, 19, 1936 Flow (cfs)	Jan. 25, 26, 1938 Elevation (ft above M.S.L.)	Jan. 25, 26, 1938 Flow (cfs)	July 23, 24, 1938 Elevation (ft above M.S.L.)	July 23, 24, 1938 Flow (cfs)	Sept. 21, 1938 Elevation (ft above M.S.L.)	Sept. 21, 1938 Flow (cfs)	Aug. 19, 20, 1955 Elevation (ft above M.S.L.)	Aug. 19, 20, 1955 Flow (cfs)	Oct. 16, 17, 1955 Elevation (ft above M.S.L.)	Oct. 16, 17, 1955 Flow (cfs)
1185	Pawcatuck River at Westerly, R.I.	--	3,150	--	--	--	--	--	--	13.2	--	4.6	1,670	6.4	2,800
1271.49	Shetucket River at Greenville Dam at Norwich (crest elevation, 21.4 ft)														
	Observed 1/	31.3	44,300	32.0	47,600	--	--	31.3	43,800	36.0	77,700	35.0	65,500	29.6	33,000
	Modified by flood control 2/	30.0	35,000	30.4	37,200	--	--	29.2	30,000	32.0	47,200	30.0	35,000	28.2	25,000
1275	Yantic River at Yantic	105.8	6,300	104.2	3,950	102.5	3,230	105.9	6,980	109.1	13,500	102.0	1,920	106.0	6,760

1/ Data for floods of July 23, 24, 1938, Aug. 19, 1955, and Oct. 16, 1955 furnished by New England Division of the Corps of Engineers, U.S. Army.

2/ Estimation of modification by storage in Mansfield Hollow, East Brimfield, Westville, Hodges Village, Buffumville, and West Thompson flood-control reservoirs had they been in operation at the time. Estimates furnished by New England Division of the Corps of Engineers, U.S. Army.

tions shown in table 15. Of minor significance is the effect upon the Shetucket River at Norwich of six flood-water retarding structures in the upper reaches of the Shetucket River basin designed and constructed since 1959 by the U.S. Department of Agriculture, Soil Conservation Service, with a combined maximum detention capacity of 310 million cubic feet.

MAGNITUDE AND FREQUENCY OF FLOODS

Knowledge of the magnitude and frequency of floods is essential to the water manager concerned with the location and establishment of flood plain encroachment lines. The maximum flood of record and mean annual flood at gaging stations in the SCRBA are given in table 16. For the Shetucket River at Greenville Dam at Norwich, the stages and flows actually measured before the completion of the six Corps of Engineers flood-control reservoirs are given and, in addition, modified figures are given indicating probably stages and flows that would have occurred had the reservoirs been in existence at the time.

For all the sites listed in table 16 which are unaffected by flood-control reservoirs, as well as for all unmeasured sites within the report area where the drainage area is 10 square miles or more, estimates of the flood flow for any recurrence interval can be made from figures 20 and 21 which have been reproduced from a flood-frequency study made by the U.S. Geological Survey (Green, 1964). The mean annual flood at any site can be found from figure 20 where the drainage area is known. Flows for other recurrence intervals up to 100 years are the product of the mean annual flood and the appropriate ratios for any selected recurrence interval from figure 21.

For the Pawcatuck River at Westerly, Rhode Island and Yantic River at Yantic stream-gaging

Table 16.--Maximum flood of record and mean annual flood at stream-gaging stations in the lower Thames and southeastern coastal river basins, as observed, and as they might have been modified by flood control reservoirs constructed at a later date

Index no. (Pl. A)	Stream and place of measurement	Observed or modified by flood control	Drainage area (sq mi)	Period of continuous records	Maximum flood of record: Date	Maximum flood of record: Elevation (ft above M.S.L.)	Maximum flood of record: Flow (cfs)	Maximum flood of record: Flow (cfs per sq mi)	Maximum flood of record: Flow Ratio to mean annual flood	Mean annual flood: Elevation (ft above M.S.L.)	Mean annual flood: Flow (cfs)	Mean annual flood: Flow (cfs per sq mi)
1183	Pendleton Hill Brook near Clarks Falls	Observed	3.85	1958-65	9-21-61	157.8	240	62.3	1.41	157.2	170	44.2
1185	Pawcatuck River at Westerly, R.I.	Observed	295	1940-65	3-16-53	a/ 7.1	3,510	11.9	1.60	5.4	2,200	7.46
1187.5	Haleys Brook near Old Mystic	Observed	4.25	1961-65	3- 6-63	--	120	28.2	1.33	--	90	21.2
1190	Great Brook at Poquonock Bridge	Observed	14.3	1946-65	9-12-54	7.9	464	32.4	--	--	--	--
1271.49	Shetucket River at Greenville Dam at Norwich	Observed Modified b/	1,260	--	9-21-38	36.0 32.0	77,700 47,200	61.7 --	4.57 2.78	27.2 27.0	17,000 16,000	13.5 --
1274	Susquetonscut Brook at Yantic	Observed	15.4	1961-65	3-12-62	--	720	46.8	1.53	--	470	30.5
1275	Yantic River at Yantic	Observed	88.6	1930-65	9-21-38	109.1	13,500	152	5.40	102.8	2,500	28.2
1276.8	Trading Cove Brook near Montville Center	Observed	5.04	1963-65	1-25-64	--	166	32.9	--	--	--	--
1277	Trading Cove Brook near Thamesville	Observed	8.70	1960-65	3- 6-63	--	520	59.8	1.37	--	380	43.7
1277.5	Oxoboxo Brook at Montville	Observed	10.2	1963-65	1-25-64	--	268	26.3	--	--	--	--
1277.6	Hunts Brook at Quaker Hill	Observed	11.3	1963-65	4-15-64	--	190	16.8	.83	--	230	20.4
1278	Fourmile River near East Lyme	Observed	4.29	1960-65	3- 6-63	--	180	42.0	1.29	--	140	32.6

a/ Maximum elevation known was 13.2 ft above M.S.L. due to hurricane tidal wave September 21, 1938.

b/ Estimation of modification by storage in Mansfield Hollow, East Brimfield, Westville, Hodges Village, Buffumville, and West Thompson flood-control reservoirs had they been in operation at this time. Data furnished by the New England Division of the Corps of Engineers, U.S. Army.

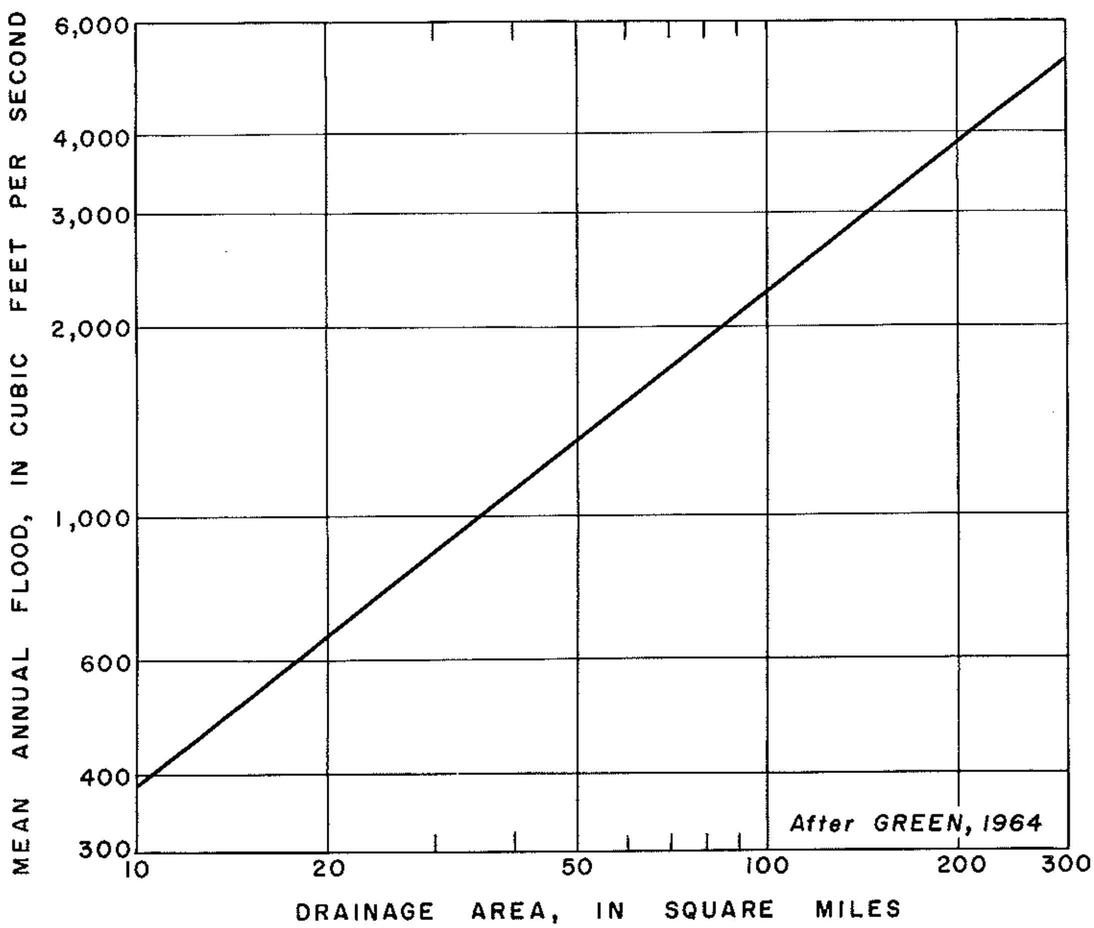
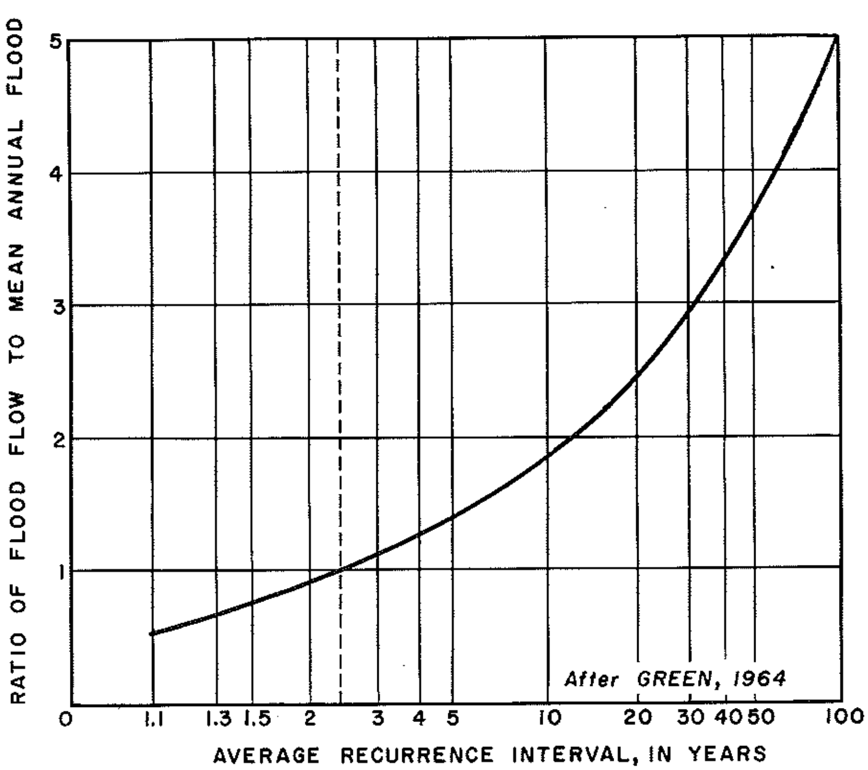


Figure 20.--Variation of mean annual flood with drainage area



Floods several times as large as the mean annual flood will occur at infrequent intervals. If the mean annual flood for any particular site is read from figure 20, this figure may be used to estimate how frequently flood flows as much as 5 times the mean annual flood may be expected at that site.

Figure 21.--Flood-magnitude frequency curve for the lower Thames and southeastern coastal river basins

stations, flood frequency tables for flood peaks (period of 0 consecutive days) are listed in table 17.

FREQUENCY AND DURATION OF HIGH FLOWS

The flood-frequency information in table 16 and figures 20 and 21 is presented in terms of the recurrence of instantaneous peak discharges. For some purposes, however, it is also useful to estimate how long periods of high flow may be sustained and how frequently these periods may recur. Table 17 presents the probable recurrence intervals of annual highest average flows for various periods at the Pawcatuck River at Westerly, Rhode Island and Yantic River at Yantic stream-gaging stations. For example, table 17 indicates that the highest average flow of the Yantic River at Yantic for a period of 30 days would be 740 cfs once in 10 years, on the average, and thus there is a 10 percent probability that 30-day average flows of this magnitude would occur in any one year. The peak flow recurring once in 10 years would be 4,600 cfs with the corresponding peak elevation of 104.7 feet. This flood peak would probably occur within the same 30-day period for which the estimated average flow is 740 cfs.

HURRICANES

Hurricanes, or tropical cyclonic storms, have affected the report area frequently in the past. The first New England hurricane of record occurred on August 15, 1635. Since the development of the Thames area, about 1660, several violent storms were recorded. The hurricanes of 1676, 1748, 1759, 1773, and 1788 were moderately severe; those of 1723 and 1770 approached the hurricane of 1635 in intensity. On August 23, 1786 there was an especially severe storm in New London.

The most disastrous storm of the 19th century occurred on September 23, 1815. This violent hurricane, combined with a much higher than normal tide, produced record high water in New London and Norwich.

History records several hurricanes of varying magnitude affecting the area during the next dozen decades, but none to equal that of 1815. Notable storms occurred in 1821, 1841, 1849, 1869, 1893, 1898, 1903, 1904, and 1927. The most severe of these was in 1893 when two August hurricanes, only five days apart, battered the Connecticut Coast.

Possibly the greatest catastrophe of the 20th Century thus far, in New England, was the disastrous hurricane of September 21, 1938. A much higher than normal tide, coupled with the storm surge, produced flood heights of 12 to 25 feet above mean low water along the eastern Connecticut shore to Rhode Island. More than 600 lives were lost and 1,700 people were injured. About 9,000 dwellings were totally destroyed and nearly 10 times as many were damaged. The total loss in southern New England, expressed in 1938 dollars, was about $300 million.

The next storm of this type occurred on September 15, 1944; however, the amount of damage and the number of deaths were much lower than in 1938.

After a lapse of 10 years, two major hurricanes hit the area only 11 days apart. Hurricane "Carol," on August 31, 1954, caused 60 fatalities and destruction of over 10,000 buildings and 3,000 boats. Total damage, in 1954 dollars, was about $460 million. Hurricane "Edna" occurred on September 11, and while it caused widespread damage, it amounted to about one half of that inflicted by "Carol."

In summary, hurricanes are not rare to the SCRBA. Statistical accounts since the first recorded New England hurricane of 1635 reveal that 5 to 10 hurricanes occur during a century, with one that is especially severe occurring in each century and a half.

QUALITY OF WATER IN STREAMS AND LAKES

NATURAL CONDITIONS

The chemical quality of stream water in the SCRBA under natural conditions is generally excellent as indicated by the chemical analyses of stream water summarized in table 18. The analyses represent samples collected at 24 sites shown in

Table 17.--Annual highest average flows and corresponding average elevations for indicated recurrence intervals at Pawcatuck River at Westerly, R.I. and Yantic River at Yantic

(Data for indicated recurrence intervals and indicated periods of consecutive days have been adjusted to the reference period October 1930 to September 1960.)

Index no (Pl. A)	Stream and place of measurement	Drainage area (sq mi)	Period (consecutive days)	Annual highest average flow (cfs) for indicated recurrence interval (years)							Annual highest average elevation (ft above M.S.L.) for indicated recurrence interval (years)						
				1.03	2	5	10	25	50	100	1.03	2	5	10	25	50	100
1185	Pawcatuck River at Westerly, R.I.	295	0	1,400	2,100	2,700	3,300	4,000	4,800	5,600	4.2	5.3	6.2	7.1	8.2	9.3	10.4
			1	1,300	2,000	2,600	3,100	3,900	4,600	5,400	4.0	5.1	6.0	6.8	8.0	9.0	10.2
			3	1,200	1,900	2,500	3,000	3,600	4,300	5,000	3.9	5.0	5.9	6.7	7.5	8.6	9.6
			7	1,100	1,700	2,300	2,700	3,400	4,000	4,600	3.7	4.7	5.6	6.2	7.2	8.2	9.0
			15	1,000	1,600	2,000	2,300	2,900	3,400	4,000	3.5	4.5	5.1	5.6	6.5	7.2	8.2
			30	900	1,200	1,600	2,000	2,400	2,800	3,400	3.4	3.9	4.5	5.1	5.7	6.4	7.2
			60	780	1,100	1,400	1,600	1,900	2,200	2,600	3.2	3.7	4.2	4.5	5.0	5.4	6.0
			150	620	840	1,000	1,200	1,400	1,600	1,800	2.9	3.3	3.5	3.9	4.2	4.5	4.8
			274	540	700	840	960	1,100	1,300	1,400	2.8	3.0	3.3	3.5	3.7	4.0	4.2
			365	500	640	760	860	1,000	1,100	1,200	2.7	2.9	3.1	3.3	3.5	3.7	3.9
1275	Yantic River at Yantic	88.6	0	1,200	2,300	3,400	4,600	6,600	9,000	12,000	100.7	102.5	103.7	104.7	106.0	107.2	108.5
			1	860	1,600	2,400	3,200	4,400	5,600	7,000	99.8	101.5	102.7	103.5	104.5	105.4	106.2
			3	620	1,100	1,600	2,100	2,800	3,600	4,500	99.1	100.4	101.5	102.2	103.1	103.9	104.6
			7	450	800	1,100	1,400	1,900	2,400	3,000	98.5	99.7	100.4	101.1	102.0	102.7	103.3
			15	340	600	820	1,000	1,300	1,600	2,000	98.0	99.0	99.7	100.2	100.9	101.5	102.1
			30	260	460	620	740	940	1,200	1,400	97.6	98.5	99.1	99.5	100.0	100.7	101.1
			60	200	360	470	540	670	820	1,000	97.3	98.1	98.6	98.8	99.2	99.7	100.2
			150	150	250	320	360	430	530	620	97.0	97.6	97.9	98.1	98.4	98.8	99.1
			274	120	200	250	280	320	400	460	96.8	97.3	97.6	97.7	97.9	98.3	98.5
			365	100	220	220	230	270	330	380	96.7	97.2	97.4	97.5	97.7	98.0	98.2

Table 18.--Comparison of chemical characteristics of water from representative streams in the lower Thames and southeastern coastal river basins under natural conditions at low and high streamflow

(From data presented in the companion basic data report by M. A. Cervione, Jr., and others, 1968)

(Chemical constituents in parts per million)

Constituent or property	Concentration in water samples collected at high flow (flow that was equaled or exceeded less than 5 percent of the time from 1930 to 1960) a/		Concentration in water samples collected at low flow (flow that was equaled or exceeded more than 90 percent of the time from 1930 to 1960) a/		Upper limit in drinking water, as recommended by U.S. Public Health Service (1962)
	Range	Average	Range	Average	
Silica (SiO_2)	--	--	b/3.6 - 16	10	--
Iron (Fe)	0.03 - 0.14	0.07	.15 - 1.3	.34	0.3
Manganese (Mn)	.00 - .03	.01	.00 - .34	.06	.05
Calcium (Ca)	2.2 - 8.9	5.0	3.2 - 16	8.1	--
Magnesium (Mg)	.5 - 1.9	1.0	.7 - 5.4	2.0	--
Sodium (Na)	2.5 - 9.8	3.9	3.6 - 7.5	5.1	--
Potassium (K)	.3 - 1.9	.9	.8 - 4.7	1.8	--
Bicarbonate (HCO_3)	2 - 12	7	7 - 36	20	--
Sulfate (SO_4)	8.6 - 22	13	9.0 - 28	16	250
Chloride (Cl)	3.1 - 9.2	5.5	4.4 - 16	7.4	250
Nitrate (NO_3)	--	--	c/ .0 - 8.0	2.6	45
Dissolved solids (calculated)	28 - 74	45	38 -150	79	500
Hardness as $CaCO_3$	9 - 30	17	14 - 62	28	--
Noncarbonate hardness as $CaCO_3$	6 - 20	11	4 - 33	13	--
Specific conductance (micromhos at 25°C)	41 -106	64	54 -215	113	--
pH	5.2 - 7.0	--	5.6 - 7.1	--	--
Color	--	--	c/ 3 - 35	9	15

a/ One sample from each of 24 sites.
b/ One sample from each of 21 sites.
c/ One sample from each of 20 sites.

figure 22 where waters are relatively unaffected by man's activities. Hardness of these samples ranged from 9 to 62 ppm, and dissolved solids ranged from 28 to 150 ppm. The general excellence of the chemical quality of these samples is emphasized by the contrast in table 18 between the maximum amounts of dissolved mineral constituents of samples and the limits of these constituents set by the U.S. Public Health Service (1962) for drinking water.

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

The degree of concentration of two relatively soluble chemical constituents, calcium and magnesium, determines the hardness of water. The average hardness shown in table 18 is 28 ppm. Water with a hardness of less than 60 ppm is considered soft.

In addition to being soft, waters that contain

E X P L A N A T I O N

Basin drainage divide

NUMBER OF SAMPLING SITE — 1183 $\frac{70}{39}$ — DISSOLVED-SOLIDS CONCENTRATION IN WATER AT LOW FLOW (PPM); DISSOLVED-SOLIDS CONCENTRATION IN WATER AT HIGH FLOW (PPM)

Area in which most wells tapping bedrock are likely to yield moderately hard to very hard water, and relatively large concentrations of dissolved solids.

Dissolved-solids concentrations at high flow were calculated from samples collected when streams within study area were flowing at an average rate exceeded only 5 percent of the time. Concentrations at low flow were calculated from samples collected when streams in the study area were flowing at an average rate exceeded 90 percent of the time.

Figure 22.--Areal variation in dissolved-solids content of naturally occurring stream water

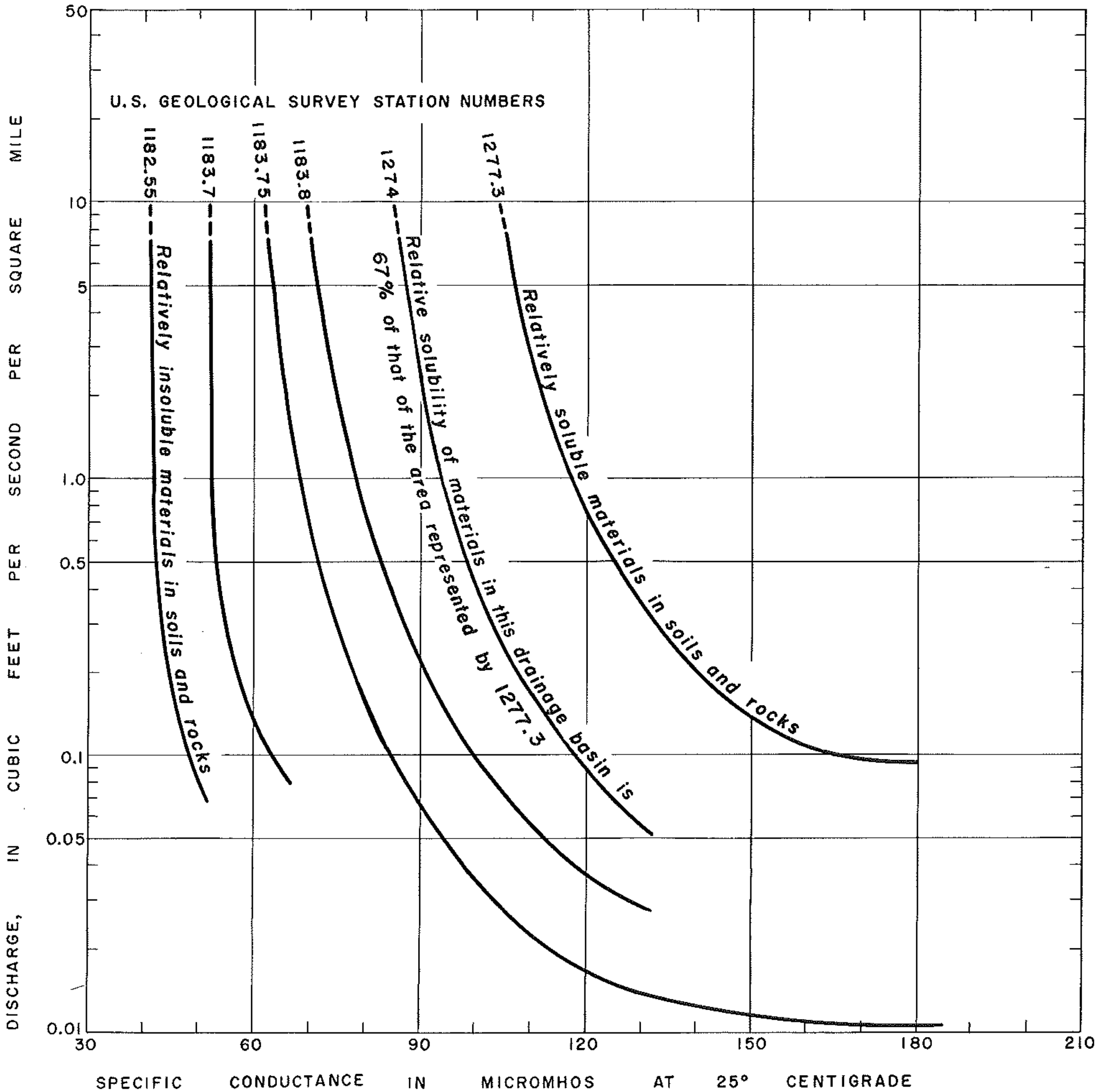


Figure 23.--Relation between specific conductance, runoff, and relative amount of soluble material in the soil and rocks of a drainage basin

Dissolved solids represented by specific conductance varies with amount of total runoff and relative amount of soluble materials in soil and rocks through which the ground-water portion of the runoff has passed.

few dissolved minerals are generally low in alkalinity. Low alkalinity, in the presence of dissolved carbon dioxide and organic acid results in slightly acidic waters as are generally found in the SCRBA. Water of this type may be corrosive at times to some metals.

The dissolved-solids concentration of stream water varies with the rate of streamflow. When streamflow is high the concentration of dissolved solids is relatively low as shown in table 18 and also in figure 22. The remarkably uniform and low concentration of all mineral constituents in these samples indicates that the chemical quality of water in streams at high streamflow represents chiefly the quality of precipitation.

The dissolved-solids concentration at low streamflow ranged from 38 to 150 ppm as shown in table 18 and on figure 22. At all sites the dissolved-solids concentration of water in the streams is greater at low streamflow than at high streamflow. Silica, which makes up more than 50 percent of the chemical composition of the rocks of the SCRBA, is a relatively minor constituent at high flow, but averages about 15 percent of the dissolved-solids concentration at low flow. The changes in silica and dissolved-solids concentration result from the presence of relatively large proportions of ground water in the stream channels during periods of low streamflow. Even under low-flow conditions, however, it is important to note that half of the streams contained less than 75 ppm dissolved solids.

The chemical quality of the stream water represents an integration of the quality of ground-water runoff from the basin upstream and the quality of the water in the stream channel. The types and amounts of the minerals in solution in ground-water runoff vary from place to place throughout the SCRBA depending upon the types of geologic environment through which the water passed. The area where ground water has the most effect on the chemical quality of stream water is shown as stippled area on figure 22. The dissolved-solids concentration and hardness of stream water in these portions of the SCRBA are relatively much higher than elsewhere, chiefly as a result of the presence of calcium silicate minerals in the rocks.

The amounts and character of the minerals present in the soil and rocks in the basin upstream from any site determine a specific curve of relationship between the flow of the stream and its dissolved-solids concentration for that particular site. Curves for all sites in a region having the same soluble minerals should be similar in shape, and the curves should theoretically diminish to a common lower specific conductance at a very high rate of runoff when the source of the water is entirely rainfall.

Figure 23 shows very clearly the relationship between discharge and specific conductance caused by difference in relative solubility of minerals in the soils and rocks in any drainage basin. The curve of lowest specific conductance is for site 1182.55 where ground-water runoff is from bedrock and unconsolidated deposits composed of generally insoluble minerals. Contrasted to this curve is the curve of highest specific conductance for site 1277.3 where the source of ground water is from materials with relatively soluble minerals such as calcium silicates. If both or each of these curves represent areas which are geologically homogeneous, then all similar curves shown between then on figure 23 represent various proportions of soluble and non-soluble source materials. For example, the curve for site 1274 represents the relationship of specific conductance to unit runoff for a drainage area in which the solubility of the source materials is 2/3 or 67 percent of that of the curve farthest to the right.

Though it is believed that the influence of the quality of ground-water runoff upon the relative position of each curve in the array is predominant, other factors such as the variances in type and chemical concentration of precipitation and dry fallout, and land use, also affect the relationship.

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

Chemical quality of samples from some of the lakes, ponds, and reservoirs at their outlets in the SCRBA are included in the companion basic data report by M. A. Cervione, Jr. and others (1968). The chemical quality of these bodies of water is generally excellent, and most are unaffected by man's activities. The dissolved-solids concentration is generally less than 60 ppm, the hardness less than 40 ppm, and the waters are slightly acidic.

In bodies of quiet water, such as lakes and reservoirs, thermal gradients may exist between top and bottom, and bottom temperature may depart considerably from air temperature. Temperature changes and stratification follow a seasonal pattern. Figure 24 is a diagram of the typical seasonal patterns that can occur in standing water bodies. In summer, the warmer water is near the surface (epilimnion), and in the middle zone (thermocline) temperature decreases with depth, and in the lower zone (hypolimnion) there is little circulation, and

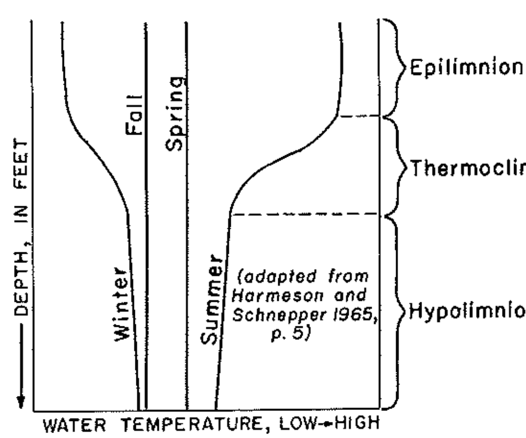


Figure 24.--Seasonal temperature variations in lakes and reservoirs

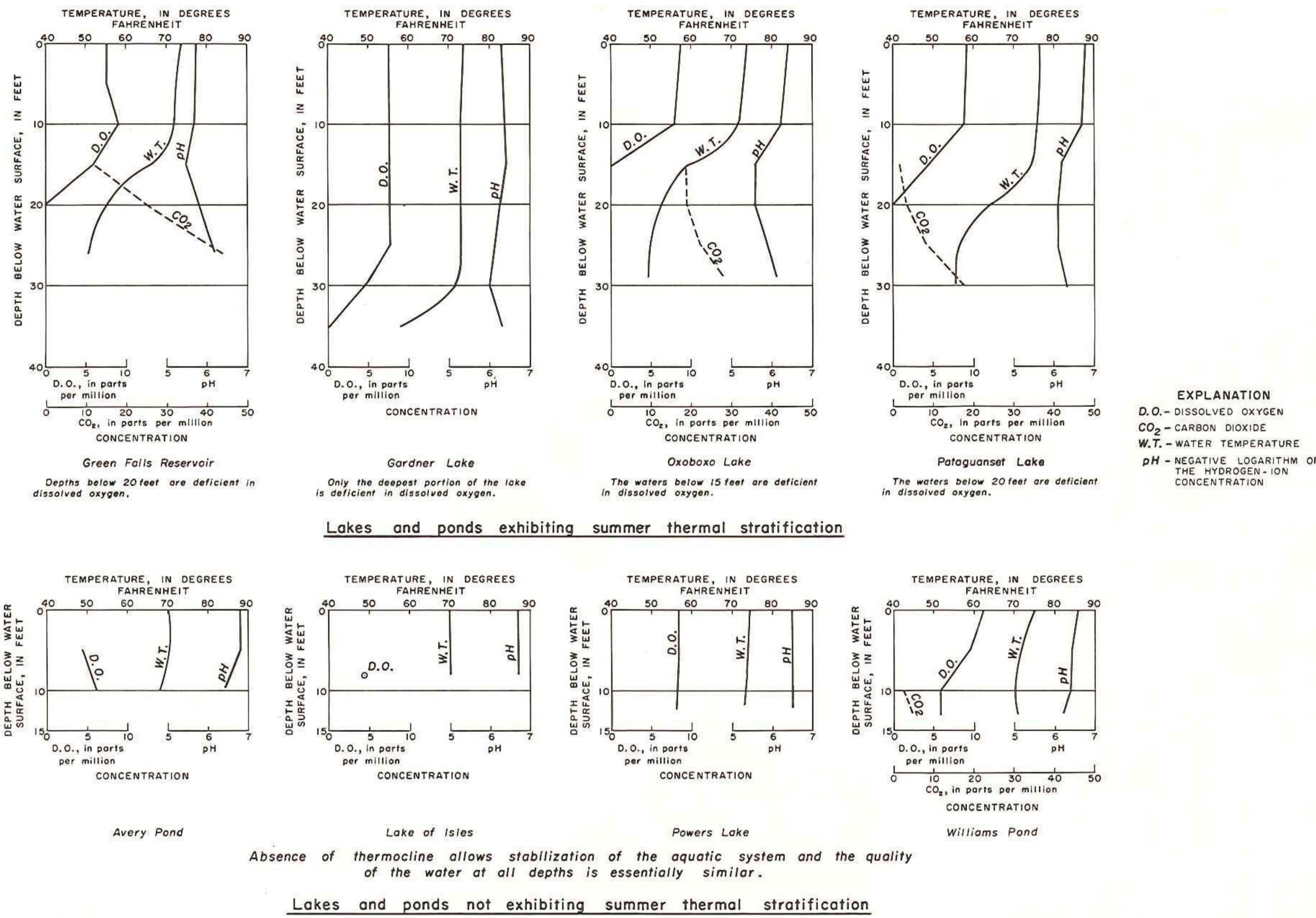


Figure 25.--Vertical profiles in selected lakes and ponds

Carbon dioxide, dissolved oxygen, pH, and temperature gradients during the summer of 1954. Upper portion of illustration represents summer stagnation in which depleted dissolved oxygen below the thermocline adversely affects the aquatic environment. (Data from Connecticut Board of Fisheries and Game)

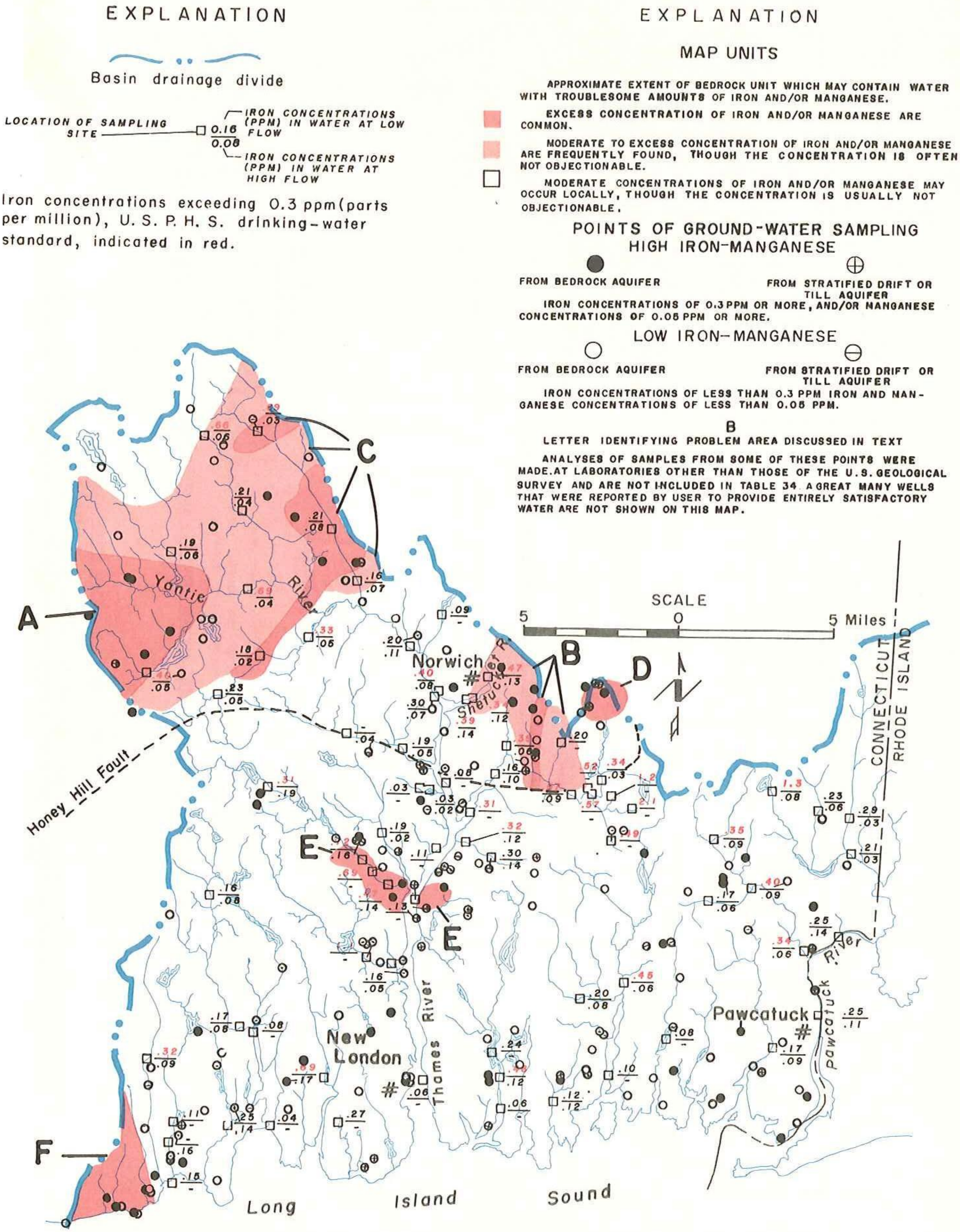


Figure 26.--Seasonal variations of iron in surface waters and areal distribution of iron concentrations in ground water

the temperature approaches uniformity. In the fall the surface temperature drops until the lake is nearly uniform from top to bottom and mixing occurs again. As the surface temperature continues to rise, the summer stratification pattern develops and the cycle begins again.

The relationship of water temperature, pH, dissolved-oxygen content, and carbon dioxide (CO_2) content to depth of water is shown in figure 25 for a few selected lakes and ponds in the SCRBA from data collected by the Connecticut Board of Fisheries and Game in 1954. The data plotted in the upper portion of figure 25 show the characteristic summer stagnation, where high air temperature warmed the water in the upper part of the surface-water bodies, while the water in their lower depth was largely unaffected causing stratification. The gradients, in the upper portion of figure 25, are largely caused by diffusion of atmospheric air at the air-surface water interface, photosynthesis by certain types of biota in regions of light penetration, respiration of plants and animals and carbon dioxide given off by decaying matter in the lower depths. The period of spring and autumn mixing breaks up the gradients and brings about a relatively even distribution of all dissolved materials in the water body. The Connecticut Board of Fisheries and Game (1959) reports that portions of Amos Lake, Gardner Lake, Green Falls Reservoir, Lantern Hill Pond, Long Pond, Oxoboxo Lake, Pataguanset Lake, and Wyassup Lake are thermally stratified.

Oxoboxo Lake, figure 25, is stratified. From the surface to about 10 feet, temperature changes little with depth. Between 10 and 20 feet, the temperature drops rapidly. The region of the lake below 20 feet is rather uniformly cool. The gradual establishment of thermal stratification deprives the lower depths of its oxygen source. Dissolved oxygen is the most significant of all the chemical substances in the natural waters of lakes and ponds as an indicator of lake conditions. Figure 25 shows for Oxoboxo Lake that the dissolved oxygen concentration diminishes rapidly with depth in summer. This summer depletion is of overriding importance in its effect on aquatic life. When it occurs it brings on major ecological changes.

The dissolved-oxygen content of water is inversely related to temperature. At 34°F the saturation value for dissolved oxygen is 14 ppm, at 80°F the saturation value is less than 8 ppm. Aquatic life may be able to adjust to the warmer waters, but it can be destroyed by the lack of dissolved oxygen. Within the thermocline there is a sharp drop in dissolved oxygen and a rise in the concentration of the gases resulting from decomposition of aquatic biota. Below the thermocline the concentration of dissolved oxygen reaches a minimal value (often zero), that of gases of decomposition a maximum one. The carbon dioxide concentration shows a general inverse relationship to the dissolved oxygen curve, that is, the concentration of carbon dioxide increases with depth.

During the spring and fall overturn, the pH of the water generally is uniform from surface to bottom. Iron, manganese, color, and turbidity may increase. Oxidation-reduction processes are triggered by dissolved oxygen and cause the precipitated iron and manganese to dissolve during overturn. Thus during overturn a vertical mixing of the waters results in a deterioration in quality.

IRON AND COLOR

Iron, though only a small part of the dissolved solids in stream water in the SCRBA, deserves special discussion because it is present in amounts large enough to be troublesome. An iron content of 0.3 ppm or more is objectionable for domestic uses, and it should be less than 0.2 ppm for many industrial uses. Iron in surface waters is derived from minerals of rocks and soils in the SCRBA or from decaying vegetation.

Streams draining swamps usually contain water with a high iron concentration. All growing aquatic plants require a continuous supply of iron and extract it from water and soil. The decay of the aquatic vegetation releases dissolved iron to the swamp water. During this decaying period, the volume of water in the swamp is generally reduced and the iron concentration in the remaining water is increased. The largest quantity of organic matter and iron from swamps enters streams during periods of heavy rainfall when swamps are flushed out, though the concentration of iron is considerably reduced by dilution.

About 70 percent of the 24 samples summarized in table 18 for streams essentially unaffected by man's activities had water containing more than 0.2 ppm iron at low flow and about 40 percent were more than 0.3 ppm. All water samples collected during low streamflow periods, having excessive iron concentrations, originate in iron-bearing ground-water areas locally present throughout the SCRBA, as shown in figure 26, and from drainage of numerous swamps. At high streamflows following the winter period, only a few of the sampling sites yielded samples containing the high iron concentration.

To show the effect of swamp environment on the iron concentration of stream water, several water samples were collected in and near Cedar Swamp near Shewville. The results are shown in figure 27. Sampling during the April high streamflow period indicated that the water entering and leaving Cedar Swamp contained a very low concentration of iron. The July sampling shows a four-to-ten-fold increase in iron concentration during the period of decay of swamp vegetation.

Iron and manganese precipitates also accumulate in the sediment and mud of lake and pond bottoms. During the early stages of turnover these two constituents redissolve from bottom sediments, circulate upwards and remain in solution until oxidation and precipitation transfer them downward again. The increase and decrease in concentration of these two constituents roughly parallels the decrease and increase in dissolved oxygen. Thus the outflow from these lakes and ponds will transport the redissolved iron and manganese and affect the quality of streams fed by these water bodies. This may account for the 1.3 ppm iron concentration in the outflow from Wyassup Lake in the September 1963 sample, shown on figure 26.

The upper reaches of most streams are characterized by clear waters, at least during the non-flood season. Relatively "pure" shallow streams appear clear due, in part, to the fact that light is absorbed quite rapidly in the first few feet. Small shallow streams which drain swamps are often colored light to dark amber. This color is probably attributable to the decaying organic material which

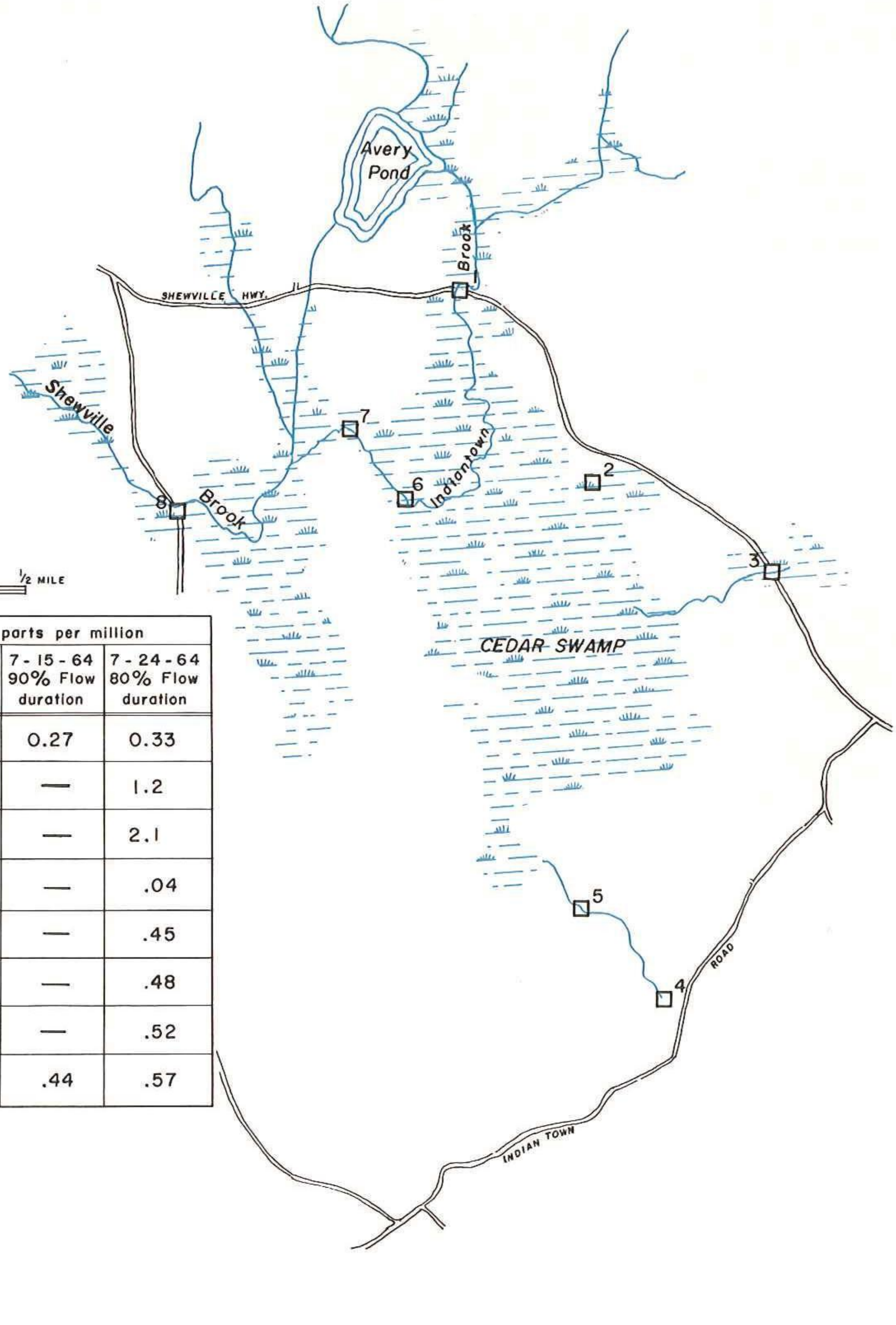
EXPLANATION

SWAMP AREA

□2
WATER-QUALITY SAMPLING SITE

Scale

0 ½ MILE



Site Number	Site Description	IRON, in parts per million 4-9-64 2% Flow duration	7-15-64 90% Flow duration	7-24-64 80% Flow duration
1	*Indiantown Bk.*	0.03	0.27	0.33
2	*Within Cedar Swamp*	—	—	1.2
3	*Stream adjacent to swamp*	—	—	2.1
4	*Spring (Ly Isp)*	—	—	.04
5	*Tributary to Cedar Swamp*	—	—	.45
6	*Indiantown Bk.*	—	—	.48
7	*Indiantown Bk.*	—	—	.52
8	*Shewville Bk.*	.09	.44	.57

Figure 27.--Dissolved-iron concentrations in water in and near Cedar Swamp

Water draining from swamp is likely to contain higher concentrations of dissolved solids than water entering the swamps, at both high and low streamflow. The iron concentrations in swamp water commonly increase severalfold during decay of aquatic vegetation.

releases dissolved plant substances such as tannin. Iron may be a significant constituent of organic color in water, but the concentration of iron does not necessarily correlate with the degree of organic color. Other streams may be colored in the autumn due to extractives from large accumulations of leaves in the water. Various extrinsic factors may also account for apparent color in streams, such as diatoms and algae. Color decreases during periods of high streamflow. One of the 24 samples of water summarized in table 12, had color as high as 35 units; the average was 9, about half the upper limit of 15 recommended by the U.S. Public Health Service (1962) for drinking water. Color as high as 188 has been observed in water associated with swamps in the SCRBA.

SALT WATER EXTENT IN STREAMS AND ESTUARIES

The southern boundary of the SCRBA forms an irregular coastline characterized by many inlets, coves, extensive tidal marshes, meadows, wetlands, and coastal streams discharging to Long Island Sound. The most prominent feature is the Thames River Estuary.

The coastal area is exposed to a twice-a-day tidal surge up the lower reaches of streams and rivers. In the Thames River the effects of the tides extend as far inland as the Shetucket and Yantic Rivers. The extent of tidal movement of sea water in an estuary or coastal stream is dependent on a number of factors, some of which are fresh-water flow, range and stage of tide, climatological and wind conditions, and man-made obstructions. In late summer and early fall, fresh-water flow is usually at a minimum, and the mean sea level for the period, which controls the movement of sea water into the estuary, is at a maximum. These conditions favor the movement of sea water upstream. During the spring, fresh-water flow increases to the maximum and the sea water recedes downstream.

Sea water from Long Island Sound is carried upstream in the estuaries and coastal streams by each flood tide and downstream by each ebb tide. Such tidal movements into the estuaries are accompanied by the continuously changing concentrations of dissolved solids and proportions of mineral constituents in the zone where sea water mixes with the fresh-water flow from the coastal streams.

Figure 28 shows the maximum extent of sea water influence on the chemical character of water in the SCRBA. Sea water movement in coastal streams and estuaries is halted in some cases by man-made dams, by the steep seaward slope of some coastal streams, or by natural rapids or riffles in the stream channel.

The general chemical composition of rivers and estuaries affected by sea water is shown in table 19, and the sampling sites are located on figure 28. Samples were collected in September 1963 during the minimum fresh-water flow period to illustrate the maximum concentration of chemical constituents at the farthest upstream influence of sea water. Significant sites were sampled again during the following April when fresh-water flow was at a maximum. Analyses from Long Island Sound, the Atlantic Ocean, and general composition of sea water (Hem, 1959, p. 10) were also added to table 19 so that the chemical quality of these waters may be compared to the composition of sea water.

The data indicate that there is very little dilution in the chemical composition by the fresh-water flow in September between the head of the tide and the mouth of either the Mystic or Niantic Rivers. The fresh-water streams in these areas were at 90 percent flow duration or greater.

The most important waterway in the SCRBA is the Thames River estuary. It is fed by numerous small streams in its 14 mile course from Norwich to Long Island Sound. Two major streams, the Shetucket River and the Yantic River, converge to form the Thames River at Norwich. They are both affected by tidal surges of sea water up the Thames River estuary. From the tidal basin at Norwich to the mouth at Groton the general composition of the estuary water is shown in table 19 to be relatively similar and varies from 22,000 to 30,000 ppm dissolved solids. "Pure" sea water contains approximately 35,000 ppm dissolved solids. The dilution of sea water by fresh-water inflow can be determined by comparing the dissolved-solids concentration of the estuary to that of sea water. In the area of Fort Shantock State Park the estuary is 67 percent sea water, and increases to 87 percent sea water at Groton. Long Island Sound in the vicinity of Rocky Neck State Park is approximately 92 percent sea water.

The waters of the Thames River estuary are usually of high salinity throughout the year, ranging from nearly "pure" sea water in the Groton-New London area to diluted sea water at the tidal basin at Norwich. Although fresh water may extend into the Norwich tidal basin at times of high fresh-water flow after heavy rains in the spring, the duration of the fresh-water conditions in the tidal basin is relatively short. The waters in the estuary are generally less subject to sudden changes in salinity than are those in the lower reaches of the river and tributary streams.

There is a fresh water-sea water interface in the lower portions of both the Yantic and Shetucket River above the tidal basin at Norwich during the low fresh-water inflow period. The data in table 20 indicate that the fresh water enters a transition zone in both rivers before flowing into the tidal basin. During the low-flow period in September 1963 the chemical composition of the Yantic River in the transition zone ranged from 33 percent sea water near the surface to 80 percent sea water near the streambed. In the SHetucket River the range was from 12 percent near the surface to 84 percent near the streambed. Samples from April 1964 indicate that the sea water is pushed out of each river mouth during the high flow period.

CONDITIONS RESULTING FROM THE ACTIVITIES OF MAN

Man uses water for various domestic and industrial needs. During its use, the quality of the water is almost always changed. After use the water contains more dissolved solids or is warmed or cooler than before. Most of the major streams in the SCRBA, and a few smaller streams receive varying amounts of waste materials. Industrial and commercial wastes discharged into the streams and estuaries of the area include cyanides, copper, nickel,

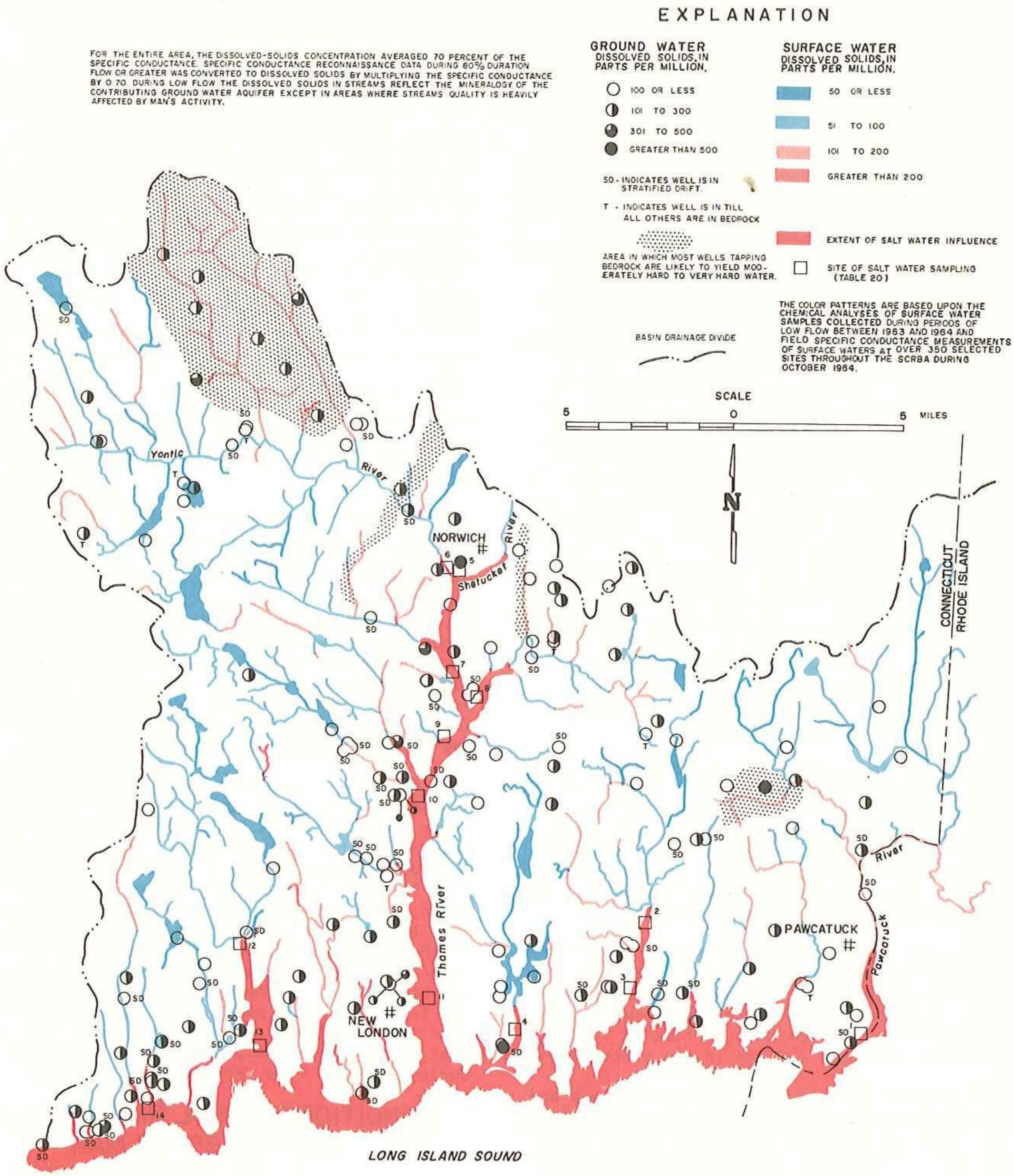


Figure 28.--Maximum observed concentration of dissolved solids in surface and ground waters in the lower Thames and southeastern coastal river basins

Table 19.--Chemical composition of selected coastal streams and estuaries influenced by sea water invasion

(Chemical constituents in parts per million)

Site no. (location in figure 28)	Source	Date of collection	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Sulfate (SO_4)	Chloride (Cl)	Dissolved solids (residue on evaporation at 180°C)
1	Pawcatuck River near Pawcatuck	9-24-63	268	780	7,160	1,670	12,900	24,800
2	Mystic River at Old Mystic	9-24-63	330	1,000	8,700	1,750	15,900	30,200
3	Mystic River at Mystic [1]	9-26-63	347	1,000	9,620	2,210	16,500	31,600
	do [2]	9-26-63	351	1,140	9,520	2,330	16,700	31,400
4	Poquonock River at Poquonock Bridge	9-24-63	329	960	9,100	2,140	16,000	30,700
5	Shetucket River at Norwich [1]	9-26-63	68	142	1,310	340	2,280	4,370
	do [2]	9-26-63	330	990	8,730	2,160	15,600	29,500
	do [1]	4- 9-64	5.6	1.0	4.8	12	7.2	53
6	Yantic River at Norwich [1]	9-26-63	135	430	3,280	785	6,070	11,600
	do [2]	9-26-63	312	977	8,350	2,020	14,700	28,000
	do [1]	4- 9-64	7.0	2.1	4.2	12	8.1	55
7	Thames River at Fort Shantock State Park	9-25-63	252	810	6,780	1,560	12,200	23,600
8	Poquetanuck Cove at Happyland [1]	9-24-63	254	820	6,820	1,590	12,400	23,500
	do	9-24-63	293	923	7,870	1,910	13,700	26,100
9	Thames River at Massapeag	9-25-63	239	740	6,180	1,490	11,500	21,900
10	Thames River at Gales Ferry	9-26-63	281	940	7,480	1,740	13,400	25,000
11	Thames River at Groton	9-24-63	328	1,000	9,020	1,970	15,800	30,300
12	Niantic River near East Lyme	9-25-63	297	830	7,940	1,870	13,800	27,100
13	Niantic River at Niantic	9-25-63	350	1,100	9,270	2,090	16,800	32,300
14	Long Island Sound near Niantic	9-25-63	347	1,130	9,670	2,250	16,900	32,100
	Atlantic Ocean at Atlantic Beach, N.Y.	4-18-56	351	1,190	9,520	2,290	17,200	33,500
	Atlantic Ocean at Montauk Point, N.Y.	1-19-61	356	1,160	9,470	2,390	17,100	32,500
	General composition of sea water [3]	--	400	1,272	10,560	2,560	18,980	35,000

1 Sample collected 1 foot below water surface.

2 Sample collected 1 foot off bottom of streambed.

3 After J. D. Hem, 1959, U.S. Geol. Survey Water-Supply Paper 1473, p. 10.

Table 20.--Comparison of chemical composition of fresh and salt water in the Shetucket and Yantic Rivers at Norwich during high and low fresh-water flow

(Chemical constituents in parts per million)

Source and location	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Chloride (Cl)	Dissolved solids (ROE at 180°C)
	LOW FRESH-WATER FLOW--September 26, 1969				
Shetucket River at Smith Avenue Bridge	8.3	3.5	14	12	79
Shetucket River at Route 12 Bridge [1]	68	142	1,310	2,280	4,370
Do [2]	330	990	8,730	15,600	29,500
Yantic River at New London Turnpike Bridge	9.8	1.6	5.8	10	67
Yantic River at Route 32 Bridge [1]	135	430	3,280	6,070	11,600
Do	312	977	8,350	14,700	28,000
	HIGH FRESH-WATER FLOW--April 9, 1964				
Shetucket River at Smith Avenue Bridge	5.8	1.1	4.8	7.2	44
Shetucket River at Route 12 Bridge	5.6	1.0	4.8	7.2	53
Yantic River at New London Turnpike Bridge	5.9	1.1	3.8	6.5	55
Yantic River at Route 32 Bridge	7.0	2.1	4.2	8.1	55

1 Sample collected 1 foot below water surface.
2 Sample collected 1 foot off bottom of streambed.

chromium, bleaches, dyes, soap, silt, acids, and alkalis. Organic wastes, including pulp fibers, starch, grease, oil, and domestic sewage are also present. Certain pollutants in streams, such as detergents, dyes, pulp and paper wastes, and salts of metals are objectionable even in small amounts since they may impart color to the water, cause toxicity to animal and aquatic life, or otherwise make the water unsuitable for use.

The relatively low dissolved-solids concentration of stream waters throughout the SCRBA, even at low flows, is illustrated in figure 28. The maximum dissolved-solids concentration at nearly all points in the SCRBA is markedly less than the 500 ppm suggested by the U.S. Public Health Service for potable water supplies. Masselli and others (1963) found that streams which receive white-water wastes from paper and paperboard production during drought conditions may at times contain dissolved solids in excess of 500 ppm. This condition might occur in Oxoboxo Brook along its lower reaches. A number of areas associated with drainage from swamps, stagnant ponds or highway runoff contained water that exceeded 200 ppm dissolved-solids concentration and in some instances over 600 ppm dissolved solids. One area located in Montville contained drainage with a dissolved-solids concentration in the order of 2,000 to 4,000 ppm. A number of industrial plants in SCRBA center around or on estuaries, and their treated or untreated waste products were discharged to the estuarine water during the period of study.

An example illustrating the change in chemical constituents, resulting from discharge of industrial waste effluent in Oxoboxo Brook, from Oxoboxo Lake to Uncasville is shown in figure 29. At time of sampling during the low-flow period a four-fold increase in dissolved solids along the stream was observed. The pattern diagrams illustrate the significant increases in concentrations of calcium, sodium, and sulfate. The decrease in dissolved-solids concentration in the lower reaches of Oxoboxo Brook is a result of a number of factors, such as dilution through increase in water volume, and storage and settling in ponded areas of the brook. The waste effluent also causes an increase in the acidity of the water in the receiving stream, until neutralization occurs in the lower reaches.

Pollution of natural waters by domestic sewage is a possible hazard to public health and safety and may stimulate undesirable growth of algae and other aquatic plants in both flowing and impounded surface waters. The presence of sewage in streams may sometimes be indicated by small amounts of detergents which cause white foam to develop on the surface of water in streams, particularly below mill dams or rapids. High concentrations of organic matter from sewage or from natural sources also may develop foam. This foam rapidly disappears in quiet waters below dams or rapids.

The upper limit for ABS (alkyl benzene sulfonate) concentration in drinking water is 0.5 ppm as recommended by the U.S. Public Health Service. Since July 1965, a new detergent material LAS (linear alkylate sulfonate), a principal constituent of soft detergents, has gradually replaced ABS. Detergent residues of LAS are more readily bio-degradable than

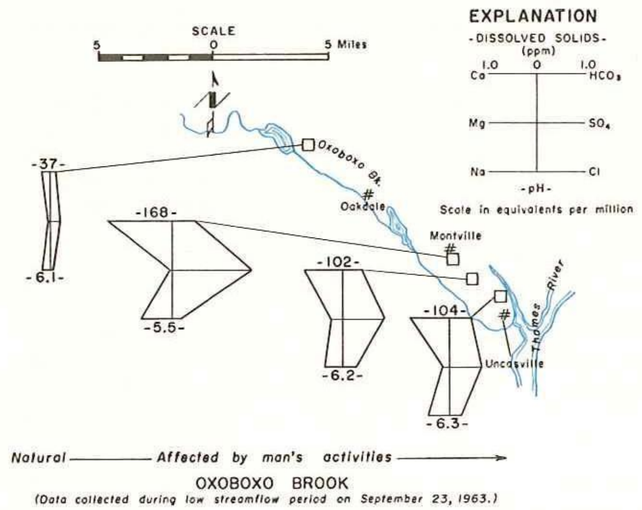


Figure 29.--Effect of waste effluent on the water quality of Oxoboxo Brook

Chemical constituents increased from natural concentrations due to industrial waste discharged to the brook. Decrease in lower reaches is a result of storage and settling in ponded areas of the brook.

those of ABS and can be reduced but not eliminated by secondary sewage treatment (Wayman, 1965).

According to a report for the Southeastern Connecticut Regional Planning Agency by Metcalf & Eddy, (1965) about 51 percent of the population residing in the Planning Region (including essentially all of the area covered by this report) is served by sewage systems that are classified either as municipal, community, or institutional. The domestic sewage from approximately 20 percent of the population is discharged without treatment into the waters of the Planning Region. Of the known industrial and commercial wastes discharged daily into the fresh waters and coastal estuaries of the Planning Region, approximately 49 percent is discharged directly into the waters without treatment or with inadequate primary treatment. With the enactment of Public Act No. 57 in 1967, the State has charged the Water Resources Commission with the fulfillment of policies more explicit in the prevention, control, and abatement of new and existing pollution of all natural waters in the State. The Commission can provide current information at any time on the extent and effect of pollution in the State.

SEDIMENT AND TURBIDITY

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

In the glaciated crystalline uplands of eastern Connecticut, erosion rates and suspended-sediment concentrations in streams are comparatively low. More sediment is present at high flows than at low flows. Even at high flow the amount of suspended sediment in streams of the report area is quite low, as shown in table 21 from results of analyses of samples from seven streams. The flow at times of sampling was the third highest peak during the 1965 water year.

Turbidity, a measure of the ability of water either to transmit or reflect light is caused by suspended or colloidal silt or clay particles, micro-organisms, pulp fibers, or other material originating in the natural process of erosion, or in sewage. Turbid water is objectionable for many industrial uses, notably for use by the food industry, the paper industry, and the textile industry, and large amounts may injure fish and other aquatic life.

The data in table 21 suggest that turbidity in the SCRBA is generally not potentially troublesome, except in the local area along the lower reaches of Oxoboxo Brook where a sample was found to contain 40 ppm (as silica) caused by industrial wastes.

TEMPERATURE

Temperature is probably one of the most important, but least discussed, factors of water quality. The temperature of water in streams and lakes changes continuously and varies in a complex fashion from place to place. Temperature patterns are, therefore, difficult to describe in detail, but the major features can be outlined.

Temperature influences, usually directly, all the chemical, physical, and biological properties of water. The ability of water to dissolve or precipitate materials is dependent upon temperature, and the aquatic life of a lake or stream may thrive or die because of the temperature. Natural stream temperatures are controlled largely by air temperature, solar radiation, and temperature of groundwater runoff.

The temperature of all surface-water bodies follows a seasonal cycle in response to air temperature. Freezing-point temperature is reached or nearly reached in most streams during the winter months, at least for brief periods of time. Maximum temperatures commonly occur in July and August. These conditions are reflected in the average temperature of the water in the Yantic River at Gilman from October 1964 through September 1965 as shown in figures 30 and 31.

The maximum and minimum water-temperature duration curves for the Yantic River (figure 31) show a narrow range in extremes. The annual extremes for the river during this period were 83°F and 33°F; however, the stream temperatures reached the 32°F point at the uppermost surface layer for a short period of time during the winter months. The maximum water temperature was 70°F or less, 70 percent of the time and figure 30 also shows that the median (50 percent) temperature of the stream closely approximates the average annual air temperature for the SCRBA.

During the 1965 water year figure 32 shows the water temperature for the Yantic River to be very similar to the water temperature of the Quinebaug River at Jewett City, where a continuous record is kept. Accordingly, the continuous thermograph at Jewett City may be used as an approximate index of temperature of related natural streams in the SCRBA. Records published in an annual series of Water Resources Data for Connecticut and current information may be obtained from the Hartford, Connecticut office of the U.S. Geological Survey.

In many smaller streams, a considerable portion of flow is ground-water runoff that entered the stream channel from the basin a short distance upstream and has not been in contact with the air. By contrast, in the major streams most of the water has been flowing in stream channels for some distance, and may have been detained in one or more ponds. Therefore, because ground water enters streams at relatively uniform temperatures, daily temperature fluctuations and the annual range in monthly average temperatures are probably somewhat less in small streams than in major rivers.

Table 21.--Analyses of suspended-sediment and turbidity at miscellaneous stream-gaging stations in the lower Thames and southeastern coastal river basins

Index no. (Pl. A)	Source and location	Date of collection	Instantaneous flow (cfs)	Percent of time flow is equaled or exceeded	Sediment concentration (ppm)	Measured load (tons/day)[a]	Turbidity (as ppm SiO_2)
1183	Pendleton Hill Brook near Clarks Falls	4-16-65	45	1	2	0.2	20
1184	Shunock River near North Stonington	4-16-65	78	9	22	4.6	13
1187	Whitford Brook at Old Mystic	4-16-65	62	8	3	.5	0
1276.8	Trading Cove Brook at Montville Center	4-16-65	24	7	8	.5	5
	do	4-16-65	26	6	8	.6	7
1277	Trading Cove Brook near Thamesville	4-16-65	40	7	10	1.1	5
1277.4	Stony Brook near Uncasville	4-16-65	40	5	18	1.9	5
1277.9	Latimer Brook at East Lyme	4-16-65	160	1	12	5.1	7
1278	Fourmile River near East Lyme	4-16-65	35	2	2	.2	7

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

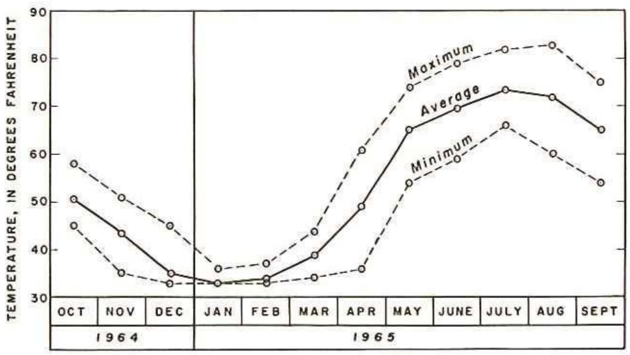


Figure 30.--Monthly water temperatures of the Yantic River at Gilman, 1965 water year

The temperature of the Yantic River fluctuates seasonally. The highest, lowest, and average water temperatures in the Yantic River at Gilman for each month were determined from continuous temperature measurements obtained about ½ foot above the river bottom.

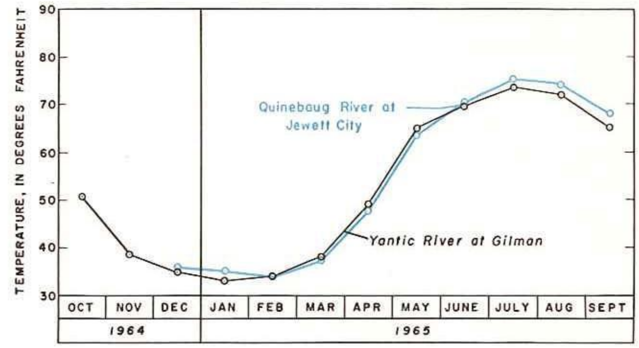


Figure 32.--Comparison of average monthly water temperatures of the Yantic River at Gilman to the Quinebaug River at Jewett City, 1965 water year

During this period there was generally only a few degrees difference in the water temperature between the two sites.

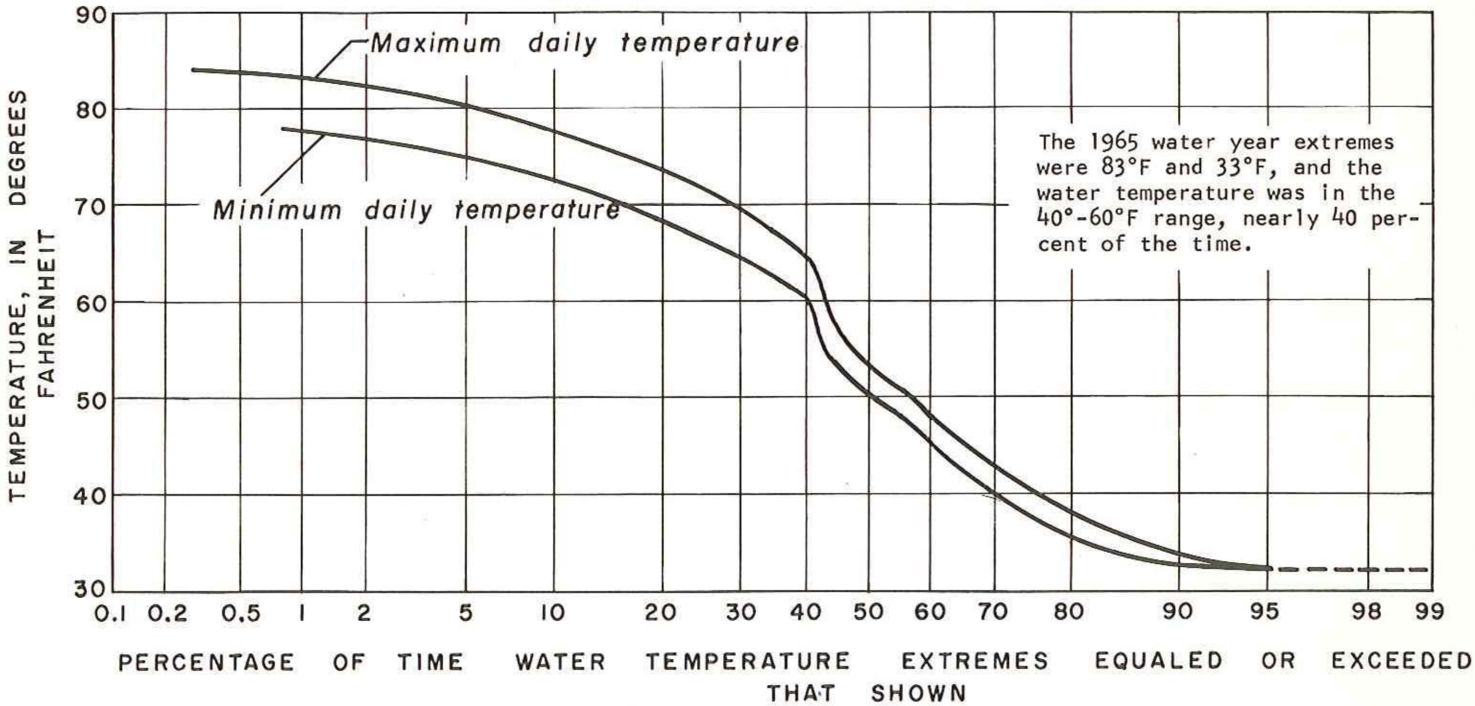


Figure 31.--Temperature-duration curve, Yantic River at Gilman, 1965 water year

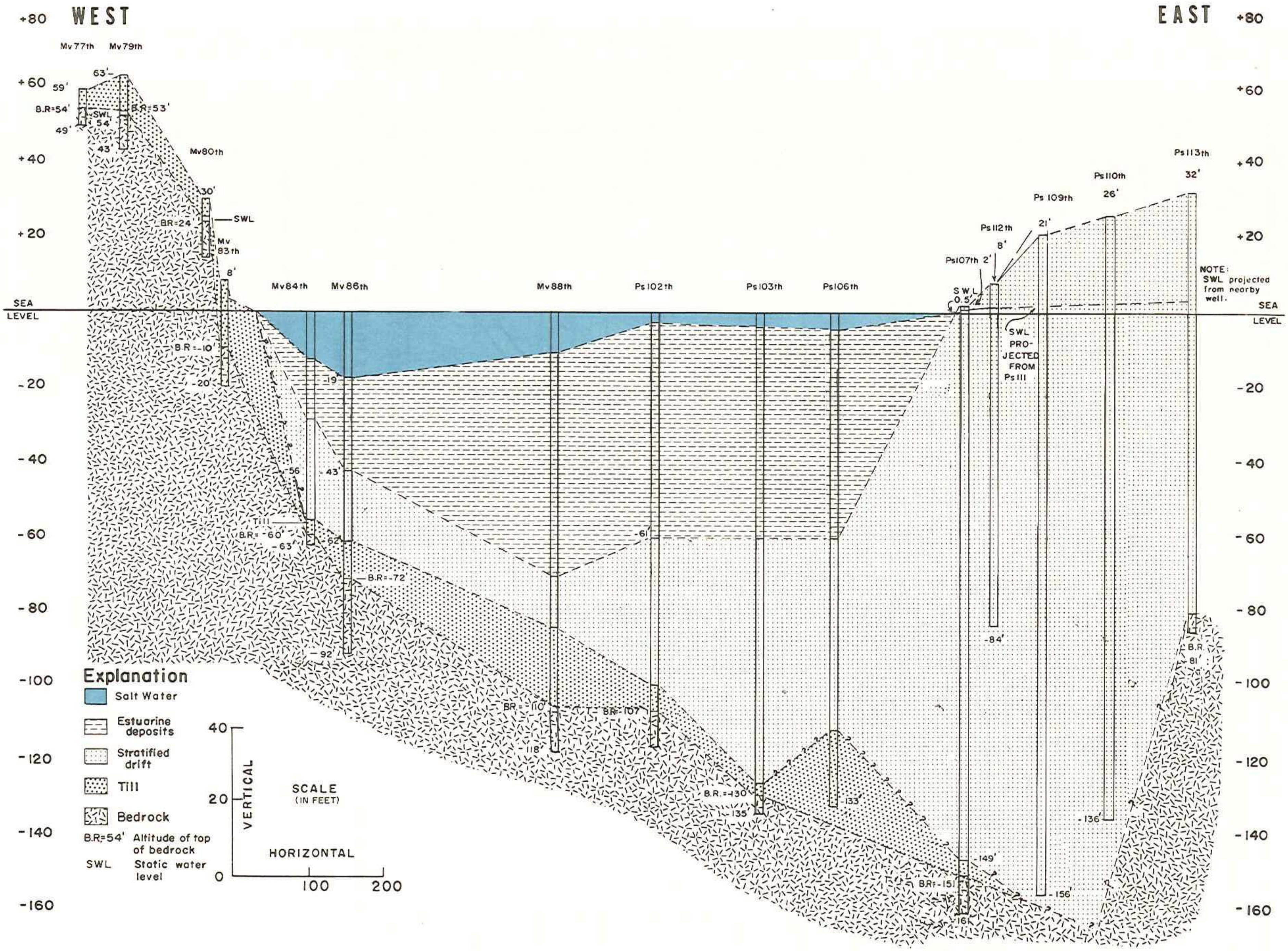


Figure 33.--Geologic section at the Thames River estuary south of Norwich from Fort Shantock State Park to Happyland

Altitudes at tops and bottoms of borings fr-- Connecticut State Highway Department. See borings Mv 86 and Ps 113 for location on plate A.

WATER IN AQUIFERS

The amount of ground water that may be recovered by pumping from wells varies widely from place, depending on the water-bearing properties of aquifers and on the available supply. Permeability (water-yielding capacity) and thickness govern the rate at which an aquifer can transmit water on a short-term local basis. The amount of ground water that can be pumped on a long-term or regional basis also depends on how much is available for delivery. This includes the amount of water from precipitation which infiltrates to the aquifers, the amount stored there, and the amount that can be induced to infiltrate from streams and lakes. An understanding of the underground part of the hydrologic cycle, is essential to sound development and management of ground-water supplies in the SCRBA.

AQUIFERS

Ground water in the SCRBA is obtained from three aquifers: (1) stratified drift, (2) bedrock, popularly called "ledge", and (3) till. The distribution and properties of the aquifers are indicated on plate B. Stratified drift is described first in the section which follows because it is by far the most important.

STRATIFIED DRIFT

Stratified drift consists of strata or layers and lenses of water-washed and water-laid gravel, sand, silt, and clay carried by meltwater from glacial ice as shown on figure 34. Despite the wide size range of its component particles, stratified drift can be divided on a hydrologic basis into two water-bearing units: (1) a coarse-grained unit capable of yielding large quantities of water, i.e., up to several hundred gpm (gallons per minute) to individual wells, and (2) a fine-grained unit capable of yielding only small quantities of water (generally less than 20 gpm to single wells). The coarse-grained unit includes all stratified drift consisting predominantly of medium sand or coarser material. The fine-grained unit includes the remaining stratified drift consisting predominantly of fine sand, silt, and clay. Subdivision of the stratified drift units is based on surficial mapping, on published surficial maps, and on subsurface information from drillers' logs of wells and test holes.

Stratified drift is the most productive aquifer in the report area and is the only one ordinarily capable of yielding more than 100 gpm to single wells on a sustained pumping basis. In most places it is underlain by till, but in some places the till is missing and stratified drift is underlain by bedrock as shown in figure 33. More rarely, thick till is underlain by stratified drift as interpreted from well logs. Such points are shown by a "T" and dot symbol, as at Shantock Brook on plate B. Stratified drift is widespread in valley and lowland areas and is scarce or absent in interstream areas and on most hillsides and uplands. It thus covers only about 20 percent of the report area.

Stratified drift may be overlain by other unconsolidated materials in places. Alluvium, where present, is commonly thin and is mapped with the underlying drift. Artificial fill ("made land") is widely scattered through the expanding urban areas of the SCRBA and at highways and bridges. However, it is thin and most of it is above the water table; therefore it is mapped with stratified drift or any aquifer that directly underlies it. Estuarine deposits are widespread in some of the major valleys, particularly in their southern reaches. These deposits underlie or border salt water in bays and other water bodies and are not shown on plate B. Swamps appear on the topographic base map; swamp deposits are outlined separately on the plate only where they may be underlain by stratified drift.

The type of stratified drift below the water table has a more direct influence on the yields of individual wells than the type exposed at the dry land surface. For this reason, plate B shows the type of saturated stratified drift below the water table rather than that at the land surface. The distribution shown on the map is somewhat arbitrary because the two units may grade into one another laterally, may overlie one another, or may be completely interbedded. Hence, the contact shown between the coarse-grained and fine-grained units commonly is less precise than is the contact shown between the stratified drift and till. However, any sequence of saturated stratified drift containing at least 10 feet of coarse-grained material in the area is included in the coarse-grained unit.

The coarse-grained and fine-grained units of saturated drift shown on plate B are generally consistent enough to permit mapping in most areas despite the diverse sources of the data. In a few places, however, subsurface data indicate a preponderance of fine-grained material even though nearby subsurface information or surficial maps indicate that at least enough coarse-grained material is saturated to designate the aquifer as coarse-grained. For example, well Ps 88 at Norwich Hospital is in an area of coarse-grained stratified drift but it reportedly penetrated chiefly fine-grained stratified drift. The site is indicated on plate B by a unit letter "x" and comparable points elsewhere are shown by the same symbol (explanation, plate B). Doubtless many exceptional points are not shown because subsurface data is incomplete. Nevertheless the map can be used as a guide for the elimination of unfavorable areas and for the selection of sites suitable for test drilling. The coarse-grained unit as defined here is more widespread than the fine-grained unit. It makes up about 90 percent of the areas covered by stratified drift.

Fine-grained stratified drift, as defined, is limited to relatively small patches where it was laid down in glacial lakes and the sluggish parts of meltwater streams as indicated on figure 34. It is scattered throughout the SCRBA but is most abundant near the northern margin of the report area. Swamps may also be underlain by fine-grained stratified drift, as are Cedar and Assekonk Swamps, and the unnamed swamp north of Deep River Reservoir. A narrow belt of fine-grained stratified drift forms a terrace deposit along the east shore of the Thames River at the U.S. Naval Submarine Base north of the Gold Star Memorial Bridge. Fine-grained material is actually more widespread in the SCRBA than its distribution on the map would indicate because, as previously mentioned, it is included with the coarse-grained unit wherever at least 10 feet of saturated coarse-grained stratified drift

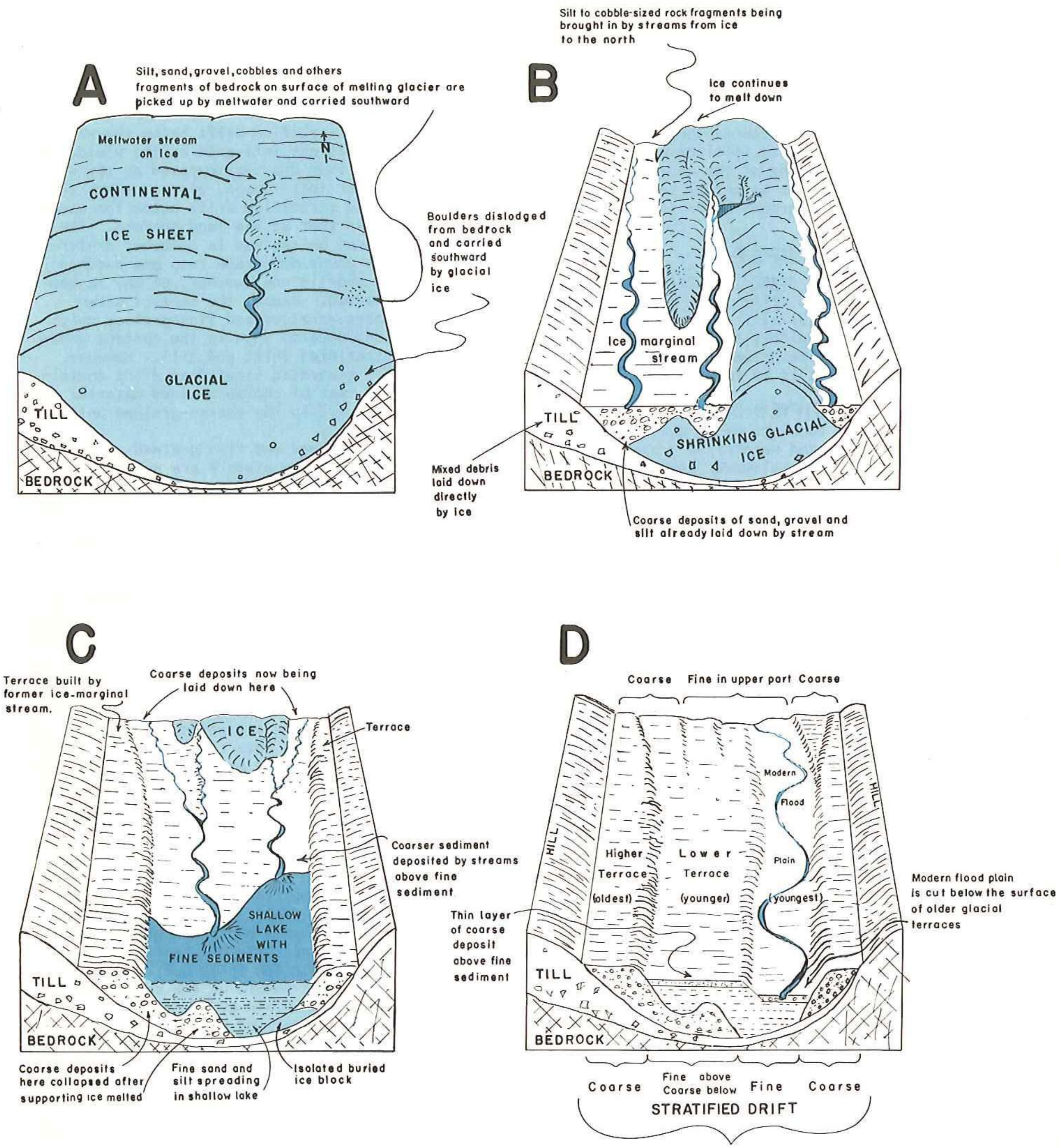


Figure 34.--Diagrams showing the origin of stratified drift deposits

Table 22.--Log, permeability, and transmissibility of well Ps 67 at Norwich Hospital

(Static water level 69 feet; yield 505 gpm)

Driller's log	Depth to bottom (ft)	Thickness (m) (ft)	Estimated permeability (P)	Estimated transmissibility 1/ (T = Pm)
Sand, coarse, brown and gray, and gravel	40	40	--	unsaturated
Sand, muddy	45	5	--	Do
Sand, gray	65	20	--	Do
Sand, coarse, water-bearing	95	2/30	2,300	59,800
Gravel, coarse, water-bearing	105	10	4,000	40,000
Sand, coarse, water-bearing	122	17	2,300	39,100
Sand, fine, brown, and clay (till?) .	143	21	--	--
Ledge (bedrock) at	143		--	--
Total; feet of saturated stratified drift		53		138,900 (total)

1/ Transmissibility equals permeability multiplied by saturated thickness of unit.
2/ Lower 26 ft saturated. $\frac{138,900}{53}$ = 2,620 (average permeability of saturated section)

is also present. As used in this report, fine-grained stratified drift includes water-laid clay, muck, silt, and fine sand, with particle sizes less than 0.25 mm (millimeters).

At a few places stratified drift deposits are of unknown grain size, because subsurface data are lacking. These have been mapped as "undifferentiated stratified drift." They generally underlie small areas and are more likely to contain fine-grained than coarse-grained material.

PERMEABILITY AND TRANSMISSIBILITY

Permeability is defined as the rate at which a unit cube of material will transmit water under unit hydraulic gradient. The standard coefficient of permeability used by the U.S. Geological Survey is the rate of flow of water in gallons per day through a cross-sectional area of 1 square foot of an aquifer under a hydraulic gradient of 1 foot per foot and a temperature of 60°F. The field coefficient of permeability is the same except that it is measured at the prevailing water temperature. The water transmitting capacity of an entire vertical section of aquifer is called transmissibility. The coefficient of transmissibility is defined as the rate of flow of water in gallons per day through a vertical strip of an aquifer 1 foot wide under a hydraulic gradient of 1 foot per foot. The coefficient of transmissibility is equal to the field coefficient of permeability multiplied by the thickness of the aquifer in feet. It is expressed mathematically as: $T = Pm$ where T is the transmissibility in gallons per day per foot, P is the field coefficient of permeability in gallons per day per square foot, and m is the thickness in feet.

This relationship between transmissibility, permeability, and thickness is very useful in estimating the average permeability of vertical sections of stratified drift deposits, as, for example, from logs of wells and test borings.

Using permeabilities read from figure 35, the average permeability of stratified drift was estimated from 245 logs of wells, test borings, or auger borings. The procedure for making estimates of average permeability is illustrated in table 22. A value of permeability is assigned to each layer of saturated material reported in the log, and the permeability of each layer is multiplied by the saturated thickness to give the transmissibility. The transmissibilities for each layer are then totaled and the transmissibility of the saturated section (shown within a range) for 145 sites where logs are available are shown on plate B (only selected test borings and no auger borings are shown on the plate). Great care and judgment are necessary in the interpretation of drillers' logs in order to assign realistic values of permeability to materials. However, experience generally allows a fairly accurate interpretation of grain size and sorting of materials listed in the logs and a fairly accurate estimate of permeability values. This is borne out by comparison of permeability values estimated from well logs with permeability values determined from specific capacity and pump test data from the same wells given in table 23.

Samples of stratified drift collected from surface exposures and from a test hole in the area were analyzed for grain size, grain-size distribution, permeability, and specific yield; results are given in table 24. Permeability and median grain size are plotted in figure 35 which includes similar plots from data collected in the Quinebaug River basin and Shetucket River basin (Thomas, M. P. and others, 1967, p. 54).

As shown on figure 35, permeability increases with median grain size. The scatter of data which

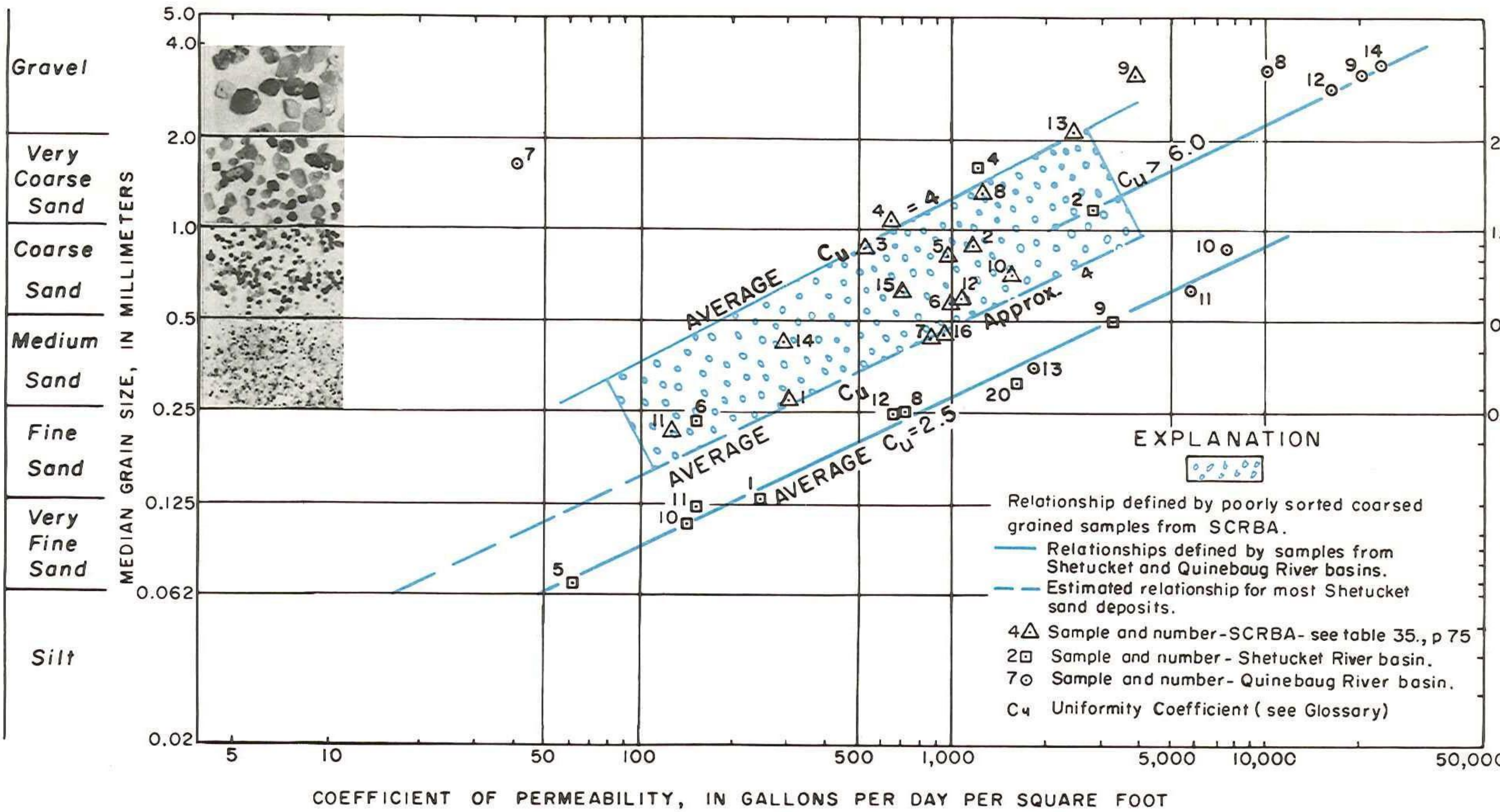


Figure 35.--Relation of permeability to median grain size and uniformity coefficient of stratified drift

Permeability is higher where median grain size is larger, and at any median grain size, permeability is higher for well sorted deposits (those with low C_u)

Table 23.--Permeability of stratified drift
(Estimated from specific capacities and logs of screened wells)

Corrected drawdown: reported drawdowns are adjusted for (1) decrease in saturated thickness using the equation derived by Jacob (Walton, 1962, p. 7) and for (2) the effects of partial penetration of the pumping well (Walton, 1962, p. 8). The ratio of vertical to horizontal permeability used in the partial penetration corrections is assumed to be 1:10.

Drawdowns are not corrected for differences in well diameters or well efficiencies. Tests are also assumed to be of sufficient duration so that the effects of delayed yield from gravity drainage on the drawdown are negligible.

Specific capacity: reported yield divided by corrected drawdown.

Transmissibility: determined by graphic methods described by Meyer (1963, p. 338) and for tests of less than 20 hours or greater than 48 hours by methods described by Walton (1962, p. 12). The coefficient of storage (S) is assumed to be 0.2 for water-table conditions and 0.002 to 0.001 for artesian conditions.

Saturated thickness of aquifer: full thickness of stratified drift below water table except in wells where fine drift directly overlies bedrock or overlies till (omitted) and in artesian wells where it is restricted to thickness of confined aquifer only.

Average permeability: transmissibility divided by saturated thickness. Rounded to nearest 100 gpd per sq ft.

Average permeability (based on well logs): method used to estimate permeability is described in text. Rounded to nearest 100 gpd per sq ft.

Remarks: well in coarse-grained unit unless otherwise stated.

Well no.	Pumping yield (gpm)	Reported drawdown (ft)	Corrected drawdown (ft)	Specific capacity (gpm/ft)	Transmissibility, estimated (gpd/ft)	Saturated thickness of aquifer (ft)	Average permeability, estimated (gpd/sq ft)	Average permeability based on well logs (gpd/sq ft)	Diameter of well (in.)	Duration of test (hrs)	Remarks
ELy 11	75	19	11.4	6.6	12,000	16	800	1,000	8	17	Probably artesian; no correction for dewatering. Gravel packed.
ELy 38	102	15	5.4	18.8	30,000	75+	400	600	10	38	Log is from ELy 40, 95 ft away. Situated 90 ft from ELy 39.
ELy 39	103	12	4.0	25.8	40,000	75±	500	600	10	48	Log is from ELy 40, 70 ft away. Situated 90 ft from ELy 38.
ELy 41	150	12.8	5.0	30.0	40,000	29	1,400	1,600	8	12	Twenty (20) ft of silt underlying aquifer excluded from saturated thickness. Gravel packed.
ELy 46	208	10±	9.2	22.6	30,000	60	500	--	6	4	Data approximate; no correction for partial penetration.
ELy 56	200	30±	15.0±	13.3±	30,000	24	1,200	1,100	8	8	Probably artesian; no correction for dewatering.
Gt 28	100	24	4.7	21.3	35,000	35	1,000	900	8	33	Gravel packed.
Gt 90	60	11	8.6	6.9	6,000	25	250	300	2½	8	Chiefly in fine-grained unit overlying 8 ft of coarse-grained unit.
Gt 113	200	13	11.5	17.4	30,000	57	500	900	8	1,200	Scheduled after completion of data collection; not used in averages.
Gt 114	150	10.2	9.1	16.6	24,000	45	500	700	8	22	Scheduled after completion of data collection; not used in averages.
Lb 19	75	12±	--	6.2±	15,000±	13	1,800±	1,900	--	24	Five (5) similar 2½-inch wells pumped at combined rate of 75 gpm. Probably artesian; no correction for dewatering or partial penetration.
Ly 24	400	21.7	9.5	42.1	50,000	35	1,400	1,600	24	4	Gravel packed.
Ly 27	125	25	4.9	25.5	40,000	34	1,200	1,500	8	24	Log is from Ly 26, about 100 ft away.
Ly 42	80	10±	4.9	16.3+	25,000	23	1,300	1,600	6	40	
Ly 79	45	10	2.2	20.5	35,000	18	1,900	1,900	8	--	
Ly 111	239	49	6.4	37.3	60,000	71	800	1,100	8	52	
Ly 116	60	22	4.9	12.2	20,000	43	500	900	--	140	Six (6) similar 2½-inch wells pumped at combined rate of 60 gpm. Permeability based on well log is probably more accurate.
Mv 25	90	17	4.5	20.0	35,000	47	800	--	10	12	Finished with "Bayard screen."
Mv 29	20	2	.9	22.2	35,000	18	1,900	1,800	8	8	Log is from Mv 30, 7 ft away. Gravel packed.
Mv 48	70	25	5.7	12.3	18,000	45	400	600	8	102	
Mv 64	90	29	13.1	6.9	15,000	21	700	1,000	8	38	Probably artesian; no correction for dewatering. Sand and gravel underlie till. Slotted casing, gravel packed.
NSn 29	223	5.4	2.4	92.9	150,000	29	5,100	3,700	8	9	Permeability based on well log is probably more accurate. Gravel packed.
NSn 51	225	17	6.0	37.5	50,000	30	1,600	1,600	12	24	Gravel packed.
OL 15	25	10±	2.0±	12.5±	20,000	16	1,200	--	2	12+	Transmissibility value may be in error because drawdown is a substantial fraction of original saturated thickness.
OL 21	75	1	1.7	44.1	42,000	21	1,900	1,500	--	3.5	Two (2) similar 2½-inch wells 2 ft apart pumped at combined rate of 75 gpm. Log is from nearby OL 78.
OL 68	15	6±	1.0±	15.0±	20,000	24	800	800	--	24	Two (2) similar 2-inch wells pumped at combined rate of 15 gpm.
Ps 67	505	16	6.4	78.9	140,000+	53	2,700+	2,600	12?	43	Gravel packed.
Sn 149	150	15	6.6	22.7	30,000±	19	1,600	--	8	10	Transmissibility value may be in error because drawdown is a substantial fraction of original saturated thickness. Gravel packed.
Sn 155	200	4	--	50.0+	60,000	29	2,100+	--	8	8	Data approximate; no correction for dewatering or partial penetration.
Sn 156	300	14	12.0±	25.0±	30,000±	45±	700±	--	24	8	Data approximate; no correction for partial penetration. Gravel packed.
Sn 163	880	42.6	11.3	77.9	150,000	80	1,900	1,900	18	235	Scheduled after completion of data collection; not used in averages. Unpublished log available.
Wt 29	125	8.3	7.5	16.6	40,000	43	900	900	--	53	Six (6) closely spaced 2½-in wells pumped at combined rate of 125 gpm. Perforated casing. Probably artesian; no correction for dewatering.
Wt 39	180	34	4.3	41.9	60,000	46	1,300	1,300	8	80	Transmissibility value may be in error because drawdown is a substantial fraction of original saturated thickness.
Wt 44	185±	--	--	9.2	15,000	20	800	1,000	--	84	Five (5) closely spaced 2½-inch wells pumped at combined rate of 185± gpm. Probably artesian; no correction for dewatering.
Wt 52	50	6.5	4.2	11.9	18,000	16.5	1,100	1,500	8	48	Gravel packed.
Wes 256	736	10.9	5.0	145.0	200,000	70	2,900	3,100	24	8	Situated in Rhode Island a few hundred feet outside area. Gravel packed. New well nearby, 75 ft deep, pumps 1,500 gpm.

Table 24.--Laboratory determinations of permeability of stratified drift from the lower Thames and southeastern coastal river basins

(All samples except no. 16 collected from surface exposures above water table and horizontally oriented. Repacked unless noted otherwise)

Description 1/	Median grain size (mm)	Particle size distribution (percent)				Uniformity coefficient 2/	Specific yield (percent)	Coefficient of permeability (gpd per sq ft)	Quad location	Sample number
		Clay and silt	Fine to very fine	Medium to very coarse	Gravel					
Sandy gravel	3.2	0.6	0.4	36.5	62.5	6.97	32.6	3,800	New London	9
Sandy gravel	2.05	1.0	3.4	45.4	50.2	11.4	30.6	2,500	New London	13
Gravelly sand	1.4	.7	5.2	52.6	41.5	7.33	26.9	1,300	Montville	8
Sand	1.1	.5	.7	83.6	15.2	2.60	34.1	630	Montville	4
Gravelly sand	.88	7.9	.9	69.8	21.4	3.43	30.3	1,200	Niantic	2
Gravelly sand	.88	.7	5.0	77.6	16.7	3.33	33.5	510	Montville	3
Sand 3/	.82	1.8	1.8	95.3	1.1	2.30	30.3	940	Norwich	5
Sand	.72	2.0	4.5	85.8	7.7	2.66	30.8	1,700	Uncasville	10
Gravelly sand	.69	.5	9.8	66.9	22.8	4.40	28.2	700	Uncasville	15
Sand 3/	.66	1.3	9.5	81.0	8.2	3.25	32.6	1,100	Montville	12
Sand	.62	.5	7.9	77.1	14.5	2.81	32.4	990	Uncasville	6
Sand	.46	3.2	13.0	83.6	.2	2.79	31.9	940	East Lyme	16
Sand	.46	1.2	5.7	89.5	3.6	1.71	37.8	860	Uncasville	7
Sand	.44	4.4	19.0	61.3	15.3	4.15	27.1	290	Old Mystic	14
Sand	.28	.6	39.9	56.9	2.6	2.12	34.6	310	Niantic	1
Gravelly sand	.22	3.9	55.9	28.2	12.0	2.50	33.3	130	Colchester	11

1/ Classification based on Pettijohn (1957, p. 27).
2/ Uniformity coefficient: See explanation in glossary.
3/ Not repacked; less disturbed than other (repacked) samples.

causes it to fall within a band rather than along a straight line, is largely a reflection of the degree of sorting of the samples. Therefore, for any given median grain size, well sorted materials (low uniformity coefficients) will have higher permeability than poorly sorted materials (high uniformity coefficients). Accordingly, several of the samples collected in the study area plot near the top (left) edge of the band indicating the relatively poor sorting and relatively low permeability of the materials collected. This was expected as the sampling was deliberately planned to obtain relationships for coarse, poorly sorted stratified drift for comparison with relatively well sorted materials collected in the the Quinebaug and Shetucket basins. Also, 14 of the 16 samples collected in the SCRBA were repacked in the laboratory prior to testing; this disturbance of natural packing and stratification undoubtedly accounts in part for the scatter of data.

The specific capacities of 36 wells in table 24 were used to estimate the transmissibility of stratified drift. The specific capacity of wells is determined by dividing the yield in gallons per minute by the drawdown at the end of the period of pumping. The derivation of transmissibility from specific capacity is not exact because the drawdown in a well is often affected by inefficiency in well construction, geohydrologic boundaries, partial penetration, and, in water table aquifers, by decrease in saturated thickness of the aquifer during pumping. In most cases these factors affect drawdowns adversely, resulting in computed transmissibilities that are lower than actual values. The reported drawdowns in column 3, table 24 have been corrected to allow computations that more nearly depict actual transmissibilities. Corrections of drawdowns for decreases in saturated thickness of the aquifers resulting from dewatering were made using an equation developed by Jacob (Walton, 1962, p. 7):

$$s' = s - \frac{s^2}{2m}$$

Where: s' = the drawdown that would occur in an equivalent nonleaky artesian aquifer, in ft.
s = reported drawdown, under water-table conditions, in ft.
m = initial saturated thickness of aquifer, in ft.

After corrections for dewatering, corrections for partial penetration were made by using an equation developed by Butler (Walton, 1962, p. 8):

$$s = Cpp\ spp$$

Where: s = drawdown in pumped well for fully penetrating conditions, in ft.
Cpp = partial penetration constant for pumped well.
spp = observed drawdown for partial penetration conditions, in ft.

The specific capacity computed from corrected drawdowns was used to estimate transmissibility by graphic methods described by Meyer (1963, p. 338) and Walton (1962, p. 12). The transmissibility was then divided by the saturated thickness to obtain the estimated permeability shown in table 23. Duplicate permeability values based on drillers' logs by use of figure 35 are shown in the same table in an adjoining column. They agree closely

Table 25.--Summary of yield and specific capacity of drilled, driven, and dug wells in coarse-grained and fine-grained stratified drift

(Restricted to wells for which drawdown and specific capacity are known)

Type of well		Depth of well (ft)		Diameter of well (in)		Yield (gpm)		Drawdown (ft) 1/		Duration of test (hrs)		Specific capacity (gpm per ft of dd) 1/		No. of wells	
		Coarse-grained unit	Fine-grained unit	Coarse-grained unit	Fine-grained unit	Coarse-grained unit	Fine-grained unit	Coarse-grained unit	Fine-grained unit	Coarse-grained unit	Fine-grained unit	Coarse-grained unit	Fine-grained unit	Coarse-grained unit	Fine-grained unit
Drilled 2/, 3/	Average	56	50	8.1	7	137	7	19.5	< 27	46	1	10.1	0.3	49	2
	Range	18 - 136	50 - 51	2.5 - 24	6 - 8	20 - 4/ 880	4 - 10	2 - 76	14 - < 40	2 - 240±	--	1.1 - 50.0	--	--	--
Driven	Average	21	--	5/ 1.9	--	5/ 13	--	5/ 8.2	--	5/ 47	--	5/ 1.5	--	5/ 13	--
	Range	14 - 28	--	1.2 - 3	--	5 - 25	--	5± - 11	--	8 - 384	--	1.0± - 2.8	--	--	--
Dug	Average	17	18	72	20	52	< 13	8.1	< 11	12	20	7.1	1.2	34	5
	Range	8.6- 35	14 - 20	12 -300±	6 -40	4±-500+	<1 - 20±	1 - 28	< 8 - 13	.4 - 96	8 - 24	.5 - 34+	.1 - 1.7+	--	--
All types combined	Average	38	28	30	16	90	11	13.9	16	30	16	7.9	.9	96	7
	Range	9 - 136	14 - 51	1.9 - 300±	6 - 40	4± -880	<1 - 20±	1 - 76	< 8 -<40	.4 - 384	1 - 24	.5 - 50.0	.1 - 1.7+	--	--
Coarse-grained and fine-grained unit combined	Average	37		29		85		14		26		7.4		103	
	Range	9 - 136		1.9 - 300±		< 1 - 880		1 - 76		.4 - 384		.1 - 50.0			

1/ Uncorrected.
2/ Restricted to screened wells.
3/ Excludes Sn 163 except as indicated.
4/ Maximum is from Sn 163; not used in averages.
5/ Includes one battery of 20 wells pumped at combined rate of 465 gpm for 384 hrs. Considered here as one well with average yield of 23.2 and average specific capacity of 2.0 gpm per ft of dd.

with the values estimated from specific capacity data. Transmissibility values derived from specific capacity data are shown directly on plate B. Where values are less precise because no specific capacity data are available, letters indicating a range in transmissibility based on logs are used. Where neither numerical values nor ranges are available, a rough estimate of transmissibility of the stratified drift at any site can be made by multiplying the saturated thickness of the deposits, shown on plate B, by the average permeability.

SATURATED THICKNESS

The thickness of stratified drift below the water table in the SCRBA ranges from a fraction of an inch to more than 120 feet. The highest yields are obtained where the saturated part of the coarse-grained unit is more than 40 feet thick. A great thickness of saturated drift is rarely uniform in lithology and a well screened in the coarsest material will derive water from elsewhere in the saturated section. Where stratified drift is thin (10 to 20 feet of saturated material), only small to moderate yields are obtainable, even where it is coarse grained. Areas lying between the 10 foot thickness line and the outer edge of the stratified drift generally yield only small supplies.

The contours indicating saturated thickness of stratified drift on plate B are based on data collected from 1963 to 1965. At the northern boundary of the SCRBA area at Preston School, south of Jewett City, they supersede older contours based on limited and older data (Randall and others, 1966). The saturated thickness contours in the valleys of the Pawcatuck and Shunock Rivers in this report may in turn be superseded by newer data collected by the Rhode Island office of the U.S. Geological Survey (Joseph Gonthier, personal communication) which indicate that the stratified drift here is thicker than shown on plate B.

DEVELOPMENT BY WELLS

The largest yields in the SCRBA are obtained from wells tapping stratified drift; the average yield of 103 wells listed in table 25 is 85 gpm. Yields range from less than 1 to 880 gpm, depending in part on the type of well construction and development. Drilled wells produce the largest yields partly because they are deeper and thus tap a thicker section of the aquifer; in addition, they commonly tap the aquifer with greater efficiency than do dug or driven wells, as indicated in the following section.

The highest yields from drilled wells in the SCRBA are obtained from those that are properly screened and developed by surging or other means. All of the 36 wells listed in table 24 are screened and over half yield more than 100 gpm. The average yield of 52 screened wells is 146 gpm with a range from 4 to 880 gpm; by contrast, the average yield of 13 unscreened wells that also tap stratified drift is 34 gpm with a range from 9 to 110 gpm. A closely spaced battery of wells hooked up to a common header pumped by a single pump is here considered as one well.

The yield of a well is only a rough index of its potential. Specific capacity is a more significant measure because it includes drawdown. The mean specific capacity of 103 wells tapping stratified drift in the SCRBA as shown in table 25 is 7.4 gpm per foot of drawdown and ranges from 0.1 to 50.0 gpm per foot of drawdown. Specific capacity can be used to compare the relative efficiency with which closely spaced wells tap the same aquifer. It can also be used to differentiate changes in well or pump efficiency in a single well with the passage of time. If pumping at a steady rate results in greater drawdowns after a period of time, the specific capacity has decreased, and a decrease in well efficiency is indicated (assuming that the saturated aquifer thickness remains the same). Conversely, if the specific capacity of a well remains the same as time goes on, but its overall productivity in gpd (gallons per day) decreases, a decline in pump efficiency is indicated. Thus, periodic measurement of pumping levels and corresponding pumping rates can pinpoint the cause of declining yields in the area.

The smallest yields and lowest specific capacities in the area are obtained from driven wells because these are generally of small diameter and of shallow depth. Moreover, such wells commonly are equipped with built-in screens selected with little regard for grain size of the water-bearing unit. Driven wells are primarily successful in medium-grained stratified drift. Driving a well is difficult or impossible in coarse bouldery gravel, and in fine-grained stratified drift, the low efficiency of driven wells can result in excessive drawdowns. No driven wells tapping fine-grained stratified drift are recorded in this study.

Supplies of water adequate for many purposes are obtainable from dug wells. Randall and others (1966, p. 55) concluded on the basis of pumping tests in the Quinebaug River basin that a dug well pumped for 8 hours may be expected to have a specific capacity of at least 2 gpm per ft of drawdown for each foot of saturated coarse-grained stratified drift penetrated. In the SCRBA, data from diggers or owners of 34 dug wells also indicate an average yield of about 2 gpm per ft of drawdown per ft of saturated coarse-grained stratified drift penetrated. The wells in the report area were pumped for periods ranging from 0.4 to 96 hours. Of these wells, 22 of 34 supply water for industrial or public use.

Dug wells are generally shallower than driven wells but they commonly yield more gpm per ft of drawdown. Moreover, the large diameter dug wells enable them to serve as storage tanks. Tables showing the capacity of round tanks per foot of depth (Anderson, 1964, p. 151) indicate that a dug wells of 48 inches in diameter (average for SCRBA) holds about 94 gallons per foot of depth. A well of this diameter with an average drawdown of 10.9 feet supplies about 1,025 gallons of water from storage in the well opening. Thus, even wells dug in fine-grained stratified drift may be satisfactory for small supplies, if short periods of intermittent pumping do not exceed the quantity in storage plus the small amount entering the well during pumping.

Dug wells are the most practical type in fine-grained stratified drift for other reasons. In fine-grained materials, interbedded clay and fine silt may clog screens, damage pumps, and render water turbid and unfit for use. Pumping from dug wells in fine-grained stratified drift avoids some of these problems because the large diameters compensate in part for low entrance velocities and also provide more space for settling of fines. However, the shallow depths at which dug wells are commonly completed, even when excavated by modern mechanical equipment, limit the saturated thickness penetrated and subsequent settling of fine sediment may reduce this even further. The depths of five dug wells in fine-grained stratified drift listed in table 25 average 18 feet and range from 14 to 20 feet.

THE PUMPING TEST-- A KEY TO QUANTITATIVE HYDROGEOLOGY

A carefully planned and controlled pumping test provides the most reliable quantitative information on overall aquifer characteristics and on the effects of large-scale withdrawals. As previously indicated, preliminary estimates of potential well yields may be made from yields of known wells and saturated thickness of stratified drift. Well logs and drawdown data provide a firmer basis for estimating permeability and transmissibility by means of corrected specific capacity as described in the section entitled "Permeability and Transmissibility." However, they cannot be used to make an adequate analysis of the entire aquifer as a unit for they do not take into account the effects of local geologic and hydrologic conditions. Moreover, they cannot provide a value for the storage coefficient (S), which must be assumed. In the SCRBA, as elsewhere in Connecticut, the most productive aquifers generally occupy relatively long narrow valleys where streams commonly act as recharge boundaries and bedrock walls and till act as impermeable boundaries. The manner in which these boundaries affect yields and drawdowns is generally the same from place to place, but because the geometry and effectiveness of the boundaries vary considerably, the magnitude of their influence is different at each site. Even if this were not so, differences in texture and bedding of the stratified drift make each site unique. Specific local conditions are best determined in the field by a carefully planned and rigorously-controlled pumping test of sufficient duration. Essentially, a pumping test is an analysis of the "cone of depression" surrounding a pumping well based on measurements of the cone's size, shape, and rate of expansion and contraction. Such tests facilitate economical construction and development of supply wells and aid in determinating the perennial rate at which the aquifer can be pumped.

The coefficients of transmissibility and storage may be determined by using a method developed by Theis and described by Wenzel (1942, p. 87-90). The analysis involves a formula which relates the drawdowns near a discharging well to the rate and duration of the discharge:

$$s = \frac{114.6\ Q}{T} \int_u^{\infty} \frac{e^{-u}}{u}\, du = \frac{114.6\ Q}{T}\ W(u),$$

$$\text{where } u = \frac{1.87 r^2 S}{Tt} \quad \text{and}$$

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

r = distance, in feet, from pumping well to observation well where "s" is measured,

Q = discharge of the well, in gallons per minute,

t = time, in days, since pumping started, (or stopped),

T = coefficient of transmissibility, in gpd/ft (gallons per day per foot),

S = coefficient of storage, a dimensionless ratio or fraction,

W(u) = replaces the integral expression and is called "well function of u," and

e = natural-logarithm base.

The formula is based on several simplifying assumptions including the following: (1) the aquifer is of constant thickness and of infinite areal extent, (2) it is equally permeable in all directions, (3) it receives no recharge and experiences no discharge within the area of influence of the pumping well except for the pumpage discharged during the test, and (4) water can freely enter the wells with 100 percent efficiency throughout the full thickness of the aquifer. Despite the fact that these assumptions are seldom realized in practice, useful determinations of the aquifer constants, T and S, can be made. Pumping tests are available from scattered parts of the SCRBA. Some of these are listed in table 26. Some well tests may be unusable because of variable pumping rates, too short a period of pumping, ambiguous data, or other inadequacies. Drillers and consultants can provide a genuine service to well owners and others interested in water management by careful collection of reliable pumping test data to enable dependable determination of the aquifer constants and to permit efficient development of the aquifer.

BEDROCK

Bedrock, popularly called "ledge," underlies the entire area. Throughout eastern Connecticut it is a hard, dense, crystalline rock consisting of tightly interlocked mineral grains. Several kinds of rock, including a variety of igneous and metamorphic types, have been described in the area. Published bedrock maps are listed alphabetically by author in the section entitled "Selected References." Despite mineralogic and petrologic differences, the water yielding characteristics of the various rocks are similar, and they are treated as one unit in this report except where a specific kind of rock directly affects the chemical quality of the water.

Bedrock is covered by glacial deposits in most of the basin. In the uplands, however, it generally crops out at the land surface or occurs beneath a thin mantle. In the lowlands, it is commonly buried beneath surficial deposits that may exceed 100 feet locally. Thus the bedrock surface resembles the land surface but is more rugged. In most valleys the bedrock surface is deeper at the axis of the valley and shallower at the sides. Exceptions are not rare as illustrated by the bedrock outcrops in low-lying Point Breeze near Montville. In the uplands exceptions are illustrated by the thick glacial deposits at Mohegan Hill. Points where thick till (more than 40 feet) are known to overlie bedrock are shown by a "T" symbol on plate B.

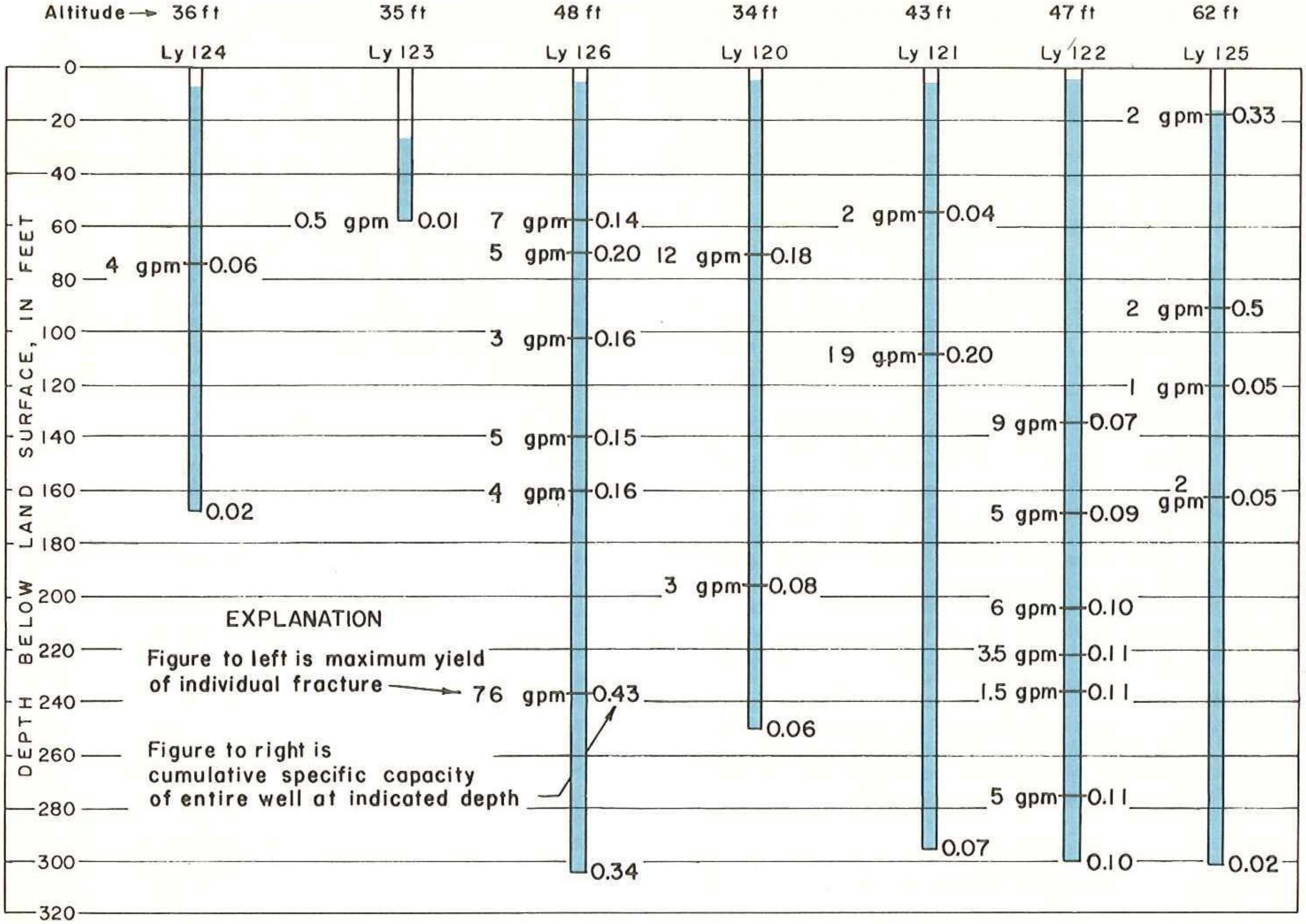
Bedrock in the area is fractured to a depth of several hundred feet, and it is along these cracks (joints) rather than through intergranular openings that most ground water moves. Parallel joints, forming a set, may intersect joints of other sets; these intersections form enlarged openings that store and transmit ground water. Loughlin (1912, p. 46) mapped 2 major and 4 minor sets of joints in the northeastern part of the report area including parts of Ledyard, Preston, and North Stonington. Steeply-dipping or vertical joints, which are very common in the area, may be connected by nearly horizontal tension joints that are roughly parallel to the configuration of the bedrock surface. These "sheeting" joints are more common in granite and related

Table 26.--Pumping test data from wells screened in stratified drift

Well no.	Pumping rate (gpm)	Coefficient of transmissibility (gpd/ft)	Saturated thickness penetrated (ft)	Coefficient of permeability: Calculated from transmissibility (gpd/sq ft)	Coefficient of permeability: Estimated from corrected specific capacity of pumping well (gpd/sq ft)	Coefficient of storage	Duration of test (hrs)	No. of observation wells	Remarks
Gt 113	150	1/ 30,000	57	525	500	0.0026	--	2	Test by consultant, Geraghty and Miller, written communication dated January 17, 1967.
Gt 114	125	1/ 19,000	45	425	500	.0002	--	3	Do
Mv 50	110	98,000	50+	1,950	2/ 2,100	--	49	6	Test by Ranney Method Water Supplies, Inc., processed report dated June 3, 1954. Basic data unavailable.

1/ Based on use of Theis type curve. Results affected by recharge from nearby pond.

2/ Based on well log.



Type of overburden	Stratified drift	Stratified drift	Till	Stratified drift	Till	Till	Till
Depth to SWL (ft) of completed well	7	27	6	5	6	5	17
Total yield	4 gpm	0.5 gpm	100	15 gpm	21 gpm	30 gpm	7 gpm
Total depth	168'	58'	306'	250 ft	295'	299'	301'
Total specific cap.	.02	.01	.3	.06	.07	.1	.02
Depth to bedrock	15'	51'	11'	14'	27	5'	4'
Remarks			Sustained yield reported to be 80 gpm.		Slotted casing 24'-30' depth.		

Figure 36.--Relationship between yield, specific capacity and depth of seven bedrock wells in Ledyard

igneous rocks. The abundance, width, and continuity of joints vary widely from place to place. Previous studies in eastern Connecticut (Ellis, 1909; Loughlin, 1912; Randall and others, 1966; and Thomas, M. P. and others, 1967) and data collected for this study indicate that joints become narrower and scarcer with depth so that the probability of encountering a significant quantity of water at depths greater than 200 to 300 feet below the top of the bedrock is slight.

PERMEABILITY

Despite widespread fracturing, the permeability of bedrock is very low. The average permeability, based on drillers' reported yield and drawdown data for 262 wells in the area, is about 2 gpd per sq ft, comparable to average values elsewhere in northeastern Connecticut (Randall and others, 1966, p. 63).

In spite of its low average permeability, bedrock yields small but dependable supplies of water to several thousands of drilled wells in the area. Yields reported by drillers for 274 wells sampled for this study range from less than 1 to less than 150 gpm and average 14 gpm. Yields reported in gallons per minute from bedrock wells are not necessarily true indices of the full potential of bedrock to yield water where the factor of drawdown is not included. Furthermore, the reported yield often reflects the minimum effort made to obtain water -- for example, most domestic wells are drilled only to depths where the amounts of water necessary for household use are obtained and wells are commonly constructed and equipped only to the extent necessary to enable pumpage of these relatively small amounts.

DEVELOPMENT BY WELLS

Based on incomplete drillers' records for a three-year period, it is estimated that more than 2,000 wells were drilled in the SCRBA in the decade 1956-65. Most of these are bedrock wells drilled for domestic use. The widespread occurrence of accessible bedrock at generally shallow depths makes it possible to drill rock wells at convenient sites almost anywhere with savings in construction, piping, and development costs. Nine out of ten bedrock wells yield at least 3 gpm, the minimum ordinarily needed for an average-sized family of four or five. "Dry holes," wells too unproductive to put into use, are scarce. Wells yielding as much as 100 gpm are even scarcer.

The use of specific capacity data allow analyses of well yields which more nearly provide indices of the potential of bedrock to yield water. However, the variables which influence specific capacity-- partial penetration, well inefficiency, and geohydrologic boundaries-- have superimposed on them other variables, unique to the fractured bedrock, which further complicate the analyses. These variables include (1) the thickness of saturated bedrock penetrated, (2) the size and distribution of water-bearing fractures, (3) the type of overburden, and (4) the testing procedure, particularly the length of the test and the amount of drawdown.

Of all the factors unique to bedrock that complicate analyses of specific capacity data, perhaps evaluation of the testing procedure is the most troublesome. This is true because the drawdown in a well penetrating fractured bedrock seldom increases in direct proportion to the yield. As the water level is drawn down below a water-bearing fracture, the maximum yield of the fracture is obtained regardless of any additional drawdown below that fracture. An unusual opportunity to examine the relationship between yield and drawdown is provided by seven wells drilled at Gales Ferry in the town of Ledyard as shown on figure 36. The wells are free of most of the man-made complications that hamper analysis of specific capacity of bedrock wells; all were drilled in the same general area for one owner (Dow Chemical Co.) by a single driller, using one type of drilling rig (air rotary) during the same period (October 13 to November 13, 1965). Moreover, an attempt was made to obtain the largest possible yields so that most of the wells were drilled to depths below the first water-bearing fractures and most were tested carefully at each water-bearing fracture penetrated during drilling.

Well Ly 124 as shown in figure 36 penetrated only one fracture at a depth of 73 feet although it was completed at a depth of 168 feet. The maximum potential yield, the yield when the drawdown in the well corresponded with the depth to the fracture, was 4 gpm and the specific capacity was 1.06 gpm per ft of drawdown. As the drawdown was increased to the bottom of the well, the yield remained constant (no additional water-bearing fractures are present), and the specific capacity decreased to 0.02 gpm per ft of drawdown. In contrast, well Ly 126 penetrated six different water-bearing fractures. The maximum yield, at the lowest fracture penetrated, was more than three times the combined yield of the uppermost five fractures: accordingly, the maximum yield (100 gpm) and highest specific capacity (0.43 gpm/ft of drawdown) of this well was obtained when the drawdown was held at the level of the lowest fracture. These two examples represent the extreme conditions-- a decrease of specific capacity with an increase in depth (well Ly 124) and an increase of specific capacity with increased depth (well Ly 126). However, in both cases, once the water level was drawn below the deepest fracture, the yield remained constant with increased drawdown and the specific capacity decreased.

Figure 37 illustrates median yields and median drawdowns in 126 selected bedrock wells for which data are also available on uncased bedrock penetrated. The data suggest that median yields increase down to uncased bedrock penetrations exceeding 300 feet but at a decreasing rate and at the cost of greater drawdowns. The depths of the deepest water-bearing fractures in these wells are not known and it is likely that some of the apparent increase of yield with depth represents wells that produce most of their water from shallow depths but have been drilled deeper in hopes of finding more water for large-scale industrial or municipal use.

The development of the air rotary method of

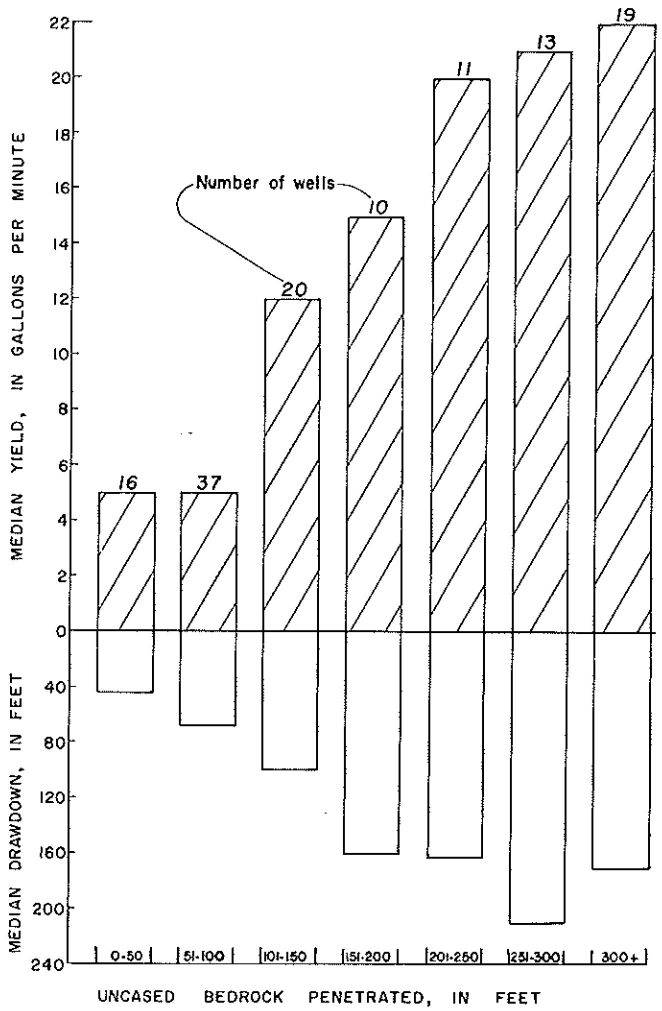


Figure 37.--Yields and drawdowns of bedrock wells related to saturated uncased bedrock penetrated

drilling makes it possible for drillers equipped with these rigs to estimate their cumulative yield and changes in yield at any depth by noting the amount of water "blown" out of the well during drilling. A written record of the water discharged by the air compressor at various depths can help provide the data needed to select a suitable pumping rate and pump setting for the completed wells at the most economical cost. Drillers using the solid or cable tool (chop) rig can perform a similar service by bailing the water level down to just below each water-bearing joint as it is encountered and measuring the quantity bailed while keeping the water level steady during testing. Bailing is more laborious than pumping and such tests customarily are ended after an hour or less so that the results are less applicable to use involving sustained pumping. Moreover, bailing tests can provide only a minimum figure in highly-productive wells where the yield exceeds the rate of bailing so that the pumping level rises intermittently during testing.

The amount of bedrock penetrated in the seven wells at Gales Ferry ranges widely, from 8 to 298 feet. Elsewhere in the SCRBA, bedrock penetrations range from 5 to 689 feet. In some cases, the yield of a well apparently tapping only a short section of bedrock may be derived partly from undetected water in the overburden leaking down around the casing. The prospective well owner may be interested in knowing the maximum depth at which water-bearing fractures occur. Figure 36 shows that the deepest fracture in the wells at Ledyard is 270 feet below the top of the bedrock. Elsewhere in the SCRBA, at least 10 wells penetrate more than 400 feet of bedrock; in eight of these, water-bearing fractures occurred at relatively shallow depths of about 20 to 180 feet below the top of the bedrock as shown in table 27. The average yield of the 10 wells is 7.9 gpm; undoubtedly most of them were carried to great depths because of their low yields at lesser depths. The available data indicate that the possibility of encountering useful quantities of water in bedrock penetrations exceeding 200 feet is slight and in penetrations exceeding 300 feet it is even less.

Drilling to great depths in bedrock seldom increases the yield of a well but it invariably increases its storage capacity. A well 6 inches in diameter, common to household wells, holds 1.5 gallons of water for every foot of depth. Thus, drilling 100 feet below a water-bearing fracture increases the storage capacity of a well by 150 gallons. The storage capacities of the wells in table 27 increased by amounts ranging from 75 to 1,000 gallons as a result of drilling below the lowest water-bearing joints. Storage of water in a well may be helpful but is no substitute for an adequate yield. Three of the ten wells were abandoned or destroyed because of insufficient yields and two others were not in use when visited. Morever, the advantage of deep storage may be offset by the added cost of a deep well and, in some cases, by the added cost of a more powerful deep well pump. Pumping costs increase if the pump setting is deepened, because the head against which the pump operates is thereby increased.

Despite these data the owner of a small parcel of land may be tempted to have an unproductive well deepened rather than have a second well drilled nearby which will, in all likelihood, penetrate the same kind of rock. However, the steep dip of many fractures and fracture zones makes it possible to drill a satisfactory well only a relatively short distance from one of low yield. For example, Ly 122, yielding 30 gpm, is only about 500 feet from Ly 125, which penetrates about the same amount of bedrock and yields 7 gpm as shown on figure 36. Elsewhere in the SCRBA, even closer spacing of productive and non-productive wells indicates that the completion of a dry hole does not rule out the possibility of an adequate well nearby.

The selection of a site for a new bedrock well involves a balance between convenience and cost. Ellis (1909) noted that in every quarry where

Table 27.--Yields of wells penetrating more than 400 feet of bedrock

Well no.	Thickness of rock penetrated (ft)	Yield (gpm)	Static water level in relation to top of bedrock (ft) 1/	Depth to shallowest water-bearing fracture	Depth to deepest water-bearing fracture	Remarks 2/
ELy 32	457	2±	-10±	<155	<155	Small quantity of water encountered at 63 ft; added 1 gpm at 180 ft; no increase in yield when deepened to 457 ft. Data from U.S.G.S. WSP 232, p. 81, 90.
Gt 52	528	1±	+10	63	160	
Mv 42	560	25	+32	<110	<110	All water obtained at depth of 108± to 118± ft.
Mv 73	491	<.5	-13±	114±	114±	
Mv 96	498	1	-13	--	--	Maximum yield reached at depth of 150 ft, no increase in yield with depth.
NL 22	420	8±	+1	<150	<150	Yield, variously reported at 3 to 25 gpm, obtained at 83 ft, no increase in yield with depth.
Nwh 25	436	12	+48	93	93	Some water at 65 ft depth. Yield, reported to be 1.5 to 3 gpm, obtained at depth of 180 ft.
OL 26	487	2	+39	180	180	Yield<0.1 gpm (well took 2 weeks to fill) obtained at depth of 20± ft. Dynamited twice with no increase in yield.
OL 52	689	0	-4	20±	20±	About six nonproductive fractures encountered from 0 to 300± ft.
OL 71	414	28	+29	314	364	Yield 5 gpm at depth of 315± ft; total yield increased to 30+ gpm between depths of 315 and 365 ft. Further deepening of well resulted in decrease of 5 gpm in total yield.

1/ (+) indicates static water level above top of bedrock; (-) indicates static water level below top of bedrock.
2/ All depths are feet in bedrock, not depth below land surface.

bedrock fractures were developed over a considerable area they constituted a series of zones of close fracturing separated by intervals in which the distance between fractures was much greater. It is likely that different layers of bedrock have responded differently to regional stresses and that a well drilled across the strike of the layering from a "dry" well is less likely to encounter barren unfractured bedrock than one drilled directly along the strike if the distances are equal. Published maps showing the attitude of the bedding in the area are listed at the end of this report in the section entitled "Selected References."

What is the optimum spacing between productive bedrock wells? The scarcity of detailed subsurface data on joints makes a precise answer impossible but the high cost of land, the growing number of wells, and the increasing cost of wells makes some working rule desirable. A rough rule-of-thumb is that the distances between wells should be at least twice the thickness of the aquifer. As previously indicated, the water-bearing part of the bedrock is ordinarily about 150 feet thick, suggesting a minimum separation of 300 feet between wells if they penetrate average bedrock or if evidence to the contrary is lacking. Two closely spaced bedrock wells in New London illustrate the rule. Well NL 22 was drilled to a depth of 455 feet and no water-bearing fractures were encountered below a depth of 185 feet (150 feet below the top of the bedrock). Its yield of 8 gpm was inadequate and a second well was drilled 150 feet away, a distance about equal to the saturated bedrock thickness at a site and about half the distance suggested by the rule. The second well was abandoned at a depth of 177 feet when a test indicated that its water level declined in response to pumping from the first well. Adequate spacing between wells does not guarantee that they will yield enough water but it safeguards whatever yields are obtainable. Where bedrock wells are spaced too closely, their cones of depression intersect and result in steeply declining pumping levels. The net effect is a decrease in the saturated thickness of the bedrock aquifer tapped by the wells and a decrease in productivity. Well interference is complicated by extreme differences in permeability between zones of fractured and unfractured bedrock. In general, cones of depression may be expected to be shallower but to expand more readily along the strike of the layering and along the more highly fractured bedrock.

Faults, fractures along which differential movement of rock masses has occurred, are an additional structural factor affecting the yields of

Table 28.--Prolific bedrock wells situated at or near faults

Well no.	Topographic situation	Depth of well (ft)	Depth to bedrock (ft)	Type of overburden	Yield (gpm)	Specific capacity (gpm/ft of dd)	Remarks
NSn 36	terrace	65	60	stratified drift	>40	>1.14	Well penetrates only 5 ft of bedrock. Near contact of gabbro and gneiss. Published in Conn. Water Resources Bull. No. 9.
NSn 40	valley	280±	17	till	<150	--	Situated near presumed eastern extension of Honey Hill fault. Water extremely hard.
NSn 41	valley	280	16	till	<150	--	Situated near presumed eastern extension of Honey Hill fault. Water extremely hard.
Nwh 15	hillside	135	19	till	55	.79	Situated about one mile west of south-trending fault and about one mile north of north-dipping Honey Hill fault.
Ps 59	terrace in valley	451	25±	stratified drift	66	.41	Situated close to Honey Hill fault. Depth to bedrock estimated from casing length of 29 ft.
Ps 60	valley terrace	387	20±	stratified drift	52	.35	Situated close to Honey Hill fault. Depth to bedrock estimated from casing length of 24 ft.
Ps 115	valley	96	15	stratified drift	50±	.8±	Situated at or near Honey Hill fault. Owner located well site by projecting a line from unfrozen patches in Avery Pond
Average	--	242	25	--	>80	>.70	

bedrock wells. Large water-bearing openings occur along some fault surfaces or along fault-associated joints. Well Ps 115 was located by its owner along a southwestern projection of a line of patches in Avery Pond that remained unfrozen longer than usual in winter. This well was drilled along a probable fault and yielded approximately 50 gpm, adequate for a public supply serving 60 people. Table 28 lists seven wells whose high yields and high specific capacities are believed to be due to their proximity to bedrock faults. Most of these are close to the Honey Hill Fault, a major fault trending eastward in the Norwich area (Goldsmith, 1963) or to its possible eastward extension. Faulted bedrock is more likely to form valleys where it is apt to be overlain by stratified drift, as suggested by the table, so that part of the above-average yields may be ascribed to other factors. Nevertheless, the average yield of 80 gpm in these seven wells is about 6 times the bedrock average of 14 gpm. However, records of wells with average or below-average yields situated near these faults indicate that locating a single well at a fault is no guarantee of success.

POTENTIAL YIELD

Geologic factors other than jointing and faulting which influence potential yields in bedrock include type and thickness of overburden,

Table 29.--Factors affecting yield of bedrock wells in the lower Thames and southeastern coastal river basins

Geologic setting	Hydrologic effects: Above-average yields	Average yields	Below-average yields
Topographic situation	Valley or lowland	Hillside	Hilltop or upland
Type of overburden	Stratified drift (sand and gravel)	Stratified drift or till	Till
Thickness of overburden	50 to 75 feet	0 to 50 feet	75 to 150 feet
Rock type	Gabbro, diorite and monzonite gneiss, schist and gneiss	Granite and gneiss, quartz schist	Quartzite

rock type, and topography. These factors have been studied in southern New England by Cushman and others (1953) and in the Shetucket River basin by Thomas, M. P. and others (1967). Some of their conclusions are summarized and adapted to conditions in the SCRBA in table 29.

It is extremely difficult to separate and evaluate these factors. For example: wells drilled in valleys may have high yields owing to favorable topography, to permeable overburden, or to both. Study of a large number of wells and their yields demonstrates that these factors are influential even if not readily separable.

Analysis of 240 wells in the SCRBA for which drawdown data are available indicates that those drilled into bedrock overlain by stratified drift yield slightly more (average 15.5 gpm) than those drilled into bedrock overlain by till or clay (average 12.3 gpm). Rock wells cased through overlying sand and gravel yield more water, on the average, despite the fact that they penetrate about the same thickness of bedrock (average about 140 feet) as do other rock wells. Similar results were obtained from bedrock wells in the Shetucket River basin (Thomas, M. P. and others, 1967, p. 61). The various factors interacting to produce differences in bedrock yields in the SCRBA are comparable to those in the Shetucket River basin in some additional respects.

Stratified drift is more permeable and transmits water to underlying rock fractures more readily than till, especially when bedrock wells are pumped (Cushman and others, 1953, p. 92). Moreover, bedrock in valleys (where stratified drift is most common) receives water from till and bedrock of the adjoining slopes whereas bedrock in hilltops and uplands, where till is the most common overburden, loses water to adjacent valleys. These conditions are reflected in the higher position of the static water level relative to the bedrock surface in the stratified drift-covered bedrock wells than in the till-covered bedrock wells. The average water level in 83 bedrock wells situated in valleys is 12 feet below land surface whereas the average water level in 133 bedrock wells situated on hillsides or hilltops is 20 feet below land surface. The pumping of a rock well on a hill results in a cone of depression whose expansion is limited by the size of the hill and by the lack of a substantial upslope area contributing water; in a valley the cone is capable of greater expansion because it can move up-valley and down-valley and because the bedrock also receives recharge from surrounding till-covered hillsides.

Stratified drift also has a greater average thickness than till. The thickness of stratified drift averages 35 feet in 63 bedrock wells compared to the average till thickness of 25 feet in 166 bedrock wells. Where overburden is thin or absent, as on steep rocky hillsides and uplands, overlying storage is largely absent and joints in the upper part of the bedrock may be dry except after soaking rains. Wells drilled in rocky uplands are likely to penetrate a greater-than-average thickness of unsaturated bedrock. The static water level is below bedrock surface in 40 percent of the till-covered bedrock wells whereas it is below the bedrock surface in only 17 percent of the stratified drift-covered bedrock wells.

Some factors partially offset the advantages favoring the bedrock wells in lowlands. Among these mitigating factors is the occurrence of a thin (about 8 feet) but widespread layer of tight glacial till between the stratified drift and the top of the bedrock (indicated on figure 34D). Another offsetting influence results from head differences in the bedrock; ground water in the center of a valley is under greater head than it is at higher elevations along the adjacent hillsides. The greater head in the valley may inhibit recharge to the bedrock from overlying sand and gravel. The overburden is commonly thicker at the center of a valley than it is at the sides and table 29 indicates that rock wells overlain by 0 to 50 feet of overburden have higher average yields than those covered by 75 to 150 feet of overburden. Possibly glacial action has removed more jointed permeable bedrock from the centers than from the sides of the valleys. Finally, competition for water is more intense in valley areas where heavy pumpage may dewater the bedrock.

In summary, the data from more than 200 wells indicate that a variety of factors, including structure of bedrock, thickness and kind of overburden, and topography influence the yield of bedrock wells. Above-average well yields suitable for small industrial, commercial, or community supply are most likely in valleys where bedrock is strongly jointed or faulted and where it is in hydrologic continuity with overlying saturated sand and gravel. The greater the number of favorable factors listed in table 29, the greater the likelihood of obtaining an above-average yield, but differences between wells are moderated by a few mitigating factors. Hence, average or below-average yields suitable for domestic or farm use can be obtained from bedrock almost anywhere in the basin.

TILL

Till, popularly called "hardpan," is a poorly sorted, nonstratified, unconsolidated deposit consisting of boulders, cobbles, gravel, sand, silt and clay laid down directly by glacial ice. It may contain thin lenses, stringers, or small irregular masses of stratified sand and gravel. Till forms a mantle covering the bedrock almost everywhere in the basin. It occurs just below the soil on most hillsides, hilltops and uplands, except where bedrock crops out. It is not shown as a separate unit on plate B but is combined with the bedrock which underlies it everywhere and is the principal source of water wherever till is the main surficial deposit.

PERMEABILITY

Permeability measurements of till in eastern Connecticut ranged from 0.2 gpd per sq ft for compact silty till to 120 gpd per sq ft for loose sandy till (Thomas, M. P. and others, 1967 p. 60). These data are based on laboratory analyses of undisturbed samples and on pumping tests of dug wells. A pumping test on well NSn 25, in the northeastern part of the SCRBA, indicated that the permeability of till there is about 0.48 gpd per sq ft. The low permeability of till is indicative of its poor water yielding capacity; it rarely yields more than a few hundred gallons per day, even to wells of large diameter.

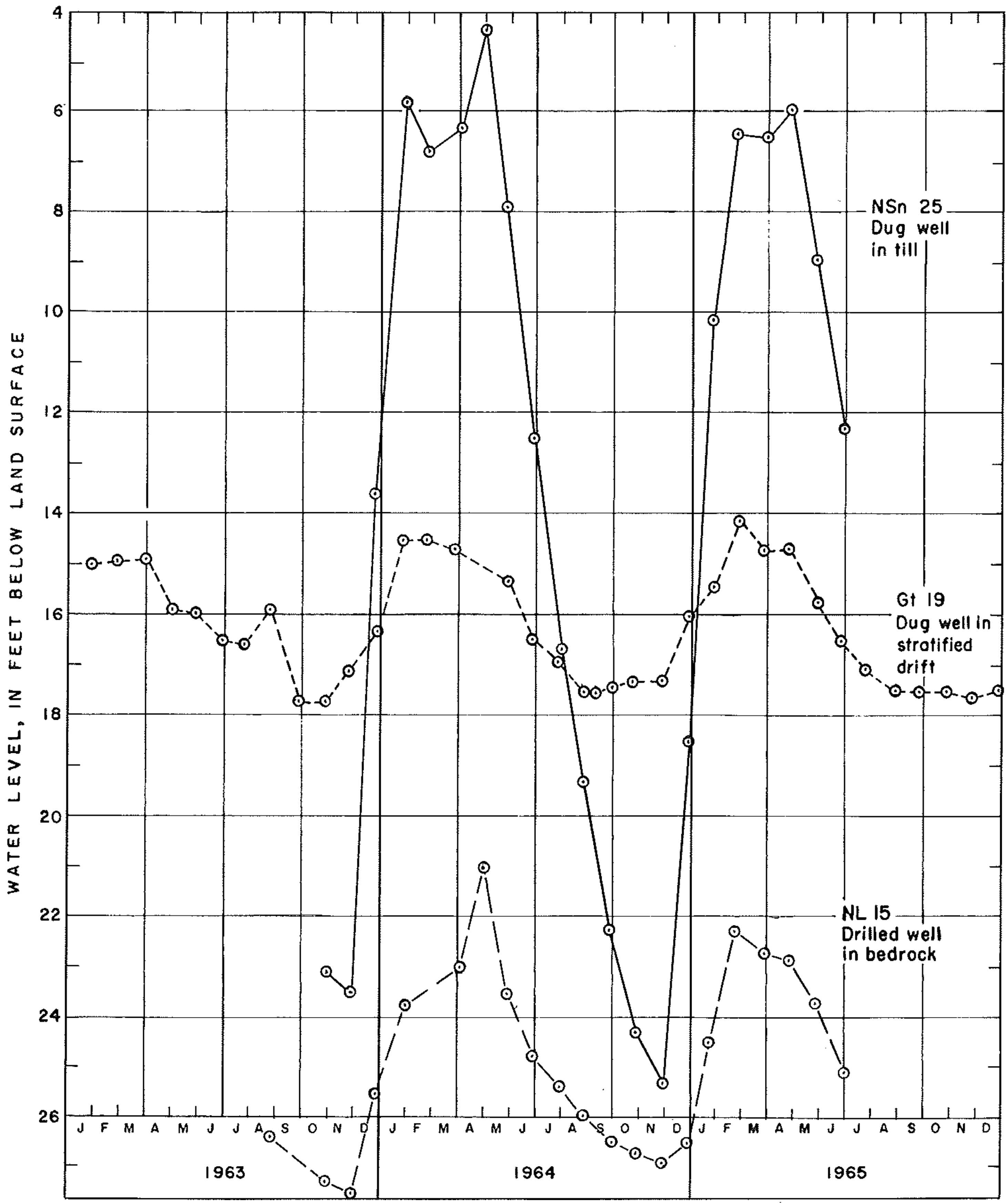


Figure 38.--Typical hydrographs of monthly water levels in wells in stratified drift, till, and bedrock

Records of a few wells pumping from till indicate that during droughts they are likely to be inadequate even for small domestic use. In Ledyard well Ly 71, shown on plate B, was inadequate for a family of four during August and September 1963 and 1964. This dug well contained at least 7 feet of water in the wet season; it was pumped dry during the dry season and recovered about 2 feet, equivalent to recharge of slightly less than 50 gallons, in 20 hours. In Preston, well Ps 117, which was ordinarily filled with 15 feet of water in the wet season, was pumped dry in the spring of 1962 and recovered about 15 feet, which is equivalent to recharge of about 550 gallons, in 12 to 15 hours. Even in non-drought years, the expansion of modern water-using appliances in the home makes it likely that the number of dug wells in till will continue to decline although a few may remain to supply small amounts of water for stock or similar small-scale use.

THICKNESS

Till in the report area ranges in thickness from less than a foot near bedrock outcrops to at least 110 feet at Stonington (well Sn 160, plate B), but commonly it is less than 40 feet. Where till is more than 40 feet thick, wells which penetrate it, and are tightly sealed into bedrock, are unlikely to be subject to contamination from near-surface sources (see p. 82). Sites where till exceeds 40 feet in thickness are shown by a "T" symbol on plate B.

WATER AVAILABLE TO WELLS

The water potentially available to wells in the SCRBA, as elsewhere in Connecticut, is from three principal sources: (1) ground-water outflow--the natural discharge of ground water to streams and the ocean, (2) induced infiltration of water from streams that flow across the aquifers and from lakes, and (3) water from ground-water storage. Additionally, some water is available from reduction of ground-water evapotranspiration losses; this potential is difficult to estimate in advance of ground-water development and is small relative to the total. Therefore, it is not considered as a source of water, and estimates are conservative to the extent that these losses are reduced. The availability of water varies with time and is dependent on the physical characteristics of the aquifers from place to place.

GROUND-WATER OUTFLOW

Ground-water outflow consists of ground-water runoff in stream channels, underflow in unconsolidated deposits underlying streams, and ground-water flow directly to the sea. In most parts of the SCRBA, underflow in deposits underlying streams amounts to less than $\frac{1}{2}$ of one percent of the total ground-water outflow. Flow directly to the sea through aquifers adjacent to the coastline amounts to nearly 40 mgd, or about 15 percent of the total outflow of 246 mgd. Ground-water runoff, on the other hand, forms most of the total ground-water outflow; accordingly ground-water runoff can be used as a conservative index to ground-water outflow.

Most ground water moves only short distances through the upper part of the saturated zone that extends from within a few feet of the land surface down to a depth of about 300 feet. It is while moving through this zone enroute to discharge outlets--in springs and seeps, stream channels, lakes, ponds, and the ocean that it can be tapped for withdrawal and use. It can also be tapped further downstream by capturing streamflow that is derived from ground water. In either case, withdrawal of ground water results in a corresponding reduction of streamflow. Withdrawal of fresh water through wells in the SCRBA amounted to only about 3,090 million gallons in 1964 as shown on figure 45. Nearly all the ground water withdrawn is returned to streams or underground disposal units in the area so that it is available for reuse.

Ground-water runoff varies seasonally each year as indicated on figure 38 by the water-level fluctuations in wells Gt 19, NL 15, and NSn 25 which tap stratified drift, bedrock, and till respectively. The rate of ground-water runoff is highest when the water table is highest. The water table is generally highest in late spring and declines rather steadily thereafter during a 4 to 6-month period lasting from late spring to autumn. The decline of the water table during this period indicates net ground-water outflow and decreased storage. This period, hereafter termed the period of no recharge, corresponds closely to the growing season, and the ground-water discharge stems largely from the demands of evapotranspiration, soil moisture, and ground-water outflow. After the growing season and when soil moisture is at maximum capacity, recharge from precipitation commences, water levels begin to rise, and the rate of ground-water runoff increases. Usually the rise is erratic during the winter owing to alternate freezing and thawing of soil and accumulated frost and snow, but in the spring, water levels rise rapidly because snowmelt and spring rains readily infiltrate thawed soil.

In analyzing the potential yield of ground-water reservoirs it is assumed (on the basis of estimates of available ground-water storage) that storage in the reservoirs is capable of supplying the withdrawals during the period of no recharge. Accordingly, with respect to withdrawals, only the annual variations in ground-water runoff are of interest--as long as the withdrawal does not exceed the annual ground-water runoff there will be no long-term decline of water levels.

GROUND-WATER RUNOFF

Long-term streamflow records on unregulated streams, necessary for hydrograph analyses of stream discharges with respect to separation of the amount of streamflow derived from the ground and the amount derived from overland flow, are not available in the report area. However, comparison of the water budget (precipitation, stream discharge, and evapotranspiration) of the report area with water budgets from the adjacent upstream Shetucket River and Quinebaug River basins (table 2) indicates close similarities in the disposition of water in all three basins. This is to be expected because precipitation and physical characteristics are similar in the three areas. Accordingly, the rate of ground-water runoff from the SCRBA was estimated as a percentage of the total runoff, based on comparative

Table 30.--Average annual ground-water runoff related to percent stratified drift in the Quinebaug River and Shetucket River basins

Station no.	Name and location	Drainage area (sq mi)	Percent of area underlain by stratified drift (%)	Average annual ground-water runoff based on hydrograph separation		Percent of time streamflows equivalent to average annual ground-water runoff are equaled or exceeded
				in	mgd/sq mi	
1254.9	Little River at Harrisville	35.5	15.9	11.67	0.556	55
1256	Mashamoquet Brook at Abington	11.00	6.5	10.53	.502	61
1269.1	Lowden Brook near Voluntown	2.40	0	7.84	.374	65
1269.23	Denison Brook at Voluntown	4.01	53.6	14.57	.694	70
1196	Ash Brook near North Coventry	2.73	0	6.72	.360	60+
1205	Safford Brook near Woodstock Valley	4.08	.8	8.43	.413	60+
1198.2	Skungamaug River at North Coventry	23.5	19.7	13.95	.664	50

data from the upstream basins. On this basis, the long-term annual average ground-water runoff from the SCRBA is about 43 percent of the total measured runoff (see p. 6), or about 11 inches.

Ground-water runoff varies from place to place and year to year depending on differences in geology and variations in precipitation. Analyses of flow-duration data for several tributary basins in the SCRBA shows that ground-water runoff increases with an increase in the percentage of stratified drift in the basin; this relationship was shown to be valid on the basis of hydrologic budget studies in several small tributaries in the Quinebaug (Randall and others, 1966) and Shetucket basins (Thomas, M. P. and others, 1967) to the north.

As a basis for estimating ground-water runoff from flow-duration data, ground-water runoffs determined by hydrograph separation methods were used to establish the relationship between ground-water runoff and the percent of time that streamflow equivalent to ground-water runoff was equaled or exceeded in seven small tributaries in the Quinebaug and Shetucket basins. These data are shown in table 30. The percent of time that streamflow equivalent to ground-water runoff was equaled or exceeded for these basins is plotted against the percent of stratified drift in the basins on figure 39, and a line is fitted to the data plots. Denison Brook basin, with 54 percent stratified drift, departs from the general relationship and is not plotted.

Knowing the percent of stratified drift in several basins in the SCRBA, the graph in figure 39 was used to estimate the percent of time in the basins that streamflow equivalent to ground-water runoff is equaled or exceeded. From the flow-duration data from the SCRBA (table 5) the amount of streamflow equivalent to annual average ground-water runoff was determined. These data are shown in table 31 for 24 small basins in the SCRBA and percent stratified drift is plotted against ground-water runoffs estimated from the flow-duration data in figure 40.

In an area containing 100 percent stratified drift almost all the total runoff would be ground-water runoff. Theoretical values of ground-water runoff were plotted on figure 40 at the 100 percent stratified-drift ordinate based on the assumption that 95 percent of the total runoff from stratified drift is ground-water runoff. These points were used as guides in constructing the curves beyond the 22 percent stratified drift ordinate in the graphs.

The estimates of ground-water runoff based on the method described above assume that 1) differences in total runoff from place to place reflect variations in precipitation, 2) the ratio of ground-water runoff to total runoff remains constant from year to year, and 3) hydrologic conditions in the SCRBA are similar to those in northeastern Connecticut.

The assumption that the ratio of ground-water runoff to total runoff remains constant from year to year introduces errors into the estimates of ground-water runoff made from the analysis of the streamflow data. Variations in total yearly runoff are due mostly to variations in direct runoff, but variations in yearly ground-water runoff are less severe. The errors implicit in the assumption are smaller in basins underlain predominently by till and bedrock and larger in basins containing significant amounts of stratified drift. This is because variations in ground-water runoff in

Table 31.--Estimated ground-water runoff at stream-gaging stations in the lower Thames and southeastern coastal river basins

Index no. (Pl. A)	Name and location	Drainage area (sq mi)	Percent stratified drift	Percent of time streamflow equivalent to average annual ground-water runoff is equaled or exceeded, from figure 38	Equivalent average annual ground-water runoff, from flow-duration curves			Ground-water runoff (inches)	
					(cfs per sq mi)	(mgd per sq mi)	(inches)	Exceeded 7 years in 10	Long-term minimum
1182.55	Green Fall River at Laurel Glen	6.79	8.4	59	0.88	0.57	11.94	9.55	6.57
1183	Pendleton Hill Brook near Clarks Falls	3.85	7.8	60	.88	.57	11.94	9.55	6.57
1183.5	Green Fall River at Clarks Falls	19.8	14.4	56	.96	.62	13.03	10.42	7.17
1183.7	Yawbucs Brook near North Stonington	2.42	13.2	57	.88	.57	11.94	9.55	6.57
1183.75	Assekonk Brook near North Stonington	1.66	2.9	63	.60	.39	8.14	6.51	4.48
1183.8	Assekonk Brook at North Stonington	4.00	17.8	54	.94	.61	12.76	10.21	7.02
1187.5	Haleys Brook near Old Mystic	4.25	11.1	58	.80	.52	10.86	8.69	5.97
1188.5	Eccleston Brook at Noank	2.94	11.9	58	.80	.52	10.86	8.69	5.97
1272	Bartlett Brook near Colchester	13.3	21.9	51	1.07	.69	14.52	11.62	7.99
1272.5	Deep River near Colchester	3.97	13.4	57	.87	.56	11.81	9.45	6.50
1272.9	Yantic River at Gilman	37.4	20.8	52	1.07	.69	14.52	11.62	7.99
1273	Pease Brook at Lebanon	3.11	3.3	63	.53	.34	7.19	5.75	3.95
1273.1	Pease Brook near Lebanon	7.77	8.6	60	.62	.40	8.42	6.74	4.63
1273.8	Susquetonscut Brook at Lebanon	5.41	9.4	59	.77	.50	10.45	8.36	5.75
1273.9	Susquetonscut Brook at Franklin	12.7	14.5	56	.87	.56	11.81	9.45	6.50
1274	Susquetonscut Brook at Yantic	15.4	16.4	55	.93	.60	12.62	10.10	6.94
1275	Yantic River at Yantic	88.6	19.8	52	1.02	.66	13.85	11.08	7.62
1276.8	Trading Cove Brook near Montville Center	5.04	8.3	60	.79	.51	10.72	8.58	5.90
1277	Trading Cove Brook near Thamesville	8.70	13.1	57	.93	.60	12.62	10.10	6.94
1277.4	Stony Brook near Uncasville 1/	4.72	16.1	55	.94	.61	12.76	10.21	7.02
1277.6	Hunts Brook at Quaker Hill	11.3	9.0	59	.85	.55	11.54	9.23	6.35
1277.7	Jordan Brook at Waterford	3.53	19.8	52	1.14	.74	15.48	12.38	8.51
1277.8	Latimer Brook at Chesterfield 2/	4.25	19.3	53	1.14	.74	15.48	12.38	8.51
1277.9	Latimer Brook at East Lyme 2/	12.5	15.8	55	1.08	.70	14.66	11.73	8.06

1/ Does not include area above, or flow from, Stony Brook Reservoir.
2/ Does not include area above, or flow from, Fairy Lake, Barnes and Bogue Brook Reservoirs.

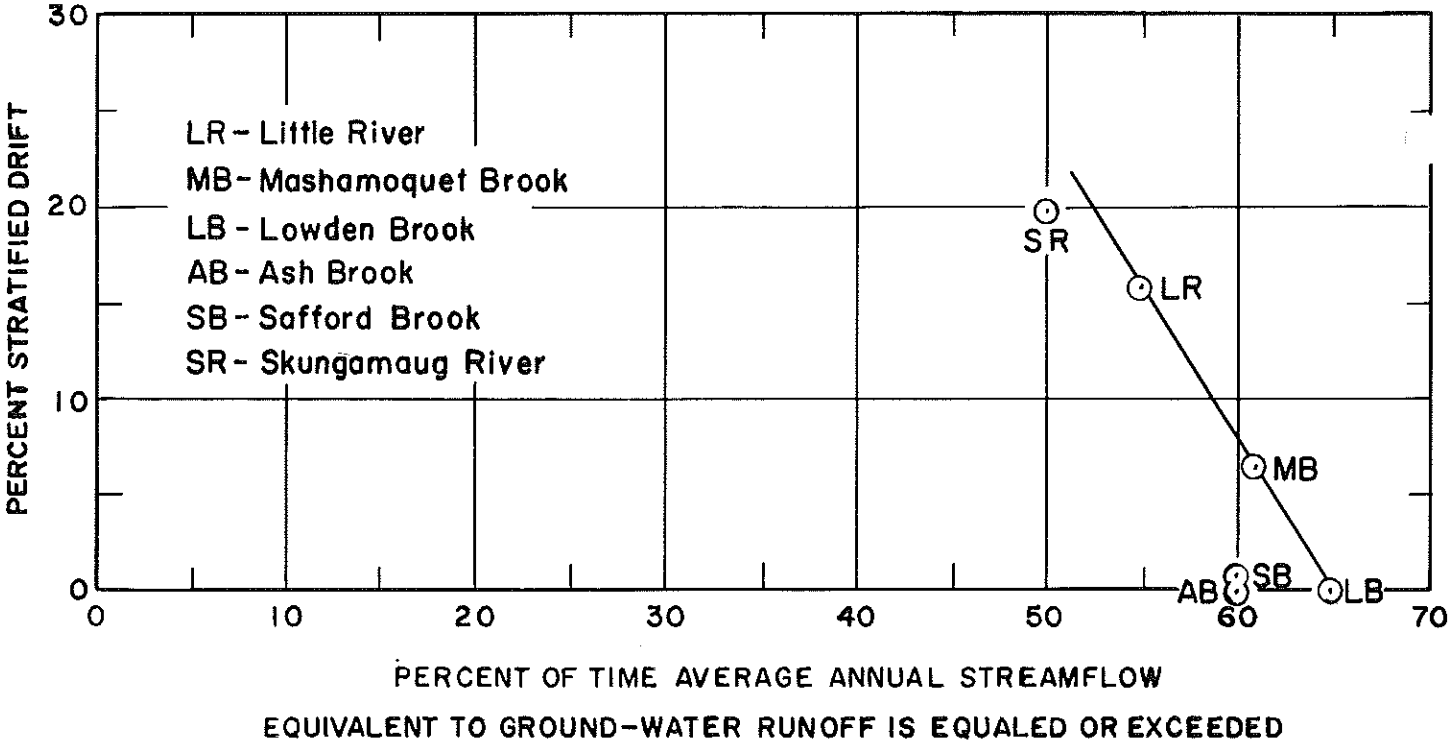


Figure 39.--Percent stratified drift related to duration of streamflow equivalent to ground-water runoff

till-bedrock basins more closely parallel variations in total runoff than do the variations in basins containing significant amounts of stratified drift.

The runoff values used to estimate average annual ground-water runoff, long-term minimum ground-water runoff, and ground-water runoff exceeded 7 years out of 10 were adjusted to average regional runoff conditions to eliminate the effects of variations in precipitation from place to place. Average annual runoff in eastern Connecticut is about 1.16 mgd per sq mi or 24.43 inches. Average annual ground-water runoff for each basin listed in table 31 was estimated by multiplying the value for equivalent average annual ground-water runoff by the ratio of regional average annual runoff to average runoff for the basin as determined from the isopleths on figure 17 (see p. 18). Long-term minimum runoff in eastern Connecticut is about 55 percent of the average runoff, and the runoff exceeded 7 years out of 10 is about 80 percent of the average runoff. Accordingly, the estimated average annual regionalized ground-water runoffs for the basins were multiplied by 55 percent and 80 percent respectively to determine long-term minimum ground-water runoffs and ground-water runoffs exceeded 7 years in 10.

Despite the limitations of the method used, the curves in figure 40 provide a useful means for making a reasonable first approximation of ground-water runoff. The curves can be used most reliably for drainage basins containing less than about 20 percent stratified drift, which includes most basins within the SCRBA. It must be remembered that in using the curves to determine ground-water runoff from a particular area, the values taken from figure 40 should be adjusted to local conditions by using the isopleths on figure 17, as described on p. 15.

GROUND-WATER STORAGE

The aquifers in the SCRBA store ground water very much like surface reservoirs store streamflow. The stratified drift aquifers make up a small part of the water-bearing deposits in the area but have large storage capacities. By contrast the till and bedrock aquifers, which make up most of the water-bearing materials in the area, have small storage capacities--the till because it is heterogeneous and thin, and the bedrock because little of its volume is occupied by open fractures.

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

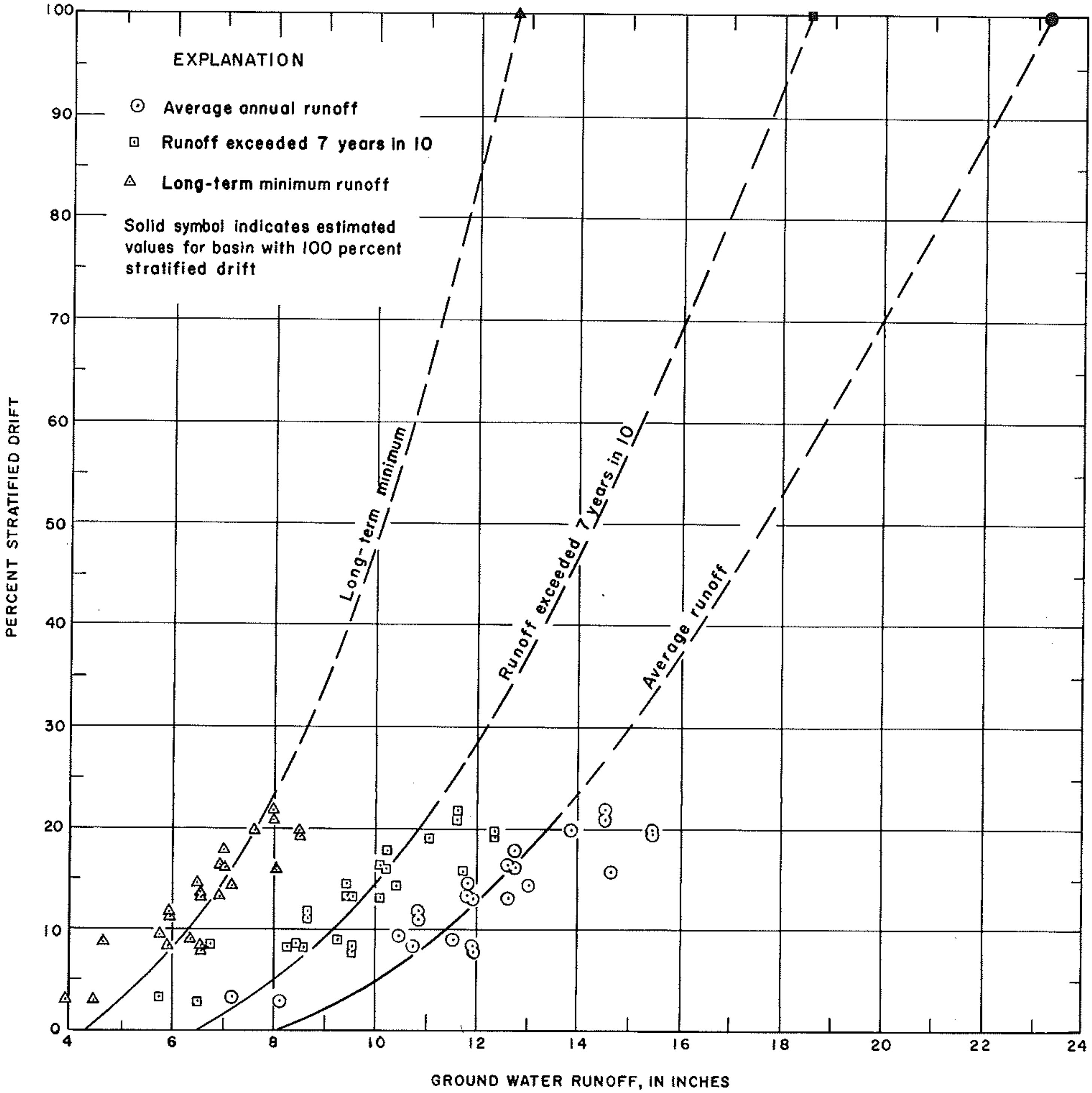


Figure 40.--Relation of ground-water outflow to percent of drainage area underlain by stratified drift

Table 32.--Long-term changes of water level in wells in the lower Thames and southeastern coastal river basins

Well no.	Depth (ft)	Main aquifer	Depth to water below land surface: Old measurement (ft)	Old measurement (date)	New measurement (ft)	New measurement (date)	Remarks
ELy 26	431	Bedrock	30	8-24-36	28.3	7-26-63	Unused.
ELy 38	100	Stratified drift	27.5	6- -35	27.3	5- 6-65	Used 6 months of year.
ELy 39	110	Stratified drift	27.5	6- -36	26.9	5- 6-65	Used 6 months of year.
Mv 18	15.4	Stratified drift	13.5	3-12-51	13.3	8-29-63	Supplies 5,000 gpd.
Mv 32	150±	Bedrock	17.5	-47	17.4	11-22-63	Supplies sanitary water for 45 people.
Mv 33	122	Bedrock	15	4- -46	12.5	9-19-63	
M 71	223	Bedrock	55	-49	56.6	9-17-65	Supplies 200 gpd.
NL 10	21.7	Till	16.6	8-20-41	17.9	8-17-64	Abandoned. Former U.S. Geological Survey observation well.
Ps 59	451	Bedrock	6.6	6-11-48	6.4	9-12-63	Abandoned.
Ps 67	120	Stratified drift	68.3	7-17-50	69.7	9-11-63	Supplies 220,000 gpd.
Ps 110	109.3	Stratified drift	70.2	9-30-53	71.3	10- 7-64	Nearby wells pumping on 10-7-64.
Ps 112	40.0	Stratified drift	6.7	10- 2-53	6.7	10- 8-64	
Wt 6	14.0	Stratified drift	9.9	11-11-37	9.9	7-18-63	Abandoned
		Average (mean)	28.0		28.0		

The specific yield of an aquifer provides an index of available ground-water storage when water levels are lowered for a period of time sufficient to allow complete drainage by gravity. Specific yield values for materials composing stratified drift deposits in the SCRBA range from 26.9 to 37.8 percent, as shown in table 24. These values are in good agreement with laboratory-determined specific yield values for similar materials in northeastern Connecticut and in the upper Pawcatuck River basin in Rhode Island (Allen, W. B., and others, 1963). However, they are probably too high as an index of the amount of water that could actually be obtained from storage because water levels would rarely be lowered for sufficiently long periods to attain complete drainage. Accordingly gravity yield, which takes into account the length of time materials are actually subject to drainage, is the most useful index of ground-water storage that is available for withdrawal. The longest period of time that a saturated section of stratified drift or other water-bearing material would be subject to drainage without recharge under ordinary conditions is the annual 4- to 6-month period of no net recharge during which water levels decline from the annual peak in the spring to the annual low point in the autumn. During this period, only the uppermost part of the dewatered section would be subjected to drainage for the entire period, and the lowermost part of the dewatered section would be subjected to drainage for only a few days at the end of the growing season before autumn recharge commences. On this basis the specific yield values determined in the laboratory as shown in table 24 were adjusted downward to determine a value for gravity yield of stratified drift allowing for incomplete drainage of dewatered section of the aquifers during 4-6 months of no recharge. A value for gravity yield of 25 percent was computed which probably is representative for average conditions throughout the area. This value probably approximates the gravity yield value for the saturated section of stratified drift at most places in the area. It is in good agreement with the value of 23 percent for gravity yield in the Quinebaug basin computed by Randall and others (1966, p. 67).

The amount of ground water in storage at the beginning of the no recharge period varies each year and is significant with respect to potential withdrawal and amount of available drawdown during the summer months. The hydrographs in figure 37 show only about two years of record but long-term measurements for Gt 19 (Meikle and Baker, 1965, p. 12) confirm the absence of a pronounced long-term trend of either higher spring or lower autumn ground-water levels. During the two-year period of record shown in the hydrographs, the water level in each well reached nearly the same peak each year--thus, under natural conditions precipitation has been almost adequate to replenish ground-water storage to close to capacity each year. The slight differences in the ground-water storage reflected by the decline in peak water levels represent only a small proportion of the total ground-water storage. Thus, where sustained large withdrawals are needed during the period of no recharge when most of the water would come from ground-water storage, the limiting factor in the development of ground-water supplies is the distribution of relatively thick, permeable materials within the stratified drift aquifer. Despite the drought, the absence of any long-term downward trend in water levels in any of the aquifers is indicated by table 32 which compares old measurements of water levels in a few wells with newer measurements separated by intervals of 11 to 30 years.

INDUCED INFILTRATION

Under natural conditions ground water in most of the SCRBA flows toward streams and lakes. However, pumping from wells creates cones of depression which may extend to the surface-water body, thereby reversing the hydraulic gradient and inducing stream or lake water to infiltrate into the ground-water

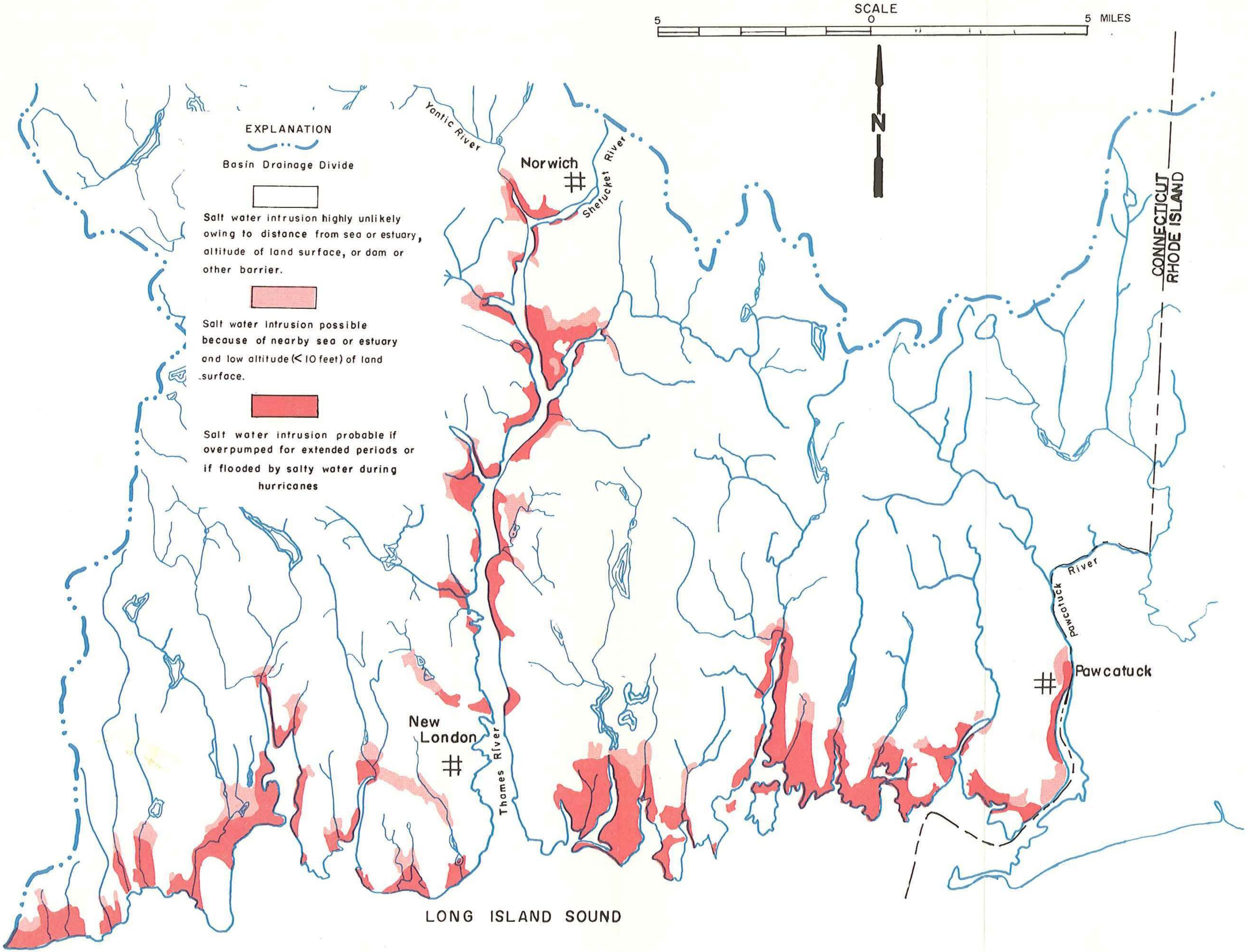


Figure 42.--Map showing salty water in the lower Thames and southeastern coastal river basins (shown only in areas of stratified drift)

reservoir. Thus where coarse-grained stratified drift borders and is hydraulically connected to a fresh-water body, surface water is an important potential source of water for wells.

The quantity of water that wells could pump by induced infiltration depends on (1) the area of streambed that is affected by pumping, (2) the vertical permeability of streambed and aquifer materials, (3) the temperature and thus the viscosity of the water, and (4) the vertical hydraulic gradient between the surface-water level and the ground-water level. This quantity may be estimated from a modified form of Darcy's law as adapted from Walton (1962, p. 14):

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

Q = Quantity of vertical leakage of water from stream or lake in gpd

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

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

Δh = Change in hydraulic head, in feet, and

m' = Thickness of the deposits retarding infiltration, in feet, and

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

The vertical permeability of the uppermost deposits lining lakes, ponds, and streams may be the chief factor limiting induced infiltration. These deposits consist largely of muck, silt and fine sand, which would restrict or prevent induced infiltration. A pumping test at Montville by Ranney Method Water Supplies (table 26) to determine whether a supply of three to five million gpd could be obtained by induced infiltration from Oxoboxo Pond at Uncasville indicated the lack of a free hydraulic connection between the pond and the stratified drift aquifer.

A study of the vertical permeability of streambed material on the Rhode Island side of the Pawcatuck River by the Providence, R.I. office of the U.S. Geological Survey indicates that the fine-grained sediments overlying the coarse-grained sediments are discontinuous. Two additional shallow test probes on the Connecticut side of the river indicate that fine-grained alluvial material is also discontinuous at these sites. Hence favorable conditions for induced infiltration prevail along both banks in reaches where streambed materials are coarse grained. Induced infiltration probably contributes to the high pumping rates of 736 gpm from a single gravel-packed well and of 1,390 gpm from a battery of 102 wells of the Westerly Water Supply Co. near the Pawcatuck River. The wells are situated a few hundred feet east of the State line in Rhode Island but stratified drift also extends along the west side of the river in Connecticut.

Calculation of the maximum potential infiltration capacity of stream- and lake-bottom deposits (table 39, column 3) is based on the equation shown above. The widths of the larger streams such as the Pawcatuck River are based on field measurements, elsewhere, they are estimated from topographic maps, as are stream lengths. Vertical permeability is assumed to be 50 gpd per sq ft for coarse-grained stratified drift and 1 gpd per sq ft for fine-grained deposits (lake-bottom and alluvial deposits). An intermediate value of 25 gpd per sq ft is used where both coarse-grained stratified drift and finer material are believed to line the streambed along closely-spaced reaches.

The permeability of the bottom deposits, like that of all deposits, is affected by changes in water temperature. Warm water can infiltrate more readily than cold water because its viscosity is lower. Thus, during the summer, when stream and lake temperatures reach 80°F or more, infiltration potential increases; during the winter, when water temperatures drop to near 32°F, it decreases. Randall and others (1966, p. 88) calculated that infiltration potential per square foot at a water temperature of 82°F in the Quinebaug River would be about one third higher than computed, and at a temperature of 32°F it would be about one third lower. Figure 31 shows water-temperature extremes of 83°F and 33°F in the Yantic River during a one-year period through September 1965. In computing values of induced infiltration, for the SCRBA, a water temperature of 55°F was assumed, based on the average of 254 measurements of streams in the area. These temperatures, ranging from 34°F to 83°F, are listed in the companion basic data report by M. A. Cervione, Jr. and others (1968). The average annual air temperature in the SCRBA is between 50°F and 51°F and mean daily water temperature in the larger streams is more commonly above than below mean daily air temperature at all seasons.

Seasonal modification of infiltration potential is less extreme than it might otherwise be because the summer period of relatively low water viscosity and consequent high infiltration potential generally coincides with the low flow period of most streams when the water is in contact with a smaller area of the stream channel. Conversely, the winter-spring period of cold temperatures and high viscosity commonly occurs during high flow periods, when more water is in contact with a larger area of stream channel. Moreover, enhanced scouring during peak flow removes fine material at these times, thereby increasing the permeability of the stream channels. However, peak water demands occur during the following summer season. Therefore, no great error will be introduced if temperature corrections are neglected in preliminary estimates of induced infiltration based on assumed vertical permeability.

Large supplies can be obtained from the stratified drift via infiltration galleries, horizontal permeable conduits for intercepting and collecting ground water by gravity flow (Todd, 1959, p. 146). The City of Des Moines, Iowa, obtains its water, amounting to more than 20 million gallons a day from an infiltration gallery about 3 miles long paralleling the Racoon River (Thomas, H. E., 1951, p. 142). Studies have shown that as much as 90 percent of the water produced by the gallery may be derived by infiltration from the bed of the river. Infiltration galleries are in use elsewhere but no such installation is known in the SCRBA. Regardless of the method used to induce infiltration, the water potentially available cannot exceed the amount of water in the stream or lake unless it is recycled. Estimates of the amount of water available from this

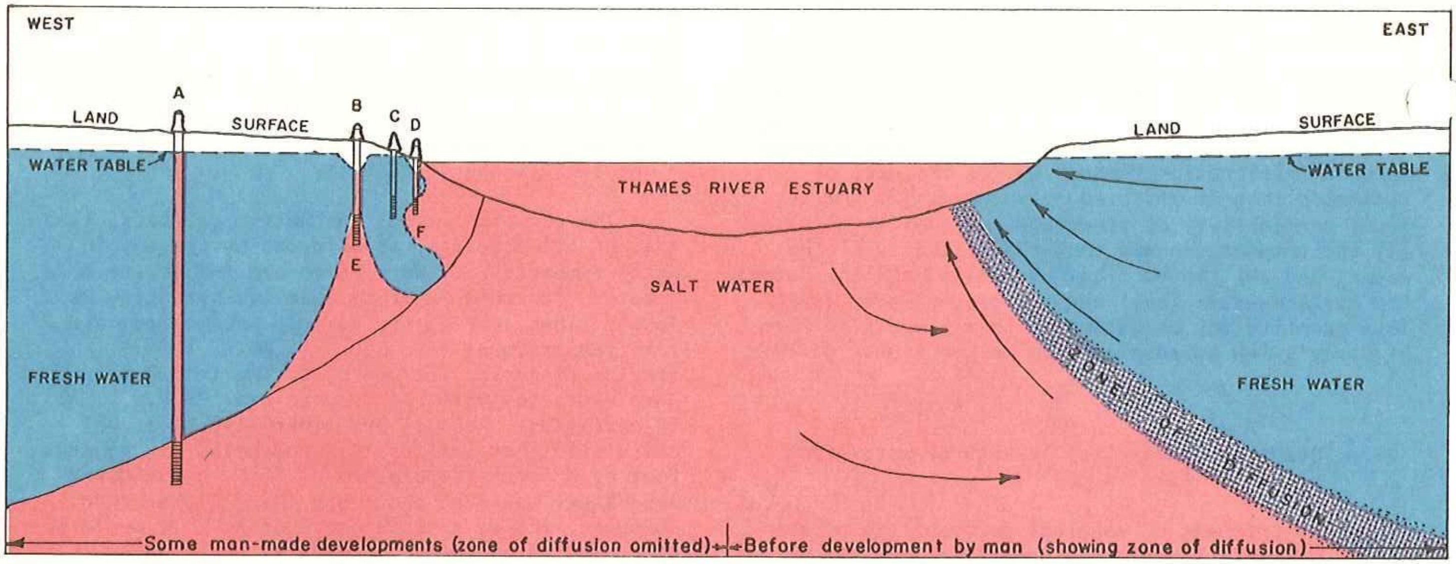


Figure 41.--Schematic diagram showing fresh-water and salt-water relationships in Thames River estuary

All wells assumed to be screened at bottom, as indicated. Arrows show direction of movement of water. (Right half of diagram adapted from U.S. Geological Survey Water-Supply Paper 1613-C.)

source should take into account the amount and variations of streamflow or lake storage.

SALT WATER ENCROACHMENT OF AQUIFERS

Salt water extends along the entire coast of southeastern Connecticut, extends inland in many estuaries and reaches its maximum northward extent at the mouth of the Shetucket and Yantic Rivers at Norwich. The subsurface relationship between salt water and overlying fresh water along the Thames River is shown diagrammatically in figure 41. The idealized spatial relationships shown in the figure are based on the work of Ghyben (1889) and Herzberg (1901). The Ghyben-Herzberg principle provides that fresh-water bodies in static equilibrium with sea water will assume definite shapes based on the difference in density. One foot of fresh water above sea level will theoretically depress the heavier sea water 40 feet below sea level in a continuous homogeneous aquifer. This relationship results in a wedge shaped fresh-water body extending inland from where it contacts sea water.

In practice, all the above assumptions are rarely met. The aquifers may not be homogeneous or may not be thick enough for equilibrium to be attained. Moreover, ground waters are not static but continually move and the contact or interface between fresh and salt water is not sharp but may grade through a thick zone of diffusion. Nevertheless the principle is generally valid and figure 41 illustrates in a general way the relationship between fresh and salt water in the SCRBA.

The geohydrologic map, plate B shows that stratified drift along the Thames River estuary occurs only in scattered patches that in any single reach may be restricted to one bank. Even where it is continuous beneath the estuary, it is rarely thick enough for equilibrium between fresh and salt water to be attained. The relative impermeability of till and bedrock underlying the stratified drift distorts the shape of the fresh water lenses. Within the stratified drift, layers of differing permeability (see log of well Ps 67, table 23) affect the symmetry of the fresh water-salt water interface.

Mixing of salt water and fresh water in the zone of diffusion results from normal ground-water movement and fluctuations in ground-water movement resulting from tides or other causes. The width of the zone of diffusion has been discussed by Petitt and Winslow (1957, p. 29). Recently, Cooper (1964, p. C1) has suggested that where a zone of diffusion exists, sea water is also in motion; it flows in a cycle from the sea floor into the zone of diffusion and back to the sea again. This cyclic flow lessens the extent to which salt water occupies the aquifer. The zone of diffusion as adapted from Cooper is shown on the east side of figure 41. Conditions are believed to be similar on the west side of the river wherever saturated stratified drift is extensive but the diffusion zone has been omitted here to avoid crowding. Instead, the effects of pumping from wells near salt water are illustrated here and are described in a following section.

Salt water has intruded aquifers in coastal and estuarine areas where wells have been overpumped near the sea. Table 33 lists 34 wells in which salty water has been encountered. Each of the three aquifers is vulnerable but intrusion is most commonly reported in stratified drift. The high permeability of the stratified drift results in relatively shallow but wide cones of depression during pumping. Expansion of the cones during heavy and prolonged pumping may result in their intersection with Long Island Sound or with a nearby estuary. Figure 42 indicates areas of stratified drift with differing degrees of vulnerability to intrusion; zone C is closest to salt water and is most susceptible to intrusion; zone B is farther from the sea and intrusion is possible, but less likely; no cases have

Table 33.--Selected wells reported to have yielded salty water in the lower Thames and southeastern coastal river basins

Well no.	Altitude above M.S.L. (ft)	Type of well	Depth of well (ft)	Aquifer	Static water level: Below land surface (ft)	Static water level: Date measured	Pumping level below land surface (ft)	Approximate horizontal distance to nearest salt or brackish surface water body (ft)	Use	Remarks
ELy 26	42	Drl	431	Bedrock	28.3	7-26-63	200	350±	Inst	Water obtained at depth of 100 ft. Salty, never used.
ELy 27	15	Dug	13.7	Stratified drift	12.1	7-26-63	--	600	Inst	Salty; abandoned. U.S.G.S. observation well.
ELy 58	10	Dug	18	Stratified drift	8	7- -65	16	280	Inst	Never used.
Gt 42	8	Dug	10.3	Stratified drift	7.9	7-19-63	--	180	Inst	Salty; never used. U.S.G.S. observation well. Chemical analysis.
Gt 45	12	Dug	9.6	Stratified drift	8.0	7-19-63	--	200±	Dom	Contaminated by Poquonock River estuary in hurricane of 1938. Formerly slightly salty in dry seasons. Abandoned.
Ly 29	10	Drl	35	Stratified drift	7	-63	11	220	Ind	Intruded by salty water in fall of 1965. Highest chloride content was 360 ppm; average was 250 ppm.
Ly 30	10	Drl	35	Stratified drift	7	-63	--	210	Ind	Intruded by salty water in 1965. Situated 10 ft from Ly 29; specific capacity and other characteristics similar. Chemical analysis.
Ly 44	9	Drl	32	Stratified drift	7	-61	7.5	170	Ind	Supplies average of 360,000 gpd of salty water for cooling 6 months of year.
Ly 45	26	Drl	500	Bedrock	20?	-60±	200	300	Ind	Driller reports fresh water at depth of 200 ft; salty at greater depth. Chloride reported to be 2,000 ppm in letter dated 1-16-61. Destroyed.
Mv 1	24	Drl	165	Stratified drift(?)	--	--	--	500	Ind	Salty since 1940±. Scavanger well; pumped to waste 24 hrs a day. Chemical analysis.
Mv 2	24	Drl	143	Bedrock	33.5	8-27-63	--	525	Ind	Unused because pumpage results in salty water. Water level influenced by nearby pumping.
Mv 48	70	Drl	129	Stratified drift	70	8- 9-57	95	670	Test	Chloride content increased from 90 ppm to 157 ppm during 102-hr pumping test. Destroyed.
NL 4	52	Drl	200	Bedrock	8	-37	--	3,000±	Ind	Too salty for ice manufacture. Chemical analysis.
NL 17	8	Drl	140	Bedrock	5.5	10-23-63	135	225	Ind	Situated 1.5 ft from NL 18. Salty; abandoned.
NL 18	8	Drl	310	Bedrock	5.5	10-23-63	--	225	Ind	Situated 1.5 ft from NL 17. Salty; unsuitable for drinking and cooling.
Nwh 3	20	Drl	184	Bedrock	20±	--	<50	150	Com	Salty; abandoned.
Nwh 18	27	Drl	203	Bedrock	10±	--	180±	1,250	Ind	Became salty in 1946; abandoned.
Nwh 28	4	Drl	225	Bedrock	1.1	7-24-64	--	120	Com	Salty; never used.
OL 48	5	Drl	110	Bedrock	8.2	8- 5-57	--	200	--	Contaminated by sea water during flooding. Unused.
OL 62	9	Drl	524	Bedrock	8	--	175	1,200	PS	Slightly salty.
OL 66	10	Drl	45 - 60	Stratified drift or bedrock	6±	--	<20	500	PS	Supplied 12 houses. Became salty; destroyed.
OL 67	10	Drl	45	Stratified drift	8	-60	18±	550±	PS	Became salty in 1962; destroyed.
OL 70	10	Drl	28	Stratified drift	7	12-17-62	<28	600	PS	Used 1962-65. Became salty; unused.
OL 72	10	Dug	13 - 20	Stratified drift	8	--	12±	550±	PS	Overpumped; became salty in 1961. Pumped for first time in 5 years in 1965 and produced fresh water. Unused.
OL 73	10	Drl	354	Bedrock	10	1- 4-35	100	250±	Dom	Salty; never used.
OL 74	8	Dug	10±	Stratified drift	2±	--	9±	250±	Dom	Became salty after hurricane; abandoned or destroyed.
Ps 58	72	Drl	120	Stratified drift	69	-50	90	275	Inst	Standby well for Ps 67 which is 14 ft away.
Ps 67	72	Drl	120	Stratified drift	69.7	9-11-63	86	275	Inst	Chloride content increased from 6.5 ppm in 1951 to 695 ppm in 1953. Later pumped fresh water at reduced rate. Chemical analysis.
Ps 112	8	Drl ?	40	Stratified drift	6.7	10- 8-64	23	60	Test	"Salt" content increased from 8± to 269 ppm at depth of 63 ft.
Sn 130	8	Dug	8.6	Stratified drift	7.3	8- 8-63	--	50	Dom	Sometimes salty following hurricanes. Chemical analysis.
Sn 139	5	Dug	8.1	Stratified drift	5.7	8-13-63	--	600	Dom	Salty following hurricanes. Chemical analysis.
Sn 157	12	Drl	132	Bedrock	10±	-34	--	950±	PS	Slightly salty in fall of 1964.
Wt 6	12	Dug	14	Stratified drift	9.6	7-18-63	--	350±	Dom	Chloride 11 ppm in 1937. Reported to be salty; abandoned.
Wt 47	10	Dug	12.3	Till	8.4	8-19-64	12	60	Ind	Formerly salty. Used as discharge well for waste distilled water.

been reported in this study; zone A is so remote from saline water or is separated from it by barriers such that it is considered to be safe from intrusion regardless of the rate or duration of pumping. The map may be used in estimating the likelihood of salt water intrusion but it is not to be considered a substitute for careful testing to delineate the precise position of the zone of diffusion and the likelihood of salt water intrustion.

At Norwich Hospital, well Ps 67 and standby well Ps 58, shown in zone C in figure 42, intermittently pumped water of satisfactory chemical quality from stratified drift at a point about 275 feet east of the Thames River. Pumpage at a rate of about 500 gpm for about 20 hours daily supplied all hospital needs of 600,000 gpd in 1951 and 1952. In the winter of 1952-53, two additional pumps with a combined capacity of 1,000 to 1,500 gpm were temporarily installed on the hospital grounds during construction (written communication dated July 20, 1955). They pumped continuously for at least several days while the supply well continued pumping so that the maximum combined pumpage amounted to about 1,500 to 2,000 gpm. A pumping rate of 2,000 gpm at this site is theoretically capable of lowering pumping levels to 21 feet below the river level. Saline water subsequently intruded the aquifer. Its progress was marked by a hundredfold increase in chloride content from 6.5 ppm in April 1951 to 695 ppm in late 1952 or early 1953 (written communication dated September 1954) and the supply wells were shut down. The temporary pumps were soon removed and in 1958, daily pumping of the supply wells were resumed at the rate of 500 gpm but for a shorter period to supply 220,000 gpd. An additional 400,000 gpd is obtained from the Norwich Public Supply. At this daily withdrawal, pumpage of water of satisfactory chemical quality at the hospital continued through the period of record (1963-65).

At the Dow Chemical Co. plant in Ledyard, wells Ly 29 and Ly 30, each situated about 215 feet east of the Thames River estuary supplied 108,000 gpd of water by alternate but continuous pumping from stratified drift at a rate of 75 gpm. After more than a decade of pumping, ground-water levels declined below the level of the estuary in the fall of 1965 following several years of drought, and brackish water intruded the aquifer. The chloride content of the water rose to an average of 250 ppm and reached a maximum of 360 ppm on November 22, 1965 (written communication) and the wells were shut down. The manner in which the salt water may have intruded laterally inland is shown diagrammatically at F on figure 41. Resumption of pumpage on a restricted basis in 1966 yielded water of satisfactory chemical quality. This indicates that where intrusion is not too extensive, stratified drift is permeable enough so that salt water is flushed out within a comparatively short time after the natural hydraulic gradient is reestablished. However, even short shutdowns can be costly, particularly for large plants or public supplies.

Lateral intrusion, rather than intrusion from below, is believed to be the more common type of salt water intrusion in the SCRBA. The likelihood of salt water contamination due to such lateral intrusion may be determined if the aquifer constants, coefficient of transmissibility (T) and coefficient of storage (S) are known (see p. 54). For this purpose, the equation $s = \frac{114.6\,Q}{T}\,W(u)$ (see p. 54) is used to determine the maximum drawdown (s) at the closest source of salt water or brackish water at any distance (r) from the supply well pumping at given rate (Q) in gpm. The method of computing drawdown at any distance from a pumping well is described by Theis in Bentall, Ray, 1963, p. 319 and a less technical account may be found in Johnson, Edward E., Inc., 1966, p. 109.

Estimation of theoretical specific capacity may be very useful for preliminary indication of lateral contamination resulting from intersection of the cone of depression with nearby salt water. It provides a means of predicting approximate drawdowns in a well resulting from different pumping rates. For example, well Ps 67, previously affected by intrusion, taps an aquifer estimated to have a transmissibility of 140,000+ gpd per foot according to table 23. The aquifer is essentially nonconfined, and for water-table conditions, the storage coefficient is assumed to be 0.2. The table indicates that the corrected specific capacity is slightly less than 80 gpm per ft of drawdown. The static (non-pumping) water level is about 3 ft above sea level and pumping at a rate of 200 gpm would theoretically result in a drawdown of 2.5 feet $(\frac{200}{80} = 2.5\text{ ft})$ at the end of 24 hours or about a half a foot above the sea level. However, pumping at a higher rate of 2,000 gpm for 24 hours would result in a theoretical drawdown 10 times as great $(\frac{2000}{80} = 25\text{ ft})$ or about 21 feet below the sea level. Similar drawdown estimates can be made for any part of the report area where specific capacity can be estimated from transmissibility and where the elevation of the water table above sea level is known or inferable.

Of 34 wells in table 33, at least 13 tap bedrock. The small and steep cones of depression developed by pumping from the relatively impermeable bedrock and their slow rate of expansion decrease the chances of salt water intrusion. Additional protection is afforded by the higher altitudes, steeper hydraulic gradients, and lower pumping rates in bedrock wells. Nevertheless, persistent overpumping near an estuary or the ocean eventually results in intrusion. Although the overall area affected by a cone of depression in bedrock may be relatively small, expansion along fractured zones may be much greater than elsewhere. Bedrock wells are the only ones in table 33 situated more than 700 feet from salt water that have been affected by intrusion.

Dug wells constructed on low-lying land near the sea may be subject to yet another type of salt water contamination that results from flooding by estuary or ocean during high water. Dug wells are most vulnerable to such flooding during storms because many are of large diameter and of loose construction. Of five wells in table 33 reported to have become saline during or following hurricanes, four are dug wells.

In some places, salt water intrusion can be prevented by the deliberate pumping of salt water so as to lower its head relative to adjacent fresh water. A "scavenger well" system as a solution to the problem of vertical salt water encroachment has been studied by Long (1965). At the Uncasville plant of the Connecticut Light and Power Co., well Mv 1, situated about 500 feet west of the Thames River estuary continuously pumps salt water to waste. Nearby well Mv 3, situated about 175 feet north of Mv 1 and about 525 feet west of the estuary, pumps fresh water whose chemical quality is satisfactory for makeup water. Pumping is not metered but pumpage from Mv 1 appears to be adequate to maintain a hydraulic gradient from Mv 3 to Mv 1 so that the latter serves as a scavenger well. Both wells were drilled into bedrock but Mv 1 was subsequently plugged back to permit tapping of the overlying sand and gravel. Thus, unconsolidated sand and gravel and underlying bedrock appear to be hydraulically continuous here. Undoubtedly scavenger wells can be more widely used in coastal and estuarine parts of the SCRBA to prevent salt water encroachment in stratified drift or bedrock aquifers. Scavenger wells can double as supply wells if saline water is used for cooling or other purposes.

Another kind of well used to combat salt water encroachment is the recharge well, which returns used water to the aquifer. Water to be recharged must be of suitable chemical quality to prevent contamination of the aquifer and to enhance its compatability with water already in the aquifer. Water used for cooling and other purposes has been returned underground through recharge wells on Long Island, New York for many years. Experience here and elsewhere demonstrates the feasibility of this method of maintaining a fresh water body of large enough size and head to keep out salt water.

The amount of salt water intrusion may be expected to increase in coastal areas as the demand for water increases and as the number of wells grows. Some of the problems already encountered or likely to be encountered, are illustrated in figure 41. Overpumping at well B has created an upward-pointing salt water "cone of impression" into the fresh water lens. Salt water in the cone moves upward at E whereas a shallower well (C) which is closer to the estuary, is unaffected. Well A pumps salt water although it is situated farther inland than C which supplies fresh water. The variety and number of problems that may arise make it necessary to plan more carefully the development of water supplies in areas where salt water intrusion is a threat. Heavy pumpage from any area in zone C, figure 42, should be accompanied by periodic measurement of water levels in suitable placed observation wells and by chloride determinations or measurements of specific conductivity of ground water. Water levels are easily measured and can be checked by unskilled personnel using inexpensive equipment. Such monitoring, combined with the application of the principles of modern geohydrology, can eliminate costly shutdowns and other intrusion problems and maintain optimum pumping rates.

QUALITY OF GROUND WATER

The chemical quality of the ground water under natural conditions in the SCRBA is generally good for most uses. The crystalline bedrock underlying the report area and the glacial drift derived from it are composed largely of minerals which are only slightly soluble in water, and the dissolved-solids concentration of the ground water is correspondingly low based on the data from natural streams at low streamflow given in table 18 and samples collected from wells shown in table 34. Of the wells sampled, 92 percent yielded water with a hardness of less than 120 ppm and 88 percent had a dissolved-solids concentration of less than 200 ppm. Iron and manganese are troublesome constituents throughout the area; approximately 25 percent of the wells sampled had concentrations exceeding 0.30 ppm iron and/or 0.05 ppm manganese. The probability of troublesome amounts of these two constituents is greater in some areas than in others as discussed later. Along the coast and for some distance upstream along coastal streams brackish to salty water occurs naturally in aquifers, or has encroached under pumping conditions; the occurrence of salty water has been discussed in the preceding section.

The results of the chemical and physical properties of 187 chemical analyses of water from 158 wells in stratified drift, till, and crystalline bedrock are summarized in table 34. Comparable information for the adjoining Quinebaug and Shetucket River basins are also shown.

The most abundant dissolved chemical constituents in natural ground water in the SCRBA unaffected by salt-water intrusion are silica, calcium, sodium, bicarbonate, and sulfate. Other than where salt-water intrusion has occurred, no major constituent except iron and/or manganese occurred area-wide in concentrations large enough to limit the use of ground water for most purposes. Calcium is dissolved to some extent from all rocks in the SCRBA, but samples from a few scattered wells that contained far more calcium than the area-wide median of 12 ppm suggest that these wells obtain water from lenses of impure limestone or other calcium-rich rocks that have been mapped in various rock units. The ground-water runoff from aquifers that have calcium-rich materials will yield the higher dissolved-solids and calcium concentrations to streams. Surface-water samples collected from natural streams during low flow (flow exceeded 90 percent or more) would represent maximum concentrations that would be expected. Therefore, as shown on figure 28, dominant calcium-rich areas generally coincide with drainage areas of natural streams having relatively high dissolved-solids concentrations.

Generally calcium, magnesium, and sodium are present in the form of bicarbonates and sulfates in various proportions which determine the chemical and physical characteristics of the water. A comparison of some properties of calcium-sulfate waters and calcium-bicarbonate waters is shown in table 35. Most samples of natural ground water collected throughout the SCRBA are of the calcium-bicarbonate type; are not excessively hard, have a low noncarbonate (permanent) hardness, and are not corrosive. A few samples are distinctly calcium-sulfate type waters and have a lower pH and a higher noncarbonate hardness than calcium-bicarbonate water. The calcium-sulfate type waters are widely scattered throughout the SCRBA and result from localized conditions. Noncarbonate hardness due to the presence of sulfates and chlorides may form scale in pipes and boilers that cannot readily be removed.

Gypsum, a common source of calcium sulfate, does not occur naturally within the area, and the presence of large concentrations of calcium sulfate in ground water may be attributed to chemical weathering of

Table 34.--Comparison of chemical and physical characteristics of ground water in eastern Connecticut

(Chemical constituents, in parts per million)

Water-bearing unit	Basin	Range	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium and Potassium (Na+K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Nitrate (NO_3)	Dissolved solids (residue on evaporation at 180°C)	Hardness (as $CaCO_3$)	Specific conductance (micromhos at 25°C)	pH
Crystalline Bedrock	Lower Thames and southeastern coastal river basins	Maximum	28	8.2	0.94	416	20	74	128	1,040	32	1,830	1,120	1,860	8.1
		Minimum	3.8	.00	.00	2.2	.2	2.7	0	1.6	.1	24	3	56	4.4
		Median	17	.10	.02	17	3.9	12	46	17	3.7	118	57	180	7.2
	No. of wells sampled		29	98	91	58	51	28	43	44	22	97	97	97	97
	Shetucket River basin	Maximum	29	7.6	.95	60	14	52	197	62	63	a/ 401	210	617	8.0
		Minimum	6.3	.00	.00	3.2	.4	3.0	3	3.4	.0	a/ 31	12	42	5.3
		Median	17	.07	.01	15	2.4	8.0	39	17	.7	a/ 91	45	143	7.0
	No. of wells sampled		66	69	65	67	67	67	68	67	64	68	68	68	68
	Quinebaug River basin	Maximum	34	4.8	.94	97	14	56	197	39	60	409	279	617	8.6
		Minimum	6.9	.00	.00	1.4	.2	2.4	2	2.4	.0	24	7	33	5.1
		Median	17	.07	.00	16	2.2	7.6	52	13	.9	100	54	153	7.0
	No. of wells sampled		97	104	105	103	101	104	104	68	100	97	100	104	104
Stratified Drift	Lower Thames and southeastern coastal river basins	Maximum	19	2.3	.78	50	41	314	72	109	43	1,270	296	2,170	7.7
		Minimum	5.6	.01	.00	.7	.1	1.6	5	1.2	.3	36	2	50	5.8
		Median	11	.10	.02	13	3.2	12	25	17	3.2	96	42	158	6.9
	No. of wells sampled		13	51	49	44	44	36	41	38	18	51	51	51	51
	Shetucket River basin	Maximum	22	.35	.89	29	5.6	21	50	27	42	a/ 167	90	260	7.6
		Minimum	6.8	.00	.00	4.0	.6	3.9	13	5.8	.1	a/ 46	14	60	6.0
		Median	12	.14	.01	11	1.8	9.2	20	11	5.8	a/ 74	36	120	6.8
	No. of wells sampled		13	11	11	16	16	16	16	16	13	16	16	16	16
	Quinebaug River basin	Maximum	21	2.8	5.7	40	6.8	63	47	37	44	330	108	455	9.3
		Minimum	7.3	.00	.00	2.4	.3	2.6	4	.2	.0	31	9	39	4.8
		Median	14	.06	.01	11	1.8	5.3	25	12	2.9	80	37	117	6.5
	No. of wells sampled		30	34	33	35	35	35	35	34	30	34	35	35	35
Till	Lower Thames and southeastern coastal river basins	Maximum	22	8.1	.27	31	6.1	30	83	41	52	678	100	1,190	7.3
		Minimum	6.6	.02	.00	6.4	1.8	--	1	30	.0	40	22	70	5.0
		Median	8.6	.14	.01	9.2	4.2	--	23	36	11	82	36	118	7.0
	No. of wells sampled		5	7	7	6	6	1	5	2	4	8	8	8	8
	Quinebaug River basin	Maximum	34	.49	.10	72	11	47	93	26	26	434	211	550	7.7
		Minimum	9.1	.00	.00	4.2	1.2	3.6	15	6.9	.3	79	38	61	5.8
		Mean	15	.09	.00	17	3.0	8.0	44	13	8.3	108	50	147	6.6
	No. of wells sampled		12	14	12	14	13	14	14	12	12	13	12	14	14

a/ Dissolved solids calculated.

Table 35.--Comparison of some properties of calcium-sulfate type and calcium-bicarbonate type waters in the lower Thames and southeastern coastal river basins

Well no.	Calcium 1/	Bicarbonate 2/	Sulfate 1/	Hardness as $CaCO_3$ (ppm)	Noncarbonate (permanent hardness as $CaCO_3$) (ppm)	Specific conductance (micromhos at 25°C)	pH
Calcium-sulfate type water							
Hv 3	13	9.3	54	68	53	198	5.9
NSn 40	23	1.6	57	1,120	1,070	1,860	6.9
Calcium-bicarbonate type water							
Fr 2	18	29	3.6	21	0	78	6.9
NSn 11	19	24	9.8	48	8	126	7.5
Wt 12	16	53	12	90	2	265	7.6

1/ Percent of dissolved-mineral content.
2/ Percent of dissolved-mineral content as carbonate.

iron sulfide minerals. Sulfuric acid, a potential weathering agent, is a product of the oxidation of iron sulfide minerals. As sulfuric acid is generated, it reacts with calcium silicate minerals and impure limestone lenses in the rocks to form calcium sulfate which is dissolved readily by ground water.

As sulfate is a substantial part of the dissolved-solids content of atmospheric precipitation, precipitation is a source of some of the sulfate in ground waters.

The dissolved-solids concentration in wells affected by sea water intrusion ranged as high as 1,270 ppm; sodium as high as 314 ppm, and chloride as high as 607 ppm. The median values of these samples ranged from two-to-four-fold over that of the fresh water samples. The maximum chloride concentration reported by private industry was 1,458 ppm, far above the limit of 250 ppm recommended by the U.S. Public Health Service (1962). High chloride concentrations cause corrosion in pipes, boilers, and other fixtures unless special corrosion-resistant materials are used.

IRON AND MANGANESE

CHEMICAL BEHAVIOR AND EFFECTS

Iron and manganese are usually present in ground water in a low state of oxidation as ferrous, and manganous ions respectively. Ferrous iron is quite soluble under proper conditions and substantial amounts may be present in ground water. However, ferrous iron is unstable in the presence of oxygen and is changed to the ferric state by the process of oxidation, much as the iron in auto bodies, nails, etc. will rust in the presence of water and air.

Whenever ground water containing more than about 0.3 ppm of dissolved iron is exposed to the air, it becomes cloudy, and usually an orange-brown film forms on the surface it contacts. Prolonged contact forms a film or scale that is difficult to remove. This iron precipitate stains sinks, tubs, glassware, and other utensils, and fabrics. In addition, iron precipitates can clog filters, nozzles, well screens, and other appliances, as well as interfere with the manufacture of many industrial products. Excessive iron will also impart a metallic taste to the water, or to beverages prepared with the water. The presence of certain iron-metabolizing bacteria ("crenothrix") can further complicate these conditions by forming colonies that later break loose in massive accumulations.

Manganese resembles iron in its general behavior. Water containing more than 0.05 ppm of manganese will darken when exposed to air or to laundry bleach, as if black ink had been added to the water. Manganese precipitate forms a black film on porcelain sinks and kitchen utensils. Because manganese is commonly associated with much larger quantities of iron, however, its effects may be masked by those of iron.

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

DISTRIBUTION IN GROUND WATER

Most wells in the SCRBA yield clear water containing little or no iron or manganese. The percentage of wells sampled whose water contained iron and manganese equal to or greater than the limits recommended by the U.S. Public Health Service for drinking water are indicated in the following table:

	AQUIFER		
	Crystalline bedrock	Stratified drift	Till
No. of wells sampled for			
Iron	96	52	8
Manganese	89	50	8
Maximum concentration			
Iron (ppm)	8.2	2.3	8.1
Manganese (ppm)	.94	.78	.27
Percent of wells sampled containing			
0.3 ppm or more of iron 1/	27	21	25
0.05 ppm or more of manganese 1/	31	36	25

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

Even these percentages may be high for the report area as a whole, because sampling was more extensive in or near areas where iron-bearing water was known to be a problem.

It is possible that a well drilled almost anywhere in the SCRBA may yield ground water containing troublesome amounts of iron and/or manganese. However, the higher concentrations of iron and manganese in the waters from the bedrock aquifers occur in areas where the rocks, mostly schists and gneisses, contain iron sulfide and iron silicate minerals. Figure 26 shows at least 6 places in the SCRBA, designated by letters, where the concentration or areal extent of iron-bearing ground water deserve special attention. In these places, the weathering of the iron sulfide and iron silicate minerals leaves a characteristic rust-colored oxide coating on surfaces of exposed bedrock.

Area A.--Area A occupies a portion of the town of Colchester in the northwestern part of the report area as seen in figure 26. The bedrock in this area is a dark rusty-weathering schist (Brimfield schist of Rogers and others, 1959). Area A is similar to problem area A and unit A in the Quinebaug and Shetucket River basins respectively. Filter systems are used on numerous wells reported by owners to yield iron-bearing water. The iron concentrations in samples from 2 wells were 2.1 and 1.3 ppm, and the manganese concentrations were 0.21 and 0.10 ppm. Wells that obtain water with troublesome amounts of iron probably tap water in layers of schist containing graphite, purplish biotite, pyrite, and manganese silicates. Wells that obtain iron-free water from the bedrock in this area probably tap water from thin layers of lime-silicate and quartzose gneiss that are found within the Brimfield schist. Available data indicate that approximately 50 to 75 percent of the wells drilled in this unit in eastern Connecticut will yield water with concentrations of iron and manganese that require treatment before it is satisfactory for domestic or most industrial purposes.

Area B.--In the town of Preston a zone of iron-bearing ground water clearly coincides with a rusty-weathering graphite schist phase of the Putnam Group mapped by Snyder (1961) in southern Lisbon and western Preston. The graphite schist contains iron sulfides, and chemical analyses of rock samples show that it has nearly twice the percent of iron or manganese as in other rock units (Snyder, 1964b). Area B is an extension of problem area B described in the Quinebaug River basin report (Randall, 1966, p. 72 and figure 44). Of the wells sampled in this problem area, concentrations ranged as high as 6.2 ppm iron and 0.24 ppm manganese. A dug well tapping till in this area yielded slightly acidic water, but the dissolved-iron and manganese content was only 0.08 and 0.01 respectively. It appears that dug wells in till overlying this bedrock unit will yield water with relatively low dissolved-iron content.

Area C.--Several different rock types with a great variety in mineral composition make up this unit which underlies a part of the northwestern portion of the SCRBA. The major iron-bearing ground water in area C is restricted to a rusty-weathering muscovite schist. A characteristic bright rust-colored oxide coating on surfaces of exposed bedrock is evidence of the presence of iron-bearing minerals in this area. Water samples from 3 wells tapping this bedrock aquifer contained from 0.78 to 2.4 ppm of iron. In the pink-shaded portion of area C, lower iron concentrations are found and a purplish to brownish stain is noted on some outcrops of bedrock indicating at least local occurrence of iron-bearing ground water. Water samples collected from wells tapping the bedrock contained from 0.03 to 0.84 ppm of iron and 0.00 to 0.15 ppm of manganese. This same unit is noted as problem area E in the Quinebaug River basin and units B and C in the Shetucket River basin. About 15 percent of the samples contained quantities that could cause slight staining of porcelain and utensils after prolonged use (Randall and others, 1966).

Area D.--As reported by Randall and others (1966), a severe iron problem also occurs in a small area around Preston City. Chemical analyses show as much as 4.8 ppm iron, and well owners' complaints delineate this area along the border of the Quinebaug River basin and the SCRBA. Iron-bearing ground water is obtained from the stratified drift aquifer as well as the bedrock.

The bedrock lithology and associated iron problems in areas A, B, C, D as described above and noted both in the Quinebaug and Shetucket River basins trend north-south in this report area and are truncated by the Honey Hill fault. South of this fault zone, bedrock consisting of interfingered gneisses and schists dominate the region and trend structually east-west rather than north-south. The presence of the iron and/or manganese in excessive concentrations in the water from the bedrock has a spotty occurrence throughout that portion of the SCRBA south of the Honey Hill fault system. The majority of the iron-bearing ground water is in wells tapping schists that contain biotite, garnet, and iron sulfide minerals which weather relatively easy.

Areas E and F.--Area E is at Uncasville in the town of Montville, and area F is in the extreme southwestern part of the SCRBA in the town of Old Lyme as shown on figure 26. Areas E and F are in discharge areas covered by stratified drift where iron-bearing ground water occurs both in the stratified drift and underlying schists.

Recent geologic mapping by Goldsmith (1967) in the Uncasville quadrangle pinpoints the source of iron in area E, as a member of the Plainfield formation which locally contains pyrite. In some cases the stratified drift overlying this bedrock unit also yields water containing iron and/or manganese in excessive quantities. Water samples collected during this study had concentrations that ranged as high as 2.3 ppm iron and 0.78 ppm manganese.

In the extreme southwestern portion of the SCRBA, area F, and iron problem occurs both in the bedrock and in the overlying stratified drift. Of 44 wells that were inventoried in both aquifers, approximately 50 percent yielded water at one time or another with troublesome amounts of iron. Analyses by the Connecticut State Department of Health reported concentrations as high as 5.0 ppm iron and 0.26 ppm manganese. Data from L. L. Lundgren (personal communication) indicate that the rock unit contributing most to the iron and manganese ground water problem includes numerous layers of schist containing magnetite, pyrite, pyrrhotite, and manganese garnet.

Areas E and F are probably not unique within the SCRBA south of the Honey Hill fault system. There are several other places in this portion of the report area where one or two isolated wells tapping stratified drift or bedrock yield iron-bearing water, but where lack of data prohibits delineation of the significant extent of poor water.

In areas where bedrock contains iron-bearing water, the overlying deposits in recharge areas probably will be free of iron, but deposits in discharge areas are likely to contain iron-bearing water--water discharge upward from bedrock contributes the iron to overlying deposits in discharge areas.

HARDNESS

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

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

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

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

Ground water in the SCRBA is generally soft to moderately hard. Samples from 156 wells were analyzed for hardness and their rating as well as a comparison of the hardness in the 3 basin studies are reported in the following table:

Rating	Quinebaug River basin	Shetucket River basin	SCRBA
	Percent of wells sampled		
Soft	67	68	62
Moderately hard	28	23	30
Hard	3	8	5
Very hard	2	1	3

The similarity of hardness in water throughout eastern Connecticut reflects the similarity in the lithology of the rock units and unconsolidated deposits.

Areal variations of hardness in ground water are shown on figure 43. Water at least moderately hard occurs at scattered locations. There are no extensive bedrock units composed principally of limestone, dolomite, or marble (calcium or magnesium carbonate) in the report area; therefore, no specific water-bearing formation will yield consistently hard or very hard water. There are scattered areas throughout the basins where the bedrock contains impure limestone lenses or where calcium silicate minerals dominate. In the stippled areas shown on figure 43, the water user will probably encounter concentrations large enough to be troublesome for some uses. In one particular area in the vicinity of the community of North Stonington, concentrations as high as 1,200 ppm of hardness have been reported, and 2 public water supply wells were abandoned because of hardness and high mineralization. Water samples collected during this study from 8 wells tapping the bedrock in the Pease and Susquetonscut Brook basins contained from 40 to 168 ppm of hardness. Treatment by the home owners would be desirable with wells yielding water having a hardness concentration above 120 ppm. Unconsolidated deposits with large concentrations of calcium and magnesium minerals would in turn be expected to yield at least moderately hard water.

The comparison of the surface water and ground water quality data on figure 27 shows that the relative magnitude of dissolved solids in natural streams is related to the dissolved-solids concentrations in the natural ground water. The comparison of figures 28 and 43 shows that areas of relatively high dissolved-solids concentrations also coincide with the areas of moderately hard to very hard water. Therefore, water from wells drilled in stream basins where natural stream water has a high dissolved-solids content as indicated on figure 28, might also be expected to have a moderately hard to very hard water.

E X P L A N A T I O N

Basin drainage divide

RANGE IN HARDNESS OF WATER FROM INDIVIDUAL WELLS, IN PARTS PER MILLION

0-60--soft water

61-120--moderately hard water

121-180--hard water

181 or more--very hard water

Samples from some of these wells were analyzed by agencies other than the U. S. Geological Survey; such analyses were not incorporated in table 34.

SD - indicates well is in stratified drift

T - indicates well is in till

All other wells are in bedrock

Area in which most wells tapping bedrock are likely to yield moderately hard to very hard water.

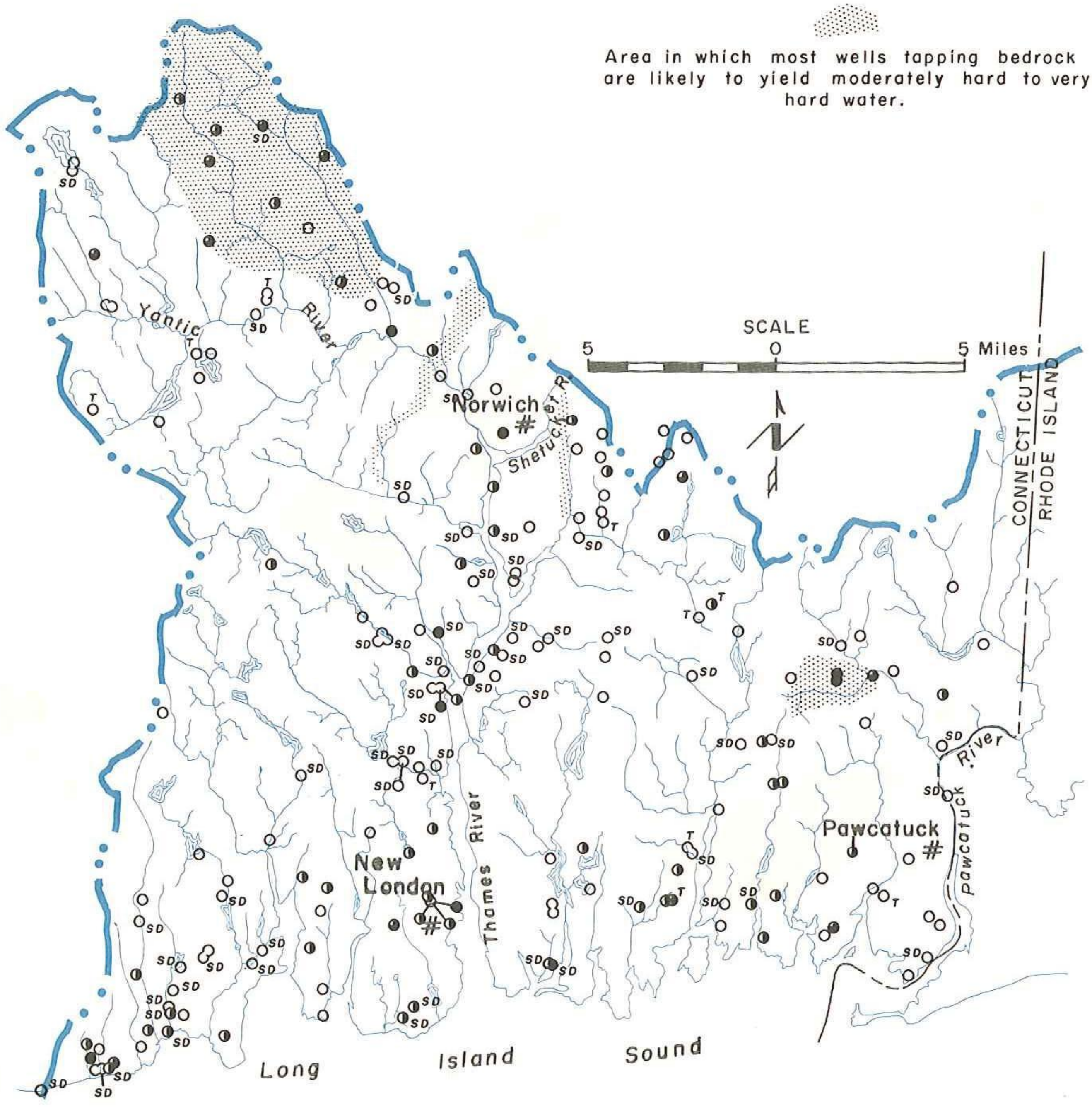


Figure 43.--Areal variations in hardness of ground water in the lower Thames and southeastern coastal river basins

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

Under natural conditions nitrate and chloride are absent or present only in low concentrations in the fresh ground water of the SCRBA although small amounts of nitrate may occur naturally due to the decay of fallen leaves, roots, and small organisms in the soil. ABS (alkyl benzene sulfonate) and LAS (linear alkylate sulfonate) are absent under natural conditions. Therefore, the presence of unusually large quantities of these constituents represents a departure from normal conditions, and in some cases (all cases, if ABS or LAS is present) may be due to some type of pollution--organic, domestic, or industrial. In some localities high nitrate concentrations in ground water can be attributed to infiltration of recharge through soils heavily treated with chemical fertilizers, but most of the nitrate in water represents the end product of aerobic decomposition of organic matter (sewage or animal wastes).

Samples from 44 wells in the SCRBA were analyzed for nitrate as shown in table 34, and 10 wells sampled were found to yield waters containing more than 10 ppm nitrate with a maximum of 52 ppm. Although many of the larger concentrations were probably derived from organic waste, this does not mean that 23 percent of the wells sampled were polluted; in many cases the source of the nitrate may have been distant enough so that the water was safe to drink by the time it reached the well, since bacteria and other contaminants may be filtered by the aquifer material. Other forms of nitrogen that are determined in a sanitary analysis, such as nitrite, ammonia, and albuminoid, are more reliable indicators of incomplete decomposition of organic waste and genuinely unsafe potable water. The upper limit for nitrate recommended by the U.S. Public Health Service is 45 ppm. Water containing nitrate in excess of 45 ppm (equivalent to 10 ppm of nitrate expressed as N in a sanitary analysis) is unsafe for domestic supply because it can cause methemoglobinemia (infant cyanosis, or "blue baby disease") when fed to infants (Comly, 1945). Only one of the wells sampled yielded water with more than 45 ppm of nitrate.

Chloride in fresh ground water throughout the area is normally in low concentrations. Only a small amount reaches the SCRBA in precipitation; the median chloride concentration detected in rainfall from several storms was 1.2 ppm as shown in table 3. Chloride-bearing minerals are scarce in the crystalline bedrock of the report area, usually less than 0.05 percent of total rock volume. Samples from 66 wells were analyzed for chloride, and 79 percent of them were found to have a chloride concentration of less than 20 ppm with a median of 8.0 ppm. The median concentration of the water from the remaining 21 percent of the wells sampled was 25 ppm. The range in concentration was 0.0 to 194 ppm for wells tapping crystalline bedrock and 2.9 to 43 ppm for wells tapping stratified drift and till.

Another source that can account for the above-normal chloride concentrations in the SCRBA other than reflecting nearby disposal of sewage or animal wastes is road salt. Sodium chloride or a mixture of sodium and calcium chloride is used extensively as road-salting chemicals for protection against hazardous icing of roads, and it is possible that road salt has infiltrated into portions of some aquifers in the report area. One well, Fr 16, had a noticeable salty taste and yielded water with a chloride concentration of 194 ppm. A high chloride content in water causes corrosion in pipes, boilers, and other fixtures, and is toxic to most plants.

ABS was the principal component of household detergents prior to mid-year 1965. Its presence in ground water results from disposal of sewage from homes or factories to the ground. ABS concentrations of about 10 ppm are typical of municipal sewage. Various studies have shown that 1 ppm of ABS in drinking water can be tasted and can cause frothing of the water. Although larger concentrations of ABS are not toxic, esthetic considerations have caused the U.S. Public Health Service (1962, p. 24) to recommend that concentrations in drinking water not exceed 0.5 ppm. The maximum ABS content in samples collected from 41 wells during the study was 0.4 ppm. However, one well inventoried was abandoned, reportedly due to detergent contamination from laundry or kitchen waste waters. Since July 1965 the ABS component of household detergents has been gradually replaced by LAS, which is biodegradable and will disappear more readily than ABS. However, if the conditions for bacterial actions in cesspool or septic tank effluents are unfavorable, the LAS will have little or no opportunity to decompose.

If the population of the report area continues to expand, the nitrate, chloride, and detergent concentrations of ground water are likely to increase also, especially in areas not served by sewage systems. Although none of the constituents are toxic in the concentrations ordinarily present even in polluted ground water (except nitrate of more than 45 ppm, as noted above), the presence of large amounts of any or all suggests that a substantial part of the water pumped was probably derived from disposal of sewage or other wastes nearby, and that pathogenic bacteria or other hazardous substances may be present.

FLY ASH

Fly ash is an unburned by-product of burning coal and is a source of landfill. It contains some of the impurities that are associated with coal in its natural state. When fly-ash landfill is subjected to leaching, an acid may be formed from these impurities, and other constituents such as iron, manganese, and aluminum may be released to the infiltration water.

In order to determine experimentally the effect of leaching on fly ash, laboratory tests were run on samples of fly ash by the Connecticut Water Resources Commission and the U.S. Geological Survey. The fly ash material was agitated in distilled water and chemical analyses made of the drawnoff solution. These analyses, shown in the following table, indicated that about 5 percent of the fly ash is soluble in water and that the solution contained concentrations of the constituents considerably greater than the distilled water used in dissolving the fly ash; for example, in the sample analyzed by the U.S. Geological Survey, sulfate increased from 0.0 to 241 ppm and dissolved solids increased from 1.7 to 742 ppm.

Chemical analyses of solutions from selected samples from two fly-ash landfill deposits

	Date of analysis	Sulfate (ppm)	Chloride (ppm)	Dissolved solids (ppm)	pH
Chesterfield-Oakdale Road site	7-16-64 1/	241	--	742	6.5
	6-15-66 2/	135	--	358	5.5
	10-26-66 2/3/	250	--	418	6.9
Moxley Hill Road site	9-22-65 2/	380	--	--	9.2
	7-13-66 2/	1,100	2,400	5,328	4.8
	10-26-66 2/	260	5,328	474	6.1

1/ Analysis by the U.S. Geological Survey
2/ Analyses by the Connecticut Water Resources Commission, Hall Laboratory
3/ Iron, 0.4 ppm; aluminum, 0.5 ppm

The sulfate content of the solutions derived from leaching the 6 samples in the laboratory ranged from approximately 20 to 60 percent of the dissolved-solids concentration, with a median of 37 percent. Additional solutes dissolved from the fly ash included minor quantities of sodium, calcium, magnesium chloride, magnesium sulfate, iron and aluminum.

Evidence from three localities in the SCRBA suggested that a field study to determine the effects of leaching in landfills containing fly ash was merited. The first locality, the so-called Chesterfield-Oakdale Road site, is in the headwaters of the Hunts Brook drainage basin about ½ mile upstream from the northern limit of the proposed Hunts Brook Reservoir. The fly-ash landfill is on the east branch of Deep Hollow Brook. Analyses of stream water samples collected by the U.S. Geological Survey upstream and downstream from the landfill in July 1964 and those periodically sampled during 1965-67 by the Water Resources Commission are summarized on figure 44 (stations 1-8). These plots show a decrease in pH and increases in dissolved-solids and sulfate concentrations on the downstream side of the landfill.

The second locality, the so-called Moxley Hill Road site, is in the headwater area of an unnamed tributary of Hunts Brook that drains into Miller Pond (figure 44, stations 9-11). As at the first locality, water samples collected by the Water Resources Commission upstream and downstream from the landfill show an increase in dissolved-solids and sulfate concentrations on the downstream side of the landfill. The inference is that at both these localities the higher mineral concentrations in stream water in the immediate downstream vicinity from the landfill results from leaching of the landfill by infiltrating precipitation.

Data on the chemical quality of ground water from wells in the immediate areas of these two localities is not available.

The third locality is along Stony Brook near the intersection of Massapeag Road and State Highway 32 in Montville where fly ash was used for landfill in a driveway. Analyses of ground water from spring Mv 2sp (table 36), which issues from stratified drift downslope from the driveway show a pH that is lower and a dissolved-solids content and sulfate concentration that is several times higher than is found in ground water occuring in stratified drift elsewhere in the SCRBA (see table 34, p. 74). The pH of the landfill, as reported by the Water Resources Commission, is also low (3.0). Again, the inference is that water from infiltrating precipitation, septic effluent, or lawn sprinkling may have leached the landfill, percolated to the water table, and moved to the discharge point at the spring.

Additional studies by the State Water Resources Commission and other federal agencies were in progress at the time of this writing (1968). Conclusions on the effects of this landfill on the surface-water supplies in the area will be released by these agencies at the end of their field study. Preliminary results from the study now being conducted by the Water Resources Commission indicate that the landfill has no adverse effects on the chemical quality of Hunts Brook.

Table 36.--Chemical analyses from spring Mv 2sp in Montville near a fly-ash landfill area

(Chemical constituents in parts per million)

Date of collection	6-3-62 a/	9-25-63 b/	7-16-64 b/
Silica (SiO_2)	--	--	--
Iron (Fe)	--	0.10	--
Manganese (Mn)	--	2.2	--
Aluminum (Al)	29	--	--
Calcium (Ca)	--	64	55
Magnesium (Mg)	--	24	8.0
Sodium (Na)	--	33	34
Potassium (K)	--	4.0	3.5
Bicarbonate (HCO_3)	--	0	0
Sulfate (SO_4)	350	287	198
Chloride (Cl)	23	25	31
Dissolved solids	636	489	376
Hardness as $CaCO_3$	200	260	170
Noncarbonate hardness as $CaCO_3$	--	258	170
Specific conductance (micromhos at 25°C)	--	734	550
pH	3.8	4.0	4.3

a/ Analysis by Connecticut Water Resources Commission, Hall Laboratory
b/ Analyses by U.S. Geological Survey

SUSCEPTIBILITY OF WELLS TO POLLUTION

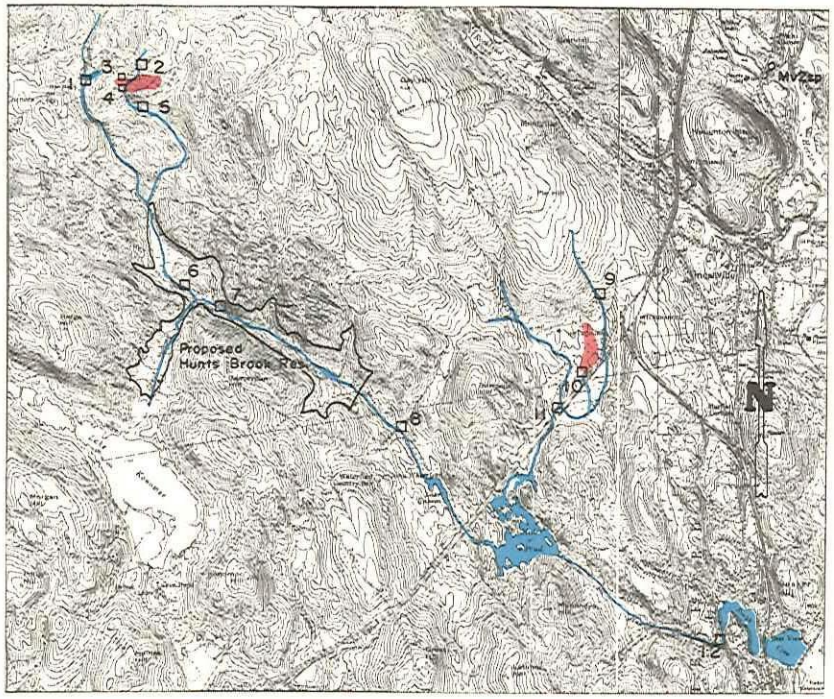
Pollution of ground water is due primarily to three causes: disposal of domestic sewage into cesspools or septic-tank fields; disposal of industrial waste into leaching pits or lagoons; and infiltration of water in barnyards, fields treated with manure and chemical fertilizers, or other sites of abundant animal droppings.

Explanation

□[2] Water-quality sampling site

♀ Mv2sp Spring (chemical analyses in table 36)

Fly-ash landfill site



SCALE

1 0 1 Mile

CONTOUR INTEVAL 10 FEET Datum is mean sea level

BASE BY U.S.GEOLOGICAL SURVEY

Explanation

Chemical analyses
1964-USGS
1965-67-CWRC

— Dissolved solids concentration
— Sulfate concentration
— pH

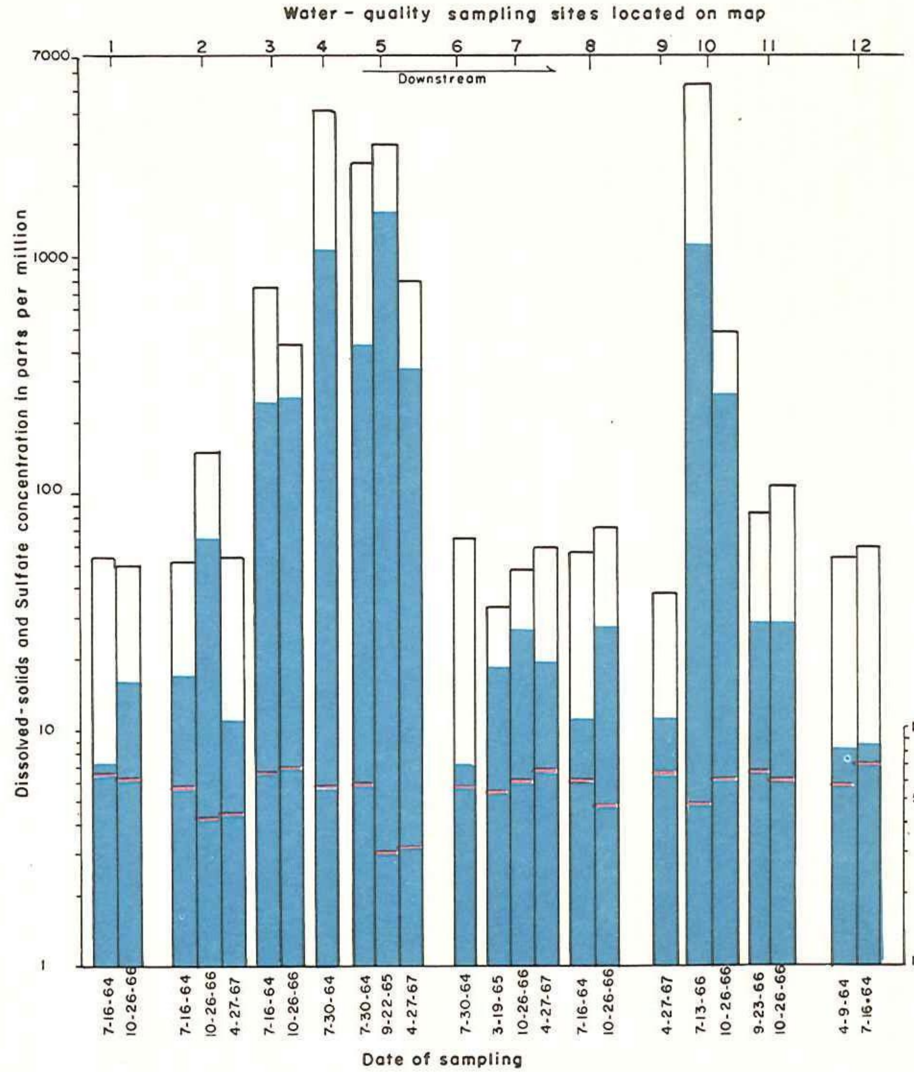


Figure 44.--Variation in the concentration of dissolved solids, sulfate, and pH at several sites in the Hunts Brook drainage basin

Chemical analyses by the U.S. Geological Survey and Connecticut Water Resources Commission.

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

1. The distance to the nearest source of pollution. Bacteria seldom are carried more than 100 feet from a source of dilute sewage effluent (Mallman and Mack, 1961), but nitrate, ABS and LAS may maintain objectionable concentrations for longer periods and therefore travel longer distances; some dissolved chemical pollutants may even remain in ground water indefinitely. Few data are available on how far viruses can travel.

2. The direction to the source of pollution. As a general rule, ground water flows slowly and transports contaminants in the direction of the average land-surface slope toward the nearest permanent stream. Therefore, wells located downslope from a source of pollution are usually susceptible to contamination.

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

The likelihood of well contamination from bacteria in septic tank effluent can be evaluated according to a system devised by LeGrand (1964). The method involves estimates of 1) depth to water table, 2) sorptive characteristics and 3) permeability of overburden, 4) gradient of the water table, 5) distances between well and septic tank, and 6) thickness of overburden. Using conservative values for the first five factors, the possibility of contamination of a bedrock well at a site where bedrock is overlain by 40 feet or more of till is, according to this system, "possible but not likely." With normal precautions taken in the placement and construction of the well and septic tanks, contamination is not very likely.

Data from the Quinebaug River basin (Randall and others, 1966) showed the importance of casing length in reducing the chances of a well becoming polluted. On the average, the greatest changes in water quality took place in wells with 0 to 30 feet of casing due to the fact that many wells with relatively casing permit entry of water near the land surface. Many people are aware that water in dug wells is susceptible to pollution unless the well is tightly sealed and properly located with respect to sewage-disposal facilities. However, Randall showed that drilled wells with less than 30 or 40 feet of casing are also susceptible to pollution, a fact that is not so widely realized. Specific localities where till is known to be at least 40 feet thick are shown on plate B.

TEMPERATURE OF GROUND WATER

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

Randall and others (1966) reported that the temperature of water in very shallow wells in the Quinebaug River basin can fluctuate as much as 20°F each year, with a low of 35°F to 40°F and a high near 55°F. The temperature in such wells rises during the spring and summer to a peak in late September, begins to decline when average air temperature drops below water temperature, and continues to decline until average air temperature rises once again above water temperature in March or April. In localities where the water table remains more than 30 feet below the land surface, ground water is insulated from change in air temperature, and seasonal fluctuations are small.

The temperature of ground water 30 to 60 feet below the land surface in most localities is within 2 or 3 degrees of the annual mean air temperature, which is about 50°F throughout the report area (Brumbach, 1965, p. 18). Local conditions can cause variations; for example, ground-water temperatures are lower below forested areas than below open fields (Pluhowski and Kantrowitz, 1963), and may also be slightly lower than average on north-facing slopes. Water obtained from depths greater than 60 feet is nearly constant in temperature.

EFFECT OF INDUCED RECHARGE ON QUALITY

The pumping of wells finished in permeable stratified drift bordering a major stream can lower the water table enough to cause substantial amounts of water from the stream to infiltrate the aquifer, as pointed out on p. 69.

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

The chemical quality of the water pumped will be intermediate between the river water and the natural ground water in the aquifer (Klaer, 1953; Rorabaugh, 1956). Non-marine surface water in the SCRBA is generally less mineralized than ground water, so that induced recharge will normally result in an improvement of chemical quality in the aquifer. However, along reaches of the major streams into which considerable industrial waste effluents are discharged, the water in the streams may at low flow have a much higher mineral content than natural ground water, temporarily reversing the normal condition. An example of such a change would be the discharge of spent dyes of an acidic condition which would lower the stream water pH and therefore redissolve iron and manganese complexes deposited or fixed along the streambed and in the adjacent sand and gravel aquifer. The pumping wells would be inducing water with a higher and possible troublesome concentration of iron and manganese as may be the case along the Pawcatuck River. The sand and gravel beds through which the induced recharge travels can also serve as large filters, generally removing all or nearly all of the bacteria, turbidity, and suspended solids that may be present in the stream but not the dissolved constituents such as nitrate, sulfate or iron.

Along the Connecticut coast and estuaries salt water has intruded aquifers at places where overpumping has reversed the natural hydraulic gradient from land to sea, as pointed out on p. 70. Induced infiltration of the recharge water brings about changes in the chemical quality of the ground water. The most noticeable change is in the increase in chloride content of the water discharged from the wells due to overpumpage. At Norwich State Hospital under normal pumpage rate the chloride content was 6.5 ppm and rose to 695 ppm in late 1952 with overpumpage. In Ledyard, Dow Chemical reported chloride concentrations averaging 250 ppm after ground-water levels declined below the level of the Thames River estuary. Connecticut Light and Power Co. at Uncasville uses a scavenger well to protect its fresh-water well field. Chloride concentrations of 400 to 600 ppm were measured in this well in 1963-64. Besides an increase in the chloride content, changes take place in the other constituents and properties affecting the quality of the ground water.

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

WATER USE--PRESENT AND FUTURE

WATER USE IN 1964

The total amount of water used in SCRBA in 1964 is estimated at 118,260 million gallons. If the water used by institutions, summer camps and cottages, along with the estuarine water used by industry is excluded, then the average per capita use is estimated to be 186 gpd. Most of the water used was withdrawn by industries for their own use. Almost all of the water used was for non-consumptive purposes. Approximately 97 percent of the water used by industry was withdrawn from surface supplies. Cooling and processing accounted for the largest use of water by industry; cooling accounted for about 97 percent, and processing for about 3 percent of the water used. Of the cooling water, 98 percent was estuarine.

The source, use, and disposal of water in the SCRBA are summarized by figure 45. The data on which this figure is based were supplied by water utilities and major industrial firms or by State agencies. The domestic use in homes having their own sources of water was computed by multiplying an estimated per capita use of 70 gpd by the difference between total population and population served by public water systems. The estimate for agricultural use represents, for the most part, the water needed to supply dairy cows, poultry, and other livestock in the basin. Relatively little water was used for irrigation. Various reports, both by the consultants and State, indicate that sewage treatment facilities in the basin are overloaded at times and proper sewage treatment of all effluent is not accomplished. There are also a few communities that have either no sewage treatment or only a portion of the community has treatment. Pollution abatement planned by the Connecticut Water Resources Commission under Public Act 57 of 1967 should eliminate these adverse conditions.

Plate C shows the locations and amounts of all major withdrawals of water from surface-water and ground-water sources and the points at which the water is returned to streams or to the ground. Diversion of water into and out of the report area is also shown.

Thirty-two municipal and private water-supply systems supplied the domestic water needs of nearly two-thirds the population of the report area. Public water supplies provided about 2 percent of the water used by industry in 1964; however, this represents about 40 percent of the non-marine water used by industry. The source of water, capacity, type of treatment, population served, and other important features of 23 selected systems are described in table 37. Plate C shows the general area served by each system and the location of all water sources.

Residents served by the 23 water-supply systems listed in table 37 generally receive soft water with low concentrations of dissolved solids. Chemical analyses of samples from 19 of the 23 water-supply systems are shown in table 38. In general, all these public water supplies serve water of good chemical quality. With the exception of a few relatively high iron or manganese concentrations, the concentrations of the constituents determined were far below the maximum concentrations suggested by the U.S. Public Health Service. North Stonington Water Company has abandoned their bedrock wells, NSn 40 and 41, and now use wells in stratified drift along the Shunock River which has improved the quality of water distributed. The fluoride concentration in water of the Mystic Valley Water Company water-supply system, the only system that fluoridated its water in 1964, is at the optimum value suggested by the U.S. Public Health Service. Color, iron, and manganese vary considerably from time to time, and the relatively high concentrations shown in table 38 may not represent average conditions. Such variations are particularly evident when the source of water is from a surface supply. Abnormally high color and high iron or manganese concentrations may also be the result of some localized condition.

WATER USE IN THE FUTURE

The amount of water used in the SCRBA in 1964 will quite likely be exceeded in future years. The increase in use will depend upon changes in the population and in the degree of industrial, agricultural, and resort development. Forecasts of such changes rely largely on study and projection of past trends. The Southeastern Connecticut Regional Planning Agency (1967) forecasts for its region which comprises most of the report area, a population increase of 143 percent by the year 2000, and that for the fresh-water use for all purposes, including industrial as well as domestic would require as much as 135 mgd. If these predictions are realized, the total water demand in the region in the year 2000 would be about 4 times as great as in 1964 or about 50 billion gallons per year. The region can certainly provide this amount of water.

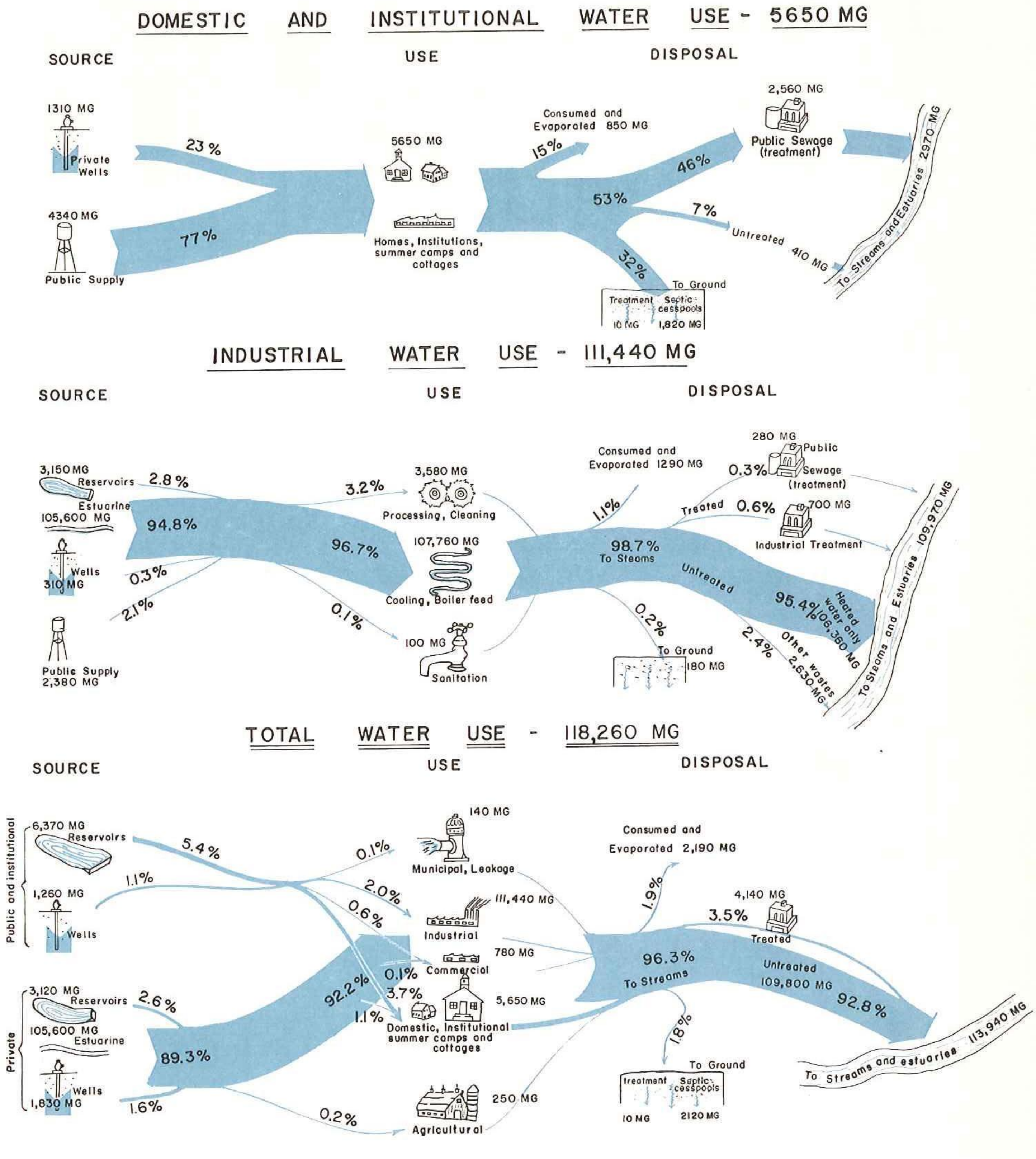


Figure 45.--Source, use, and disposal of water, in million gallons, in the lower Thames and southeastern coastal river basins during 1964

Most water used in the basin is obtained from surface water sources. Industry is the largest user of water, most of which is used for cooling and boiler feed. Estuaries receive the largest proportion of discharge water, most of it is untreated. Most water discharge from homes and institutions is treated and discharged to streams and estuaries.

Table 37.--Description of selected public water-supply systems in the lower Thames and southeastern coastal river basins

(Data are for 1964, except as noted, and are based on estimations and records received from water utility officials)

Public water-supply system	Community(ies) supplied	Town(s) in which community(ies) served	Total population served	Primary source of water and supply	Percentage (%)	Auxiliary or emergency sources	Treatment	Capacity of treatment plants (gpm)	Raw water storage (thousand gallons)	Finished water storage (thousand gallons)	Total use in 1964 (mg)	Percentage of use: Domestic	Percentage of use: Commercial	Percentage of use: Municipal and leakage	Percentage of use: Industrial	Remarks
Barrett Water Company	Barrett Park	Ledyard	230	well	100	none	none	--	--	3	3.3	100	0	0	0	
Best View Water Company	Quaker Hill	Waterford	200	well	100	none	Disinfection (hypochlorite)	--	--	2	4.4	98	2	0	0	
Black Point Water Company	Black Point Beach Club	East Lyme	a/3,000	3 wells	100	none	none	--	--	50	20.7	100	0	0	0	a/ In operation only 7 months/year.
Cedar Ridge Association	Cedar Ridge	North Stonington	540	well	100	none	none	--	--	10	11.8	100	0	0	0	
Country Squire Water Company	Avery Park	Preston	96	well	100	none	none	--	--	15	2.0	100	0	0	0	
Eastern Water Company, Incorporated	Bel Aire	Groton	a/678	well	100	well	Disinfection (hypochlorite)	--	--	10	12.1	96	0	4	0	a/ also serves junior high school.
East Lyme, Town of, Water Department	Niantic a/	East Lyme	3,100	well	100	none	none	--	--	100	23.7	77	20	2	1	a/ In part.
G and J Water Company, Incorporated	Mohegan	Montville	720	2 wells	100	none	none	--	--	a/10	11.5	99	0	1	0	a/ 50,000 gallon storage tank was added in 1965.
Groton, City of, Water Department	Groton	Groton	28,300	Poheganut Reservoir Smith Lake Poguonnock Reservoir Ledyard Reservoir Buddington Pond Morgan Pond Rosemond Pond	15.1 29.4 17.3 32.1 1.4 1.4 3.3	none	a/ Coagulation (alum, soda ash, lime), sedimentation, rapid sand filtration, disinfection (chlorine)	8,333	223 436 256 476 20 20 50	4,450	2,917.7	7.9	b, c/29.6	.1	62.4	a/ Groton Filtration Plant-supplied directly from Poquonnock Reservoir (called Groton Reservoir). b/ 1.4% of total consumption is sold to the Groton Long Point Association, Incorporated, Water Department and the Noank Fire District Water Department. This water has been included under the heading "commercial." c/ A large percentage of water used normally under the heading "domestic" is sold under commercial rates, and therefore is included under said heading.
Groton Long Point Association, Inc., Water Department	Groton Long Point	Stonington	2,000	City of Groton	100	none	a/	--	--	--	18.0	98	1	1	0	a/ No additional treatment.
Lifetime Homes, Inc.	The Highlands	Ledyard	1,200	well	100	well	Chlorination	300	--	300	a/32.8	100	0	0	0	a/ estimated.
Lord's Point Association, Inc., Water Dept.	Lord's Point	Stonington	a/400	well	100	none	none	--	--	13	8.6	100	0	0	0	a/ In operation only 7 - 8 months/year.
Montville Water Works Company	Montville Manor	Montville	1,696	4 wells	100	2 wells	none	--	--	65	29.6	99	1	0	0	
Mystic Valley Water Company	Mystic Stonington	Groton Stonington	14,350	a/Dean Pond Palmer Pond	b/100	well	Coagulation (alum, soda ash), sedimentation, activated carbon, rapid sand filtration, disinfection (chlorine), calgon, fluoridation	c/694	35 80	2,000	332.7	88	1	1	10	a/ Dean Pond flows into Palmer Pond (both are called Mystic Reservoir); Palmer Pond is the direct supply of the treatment plant. b/ Dean Pond and Palmer Pond supply 100%, except during September-November when the auxiliary well supplies 2%. Well water is pumped to Copps Brook which flows into the reservoir. c/ Design capacity - 2 mgd.

Table 37.--Description of selected public water-supply systems in the lower Thames and southeastern coastal river basins--Continued

Public water-supply system	Community(ies) supplied	Town(s) in which community(ies) served	Total population served	Primary source of water and supply	Percentage (%)	Auxiliary or emergency sources	Treatment	Capacity of treatment plants (gpm)	Raw water storage (thousand gallons)	Finished water storage (thousand gallons)	Total use in 1964 (mg)	Percentage of use: Domestic	Commercial	Municipal and leakage	Industrial	Remarks
New London, City of, Department of Public Works, Division of Water Supply	New London	New London Waterford Montville	35,652	Lake Konomoc Barnes Reservoir Bogue Brook Reservoir Fairy Lake	52.1 13.2 16.5 18.2	none	a/Disinfection (chlorine), Calgon	6,944	672 170 212 235	6,217	1,619	b/89		2	9	a/ Lake Konomoc Filtration Plant b/ 0.9% of total consumption is sold to the Ridgewood Park Company. This water has been included under the heading "commercial."
Noank Fire District, Water Department	Noank	Groton	700	City of Groton	100	none	a/	--	--	250	26.5	95	1	4	0	a/ No additional treatment.
North Stonington Water Company	Kingwood Meadowood	North Stonington	450	a/ 2 wells		2 wells	Hungerford-Terry softening system	125	--	b/10	7.2	98	1	1	0	a/ New system of 4 gravel-packed wells along the Shunock River was installed in 1965. Test wells indicated a potential of 300 gpm. b/ 20,000 gallon storage tank was added with new system.
Norwich, City of, Department of Public Utilities, Water Division	Norwich Yantic Fitchville Gilman	Norwich Preston Bozrah Lebanon Montville	41,418	a/ Fairview Reservoir Stony Brook Reservoir Deep River Reservoir	33.7 37.5 28.8	none	b/Disinfection (chlorine)	c/4,167	450 500 384	--	1,105.8	58.4		8.1	33.5	a/ Ponemah Reservoirs (Nos. 1,2,3) have a 111 mg storage capacity. These reservoirs owned by Norwich but separate from the Norwich system and serve Taftville. Ponemah figures are not tabulated in any columns in this table. b/ At reservoirs-Fairview, Deep River. At pumping station-Stony Brook Reservoir. c/ At each treatment plant.
Point O'Woods Water Company	Point O'Woods	Old Lyme	a/3,200	5 wells	100	well	b/Calgon	--	--	17,500	22.5	99	1	0	0	a/ In operation only 7 months/year. b/ Treatment for iron.
Ridgefield Park Company	Ridgewood Park	Waterford	200	City of New London	100	none	a/	--	--	--	14.0	100	0	0	0	a/ No additional treatment.
Tower Water Company	Christy Hill Estates	Ledyard	1,000	well	100	2 wells	none	--	--	40	25.9	100	0	0	0	
Westerly Water Works, Department of Public Works, Rhode Island	Pawcatuck	Stonington	6,786	a/wells	100	none	--	--	--	b/1,900	c/328.5	35	6	4	55	a/ 1 gang of 64 driven wells, 1 gang of 85 driven wells, 1 gravel-packed well. b/ 1 million gallon storage tank was added in 1965 for the Pawcatuck service. c/ Consumption figures for Connecticut service only.
White Sands Beach Water Company	White Sands Beach	Old Lyme	a/700	5 wells	100	none	--	--	--	10	1.9	99	1	0	0	a/ In operation only 7 months/year.

Table 38.--Chemical analyses of water from selected public water-supply systems in the lower Thames and southeastern coastal river basins

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

Public water-supply system	Date of collection	Source	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (residue at 180°C)	Hardness as $CaCO_3$: Calcium magnesium	Hardness as $CaCO_3$: Noncarbonate	Specific conductance (micromhos at 25°C)	Temperature (°F)	pH	Color	Detergents as MBAS	Turbidity as ppm SiO_2
U.S. Public Health Service 1962 drinking water standards (upper limits)	--	--	--	0.3	0.05	--	--	--	--	--	250	250	[a]1.3	45	500	--	--	--	--	--	15	0.5	5
Barrett Water Company	5-20-65 F	Well Ly 88	16	0.02	0.02	17	3.5	11	2.6	38	12	21	0.2	14	134	57	26	190	--	6.4	1	0.1	0.8
Best View Water Company	5-19-65 R	Well Wt 56	9.0	.03	.02	10	2.7	14	2.2	24	17	24	.2	1.8	100	36	16	161	53	6.2	3	.0	.4
Black Point Water Company	5-19-65 R	Well ELy 34	28	.04	.04	15	5.7	15	2.6	54	23	15	.2	3.8	138	61	17	192	53	7.5	2	.1	.4
Cedar Ridge Association	5-28-65 R	Well NSn 29	12	.10	.02	6.4	2.4	7.3	1.0	16	9.3	10	.1	6.8	71	26	13	92	--	6.7	5	.0	.7
Country Squire Water Company	5-26-65 F	Well Ps 115	13	.01	.01	33	2.6	5.8	2.1	96	21	7.5	.2	1.0	132	93	14	221	--	7.6	2	.0	.9
Eastern Water Company, Incorporated	5-25-65 F	Well Gt 29	13	.62	.23	17	6.7	14	.9	31	26	30	.2	4.0	142	70	44	215	--	6.7	3	.0	.4
East Lyme, Town of, Water Department	5-19-65 F	Well ELy 36	5.6	.03	.17	5.9	2.1	9.1	.8	13	9.9	15	.1	2.6	78	23	12	104	--	6.5	1	--	.5
G and J Water Company, Incorporated	5-25-65 R	Well Mv 63	19	.06	.00	7.4	2.3	6.2	.6	38	1.2	5.2	.1	3.2	65	28	0	88	--	7.0	2	--	.4
Groton, City of, Water Department	6-24-65 R	Groton Reservoir	1.9	.24	.01	4.6	1.3	5.4	.8	11	9.3	7.6	.1	.4	44	17	8	69	--	6.5	7	--	.7
	6-24-65 F	Groton Reservoir	1.9	.15	.00	9.8	1.3	5.4	.8	15	15	11	.1	.0	60	30	18	101	--	6.6	3	--	.7
Lifetime Homes, Incorporated	6-28-65 R	Well Ly 24	--	.01	.01	--	--	--	--	--	--	7.5	.0	--	49	21	--	82	--	6.9	--	.0	--
Montville Water Works Company	5-24-65 F	Wells Mv 37 & 38	20	.02	.13	18	4.1	8.0	1.1	58	20	5.0	.4	1.4	110	62	14	153	--	6.5	3	.0	.8
Mystic Valley Water Company	5-12-65 R	Palmer Pond	4.4	.37	.02	4.1	1.9	5.5	.4	9	12	8.3	.1	.4	50	18	10	71	64	6.4	24	--	0
	5-12-65 F	Palmer Pond	4.7	.17	.02	6.2	1.6	12	.4	18	20	10	1.0	.1	70	22	7	115	--	6.7	2	--	0
New London, City of, Department of Public Works, Division of Water Supply	6-24-65 F	Lake Konomoc Reservoir	2.0	.12	.00	3.4	.6	4.0	.6	1	9.1	7.0	.1	.0	35	11	10	58	--	4.9	2	--	.6
North Stonington Water Company	5-25-65 R	Well NSn 40	22	1.6	.39	416	20	23	3.2	60	1,040	31	1.4	.4	1,830	1,120	1,070	1,860	--	6.9	3	.0	.7
Norwich, City of, Department of Public Utilities, Water Division	6-25-65 R	Fairview Reservoir	1.0	.09	.02	4.7	1.3	4.5	1.2	8	11	7.2	.1	.3	41	17	10	68	--	6.5	2	--	.3
	6-25-65 F	Fairview Reservoir	1.7	--	--	4.0	1.4	3.7	1.0	5	9.3	6.1	.1	.2	40	16	12	62	--	5.9	--	--	--
Point O'Woods Water Company	5-18-65 R	Well OL 21	11	1.0	.13	7.1	2.1	10	1.7	5	22	16	.2	1.2	80	26	22	126	49	5.3	3	.0	.6
	5-18-65 R	Well OL 23	--	.10	.04	--	--	--	--	--	--	--	--	--	80	28	--	128	50	6.6	--	--	--
Tower Water Company	5-20-65 F	Well Ly 27	10	.63	.30	13	5.7	14	1.2	14	25	23	.1	16	123	56	44	186	--	6.5	2	.2	.4
Westerly Water Works, Department of Public Works, Rhode Island	5-26-65 R	Wells Wes 103-106	11	.02	.03	6.2	1.1	10	1.2	22	11	9.2	.1	7.0	68	20	2	98	--	7.0	2	.0	.4
White Sands Beach Water Company	5-18-65 R	Wells OL 15-17	10	.02	.03	11	3.5	15	1.7	14	12	22	.0	27	136	42	30	184	53	6.6	2	.1	.7

a For optimum and lower limits.

FAVORABLE AREA			GROUND-WATER OUTFLOW					INDUCED INFILTRATION				GROUND-WATE
			Favorable area plus adjacent territory which contributes ground water under natural conditions		(1)	Drainage area of principal streams entering favorable area		(2)	(3)	(4)	(5)	(6)
Symbol (Pl.D)	Location and extent	Size (sq mi)	Total area (sq mi)	Percent stratified drift	Ground-water outflow exceeded 7 years in 10 (mgd)	Total area (sq mi)	Percent stratified drift	Streamflow equaled or exceeded 90 percent of the time during 1931-60 for principal streams entering favorable area (mgd)	Maximum potential induced infiltration capacity of stream- and lake-bottom deposits (mgd)	Maximum number of consecutive days during 1931-60 that streamflow of principal streams was less than column (2) or column (3) whichever is less (days)	Average streamflow during time listed in column (4) (mgd)	Water in aquifer storage which would drain during the six-month period of no recharge (mgd)
A	Pawcatuck River, Laurel Glen to White Rock a/	2.05	8.78	46	5.8	286	--	77	49	13	43	26
B	Shunock River, Hewitt School to North Stonington a/	.99	5.88	29	3.4	6.42	16.0	.9	11	74	.5	7.2
C	Pawcatuck River, North Stonington to Pawcatuck b/	2.94	8.81	49	6.0	265	--	72	62	35	46	50
D	Anguilla Brook, New London Turnpike to West Broad Street	1.35	5.54	37	3.4	1.71	0	0	2.6	--	--	14
E	Whitford Brook, Long Pond to Old Mystic c/	2.02	7.21	37	4.4	7.19	15.3	.9	92	76	.5	38
F	Great Brook, Ledyard Reservoir to Boston Post Road c/	1.55	5.04	44	3.3	8.79	17.6	1.2	190	72	.7	24
G	Bartlett Brook, Williams Pond to Savin Lake	.98	5.61	36	3.4	8.12	13.1	.8	50	71	.5	8.9
H	Yantic River, Fitchville Pond to Norwich	1.79	15.2	22	8.1	87.6	18.0	12	29	69	7.0	19
J	Trading Cove Brook, Leffingwell School to State Highway 32	1.50	7.19	37	4.4	4.32	8.2	.3	6.0	118	.1	16
K	Oxoboxo Lake and Gardner Lake area a/	1.44	4.54	41	2.9	d/0	--	--	460	--	--	28
L	Oxoboxo Brook, Oxoboxo Lake to Wheeler Pond a/	.62	4.11	27	2.3	4.87	29.0	1.2	55	63	.7	5.1
M	Oxoboxo Brook, Rockland Pond to Uncasville c/	.26	2.48	19	1.3	9.04	29.2	2.0	4.9	58	1.3	2.8
N	Jordan Brook, near State Highway 85 to Waterford c/	.88	3.87	29	2.2	2.16	18.8	.3	3.7	63	.2	7.1
P	Latimer Brook, Cranberry Meadow Brook to Connecticut Turnpike a/	.40	1.60	35	1.0	1.76	19.8	.3	3.5	73	.2	2.1
Q	Lake Konomoc area, Chesterfield to Connecticut Turnpike	.85	2.91	38	1.8	d/0	--	--	100	--	--	4.5
R	Pataguanset River, Powers Lake to Gorton Pond a/ e/	.90	2.92	43	1.9	3.69	22.7	.7	96	68	.4	10
S	Bride Brook, Connecticut Turnpike to State Highway 156 a/	.75	3.57	38	2.2	.44	45.6	.2	32	60	.1	12
T	Fourmile River, Military Reservation to Connecticut Turnpike a/	.90	3.06	40	1.9	2.63	10.1	.2	6.0	77	.1	8.7

a/ May be hydrologically continuous with adjacent favorable area, see plate B.
b/ Substantial additional supplies in Rhode Island not considered to be part of area.
c/ Part of area restricted because of proximity of salt water.
d/ No outside stream enters favorable area.
e/ Excludes Pataguanset Lake and Bosch Pond.

Table 39.--Estimates of long-term yields in favorable grou

ER STORAGE

ESTIMATED LONG-TERM YIELDS

(7)	(A)	(B)	(C)	(D)	(E)	(F)	
	During recharge period (185 days)	During period of no recharge (180 days of withdrawal from storage)				Average daily yield for the year, exceeded 7 years out of 10	
		During days of deficient streamflow		During days of adequate streamflow			
Practical yield from aquifer storage during the six-month period of no recharge; 1/3 of column (6)	Use column (2) or column (3), whichever is less Column (1) + column (2) or column (3) If column (1) is greater than column (7), use: 2 x column (1) - column (7) + column (2) or column (3), whichever is less	Column (4)	Column (1) or column (7), whichever is less, + column (5)	180 - column (4)	Column (1) or column (7), whichever is less, + column (2) or column (3), whichever is less	185 x column (A) + column (B) x column (C) + column (D) x column (E) ÷ 365	Symbol (Pl.D)
(mgd)	(mgd)	(days)	(mgd)	(days)	(mgd)	(mgd)	
8.7	55	13	49	167	55	55	A
2.4	5.3	74	2.9	106	3.3	4.2	B
17	68	35	52	145	68	66	C
4.7	3.4	--	3.4	180	3.4	3.4	D
13	5.3	76	4.9	104	5.3	5.2	E
8.0	4.5	72	4.0	108	4.5	4.4	F
3.0	4.6	71	3.5	109	3.8	4.1	G
6.3	22	69	13	111	18	19	H
5.3	4.7	118	4.5	62	4.7	4.6	J
9.3	2.9	--	2.9	180	2.9	2.9	K
1.7	4.1	63	2.4	117	2.9	3.4	L
.9	3.7	58	2.2	122	2.9	3.2	M
2.4	2.5	63	2.4	117	2.5	2.5	N
.7	1.6	73	.9	107	1.0	1.3	P
1.5	2.1	--	1.5	180	1.5	1.8	Q
3.3	2.6	68	2.3	112	2.6	2.5	R
4.0	2.4	60	2.3	120	2.4	2.4	S
2.9	2.1	77	2.0	103	2.1	2.1	T

und-water areas in the lower Thames and southeastern coastal river basins

DEVELOPMENT OF WATER SUPPLIES

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

SMALL SUPPLIES FOR HOMES AND SHOPS

Enough water for the average home or small business establishment can be obtained from aquifers almost anywhere in the SCRBA. As pointed out under "Water in aquifers," about 90 percent of the domestic wells drilled into bedrock supply 3 gpm or more, and at least several gpm can be obtained in many areas of stratified drift even from dug or driven wells. Glacial till, the poorest aquifer, can provide enough water for a home at only a few sites.

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

Dug or driven wells are most practical at sites with a shallow water table and a substantial thickness of saturated drift and where the likelihood of pollution is small. Dug wells in till usually require penetration of a greater saturated thickness than do those in stratified drift, because in till the drawdowns are greater and the seasonal fluctuations of the water table are larger at most sites. Driven wells may obtain small supplies in medium sand or fine gravel. Where there is a substantial saturated thickness of coarse-grained stratified drift, drilled screened wells can provide satisfactory supplies for small as well as large water needs.

The quality of naturally occurring ground water is satisfactory for domestic and commercial use in most places. In some localities ground water contains excessive amounts of iron, but iron may be removed from water by treatment. Areas where iron is likely to be a problem are described in the section on ground-water quality. Pollution may occur in some heavily populated areas utilizing underground waste disposal unless wells are cased to a depth of at least 40 feet. Each of the three aquifers located in coastal and estuarine areas is vulnerable to salt water encroachment; however, it is most commonly reported in the stratified drift aquifer. Areas where salt water encroachment is most likely under specified conditions are described on pages 70 to 73.

LARGE SUPPLIES FOR COMMUNITIES AND INDUSTRIES

Areas that have a potential for large water supplies within the SCRBA are depicted on plate D. The only sources from which supplies of 100 gpm (0.14 mgd) or more can generally be obtained are the larger streams and the stratified drift. These sources are closely related, for the larger streams are bordered by stratified drift nearly everywhere, and the ground-water runoff which sustains streamflow during dry weather comes largely from bordering stratified drift. In addition, the yields of large-capacity wells in stratified drift may be sustained in part by induced infiltration from streams.

LARGE SUPPLIES FROM STREAMS, LAKES, AND RESERVOIRS

Streamflows equaled or exceeded 90 percent of the time are shown on plate D as an index of surface-water availability from unregulated streams. These values of streamflow could be considered as a first approximation of the average yield available from a low run-of-the-river impoundment dam, as only a small amount of surface storage or supplemental ground-water supply would be needed to provide these amounts of water continuously in most years. The volume of usable storage in existing lakes and ponds is also shown on plate D. Thus, it shows the general distribution and magnitude of surface-water resources in the SCRBA. However, the reader concerned with developing a particular stream as a source of water supply or waste dilution may compute in greater detail such streamflow characteristics as flow duration, low-flow frequency, and storage-required frequency, at the site of interest as outlined in the section "Water in streams and lakes." The yields available from existing lakes and reservoirs are summarized in table 12. Several sites in the report area have been studied for their potential as reservoir sites by Metcalf & Eddy (1962).

The Thames River estuary and other estuaries in the report area are potential sources of large quantities of water for specialized uses where quality is not a limiting factor. The amount of water in motion in the estuaries is not known at this time. However, the theory of tidal flow is known, and tidal volume interchanges can be computed, if proper basic data are secured. Therefore, it is recommended that tidal volume be computed in the Thames estuary because it is probable that more water will be needed for industrial growth, urban expansion, and anticipated anti-pollution measures than is now readily available.

If demand for water is small in relation to streamflow during periods of low flow, development of a water supply may require only a small impoundment dam and intake facilities. However, if the demand is large, then large reservoirs may be required for the storage of water. This report does not identify nor evaluate individual sites as to suitability for dam construction; such evaluation would require consideration of the engineering geology of the proposed dam sites, economic losses in the areas flooded, and other questions beyond the scope of this report.

LARGE SUSTAINED SUPPLIES FROM STRATIFIED DRIFT

Large supplies of ground water can be pumped for long periods from favorable parts of the SCRBA. These favorable areas, shown on plate D, contain a substantial thickness (generally at least 40 ft) of permeable coarse-grained stratified drift as nearly as could be determined from available data and most are favorably situated for induced infiltration from a stream. Estimated long-term overall yields of 18 promising areas range from 1.3 to 66 mgd (table 39, col. F). Individual wells of large capacity drilled in some of these areas may pump as much as 880 gpm (Sn 163). However, within the same areas even properly constructed and developed wells may produce only small yields at some sites. Therefore, exploratory drilling and test pumping are necessary to determine the optimum site and design for development. The geohydrologic map (plate D) is thus a guide to favorable areas and not a substitute for field tests.

In other parts of the SCRBA yields of about 0.1 to 1 mgd can be sustained where saturated stratified drift is thinner, less permeable, or closer to salt water. Semi-favorable areas are also shown on plate D and are listed in table 40. Yields from individual wells in semi-favorable areas commonly are less than 100 gpm, but may exceed 200 gpm. Test drilling to locate favorable sites here must be supplemented by pumping tests designed to locate impermeable boundaries or to determine the relation of the cone of depression to the adjacent salt water. The overall yields in these areas have not been estimated and it is possible that some may exceed 1 mgd. The methods used to estimate long-term yields in the favorable areas,

Table 40.--Semi-favorable ground-water areas

(Smaller volume of stratified drift, or lower streamflow than areas in table 39, or development limited by proximity of salty water)

Symbol (Pl.D)	Location and extent	Length (ft) 1/	Width (ft) 1/	Thickness (ft) 1/	Principal stream or lake	Remarks
a	Bell Cedar Swamp - Spaulding Pond area	8,000	2,000	15	Pendleton Hill Brook, Spaulding Pond	
b	Preston School to Avery Pond area	12,000	2,000	30	Amos Lake, Avery Pond	Extends northwestward into Quinebaug basin
c	Norwich State Hospital to Poquetanuck area	8,000	2,000	30	Dickermans Brook	Salt water in south, east, and west
d	Deep River, Deep River Road to Reservoir Road	14,000	1,000	15	Deep River, Deep River Reservoir	
e	Latimer Brook, Barnes Reservoir to Silver Falls	15,000	1,000	10	Latimer Brook	
f	Pataguanset River, Gorton Pond to State Military Camp	5,000	4,000	40	Pataguanset River	Salt water in south and east
g	Mile Creek, above Hawks Nest Beach	10,000	2,000	10	Mile Creek, Swan Brook	Salt water in south

1/ Approximate or average.

which are also applicable to the semi-favorable areas, are described in the following section.

METHOD OF ESTIMATION

The long-term yield is the total amount of water which could be withdrawn from an area indefinitely without permanently lowering water levels. Estimation of long-term yields from favorable areas is based on available hydrogeologic information and involves assumptions because several factors vary with time and data are incomplete. Moreover, practical considerations limit water development to less than the theoretical maximum. For example, it is assumed that each favorable area is to be tapped by high-capacity screened wells yielding 100 to 800 gpm spaced 200 to 2,000 feet apart in reaches favorable for induced infiltration. It is further assumed that this pumping pattern and spacing would readily permit withdrawal of one third of the ground water in storage in the favorable areas during the no-recharge period. In reality, more water could probably be withdrawn by a larger number of small-capacity wells but the added costs involved in site acquisition and in drilling, developing, using and maintaining a greater number of wells makes this alternative infeasible.

Ground-water outflow exceeded 7 years in 10 (column 1 in table 39) is a practical value of water available from a favorable area. During the 3 years in 10 that it fails to equal this value, it can be augmented by ground-water storage or induced infiltration from surface water. Ground-water outflow exceeded 7 years in 10 is derived from figure 40. The values are based on the percentage of stratified drift in each favorable area and the territory draining into it.

Streamflow exceeded 90 percent of the time during the period 1931-60 (column 2) is a practical value for estimating water available from induced infiltration. It is available nearly all of the time, and it is a value that minimizes the possibility of "drying up" of the streams--considered undesirable in most areas. In most years streamflow occasionally drops below the 90-percent duration value. The maximum number of consecutive days of such a deficiency and the average streamflow during those periods during the period 1931-60 are taken into account. For calculation of column 4, the maximum potential capacity of the stream bottom deposits for induced infiltration (column 3) is taken as the limiting factor where this value is less than the 90-percent flow duration (column 2). It is also assumed that the time of deficient streamflow in each area occurs during the six-month period of no recharge, which is, in fact, the time of lowest streamflow.

Streamflow equivalent to the 90-percent flow duration (column 2) was determined for all the principal streams entering each favorable area, using available flow-duration curves of the streams. Where these curves were not available, regional flow-duration curves in figure 18 based on percent of stratified drift in the drainage area were used and values were adjusted to local conditions using figure 17.

Calculation of the maximum potential infiltration capacity of the bottom deposits in streams (column 3) is based on the equation on p. 69. The widths of the larger streams, such as the Pawcatuck River, are based on field measurements, elsewhere, they are estimated from topographic maps; all stream lengths are determined from topographic maps. Vertical permeability is assumed to be 50 gpd per sq ft for coarse-grained stratified drift, and 1 gpd per sq ft for fine-grained deposits (lacustrine and alluvial deposits). An intermediate value of 25 gpd per sq ft is used for reaches containing substantial amounts of both.

Usable streamflow is considered to be either the 90-percent duration flow or the maximum potential induced infiltration capacity, whichever is less. The maximum number of consecutive days that actual streamflow was less than the usable streamflow during 1931-60, shown in column 4, and the average streamflow during this period, shown in column 5, were interpolated from graphs based on lowest average flow for a 31-year recurrence interval for periods of 7, 30, 60, and 120 days from table 8, and from the lowest daily flow not exceeded during the same periods from ratios given in paragraph 2 on page 23.

Ground water available from storage during a six-month period of no recharge is estimated from the volume of saturated stratified drift in each favorable area (column 6). Volume multiplied by a six-month yield figure of 30 percent is then converted to gpd for 180 days. Only one-third of this amount is considered developable in practice during a six-month period (column 7). For the semi-favorable areas listed separately in table 40, a similar procedure can be used. The volume of saturated drift in any semi-favorable area can be roughly estimated by multiplying its length, width, and thickness (columns A, B, and C) with due regard to the lack of accuracy in these averages.

SUMMARY OF ESTIMATED LONG-TERM YIELDS

Water available in the report area varies from time to time, and the long-term yields in table 39 are therefore selected for some expectable hydrologic conditions: (Column A) for a recharge period of 185 days; (B and C) for a no recharge period of 180 days during part of which streamflow into the favorable area is deficient; and (D and E) during part of which streamflow entering the favorable area is adequate; and (F) the average daily yield for a complete year, exceeded 7 years out of 10. The yield during deficient streamflow, column B and C is important, it is the maximum yield which can be sustained continuously throughout the year without having to adjust withdrawals to account for seasonal changes in hydrologic conditions in the favorable area.

For example, in favorable area E (Whitford Brook, Long Pond to Old Mystic) water available from induced infiltration from streams is determined by the 90-percent flow duration (0.9 mgd), which is less than the induced infiltration capacity of the bottom deposits (92 mgd). During the period 1931-60 the streamflow for any one year dropped below 0.9 mgd for a maximum of 76 consecutive days. The average rate of induced infiltration during such a period is therefore reduced to the average streamflow during those 76 days (0.5 mgd).

The magnitude and timing of differences in yields during the course of a particular year depend largely upon the adequacy of water available from storage and upon variations in streamflow. For example in favorable area E, enough usable water is in storage (13 mgd) to sustain withdrawals at the average ground-water outflow rate (4.4 mgd) during 180 days when 4.4 mgd must come entirely from storage. Thus in this area withdrawals can be sustained at the average ground-water outflow rate throughout the year, even without induced infiltration.

Therefore, in any favorable area where enough water is available from ground-water storage, there are merely two different yield values during the year--one for times of adequate and another for times of deficient streamflow. In area E, total yield during times of adequate streamflow (289 days out of the year) is 4.4 + .9 = 5.3 mgd, and for 76 days of deficient streamflow, 4.4 + .5 = 4.9 mgd. The average daily yield for the entire year is the weighted average of the two values, 5.2.

In seven of the favorable areas, the amount of water available from storage is not enough to sustain withdrawals at the average ground-water outflow rate during 180 days when withdrawals (exclusive of induced infiltration) must come entirely from storage. For example, along the Yantic River (favorable area H), the amount of water which can be removed from storage in 180 days, 6.3 mgd, is 1.6 mgd less than the average ground-water outflow rate for the year, 8.1 mgd. Consequently, during the six months that withdrawals must come from storage, pumping from this source cannot exceed 6.3 mgd, although during the other half of the year (185 days) withdrawals can be 1.6 mgd greater than average, or 9.5 mgd, because recharge is sufficient to sustain withdrawal and completely replenish the depleted reservoir. In this area, streamflow was deficient for a maximum of 69 consecutive days during the period 1931-60. Therefore total yield must be reduced still further to take into account such a period of decreased water available from induced infiltration occurring during the 69 days of pumping from storage.

Thus in any area where usable storage is a limiting factor, yields are different for three periods during the year. In the above example, for the 185 day recharge period, the yield is 9.5 + 12 = 21.5 mgd; for the 69 day period of no recharge, 6.3 + 7.0 = 13.3 mgd; and for the 111 day period of adequate streamflow and no recharge, 6.3 + 12.0 = 18.3 mgd (the figures are rounded in table 40). The average daily yield for the whole year is the weighted average of the three values or about 19 mgd.

EFFECT OF WATER QUALITY ON DEVELOPMENT

The adequacy or utility of a water source is dependent on the quality as well as the quantity of water available. Excessively large (or small) concentrations of various constituents may prohibit certain uses, or at least increase cost because of the treatment required. Table 4 lists the effects and significance of a variety of constituents and properties of the water found in the SCRBA.

Water distributed by public supplies must meet certain water quality standards. In the report area, the quality of such water supplies, based on the constituents determined, is within the drinking-water standards applicable to common carriers in interstate commerce recommended by the U.S. Public Health Service (1962), and which are widely accepted as standards for public water supplies, as they are by the State of Connecticut. They appear in table 4 and are also given in various tabulations of chemical analyses throughout the report.

Industrial water-quality requirements vary according to the specific use of the water. For example, water used in the manufacturing of textiles and fine paper must be soft, colorless, and low in iron, manganese, and dissolved solids. Boiler operations require low concentrations of calcium, magnesium, sulfate, and silica to avoid deposition of hard scale which reduces efficiency. Excessive iron, manganese, or turbidity causes spots and discolorations in tanning of hides and leather goods and in the laundering of clothes. Water-quality requirements for many industries are more stringent than those for public-water supplies. Table 41 lists some of the tolerances that have been established for certain industries, and for comparison gives the ranges in concentration of selected constituents and properties found in water in the SCRBA during this study.

The chemical quality of most of the water in the SCRBA in its natural state is satisfactory for a wide variety of uses, and with suitable treatment may be used for most purposes. However, the water in certain reaches of streams at various streamflows contains sufficient industrial and municipal wastes to prohibit use for public water supply or recreation and for many industrial purposes. Although brackish or saline water is corrosive to most equipment, an unlimited supply is available along the coast and estuaries. This source with the use of proper equipment has a great potential for large industries as a coolant. In an effort to abate pollution the State has accepted responsibility under the Federal Water Quality Act of 1965 and the State Public Act 57 of 1967 by adopting standards of water quality to both intra- and interstate streams. The criteria used in the classification can be obtained from the Connecticut Water Resources Commission.

Areas where serious ground-water quality-problems exist are indicated on plate D. Scattered wells yielding iron-bearing water outside the problem areas shown on plate D are indicated on figure 26. Water from about 8 percent of the wells in the report area yield water classified as hard or very hard and in some areas, salt water intrusion may be a problem.

CONSEQUENCES OF DEVELOPMENT

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

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

Ground-water levels are lowered in the vicinity of any well from which water is pumped. Knowing the transmissibility and storage characteristics of the aquifer, and the hydrologic boundaries, it is possible to predict the amount of water-level decline at any point for any given pumping rate and time. In the report area, as elsewhere in eastern Connecticut, the inhomogeneity of the aquifers, and boundary conditions limit the use of procedures for predicting drawdowns. For the stratified-drift aquifer, a pumping test as discussed on page 54 is a more practical way to determine the effects of pumping on water levels in a particular area.

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

FUTURE DEVELOPMENT--ITS EFFECT ON THE AVAILABILITY OF WATER

Accurate measurements and complete records of past hydrologic events cannot portray the effects of the man-made changes that take place in the future. The reader who wishes to evaluate the quantity and quality of water available at some location should consider whether any major development has taken place nearby or in portions of the basin upstream from that location since 1965. Have there been any important water-regulating structures erected upstream? Have any municipal, industrial, or agricultural users begun to withdraw large amounts of water from the stream or adjacent stratified drift? If withdrawals are returned to the streams, how has the quality been changed? If the water is being diverted elsewhere, how much is being taken and when? Are there any new waste-treatment plants upstream? Are there any new major well fields or waste-disposal facilities nearby? Careful consideration of questions such as these should permit local modification of conclusions presented in the report where necessary, in such a way that the report can be useful for many years. The effects of future development can be measured by continued operation of gaging stations on selected streams, measurements of water levels in selected observation wells, and monitoring of chemical, bacteriological, and physical quality of water. Such measurements would permit a thorough reappraisal of the water resources of the report area should it become necessary sometime in the future

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Table 41.--Water quality limitations for industrial use and range in water quality available in the lower Thames and southeastern coastal river basins

Maximum limits or ranges in limits of significant properties and constituents of waters acceptable for certain industrial uses.

(Source of data: American Water Works Assn., 1951, Water Quality and Treatment, p. 66-67, unless otherwise noted)

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

Range in limits of selected properties and constituents of waters from various sources found in the lower Thames and southeastern coastal river basins

Source																								
Natural Streams (non-marine)	--	3-35	--	--	--	9-62	1-30	5.2-7.1	28-150	2.2-16	0.03-1.3	0.00-0.34	--	--	3.6-16	--	--	0	2-36	--	--	--	--	--
Contaminated Streams (non-marine)	5-40	5-33	--	--	--	14-1,280	1-94	3.9-7.4	36-4,100	3.9-268	.04-1.1	.00-.19	--	--	3.5-11	--	0.0-0.2	0	1-115	--	--	--	--	--
Bedrock Wells	--	--	--	--	--	3-1,120	0-105	4.4-8.1	24-1,830	2.2-416	.00-8.2	.00-.04	--	--	3.8-28	--	.0-1.4	0	0-128	--	--	--	--	--
Stratified Drift Wells	--	--	--	--	--	2-296	4-79	5.8-7.7	36-1,270	.7-50	.01-2.3	.00-.78	--	--	5.6-19	--	.0-.2	0	5-96	--	--	--	--	--
Till Wells	--	--	--	--	--	22-100	1-68	5.0-7.6	40-678	6.4-31	.02-8.1	.00-.27	--	--	6.6-22	--	--	0	1-83	--	--	--	--	--

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

b/ A - No corrosiveness; B - No slime formation; C - Conformance to USPHS drinking-water standards necessary (see table 4); D - Maximum limit of NaCl, 275 ppm.

c/ Color units, not ppm as erroneously shown in original table.

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

e/ Some hardness desirable.

f/ Figure given in original table has been corrected.

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

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

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

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

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

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

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

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

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

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

SELECTED REFERENCES

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

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

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

Anderson, K. E., 1964, Water well handbook: Rolla, Missouri, Missouri Water Well Drillers Assoc., 281 p.

Badon, Ghyben, W., 1889, Nota in verband met de vourgenomen put boring nabij Amdsterdam: Inst. Ing. Tijdschr., 1888-89, p. 21, The Hague.

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

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

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

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

------------------ 1957, Connecticut flood planning session, basic magnitude and frequency relationships: Connecticut Soc. Civil Eng. Ann. Rept., p. 76-92.

Brown, J. S., 1925, A study of coastal ground water with special reference to Connecticut: U.S. Geol. Survey Water-Supply Paper 537, 101 p.

------------------ 1928, Ground water in the New Haven area, Connecticut: U.S. Geol. Survey Water-Supply Paper 540, 206 p.

Brown, R. C., 1962, Report on methods of removing accumulating deposits from the Oxoboxo River, town of Montville, Connecticut for State of Connecticut Water Resources Commission: New Haven, Conn., Roger C. Brown, 27 p.

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

Cervione, M. A., Jr., Grossman, I. G., and Thomas, C. E., Jr., 1968, Hydrogeologic data for the lower Thames and southeastern coastal river basins, Connecticut: Connecticut Water Resources Bull. No. 16.

Clark, W. E., 1963, Evapotranspiration and the relation of ground water to surface water in the Pond Creek basin, Oklahoma: U.S. Geol. Survey Prof. Paper 450-E, p. E142-E145.

Comly, H. H., 1945, Cyanosis in infants caused by nitrates in well waters: Am. Med. Assoc. Jour., v. 129, p. 112-116.

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

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

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

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

------------------ 1964, Connecticut takes stock for action: Connecticut Interregional Planning Program, 143 p.

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

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

Cooper, H. H., Jr., 1964, A hypothesis concerning the dynamic balance of fresh water and salt water in a coastal aquifer, in sea water in coastal aquifers: U.S. Geol. Survey Water-Supply Paper 1613-C, p. C1-C12.

Cushman, R. V., Allen, W. B., and Pree, H. L., Jr., 1953, Geologic factors affecting the yield of rock wells in southern New England: New England Water Assoc. Jour., v. 67, 2, p. 77-95.

Dalrymple, Tate, 1965, Flood peak runoff and associated precipitation in selected drainage basins in the United States: U.S. Geol. Survey Water-Supply Paper 1813, 406 p.

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

Feininger, Tomas, 1964, Petrology of the Ashaway and Voluntown quadrangles, Connecticut-Rhode Island: U.S. Geol. Survey open-file rept., 219 p., 6 pl.

------------------ 1965, Surficial geologic map of the Voluntown quadrangle, Connecticut: U.S. Geol. Survey Geol. Quad. Map GQ-469.

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

Flint, R. F., 1929, The glacial geology of Connecticut: Connecticut Geol. Nat. History Survey Bull. 47, 294 p., 1 map.

Foote, F. M., 1962, Analyses of Connecticut public water supplies, sixth edition: Connecticut State Dept. of Health, 2 p.

Gambell, A. W., Jr., 1962, Indirect evidence of the importance of water-soluble continentally derived aerosols: Tellus, v. 14, p. 91-95.

Goldsmith, Richard, 1960, Surficial geology of the Uncasville quadrangle, Connecticut: U.S. Geol. Survey Geol. Quad. Map GQ-138.

------------------ 1962, Surficial geology of the Montville quadrangle, Connecticut: U.S. Geol. Survey Geol. Quad. Map GQ-148.

------------------ 1962, Surficial geology of the New London quadrangle, Connecticut-New York: U.S. Geol. Survey Geol. Quad. Map GQ-176.

------------------ 1963, Geologic sketch map of eastern Connecticut: U.S. Geol. Survey open-file rept., 1 map, 1 cross section.

------------------ 1964, Surficial geology of the Niantic quadrangle, Connecticut: U.S. Geol. Survey Geol. Quad. Map GQ-329.

------------------ 1967, Bedrock geologic map of the Uncasville quadrangle, New London County, Connecticut: U.S. Geol. Survey Geol. Quad. Map GQ-576.

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

Green, A. R., 1964, Magntidue and frequency of floods in the United States, Part 1-A, North Atlantic slope basins, Maine to Connecticut: U.S. Geol. Survey Water-Supply Paper 1671, p. 2-5, 154-155.

Grossman, I. G., 1965, Connecticut <u>in</u> Ground-water levels in the United States 1958-62: U.S. Geol. Survey Water-Supply Paper 1782, p. 9-10.

Hanshaw, P. M., and Snyder, G. L., 1962, Surficial geology of the Norwich quadrangle, Connecticut: U.S. Geol. Survey Geol. Quad. Map GQ-165.

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

Hem, J. D., 1959, Study and interpretation of the chemical characteristics of natural water: U.S. Geol. Survey Water-Supply Paper 1473, 269 p.

Herzberg, Baurat, 1901, Die Wasserversorgung eininger Nordseebacher (The water supply on parts of the North Sea Coast): Jour. Garbeleuchtung and Wasserversorgung, Jahrg. 44, Munich.

Hubbert, M. K., 1940, The theory of ground-water motion: Jour. Geology v. 48, no. 8, part 1, p. 785-944.

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

Johnson, K. E., 1961, Ground-water map of the Watch Hill quadrangle, Rhode Island-Connecticut: Rhode Island Water Resources Coordinating Board GWM 14.

Junge, C. E., 1963, Air chemistry and radioactivity, New York, Academic Press, 382 p.

Kimmel, Grant, 1964, Ground-water resources and surficial geology of Colchester Township (sic), Connecticut: Columbia Univ. unpub. master's thesis, 58 p., 2 pl.

Klaer, F. H., Jr., 1953, Providing large industrial water supplies by induced infiltration: Mining Eng., v. 5, p. 620-624.

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

LaSala, A. M., Jr., 1960, Ground-water levels in Connecticut, 1956-1959: Connecticut Water Resources Bull. No. 2, 33 p.

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

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

Long, R. A., 1965, Feasibility of a scavenger-well system as a solution to the problem of vertical salt-water encroachment: Louisiana Dept. of Public Works Water Resources Pamphlet No. 15, 27 p.

Loughlin, G. F., 1912, The gabbros and associated rocks at Preston, Connecticut: U.S. Geol. Survey Bull. 492, 158 p.

Lundgren, L. L., 1966, The bedrock geology of the Hamburg quadrangle: Connecticut Geol. Nat. History Survey Quad. Rept. 19.

Mallman, W. L., and Mack, W. N., 1961, Biological contamination of ground water, <u>in</u> U.S. Public Health Service, 1961, Ground water contamination: R. A. Taft Sanitary Eng. Center Tech. Rept. W 61-5, p. 35-43.

Masselli, J. W., Masselli, N. W., and Burford, G. M., 1963, White water wastes from paper and paperboard mills: Pollution sources and methods of treatment, New England Interstate Water Pollution Control Commission, 55 p.

Meikle, R. L., and Baker, J. A., 1965, Ground-water levels in Connecticut 1960-1964: Connecticut Water Resources Bull. No. 7, 26 p.

Metcalf & Eddy, 1962, Report to Eastern Connecticut Industrial Fresh Water Development Commission upon surface water supplies available in southeastern Connecticut: Boston, Mass., Metcalf & Eddy, 141 p.

----------------- 1965, Sewerage problems: Southeastern Connecticut Regional Planning Agency, 134 p.

McKee, J. E., and Wolf, H. W., 1963, Water quality criteria, second edition: California Water Control Board Publ. No. 3-A, 548 p.

Meyer, R. R., 1963, A chart relating well diameter, specific capacity, and the coefficients of transmissibility and storage, in Bentall, Ray, Methods of determining permeability, transmissibility and drawdown: U.S. Geol. Survey Water-Supply Paper 1536-I, p. 336-347.

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

Morgan, M. F., 1939, The soil characteristics of Connecticut land types: Connecticut Agr. Expt. Sta. Bull. 423, 64 p.

Olmstead, F. H., and Hely, A. G., 1962, Relation between ground water and surface water in Brandywine Creek basin, Pennsylvania: U.S. Geol. Survey Prof. Paper 417-A, p. A1-A21.

Pessl, Fred, Jr., 1966, Surficial geologic map of the Fitchville Quadrangle, Connecticut: U.S. Geol. Survey Geol. Quad. Map GQ-485.

Petitt, E. M., Jr., and Winslow, A. G., 1957, Geology and ground-water resources of Galveston County, Texas: U.S. Geol. Survey Water-Supply Paper 1416, 157 p.

Pluhowski, E. J. and Kantrowitz, I. H., 1963, Influence of land-surface conditions on ground-water temperatures in southwestern Suffolk County, Long Island, New York: U.S. Geol. Survey Prof. Paper 475-B, p. B186-B188.

Prickett, T. A., 1965, Type curve solution to aquifer tests under water-table conditions: Ground water, v. 3, no. 3, p. 5-14.

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

Randall, A. D., Bierschenk, W. H., and Hahn, G. W., 1960, Ground-water map of the Voluntown quadrangle, Connecticut - Rhode Island: Rhode Island Water Resources Coordinating Board GWM 13.

Randall, A. D., Thomas, M. P., Thomas, C. E., Jr., and Baker, J. A., 1966, Water resources inventory of Connecticut, part 1, Quinebaug River basin: Connecticut Water Resources Bull. No. 8, 102 p., 4 pl.

Rankama, K., and Sahama, T. G., 1950, Geochemistry: Chicago, Univ. of Chicago Press, 912 p.

Ranney Method Water Supplies, Inc., 1954, Report on hydrogeological survey for Robert Gair Co., Inc., Thames River Division, Survey S-69, processed report.

Rogers, J., Gates, R. M., and Rosenfield, J. L., 1959, Explanatory text for preliminary geologic map of Connecticut, 1956: Connecticut Geol. Nat. History Survey Bull. 84, 64 p.

Rorabaugh, M. I., 1956, Ground Water in northeastern Louisville, Kentucky: U.S. Geol. Survey Water-Supply Paper 1360-B, p. 101-169.

Schafer, J. P., 1965, Surficial geologic map of the Watch Hill quadrangle, Rhode Island-Connecticut: U.S. Geol. Survey Geol. Quad Map GQ-410.

Schneider, Robert, 1962, An application of thermometry to the study of ground water: U.S. Geol. Survey Water-Supply Paper 1544-B, 16 p.

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

Simpson, E. S., 1952, The ground-water resources of Schenectady County, New York: New York Power and Control Comm. Bull. GW-30, 110 p.

Snyder, G. L., 1961, Bedrock geology of the Norwich quadrangle, Connecticut: U.S. Geol. Survey Quad. Map GQ-144.

----------------- 1964[a], Bedrock Geology of the Willimantic quadrangle, Connecticut: U.S. Geol. Survey Geol. Quad. Map GQ-335.

----------------- 1964[b], Petrochemistry and bedrock geology of the Fitchville quadrangle, Connecticut: U.S. Geol. Survey Bull. 1161-I, 63 p.

Swenson, H. A., and Baldwin, H. L., 1965, A primer on water quality: U.S. Geological Survey, 27 p.

Southeastern Connecticut Regional Planning Agency, 1963, Land characteristics, southeastern Connecticut region: Norwich, Conn., June 1963, 64 p.

----------------- 1963, Population and housing, southeastern Connecticut region: Norwich, Conn., December 1963, 58 p.

----------------- 1967, Recommended regional development plan, southeastern Connecticut region: Norwich, Conn., February 1967, 53 p.

Stiff, H. A., Jr., 1951, The interpretation of chemical water analysis by means of patterns: Jour. Petrol. Tech., October 1951, p. 15.

Theis, C. V., 1935, Relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using ground-water storage: Am. Geophys. Union Trans., pt. 2, p. 519-524; dupl. as U.S. Geol. Survey Ground Water Note 5, 1962.

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

Thomas, C. E., Jr., Bednar, G. A., Thomas, M. P., and Wilson, W. E., Hydrogeologic data for the Shetucket River basin, Connecticut: Connecticut Water Resources Bull. No. 12, 48 p., 1 pl.

Thomas, H. E., 1951, The conservation of ground water: New York, McGraw Hill, 327 p.

Thomas, M. P., 1966, Effect of glacial geology upon the time distribution of streamflow in eastern and southern Connecticut: U.S. Geol. Survey Prof. Paper 550-B, p. B209-B212.

Thomas, M. P., Bednar, G. A., Thomas, C. E., Jr., and Wilson, W. E., 1967, Water resources inventory of Connecticut, part 2, Shetucket River basin: Connecticut Water Resources Bull. No. 11, 96 p., 4 pl.

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

Thornthwaite, C. W., 1952, An approach toward a national classification of climate: Readings in the Geography of North America, Am. Geol. Soc. Repr. Ser. No. 5, p. 374-413.

Thornthwaite, C. W., and Mather, J. R., 1957, Instructions and tables for computing potential evapotranspiration and the water balance: Drexel Institute of Technology, Publications in Climatology, v. 10, no. 3, 311 p.

Todd, D. K., 1959, Ground water hydrology: New York, John Wiley and Sons, 336 p.

Upson, Joseph E., and Spencer, C. W., 1964, Bedrock valleys of the New England coast as related to fluctuations of sea level: U.S. Geol. Survey Prof. Paper 454-M, 44 p., 5 pl.

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

U.S. Geological Survey, issued annually through 1960; Surface water supply of the United States, part 1, North Atlantic slope basins, and, from 1951, part 1-A, North Atlantic slope basins, Maine to Connecticut: U.S. Geol. Survey Water-Supply Papers.

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

----------------- 1940, Hurricane floods of September 1938: U.S. Geol. Survey Water-Supply Paper 867, 562 p.

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

----------------- 1954, Compilation of records of surface waters of the United States through September 1950, part 1-A, North Atlantic slope basins, Maine to Connecticut: U.S. Geol. Survey Water-Supply Paper 1301, 380 p.

----------------- 1960, Floods of August-October 1955, New England to North Carolina: U.S. Geol. Survey Water-Supply Paper 1420, 854 p., 6 pl.

----------------- issued annually, 1961-64, Surface water records of Connecticut.

----------------- 1964, Compilation of records of surface waters of the United States, October 1950 to September 1960, part 1-A, North Atlantic slope basins, Maine to Connecticut: U.S. Geol. Survey Water-Supply Paper 1721, 317 p.

----------------- 1965, Water resources data for Connecticut.

U.S. Public Health Service, 1962, Drinking water standards, 1962: U.S. Public Health Service Pub. 956, 61 p.

----------------- 1964, Waste water disposal by Connecticut industries-inventory as of January 1, 1961: U.S. Public Health Service, 287 p.

U.S. Weather Bureau, 1912-65, Climatalogical data, New England.

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

Wayman, C. H., 1965, A hard look at soft detergents: Bull. Atomic Scientists, v. 21, no. 4, p. 23-26.

Wenzel, L. K., 1942, Methods for determining permeability of water-bearing materials: U.S. Geol. Survey Water-Supply Paper 887, 192 p.

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

----------------- 1963, Iron water control for the home: Coop. Ext. Service, Purdue Univ. Ext. Cir. 507, 8 p.

Winslow, J. D., 1962, Effect of stream infiltration on ground-water temperatures near Schenectady, New York: U.S. Geol. Survey Prof. Paper 450-C, p. C125-C128.

ABBREVIATIONS

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

EQUIVALENTS

1 cfs = 646,317 gpd = 0.646317 mgd.

1 mgd = 694 gpm = 1.547 cfs.

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

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

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

GLOSSARY

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

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

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

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

Aquifer: A unit of earth material, either consolidated or unconsolidated, capable of yielding usable quantities of water.

Alluvium: Stream-deposited gravel, sand, and silt.

Artesian condition: A condition in which an aquifer is confined between rocks or deposits of lower permeability. Ground water in such an aquifer is under supplemental head, or pressure, so that it will rise above the level at which it is encountered in a well where the aquifer is unconfined.

Bayard screen: Obsolescent term for slotted or perforated casing set opposite the water-bearing material to act as a screen.

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

Bedrock valley: A valley cut in bedrock partly or entirely filled with glacial drift.

Boulder: Any detached rock fragment larger than a cobble; commonly boulders have been carried by ice or other agents, as shown by the partial rounding.

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

Cement grouting: Application of cement slurry to a well to seal the annular space between the casing and the earth materials.

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

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

Clay: Particles of sediment smaller than 0.004 millimeters in diameter.

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

Coefficient of permeability: The standard coefficient of permeability used by the U.S. Geological Survey is the rate of flow of water, in gallons per day, through a cross sectional area of 1 square foot of an aquifer under a hydraulic gradient of 1 foot per foot at a temperature of 60°F. The field coefficient of permeability is the same except that it is measured under prevailing conditions, particularly with respect to temperature of water.

Coefficient of storage (of an aquifer): The volume of water released or taken into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface. Under water-table conditions, coefficient of storage is virtually equivalent to specific yield.

Coefficient of transmissibility (of an aquifer): The rate of flow of water at the prevailing water temperature, in gallons per day, through a vertical strip of the aquifer 1 foot wide extending the full saturated height of the aquifer under a hydraulic gradient of 100 percent (one foot per foot). It is equal to the product of the field coefficient of permeability and saturated thickness.

Coefficient of uniformity: See uniformity coefficient.

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

Collector well: A vertical caisson or casing, several feet in diameter, from the bottom of which horizontal pipes radiate in unconsolidated material in several directions with openings to collect water from a nearby stream, lake, or pond.

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

Cone of depression: A dewatered underground area, shaped like a cone with its broad side up, produced by pumping a water-bearing material.

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

Crystalline bedrock: Solid rock composed of closely interlocking minerals.

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

Dip: The angle of inclination of a joint, fault, layer, etc. from the horizontal. A dip of 90° is vertical; a dip of 0° is horizontal.

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

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

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

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

Drawdown, in a well: The difference in the water level in a well before and after pumping.

Drift: Unconsolidated gravel, sand, silt, or clay deposited by glacial ice or meltwater during the Pleistocene "ice age."

Drilled well: A well constructed by chopping or grinding a hole in the earth.

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

Dug well: A well constructed by excavating a hole in the ground, usually at least 2 feet in diameter, by means of hand tools or with power digging equipment such as clamshell buckets or augers. Such wells are commonly lined with tile or with fieldstone.

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

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

Fault: A fracture or fracture zone along which differential movement has taken place.

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

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

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

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

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

Frequency: See "recurrence interval."

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

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

Gneiss: A coarse-grained cyrstalline rock in which bands of minerals alternate with other bands.

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

Ground water: Water in the zone of saturation.

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

Ground-water runoff: 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. It has soap consuming and encrusting properties, and is expressed as the concentration of calcium carbonate ($CaCO_3$) that would be required to produce the observed effect.

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

Induced infiltration: Water which infiltrates from a stream or lake into an aquifer because of pumping of nearby wells.

Infiltration gallery: A horizontal permeable conduit for interception and collection of ground water.

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

Joint: A fracture in bedrock along which no differential movement has taken place.

Leach: To dissolve out by a percolating liquid.

Limestone: A sedimentary rock consisting chiefly of calcium carbonate ($CaCO_3$).

Lithology: The physical characteristics of a rock or sediment.

Millimeter (mm): 1/1,000 of a meter or 0.04 inches.

Mineral: A homogeneous naturally occurring inorganic solid whose chemical composition is definite or varies within definite limits. Most rocks are composed of many different minerals.

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

Outcrop: Bedrock naturally exposed at the land surface.

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

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

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

Pegmatite: A coarse granitic rock occurring in dikes or veins.

Permeability: The ability of any earth materials, consolidated or unconsolidated, to transmit water. See coefficient of permeability.

pH: The negative logarithm of the hydrogen-ion concentration indicating acidity or alkalinity. Ordinarily a pH value of 7.0 indicates that the water is at its neutral point, being neither acidic or alkaline. Values lower than 7.0 denote acidity and above 7.0 denote alkalinity.

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

Porosity: The property of containing voids or open spaces, expressed as the percent of the total volume of rock or sediment that is occupied by void spaces.

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

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

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

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

Reference period: A period of time chosen so that 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.

Riffle: A reach of stream channel characterized by relatively great slope, shallow water depth, and rapid flow.

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

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

Scavenger well: A well which pumps salt water to lower the salt water head and thus enables a nearby supply well to pump fresh water.

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

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

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

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

Silt: Rock particles bigger than clay and smaller than sand, or between 0.004 and 0.0625 millimeter in diameter.

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

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

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

Specific gravity: The weight of a substance compared with the weight of an equal volume of water.

Specific yield: The ratio of the amount of water, by volume, that a fully saturated rock or unconsolidated material will yield by gravity drainage, to the total volume of the rock or unconsolidated material, commonly expresses as a percent.

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

Streamflow: The discharge that occurs in a natural channel.

Streamline hills: Elongated hills of till and bedrock shaped partly by glacial erosion and partly by the molding action of glacial ice as it flowed around and over topographic highs.

Strike: A line representing the intersection of a joint, bed, fault, layer, or other tabular body with a horizontal plane.

Texture: The grain-size characteristics of a deposit.

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

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

Transmissibility: The ability of a vertical section of a rock or sediment to transmit water. See coefficient of transmissibility.

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

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

Unconsolidated: Refers to loose materials whose constituent grains are not firmly cemented together or interlocked.

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

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

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

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

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